MEDICAL PROBLEMS OF ORBITAL FLIGHT

By Dr. J. C. Lane

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THE effects on the circulation of accelerations of 4 and 5 times gravity—blackout—were noted in the late 20's, notably during preparation for the Schneider Trophy races. These effects became of considerable military importance ten years later and much effort was put into countermeasures, ultimately successful, in the form of leg and body constricting garments. The effect of posture, with long body axis perpendicular to the acceleration vector, was noted but could not then be put to practical use.

The accelerations experienced in the launch of space vehicles exceed 4 times gravity for duration of a minute or rather more and reach peaks of 8 times gravity or higher. The vast amount of energy expended in raising the vehicle 100 miles against gravity and in accelerating it to orbital speed must be repaid during re-entry. The braking effect of atmospheric drag produces accelerations of the same magnitude and duration while the energy to be dissipated appears as heat.

Transverse posture offered the promise of providing human tolerance to satisfy these demands, but it would have been difficult indeed to check human performance experimentally without the human centrifuge far-sightedly commissioned by the U.S. Navy some ten years ago. In this large and versatile device it has been possible to programme the acceleration profiles not only of normal launch and re-entry but of the more severe emergency or off-design situations. With refinements in support such as individually moulded couches, it has been found that healthy adults can not only tolerate these stresses but can, if provided with suitable hand controls, perform very satisfactorily tasks such as controlling an aircraft's or spacecraft's attitude.

Speculation on the effects of weightlessness began in the 19th century, but received its first precise formulation in a paper of Gauer Haber written in 1946. In this paper, their concern centred on questions of orientation. In a person free to float vision would provide the only means of orientation. It was suggested there would be grossly altered and deficient information from the joints, tendons, muscle and skin, i.e. the kinesthetic sense would be disturbed. The balance mechanism of the internal ear would provide none of the usual orienting information.

Difficulties were predicted because of the gross discrepancy anticipated between vision and the sensations from the internal ear. It was thought that the utricular receptors might over-respond to the small inertial effects of head movement when there was no overriding force of gravity to pin them down.

It was further suggested there would necessarily be a sensation of falling. It is surprising that these notions gained credence, since they are not in accord with the sensations actually experienced in the transient weightlessness of parabolic flight in an aircraft or even in a dive off a high springboard. Circus acrobats control their body movements with notable precision during short ballistic and hence weightless manoeuvres. It would seem that rapid adaptation to the weightless state occurs.

Sounding rocket experiments of ten years ago showed that, in monkeys, weightlessness had no effect on the electrocardiogram, respiration and blood pressure—results later confirmed for dogs and other animals.

The first human subject to be in orbit remained there for one and one-half hours. During this time, he reported no difficulties "in the sensory or motor sphere". The second subject, Titov, made several observations that relate to these original questions. He described the usual sensation of tumbling at booster cut-off, just at the initiation of the weightlessness state. Despite this evidence of normal inner ear response, he reported no falling sensation during weightlessness. He had no difficulty with hand movements or the use of controls. He ate three meals successfully and slept, at first fitfully, then for several hours. He was able to perform exercises, write notes, and remain according to his account, clear-headed and cognizant of his situation.

However, after the sixth orbit, Titov reported "unpleasant" sensations of vestibular character which were felt stronger and stronger, especially when he sharply turned his head. After some sleep, these symptoms decreased but did not disappear before the beginning of the "re-entry overloads". It is further stated that "the sensation of some discomfort accompanied a considerable portion of the flight and resembled seasickness".

It is worth noting that, according to his account given to the press, Titov ate breakfast, considered shaving, discussed problems connected with re-entry, and elected to parachute instead of staying with the capsule.

Nevertheless, these sensations raised interesting questions which, again according to the accounts given to the press, have had light thrown on them by the four and three-day orbiting flights of the Vostok 3 and 4. The reports from these flights describe the subjects' freedom from any symptoms, attributing this to a "new" "diversified" training programme. They had no nausea or other symptoms suggestive of motion sickness throughout these prolonged flights. Their condition at recovery was described as excellent and the pilot of Vostok 3 states that he "did everything during flight as though he was on the ground". The reports point to no major incapacitation by periods of weightlessness lasting up to four days.

The Mercury programme has so far yielded three periods of 6 minutes weightlessness, one of three hours, two of 4½ hours; one of nine and recently one of 34 hours.

The performance of the astronauts was determined by analysis of the voice records, of the on-board camera films and of the manner in which various tasks were accomplished. The main physiological responses were determined from records of body temperature, heart rate, respiration rate, electro-cardiogram and blood pressure. This information, together with a great amount of data concerning the behaviour of the capsule and its systems—voltages, temperatures, pressures, quantities, angles, more than 100 items in all—were encoded, transmitted to ground stations by radio and there reconstructed so enabling the astronaut's condition as well as that of the capsule to be monitored at frequent intervals during the entire flight. The Russians with their greater payload have recorded additional functions such as the e.e.g., G.S.R. and nystagmus.

There are some 15 stations around the world whose functions are to track the capsule with radar, communicate with the astronaut and monitor the status of the capsule and its occupant by means of telemetered information.

The voice records have been consistently accurate, confident and coherent throughout the weightless state. Glenn's prompt responses to ground transmissions and to sounds from the spacecraft indicated that he experienced no decrement in hearing ability. Visual acuity was maintained and the fact that his reports as to visual perception were accurate was confirmed by photographs taken in flight.

There have been no disturbances in spatial orientation. Voluntary rapid head turning movements caused no unpleasant sensations suggestive of a vestibular disturbance. The report of a brief sensation of tumbling forward occurring after sustainer engine cut-off and a feeling of backward acceleration with retro-rocket firing show that his vestibular sensitivity was not abnormally depressed. Weightlessness did not disturb the actions of food chewing, swallowing or micturition. Numerous bio-chemical studies showed that metabolism was not disturbed, and that there was normal absorbtion of a xylose pill. Indeed according to Glenn the 4½ hours of weightlessness were described as a pleasant sensation and his psychological functions and performance during this period appeared to have been essentially undisturbed.

These results have been confirmed and extended by the subsequent 3 orbit flight of Carpenter, the 6 orbit flight of Schirra and the 22 orbit flight, yielding 34 hours of exposure, of Cooper last May.

As to orientation it is important to recall that these observations have been made on subjects who were held firmly in place and thus had good kinesthetic sense of their position. However if we take into account the work of the past 15 years with humans and animals in parabolic aircraft flights, immersion tanks and ballistic rockets it is possible to say that no significant disturbance has occurred in properly orientated subjects subjected to the weightless states for periods of hours. Indeed the astronauts in Vostok 3 and 4 appear to have practiced acts of fine hand-eye co-ordination such as threading a needle when floating detached in the spacecraft.

Whether there will be effects on longer exposure is a matter still for conjecture. There are still some who believe that there will be a space sickness due to changes in inner ear sensations, a result which appears, to me, improbable in the light of the known human adaptation to motion sickness.

Another question that has been raised is that of a possible hypnodynamic effect of weightlessness on the circulatory system. That some such effect may be taking place is suggested by a slight increase in the variability of the pulse rate as the duration of orbital flight is extended. However any such changes in vascular reactivity would not necessarily lead to a significant disturbance of tolerance to the transverse acceleration of re-entry.

The Mercury programme so far has vindicated the attitude of those who believe that putting an astronaut into a satellite would greatly improve the overall reliability of the system. I have heard that at one point it was suggested, apparently seriously, that the astronaut should be put into orbit in an anaesthetised condition so that he wouldn't "interfere" with the automatic operation of the capsule systems. The programme to date however has shown not only that the astronaut performs well in space but that his ability to respond to unusual circumstances has been absolutely essential to safe re-entry and recovery in two out of the four manned orbital flights in the American programme. This is exemplified most strikingly by the recent 22 orbit flight in which successive equipment failures completely disabled the automatic retro-fire and re-entry sequences. Nevertheless astronaut Cooper was able to perform this procedure manually and land the spacecraft within two miles of the waiting carrier.

Discussion

THE CHAIRMAN (DR. A. SINCLAIR): I wonder whether it is necessary to be of a certain psychological make-up to do what these extraordinary men do. Moving to more mundane matters—what do you do about eating; what do you do about your bowels; and what do you do about your bladder? Have any of these remarkable men shown any psychological abnormalities as a result of the phenomenal tasks they undertake?

DR. J. C. LANE: These people are, in fact, quite unusual in their general set-up and their ability to maintain their performance in the presence of a good deal of anxiety-producing stress. If you think of the way that people are selected—the selection was based on having people who were experienced test pilots, who have had substantial experience in flying experimental aircraft, prototype aircraft, with all the unusual hazards and unpremeditated experiences that go with these things. As you know, test pilots have no small death rate, and this was the population from which these people were selected, people who had been through the mill, who had the skill to pilot high performance aircraft, to meet unexpected problems, and ability to cope with these things. They were proven almost before they were started. They were asked to volunteer, and those who had particularly good background were briefed as to the nature of the job, the rather long training and preparation time, the fact that there would be long periods of waiting and perhaps set-backs and periods of boredom, and they were asked to make their own decision, having regard not only to the effect on themselves but on their families, and the people who came out of the selection procedure were the people who had gone through this sort of mill. I think three out of the four astronauts were presented with quite stressful anxiety-producing situations, and in two cases quite difficult control problems, and they all proved equal and more than equal to those tasks. Glenn was presented with a completely unpredicted situation in which they thought the heat shield might be loose and he was going to be a fried egg, and yet the films showed that he received this news phlegmatically and carried out his re-entry quite unscheduled and in correct sequence with perfect skill.

As to these other matters, the matter of eating is essentially the practical problem of getting the food into your mouth. Once you have got the food or liquid in your mouth you can masticate and swallow it without trouble. In the case of drinking, of course, you cannot pour some water into a glass and drink it because it separates into small globules and flies around. In the case of eating, the trick is to have the material either as a semi-solid which you can squeeze out of a tube, or have it in chunks which are essentially bite-size so you can put it all in the mouth at one go. There are technical problems in fabricating food in that manner. Schirra had some cubes of solid material and these crumbled when he unwrapped them. As to the excretory functions, the bowel problem has not arisen, because the astronauts are put on a low residue diet for three days before the shot. This is not a solution in the long term, but it is impossible to get out of these pressure suits without a lot of gymnastics, so until they have more space it is not possible. The urinary problem is not only the question of disposing of it, but also of collecting it for analysis, and this is simply done with a simple pocket and a urine-collection device which is familiar in medicine. This is not a long-term solution, but the mechanics of this problem are not insoluble. They do require space so that people can be in the space-craft in a virtually ordinary clothing situation, not all the time in a full pressure suit, and this means you have to have a reliable cabin, so the solution is essentially an engineering one.

MR. G. H. LUSH, Q.C.: The actual time of the firing of the retro-rocket must be vital, and the range of error must be of the order, I think, of a second. Must it be done at ground command, or is there any element of human judgment in it?

DR. J. C. LANE: The time of retro-fire for a given impact point is determined once and for all by the computer, so the problem is simply to fire them at the right time. This can be done in a number of ways. There is a clock on board the spacecraft which is virtually an alarm clock, set for the time of retro-fire, and then if the sequence is automatic, it will fire at that time. If it does not run perfectly it may have to be reset or corrected by the astronaut on information from the ground, if it is running fast or slow. Then if, for whatever reason, it is desired to fire the retro-rockets by ground command, these could be fired by a radio transmitted ground command at the predicted time, again simply based on collated clock time. The third possibility, which actually took place in Cooper's flight, was that he fired the retro-rockets manually, again at a pre-determined time which appeared both on his clock and was transmitted to him by voice from the ground, in this case from Glenn who was on a ship off Japan. Glenn gave him a 30-second count-down and then a further 10 seconds, and then he pulled the levers. The time is a time which is predicted by a computer and it is simply a matter of how you get the rockets to fire at the time you want them to fire.

MR. RAYNES DICKSON: May I ask, Doctor, whether there has been any deleterious effect proved on the first few astronauts from the radiation side? Is there any long term deterioration at all? I understand the first Russian did go through this Van Allen belt and suffered from radiation.

DR. J. C. LANE: The two environmental factors in which flying is different from the ground are, of course, first of all this weightlessness, and the other one is the effect of ionizing radiation. I didn't mention this very much because this is really a problem of interplanetary flight or flight from the earth to the moon, rather than orbital flight of manned vehicles which have fairly low orbits of the order of 100 to 200 miles above the surface of the earth and in this altitude range you are pretty well below the Van Allen belt so that ionizing radiation has not been a problem. They have measured it, of course, and the dose actually for those turned out to be about 0·6 of a milligram which is really quite small. I think that was one of the Russian ones, about 24 hours exposure, so that at present ionizing radiation has not been a problem nor was it really expected to be. An ionizing radiation problem becomes of great importance when you are considering flights which have to penetrate the Van Allen belts and also have to get out into deep space, you might say where we are not protected by the extraordinary protection of the atmospheric blankets. The Van Allen belts are really a protective shield in the sense that the radiation is dropped by the magnetic field of the earth. When you get past these things ionizing radiation becomes one of the limiting factors. So this is a major problem of deep space flying. It is not a problem of orbital flying.

MR. P. H. OPAS, Q.C.: We must now be at the stage where it must be proved that man can take a flight to the moon if the vehicle can get him there. Would I be right, Dr. Lane, in saying that it is now proved to the satisfaction of men such as yourself who have been engaged in this, who have been watching the E.C.G. results from a distance, that a man could stand such a flight and could get back again?

Secondly, the question of wearing this suit. Are the garments of such quality now that one could wear them continually for such a great period?

The third matter is the bowel functions of the patient. Is it not a fact that at the Antarctic they just had to carry the results of their excretions around with them until they got inside a warm building. Would much the same thing as that have to happen, whether in boxes or containers, or something of the sort, in such a flight to the moon and back?

DR. J. C. LANE: Has it been established to the satisfaction of all concerned that people can make a flight to the moon and back if the vehicle can go there? Well, not quite, unfortunately. No one was quite sure that people would in fact stand up to weightlessness until someone had been made weightless for more than a few seconds. We now know this is no problem for short periods, and if we accept the Russian experience, for four days it seems to have caused no problem. Whether this is so for long periods of time is still not known. If the question comes up of putting up a manned observatory, for example, in earth orbit, for logistical reasons they could not rotate the crew of such an observatory more frequently than once every few months, so that you would have to consider people living and working in a weightless environment for perhaps several months at a time. Whether the present results are necessarily true for that period is not known, and again, no one will know until it has been tried. As to the question about pressure suits, Dr. Adamson is more expert than I. Of course, they have worn suits on the ground for extended periods, but I think the general experience is you cannot, in fact, wear these things for very long.

CAPTAIN D. ADAMSON: They have worn the suits for several days, but it is impractical to wear these tight fitting garments for much longer than that because there are too many friction points and also there is the nature point. Even with the U.2 flying we have a problem here of variation in individuals. Some people have more sensitive skins than others, so they have to use a silicon lubricant because you cannot mix grease and oxygen. As these problems come along you have to solve them. They are magnified immensely when you consider long term flying, so this question of cabin control is the only solution for any extended period in space.

MR. BURNSIDE: Does the capsule while it is actually in this orbital flight remain at a fairly constant attitude? Does it go into a tumbling effect at all, and if it does, what is the effect on the astronaut? What is his feeling? Does he feel that he is sitting still and everything else is moving around?

DR. J. C. LANE: The capsule is completely free. There is no aerodynamic stability, so it is just like any other body floating around unrestrained by any other force, so it will move according to the last set of forces that are applied to it. Because attitude control is important because of re-entry, the capsule has got sets of small jets—actually they are called peroxide jets—in pairs with quite low thrust of one in most cases, and by operating controls inside the spacecraft you can make them fire in proper sequence, so by applying torque to the capsule you can make it rotate as you please or you can stabilise it if you want to. You might want to stabilise it for the purpose of some observation. You certainly have to stabilise it for the purpose of re-entry. In Schirra's flight and then in Cooper's, in order to conserve fuel, because these jets have to be driven by peroxide, they allowed the capsule to go into drifting flight, so that it very slowly tumbled according to the last piece of torque that happened to be applied to it. This did not cause any discomfort at all to the astronaut. The reports indicate that the orientation one gets is the same as in an aircraft doing aerobatics. You are oriented with respect to the vehicle you are in. You are firmly attached to it and it is the external world that is revolving. The thing was never allowed to get very high rates of roll, as it can have disturbing effects. At all events, it was no problem.

Mr. R. Tadgell: Is Dr. Lane able to comment on the hazards or dangers to which a space vehicle is subject while in flight apart from the rather obvious danger of contact to ground, particularly the hazards the vehicle itself as opposed to the gentleman in it, is subject. For example, is there any real danger of a collision between a space vehicle with any other object, a meteorite or another space vehicle, for example, or of over-heating, or are there any other hazards?

Dr. J. C. Lane: About the only hazard to the vehicle itself in orbital flight, is in fact, a meteorite. This is thinking of the vehicle but does not concern what is going on inside. The meteorite collision is about the only substantial hazard in actual orbital flight. They have reasonable data now on meteorite collision probabilities and this probability is extremely low for periods of short duration. In long flights of course if they are going from Earth to Mars, which will take about a year, the probability is by no means small. There are substantial hazards to the vehicle both on launch and on re-entry. There is a period during launch during which the booster and capsule are subjected to fairly high loads, both from acceleration and from centrifugal forces, and this is a critical period, during launch, and in fact it is particularly important in this particular case because the vehicle they are using, the Atlas booster, is a rather sophisticated structure. It depends for its integrity on the fuel tanks being pressurized. It is like a great cylindrical aluminium balloon and if you have not got pressure inside it it is not strong structurally. So there was, in fact, initial doubt as to whether the Atlas booster was strong enough to take the 72 ton capsule. If the launch is not going according to programme, there is a danger that the loads will exceed the strength.

During re-entry the important point here, as I mentioned, was to judge the attitude of retro-fire accurately, and to keep the attitude of the space craft as it starts to penetrate the atmosphere correctly, because if you hold the right angles you get the minimum amount of heating and minimum acceleration but if you do not hold these correctly you can get an incandescent re-entry in which the heating problem is greater, and this is quite an undoubted risk. There are structural risks on launch, penetration risks in orbit and heat and structural risks on re-entry.