SPACE MEDICINE*

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Space medicine is the key to Man's survival in a new dimension. It represents his only hope of staying alive in the hostile environment of space and of his subsequent safe return to earth.

Until recently, space flight appeared to be only a remote possibility of the far distant future. As a direct result, however, of considerable research and development in the field of rocket technology, dating from the brilliant pioneering by Robert Goddard and culminating in the spectacular achievements of Werner Von Braun and others, it is at present not merely a possibility but a very distinct probability.

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SPACEMEN AND SPACE VEHICLES

With assorted sputniks, satellites, solar rockets, and other devices in orbit round the earth and the sun, the public may be forgiven for taking it for granted that soon enough now a fellow human-being will be shot off into space in one of these vehicles. However sensational and eagerly awaited such an event may be, the assurance can be given that as of now certain considerable physical and psycho-physiological barriers remain to be overcome before Man himself can become an interplanetary traveller.

While rocket engines were being developed during the last decade or two to provide power for a space vehicle, a great deal of human engineering has been taking place to provide Man with the necessary protective equipment to withstand the rigours of space travel.

Simultaneously a vast amount of fundamental research has been undertaken by workers in the field of aviation medicine with the result that equally spectacular advances have been made in this direction with a view to keeping Man abreast of the demands made on his physiology by the performance factors inherent in modern high-performance turbojet and rocket aircraft.

From the very considerable endeavours by workers in these related fields the new concept of space medicine has emerged. Space medicine is a direct development and extension of aviation medicine and deals with the same fundamental problem of how to keep Man, who is confined by relatively narrow physiological limits of pressure, temperature and atmospheric composition, alive at altitudes and speeds of a magnitude unheard of even a few years ago. Seeing Man safely past these physiological and physical barriers is the abiding and exacting task of aviation and space medicine.

To achieve space flight both Man and his vehicle must be adapted to the rigid requirements of the space environment. In other words, to be effective, space medicine must be wedded to space engineering, since failure of either Man or machine in space will be an irretrievable disaster. Space medicine will ensure that everything that can possibly be done in advance to ensure the safety, survival and performance of those who will be the first to orbit the earth and later to soar into true space, will in fact be done.

Whenever space or rocket flight is mentioned it conjures up visions of manned trips to the moon and the various planets. At the present moment there are probably a dozen or more satellites in orbit which prove the feasibility of space flight and show that rocket propulsion has opened up the true vertical dimension of flight. As a result of intensive study of the diverse and complicated aspects of space medicine over several years, authoritative opinion now holds that from the point of view of human tolerance and of the rational functioning of spaceship crews, short duration flights such as limited orbiting in the space-equivalent region near the earth, are physiologically acceptable and are presently attainable. An example of this type of flight is the X-15 project which is currently under way in the United States Air Force. It is envisaged that, at the present rate of development, true space flight will eventually become possible and enable Man to break his bonds with earth and so achieve the extravagant accomplishment of penetrating beyond the threshold of space.

EVOLUTION OF SPACE FLIGHT

What then, one may ask, is holding manned space flight back? A review of the known physical and psycho-physiological barriers to flight by Man into space shows that none are apparently insuperable, yet a great deal of information is still required before these flights can take place. It can safely be predicted that the full exploitation of the application of the revolutionary rocket principle of propulsion to space flight will probably follow the pattern of a gradual evolution. With this in mind a simple classification of the present and future stages of manned flight, which will allow a realistic assessment and evaluation of the whole question, can be devised.

The stages of the evolution can best be understood by examining 3 factors: (1) The physiological and mechanical properties of the space environment; (2) the speeds attained in space flight; and (3) the distances rockets travel over and away from the earth.

1. *Environment*

The border between the atmosphere and space in astrophysical and meteorological terms lies at an altitude of approximately 600 miles. As an environment for the space pilot and the rocket carrier the atmosphere shows conditions typical of space at much lower altitudes. One encounters within the atmosphere, beginning at 50,000 feet, a region which becomes increasingly space-equivalent with regard to one or more of the conditions important for manned flight. These conditions are: absolute anoxia at 50,000 feet, the vaporization of body fluids at 63,000 feet, the necessity for a sealed cabin at 80,000 feet, the possibility of collisions with meteors from 75,000 feet and the darkness of space from 100 miles.

Above 120 miles we find space-equivalence in almost all respects. The atmospheric region from 50,000 feet, or about 10 miles, up to 120 miles may be considered partially space-equivalent. This border-zone of space is also called the 'aeropause' because the effects of the atmosphere on man and craft begin to come to an end. It is the region in which flight is in fact currently possible. The region above 120 miles is totally space-equivalent since the atmosphere is imperceptible to the flyer, although for the astronomer it exists up to 600 miles.

This being true, the rocket-powered X-2 plane which has carried a man to 130,000 feet, and the recent balloon flight by Major Simons of the United States Air Force to approximately 120,000 feet, occurred in a region which is space-equivalent to a high degree. The flight by the late and much lamented dog in Sputnik II took place in conditions of total space-equivalence. From the standpoint of environment we have now reached the partial space-equivalent phase of manned space flight.

2. *Speed*

Just as certain levels in the atmosphere are characteristic in the environment around the earth, so there are certain characteristic points in the factor of speed. They also mark distinctive stages in the development of flight.

The first of these is the speed of sound — 762 m.p.h. (Mach 1 at mean sea level). The present record in the supersonic range exceeds Mach 2. In the higher range of Mach 3 and 4 in horizontal flight, centrifugal forces begin to counteract gravitation to an increasingly noticeable degree and bring on the phenomenon of decreased weight or subgravity.

At 18,000 m.p.h., or approximately 5 miles per second, in horizontal flight the gravity-free or weightless state is finally reached, where centrifugal force equals the gravitational pull of the earth. This speed is known as the orbital or circular velocity and is the minimum speed necessary to place an artificial satellite in fixed circular orbit about the earth. This achievement was first accomplished by the Russians with their Sputnik I.

At 7 miles per second or 11 kilometres per second, the craft breaks away from the earth's gravitational pull and escapes into the depths of interplanetary space. This is called the escape velocity.

As is well known, the 3-stage rocket has demonstrated its ability to attain orbital velocity in the totally space-equivalent region up to a reported altitude of thousands of miles. The attainment of escape velocity with multistage rockets has been dramatically demonstrated by the Russian Lunik or lunar probe which has successfully escaped from the earth's gravitational field and is now a minor planet revolving round the sun.

3. *Distances*

The various stages of flight can also be classified by the factor of the distances they cover. The craft may fly from one point to another on the globe, in a certain distance around the globe, or far away from the globe into space. If the factors of environment, speed and distance with their characteristic levels are combined, an evolutionary course in the development of manned flight is apparent.

The long distance flights of today take us at subsonic speed, under normal gravitational conditions in pressurized cabins, through the lower regions of the atmosphere from one point to a distant point on the globe, across a number of time zones and/or across zones of different seasons in a single day. These are global atmospheric flights. This epoch in flying began when Lindbergh crossed the Atlantic in 1927.

We are now on the threshold of the next stage. Rocket-powered planes will take us at supersonic speed under sub-gravitational conditions and in sealed cabins through the space-equivalent regions of the atmosphere from one point on the globe to an extremely distant point in a matter of hours. Still bound to the earth, these journeys will fall into the category of global space-equivalent flight, e.g. the X-15 project.

The precursors of the long-distance space-equivalent space flights are seen in the short-distance, short-lived flights of rocket-powered planes of today. They can be termed local space-equivalent flights. As soon as the orbital velocity of 5 miles per second is reached, flights of long duration around the globe in a satellite orbit under conditions of zero gravity and in an environment equivalent to space will become possible. But these craft will still operate within the gravitational hold of the earth and will remain within the earth's vicinity. This eventual stage may be called circumplanetary space flight.

The next step will follow when the escape velocity of 7 miles per second is reached. When eventually a manned rocket leaves the earth, attains this speed and moves freely in space, then we will have arrived at interplanetary space flight or what may be called space travel.

A classification of space-flight evolution such as this has been devised by Dr. Hubertus Strughold of the Department of Space Medicine, United States Air Force, and gives a clearly defined and realistic picture of the stage at which we stand today and of the possibilities we may expect in the future (Table I).

At present we are actually in the first phase of space flight, the phase defined as global space-equivalent flight. Solution of the medical problems in this stage is therefore of immediate concern to the physiologist, the engineer and the pilot. What are the special medical problems encountered in space flight?

MEDICAL PROBLEMS OF THE SPACE FLIGHT

Many of these problems are basically those of high altitude flight as we know it today and most of the medical problems involved in true space flight are encountered in the stage of global space-equivalent flight. It has in fact been said that the fingers of space medicine reach right down through the atmosphere to as moderate an altitude as 10,000 feet, above which hypoxia commences. The most critical areas in both aviation- and space-medicine are naturally concerned with the protection of aircrew against the hazards of high-altitude and high-speed flight both inside and outside the atmosphere of the earth.

Hypoxia

In considering the aeromedical aspect of flight at extreme altitudes, the central problem concerns lack of oxygen. Hypoxia is a syndrome that results from inadequate oxygenation of the tissues due to a decrease of the partial pressure of oxygen in the inspired ambient air.

Symptoms

The symptoms are dependent on a series of variable factors like absolute altitude, rate of ascent, duration at altitude, ambient temperature, physical activity, and individual susceptibility and tolerance, but the inevitable end-result is a progressive descending depression of the central nervous system and a disruption of the psychomotor functions, causing serious incapacity of the pilot and invariably leading to loss of control of the aircraft.

To obviate this danger it has long been standard practice to provide an oxygen system to supplement the alveolar oxygen partial pressure and at present an automatic pressure-demand oxygen regulator is used on all jet aircraft. Unfortunately the protection afforded by even the most sophisticated oxygen system is not unlimited since present-day high performance aircraft can comfortably exceed altitudes where the total ambient pressure is not as high as the partial pressure of oxygen necessary for the required normal 90 - 95% oxygen saturation of the blood. Such a critical height occurs at the moderate altitude of 34,000 feet where the barometric pressure is 187 mm.Hg. At this altitude the pilot on 100% oxygen will have an alveolar partial pressure of 160 mm.Hg which is equivalent to the normal conditions at sea level. However, on exceeding 34,000 feet on 100% oxygen, he will exhibit symptoms of hypoxia ranging through the undetectable, to the compensatory, the disturbance, and ultimately the critical stages ending in death exactly as if he were ascending above 10,000 feet without oxygen.

Pressurized Cabins

To overcome this limitation, use is made of a pressurized cabin to surround the pilot artificially with a pressurized environment which is equivalent to an altitude lower than the height at which the aircraft is flying.

Even cabin pressurization, however, is not the complete answer, because in the rarefied air above 50,000 feet very large and heavy compressors are needed to maintain cabin pressurization. Between 60,000 and 70,000 feet the air-

TABLE I. CLASSIFICATION OF DEVELOPMENTAL STAGES IN MANNED FLIGHT

	1. Global atmospheric flight	*2. Global space-equivalent flight*	*3. Circumplanetary space flight*	*4. Interplanetary space travel*
Distance	Geographic dimensions	Geographic dimensions	Vicinity of earth	Interplanetary dimensions
Environment	Lower atmosphere	Space-equivalent regions of the atmosphere	Circumplanetary space	Interplanetary space
Speed	Sub- and supersonic speed	Supersonic speed	Orbital velocity	Escape velocity
Gravity	Normal gravity—1 G*	Sub-gravity	Zero gravity	Zero gravity

*G = Gravity

craft will encounter the ozone layer between the stratosphere and the ionosphere, and ozone in the cabin in concentrations of more than 6 parts per million under a pressure of 2·7 lb. per square inch is fatally toxic.

While cabin pressurization up to a certain altitude is a satisfactory solution, the attainment of higher altitudes requires an additional method of ensuring the survival of the pilot should cabin pressure be lost as the result of explosive decompression.

The consequence of such an explosion is to transport the pilot instantaneously from his artificial atmosphere inside the pressurized cabin to the actual altitude he happens to be flying at; for instance from, say, 18,000 feet to 55,000 feet in a split second. Now above 50,000 feet a given volume of gas will expand to 14 times its volume at mean sea level. Seeing that all the gases trapped inside the body in the lungs, gastro-intestinal tract, and other cavities are subject to this expansion, the pilot may be in danger of rupture of his alveoli, with subsequent air embolism, should the expanded gases not be able to escape freely.

Pneumatic Counter-pressure Suit

To obviate this danger of sudden exposure to the hazards of extreme altitude the pneumatic counter-pressure suit was introduced. This garment is in effect a personalized pressure environment which is barostatically controlled and is instantaneously inflated to maintain adequate pressurization around the pilot's body when explosive decompression takes place. This application of counter-pressure to the body in conjunction with emergency pressure breathing will give the pilot a reasonable chance of survival provided he is able to descend quickly to lower altitudes.

At an altitude of 63,000 feet, however, the total barometric pressure drops to a mere 47 mm.Hg, which is equal to the water-vapour pressure of the saturated gases in the blood-stream at the normal body temperature of 37° C. Exposure to this altitude would lead to boiling of blood in the vessels and filling up of the lungs with steam. This altitude is known as the space-equivalent because survival times at any altitude above 63,000 feet would be identical. From here onwards only 12% of the total blanket of the atmosphere remains and for all practical purposes space flight commences.

Hermetically-sealed Cabin

For the purpose of space flight, and indeed for all sustained manned flights above 70,000 feet, all the aids to conventional high altitude flying become inadequate in themselves and such flying is only possible when Man carries his own atmosphere in an hermetically-sealed cabin. Such a self-contained sealed cabin is the essential basis for the spaceships of the near future and, like the rocket motors which must be used for propulsion at altitudes of 80,000 feet and above, it is atmospherically independent and will carry its own oxygen supply.

This necessitates the provision of a closed ecological system in which Man can live for a considerable period. It is essential that whatever is needed by Man to sustain him adequately for the entire duration of any contemplated flight, including air, water, food and recreation, must be complete within the sealed capsule of the vehicle. In addition to a constant supply of these necessities, all waste materials must be eliminated or converted for re-use. If this capsule can be made efficient then the absence of ambient air, as such, does not present a problem from the respiratory standpoint. What does pose a problem, however, is the supply of sufficient oxygen for long flights which may last a few weeks. Ordinary containers will do for short flights, but will be impracticable for longer trips.

Studies are currently proceeding concerning the use of plants for photosynthesis, oxygen production and carbon dioxide removal in a closed system. It has been determined, for instance, that an 8-cubic foot suspension of a certain green alga, *Chlorella pyrenoidosa*, would be sufficient to balance the gas metabolism of one man and do away with the need for bulky cylinders. Although this is an attractive solution from an academic point of view there are enormous biological and engineering difficulties in the way, but it is hoped eventually to achieve artificial photosynthesis and to devise methods for the reconversion of waste solids and fluids to a usable state.

There are at present sealed cabin simulators in use which now serve as research tools and will later be used for purposes of conditioning.

Stresses of Rocket Thrust

If it is now assumed that this sealed capsule will adequately protect the space traveller against the hazards of anoxia and supply him with a personalized pressurized environment. The next series of hazards lie in the field of tolerance to the thrust of rocket propulsion and the orbital or escape velocities involved.

Experience has shown that very high speeds are not significant *per se*, and that there is little doubt that Man, if properly protected, will tolerate a constant velocity well in excess of escape velocity.

But speed is vitally important as a producer of stress mainly through the application of linear, angular and radial acceleration.

It has been experimentally determined in the human centrifuge that the average healthy young pilot can tolerate pressures up to 5 positive G* for 5 seconds, 3 negative G for 3 seconds and 12 transverse G for 3 seconds before lapsing into unconciousness. To improve tolerance, an automatic anti-G suit has been developed which provides automatically controlled counter pressure over certain vital body regions like the abdomen and lower limbs, to prevent the pooling of blood under the influence of increased gravitational pull.

As in conventional flight the most critical phases of rocket flight occur at take-off and landing. Unfortunately, in these critical procedures the principles of rocket engineering run counter to the interests of the physiologist. The engineer requires maximum acceleration in the shortest time, but human tolerance even in an anti-G suit is limited. However, it has been calculated that Man, properly conditioned and protected, will be able to withstand the application of high G-values for as long as it would take a 3-stage rocket to attain escape velocity.

The order of values the physiologist will have to deal with varies from 10 G attained for an acceleration time of approximately 2 minutes to 4 G during an acceleration lasting approximately 6 minutes.

* G is the symbol for normal gravity at mean sea-level.

Reaction-time Limitations

Apart from the component of acceleration, the attainment of hypersonic speeds expose yet another inflexible physiological limitation in Man, namely that of reaction time. Although perfectly adequate in terrestrial situations, human reflexes, which travel at a mere 200 m.p.h., become totally inadequate at these speeds.

A few insignificant seconds required under normal situations before a potential danger can be seen and evaluated, and evasive action can start, attain awesome proportions in high-velocity flight. Pilots of aircraft flying at supersonic speed in opposite directions may in fact only see each other after they have passed. Known as the 'coming-past interval', this phenomenon occurs where the sum of the closing speeds exceeds the speed of transmission of the visual images of the eye to the brain.

It can therefore be defined as the present perception of an event that has already occurred in the past. The problems resulting from those basic reaction-time limitations of human control can, however, be overcome by the installation of electronic devices which can react much faster than man to control the aircraft or spaceship.

Orientation in Weightless Conditions

Having attained escape velocity, the spaceship will break away from the earth's gravitational pull and the crew will experience a state of weightlessness. When the normally-present stimulus of gravity is lacking, some doubts are entertained regarding deterioration of Man's sensory and motor performance.

Spatial orientation, for instance, depends largely on the presence of gravity, and to orientate himself Man will have to be conditioned to depend on visual re-orientation. For short periods Man may be able to adapt himself to weightlessness, but it becomes important for the physiologist to know how long the interplanetary navigator must be subject to the gravity-free state.

Trips to Venus or Mars at a speed of say 30 kilometres per second over distances of about 100 and 200 million kilometres, respectively, amount to about 5 and 10 weeks, or for a round trip, 10 and 20 weeks, respectively.

If sufficiently large quantities of fuel energy are available, this travelling time could be reduced considerably by continuous acceleration during the first half, and by corresponding deceleration during the second half of the journey. This has the further advantage that during the whole trip a small component of acceleration which would simulate gravity could be present with a steady acceleration of say 0·1 G. The trip to Venus and Mars could then be carried out in about 5 - 6 days. The spaceship would, in this instance, attain a peak velocity of 200 to 250 kilometres per second relative to the sun, which is roughly 1/10,000 of the speed of light.

Other Space-flight Problems

There are many more problems, classified under the physiological-environment problems of space flight, which include such matters as solar and cosmic radiation and the danger of collisions with meteorites.

Physical Problems

The maintenance of a proper temperature level within the ship is of major importance. Fortunately, knowledge of the laws of radiation in connection with the respective spectral absorption co-efficients of the hull's material permits a fairly accurate calculation of the equilibrium temperature the ship will attain. Computed temperatures during the most adverse conditions of re-entry are of the order of 150° F. for less than 5 minutes. This is considered to be well within acceptable limits for human beings.

Cosmic rays, which include bombardment with heavy primary nuclei, may constitute a serious radiation hazard to space travellers, but experiments with animals in very-high-altitude balloons indicate that depigmentation of the hair is the only observed defect so far.

The recently discovered Van Allen band of intense radiation is important only to manned earth-orbiting flights but not to true interplanetary flight since it is only a local phenomenon, and at escape velocity the spaceship will pass through this layer so quickly that no significant radiation is feared.

As regards the probability of collisions with meteorites it has been calculated that a collision of the spaceship with a meteorite must be anticipated within the period of about 1 month. These figures constitute a considerable hazard for the crew of a spaceship. The high velocities of meteorites give them the power to puncture even thick steel plates. The collision with a meteorite of several hundred grams, which size fortunately is very rare, would, by causing explosive decompression and instantaneous loss of the cabin air, be catastrophic.

Psychological Problems

A final vast complex of problems is more of a psychological nature, including the problems of psychic aptitude, fatigue, claustrophobia, etc. A peculiar problem is the recent spate of reports by pilots of very-high-flying aircraft of being completely free of all earthly associations; this has been termed the 'break-off phenomenon'. This overwhelming sense of detachment from the earth may adversely affect air-crew performance, but prior knowledge and adequate conditioning may enable Man to adapt himself successfully even to the strange environment of space flight.

The chief subjective feelings related to this break-off phenomenon are those of remoteness, loneliness and anxiety, with the ever-present fear of permanently losing contact with the earth. These manifestations may lead to a serious loss of efficiency in the performance of crew members.

To explore these subjective phenomena research is at present being conducted by the United States Air Force in the so-called space chamber. Various subjects have in fact been making week-long make-believe voyages into space under accurately simulated space-flight conditions. Eventually, spaceship crews will undergo conditioning flights in such chambers preparatory to crossing the vertical frontier into outer space.

CONCLUSION

Will these manned flights take place in the near or, indeed, the foreseeable future? Informed opinion is not unanimous on this score, but in conclusion I should like to quote the views expressed by Dr. F. L. Whipple, Director of the Smithsonian Astrophysical Laboratory in Massachusetts. According to him the American space-flight timetable calls for the following:

1. Sending a satellite with scientific intruments around the moon and back again by 1960.

2. Landing scientific equipment on the moon by 1961.

3. Placing a man in an outer-space orbit 2,000 miles up and returning him safely to earth by 1962.

4. Allowing a man to circumnavigate the moon in a rocket and returning him to earth by 1965.

5. Sending a small manned expedition to the moon by 1968.

OPSOMMING

Oorlewing in die vyandige omgewing van die buitenste ruimte sal grotendeels deur die toepassing van die beginsels van ruimtegeneeskunde bepaal word. Tot onlangs is ruimtereise as denkbeeldig beskou, maar vandag nader hierdie moontlikheid sy verwesenliking.

Daar is egter nog baie fisiese en psigo-fisiologiese probleme wat finaal opgelos moet word alvorens die mens met veiligheid ruimtereise kan aandurf. Baie van hierdie probleme is reeds deur navorsers in die lugvaartgeneeskunde voorsien en bestudeer, maar ruimtegeneeskunde is feitlik 'n nuwe begrip wat spruit uit die ontsaglike mediese en tegnologiese vooruitgang van die laaste paar jaar. In hoofsaak is die ruimtegeneeskunde toegespits op die sentrale probleem van menslike oorlewing op ongehoorde hoogtes en snelhede.

Ingeligte ruimtegeneeskundiges gee inderdaad reeds die versekering dat hierdie probleme nie in die lig van huidige kennis onoorkombaar is nie. Ontwikkeling vind egter nog plaas in die toepassing van hierdie kennis op ruimtevlug.

'n Poging is aangewend om die probleme wat hier bespreek word in perspektief te stel teenoor die astrofisiese eienskappe van die ruimtes. Verder word 'n reeks fisiologiese vraagstukke van die vlieënier bespreek, soos hipoksie, die uitwerking van radiale versnelling en verdraagsaamheid met betrekking tot straal- en vuurpylvoertuie met hoë prestasie, verlies van swaartekrag, psigiese probleme, ens.

'n Tydtafel vir ruimtereis word gegee.