THE SPACE MEDICAL PROBLEMS INVOLVED IN A MANNED ARTIFICIAL SATELLITE

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For about six years Space Medicine, a branch of Aviation Medicine, has been studying the human factors involved in flights into the upper atmosphere and beyond, into space. There are various phases of this kind of flight, depending upon the physical and physiological characteristics of the environment, the speed of the vehicle, and upon the destination of the flight.

The first stage of space flight will be the long distance flights at supersonic speed through the space equivalent regions of the upper atmosphere that we can expect in the immediate future. These flights are the logical development of the present day long distance atmospheric flights on a global scale and can justly be called global (or long distance) space equivalent flights. With regard to motion dynamics the vehicle exhibits partially airplane status and partially projectile status. We are now at the threshold of this first phase of space flight, namely, global space equivalent flight.

A decisive phase in the development of flight will have been achieved as soon as the speed of about 5 mps or 18,000 mph has been reached. This is referred to as the circular orbital velocity which enables a vehicle to circle permanently around the Earth in an orbit; such a vehicle takes on a satellite status like the moon. This is circumplanetary space flight

As soon as a speed of 7 mps or 25,000 mph has been reached, the vehicle will break away from the gravitational contrpl of the earth and escape into deep space. This vehicle will then have attained spaceship status; this will be the final phase of space flight and can truly be called interplanetary space travel.

This is a classification of the possible developmental stages in human flight, based on physical, technical, and medical considerations and refers to manned flight only.

It is my purpose in this paper to discuss the medical problems involved in the second phase of space flight, namely, that of ~~circular orbital~~ circumplanetary space flight or satellite flight. This is full-fledged space flight in its simplest form. Full-fledged, because ~~it shows nearest the earth~~ all of the strange environmental and motion conditions associated with space flight are encountered; in its simplest form, because the vehicle movement is uniform and unidirectional. [redacted] Circumplanetary space flight, therefore, is an especially suitable topic for ~~a~~ discussion of the fundamental medical problems confronted in space flight.

The first step in the direction of this phase of space flight is the instrumented unmanned satellite, such as the one recently ~~announced~~ proposed ready for launching in 1957; but we will take a step further and assume, for the purpose of our discussion, an instrumented manned satellite. We will not, however, discuss how this vehicle arrives at its orbit and the medical (acceleration) problems involved - which are not unsurmountable - but rather we shall presume to be at the stage where the vehicle has already reached a certain orbit and has attained satellite status.

The speed required to attain satellite status is nearly 18,000 mph near sea level. The denser regions of the atmosphere would prohibit this speed because of air resistance and friction heat. At about 120 miles or 200 km., however, the air is without noticeable effect in both respects. This aerodynamic and aerothermodynamic border of the atmosphere can therefore be designated with the more general term, ~~astronautical border~~ effective limit of the atmosphere. The actual material ~~Border or astronomical border~~ border of the atmosphere, however, reaches into the area of 600 miles or 1000 km. from where we enter through a 600 mile wide spray zone into interplanetary space. But it must be emphasized that above the astronautical border, the atmospheric environment is space equivalent in practically every respect. It is here that the field of aerodynamics ends and that of astrodynamics begins, rather than at the ~~astronomical~~ border.

Above 120 miles, therefore, the nearest satellite orbit is conceivable. The orbital speed required at this level is roughly 17,500 mph and the period of revolution is about 88 minutes. Naturally, with increasing altitude, the orbital velocity decreases, and the period of revolution increases (See Table I).

Now, for our medical discussion, let us assume a 300 mile altitude orbit. At this altitude we are beyond the F layers of the Ionosphere and far beyond the astronautical border. The orbital velocity here is 17,000 mph and the period of revolution 95 minutes.

Characteristic of the orbital velocity is the fact that the gravitational pull of the earth and the centrifugal forces caused by the vehicle's inertia are balanced. This means that the vehicle and its occupants are in the state of weightlessness or zero-gravity - the first medical problem that I would like to discuss. This is a two sided problem: 1) a general medical side regarding the well being of the occupants, and 2) a sensory physiological side with regard to sensory perception of position of the body in space and sensory-motoric control of the body movements. So far, experiments on man to study this problem have been carried out for only 40 seconds in parabolic flight maneuvers. The experiments of Henry, Simons, and Ballinger in Wright-Field Aeromedical Laboratory in 1952, those of von Beckh in Buenos Aires, South America in 1953, and most recently those of S. J. Gerathewohl in Randolph Field, Texas, do not indicate a serious disturbance in the autonomous nervous system, and there is no reason to believe that this would be any different during a longer period of time such as would be found in a satellite. It is therefore too early to draw the devil of a space disease upon the wall similar to motion sickness. At this point I would like to add that a manned artificial satellite is the only means of bringing about a final solution of this whole problem because it alone offers the possibility of experiencing nearest the earth the gravity free state over days, weeks, and months.

As to the second or the sensory side of the gravity free state, there is this to be said: we have several sense organs that serve as gravi-receptors, such as the centrally located otolith organ, and distributed peripherally over the entire skin receptors of the pressure sense (about 20 per cm^2), specific nerve endings in the muscles, the so-called muscle spindles and finally, specific nerve endings in the [struck out] connective tissue, the Pacinian corpuscles. They all belong to the category of mechano-receptors; these mechano-receptors have an exteroceptive function insofar as they react to external forces and inform us about the outer world. One of such external forces is the gravitational pull of the earth. They also have an enteroceptive or a proprioceptive function insofar as they inform us about the tension conditions in the skin, the muscles, and the connective tissue. They play, therefore, an important role in the sensory motor control of the body's movement. In the case of the vestibular apparatus and the pressoreceptors of the skin, the exteroceptive function is more pronounced, in the other mechanoreceptors the proprioreceptive function is dominant.

In the gravity free state the exteroceptive or the gravi-receptive function of the mechanoreceptors is eliminated; the proprioreceptive function, however, is not. For this reason, a man making a high dive from a diving board, during which time he is in a gravity free state, is well able to perform skillfully, a variation of many acrobatic jumps. The absent gravi-receptive function of the mechano-receptors is substituted by our exteroceptive sensory organ par excellence: the photoreceptors, or - in other words - the eyes. In the gravity free state, like when in a satellite, the eyes will be the only sense organ that informs the occupants of their position in space. This brings us to the problem of vision in space.

Of what kind are the light sources that confront us in Space?

Direct sunlight and starlight are first; we are also confronted by indirect sunlight coming from the earth, reflected by the continents, the oceans, and especially by the clouds. Moreover, some of the indirect sunlight is scattered from the denser layers of the atmosphere back into space. Finally we have indirect sunlight reflected from the moon's surface. But there is no skylight, and this is the factor that makes the visual conditions so strange in the regions where satellites are conceivable. Skylight is sunlight scattered in all directions by the air molecules. Because the short wave part of the visible spectrum is especially affected, the scattering produces the diffuse blue daylight in the denser regions of the atmosphere, as it is observed from the Earth's surface. Against this rather bright skylight, during the day time the Moon and stars fade into oblivion. With increasing rafification of the air molecules in higher altitudes, scattering of light diminishes gradually and ceases at about 100 miles. Beyond this level the sky is permanently dark. The extra-atmospheric sky brightness is only 10 millilambert as compared with that of 500 millilambert in the lower atmosphere. But the sun is visible in its full brilliance against the dark sky, except of course when the satellite moves through the shadow of the Earth. The stars too are visible all the time, and when its position allows, the moon can be seen in full light intensity together with the sun. Because of the lack of skylight in space, the contrast between light and darkness is a dominant feature. Everything that is exposed to sunlight appears in full brightness and vivid color, and everything else is in the darkness of shadow. The extra-atmospheric illumination is around 13,500 foot candles as compared with 11,800 foot candles at the Earth's surface. Light and shadow dominate the scenery comparable to the light and shadow effects ~~such as those~~ produced on the stage for the magician. This strange photoscotic condition poses medical problems in the field of contrast vision and retinal adaptation. And the strange distribution of the light sources, Sun, Stars, and the indirect sunlight from the earth and moon are of special interest from the standpoint of orientation in Space.

At this point I would like to make a comparison with an environment that is, so-to-speak, the extreme opposite of that found in space: the deep sea.

But, there are also some similarities, according to the wellknown proverb: "les extreme se touche."

W. Beebe observed in his "bathysphere" that the light intensity decreases rapidly with increasing depths, while the spectrum shifts towards blue-violet. But at a depth of 1600 feet, light is completely absent in the Atlantic ocean. In these regions we find fish with luminous organs and telescopic cylindrical eyes. At depths of about 10,000 feet there are fish with only vestigial eyes. These deep sea fish rely almost entirely on the mechano-sensory system of their skin to sense the environment. This represents an extreme contrast to the situation that will be experienced by man under space conditions. In the darkness of the deep sea, where the photoreceptors are out of function, the position and movement of the fish is controlled solely by the gravi-receptors and mechano-receptors; in the darkness of deep space and under the conditions of gravitational orbital fligh where the gravi-receptive function of the mechano-receptors is eliminated, orientation depends entirely upon the photoreceptors or upon vision. The sun, the stars, and the earth and moon are the optical footholds for the visual orientation in space.

The observation of the sun, however, poses an important medical problem. The brilliant radiance of the sun in its original intensity, ~~while not affected by~~ without atmospheric absorption, represents a hazard to the eyes. In space A much shorter time of exposure is sufficient to cause a retinal burn, such as that known to the ophthalmologist, as it occurs occasionally when someone observes a solar eclipse through an ~~properly~~ smoked ~~insufficiently blackened~~ glass. Such a solar radiation effect upon the fovea of the retina is demonstrated in this picture which shows a small distinct spot of alterated tissue. This is a picture of the retina of my right eye, which shows a retinal injury which I acquired when I observed a total solar eclipse in 1911 as an inexperienced space-curious boy of ~~12xyxxxxx~~ twelve. The result of such a so-called eclipse blindness is a scotoma or blind spot ~~perforation~~ in the visual field. Outside of the atmosphere, the danger of such a retinal injury by direct solar light is ~~mxxx~~ much greater and from an artificial satellite the sun should be observed only through glass with very high absorptive power.

In connection with the optical conditions found in the space equivalent regions of the atmosphere beyond 120 miles, and in interplanetary space, I would like to bring to y our attention a physiological problem that has never been touched upoh in space medical discussions. It is the problem of maintenance of an adequate physiological day-night cycle for the occupants of a space vehicle.

In space flight, such as that in a satellite, the concept of night loses its meaning and must be replaced by that which night really is, namely, the shadow of the earth.

The shadow or umbra of the earth tapers down in the form of a cone 859,000 miles or 1,385,000 kilometers deep into interplanetary space. Travelling through its greatest width would take a satellite vehicle less than an hour. During the remaining time (also about one hour) the vehicle is surrounded by the mysterious darkness of space as described before. This is always the case when the satellite orbit passes through the earth's shadow.

All kinds of planes for the orbit are conceivable; in some of them a satellite would not touch the umbra at all. Be that as it may, in orbital space flight an adequate ambient physical day-night cycle is absent because the day-night, or more precisely, the light ~~and~~ shadow cycle is less than two hours. Therefore, we must create ~~artificially~~ and maintain ~~a~~ an artificial cycle within the satellite to meet the physiological requirements of the occupants. For, adequate diurnal cycling is of great importance to the health and efficiency of the occupants. In fact, we are so strongly adapted, or so physiologically bound to a day-night cycle, manifested in rest or sleep and wakefulness or activity, that to ignore this physiological ~~routine~~ requirement would, after a week or so, lead to a complete nervous breakdown.

How can an adequate day-night cycle be achieved for the occupants of an artificial satellite?

The night time must be induced for them in a special night compartment. The question is posed as to the length and time interval of such an artificial day-night period.

In this regard reference is made to the important basic experiments carried out in the Mammouth Cave in Kentucky, 1940, by N. Kleitmann, Professor of Physiology at the University of Chicago. Dr. Kleitmann spent two months in this cave, with several co-workers, under artificially produced day-night cycles of different lengths. The result of these experiments showed that man can adapt himself to a diurnal cycle only in the range of from 18 to 28 hours. Within this range the temperature curve of the body follows the various cycles.

When a cycle shorter than 18 hours or one longer than 28 hours was introduced, the temperature curve returned to its normal cycle of 24 hours.

This gives us the clue to solving the problem of diurnal cycling in a manned satellite. If we assume a minimum day-night cycle of 18 hours, divided into 8 hours sleep, 2 hours recreation and 8 hours duty, that would be a reasonable solution. Or, if a 24-hour day-night cycle is applied, the best plan for a subdivision of the cycle would be 8 hours sleep, 8 hours rest and recreation, and 8 hours duty. All this presupposes that the crew is large enough to be subdivided into three groups. In the case of an 18 hour day-night cycle, ~~a~~ two group crew would be more acceptable from the psychological point of view.

~~For comparative purposes, we~~ We may assume that the metabolic rate of an occupant of an artificial satellite during his duty hours, is about the same as that of an occupant on Earth during moderate working hours; the total metabolism during a 24-hour period, including sleep and recreation would then be in the order of 2800 cal. This brings us to the respiratory requirements for the satellite crew, or more ~~specifically~~ generally speaking, to the climatization of the cabin. The cabin in a satellite must of course be completely closed, a sealed cabin in which an adequate atmosphere is artificially created and controlled. It must be emphasized that such a type of cabin is required even down to the atmospheric region of 70,000 to 80,000 feet.

One of the vital tasks in the climatization of the sealed cabin is the ~~solving~~ solution of the oxygen problem for respiration.

From the aforementioned metabolic rate of 2800 cal per man per day, we can calculate the amount of oxygen required by one man per day. The physiological thermal equivalent of 1 liter of oxygen is 8.5 cal. under normal nutritional conditions. This means that the biological production of 1 cal. requires 115 cm^3 of oxygen. Consequently, the total amount of oxygen consumed per man per day is 500 liter or 0.7 kg. This amounts to 46 kg. of oxygen per man for 1000 satellite revolutions that take place in 66 days in our assumed orbit at the 300 mile altitude, or 276 kg. O_2 for a crew of six. Replacement of the consumed oxygen from the storage tanks must be contpolled in such a way that the oxygen pressure does not fall below 95 mm Hg. This is the minimum limit permissible for comfort and efficiency; it should not surpass the permissible maximum of 325 mm Hg because O_2 concentrations above this level are toxic. Whereas oxygen is consumed in the metabolic processes of the body cells, carbon dioxide is produced in the same process and exhaled. Under normal nutritional conditions the ratio between exhaled carbon dioxide and consumed oxygen, the so-called respiratory quotient, is 0.85. With our example, one man produces 425 liters of carbon dioxide or 0.837 kg. per day or 55.2 kg. per 1000 satellite revolutions. This would be 331.2 kg. for a crew of six. Carbon dioxide in ~~higher~~ concentrations above 4 vol. percent is toxic; the permissible limit lies at about 2 vol percent under standard barometric pressure or at 15 mm. Hg. The removal of the excess Carbon dioxide in the sealed cabin vehicle, which can be achieved by certain chemicals is, therefore, just as vital as the maintenance of an adequate oxygen pressure.

Since the consumed oxygen appears again in bound form, namely within the carbon dioxide of the expired air, it has been suggested to try to regain the oxygen from the carbon dioxide, in this way eliminating a toxic gas and at the same time facilitating the problem of oxygen supply.

A natural method accomplishing this, is known to us in the process of photosynthesis, found in chlorophyl bearing plants. Photosynthesis is the reverse process of respiration as a comparison of their reaction formulae shows:

Respiration: $C_6O_{12}O_6 + O_2 \longrightarrow 6CO_2 + H_2O$ + Energy

Photosynthesis: $6CO_2 + 6H_2O$ + Solar Energy $\longrightarrow C_6O_{12}O_6 + O_2$

In respiration ~~respiration~~ or biological oxydation, oxygen is consumed and carbon dioxide and water are produced. This process requires several so-called respiratory enzymes. In photosynthesis oxygen is produced and carbon dioxide and water are consumed. This process requires the presence of chlorophyl as an activator.

In special studies sponsored by the USAF School of Aviation Medicine it has been found by Dr. Jack Myers, Professor of Zoology, University of Texas, that 2.3 kg. fresh weight of a certain alga - the alga chlorella pyrenoidosa - with regard to ~~their~~ gas metabolism~~s~~, under optimal conditions, are equivalent to one man. This means that this mass of algae consumes as much carbon dioxide and produces as much oxygen per time unit as one man produces carbon dioxide and consumes oxygen. Both, therefore, could live together and support each other with regard to the respective respiratory and photosynthetic requirements in a [symbiotic-like state] ~~like symbiosis~~, in a closed system for a considerable length of time.

Plants like the alga chlorella are especially suitable as a photosynthetic gas exchanger. They are small round bodies about the size of red blood cells and are dispersed in a nutritional solution. These primitive plants are perfect photosynthetic machines, since they have no specific organs nor various functions like the higher plants. Their only function is to build up, photosynthetically, carbohydrates and to produce oxygen. Primitive plants of this type already appeared on this planet one and one-half billion years ago. And they might have been responsible for an early build-up of an initial stock of oxygen in the primitive atmosphere of the natural satellite of the sun, namely the earth. And now, the same biological process may some day be used in the climatization of artificial satellites of the earth. But the difficulties for the use of such photosynthetic gas exchangers lie in the volume and weight of the device and in arrangement of ~~and~~ the power requirement for illumination. As for the latter, solar energy may be the answer. For flights of short duration, however, we certainly will never resort to a biological gas exchanger. For flights over weeks and months it might be different. Maybe some day we will have a type of photosynthesis that can utilize infrared, or, (and??) the effort to achieve artificial photosynthesis may one day be successful. ???

In the sealed cabin also, the moisture given off - in amounts of from 50 to 80 gram per man per hour through respiration and perspiration under comfortable temperature conditions by the occupants, must be kept within the comfort limits that range between 30 and 50 percent relative humidity. And finally, the barometric pressure should be kept at levels corresponding to that found near sea level and up to 8,000 feet. In this respect, however, the physiologist could make concessions to the engineer, who would probably desire a lower pressure differential between the cabin's air and the surrounding near vacuum for structural reasons. From the physiological point of view a minimal barometric pressure, corresponding to an altitude of 15,000 feet would be acceptable.

The multitude of factors involved in the climatization of the sealed cabin requires a complex of instrumentation for automatic control. The USAF School of Aviation Medicine, Randolph Field, Texas, now has an experimental sealed chamber in which we can study the changes of the atmospheric conditions caused by the presence of the occupants, and the means to control these factors. (FIG._____). This device can also serve as an indoctrination chamber in handling the situation in case the automatic controls fail or the cabin develops a leak.

With this point we touch upon the Achilles' heel of the sealed cabin vehicle. One of the causes of a leak might be a collision with a meteor, a probability which is very remote; however, the occupants of a satellite vehicle must be prepared for such an event, even though meteor or bumpers or screens - suggested by Whipple and others - might offer effective protection.

In the lower atmosphere, the time rate of decompression of the pressurized cabin is governed by three factors: the volume of the cabin, the size of the hole, and the barometric pressure of the ambient atmosphere. In a satellite vehicle, the latter factor is practically zero, which means that under other equal conditions the decompression will be more violent and faster. In any event, the crew must know that a drop in oxygen pressure to 90 mm Hg. will affect their efficiency, as aforementioned, and that at 60 mm Hg. the situation becomes critical and dangerous. See Table . Before this critical level is reached, the source of the leak must be sealed, otherwise, the crew would face the whole physiological sequence of decreasing air pressure effects.

These are some of the medical problems encountered in manned satellite flight. I have not touched upon the radiation problem, which is the experimental field of Major Simons. All of the space medical problems discussed so far are also encountered in transfer orbits, that is, in interplanetary Space Travel. They are, however, also faced, more or less - during a certain portion ~~at least -~~ of in space equivalent flights, that is, in long distance flights at hypersonic speed through the space equivalent regions of the atmosphere. But we find them, so-to-speak, in classical form in circular orbital flight or in a satellite vehicle. The unmanned instrumented satellite planned by the United States for launching in 1957 or 58, will be the indispensable exploratory forerunner of the manned satellite, which will certainly come some day.

Be that as it may, the main reason that I have chosen this phase of space flight was that a satellite vehicle would offer an ideal platform for the discussion of the problems of space medicine in general and for giving you an up-to-date picture of the progress made by this fast developing branch of Aviation Medicine.

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~~progress made by this branch of Aviation Medicine which is fast coming into the realm of importance in high altitude/space flight and eventual space travel.~~