BIOLOGICAL CONSIDERATIONS OF MANNED SPACE FLIGHT*

Captain Ashton Graybiel, MC, USN**

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**Director of Research, U. S. Naval School of Aviation Medicine, U. S. Naval Aviation Medical Center, Pensacola, Florida. Opinions and conclusions contained in this report are those of the author and do not necessarily reflect the views or endorsement of the Navy Department.

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In the exploration of outer space man continually will be exposed to hazards and stresses. For our purpose here a stress is defined as a factor which disturbs bodily equilibria but which man is expected to experience and bear, while a hazard is a noxious factor with only a probability of occurrence but which may or may not be tolerable. The distinction between the two is always important but cannot always be made unless the conditions are known. A particular factor, say ionizing radiation, may simultaneously exist as a stress and pose as a hazard, the essential difference being quantative in nature. Physical hazards, many general psychological stresses, and prolonged exposure may in turn pose a hazard to health.

In manned space flight, stresses and hazards have their origin in 1) the great distances to be transversed, 2) the lack of any known destinations with a favorable environment, 3) the exposure to a near vacuum, and 4) the changes in the gravitoinertial force environment.

Distance as a function of time will forever limit an individual in the exploration of the universe. The six nearest stars are 4.3 to 8.6 light years away; and beyond, these distances multiply. Even assuming near relativistic velocities, an almost miraculous assumption, it would take about 12 years to reconnoiter the nearest star, Alpha Centauri, and return. Time is far from a negligible factor in the exploration of our own solar system. Until true space ships are available, the estimated time on a transfer elipse from earth to Mars is in the neighborhood of 200 days and the return between 80 and 100 days. The implications in terms of maintaining integrity of man and machine are apparent.

The hostile character of all known extraterrestrial environments and the present lack of any docking facility not only makes extravehicular missions hazardous but also, and more importantly, requires that provisions be made for a "round trip." Generally speaking, it is the final rather than the initial phase of the flight or mission which is more stressful, more hazardous, and more difficult. Launch is contingent on a state of preparedness little short of perfection, involving the vehicle and its various control and life support systems, the astronaut(s), and flight operations. Moreover, the transition from launch to orbital flight is not severe. Re-entry is obligatory within a specified period, makes heavy demands on the astronaut, and terminates with an impact in a specified area rather than a predetermined point. Indeed, a very important aspect of the final phase of flight is evaluation at periodic intervals of astronaut fitness for re-entry, and, in addition, early recognition of symptoms or manifestations that might eventuate in "unfitness" will provide invaluable lead time.

The near vacuum in outer space not only is a hazard per se but also offers no support for a spacecraft and no protection from meteorites, cosmic and solar radiation, or cold. It does have two advantages, namely, the absence of friction and free transmission of useful solar energy.

Meteorites, at one time believed to be a serious if not insuperable hazard, are no longer so regarded. The locations of large meteorites are known or can be determined, and the spacecraft will afford protection against micrometeorites. Only when the astronaut leaves the spacecraft will micrometeorites pose a problem.

Radiation is at once a stress and a hazard. For example, in orbital flight an inclination of 30° to the geographic equator is chosen to take advantage of the protection afforded by the geomagnetic field and an altitude under 300 nautical miles is chosen to avoid the trapped particles, mainly protons, in the Van Allen belts. Within these constraints under ordinary conditions the radiation burden inside a spacecraft is well within acceptable limits. Emulsion measurements carried out by Schaefer[1] on the MA-9 orbital flight indicate that the total exposure was 40 millirems. A sizable portion of this total was registered during orbits which passed through the South Atlantic anomaly where protons of the inner Van Allen belt have exceptionally low mirror points. Although 40 millirems is far short of the weekly permissible limit of 300 millirads, it is nevertheless tenfold greater than the normal exposure level from cosmic radiation.

Even within the orbital constraints and altitude, it is necessary to take into account the hazards from solar flares[2]. A solar flare has two important effects. The first is an increase in proton flux which reaches the vicinity of the earth in a characteristic time-intensity pattern. Although solar flares have not been visible on the solar disc for as long as one hour, the particle flux does not reach its maximum until some minutes after the visible flare has disappeared. A high level of flux is maintained for two to three hours followed by a decay of the proton beam over a period as long as two days. The second effect is in the nature of a geomagnetic storm occurring about 24 hours after the appearance of the solar flare. This storm is characterized by a disturbance in the earth's magnetic field which reduces to a large extent the shielding effect of the geomagnetic field. Thus a single flare will decrease the normally protected equatorial region initially by virtue of the momentum spectrum of the proton beam and later on through the additional cancelling effect of the geomagnetic storm. Solar flares may occur in series. A second solar flare with its peak proton beam arriving during the geomagnetic storm generated by a preceding flare would have an abnormally great effect.

Solar flares are categorized as "ordinary" or "relativistic." The momentum spectrum of an ordinary flare is usually below 1.5 billion e-volts/c. Relativistic flares while rare, only seven have occurred in the past 20 years, have a particle flux which may reach momenta as high as 10 billion e-volts/c. Such energies resemble those of galactic protons and would reach the vicinity of the earth as far down as 15° latitude even in the absence of a geomagnetic storm. Moreover, shielding adequate for protection against ordinary solar flares would only serve to increase the "secondaries" from relativistic flares and thus the exposure hazard.

The prevention or treatment of radiation effects poses at once a great challenge and opportunity. In this connection, it may be mentioned that Zhukov et al.[3] have studied the protective properties of mercaptopropylamine on the phage producing activity and "genetic apparatus" of E. coli. They found that this agent does not protect the genetic apparatus against lethal effects but does reduce the level of phage producing activity.

The hostility of the outer environment requires that a spacecraft contain all provisions for man's protection and life support except insofar as solar energy can supply his need for power. The integrity of the spacecraft and all of its essential operational and life support systems must be maintained. Food, water, and a comfortable clean atmosphere must be provided and arrangements made for waste disposal or regeneration. The operational constraints will, for many years, limit the size of the spacecraft and the weight of its contents. The astronaut will be exposed to such stresses as confinement, limited social contacts, the threat of hazards from without, and

and fear of malfunction within. Care of the astronaut aloft is a many faceted problem, and the rigid demands of ensuring his medical and professional fitness for re-entry must be met.

Of all the stresses and hazards which man will encounter in orbital space flight, prolonged exposure to weightlessness represents the great unknown. Two choices to combat this are open, either the use of countermeasures in a weightless environment or the generation of artificial gravity in a rotating environment.

The American astronauts did not complain of weightlessness, and the available reports contain little information which cannot be summarized by the statement that, if anything, they fared a little better than if the vehicle had been airborne. While this is reassuring, the experience thus far does not afford a sufficiently solid foundation for a big leap forward. Hence, we have a stepwise man in space program, leaving the big jump for animals which, in the classical tradition, precede man into hazardous situations.

Recently, the Russian scientists have described the findings of experiments carried out in weightlessness and, reportedly, implied that exposures for more than five days might not be without risk. At the very least it has focused attention very sharply on this curious stress or hazard.

Weightlessness is not a single variable in the ordinary use of this term but an influence of almost increditable complexity causing second or third order effects which dictate an utterly different way of living and, conceivably, an impossible way of life. Man has evolved as a terrestrial animal and, through the ages, he has undergone not only countless adaptations to gravity but also has taken it into account in much of his training and experience. In a spacecraft while exposed to weightlessness he must cope with unique physical factors in the environment, including instability of objects, lack of friction, lack of convection in the atmosphere, and changes in gas-field interfaces. His homeostasis is affected notably by deafferentation of gravireceptors, lack of stimulation to antigravity muscles, loss or alternation of cardiovascular reflex mechanisms and, possibly, by more subtle influences at the cellular or subcellular levels. In man's interaction with his environment he is handicapped in walking, working, eating, drinking, and elimination of wastes. He is exposed to the hazard of particulate matter in the atmosphere and of injury, especially to the eyes from moving objects. Thermal balance may be affected by the lack of convection and drainage of sweat.

When the possibility arose that space vehicles might be rotated to generate an inertial force and thus abolish the undesirable effects of weightlessness, it seemed worthwhile to simulate such rotating environments in the laboratory. To this purpose we constructed a nearly circular room, called the Slow Rotation Room, about 15 feet in diameter, around the center post of our human centrifuge and exposed men or animals to angular velocities ranging from 1.0 to 20.0 RPM for varying periods of time. It was immediately evident that we now had a means of studying a type of motion sickness under almost ideal laboratory conditions, and the range of velocities was even greater than that seriously considered for use in space vehicles aloft.

At a constant angular velocity, the experimental subject does not perceive that he is rotating. Seated near the center of the room, he is scarcely aware of the small centripetal force and with head fixed, he is comfortable. In preliminary experiments we were struck with the disparity between the small magnitude of the force environment and the great severity of symptoms experienced by the subject when randomly moving his head. The precipitating factor was the gyroscopic accelerations generated whenever the head was rotated about an axis other than that of the room. This was an effective stimulus to the semicircular canals which are uniquely structured to respond to angular and Coriolis accelerations. The pattern of stimulation caused by the latter was unusual and resulted, presumably, in a bizarre pattern of afferent impulses which evoked the observed changes in intrinsic and extrinsic behavior.

It was quickly apparent that a type of motion sickness we later termed canal sickness might present a problem in rotating space vehicles and that we had a new and useful experimental device for studying this functional disorder. Experiments dealing with the clinical features consisted of brief exposure to rotation for evaluating individual susceptibility to motion sickness and prolonged exposures to study the time course of adaptation. Typical symptoms included the nausea syndrome, somnolence, pallor, and cold sweating. The atypical symptoms were more characteristic of anxiety or psychoneurosis than of motion sickness and were further characterized by a discrepancy between the subjective and objective symptomatology. Subjects with low susceptibility usually manifested typical symptoms.

Prolonged rotation in the Slow Rotation Room affords the opportunity of studying the complete symptomatology evidenced by subjects both during and after rotation and how it affects their performance. When subjects were exposed to a severe stress (10 RPM) for 12 days, significant changes occurred during three periods along the time axis of the experiment, namely, initial and final perrotation periods and post-rotation. In the initial adaptation period the subjects restricted their head movements to prevent the nausea syndrome. This subject-paced stimulus level was well below the unpaced level and was individually adjusted to the time-course of adaptation to this unpleasant syndrome. With the disappearance of nausea head movements were increased, thereby greatly increasing the stimulus to the semicircular canals. This introduced the final adaptation period which presented a different clinical picture. Nausea was absent but drowsiness and fatigue were prominent. The most significant biochemical alterations were observed in this final period, including 1) an increase in the release of corticosteroids, reflecting stimulation by way of the pituitary-adrenal axis, 2) a striking increase in glucose utilization, and 3) an equally striking increase in the plasma level of the enzyme, lactic dehydrogenase. The post-rotation period reflected both the reappearance of certain symptoms and the gradual disappearance of others. The former included ataxia and very mild symptoms referable to the nausea syndrome. It required about two days for the disappearance of fatigue and other "residual symptoms."

A group of eleven deaf persons with bilateral vestibular defects did not experience any unpleasant symptoms in the Slow Rotation Room. Parenthetically, it may be added that the same results were obtained when they were exposed to all of the unusual force environments at our disposal. An exception to this was one subject who suffered from acrophobia and manifested symptoms of anxiety in aircraft. If the assumption is made that these subjects are representative of their kind, then the conclusion is warranted that the symptoms experienced by the normal subjects must have their genesis directly or indirectly in the vestibular organ.

Through the kindness of Professor Schuknecht we have evaluated four of his patients who had been relieved of their symptoms of Menière's disease following treatment with streptomycin sulphate. None manifested symptoms of canal sickness in the Slow Rotation Room although three of the four had a high level of residual function of the semicircular canals on one side. We have also evaluated subjects who had recovered from labyrinthitis, and the results indicate that either unilateral loss of canal function or slight loss bilaterally rendered these individuals relatively unsusceptible.

Our studies indicate that susceptibility to canal sickness in the Slow Rotation Room correlates quite well with susceptibility to other types of motion sickness. Insofar as this is true, we have a laboratory device for studying motion sickness under controlled conditions and evaluating its prevention by means of drugs. We have only begun experimenting with drugs, and I hesitate to say much about our results. We did find in one experiment, wherein several drugs given in ordinary doses were compared, that hyoscine and a combination of hyoscine and d-amphetamine gave the best protection.

REFERENCES

1. Schaefer, H. J., Radiation monitoring on Project Mercury: Results and implications. Aerospace Med., in press.
2. Schaefer, H. J., Personal communication.
3. Zhukov-Verezhnikov, N. N., Maisky, I. N., Rybakov, N. I., et al., Cited in Sisakyan, N. M., Gazenko, O. G., and Antipov, V. V., Satellite biological experiments. COSPAR Symposium, Florence, Italy, May, 1964.