MEDICAL PROGRESS

SPACE MEDICAL RESEARCH

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SPACE medicine, today, can look back upon a ten-year history. It came officially into being in February, 1949, with the foundation of a special department of space medicine at the School of Aviation Medicine, Randolph Air Force Base, Texas, by its commandant, Major General Harry G. Armstrong. At about the same time preparations for animal experiments in rockets were started at the Aero Medical Laboratory, Wright–Patterson Air Force Base, Dayton, Ohio. Facilities available for these grand-scale experiments, at Holloman Air Force Base, New Mexico, later became an independent institution under the name of Aero Medical Field Laboratory.

At that time space technology had advanced not very much beyond the V-2 rocket capabilities — that is, not beyond suborbital trajectories. Today, ten years later, man has seen nearly a dozen orbital rocket flights or satellite flights in a geocentric orbit, and even artificial planetoids are on their way around the sun or in a heliocentric orbit. The two basic types of astronautical or cosmic velocities — namely, orbital velocity and escape velocity — have now been attained. Their accomplishment is of historical significance.

Since the vehicles involved in the first of these ventures were unmanned, instrumented research devices, these successes were exclusively the work of space technology. The next steps of historical significance left for space technology may be a lunar, Martian or Venusian probe. At the same time, one may expect to see the first manned space flight in a suborbital trajectory, for which the rocket-powered plane X-15 has been designed, and the first manned orbital flight, known under the name "Project Mercury." There is no question that the accent is distinctly shifting from the exclusive technologic tasks to combined efforts of technology and medicine. Rocket flights with animals are paving the way in this respect. The first manned space flight will probably eclipse — as far as the historical significance is concerned — the successes with unmanned vehicles. This presents to medicine a unique challenge. This report traces the progress that space medicine has made during the past ten years to meet this challenge.

As with any new scientific field, space medicine started with theoretical considerations based on physiologic evaluations of physical and astronomic data and on medical analysis of the human body's response to and tolerance of the exotic space-flight situation.[1] These considerations were followed by experimentation in a simulated form in the laboratory, by experimental studies on animals in actual rocket flight[1,2] and in jet and rocket-propelled planes with man.[3] Much of the scientific material of the early (theoretical) phase was presented at the First International Symposium on the Physics and Medicine of the Upper Atmosphere, held in 1951 in San Antonio, Texas.[4] The present state of the knowledge and art in space medicine has been described in 44 papers presented at the Second International Symposium on the Physics and Medicine of the Atmosphere and Space, held at the end of the Geophysical Year 1958 in San Antonio.[5] They relate to space environment, propulsion systems, medical problems involved in space-flight dynamics and space cabins, and conditions on other celestial bodies.

In this article we shall confine ourselves to four broad research areas to demonstrate the progress made in space medicine: biophysics, or ecology of space; the space-cabin environment; biodynamics in space flight; and the problem of selection and training of astronautic candidates. This will be followed by a few remarks about the significance of space medical research for medical thinking and methods in general.

Ecology of Space

Space is essentially an environment of radiations of both the electromagnetic and corpuscular kinds, and they may be of solar and galactic origin. It contains very thinly dispersed gaseous matter (about 1 to 10 gas particles, mainly hydrogen in 1 ml.) and also dust particles. Furthermore, this ultrahigh vacuum is crisscrossed by meteorites of all sizes, from micrometeorites as small as white blood cells to large lumps of matter. Such is the basic environmental pattern of interplanetary space. This is in extreme contrast to the earth's atmosphere, which — near its surface — is an environment of dense gaseous matter, permeated by mild radiations and practically free of meteorites.

The knowledge of the basic properties and ingredients of interplanetary space is not enough for a medi-

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Reprinted from the *New England Journal of Medicine*
261:494-502 (September 3), 1959

cal consideration of manned flight. There are enormous regional differences in the various parts of the solar system. They represent specific danger zones and impose definite spatial limitations to astronautics. This requires a topographic approach to space ecology after the fashion of geography. For an extension of such geographic thinking into the realm of space, "spatiography" would be a suitable designation.

The first important spatiographic question is, Where above the earth's surface does Space begin? According to modern theories in astrophysics, the atmosphere as a material continuum extends to about 600 miles. In this region collisions between air molecules or atoms become very rare, and the atmosphere thins out in the form of a spray zone (exosphere) into the nearly perfect vacuum of space. But this astrophysical aspect is not relevant to astronautics and especially not to manned space flight. In this respect the cessation of the atmospheric functions and effects determine the border between atmosphere and space. At these functional borders one encounters spacelike or space-equivalent conditions regarding the various factors in question. Both these concepts — that of the *functional borders*[6] and that of *atmospheric space equivalence*[7] — were developed in space medicine ten years ago and are today in general use. They show that as low as about 12 miles the atmosphere attains, so far as its pressure functions for the human body are concerned, the equivalent of a vacuum as manifested in the so-called "boiling" of body fluids, or *ebullism.* With increasing altitude other properties and ingredients of space enter the picture, gradually, until at about 120 miles, where the last traces of air resistance disappear, the environmental picture of space is practically complete, despite the fact the the atmosphere as a continuous medium (in terms of astrophysics) reaches as far as 600 miles. But above 120 miles it is no longer effective in any respect.[8] The knowledge that the atmosphere attains at relatively low altitudes the qualities of space demonstrates that — from a medical point of view — man has already been more deeply involved in space flight than it is generally realized. The high-altitude balloon flights during recent years (made by Colonel D. Simons and M. Ross) and the last record flight of Captain Ivan Kincheloe in the rocket-powered plane, Bell X-2, up to 126,000 feet, were flights of an experimental space-equivalent type.

Now beyond the "mechanical border" of the atmosphere (120 miles) one enters the *environment of space*, with all the basic factors named above.

As already mentioned, of special interest from a medico-ecologic point of view are the deviations from the normal basic interplanetary pattern in the form of *regional variations* of both kinds of radiations, corpuscular and electromagnetic. That tremendous regional variations occur has been brought to general attention by Van Allen's[9] discovery of two particle *radiation belts* formed by the geomagnetic field. From the standpoint of manned space flight the existence of these belts over the geomagnetic equator is a matter of serious concern. Although the exact topographic intensity pattern is not known, this much can be said — that orbital flight below the 500-mile level probably will offer no serious radiobiologic problem. Whether or not repeated satellite passage through the corridor between the two belts (from about 4000 to 8000 miles) will be medically permissible requires further exploration. In more extended space operations or in deep-space operations, protective measures must be considered: to avoid the danger zones by choosing the polar regions as exit and re-entry routes, to attain higher velocities to shorten the time of exposure and to provide shielding, or a combination of two of them. This is a problem that will occupy the physicist, rocket engineer and space doctor in the coming years. The same thing is true concerning the possible occurrence of similar radiation belts around other celestial bodies, such as Venus and Mars. These localized *corpuscular radiation concentrations* seem to be more important from the standpoint of radiation hazards in space than the more or less evenly distributed omnidirectional *cosmic rays,* including their heavy components.[10]

Corpuscular rays represent only one side of the radiation environment in space. *Electromagnetic radiations,* too, offer some points for discussion, especially when one considers their regional intensity variations in the range from Mercury to Pluto. These variations, following the inverse-square law as a function of the distance from the sun, are tremendous and involve, of course, all sections of the solar spectrum — heat rays, visible rays, ultraviolet rays and so on. For instance, heat radiation as expressed by the solar constant is at the orbital distance of Venus twice, in the orbit of Mercury six times, in that of Mars a little less than half, at Jupiter's mean distance 1/27th, and in the remote regions of Pluto 1/1600th of the terrestrial value (2 g. cal./$cm.^2$ min.). It is then immediately recognized that there is a zone in the solar system in which heat radiation is not too different from that at the earth's distance and, therefore, not so hostile to space operations; on both sides of this zone, however, there are extremes. One can therefore differentiate between a *euthermal zone* (from Mars to Venus) surrounded by a hyperthermal and hypothermal region. Heat radiation, of course, has some influence upon the occurrence of water on the planets in its biologically usable — that is, liquid, form. Harlow Shapley[11] speaks of a *liquid water belt* in the planetary system.

A similar regional variation is observed with regard to light as produced by solar illumination so that one can speak of a *euphotic zone* surrounded by a hyperphotic and hypophotic region. The sky in space, of course, is black, owing to the absence of a light-scattering gaseous medium. Finally, great differences can be assumed for ultraviolet of solar radiation, as evidenced by its effect upon the planetary atmospheres. In a certain distance range from the sun these gaseous envelopes, which originally, some two billion to two and a half billion years ago, all consisted of hydrogen and hydrogen compounds such as methane and ammonia, have been transformed photochemically into oxidized atmospheres, but only in the distance range from Venus to Mars, where they form a kind of *oxygen belt* in the planetary system. All these life-favoring zones or belts lie about the same distance from the sun; they are therefore parts of a general life-supporting zone, or *ecosphere,* in the solar system. It can be assumed that this ecologic sphere extends from Mars to Venus, or to the vicinity of Venus.

To an astronomer and astrophysicist such a zonation of the space in the solar system may seem to be strange and artificial — in fact, it is somewhat artificial, but in medicine one is accustomed to think in terms of thresholds and tolerable limits; in ecology one speaks of so-called cardinal points such as the minimum, optimum, maximum and ultimum of conditions. These considerations immediately indicate certain *topographic limitations of manned space flight,* based on the tremendous *regional variations* in the *electromagnetic-radiation climate* as a function of the distance from the sun. Regarding the temperature control of a space cabin, for instance, it makes a great difference whether a space vehicle stays in the earth-moon region or whether an excursion is intended into the torrid sun near border regions of the ecosphere beyond Venus, or into the weakly irradiated space beyond Mars. The temperatures measured within the shell of the Explorer satellites were well within the physiologically tolerable range, around 25°C. But a space ship penetrating the intramercurian space would inevitably run into a kind of solar heat barrier, as symbolized by Icarus's legendary flight. And an expedition into the remote regions of the outer "permafrost" planets would require extraordinary measures for controlling cabin temperatures.

Most of these regional variations in the radiation "climate" in the solar system are not in a steady state; they show *temporal variations* as the result of variations in the activity of the sun (solar flares and eruptions associated with sunspots). The resulting temporary intensification of electromagnetic radiations, especially ultraviolet, and sudden ejections of huge amounts of ray particles (protons, electrons) represent times of increased hazards, which, as far as the particle rays are concerned, may be especially noticeable in the localized radiation belts described earlier.[12] Increased solar activity repeats itself in an eleven-year sunspot cycle; the resulting time pattern in the ecologic variations of space must be considered in schedules for manned space operations.

In the discussions about hazards in space, *meteorites* are always a favored topic.[13] The average meteoric hit probability seems to be not so high as it was formerly assumed. This has been confirmed by recordings in satellites. But here, too, one must consider regions of increased danger in the form of *meteor streams* that move in the orbits of disintegrated comets. They also show temporal variations in the form of *meteor swarms.* These meteor concentrations cannot be ignored in the topographic ecologic picture of space.

The realization that space is not a homogeneous medium but rather an environment with extreme regional and temporal variations certainly makes necessary a topographic consideration of space, as mentioned before. For an astronomer, who sits behind the telescope under a comfortable dome surrounded by fresh mountain air, such considerations are of no concern. But for the astronaut, who leaves the life-protecting and life-supporting atmosphere and ventures into space, having an ecologic spatiography, or space map, is just as necessary as it is for a captain of a ship to know sea currents, winds, routes of icebergs and the location of dangerous reefs in the vicinity of an island. The target islands in the sea of space are the neighboring celestial bodies.

We cannot discuss the *ecologic conditions on these celestial bodies,*[4] but one thing is sure — the first two astronautical targets will be the moon and Mars. In terms of terrestrial standards, the conditions on both of them are very severe, especially those on the moon. Space, with all its properties, immediately touches the surface of the *moon.* Occupants of a temporary lunar base, which is not too hypothetical to consider, will therefore need the same protection required on the journey to this airless celestial body (as discussed below). On *Mars* the environmental conditions are considerably better, but this planet is not a "second earth." The barometric conditions on its surface are similar to those in the lower region of the earth's stratosphere. This means that pressure suits will be required, or under more favorable conditions in the lowlands on Mars, oxygen equipment with pressure breathing will be sufficient for the astronaut when he leaves the sealed compartment of his ship. The conditions on Venus are still wrapped in mystery because of a dense cloud cover. On the road to this planet a space traveler might run into the outskirts of the sun's corona, into a circumvenusian radiation belt or into very high surface temperatures due to a greenhouse effect of the carbon dioxide enriched atmosphere. If Venusian probes should prove this to be true, Venus might be out of the race as an astronautical target.

Space-Cabin Climatization

As it is now generally understood, a trip to any of the target celestial bodies requires for the crew a completely *sealed cabin*. This cabin has to take care of the occupants in the same way as the atmosphere takes care of the population on the earth. It must provide all the respiratory and nutritional necessities, and protection against external factors such as radiation and meteorites.

The task of keeping a man alive and alert in such an isolated synthetic little earth, as the space cabin can be characterized, is tremendous — especially when one considers the time factor involved in extended space operations such as a flight to Mars. The complex of biophysical factors must be controlled in terms of human comfort and health and economic logistics. Two stages of control must be differentiated: control by replacement and storing or elimination or both; and control by recycling (this represents a closed ecologic system in its true sense).

The first stage is *the* method for short-time space operations, such as the Mercury project, and is based on physical and chemical methods. It includes replacement of the consumed oxygen from tanks, elimination of carbon dioxide and water vapor by chemical absorbents and storing or elimination of liquid and semisolid waste products.

The second stage will be required in space flight of long duration and includes recycling of oxygen, carbon and nitrogen in the same manner as it is observed in free nature in the process of photosynthesis. Photosynthesis is the reverse process of respiration and is therefore the logical method to counteract the change of the environment caused by respiration.

All these methods have been under extensive study in the laboratory, and some of them have been used in actual space-equivalent and space test flights.[10,14-18]

Some of the important points on the state of the art in this field may be enumerated as follows:

The first stage of environmental regeneration — by replacing and storing — was successfully applied by David G. Simons[18-20] in 1957 in a sealed gondola during a thirty-two-hour balloon flight, with altitude peaks of 18 miles (102,000 feet) in the MANHIGH project of the Air Force. Similar flights — of somewhat lower altitudes — were made by M. D. Ross and M. L. Lewis[21] in the STRATOLAB project of the Navy.

Secondly, in the space-cabin simulator of the United States Air Force School of Aviation Medicine, which was built as early as 1954,[22] a number of experiments have been carried out from a few to more than seven days' duration by Steinkamp and his co-workers[23] during the past two years (Fig. 1). This period would completely cover a flight to the moon and return, and could easily be expanded to last for a period of the order of weeks.

Thirdly, the Russian dog, Laika, was kept alive by physicochemical regenerative means in actual orbital flight for a number of days.[24]

Fourthly, concerning the second stage of regeneration — by recycling based on photosynthesis — Myers,[25] of the University of Texas, has found that about 2.5 kg. of fresh weight of the alga *Chlorella pyrenoidosa* is capable of meeting the metabolic respiratory requirements of one man. Recently, in the Department of Space Medicine, Randolph Air Force Base, Texas, another micro-organism, the alga *Anacystis nidulans* has been found to be three times as effective under conditions of light saturation. Three mice were kept alive in a small, closed ecologic system equipped with such a photosynthetic gas exchanger for more than twenty-seven days in our laboratory.

Research in this field goes on directed to finding still better strains of green micro-organisms and of attaining higher rates of light saturation under operational conditions. Photosynthetic recycling, of course, must also include metabolic nutritional factors. The first pilot studies are under way with the alga synechocystis, which can utilize urea as a nitrogen source.[26]

An interesting but hazardous by-product of photosynthesis has been discovered by S. Wilks, of the Department of Physiology at the School of Aviation Medicine: he has observed that *carbon monoxide* is produced in small amounts during photosynthesis; this might over a period accumulate to toxic quantities. Until now this was not known in botany, but a solution has already been found to counteract this danger by eliminating this hemoglobin-blocking gas by means of oxidizers such as hopcalite and potassium peroxide.

Another interesting point has recently been called to our attention by Clamann[15] in a metabolic study concerning water supply in a closed ecologic system. He emphasizes the fact that in a recycling system it is not necessary to take along all the water needed for a long trip. The human body gives off about 10 per cent more water than it takes in. These increments represent the so-called *metabolic water* produced in cellular oxidation of food. A small amount of water initially will suffice, then, because more will be produced physiologically during the trip.

These are only some of the steps of progress made in the complex of the problems involved in a closed ecologic system as it is required in space flight.

Biodynamics of Space

In the accomplishment of space flight the space craft must be launched, progress through the earth's atmosphere into space, undergo space flight, itself, in orbital or ballistic pattern, re-enter the atmosphere and, finally, be recovered from a land or water landing.

To rise above the surface of the earth to a height of 120 miles, or higher, and to attain orbital velocity, or eventually escape velocity, require an extremely great quantity of energy in the form of vertical thrust. The great kinetic energy applied at launch must eventually, and in great part, be dissipated during the re-entry phase. Thus, space flight involves the application of great thrust and high acceleration in initiating the flight, followed by prolonged periods of zero gravity as the inertial force of the space craft equalizes the gravitational force of the earth. The problems of re-entry into the atmosphere are those of decelerative forces, potentiality of buffeting and heat created by friction. Astronautical engineers have determined, theoretically, that the angle of descent is a critical consideration in manned space flight with predicted narrow margins of safety.

During the past twenty-five years aeromedical and space-medical investigators have, with great energy and ingenuity, been able to anticipate many of the problems of space flight and to simulate them in the laboratory.[27,28] Laboratory subjects and flying personnel have been studied under nearly all the stresses to which the occupant of a space vehicle might be subjected.[29-31] Accelerative and decelerative forces, resulting in high forces, have been studied at ground level in large and elaborate human centrifuges, on rocket-propelled sleds, on ejection seats and on impact swings. In these devices the rate of onset and decay of the kinetic forces can be controlled, and the biologic effects quantitated. The hyperthermia room has come into vogue as a means of assessing human tolerance to high temperatures, and other chambers have been employed to study the effects of isolation and sensory deprivation.[32] Finally, to study the unique condition of weightlessness, aircraft of suitable configuration and performance have become laboratory tools.

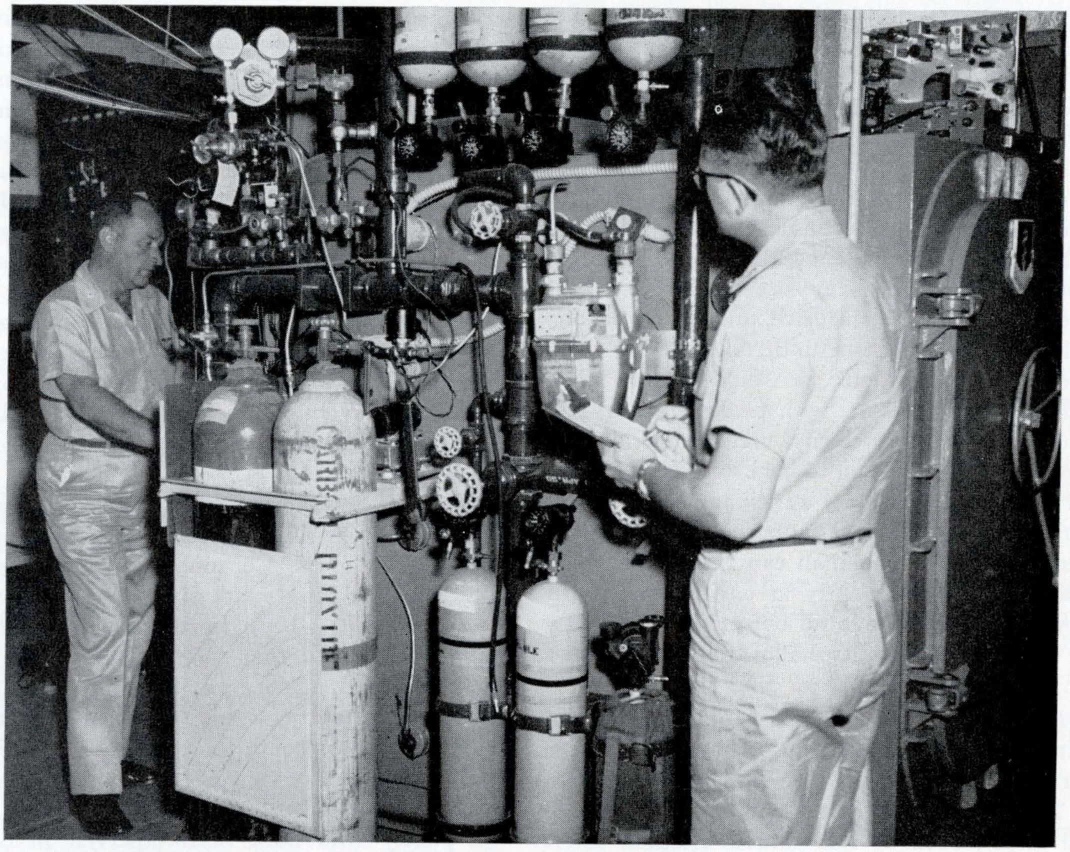

FIGURE 1. *Space-Cabin Simulator, School of Aviation Medicine, Randolph Air Force Base, Texas.*

The most recent work on the Navy Johnsville centrifuge by Clark and Hardy[33] denoted that human tolerance to acceleration is determined, not so much by the force magnitude, as by body distortion and blood shift. Tolerance is improved when displacement or distortion is prevented as by body positioning and by various forms of support. Stapp[31] has stated that "by trading off magnitude against duration, man can modulate the exposure to accelerative and decelerative forces at relatively high degrees." The body position is one of the crucial factors in human tolerance because of circulatory dynamics and stretch effects on the diaphragm and liver attachments. Several studies of the Naval Medical Acceleration Laboratory have shown that a contoured, or body-molded, support, covering much of the body, gives vastly improved support. One of their subjects withstood a peak load of over 25 g for forty seconds without evidence of "grayout" or other major effect. This laboratory and the United States Air Force Aero Medical Laboratory have tested a number of subjects under high g forces while essentially supine in a water-immersion capsule. It was concluded from these series of tests that water immersion gives twice the tolerance in the range of 3 to 20 g. Further studies on the human centrifuge of recent date disclose that 3 g can be tolerated for at least an hour after reflex cardiovascular compensatory mechanisms become established.

There is some speculation that, after prolonged weightlessness, tolerance to ensuing high g might be diminished. This was suggested after the Russian experiments employing dogs in rocket vehicles.[34] The data are meager and inconclusive, and studies involving multiple stresses must be undertaken.

Three-stage accelerations, as would occur with a three-stage ballistic missile, with peaks to 12 g, sufficient to reach orbital velocity, can be tolerated by man in the transverse front-to-back direction for the number of seconds of thrust anticipated.[29] He must be optimally positioned and supported, of course. It is the consensus, too, that man can tolerate the high decelerative forces of re-entry as envisioned for the Mercury* system and the lower but more prolonged g pattern of Dyna Soar† in its shallow angle of re-entry pattern.

Weightlessness in space flight is not a function of the distance from the gravitational center of the earth; rather, it is the result of motion dynamics in space. This dynamic weightlessness occurs when no external forces, such as atmospheric friction, interfere with the free interaction of gravitational and inertial forces of the vehicle. The atmospheric borderline between permanent dynamic weightlessness and weight is about 120 miles above the earth. On Mars this line may not be very much lower, but on the moon dynamic weightlessness is near its surface. Weightlessness in the universe seems to be the rule, and weight the exception. An astronaut in an orbiting space vehicle probably will experience weightlessness for practically the entire voyage. There is no comparable human experience in a terrestrial existence, and no simulation has ever been devised. For some purposes simulation in a swimming pool has been utilized, but the experimental limitations are great.

At the School of Aviation Medicine more than 4000 parabolic flight maneuvers have been carried out employing a large number of trained subjects.[35] Similar flights have been performed at the Aero Medical Laboratory[36] and the Aero Medical Field Laboratory.[37] A typical keplerian trajectory is flown in which the aircraft is guided along a parabolic arc.

In all our brief human experiments (lasting for fifty seconds or less) we have found no major alterations in the physiologic functions measured. The heart rate and respiratory rate and volume have been recorded, and the functions of micturition and deglutition observed.[38] Spatial disorientation and neuromuscular co-ordination have not been significantly impaired as long as the visual function was intact. Some observers have reported evidences of motion sickness in their subjects, but they used personnel unaccustomed to aerial flight and failed to distinguish the part played by zero gravity in distinction to the effect of the dive and pull-out in the over-all aerial maneuver. Spatial orientation is maintained by means of the vestibular apparatus, the mechanoreceptors and vision. They all react to external stimuli and provide information concerning the immediate environment. In space flight vision is the cardinal sense for orientation in reduced-gravity states.

Possibly, the main problem of weightlessness will turn out to be difficulty in adapting to prolonged periods of exposure. Certainly, it will be exasperating to attempt the simple task of driving a nail and find oneself recoiling with a force equal to the blow. It might be assumed that such a function as maintenance of blood pressure, in the absence of vascular hydrostatic pressure, would be taken over and regulated by a vasoreceptor or pressoreceptor. From the psychologic point of view our data are too meager for generalizations. The trained subjects (flight surgeons and pilots) who have been observed in our zero-gravity studies seem to have enjoyed the brief experience. Definitive studies on weightlessness will have to wait until more and larger satellites, containing animals and ultimately man, are placed in orbit.

Selection and Training

The National Aeronautics and Space Administration announced on January 27, 1959, that the first American destined for a flight into space was being selected. It was stated that the first astronaut would be a healthy young man under forty years of age, in superb physical condition; he would be not taller than 5 feet, 11 inches, and he must be a military test pilot and a university graduate with a degree in engineering or physical science. The records of all military test pilots were reviewed to obtain the basic roster of potential candidates from which volunteers with all the desired attributes were to be found.

The supposition is made that the first flights into

*National Aeronautics and Space Administration program for manned space flight.

†Department of Defense Advanced Projects Agency program for high-performance rocket-glide vehicles.

space will be both hazardous and stressful. Quite obviously, each candidate must be a man at the peak of his physical maturity with a physique as nearly perfect as the medical profession can select. The selection of university graduates with earned degrees in exacting but practical disciplines and the further choice of men who have sought and mastered a highly technical and dangerous vocation go far in providing men with intelligence, courage and motivation and of demonstrated effectiveness. Every advantage would have been taken of the screening processes employed by the universities and the military establishments, and the process of election or autoselection comes into play.[39]

Selection of astronauts for their future role in manned space flights is, in reality, a complex procedure that must embrace numerous areas within the field of medicine. Since not all the parameters of the space-flight situation are definitively known at this time, there is a need for criteria of medical selection, extended and refined through continuous research.

Selection of suitable men for astronautics will be based on an examination of the candidates' tolerance to the physiologic and psychologic stresses of "high-performance" flight. One quite naturally starts with the young man in obvious good health who has the basic motivation. A more searching physical examination than usual will be given initially to ensure that the candidate, in fact, is sound and in perfect health. The candidate will be tested for his tolerance to high g forces for varying periods, against pressure breathing and breath holding and against hypotensive stress; his reaction to excessive heat will be determined. An adequate test of response to reduced-gravity states is lacking at this time. We are proposing, additionally, that candidates be placed in a sensory-deprivation situation and that they be studied in a space-cabin simulator under the varied environment of isolation, pressure of half an atmosphere (advocated for the Mercury capsule), increased carbon dioxide and alterations in the day-night cycle. New test instruments to be added to the medical armamentarium are the total-body irradiation counter, the hyperthermia tester, the space-cabin simulator and the human centrifuge.

Since one of the stated objectives of the national "man-in-space" program is to investigate the capabilities of man in the new environment of space it is apparent that the early astronauts will also be pilots with important tasks to perform. They must thus be capable of making important observations and necessary decisions. It readily follows that the candidate selected must have a superior tolerance to both physiologic and psychologic stresses. We hope that the engineers will not permit encroachment on the physiologic reserves of the pilot, but rather that these capabilities will be held for the emergency situation that requires full mobilization of all bodily resources.

We have come to the point of view that training can be almost as important a consideration as selection. By adequate training we can ensure better responses under stress and perhaps improve stress tolerance.

Influence of Space Medicine on Future Medicine

We would like to close this discussion with the question, *What general knowledge and other benefits* may we gain from these space medical studies *in the interest of future medicine in general?* Undoubtedly, space medicine already has an influence on medical thinking — an influence similar to that of aviation medicine. If the various types and effects of oxygen deficiency, the interrelations between respiration, blood and circulation, the role of carbon dioxide in hyperventilation, the mechanism of syncope and so forth are better understood today it is due to the successful aeromedical research carried out during the past thirty years in high-altitude chambers and on large centrifuges. The influence of space medicine upon medicine will be still more noticeable because the ecologic and dynamic conditions encountered in space flight are much more extreme, and some are even exotic — for instance, the state of weightlessness.

It is interesting that one does not find the word *weightlessness* in textbooks on physiology, and yet in the fall reactions of cats, described therein at some length, weightlessness is involved. It was overlooked until space medicine called attention to it. Under weightless conditions, in which the hydrostatic pressure of the blood is absent, one learns more about hemodynamics. By eliminating gravity one understands better the exteroceptive and proprioceptive functions of the mechanoreceptors and "gravireceptors," such as the otolith organ, nerve endings in skin, muscles and connective tissue, under normal gravitational conditions and their abnormal functions in pathologic cases. The physiologic studies about the effects of *extreme g forces,* carried out on rocket-powered sleds,[31] have not only provided the knowledge of how to cope with the dynamic conditions during launching and atmospheric re-entry, they are also of greatest value for the analysis of mechanical injuries and protection in all kinds of traffic accidents on the earth's surface.

The study of the biologic effect of *cosmic rays* upon tissue in ultra-high-altitude balloons has already considerably increased knowledge about the microscopical picture of the impact of these ionizing radiations.[12,40] Now Van Allen's discovery of two radiation belts surrounding the earth, consisting of protons and electrons that may produce x-rays in the space cabin's hull, calls for a large research program.

That the results of these studies, which will concentrate upon the mechanism of the biologic effect, shielding and permissible doses, will be of interest for every physician does not need to be emphasized.

In space-cabin simulators we study more than ever before details in *metabolism* and nutritional requirements of the human body, the *physiology of the day-night cycle* and the *psychophysiology* of *sensory deprivation* and *confinement*.[32]

New *methods* are being developed to control the various physical factors of the environment in the space cabin and to record the electrocardiogram, electroencephalogram and body temperature. Because of the tight economic logistics in space operations, all have to be based on *minimization in weight* and *miniaturization in volume,* and the data must be sent down to earth by means of *telemetry.* Hospitals will benefit from this *astroinstrumentation.* It may soon be possible for a physician to send the electrocardiogram via communication satellite to a distant heart specialist for consultation. Also, for reasons of economic logistics, *multiple-purpose equipment* is required in space flight; developments along this line may also find useful application in tropic and arctic survival equipment.

As shown by these examples, then, space medicine will contribute not only to the realization of space flight but also to medicine in general.

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