SPACE MEDICINE

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Medicine, in its beginning - at the time of the caveman and the medicine man - was essentially a primitive "general practice." During the course of historical development this basic stage of medicine branched out into a number of specialties; some are based on different methods of treatment such as surgery and internal medicine; others specialized with regard to the various anatomical organs and functional systems such as gynecology, neurology, cardiology, and so on; still others are related to a specific occupation and environment such as industrial medicine, tropical medicine, etc. One of the most important branches in the category of environmental medicine is Aviation Medicine, which started some 40 years ago and has aided the engineer and the flyer in the conquest of the air ocean; without a doubt, Aviation Medicine has contributed its share to the development, safety and efficiency of transportation by air or of atmospheric flight. And now,

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with the rocket at our disposal, the conquest of space is in sight. This adventure, which will carry man completely out of the atmospheric medium ~~and is~~ so vital to him, will pose even more medical problems and will require even more medical support. That new field of medical science which studies the human factors involved in the penetration of space is <u>Space Medicine</u> - a branch or an extension of Aviation Medicine. With space medicine, medical research for the first time is directly linked to scientific fields which deal with matters of extraterrestrial nature such as astrophysics and celestial mechanics. These associations reflect the specific and novel mission of this new and fascinating field. With Aviation Medicine, Aesculapius - the Greek god of Medicine - pushed his realm high into the sky; with Space Medicine, he extends it beyond the atmosphere into space and perhaps, some day, even into the areas of Venus and Mars. Thus, we see an interesting development in medicine from the simple art of healing in the time of the caveman to a protecting function for the spaceman.

Space Medicine is now about 7 years old. It came into existence with the foundation of a department of

Space Medicine at the United States Air Force School of Aviation Medicine at Randolph Air Force Base, Texas, in 1949, under its Commandant General Harry G. Armstrong. At the same time preparations for experimental medical or physiological studies in rockets began at Wright-Patterson Field in Dayton, Ohio. Since 1951 the Air Force has had a Space Biological Branch at the Aero-medical Field Laboratory at Holloman Air Force Base, New Mexico, under the supervision of Lt Colonel John P. Stapp and Major David G. Simons. The Soviet Union has an institute called Institute of Astrobiology, for the study of the ecological conditions on other planets. Similar studies are going on at the School of Aviation Medicine at Randolph Air Force Base, Texas.

So much for the general and historical remarks about Space Medicine.

It is indeed a great honor for me to discuss with you this evening, in this great City of Detroit, world center of motor technology, some of the problems involved in Space Flight. As a medical doctor, I always enjoy speaking to an audience of engineers

If there is/in any field a vital need for a close cooperation between engineers and medicine, it is in the field of Space Flight. The engineer is concerned with the hard component, the medical doctor with the soft component in Space Flight. Both therefore have different aspects which must supplement each other. Both have also a different terminology which makes a discussion on a common platform interesting and fruitful.

The medical problems in space flight, or generally speaking in Space Operations, arise from the environment of space per se and from the process of movement through this environment. Of special interest to us is, where and at what altitudes these characteristics of space flight begin, and protective measures must be provided: one of the most important of these is human engineering of the cabin. Other problems encountered are: high accelerations during launching and decelerations during reentry into the atmosphere, the state of weightlessness, visual problems, day-night cycling, in an environment where there is no sequence of day and night, psychological problems in closed systems, selection of crew, toxidity of rocket fuel and so on. ~~It is too early, to discuss all of these problems in the present developmental state.~~ We shall therefore, confine our medical considerations to

1) an analysis of the environmental and motion conditions of space operations and at where above the earth surface they begin.

2) the various kinds of space operations

3) human engineering of the space cabin, and

4) the state of weightlessness.

First, What are the environmental properties and motion characteristics in space operations from the standpoint of manned flight? They can best be explained by comparing them with the environmental properties and motion characteristics found in atmospheric flight. These are determined by the various functions that the atmosphere offers for manned flight. By and large, these functions can be divided into three principle categories: life sustaining pressure functions, life protecting filter functions, and flight supporting aerodynamic functions.

By subdividing them more into detail and contrasting them with the conditions to be found in space we arrive at the following ten points:

(1) The atmosphere supplies us with oxygen for respiration - in space there is no oxygen.

(2) The atmosphere exerts upon us sufficient barometric pressure to maintain our body fluids in the

liquid state - in space no barometric pressure exists;

(3) Up to a certain altitude the atmosphere can be used for the pressurization of the cabin - in the emptiness of space no ambient air is available for compression;

(4) In the lower zones of the atmosphere we are protected from the too extensive cosmic radiation by the atmosphere's filter function - in space no such natural protection can be expected;

(5) The same situation holds true for the ultra-violet part of the solar spectrum.

(6) The atmosphere also protects us from the meteorites.

(7) In the atmosphere, light is scattered by the air molecules; producing the so-called skylight. Space is permanently in a mysterious state of darkness.

(8) The atmosphere transmits sound waves - in spce there is no medium for sound propagation; space is totally silent.

(9) The atmosphere provides mechanical support or lift to the moving craft. In the vacuum of space, no such support can be expected - a fact which leads to the permanent occurrence of the state of weightlessness.

(10) Finally, the atmosphere with its tightly packed molecules contains and transfers heat by convection and conduction. In space the carrier of heat energy is exclusively solar radiation.

These ten points represent the principal differences between our atmosphere and space - as an environment for manned flight, and reflect the specific nature of the space operations.

Now, the next question is, where and at what altitude do the atmospheric functions just mentioned come to an end and the space flight characteristics begin?

The atmospheric functions do not terminate at the end of the physical extension of the atmosphere at 600 miles. At this altitude the atmosphere ceases to be a continuous medium because collision of the air particles become very rare. This is the physical or material border between atmosphere and space in terms of astrophysics. The functions of the atmosphere for manned flight, however, come to an end at different altitudes and much lower, some even within the stratosphere. These altitude levels are called the functional borders between atmosphere and space, or the functional limits of the atmosphere. At and above these levels we face space equivalent conditions with regard to the function in question. In using the concept of functional limits of the atmosphere and that of space equivalence within the atmosphere we learn where space begins for the flyer.

Now returning to our ten points:

1) The atmosphere supplies us with oxygen for respiration - in Space there is no oxygen. This atmospheric function comes to an end at 50,000 feet.

At first glance this seems strange because up to 70 miles the atmosphere contains free biatomic oxygen (O_2), the kind we use in respiration. The reason lies in the fact that an air body of about 3 liters is interposed between the external atmosphere and the "milieu enterieur" of our body. This airbody, the alveolar air, constantly maintains a rather high content of carbon dioxide pressure (40 mm Hg.) and water vapor pressure (47 mm Hg.). Their combined pressures amount to about 87 mm Hg. As soon as, with increasing altitude, the barometric pressure drops to 87 mm Hg., the influx of oxygen into the lungs from outside becomes impossible, because the alveoli are already occupied to the full barometric pressure of the atmosphere by carbon dioxide and water vapor, both issuing from within the body itsalf.

The air pressure of 87 mm Hg. corresponds to an altitude of about 50,000 feet. At this altitude then, the contribution of the atmosphere to respiration is Zero, just as if we were surrounded by no oxygen at all, as in Space. This is the first of the most important functional limits of the atmosphere, or space equivalent levels within the atmosphere.

2) The atmosphere exerts upon us sufficient <u>barometric pressure</u> to keep our body fluids in the liquid state and prevent them from passing into the vapor phase.

This atmospheric function ceases as soon as the barometric pressure decreases to the vapor pressure of our body fluids. The water vapor pressure of our body fluids at normal body temperature is about 47 mm Hg. We can expect, therefore, that as soon as the barometric pressure decreases to 47 mm Hg. or below our body fluids will "boil." Experiments on warm-blooded animals in a low pressure chamber, carried out as early as 1935 by H. G. Armstrong, showed this to be true. This "boiling" effect is manifested by the appearance of gas bubbles in the tissue and blood depending upon the different pressures in the various sections of the circulatory system. But this low-pressure - low-temperature boiling - as it is found in the high altitudes, must not be confused with the process of boiling used as a method of preparing food which includes coagulation of the proteins. It is simply a formation of bubbles consisting of water vapor.

An air pressure of 47 mm Hg. is found at 63,000 feet, above this altitude then, if not artificially protected we lose the vitally important protection of air pressure against profuse unhindered evaporization, just as if we were surrounded by no atmosphere at all, as in space. This is the second functional border of the atmosphere or space equivalent level within the atmosphere.

omit The vacuum of interplanetary space with 1 particle per 1 cm^3 is immeasureable. The best vacuum obtainable on earth is in the order of 10^{-8} mm Hg. The technical vacuum begins at 1 mm Hg. Physiologically the vacuum begins at 47 mm Hg. or 63,000 feet. This pressure condition is - from the standpoint of human physiology - equivalent to free interplanetary Space.

3) In the denser zones of the atmosphere, the ambient air is used for the pressurization of the cabin. In space, we need a new type of cabin which is pressurized from within, because there is no outside air available to be compressed. It must be a completely closed

compartment, a sealed cabin in which a climatically adequate atmosphere for the occupants must be artificially created and controlled. This type of cabin has no altitude limits; it is in fact THE space cabin. But it must be emphasized that such a space cabin is required even down to 80,000 feet. At this altitude the air density is only 1/27th of that at sea level. Compressing this thin air to physiological levels is beyond the capabilities of present day compressors. And even if this were possible, the compressed cabin air would attain such high temperature as to be intollerable for the occupants. Therefore, with regard to the necessity of a sealed cabin, space begins at 80,000 feet.

We now proceed to the atmospheric filter functions.

4) In the lower altitudes we are protected from the cosmic rays in their original "Space form" and energy by the atmosphere's filter function.

When these primary cosmic rays - which consist of 79% of protons, 20% of Helium nuclei and 1% of nuclei of heavier atoms up to iron - enter the atmosphere from a certain density level on, namely about 120,000 feet, they lose their original powerful form in collision with the air's atoms or their nuclei. The collision products, or secondary rays - protons, electrons, neutrons, etc., which penetrate down through the lower layers of the atmosphere, are less powerful than the original primaries but powerful enough to penetrate several hundred feet into the water. So, at sea level and in the conventional flight zones we are exposed only to the splinters of these bullets from outer space. Above 120,000 feet, however, the vehicle will be exposed to the more powerful bombardment of the original cosmic ray particles. Here we are beyond the protecting shield of the atmosphere, as in space.

5) In the lower layers of the atmosphere we are protected from the sunburn producing ultraviolet of solar radiation.

It is the triatomic oxygen or ozone (O_3), concentrated between 70,000 and 140,000 feet within the atmosphere, that offers a kind of umbrella against ultraviolet by absorbing the larger portion of these rays. Beyond 140,000 feet ultraviolet is biologically effective in its full range as in Space.

6) In the denser layers of the atmosphere visible light is scattered by the air molecules producing the so-called skylight or the beautiful blue daylight. Against this bright sky light the stars fade into

invisibility. In interplanetary space, the particle density is too low for a noticeable scattering effect.

With the absence of sky light in space, therefore, the stars are visible against a dark background at all times even together with the bright sun. This strange darkness of space is reached at about 80 to 100 miles, DUE TO the rarification of the air molecules. This is the transition zone from atmospheric optics to space optics.

7) From ground level we often see meteors in the sky but always at a great distance and greater heights. Space is criss-crossed by these pieces of cosmic matter.

As soon as meteorites enter the atmosphere most of them are burned out by friction with the air molecules. This takes place between 25 and 75 miles. Above this level we are beyond the "meteor safe" wall of the atmosphere, as in Space.

So much about the protecting atmospheric filter function.

8) A very important atmospheric function is transmission of sound.

In higher altitudes, sound propagation becomes impossible as soon as the free path between the air molecules is in the order of the wave length of sound.

In higher altitudes, sound propagation becomes impossible as soon as the free path between the air molecules is in the order ~~of the order~~ of the wave length of sound. The region where this occurs lies between 60 and 100 miles. Automatically - first in the lower regions the higher tones are affected, and finally in the higher regions the lower tones disappear, too. Above this transaccoustic zone we enter the anacoustic zone of the atmosphere or the silence of space; there is no more sound barrier, and therefore the Mach number becomes meaningless, as in Space.

9) The atmosphere provides aerodynamical support or lift for a moving craft. In Space - no such environmental support can be expected. It is replaced by centrifugal forces caused by the vehicle's tremendous speed. The dynamical support from the air ceases at 120 miles, for any speed. This then is the aerodynamical border between atmosphere and space. When the dynamical support by the air vanishes, and the centrifugal forces take over this support completely, balancing the gravitational pull of the earth, then the vehicle and its occupants become weightless. Weightlessness or zero-gravity is a typical space condition. Above 120 miles this condition can be produced for a considerable length of time.

10) The atmosphere transmits heat energy. This poses a hazard in the form of the heat barrier in the denser atmospheric regions when high friction and stagnation heat in the boundry layers of supersonic and hypersonic craft is produced. Above 120 miles this has no more effect upon the temperature of the cabin because of decreased heat transfer, due to the extremely low density of the air. In this respect this level can also be called the aerothermodynamic border of the atmosphere. Above this level the temperature of the cabin's hull is determined exclusively by solar energy, as in interplanetary space.

This space medical analysis of the atmosphere, based upon the concept of the functional borders and atmospheric space equivalence and reveals the amazing fact that the larger portion of the atmosphere is equivalent to free space. We encounter space equivalence within the atmosphere, step by step, with regard to milieu conditions concerning oxygen at 50,000 feet; air pressure at 63,000 feet; cosmic rays at 120,000 feet, ultraviolet of solar radiation at 140,000 feet, meteorites at 75 miles; scattering of light at 80 to 100 miles; propagation of sound at 80 to 100 miles. With regard to motion dynamics, concerning aerodynamics, at 120 miles and aerothermodynamics at 120 miles. The area in which we encounter one, two or more, but not yet all factors typical of space, must be considered as <u>partially space equivalent</u>. This begins at 50,000 feet. The area above 120 miles is distinguished by <u>total space equivalence</u> when we ignore some variations caused by the bulk of the Earth itself, its magnetic field, its speed, and its own reflected radiation.

The atmosphere as a material continuum reaches up to 600 miles; space as a functional environment with practically all of its properties reaches down to 120 miles, and with some of its properties extends down as low as 63,000 or even 50,000 feet. The well known classification of the atmosphere in terms of physics, must therefore be supplemented by a biophysical one. Based upon the foregoing consideration we can divide the whole atmosphere into four zones:

1) the physiological zone (from sea level to 10,000 feet)

2) the physiologically deficient zone (from 10,000 to 50,000 feet)

3) the partially space equivalent zone (from 50,000 feet to 120 miles, and

4) the totally space equivalent zone (from 120 miles to about 600 miles.

For the flier the atmosphere beyond 120 miles is no longer tangible, it is imperceptible. Here the atmosphere turns into a pseudo-atmosphere. The area around 120 miles is, therefore, the final functional limit of the atmosphere. Beyond this final functional limit the laws of aerodynamics lose their meaning and those of astrodynamics become fully effective.

The fact that manned rocket powered planes operate today in the transition zone where atmosphere and space overlap, demonstrates how close we are to space flight. From the standpoint of the medical implications of the environment and of the movement in this environment we are at present in the space equivalent phase of human flight.

The Various Kinds of Space Operations

Space equivalent flight is the first phase in the coming era of space operations. What are or what might be the other operational developments in the direction toward space? An attempt to classify the possible phases of space operations can be based on three factors: the environment, the destination of the flight, and especially, on the factor of speed. In so doing we see an evolutionary course of development of manned flight ~~as shown in this table. For the sake of completeness~~ the

~~the present day conventional flight is included.~~

The manned space operations that may be expected in the near and remote future can be divided into three principle categories - long distance space equivalent flight, circumplanetary space flight which is identical with satellite flight or orbital flight and finally interplanetary space travel. It is advisable to use for this final phase of space operations the word "travel" and for this phase only. ~~The Table shows the status of the vehicle in these various operations, and their characteristics such as environment, speed and gravitational condition.~~ There are, of course, transitional stages such as Kraft Ehricke's satelloid and lunar operations. Thus, we shall have a whole family of rockets and space vehicles. Just as the Zoologist speaks of a family tree of fish, or of amphibians and dinosaurs, we can speak of a family tree, based on the jet propulsion principle.

The first descendant of the geneological tree of jet propulsion is the earthbound air-breathing jet engine with which you are familiar; its maximum altitude ceiling is about 20 miles. The rocket - independent of the presence of air - is the spacebound descendant of the jet propulsion principle. The first rockets as designed by Goddard and von Braun can be considered the proto rockets. Their descendants will be the intermediate and intercontinental ballistic missiles. The manned counterpart of the intercontinental ballistic missile will be an intercontinental rocket craft for long distance space equivalent flights. A logical development of the small research satellite will be a larger manned satellite vehicle, and a space ship designed for interplanetary travel will be the final descendant on the family tree of rocketry.

This classification gives us, I believe, a realistic picture of the stage at which we stand today and of the possibilities we may expect in the future. The time table of the development will, of course, be determined by technology, but we in the medical field must be prepared for all of these possibilities.

In a field like space flight - which is especially apt to invite wild speculations from the public - we must have clear concepts and a realistic approach. It is not a trip to the ~~Moon or~~ to Mars or Venus which interests the Air Force at the present time; but to overlook the fact that there are stages between atmospheric flight and interplanetary space travel such as space equivalent flight, would be a great mistake.

Without a doubt we have trespassed the threshold of this first phase; and in this preliminary phase of space equivalent flight we already encounter - to a certain extent - some of the basic medical problems that will be faced in a manned satellite flight, lunar space operation and interplanetary space travel. The main difference is the duration of the flight.

One of the most important space medical problems is to provide the crew with a cabin which offers a suitable, climate, safety and insofar as possible - comfort. This is what we might call human engineering of the space cabin in an environment which is so strange and hostile to the human body as the atmosphere is to the deep sea fish. This is - as the term human engineering indicates - to a great extent an engineering problem, but space medicine must inform the engineer about the physiological requirements. The cabin of course, as already mentioned, must be a completely closed compartment, sealed off from the surrounding vacuum. It is a closed ecological system which must provide all the physiological necessities of a habitable climate like that found close to the ground; it must perform all the various vital functions that are ordinarily taken care of by the air around us or in moderate altitudes.

One of the vital tasks in the climatization of the space cabin is supply of ozygen for respiration. We may assume that the metabolic rate of an occupant of a space vehicle during his duty hours is about the same as that of an individual on earth during moderate work; the total metabolism during a 24-hour period, including sleep and recreation would then be in the order of 2500 kg for a 70 kg man. At this metabolic rate the amount of oxygen required by one man per day is roughly, 500 liter or 0.7 kg. Replacement of the consumed oxygen from storage tanks must be controlled in such a way that the oxygen pressure does not fall below 100 mm Hg. This is about the minimum permissible limit for comfort and efficiency; it should not surpass the permissible maximum of about 350 mm Hg. because O_2 concentrations above this level are toxic. The fact that we can tolerate a rather wide variation in oxygen pressure (from 100 to 350 mm Hg.) facilitates considerably the oxygen problem in space flight.

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. In our example, one man produces 425 liters of carbon dioxide or 0.837 kg. per day. Carbon dioxide in concentrations above 4 vol percent is toxic; the permissible limit for a longer period of time lies at about 1 vol percent under standard barometric pressure and temperature conditions or at about 8 to 10 mm Hg. The removal of the excess carbon dioxide in the sealed cabin vehicle, which can be achieved by certain chemicals or in a physical way is, therefore, just as vital as the maintenance of an adequate oxygen pressure. In this respect we can learn very much from the experiences made by the Navy in submarines.

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.

In respiration or biological oxidation, oxygen is consumed and carbon dioxide and water are produced. In photosynthesis oxygen is produced and carbon dioxide and water are consumed.

In special studies sponsored by the USAF School of Aviation Medicine, it has been found by Dr. Jack Myers, Head of the Department of Algal Physiology, University of Texas, Austin, Texas, that 2.3 kg. fresh weight of a certain alga - the alga chlorella pyrenoidosa - with regard to gas metabolism, under optimal conditions, are sufficient to support 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 during the same period of time. Both, therefore, could live together and support each other with regard to the respective respiratory and photosynthetic requirements in a symbiotic-like state, in a closed system for a considerable length of time.

Plants like the alga chlorella are especially suitable as a photo-synthetic 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 carbohydrates and to produce oxygen photosynthetically. Primitive plants of this type already appeared on our 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 or proto-atmosphere of the Earth. But the difficulties for the use of such photosynthetic gas exchangers in space vehicles lie in the volume and weight of the device, in the arrangement of and in the power requirement for illumination. As for the latter, solar energy may be the answer. For flights of short duration, however, we certainly shall never resort to a biological gas exchanger. For flights over weeks and months as in manned satellite vehicles it might be different. Perhaps some day the efforts that have been made for a number of years in order to achieve artificial photosynthesis, may one day be successful.

In the sealed cabin also, the water vapor 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.

The climatization of the space cabin also includes humidity control, and temperature control. Temperature control is perhaps one of the most delicate problems in Space Flight.

And finally, concerning barometric pressure the engineer, for structural reasons - would probably desire a pressure differential between the cabin's air and the surrounding near vacuum as low as possible. From the physiological point of view a minimal barometric pressure of 7.5 psi, corresponding to an altitute of about 18,000 feet would be acceptable.

The multitude of factors involved in the human engineering of the space cabin requires careful studies in the laboratory. The School of Aviation Medicine, USAF, Randolph Air Force Base, Texas, 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. Only recently my coworkers Capt. Roth and Dr. Gaume carried out an experiment of a 24-hour duration and soon we will be able to extend the time to days or even weeks. This space cabin simulator can also serve as an indoctrination chamber in handling the situation in case the automatic controls fail or the cabin develop a leak.

With this point we touch upon the Achilles' heel of the space cabin vehicle. One of the causes of a leak might be a collision with a meteor, a possibility which is very remote; however, the occupants of a satellite vehicle must be prepared for such an event, even though meteor bumpers or screens - suggested by F. Whipple and others - might offer effective protection. Such a meteor bumper is a secondary metallic skin surrounding the primary wall, to absorb the energy of the colliding body.

In any event, the crew must know that a drop in oxygen pressure to 100 mm Hg. will affect their efficiency, as aforementioned, and at an oxygen pressure of 60 mm Hg the situation will become critical and dangerous. Before this critical level is reached, the source of the leak must be sealed, otherwise, the crew would face the whole sequence of decreasing air pressure effects upon the body.

Cosmic Rays

Another problem concerning human engineering of the space cabin may be that of protection against cosmic ray particles. About their biological effects intensive studies on biological specimens have been carried out during the past 5 years by Major David G. Simons at Holloman Air Force Base, New Mexico, in balloons floating at an altitude of about 100,000 feet and more for several days. So far the findings indicate that hazards from cosmic rays may have been somewhat over-rated, however, the final answer on this question is still awaited and it is therefore too early to comment on protective measures against these nucleonic bullets from outer space.

Actually, the earth itself is a giant spaceship with 2.8 billion occupants moving with an orbital velocity of 18.6 mps through the vacuum of interplanetary space. And its atmosphere is practically a closed ecological system, it is sealed off by the geogravitational pull which prevents the heavier vital elements from escaping into space. And what we must do if we leave this mother spaceship is to just simulate in the sealed cabin craft the life sustaining and life protecting processes which the earth performs for us on a global scale.

Weightlessness

There is one environmental factor, however, that can hardly be substituted in a space craft - the normal gravitational force of the earth - the force responsible for our weight. In space flight the vehicle and the crew are weightless, a condition never before experienced by man. It is produced in all flight maneuvers in which the gravitational pull of the earth is balanced by centrifugal forces. The reduction and complete removal of weight by a mechanical process makes us realize that mass and weight of a material body are not the same. Mass is an intrinsic property of matter, weight is an extrinsic property of matter, depending upon external forces, such as gravitational and accelerational forces. And now in certain flight maneuvers this property of matter, ever present on earth is reduced or even removed. This is perhpas the most revolutionary feature in the coming development of flight. It is also the problem which causes the most confusion as expressed in the question: where and when do we leave the gravitational field of the earth? The answer is - Nowhere and Never.

It is true that the force of gravity decreases with the inverse square of the distance from the earth's center. At a height of 4,000 miles above the earth's surface, or twice the earth's radius from the earth's center, the force of gravity is only 1/4th that on the ground; at 8,000 miles it is only 1/9th, and so on. At a distance of 36,000 miles it is reduced to a mere 1/100th. But all this could only be valid for a supported body - one lying, for example, on a tower 4,000, 8,000 or 36,000 miles above one of the earth's poles, if such a thing were conceivable. Only a suppported body exerts weight.

With a vehicle in flight, however, the situation is quite different. Here weightlessness is produced by the motion of the vehicle itself when the gravitational force of the earth is counteracted or balanced by another force, namely, the centrifugal force. The simplest case is the free fall. Other examples in flight are found in all such curves that follow Keplerian trajectories. In these maneuvers the center of the earth is the focus or one of the foci of the curve. In all these cases weightlessness is produced by motion; it is, therefore, a kinetic phenomenon and not a question of topographical location above the earth's surface.

Now, although weightlessness in flight has nothing directly to do with the distance from the earth, indirectly, it depends upon the distance with regard to its duration. The factor that sets the limits for the duration of the gravity free state near the earth's surface, is the resistance or drag by the air, which depends upon the density of the atmosphere and the speed of the craft.

When we make a so-called parabolic flight maneuver in a jet, which can be done for half a minute or so, the plane actually flys through a very small portion of an ellipse, the vertex of the apogee. The speed at the apogee is smallest of the whole elliptic trajectory and the resistance of the air is therefore negligible. The same is true for a rocket zooming for 3 to 4 minutes in a narrow elliptic orbit through the upper atmosphere. The resistance of the air becomes more important in circular or nearly circular orbits. In these cases very high speeds around 18,000 mph are required to balance the Earth gravitational pull. The air resistance in the denser regions of the atmosphere would scarcely permit such speeds. At about 120 miles, however, as already mentioned, the density of the air is too low to produce any resistance or drag at any speed, and also any mechanical support. At this altitude and above, weightlessness can be attained for a considerable or any length of time. It is the region, where the hunting ground for artificial satellites begins.

But it is important to note that we must reckon - in present day flight maneuvers in jet planes - with weightlessness for about 40 seconds. Hypersonic space equivalent flights of the immediate future will involve durations of 20 minutes. This makes the study of weightlessness an urgent topic in medicine. There are two main medical questions involved:

1) What is the effect of weightlessness upon the pilot's orientation in space and upon his ability to control the craft?

2) How does weightlessness affect the general well being?

We have several sense organs, or specific nerve endings that serve as gravi-receptors, such as the centrally located otolith organ, and the receptors of the pressure sense distributed peripherally over the entire skin (about 20 per cm^2); specific nerve endings in the muscles especially in the anti-gravity muscles of the limbs, the so-called muscle spindles and finally, specific nerve endings in the connective tissue, the Pacinian corpuscles. They all belong to the category of mechano-receptors; these receptors have an <u>exteroceptive function</u> insofar as they react to external forces and inform us about the outer world. One such external force is the gravitational pull of the Earth. They also have an enteroceptive or a <u>proprioceptive function</u> 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 movements of the whole body as wall as of its parts.

In the gravity free state the exteroceptive or the gravireceptive function of the mechano-receptors is eliminated; the proprioreceptive function, however, is not. For this reason, a man making a high dive from a diving board is able to perform a variety of acrobatic jumps quite skillfully, although he is in a gravity-free state throughout the dive. In a gravity-free state the absent gravireceptive (exteroceptive) function of the mechano-receptors must be substituted by the exteroceptive sensory organ par excellence; the eye. When in the gravity free state, the eyes will be the only sense organ that informs the occupants of their position in space.

Concerning the precision of the movement of our limbs in controlling the craft, this can be said. A great number of experiments have been carried out recently by Major David G. Simons at Holloman Air Force Base, New Mexico, and by Dr. S. J. Gerathewohl in Randolph Air Force Base, Texas, during parabolic flight maneuvers in jets. The subject had to perform certain aiming tests during the state of weightlessness. The result was that most of the men learned very quickly to cope with this situation.

Some of the gravireceptors, namely, the otolith organ and those found in the abdomen have strong reflex connections with the autonomic nervous system, which controls circulation, motion of stomach and intestines, etc. During abnormal motion conditions, as on a ship during rough weather, these reflex connections manifest themselves in the form of nausea and motion sickness. The opinion has frequently been expressed that we might expect similar disturbances in space flight. However, during the state of weightlessness such abnormal rhythmic excitations do not occur; instead, the gravireceptors after a short transition period, reach a new equilibrium.

Dr. J. P. Henry, et al, on their recordings on monkeys in rockets during a 3 minute period of weightlessness found no evidence of a significant disturbance of the cardio-vascular and respiratory system. Observations on man during parabolic flights in jets, made by Dr. E. R. Ballinger in Wright Field, by Major David G. Simons in Holloman and Dr. S. J. Gerathewohl at Randolph AFB, Texas, do not indicate as a rule a general disturbance of the autonomic nervous system. In a great number of parabolic flights carried out during the past months, Dr. Gerathewohl found that about 25 percent were susceptible and showed signs of nausea, 25 percent were indifferent, and the others - the majority - found it even pleasant and enjoyed it.

The whole problem boils down to the question of the possibility of adaptation to the state of weightlessness. And an adaptation seems to be in the realm of possibility or even probability.

A final solution can only be found as soon as we are able to produce the state of weightlessness for 20 minutes or even hours or days. For this latter we will need a manned artificial satellite.

The question of tolerance of weightlessness is an important problem for the engineer. If the crew cannot tolerate weightlessness, then the engineer must provide for artificial gravitation by rotating the vehicle, which of course poses additional technical difficulties.

These are only some of the medical problems involved in space flight, centered mainly around human engineering of the space cabin and the state of weightlessness.

Space Medicine research is still in its beginning and it is understandable that many problems are still unsolved.

Nevertheless, after 7 years of intensive theoretical and experimental studies at various places, we can make the cautious statement, that all the medical problems involved in space operations seem to be not insurmountable, unless there are still factors in space completely unknown to us - which, however, is unlikely.

The human factor is probably not an absolute limiting factor - it is a modifying factor. This is encouraging for all of us working on this grand project of our Century.

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