Aero Medical Problems of Space Travel

Panel Meeting, School of Aviation Medicine

General Harry Armstrong, *Chairman*, Dr. Heinz Haber and Dr. Hubertus Strughold

General Harry Armstrong

THE TOPIC for the panel is "Aeromedical Problems of Space Travel." Space is defined as:

> "That which is characterized by extension in all direction, boundlessness, and indefinite divisibility; that in which all physical things are ordered and related at one time; the subject of determinations of position and direction. According to this, space is boundless, but not infinite, in extent, and a ray of light traveling a sufficiently long time, estimated by Einstein as 500 billion years, would return to its starting point."

I would like to say a word about the selection of the subject for this panel discussion. It was agreed upon by a representative of the National Research Council, the director of the Aero Medical Research Laboratory at Wright Field, a representative of the Air Surgeon's Office, and representatives of the staff of the School of Aviation Medicine. We sought a topic which would be timely, of general interest, and one which would lend itself to discussion by individuals qualified in the different fields of medicine and the basic medical sciences. During our deliberations, I happened to mention that six months previously I had asked two of the scientists at the school to collect the data in the open literature on conditions in the atmosphere at variable distances from the earth's surface which would cause medical difficulties if one were exposed to those conditions. These two gentlemen had just about completed their review of the literature, and it was thought by all present that this topic would make a very timely and realistic problem for the panel.

At the present time, rockets are being sent to considerable heights, and it would be of great advantage if they could be manned. Thus, we are not contemplating something in the indefinite future but a problem which exists today and will increase in importance as time goes on.

Dr. Heinz Haber, astrophysicist of the School of Aviation Medicine, and Dr. Hubertus Strughold will outline very briefly, and in a rather general way, the problems they have uncovered from a review of the literature and will then discuss in some detail one or two specific points.

Dr. Heinz Haber

The greatest difficulty to be encountered in possible future interplanetary travel is the accumulation of an adequate energy supply which would enable a space ship to overcome the gravitational field of celestial bodies, particularly that of the earth. It is generally agreed that the necessary amount of energy can hardly be procured by chemical fuels, unless extremely unfavorable ratios between fuel amount and payload are tolerated. Yet, atomic energy, in its utilization for rocket-type power plants, has not reached the stage of perfection which would make it applicable for the solution of interplanetary travel.

The problems concerning the human factor of space travel will become most urgent if a suitable propulsion becomes available; it can easily be concluded that the physiological part will play a more decisive role in the initial stages of space travel than it did during the early stages of aviation. The future-minded aeromedical science, therefore, must concern itself with an anticipation of medical problems in relation to the possibility of interplanetary travel. Interplanetary travel will create a close relation between two sciences hitherto unaware of each other: astronomy and medicine. We cannot afford to postpone a close collaboration between medical men and astronomers any longer. Medicine may find it profitable to adopt a principle generally practiced in astronomy: astronomers have a habit of working for the future, for their grand-children. Due to this habit, we today are in possession of observations which were gathered by our forefathers and left for our benefit as very fine specimens of pure scientific curiosity. In the same way, future medical science will take advantage of efforts made at present. Obviously, it is worth our while to concern ourselves with this somewhat futuristic problem.

As has been pointed out before, chemical fuels do not quite fulfill the requirements for an energy supply of a space ship. So, this discussion will be based on the assumption that a source of energy is available which is about ten times as efficient as the best chemical fuels to date.

If we are going to shoot a body away from the earth, finally enabling it to travel through space, we have to accelerate it along a radius of the earth, for instance. If the propulsion is shut off too early, the body will fall back. In other words, a critical velocity must be attained which will enable the body to break free from the gravitational pull of the earth. A body having been accelerated to or beyond this critical speed will continue to rise even without propulsion, yet with decreasing velocity. However, before the velocity relative to the earth has become zero, the body will be subjected to the composite gravitational fields of the bodies of the solar system, particularly to that of the sun; then the body will describe a Keplerian orbit whose elements are determined by direction and size of its velocity and by the combined gravitational pull of the celestial bodies. No further propulsion is required in order to keep the body traveling.

This critical velocity mentioned before is called escape velocity. For our home planet the escape velocity amounts to 11.2 kilometers per second. This is a figure large enough to bother the engineer as much as the physiologist. Unfortunately, in the important and critical procedure of take-off and landing, the principles of rocket engineering run counter to the interest of the physiologist. The task of the physiologist is to protect the interplanetary navigator from harm, whereas the engineer regards economy of the energy consumption as the essence of his task. This divergence is due to the fact that the fuel consumption decreases decisively with increasing acceleration of the ship. It is for this reason that a successful attempt to overcome the earth's gravitational field can likely be accomplished only with an energy source more efficient than those available to date. Yet, research on the influence of gravitational forces on man indicates that one will be able to reckon with this difficulty as far as its physiological part is concerned. The physiologist will be interested to know how long man—in order to attain the escape velocity—must be subjected to accelerations higher than 1 g. Disregarding the friction of the air in the first phase of the take-off procedure, the correlation between the acceleration applied and the time required can easily be computed. Table I shows this correlation for some rates of acceleration computed for a launching from above the atmosphere.

TABLE I

Acceleration Physiologically Effective	Duration of Acceleration
3	9 min. 31 sec.
4	6 min. 21 sec.
5	4 min. 45 sec.
6	3 min. 48 sec.
7	3 min. 10 sec.
10	2 min. 6 sec.

This is the order of values the physiologist will have to deal with, provided the engineer does not limit the physiologist's choice any further.

As mentioned before, the space ship, once liberated from the earth's immediate gravitational field, will be carried further through space along a Keplerian orbit. The ship then must be considered as a celestial body, equal in rank to planets, moons, and comets. These bodies are in an ideal equilibrium between the gravitational forces exerted upon them by other bodies, chiefly the sun, and the forces owing to their proper inertia. This means, physically, that the component of all forces of gravitation and inertia is exactly zero, since the gravitation due to the ship's own little mass will be almost immeasurably small. It means physiologically that the ever-present stimulus of gravity is absent; this condition subjects man to a state unexperienced before. Only during a small fraction of time can this condition be realized within the earth's atmosphere—at the instant after a man has jumped from a diving board, for example, as long as friction of the air is small enough not to impede his body from falling freely at the exact rate of the law of free fall. Disregarding friction, the aforementioned ideal equilibrium exists during this small period of time.

As soon as a change of the ship's orbit becomes necessary, the rocket propulsion must be started again; in this case the ideal equilibrium will be disturbed, resulting in forces which are experienced as "gravity" by the navigators. Their orientation will be restored immediately, and they will sense the direction of the rocket exhaust as being "down."

Regarding these facts, the physiologist will be interested to know how long the interplanetary navigator must be subjected to the gravity-free state, in order to reach our moon and the neighbor planets, Mars and Venus.

A rather simple consideration will enable us to estimate the length of time required for a journey to neighboring celestial bodies. The speed of a space ship on a trip to the moon will be of the order of the home planet's parabolic velocity (11.2 km. per sec.); on the average, however, it will be somewhat lower, because, if circling the moon, the space ship must enter into the moon's range of influence. It will be possible for the ship to be caught by the moon's gravitational field, only

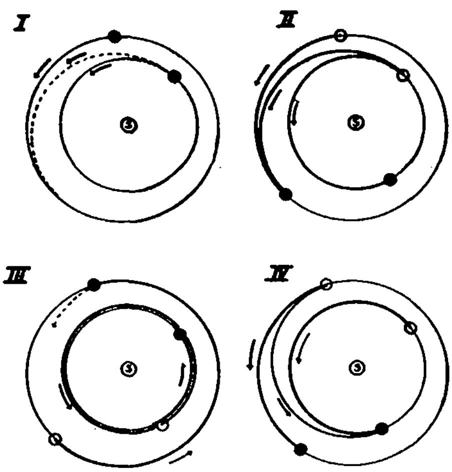

Fig. 1. A trip to Mars and back. (I) Position of planets (black circles) at beginning of trip (broken line shows orbit traveled by spaceship). (II) Position at moment of arrival on Mars (previous position shown by white circles). (III) Position at date of departure from Mars (Mars has completed the whole journey from the white to black circle and the earth has traveled around its whole orbit almost one and one-quarter times). (IV) Position at date of spaceship's arrival on earth. (Courtesy of the Viking Press: Rockets and Space Travel, by Willie Ley).

if the speed of the ship, relative to the center of the moon, is comparatively small. For example, to circle the moon at a distance of 100 km., the space ship must have a tangential velocity of 1.17 km./sec. relative to the moon's gravitational center. Accordingly, the ship's average speed will be between the limits of about 11 km./sec. and 1 km./sec. Its exact velocity will be determined by the characteristics of that orbit which results in the most economical energy consumption. Under these circumstances, the distance to the moon would be covered within a period of about twenty to forty hours. When traveling to the neighboring planets, Venus and Mars, the space ship must leave the earth-moon system. For reasons of fuel economy the ship must, as soon as possible, take a course similar to the orbit of a comet around the sun. The elements of this orbit should be such that the space ship is brought near to the target planet in such a manner that, on arrival, its speed as to direction and magnitude approximately equals that of the planet. Orbits of this kind are, in general, elliptical; their eccentricity is about 0.8 to 0.95. Figure 1 shows some examples of orbits which were calculated by Hohmann about thirty years ago. In the center of the figures we have the sun; the inner circle represents the orbit of the earth, the outer one that of Mars. The black dots on each orbit indicate the position of earth and Mars, respectively, at the moment when the space ship leaves the home planet. Once the gravitational field of the earth has been overcome, the space ship must be accelerated by a small amount. This additional acceleration relative to the sun will enable the ship to travel along the ellipse around the sun to meet Mars at the position II. For the travel back to earth, the energy available will be the determining factor. In case we have to save energy at any cost, we would have to wait more than a year in order to get another equally favorable position of the two planets, suitable for an economic orbit. The orbit which leads back to earth is shown by positions III and IV of Figure 1.

As to the lengths of time required to travel to the neighboring planets along such orbits, we can state the following: The ship will travel at velocities close to the order of the revolutionary velocities of planets around the sun at the distances of Venus, earth, and Mars from the sun. These velocities are: Venus, 35.7 km./sec.; earth, 30.5 km./sec., and Mars 25.5 km./sec. The speed of the space ship, therefore, will be around 30 km./sec. The lengths of the respective sections of the ship's orbit to Venus and Mars are about 100 and 200 million km., respectively. The traveling time computed therefrom amounts to about five and ten weeks, respectively, or, for a round trip, ten and twenty weeks.

These lengths of time become important to the physiologist, when considering a visit to any of the neighboring planets, especially since the periods must be spent in a state entirely free of gravity.

If sufficiently large quantities of fuel energy are available, this traveling time could be reduced considerably by continuous acceleration during the first half, and by corresponding deceleration during the second half, of the journey. This would have the further advantage that, during the whole trip we would always have some acceleration in the direction the ship's propelling force is acting (giving us a quasi-gravity of less than 1 g). With a steady acceleration of 0.1 g, for instance, the trip to Venus and Mars could be carried out in about five to six days. The space ship would in this instance attain a peak velocity of 200 to 250 km./sec. relative to the sun.

After the space ship has left the earth, it will be necessary to employ extremely accurate navigation in order to check constantly whether the ship is traveling along the preassigned orbit. Speaking astronomically, the elements of the ship's orbit must be under constant surveillance. The problem of navigation of a space ship has been discussed frequently in numerous publications. The navigation of a space ship is accomplished by taking planetary bearings relative to the background of the fixed stars. As long as the distance of the ship from earth is small, the earth's diameter, its angular distance from the moon, and their relative projections against the background of fixed stars, will permit navigation of sufficient accuracy. Yet, with the space ship at a point about halfway between earth and Mars, for instance, the accuracy required is very high. In view of the immense distances involved, we will have to deal with two main difficulties:

1. The residual rotation of the space ship. After leaving the terrestrial atmosphere, and after cutting off the driving rocket mechanism, the space ship will rotate about an axis which cannot be determined beforehand. The rotational period will also be unknown beforehand. Even if the rotation of the ship can be controlled by either lateral drives or a three-dimensional gyroscopic device, the space ship will always have slight shifts in rotary balance, since any movements of the occupants will affect the ship's rotatory period and axis. These slight oscillations, due to the unavoidable rotatory shifts, constitute considerable astronautic difficulties, since the accuracy of the sextant is inadequate. Bearings taken by means of transit instruments must be corrected with respect to the rotatory shifts, but, as mentioned

above, a technique for determining the degree and variations of such shifts has yet to be devised. Photographic methods and statistical evaluations of visual observations may solve this problem.

2. The problem of clock corrections. It will be difficult for the crew of the space ship to correct their timepieces with the accuracy necessary for a journey into cosmic space. Astronomical time measurements are impossible because for this purpose the position of the ship within the solar system must be known in advance. Observation of *objective* astronomical phenomena (eclipses of the earth, its moon and Jupiter's moons) will not help, since for these cosmic distances the finite velocity of light cannot be neglected. As long as time signals can be received from the earth, time corrections can be performed with sufficient accuracy because the diameter of the earth, as measured by the visual angle, or the angular distance between the earth and moon, will permit a satisfactorily accurate computation of respective distances from the earth. Thus we are able to take into account the time interval which elapses between transmission and the reception of the signals.

There is another technique which might possibly be of assistance in accomplishing space navigation. If a powerful light source were available on the space ship, the space ship could be observed by a terrestrial observatory. If the lamp were of 1,000,000 candle-power and had a signal duration of twenty minutes, the space ship could be observed by the most powerful telescopes to a distance of about three times that of the moon. This illustrates the immense power of modern astronomical instruments. Because it takes the ship about a day and a half to travel this distance of about 1,000,000 kilometers, it would be possible to photograph the light of the ship during the twenty minutes of the signal's duration. One observation could be made at the beginning of the night, a second at the end of the night, and a third at the beginning of the next night. Then, the position of the ship at three periods, necessary as a basis for calculation of the orbit of a celestial body, would be available. The elements of the ship's orbit then could be calculated in the calculating division of the observatory, where all facilities for an accurate and fast calculation would be available. The elements of the orbit, plus the necessary corrections could be transmitted to the ship which, at this time, would still be within the reach of modern transmission equipment.

The space ship traveling through space is exposed to radiation of various kinds. The solar radiation hits the ship's outer hull in its original form, i.e, undiminished by the filter effect of the atmosphere surrounding the earth. In this case we must consider the hull of the space ship as quasi-atmosphere, affording a protection similar to that which the terrestrial atmosphere gives to all life on earth. The hull should be able to absorb, reflect, or transform the sun's radiation. Fortunately, in order to anticipate the results, no major difficulties will be encountered; on the contrary, the solar radiation will be of great usefulness for maintaining the comfort level of temperature inside the ship without any heating devices. The extraterrestrial solar radiation differs from the radiation mixture which hits the earth's surface only in the non-visible ranges of infrared and ultraviolet radiation. Only the ultraviolet radiation, which normally is filtered to a large extent by the terrestrial atmosphere, has a harmful effect. This ultraviolet radiation easily can be either absorbed or reflected by metal, i.e., in our case, by the hull of the space ship. The windows of the space ship must likewise possess an adequate absorptive quality. This is highly important in view of the local solar eruptions which eventually radiate an extremely high rate of ultraviolet radiation. In the range of wave lengths between 1,500 and 2,000 Ångstroms, one can occasionally observe an intensification of the radiation by 10 to 100 times. This corresponds to a radiation increase in the field of eruption on the sun's surface by 1,000 to 10,000 times, since the area of these fields covers about one hundredth of that of the whole sun. The window structures of a space ship must cope with these values. Streams of corpuscles, such as the sun occasionally emits to give rise to the aurora borealis here on earth, are very rare and dispersed. Furthermore, the velocity of these particles is too low (1600 km./sec.) to produce any harmful effect.

As mentioned before, maintenance of a proper temperature level within the ship is of major importance. The laws of radiation, in connection with the knowledge of the respective spectral absorption coefficients of the hull's material, permit a fairly accurate calculation of the equilibrium temperature the ship will attain.

Whereas the various kinds of radiations prevailing in space hardly will be harmful to the passengers of a space ship, there is a hazard which must be anticipated seriously—the possible collisions of the space ship with meteorites. Numerous calculations as to this probability have been made. In view of the greatness of this hazard, we thought it necessary to study this problem in detail.

The space of the planetary system is interspersed with a large number of meteorites which, in relation to the space ship, travel at high speeds. According to their velocities and characteristics of their orbits, the meteorites are classified into two groups:

1. The system of the interstellar small bodies which traverse the spaces of the solar system in chiefly hyperbolic orbits. Their velocities near the earth range above 42 km./sec.

2. The swarms of meteorites pertaining to the solar system. Some of these have been proved to be relics of decomposed former comets. These swarms revolve around the sun in ellipses of varying eccentricity, and their velocities near the earth are less than 42 km./sec. There is a periodical occurrence of meteorite showers during certain periods of the calendar year. These showers occur whenever the earth, during its trip around the sun, intersects the orbit of such a meteorite swarm. The density of meteorites within the swarms pertaining to the solar system is much higher than that of the system of the interstellar small bodies, but fortunately, the solar swarms are composed of much smaller particles, most of them being fine dust-like particles. The average density of

meteorites in space has been determined by various astronomers. Determinations of this kind are difficult, and, for this reason, the figures arrived at by the different astronomers differ considerably. Taking the findings of Schalén, H. N. Russell, C. Hoffmeister, and F. Noelke, the average concentration of meteorites in space lies between the limits:

$$3 \times 10^{-24} \text{ per cm}^3 < N < 9 \times 10^{-22} \text{ per cm}^3$$

N is the number of meteorites. The results differ by the factor 300. Yet, these figures are valuable for a calculation of the probability of a collision. In calculating this probability, certain assumptions as to the size of the ship's cross-section must be made, whereas the speed of the meteorites is fairly well known. The result is as follows: Taking, for instance, the higher figure for the mean density of meteorites in space, a collision of the space ship with a meteorite must be anticipated within the period of about one month. These figures constitute a considerable hazard for the crew of the space ship. The high velocities of meteorites give them the power to puncture even thick steel plates. The collision with a meteorite of several hundred grams —which size, fortunately, is very rare —would, by resulting in instantaneous loss of the cabin air, be catastrophic.

The last part of this discussion will concern the conditions to be anticipated on the moon and on our neighbor planets, Venus and Mars. Compositions of atmospheres and prevailing temperature ranges will be the most important factors.

Starting with the moon, we have to state that it does not have any detectable traces of an atmosphere. All investigations apt to discover a lunar atmosphere have failed to do so. In addition to this, there is theoretical evidence that the moon, if it ever had an atmosphere, would have lost it within a short period of time. The moon's gravitational force—it being about 1/6 of the terrestrial value—cannot prevent the molecules of a gaseous atmosphere from dissipating into space. As a result of the absence of an atmosphere, the solar radiation hits the lunar surface unimpaired by any atmospheric absorption. For the same reason, the lunar surface does not have any mechanism for preventing the heat from being radiated during the night; the result is a pronounced drop in temperature. Taking the lengths of day and night on the moon—two weeks each—into consideration, the temperature of the lunar surface is subjected to strong variations. There are extreme temperatures of +135° C. at noon, and of —170° to —200° C. at night. In the depths of the craters sheltered by shadows from the direct sunlight, one may find places where the radiation of the heated lunar formations produces ground temperatures from 0° to 40° C. for limited periods of time. Yet, even if the difficulties resulting from the temperature hazards could be overcome, leaving the space ship on the moon with an air-conditioned protective suit would be hazardous. The freedom of movement would be limited in such a suit, especially due to the moon's small gravitation. The muscles and the equilibrium co-ordination of man are primarily adapted to the conditions prevailing on earth. Moreover, the surface of the moon presumably is covered with a more or less thick layer of finest dust, which is partly of meteoric origin and partly a product of weathering. Yet, weathering is hardly the right expression in view of the absence of a lunar atmosphere; for millions of years, a strong variation of temperature, with a change of more than 300° C. every two weeks, has been tearing and working at the rocks of the moon's surface, grinding them to dust. The debris has never been blown away by winds or washed away by water, since there is no atmosphere. This layer of dust constitutes a further impediment to walking even if we disregard the prevailing temperatures.

Venus, the inner neighbor of earth in the solar system, is the planet most similar to the earth. It has about the same size and mass as the earth; its gravitational field is 0.84 of the terrestrial value. The surface of Venus, however, is constantly covered by a thick layer of white clouds whose nature still is undisclosed. Weighing the physical similarity, one may expect almost earthlike conditions on Venus, as far as temperature and climate are concerned. Yet, this is not the case, as a number of successful investigations on the Venusian atmosphere, its composition and its temperature, have demonstrated. These investigations were carried out chiefly by Adel at the Lowell Observatory near Flagstaff, Arizona. Adel attempted a chemical analysis of the atmospheric gases of Venus. In the infrared part of the Venusian spectrum, characteristic absorptions were found which were compared to tests carried out in the laboratory. The results of these comparison studies established that the specific absorptions present in the Venusian spectrum are those due to carbon dioxide, which must be present there in considerable amounts. This was concluded from the fact that an absorption less than that observed in the Venusian atmosphere could be produced from a layer of pure CO_2 not less than a mile thick at a pressure of one atmosphere. Water vapor and oxygen have not yet been determined to be present in the Venusian atmosphere. The temperature of the Venus atmosphere—at least for those layers accessible, due to the radiation we can observe—has been determined by spectroscopic means. Again, the spectrum of carbon dioxide, which seems to be the primary atmospheric matter of Venus, was used. A method involving the relative intensity of the different rotational lines of the CO_2-band spectrum revealed temperatures of about 50° C. pertaining to these high atmospheric layers. The large quantities of free carbon dioxide must produce a powerful "greenhouse effect," with the result that the surface temperature of Venus will hardly be less than 150° C.

Mars, the outer neighbor of the earth in the solar system, seems to be, thus far, the only friendly body in the list of planets we can possibly reach. Figure 2 shows photographs taken of Mars at the Lick Observatory near San Jose in California. The two upper pictures are also shown as

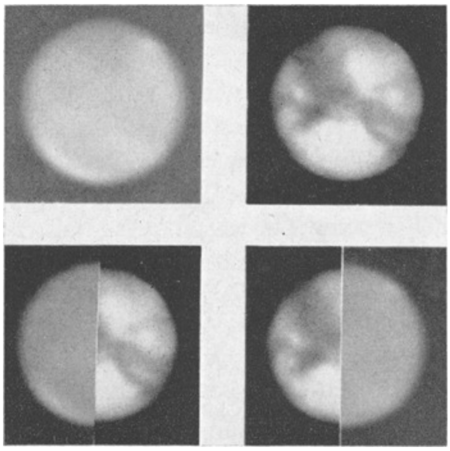

Fig. 2. Photographs of Mars by violet and red light, with halved images for comparison. (Courtesy of N. U. Mayall, University of California).

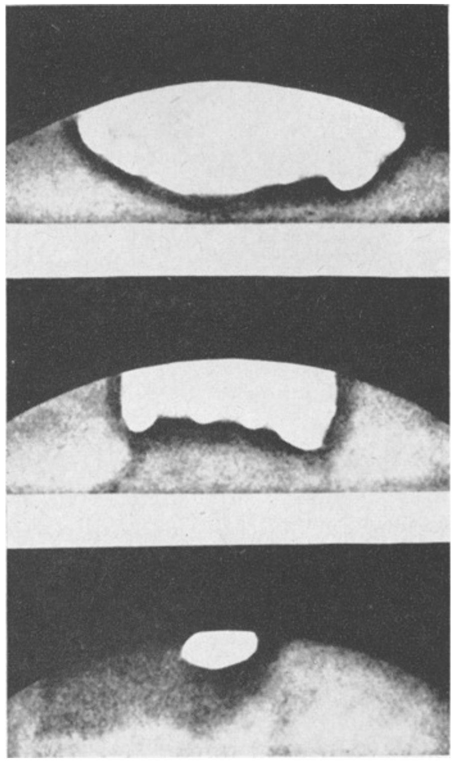

Fig. 3. Diminution of the southern polar cap of Mars, July to September, 1924. *(Above)* July 20, longitude 300°. *(Center)* August 25, longitude 5°. *(Below)* September 5, longitude 230°. (Courtesy of Springer-Verlae: Handbuches der Astrophysik, vol. 4, pp. 376 and 379).

halved images, for comparison of size. The larger one was taken with a violet filter, the smaller one with a red filter. The difference in size is due to the fact that blue rays, characterized by small wave-lengths of light, are scattered and reflected by the Martian atmosphere yielding a picture of Mars that includes parts of its atmosphere. The red rays, characterized by longer wave lengths of light, have the power to penetrate the atmosphere; they are reflected by the solid surface of Mars and yield a picture of the planet itself without the atmosphere. These pictures establish clearly the presence of a transparent atmosphere—more transparent for red light—similar to the characteristics of our own atmosphere. Even more so, another feature, familiar to man here on earth, is demonstrated by Mars, and has been observed for years. Figure 3 shows three pictures of Mars, taken with an interval of about one month between each. The period covers the Martian season of spring for the hemisphere in question. In the first picture, the polar area of Mars is covered by a distinct white cap which, during the period of roughly two months, recedes and almost vanishes. This observation was taken to be a seasonal melting process, though the exact nature of the "snow" remained unknown. Taking the results of former temperature determinations on Mars—0° to —100° C.—the white polar caps could consist either of ice or of solid carbon dioxide. Within the temperature range prevailing on Mars, carbon dioxide could freeze out of the atmosphere and settle down in the polar region. The increasing temperature during the spring season would cause the solid carbon dioxide to vaporize. A decision as to whether the polar caps consist of carbon dioxide or of ice was recently made possible. Both substances can be differentiated by their respective reflection coefficient in the infrared region of the Martian spectrum. By means of a special PbS photo-electric cell, this difference could be observed in the case of the Martian polar caps. It was determined that the polar caps consist of ice, or, rather, a thin layer of frost, since they melt away rather fast. We, therefore, can conclude that water vapor is present in the Martian atmosphere, possibly accounting also for thin clouds which have been observed on Mars occasionally. Search for the presence of oxygen has been unsuccessful to date; a definite decision as to the presence of oxygen on Mars can hardly be expected, since all observations to this effect necessarily must be made through our own atmosphere where oxygen is abundant. However, possible limits of the abundance of Martian oxygen can be established. Thus, we know that we have to expect less than 1/300 of the terrestrial amount of oxygen, if any. The Martian atmosphere probably is built up chiefly of nitrogen and the heavier rare gases, with traces of carbon dioxide, water vapor and possibly oxygen. During the latest opposition of Mars, the presence of lower forms of life was indicated as probable on Mars. By comparing the spectrum of the greenish spots on Mars, appearing occasionally during the Martian spring and summer season, with the spectrum of terrestrial plants here on earth, it was concluded that certain species of mosses and lichen-like plants exist on Mars.

Thus, a survey of the neighbor worlds of our earth reveals that Mars seems to be the sole celestial body in our neighborhood on which man can set foot without encountering too great difficulties.

Dr. Hubertus Strughold

Whereas the physical and astronomic study of space flight is based on the solid foundation of natural sciences, the physiological study seems to add new problems to the great mystery of life. Yet, modern physiology can make certain predictions that are well based on scientific facts as to physiological possibilities, limits, and support by physiological means. This is possible due to the scientific progress made and experiences undergone in aviation medicine and submarine medicine, especially during the last fifteen years.

The physiological problems of space flight arise on the whole from the following fact: Man on earth is exposed and adapted to certain terrestrial and extraterrestrial factors and conditions. The terrestrial factors are: the gravity of the earth; the tensions of the atmospheric gases, which incidentally depend also on gravity; the rotation of the earth; the revolution of the earth, et cetera. The extraterrestrial factors consist mainly of the solar rays, which supply the atmosphere with light and heat energy and determine its water balance. The combined actions of terrestrial and extraterrestrial forces constitute certain physical conditions to which man, animal, and plant are exposed and adapted.

If man is lifted from earth in a space ship, a shift occurs in the balance between terrestrial and extraterrestrial, or sidereal, energies and conditions to which he is accustomed. He moves away from the terrestrial environment, and, after leaving the protecting atmosphere, becomes exposed to a greater extent to solar and cosmic energies and strange conditions which exist on other celestial bodies. The terrestrial milieu is replaced by the interplanetary one, which is free of gravity and oxygen but rich in radiated energy and in meteorites. Or, it is possibly replaced by the milieu of the moon or of planets.

The problems which arise then in space medicine are briefly the following:

1. Tolerance of the conditions resulting from the absence of terrestrial factors and from the increase in radiated solar energies.

2. Artificial maintenance of quasi-terrestrial conditions in the space ship and protection from solar energies and meteorites.

3. Prospects of life and artificial means of sustaining life on other celestial bodies.

These three problems can be classified under the physiological milieu problems of space travel.

Another vast complex of physiological problems arises from the technical process of the travel. It is, therefore, inherently connected with the navigation of the space ship. Speed of the space ship and velocity of the mental processes involved in its control, latent time of perception and recognition, reaction time during take-off and landing, the so-called "dead distances" which are covered by the reaction time, time sense, and acceleration—these are the principal problems which are included in the complex of the physiological navigation problems of space flight. Gravity and acceleration represent the connecting link between these two large complexes.

A third complex of problems has more of a psychological nature, involving, as it does, the problems of psychic aptitude, fatigue, living in a confined room for a rather long time, et cetera. This complex may be designated as the psychological problems of space flight, which naturally are closely connected with the milieu problem and the navigation problem.

Due to the shortage of time, I am going to discuss only a few problems, particularly those that are related to my special field of work in physiology.

A comfortable physiological milieu requires adequate oxygen supply. In this connection I would like to discuss only the storage of a sufficient amount of oxygen in the space ship. We can assume that the oxygen consumption of the astronaut is very low. This would tend to minimize the whole problem, since under gravity-free conditions no work has to be performed to overcome gravity; we think that the metabolic rate would not significantly exceed that of basal metabolism. Unless exercise is indicated in the space ship to avoid muscle atrophy, the maximum amount of oxygen required might be around 500 liters per day per person. The oxygen problem can be further minimized by utilizing the upper limit of physiological tolerance of increased oxygen pressure. As we know, the minimum oxygen pressure required in the air is about 100 mm. of Hg. At a pressure lower than 100 mm., the individual succumbs to altitude sickness. Furthermore, through the experiments of Behnke, Clamann, and others, accomplished during the last ten years, we know that man can tolerate increased oxygen pressure as high as 425 mm. of Hg for a prolonged period of time without suffering any injuries. At pressures above this level, symptoms of oxygen poisoning will appear after several days' exposure.

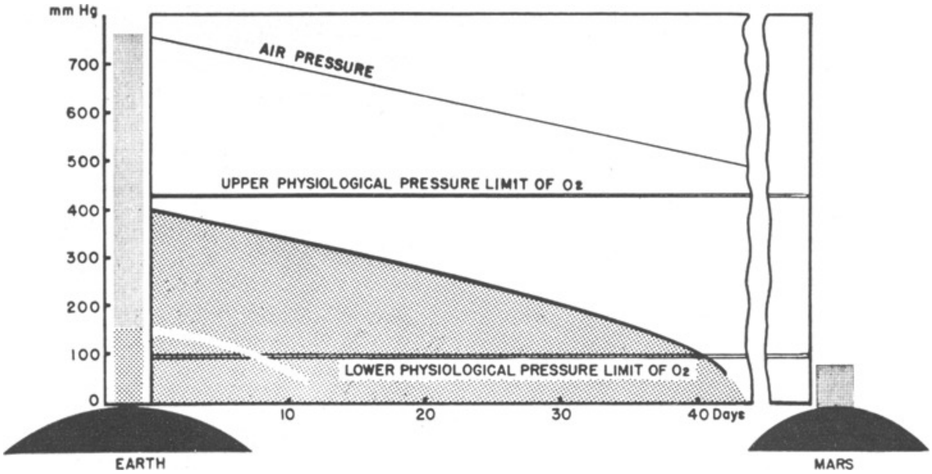

Fig. 4. Utilization of physiological tolerance of oxygen pressure on a trip to Mars.

As economy has to be practiced in regard to oxygen consumption in the space ship, it seems advisable to utilize this range of physiological tolerance of oxygen pressure. The advantages involved in this method are shown in Figure 4. The left column shows oxygen pressure and air pressure on the earth; the right side, the air pressure on Mars.* If 40 cubic meters of air were available to a person in a space ship, then the normal oxygen pressure of 160 mm. would be reduced by respiration at a rate similar to that shown by the lower curve. Within five to six days the lower physiological limit of oxygen pressure would be attained. However, if the pressure of oxygen were increased to levels indicated by the shaded area, for example, up to 400 mm., that is, close to the upper physiological oxygen limit, the lower physiological limit of oxygen pressure would be reached only after several weeks. Consequently, if we utilize a higher pressure of oxygen, we achieve considerable economic advantage. It is obvious that this method is also of great interest with regard to prolonged flights in the stratosphere and ionosphere. The only disadvantage would

*This value for the pressure is only tentative.

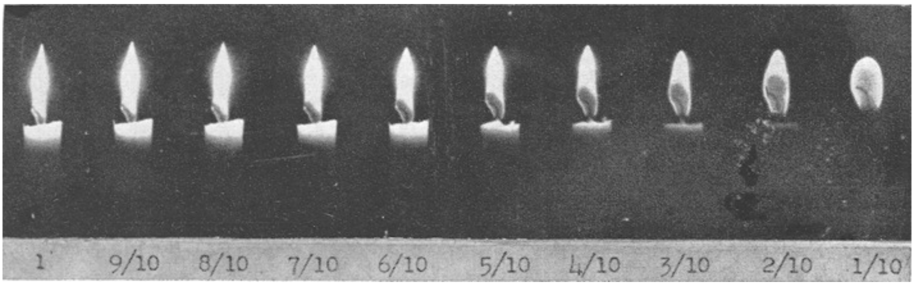

Fig. 5. Flames of a candle burning at different degrees of decreased atmospheric pressure. On the left is one atmosphere of pressure. The atmospheric pressure falls off to the right in the decrements of 1/10 so that the last candle is seen burning at 1/10 of an atmosphere.

be an increased danger of fire. A further advantage, however, is the fact that, due to the elimination of carbon dioxide by chemical agents or by freezing, the air pressure in the space ship is very gradually adapted to the air pressure of Mars, as it is shown in the upper curve. If we apply this method, all the oxygen that is carried in cylinders is reserved for use on the respective celestial body or possibly on the return trip to earth.

The planetary atmospheres have always been of special interest in regard to oxygen and prospects of life. (See "Life on Other Worlds" by H. Spencer, and "Atmospheres of the Earth and Planets," edited by G. P. Kuiper.)

If we study the planetary atmospheres from the physiological aspects, we must classify them with regard to the quantity and quality of the gases and as to the question of whether they are relatively or absolutely nonphysiological. Apart from temperatures, the atmospheres of Jupiter and Venus are absolutely nonphysiological with regard to their quality; the former contains methane and ammonia gases; the latter abounds in carbon dioxide, according to spectroscopic studies made at Mount Wilson and Lowell observatories. The atmosphere of Mars must be classified as qualitatively physiological but quantitatively nonphysiological. To alight on Mars, it might not be absolutely necessary to wear a pressure suit; the oxygen mask perhaps would be sufficient if the air pressure is above 150 mm. Hg. On Venus and Jupiter, man would have to be tightly sealed in a space suit against the penetration of noxious gases. As for the moon, it is impossible for man to set foot there without wearing a pressure suit, since this celestial body is not able to retain any atmosphere due to insufficient gravity.

A vital factor in living on our earth is the production of energy by oxidation through fire. Origin and maintenance of fire require a certain minimum pressure of oxygen. Figure 5 shows a series of pictures which demonstrates flames at various atmospheric pressures, reduced in each case by one-tenth of an atmosphere. Between one-tenth and one-fifteenth of an atmosphere—that means at an oxygen pressure of about 15 mm.—the candle light is extinguished. The oxygen pressure on Mars, for example, is probably not that high. The astronauts therefore, may find themselves unable to light a fire on Mars. If the atmosphere of Mars were to contain about 20 per cent oxygen, the picture of the flame would be approximately similar to that obtained on the earth at a height of 50,000 feet, and it would therefore, correspond to the flame shown in the last exposure in Figure 5. On Mars, a flame burning in pure oxygen would be weak and dim, but very extensive—as in Figure 6—corresponding to the low atmospheric pressure which is in part due to the low gravitation of Mars. The flame in this picture is burning in a low pressure chamber in pure oxygen. The pressure corresponds to that existing at an altitude of 15,000 meters (45.-000 feet) in pure oxygen, and that produces a flame that would be similar to one made on Mars in pure oxygen.

Dr. Haber discussed the probability of a collision of a space ship and a meteorite. What would be the physiological effect in case such a collision would actually occur? If a space ship were hit by a meteorite the size of a pea, the effect would be similar to that following the leakage of a pressure cabin aircraft in the stratosphere, although more violent. Within a fraction of a second the conditions of a "hard" vacuum would be attained. In addition to the effect of a superacute anoxia, the result would be a superacute gas edema of the tissues and subsequent destruction of the tissues. The skin, for instance, would form large blisters filled with oxygen, carbon dioxide, nitrogen, et cetera. One can observe such manifestations in rabbits that are exposed to explosive decompression up to 60,000 feet in low pressure chamber. In analogy to the term "horror e vacuo" which was coined in the Middle Ages when the investigations on air pressure were

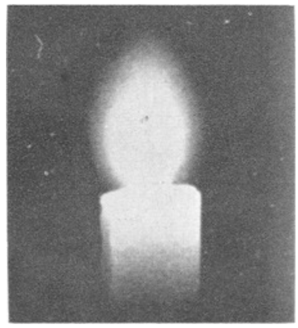

Fig. 6. Flame of a candle in a low pressure chamber at an air pressure corresponding to a height of 45,000 feet but in pure oxygen.

started, we might designate such effects as "gaseous edema e vacuo" or "epidermolysis e vacuo." These manifestations are, of course, only a violent form of aeroembolism. We would encounter the "horror e vacuo" also upon setting foot on the moon without an adequate pressure suit.

I have mentioned gravitation repeatedly. Generally speaking, gravitation is a most important milieu factor. In daily life we do not become aware of its importance, yet, even the plants show the effect of gravity in the form of geotropism. Whereas, aviation presents the problems only of multiplied gravitation, astronavigation has to deal with multiplied and divided gravitation or multiplied and divided g (H. Haber and O. Gauer, W. Ley).

The range of multiplied g comes into play upon take-off and landing, as you have already heard. Because of the shortage of time, I would like to mention only that the multiplied g

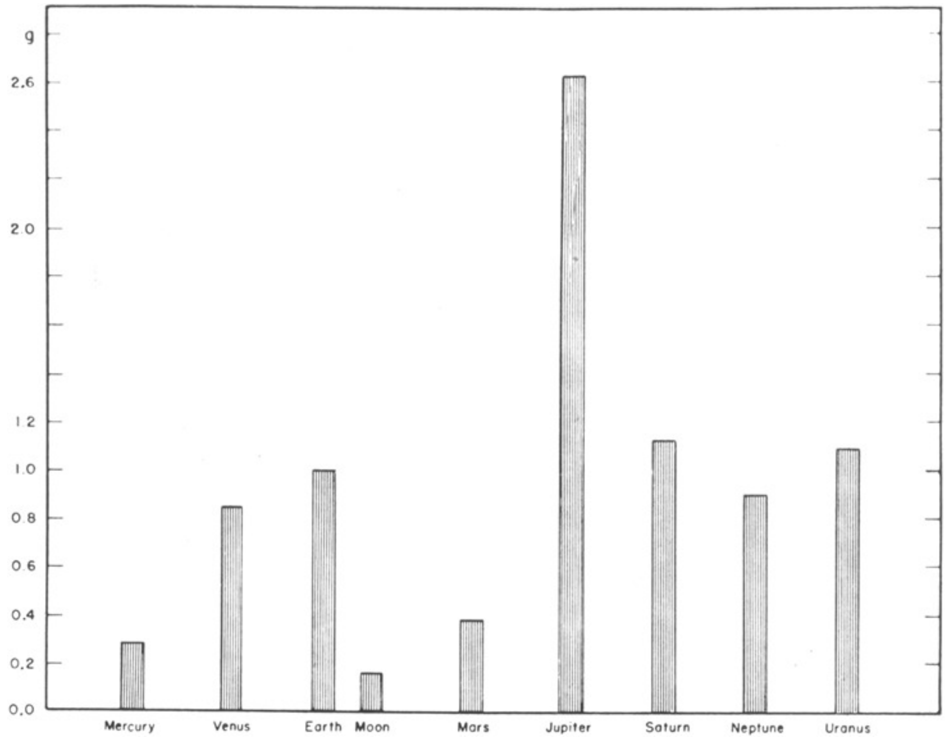

Fig. 7. Gravity expressed in g on the surface of the various planets and the moon.

does not present great physiological problems if proper position of the crew is presupposed. This has been proven by experiments carried out on large centrifuges by Armstrong, Heim, Bergeret, Wood, Gauer, Gougerot, and others.

The range of divided g or of subnormal gravitation, as we might call it from the physiological point of view, is the "terra incognita" of space flight physiology. In the interstellar space gravitation is zero because the space ship is in a state of ideal equilibrium between gravitational and centrifugal force.

Figure 7 gives an over-all picture of gravitation on the surface of the various planets. On Mars, there is 37 per cent of the terrestrial gravity, on the moon 17 per cent.

The physiological problem of subnormal gravitation involves two basic questions:

1. What are the effects of a constant reduced level, or the absence, of gravity?

2. What are the physiological effects of a decrease and increase in gravity in the subnormal range upon leaving and returning to the earth?

Any physiologist will hesitate to make definite predictions here. But let us try to draw, in small sketches, the situation which we must face in the gravity-free space. In a gravity-free state, our weight decreases to nothing. A feather and a piece of iron have the same weight, or rather both have no weight. If we would move our arm, we would not feel its weight. But the power of our muscles remains the same. One could perhaps compare the work of the muscles in gravity-free space with the light work of the eye muscles here on earth, which do not have to work against gravity but only against friction and tensions. Lifting, for instance, a safe in the space ship requires no more strain than moving the eyes. This strange discrepancy between the muscle energy available and the muscle energy required in gravity-free space might bring some difficulties to our *sensory motor system.*

Normally, the movements of our limbs are controlled by a threefold sensory system, of which the muscle sense and the pressure sense of the skin are best known. But experiments performed about twenty years ago indicate that even when the pressure sense nerves of the skin, for instance of the finger, are anesthetized and the muscle sense is eliminated by a special experimental technique at the same time, we are still able to make very precise movements. The so-called Vater-Pacini corpuscles scattered throughout the tissue can be considered as the receptors for this third component of the control mechanism for the movements of the limbs, according to M. V. Frey. Because tension of the tissue, and not gravity, represents an adequate stimulus for this little-known sense organ, it might have an increased significance in the gravity-free space. For it would be conceivable that this component could, through adaptation, to a certain degree compensate in gravity-free space for the elimination of both the others, which must be considered as gravireceptors.

I am a little optimistic, therefore, as to the sensory motor system of the muscles of our limbs in gravity-free space and as to the sensory control of the movements of our entire body, if a modified basal tonus of the muscles, which depends on the vestibular apparatus, does not spoil the picture.

The movement of the entire body will involve floating in the air of the space ship, and the orientation for movement in the space ship will have to be accomplished optically, whereas on the earth it is done optically, by means of the eyes, and gravireceptorially, by means of the vestibular apparatus muscle sense and the pressure sense of the skin. We do not know whether men can adjust to a purely optical orientation in space. Fish can be trained to an optical orientation in space. Only recently it was found by V. Holst that, when the top of an aquarium standing in a dark room is covered with a black plate and the light penetrates through the glass bottom, some fish will always swim upside down, will look for fresh air at the bottom, and will swim to the dark surface of the water when they want to rest.

With reference to respiration and circulation, the absence of gravity probably involves less difficult problems. The heart muscle, maintaining its power, has less work to perform since the weight of the blood is nil. It is significant whether or not the heart can adapt itself to this situation. And, if it can adapt itself to the gravity-free space, will it be able to accept the additional stress when gravity returns? Here, at the return to earth, the weak point for circulation seems to arise. We have no reasons to assume that the respiration apparatus will be impaired by the absence of gravity. However, one difficulty, not due to the respiratory apparatus itself, but due to the ambient air, should be mentioned here. No thermal convection exists in the air within the space ship when gravity is absent; hence, the expired air will remain in front of the nose of the astronaut. This means that some type of ventilation must be provided for the space ship's air to prevent the formation of localized bodies of air containing little oxygen and much carbon dioxide.

To conclude the question of subnormal gravitation, I should like to mention the importance of the relationship between basic excitation and additional excitation of the gravireceptors if gravitation is changed. This concept, which is based on Weber's law and which was brought up for discussion for the first time by O. Gauer, can be considered as a basic foundation for the explanation of the disturbances to be anticipated in both the autonomic and the somatic nervous system.

This, in short, sketches the picture of gravity-free space with only some of its physiological problems. We can only guess the facts here; experiments must give the final answer. In case the gravity-free state involves too many physiological difficulties, the physiologist would have to demand a continuous slight acceleration of the space ship to attain a certain amount of quasi-gravity.

Finally, I would like to broach a problem that belongs to the physiological complex of navigation. Of great interest in this respect, for instance, is the comparison between the speed of the space ship and the velocity of the nervous processes involved in its control. This is a space-time-brain problem.

About twenty years ago, when the speed of aircraft had exceeded the velocity of nerve conduction, the reaction time of man was for the first time correlated with flying speed. The distance covered by the reaction time, during which a change in course is impossible for physiological reasons, was called "dead space" or "dead distance." This concept requires further elaboration in supersonic speed. The simple reaction time is 150 to 200 milliseconds. The sensory part of it, the so-called latent time of perception, ranges between 35 and 70 milliseconds. This latency of perception conditions a shift in time or anisochronia between physical reality and perception. The impressions which are produced in our mind lag behind the actual events by one-twentieth to one-tenth of a second. This lag is not noticeable in ordinary life at high speed. This physiological lag, however, becomes evident, with regard to space, as a nonperceptive interval. This is the distance covered during the latent time of perception at the various speeds. At a speed of 1 km. per second the nonperceptive interval would cover approximately 50 to 100 meters, the simple reaction time would cover a physiological "dead distance" of 200 m.

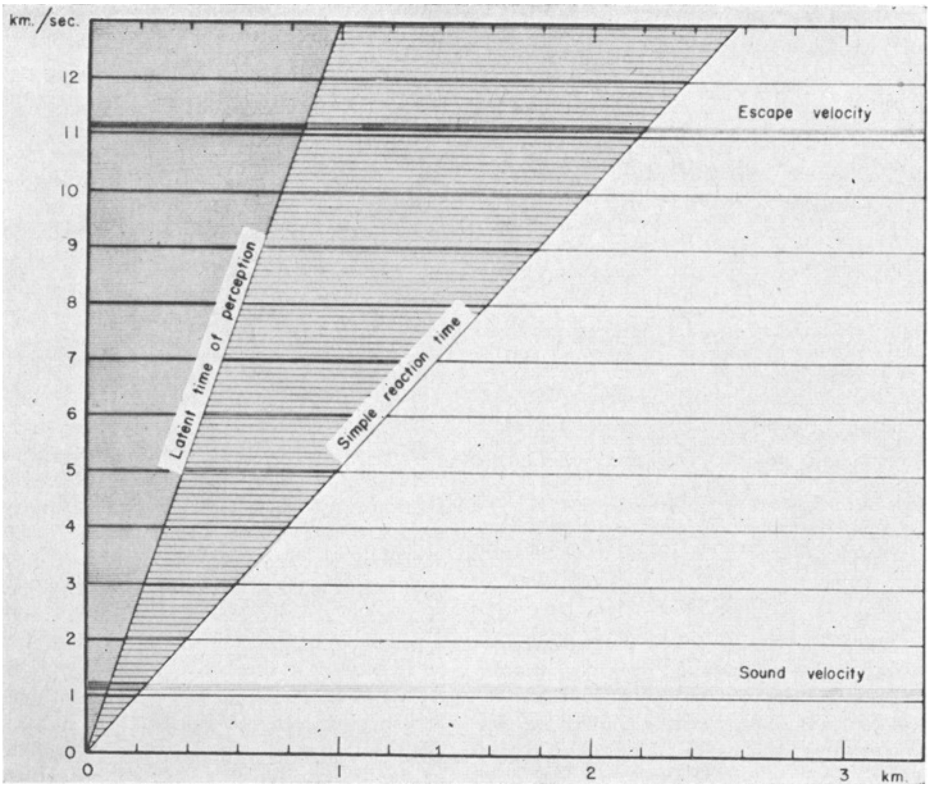

Fig. 8. The distances covered by the latent time of perception and simple reaction time at various speeds. Abscissa: distances (expressed in km.). Ordinate: speed (expressed in km./sec.).

(Fig. 8). With the reactions of higher order, such as recognition reaction time, et cetera, which may last as long as one or two seconds, we have to consider a "dead distance" of up to 1 kilometer and more. If, in addition, we consider the physically dead distance, which results from the lag of the controls of the space ships, we obtain a total dead distance of many kilometers. Over this distance a change in course is impossible because of both physiological and physical inertia. Upon landing or circling around the moon, for example, the existence of nonperceptive and nonreactive intervals must be taken into account.

I would like to conclude this discussion with this brief remark. One might perhaps say that space flight physiology belongs to the realm of imagination. However, we should always be aware of the fact that, in numerous instances, the imagination of yesterday is the reality of tomorrow. And even if a round trip to the moon should never be realized, a meticulous study of the problems arising in this field will reflexly aid in the investigations of the terrestial conditions on our home planet. We might add better understanding, for instance, of our sensory motor system by visualizing its function in the absence of gravity. In any case the occupation with the subject of space medicine will give impetus to science.

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DISCUSSION

DR. A. C. IVY: It seems to me that the subject is one we should consider at this time in a serious way, because from what we hear about the remarkable advances the engineers are making with rockets, it may not be long until the physiologists, biophysicists, and psychologists will be presented with the questions which Dr. Strughold has raised in his discussion.

Further, I believe that this is a subject worthy of serious consideration because experiments which may be directed to answer some of these questions may yield results which will apply to flight in the stratosphere of our own earth and permit us to travel more rapidly from one place on the earth's surface to another.

My reaction to Dr. Haber's presentation was that insofar as a flight to the moon is concerned, it is not very inviting because of the hazard of dust and the extremes of temperature. The flight to Venus is not very inviting because, as the mythological connotation of Venus implies, she is too hot and suffocating. Of the three extraterrestrial bodies which we might visit, it would seem that Mars is by far the most inviting. But when we contemplate the problem of meteorites, it looks as though the warlike inhabitants of Mars, the Martians, have prevailed on Providence to fill space with dangerous missiles.

If the chance of a collision is one per month, and if it will require three, perhaps four, months to make the round trip, the chances of colliding with some of these missiles is quite great. I wonder, in this connection, if we might be able to study experimentally the concentration of missiles in the space between the earth and the moon by sending rockets to the moon. This would seem to be possible in the not too distant future, and would seem to be necessary before a long trip in space is undertaken with men aboard.

The most intriguing problem to me, presented in the discussion by Dr. Strughold, is that of the behavior of man in a space free of gravity. This problem has raised three questions in my mind which I cannot answer with certainty, and which I hope someone may be able to answer. The first is: Is it possible on the earth to create a gravity-free space or situation? Could it be simulated by placing some sheets of iron on the body of a man and then suspending him in a magnetic field? Would it be possible in this way, though crude, to simulate a gravity-free situation and obtain results on psychomotor performance and on physiological functions which might be applicable to more perfect gravity-free situations?

GENERAL ARMSTRONG: Thank you, Dr. Ivy. Dr. Haber, can you answer his question about producing an experimental situation where we could create this gravity-free effect?

DR. HABER: Physically speaking, there is only one possibility of doing so, namely, by dropping the human body in free air from considerable altitude and taking advantage of the first few seconds when the friction of the air is small enough not to impede free fall. If we would take a cabin built like a projectile, so that the friction is minimal, at least during the very first part of the fall, we could produce such a situation for the duration of about twenty seconds. This period of time is necessarily short because the speed of this falling body must be kept small for two reasons: first, because even in the rarefied air of high altitudes, a friction (i.e., counter-gravity) effect will result if the speed is very great; and second, the speed of the experimental cabin must be small enough so that it can be braked adequately by a parachute or some other device before striking the earth.* Perhaps an engineer might be able to extend this figure, because twenty seconds, of course, is very small. However, any other means such as floating in a liquid, or, as you just stated, utilizing a magnetic field, would not be suitable, since it would not alter the weight of the blood, for instance, or the weight of the tissues resting against the metal suit.

Dr. Ivy: Would it be possible to build a space ship that would free itself from the gravity of the earth, and follow an orbit around the earth, and use it to make studies on the behavior of man in gravity-free space? This would reduce the hazards of a trip to the moon or Mars.

Dr. Haber: Yes, it would be possible if the critical velocity for such an orbit could be attained. The orders of such velocities differ somewhat, depending upon whether you aim at a circular orbit or elliptic orbit. All these orbits require velocities of the order of about 10 kilometers per second speed. However, we must lift the projectile well beyond the last traces of the atmosphere, otherwise friction would disturb the orbit by decreasing the velocity; as a result the tangential velocity would decrease and finally the body would fall to earth.

Dr. Ivy: Do you believe a study of that sort would have to be made before you would be willing to put a man in a space ship and send him around the moon?

Dr. Haber: Oh yes, definitely.

I think it might be worthwhile to study the physiological and psychological effects when suspended in space in the state of free fall. It lasts only a few seconds, that is true, and I do not know what the physiologist will say when he has a chance to make observations for only a few seconds. Whether any worthwhile results can be obtained in such a short time is questionable. However, it might be possible through careful planning and concentration of effort on a single function to obtain certain information. For instance, when suspended in the gravity-free state, we would have, at first, a sensation of falling free, not unlike that of jumping from a high diving board. But, whenever the speed becomes high enough to be decelerated by the friction of the air, or even when the rate of acceleration is changed from the exact rate of free fall, then additional forces will be applied, producing an effect of increasing "weight."

General Armstrong: We will proceed with the discussion. The next speaker will be Commander Charles F. Gell, of the United States Navy.

Commander Charles F. Gell: Strictly speaking, I feel that space flight leaves the realm of aerodynamics rather completely and becomes the field of experts in rockets and ballistics. Even the term aviation, which according to Webster means "the flight of a heavier than air machine" becomes a misnomer because in rocket travel little time

*Generally, within the gravitational field of the earth, gravity can be removed only kinematically, i.e., by imitating the motion of a celestial body which moves without encountering friction from ambient air. Ballistic trajectories in a vacuum also pertain to the category of celestial orbits which are characterized by an equilbrium between forces of gravity and that of inertia. These considerations lead to a method of producing the gravity-free state by means that are presently available. It is assumed that an aircraft flying at high altitudes ejects itself upward, at a certain angle, by means of rocket boosters in addition to the power of its engines; the aircraft must then follow a parabolic course characterized by a constant, vertical acceleration of one g. By use of the rudders and the engines the friction of the air can be overcome so that the airplane is enabled to imitate the ballistic trajectory a body would describe in a vacuum. To this effect, rudders and engines of the airplane must be controlled by an automatic pilot which is activated by a three-dimensional accelerograph. During the entire ascent and descent along the parabola, the gravity-free state prevails for the passengers of the aircraft. Depending on the boosted rate of climb and on the safety limit of diving speed of the aircraft, gravity can be removed for not less than thirty to forty-five seconds.

will be spent in the atmosphere and much in space. Flight, as we know it, will not even be approximated in rocket travel through outer space. Our space aeronaut, or shall we call him "spacenaut," probably will be very different from our present "aviators." The space flyer probably will become a push button man, dependent not so much upon his sensorium but upon his knowledge of outer space and astral navigation.

We must have some reason for contemplating space flight other than that of scientific curiosity. In the future, there may be many reasons for desiring to leave this planet. If Malthusian philosophy ever becomes a fact and the population of the world becomes so large that mankind cannot feed itself, new livable worlds will be desirable and very necessary. Also, other planets may be found to be rich storehouses of mineral wealth that are scarce upon the earth.

The immediate practical use for space travel in my estimation appears to be point-to-point travel on the earth just above the earth's atmosphere. Whether or not this is more practical than stratospheric travel may be questionable, but we must consider the fact that recent investigations of the atmosphere at the upper levels, by sounding balloons, indicate the presence of great storms and disturbances in the stratosphere which may make traveling in space just above the atmospheric level more desirable. Furthermore, this type of elementary space travel may be the proving ground for later interplanetary flight.

The problems of a physiological nature encountered in space flying will undoubtedly include all of the old and many new ones. Probably the only present problems we will be able to write off the books is that of explosive decompression. I see no solution for that problem when it occurs in outer space. While it appears that the engineering aspects of space machines will shift from the province of the aerodynamic engineers to that of the experts in rockets and ballistics, I know of no group better fitted to cope with physiological and medical aspects of space flight than our present flight surgeons and physiologists.

The various apparent physiological problems have been discussed so far in this panel quite thoroughly. The problem of oxygen supply, elimination of noxious gases, protection from heat, cold, and linear and angular acceleration have been covered, and I should like now to venture into a field in which I am most certainly a novice and ask some questions that appear pertinent to me as a medical officer. While I am well aware of the old adage that "fools rush in where angels fear to tread," I am going to jump with both feet into the matter of cosmic rays and other types of ionizing radiation which may be present in dangerous or even lethal quantities in outer space.

As we all know, when the tissues are bombarded by alpha, beta, gamma or x radiation or by protons, neutrons and electrons with sufficient kinetic energy to cause ionization, disintegration and necrosis of the tissue results. To refresh your memory, the exact mechanism of this tissue disintegration is not known, but it is thought to be due to a chemical breakdown of tissue molecules when a valence electron of a contained atom is knocked out of its orbit by a high energy particle. This is the process of ionization, and large amounts of these ionizations may result in acute radiation illness or even death. Mankind has been bombarded and had his tissues ionized from the very beginnings by cosmic radiation, which is one type of extraterrestrial ionizing radiation about which we know. Cosmic radiation, consisting of primary particles entering our atmosphere from space, is very penetrating, having been recorded in the depths of the earth and the sea. Cosmic rays bombard the nuclei of atoms of the atmosphere and result in showers of atomic debris, consisting of protons, neutrons, electrons and alpha, beta and gamma radiations.

Cosmic radiations are placed in the electromagnetic scale above gamma rays, having a shorter wave length, and are now thought to be actual particles instead of photons. That mankind is constantly suffering ionization of his tissues by cosmic radiation is unquestioned. I recently read a statement to the effect that, inasmuch as mankind has certainly suffered enough unsatisfactory mutations of sex cell chromosomes during his natural existence, we should not aggravate a sorry enough situation through the promiscuous use of the atom bomb. The thought came to me that perhaps the mutations occurring in nature may have been produced by aberrations of sex cell chromosomes brought about by the ionizing effects of cosmic radiation over man's span of existence.

Studies of cosmic ray activity and their ionization potential in human tissue indicate that they are not a very dangerous factor in our atmosphere. However, I believe that we cannot assume that this is true in outer space without further investigation.

To my knowledge, the highest sounding of our atmosphere made to date has been 75 miles or to its upper limits. Consequently, we do not actually know what ionizing radiation, other than cosmic, is contained in outer space. I speak, of course, of alpha, beta and gamma radiation. The kinetic energy and quantity of alpha, beta and gamma radiations would determine their dangerous potential to humans flying through space. Extraterrestrial alpha, beta and gamma radiation striking our atmosphere would be absorbed by the upper layers, and it would be relatively difficult to determine their quantity at the earth's surface or possibly even at the lower limit of the stratosphere. We would expect this absorption to be manifested by spectrographic phenomena or by a radiant display such as the "northern lights." However, I do not think positive conclusions have yet been made in this regard.

That alpha, beta and gamma radiations are present in space may be illustrated by the assumption of the correctness of the thermonuclear reaction theory of the sun. It is hypothesized that the gravitational pull of the sun upon its gaseous body has caused compression of the gases, with a consequent heat production of 20 million degrees Centigrade at its center.

With these high temperatures the kinetic energy of thermal motion becomes so great that the violent mutual collisions among the irregularly moving particles cause nuclear disintegration. At 20 million degrees, the kinetic energy imparted to a particle would be easily equivalent to that energy imparted to a particle in a cyclotron. The electron shells of the individual atoms are stripped off and the sun's mass consists of bare or completely ionized nuclei with free electrons rushing about. The naked nuclei are not cushioned by their electron shells and are vulnerable to violent direct impacts which often cause their disintegration. These are thermonuclear reactions and are responsible mainly for the energy production of the sun. In these reactions, alpha, beta and gamma radiation is constantly produced.

It appears possible that vast quantities of these ionizing radiations may escape the gaseous envelope of the sun and be ejected into space. While it is reasonable to assume that these ionizing radiations would become homogenous in space, it is also reasonable to envision that a sudden solar explosive release of gases might eject a vast quantity of ionizing radiations into space which would travel in a cloudlike manner, remaining ever a threat to a space ship that might traverse its volume.

The possibility of radioactive dust clouds and radioactive masses in space must also be considered. A large mass of cosmic matter consisting of radioactive elements, with no atmosphere to absorb its radioactive emanations, would be a distinct threat to life aboard a space ship.

The magnetic field of the earth certainly must deflect away a vast number of ionizing particles which have a lesser kinetic energy than that seen in cosmic rays. Since all charged particles are affected by a magnetic field, it is conceivable that only the most penetrating radiations would eventually reach the earth, except in the polar regions. This is demonstrated by the latitude effect on cosmic radiation counting. The magnetic field of the earth would be expected to affect these radiations, quoting from Stranathan's "Particles of Modern Physics." It was shown by Stormer and by Lamaitre and Vallarta that the earth's magnetic field would influence the motion of charged particles coming from outer space in such a way that it might explain quantitatively the observed variation of intensity with latitude. It is true that the supposed charged particles would have to possess tremendous energies in order to penetrate the earth's atmosphere and more. It might be suspected also that the relatively weak magnetic field about the earth would have a negligible influence upon the direction of such energetic particles; but when it is recalled that the earth's field extends hundreds or even thousands of miles above the earth's surface, it becomes apparent that the total bending effect upon even a very high-speed particle might be quite appreciable, sufficient perhaps to deflect it away from the earth.

It has been calculated that the magnetic field 15,000 miles from the surface of the earth is approximately 1 per cent of the value at the surface. In considering the magnetic field distribution over such an extended region, it is permissible to regard the earth as a bar magnet having a magnetic moment of 8.1 x 10^{25} e.m.u. Now if a charged particle moves at any angle other than 0° with the direction of a magnetic field its motion is modified by the field. If the particle moves at constant speed in a direction perpendicular to a uniform field, its path is a circle. The more energetic the particle, the larger is the radius of the circular arc described. If the magnetic field is not uniform, the path is a section of a spiral rather than the arc of a circle. If the particle moves at any angle other than 0° or 90° with the magnetic field, then it executes a helical path about the field lines.

Analytical treatment shows that if charged particles of various energies come equally from all directions of outer space, then the effect of the earth's magnetic field is to allow more particles to strike the earth at high latitudes than at low. Consider first a charged particle moving vertically toward the earth at one of the magnetic poles. This particle will be moving parallel to the magnetic field; it will not be deflected by this field. As a consequence, as far as any effect produced by the magnetic field is concerned, particles of all energies can reach the earth equally well at the poles. It is true that a particle must have considerable energy to penetrate the atmosphere, and this fact alone would exclude some of the lower energy particles from the group that reaches the earth. Consider next a particle moving vertically in the magnetic equatorial plane. This particle has a direction of motion perpendicular to the magnetic field. Other factors being equal, it will be deflected a maximum amount. As an example, think of a particle moving vertically toward the earth but still 4,000 miles above the earth's surface. It is obvious that such a particle will never strike the earth if it describes an arc having an equivalent radius less than 4,000 miles.

It would be possible to calculate the limiting paths which particles might describe and still reach the earth. Since the particle must describe a path having a not too small radius of curvature, it is apparent that there exists a critical energy below which it is impossible for a particle of given e/m to reach the earth in the equatorial region. This critical energy is of the order of 10^{10} electron volts. All particles having an energy smaller than this critical value are bent sufficiently by the magnetic field so that they turn away from the earth before striking it. Is it not then a possibility that many particles with tissue ionizing potential do not reach the earth's atmosphere because of magnetic deflection, but remain a threat to the traveler in space?

In 1931, Karl J. Jansky discovered that stellar bodies radiate not only heat and light but also radio waves. This has been demonstrated satisfactorily by actually picking up, on specially built reflectors, radio static of extraterrestrial origin coming from the sun and stars in the Milky Way. Since it is apparent that electromagnetic radiations, extending from radio waves through cosmic rays, are emanating from heavenly bodies, it is then also reasonable to assume that large quantities of gamma and x radiations are present also, since in the electromagnetic spectrum they lie between radio waves and cosmic radiation.

In summation then, I should like to point out that while the physicists consider the primary and secondary cosmic radiation of limited tissue ionizing value, is it not reasonable that the conglomerate whole—including cosmic radiation and other corpuscular radiation, such as alpha, beta and gamma radiation and perhaps even x-rays from heavenly bodies and the mass of particles of lesser magnetic field—may present in the aggregate a real threat to the space traveler? If this is true, then certainly a great amount of investigative work remains yet to be accomplished before man can safely traverse space. Our space traveler will be protected from various ionizing radiations by the skin of the space ship, but he will not have the atmospheric mass and the earth's magnetic field to protect him from low energy ionizing particles. It is possible then that our space traveler, after spending twenty or thirty hours in travel, may arrive at his destination with an induced radioactive hull as dangerous to him as our ships were after test Baker at Bikini. As you know, we have been forced to sink these.

In conclusion, I should like to state that these are the ruminations of one not trained in physics, and my assumptions may be faulty to the extreme. If these questions are already answered, I have been unable to find evidence of it in the literature. I should like to be proven all wrong, but until the errors in these assumptions are proven, rather disturbing possibilities will present themselves.

Dr. John C. Flanagan: I am going to confine my remarks to three aspects of this subject. The first is the general problem of reaction time, the second is orientation, and the third is the divided g or acceleration problem.

With respect to the reaction time, since being invited to participate in this panel and also having the benefit of an opportunity to read the remarks of Dr. Haber and Dr. Strughold, which I found very illuminating and very stimulating, I have enjoyed two or three interplanetary trips in my imagination, and on these trips I did not find any particular difficulty with the problem of perception and response time.

Now it's true that some of these trips were at 500,000 miles per hour. But at 500,000 miles per hour, when you are going through a space where the earth looks like a small ball, and the moon, coming up, looks pretty small also, and Mars over here is not too large, the fact that you are going 500,000 miles an hour does not make much difference. It is just as though you were traveling at 30,000 feet; the ground seems to be moving very, very slowly, and you do not have any problems. It is only when the objects get close that they really seem to be moving rapidly. I think that that would be the case in space travel. As long as you are out in the wide open spaces, you would not be bothered by perception or response time. It is only when you are coming in for a landing that that really becomes important, and even there, if you have ten minutes after you get into gravitational pull to slow down, it probably is not going to put any special demands on response time. Various recent studies at Wright Field and other places have shown that it takes about two or three seconds to perceive the need for doing something and to initiate the action to do it. To use controls, of course, will take some time longer, but I believe that, whereas it will put some premium on moving rapidly, still if there is going to be a period of two or three seconds differences, individual differences of one-tenth of a second will not make much difference.

On the matter of orientation, with special reference to acceleration and deceleration and the practical elimination of gravity, various studies—such as those of Dr. Whitkin here at Randolph Field and at Brooklyn College—have shown that the "seat-of-the-pants" type of orientation is not very accurate for many individuals anyway. With the positive acceleration of something like 2 or 3 g, which one receives when the ship is leaving the earth's atmosphere, you get an effect something like going up in an elevator, if this reaction is against the direction of motion. So, if you imagine this space ship, you feel a strong pull toward the rear end of it and any walking or orientation that you would be doing, would be with a component of the earth of say one g, and a component of the space ship that was going directly away from the earth of a certain number of additional g, all in the same direction, you would be going up, presumably straight up, and you would be oriented in that direction. If you wanted to look out the way you were going, you would have to look up over your head, just as you would look at the top of the elevator when you are moving in that direction. You might find that it would be more comfortable to look where you are going by lying down on a bed and looking at the ceiling, to see where you are going, since you are going in the direction of the ceiling, than try to keep straining your neck, looking up over your head. To take care of either acceleration or deceleration one will need a seat to hold one in, and I think of it as sort of being sandwiched between two mattresses, because when in the "no g" area or a very, very small divided g, one will tend to float around the cabin of the ship. If, for example, you sat down at a table and started to write, the pressure of your pencil against the table would tend to lift you off your chair, and you probably would have to be strapped into your chair some way or another in order to get any leverage to do anything in the way of operating any controls or making any records, et cetera. For purposes of orientation a movable seat would be needed which could be shifted around in various positions. Perhaps to give practice to people who had not been around, one could think of various training devices in which a representation of various speeds could be given by having little balls in space, here and there, and simulating those speeds in one's motions with respect to them.

The problem of divided g was quite an interesting idea, and like Dr. Ivy, I had begun to speculate a little bit about what you could do about simulating the conditions of "no g" or very small amounts of g. I cannot follow the reasoning at all that within the free-fall situation, or any other conceivable situation within the earth's field, you would be relieved of g. It seems to me that if you are in an elevator and it starts to leave you, dropping out from under you, that does not have the effect of making your arm or your brief case suddenly of no weight. It removes any pull on your arm, but, you would have to act against one "g" to lift it. It seems to me that the physics which I learned suggests that if you are within the earth's field, there is going to be a force of one g operating on your brief case and on your arm and on your body at all times, regardless of what particular velocities you have or what other accelerating forces you are subject to in the particular situation. Therefore it seems to me one cannot get away into a "no g" by any free fall or any application of other accelerations, and I was led to the same sort of conclusion as Dr. Ivy was as to what was needed. My proposal would be to use a suit of long winter underwear made of a metallic cloth which would be of a highly magnetizable alloy, and then to set up a magnetic field above the suit. Now, it must be noticed that that magnetic field *has* to be right directly above you on a line between the center of the earth and your body, or your particular arms, or whatever the other parts of the body that you are interested in are so that it directly counteracts the pull of gravity. If the action is off to one side, then there will not be a counteraction but another set of pull. But it seems to me that by such a method one could counteract the weight of the arm, which would not be done, as I see it, in a free-fall situation, in an elevator, or anything of that sort. You would still have to bring your arm up, and it is still being held down by gravity; but if with a covering of some sort you take the weight off that arm by pulling it up by gravity to the same extent that it is being pulled down by the weight of the gravitational pull of the earth, it seems to me you would begin to simulate, at least for the major parts of the body, the type of situation which one has in a no gravity situation.

Now, one has to recognize immediately that there is no device that he can think of at the moment for magnetizing the corpuscles of the blood, or the skin, or the contents of the stomach, et cetera, and so the above situation would not be entirely comparable to a no gravity situation out in space. What would happen to the digestive processes, et cetera, with no gravity, I do not know, and I cannot see any way of simulating that. On the other hand, it does seem to me that the forces acting on arms, legs, head, et cetera, could be counteracted to a considerable extent by such a metallic suit, and I think one might learn quite a little bit about the no gravity situation by trying to operate controls and do other tasks with that type of gravity eliminated.

In general, it seems to me that the problems that one would encounter on this space trip would not be so greatly different from the ones that we encounter in high speed planes at the present time. A good number of the finer adjustments would probably have to be made automatically because of the very rapid speeds involved, both in departing and in returning. Now, those speeds would not be of such great importance in outer space, but the fact that one leaves in a hurry and comes back at a very rapid rate also would certainly put too much of a demand upon human factors of perception and response with respect to many finer adjustments. The individual would still have to watch things, and see that things are going according to plan, and make plans and make decisions, but they would have to be made a good deal ahead of time, and one could not allow for direct control the way one does in a small airplane of the type that we have at the present time.

Dr. Behrens: I have been greatly impressed, and I am sure we all have, with this presentation by Dr. Haber and Dr. Strughold.

There are several questions that come to my mind, and the first one is the one raised by Dr. Haber: the question of the possibility of having a great increase in the ultraviolet radiation produced by solar eruptions.

I would certainly think that the suggestion made by Dr. Haber, that we could prevent any serious damage to the eyes by excluding this excessive ultraviolet radiation by means of the coloring of our windows, is excellent. I presume also that we could protect ourselves further, if necessary, by the means of goggles. I am not so sure, however, about the possibility raised by Dr. Gell.

Dr. Gell raised the question, of course, of these other radiations, and I had planned to ask Dr. Haber, because it is entirely out of my field, whether it is true that the cosmic radiations can split the atom much better than man has so far been able to do. And, if so, whether or not there is some danger from these various radioactive emanations that might be present particularly in the outer atmosphere.

Dr. Haber: I think the best way to answer this question would be to consider those bodies which are already out in space. There is one very delicate indicator for any sort of radiation which does not reach the earth. This indicator is not subject to such magnetic deflections as Dr. Gell has pointed out. The indicator I have in mind is the tail of a comet, and the effects of such radiations upon it can be studied. The tail of a comet consists of widely dispersed gases and dust-like matter. Studies have been made on the spectra of comets' tails by Wurm, and by others, and they were able to measure the ionization produced in this matter by radiation. In one particular case—this work was done by Dr. Richter of the University Observatory of Berlin—there is a comet which has an almost circular orbit around the sun, a very rare case among comets, most of which have elliptical orbits. This comet has a tail which is nothing more than a short extension of its atmosphere on the side away from the sun. This comet revolves around the sun at a distance about equal to that of Jupiter. This comet reacts to a high degree to all the ultraviolet outbursts of the sun, and it can be shown that a very close relationship exists between ionization of our atmosphere and that of this comet. Studies made by Wurm and others have shown that the ionization effect upon this material in outer space, without deflection by a magnetic field, since the comet has almost none, is limited. The solar corona, which is a kind of atmosphere around the sun, extending about twice the diameter of the sun beyond its actual surface, has been made the subject of many studies during total sun eclipses. Recently the spectrum of the corona has been identified as being produced by atoms of a very high ionization. This ionization, however, is such that fourteen electrons are missing in the iron atom and thirteen in the nickel atom. We believe that this ionization takes place in the following way: electrons spinning in the magnetic field of the sun can circle around the sun many times, thus gathering up speed and then eventually hitting one of the iron or nickel atoms which owe their presence to vaporized meteorites. The atoms are excited, ionized, and then they will emit those specific spectral lines. This answers the question with respect to ionization. It shows equally that in space the density of matter is so low that electrons, like those traveling around the sun, can travel millions and millions of miles before encountering a particle.

As far as cosmic radiation effect on the space ship is concerned, the entire shell of the space ship will be exposed to the primary component. The crew of the ship itself will be exposed to a considerable part of this primary component of cosmic radiation; in addition to this, we will have secondary radiation produced within the wall by action of the primary component. The air equivalent of the hull of the space ship can be estimated approximately. Thus, we can find above the ground level on earth, an altitude with nearly equivalent ratios of primary and secondary radiation. This equivalent altitude is about 75,000 feet above sea level, depending, of course, on the thickness of the ship's hull. Ascents to these altitudes with manned balloons have already been carried out (Piccard). Critical effects of cosmic radiation on man in a space ship are hardly to be anticipated.

So space, at least as far as astrophysics can tell to date, contains particles of various kinds and speeds but at such a low density that I would conclude that there is no danger at all as far as those unknown parts of corpuscular radiation within our solar system are concerned.

Dr. Behrens: I would like to continue with another question, if I may, on the problem of meteorites. I understand that they might be as small as 1 mm. in diameter. If they were able to penetrate a space ship and you could close the opening of the space ship made by this meteorite, so that you did not have explosive decompression, then we might have foreign bodies getting into the eye. I wonder whether there is any possibility that one of these 1 mm. foreign bodies could penetrate the ordinary ship we have today. Of course, we do not know what the space ship is going to be like if we do have one.

Dr. Haber: The speed at which such particles travel is very high, and it can be calculated that a body having the weight of 1/100 of a gram can develop 2,400 horsepower during a second. This probably is enough to penetrate a very thick steel plate. As a matter of fact, we made a rough calculation which is going to sound incredible to a ballistics man, but it shows that such a particle could penetrate a steel plate many feet thick. But of course we do know that such an extrapolation of the known laws of ballistics is not applicable. Still, serious damage to the ship by a meteorite must be anticipated, and that is one thing I would like to stress.

I am very anxious to hear comments from someone who knows ballistics much better than I do. What would happen if a particle with a speed fifty times as great as we can now produce on earth for large particles hit a steel plate? I would be very much interested in hearing the answer to that. It is entirely impossible for me to make even a rough guess.

Dr. Behrens: I take it, then, that it requires a certain mass to penetrate the skin of a ship. I do not know what that would be, but I do not believe a 1 mm. particle would do it. That is a guess.

Dr. Haber: I could not say.

Dr. Behrens: Another problem arises in regard to this matter of particles penetrating the hull of the ship. If these particles did get in the eye, are they magnetic as a rule?

Dr. Haber: About 80 per cent are composed of iron and nickel and 20 per cent of a stone-like material.

Dr. Behrens: So the majority could be taken out.

Dr. Strughold's paper raised several questions also: first, the question of reaction time. I think we are all impressed when seeing the aircraft of today fly, the jet ships particularly, with the need for increased ability to react promptly. Certainly that should be true of the eye, and particularly in these space ships, when we get close to the ground, as has been brought out by Dr. Flanagan. I believe we should, in considering this, consider normal vision, of course, a combination of no-fatigue and good fusion aptitude. I think that might help us in responding rapidly so far as the eye is concerned. This is, of course, predicated on our having a type of ship similar to those we have today. As to what we may have later, I would not care to hazard a prediction.

A second question is that of pressurization of cabins. Even if we did pressurize, let us say to a level of 7,000 feet or whatever is indicated, I am wondering whether Dr. Strughold feels that we might, in the course of the necessarily protracted time spent in such a ship, get very serious effects so far as eye reaction is concerned, from the anoxic hypoxia caused by the accumulation of gases other than oxygen. I think he partly answered that, but unfortunately the acoustics did not permit me to hear everything he said. Would you want to answer that now?

Dr. Strughold: In that case, one could take advantage of the oxygen which would be stored in cylinders and so there would be no danger in regard to anoxic hypoxia.

Dr. Behrens: I was impressed by this factor while flying up from Florida recently. Then even at that pressurization of the cabin and over a relatively short period of time, the engineer and the pilot, who was a man fifty years of age, felt the need of taking oxygen. Certainly, in the case of passengers that would be stretched because I know how little people like to do that.

Lastly, the question of ocular movements has been brought up, and I cannot see that that is going to impose a very serious problem. I believe they will be able to move their eyes properly if we eliminate such difficulties as lack of oxygen or the accumulation of noxious gases in the atmosphere of the cabin.

Lt. Col. Gagge (Wright Field): When I was fortunate enough to read Dr. Strughold's and Dr. Haber's papers, I asked myself, "How best can I intelligently contribute to this program?" It seemed to me the one big factor that should be clarified for this audience is the effect of acceleration on man. During take-off he may have to suffer quite high acceleration, according to Dr. Haber, in order to enjoy the economy in fuel that is theoretically possible.

Another big problem, if one has the ambition to fly in one of these vehicles, is the problem of landing on earth and the possible decelerations one may have to suffer in order to hit the ground and be able to walk out of the crash. So I thought I would just present a very broad picture of acceleration as we see it today from the results of our work at Wright Field over the past ten years and the results of all the integrated work on this subject of deceleration. This will be a very broad generalized picture.

While I speak of positive acceleration, you must remember that we are describing body position in relation to the direction of acceleration. Figure 9 is drawn for the normal sitting position. Whenever one talks about acceleration, one must always consider the independent variables. First, the magnitude of acceleration in g's, and secondly, its duration in seconds. Now, in our normal experience of curvilinear flight, the accelerations last from three seconds to fifteen seconds, depending on how long the pilot takes to make his turn. During the war, we did a great deal of work on acceleration in the range from ten to fifteen seconds, and the blackout level indicated is the figure fairly well established for the average man. There is always a problem of what happens to the man where he is exposed to accelerations of higher magnitudes for shorter periods of time, and, as you see, there is a very critical value for this—around three seconds. Above three seconds, blackout is usually associated with fluid shifts in the body. As the acceleration increases and the time decreases, you finally reach the point where there is no fluid shift involved and the body circulation is more or less held immobile. That occurs approximately on the three-second line. Now, of course, if you keep increasing the g force, there will be some point where you have a skeletal fracture. That figure has forces. Figure 10 shows the force time curves of two actual cases taken from studies of people riding the ejection seat. The dotted line indicates the actual g time

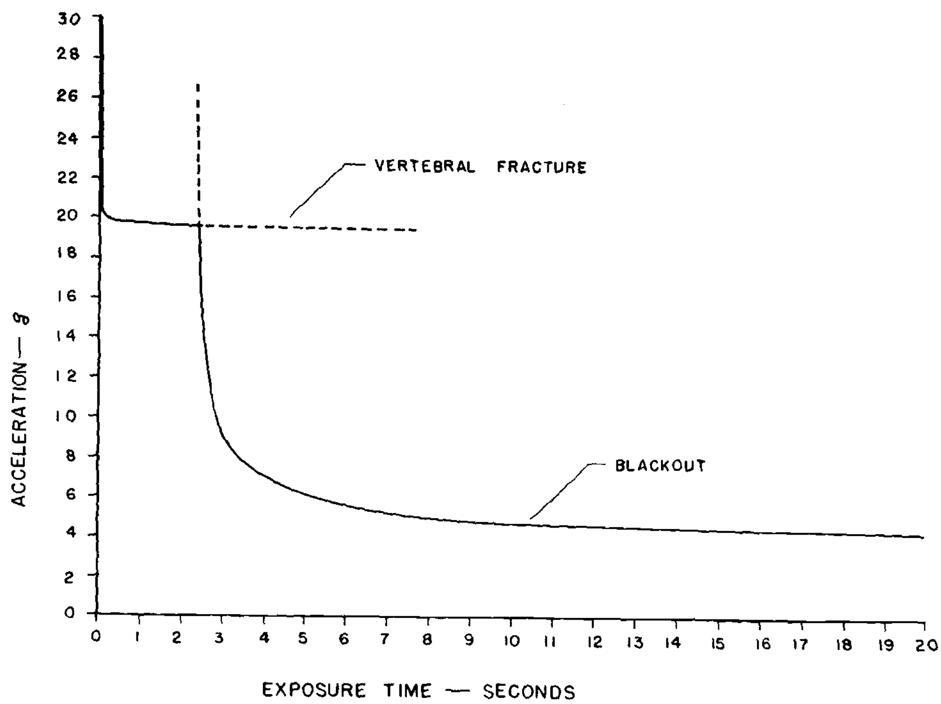

Fig. 9. Time-g tolerance curve for positive acceleration.

been indicated on the chart as 20 g. Theoretically, if you had an infinitely short time, you could take an infinite force without producing a fracture or even blackout. In summary, the principal factors involved in effects of acceleration are the amount of g force, the duration of its application, and the relative position of the body to duration of force. For example, the blackout level would obviously change if you change the man's orientation. If he were put in a supine or prone position with reference to the directional force, the blackout level line would very likely be considerably higher, around 10 to 14 g, depending on how much he has to raise the head to see what he is doing.

There is one other factor which should be considered in dealing with accelerating relationship applied to the pilot himself, riding the ejection seat. The solid line gives the g time pattern that he actually suffers physiologically. Now, if man were inelastic and solid, it is very likely that the two curves would coincide; but man happens to be an elastic bag held together by skin and bones, a little bit like jelly with a few rigid staves inside, and if a very high force strikes him, he tends to set up internally natural oscillations and frequencies. There are certain frequencies which he may have resonance to, and that, in a way, may account for some of this over-shooting you see. To avoid stimulating any of the resonant forces, we have learned in our studies of g and time that the g increase per unit time must be held below a certain minimum, which has more or less been accepted now as around 150 to 200 g a second. This same factor, of course, in reverse, occurs in deceleration when you are striking the ground, as in trying to land this ship.

At one time I was visiting the Naval Medical Center at Bethesda and was permitted to use one of their underseas diving masks. I went down in one of their big

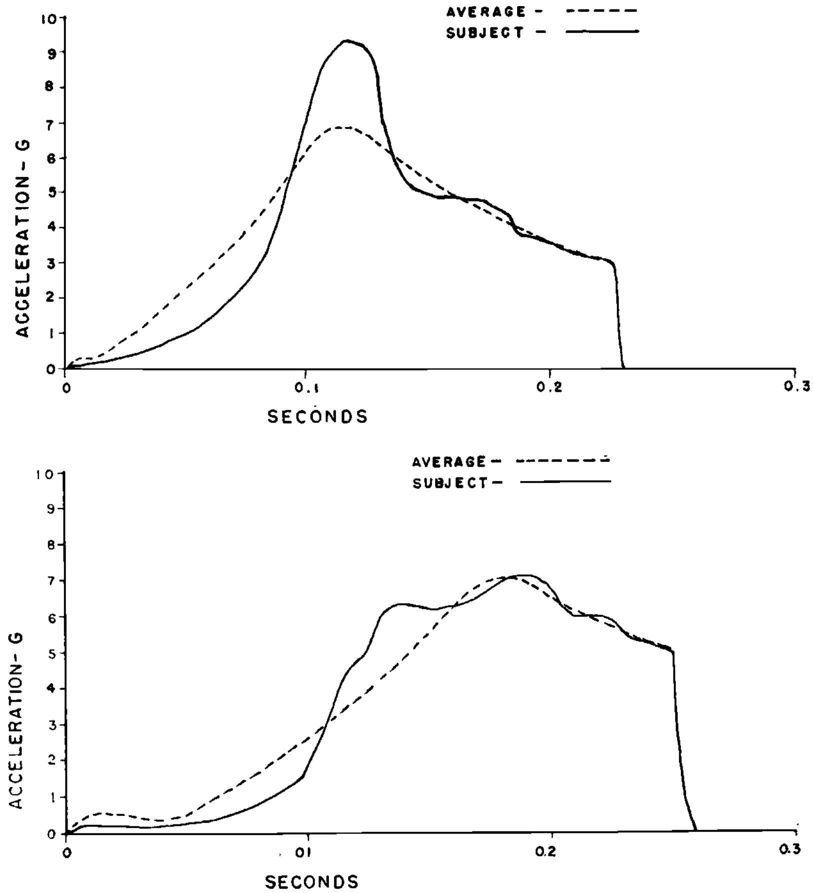

Fig. 10. *(Above)* Acceleration-time diagram showing "overshooting" of subject. *(Below)* Acceleration-time diagram showing the effect of a low rate of increase of acceleration on "overshooting."

These two charts, I think, will give you a very quick thumbnail idea of the principal factors that one must consider physically associated with acceleration.

One other factor I would like to discuss. Dr. Flanagan mentioned the problems of life in a zero g field. He mentioned one analogy of being in an elevator just as it drops. It seems to me I have another analogy worthy of your consideration.

swimming pools that go down twenty feet. It seems to me that if one were at the bottom of this pool, and did not use any swimming motion, he would have some of the sensations of a person in a no g field. Imagine yourself under water in a pool, not swimming, but trying to sit in a chair—you are continually trying to find something to apply reactive forces to. I should like to make the suggestion to Dr. Flanagan, if he wants to do physiological studies of motions in a no g field, to try them in a swimming pool under water. Of course there he would have the advantage of the resistance of the water, but, at least, since we have no other way of simulating a no g field—practically speaking—this might be one way of doing it.

In conclusion, I would like to ask Dr. Haber a question which seems to be very obvious. What is his idea of what this space ship would look like? What would be the general configuration of this ship as he imagines it? I was unable to visualize this from his talk. Just what positions would he recommend all the passengers or the pilots sit in on take-off and on landing?

DR. HABER: Well, to be frank, I would hate to make a statement along that line because this is a highly technological question and would require a great deal of time, research, and consultation to come up with satisfactory answers.

DR. HALL: I think that I will just make two or three remarks in order to shorten the time and hope that you will have an opportunity to ask some questions as we go along with this program.

It seems to me that if we were to classify the remarks that have been made up to the present time, that we would find the problems fall into two or three different categories. They divide themselves mainly into the engineering and the physiological. The main problem of the space ship, sending a space ship to Mars, is an engineering problem. When we consider the human body that is to travel in this space ship, we know pretty much what the limitations are. We know that the resting human being is going to use about a gram of oxygen a minute; he will have to live within a certain temperature range, and he will have to have a certain partial pressure of oxygen. I think we can set that limit fairly accurately. We know that if he loses the pressure of his space ship, he will have about ten seconds of consciousness, and we know pretty much what the effects of acceleration are on the body.

The factor of acceleration that disturbs me more than the others that have been mentioned, such as blackout and the effect on orientation, is the general immobilization that may occur. If you examine the speed records of Dr. Haber, you will see that there is almost a constant acceleration of 3 or more g's for quite a long period of time. Now, if you will remember the difficulties the fliers had during the war in escaping from spinning aircraft, you will recall that it was a very serious problem. Experiments on the centrifuge showed that men may be effectively immobilized by accelerative forces. They may be able to see and remain conscious, but they can do nothing in the way of moving their body, and if we are going to have a 3 to 4 g force, or higher, on the body for a long period of time, that to me seems to be rather disturbing.

Most of these ordinary physiological limitations are pretty well known at the present time. However, the two that are not known are the effects of radiations and effect of absent or diminished gravity. The atomic energy field people are studying the effects of radiation; that leaves the big problem of the effect of absent or diminished gravity which nobody seems to be studying.

Previously, I mentioned the magnetic suit. Perhaps, in this connection, we will have a pro-g suit in place of the anti-g suit. But there have been some rather elementary experiments on this on the lower forms of life. Some of you remember the experiment on the crayfish where the particles in the ear were replaced with iron filings and the orientation of the crayfish was changed by magnetic means. Now that is rather far fetched in its application here, but some equally ingenious scientist will probably find a solution to this matter of gravity. So I would like to make the plea for a study of the effect of gravity, and I would like to agree with Dr. Strughold that even though we do not accomplish a trip to Mars, we may learn something that will have some other value in science. The whole history of science seems to indicate that investigation in any field—if we have some one goal—while it may not accomplish that particular goal, the information gained is of value in some other way.

COMMANDER GOODWIN (U. S. Navy): It occurs to me—assuming of course that the space ship does, at some future time, become a reality—that the flight surgeon is going to have quite a considerable problem. I am thinking, I might say, along a little more prosaic lines than the general trend this discussion has taken. I am thinking particularly of the matter of pilot selection.

Now, according to the literature, I think medical science did not concern itself much with the problem of pilot selection until about 1910. Considering that, that would make it almost forty years since we began evolving the best methods of pilot selection. By trial and error, by benefiting from past experiences, and also, by a tremendous amount of research, we have now a workable system or method of pilot selection. I say workable, because as most of you know, while we do have the best methods now known, we have still fallen far short of a perfect method of pilot selection. When you consider, then, that during these past forty years the aim has been to select an individual best fitted or best adapted to fly in a medium about which considerable was known, and when you compare that medium to what you will encounter in the far regions of outer space, then we are confronted with the fact that many of the yardsticks by which we, at the present time, measure physical and mental attributes of our military pilots will, no doubt, become useless in a large degree. What then will be the criterion by which we shall judge the space pilot? How shall we select him? What will his needs be? Will it be necessary to emphasize the physical qualifications, as we now do in our military pilots, or, on the other hand, will he need to be a very highly trained scientist, a sort of mental giant as it were? If so, how are we going to combine what appears to be necessary quick reaction time of young individuals with the profound knowledge of trained scientists. Of course, it is not inconceivable that the so-called space pilot might be just an average individual, even as you or I, with a few push buttons at his fingertips to worry about. I bring this question up without any attempt to answer it. In fact, I do not think it can be answered now. But it does seem to me that the flight surgeon should be thinking about this problem with which he may someday be faced.

General Armstrong: I have asked Dr. Dill to be prepared to give us a summary of this discussion when he completes his own personal remarks. So before asking him to speak, I would like to know if there are any remarks from the floor.

Dr. Buettner: I would like to add some remarks which came out in the discussion with Dr. Strughold and Dr. Haber.

Climatization of the space ship is similar to that in the pressurized aircraft cabin as far as heating, cooling, and ventilation are concerned. The fuel consumption for heating and cooling would be reduced by coating the outer surface of the space ship with substances which reflect heat rays, either the incoming solar radiation or the outgoing radiation from the ship. Three cases may be considered.

1. For large distances from the sun, where heating by solar rays is negligible, minimum loss of heat (infrared rays) may be achieved by coating the ship's entire surface with aluminum.

2. For medium distances from the sun, like that of the earth, the following example may illustrate the principle: a white (I) painted surface absorbs only a small amount of heat and emits nearly 100 per cent, whereas a black (II) one absorbs and emits nearly all radiation. Bright shiny nickel (III) absorbs a relatively high amount of the shorter waves of the sun and emits very little. If we make one-third of the cylindrical surface black and two-thirds shiny aluminum, we can turn the black (IV) or the aluminum side (V) toward the sun alternately. At a distance equivalent to that of the earth, the hull, made of well heat-conducting material and without interior heat sources, will, in space, reach the following average temperatures:

White I	Black II	Nickel III	IV	V
—150° F.	+80°	+450°	+220°	—50°

3. Near the sun, white paints, such as magnesium oxide, which show the highest

reflectivity of solar radiation and the highest emissivity for infrared, will afford the greatest protection from overheating. We must bear in mind that heating of the ship by built-in equipment is always much easier than attempting to cool it by similar means.

The heat generated by air friction and adiabatic pressure in the lower atmosphere during take-off must be counteracted as soon as possible. Through radiation this may be accomplished by using white or black paints, as indicated (cf. the table in the preceding paragraph). Out in space, excessive cooling due to radiation loss through the windows could be prevented by coating the windows with a thin layer of gold (30 to 50 mμ). This would result in only a small loss in transparency.

In the nongravitational field, there is practically no air convection, and consequently man can neither dispose of his heat to the air nor evaporate his sweat, without artificial ventilation. CO_2, water vapor, saliva, dust, et cetera, will accumulate around man, and oxygen will decrease. Fire will not burn in the usual way since hot air will not rise; therefore, fresh air will not be sucked in. Presumably, there might be very small random explosions in various directions.

To insure comfort, ventilation must be provided for the crew, including filtration and absorption of water droplets, water vapor, dust, CO_2, body gases, et cetera. If CO_2 and other gases of similar freezing temperature are not thoroughly absorbed by filters, they will precipitate and accumulate in frozen form on the outer walls during the cosmic flight. By reheating, this CO_2 may evaporate so fast that poisoning could occur.

Meteorites, even small ones, may penetrate the hull, injuring men and damaging equipment directly or, more probably, by fragments. To avoid aeroembolism of man, and fire or fire-like explosions of clothing or equipment, we should use helium instead of nitrogen as a chamber filling gas. Automatic closure of accidental leaks may be provided by allowing an open space, filled with numerous partially inflated rubber balloons between the steel hull and thermal insulation layer. In case of a puncture, these would expand instantaneously and float with the outgoing air into the leak.

General Armstrong: Dr. Dill, would you make any remarks that you have in mind and then summarize what we have discussed this afternoon?

Dr. Dill: General Armstrong has put me in rather a difficult spot in asking me to summarize in a few minutes these exceedingly interesting presentations made initially by Dr. Haber and Dr. Strughold, as well as the many interesting and illuminating comments made by the other speakers.

I shall mention only a few of the outstanding points. It does appear from the first presentations that the oxygen supply would not be an insuperable problem. While Dr. Haber has refused to give any specifications of the space ship, Dr. Strughold by implication has given a very definite specification, as I understand it, which amounts to fifteen cubic meters per man. It appears that if there is no leakage, the oxygen supply can be taken care of over a fairly long period. The opinion seems to be that we need have no particular fear of radiation injury, although I must say the hazard of impact by meteorites strikes me as a very serious one. Again the visual problems do not seem to be too difficult, provided we can keep far enough away from the objects which we wish to observe.

Another matter, discussed by Dr. Buettner the temperature regulation—does seem very complicated but presumably is a problem that can be solved by engineers.

However, the feature of space travel which seems to have had too little emphasis is the human problem. We have not considered all the phases of it. Dr. Flanagan has touched on some aspects, Dr. Hall on others. But if one reads the chapter headings in General Armstrong's book on aviation medicine, for example, we find quite a number of stresses that were recognized ten years ago that have not been mentioned this afternoon. Surely those stresses that were experienced in military aircraft of ten years ago are going to be far more serious in the space ship. Consider the question of flying fatigue. This is not a simple phenomenon; it arises out of frequent exposure to hazards of varying intensity. General Armstrong lists, for example, anxiety and fear as contributing factors. Surely the hazards of space travel will make fatigue a serious problem here.

No one has raised the question, "What is the goal of the space ship?" Presumably, once the space ship is well beyond the earth's atmosphere, the goal is not military; we have no war to fight on the moon, nor on Mars, nor on Venus. Is it adventure? It may well be. If we consider history and try to find some analogy with setting out on a space ship for the moon, the nearest analogy that occurs to me is that of Columbus setting out for what he dared to believe was a new world. The sort of emotional problems that Columbus faced among his crew will be faced by the pilot of the first space ship. Would not fear and fatigue outweigh problems of vision, acceleration, temperature regulation, and possibly even the hazards of meteorites?

The spirit of adventure that actuated Columbus must characterize those who first man space ships. Columbus got his trip financed by lure of gold. Space ship explorers will need another motive and another basis for financial support. A realistic approach would be to look upon the space ship as a device for exploration which can add a great deal to our scientific knowledge. There is no agency other than the government that can possibly provide the resources necessary for such an adventure. Assuming such support can be obtained, let us map out the necessary fundamental research programs that must be undertaken before the goal of space travel can be realized.

As a physiologist, I would like to mention, in conclusion, two fields which seem to need thorough cultivation in order to make space travel a reality. One of those, neurology, has not been mentioned today. It is crucial to the future success of aviation within our own atmosphere, let alone space ship navigation. We need to know very much more about the human machine, about the ordinary man, not as a patient in the hospital but as an ordinary man in his everyday life.

Another field of major importance to space travel is that of metabolic research. We have not mentioned the food supply on these ships. For a group to be isolated for three or four weeks in very cramped quarters raises major problems of food supply. Would it be practical to overfeed the members of this crew for a few weeks in advance? Could they store up enough energy within their body, which, supplemented by a little carbohydrate, would carry them through? There have been no studies, no investigations of that sort. What do we know about the mental efficiency of the man who is living off his own fat? We know very well he cannot do very much work. There is no basis in scientific research from which one can determine man's ability to carry on intellectually if he is surviving on his own fat with a small supplement of extraneous carbohydrates, enough to prevent ketosis.

Atomic Defense Training

A helping hand has been extended by the U. S. Air Force School of Aviation Medicine, Randolph AFB, to the Texas State Department of Public Health whereby that agency can avail itself of the expert training in atomic defense being offered at the air medical school.

Apparently with a weather eye toward civilian defense in atomic warfare, the Texas Health Department sought, and has received, permission for six of its representatives to attend the course in radiological monitoring now offered at the School of Medicine for selected enlisted men. This two weeks' concentrated course will be offered six times before June 30, and one representative from the Texas Health Department will attend each course.

In this course students are taught how to detect and measure radiation, the use of Geiger counters and ion chambers, and photograph dosimetry.