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MEDICAL PROBLEMS OF SPACE OPERATIONS*

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Medical practice, in its earliest beginnings, was that of general medicine, treating illness and disease as an affliction of the body as a whole. As medical knowledge progressed, skills in more limited fields were developed, and various medical specialties were born, so that now there are many specialties - some based upon methods of treatment such as internal medicine, radiology, and surgery; others based upon anatomical structures such as cardiology, gynecology, and urology; and still others related to a specific occupation or environment, such as industrial medicine and tropical medicine. One of the most important specialties under environmental medicine is that of aviation medicine, which had its beginning about forty years ago and is now developed to a high degree. In February 1953, aviation medicine was established as a separate specialty under the American Board of Preventive Medicine.

Even before this formal recognition, an extension of this field had already begun. Because of the rapid progress in aeronautics and in rocket propulsion by 1949,

*See last page for explanation

Brigadier General Harry G. Armstrong, as Commandant of the School of Aviation Medicine, established the Department of Space Medicine. This new area in Medicine deals with the study of human factors involved in manned flight through the "space-equivalent" portion of the atmosphere, and in "free space." Medical research has played an important part in the development of aviation, and will continue to do so, to an even greater degree, in preparing man for the coming of space flight.

SLIDE 1 (Family tree of rocketry)

This rapid development of flight, which has carried us beyond the brink of space, has necessitated a revision of our concept of the stages of manned flight, especially with regard to the present and future phases. Such a revision is illustrated in this slidd---

SLIDE 2 (Present and future stages of human flight)

Many of the problems involved in this classification are extensions of problems already encountered in present-day operations. These include acceleration, deceleration, oxygen supply and pressurization; but, in addition there will be many new problems not heretofore considered to any great degree in manned flight. These are [include] climatization of a sealed cabin, carbon dioxide control, protection from meteors [ultraviolet], solar and cosmic radiation, new visual problems, [and] physiological and psychological effects of weightlessness, and waste disposal.

In order to clarify our thoughts on these matters, let us return to the terms "Space" and "Space-equivalence", and define them. SPACE may be defined as that area wherein there is an absence of the atmospheric medium to which we are accustomed and upon which we are dependent for its life-sustaining characteristics. The physical limit of the atmosphere has been designated as being 600 miles from the earth. Beyond this is true "Space". However, insofar as man is concerned, space begins at a much lower level--even as low as 50,000 feet, or about ten miles! Why so? Because this is the lowest altitude at which occurs the cessation of one of the functional characteristics of the atmosphere. There are various altitudes between ten miles and six hundred miles at which other functions of the atmosphere cease. These are called the functional borders of the atmosphere.

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All these borders together have given rise to the concept of "space-equivalence" within the atmosphere--a concept evolved by Dr. Hubertus Strughold, Chief of our Department of Space Medicine. They are as follows:

1. The Oxygen Border occurs at about 50,000 feet, where the barometric pressure is so low that the partial pressure of oxygen in the ambient air is not high enough to cause normal gas exchange in the lungs.

2. <u>The pressure border</u> at 63,000 feet the still lower barometric pressure no longer is able to keep body fluids in the liquid state, and results in the so-called boiling of the blood. A new term - EBULLISM - has been coined for this condition. With the continually lowering barometric pressure as the altitude increases, it becomes necessary to provide more than a mere pressurized cabin as we now have. The cabin must be pressurized from within, at a constant pressure, [and] must be completely sealed and not dependent, in any way upon the outside environment. The cabin must be sealed, above 70,000-80,000 feet, for the following reasons:

a. <u>Technical reasons</u>: at 80,000 feet the air density is only 1/30th of the air density at sea level. To compress this air to acceptable pressure levels would require equipment which would be prohibitive from the standpoint of size and weight.

b. <u>Thermodynamic reasons</u>: were it technically feasible to compress the air at these high altitudes, such compression would elevate the temperature of the cabin air well beyond human tolerance.

c. <u>Toxicological reasons</u>: at 65,000 to 80,000 feet the air is rich in ozone. If this air were compressed to a tolerable pressure, the high ozone concentration would be toxic to humans, and destructive to equipment, since ozone is very active chemically.

d. In travel beyond the atmosphere, the ship will pass through the first 80,000 feet of the air envelope with such speed that there will be very little time for the outside air to be used for cabin pressurization.

For these reasons, one can readily see that a completely sealed cabin will be absolutely necessary in all forms of space operations.

In addition, there is one other important reason for a sealed cabin although it has nothing to do with space operations. In flying through areas of radioactivity in any type of aircraft, even helicopters, this is the only kind of cabin which will give complete protection to the occupants of the aircraft. All cabins which depend upon ambient air for pressurization would be contaminated immediately upon flying into the area.

These two borders are physiological functional borders.

Under the heading of physical borders there can also be included the protective functions of the atmosphere. In addition to the life-sustaining properties, the atmosphere also has as protective function for life on the earth. Let us consider some of these extraterrestrial factors found within the atmosphere, and <u>from</u> which we are protected by the atmosphere, itself. These will be important to us in future space flight and travel.

The air envelope affords us very important protection from such highly dangerous entities as cosmic rays, solar radiation and meteors. At 120,000 feet, cosmic rays begin to collide with the air molecules causing a shower of secondary radiation as illustrated in the next slide----

SLIDE 4

This process is repeated, perhaps many times before the rays reach us on the ground. Without the protection of the air, we would be under a continuous bombardment from these potentially harmful rays.

At 140,000 feet the ultraviolet of solar radiation begins to react chemically with the oxygen of the air, producing ozone. Thus, we are protected from excessive ultraviolet radiation. The maximum concentration of ozone is at 65,000-80,000 feet. Without the air to protect us we would be subjected to intense infrared radiation, too, which would have serious effects.

In the region of 400,000 feet or about seventy-five miles, begins the destruction of meteors by heat produced by the friction of the meteors when they collide with the air molecules. This destruction is usually completed well above the earth's surface. Without the air ocean surrounding the earth, meteors would be raining down upon us constantly.

In the thinning atmosphere above 400,000 feet the mean molecular pathway of the air molecules becomes greater than the wave length of audible sound, and therefore sound waves will no longer be transmitted. The higher frequencies will disappear first, followed by lower and lower frequencies. This results in the absolute silence of space.

This same thinning of the atmosphere eliminates its capacity to scatter visible light, and the sky becomes completely black, with the stars and the sun visible at the same time.

The last physical functional border of the atmosphere lies at 120 miles. Above this point a craft moving at any speed ceases to obtain "lift" from the air and there is no longer friction heat and heat transfer to the interior of the vehicle. The loss of these functions is due, again, to the reduction of air density.

Slide 4

As you can see from these facts the conditions of space are encountered, not all at once, but in a stepwise fashion, beginning as low as 50,000 feet, and ending at 120 miles. This is the area of partial space equivalence. Between 120 miles and 600 miles, although still within the physical limits of the atmosphere, lies the area of total space-equivalence.

What are the medical problems which will be encountered in the evolution of space flight? Rocket-powered planes have already flown above the estimated limit of 80,000 feet for mere pressurized cabins, but for only 2 or 3 minutes. Manned balloons have risen to the same altitudes for longer periods of time, but these gondolas were sealed. ~~Two~~ Three-stage rockets have now reached a height of ~~250~~ 600 miles, well beyond a minimum orbit for satellites. How long will it be before a rocket ship is built, with a sealed cabin, to accommodate human occupants? Will man be able to withstand the stresses of the flight and survive? We must have the answers to these questions before that time comes, and come it shall, because the pioneering nature of man will not be held to this earth!

Let us consider, now, the factors involved in a typical rocket flight, in the order that they will be encountered by the crew.

The first factor is noise and vibration during takeoff, and at other times when the motors are functioning. This will be a problem because of the pitch and intensity of the sounds. The duration of these sounds will be for only a short time, however, and an acceptable protection can be provided. Once the craft is beyond the atmosphere and after motor cutoff, the silence of space will prevail.

Naturally, inside the cabin there will be the noises caused by equipment, radio, and conversation among the crew members.

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The <u>second factor</u> will be the acceleration force produced at takeoff. This force, expressed in G's, will depend upon the type of fuel used in the rocket motors. Liquid fuels, at present, produce accelerations of 5 to 8 G's for about one and one-half [to 2 1/2] minutes. Solid propellants, on the other hand, produce more severe accelerations - up to about 15 G's - for several seconds. Eight to 10 G's is considered the upper limit of tolerance in the sitting position for periods of several ~~minutes~~ [seconds]. These forces are made more acceptable if the ~~crew~~ [man] is in a contour chair position with the long axis of the body perpendicular to the direction of acceleration. Much research has been done in this field in large human centrifuges and on rocket track facilities by both the Navy and the Air Force at their respective research centers.

The climatization of this sealed cabin will be the next problem under consideration. This involves oxygen supply, absorption of the carbon dioxide produced by the occupants, humidity, odor, and temperature control, and regulation of the barometric pressure. Under normal activity, one man will use approximately .7 kg [or about 1 1/2 lbs] of oxygen per day. Oxygen supply will not be a problem on flights of short duration, because sufficient amount can be carried in high-pressure containers in the gaseous or liquid state. However, when the era of the manned satellite and space travel does arrive, an oxygen-carbon dioxide exchange system may be necessary. Such a system is photosynthesis in green plants. Plants, in the presence of sufficient light, absorb carbon dioxide from the air and give off oxygen to the air. Basic research in this area is now being carried out here at the University of Texas by Dr. Jack Myers. So far, Dr. Myers has found that five pounds of the common alga Chlorella pyrenoidosa is sufficient to balance the respiratory cycle of one man. This is not a practical method at present, but it may be at some future time. Several research groups in this country and in Japan, have been working for a number of years on the utilization of such plant life as food supplements. They have found that some algae contain most of the essential protein requirements and some of the vitamins necessary in our diet.

The cabin will be sealed at ground level at an altitude equivalent to about 18,000 feet. Ground level pressure would be more difficult to maintain, because of the increased leak potential as the craft approaches space, and would require greater structural weight, and size of pressurization equipment.

Temperature, humidity, and odor control can be maintained by the use of modified air-conditioning systems and heating elements. Power requirements for these items may be considerable, but when solar power becomes available in space craft, the power source may be unlimited. The chief factors, then, would be the weight and size of the conversion equipment. It is possible that solar energy equipment can be used for all power requirements on the craft, such as the light source for the algae exchange system, compressors, motors, and so on.

Odor filters or oxidation devices for the destruction of odor particles, can be incorporated into the air conditioning system. Water vapor would be condensed from the air in the cabin by this unit, purified, and returned to storage tanks for use over and over again. Theoretically, there would be no loss of moisture from such a sealed system.

Recently, my co-worker Dr. Roth and I conducted an experimentxx in our Space Cabin Simulator in which a volunteer volunteer subject was sealed in the chamber for 24 hours, his atmosphere regulated automatically with regard to oxygen, and carbon dioxide.

SLIDE 6

SLIDE 7 Cartoon and 8 9 ~~10~~ (Cabin).

One of the most pressing temperature problem already encountered in the latest research planes, is that of friction heating and heat transfer. At high supersonic speeds, at altitudes up to 120 miles, friction heat is produced by the movement of the vehicle through the air molecules. This heat can elevate skin temperatures of the craft to 700°F or more, and poses the additional problem of preventing transfer~~ence~~ of this heat to the interior of the cabin.

Heating is not so pronounced on takeoff and in movement through the atmosphere into Space, but will be quite severe on re-entry into the atmosphere from Space at hypersonic speeds. A few years ago, the sound barrier seemed to be an insurmountable problem, but it has been conquered and the next one, the heat barrier, is now being attacked. This is thought to be encountered at speeds of more than Mach 3 ~~or more~~, with regard to partial space-equivalent flight. In the area of 120 miles, friction heating becomes a lesser ~~of a~~ problem and solar heating becomes a greater ~~more of a~~ problem, because the protection of the atmosphere is lost.

Visual perception in Space will be quite different. As previously mentioned, the sky will be black. The simultaneous perception of the sun, the stars and the Earth in a black sky may give one a feeling of disorientation.

At least, some confusion may exist until adaptation to these visual characteristics occurs. The eye will be exposed, in looking toward the sun, to the full intensity of solar radiation, without the protective property of our atmosphere. Thus, one must use a protective glass with very high absorptive properties in order to prevent retinal damage.

Now - to the most completely different phenomenon of space flight--that of weightlessness. Weightlessness is characterized by the absence of the usual gravitational force which holds us to the earth. One is [the] subnormal in weight, or weightless, for only a moment when an express elevator begins its descent. One is also weightless for a moment in passing the crest of a rise during a ride on a roller coaster. You have all experienced this sensation. At first the feeling is more or less pleasant, but how would one feel if this state were to continue for an indefinite period of time? Could one adapt to it, or would one become disoriented, nauseated, and unable to function properly? At present, we have only partial answers to these questions. The chief reason for the paucity of information in this area, is the difficulty in maintaining a gravity-free state for a sufficient length of time, for the subject's reactions to be evaluated.

We are currently studying the effects of gravity-free states on test subjects while flying a curve in the shape of a parabola, in an F-94 jet-interceptor, [aircraft]. The gravity-free state can be maintained for a period of 30-40 seconds in these planes. This is a relatively short time and not too much information can be obtained as yet. However, test subjects fall into three general groups - those who find zero-gravity unpleasant but not intolerable (25 percent), those who find it quite pleasant and enjoy it (50 percent), and those who become quite ill and disoriented (25 percent). Three factors are most important in producing these reactions - visual orientation, the information received by the brain from the gravireceptors or proprioceptive end-organs, and the effect upon the vestibular mechanism of the ear. The part played by each of these factors varies considerably in different individuals.

Longer periods of the gravity-free state can be obtained during a rocket flight. Monkeys and mice have been weightless for about two and a half minutes. As observed by the motion picture camera, the mice seemed to experience some disorientation, except one mouse whose vestibular mechanism of the ear had been destroyed. This mouse had little or no disorientation, having adjusted himself to the situation some time before when that part of his anatomy became non-functional. Now, we must determine whether disorientation is the result of weightlessness in itself, or the change from multi-gravity to zero-gravity and back again. I, myself, am of the opinion that the change from one state to the other contributes mostly to such a reaction [disorientation]. At least, I have drawn this conclusion from my own reactions during such flights. The final answer to this question will have to wait until longer periods of weightlessness can be obtained, either during longer rocket flights or during satellite flight.

MOVIES - (1) Mercury; (2) Mice.

As you know, all life processes occur in cycles or rhythms. The most significant of these is the physiological day-night cycle, which is characterized by rhythmic changes in bodily processes such as respiration, digestion, circulation and cellular metabolism. These changes are closely related to the physical manifestations of day and night caused by the rotation of the earth. All of you ~~You all~~ know of the adjustment ~~which~~ one must make, in changing from a day to a night shift in a hospital, in a factory ~~factories~~, or on board ship, or ~~and~~ [~~to a lesser degree~~,] even the change from one time zone to another. ~~adjacent one~~. The problem of adjustment is just as acute in travel by fast plane across large areas of the globe. In some instances, the adjustment difference may be as much as twelve hours. Thus, after such a journey, an individual may arrive in time for an important conference in the afternoon, when his physiological ~~processes~~ rhythym indicates that it is time for sleep and not for alert mental activity. The period required for natural adjustment in such cases may be as long as a week for some individuals. Others make a very rapid adjustment. Dr. Kleitmann, of the University of Chicago, in his research on this subject, found that the body can adapt itself, within certain limitations, to ~~time changes of this nature.~~ changes in the day-night cycle.

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He and his associates remained for two months in Mammouth Cave, in Kentucky, ~~without seeing the light of day.~~ During this time, their cycle of work or activity, and rest, recreation and sleep, was varied from less than 16 hours to more than 32 hours. They found that the cyclic rhythm can be maintained in periods as short as 18 hours and as long

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as 28 hours without significant alteration. Beyond these limits the body will re-establish a rhythm corresponding to that of a more or less normal day. This information becomes extremely important in planning for the crew of a manned satellite. Will it be necessary to plan for three crews ~~for a 24 hour period,~~ working in 8-hour shifts or can two crews operate efficiently on ~~an~~ a 2-shift 18 hour day? The difference in weight alone would be a significant factor.

The physical day-night period in a satellite orbit would be quite different from that on the earth. For instance, Wehrner von Braun, noted German rocket scientist, now in this country, has proposed a manned satellite

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circling the earth in an orbit at 1,075 miles. The time required for one revolution of the earth would be approximately two hours at a speed of almost 16,000 m.p.h. Twelve times in 24 hours, the satellite would pass through day and night. The night would occur during the movement of the vehicle through the ~~penumbra, or~~ shadow of the earth, ~~The "night" of the satellite orbit, then,~~ and would be only about 40-~~50~~ minutes in duration. This is assuming that the satellite is travelling around the earth in the same plane as the sun's rays. If the satellite were to circle in a plane ~~perpendicular~~ at right angles to the sun's rays, there would be no night at all. Therefore, it will become necessary to create an artificial day-night cycle which would correspond rather closely to that of our metabolic clock, if satellite operations are to be efficiently maintained.

SLIDE ____

Proposed Research in the IGY Satellite Program is to include eight experiments with the launching of the first man made moon. These will include:

1. Density of the outer atmosphere
2. Composition of the earth's crust
3. Geodetic determinations--oblateness of the earth
4. Temperature within the satellite and on its surface
5. Pressure--shell will be airtight with an inert gas inside. Gauges will check on leakages, in connection with meteoritic effects
6. Meteoritic impacts
7. Ultra-violet radiations--will measure the extreme radiation, in the Lyman-alpha region. Observations can be made on a long-term basis and thereby can determine the influence of solar flares on its emission from the sun. Also will be possible to make simultaneous observations from other directions. By correlating intensities observed directly from the sun with those observed at an angle, it should be possible to estimate the average density in space of hydrogen atoms and ions.
8. Cosmic rays - can make direct studies of the primaries. Orbit will be inclined 40 degrees from the equator. Launching-E. coast Florida.

All but two of these experiments will have a direct bearing in one manner or another, on the future of space flight.

These, then, are the problems for us in the field of Space Medicine: acceleration factors, effects of noise and vibration, climatization of the sealed cabin, visual perception in Space, effects of weightlessness, cosmic rays and ultraviolet radiation, regulation of the day-night cycle, and last, but certainly not least, the unique psychological stresses which will be associated with the Conquest of Space!

The mere listing of some of the stresses which come to mind most readily in this category, presents an impressive array of psychological problems to be solved. Some of these are:

1. Responses of different personality types to the various stress situations to be encountered in space operations.

2. The determination of the best combination of personality types to be included in the same crew.

3. Effects of noise and vibration on work capacities and on emotional tolerances.

4. Effects of high temperature and humidity, and very low temperature, and the sudden change from one to the other, and work capacities under such conditions.

5. Latent claustrophobic tendencies and the means of detecting or predicting their presence in potential space crews.

In line with this vein of thought I would like to show you what the space cadet or space pilot of 1977 looks like. Here he is:

In 1977, this lad will be 26 years of age - the near-optimum age for the fully trained space pilot. It will require that much time to complete the training program already outlined. Those of you who have sons of this approximate age may receive a jolt when you realize that this is the age-group which will be involved in routine space operations which to us today are nebulous dreams of the somewhat distant future.

In the past 12-15 years engineering progress in this field has been almost exponential, particularly in the area of propulsion. Should progress continue in proportion to these past years, my estimates may be much too conservative.

6. Psychological aspects of Visual orientation in space.

7. Results of changes in the diurnal cycle. Selection on the basis of like adaptability characteristics.

8. Effects of the realization that one is "alone in space" combined with the above factors.

9. Stresses which will be associated with the landing of a space craft, especially on another celestial body, and the factors associated with a take-off from such a body.

[10. Effects of possible loss of radio contact with the earth or with a sister ship.]

11. Psychological effects of weightlessness.

The selection of space crews will be the most complex task of this nature yet presented to Air Force Psychologists and psychiatrists. The first crews will most certainly be chosen from volunteers among the pool of highly trained jet and rocket plane test pilots, who are accustomed to flying new and untried experimental craft. These men, [as you know,] are all highly motivated individuals who are endowed with a peculiar combination of ~~adventurousness,~~ caution + daring, ~~caution and conservativeness~~ in their flying. They are the men who are able to put all thoughts, other than those of the task at hand, from their minds. These attributes were not born in them, but rather were developed through the long years of their flying experience, as a result of the handling of emergencies, and other situations which required accurate, split-second decisions. They are the men who learned early in the game that the hot~~-rock~~ pilot may ~~very~~ well be the dead pilot, and who have survived any foolhardy tendencies they may have had as neophytes. No man can be all this unless he possesses the inner equanamity which is found in the mature, emotionally well-adjusted person. These men will have to be their own instructors, and will form the nucleus of the pool of instructors who will train future pilots. They will also have to be well-versed in the physiological and medical problems of space flight.

The selection and training of crews who will operate in the more distant future, should begin now, at the early college level. It should be determined via questionnaires + aptitude tests, who is the most interested in space flight sciences, and from this group selections for space crews can be made on the basis of physical fitness, the ability to withstand special stresses, maturity of emotional development, a preference for teamwork, exceptional learning capacity, and special aptitudes in the sciences necessary as a background for space flight. A good sense of humor would also be an excellent quality to possess. No extraordinary degree of physical strength seems indicated at the present time. Special sense characteristics may be much more important.

Following the selection of these candidates, their academic training should be directed toward an engineering degree with emphasis on mathematics, electronics, nuclear chemistry and physics, astronomy, and related subjects. During this phase of training, the candidates should also undergo testing for their ability to withstand ~~special~~ certain physical stresses, and at the same time participate in a carefully supervised physical fitness program. After graduation, flying training can begin and progress to include advanced simulator training and test piloting of experimental craft, before becoming a full-fledged space pilot. This phase could include also, complete instruction in the medical problems involved.

It ~~may be~~ appears now that it will be advisable for the ~~candidate~~ space cadet to assist in the design of his spaceship, so that he can "grow up" with the ship. ~~By~~ In so doing ~~this~~ he will have a complete knowledge of its structure, and of the function of each part. Thus, he will be better equipped to cope with emergencies that might arise. Early crewmen ~~may~~ will be cross-trained in all positions aboard, and are likely to be the most "multi-~~headed~~ trained personnel monsters" in existence.

It is evident that human factors interests and research must keep abreast or ahead of engineering progress, or total development will lag.

[I have given you] This has been only a brief resume of the problems and the challenges which confront us in Space Medicine, but I hope that I have contributed to a better understanding of the areas involved in Space Operations, which are in progress, even now.

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