BIOMEDICAL PROBLEMS IN ORBITAL AND SUBORBITAL MANNED SPACE FLIGHTS

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Introduction

The recent successful orbital and suborbital manned space flights mark an exciting phase in space technology and space medicine. The space programme which gathered tremendous momentum with the ushering in of the International Geophysical year has kept its tempo ever after. During this short span many satellites have been launched into space and some of them brought back successfully. They gave useful data about the upper atmosphere and space, and also helped in solving different problems associated with launching, orbiting and re-entry.

In an orbital or suborbital flight, from count down to safe rescue, the cosmonaut is subjected to different types of stresses. These stresses arise mainly due to (*a*) excessive acceleration, (*b*) extreme temperatures, (*c*) weightlessness, (*d*) radiation, (*e*) problems of pressure and oxygen and (*f*) necessity for escape during a malfunction of the flight system.

Accelerations

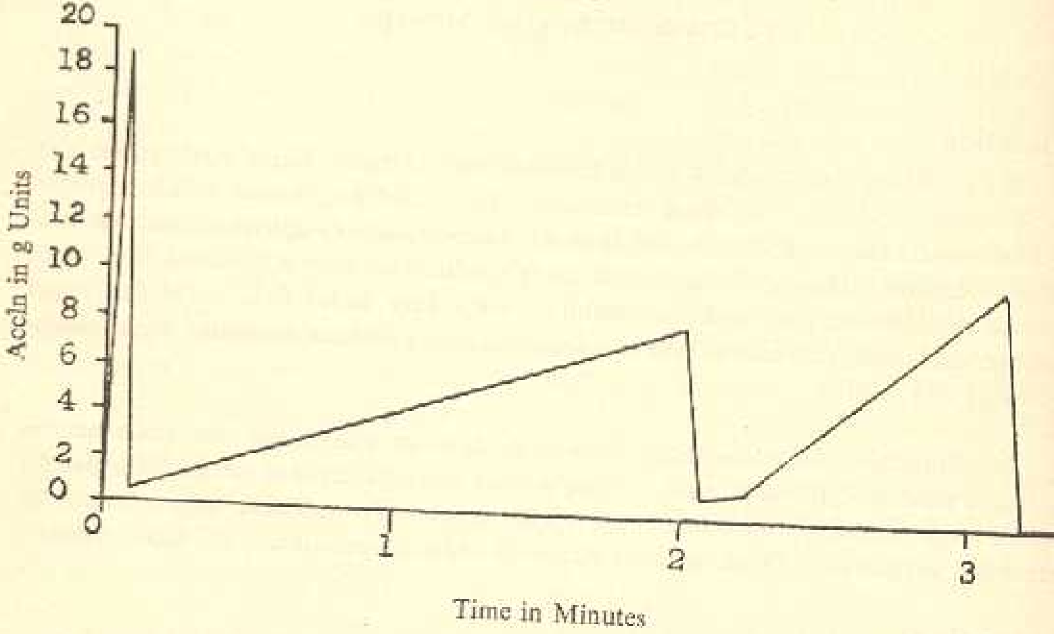
For an orbit as in the case of Vostok I (perigee 112 miles and apogee 203 miles) a velocity of the order of 18,000 mph is necessary for the space craft. To attain this velocity, exposure to accelerative force approximately 825*g* sec. is necessary, which is spread over the entire period of powered flight.

The accelerations act for longer durations, of the order of minutes and hence are similar to those obtained in a human centrifuge. Duplication of the acceleration in the centrifuge makes possible selection of crew on the basis of tolerance to acceleration, and also aids in giving experience to accelerative stress. Determination of human tolerance values and specifications of how acceleration is to be applied in actual flight are also based on the centrifuge studies.

The factors of significance which limit human tolerance to acceleration
direction of accelerative force with respect to the body, (*b*) rate of attainment of the
acceleration, (*c*) total *g* sec. value and (*d*) resistance of the body to fluid displacement.
tolerance value of acceleration in the case of a cosmonaut corresponds to a level whe
vision, judgement and performance are not seriously impaired.

Various experiments on a human centrifuge indicate that the highest *g* sec. is tole
better when applied transversely, with the subject's trunk making an angle of 65
degrees with the direction of acceleration and with the thighs kept parallel to the force
this position 4*g* is tolerated for over 15 minutes. Above 4*g*, respiration becomes di
and the tolerance time for higher values of *g* increases with subject's ability to do f
abdominal breathing.

FIG. 1

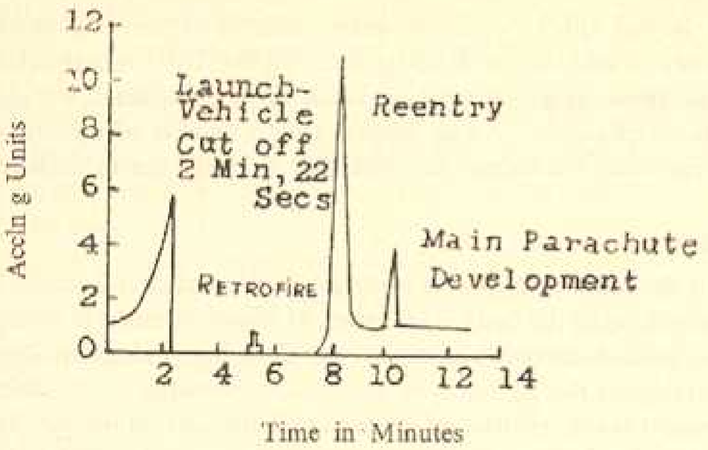


For an orbital flight the acceleration profile follows a pattern shown in fig. 1. T
take off boost lasts about 1 sec. peaking at approximately 20*g*. The next stage reache
peak of 8*g* in approximately 2 minutes building up at the rate of 1*g*/12 sec. Then stagi
occurs and acceleration drops abruptly to 1*g* but builds up to 9*g* by the time the sustain
rocket burns out in about 1 minute. The rate of build up is about 1*g*/7 sec. If the positio
ing of the subject corresponds to the best tolerable alignment these accelerations do n
produce any serious effect.

In the first U. S. suborbital manned flight, the maximum velocity attained was 5,18
mph. The acceleration profile for the flight from launching to parachute deployment is
in fig. 2.

FIG. 2

From Proceedings of a Conference on Results of the First U. S. Manned Suborbital Space Flight



The different types of acceleration met with in an orbital flight can be resolved into two groups (*a*) radial and (*b*) horizontal. In the radial direction there are (*i*) acceleration produced by the change in the rate of decrease or increase of altitude $\frac{d}{dt}\left(\frac{dr}{dt}\right)$ where r represents the distance of the satellite from the centre of the earth. (*ii*) The centrifugal acceleration $\frac{V_h^2}{r}$ where V_h is the horizontal component of the satellite speed (*iii*) $\frac{G_r}{m}$, component of the gravitational field in the radial direction and (*iv*) $\frac{D_r}{m}$, component of the drag per unit mass in the radial direction. The equation for radial motion will then be $\overrightarrow{\frac{d}{dt}\left(\frac{dr}{dt}\right)} + \overrightarrow{\frac{V_h^2}{r}} + \overrightarrow{\frac{D_r}{m}} + \overrightarrow{\frac{G_r}{m}} = 0$

In horizontal direction there are (*i*) the tangential acceleration $\frac{dv_h}{dt}$ (*ii*) coriolis acceleration $\frac{V_h}{r}\frac{dr}{dt}$ (*iii*) $\frac{D_h}{m}$, horizontal component of drag and (*iv*) the horizontal of component of the gravitational field $\frac{G_h}{m}$. Equation of motion will be $\overrightarrow{\frac{dv_r}{dt}} + \overrightarrow{\frac{2V_h}{r}\frac{d}{dt}} + \overrightarrow{\frac{D_h}{m}} + \overrightarrow{\frac{G_h}{m}} = 0$. $\frac{G_h}{m}$ is due entirely to the oblateness of the earth and is negligibly small for practical purposes. It assumes significance only in interplanetary travel.

In the re-entry period where the acceleration is maximal, the motion is radial. Radial drag force and gravitational force dominate in this phase. As is seen from fig. 2 the re-entry acceleration reaches a peak value of 11g built up approximately at 1g/3 sec.

Accelerations of high value are also met with when the main parachute deploys during landing. In the first U.S. suborbital flight the parachute opening shock was about

Normal impact shocks even on water could be of the order of 40 g for a few r seconds with a rate of build up of 10,000 g/ sec. In the U.S. suborbital flight the lanc deceleration was about 14 g. This lower value of impact shock was achieved by spe impact attenuation techniques. An air cushion with a number of apertures was attached the base of the capsule. On impact the entrapped air oozed out through the apertures.

Weightlessness

Normally the meaning of weight includes the gravitational force of attraction. Th however, is true as long as the body is in a state of rest or of uniform motion. In the ev of an accelerated motion, forces of inertia act upon the body (viz., centrifugal force genera in a human centrifuge or the g pulled in different manoeuvres of an aircraft). What c experiences as weight is the resultant of gravitational and inertial forces. It is also shown the general theory of relativity that gravitational forces and forces of inertia are inc tinguishable and are thus different manifestations of the same physical entity.

When the space capsule is in orbit, the centrifugal acceleration cancels t gravitational field, the coriolis acceleration opposes the tangential acceleration and t cosmonaut becomes weightless. In the suborbital flight the subject is weightless wh tracing the peak of the parabolic trajectory, (between cessation of powered flight ar initiation of re-entry acceleration) where gravity is balanced by the resultant inertial forc Thus the duration of weightlessness in the manned Mercury-Redstone suborbital flight w 5 minutes.

Apart from orbital and suborbital flight, the only other practical method of achie ing zero gravity is by tracing a Keplerian trajectory in an aircraft. The duration of th weightless stage in such cases is limited to about a minute or two. As such there are onl limited studies on physiological response to weightless conditions, especially effects c continued weightlessness of long durations.

Zero and subgravity conditions of short durations produced in animals and huma beings give rise to disorientation and disturbance of neuromuscular co-ordination. N significant cardiovascular, pulmonary or respiratory changes have been noted nor wa there any pathological ill-effects. In Sputnik II the dog Laika was exposed to weight lessness for six days. No appreciable changes of physiological functions have bee recorded. Likewise no physiological disturbance under weightless conditions could be notec from the recorded pulse rate, respiration rate and the electrocardiogram of the U.S astronaut. Astronaut Gagarin who experienced zero g for moderate duration felt nc abnormality under weightlessness. In his own words " Everything was easier to perform Legs and arms weigh nothing. Objects were swimming in the cabin and I did not sit in th chair, as before, but was suspended in mid-air. During the state of weightlessness I ate and drank and everything was like on Earth. Handwriting did not change though the hand was weightless. But it was necessary to hold the writing block, as otherwise it would float away from the hand ".

These indicate that weightlessness of short or moderate durations may probably not produce any appreciable physiological effects, and may be tolerated satisfactorily when properly conditioned.

Heat Stress

The temperatures at altitudes of 200 miles and above corresponding to the normal orbits are of the order of 1,500° C. But as there are very few molecules to convey this temperature to the satellite by collisions, the satellite will never attain high temperatures. The actual satellite temperature will be determined by the balance between heat received from the sun and the heat radiated out. Thus the satellite temperatures may not reach values much above 50° C.

By giving the space capsule an orbital velocity of say 18,000 mph, considerable kinetic energy would be imparted to the orbiting mass. Bringing back the space capsule to rest would mean the dissipation of this energy mostly as heat. Every pound of the orbiting mass has equivalent heat energy of 7,700 C.H.U. (Centrigrade heat unit).

Reverse thrust rockets may be used to dissipate the energy of the re-entering mass in space itself before the spacecraft enters the denser layers of atmosphere. This would require rockets several times the weight of the space capsule itself, making the payload hurled into the orbit very high. Obviously the alternative is to derive decelerations from the atmosphere itself, which means considerable heating of the spacecraft and surrounding air. The re-entering capsule is normally shaped as a blunt nose for the purposes of reducing heat load on the spacecraft. The kinetic energy of the capsule is diverted to heat up the atmosphere instead of heating the cabin, through shock wave action. The molecules which strike the nose, rebound with very high velocity and collide with other oncoming molecules, changing their path. This prevents heating of the capsule from direct impact of the molecules. The layer immediately in front of the advancing nose is bounded on its forward surface by a shock wave. A stronger shock wave thus transfers a greater portion of the total heat to the atmosphere. In the case of the Mercury capsule the shock wave action can divert about 99% of the heat energy into the atmosphere.

The heat that is imparted to the space capsule is prevented from reaching the cabin by an ablating heat shield. A heat shield with fibre glass takes away about 2,800 C.H.U. per pound in the process of ablation (heating, melting and vaporising).

The total heat in the cabin will be derived mainly out of (a) metabolic heating from the astronaut (b) the heat set free by the absorption of carbon dioxide and water ar (c) heat reaching the cabin through the insulation from the nose cone. In the Soviet spac ship Vostok I, an air conditioning system maintained a temperature range of 15 to 22° C i the astronaut's cabin, with a liquid cooling agent absorbing the heat. The environment control system of the Mercury capsule is as in Fig. 3 where cabin temperature is controlle by heat exchangers and a fan.

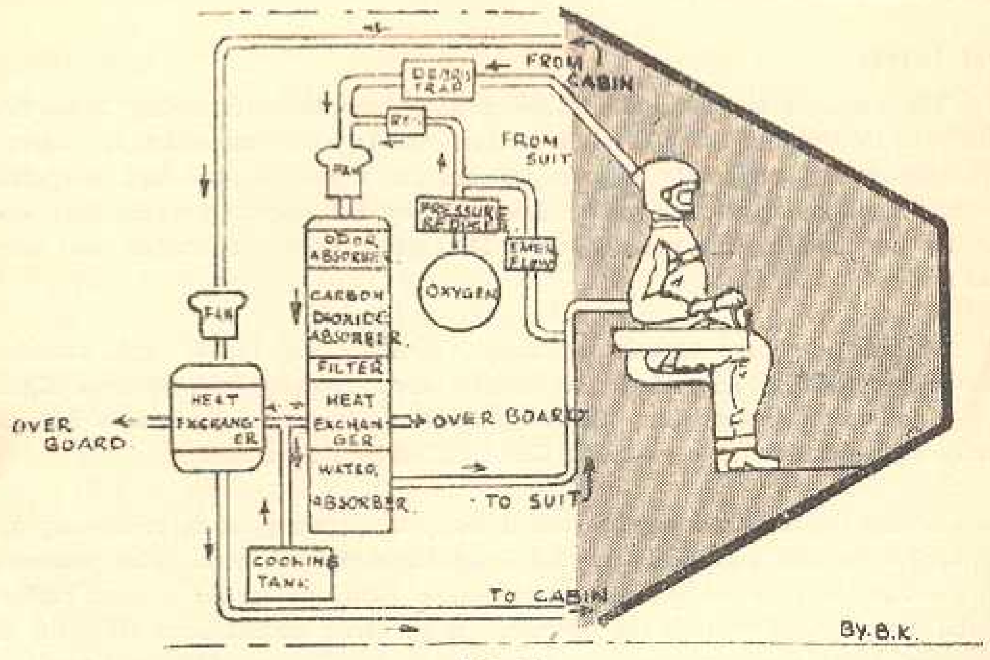


FIG. 3

From Proceedings of a Conference on Results of the First U. S. Manned Suborbital Space Flight

Escape in an Emergency

One of the most serious problems associated with manned orbital and suborbit flights is the escape of the astronaut to safety in case of a malfunction or catastrophe whic may occur in any phase of the flight programme. If any malfunction of the propulsic system then occurs the thrust developed would be insufficient to maintain the u ward path. The space vehicle falls back to earth from low altitudes. There is then th necessity to catapult the astronaut from the main vehicle, lest he lands in an area where a explosive blast may occur when the vehicle, reaches the ground. An ejection seat or se capsule, provided with a rocket catapult firing at a fast rate supplemented with rapidly opening parachute gives some answer to escape under such conditions. The hig accelerations to be encountered are of significance in this case. The final stage of the ma vehicle, *i.e.*, the space capsule itself, may be useful as the escape means during such lo altitude accidents.

During the initial stages of powered flight, up to altitudes of the order of 30 kilometres, escape using an ejectable capsule may still be feasible. The problem is not very much different from high altitude escape from a high speed manned aircraft. For higher altitudes, air drag is not the main consideration for suitability of the escape system (drag to weight ratio is taken as the limiting factor for high speed moderate altitude aircraft.) Factors, like efficient dissipation of acquired kinetic energy and provisions for survival in the environment, assume importance. All these necessitate the ejection of the space capsule itself for successful escape.

The orbits chosen for the manned satellites, are such as to have re-entry possible even when the retro-rockets fail to function. By having a lower height of orbiting or by keeping the perigee altitude low, ultimate re-entry of the satellite after a few orbits is ensured. If a circular orbit at a high altitude (*e.g.* 1,000 kms) is chosen, it can be permanent if the retarding rockets fail to function and in consequence fail to initiate re-entry. In the case of Vostok I, the design of the spaceship ensures the astronaut's descent to the earth in the event of retro-rocket failure by the action of atmospheric drag within 10 days. The supplies in the spacecraft were sufficient for this period.

In Vostok an ejector seat was provided for the astronaut, who, protected by a space suit, could then leave the spaceship in case of an emergency. In the Mercury-Redstone suborbital flight, an escape system with a solid propellant rocket is attached to the spacecraft. If the launch vehicle fails on the pad, the escape rocket lifts the spacecraft to an altitude sufficient for the main parachute to deploy. This system is useful even for escape at high altitudes. Normally the escape tower is discarded at the end of the powered flight. When an escape is attempted at maximum dynamic pressure, the deceleration produced is considerable. In this case as the spacecraft is travelling with high speed, a large drag force acts suddenly when the escape rocket burns out. The acceleration change can be of the order of 18 *g*.

Cabin Pressure and Oxygen

The ideal pressure for the astronaut's cabin would of course be 760 mms of Hg. For structural reasons it is not possible to have too high a pressure differential between the cabin and the near vacuum outside. A pressure of 7.35 p. s. i. is quite sufficient for prolonged orbital flights as the body can tolerate this without bends. For short or moderate duration flights the pressurisation can be of a lower order. In the U. S. suborbital flight the pressurisation level was kept at 5.5 to 4.0 p.s.i. The control system is given in fig. 3. In the Vostok cabin, normal pressure was maintained.

A sealed cabin is always necessary, as after an altitude of 20 kms pressurisation by compressing the surrounding air is prohibitive owing to the enormous bulk of the compressor system.

A pressure suit is required to be worn by the astronant to give protection in case of cabin pressure loss. In the Mercury-Redstone suborbital flight, the pressure ins the suit was maintained by a demand type of regulator. Normally the pressure in the sui maintained at that of the cabin. In the event of cabin pressure failure the regulato activated and the pressure inside the suit is built up to 4.6 p. s. i.

The oxygen requirement for an absolutely sealed cabin will be based on the oxyg consumption of the astronaut, and 2 lbs. of oxygen per day per person is sufficie Mercury environmental control system provides for a 28 hour flight mission and caters f leakage of the cabin up to 300 cc/minute at S.T.P. This necessitates 8 lbs of oxygen for capsule. In the Mercury system a complete oxygen atmosphere was maintained in cabin. Even for prolonged flights the total quantity of oxygen required is not very muc A cylinder capable of supplying 6,500 litres will be sufficient for one man for about 11 da taking the consumption to be 24 litres per hour.

Radiation Hazards

Solar radiations and cosmic rays constitute the radiations in the atmosphere. As as solar radiations are concerned at sea-level and at low altitudes, only the useful a harmless rays are received, though the sun is sending out a whole range of the electr magnetic spectrum from infra-red to X-rays, because of the filtering action of the atmospher In the lower layers of the atmosphere the nature and dose of the cosmic rays also, is su that no physiological damage is produced by the radiations.

The cosmic radiations below 25 kms are mainly secondary radiations produced the interaction of the atmosphere with the primary cosmic rays and have no significa radio-biological effect. But above this height the primary cosmic rays, which are constitut of 80% protons, 19% *alpha* particles and 1% heavier nuclei, assume importance.

When in the orbit, the spacecraft is directly exposed to cosmic and solar radi tions devoid of atmospheric protection. Radiations like X-rays, ultra-violet rays, etc emitted by the sun, and most of the light cosmic ray particles are stopped by the skin of th space capsule and by the material of the observation windows. But the effectiveness of th shield to the fast heavier component of the primary cosmic rays (nuclei heavier than heliu nuclei) is doubtful. Some of these heavy nuclei, which are fast enough, may penetrate th spacecraft skin and produce new particles through shower phenomena. These radiatio are considered more harmful to human organism, if they are absorbed.

The radiation hazard in space is mainly derived from (*i*) the heavy primary cosmic ra particles as they have more specific ionisation and hence dense ionisation tracks are produce in the tissue which they strike, (*ii*) enhancement of intensity of radiation during solar flar and, (*iii*) the highly intense radiations girdling the earth at altitudes between 2,200 to 5,400 km and 13,000 to 19,000 kms. Radiation data from Sputnik III Mechta, Pioneer III an

Explorer IV have conclusively proved the existence of these radiation belts, now termed Van Allen Radiation belts. In the heart of the inner belt, the intensity approaches as high a value as 250 roentgens/day, very high compared to 30 milli roentgens/day possible with appropriate combination of latitude and altitude in the lower atmosphere.

Though a good amount of knowledge has accrued out of researches in the past two decades on the physiological effects of X-rays, U. V. rays, radiations from radioactive substances, etc., the effects of radiations like the heavy primaries are still unknown. This is due to the fact that no accelerator exists that can duplicate such high energy particles with high rate of energy dissipation in the laboratory. Experiments using particles having approximately similar properties (accelerated with the Berkeley synchocyclotron) over long periods suggest that low intensity heavy cosmic ray primaries might produce deleterious effects on the central nervous system. White matter and the hypothalamus appear to be more sensitive to protons, deutrons and *alpha* particles than gray matter. The recently attained energy level in the heavy ion linear accelerators at Berkeley and Yale may be useful in the understanding of the primary cosmic rays.

The deleterious effects of the radiations present in the upper atmosphere on an orbiting astronaut will only be clear after future experimentations. There are scientists, who believe that Gagarin and Titov are going to show some delayed radiation effects, and there are others who have expressed the opinion that there is little to warrant immediate concern at performance levels in the early stages of orbital flight. Supporting the latter view is the knowledge that the two dogs which orbited 18 times in August 1960, have not exhibited any effects of radiation. Further, one of them gave birth to six pups, which are reported to be genetically normal to all appearances.

Conclusion

Manned satellites orbiting at higher altitudes and for longer durations could be the next step in the space programme. The main limitation to the achievement of very high orbits, a perigee above 1,000 kms, is the existence of the Van Allen belts. More information, leading to proper protection from these radiations is needed. This could be collected with satellites carrying animals and equipped with radiation counters. The apogee also has to be kept at low values to ensure ultimate re-entry, till the retro-rocket systems have proved completely reliable. Manned orbital flights of long duration may also be able to give information on the cumulative physiological effect of an environment, devoid of earth's rotation and gravitational field. The biomedical data, which could be obtained from manned orbital flights, are invaluable, as they could not be gathered reliably through other sources. This knowledge will be helpful for launching deeper probes into space and for safe interplanetary space travel.

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