RESEARCH IN SUSTAINING LIFE
DURING LONG DURATION SPACE FLIGHTS
by

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Research to sustain man on long-term space flights of the future includes the determination of the effects of space flight on man and the development of new and improved techniques and equipment with which to support him.

Prior to the historic first American manned space flight of Alan B. Shepard on May 5, 1961, little was known of the influence of this new environment on the integrity of human function. Speculations on this aspect of manned space flight, although based upon existent experience and research, covered a very broad range and did not permit relative value assessments with respect to likelihood of appearance or severity. With each flight mission since then, potential problems which might confront man on very long-duration space flights have become better defined, and quantitative data bearing on these questions have increased. In 1966, the Gemini program was completed. One of its missions, the Gemini 7 flight of Borman and Lovell, proved that man cannot only survive a 14-day space flight, but can do so with no overt manifestations of physical, mental, or functional deterioration. At the same time, medical investigative efforts, carried out throughout the Gemini series, have identified subtle physiological changes significant to preparations for the support of man during long-duration space travel of the future.

NASA's program of in-flight medical investigation has as its objectives the determination of the effects of space flight on man, the mechanisms by which these effects occur, means of predicting their onset and severity, and means of preventing or correcting them. Its constituent experiments are a series of controlled measurements designed to identify and quantitate very early changes and to establish the course of these changes as the duration of flight expands. By virtue of these time-line analyses, predictions of man's welfare and protective requirements will become increasingly accurate as the accumulation of pertinent data from each flight mission continues.

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Throughout Mercury and Gemini, flight crews were given careful physical examinations before and after each flight. Detailed post-flight debriefings were also conducted. For purposes of flight safety, blood pressure, electrocardiogram, respiratory rate, and body temperature were monitored during each mission. In addition, a number of flight medical investigations were carried out, several more than once, during the Gemini program.

These included pre- and post-flight tilt table, blood volume, and exercise tolerance studies; the evaluation of pneumatic thigh cuffs as a preventive of circulatory changes; in-flight exercise effects; phonoelectrographic responses; the bioassay of body fluids; bone density measurements; mineral balance evaluations; in-flight sleep analysis by electroencephalography; and vestibular studies.

With the exception of a few mild symptoms such as dryness of the nose and normal fatigue, all ~~observed~~ changes observed in the astronauts were of a low order of magnitude and had no effect on feeling of well being or on performance either in or following flight. All of them were temporary. The changes ~~observed~~ were mild but clearly demonstrated alterations of circulatory responsiveness (tilt table responses), diminution of red cell mass, variations of plasma volume, reduction of bone density, lessening of exercise tolerance post flight, increased output of nitrogen in flight, post-flight fluid and electrolyte retention, and dehydration. ~~All of~~ These ~~changes~~ were anticipated on the basis of weightlessness, thermal stress, the 100% oxygen atmosphere, or other environmental factors of space flight (Table I). Other anticipated changes have not yet been observed in American flights. No change in electro-mechanical timing of cardiac contraction, electroencephalographic sleep patterns, visual acuity, or orientation ability borne out by tests of otolith function have so far been established. These studies will be repeated; and others will be added on future flights to identify new or late appearing ~~changes~~ effects, verify positive findings, identify causal relationships, and correlate the development of changes more clearly with duration of flight.

The determination of the effects of space flight on man is supported by completed and planned research ~~on~~ with in-vitro cells, plants, and lower animals. One such study, carried aboard Gemini, is the investigation of the effects of radiation from a carefully calibrated artificial source on small test-tube samples of human white blood cells in space as compared with those observed from the same exposures on the ground. The cells are examined for chromosomal changes, and these are quantitatively assessed. When completed, this experiment will provide evidence for or against the possibility of synergistic effects of exposure to the combination of radiation and weightlessness.

The biosatellite program, a series of flights of an automated recoverable biological flight laboratory, will further extend investigations of synergistic effects as well as many other pertinent areas of interest. It will carry cell and tissue cultures, seeds, plants, primates, and lower animal forms. The research to be conducted on board is designed to shed further light on the question of synergism of radiation and weightlessness; synergism of vibration and acceleration; the behavior of biorhythms in the changed day-night cycles of space; metabolic, cardiovascular, and musculoskeletal changes in weightlessness and the mechanisms of these changes;

neurological and behavioral changes in primates on long-duration space flight; and effects of prolonged weightlessness on cellular processes in plants and animals.

Both human and lower ~~biological flight~~ species investigations into the effects of space flight are supported by a larger ground-based research effort. Each flight experiment and measurement is backed by a series of control studies on the ground. In addition, measurement techniques and equipment designed to function accurately under the unique conditions of space flight are tested and qualified under simulated conditions on earth.

Most of the conditions of space flight can be individually attained to a reasonable degree here on earth. The notable exception is prolonged weightlessness. Actual weightlessness can be achieved by aircraft flying ballistic trajectories, but the usefulness of this technique in biomedical research is limited by the fact that it can only be sustained for 30 to 40 seconds. It is, therefore, used extensively for training, equipment testing, and short-term observations of all kinds; but for the study of long-term weightlessness on human function, we are dependent upon either bedrest or water immersion for weightlessness simulation. At bedrest, the circulatory system is not required to support the weight of the column of blood nor the musculoskeletal system the weight of the body in the long axis. In water immersion, buoyancy eases the musculoskeletal requirements imposed by gravity, motion is free about any axis, and the pressure of the water outside the body causes a redistribution of blood and resultant circulatory responses which parallel those in the weightless state. Bedrest and water immersion studies provide a great variety of data concerning the effects of prolonged weightlessness on body functions and systems. These studies are also utilized for the evaluation of measurement and preventive techniques proposed for actual flight.

Other forms of simulation help to provide prognostic information on other environmental factors of space. Pressure chambers are used to study the effects of spacecraft atmospheres, either actual, possible, or planned. Thermal simulation is either incorporated into these studies or is frequently done in separate rooms or chambers designed for that purpose. Human and animal centrifuges are used to study accelerative effects; drop towers, rocket sleds, and other devices for impact effects; vibrating platforms of various kinds for the effects of vibration. Similarly noise, decompression, illumination, confinement, circadian rhythms, and other factors of the space environment are studied by simulation. For the quantitative bio-physical assessment of ionizing radiation, studies of the effects of proton and other heavy particle beams not ordinarily of biological concern on earth are carried out on lower life forms. For human effects, reliance is placed on the careful evaluation of existing and accumulating data on clinical radiation therapy combined with a growing knowledge of the physics of ionizing radiation and radiation shielding, and of the radiation environment in space. Pertinent total stress effect data have been obtained by medically monitoring individuals during sports events such as sky diving, sports car racing, hockey, and other activities.

Data derived from these studies serve an an important basis of comparison in the evaluation of flight data.

Factors to be considered in the support and sustaining of life on long-duration space flights are listed in Table II. All of the information derived from the effort to determine the effects of space flight on man are directly pertinent to the provision of his support on future long-duration missions.

The environmental control system is the system which provides the gaseous atmosphere of the spacecraft, its appropriate composition, pressure, temperature and humidity, ~~control,~~ circulation, and freedom from toxic and particulate contaminants. It must supply an optimal partial pressure of oxygen and remove carbon dioxide as it is produced. The Apollo configuration, like that of Mercury and Gemini, is a 100% oxygen atmosphere at a pressure of 5 pounds per square inch (psi). Pressure chamber studies of up to 30 days have demonstrated that this atmosphere is harmless to humans for that duration. Yet, other studies, including the early effects on red cell mass noted in Gemini flight missions, tend to shed doubt on the habitability of this atmosphere for extended flights beyond that period. On the credit side, the 5 psi 100% oxygen atmosphere has the advantages of engineering simplicity and of reducing the hazard of "bends" if an emergency cabin decompression should call for sudden suit pressurization at its pressure of only 3.7 psi. On the debit side, this atmosphere has undesirable physiological implications for extended flights, particularly with respect to the blood and respiratory systems. ~~and~~ It also imposes a potential fire hazard. Research is therefore directed toward the development of a two-gas system; the methods which would ~~to~~ minimize the possibility of "bends" in the event of sudden recourse to suit inflation; toward the determination of the best choice of inert diluent gas, such as nitrogen, helium, or the rare gases, from both the engineering and physiological standpoints; and ~~into~~ to the prevention, ~~behavior,~~ and control of fire under weightless conditions, in part, as a function of the atmosphere supplied. Additional investigation is being carried out into the behavior of particulate matter in the weightless environment, its evaluation as a potential respiratory hazard, and its control. On very long-duration flights, it may prove difficult to carry a full supply of oxygen. Consequently, considerable attention is being given the development of oxygen regenerative systems which will salvage the oxygen from the carbon dioxide produced by the body.

The space suit is, in effect, a portable atmospheric envelope for the astronaut which allows him the unique feature of movement. It must, therefore, provide all of the features of an environmental control system plus thermal, micrometeoroid, and radiation protection. Ideally, it should provide a total pressure as close as possible to that of the spacecraft with minimal restriction of movement and agility. It should also be capable of quick donning and doffing and should permit easy stowage. Since movement of any kind in a pressurized suit requires a significantly augmented effort, metabolic heat production is increased and provision must be made for its disposition. Furthermore, it must contain adequate provision for communication, physiological monitoring, unimpaired vision, either by restriction of size of the visor or fogging, maximal redundancy and repairability, resistance to tearing, and provision for maximal duration of independent activity. In the case of extravehicular activity in space, the astronaut must have a means of propulsion. Space suit research and development is a continuing activity encompassing all of these factors with the aim of constantly improving beyond existing limitations.

Research in food and food packaging has led to the development of the presently used freeze-dehydrated foods and bite-sized foods. Space food, like any other food, must be both nutritious and appetizing. It must be easily stored, easily prepared and eaten in a weightless environment, and must not give off crumbs, since these free-floating particles can be a respiratory hazard. Nutritionally, it must be adequate to support all energy requirements and compensate for physiological changes such as alterations of mineral balance, which may occur. For the purpose of providing accurate intake information, all of its constituents should be precisely known; and the amounts actually taken should be easily calculable. It should, of course, not be conducive to undesirable side effects such as allergies or renal stones, a factor which is also dependent upon a thorough medical knowledge of the flight crew. Because of continuing research in this field, well over 100 varieties of foods are presently available to astronaut crews. Nutritional research into daily requirements, standards of purity, and trace mineral and other deficiencies is widespread. Food packaging and preparation in flight is also a continuing study effort. Metabolic requirements are being investigated as a part of the program of in-flight medical ~~investigation~~ experimentation. Investigations into artificial and resynthesized foods are in progress, as is research into the possibility of recycling food constituents from waste materials.

Potable water is presently stored aboard. The purification of fuel cell water for extended flights is the subject of current research. Also under study is the recycling of water from waste materials.

The problem of waste management in space is the center of considerable investigative attention. The behavior of matter in a weightless environment dictates that body products must either be immediately entrapped or directed through the disposal system by a force, such as a flow of air. At the same time, provision must be made for sampling or the determination of total output ~~and sampling~~ for the purpose of physiological investigations to be carried out on selected flights. Means of reclaiming water and food elements which can be reconstituted, a concept which may be of great importance to future interplanetary travel, are also currently under study.

Maintenance of adequate living conditions and standards aboard the spacecraft includes such factors as body hygiene, care of the skin, hair, and nails, beard removal and dental hygiene. Studies of optimum work-rest-sleep cycles are in progress as are evaluations of minimum volume requirements for living quarters, the requirement for areas of privacy, and ~~diversional~~ recreational activities. Our present astronauts have been selected from an already highly preselected group of individuals. Applicants for pilot astronauts had successfully passed rigid military, aviation, and test pilot selection procedures and had already attained a very high degree of professional skill and education. In a sense, the training program is part of the selection process, in that an astronaut is not fully selected until he is assigned a mission. Up to that point he receives a great deal of highly diversified training which includes, among other things, a basic course in physiology. The first group of scientist astronauts has now been selected. These applicants were chosen on the basis of scientific achievement as well as suitability for aviation training to military standards. For both types of astronauts, cross training as well as further specialized training is important in order to enable small flight crews to accomplish the broad spectrum of tasks required. At some time in the future, flight constraints may diminish sufficiently to permit the selection of a third category of crew member, the scientist passenger. All selection and training criteria, standards, and methods are continually assessed to assure that the brilliant performance of our past flight crews is matched by those of the future in the accomplishment of the unique task requirements of their missions.

Protection against the possible undesirable effects of weightlessness requires ~~necessitates~~ the identification of these effects, and the evaluation of preventive and corrective measures, both of which are being explored in the program of in-flight medical investigation. The inflatable cuffs about the thighs have been tested in Gemini, and an elastic anti-G garment to be donned prior to reentry will be investigated in the near future. The effectiveness of whole body exercise and other measures are also being prepared for flight evaluation.

Problems related to acceleration, noise, and vibration are being studied under terrestial conditions. These studies seek to establish tolerance limits to inertial forces of various kinds and from various directions; to determine physiological, anatomical, and performance effects of these forces, both singly and in combination; and to develop satisfactory attenuating devices. A special area of study is the problem of Coriolis and other vestibular effects on humans exposed to a rotational environment. This is of particular importance in considering the possible induction of artificial gravity by vehicular rotation, which may be indicated on very prolonged missions of the future.

Within the electromagnetic spectrum, infrared, ultraviolet, radio waves, and ionizing radiation are all potential space hazards. Of these, ionizing radiation is perhaps the subject of the most intensive investigation. This research, alluded to earlier, consists of the study of the behavior and effects of high energy heavy particles which emanate from solar and galactic sources and of the proton and electron spectrum of the Van Allen belts. The overall effort has assumed three major directions: definition of the space radiation environment, shielding and dosimetry, and biological effects. The early identification of and protection from solar flares, and the establishment of acceptable dose limits for particular missions are important objectives of this research.

A micrometeoroid penetration of the spacecraft, a rare possibility, can be expected to cause some loss of cabin pressure and may, in a high oxygen environment, result in a flash fire. The problems of loss of pressure and dysbarism are essentially the same as those with which aviation medicine has been working for many years but are quantitatively more extreme, since the ambient pressures in space are virtually nil.

The possibility of microbial cross-contamination of two or more persons living in a closed environment for a long period has also merited attention. Ground-based studies are currently in progress and will shortly be accompanied by in-flight evaluations of the microbial environment and changes which may occur during space flight.

Illness and accident prevention and treatment are important aspects of preparation for prolonged space flight. Under evaluation are the equipment requirements and techniques for remote medical diagnosis and therapy, as well as the possibility of an on-board physician member of the flight crew.

In the area of medical monitoring, new methods for the remote measurement of physiological functions have evolved from the Mercury and Gemini programs. This effort has resulted in the development of such equipment as an automated blood pressure monitoring device, long-term sensors, an automated urinalysis device for lower animal evaluation in flight, and "spray-on" electrodes for the placement of electrocardiographic and other sensors on the body. The availability of remote monitoring devices through expanded research in bioinstrumentation has led to the growth of medical research into human function under dynamic rather than static conditions. Research efforts are continuing to constantly improve this instrumentation to render it less encumbering, more accurate, more economical, and capable of measuring more physiological functions.

A related area of effort is the development of post-flight survival equipment. This has resulted in refinements such as an unusually stable inflatable life raft, a more efficient and compact life vest, and an inflatable antenna.

The computerized collection and statistical evaluation of medical data obtained from space flight is a relatively young area which is receiving expanded research emphasis. It offers as advantages, ease of storage and handling, quick recall, rapid statistical analysis, convenient and accurate display, and the opportunity to derive new correlates such as information on rates of change and derivatives thereof.

Finally, certain missions impose unique research requirements. For lunar missions, locomotion at 1/6 G and the metabolic cost of activity in this gravitational field are under study. Similarly, missions characterized by high orbits, polar orbits, rendezvous, prolonged planetary travel, and extravehicular activity each impose the need for specific research and developmental efforts.

The medical support of man in space entails an extensive, well-planned flight and ground-based research program whose objective is to enable future flight crews to meet all of their mission requirements without impairment or deterioration of function or well being.

very excellent, readable, and complete

Joe

TABLE I

ENVIRONMENTAL FACTORS OF POTENTIAL SIGNIFICANCE
IN PROLONGED MANNED SPACE FLIGHT

Weightlessness

Radiation

Confinement

Artificial Atmosphere

Particulate Matter

Toxic Products

Micro-organisms

Circadian Rhythm Change

Thermal Stress

Ultraviolet Exposure

Infrared Exposure

Relative Isolation

Monotony

Synergistic Combined Factors

TABLE II

LIFE SUPPORT FACTORS

1. Atmosphere
2. Pressure Suits
3. Food
4. Water
5. Waste Management
6. Living Conditions and Standards Aboard
7. Crew Selection and Training
8. Hazard Protection
9. Medical Monitoring
10. Data Analysis
11. Mission Specific Requirements