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THE MAN-RELATED ACTIVITIES OF THE GULF STREAM DRIFT MISSION

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Program Development

September 21, 1970

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NASA's objectives for the next decade include developing systems to permit man to live and work in a confined and isolated environment for long durations. To plan and design such systems, extensive knowledge is required of the interaction of motivated groups performing useful scientific work in a stressful, isolated, and confined environment. With this knowledge requirement recognized, NASA participated in the Gulf Stream Drift Mission (GSDM) to conduct a program directed at studying the man-related activities of that mission.

The primary objective of the GSDM was to permit the Ben Franklin, a deep submersible vehicle, to drift with the Gulf Stream at depths from 600 to 2000 feet while the crew performed scientific oceanographic studies. The Ben Franklin is a 50-foot-long, 10-foot-diameter cylinder designed for a 200-foot operational depth and 36 man-weeks of life support. There were six crewmembers on board during the GSDM, including the world-famous ocean systems designer, Dr. Jacques Piccard, and the NASA representative, Mr. Chester B. May of MSFC.

This report discusses those aspects of the GSDM that offer potential knowledge for application to long-duration manned space missions. The objective of the NASA program on the GSDM was to investigate the feasibility of utilizing an undersea vehicle as a space station analog to study living and working problems, and as a potential hardware test bed.

The GSDM satisfied the following space station operations analog requirements: provided a real scientific mission; simultaneously removed the crew from their natural social environment and from their natural earth environment; and provided similar confinement, a similar closed

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Based on these similarities, NASA developed a program study in the following areas: human behavior, habitability, environment, microbiology, and maintainability. This document contains the author's views and observations as the result of actually participating in the mission as one of the crewmembers.

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I would like to express my sincere appreciation for the cooperation provided the NASA program by the other crew members: Jacques Piccard, Donald J. Kazimir, Erwin Aebersold, Roswell F. Busby, and Kenneth Haigh. I would also like to thank the Grumman Corporation and their employees who worked so hard to make the GSDM a success. The NASA program could not have been so fruitful without Mr. Melvin Markey of NASA Headquarters; Mr. Dick Heckman, NASA backup crewman; and many NASA personnel at the Manned Spacecraft Center, Langely Research Center, and Marshall Space Flight Center.

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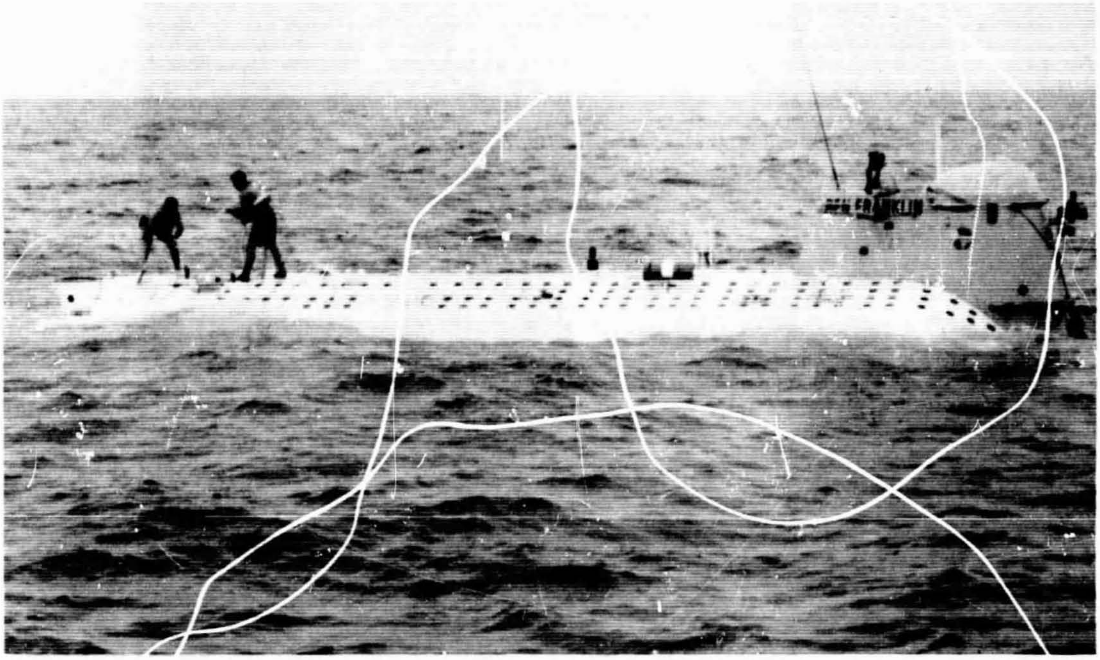

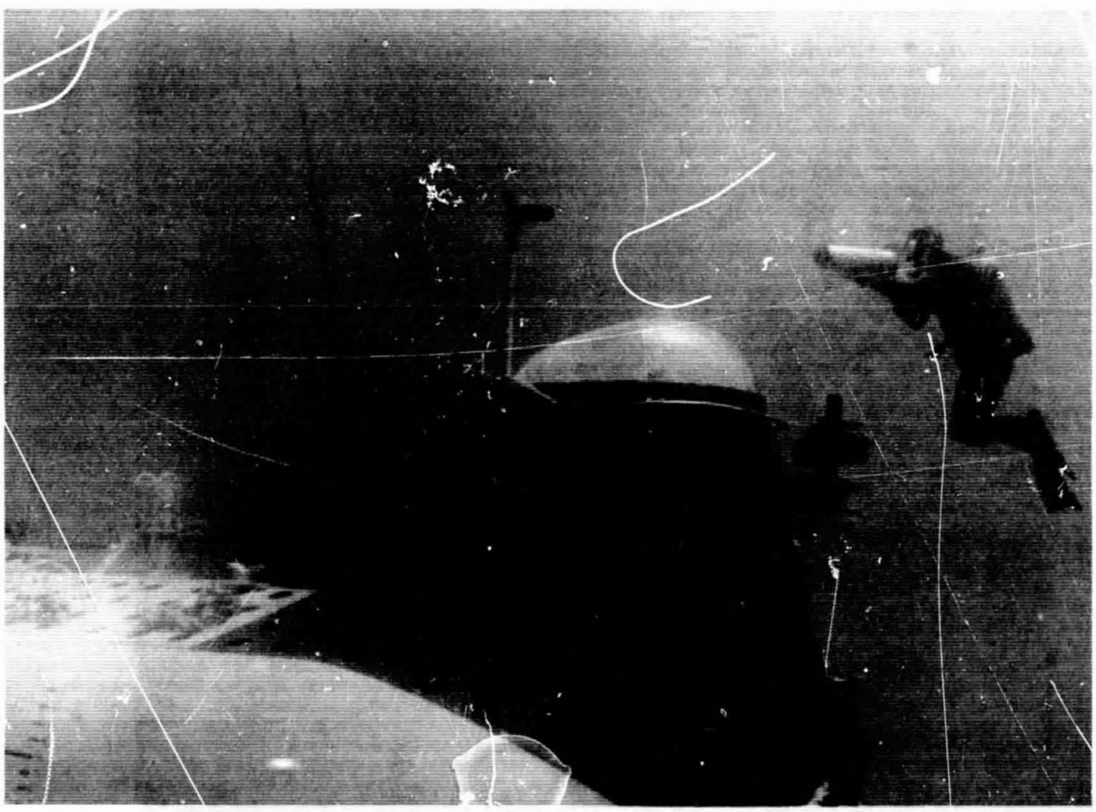

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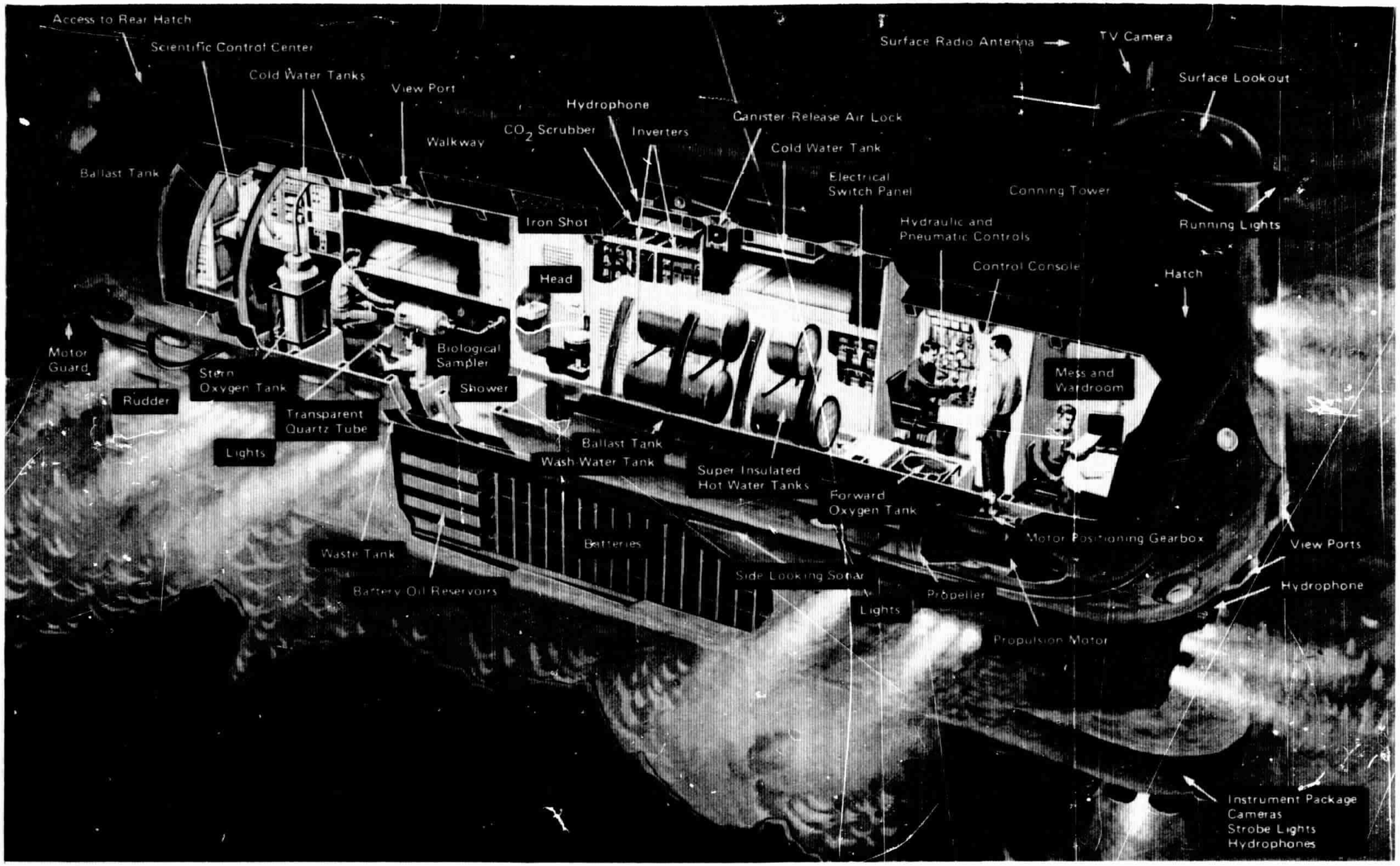

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TECHNICAL MEMORANDUM X-64548

THE MAN-RELATED ACTIVITIES OF THE GULF STREAM DRIFT MISSION

SUMMARY

NASA's objectives for the next decade include developing systems to permit man to live and work in a confined and isolated environment for long durations. To plan and design such systems, extensive knowledge is required of the interaction of motivated groups performing useful scientific work in a stressful, isolated, and confined environment. With this knowledge requirement recognized, NASA participated in the Gulf Stream Drift Mission (GSDM) to conduct a program directed at studying the man-related activities of that mission.

The primary objective of the GSDM was to permit the Ben Franklin, a deep submersible vehicle, to drift with the Gulf Stream at depths from 600 to 2000 feet while the crew performed scientific oceanographic studies. The mission began at 8 p.m. on July 13, 1969, and ended at 8 a.m. on August 13, 1969 (total mission time of 30 days, 12 hours). With respect to the vehicle's operation and NASA's program for the GSDM, the mission was considered completely successful. The Ben Franklin vehicle is a 50-foot-long, 10-foot-diameter cylinder designed for a 2000-foot operational depth and 36 man-weeks of life support. There were six crewmembers on board during the GSDM, including the world-famous ocean systems designer, Dr. Jacques Piccard, and the NASA representative, Mr. Chester B. May of MSFC.

This report discusses those aspects of the GSDM that offer potential knowledge for application to long-duration manned space missions. The objective of the NASA program on the GSDM was to investigate the feasibility of utilizing an undersea vehicle as a space station analog to study living and working problems, and as a potential hardware test bed.

The GSDM satisfied the following space station operations analog requirements: provided a real scientific mission; simultaneously removed the crew from their natural social environment and from their natural earth environment; and provided similar confinement, a similar closed environment with associated embedded stress conditions, and similar crew sizes and backgrounds.

Based on these similarities, NASA developed a program study in the following areas: human behavior, habitability, environment, microbiology, and maintainability. This document contains the author's views and observations as the result of actually participating in the mission as one of the crewmembers.

GENERAL DISCUSSION OF REQUIREMENTS

The recent report by the Space Task Group to the President has defined in terms of goals and program options the challenges that face our country in the exploration of space. It will probably be some time yet before we know how and to what degree our country will respond to these challenges. For the purpose of this discussion, let us assume that the challenges will be met to a reasonable degree. Based upon this assumption, one can examine the goals and programs in terms of things that have to be accomplished here on earth to ensure that the work was performed to the fullest extent prior to sending man to explore the planets.

The major elements of the space program, as defined by the Space Task Group, dealt with planetary exploration, development of earth-orbital space stations (to conduct scientific studies in the areas of astronomy, physics, the earth, and life sciences), and extensive exploration of the moon.

For planetary exploration within this century, we need now to develop a capability to deliver 6 to 12 men to Mars and to sustain their lives for periods ranging from 2 to 4 years.

With respect to the space station, our current plans are to start with 6- to 12-man modules and build up to 50- to 100-man space base. These systems will stay in orbit around the earth for 5 to 10 years with an average crew exchange of 90 days.

Exploration of the lunar surface will consist of building a lunar base with lunar surface transportation systems and scientific laboratories set up to accommodate men for long time periods.

NASA is now entering into a phase of space exploration that will require man to leave the social environmental structure to which he has become accustomed over the centuries. The time periods and the conditions under which men will be required to operate in this new phase of space exploration require detailed empirical data upon which many of the decisions and designs that will be required to successfully meet this new challenge will be based. The author believes that the current drive to explore the ocean faces problems similar to those faced by the space program. Therefore, the two programs are complementary and, through cooperation, mutual gains can be realized. NASA can benefit from the programs designed to explore the ocean; in return, space technology can assist in the design of ocean systems and techniques to more economically explore the oceans.

The oceanographers seem to believe that to completely understand the ocean they must perform in situ studies. Consequently, vehicles and habitats are needed to carry them to desirable depths to obtain their data. The most economical way to accomplish most of the studies would be to go to the desired depths and areas and remain there for long periods of time. It is from these long-duration missions that the space program can derive some benefit.

We believe that there are certain requirements which the ocean studies must meet to warrant NASA interest. They are the following: a real scientific mission, duration period of 30 days or longer, isolation from society, a scientific and engineering crew, and allow NASA to provide at least one crewmember per mission.

The scientific mission requirement is necessary to ensure high morale, to maintain urgency of obtaining the data (and by so doing will call upon the crew's best efforts and ingenuity in keeping the equipment functioning), and to provide the incentive for a highly skilled crew to participate in the mission, as will be required for space flight.

The 30-day duration is required because it takes at least that long for one to feel the impact of isolation and for the individual crewmembers to begin projecting representative feeling caused by the isolation.

Obviously, from the above discussion, it can be concluded that to meet the NASA requirements (NASA could assist the oceanographic programs in terms of assuming part of the mission cost and providing space technology), it is necessary to have a cooperative effort between various government agencies, universities, and industry.

NASA'S ROLE IN GSDM

Introduction

Dr. S. B. Sells[1] defined human behavior characteristics in terms believed appropriate for one to discuss certain aspects of the NASA program for the GSDM. Sells stated that, "We must have empirical verification rather than pronouncements by an authority." This statement refers to empirical data on human behavior under conditions similar to those that one expects to encounter in future, long-duration space missions. Hopefully, the following discussion will provide a data point from the world of empirical studies.

This report does not provide the quantitative results of the study,[2] but rather the program from the NASA program manager and crewmember's point of view is discussed. NASA was primarily interested in evaluating the mission operations of the GSDM in terms of a space station operations analog, particularly the man-related acitivities. NASA was not concerned with the subsystem operations because the hardware was not similar to space station hardware.

The hypothesis upon which NASA's participation in this study was based is as follows: "Underwater oceanographic missions such as the GSDM and vehicles such as the Ben Franklin can be used as a space station analog relative to mission operations and human behavior." To meet the analog criteria, the system environment or mechanism being studied must be very similar to the real world in which one intends to apply the knowledge. The development of a convincing argument for the similarity (and thus the analog) of two types of missions relative to human behavior is a difficult, if not a monumental, task. In the area of human behavior, everyone has his own ideas and often is very reluctant to accept ideas contrary to his. He is, at times, even indignant when something is stated contrary to his ideas. However, an argument will be established for the analog, and the program used to obtain quantitative and qualitative data during an actual mission will be described.

Present planning indicates that the size of space and ocean exploration teams for the next decade or two will be 6 to 12 men, who will be selected from

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1. Paper presented at the Conference on Bioastronautics, Blacksburg, Va., 1967.

2. Quantitative results are provided in detail in the Final NASA Report OSR-70-4 through -8.

the engineering and scientific communities. These two criteria quickly narrow the literature search down to those studies conducted on small group dynamics, preferably those with a scientific mission conducted over a long time period under isolated (both social and environment) and confined conditions. If the criterion of stress caused by fear of loss of life (embedded stress condition), etc., is added to be considered an analog, then the literature from which data can be taken is small indeed or even nonexistent.

Often the question arises, "But, what about submarines, antarctic exploration, prison camps, shipwrecks, and isolated duty stations? Are those not similar relative to human behavior?" The general consensus is that data obtained from studies of these areas are similar only in that they all closely agree on what is required to make an environment habitable; e.g., good food, good personal hygiene facilities, good recreational facilities, a good crew, good communication with the outside world, etc.

The absence of one or more of the following factors removes the data available in the aforementioned areas from realistic consideration in a space station analog sense: the difference in missions and goals (which is considered a necessity), the absence of simultaneous removal of the crew from their natural social environment and from their natural earth environment (e.g., sun, trees, wind, rain, etc.), the absence of confinement (i.e., the ability to move out of and into a confined area), the absence of similar embedded stress, and the difference in the size and background of the crew.

To utilize a system as an operations analog, the conditions must be similar enough to enable the evaluation of crew performance and responses to the different events and problems that occur during the implementation of the mission.

The GSDM, as well as a wide variety of future oceanographic missions, satisfies the following operations analog requirements: a real scientific mission, simultaneous removal of the crewmembers from their natural social environment and from their natural earth environment, similar confinement, similar embedded stress conditions, and similar crew sizes and backgrounds. There is also the potential that future underwater oceanographic laboratories can be designed or modified to use space hardware. If so, they can then serve as a test bed for obtaining reliability data on the long-term operation of specific pieces of space hardware under actual operational conditions.

NASA'S Program for the GSDM

The objective of the NASA program for the GSDM was to study those aspects that could be identified as being similar to space station missions. Within the GSDM mission constraints and funds available for NASA's participation in the mission, a program was developed to study the following: human behavior, habitability, microbiology, environmental gas contaminants, and maintainability.

Human Behavior

The human behavior aspects of the mission are discussed in terms of the mission and objectives, individual philosophy, personnel composition, crew organization, physical environment, and what is referred to as the temporal effects. Also, the effect of the habitability systems on the crew morale and effectiveness is discussed.

MISSION AND OBJECTIVES

If the effects of long-term isolation and confinement on men with respect to their performance and effectiveness for application to the space program are to be evaluated, then the mission must have a real objective and not a simulated one. The realness of the mission provides the motivation necessary to get representative scientists and crewmembers to participate in the mission. The realness also calls upon the crewmembers to use their best ingenuity to ensure the collection of all the data they approach and to give the extra effort that often spells the difference between the success and failure of the mission.

Under simulated conditions, scientists and engineers, as a rule, will not give enough of their time during a mission to obtain the required data. Even if they did, their performance and responses probably would not be similar to those during an actual space mission. The simulated habitability data would be similar to actual space conditions, but the data on the effectiveness of performing the scientific and operational tasks necessary to make the mission a success would not.

It is important to plan the science program so that the data collected during the final week of the mission are just as important as the first week. One way to achieve this is to plan for short-term accomplishments or milestones within the program. This will become necessary as mission times go beyond the 30-day time period.

PHILOSOPHY (CREW)

It is obvious that future space flights will deal in some way with scientific studies. This could and should mean that scientists or scientist types will be members of the crews, as well as operational astronauts.

The scientist's philosophy and the attitude he takes toward risk-taking, authority, cooperation, trust, and personal relationships are quite different from the philosophy of operational astronauts with their test pilot backgrounds. These differences are widely recognized; but no known effort is being made to identify these differences in terms of alternatives and solutions to the problem. NASA should take advantage of any and all long-duration underwater oceanographic missions. Through such missions they will be able to identify problems associated with a social environment that will be occupied by these two very individualistic-type people.

Because of the dedication and loyalty of the crewmembers to their mission, data on conflicts and crew dissatisfaction during the performance of these missions, which occur as a result of the differences discussed above, will be difficult to obtain. One of the primary reasons is that the scientists and crew involved in these missions are very sensitive to what the world thinks of the accomplishments of their mission, and they do not want anything to detract from those accomplishments. This is of real concern to them, and it is difficult to convince them that any information they can provide on crew conflicts would be treated confidentially. They seem to fear that any revelations of problems among the crew might preclude their being assigned to future missions, and thus alienate their careers.

Missions up to 30 days that involve the scientist and operational astronauts will continue to be successful relative to crew interactions. This success will be primarily a result of the high motivation usually associated with these missions. This motivation and the associated time duration will enable all participants to carefully avoid direct confrontation when problems occur; however, this might not be the case as mission times increase in duration.

CREW COMPOSITION

In the GSDM, six individuals were brought together, not because they were compatible as a group, but because of their professions and because of what they could learn through the GSDM to further their professional goals. It is very difficult to select a crew for a scientific mission, because scientists cannot be trained in the same manner as pilots. They have to be selected from scientists who are available in those areas required and who have particular interest and willingness to perform in situ studies in space.

The scientists selected on this basis may not be the best individuals to ensure a harmonious society for the space station. Trade-offs will have to be made, and they will probably involve having less technically competent scientists but more socially compatible ones, or possibly training a technical man to work with the scientist on the ground.

Three to six months is a long time for one to be isolated and confined in a hazardous environment. Crews will have to be more than just technically compatible to maintain the morale and effectiveness at a level necessary to successfully explore the whole of the space environment.

The possibility of having an international crew on board some of the space missions is being considered. Two requirements for an international crew are as follows:

1. The language used on the space mission should be common and spoken fluently by all crewmembers. All communication should be in this common language.

2. The social background should be similar. This requirement tends to be more important for an international crew than for a crew of only one nationality.

The differences and problems that can be expected between the operational astronauts and the scientists and the need for identifying them in a real sense are major concerns. Without elaborating on these differences, we offer one solution that we believe would help to minimize them. It is important for every crewmember to feel he is part of the team and involved to some extent in all aspects of the mission. This can be accomplished through cross training. The operational astronauts should be cognizant of the scientific experiments on board the mission, and the scientists should have some knowledge of the operations of the overall space station. In this way, each group relates to the needs and problems of the other.

History has revealed that attempts by man to explore and settle new frontiers without the aid of women have been unsuccessful. Although the inclusion of women into these types of explorations may cause problems, we believe that these problems can be solved and efforts should be continued in that direction. There is little doubt that men and women can work side-by-side in exploring the universe, just as they have done so successfully in all corners of the earth. It is significant that in 1969 four women scientists were included for the first time as part of the crew of an antarctic scientific mission; and, more recently, a crew composed only of women performed in the Tektite II mission.

CREW ORGANIZATION

Every attempt should be made to avoid structuring the command and control function on a space station in the traditionally military fashion. The management structure, of course, must be well defined, and the space station commander should have the ultimate decision-making power; but this should be accomplished without establishing a rank-conscious environment on board space stations with a scientific crew. One way of achieving this would be for the engineering and scientific crewmembers to provide the commander with data from their respective areas to assist him in making decisions that affect the entire crew or operation of the vehicle.

Any decision made either on the ground or by the commander that impacts the living and working functions of the crew should be discussed with the crew prior to making the final decision. This method of management should foster good relationships among the crew and between the crew and the commander.

PHYSICAL ENVIRONMENT IMPACT

The two major frontiers challenging man today (space and the ocean) have environments that place hardships and physical stress upon him, relative to living and working there, unlike any frontier that he has tried to conquer before. These environments require him to live in a confined and isolated habitat, completely removed from his natural and social environment. He must depend on the continuous functioning of mechanical and electrical equipment for his survival, and the constant possibility of a failure that might endanger the crew or the mission is one of the major causes of stress during a mission. These stresses are well known, but the questions that remain unanswered are: "How do they affect the success of the mission?" "What is their relative importance?" "What can be done to minimize them on long-duration missions?"

There will always be risk factors for crewmembers on missions in space and ocean environments, and those who choose to participate in these missions must reckon with these risks in their own way. The author rates this factor very low in terms of the effects that it has on the crewmembers in the performance of their duties in the mission. It is believed that one acquires a clear understanding of the vehicle he is to live in prior to the mission and develops a strong confidence in the operation of the system with each passing day. Thus, the effect of stress as a result of just being in this different environment will, with experience, be negligible.

The stress caused by isolation and confinement cannot be dismissed as easily as the risk factor discussed before, because it is these isolation and confinement factors that so greatly tire the crew as mission time increases. It is very important that the characteristics of these factors be identified in minute detail and that solutions be found which will minimize their effect on the crew.

Stress caused by isolation is the most important stress-causing factor and stems from being separated from one's family, friends, and normal social environment. It also stems from being separated from the environmental stimuli (e.g., sun, trees, rain, snow, etc.), which are a very important part of our everyday lives. Designs and solutions that can minimize this stress will be a necessity in long-duration space stations.

A real appreciation for the necessity of a good habitability design for space stations was acquired as a result of the GSDM. The proper design of recreation, space, facilities, work areas, eating and sleeping areas, and personal hygiene facilities is very critical in minimizing the isolation stress discussed before. The proper selection of crewmembers for social compatibility is an even more important factor as mission duration increases. One of the fundamental problems facing the designers of manned space systems is the living and working problem as opposed to the hardware problem.

Confinement is believed to be the second most important stress-causing factor. The inability to experience relief of psychological pressure by the leaving and reentering of an environment is cause for concern. The design and layout of areas that provide individuals a choice of several places to go can help minimize this problem. One such area could be a physical recreation area that could consist of exercise equipment, sauna-type baths, sunbathing facilities, and access to plants and flowers or other similar naturalistic sources that can, in essence, provide a feeling of temporary escape from the world of isolation and confinement.

To reiterate for space station designers, we ask, "Why place so much emphasis on the factors that affect man's living and working capabilities?" One should remember that a major requirement that must be satisfied in the space station proper is to provide an environment that is conducive to accomplishing scientific research. This requires the designers to think beyond simply providing a safe and liveable environment for the crew that maintains the space station. A habitability design must be provided that will minimize stress on the crew and leave the mind free for analytical and creative thinking.

Habitability Systems

The design requirements for the habitability systems are dictated by the type of people who use them and by the type of mission that they must accomplish. This report clarifies and emphasizes that the habitability requirements of a space station designed to be occupied by scientists should be very different from one designed for an operational crew performing a probe-type mission only.

Man, the scientist, in his everyday life on earth, lives in a house and travels to his laboratory to accomplish his work. In designing the space station, it seems only natural to separate these functions in terms of living and working areas. The space station concept can then be thought of as a place to live (the space station proper) and a place to work (the various scientific laboratories or modules). Once these functions are separated, then a functional and livable space station design can evolve.

A house is partitioned into rooms, each having a function according to the family's needs or desires. Some of the rooms required to satisfy the family functions are a recreation room, a kitchen, bedrooms, physical exercise areas, sauna baths, greenrooms for plants, a conversation or living room, a reading or study room, and personal hygiene rooms. The space station should provide areas for these types of functions for the space family.

Consideration should be given to private rooms for all individuals with doubling-up considered only during the resupply or crew-change period.

Showers should be considered as opposed to washcloth-type bathing or hand-held water sprinkling systems.

A 6-day workweek should be considered as opposed to the 7-day workweek now being planned. The day off is needed to allow the mind to take stock of what is happening in a relaxed environment.

Hot water should be considered as the means of providing sterilized water, at least for the purposes of drinking and food preparation. Chemicals that affect the taste of the water can have a very significant negative impact on the morale of the crew.

The diet should be widely varied, and there should be a capability to prepare cooked foods. To have all foods of the dehydrated or freeze-dried nature for long-duration missions would be placing an unnecessary stress on the crew. This could affect the crew's performance in accomplishing their scientific mission.

Environmental Gas Analysis

In closed ecological systems designed to sustain life, the capability must be provided to sense and analyze the various constituents in the air. Presently, there is no practical way of detecting and measuring all the contaminants that could endanger the lives of the crew in a space station. The primary sources of these contaminants will be from materials used in the construction of the vehicle and the onboard equipment, from fluid storage, and from man living in the environment. Every precaution will be taken in the design phase to select only those materials that will be compatible with the manned environment; however, this should not preclude the capability to detect a wide range of contaminants caused by the complexity and uncertainties associated with developing a capability to operate in the space environment.

The GSDM was believed long enough in duration to cause concern about contaminants that might show up in the environment. This being the case, NASA was presented with an opportunity to evaluate several techniques for contaminant detection and control of a completely closed ecological system of similar duration to the first workshop.

Throughout the mission, contaminants were checked both on a daily and a weekly basis. The instruments used for detection and analysis during the mission were drager tubes and a gas chromatograph. Air tubes were also used to collect samples periodically throughout the mission for detailed laboratory analysis after mission completion. The drager tubes were used to monitor 10 metabolic contaminants on a daily basis, and an additional 28 contaminants were checked on a weekly basis. The gas chromatograph contained two columns that were used to check for the presence of nitrogen, oxygen, carbon monoxide, carbon dioxide, hydrogen sulfide, and methane in the environment.

Through the daily contaminant checks, carbon monoxide was detected and monitored throughout the mission. This gas steadily rose in concentration during the mission, and all attempts to control the rise were to no avail. The concentration at the end of the mission was 44 ppm, and it was decided arbitrarily that should the level reach 50 ppm, the mission would be aborted. Hydrazine and acetone contaminants were detected in the weekly checks. The concentration of these contaminants stayed well below the safe levels.

The gas chromatograph field unit was used without a built-in heating element. It is believed that the lack of this heating element decreased the sensivity of the unit and caused the inconsistent readings obtained during the mission. The use of this instrument is time consuming for the crewmembers who collect and analyze the data. A system that could perform this operation automatically is most desirable.

Aside from the safety aspects of not being able to measure the contaminants, there is a potential psychological stress associated with the uncertainty of the contaminant status of the environment. This uncertainty can only be dispelled with the appropriate instrumentation that can monitor the status of the environment at all times.

Microbiology

Normally, the total number of micro-organisms found in the human flora is relatively fixed, and a state of equilibrium is maintained between the number of potentially dangerous (pathogenic) and harmless (nonpathogenic) species; this equilibrium is evidenced by the host's health. The probability of disease grows with any disturbance of this equilibrium; but living in the open ecology of office or home, such disturbances are quickly overcome by the body's normal defenses and the host remains healthy.

Once confined to closed quarters within the regime of biological isolation, as in a space vehicle, the flora of each of the crewmembers will be in intimate contact with each other and with the vehicle interior long enough to permit alteration of the ecological relationship. This may manifest itself in simplification, transferences, and shifts of the flora. Actions and interactions may be further intensified by any degradation in personal hygiene and in the cleanliness of the environment.

To date, few microbiological data have been collected on man, his environment, and sustenance during total biological isolation in a stressful environment. Although this area presents critical and perhaps even limiting constraints on long-duration manned missions in stressful environments, not enough has been done to identify problem areas and to devise solutions. The Ben Franklin vehicle used in the GSDM provided an excellent opportunity to add data points on the microflora aspects of a long-duration mission under stress conditions.

The mission was used to obtain data in the microbiological area using an onboard crewmember to collect, analyze, and act on the analysis in a decision-making capacity.

The equipment used to collect these data consisted of swabs, rodac plates, millipore field monitors, and an Anderson sampler (to collect airborne particles). The areas from which data were taken were the water system, environmental surfaces and air, and the human body. [3]

The results of this effort thus far indicate the following:

1. For a manned system, contaminant control features involving biological isolation should be considered during conceptual design.

2. The microbiological contamination must be considered.

3. Systems should lend themselves to flushing, cleaning, and sterilization.

4. Materials should be selected to be biocompatible.

5. For safety and psychology reasons, onboard sampling of water, environment, and humans response should be accomplished during long confined missions.

Data are needed on 60- and 90-day missions to determine whether breakdown of personal bacteria will occur and persist; incorporate resupply and crew changes to investigate the possibility of bioshock; and consideration should be given to hot water systems as a means of sterilization.

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3. See Final Report OSR-70-7 for the detailed results of this study.

Maintainability Study

To successfully maintain systems in a space environment, careful consideration must be given to many factors, some of which follow:

1. Man's capability to do work in a stressful environment.

2. Man's time spent performing maintenance.

3. Design of systems for maintainability.

4. Level of maintenance that can be accomplished.

5. Commonality of equipment and components.

6. The cost of performing maintenance.

A maintainability analysis of the Ben Franklin systems was performed before the mission, and a maintainability plan was developed that included scheduled maintenance actions, spares required, and crew time required for accomplishing the predicted maintenance actions.

There were subsystem failures very early in the mission that might have caused the mission to be aborted had the system not been successfully repaired. Although the mission planners did not consider that certain skills were critically needed on board for maintenance and repair in case of a subsystem failure, through good fortune, the necessary skills were available on the mission to allow the repairs to be accomplished. As mentioned before, the spares required were predicted; but, because of a volume constraint, very few spares were on board. The lack of spares forced the crew to repair parts in order to keep the systems functioning.

Having all the spares that were predicted as being needed would not have solved our problems, because the majority of the failures that occurred were not predicted. Some of the failures occurred in the scientific instrumentation areas, which were not a part of the maintainability analysis. There was a considerable amount of cannibalizing of equipment, and even some circuit redesign had to be done to keep all the equipment operating. The equipment that failed but was not repaired was inaccessible; i.e., it was located on the outside of the vehicle. Also, equipment that failed toward the end of the mission was not repaired when it was not required for completion of the mission.

The author has always been a strong supporter of blackbox replacement with commonality where practical as the way to force the maintenance philosophy for the space program. However, this should be examined closely and traded off against higher skills and lower levels of maintenance.

Conclusion and Recommendation

One of the fundamental problems confronting NASA in the space program is that of providing a habitable environment where man can learn to live and work in space. Data obtained by NASA from the GSDM prove conclusively that the space program can gain considerable experience and data by actively participating on teams that will explore the ocean in the next decade.

The oceanographic community, although not yet well organized, has plans to explore the ocean at an unprecedented rate over the next decade. The missions being studied will utilize both fixed and mobile habitats. It would be especially fruitful for NASA to participate in those missions lasting 30 days or more. Each type of habitat has its own unique features that can provide useful data in areas related to space systems.

In return, NASA can integrate a considerable amount of technology into the design of equipment to be used in the ocean explorations. A sharing of the cost of these missions makes it more cost effective to cooperate in future missions for maximum output.

APPENDIX

GRUMMAN/PICCARD BEN FRANKLIN GSDM

The objectives of the GSDM commenced with the first concepts of a drift mission in the Gulf Stream set forth by Dr. Jacques Piccard and have evolved over a period of several years. In addition to Dr. Piccard, the interests of the Grumman Corporation (Grumman), the U. S. Naval Oceanographic Office (NAVOCEANO), the National Aeronautics and Space Administration (NASA), and countless individuals in the scientific community have contributed to the evolution of these objectives.

Primary Objective

The primary objective was to permit the deep submersible Ben Franklin to drift with the Gulf Stream safely for 30 days while the crew performs scientific oceanographic studies within the capabilities of the craft and support system.

Supplementary Objectives

The supplementary objectives were as follows:

1. Travel the maximum distance along the track of the core of the Gulf Stream at varying depths.

2. Investigate the analog aspects between a submersible vehicle and a space station during a long-duration, closed-environment, stressful voyage.

3. Demonstrate the engineering/operational concepts associated with long-duration submersible operation.

Ben Franklin Characteristics

Net weight	— 142.95 tons
Internal volume	— 3769.7 ft^3
Length	— 48 ft
Outside Diameter of pressure hull	— 10.33 ft
Beam (over ballast tanks)	— 13.33 ft
Beam (including motors)	— 18.5 ft
Beam (including motor guards)	— 20 ft
Height	— 21 ft (to top of sail)
Draft	— 14 ft
Access	— Two 30-in. hatches
Maximum operational depth	— 2000 ft
Collapse depth	— 4000 ft plus
Battery power	— 750 kW-h (10-hr rate)
Propulsion	— Four 25-hp, 3-phase variable frequency motors
Power conversion	— Two variable frequency (60 kV-A) solid-state inverters for propulsion
	— Two fixed frequency (3 kV-A) solid-state inverters for rotating propulsion motors 360 deg
	— Two 110-Vac solid-state inverters for various onboard equipment

Visibility	— 29 viewports
Potable water	— 188 gal hot water 380 gal cold water
Total life support	— 6 men for 4 wk with a 2-wk reserve
Emergency ballast	— 6 tons of steel shot
Maximum ascent rate (calculated)	— One-shot ballast tank — 180 ft/min Two-shot ballast tanks — 257 ft/min With motors — 2 m/sec
Normal descent rate	— 1.4 ft/sec (calculated)
Maximum submerged speed	— 4 kt
On surface time from full ahead to stopped, using all back full	— 20 sec
Endurance (calculated 8 hr at full speed)	— 2 kt, 2 motors — 0.126 n. mi./kW-h 3 kt, 2 motors — 0.074 n. mi./kW-h
Thrust	— 1000 lb per motor (nominal max)
Trim and list angles (calculated)	-- Normal trim ±10 deg — Emergency trim ±25 deg Normal list 0 deg — Emergency maximum list ±17.6 deg
Submerged Buoyancy Gravity (BG)	— 10.3 in.

Grumman-Piccard Experiment — Oceanographic Optics

EXPERIMENTAL PROCEDURE

Measurements will be made of chlorophyll (plankton), minerals (fluorescent), and bioluminescence.

The measurements of chlorophyll and minerals are to be taken approximately every 8 hr, preferably during the night because residual light from the sun penetrating the sea causes an undesirably high background level that obscures precise measurements of the desired parameters.

The measurements of chlorophyll and minerals will also be taken if any unusual phenomenon occurs, such as a change of sound velocity in the sea or a change in downwelling light, and before and after any depth or position change of the Ben Franklin.

The measurements of bioluminescence are to be taken during forward propulsion maneuvers.

All measurements will be taken, if possible, with external Ben Franklin lights out, and preferably with internal lights out, or at least with internal light to the aft portholes blocked so that the sensors have as low a light background as possible.

No measurements will be taken during the day at depths less than 100 ft, because they will be generally worthless as a result of the high background light, and the photomultiplier sensors may be damaged.

Date and time of all measurements are to be recorded.

NAVOCEANO Scientific Program

The scientists of the Oceanographic Office are particularly interested in the GSDM, one of the most extensive scientific operations ever to be conducted aboard a manned submersible, because it is expected to yield valuable data on the nature of the stream, the marine plants and animals associated with the stream, and the sea floor topography over which it flows. The mission also will provide the oceanographic Office with valuable knowledge on the use of a deep-diving, manned submersible for ocean research and survey work.

OCEANOGRAPHIC OBJECTIVES

Nature of Gulf Stream. One of the primary oceanographic objectives of the GSDM will be to investigate the nature of the Gulf Stream. This objective will include studies of the stream's velocity (speed and direction), its turbulence, and its physical and acoustical properties as they are associated with depth and time.

Current Study. Hoping to stay within the stream's high-velocity jet (that portion of the Gulf Stream where the current is strongest and where both temperature and salinity can reach their extremes), the scientists want to drift 600 ft below the surface with the high-velocity jet as it flows at speeds varying from 2.7 kt in the northern Florida Straits to 1.3 kt off Cape Hatteras, North Carolina.

Instruments. While drifting in the Gulf Stream at a depth of 600 ft, the scientists will use deck-mounted current and turbulence sensors to obtain relative data on the stream's direction and speed. They will also be measuring its temperature, salinity, sound velocity, and pressure using a water sensor pod developed specifically for submersibles. This pod continuously senses these characteristics and records its measurements on magnetic tape every 2 sec.

To measure the relative transparency of water masses encountered by the submersible, the scientists will use a transmissometer, an instrument that records the amount of light absorbed by 1 m of water.

The scientists will also use an ambient light photometer to measure the percentage of sunlight penetrating the water to the submersible's level of operations at 600 ft.

Acoustical Properties of Deep Scattering Layer. In addition to studying the nature of the Gulf Stream, the oceanographers aboard the Ben Franklin want to observe the deep scattering layer (DSL) (layers of migrating marine organisms that reflect sound as they ascend to the surface at sunset and descend to middepths at sunrise). Other than knowing the migration habit of the DSL, scientists have little knowledge either on what marine animals compose the layers or how they behave in the layers. While drifting at depths of 600 ft, the scientists hope to see the layer as it passes the submersible. As it passes, they plan to transmit sound waves into it. They also want to transmit sound waves into the layer when it is below the submersible and when it is above the deep-diving vehicle. From this experiment, they will learn more about how the layer scatters sound and also how to discern the frequency of echoes bounded back by the layer. To record the acoustical properties of the DSL, the scientists will use an acoustic system that consists of two transducers to transmit sound waves and a receiver to return the scattered echoes back to the scientists. The sound waves and echoes will be recorded on magnetic tape for later analysis. As the DSL passes the submersible, the scientists hope to determine the types of marine animals or components comprising the layer by identifying them visually and photographically. While the layer passes the submersible, the researchers will sample the water around it to obtain an idea of the environmental conditions that sustain the marine animals in the layer.

Two 70-mm cameras are mounted on the bow of the submersible, and 70- and 16-mm cameras will be operated by scientists watching the layer pass by two of the submersible's 29 viewports. The 70-mm cameras mounted on the vehicle's bow will produce stereographic pictures, from which the actual size of the marine animals in the layer can be determined. For their lighting system, the scientists will use a Sea Arc light while the 70-mm cameras mounted on the bow are in operation. This light projects a ray of almost constant intensity and diameter several feet into the water.

Sea-Floor Geology. During the drift mission, the NAVOCEANO scientists plan to make six excursions, each 24 hr long, to depths of 2000 ft in an effort to delineate the sea floor over which the Gulf Stream flows. During all of the excursions, the scientist will inspect the surface sediments of the sea floor to determine visually the differences in sediment size and color, and natural characteristics. They also hope to observe sediment properties (such as ripple marks), plants growing on the sea floor, and inhabitants of the plateau. These visual observations will help them to determine the relationship of one to another. The scientists will combine their visual observations with acoustic and photographic measurements.

To acoustically map the sea floor, the scientists will use a side-scan sonar system that is designed to record profiles of a sea floor area 200 ft wide on each side of the submersible hovering at 30 ft over the bottom.

The scientists will use two 35-mm cameras and two 250-W-sec strobe lights to obtain 3300 stereo-pair photographs of the sea floor. These cameras will provide pictures that the scientists can later use to determine the dimensions of objects photographed on the sea floor. They will also take pictures through the viewports with hand-held, still, and motion-picture cameras.

Sub-Bottom Geology. While hovering over the sea floor, the scientists also hope to obtain profiles showing the layering of sediments beneath the surface of the sea floor. The sub-bottom profiler to be used by the scientists aboard the Ben Franklin is capable of generating 5.5-kHz frequency sound waves that penetrate the sea floor's sediment layering and are reflected off the bedrock back to hydrophones mounted on the submersible's hull.

Bottom Loss. At selected locations during the drift at 30 ft above the bottom, the scientists will measure acoustic reflectivity or "bottom loss." Often during sonar ranging operations, scientists and naval personnel cannot account for the loss of sound pulses. They know that some of the sound pulse emitted into the water column spreads out into the water, some of it is absorbed by the water, and some of it is lost when it hits a target. To measure this sound loss, the scientists will use a hydrophone designed to receive signals from noise produced by detonating explosives from a support ship.

Gravity, Magnetic Anomalies. During selected bottom excursions, the scientists will periodically measure both gravity and magnetic deviations called "anomalies." Gravity anomalies occur as differences between observed gravity and theoretical gravity, which is based on accepted figures for gravity as related to the size and shape of the earth. When gravity anomalies are found, geologists may be able to associate them with geological structures and may also be able to determine the elevation of the surface of the sea floor. By taking gravity and magnetic measurements, the scientists aboard the Ben Franklin not only may discover uncharted geological features, but also will obtain a general outline of the geophysical characteristics of the sea floor. To measure the gravitational attraction, the scientists will use a La Coste-Thomberg gravimeter geared with sensors designed to measure the pull of gravity. The gravimeter also has a recorder to store the measurements. To record the earth's magnetic field and any local deviations in the field's intensity and direction, the scientists will use a magnetometer.

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APPROVAL

THE MAN-RELATED ACTIVITIES OF THE GULF STREAM DRIFT MISSION

By Chester B. May

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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