# SPACE MEDICINE FOR THE NEXT DECADE
# AS VIEWED BY THE ENGINEER

by

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The series of titles of the papers presented at this celebration of the Tenth Anniversary of the Department of Space Medicine, School of Aviation Medicine, Randolph Field reflects quite aptly the various fields of science that are working together in order to make space flight a success. The Department of Space Medicine originally consisted of representatives of those sciences. If we investigate today the groups, associations, agencies, and industrial companies that make up the team working on space flight, we see a similar representation. Space flight really encompasses all fields, and not one company or agency alone is able to carry out the necessary work without asking for help from other fields.

The title of my paper therefore is not a paradox when it combines two sciences which apparently have nothing to do with each other--that is, medicine and engineering. Such a combination is not a strange phenomenon as far as space flight is concerned. In this presentation I would like to discuss some of the correlations that exist between the two fields. I would like to show how requirements of one field impose restrictions on the other and how advancements of the state of the art of the one field simultaneously permit the widening of aspects in the other.

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The title further implies that space medical problems and their relation to engineering in the next decade should be discussed. It is, of course, always difficult to make predictions. Now, if one doesn't know how to predict something, it is always an easy way out to observe the trend of events during the past and project this same trend into the future--a procedure known as extrapolation. Therefore, instead of making a prediction, I would like to make some extrapolations. I believe I should give you an example of what I mean with this extrapolation.

About twenty years ago it was a major accomplishment to fly at altitudes of about 40,000 feet. At that time aviation medicine was very much concerned with keeping a man alive at such altitudes where oxygen is not as plentiful as at sea level. The associated physiological phenomena were under intense study in order to understand as much as possible what happens to man under conditions of oxygen deficiency. New equipment had to be devised to enable man to live safely at such altitudes. Later oxygen equipment and pressurized cabins were perfected so that in the decade '40 to '50 flights at about 20,000 feet became routine first in military and later in commercial operations. In the following decade, in which we are now living, military operations at 40,000 feet became commonplace and those altitudes are now becoming the airways for commercial aviation. What was a major accomplishment twenty years ago is now something that Grandma Moses can do by flying in a commercial jet airliner from New York to Paris at 40,000 feet.

What is the essence of this example? It shows two things: First, we see how a major feat of yesterday becomes a routine today. It is not difficult to predict that similar things will happen in the area of space flight. But the example is also significant in another way. It certainly shows how the perfection of the state of the art eventually removed all restrictions and limitations that existed in this area. The problems of aviation medicine of twenty years ago hardly exist anymore because the final engineering of the technical article practically removed the basis for the existence of the problem. The problems of 20 years ago were primarily associated with the then-existing technology.

Space flight of today is comparable to aviation in its early history. You only have to look at the crude way in which we attempt to accomplish space flight in order to see this point. Very soon we will put a fellow into a cramped, little capsule, shoot him into the sky with tremendous force, let him fly helplessly around the Earth, then on his return we let him collide with the atmosphere where again he is subjected to tremendous forces together with roasting temperatures. Finally we drop him some place where we hope to find him at a landing spot whose selection is only under very little or no control. Presently this is the best we can do. The state of the art is just about far enough advanced so that we can risk sending a man into space. It is obvious that we have to do much better if we want to make such flights a daily routine.

Now, coming back to predictions and extrapolations, I believe it is safe to say that space flight, space medicine, and its associated problems will go through similar phases of development as did aviation and aviation medicine. Many of the space medical problems that we are fighting today are due to the technology of today. The advances of the state of the art may alleviate many of those problems and will make space flight as similarly routine as the flights of Grandma Moses today at 40,000 feet and almost sonic speeds from New York to Paris. It is not only likely but practically certain that one of us in this audience will go out into space without meeting the rigid medical requirements that have to be met today in the selection of a space pilot. I do not know, of course, if it will happen in the next decade, but is is certain that steps in this direction will be taken.

I wish to emphasize that I do not want to imply that the engineers are the ones who will solve all medical problems. They just do not roll up their sleeves, design a better gadget, and tell the medicine man to go home. Just as aviation medicine has made excellent contributions to the general science of flight and has set goals for the engineer, in the same way space medicine is a vital factor--not only today but also in the future. It is for the understanding of the human problem and for the guidance as to the human limitations that the engineer will always look to his space medicine team-mate.

So far I have talked to you in generalities. I would now like to discuss a few areas where I can illustrate the correlation between the state of engineering art and the space medical problems. I want to explain with a few simple cases why we have the medical problem today and what must be done to alleviate or even remove it.

Take, for instance, the acceleration during launch which, for an orbital vehicle, is approaching the human tolerance. It is quite useful to consider the reasons for the high acceleration as we have it today and then consider the possibility of reducing those accelerations to a level which is tolerable for a more average person rather than a specifically-selected man.

It is common knowledge that today's rockets are burning fuel at a tremendous rate. In order to bring a satellite into orbit, a major portion of the weight of the entire rocket on the lauching pad is made up of fuel. It is obvious that for raising the rocket from the launching pad, the thrust must be greater than the weight. Let's assume for the purpose of this discussion that we have a rocket weighing 100 tons and that the thrust exceeds this weight by 50%. The thrust is then 150 tons. This is another way of saying that the initial acceleration is 1.5 g's. If it were possible to design a single-stage rocket to put the satellite into orbit, then approximately 95% of the take-off weight would be fuel; that is, 95 tons. This means, of course, that at burn-out, after all the fuel has been consumed, the final weight which is leftover is only 5% of the initial weight, or 5 tons. Since, however, the thrust of the rocket engine is undiminished and remains at 150 tons, we have now a tremendous acceleration. A force of 150 tons is now propelling a mass weighing only 5 tons, resulting in an acceleration of 30 g's. The tremendous fuel consumption reduces the total weight so drastically that we finally obtain those high accelerations. You can clearly see the correlation between the engineering fact of fuel consumption and the medical fact of the acceleration imposed on the man in the vehicle.

Quite fortunately for the poor prospective pilot, it is almost impossible to build a rocket which has an empty weight of only 5% of the total weight. It is very difficult to obtain such light structures and rocket engines. The engineers, therefore, long ago developed a trick known as "staging." This permits higher structural weight percentages, and it makes use of the fact that not the entire structure has to be lifted into orbit but that parts of it are jettisoned at lower altitudes and velocities, thus saving major portions of the work to be done. In this way relatively more structural weight and payload is permissible on the launching pad and of course is also left over at burn-out of each stage. Consequently, the very high accelerations are not obtained. This now is a case where the shortcomings of technology are helpful to the human factors.

Figure 1 shows the reduction in peak acceleration due to staging. It shows how the peak is drastically reduced if two stages are used instead of one and how further reduction can even be achieved by going to three stages. It is obvious, of course, that the duration of the acceleration is increased by the use of multiple-stage rockets because the time integral of acceleration must be the same in order to obtain orbital velocity.

As pointed out before, today's rockets are burning fuel in large amounts, and it has been shown how fuel consumption during the flight reduces total weight, thereby increasing the acceleration. This is the present state of the art. The reason for this high fuel consumption is the limited velocity of the exhaust gases. If it were possible to increase this velocity, the same amount of thrust could be achieved with a lower mass flow of combustion products since, in accordance with Newton's laws, the thrust is the product of mass flow times velocity. We can trade higher velocity against smaller mass flow for the same thrust. In this way a rocket engine with a lower total fuel consumption would be obtained with the associated smaller amount of total fuel.

Immediately now it becomes clear that we could build a rocket that is, let's say, only made up of 50% fuel rather than 95%, as above. If we again had an initial acceleration of 1.5, the acceleration at burn-out would only go to 3 g's. This would require an exhaust velocity of about 30,000 feet per second.

To show this in more detail, we turn to Figure 2 which depicts the reduction in peak acceleration with increased exhaust velocity. Today exhaust velocities of approximately 8-10,000 feet per second are possible which, depending on the number of stages, produce peak accelerations up to 30 g's. Substantial reduction in this acceleration peak can be obtained with an increase in exhaust velocity. Staging decreases the acceleration peak even more. Therefore, success in achieving higher exhaust velocities will benefit the space pilot.

Another way of making accelerations more tolerable for man would be to control the thrust of a rocket engine in such a manner that the thrust diminishes in proportion to the decreasing weight as the fuel is consumed. Rocket engines of today, though being perfected to quite a degree, are still rather crude. The process to provide thrust from such a device constitutes a barely contained explosion in a suitably formed compartment. Things are getting more difficult if attempts are made to control or throttle the thrust. First attempts are made in this direction in the rocket engine of the X15, and it may well be that efforts may be directed towards applying similar procedures to large rocket engines to control thrust in order not only to control acceleration but also the flight path.

Everyone associated with rocket engineering and space flight is aware of the fact that low weight of all devices installed in a rocket is of utmost importance. If we plan today to put a man into orbit, all the equipment necessary to sustain the man's life must be as light as possible. Excessive weights are just not tolerable. This, of course, imposes severe restrictions on all the equipment to be used. If it were possible to relax from these restrictions, life for the man in the orbital vehicle could be made much easier. This restriction is again a consequence of today's technology.

As pointed out above, most of the rocket's total weight is made up of fuel. In Figure 3 it is shown how the weight distribution depends on exhaust velocity. This figure shows the weight distribution for a single-stage orbital vehicle, and it clearly indicates how much more structure and payload could be installed if the exhaust velocity could be made higher. Today with exhaust velocities in the order of 8-10,000 feet per second, only a few percentages of the total weight can be made available for payload and structure, while at higher exhaust velocities this percentage increases rapidly.

Again, staging helps significantly in this respect, as can be seen from Figure 4 which shows the weight distribution for multi-stage rockets. It is evident that only staging today grants us enough weight allowance for payload and structure to make space flight possible at all. But increases in exhaust velocity would substantially improve the situation for all cases.

It should be noted that staging is a necessary evil. It certainly does not improve the reliability of the vehicle, as experience in the past has shown. It is quite clear that a single-stage rocket is much simpler because nothing can be wrong with the gadgets which just are not there. But for the time being, we have to live with multi-stage rockets.

It is beyond the scope of this paper to make predictions as to when such increase in exhaust velocity may be achieved. The chemical-fuel rockets with the presently-known fuels already make the best use of the available energy. Significant increases in exhaust velocity with such fuels are not very likely. Other means of accelerating the propelling gases are being studied. Some promise appears to come from a new field which is called "magneto-hydrodynamics." This new field of science in its applications is fairly new and is being worked on quite effectively. The behavior of gases is studied under conditions of very high temperatures where, through ionization, gases become electrical conductors. Such a gas in a magnetic field behaves then exactly like any other current-carrying conductor as, for instance, a wire in an electric motor. It is possible then to accelerate the gas through magnetic forces. It is still too early to say how much improvement really can be expected from it.

As a sideline thought, it is interesting to note that this new field has strong relations to astrophysics where magneto-hydrodynamic forces have been known for quite some time as major forces acting in the Universe.

The problems discussed so far were all concerned with the launching of the vehicle. A solution to those problems appears rather simple. In contrast, the problems of re-entry are formidable.

Everyone knows that most of the satellites which have been put into orbit have all met a fiery death when they finally returned into the atmosphere. Aerodynamic heating and tremendous forces destroyed the satellite vehicles as they came in contact with the atmosphere again. How can we expect to safely bring a man back to Earth from a satellite orbit?

I believe that despite those difficulties we will see exactly such a feat accomplished in the next decade. An enormous amount of engineering work has gone into investigating the problems associated with re-entry, and the general subject is pretty well understood. It is evident that the tremendous kinetic energy which the satellite has relative to the Earth must be dissipated in some fashion in order to gradually reduce the velocity. The energy which was put into the satellite during launch with so much effort appears now as a major source of trouble. Every inch-ounce of work that was put into the satellite during launch must now be dissipated. Each pound orbiting around the Earth has an energy of about 4 KWh, or approximately 13,000 BTU. You will appreciate this amount of energy if you consider that less than 10% of this energy is enough to bring the temperature of a re-entering pound of steel not only to the melting point but to the boiling point.

This great energy brings two major problems in the re-entry phase. One is again the problem of high forces of inertia--this time due to deceleration. The other is the problem of high temperatures. In this area engineer and space flight surgeon have to work closely together because all parameters are so critical that only the slimmest margin exists.

To show you what I mean with this, let's first discuss the problem of deceleration. All the schemes proposed so far utilize a simple shape for the re-entry vehicle which is slowed down by air drag only. The control of the trajectory is very critical. Especially the initial flight path angle relative to the horizontal can make a tremendous difference to the peak deceleration that occurs during re-entry.

This is shown in Figure 5. (Figures 5 through 9 are all based on reference 1) depicting the peak decelerations as a function of this angle. It can be seen that the deceleration peak increases sharply with increasing initial angle and soon trespasses human tolerances. It is evident that quite an elaborate guidance system is required during launch first to establish an orbit that is within certain tolerances so that the entry angle does not generate too much of a deceleration at the eventual re-entry. None of the satellite orbits achieved today was accurate enough to meet these requirements. This statement, by the way, includes also the Russian satellites. Also, for a controlled re-entry some system is required to ascertain proper re-entry conditions. As you can see, there is a very definite correlation between human tolerance and engineering requirements, and it is obvious that this correlation is very critical.

Figure 5 indicated that the acceleration peak is minimized if the initial angle is close to 0 degrees. Still this peak is in the neighborhood of 8 g's. The question now arises: What can be done to minimize this deceleration even further in order to make it more tolerable for the average human being? So far we have discussed re-entry using aero-dynamic braking by drag only. Wouldn't it be sensible to try to apply aerodynamic lift as well? Lift could be used to prevent the satellite from losing altitude too rapidly after the initial braking has taken place. In this way, the trajectory could be maintained at high altitudes with a resultant decrease in the peak deceleration.

Figure 6 shows the reduction of peak deceleration if lift is applied. The curve is plotted using the lift/drag ratio as parameter, and it can be seen that for a lift/drag ratio equal to 0, we again obtain about 8 g's for the peak deceleration. Lift/drag ratio of 0, of course, constitutes a pure drag vehicle without any lift. As the lift is made larger, substantial reduction in deceleration can be achieved. As in the case of launching, of course, the duration of deceleration is increased since, again, the time integral of the deceleration must be equal to the orbital velocity. This picture looks quite tempting if we only look at the reduction in peak deceleration. It is obvious that a space medicine man would like the engineer to employ lift in order to get better conditions for the pilot. This appears especially desirable since a lifting device at the same time could provide some control in the later phases of the re-entry and possibly permit selection of a suitable landing spot.

There is, however, another side to this picture. The problem I am referring to now is the heating problem. The employment of lift can have an influence in this area.

We have seen above that the kinetic energy, if totally converted into heat and transferred to the vehicle, can melt and vaporize any orbital vehicle. Quite fortunately the total kinetic energy is not transferred to the body as heat. A significant fraction remains in the air as heat and turbulent motion. It is now necessary to minimize, by choice of proper design, that part of energy which is transferred to the vehicle. Two extreme cases are useful to consider.

The first one employs a very light structure with a negligible capacity for heat storage. This design will heat up very quickly and has to rely on heat radiation to dissipate the energy. The second case is represented by a structure with a large capacity for heat. This design gets rid of the heat by just letting the surface gradually melt away or storing the heat in a so-called "heat sink" which jettisoned after the heating peak is passed.

The two cases require different re-entry conditions for minimum temperatures. Let us assume that we could design a vehicle of either kind in such a way that both attain a certain temperature without the use of lift. As we employ lift, we will obtain different temperatures. Figure 7 indicates the variation of temperature we can expect as we add lift to our vehicle. We can see that the first case; that is, the low-capacity structure, benefits by using lift, whereas the high-capacity structure is adversely affected. Lift may be harmful or useful, depending on the type of structure. Therefore, our aforementioned desire to use lift in order to reduce the deceleration must now be checked in view of the heating problem. Careful studies have to be made in order to arrive at the optimum solution.

Presently a non-lifting vehicle appears as the simplest solution. The first manned satellite, therefore, will be of this type. In the future the engineer may again be able to oblige his space medical colleague by reducing the high decelerations with the help of lift of some kind. Again magneto-hydrodynamics may play a role in providing this lift.

During the next decade we will certainly see a manned satellite. It can further be assumed that after the first adventurous undertaking such events become more routine due to further progress. The flights will first last for a relatively short time of a few days. The present state of the art can provide for the subsistence of life during such a short time. For longer flights this system of simple provisioning is no longer feasible and a closed ecological system becomes necessary. Such a system does not yet exist and its development is quite a challenge to the physiologist. In contract hereto the technological basis for extended orbital flights is available. Such flights in manned vehicles could be undertaken if a closed life-sustaining system would exist. During the next decade we certainly can expect some developments in this direction.

This work will then lay the groundwork for interplanetary flights, which technically appear also feasible today. New problems will arise as we tackle visits to other planets. The differences in gravitation and atmospheres change the picture of launching and re-entry, and it is quite interesting to compare some of the aspects of re-entry into atmosphere of other planets.

We first show the deceleration encountered when entering the atmosphere of the planets Jupiter, Mars, and Venus in comparison to the deceleration experienced in the terrestrial atmosphere. Figure 8 shows this effect.

You can see that Mars will pose the smallest problem as far as deceleration is concerned. The reason is, of course, that the atmosphere is rather thin and gravity is only about one-third of a terrestrial g. Venus is about the same as Earth, as was shown in Figure 6, but Jupiter certainly poses a problem. A pure drag vehicle would produce too much of a deceleration, and lift is absolutely necessary. Sustained flight at low velocities appears quite troublesome due to Jupiter's high gravity.

Aerodynamic heating in the various planetary atmospheres is also quite different from the heating in the terrestrial atmosphere. Let's assume that a non-lifting vehicle is designed to reach 2000°R upon re-entering the atmosphere of the Earth. If we have a low-capacity structure, the temperature will vary with the application of lift, as explained before. The same vehicle in other atmospheres will attain temperatures varying in about the same manner as is shown in Figure 9. The temperature level, however, differs greatly depending on the planet. Again, Mars offers the least difficulties with Venus, Earth, and Jupiter following. Jupiter in all respects shows itself certainly as a forbidding planet.

I attempted to give you a brief glimpse at the problems of re-entry. Their implications relative to a manned satellite need no further explanations. Again, there is a strong correlation between the state of the art and the space medical problems. Today the only way to control re-entry is by means of aerodynamic forces. Drag, being the simplest one, will be used first; and later certainly lift will be employed as soon as the problems associated with lift generation for practical applications are mastered. In the future when engine thrust can be used more efficiently not only for launching but also for re-entry and when the generation of forces through other means than aerodynamics becomes feasible, the problems of a re-entering vehicle and its consequences for its occupant become greatly relieved.

I am confident that in the next decade we will see such progress, where refinements of the present state of the art will take place. It is also clear that major breakthroughs are required to take space flight out of the adventure category and make it a practical routine.