Resume of Present Knowledge of Man's Ability to Meet the Space Environment

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INTRODUCTION

TWO YEARS OF manned space flight have been completed. The pace of flight progress has increased regularly as each major milestone has been passed. In the 1 year since the previous manned flight progress report at the Aerospace Medical Association annual meeting, the United States and the Soviet Union have extended the experience to a major degree in answering the questions of how man is able to meet the space environment. The United States program, which had completed its first three-orbit flight, has repeated this feat and has also accomplished a six-orbit flight. It is now ready to attempt its first full day operation. The Soviet Union has successfully launched and recovered the paired flights of Vostoks III and IV, which exposed man to 4 and 3 days of orbital time, respectively. In addition, the second generation of orbiting space vehicles is under development and the biomedical inputs are being required now in order that they may be reflected in the design. Therefore, it is time to review the data acquired concerning the manned experience in order that it might be used to aid intelligently in the design of future vehicles and operations.

REVIEW OF FLIGHT INFORMATION TO DATE

Review of Physiological and Clinical Findings:—In order to determine accurately both the state of health and normal physiological functions or aberrations therefrom, a system of thorough examination and in-flight monitoring has been developed and effectively utilized by both American and Russian physicians. In our program, baseline medical data have been collected on all the flight crew from the moment of their selection. Each exposure to a new stress during the extensive program produced additional data which were valuable for later comparison with that obtained during the actual flight mission. In addition to extremely thorough and complete-selection physical examinations which have been detailed in earlier papers, annual physicals were conducted and then a series of examinations were conducted not only by the flight crew surgeon but also by a group of selected specialists. The entire series of examinations involving both our suborbital and orbital space flights have revealed no significant previously unknown physical abnormality, either preflight or postflight. The only evidence of detectable physical change noted after space flight was a lability of pulse and systolic blood pressure with changes in body position, supine to standing, for about 21 hours postrecovery. The rate increases were mild in nature, 30 to 40 beats per minute, and the systolic pressure drop was also minimal. This condition was accompanied by engorgement of the dependent lower extremity veins but there were no symptoms whatsoever. This condition is not unlike the orthostatic changes noted following bedrest but is a minimal finding and will be investigated in detail with tilt-table studies both preflight and postflight on the next mission. The Russians have reported no physical abnormalities preflight or postflight, and specific discussion with their scientific team has confirmed the lack of positive findings. Details of the Project Mercury physical examinations have been reported in the results of our space flight program.

In addition to the detailed physical examinations, a considerable amount of laboratory work has been done involving blood and urine. The detailed blood examinations, including blood chemistries, and the extensive urine examinations, including electrolytes, are all within normal limits and showed no significant changes from the preflight values. The Russian data have been similarly negative.

In an effort to obtain accurate information concerning the in-flight physiological state of the space crew, a number of data sources have been used. In our own flights, these sources have consisted of observations of an onboard film (television will be used on the next flight), the monitoring of radio communications between the astronaut and the range stations, observations concerning his flight performance and timing of flight plan activity, and the telemetering of certain biosensor data including two leads of an electrocardiogram, blood pressure, respiration, and body temperature. The details of these sensor systems have been previously reported. In addition to the above named monitoring tools, the Russians have added electroencephalography, galvanic skin response, and electrooculography. The results obtained from this inflight monitoring have been extremely helpful in allowing the ground-bound flight surgeon medical monitors to determine that the astronaut was indeed capable of completing the mission or continuing his task. Some of the values obtained would have been startling if obtained in the bedside or physician's office situation. These findings have included variations in pulse rate with ranges of 56 to 170 beats per minute, the highest value being noted just prior to retrofire. Various changes noted in the electrocardio-

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grams have included alterations in the pacemaker activity and aberrant rhythms (nodal beats, premature atrial and ventricular contractions, sinus brachycardia and atrial rhythm). All these "abnormalities" are considered normal physiological responses when related to the dynamic situation in which they were encountered. Other evidence of cardiovascular function such as preflight and in-flight blood pressures have also been normal. Russian experience even with the additional parameters monitored and the prolonged weightless periods has been similar in the lack of significant abnormal changes. The incidence of normal variants indicates a need to study man's reactions in dynamic situations.

The value of the comparison of multiple parameters in the correlations with environmental (sealed cabin) data has been repeatedly proven. Abnormal values or lost given measurements attributed to instrumentation difficulty have frequently been obtained, but it has been found that an interpretation of the astronaut's physiological condition could be made by the use of the parameters remaining or the correlation of those remaining with environmental data.

It is important to realize that our biomedical sensors are being used as a means of flight safety monitoring. Primarily, these sensors serve to aid in determining whether the astronaut is capable of continuing the mission from a physiological and performance point of view. There has been no attempt under the current operational conditions to perform detailed systems evaluation or analysis. The work is being conducted within broad limits in order to make go-no-go decisions. Further, it should be understood that the current monitoring methods may be far from ideal. They do not provide the ultimate in measure of man's ability to perform a mission. It would be most desirable to have a single parameter which would tell the ground monitor whether the nervous system of the pilot was capable of the peak performance necessary. To date, there is no such single or even multiple measures, and an attack must be made upon this problem from the periphery.

Review of Performance of the Astronaut:—The Mercury vehicle was originally designed to be a completely automatic system with various backup systems, and the astronaut was to perform by observing the function of these systems and initiating manual action if the automatic devices failed to perform as programed. Provisions were made for the astronaut to take over the spacecraft control system in a single axis or in all three, and the pilots initiated an early program in the flight schedule to show that they could do such tasks effectively and efficiently. Each flight plan has further reduced the automatic activity and provided more necessary pilot input. Performance has been studied by analysis of radio transmissions, evaluation of the completion of flight plan, and telemetered and onboard taped records of control activity. The results of the flights to date have shown that man is quite capable of adequate spacecraft control activity and that he may be relied upon as a competent link in the man-machine spacecraft systems.

Man has consistently shown great adaptability to new challenges, and, as a result of the Mercury experience, future spacecraft are being designed with man as a vital link in the system. This design allows great weight saving, less complexity, and increased reliability. The removal of redundant systems in the Mercury spacecraft has provided greater mission capability. In Gemini, the pilots will be able to control full shutdown in the launch vehicle, which is a highly critical task. In the proper performance of such a task, the provision of adequate instrumentation to present timely and meaningful information on which the pilot may make rapid real time (instantaneous) decisions is imperative. In summary, the space crew have shown a remarkable ability to perform a new mission adequately and demonstrated the wisdom of making man a vital link in the spacecraft launch-vehicle system.

REVIEW OF MAN SUPPORT EQUIPMENT

Environmental Control:—The past year has been a memorable one in the spacecraft environmental control area because it has been shown conclusively that the environmental design criteria and approaches are valid and reproducible. Much data were available one year ago; however, such items as body and equipment temperature control, cabin leak control, and instrumentation for measurement of environmental parameters remained open. During the past year each of these areas has been resolved. The problem of body temperature control was traced to subtle freezing occurring silently in the dome of the heat exchanger. A small amount of ice has been shown to shift the maximum cooling capability of the heat exchanger to a degree that the total capacity was decreased. Further, it was shown that the freezing in the dome was detectable by the astronaut only after a major decay in the efficiency of the unit. The movement of the exhaust temperature sensor from the overboard steam tube to the dome of the heat exchanger provided the answer to both difficulties. The temperature in the dome of the heat exchanger is directly read by the astronaut. A drop in temperature could be detected before the ice began to collect and before the heat exchanger's efficiency was in jeopardy. Also, the astronaut now has a more sensitive control which permits him positive control of his suit-inlet air temperature.

The study of the problem of equipment temperature control showed that two major factors were active in producing the problem. The rapid development and use of solid-state electronics had not permitted thorough analysis of the temperature ranges over which such electronics could operate satisfactorily. During this year, a series of studies have been completed which show that such items can be allowed to operate at higher temperatures than past experience would indicate. This finding along with the provision of a better duct design to carry the air from the hotter areas within the spacecraft permitted more efficient use of the cabin heat exchangers. Second, the effect of operating a cabin with equipment turned on and off as needed during flight was studied and was shown to be an effective technique for cabin temperature control.

The difficulty of controlling cabin leak has plagued aviation since the beginning of pressure cabins, but effective control has been demonstrated only during the Project Mercury program. It had been shown previously that a vehicle with no penetrations through the walls could be sealed adequately. However, the history of cabin-leak control in aircraft construction when there were multiple wall penetrations had been erratic; operational use and repair by maintenance personnel had further aggravated this record. The construction of later Mercury spacecraft has resulted in leak rates of 600 cc./min. or less. Changing systems, replacing parts, and cutting new penetrations through the walls have been accomplished without losing control of this excellent leak rate. Progress in the control of the leak rate permits predictable control of the environmental system expendables and thus better flight planning and in-flight management of the system.

Flight instrumentation for the measurement of oxygen and carbon dioxide partial pressure and coolant quantity remaining have been developed and made ready for flight during this year. These instruments were not needed for the flights to date; however, the 1-day mission and flights of longer duration will require these instruments for proper management of expendables. The resolution of the instrumentation problem permits the extension of environmental system technology to the 14-day maximum required for the missions of Projects Gemini and Apollo.

The environmental system presently used in the Russian manned program consists of a chemical oxygen regeneration system. This system is backed up by an emergency high-pressure oxygen supply. The atmosphere is carried at normal sea level pressures and gaseous partial pressures. The flight duration of the expendables of their system is reported as 12 days. Ventilation of the man is accomplished by pumping cabin air through the suit and then exhausting it back to the cabin. In an emergency, the suit is sealed off from the cabin and maintains its pressure and ventilation by the way of the high-pressure emergency oxygen supply. The Russian scientists state that their environmental system has excellent flight records. Data obtained from the released reports verify this conclusion.

Space Suit Development:—The space suit development has been limited to two major activities during the past year. First, there were many minor changes in the Project Mercury suit. Such modifications as improved wrist bearings, improved shoulder design, new communications microphones, a mechanical visor seal to replace a pneumatic one, improved disconnects at the suit environmental system connections, improved finger dexterity in the glove design, the incorporation or a urine pump to move urine from inside to outside of the suit without loss of pressure integrity have all been incorporated during the past year. The success of these changes and the continued experience and the confidence gained in the Mercury suit design have led to the second activity, that of the development of the Project Gemini and Project Apollo garments. The Project Gemini suit has incorporated a partial undress concept and the zipper placement has been designed to permit the removal of body wastes from the inside of the suit. In addition, the Project Gemini suit will be designed to permit safe short duration extravehicular activity by the astronaut. The extravehicular activity will cause the development of the first personal life support system for use with the suit. This suit will provide the complete environmental control system, communication system, and astronaut tether system while the man is free from the spacecraft systems. A second new undertaking was the start of the development of the lunar extravehicular suit. The concept which utilized a "balanced convolute" system has been selected as the approach to be used to provide the necessary mobility in the joints of the suit. Another major advance in the lunar suit development program was the demonstration that conventional suit materials, now available, can be used to handle the solar energy load which will impinge upon the suit surface on the lunar surface. This advance will relieve greatly the temperature loads required of the personal life support system and thus will simplify and lighten this unit.

REVIEW OF FOOD AND WASTE HANDLING SYSTEM

Food:—The data gained from the flights of the Russian and United States programs have shown no problems of mastication. All forms of food have been tried in weightless flight. Crumbling of foods and melting of coating on the food were encountered but were easily solved through the development of a thin dissolvable methyl cellulose covering which keeps all particles together until after they are placed in the mouth.

The program to develop the diet for Projects Gemini and Apollo is well underway. Freeze-dehydrated foods will be used. The available menu of freeze-dried foods has been extended to permit three meals a day for 7 days without the need for repeating the main courses.

Man's metabolism while he is operating in space has not been studied completely; the diet, the water, and other provisions provided for a moderately heavy activity. As an example, the diet provides 2,550 calories per man per day. Further experience in flight will be used to define the actual requirements and the provisions will be adjusted to match actual needs.

Waste Handling:—The missions of increasing flight durations have necessitated the development of a urine pumping system to move the urine from the inside of the suit to the outside of the suit without breaking the pressure integrity of the suit itself. This suit has been incorporated into the suits for the next Mercury flight.

Defecation has been controlled through the use of a low-residue diet in the United States flights to date. However, data are not available concerning the length of time a healthy person may be maintained on a low-residue diet without difficulty. This study is being undertaken. In addition, studies are being conducted to develop a plastic bag for feces. This bag will permit the collection, the cessation of the bacteria activity, and suppression of odor production. Fecal wastes will be stored for the remainder of the flight. Russian scientists report that normal sensations and defecation habits have been found in their flight experience. They also use waste collection and storage as the handling method during their flights.

PROBLEM AREAS OF MAN MEETING THE SPACE ENVIRONMENT

This section of the paper will be directed toward those special areas which have received extensive review and recognition as areas of limitation for man while in the space environment.

Weightlessness:—The effects of weightlessness on man has been an area of primary concern in exposure of space crews to this new environment. It has caused the space medical community concern because it must be investigated by actual space flight. Thus, though answers are needed concerning risk prior to exposure, the only method of obtaining such answers is exposure of the crews to the actual in-flight weightless state. The need for careful crew evaluation on flights of increasing time increments is thus obvious. Many dire physiological effects have been suggested as resulting from such exposure. These have included anorexia, nausea, disorientation, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g tolerance, gastrointestinal disturbance, urinary retention, diuresis, muscular incoordination, muscle atrophy, and demineralization of bone. The excellent review by Henry, Laughlin, and Mosely given at the 1962 meeting included data through MA-6 (Glenn). They noted that the data were limited by the "tied down" position of the astronauts and the presence of adequate visual and kinesthetic cues. The conclusions reached at that time are still valid for considerably longer periods: 9½ hours in the program of the United States and 4 days in the Russian experience.

Pilots have carried out complex visual motor coordination tasks proficiently. The respiratory and cardiovascular systems have functioned normally. Eating of solids (cubes), tube food, and liquids has been easily accomplished when the food is properly packaged. Intestinal absorption has been normal and micturition has occurred quite normally in timing and amount. The nausea reported by Titov appears to be an individual idiosyncrasy in view of the lack of any such symptoms on the United States' 9½ hour flights and 3- and 4-day Russian flights. In addition, the Russians have reported normal sleep on three flights. This phenomenon will be investigated for the first time on the MA-9 flight. Another question which was unanswered has been studied on the 3- and 4-day flights where the crew were unstrapped and were free floating in the cabin for 50 to 60 minutes per day. They reported no difficulty resulting from such exposure nor did the 3- and 4-day exposures cause any problem at the time of entry.

Certainly there is much to be learned about prolonged exposure to weightlessness, and flights of increasing duration should provide this knowledge.

Orientation:—Questions concerning man's ability to maintain his orientation while in space flight were raised with a frequency which vied with weightlessness as the most likely area to produce difficulty. The area of orientation has been extensively discussed and planned for from the onset of the manned missions. Experience with instrument flying had demonstrated that vision was the body sense which could be relied upon to provide the necessary adjuncts for orientation. It was assumed that similar efficiency could be given to the astronaut through proper visual provisions within the spacecraft. A window was placed directly in front of the astronaut to permit direct orientation to earth, the horizon, or celestial bodies. A periscope to permit indirect outside vision was included to assure that the astronaut would have every opportunity to use all of the visual clues. As the flights have been accomplished, the ability to navigate and orient one's self has been studied by each astronaut. It has been found that the direct visual clues during earth orbit are powerful ones and have been effective even on the dark side of the earth. Horizons are distinct during the daylight and night phases. Identification of the celestial bodies and localization over the earth are equally exact. The direct visual capability through the window has been so effective that the periscope has been removed.

The inside of the spacecraft was planned to aid the astronaut through visual organization. System grouping of instruments, size of instruments, color coding, and organization of priority instruments were done to permit the astronaut to see them through the visual field of the visor of the helmet.

During the flights of Astronauts Carpenter and Schirra, attempts were made to identify the importance of orientation at all times while they were weightless. In each case, the men reported that they experienced periods where they did not know where the earth was, whether they were flying upside down or not, or whether they were flying backward or forward but that each did not feel that this was important. The instruments available and the window permitted a full capability to reorient themselves when the tests were over.

Discussions with the Russian scientific space team at the International Symposium on Basic Environmental Problems of Man in Space in Paris in 1962, reported similar results from all of their flights.

In summary, the questions of the importance of orientation and the methods by which positive orientation can be provided have shown that the use of vision as the prime body system is effective and that the importance of continuous orientation has not been of importance during the phases of flight which are not dependent upon accurate maneuver.

Isolation and Break Off:—Another area about which there had been dire predictions is the psychological response to the "isolation" of space. Our space crew have been anything but isolated and indeed have complained about the excess of radio contact. Responses and performances have been absolutely normal and no evidence of any isolation effect or break off phenomenon has been noted. There has been a feeling of elation at the succesful launch and the beauty of the cosmic view but no feeling of detachment from the earth.

Radiation:—The orbital trajectories chosen for Project Mercury were deliberately selected to keep the astronaut from encountering the radiation belts. The radiation hazards in Project Mercury were therefore reduced to that due to galactic radiation particles. The high altitude balloon studies had reduced this risk to a very low probability of occurrence. Satellite and balloon flights continuously confirmed and further defined the belt data. Therefore, radiation was set aside as no problem for Project Mercury. The establishment of the artificial electron belts by the high altitude nuclear tests reopened the problem for Project Mercury. Accelerated analyses of the satellite data on the energies found in this belt were made. Studies were also made on the shielding inherent within the walls of the spacecraft. It was found that there was minimal natural shielding provided by the wall of the spacecraft. Calculations indicate that the effective shielding is approximately 0.8 grams/square centimeter. The calculation of the radiation which would reach the astronaut indicated that the dose to be received would be 16 millirads to the skin and 200 millirads to the eyes. Flight data confirmed this and resulted in reports of the skin receiving 13 millirads and the eye receiving 160 millirads during Astronaut Schirra's flight.

The Russian scientists came to the same conclusions. The similar problems of low orbital flight and their resulting flight data indicate similar results. The Russian cosmonauts received approximately 10 millirads/day/man in flights of Vostoks I, II, III, and IV.

The flight programs of Project Gemini will result in similar radiation exposure as that seen in Project Mercury. During the extravehicular operation in the low orbits, the man will be covered only by his suit and the free space radiation will be directly impacted upon the man. Unless additional artificial radiation belts are established there should be no serious problem. Study is underway to assess the radiation exposure on the Gemini high elliptical flights which pass into the Van Allen Belts during the rendezvous missions.

The Apollo program will be concerned with the radiation hazards of the travel through the natural belts, the exposure to solar flare energies, and the galactic particles. In addition, the exposure will be extended over periods of up to 2-weeks duration. Studies similar to that performed for Astronaut Schirra's flight are underway. The environment is being defined; the natural shielding inherent in the spacecraft wall is being calculated; and astronaut exposure limits are being established. The completion of these three areas of study will permit the analysis of the risks in radiation for the lunar mission. Further definition of the environment is dependent upon study of the next solar cycle. The effectiveness of the shielding inherent in the spacecraft is dependent upon the final design organization of the equipment in the vehicle. The dosage limits are dependent upon the risk an astronaut is allowed to accept while he is undertaking such an exploration.

Recycle Time:—Early in the space flight program, on the first orbital flight, it was necessary that a decision be made concerning a proper astronaut recycle time. At that time, spacecraft and launch-vehicle factors had recycle times in excess of those felt required for the astronaut and the problem was circumvented. As the formulation of a plan is made for Project Gemini, the problem is again under study. It is the opinion of NASA that evidence would indicate that the space crew could be recycled to attempt launch again after a 12-hour rest period. It should be realized that most of the conditions that would cause an aborted launch will require recycling maintenance and spacecraft crews and range personnel, and this period will usually encompass more than the 12-hour astronaut recycle time.

The problem area of man meeting the space environment can be summarized by stating that, prior to actual flight experience, there had accumulated in literature a large series of projected problems associated with space flight which forewarned that men would be in jeopardy or have serious limitations while in space. As this review has indicated, these dire predictions have not developed. There is no evidence that a catastrophic emergency involving the pilot will be forthcoming, and there is increasing evidence that any change to be observed will appear as a slow shifting from the normal values. This knowledge will make the monitoring of trend information of increasing value when the status of the astronaut is to be ascertained.

CONCLUSIONS

Many of the projected bioscience problems associated with manned space flight have not been borne out in flight experience. Man has been shown to be able to live and work in the space environment up through 4-days exposure as long as adequate life support is provided.

The flight experience indicates that the changes in man occurring while he is exposed to the space environment will be a gradual one rather than the catastrophic event predicted in some of the early literature, that no sudden and bizarre events have been seen, and that trend data will be of more value than a major emergency alarm system. Any catastrophic event will have its origin in vehicular failure rather than with man.

Design criteria and test results for support equipment for man have been proven valid. Techniques of assuring weightless operation of equipment have been shown to be sufficient. Demonstration of the validity of these factors now permits the safe design of future systems through the maximum 2-week duration flights of Projects Gemini and Apollo.

Russian and United States experiences are complementary. The studies undertaken within the USSR manned-flight program are comparable to those of the United States. The Russian scientists feel that man can operate for several days in weightless flight without jeopardy. They feel that this area should be studied further on progressively extended flights to permit safe extension of man into missions of longer durations.

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