BELLCOMM, INC.

TR-67-710-1

MEDICAL REQUIREMENTS IN SUPPORT OF LONG DURATION MANNED SPACE FLIGHT

November 20, 1967

D. B. Hoffman
A. N. Kontaratos

Work performed for Manned Space Flight, National Aeronautics and Space Administration under Contract NASW-417.

TABLE OF CONTENTS

ABSTRACT

The objective of this study is to suggest a broad medical program in support of advanced manned missions. Twelve factors which concern the general health and performance of the crew are examined; appropriate decisions necessary to prevent or rectify possible failures are established; engineering implications are discussed; and pertinent ground-based or in-flight studies are proposed. These factors include: weightlessness, radiation, meteoroids, extraterrestrial life, magnetic fields, habitability, atmospheric contaminants, mechanical forces, artificial atmospheres, nutrition, and medical care.

From this analysis eleven major medical decisions were identified, their significance discussed and their implications reviewed. Finally, research activities were integrated into a program sequence and medical decisions were time phased to illustrate both the type of planning required and the extent of interoffice coordination needed to support a pacing goal.

INTRODUCTION

This study originated as a response to a query by NASA/MM to generate a display of the in-flight biomedical/ behavioral experiments program. However, the work reported here transcends the original request and, in anticipation of future needs, attempts to define medical requirements and objectives as they affect the planning of advanced space flight missions.

Future plans for manned space flight are based on the assumption that man can function in space for extended periods without deleterious effects. However, environmental factors endemic to space flight may cause physiological and performance decrements the determination and prevention of which necessitate the planning of a comprehensive research program.

The objective of this study is to define a broad medical program aimed at the identification of the information needed to determine both the effects of prolonged space flight on man and the means of sustaining him in the space environment. For this purpose the environmental stressors to which astronauts could be subjected have been determined; their effects on body functions have been reviewed; the resulting medical decisions have been identified; the engineering implications of these decisions have been established; and research requirements such as ground-based R&D, and inflight experiments have been defined.

This analysis resulted in the discrimination of eleven major medical decisions with varying research and engineering implications. In order to illustrate the effect of such implications on the evolvement of a typical program, the established major medical decisions have been time phased over a ten-year period. However, since time phasing of decisions is necessary only if demands imposed by a pacing goal are to be met, a manned planetary reconnaissance mission was assumed as an end point forcing medical and medically oriented research activities during the interim period.

RESEARCH OBJECTIVES

In this section the scope of Space Medicine is briefly reviewed and research requirements are identified as a result of stressors to which astronauts could be subjected.

Space Medicine is the science devoted to the support of man in his quest to explore and exploit extraterrestrial space. It identifies the environmental factors associated with space flight and investigates the effects such factors have on man. In addition, it seeks to develop techniques either for the prevention or for the recognition and treatment of performance degrading conditions.

Factors that are believed to be significant for man in space can be arbitrarily classified as follows:

I. NATURAL ENVIRONMENT FACTORS

- Weightlessness
- Radiation (ionizing and non-ionizing)
- Meteoroids
- Extraterrestrial Life
- Magnetic Fields

II. INDUCED ENVIRONMENT FACTORS

- Habitability
- Atmospheric Contaminants
- Mechanical Forces

III. LIFE SUPPORT FACTORS

- Artificial Atmosphere
- Nutrition
- Medical Care

Implications introduced and research requirements imposed by each of these factors are identified in Tables 1 through 12. It is evident from these tables that attainment of medical goals in support of overall NASA objectives involves a multiplicity of research tasks. Proposed studies can be classified into three major areas in terms of their scope. Namely, Medical Operational Support, Ground-Based R&D and In-Flight Experiments. The Medical Operational Support effort encompasses such activities as preflight preparations, post-flight examinations, and inflight monitoring for real-time operational decision making. Earth-bound Research and Development encompasses simulation studies and provides the advanced technology required for sustaining and supporting man during extended space flight. Finally, the In-Flight Experiments Program seeks to identify the effects of space flight on man and determine the etiology of the findings observed.

The classification of research activities into three major areas and subordinate categories is shown schematically in Figure 1. The need of strong interoffice coordination between OMSF, OSSA and OART is evident and the suggested breakdown could be used to assign programming responsibilities.

Space environmental stressors act collectively, affect individually more than one area of body function and are difficult to evaluate singly. Some stresses can be simulated in ground-based studies, but the actual flight situation cannot be duplicated in the laboratory. Consequently, the inflight experiments program constitutes the only approach that can help establish the effects of prolonged space flight on man, reveal the time courses of these effects, determine the mechanisms by which these effects are mediated, identify means of predicting the onset and severity of these effects and develop preventive or remedial techniques to cope with them.

The current program of inflight medical experiments is the product of an integrated study comprised of a number of NASA in-house efforts and contracted industrial participation (Ref. 1, 2, 3, 4, 5, 6 and 7). For R&D purposes, the total program has been divided into eight component areas of body function, and the required measurements and procedures within each area have been defined on a medical necessity rather than on a state-of-the-art or payload capability basis. These eight areas and their component measurements and procedures have been reviewed, revised, and approved by the Medical Advisory Council. The resulting program, slightly amplified, is displayed in Figure 2 as a series of objectives, selected knowledge requirements, and identified measurements.

TABLE 1

FACTOR	WEIGHTLESSNESS
EFFECTS ON BODY FUNCTIONS	1. Significant changes involving the cardiovascular, musculoskeletal, and hematopoietic systems have been observed to date. These appear to be adaptive in nature and are measured principally during the period of readaption to normal Earth conditions. 2. Lack of dynamic stability degrades performance during EVA.
DECISIONS TO BE MADE	1. Establishment of acceptable limits to space-induced physiological changes. 2. Necessity of inflight artificial gravity a. Continuous b. Intermittent c. Prior to re-entry only 3. Adequacy of countermeasures other than artificial gravity (see Figure 2 under cardiovascular).
ENGINEERING IMPLICATIONS	1. Artificial gravity alternatives: a. Onboard centrifuge b. s/c rotation c. Tethered rotation 2. Provisions for resupply and observational experiments under mode (b) or (c). 3. IVA and EVA technology.
GROUND BASED R&D	1. Determine the psychophysiological effects of enviromental factors other than weightlessness and radiation on animals and humans. 2. Obtain astronaut physiological baselines. 3. Develop and improve physiological deconditioning countermeasures (other than artificial gravity). 4. Develop zero-g tools, body restraints, mobility aids, training procedures and operational techniques for EVA applications. 5. Continue investigations of vertigo, coriolis and gravity gradient effects should artificial gravity (rotation) prove necessary. 6. Refine crew selection criteria. 7. Develop means to aid astronaut housekeeping (e.g. laminar flow control of s/c atmosphere, adhesion, magnetic retention, suction, etc.).

TABLE 1 (CONTINUED)

FACTOR	WEIGHTLESSNESS
IN-FLIGHT STUDIES	1. Determine man's physiological response to space flight (Pertinent measurements are listed in Figure 2). Identify body functions involved, extent of involvement, time courses and mechanisms. 2. Determine readaptation response of man to terrestrial conditions following prolonged space flight. 3. Determine the effectiveness of deconditioning countermeasures (other than artificial gravity). 4. Determine minimum acceptable g-level, if artificial gravity proves necessary. 5. Conduct cellular and animal physiological studies to delineate problem areas and supplement human research (pilot studies). 6. Evaluate human performance and effectiveness of supportive hardware during crucial EVA phases (e.g. rescue, transfer, assembly, etc.).

TABLE 2

FACTOR	RADIATION (ionizing)
EFFECTS ON BODY FUNCTIONS	1. Early lethality* a. Hematopoeitic depression b. Skin desquamation c. Gastrointestinal Tract denudation d. Central Nervous System disruption 2. Early sublethal effects a. Prodromal reaction (nausea, vomiting, diarrhea) b. Incipient effects (skin erythyma, bone marrow depression. c. Temporary sterility 3. Delayed effects a. Reduced Life Expectancy b. Leukemia induction c. Increased occurrence of malignancies d. Cataract formation 4. Genetic effects
DECISIONS TO BE MADE	1. Establishment of mission-specific radiation protection guide lines. 2. Establishment of operational procedures during radiation emergencies. 3. Establishment of preventive and remedial treatments.
ENGINEERING IMPLICATIONS	1. Mission-specific shielding requirements (type, thickness, configuration). 2. Provision for areas of maximum safety. 3. Radiation hazard warning system (both ground based and onboard).
GROUND BASED R&D	1. Continue current programs to understand radiobiological processes and to better define dose-effect relationships. 2. Continue analytic efforts to quantify the space radiation enviroment. 3. Continue research on tissue equivalent dosimeters and spectrometers to measure both rate and total absorbed dose at various body depths and to reveal the type of radiation absorbed. 4. Develop preventive and remedial treatments. 5. Study the potential application of non-conventional shielding (e.g. pure magnetic, plasma, etc.).

---

* Unlikely under space flight exposure.

TABLE 2 (CONTINUED)

FACTOR	RADIATION (ionizing)
IN-FLIGHT STUDIES	1. Monitor the radiation dose to which astronauts are being exposed. 2. Maintain a complete record of radiation exposure sustained by each astronaut throughout his flying career. 3. Continue unmanned measurements to improve the description of the radiation environment. 4. Determine the combined effects of weightlessness and radiation on animals.

TABLE 3

FACTOR	RADIATION (non-ionizing)
EFFECTS ON BODY FUNCTIONS	1. Lack of light dispersion medium in space results in strong contrasts of simultaneously perceived brightnesses. 2. Visible light emanating from the sun is potentially damaging to vision (retinal destruction). 3. Ultraviolet radiation produces photochemical reactions in exposed tissues. 4. Solar infrared radiation is potentially damaging to the face and the eyes (lens) where protection is minimum. 5. Intense microwave radiation can produce lethal internal damage.
DECISIONS TO BE MADE	1. Hazard evaluation (mission specific). 2. Establishment of acceptable threshold limits.
ENGINEERING APPLICATIONS	Intravehicular and extravehicular safety provisions (thermal garments, effective visors, absorbing window panels, window shades).
GROUND BASED R&D	1. Continue research on thermal garments for EVA. 2. Continue research on helmet-visors to minimize exposure without impeding vision. 3. Determine dose-effect relationships.
IN-FLIGHT STUDIES	Validate design adequacy of space suits and protective crew equipment.

TABLE 4

FACTOR	METEOROIDS
EFFECTS ON BODY FUNCTIONS	1. Decompression following penetration. 2. Burns due to fire or flash. 3. Physical injury from fragments. 4. Flash blindness.
DECISIONS TO BE MADE	1. Mission-specific risk probabilities must be established. 2. Emergency procedures following penetration must be established.
ENGINEERING IMPLICATIONS	1. Shielding requirements (mission specific). 2. Safety provisions in S/C design which minimize effects of penetration (type of atmosphere, hull and subsystems accessability, maintainability and fire resistance).
GROUND BASED R&D	1. Continue current theoretical programs to describe the meteoroid and asteroid environments. 2. Continue research on hypervelocity impact processes. 3. Continue research on penetration consequences in an operational spacecraft structure. 4. Continue assessment of the effectiveness of various types of shielding (e.g. bumpers, etc.). 5. Develop emergency operational procedures (i.e. detection, crew protection, damage location, diagnosis, repair and reactivation). 6. Develop fire resistant materials for S/C and astronaut suits. 7. Develop hazard detection, penetration warning systems and sealing techniques. 8. Develope self-contained emergency breathing apparatus for protection against decompression and fire.
IN-FLIGHT STUDIES	Encourage unmanned programs to study the deep space meteoroid environment.

TABLE 5

FACTOR	EXTRATERRESTRIAL LIFE
EFFECTS ON TERRESTRIAL LIFE	1. Potentially pathogenic to man or other terrestrial species. 2. Potentially disruptive to existing ecosystems.
DECISIONS TO BE MADE	1. Determine decision criteria for return of lunar and planetary samples to Earth. 2. Necessity and scope of activities of an astronaut-biologist. 3. Sample handling methodology.
ENGINEERING IMPLICATIONS	1. Sterilization of probes and sampling devices (killing and/or removal of biological material or debris). 2. Biologically isolated laboratory for in-flight detection, characterization and preservation of alien life.
GROUND BASED R&D	1. Improve sterilization methods and techniques. 2. Develop systems for biological isolation and remote manipulation. 3. Develop facilities for assembly, checkout, maintenance and repair of components after final sterilization for both preflight and inflight applications. 4. Develop appropriate life detection and characterization equipment, procedures and techniques (both for manned and automated planetary explorations). 5. Validate developed equipment and techniques for life detection and characterization in the terrestrial biosphere. 6. Establish cross contamination control procedures. 7. Continue studies on the effects of simulated planetary environments on terrestrial life forms and vice versa.
IN FLIGHT STUDIES	1. Unmanned missions. Obtain information regarding the physical and biological characteristics of other celestial bodies.

TABLE 5 (CONTINUED)

FACTOR	EXTRATERRESTRIAL LIFE
IN FLIGHT STUDIES	2. Manned missions. Examine retrieved samples as soon as possible (post-recovery). Search for life, determine its basic attributes, if present, and develop means to preserve it for subsequent earth-based studies.

TABLE 6

FACTOR	MAGNETIC FIELDS
EFFECTS ON BODY FUNCTIONS*	1. Low-intensity magnetic fields (Lunar, Martian, Venusian, and interplanetary environments). a. Human subjects exposed to intensities below 50 gammas for 10 days showed a progressive decrease in the scotopic critical flicker-fusion frequency which returned to normal post-exposure. All other physiological tests yielded negative results. b. Mice exposed to intensities below 100 gammas for periods of 4 to 12 months showed positive histopathological alterations and their progeny exhibited abnormal physiological and behavioral manifestations, as opposed to control specimens. c. Cell cultures, as compared to controls, showed a fifteen-fold reduction in the number of colonies, as well as some reduction in colony size when exposed to intensities approximately one-tenth of that of Earth. 2. High-intensity magnetic fields (possible future use of pure magnetic or plasma radiation shielding and MHD propulsion). a. Magnetic fields of up to several thousands oersteds can be tolerated by human subjects for brief periods of time. b. There is evidence from experiments with sub-human systems that the application of magnetic fields of a few hundred oersteds over long periods can result in functional alterations and physiological damage.
DECISIONS TO BE MADE	Hazard evaluation (mission-specific).
ENGINEERING IMPLICATIONS	None at present.

* Data cited is taken from "Biomagnetics," NASA CR-889.

TABLE 6 (CONTINUED)

FACTOR	MAGNETIC FIELDS
GROUND BASED R&D	Continue and refine investigations of the effects of magnetic fields on animals and humans.
IN-FLIGHT STUDIES	Measure the magnetic field intensity to which astronauts are being exposed.

TABLE 7

FACTOR	HABITABILITY (Confinement, Isolation, Relative Immobility, Living Conditions, Personal Hygiene, Crew Safety and Performance)
EFFECTS ON BODY FUNCTIONS	1. Psychological Responses a. Behavioral Changes b. Performance decrements 2. Physiological Consequences a. Non-specific stress response b. Cardiovascular deconditioning c. Musculo-skeletal deconditioning
DECISIONS TO BE MADE	1. Mission-specific minimum volume per man, S/C configuration, crew size and crew composition. 2. S/C accommodations, decor, illumination, conveniences, personal hygiene, furnishings, personal territoriality, etc. 3. Work-rest scheduling, task allocation, and recreation activities (circadian rhythms should be considered). 4. Length and type of mission simulation required to reveal problems. 5. Type and extent of crew training and preconditioning required to minimize problems. 6. Crew safety, provisions and emergency procedures in such cases as solar flares, decompression, fire and system failures. 7. Necessity and extent of inflight training for skill maintenance. 8. Allocation of functions among the crew, between man and machine, and between ground and flight crews.
ENGINEERING IMPLICATIONS	1. S/C architecture, interior design and safety features. 2. Maintenance of an artificial atmosphere both physiologically and psychologically acceptable. 3. Satisfactory waste management provisions. 4. Adequate diet and psychologically acceptable foods. 5. Non-mission oriented earth communication facilities (e.g., entertainment, education, etc.). 6. Tools, restraining systems and mobility aids. 7. Satisfactory cleansing and sanitation facilities. 8. Systems redundancy, accessibility, maintainability, and repair. 9. Adequate warning systems (i.e. fire, decompression, contaminants, radiation, system failures)

TABLE 7 (CONTINUED)

FACTOR	HABITABILITY
GROUND BASED R&D	1. Develop test procedures to measure and evaluate astronaut performance. 2. Encourage small group interaction and confinement studies relevant to actual flight conditions. 3. Develop techniques and materials for personal hygiene (e.g., disposable clothing, methods of laundering and cleansing). 4. Develop flash and fire resistant materials. 5. Develop self-contained emergency breathing apparatus (protection against fire, decompression, etc.). 6. Develop emergency procedures and rescue techniques (including medical treatment and psychological aids). 7. Develop systems to remove contaminants of human and material origin. 8. Develop advanced life support systems and suits for comfortable intra-capsular living and effective extravehicular activity. 9. Develop methods to maintain the operational skill and the scientific proficiency of the crew during prolonged space flight.
IN-FLIGHT STUDIES	1. Monitor crew performance. 2. Validate crew selection and composition criteria and training techniques. 3. Evaluate physical adequacy of and emotional satisfaction provided by the crew quarters. 4. Evaluate crew protective systems and emergency operational procedures.

TABLE 8

FACTOR	ATMOSPHERIC CONTAMINANTS
EFFECTS ON BODY FUNCTIONS	1. Aerosols produce eye and tissue irritations, allergies, and asthma. 2. Toxins produce wide range of systemic and tissue disorders. 3. Microbes carried on condensation droplets or airborne particles can cause infections and disease. 4. Non-toxic odorous gaseous contaminants can produce nausea and psychological stress.
DECISIONS TO BE MADE	1. Limits on allowable size and density of particulate matter. 2. Establishment of acceptable tolerance limits for contaminants and their combination with bacteria and/or drugs. 3. Astronaut selection based on respiratory sensitivity to contaminants.
ENGINEERING IMPLICATIONS	1. Inclusion of nephalometric capability. 2. Methods of control of all atmospheric contaminants to acceptable levels. 3. All exposed s/c materials must be non-toxic, and relatively free of outgassed toxic compounds and toxic thermal degradation products.
GROUND BASED R&D	1. Continue studies to assure that S/C materials do not interact with the intravehicular environment to produce toxic substances, nor yield toxic thermal degradation products. 2. Study the indigenous microflora of man and its response under conditions of biological isolation. 3. Establish appropriate non-toxic atmosphere sterilization methods (i.e., biological filters). 4. Evaluate the microbic shock hazard following prolonged biological isolation. 5. Study the effect of atmospheric composition and pressure on the toxicity hazard introduced by space cabin contaminants. 6. Study dose-effect relationship of atmospheric contaminants under prolonged and continuous exposure.

TABLE 8 (CONTINUED)

FACTOR	ATMOSPHERIC CONTAMINANTS
	7. Develop lint-free fabrics, non-flaking and particle-retaining surfaces, scuff-proof materials, etc. 8. Develop methods to remove human and S/C debris.* 9. Develop emergency breathing apparatus as protection against atmospheric contaminants during emergencies. 10. Improve gaseous contaminant detection and removal systems.
IN FLIGHT STUDIES	1. Monitor the environment for contaminants (identification, concentration, sources). 2. Validate ground established tolerance limits. 3. Investigate bacteriological ecological shifts and delineate potential problems (e.g. readaptation to terrestrial ecosystems; in-flight impact on digestion, nutrition and immunity). 4. Evaluate effectiveness of contaminant detection and removal systems.

---

* These can build up as a result of:
a. Housekeeping (e.g., food particles, nail-clippings, hair-trimmings, etc.).
b. Onboard maintenance and repair (e.g., filings, saw-dust, wire ends, solder balls, lubricants, chips, stray hardware, etc.).

TABLE 9

FACTOR	MECHANICAL FORCES
EFFECTS ON BODY FUNCTIONS	1. Rotation - Disturbance of vestibular and visual functions, disorientation and nausea. 2. Linear acceleration - Disturbance of circulatory and respiratory functions. 3. Noise - Discomfort, speech interference and possible ear damage. 4. Vibrations - Resonance of tissues and organs, discomfort and possible body damage. 5. Impact - Possible damage to organs and tissues.
DECISIONS TO BE MADE	1. Establishment of acceptable levels to all forms of mechanical stressors taken singly, combined, and in synergism with other environmental factors. 2. Acceptability of dynamic profiles (mission specific). 3. Optimum angular velocity for artificial gravity, if necessary.
ENGINEERING IMPLICATIONS	1. Minimize high intensity noise, low frequency vibrations and impact forces. 2. Design of stabilizer system to keep artificial gravity, if necessary, purely rotational.
GROUND BASED R&D	1. Continue current programs to delineate effects of mechanical forces on the body and on performance. 2. Investigate vertigo, coriolis and gravity gradient problems in case artificial gravity is required. 3. Identify operational procedures and improve restraints to minimize linear and rotational acceleration effects. 4. Continue development of vibration and impact damping couch systems. 5. Develop protective devices to reduce discomfort and prevent damage from excessive noise during launch.

TABLE 9 (CONTINUED)

FACTOR	MECHANICAL FORCES
IN-FLIGHT STUDIES	1. Monitor the dynamic profile during manned missions. 2. Study the effectiveness and limitations of any adopted inflight artificial gravity concept. 3. Determine whether acceleration and vibrational effects are more severe during or following exposure to weightlessness than before exposure. 4. Evaluate effectiveness of protective devices.

TABLE 10

FACTOR	ARTIFICIAL ATMOSPHERE (Pressure, Composition, Temperature, Relative Humidity)
EFFECTS ON BODY FUNCTIONS	1. Pulmonary and aural atelectasis is a potential hazard when pure or practically pure oxygen is breathed. 2. Shortened red cell life span may be induced by chronic exposure to oxygen pressure above the normal level. 3. General irritation of the eyes, ears, and respiratory tissues has been observed during pure oxygen exposure. 4. Dysbarism is a potential hazard following operational (planned) or emergency decompressions in two gas atmosphere. 5. Temperature and relative humidity variations beyond acceptable limits could cause discomfort and performance decrements.
DECISIONS TO BE MADE	1. Concerning the question of one vs two gas atmosphere, the following decisions have been made for missions exceeding 30 days: Intravehicular operation - 5 psi, 69% O_2, 31% N_2.* Emergency (suited) operation - 5 psi (initial), 3.9 psi (min), 100% O_2. 2. Temperature and humidity limits should be firmly established.
ENGINEERING IMPLICATIONS	1. Intravehicular ECS design. 2. Extravehicular PLSS design. 3. Operational (EVA) or Emergency (meteoroid penetration, fire, etc.) decompression procedures. 4. Environmental monitoring (intravehicular, suit system). 5. Individual emergency breathing apparatus for protection against fire and decompression. 6. Prevention of contamination of the space suit system with inert gases.

* This environment appears physiologically safe for missions up to 8 months duration based on animal tests. For longer missions this decision must be re-examined.

TABLE 10 (CONTINUED)

FACTOR	ARTIFICIAL ATMOSPHERE
GROUND BASED R&D	1. Analyze pulmonary derangements caused by the pressure and composition of various gas mixtures breathed. 2. Investigate the effect of space cabin atmospheres on oxidative hemolysis. 3. Elucidate the biological role of molecular nitrogen. 4. Continue assessment of physiological risks and determine operational procedures during controlled or emergency decompressions. 5. Study the effect of environmental stresses (i.e. temperature, total pressure, pO_2 and humidity extremes) on highly skilled psychomotor task performance. 6. Study the physiological effects of alternative spacecraft atmospheres. 7. Study the physiological response following the transit from the intravehicular two gas atmosphere to the one gas space suit environment. 8. Simulate operational and emergency metabolic loads in order to validate ECS and PLSS designs. 9. Determine the flammability of materials in various S/C atmospheres (fire and flash hazards). Critical tests will necessarily require validation in weightless and high-g states. 10. Develop pressure, temperature and humidity sensors, and regulation devices for two gas system application.
IN-FLIGHT STUDIES	1. Validate the selected atmosphere under operational and emergency situations (collective evaluation of body functions is required during prolonged space flight). 2. Measure energy expenditures during both intra-capsular living and extravehicular activities to validate requirements. 3. Evaluate performance of advanced ECS concepts.

TABLE 11

FACTOR	NUTRITION (Food, Water)
EFFECTS ON BODY FUNCTIONS	1. Nutritional deficiencies cause structural and functional disorders. 2. Psychological and motivational degradations are possible due to unacceptable food presentations and unsatisfactory waste management provisions.
DECISIONS TO BE MADE	1. Acceptability of non-conventional concepts such as bioregenerative life support systems and highly concentrated or synthetic food. Practical questions include also the percent of total food required in natural state and supplements (e.g. vitamins, etc.) 2. Necessity of regulating water uptake. 3. Nutritional requirements during prolonged space flight (i.e. caloric content, ingredients and physical form).
ENGINEERING IMPLICATIONS	1. Bioregenerative life support systems and/or food provisions (preparation and storage). 2. Satisfactory waste management provisions.
GROUND BASED R&D	1. Establish baseline metabolic data. 2. Determine trace nutrients and establish their importance. 3. Study the nutritional acceptability of bioregenerated, highly concentrated or synthetic foods over extended periods of time. 4. Develop physiologically and psychologically acceptable diets for space applications. 5. Improve food reconstitution techniques. 6. Develop accurate metabolic measuring procedures (uptake control and waste analysis). 7. Continue research on bioregenerative systems.
IN-FLIGHT STUDIES	1. Validate space dietary requirements. 2. Determine long-range metabolic response (e.g. intake and excretion of nitrogen, calcium, potassium, etc.). 3. Evaluate adequacy of nutritional provisions (i.e., type, form, preparation, storage and preservation). 4. Evaluate performance of bioregenerative life support systems.

TABLE 12

FACTOR	MEDICAL CARE
SCOPE	1. Sanitation and personal hygiene. 2. Preventive medical survillance. 3. Maintenance of physical fitness. 4. Diagnosis and treatment of: a. diseases b. physiological decrements c. injuries. 5. Surgical emergencies. 6. Psychological aid. 7. Dental treatment.
DECISIONS TO BE MADE	1. Extent of inflight diagnostic and treatment capabilities. 2. Necessity of onboard medical personnel (mission specific) and delineation of required skills. 3. Definition of easily measurable indices which predict physiological and performance degradations before they become critical. 4. Nature of prophylactic clinical treatment (e.g., appendectomy) prior to non-orbital missions.
ENGINEERING IMPLICATIONS	1. Medical examination and treatment area. 2. Sick-bay area with isolation features (requires microfiltering of exhausted atmosphere). 3. Physical fitness and skill maintenance provisions. 4. Possible use of onboard or ground-based computers to facilitate medical diagnosis and aid.
GROUND BASED R&D	1. Improve the adequacy and timeliness of post-flight medical examinations. 2. Develop information management system to process existing and future spaceflight medical data. 3. Identify the most probable pathological manifestations which might occur during space flight (e.g., study epidemiology of closed environments).

TABLE 12 (CONTINUED)

FACTOR	MEDICAL CARE
	4. Analyze the impact of potential in-flight pathological developments on the operational profile of non-orbital missions. 5. Develop a system which will provide the crew with direct physiological assessment and will eliminate physical interference during critical operations (e.g., biosensors - transmittors linked via telemetry to a data management and display system). 6. Automate physiological data collection for medical checkups and emergencies (i.e., monitor astronauts without body sensors*). 7. Identify the amenable systems failures that could occur in-flight; analyze their impact on crew safety and performance; and develop devices to protect crew while corrective action is being taken. 8. Develop diagnostic and therapeutic (including surgical) equipment and techniques for space flight applications (e.g., utensil and instrument sterilization provisions, x-ray pharmaceutical preparations, modes of drug administration, etc.).
IN-FLIGHT STUDIES	1. The following animal (or opportunistic human) studies are suggested: a. Tissue reaction and healing assessment. b. Assessment of microbial and viral defense mechanisms. c. Delineation of any clinical symptomatology endemic to space. 2. Validate clinical methodology and medical laboratory equipment. 3. Study the ecology of the bacterial environment. 4. Monitor the degree of performance retention as a function of flight duration.

---

* The "field-effect device," a remote detector of electromagnetic impulses produced by blood flow, is an example of the possibilities in this direction.

MAJOR MEDICAL DECISIONS

In this section, major medical decisions are identified, their significance discussed and their implications reviewed.

The effectiveness of man as an integral part of the space system depends upon overcoming potential medical problems attributable to prolonged flight. Decisions must be made concerning the physiological requirements necessary to sustain man in space and the medical techniques needed to ameliorate hazards imposed by the environment.

Based on information presented in Tables 1 through 12, eleven major decisions have been discriminated. These require the establishment of:

1. The necessity of artificial gravity.
2. Radiation protection guidelines.
3. Emergency procedures following S/C penetration by meteoroids.
4. The desirability of handling and/or returning retrieved lunar or planetary samples.
5. Crew size, crew structure, and crew selection guidelines.
6. The psychological acceptability of the S/C environment (volume, configuration, furnishings, etc.).
7. Means of controlling atmospheric contaminants to acceptable levels.
8. The physiological acceptability of the S/C atmosphere.
9. The optimum duration and type of mission simulation and preconditioning.
10. The necessity and extent of in-flight medical care.
11. The desirability of bioregenerative life support system.

Such decisions have varying implications which in general are mission mode and time specific. These are considered below.

I. The Necessity of Artificial Gravity.

Common to all future manned program alternatives is the necessity for man to function normally in space, to tolerate re-entry stresses and to readapt successfully to normal Earth conditions.

Artificial gravity can provide a means of sustaining man in the space environment if physiological problems attributable to weightlessness are revealed during or following prolonged space flight. A decision regarding the necessity of artificial gravity must be made on the basis of whether or not bodily functions are maintained within certain prescribed limits. Their establishment, however, may prove difficult inasmuch as physiological norms in space would differ from those on Earth.

From an engineering point of view, artificial gravity is undesirable and, therefore, emphasis should be placed upon avoiding it rather than trying to find the best way to implement it. Investigation of possible artificial gravity substitutes with minimal engineering implications (such as exercise*, elastic garments, medications, etc.) should parallel all other space flight activities. Such substitutes would have to be tested and rejected before artificial gravity is adopted as the solution to revealed problems.

Presently, two modes of obtaining artificial gravity are being considered, an onboard centrifuge or spacecraft rotation. Spacecraft rotation could interfere with scientific experiments, demanding either new experimental design or non-rotating accessory experimental modules. Conversely, the onboard centrifuge will necessitate stabilizing provisions but would have less of an influence on the experiments.

II. Radiation Protection Guidelines.

Uncertainties exist regarding both the radiation environment in space and the physiological effect of this environment on man. For missions at synchronous altitudes

---

* It is the belief of the authors that the muscular effort required for unrestrained IVA inside a large enough spacecraft will counteract any detrimental effects of weightlessness on the cardiovascular and musculoskeletal systems.

or outside the Earth's magnetosphere, evaluation of the radiation hazard is limited by the particular model chosen for predicting solar flare activity. Likewise, the extent of damage to humans as a result of radiation exposure is not precisely known, mainly because the conditions of exposure are uncertain (accident victims), or physiological responses are compounded by underlying disease manifestations (therapeutic irradiation).

In a recent study, the Space Science Board of the National Academy of Sciences has defined radiation dose-effect relationships for space flight applications (Ref. 8). This information can be utilized by the operating agency to establish radiation protection criteria. These should be mission type and mission duration specific, and they must represent trade-offs among astronaut hazard, anticipated gain, penalty of increased shielding and mission abort capability.

Special consideration should be given in developing protection schemes. For example, radiation shelters appear to be a desirable feature of future manned module in non-orbital trajectories. Also, transmission time lags and intermittent communication links with earth-based warning systems, indicate the need of including solar flare surveillance as an inflight task during planetary missions.

III. Emergency Procedures Following S/C Penetration by Meteoroids.

Meteorites constitute a hazard because of their ability to puncture the hull of the spacecraft and cause physical damage to both systems and crew. A deeper understanding is, therefore, needed of hypervelocity penetration consequences in connection with astronaut safety. While the meteoroid environment in the near Earth space is reasonably well defined, the penetration hazard in deep space deserves further scrutiny, particularly for flights with aphelion inside the asteroidal belt.

Medical decisions concern primarily the establishment of emergency procedures to assure crew safety in case of penetration. Depending on the risk involved (mission type and mission duration specific), these decisions could have engineering ramifications such as vehicle compartmentalization, penetration warning network, systems accessibility and maintainability.

IV. The Desirability of Handling and/or Returning Retrieved Planetary Samples.

Alien forms of life could be inherently pathogenic to Earth organisms, or may acquire pathogenic characteristics through adaptation once inside the terrestrial biosphere.

Thus, until future findings unquestionably prove otherwise, the assumption that a potentially hostile exobiota exists must remain and the requirements for safeguard against crew and back contamination must be defined and implemented as carefully as possible.

V. Crew Size, Crew Structure and Crew Selection Guidelines.

While engineering constraints can be used to yield a minimum crew size, the interpersonal-social requirements which must also be satisfied are not easily quantifiable. Stress could be caused by limiting both the range of social roles available to the individual and the degree of interpersonal interaction to which each crew member is exposed (Ref. 9).

In the anecdotal literature, group structure has generally been predetermined and the leadership has been able to maintain its authority. Studies of selected crews revealed that crewmen rated each other in terms of achievements and their officers in terms of effectiveness (Ref. 10). Social compatibility becomes increasingly important for longer missions.

More research is necessary before quantitative criteria for crew selection (applicable to the planning of long-duration space missions) can be established.

VI. The Psychological Acceptability of the S/C Environment.

Isolation and confinement during prolonged space flight are potential stressors about which engineering decisions based on psychological considerations must be made. Experimental data indicates that "volume per man" is a controlling factor in reducing behavioral aberrations and that highly habitable environments help in reducing performance decrements and personal stress. However, the relationship between the acceptable minimum volume per man as a function of mission duration (for extended space flight) has yet to be determined (Refs. 9, 11 and 12) and habitability requirements remain uncertain.

A basic need even of socially well-adapted humans is the opportunity for some solitude. As long as population density (or volume/man) is tolerable, sacrifices will be made for a common cause. Beyond this point, behavioral problems are unavoidable, suggesting that personal territoriality (regardless of the hierarchical ranking of the individual) should be considered in S/C design.

In connection with work-rest scheduling, medical decisions to be made are the necessity of maintaining a twenty-four hour periodicity, the establishment of an optimum work-rest ratio, and the designation of a minimum continuous sleep period.

Intervening long flight times plus the physiological and psychological demands of the mission may be expected to degrade astronaut operational skill and scientific proficiency. Inflight live practice runs, simulations, or even tutoring from the ground via communication links should be considered essential in helping to maintain such crew attributes.

VII. Means of Controlling Atmospheric Contaminants to Acceptable Levels.

Sources of cabin contamination are of both human and material origin. Normally non-toxic atmospheric contaminants may cause adverse physiological effects (ranging from non-specific functional shifts to incapacitation) under prolonged and continuous exposure. Therefore, it is necessary to determine tolerance limits, to identify means of detection and to establish methods of control to acceptable levels. Operational tolerance limits should be determined through simulations and validated during long-duration flights in Earth orbit. Spacecraft materials must also be studied to identify the extent of toxic and fire hazards they present.

It has been observed that under conditions of biological isolation, the ecology of the indigenous microflora of humans are altered or even disrupted. Different species predominate and "microbic shock" could develop upon return to normal Earth conditions. Digestion, nutrition and immunity could also be affected during flight.

VIII. The Physiological Acceptability of the S/C Atmosphere.

The standards for acceptable cabin atmospheres should assure maintenance of maximum physiological comfort, physical efficiency, and safety during the flight. These include the barometric pressure, the nature and abundance of constituent gases, the temperature, the humidity, and the rate of circulation.

At present, the utilization of a two gas (oxygen/nitrogen) atmosphere at a total pressure of 5 psi has been adopted for missions exceeding 30 days (Ref. 13). Based on animal studies, this atmosphere has been shown to be physiologically acceptable for at least eight months (Ref. 14). A test program may be required to validate this atmosphere for longer missions.

Successful application of a two gas system necessitates the initiation of an intensive ground-based program in developing gas monitoring and control equipment to provide a solution to the difficult problem of maintaining the ambient medium relatively constant.

IX. The Optimum Duration and Type of Mission Simulation and Preconditioning.

Very little is presently known about the relative duration and type of ground-based simulation necessary to validate a given mission. Extrapolations from simulated to actual events may not have fidelity if only because crew motivation is expected to vary.

Techniques for drawing meaningful inferences from ground-based simulations need to be developed.

X. The Necessity and Extent of Inflight Medical Care.

During manned planetary flights, it is neither possible to abort the mission nor feasible to replace an incapacitated man. Therefore, the clinical aspects of space flight that would provide rapid determination of pathological states and means of effective medical assistance must be developed. Reference should also be made to the experience gained in naval medicine which has at its disposal fairly extensive statistical information pertaining to pathological effects in isolated groups of people under demanding conditions. It should be recognized, however, that the concurrent action of several environmental factors endemic to space could cause manifestations unknown to conventional practice.

XI. The Desirability of Bioregenerative Life Support Systems

The desirability of bioregenerative life support systems will be decided on the basis of both medical and engineering considerations. The former concern the physiological and psychological acceptability of the regenerated food, its palatability, toxicity, and the percent of natural food, vitamins, and other supplements which must be added to prevent deficiencies. Palatability and acceptability of the food are known to be important in maintaining morale, and meal time has been shown to serve an important social function in isolated groups.

PROGRAM SEQUENCE AND DECISION TIME PHASING--A HYPOTHETICAL EXAMPLE

In this section, research activities are integrated and medical decisions are time phased to illustrate both the type of planning required and the extent of interoffice coordination needed to meet the challenge of a pacing goal.

The establishment of any given goal constrained within a fixed time period provides the vector along which and by which all contributory steps tend to orient and size themselves, respectively. If the end point is uncertain or inadequately defined, the orientation of this vector could be perceived differently by different responsible people. Confusion may result if the individual objectives of parallel or sequential evolutionary steps are diverging instead of converging.

It is important to realize that the establishment of any one objective will suffice to bound a program, while the choice of the objective itself will force program definition and planning in a particular direction. Consequently, identifying an objective can be more important than the objective itself.

Inasmuch as the more ambitious the objective the more demanding the requirements are, a manned Mars reconnaissance mission at the earliest opportunity is adopted here as the pacing goal to exemplify program definition during the interim period.

In Figure 3, the precursor activities and the time phasing of decisions in support of a manned Mars flyby mission are indicated. These are discussed below.

I. Precursor Activities.

An engineering type program will be needed for the design, fabrication, testing and validation of the flyby module. A dress rehearsal in earth orbit of the entire mission is envisaged to evaluate both systems and operations and allow sufficient time for development and observation of subtle effects. The evolution of this program places a constraint upon the time at which pertinent information from all other precursor activities must be available for decision making.

Medical, physiological and behavioral knowledge essential to the success of prolonged manned missions will be obtained from a series of manned flights of increasing length coupled with routine in-flight observations and systematic ground-based research. These routine observations will be extended to finer measurements and discriminations as required by revealed problem areas until the etiology of the findings observed has been adequately understood and until remedial or preventative techniques have been satisfactorily established. Advance scheduling of individual studies is not applicable to the program since it is uncertain what problem areas will be revealed.

An "Integrated Medical Behavioral Laboratory Measurement System" (IMBLMS) for the acquisition of in-flight medical data is presently undergoing final definition. The IMBLMS is a compact unit built in modular form which will allow simple exchange of measuring equipment. The basic reason for specifying modular design is to give versatility to the system, enabling the replacement of equipment no longer needed with higher precision instrumentation necessary for detailed study of revealed problem areas in future flights. It also allows integration of the conceived in-flight medical experiments and optimization of equipment commonality and crew tasks. It consists of physiological, biochemical, performance, and data management components.

An important issue concerning medical validations is the biological defensibility of the choice of the presently adopted incremental approach through twofold increases in flight duration. Problems may arise if any physiological responses to stress are initiated as threshold phenomena rather than monotonic functions of stress duration. The extent to which such threshold responses occur in humans is uncertain. However, if they do, their identification and characterization are crucial to program planning.

A related question concerns the flight duration necessary to qualify man for interplanetary missions. Based on the observation that the adaptation times for human response seldom exceed 30 to 90 days and are generally much shorter, missions of 90 days will probably suffice to reveal any medical problems which could question the feasibility of long duration manned missions.

Animal studies including those of simpler organisms could be beneficial and could contribute greatly to our knowledge of physiology in space. Activities should include experiments investigating the biological effects of the space environment on cellular as well as on higher levels of organization. Particular emphasis should be placed on studies in genetics, development, and mammalian physiology. In addition, mammalian behavior under the stress of the space environment, including the effects of the disruption of natural biorhythms, should also be studied. Experiments on organisms other than man have the obvious advantages of allowing wide use of implanted sensors and permitting specimen sacrifice and subsequent histological studies. However, to assure the validity of in-flight results, species should be selected which will minimize the problem of extrapolating the animal data to man. In addition, this program must be planned so that it is a pilot rather than a follow-up validation effort.

Experiments should also be performed on mammals to determine their response to injury, medication, and infection under space flight conditions. This program would aid in the development of inflight diagnostic procedures and clinical techniques which could be necessitated during prolonged non-orbital missions.

During the hypothesized Mars flyby mission, planetary surface, subsurface, and atmospheric samples would be acquired by means of an unmanned recoverable probe. Payload recovery is achieved under sterile conditions to prevent cross-contamination. Inflight examination of the planetary samples behind a biological barrier would be begun immediately post-recovery by a biologist-astronaut in case Martian biota, if present, should fail to survive the return trip to Earth (Ref. 15). Consequently, a research effort would be undertaken to design a planetary module with a biolab and to develop techniques for cross-contamination control, specimen handling, and specimen preservation. Also, a sample analysis rehearsal in earth orbit to retrieve and analyze a known sample should be scheduled at least two years before an actual interplanetary mission. The goals of this flight would be to validate the equipment, to evaluate sample handling methodology, and to ascertain problem areas in time to avoid program dislocation.

Research and development in biotechnology and human engineering should continue in areas such as advanced life support and protective systems, EVA technology and procedures (rescue, transfer, assembly), and improvements in systems maintainability and spacecraft habitability. The application of this program to the flight situation will increase human safety and performance.

Finally, an unmanned deep space program will be required to validate the meteoroid, asteroidal and radiation environments, and to provide preliminary information concerning the physical and biological characteristics of Mars. Such environmental data will help optimize systems design and increase the effectiveness of the data return from the flyby mission.

II. Decision Points.

Medical decisions must be made regarding both the feasibility of long duration space flight and the techniques necessary to ameliorate hazards imposed by the environment. While decisions as such are required by the flight sutuation alone, irrespective of any end points, time phasing of these decisions is only necessary if demands imposed by a pacing program are to be met. Decisions and decision points would then be established and assigned, respectively, on the basis of their relevance to the program. For example, decisions which could have large engineering ramifications requiring long development lead times must be made at the earliest possible time in order to avoid dislocations. This "earliest possible time" may vary for decisions concerning the same hazard if alternative engineering remedies (generally having different impacts) can be used. Medical decisions are expected to impact heavily on the engineering implementation of the flyby module and should be made before final design and development are underway. However, because of rapid program pacing, some decisions have to be prematurely forced and await operational validation. It is believed that these "forced" decisions could be made as early as 1969, if necessary.

The decision concerning artificial gravity should be made following at least a 60, better yet a 90, day duration mission and preferably before final design of the Mars module is completed. A decision not to include artifical gravity will require physiological validation during the first long duration flight (e.g., 1 year).

Enough information will be available to make decisions by 1968 concerning radiation exposure guidelines for short term synchronous and lunar missions. For Mars flyby, a decision 4-6 years before flight is desirable although any delay in reaching it is not expected to impact heavily on S/C implementation.

Biomedical considerations concerning crew protection following S/C penetration by meteoroids or asteroids could lead to decisions having engineering ramifications. Such decisions must, therefore, be made before the final design of the flyby module is completed.

An a priori decision could be made at any time concerning the desirability of introducing planetary samples into the earth's biosphere. Such a decision could be based on the effectiveness of handling techniques evolved for the returned lunar samples. A final decision bearing on the desirability of returning Martian samples to Earth could await inflight detection and preliminary characterization of possible Martian biota, preferably on an unmanned basis.

If research is properly directed toward the space flight situation, a decision on crew size and composition could be forced on the basis of ground-based studies, and validated during subsequent long duration flights in Earth orbit. This decision will have an impact on the size and configuration of the planetary module.

Present knowledge indicates that ground-based research supplemented with long-duration AAP missions is necessary before habitability requirements can be identified. However, since the relatively long times required to develop space systems make an early decision desirable, experiments in habitability should constitute a basic objective of early orbital workshop missions. Decisions concerning habitability requirements could be made following the workshop missions and validated during subsequent long duration flights in Earth orbit.

The determination of adequate means of maintaining atmospheric contaminants to acceptable levels could be made at project go-ahead and validated by ground-based studies.

Enough flight information will be available in late AAP to validate the decision (already made) to use a 5psi (69% O_2, 31% N_2) atmosphere in prolonged missions.

A dress rehearsal of the Mars mission in Earth orbit is envisaged to test systems and operations. This rehearsal will also offer the opportunity to validate crew performance under conditions most closely simulating the actual flight.

A decision indicating the nature of clinical implementations necessary for planetary flights could be forced soon based on available naval medical experience. This decision would be validated through clinical and therapeutic studies on mammals in Earth orbit.

Current estimates indicate that for advanced manned missions prior 1980, food regeneration is not feasible because of the long lead times required for systems development and validation. Conversely, water recycling and oxygen reclamation appear to be within present technological capabilities.

CONCLUSIONS

The attempt has been made in this report to put the medical program in support for advanced manned missions into proper perspective. In-flight and ground-based research objectives have been proposed, major medical decisions have been identified and program planning has been considered. As an example, a manned planetary reconnaissance mission has been assumed to illustrate the requirements that must be considered. Decision and validation points have been identified and supportive activities have been established to meet the requirements of a representative program constrained by a definite goal.

It is evident from this analysis that coordination and integration of medical and medically related efforts within the three NASA offices and their centers is necessary to support a manned space flight program.

ACKNOWLEDGMENTS

The authors wish to acknowledge, with thanks, the valuable discussions, helpful suggestions, and constructive criticisms of Dr. S. P. Vinograd - NASA/MM, Dr. M. I. Radnofsky - MSC/EC7, Mr. H. S. Brownstein - NASA/MM, and Messrs. T. A. Bottomley, A. N. Chambers, M. A. Robinson and G. T. Orrok of Bellcomm. Responsibility for views expressed here rests solely with the authors.

D. B. Hoffman
D. B. Hoffman

A. N. Kontaratos

1011-$^{\text{DBH}}_{\text{ANK}}$-cb

REFERENCES

1. Preliminary Human Factor Requirements for a Manned Orbiting Laboratory, Biotechnology and Human Research Division, OART, April 3, 1963.

2. Report of the Orbiting Research Laboratory Biomedical Experiments Working Group, Revision A, October, 1964.

3. Biomedical and Human Factors Requirements for a Manned Earth-Orbiting Station. Final Report, North American Aviation, SID-63-1392, November 18, 1963.

4. Biomedical and Human Factors Requirements for a Manned Earth-Orbiting Station. Final Report, Republic Aviation, RAC1781A, January 3, 1964.

5. Biological Measurements of Man in Space. Lockheed Missiles and Space Company:

   Vol. I "Biomedical and Human Performance Program," M-61-64-1-I. March 15, 1965.

   Vol. II "Conceptual Design Measurement System for Apollo X," M-61-64-1-II. December 3, 1964.

   Vol. III "Conceptual Design of Measurement System for AES," M-61-64-1-IV. March 15, 1965.

   Vol. IV "Preliminary Requirements Data Book," M-61-64-1-V. May 3, 1965.

   Vol. V "Time Line and Feasibility Analysis for AAP Biomedical Experiment Program," M-61-64-1-VI. January, 1966.

6. Medical Aspects of an Orbiting Research Laboratory, Space Medicine Advisory Group, NASA SP-86, 1966.

7. Advanced Earth Orbital Mission Definition Document, NASA/OMSF, January 19, 1965.

8. Evaluation of Potential Radiation Hazards in Manned Space Flight Operations, Publication 1487, National Academy of Sciences.

9. Behavioral Aspects for Consideration in Long Duration Space Flights, D. B. Hoffman, Memorandum for File, Bellcomm, Inc. March 16, 1967.

10. The Relationship of Work-Rest Schedules, Confinement and Habitability to Crew Performance as Anticipated for Space Mission, Crane, B. H. Bellcomm, Inc. 1964.

11. Proceeding of the NASA Symposium on the Effects of Confinement on Long Duration Manned Space Flights, NASA/OMSF, November 17, 1966, Part I and II.

12. The Effects of Confinement as a Factor in Manned Space Flight, T. M. Fraser, NASA CR-511, 1966.

13. Letter from Dr. G. E. Mueller to Dr. R. R. Gilruth dated December 22, 1966.

14. Third Annual Conference on Atmospheric Contamination in Confined Spaces, Dayton, Ohio, May 9-11, 1967. Trip report by T. A. Bottomley, Jr., Bellcomm, Inc., June 26, 1967.

15. A Proposal for Sample Acquisition During a Manned Flyby Mission to Mars, A. N. Kontaratos and C. A. Pearse, Memorandum For File, Bellcomm, Inc., July 20, 1966.

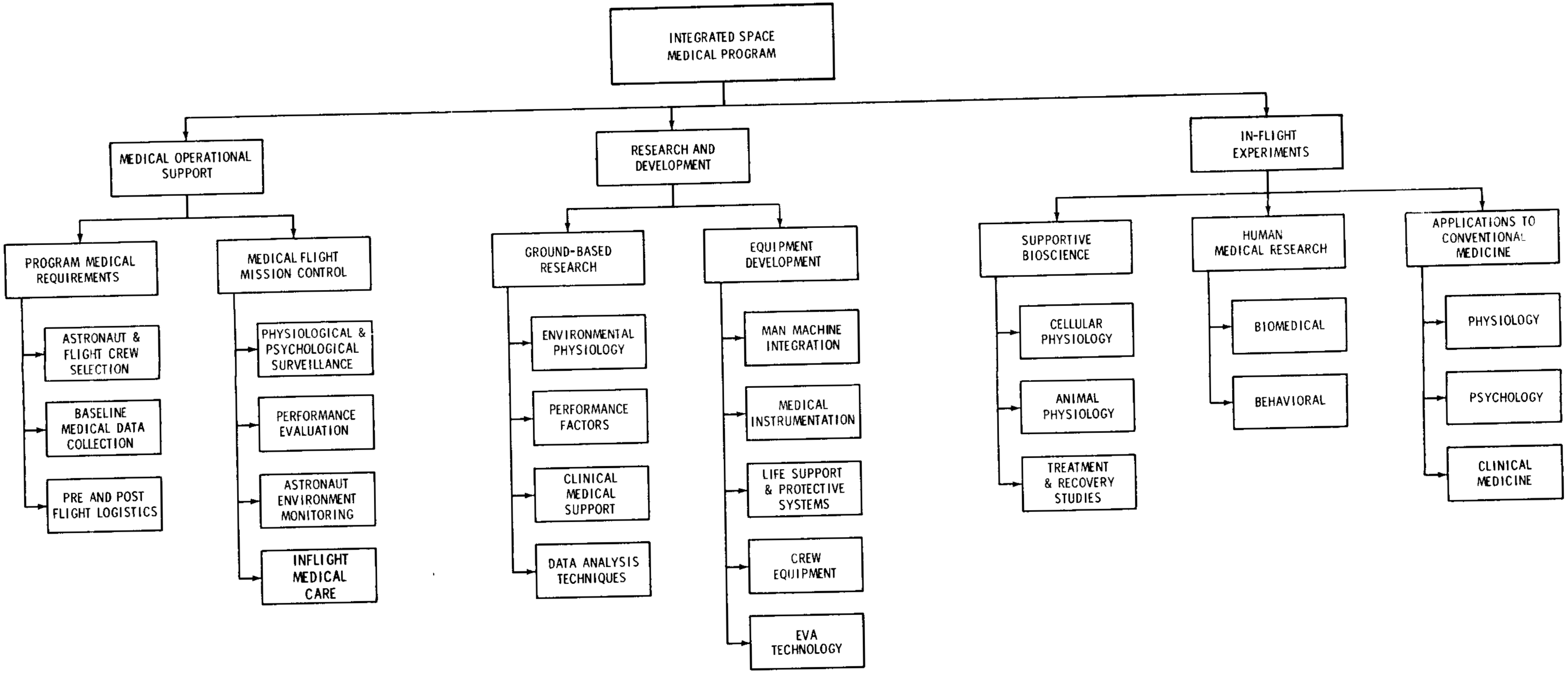
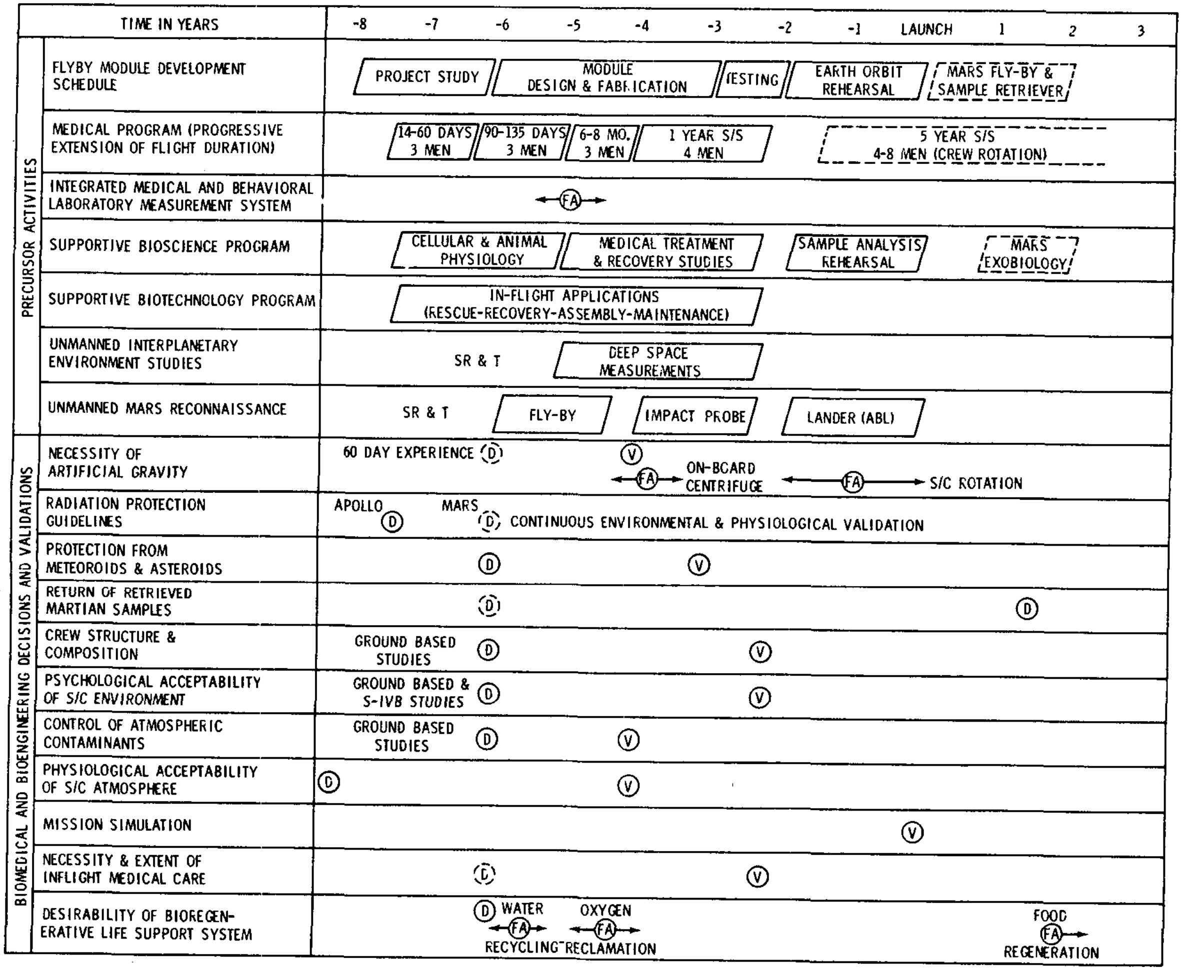


FIGURE 1 - MEDICAL ACTIVITIES IN SUPPORT OF MANNED SPACE FLIGHT

FIGURE 3 TENTATIVE PROGRAM SEQUENCE AND DECISION TIME PHASING



KEY: DECISION Ⓓ, VALIDATION Ⓥ, FLIGHT AVAILABILITY OF SYSTEM (FA), DECISION WITHOUT SEVERE PROGRAMMATIC IMPACT (D), SUPPORTIVE RESEARCH AND TECHNOLOGY SR & T.

DISTRIBUTION LIST

NASA Headquarters

W. C. Beckwith - MTP
F. B. Benjamin - MM
H. S. Brownstein - MM
E. M. Cortright - MD
P. E. Culbertson - MLA
J. H. Disher - MLD
F. P. Dixon - MTY
G. H. Duncan - SB
L. G. Goff - SB
T. Hagler - MTE
E. W. Hall - MTS
W. J. Hamon - MTY
C. A. Huebner - MTE
J. W. Humphreys - MM
D. W. Jenkins - SB
W. L. Jones - RB
T. A. Keegan - MA-2
D. R. Lord - MTD
B. Maggin - PT
J. A. Mason - MTE
C. W. Mathews - ML
E. J. McLaughlin - MM
L. N. Mogavero - MTX
K. F. Okano - MAR
S. C. Phillips - MA
J. E. Pickering - MM
M. J. Raffensperger - MTE
L. Reiffel - MA-6
O. E. Reynolds - SB
A. D. Schnyer - MTV
R. F. Trapp - RBA
J. H. Turnock - MA-4
S. P. Vinograd - MM

NASA Manned Spacecraft Center

G. C. Armstrong - DB-2
C. A. Berry - DA
L. F. Dietlein - DB
W. E. Hull - DB
R. S. Johnston - EC7
M. I. Radnofsky - EC7
M. A. Silveira - ET25
W. E. Stoney - ET
J. M. West - AD

NASA Ames Research Center

J. Billingham - LT
L. Roberts - MAD (2)

NASA Marshall Space Flight Center

H. S. Becker - R-AS-DIR
R. J. Harris - R-AS-VP
J. D. Hilchey - R-AS-VO
B. G. Noblitt - R-AERO-XA
F. L. Williams R-AS-DIR

STAC Biomedical Subcommittee

S. Bennett
W. H. Sweet
C. H. Townes
G. Zuidema

NASA Kennedy Space Center

J. P. Claybourne - EDV4
R. C. Hock - PPR2
N. P. Salvail - MC

Bellcomm

F. G. Allen
G. M. Anderson
T. A. Bottomley
A. P. Boysen
T. H. Crowe
J. P. Downs
R. E. Gradle
D. R. Hagner
P. L. Havenstein
W. C. Hittinger
B. T. Howard
D. B. James
J. Kranton
K. E. Martersteck
R. K. McFarland
J. Z. Menard
I. D. Nehama
G. T. Orrok
T. L. Powers

Distribution List (Continued)

I. M. Ross
P. F. Sennewald
W. Strack
C. M. Thomas
C. C. Tiffany
J. M. Tschirgi
R. L. Wagner
J. E. Waldo
All members, Division 101
Central Files
Department 1023
Library

FIGURE 2

IN-FLIGHT BIOMEDICAL BEHAVIORAL EXPERIMENTS PROGRAM