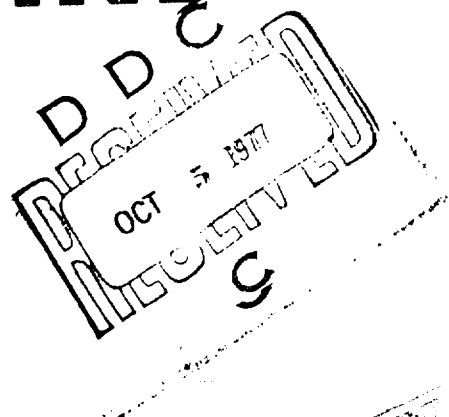
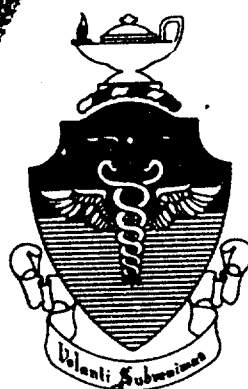


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VOLUME 1

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HUBERTUS STRUGHOLD, M.D., Ph.D.

USAF SCHOOL OF AEROSPACE MEDICINE
AEROSPACE MEDICAL DIVISION (AFSC)
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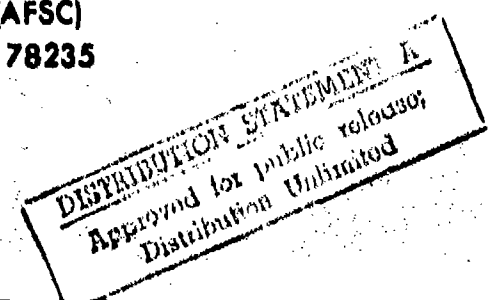
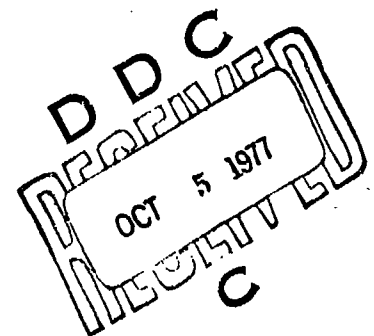
COMPENDIUM OF AEROSPACE MEDICINE

VOLUME 1

Hubertus Strughold, M.D., Ph.D.

Published July 1977

USAF School of Aerospace Medicine
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235



PREFACE

On 19 January 1977 the Aeromedical Library in the USAF School of Aerospace Medicine, Aerospace Medical Division, Air Force Systems Command, Brooks Air Force Base, Texas, was renamed the "Hubertus Strughold Aeromedical Library" in special ceremonies honoring the retired chief scientist of the Aerospace Medical Division. Dr. Strughold is a pioneer in aviation medicine and has earned the right to be called the "Father of Space Medicine."

The library, built in 1963, houses medical, technical, and scientific works that are required for the research and teaching programs at the USAF School of Aerospace Medicine. With over 107,000 volumes and 1,900 current journals, the facility is the largest medical library in the Air Force.

To commemorate the rededication of the library, this compendium of previously unpublished papers of Dr. Hubertus Strughold has been compiled. The collection will serve as a valuable resource to students of aviation medicine.



ROBERT G. MCIVER
Brigadier General, USAF, MC
Commander
USAF School of Aerospace Medicine

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HUBERTUS STRUGHOLD, N.D., Ph.D.

HUBERTUS STRUGHOLD, M.D., Ph.D.

BIOGRAPHY

Hubertus Strughold was born in Westfalia, Germany, on 15 June 1898. He studied medicine and natural sciences at the Universities of Muenster, Goettingen, Munich, and Wuerzburg and received his Ph.D. degree from the University of Muenster in 1922. He received his M.D. degree from the University of Wuerzburg the following year.

After receiving his degrees, Dr. Strughold served as research assistant to Professor Max von Frey at the Physiological Institute in Wuerzburg until 1928. Specializing earlier in aviation medicine, Dr. Strughold gave the first lecture ever on that subject in 1927 at the University of Wuerzburg. When he told his students that thousands of people would be flying across the Atlantic in ten years, they laughed. But they stopped laughing ten days later when Charles Lindbergh made his historic flight across the Atlantic.

As a Fellow of the Rockefeller Foundation from 1928 to 1929, Dr. Strughold performed research at Western Reserve University in Cleveland, Ohio, under Professor Carl Wiggers, and at the University of Chicago under Professor A. Carlson.

From 1929 to 1935, Dr. Strughold was research assistant and associate professor in Physiology and Aviation Medicine at Wuerzburg. He was director of the Aeromedical Research Institute in Berlin and associate professor of Physiology at the University of Berlin from 1935 to 1945.

After World War II, Dr. Strughold became professor of Physiology and director of the Physiological Institute at the University of Heidelberg. In 1947, he accepted an invitation to join the staff of the USAF School of Aviation Medicine at Randolph Field, Texas, and has been active in the Air Force aerospace medical program ever since.

Major General Harry Armstrong, then a colonel and commandant of the School of Aviation Medicine, created the Department of Space Medicine, with Dr. Strughold in charge, in 1949. This department was the result of General Armstrong's realization that jet and rocket aircraft were taking men into a region so far above the ground that it was physiologically indistinguishable from space.

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During the next eight years, the Department of Space Medicine started the medical groundwork for the man-in-space program which was adopted as a national policy of the United States. The first studies of the environmental effects of space travel were conducted at the Department. At Dr. Strughold's suggestion, the Department also designed and built to his specifications the first space cabin simulator, which was in effect a laboratory prototype of a spacecraft similar to those used for the space program.

In 1951, the Air University, which included under its command all the educational functions, conferred the academic title Professor of Aviation Medicine on Dr. Strughold. It named him Professor of Space Medicine in 1958. He is still the only person to be so honored, and for this reason he is often referred to as the "Father of Space Medicine."

Dr. Strughold became a naturalized citizen of the United States on 20 July 1956.

From 1957 to 1962, Dr. Strughold held the position of Adviser for Research at the School of Aviation Medicine, USAF, Randolph AFB, and at the newly formed Aerospace Medical Center, Brooks AFB, Tex. In 1960, he was assigned the additional duty of chairman of the Advanced Studies Group at the Center.

When the Air Force Systems Command organized the Aerospace Medical Division (AMD) in 1962 to supervise the conduct of aerospace medicine research for the Air Force and in support of the national space program, Dr. Strughold became chief scientist of the new organization. Throughout his career with the Air Force, Dr. Strughold exerted a great deal of influence on research of the medicobiological problems encountered in the "vertical frontier."

Dr. Strughold held the position of chief scientist at AMD until his retirement in 1968. At that time, he was named honorary consultant to AMD.

Dr. Strughold is the author and coauthor of several books. Perhaps the best-known of these is *Your Body Clock (Its Significance for the Jet Traveler)*, which deals with the effects of travel across time zones and in space on the body clock. He also wrote *The Green and Red Planet: A Physiological Study of the Possibility of Life on Mars*, and he co-authored the textbook, *Principles and Practices of Aviation Medicine*. He was coeditor of the book, *Physics and Medicine of the Atmosphere and Space*, and has authored over 180 professional papers on physiology, aviation medicine, and space medicine.

BIOGRAPHY OF HUBERTUS STRUGHOLD

Dr. Strughold is responsible for many of the terms used daily in the field of aerospace medicine. These terms include "bioastronautics," which concerns itself with the effects of space travel on man; "gravisphere," the area within which the gravitational field of a body is dominant; and "astrobiology," the study of the forms and phenomena of life on celestial bodies.

Notable scientific contributions by Dr. Strughold include the following:

- a. Effects of global flight on the day-night cycle of the human body.
- b. Levels of the Earth's atmosphere where conditions are comparable to those in space (known as "atmospheric space equivalence," another term coined by Dr. Strughold).
- c. Regions favorable to life in the solar system ("ecosphere," another of his terms).
- d. Studies of Earth organisms under simulated Martian conditions.
- e. Development of a geography of space ("spatiography," yet another term coined by Dr. Strughold).
- f. Visual problems in space flight.

Dr. Strughold has been the recipient of numerous professional awards and honors. For his pioneer research in space medicine, he received the Herman Oberth Medal of the German Rocket Society in 1954; the Theodore C. Lyster Award of the Aerospace Medical Association in 1958; the Exceptional Civilian Service Award, presented by Secretary of the Air Force James H. Douglas, Jr., in 1958; and the John J. Jeffries Award of the Institute of Aeronautical Sciences in 1959.

He was also awarded the Melbourne W. Boynton Award of the American Astronautical Society, Inc., in 1964, and several other awards from Yugoslavia, Sweden, and Hungary, as well as the United States.

In 1970 the editor of the *Mark Twain Journal* conferred the title "A Grand Knight of Mark Twain" on Dr. Strughold in recognition of his outstanding contributions to modern medical science.

SPEECH PRESENTED AT DEDICATION OF
STRUGHOLD AEROMEDICAL LIBRARY
19 January 1977

Hubertus Strughold, M.D., Ph.D.

General Dettinger, General Unger, General Elect McIver, members of the Aerospace Medical Division, and guests. This dedication of the Aeromedical Library is the greatest honor in my life. I am very grateful to those involved in planning this dedication and all of you here present. Now I would like to give a few historical personal remarks about certain facts which are not so well known.

It was General Harry G. Armstrong who extended aviation medicine into space medicine by creating a special department in 1949 and appointing me as chief of it. This new field attracted numerous young medical scientists who have later made great contributions to its progress. General Armstrong and General Otis Benson started the First International Symposium on Bioastronautics, thereafter held every four years, that gave Brooks Aerospace Medical Division an international reputation. They attracted the visits of famous scientists and engineers including Dr. Weinher von Braun.

At this point, I would like to mention a personality outside the Air Force who was the promoter of the United States exploration of space--Lyndon B. Johnson. He was the politician in Washington who visited the laboratories of the School of Aviation Medicine, and encouraged the spirit of the medical researchers in their "out-of-this-world" experiments.

Many of you remember his presence at the end of Airman Farrell's eight-day experiment in the first space cabin simulator in 1958. In the same year, the then Senator Lyndon B. Johnson, in a letter thanking me for articles in the development of space medicine, stated, "I must say that rarely have I encountered a field of scientific endeavor more interesting than this one in which you played so outstanding a part nor is there any field of more immediate concern to our country and to the world as we enter the age of space."

Now back to the collection of the aerospace-related literature. This library of the School of Aerospace Medicine, opened in 1963, is a fountain of knowledge about the past, the present, and the future of man's advance on the vertical frontier. Its excellence is essentially due to the fine work of the library staff, of the librarians; or more to the point, the "librarianesses." In addition to the fundamental

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terrestrial global aviation medicine, space medicine, and lunar medicine, this library of progress might include Mars medicine at the end of this century, which makes it an interplanetary library.

At this point, or in this connection, I would like to mention some experiences with the famous Walt Disney. On a trip to Europe in 1957 on the ocean liner Queen Mary, I had the honor to meet the famous science fiction and movie producer Walt Disney. He asked me to inform him about the research in the Division of Space Medicine in Texas. At one point, he said, "I am now 54 years old; maybe I can work five years or ten years. I have seen so many discoveries and inventions during my lifetime that if somebody tells me that during my still coming lifetime somebody flies to the moon, damn, I believe it." Two weeks later the first satellite was in orbit. Walt Disney died ten years later. He had not seen a flight to the moon, but he witnessed the preparation of it. It was Walt Disney who had made the general public space minded.

In conclusion, just the same as this library has all of NASA's Apollo flight records, it will be able to collect in the next century the biomedical manned Mars flight data. Manned flight for Mars will become a reality. It will be the only interplanetary expedition. But books about manned interstellar flight will always be a matter of speculation. All of this is, so to speak, the whole spectrum of biomedical cosmology, which is reflected and will be reflected by the literature in this great library. I thank you very much. God bless you and your body clock.

FROM AVIATION MEDICINE TO SPACE MEDICINE*

Hubertus Strughold, M.D., Ph.D.

Space Medicine, for the first time, appears with a special program of papers on the public platform of a scientific society--the Aeromedical Association. For this reason, it would seem most appropriate that the program begin with a few introductory remarks. It is indeed a great pleasure and privilege that this task has been delegated to me.

At first glance, Space Medicine appears to many people as a capricious or whimsical idea in Aviation Medicine. However, upon closer examination, it proves itself to be a very logical step of development. We gain a better understanding of its scope and meaning if we view it from a historical standpoint, starting with the predecessors of Aviation Medicine.

Aviation Medicine, developed 40 years ago, benefited by the experiences gained in high mountain physiology. As a science, high mountain physiology is nearly 100 years old. Mountain sickness, however, was first described in 1588 by Jose de Acosta. The first inkling of this uncomfortable effect of thin air can be traced back to Greek literature since it was Aristotle who observed that men could not live on the top of the 10,000-ft Mount Olympus in Thessaly without breathing through a wet sponge. So, high mountain physiology, with all its descendants, had its birthplace on a holy mountain dedicated to Zeus or Jupiter.

In the 20th Century, it was logical that Aviation Medicine in its first years was more or less concerned with problems such as cadet selection, reaction time, orientation, and crashes. A look into the first volumes of the Journal of Aviation Medicine proves this. However, in a short time interest in higher altitudes increased more and more. Experiments in low-pressure chambers and explosive decompression chambers opened the way into the Tropopause and Stratosphere. Extreme explosive decompression experiments and the medical evaluation of the balloon flight of the Explorer II already touched the area of Space Medicine. Because of the accomplishments of Aviation Medicine, aviation had reached a very high level in safety, efficiency, and comfort. Only high-powered propeller planes and jet planes could still bring some progress in speed and high-altitude flying.

It was in this situation that the first rocket appeared in the sky and, within 5 years, exceeded all altitude records by twenty times. This

*Presented at the meeting of the Space Medical Association during the annual meeting of the Aeromedical Association, Washington, D.C., 17-19 Mar 1952.

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was not only a signal for the engineering world, but a challenge to all sciences concerned with the human factor. This new, revolutionary development becomes quite clear when we review the records of altitudes reached during the past 150 years by means of the balloon, airplane, and rocket. The balloon and airplane, both depending on air, are--in a way--confined to two-dimensional movement in the horizontal plane around the globe; whereas, only the rocket has really conquered the vertical, the third dimension, moving away from the Earth. Considered from a global point of view, this shift in dimensions is the most conspicuous mark in the new development of flight. A new frontier has now been opened--the "vertical" frontier.

The vertical extent of the ultimate operational limits of propeller, jet, and rocket craft is: for propeller-driven planes, about 18 km or 55,000 ft; for jet planes, about 25 km or 75,000 ft; and for rockets, no limit.

In regard to speed, propeller-driven and jet planes attained velocities in the neighborhood of the speed of sound. Rockets have no speed limit.

For conventional planes, including jets, the limiting factor in height and speed is the atmosphere. However, in the realm of the rocket, flying is no longer dependent upon air as a supporting medium. Thus, the factors with which we must deal in rocket flight are not properties of the atmosphere, but rather attributes of free space.

For this reason the creation of a new branch of Aviation Medicine--namely Space Medicine--was a logical step and a daring one. In anticipation of this development, a special department--the Department of Space Medicine--was founded in 1949 by Major General Harry G. Armstrong, then a colonel and commandant of the USAF School of Aviation Medicine at Randolph Field, Texas, which place can now be claimed as the birthplace of Space Medicine. Other laboratories also began to study similar problems about this same time.

The first open discussion in this field of Space Medicine was started at two earlier meetings; one called by General Armstrong in 1948 at the USAF School of Aviation Medicine at Randolph Field, Texas, and another planned by Drs. Andrew Ivy and John D. Marbarger in 1950 at the University of Illinois in Chicago.

At the 1950 meeting of the Aeromedical Association in Chicago, the creation of a Space Medicine branch was proposed; and at the 1951 meeting in Denver this branch was established with Colonel Paul A. Campbell as its first chairman. The foundation of this branch was a necessity so that we could have a medical counterpart of the various Rocket Societies, Space Flight Societies, Astronautical and Interplanetary Societies, which are exclusively technical in nature. It must be acknowledged that these societies, which exist in more than half-a-dozen countries, have shown great activity and success during recent years. The human factor in space flight, however, is as important as the technical factor.

FROM AVIATION MEDICINE TO SPACE MEDICINE

Today, the Space Medical Branch of the Aeromedical Association offers a special program. Now, Space Medicine is no longer the diffuse area which it may have appeared to be a few years ago. The scope of its problems is now clearly defined. They have been clarified by the introduction of a new concept of the boundaries between the atmosphere and space, based on the function which the atmosphere has for man and craft. This functional consideration demonstrates that at relatively low altitudes the various functions of the atmosphere cease, one after the other. Consequently, the various space factors take over. Such levels are properly called space-equivalent altitudes. In mentioning only a few of them, we meet space-equivalent conditions with regard to:

Anoxia at 16 km or 52,000 ft;

Body fluid boiling at 19 km or 65,000 ft;

Heavy primaries of cosmic radiation at 30 km or 120,000 ft;

Ultraviolet solar radiation at 45 km or 135,000 ft;

Optical appearance of the sky at 135 km or 400,000 ft; and

Meteors at 140 km or 500,000 ft.

It may be added that only the Earth with its bulk, its magnetic field, and its radiation, modifies some of these conditions, making them different from those found at greater distances.

Space-equivalent stages within the atmosphere must be considered in regard to the necessity for sealed cabins, and also with regard to pure radiation climate above a certain altitude. Further, conditions characteristic of space originate in the motion of the craft; here, weightlessness is the most outstanding phenomenon.

This approach, based on a functional concept of the atmosphere, clearly indicates that a differentiation must be made between two distinct regions of the physical atmosphere: the lower section is the realm of conventional flight where the properties of the atmosphere can be utilized; the upper section (beginning as low as 50,000 ft), where the functions of the atmosphere gradually become ineffective, has many properties in common with free space. It is indeed amazing to observe that various environmental factors of space penetrate down to rather low altitudes. The usable portion of the atmosphere is a very thin shell. The so-called upper atmosphere of the physicist is equivalent to free space, for all practical purposes.

A symposium on the physics and medicine of the upper atmosphere was held in San Antonio, Texas, in November 1951. This meeting, which was planned by Brigadier General Otis O. Benson, Jr., Commandant of the USAF School of Aviation Medicine, and Dr. Clayton S. White, of the Lovelace Foundation, must be considered an important step toward clarifying the

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medical problems involved in flight in the highest strata of the atmosphere, where the various benefits derived from the presence of air fall short. The problems of flight in this area are different from those encountered in the lower sections of the atmosphere and, to some extent, from those encountered in free space. For this reason, the area was designated by a special term, namely "aeropause." In a way, flight at present is in an amphibian stage, in a phase of transition between conventional aviation and future space flight.

The technical development clearly points to the final conquest of free space. We must be prepared to meet the necessities of this day. The field of Space Medicine must be furthered in time to eventually cope with the human problems which will most certainly arise.

DEFINITIONS AND SUBDIVISIONS OF SPACE:
BIOASTRONAUTICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

Whenever matters of astronautics are discussed, the word space is used in a great variety of ways, such as outer space, deep space, free space, interplanetary space, cosmic space, and so on. But space is an immensely vast area even within our solar system and its environmental conditions are by no means uniform. We need an exact definition of what is meant by these terms, where above the Earth's surface does space begin, and what subdivisions of space may be conceivable and practical. In brief, we now need a kind of "geography of space"-- what we might call spatiography. This term refers, of course, only to the space itself between the celestial bodies. The description of the environmental conditions on the planetary bodies is called planetography, of which geography (Earth), areography (Mars), and selenography (Moon) are special cases. Both spatiography and planetography are subdivisions of an all-embracing cosmography. In the following we shall confine our discussion to the "empty" space of the solar system based essentially on space medical considerations or on bioastronautics. A spatiography of this kind may also be useful for other aspects of astronautics such as space technology and space law.

The first and perhaps the most important question that interests us is: Where above the Earth's surface does space begin? According to theories in astrophysics, the atmosphere as a material continuum extends to about 1000 kilometers, or 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 determines the border between atmosphere and space.

As low as 15 km (about 10 mi) and 20 km (12 mi), the atmospheric pressure functions to provide the lungs with oxygen and to keep the body fluids in the liquid state are no longer effective.

At about 25 km (16 mi) the air, due to its low density, can no longer be utilized for cabin pressurization; instead, we need a sealed cabin, the same type as is required in space.

*Discussion remark at the Colloquium on "The Law of Outer Space" in the Chamber of the House of Parliament, the Hague, at the IX Annual Congress of the International Astronautical Federation, 29 Aug 58.

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At 40 km (24 mi) we are beyond the region of absorption for cosmic rays.

The same is true at 45 km (28 mi) concerning ultraviolet of solar radiation.

The 50 km (30 mi) level is the limit for aerodynamic lift and navigation even for the fastest winged craft.

At about 100 km (60 mi) the rarified air ceases to scatter light and to transmit sound, resulting in the strange darkness and silence of space.

At 120 km (75 mi) we are beyond the meteor-absorbing region of the atmosphere.

This is practically also the aerodynamic heat limit.

And, finally, at about 200 km (120 mi) air resistance approaches zero. This mechanical border of the atmosphere is its final functional limit. At this altitude the "appreciable" or effective atmosphere terminates.

For the whole atmospheric range within which the various atmospheric functions for manned flight cease, the term "aeropause" has been suggested.

We can also explain the environmental situation in this region by saying that with the vanishing of its functions the atmosphere becomes partially space equivalent at 15 to 20 km and progresses step by step to total space equivalence at 200 km as far as the effectiveness of the atmospheric functions is concerned.

Three of these steps on the ladder to space, or in the intra-atmospheric space-equivalent region where atmosphere and space overlap, deserve special attention.

1. The physiological zero line of air pressure at about 20 km (12 mi) at which the environment for the unprotected human body attains the equivalent of a vacuum;

2. The technical zero line for useful aerodynamic lift and navigation by control surfaces at 50 km (30 mi). Above this line we deal exclusively with ballistics, and navigation by control surfaces has to be replaced by reaction control. This altitude is considered by some law experts the limit for national authority over the airspace; and,

3. The mechanical zero line of air resistance at about 200 km (120 mi). Here we enter the region of the "Kepler Regime" where the

DEFINITIONS AND SUBDIVISIONS OF SPACE

laws of celestial mechanics, unhindered by air resistance, are fully effective. It is here where space in its connotation "outer space" actually begins.

Such is the picture of the border between atmosphere and space based on a physiological and technological analysis.

For astronomical purposes, what are the possibilities of subdividing the void of our solar system beyond the Earth's mechanically effective atmosphere?

At first glance it may seem strange to draw borderlines or demarcation lines in an environment in which emptiness is the rule and concentrations of matter, in the form of celestial bodies, are the exceptions. However, space can be subdivided in several ways on the basis of environmental-ecological, gravitational, and topographical astronomical considerations.

First, of vital interest to the astronaut, are the environmental-ecological differences in the environment of space itself, before he considers the celestial bodies.

To begin with, the space environment in the vicinity of celestial bodies is different from that in free interplanetary space. It shows some peculiarities caused by the mere presence of their solid bodies, by optical properties of their surfaces, and by forces originating in these bodies and extending into space.

In the vicinity of the Earth, for instance, on one side we are protected from cosmic rays and meteorites by the solid body of our globe itself--just as we are protected on one side of a house against rain, hail, or wind. Other peculiarities of the space environment near the Earth are its shadow, its own radiation, and reflected solar radiation, which influence the heat balance of a space vehicle and pose special visual problems.

The forces which cause special regional environmental differences in the space near the Earth are those of the geomagnetic field. The magnetic field of the Earth strongly influences the influx of corpuscular rays of solar and cosmic origin by channeling them into the polar regions and storing them or deflecting them back into space over the equatorial regions. The polar lights and the high intensity radiation belts, above 600 miles over the magnetic equator, recently discovered by James Van Allen by means of the Explorer Satellites, are manifestations of this geomagnetic influence upon the density distribution of ray particles in Earth near space.

For all these reasons, space in the vicinity of the Earth is distinctly different from open interplanetary space. If we wish to

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emphasize this fact, we might use for that region in which the Earth's influence upon the environmental-ecological qualities of space is distinctly recognizable the designation circumterrestrial space. The same consideration applies more or less to the other planets and the moons (for instance, circumlunar space). For the circumterrestrial space, or nearby space, we might assume an extension up to 5 Earth radii, depending on the outer boundary of the great radiation belt. Beyond this region we may speak of deep space.

In a certain respect, however, the Earth's influence reaches much farther into space than explained above. The factor in question is gravitation, the environmental dynamical substrate for space navigation.

Theoretically, the gravitational field of the Earth, as of every other larger celestial body, extends, of course, to infinity in terms of celestial mechanics; but the astronaut is especially interested in those areas in which the gravitational force of a celestial body prevails over those of other celestial bodies. In the astronautical literature they are known as spheres of gravitational influence. We might call them, briefly, gravispheres.

The gravisphere includes the potential satellite sphere, which in the case of the Earth reaches as far as about one and one-half million kilometers or nearly one million miles. This is the reach of the Earth's satellite holding power. Beyond this distance at which interplanetary space begins the gravitational field of the Sun becomes predominant for a space vehicle, and the Earth can exert some influence upon it only in the form of disturbances. The potential satellite sphere of our Moon, according to Oskar Ritter, extends to about 60,000 km from its center; that of Venus 1 million, and of Mars one-half million km; Jupiter's potential satellite sphere is more than fifty million km in radius.

The first order gravisphere in our solar system is, of course, the gravitational empire of the Sun, which blends far beyond Pluto with the gravitational no-man's-land between the stars. As second order gravispheres then can be considered those of the planets, and as third order gravispheres, those of the moons, the smallest gravitational provinces in our solar system. Thus we arrive at a subdivision of space based on the extension of the gravitational territories, or domains, of the various celestial bodies.

This dynamographic aspect of space may be useful for a better understanding of the nature and spatial extension of satellite flight and (gravitational) escape operations such as lunar, interplanetary, and planetary space flight.

But, we can subdivide space on still a larger scale based on intensity variations of solar electromagnetic radiation as we encounter

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them in interplanetary space when travelling through the whole planetary system from Mercury to Pluto; in other words, as we observe them as a function of the distance from the Sun. Because this function follows the inverse square law, these variations are very extreme and they involve, of course, all important portions of the solar electromagnetic spectrum (heat rays, light, and ultraviolet rays). In fact, we would not go too far by speaking of a zonation of interplanetary space in this respect, an analog to the torrid, temperate, and cold zones in the Earth's climate.

Such line of thinking leads to the assumption of a zone which is not too hostile to space operations and in which the conditions on planets are compatible with the possibility of life as we know it. This zone may extend from the region of Venus to Mars and can be called 'ecosphere of the Sun. A further discussion of this ecological subdivision of the space within our solar system, however, and also that of a topographical astronomical subdivision of space (such as cislunar, translunar space (Krafft Ehrlicke), interstellar, intra-galactic, and intergalactic space) goes beyond the scope of this symposium.

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BIBLIOGRAPHY

1. Buettner, K., and H. Haber. The aeropause. Science 115:656-657 (1952).
2. Cooper, J. C. High altitude flight and national sovereignty. International Law Quarterly 411:417-418 (1951).
3. Haber, H. Man in space. New York: Bobbs-Merrill, 1953.
4. Haley, A. G. Current international situation and the legal involvements with respect to long range missiles and earth circling objects. In Vistas in astronautics, pp. 310-323. New York: Pergamon Press, 1958.
5. Haley, A. G. International cooperation in rocketry and astronautics. Jet Propulsion 25, No. 11 (1955).
6. Schachter, O. Who owns the universe? In C. Ryan (ed.). Across the space frontier, pp. 118-131. New York: The Viking Press, 1952.
7. Strughold, H., H. Haber, K. Buettner, and F. Haber. Where does space begin? Functional concept at the boundaries between atmosphere and space. J Aviat Med 22:342-349 (1951).
8. Strughold, H. Space equivalent conditions within the atmosphere. Astronautica Acta 1:32 (1955).
9. Strughold, H. The ecosphere of the sun. J Aviat Med 26:323-328 (1955).
10. Welf, Prince Heinrich von Hannover: Luftrecht und Weltraumrecht, Doctoral Dissertation submitted to the faculty of Law and Political Science at the George August University of Goettingen, 1953.
11. White, C. S., and O. O. Benson. Physics and medicine of the upper atmosphere, a study of the aeropause. XXIV, p. 611, Univ. of New Mexico, Albuquerque, 1952.

SPACE MEDICINE OF THE NEXT DECADE AS VIEWED BY A
PHYSICIAN AND PHYSIOLOGIST*

Hubertus Strughold, M.D., Ph.D.

I feel very honored to open the series of discussions of the proto-members of the Department of Space Medicine--Dr. Heinz Haber, Dr. Konrad Buettner, and Dr. Fritz Haber--on Space Medicine Within the Next Decade as Viewed by a Physician and Physiologist.

Crystal-ball gazing is always a matter like this: it can include the following approaches or features--logical extrapolation, imagination, speculation, fantasy, and illusions. A sound crystal-ball gazing must, of course, contain a dose of horse sense. In my space medical crystal-ball gazing, I will try to keep the predictions within the limits of logical extrapolation, imagination, and horse sense.

Basically, the time table in astronautics will be determined by the physical sciences, technology, and the rocket industry. The predictions made from this point of view are usually realistic and therefore dependable; even so they, too, occasionally become outdated unexpectedly by so-called breakthroughs in one field or another, in this or another country.

Recently the Select Committee on Astronautics and Space Exploration of the House of Representatives published quite a collection of the predictions of 56 scientists, engineers, industrialists, military officials and government administrators on the next 10 years in space. These predictions ranged from new shock-producing surprises to ultraconservative opinions. In these statements manned space flight played an important role, and this is the area where space medicine enters the picture.

In a life science, such as space medicine, the predictions that follow a strict timetable are somewhat strange. This is especially true since the pace of the advance on the ladder into space in the first place will be determined in the technological sector of astronautics--as has already been mentioned. We in the medical sector must carefully consider the various kinds of space operations, the pertinent types of vehicles, and the propulsion methods and their thrusts that are proposed by technology. From a medical point of view, we must then have a sense for estimating their usages and their limitations, and must develop a research program that can improve the usages and shift the limitations. Only in this sense then do I dare to make some predictions from the point of view of space medicine.

*Presented at the Tenth Anniversary Commemoration of the Founding of the Department of Space Medicine, at the USAF School of Aviation Medicine, Randolph Air Force Base, Texas, 9 Feb 1959.

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A brief review of space medicine in the next 10 years can, essentially, be only a consideration of what should be done and what actually can be achieved during this period of time to further man's advance on the vertical frontier. I would like to mention that some of the research that will be done during this time will not bear fruit until perhaps 20 years from now, or even later.

Space medicine, like aviation medicine, belongs in the category of industrial and environmental medicine. Its industrial medical tasks are centered around the launching sites which exhibit all the hazardous features of a giant factory; hazards such as dangerous fuels accumulated en masse, noise, tight time schedules during countdown, etc. At present we are concerned principally with the toxicity of classical liquid fuels and the characteristics of the propellants for the so-called first generation of rockets. They will be replaced by exotic fuels in different stages of aggregation. In 10 years semisolid and solid fuels will be one of the concerns of the doctor assigned to duty on launching sites such as Cape Canaveral or Vandenberg. The Minuteman rocket is the best known representative of this development. With this evolution of propellants, space medical toxicology will become exotic.

As an environmental science, space medicine encompasses a much greater area of interest: the biophysics of the environment of space; the artificial environment to be created in the cabin; and the biodynamics of the vehicle moving to, through, and returning from the environment of space.

Concerning the biophysics or ecology of the space environment, its basic biocidal quality is generally understood. Within the next 5 years much of the exploratory efforts will be devoted to the study of the topographical and temporal environmental variations or differences in space. They can present specific danger zones or time periods of increased hazards for manned space operations. Several years from now we will have sufficient knowledge about the topographical intensity distribution of J. Van Allen's great radiation belt for biological evaluation. Even now it can be said that--for safety reasons--the arena for manned satellite operations will be only 500 miles wide reaching from 120 to about 600 miles. The two cores of the radiation belt will be off limits for manned space flight; whether or not orbiting through the corridor between them, i.e., between 4,000 and 8,000 miles, is medically permissible will be a matter of navigation precision and further exploration.

In contrast to these nearby space operations, this great radiation belt will pose even greater difficulties to deep space operations. Nearby space can be defined as that region within which the Earth's influence through its solid body, its atmosphere, and especially through its magnetic field upon the ecological qualities of space, is distinctly recognizable. Beyond this region--determined by the outer boundary of the great radiation belt--we enter deep space. It blends with interplanetary space at a distance of about one million miles, the region of the gravitational divide between

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the Earth and Sun. Manned deep space operations, whether with subescape or escape velocities, will probably be achieved around the end of the next decade. Before this, with regard to the great radiation belt, we should know what protective measures must be taken: evasive action through the polar regions, higher velocity, and shielding; a combination of all of them, or a combination of some of them. In deep space operations, the knowledge of meteor streams will also become important and must be explored by deep space probes. The results of all these probes will enable us to draw up a space chart or space map of the biophysical conditions encountered in the void between us and other celestial bodies. Such an ecological cartography of space, or briefly spatiography, will--to a great extent--be based on considerations concerned with hazards for the crew and will eventually become routine teaching material at universities and high schools. For astronautics, advance knowledge of all of this is equally as important as the knowledge the captain of a ship must have about the wind and water currents, the routes of the icebergs and the cliffs in the ocean on his way to an island.

The target islands in space are the Moon, Mars, and Venus--the latter a question mark. Venusian probes within the next 10 years will have cleared the question--whether or not in the direction of Venus we run into the outskirts of the solar corona, and whether or not the temperature on Venus reaches biocidal levels due to a greenhouse effect in its carbon dioxide enriched atmosphere, as G. Kuiper believes it to be. Concerning Mars, probably the only sure target planet for exploration, we still do not know if it is a red and green planet, i.e., are the green areas real or a visual contrast phenomenon? Only from a distance of a quarter of a million miles are such dark areas as the Syrtis Major large enough to be recognized in their true color by the unaided eye. Green or not green, it does not exclude the possibility of life on Mars. By the way, in the future, all astronomers should have their color vision examined; also the astronaut should have normal color vision so that the information he brings or sends back on the optical world in space is reliable.

Space medicine will also have a word to say in the evaluation of increased solar activity, which is the essential cause of temporal variations in the particle and electromagnetic radiation climate. With them the solar 11-year cycle enters the program of scheduling space operations of both nearby and deep space operations.

But the principal field of work for the space doctor is not the physiological evaluation of the external environmental factors, rather it lies inside the space cabin, to create an intracabin environment which meets the climatic, the respiratory and nutritional metabolic, and the anthropometric requirements of the astronaut in terms of economic logistics.

To keep a man alive and alert in a completely sealed compartment is the *suprema lex* in the space medical efforts and the prerequisite for all other questions. What possibilities does space medicine offer in this respect today? What will it be able to offer in the next 10 years?

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The crucial point in this question is the time factor, the duration of the flight. For a better understanding of this vital problem we must remember that there are two methods or stages for the supply or regeneration of the respiratory and nutritional necessities.

The first stage is accomplished by replacing the consumed materials from stores and the storing and/or elimination of waste products. This method is based on physical and chemical procedures and has been used and tested in experiments carried out in the space cabin simulator at the School of Aviation Medicine for 4 years. This method was used by Lt Colonel D. Simons in his space-equivalent balloon flight in 1957 and by the U.S. Navy. As proved by more recent space cabin simulator experiments, the duration of keeping a man alive and alert in a sealed cabin can now be expressed better in the order of weeks than days. Nearby space and deep space flights as they are in the capability range of the NASA program in the coming years could be handled with these physical means of replacing and storing, if their duration remains in the order of weeks. It all depends on the permissible payload. Also the introduction of new exotic absorbents for carbon dioxide and humidity might prove the time limitation. It seems to me that a more refined physicochemical system will be the method for the regeneration of the intracabin environment for the next 10 years. It would allow circumlunar and lunar missions and deep space penetrations approaching the duration of 1 or 2 months. Beyond a certain time, however, we must resort to another method: recycling, namely, recycling of all the vital bioelements like oxygen, carbon, nitrogen, and hydrogen in the same manner as observed in free nature in the process of photosynthesis in green plants. With this stage we deal with a true closed ecological system. This is the method for long voyages such as would be used in interplanetary and planetary missions. This method will not be available operationally within the next 10 years and may not even be required during that time. However, intensive efforts in this field must and will be made within this decade, to make recycling available for the decade following. Considerable progress has been made during the past 4 years in studies on algae in a photosynthesarium. More and more efficient strains of algae have been found, to recycle not only the gaseous components of metabolism, but also the fluid and semifluid waste products. The principal difficulties in these biological gas exchangers lie in the size of the device, the volume of the nutrient solution, and in illumination. With regard to the source of light, solar light may well be the answer. Photosynthesis did not start on Earth on the basis of visible light. It started with infrared rays. This is thermosynthesis. Apparently some 2 billion years ago the Earth's atmosphere was not as transparent as it is today. Some microorganisms of this kind, namely, purple bacteria, still exist. But in thermosynthesis, only carbohydrates are produced but no oxygen. Within the next 10 years, efforts will be made either to find an effective thermosynthesis or some transition stage between photosynthesis and thermosynthesis. To work for the future, we sometimes must look back into the past and also to the distant celestial bodies. For instance, G. Tikhov

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at Alma Ata, USSR, believes that the green vegetation on Mars uses infrared for "photosynthesis." He concludes this from spectrographic studies of these areas.

Photosynthesis is a process taking place within the cells. Extracellular photosynthesis is the next method we will look for within the next 10 years. This leads to artificial photosynthesis, which may be one of the solutions.

These are the areas with which space medicine will be concerned in the coming decade in order to develop an efficient closed ecological system usable for space operations of long duration, such as a trip to Mars. Because of the limited time, I cannot go into other important research areas such as day-night cycling, psychological problems, flight dynamics, etc. I have concentrated upon the closed ecological system because the construction of a synthetic little earth is the prerequisite of the entire space adventure. It must take care of the astronaut and his vital necessities in a similar manner as does the Earth on a gigantic scale for its 2 billion passengers.

So far I have discussed space medicine as an applied science, applied solely to further manned space flight. In concluding this paper I would like to make a few remarks about how space medicine will influence our thinking and methods in medicine in general in the future.

There is no question that space medicine has already broadened our medical and physiological thinking in the direction of a cosmic spectrum which will pay off and will be of benefit to the progress in Earthbound medicine. For example, we do not find the word "weightlessness" in the text and handbooks of medicine and physiology. Yet, numerous experiments on the statokinetic reflexes, on the fall reaction of the cat in which weightlessness is involved, have been carried out and described in the 1920s. It has been completely overlooked, however, until the first theoretical space medical papers 10 years ago brought it to our attention.

Today, we observe almost a boom in weightlessness, especially in the popular literature. In scientific papers and lectures we begin to speak of a special category of gravireceptors and antigravireflexes. The study of circulation under zero gravity--in which the hydrostatic pressure does not exist--will give us a better understanding of hemodynamics. Following a lecture at the University of Maryland 2 months ago, someone asked me the question: What would happen to a baby born under zero gravity conditions? I think a speculative study of this question would be worthwhile, especially when we consider that a child's biggest problem during its second year is the constant battle with the Earth's gravity. A hypothetical zero-gravity baby brought, after some time, into the Earth's gravity would probably first learn to swim and then later to walk following the developmental pattern in paleontology.

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Now, let's take the closed ecological system again. Experimentation in this field is novel in the history of medicine and biology. New methods for recording environmental factors, such as oxygen and carbon dioxide pressures and physiological processes, are being developed, all based on the principle of minimization in weight and miniaturization in volume and with the possibility of telemetry. From this astroinstrumentation even hospitals will benefit. I would like to remind you that a micromanometer to measure the blood pressure within the heart was developed by aeromedical scientists. Colonel Stapp's biodynamic experiments on the rocket-powered sled, carried out in respect to the high G's during launching and atmospheric reentry, are also extremely valuable for the medical analysis of automobile accidents. One could, however, relate many more examples.

An entire medical astroglossary will be developed within the next 10 years which will not only serve its purpose in astronautics but also help to clarify definitions in terrestrial medicine.

Several hundred years ago, with the invention of the microscope and the subsequent discovery of cells and bacteria, medicine learned about the riddles of the microcosmos. Now, with the development of giant rockets, medicine in its youngest branch, space medicine, has the unique opportunity to aid technology to open the gates into the distant world of the macrocosmos. With this the cosmic spectrum of medicine is complete.

We live, indeed, in a wonderful era of science and technology for the first time in human history--in a cosmic era. It is gratifying to see that medicine, in this cosmic era, will play an important--in fact a decisive--role. To witness this is perhaps the greatest reward for all of those who have been associated with the foundation of space medicine in the past; and it will be a stimulus for the medical and biological researchers of the future.

THE CHANGING VISUAL SCENERY
FROM AERONAUTICS TO ASTRONAUTICS*

Hubertus Strughold, M.D., Ph.D.

I consider it a special privilege and honor to have been invited as guest speaker at the Dining-In of this important and famous air base. As a topic I have chosen "The Changing Visual Scenery from Aeronautics to Astronautics," or in the realm from atmospheric flight to space flight. In both of them the human eye is an indispensable and irreplaceable instrument in orientation and navigation, and an unsurpassable sensor in the exploration of the terrestrial and extraterrestrial environments. There is no question that the human eye can perceive things that cannot be recorded by any electronic instrument. I think this topic is especially suitable for this occasion and addressed to this audience of aerospace craft pilots. The visual panorama encountered in the atmosphere, in space, and on other celestial bodies represents a subject matter of highest scientific and flight professional interest and at the same time has enjoyable qualities for entertainment. I hope that I will be able to present it in such a way that it may contribute to this colorful evening. So let's begin our theoretical sightseeing trip along the vertical frontier, and to make the story complete let's start at the bottom of the ocean and end it beyond the dimly illuminated regions of Pluto in interstellar space.

The question, of course, arises how can we have knowledge about this and how can we make statements especially about the light conditions in deep space and on other celestial bodies? The answer is this! First of all, certain predictions can be made based on extrapolations of our familiar photic environment, on evaluations of astrophysical space data, on astronautical recordings and photographs, and last but not least based on the knowledge of the sensory capabilities of the human retina. Furthermore, actual visual observations on the spot are already available with regard to the higher atmosphere made by balloonists, and by pilots of jet- and rocket-powered aerospace craft and by astronauts in suborbital and orbital flights in near space.

Now, let's theoretically dip to the bottom of the ocean! In the deepest regions of the oceans there is permanent darkness. Despite this, there are numerous fish. Some types have eyes and produce their own light by means of luminescent organs. There are also fish with vestigial non-functioning eyes. Orientation and motion of these blind deep-sea fish in this world of eternal night are controlled by means of mechanoreceptors only.

*Presented at the Dining-In (U2 pilots), Laughlin AFB, Del Rio, Texas, 22 Sept 1961.

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This so-called aphotic zone of the seas ends at about 500 to 600 meters below sea level, insofar as here the first slight traces of light become perceptible by the human eye, according to the observations made by W. Beebe and Jacques Piccard in their bathyspheres. They are of bluish color and shift with decreasing depth to green and greenish-yellow in the subsurface regions. In the upper 5 meters of this photic zone, solar illuminance increases from 10,000 to some 50,000 lumens per square meter or lux (1/10 of one foot candle).

Emerging from the hydrosphere to the bottom of the atmosphere, we see during a cloudless noon--the Sun, high in the sky, its rim blurred by an aureole which blends into a dome-shaped sky of bluish light. The aureole is caused by indirect sunlight, reflected by ice crystals and dust in the higher and upper atmosphere, and the blue sky is indirect sunlight, scattered by the air molecules. Behind this veil of scattered light the stars remain invisible, and the moon is barely discernible. The illuminance from the Sun is roughly 100,000 lux, which is the average value at noon during sunshine at sea level at middle latitudes in summer.

When we now ascend in a space vehicle, we observe in the higher and upper atmosphere a radical change in the photic environment. The sky gradually becomes darker and the Sun brighter, because of the rarification of the air and the resulting disappearance of light-scattering. This has been observed in high-altitude balloon flights by Jean Piccard, A. W. Stevens, O. A. Anderson, D. G. Simons, M. D. Ross, and M. L. Lewis. From 30 km (20 mi) the brightness of the sky decreases considerably and at about 100 km (60 mi) the sky is dark. Now the stars are visible all the time despite a bright shining Sun. Because of the absence of a reflecting and scattering medium, the Sun now shines without an aureole, as a luminous disk on a dark background.

The Sun's corona scatters some of the light emitted from the photosphere amounting, totally, to one-half of the brightness of the full Moon. But against the brilliance of the solar disk this will not be perceptible to the human eye. (The situation is different, of course, during a total solar eclipse as seen either from the Earth's surface or from space.) The color of the Sun (and of the stars) should be more whitish, because no blue rays are scattered by an atmospheric medium. Solar illuminance increases from its maximal sea level value of about 100,000 lux to about 140,000 lux at the top of the atmosphere. This extra-atmospheric value, which is practically reached at 50 km altitude, is called the solar illuminance constant.

Such are the basic differences between the atmospheric and the extra-atmospheric light conditions in near space during the day; a bright blue sky of indirect sunlight with a bright Sun in the lower atmosphere, and a permanent dark sky with the direct light of a still brighter Sun in space at the Earth's orbital distance.

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But this darkness of space is not the same as that in a moonless, clear sky on Earth at midnight. Our terrestrial nightly sky is always slightly illuminated by the so-called night airglow--a faint diffuse light, emitted by atomic oxygen, nitrogen, and sodium in the upper atmosphere brought into excited states by solar ultraviolet rays. This night airglow is stronger than all the light emitted from the stars and gives the background luminance a slight bluish shade. The dominant light source in our nightly sky therefore is not the stars; it is the airglow. In space, this light source is absent, which makes the sky appear darker.

Against the darker background in space the stars should appear brighter by contrast--actually they are brighter by about 30%--this is the amount of light which is absorbed on its way vertically through the atmosphere. For the same reason more stars should be visible from above the atmosphere than at its bottom or at the Earth's surface. And, of course, they would not twinkle because no atmospheric turbulence interferes. This has been observed by D. G. Simons during his balloon flight up to 30 km in 1957. The Moon, too, would appear about 30% brighter than as seen from Earth.

Basic light conditions in the sky in space can be observed by an astronaut orbiting around the Earth in the relatively radiation-safe altitudes from 200 to 800 km below the Van Allen radiation belt. At these altitudes the astronaut's attention will be attracted more by the Earth itself as a source of light, than by anything else.

Thirty-six percent of the solar light falling upon our planet in toto is reflected or scattered back into space. Thus the Earth appears as an illuminated celestial body with an albedo value about five times as high as that of the Moon (7%). Numerous photographs of the Earth have already been made from rockets at considerable altitudes. The color of the sunlight reflected or scattered back from the Earth's atmosphere is bluish white (a conclusion which has been made from spectrographic studies of the "earthlight" on the Moon). Certain parts of the Earth would also show to the orbiting astronaut the moonlight on the Earth, just as we see from Earth the earthlight on the Moon's dark areas. I should like to add that for the first time a bird's-eye view of the polar lights will be possible from a polar satellite. It might be interesting to learn whether or not astronauts will be able to perceive the so-called Gegenschein, or counter glow--a faint luminosity far above the Earth's atmosphere opposite the Sun, the cause of which is still a matter of dispute. Some astronomers think that it is light scattered by a miniature cometary tail of atmospheric material which the Earth might possess.

How much of the Earth's hemisphere can we overlook at different altitudes? What can we recognize on the Earth's surface? To see, or not to see! That is the question! At 75 km, which is about the so-called von Karman line--the limit for aerodynamically controlled flight--we can overlook 1% of the Earth's hemisphere; at 100 km, 2%; at 200 km, 4%;

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at 500 km, 8%, i.e., a territory of 5000 km or 3000 miles in radius; at 1000 km, 14%; at the distance of 1 Earth radius, 50%; at 4 Earth radii, 75%; at 10 Earth radii, 90%; and at 100 Earth radii, 99%. That means from 4 Earth radii upward, astronauts will have almost a complete hemispheric view of the Earth.

Now, not everywhere is there sunshine and earthshine in nearby space. There are the shadow cones of the Earth and of the other nonself-luminous celestial bodies. The cone of the Earth's shadow extends to 1,385,000 km; that of the Moon to 375,000 km, and the giant shadow cone of Jupiter is 90 million km in length. These shadow cones are not as such visible to the astronaut because of the absence in space of light-scattering gaseous matter. He will become aware of them only when he is moving through them, in which case the Sun is blocked out of the black sky. This is satellite night. The satellite night is always a cold winter night because heat radiation is blocked out, too. This is of importance with regard to temperature control of the space cabin.

Now, this whole complex of the physical-optical situations in the upper atmosphere and nearby space poses psychologic, physiologic, and medical problems for the astronaut.

First, the appearance of the Earth as a light source in the photic environment of nearby space leads to a strange situation, in that it is bright "below," or more precisely earthward, and dark "above," or spaceward, as seen from an orbiting space vehicle. This is the reverse of the situation on the Earth's surface, which appears generally--except in winter--dark green or brownish in color, with a bright dome of skylight above. This strange spatial distribution of light and darkness in nearby space affects the astronaut's orientation, especially since the eye is the only sense organ on which the astronaut can depend in space flight because he is weightless. Under this condition the graviresponsive mechanoreceptors or gravireceptors such as the otolith organ, the pressoreceptors of the skin, etc., cannot provide any information concerning his position and movement in space. He depends entirely on vision. This is an interesting contrast to the life of the aforementioned blind deep sea fish who depend entirely on their mechanoreceptors for orientation.

The darkness of the space sky, combined with an intensive illumination from the Sun, represents a strange optical situation found on Earth only under artificial conditions, for example in theatrical stage lighting. Everything that is exposed to sunlight--outside and inside the cabin--appears extremely bright; everything in the shadow is dark. Light and shadow dominate the scenery. This light-shadow combination poses interesting problems in the field of contrast vision and retinal adaptation, and requires special attention in human engineering of the space cabin windows.

The bright Sun in a black sky gives the impression that in space there is, so-to-speak, day and night at the same time. But an astronaut needs a sequence of rest and sleep and activity, which requires artificial day-night cycling.

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Hazards resulting from observation of the light sources themselves must be considered. Beginning with the weaker one, the Sun-illuminated portion of the Earth might produce an illuminance value high enough to cause a dazzling glare especially when the orbiting astronaut emerges out of the shadow of the Earth.

Special medical attention must be given to possible hazards to the eye caused by looking into the Sun in the form of retinal damages of the same kind as occur frequently on Earth when a solar eclipse is observed with an insufficiently smoked glass, especially by children. The result may be an inflammation of the retina, retinitis solaris, and in severe cases a retinal burn. I acquired a retinal burn in Europe when I observed the total solar eclipse on the 17th of April 1912 with my right eye insufficiently protected. A photograph, made more than 40 years later, shows that such retinal lesions are usually irreparable. The subjective symptom is a small blind area or scotoma in the visual field.

The critical exposure time for the development of eclipse blindness is estimated to be one minute or less. Outside the atmosphere the danger of such retinal lesions associated with visual defects is, of course, greater and the critical exposure time somewhat shorter--10 seconds or less.

Caution in this respect, therefore, is indicated and protection of the eye by means of automatically functioning light-absorbing glasses or electronic devices must be considered. The zone of the retina-burning power of the Sun extends as far as the region of Saturn.

With this, we have already touched upon the light conditions found in deep space, and we shall include the whole solar space from Mercury to Pluto.

In this area the illumination from the Sun is the factor which interests us most because it is subjected to considerable variations with increasing planetary distances. This is in contrast to the brightness of the sky, which is dark everywhere in space, and may become a shade darker in the extrajovian space because of the disappearance of the zodiacal background light which is solar light reflected from micrometeorites and dust and observed only in the ecliptic plane.

As mentioned before, solar illuminance above the Earth's atmosphere at the Earth's mean solar distance amounts to about 140,000 lux. According to the inverse square law in the region of Venus this value increases by a factor of 1.9 to 268,000 lux, and at Mercury's distance by a factor of 6.7, or to almost 1 million lux; it decreases at the distance of Mars to 43%, at Jupiter's distance to 4%, and at the mean orbital distance of Pluto to 90 lux (.06 of 1%).

From a biological point of view these tremendous variations in solar illuminance suggest a subdivision of the space of the solar system into photic zones. We might not go too far in speaking of a euphotic belt,

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which is the zone favorable to space operations and may include about 50 million km in the sunward direction, and some 100 million km in the opposite direction as seen from the Earth's orbital distance; this zone is adjoined by a hyperphotic and hypophotic zone.

The euphotic belt, or we might also call it biophotic belt, is an important component in the concept of a general life-favoring zone or ecosphere in the planetary system.

In this connection, it might be interesting to consider the apparent size of the Sun as seen at the distances of the various planets.

To an observer on Mercury, the diameter of the solar disk would appear nearly three times as large as seen from the Earth. As seen from Mars, the Sun would have a considerably smaller apparent dimension, about two-thirds as seen from the Earth. At the distance of Jupiter, the Sun's diameter is one-fifth as large as seen from the Earth; and at the distance of Pluto, the Sun would appear only about three times larger than the evening star (Venus) appears to us on Earth.

The illuminance from the Sun at the mean distance of Pluto is still 90 lux; this is considerably above the threshold for color vision. Color discrimination becomes difficult below 10 lux. Solar illuminance decreases to this value in the region about three times the distance of Pluto, or about 18 billion km (or more than 10 billion miles) from the Sun. Here, then, begins the colorless world of interstellar space, as far as it is related to the Sun's illuminating power. And the Sun, itself, as seen with the eyes of an interstellar space traveler, gradually joins the conventional scale of stellar magnitudes.

Returning to our local universe--the solar system--we have discussed so far the light conditions found in space itself as an astronaut would encounter them during orbital flight or on a journey to the target celestial bodies. What about the light conditions on the celestial bodies themselves?

On the Moon without an appreciable atmosphere, solar illuminance is about the same as above the Earth's atmosphere, i.e., 140,000 lux; 93% of this is absorbed by the surface as indicated by the low lunar albedo value (0.07). This means that to a visitor on the Moon the sunlit terrain would not appear brighter than the landscape appears to us on Earth. Because of the absence of a light-scattering atmosphere, the lunar sky is permanently dark despite a bright shining Sun, just the same as in space. The lunar sky is just a plain space sky! Light-scattering ceilings on a lunar base and light-scattering visors attached to the helmet of the astronaut, serving as a kind of blue sky simulator, may be useful to weaken and diffuse the Sun's concentrated burning rays, and to produce sky conditions to which we are accustomed, under the dome of the terrestrial atmosphere.

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The light conditions in the Moon's craters are also of interest, because they may be selected as the sites for lunar stations. There might be a great variety of light effects as the result of shadows and illumination from opposite sunlit crater rims which is actually moonlight on the Moon. The Earth, of course, three times as large as the Sun, will always attract the astronaut's eye as a beauty of a celestial body in the lunar sky, if not for sentimental reasons. Moreover, the earthshine on the Moon at full Earth is 75 times stronger than the moonshine on Earth at full Moon, high enough to read a newspaper. Thus, the earthshine may be a welcomed useful component in the photic environment on the Moon.

As mentioned before, the Moon has no specific lunar sky, but rather a universal space sky. This is different on Mars. Its atmospheric density at ground level is somewhat equivalent to that found in the region around 15 km in our atmosphere, i.e., high enough to produce a sky of indirect sunlight, i.e., a specific Martian sky. The color of this Martian sky is probably whitish blue (G. Kuiper) due to scattering effects by hazy cloud layers. The intensity of daylight, which at the top of the Martian atmosphere amounts to about 60,000 lux, is of course at ground level somewhat lower than on Earth, but is still in physiologically desirable ranges.

In the telescope as seen from Earth, Mars shows dark green areas supposedly vegetation surrounded by reddish deserts. The question is, are they really green, or are they actually gray and appear only green as a visual contrast phenomenon against the reddish surrounding? This can be decided with the naked eye only if we come closer than half a million kilometers or 150 Mars radii to this planet. But green or not green, it does not of course exclude the possibility of life on Mars.

About the light conditions on Venus, we can only speculate because of the dense veil of clouds covering this celestial body. The Sun is probably seldom visible on Venus. It is certainly not so bright and sunny and attractive. Night airglow as described before might make the Venusian nights a dimlight affair.

On Mercury, the closest planet to the Sun and without an atmosphere, solar illumination on the one side is nearly 13 times higher than maximally on Earth with temperatures high enough to melt lead, and the other side is permanently dark and the coldest place anywhere in the solar system! On the surface of the outer planets from Jupiter to Pluto, far away from the Sun and covered by dense clouds it is probably permanently dim to dark. In addition, it is there constantly icy cold.

This ends our theoretical sightseeing trip through our solar system. I think a description of the light conditions in space and on the celestial bodies is illuminating; it shows us in a simple form the prospects and limitations of manned space operations, as far as solar radiation is involved. We may say that where there is adequate sunlight, there is the green-light for space flight. Furthermore, by studying the exotic visual panorama in space we better understand and appreciate the visual scenery on Earth, its beauty and majesty.

ECOPHYSIOLOGICAL PROFILE TABLES
OF SPACE, MOON, MARS, AND EARTH*

Hubertus Strughold, M.D., Ph.D.

One of the most intriguing developments in medicine and biology in this Space Age is their relation to astronomy; particularly to its subfields: astrophysics and celestial mechanics. In this association the ecological evaluation of the physical environments on the prospective astronautical target celestial bodies, from a human physiological and general biological point of view, plays an important role. In the following, the presently known physical data (planetary elements and orbital characteristics) as they are found in tables in the astronomical literature, are projected, essentially, against human physiology, as a background. In this way we obtain a collection of data which represents, so to speak, ecophysiological profile tables or bioastronautical index tables of the celestial bodies in question. Since in the foreseeable future only the Moon and the planet Mars can be considered as possible targets for manned space operations, only these two neighboring celestial bodies are considered.

For a better understanding of the physiological implications of these extraterrestrial environments, we must include (for comparison) the environment of the Earth, which, after all, is the point of departure and the target of the homeward-bound astronauts. And, finally, we shall contrast all of these environments with that of space, which has an intraatmospheric beginning and is the milieu surrounding the spaceship on its journey.

The basic characteristics of the space environment are: a hard vacuum of less than 10^{-10} mm Hg pressure, with its physiological implications (anoxia, ebullism); solar electromagnetic radiation with its thermoecological and photoecological aspects; ionizing radiation of the electromagnetic and particulate type of solar and galactic origin, with its radiobiological effects; the occurrence of meteoritic material of micro and macro dimensions; magnetic-field forces; and gravitational-field forces.

These basic characteristics of space show modifications in the neighborhood of the planets and the Moon, and in these regions the ecological picture of space gradually or abruptly blends with the ecological profiles of the celestial bodies.

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Beginning with the terrestrial environment, the face of the Earth consists of 71% water (hydrosphere), which includes the polar ice caps, and 29% land (lithosphere). The face of the Moon is completely lithospheric; however, an ice layer at a depth of 30 m has recently been postulated by Thomas Gold. On Mars, a thin hydrospheric cover in the frozen state exists only in its polar regions.

The atmospheres, ecophysiologically, must be considered with regard to their life-supporting, life-protecting, and flight-supporting capabilities. Concerning life support, the presence of oxygen (O_2) is of vital interest. Depending on oxygen pressure, the lower 4 km of the terrestrial atmosphere represent the physiological zone; above this level we enter the subcritical, and at 7 km, the critical hypoxic zone. At 15 km no oxygen can enter the lungs for physiological reasons, leading to anoxia. On the Moon and Mars, with practically no oxygen, unprotected astronauts would face anoxia at surface level.

In contrast to the rather high sea-level barometric pressure of 760 mm Hg on Earth, on Mars it is 65 to 70 mm Hg, and on the Moon in the order of 10^{-10} mm Hg, or less. The Martian air pressure value corresponds to an altitude of 15 km on Earth, and the lunar value to altitudes higher than 200 km. Water, then, would boil on Mars at $40^\circ C$, compared with $100^\circ C$ on Earth at sea level; and on the Moon's surface, liquid water cannot exist at all. The body fluids of a terrestrial visitor with a temperature of $37^\circ C$, start to boil at 47 mm Hg, which corresponds to approximately 20 km in the terrestrial atmosphere; on Mars this phenomenon, called ebullism, would be observed at an altitude of 5 km; and on the Moon, at surface level.

To provide a safe level of air pressure and oxygen pressure, a hermetically sealed pressure suit is required on Earth slightly below 15 km; but on Mars and on the Moon, at their surfaces.

Propagation of sound in the Earth's atmosphere disappears above 100 km; on Mars it might be at the same height or even higher. The Moon is a "temple of silence" immediately above its surface.

The region in the Earth's atmosphere where propagation of sound gradually ends is also no longer effective for aerodynamic navigation by control surfaces. This so-called von Karman line is found at about 60 to 80 km, depending, of course, also on the vehicle's configuration and speed. On Mars this line may be even higher. The Moon offers nothing in this respect.

On Earth, air resistance at about 200 km decreases to a level so as to allow a satellite flight of worthwhile lifetime. On Mars, this so-called mechanical border of the atmosphere may be found at the same altitude or even higher. Beyond this limit of the "effective or appreciable" atmosphere, the gaseous material extends several thousand kilometers into space, but this portion of the atmosphere on both the Earth and Mars is ecophysiologically insignificant.

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The ecological profile of the planets reaches far deeper into space, manifested by the efficacy of forces exerted by these bodies. First, the geomagnetic field has a distinct influence upon the flux of particulate rays of both solar and galactic origin by channeling them into the polar regions, causing the polar lights; by deflecting some of them back into space; and by trapping others over the equatorial regions, forming a large radiation belt (discovered by Van Allen in 1958). Knowledge of the spatial intensity profile of this radiation belt is important with regard to the safest areas of orbital flight and the safest routes and protective procedures for deep-space operations. Recently the region within which the magnetic-field forces are strong enough to affect the particulate rays in the aforementioned manner, has been termed "magnetosphere" (Th. Gold). Its extension is determined by the outer border of the outer radiation belt; i.e., 10 to 15 Earth radii = 60,000 to 90,000 km. The magnetosphere represents a radiobiological hazard in space flight, but it also prevents particulate rays from reaching the Earth, thus serving as a protective shield. However, some particulate rays of the high-energy type pass through the magnetic field and penetrate the atmosphere in their primary form and intensity, down to 40 km. Here, colliding with the molecules of the denser atmosphere, they are splintered into less powerful secondary and tertiary rays, which reach and penetrate the surface layers of the ground. In all probability Mars has a magnetic field, to be classified a magnetosphere. Then the spatial pattern of the radiation flux might be similar to that on Earth, but with different intensities due to a weaker magnetic field. The Martian atmosphere offers enough absorbing power to protect the surface from primary cosmic rays. The Moon, with no noteworthy atmosphere and no effective magnetic field, is open to the omnidirectional flux of all primary particulate rays, and their transformation into secondary rays takes place in the surface layers of the soil.

Another force originating in the Earth, which represents an effective factor in the overall ecological profile of the Earth, is its gravitational force. If we take the gravitational attraction on the Earth's surface as the basic unit, 1 G, then this force on Mars is 37.6%--and on the Moon, 17%--of 1 G. This lunar gravitational force may be just sufficient to enable a terrestrial visitor to keep his sensorimotoric system in balance, and to walk.

Together with solar irradiance, gravity is responsible for the amount, density, and extension of a planetary atmosphere. The result of the lower gravity on Mars is that its atmosphere is less concentrated near the surface and that it may extend farther into space than the terrestrial atmosphere, despite its much lower total mass (1/10).

Another ecological point related to gravity and worthy of mention is that meteoroids are less accelerated by the gravitational-field forces of Mars and the Moon than by those of the Earth.

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Of special astronautical interest is the extension of a planet's predominant gravitational attraction, or its gravisphere. This is the sphere within which a planet can hold a satellite in orbit. The radius of the Earth's gravisphere is 1.5 million km; of the Moon, 60,000 km; of Mars, 1/2 million km; and of Venus, 1 million km. The border of a planet's gravisphere terminates its ecological profile, which totally includes the magnetosphere, atmosphere, hydrosphere, and lithosphere.

So far we have not considered the solar electromagnetic irradiance intensity pattern--which determines to a high degree, directly or indirectly, the ecophysiological qualities of the environment, both extraatmospheric and intraatmospheric. As to the latter, atmospheric absorption resulting in photochemical reactions such as photodissociation, photoionization, and excitation, together with light reflection and scattering, form the chemical, thermal, and photic structure of the atmospheres.

Ultraviolet radiation in the range from 2,000 to 3,000 Å is responsible for the existence of an ozone (O_3) layer in the Earth's atmosphere in the region from 25 to 45 km. The prerequisite of such an ozonosphere is a significant presence of diatomic oxygen (O_2), from which ozone is formed. Consequently, with only traces of oxygen in the Martian atmosphere, there should be no ozonosphere on Mars, not to mention the Moon. Since the ozonosphere acts as a protective shield against ultraviolet rays, these sunburn-producing rays may reach down to the surface of Mars and, of course, the Moon.

The shorter ultraviolet rays below 2,000 Å are absorbed by nitrogen and oxygen in the upper terrestrial atmosphere, producing a four-layered ionosphere. The existence of an ionosphere is expected to be found in the Martian atmosphere, although probably weaker. If so, the problem open to exploration is the range of the radio window, which is vital for interplanetary telemetry and voice communication. For the Moon, this point is of no concern.

Ultraviolet radiation also produces, via photoexcitation, the night airglow, giving the night sky a slight luminosity; seen from an orbiting vehicle, this forms a hazy layer around 90 km at the horizon (S. Carpenter). Due to the greater solar distance, the Martian night sky might show a less intense airglow, and the lunar sky is identical to the universal black space sky.

With this we have touched upon the light conditions, or visible rays, to which two biological substances specifically react: rhodopsin, in the human retina; and chlorophyll, the green pigment of plants. Solar illuminance at the top of the terrestrial atmosphere amounts to 140,000 lumens per square meter, or lux. On the way through the atmosphere some light is reflected back into space, primarily by clouds;

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some is scattered by the air molecules in all directions, leaving maximally 100,000 lux at the Earth's surface. Light scattering practically terminates above 50 km, leading to a black sky despite a bright shining sun. At the orbital distance of Mars, solar illuminance is 60,000 lux. If we allow 30% attenuation by scattering and reflection, solar illuminance at the Martian surface should reach, maximally, 40,000 lux, which is well within ecophysiological limits, both for vision and photosynthesis of the terrestrial type. For the Moon's surface we can assume, maximally, 140,000 lux--the same as in the higher terrestrial atmospheric region.

Finally, the solar constant as a unit of measure for thermal solar irradiance at the top of the Earth's atmosphere, amounts to $2 \text{ cal cm}^{-2} \text{ min}^{-1}$. Partially absorbed by water vapor and carbon dioxide, this value decreases at the Earth's surface to $1 \text{ cal cm}^{-2} \text{ min}^{-1}$ and lower. The resulting air temperatures near surface vary from $+45^{\circ}\text{C}$ to -60°C . The Martian solar constant is $0.84 \text{ cal cm}^{-2} \text{ min}^{-1}$. This can heat up the near-surface air temperature to $+25^{\circ}\text{C}$, maximally; and due to stronger radiational cooling, the minimum temperature can drop to -70°C during the night. The Moon's surface is exposed to a solar thermal irradiance of practically the same value as the solar terrestrial constant, and its temperature can reach, maximally, $+130^{\circ}\text{C}$ at lunar noon; and due to the lack of an isolating air mantle and, consequently, strong radiational cooling, it can drop to -140°C at lunar midnight. The day-night cycle on Mars is only 39 minutes longer than on Earth, but on the Moon it lasts 27.3 days.

In circumplanetary space flight, the shadow cones, or umbrae, have some ecophysiological significance--at least in their lower portion--because, within their dimensions, solar illuminance and heat irradiance are practically zero. The umbra of Earth extends to 1,385 million km; that of the Moon, to 375,000 km; and Mars, to 1.118 million km. These shadow cones are, of course, invisible in the profile complex of the celestial bodies, and astronauts become aware of them only when they are orbiting through them.

After this review of the various ecologically significant features in the environmental profiles, details are shown in the Ecological Index Table for the Earth, for Mars, and for the Moon.

Whether or not there is an indigenous biotic component in a planet's environment is, of course, tremendously important both intrinsically and from a bioastronautical point of view. Various astronomical data strongly support the vegetation theory to explain the dark green areas on Mars. But definite proof must wait until biological research sondes probe Martian surface material and analyze it on the spot or until man himself sets foot on this red and green planet. For both unmanned and manned probes of Mars, a new approach, called the Bio-Courier Project, has been developed by Dr. W. G. Glenn of the Astromicrobiology Section

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of the USAF School of Aerospace Medicine. The Bio-Courier Project is designed to give the world (i.e., the people on Earth) advance information directly from the planet (or the Moon). It is based on telemetry of immunobiological reactions of the Martian material which can be compared with previously determined reactions of Earth forms. Thus, this approach allows identification of the relationship of Martian and Earth life "par distance interplanetaire."

If there actually is life on Mars, then in all probability, because of the severe climatic conditions, this has no particular influence upon other components in the Martian environmental profile, in contrast to the situation on Earth. Nevertheless, without the knowledge of whether or not Mars has a biosphere, the picture of the Martian ecophysiological profile would not be complete. The same is true of the Moon, which might have some subsurface biotic potential.

ECOLOGICAL INDEX TABLE

Ecological characteristics		Earth	Mars	Moon
Air pressure	(mm Hg)	760	65-70	10 ⁻¹⁰
Oxygen pressure	(mm Hg)	160	zero	zero
Anoxia	(km altitude)	at 15	zero	zero
Ebullism	(km altitude)	at 20	5	zero
Water vapor, max	(mm Hg)	15	0.7	-
Carbon dioxide pressure	(mm Hg)	0.23	0.26	-
Solar constant	(cal cm ⁻² min ⁻¹)	2	0.84	2
Surface temp, max	(°C)	+45	+25	+130
Surface temp, min	(°C)	-60	-70	-140
Solar illuminance	(lux)			
Extraatmospheric		140,000	60,000	
Surface, max		100,000	40,000	140,000
Albedo		0.44	0.15	0.07
Day-night cycle		24 h	24 h 39 m	27.3 d
Primary cosmic rays	(km)	above 40	above 40	at zero
Meteoroids	(km)	above 120	above 120	at zero
Gravity	(g)	1	0.376	0.17
Gravisphere, radius	(km)	1,500,000	500,000	60,000

THE ECOLOGICAL PROFILE OF MARS:
BIOASTRONAUTICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

An ecological evaluation of the conditions on a planet, in terms of bioastronautics or space medicine, must include the following components: the gravitational, magnetic, radiational, atmospheric, hydrospheric, lithospheric, and biotic environment.

The basic components of the ecological profile of a planet are determined by the physical planetary and orbital elements. By evaluating ecologically, for the purpose of astronautics, these factors found in the astronomical planetary data tables, we obtain bioastronautical planetary data tables which provide the environmental and operational background information vital for the success of a manned planetary flight. They particularly reveal the requirements for the life-supporting and life-protecting systems of a planetary station.

In all probability Mars will be the first planetary astronautical target for a landing mission. It is a great privilege for me to apply the just-mentioned ecological bioastronautical approach to this planet. A logical way to do this is to imagine that we are in a spaceship approaching the "red planet." In this way we become acquainted with the various components of the Martian profile, in the sequence they will be encountered by future astronauts or areonauts on a landing mission.

The characteristics of the flight trajectory and the mode of landing will not concern us here, but it should be mentioned that from a space medical point of view, a "high-energy trajectory," instead of a "minimum-energy" trajectory, would be very desirable to shorten the duration of the flight.

Gravisphere: As soon as our Mars-bound spaceship (which we might call "Marsella") comes closer than one-half million kilometers to this planet, it enters its sphere of predominant gravitational attraction, or gravisphere. This is the potential satellite sphere. It now can go into a parking orbit for observation and to prepare for the landing maneuver.

At an orbital altitude of 1,000 km (600 mi) our spaceship would speed around Mars with a velocity of 3.13 km/sec in 147 minutes; and

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at an altitude of 300 km (180 mi), with a velocity of 3.41 km/sec in 118 minutes. This altitude brings us 1,000 times closer to Mars, optically, than the best Earth-based telescope, and we should be able to discern with the naked eye, on the Martian surface, minimal distances between two points in the order of 100 meters. We must mention that our spaceship has orbital company in the form of the two natural Martian satellites: Deimos, which moves at a mean distance from the Martian surface of 20,000 km in 30 hours 18 minutes around its primary, and Phobos, the other satellite, at a mean altitude of 5,980 km in 7 hours 39 minutes. From Phobos we could discern distances on the Martian surface between two points in the order of 2 km.

Part of the period of revolution, our orbiting spaceship "Marsella" will be within the Martian shadow cone (umbra) which extends to 1.1 million km.

Magnetosphere: Of greatest importance for the safety of orbiting areonauts is the question: Are there radiation hazards from a Van Allen-type radiation belt? Speculations among the experts are that such a possibility cannot be ignored. A prerequisite for a radiation belt would be a Martian magnetic field strong enough to trap particle rays. The region within which the Earth's magnetic field forces are effective to influence the flux of these rays has been termed "magnetosphere" by Thomas Gold. Since Mars, among the metallic-rocky planets which are the inner planets, is considered more on the rocky side, its magnetic field should be weaker than that of the Earth. Consequently, a circum-Martian radiation belt should also be weaker; and it might have a different configuration and different particle composition. But all of this remains open for exploration by means of Martian fly-by's and orbiters.

Atmosphere: What is the lower limit for an artificial satellite orbiting around the "red planet"? On the airless Moon this limit is determined by the highest mountains; on Earth, by drag caused by air resistance, which below 200 km (120 mi) significantly shortens the lifetime of satellites ("mechanical border" of the atmosphere, H. Haber).

The total mass of the Martian atmosphere is about one-fifth of that of the terrestrial atmosphere (G. de Vaucouleurs). However, because of its lower gravity (0.38 G), Mars does not attract the atmospheric material as much as does the Earth. It is even assumed that the Martian atmosphere is denser above 26 km than the terrestrial atmosphere at the same height. The Martian atmosphere, therefore, may extend just as far into space as the Earth's inner atmosphere, for which the height of 700 km is generally accepted (astronomical border). Similarly, the mechanical or astronautical border manifested in significant air resistance and drag, may lie not lower on Mars than on Earth (200 km). Atmospheric entry would probably be smoother and, consequently, would produce less aerodynamic and aerothermodynamic problems, and resultant physiological deceleration stresses and thermal hazards, than the terrestrial atmosphere.

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In contrast to the airless Moon, landing on Mars makes using a winged vehicle feasible. The altitude border for aerodynamic navigation by control surfaces may be not much different from that on Earth; i.e., around 60 to 100 km (von Karman line). It may be mentioned at this point that the air density below this level should be high enough for sound propagation. This might be, psychologically, a welcome surprise for terrestrial visitors after their long journey through the silence of space.

Of vital importance for a landing mission, are the life-supporting and life-protecting qualities of the Martian atmosphere at ground level. The most likely chemical composition of the Martian atmosphere, according to G. de Vaucouleurs, is 93.8% nitrogen, 4% argon, 2.2% carbon dioxide, and traces of water vapor and oxygen. The barometric pressure at ground level is about 65 mm Hg. This pressure corresponds to an altitude of about 17 km in our atmosphere. Barometrically, this altitude is the Mars-equivalent level in our atmosphere. However, the oxygen pressure at ground level on Mars is even lower than in our stratosphere.

From this comparison we can immediately draw the conclusion that an unprotected terrestrial visitor, suddenly exposed to this environment, would experience complete anoxia. His "time of useful consciousness" or "time reserve" would last not longer than 15 seconds; corresponding to an altitude of about 17 km in the terrestrial atmosphere. He would not, however, show the symptoms of ebullism; i.e., boiling of body fluids. This pathological effect would become manifest on Mars at an altitude of 5 km, which corresponds to 19 km in our atmosphere.

The Martian atmosphere, therefore, fails to offer any respiratory life-support for terrestrial visitors. An artificial atmosphere with life-supporting qualities of the terrestrial type must be provided in hermetically sealed compartments in the Martian station. And when leaving the sealed compartments of the stations, the areonauts must wear full-pressure suits for respiration, even in the lowlands.

What type of atmosphere should be used in a Mars station? The best would be the familiar type of atmosphere to which the areonauts had been adapted on their home planet; i.e., a mixture of oxygen and nitrogen. The ambient Martian atmosphere would offer a convenient source for nitrogen. Oxygen has to be provided by photosynthesis. The air pressure could be kept at one-half of our atmosphere, but with 40% instead of 20% oxygen, to provide the terrestrial atmospheric oxygen pressure of 160 mm Hg. As experiments in space-cabin simulators have shown, such a two-gas pressure combination is physiologically acceptable. The danger of fire would not be a matter of concern. This would be different in a pure oxygen atmosphere even at very low pressures. Outside the Martian station in the ambient atmosphere, fire, of course, is not possible at all.

In the event of a leak in the hermetically sealed compartments of the station, or outside in the pressure suit, the areonauts would encounter

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the same rapid decompression effects, including aeroembolism and anoxia, as do pilots in our atmospheric region at 17 km. The areonauts, however, would not experience the boiling of body fluids, as already mentioned; not even on the highest Martian mountains, which probably do not exceed 2,000 meters.

Could a hit by a meteorite be expected to be the cause of such a decompression occurrence? On Earth, meteoritic hazards are to be reckoned with above 120 km. The airless Moon offers no meteoritic protection at all. On the Martian surface there should be no such danger; not more than for aircraft flying in the lower regions of the Earth's stratosphere.

The Martian atmosphere should also offer adequate protection from harmful energetic particle rays, including cosmic rays. It is dense enough to absorb the primaries and transform them into secondary and tertiary rays. The particle ray situation on the surface of Mars might be similar to that at around 17 km in our atmosphere. If Mars has an effective magnetic field or magnetosphere, it would channel some solar particulate radiation into the polar atmospheric regions, producing polar lights. Over the equatorial regions, some rays might be deflected back into space, or trapped, forming a Van Allen-type radiation belt. In any case, the equatorial atmospheric regions would be sufficiently protected from the influx of particle rays.

Of greatest significance for the climate on Mars, is the filter function of its atmosphere concerning solar electromagnetic radiation. Some of these rays reach the surface; some are absorbed within the atmosphere; and others are scattered in all directions by the air molecules, or absorbed or reflected back into space by liquid and solid particles such as found in fog and clouds. There are three kinds of clouds: low, yellow-dust clouds; high, white, ice-crystal clouds; and the extremely high blue haze consisting of very minute water-ice crystals. All of them affect solar irradiance in one way or another.

This, in brief, pictures how the intensity and spectral range of solar irradiance may change on its way from the top to the bottom of the Martian atmosphere. The intensity factor of solar irradiance at the mean orbital distance of Mars (228 million km) is 0.431 (compared with that of Earth, 1). The spectrum of solar radiation in space during the time of normal solar activity, ranges from soft x-rays of 6 Angstrom to radio waves of more than 10 meters.

It can be assumed that the soft x-rays and rays of the wavelength up to 2,000 Å are absorbed in the Martian upper atmosphere, producing an ionosphere, perhaps consisting of several layers.

Whereas on Earth, solar ultraviolet rays from 2,000 to 2,900 Å--known for their sunburn-producing effects--are absorbed to a great extent

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in the process of ozone formation and destruction at 25-45 km (ozonosphere), on Mars, with only traces of atmospheric oxygen, no such ultraviolet-ray absorbing process in the higher atmosphere can be expected. They may reach the Martian surface in their full range and intensity unless some portions are absorbed by the previously mentioned various cloud layers. But, due to the greater solar distance of Mars, their mean intensity is less than one-half of that at the Earth's orbital distance. Furthermore, the Martian station and space suits will provide adequate protection from ultraviolet rays.

Visible rays, or light, are important with regard to physiological optics and utilization for photosynthetic regeneration of the intra-station environment. At the top of the Martian atmosphere, solar illuminance averages 60,000 lux (lumens per square meter). If we allow 30% for loss of light by scattering, reflection, and absorption, by the Martian atmosphere and the various cloud layers, then the intensity of daylight in the subsolar regions would be, of course, considerably lower than on Earth, but certainly still within desirable physiological limits for vision and far above the minimum required for the photosynthetic regeneration of the station's environment and waste products of its occupants.

The color of the Martian sky is probably dark blue, as in our stratosphere, with light blue or even whitish shades in the regions of the white clouds.

There should be no specific ophthalmological problems on Mars. The size of the Sun is about two-thirds in diameter as seen from the Earth. Looking directly into the Sun is not advisable since its retina-burning power reaches much farther than Mars--possibly as far as Saturn (O. Ritter). And, finally, the Martian day-night cycle--only 39 minutes longer than that on Earth, will pose no sleep-and-activity-cycle problems. In general, then, the light conditions on Mars should be agreeable for terrestrial visitors.

This is different concerning the temperatures on Mars. Whereas, at the top of the Earth's atmosphere, solar thermal irradiance amounts to $2 \text{ cal cm}^{-2} \text{ min}^{-1}$ (known as the terrestrial solar constant); at the mean orbital distance of Mars, it amounts to only $0.84 \text{ cal cm}^{-2} \text{ min}^{-1}$. As a result, the general temperature level on the Martian surface is at least 25°C below that on Earth. During the day the surface temperature in summer in the equatorial regions may reach, maximally, 25°C , which is ecologically close to an optimum; but after sundown the temperature drops very quickly to -45°C , and even lower, due to radiational cooling. A summer night on Mars is always like an Arctic winter night on Earth. This poses problems for the temperature control of a Martian station unless subsurface spaces are chosen for its site.

This leads us to the physical, chemical, morphological, and, perhaps, biotic characteristics of the surface of Mars.

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But, first, we must inject here a brief remark concerning surface gravity with regard to human physiology. Gravity on the Martian surface is 38% of our terrestrial standard of 1 G; this might facilitate the life of areonauts in the Mars station in various respects. It might tend to decrease their metabolic rate to 2500 calories per day, which would be logistically significant. On the other hand, decreased weight leads to a general asthenia, which has to be prevented by exercise, primarily of the isometric type. The sensomotoric control of the body balance during walking should pose no difficulties at a surface gravity twice as high as on the Moon, where it might require some caution.

Hydrosphere: On the Martian surface, if we ignore the ice or hoarfrost-covered polar regions (identified as H₂O by G. Kuiper), there are, in contrast to the Earth, no open bodies of water; i.e., no hydrosphere. In fact, it is the generally accepted opinion in astronomy that Mars is a dried-out planet.

However, in 1952 H. E. Suess, University of Chicago (according to a reference in H. Urey's book The Planets) suggested that "substantial quantities of water may be buried under dust and never become volatile at the low temperatures of parts of the planet." Recently V. D. Davydov, Russia, has theorized along the same line that there might be a subsurface ice layer 400 meters thick in the equatorial region, increasing to 2,000 meters in the polar regions.* Beneath this Martian ice layer, water might be found in the liquid state, according to Davydov. And when cracks in the ice layer occur, caused by Mars quakes, water may reach the surface, producing white streaks of fog. This theory, if correct, logistically would mean a "gold mine" for areonauts, by solving the problem of water supply. But at present there is no proof of the existence of a subsoil frozen hydrosphere, and bioastronautics must face the fact that there is no liquid hydrosphere on the Martian surface, which, therefore, must be classified as lithospheric in nature.

Lithosphere: The surface lithosphere on Mars represents an area of 14.5 million km². Three-fifths of it is reddish in color; two-fifths is dark bluish-green. The relief is rather smooth, with plateaus not higher than 2,000 meters (in the polar regions) and with some lowlands, approximately 1,000 meters below the general ground level. The reddish area is considered to be a huge monotonous desert covered with minerals such as limonite and feldspar. In contrast, the dark areas show impressive topographical and seasonal color variations (E. C. Slipher). They are the main reason for the belief that there is plant life on Mars.

Biosphere: With this we arrive at the last component to be discussed in the Martian profile: the possibility of a biosphere. (This term, coined by V. I. Vernadskiy, 1929, is used for those portions of an environment which are populated by living organisms.)

*Two years ago an ice table of 30 meters below the Moon's surface was suggested by Thomas Gold, Cornell University.

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Ecologically, the existence of a biosphere is significant in that it can influence the properties of an environment--its chemistry, humidity, and temperature. For bioastronautics it is of specific interest because the biotic material may be useful or harmful for visiting terrestrials.

There are pros and cons concerning the vegetation theory of the dark areas on Mars. The opponents explain the dark areas as products of volcanic activity. The color changes are interpreted as being caused by reactions of some hygroscopic inorganic material to variations of the soil's humidity. The blue-green color is also considered a visual contrast phenomenon against the reddish surroundings. To some observers they always appear to be dark gray. Regarding the latter point, it must be emphasized that any astronomical color observation requires normal color vision of the observer. We must remember that 7% of the male population are color defective. The truth in this physiological Martian color dispute may lie somewhere in between. Visual contrast effects certainly occur, especially if the areas are small, but the blue-green coloration of the large areas such as the Syrtis Major is in all probability, real. But green or not green, it does not exclude the existence of a biosphere on Mars.

The proponents of the vegetation theory base their belief particularly on the findings (Dr. William M. Sinton, Smithsonian Institute) of a strong absorption band near $3.4 \mu\text{m}$ over the dark areas--the wavelength of the carbon-hydrogen bond. This indicates the presence of organic molecules. The reddish areas do not show this absorption band. Comparative polarimetric and spectroscopic studies by A. Dollfus, Paris, and G. Tikhov, Alma Ata Observatory, of the dark green areas on Mars and of terrestrial plants, are also in favor of the vegetation theory. Furthermore, if we take into account the strong adaptive power of life to severe climates, the more moderate conditions of the so-called microclimate found near the surface and in the subsurface spaces such as caves, and, finally, the actual solar energy which Mars absorbs due to its low albedo (0.15), then we must come to the conclusion that Mars definitely has a biotic potential but of a much lower degree than the Earth. Studies in Mars chambers, in which most of the Martian conditions are simulated, indicate that terrestrial microorganisms such as anaerobic and facultative aerobic bacteria, and others, could survive on Mars.

It is the challenging mission of astronautics to solve the problem of life on Mars, first by biosondes which can pick up surface material, analyze it, and telemeter the findings back to Earth. But, of course, a manned Martian expedition offers greater possibilities in this respect. Astronauts would be able to look into the Martian biotic past by examining fossilized organic rock formations, which might give some clues of a former, now extinct, life, or of a paleobiosphere that might have existed on proto-Mars.

If the aforementioned hypothesis of a subsurface frozen hydrosphere, with water at its bottom, should be found to be correct, then the idea

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suggests itself that there might be a subice aquatic biosphere, populated with various kinds of microorganisms adapted to the temperature, gas, and mineral content of this permanently dark Martian watery layer. The assumption of a second biosphere on Mars, hidden deep below the ground, is certainly not beyond reasonable ecological considerations. Be that as it may, Mars is the planet on which to look for "exolife." If the answer is positive, this would be the "news of the millenium." And for biology it would open a new era--the transition from the Earth-related Cenozoicum to the Cosmozoicum.

Astronautics will play a decisive role in this development. To guarantee success we must have in advance an exact picture of the ecological profile of Mars, viewed from the standpoint of human physiology. Fortunately, we biologists can resort to a rich treasure of knowledge provided by modern astronomy, to secure the necessary reliable bioastronautical data.

In conclusion, Mars, when we consider all its ecological qualities, lies somewhat in the middle between the Earth and the Moon. Decisive are the atmospheres. From a human physiological point of view, the altitude up to 5 km in the Earth's atmosphere is the physiological zone in which 99% of the world's population lives. The atmosphere on the surface of Mars corresponds to a height of 17 km in our atmosphere, or twice the height of Mt. Everest. This, physiologically, is a critical atmosphere and the beginning of atmospheric partial Space equivalence. The tenuous lunar atmosphere is comparable to ours at 300 km or higher. This, physiologically, is a supercritical atmospheric medium, and equivalent to true Space. The Moon is closer to us topographically, but Mars is closer to us ecologically.

For a lunar trip it is the target, the Moon itself, that causes the greatest problems from the standpoint of bioastronautics or space medicine, and not the relatively short journey. In contrast, for a Martian expedition it may be the long journey, and not so much the target, that concerns us most, unless a high-energy trajectory is chosen.

Such is the situation with which bioastronautics is faced in the decades to come. The challenge is tremendous but the difficulties are not insurmountable if the disciplines involved--astronomy, space technology, and the life sciences--work closely together, as we have seen at this symposium on the exploration of Mars.

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REFERENCES

1. Antoniadi, E. M. *La Planete Mars*, Librairie Scientifique. Paris: Hermann et Cie, 1930.
2. Davydov, V. D. Behavior of the hydrosphere under Martian conditions and the phenomena observed. *Voprosy kosmogonii*, vol. VII, 1960.
3. de Vaucouleurs, G. The physical environment on Mars. In O.O. Benson, Jr. and H. Strughold (eds.). *Physics and medicine of the atmosphere and space*, ch. 39. New York: John Wiley & Sons, Inc., 1960.
4. Dollfus, A. Polarimetric and photometric observations indicating a possibility of life on Mars. *Publications of the Astron Soc of the Pacific* 70:50 (1958).
5. Fulton, J. D. Survival of terrestrial microorganisms under simulated Martian conditions. In O. O. Benson, Jr. and H. Strughold (eds.). *Physics and medicine of the atmosphere and space*, ch. 40. New York: John Wiley & Sons, Inc., 1960.
6. Hess, L. Mars as an astronomical objective. In F. I. Ordway III (ed.). *Advances in space science and technology*, vol. 3. New York: Academic Press, 1961.
7. Jones, S. *Life on other worlds*. New York: Macmillan Co., 1940.
8. Kuiper, G. P. *Planetary atmospheres and their origin*. Chicago: University of Chicago Press, 1952.
9. Levitt, I. M. *A space traveler's guide to Mars*. New York: Henry Holt and Co., 1956.
10. Ley, W., and W. von Braun. *The exploration of Mars*. New York: The Viking Press, 1956.
11. Lowell, P. *Mars as the abode of life*. New York: Macmillan Co., 1958.
12. Moore, P. *A guide to Mars*, 2d ed. New York: Macmillan Co., 1958.
13. Oparin, A., and V. Fesenkov. *Life in the universe*. New York: Twayne Publishers, Inc., 1961.
14. Ordway, F. I., III, J. P. Gardner, and M. R. Sharpe, Jr. *Basic astronautics*. New Jersey: Prentice-Hall International, Inc., 1962.

COMPENDIUM OF AEROSPACE MEDICINE

15. Pereira, F. A. Introducao a Astrobiologia. Biblioteca Internacional de Ciencia, vol. 1. Sao Paulo, Brazil, 1958.
16. Richardson, R. S. Exploring Mars. New York: McGraw-Hill Book Co., 1954.
17. Sagan, C. On the origin and planetary distribution of life. Radiat Res 15:174-192 (1961).
18. Salisbury, F. B. Martian biology. Science 136:17 (1962).
19. Schmidt, I. Application of recent advances in physiological optics to astronomy. Publications of the Astron Soc of the Pacific 70:74 (1958).
20. Sinton, W. Spectroscopic evidence of vegetation on Mars. Publications of the Astron Soc of the Pacific 70:50 (1957).
21. Slipher, E. C. The photographic story of Mars. G. S. Hall (ed.). Flagstaff, Arizona: Northland Press, 1962.
22. Strughold, H. The green and red planet. Albuquerque: The University of New Mexico Press, 1953.
23. Strughold, H., and O. L. Ritter. Planetary gravispheres. Astronautics 7(1):26 (1962).
24. Tikhov, G. A. Astrobiologiya. Moscow, 1953.
25. Vernadskiy, V. I. La biosphere, Alcan, pp. 77, 729, Paris, 1929. The biosphere and the noosphere. Am Sci 33:729 (1945).
26. von Braun, W. Das Mars Project. Frankfurt, A.M.: Umschau Verlag, 1952. English transl: H. S. White. Urbana: Univ. of Illinois Press, 1953.
27. Tombaugh, C. W. Mars. Astronautics, 1962.
28. Urey, H. C. The planets, their origin and development. New Haven: Yale University Press, 1952.
29. Wattenberg, D. Mars, Der Rote Planet. Leipzig/Gena: Urania-Verlag, 1956.
30. Whipple, F. L. Earth, moon, and planets. New York: Grosset & Dunlap, 1958.

LUNAR MEDICINE*

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Introduction. Lunar Environmental Medicine, or briefly Lunar Medicine, is the application of the ecophysiological principles of terrestrial environmental medicine to the conditions found on the Moon. In terrestrial environmental medicine we deal with man, homo sapiens terrestris, an oxygen-breathing, homeothermic creature, protected by a dense atmospheric envelope, synchronized with a dark-light period of 24 hours in his sleep and wakefulness time pattern, and statokinetically adapted to the Earth's standard gravitational force of 1 G. His metabolic processes are regulated in such a way as to keep the physical properties and chemical composition of his "milieu interne" (Claude Bernard, 1860), the intercellular fluid called the "fluid matrix" of the cells, in any external environment nearly constant, a tendency termed "homeostasis" (5).

Homeostasis is a precondition for man's health, well-being, and intact sensomotoric and intellectual activities. If one of the physical or chemical components of the external environment deviates from the normal, but is still above the physiologically required minimum or below the permissible maximum, the human body reacts with coordinated effective compensatory or defensive responses (change of metabolic rate by muscular action, respiratory and cardiovascular reactions, perspiration, etc.). Beyond these two ecological "cardinal points," the psychophysiological functions deteriorate. Maintenance of a nearly steady state of the body's "fluid matrix" is the function of the autonomic nervous and endocrine systems, governed by a control center in the thalamus and hypothalamus of the diencephalon, or interbrain. Homeostasis is a fundamental feature in the physiology of the human body, and as such is a very fruitful departure point for a medical study of man in relation to any environment, or for a medico-ecological analysis of the fitness of an environment for man. This is particularly true concerning the natural environments on other celestial bodies including artificial environs such as those in spaceships, space suits, and in lunar and planetary stations.

Scope of Lunar Medicine. In Lunar Medicine we deal with a very demanding high-level homeostatic terrestrial creature--the selenonaut--on the one hand, and with an extraterrestrial celestial body, the Moon, with a very low to zero level ecological environment on the other. It is, then, the task of Lunar Medicine to analyze this environment in terms of

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human physiology and to propose to technology the life-supporting and protecting systems required inside a Lunar station, such as the Lunar International Laboratory (LIL) (14). Actually, it must cover the entire Lunar manned mission: Selection and training of the selenonauts, pre-flight preventive clinical measures, the medical problems encountered en route to the Moon, the environment on the Moon itself, the physiological requirements in the Moon station and during extra-stational surface excursions, safe return to Earth, and the evaluation of the medical experiences for future planning such as a flight to Mars.

A medical evaluation of the Lunar environment can now include the exploratory experiments and close-up photographs of automated lunar orbiters and landers (Ranger, Luna, Surveyor). With regard to the physiological space flight effects, we can make cautious extrapolations from manned orbital flight durations of 2 weeks (3, 7).

In the following discussion, I shall confine myself to brief remarks about some medical problems en route to the Moon, including circumlunar parking orbits, cardiovascular behavior under lunar gravity, the selenonauts' physiological clock, maintenance of homeostasis in the artificial environment inside the station, sensorimotoric control of equilibrium during walking on the Moon, and to some ophthalmological items.

Route to the Moon. We shall first consider some points of medical interest associated with the route to the Moon. Meteoroids should be of no particular concern, because most of them in this region of the solar system are of cometary origin and less frequent and violent than was expected some 10 years ago (19). This might be true even in case the Earth-Moon system moves through a meteor stream, which is the orbit of a disintegrated comet. This is indicated by the fact that so far four manned orbital space flights have been under way on the Earth's crossing dates of meteor streams without any incident. But stream meteoroids are also occasionally concentrated in the form of a meteor swarm. During such penetration events which, fortunately, are very rare, extravehicular activities in parking orbits and on the Moon might be hazardous.

If, for a flight to the Moon, a circumterrestrial orbit is chosen as the departure base, the region below the inner Van Allen belt, 200 to 800 km, would be medically the logical one due to its low radiation intensity. The radiation dose recorded in manned orbital flights in this region has been less than 1 millirad per hour. The penetration of the two Van Allen belts, of several hours duration, would lead to an absorption of around 10 rad, which is medically acceptable. The flight beyond these belts to the Moon's distance should add less than 1 rad. All in all, the total radiation dose en route to the Moon and return under normal quiet Sun conditions would be in the order of 20 to 30 rad if the wall of the Moon ship had an absorbing power equivalent to 1 cm of steel. This is far below the permissible dose rate, and could be reduced even more by additional shielding.

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The state of weightlessness during the 3-day Lunar trip should pose no physiological problems if proper physical exercise is applied, as proven by the much longer manned orbital flights.

As soon as the spaceship comes closer than 60,000 km to the Moon, it enters its sphere of predominant gravitational attraction, or gravisphere, and can go into a parking orbit for the preparation of the landing maneuver. Fortunately, there are no additional radiation hazards in circumlunar space, because the Moon has no effective magnetosphere to trap energetic particle rays. There are, therefore, no "off limits" regions for parking orbits in contrast to the situation in circumterrestrial space. If a parking altitude of 100 km should be chosen, then the circular orbital velocity would be 1.63 km/sec and the period would last nearly 2 hours. From this distance the resolving power of the unaided human eye (minimum separable) would be 20 to 30 meters. This would give the selenonauts an excellent observation basis for detailed identification of the relief of the lunar surface.

Lunar Gravity. With the beginning of deceleration during the landing maneuver, gravity enters the life of the selenonauts again after 3 days of weightlessness. They should have no difficulty in becoming adapted to the lunar gravity of 1/6th of 1 G.

In this respect, it might be interesting to note that in all manned orbital space flights a slightly lowered blood pressure and reduced heart rate were recorded. The interpretation of this has been that of the two divisions of the autonomic nervous system, the sympathetic and parasympathetic, the latter is dominant during weightlessness (15). If this is so, then we also might expect to some degree a parasympathictonia (vagotonia) in the gravitational milieu on the Moon.

The hydrostatic blood pressure in the blood columns of the human body when in the upright position might show a smaller difference between their lower and upper parts than on Earth (12). Less regulatory action of the vasoconstrictors, which are sympathetic nerves, would then be required to provide ample blood supply to the upper parts of the body, particularly to the brain. Thus, maintenance of a high-level homeostatic balance of blood circulation, a precondition for the selenonauts to think and work effectively, should present no difficulties under the lower lunar gravity.

But they also need rest and sleep. Research on sleep has shown that during this state, too, the parasympathetic is dominant. The astronauts and cosmonauts all experienced a sound cosmic slumber when the noise level was kept in proper relation to the silence of space. We might, therefore, expect a sound lunar sleep, also. Sleep on the Moon might be even better than on Earth for the following reason: Under the terrestrial gravity of 1 G, man changes his position slightly about 15 times during an 8-hour sleep period, which prevents compression anemia of the same skin areas. This has been recorded by means of a device called hypnograph.

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The hypnogram of a selenonaut probably will show fewer of these occasionally sleep-interrupting body movements. Thus, sleep could be more refreshing in the gravitational arms of Luna, the Goddess of the Night.

The question arises as to how to arrange the time for sleep and activity on the Moon where the light-dark cycle lasts about 27 terrestrial days. This does not offer any time clue or "zeitgeber" (2) for the "physiological clock" of the selenonauts, which is adapted to the duration of the terrestrial day-night of 24 hours. This so-called physiological "circadian cycle" (from "circa" and "dies" = around one day) (9), an inborn property of the human nature, has to be maintained in about the same temporal pattern for health and efficiency reasons (17). This can be done by arranging shifts among the occupants of the lunar laboratory, but at least one cycle must be synchronized with the time zone of the Manned Lunar Mission Control Center on Earth for reasons of radio communication.

Environment Outside and Inside the Lunar Laboratory. Whereas, the gravitational milieu on the Moon might offer no particular physiological difficulties, all other environmental conditions are extremely hostile to man (Table 1). They lie either far below the required ecophysiological minimum or far beyond the permissible maximum. The atmosphere, if it can be so called, might have a density of one-billionth, or less, of that of the Earth at sea level. This would correspond to an altitude higher than 300 km above the Earth's surface. A man suddenly exposed to this tenuous gaseous medium would immediately experience complete anoxia and boiling of the body fluids (ebullism). His "time of useful consciousness" (1) would last 10 to 15 sec; and the survival time reserve maximally 4 minutes, as recent experiments on chimpanzees indicate. The solution for the habitability of the Moon for terrestrials, therefore, is a closed ecological system with adequate life-supporting and protecting subsystems to meet the respective requirements of man as a homeostatic system.

Without going into detail, these are some of the physiological requirements:

The oxygen pressure should be kept at the normal terrestrial level, i.e., around 160 mm Hg, or about 200 millibar. Temporary variations in the range of 160 ± 40 mm Hg, would be medically acceptable. It would keep the oxygen pressure of the alveolar air, which is the intermedium between the ambient air and the blood in the capillaries of the lungs, at a physiologically required level. The permissible maximum CO_2 pressure is about 5 mm Hg. A two-gas atmosphere in LIL is preferable to a one-gas atmosphere of pure oxygen. The natural diluent in a two-gas atmosphere is nitrogen; however, it could be replaced by helium for certain purposes. The total barometric pressure does not need to be 1 atm, or 1000 millibar. One-half atm would be even better for technological reasons and for the preparation of extra-stational excursions. A temperature of $20^\circ \pm 4^\circ\text{C}$ with humidity of $50\% \pm 20\%$ would be in a desirable range.

So much about the ambient climatic milieu of the selenonauts inside the LIL, which has to be kept in the physiological tolerance range within which the regulatory system of the human body can maintain homeostasis of its interior milieu, the intercellular body fluid. A discussion of the regeneration of the artificial atmosphere and waste products and control of contaminants goes beyond the scope of this treatise. (For more detail, see 4, 6, 18.)

In addition to providing life support, the closed ecosystem must possess walls capable of protecting its occupants from ionizing electromagnetic radiations and energetic particle rays. In this respect, about the same absorbing power as the Earth's atmosphere would be required. In case of proton outburst after solar flares the selenonauts would have to retreat into shelters. This would not be necessary when the Moon moves through the magnetic tail of the Earth. Finally, needless to say, the wall of the station has to be designed to play a part in the station's temperature control under a solar thermal irradiance of $2 \text{ cal cm}^{-2} \text{ min}^{-1}$ and zero solar heat influx during the almost-one-terrestrial-month lasting Lunar day-night cycle.

Considering all the life-supporting and protecting factors we have discussed in the foregoing, the research laboratory has to be in its very nature a terrestrial island, or a Terrella on Luna.

Excursions Outside the Station. The scientific exploration of the Moon requires excursions outside the laboratory. In this respect, I would like to make a few comments about the sensorimotoric control of the body's equilibrium during walking on the lunar surface. The sense organs involved in this function are: the eye, the labyrinth (otoliths, semi-circular ducts), and extra-labyrinthine peripheral mechanoreceptors. Generally the labyrinth organ is in the center of the discussions about this threefold equilibrium system (8). I, therefore, would like to confine myself to the extra-labyrinthine peripheral mechanoreceptors. They are: the muscle sense (receptors: neuromuscular spindles); the pressure sense of the skin (receptors: Meissner corpuscles and nerve plexuses around the hair roots); and the posture sense (receptors: Pacinian corpuscles in the connective tissue). Their adequate stimulus is mechanical in nature, such as pressure, tension, stretching, etc., and they control sensorically to a great extent, position and movement of the body and its parts by coordinating the required muscular reactions (contractions, relaxation, and change of tone).

The number of motoric nerve impulses sent from the cortex of the brain during voluntary muscular movements is about 10 per sec; in the spinal cord they are transformed into 30 to 100 per sec, depending on the number of bundles of muscle fibers stimulated and resulting in smooth muscular movement. The cerebellum does not initiate these impulses but rather acts only as modulator.

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Assuming a man of 70 kg mass, or 70 kilopond = 70 kg weight, walks on the Earth's surface, the pressure upon the mechanoreceptors in the soles of his feet and particularly the tension with its changes within the muscles provide adequate stimulation to coordinate the movements of the flexor and extensor muscles; moreover, when walking up a stairway or on a rough surface, the increased muscular tension and its abrupt changes produce proprioceptive reflexes in the involved leg muscles thus increasing their strength and counteracting disbalances more effectively (10).

On the Moon a man with 70 kg mass has a weight of 12 kilopond. This might still produce enough gravitational stimulation for the peripheral mechanoreceptors in the legs, as lunar gravity simulation experiments indicate (13). Moreover, balance during walking could be facilitated by increasing the selenonaut's weight by carrying, in addition to the life-support equipment, some 30 kilopond of material around his waist. This would increase the tension in the extensor muscles of the legs and even facilitate proprioceptive reflex support, and this should make walking on the Moon's pebble-covered surface safer. It would make the stimulation of the peripheral mechanoreceptors more Earth-gravity equivalent. Of course, it would not affect the otoliths. (By the way, similar measures are used by aquanauts when walking on the bottom of the sea.) There is no question that the role played by the extra-labyrinthine mechanoreceptors, in addition to that of the labyrinth organ and the eye, in statokinetics deserves special attention, particularly in the range of decreased gravity, such as that on the Moon.

Exploratory Efficiency of the Eye. The superiority of the sensors in the human eye in the range from 3800 to 8000 Angstrom, compared with technologic sensors, is one of the reasons for the necessity of manned landing missions on the Moon and Mars.

I had the privilege of presenting a paper at the Session of the LIL Committee in Washington, D.C., 1961, on vision on the Moon, and therefore I would like to confine myself only to a few points.

First, selenonauts will never see the scenery around and above the station with the naked eye; they will always look through windows or visors. If these consist of 2 layers of transparent material, about 10% to 15% of the light does not reach the retina; this is the amount of light reflected by their four surfaces. Solar illuminance at the Earth-Moon distance from the Sun is 140,000 lux (lumen per m²); only 100,000 lux reaches maximally the Earth's surface because of reflection, scattering, and absorption of light by the atmosphere. On the airless Moon about 120,000 lux might be the illuminance level behind the windows and visors; for the glass-protected eye on the Moon solar illuminance is then still considerably higher than maximally at the bottom of the Earth's atmosphere for the naked eye. Furthermore, the glasses do not change the color as atmospheric scattering and absorption do, and the stars seen from the Moon do not twinkle.

Looking directly into the Sun for a number of seconds is not advisable because this can cause a retinal burn resulting in a blind spot in the visual field (helioscotoma). It is not ultraviolet but heat radiation that causes such a retinal injury, which is the same as eclipse blindness (scotoma helieclipticum); but even a brief glance at the Sun affects the sensitivity of the eye for minutes. The use of instant photoreactive glasses should reduce these disturbing blinding effects.

Nondirect Sun-illuminated areas of the Moon may be illuminated by indirect sunlight reflected from the Earth. The illuminance of this so-called Earth shine is essentially of bluish-white color and is 80 times higher at full Earth than moonlight on Earth at full Moon. The latter amounts to 0.20 lux. This is just at the threshold of color perception. The much brighter Earth light on the Moon--about 16 lux--therefore, might be welcomed by the selenonauts for some of their activities. It is enough light for reading.

For observational tasks certain ophthalmological items are of special interest such as the enormous difference in the retina's sensitivity between the light- and dark-adapted eye, the "minimum perceptible," the "minimum separable," differences between subjective perception and objective reality as manifested in brightness contrast and in color contrast effects, misjudgment of object size and distance, etc.; in other words, visual illusions.

Will selenonauts have the experience of an analog to the "Moon illusion" as seen on Earth, namely, an "Earth illusion"? The Moon when close to the terrestrial horizon appears to be larger than when high in the sky near the zenith.

A psychophysiological explanation relates this apparent change in size to the difference in eye elevation. Furthermore, loss of details on the lunar disk, when viewed through the dense, strong light-absorbing lower atmosphere (aerial perspective), may make the Moon appear farther away, which gives the subjective impression that it is bigger. In this case distance misjudgment would be the cause of an overestimation of size ("apparent distance theory"). The same would be true, if the Moon is seen in view of close objects across the terrain, such as mountains, buildings, etc. Their comparison, again, projects the Moon into a greater distance, thus making it appear magnified. This theory, advanced some 2000 years ago by Ptolemy of Alexandria and confirmed by modern testing, is today the favored one (11, 16). On the airless Moon only the last interpretation of the "apparent distance theories" is applicable and certainly makes the Earth illusion on the Moon a probability. In fact, a study of the Earth illusion by the occupants of the lunar research laboratory might clarify the question as to which of the aforementioned explanations is correct, or which factor is dominant in producing the Moon illusion on Earth.

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In concluding this paper, one thing is certain: The establishment of a Lunar International Laboratory is not an illusion, as it might have appeared at the time when the LIL Committee was founded by Th. von Karman and F. J. Malina in Stockholm, 1961. It will become a reality; it is medically conceivable, and Lunar Medicine in close cooperation with technology will make its contribution to insure safety, comfort, and success of this international scientific Lunar undertaking. Furthermore, the experiences that will be gained on the Moon will be of greatest value for the next step in the exploration of the Solar System, a manned landing mission to Mars, and the establishment of a Martian International Laboratory (MIL).

TABLE 1. MEDICO-ECOLOGICAL DATA TABLE OF THE MOON

Atmospheric density	Less than 10^{-10} of the terrestrial atmosphere
Anoxia	At ground level
Ebullism	At ground level
Solar thermal irradiance	$2 \text{ cal cm}^{-2} \text{ min}^{-1}$
Surface temperature	
Lunar noon	+130°C
Lunar midnight	-140°C
Solar illuminance	140,000 lux
Albedo	0.07
Day-night cycle	27.3 Earth days
Gravity	0.17 g
Gravisphere (radius)	60,000 km
Circular orbital velocity	0.68 km/sec
Velocity of escape	2.38 km/sec
Magnetic field intensity	Less than 1/400 that of the Earth
Circumlunar radiation belt	None

REFERENCES

1. Armstrong, H. G. Aerospace medicine. Baltimore: The Williams and Wilkins Co., 1961.
2. Aschoff, J. Zeitgeber der Tierischen Tages Periodik. Nahrungswissenschaften 41-49 (1954).
3. Berry, C. A., et al. Gemini Mid-Program Conference, Part I, NASA Manned Spacecraft Center, Houston, Tex., 1966.
4. Campbell, P. A. Earthman, spaceman, universal man? New York: Pageant Press, Inc., 1965.

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5. Cannon, W. B. Organization for physiological homeostasis. Physiological Review 9.399, 1929. In The wisdom of the body. New York: Norton Publishing Company, 1932.
6. Clamann, H. G. Space medicine. In Medical physics, Vol 3. Chicago, Ill: The Year Book Publishing, Inc., 1959.
7. Gzenko, O. G. Medical investigations on spaceships, "Vostok" and "Voskhod." Chapter XVIII in Ref. 14.
8. Graybiel, A. The labyrinth and space flight. Chapter XVI in Ref. 14.
9. Halberg, F. Physiological rhythms in physiological problems in space exploration. In T. D. Hardy, (ed.). Springfield, Ill: Charles C Thomas, 1964.
10. Hoffmann, P., and H. Strughold. Ein Beitrag zur Frage der Oszillationsfrequenz der willkurlichen Innervation. Zeitschrift fur Biologie Bd. 85 (1927).
11. Kaufman, L., and I. Rock. The moon illusion, I. Science 136:953 (1962).
12. Lamb, L. E. Influence of aerospace flight on the normal cardiovascular system: stresses and effects. Am J Cardiol 6:8-18 (1960).
13. Lomonaco, T., et al. Osservazioni Fisiologiche Sulla Motilita Dell'uomo con Parziale O Totale Alleggerimento Del Peso Corporeo II; Vol II, VI Congresso Internazionale E. XII Europeo Di Medicina Aeronautica E Spaziale, Roma, 1963.
14. Malina, F. G. Lunar International Laboratory. In T. C. Bedwell, Jr., and H. Strughold (eds.). Bioastronautics and exploration of space, chapter XXI, Brooks AFB, Tex., 1965.
15. Parin, V. V., R. M. Bayevsky, and O. G. Gzenko. Heart and circulation under space conditions. Acta Cardiologica T. XX, fasc. 2, pp. 105, (1965).
16. Schmidt, I. Is there a moon illusion in space? Aerosp Med 35:572 (1964).
17. Strughold, H. The physiological clock in aeronautics and astronautics. Ann NY Acad Sci 134, 413 (1965).
18. Welch, B. E., and W. G. Robertson, Effect of inert gases in cabin atmosphere. Chapter XIV in Ref. 14.
19. Whipple, F. L. Meteoroids and dust, Chapter II in Ref. 14.

BASIC PHYSIOLOGICAL CONCEPTS FOR BIOENGINEERING*

Hubertus Strughold, M.D., Ph.D.

Never before since the beginning of the technologic age which started with the appearance of the steam engine and electric power has there been a closer relationship between engineering and the life sciences than with the beginning of the space age. This is proved by the fact that first a machine became an aid to man's activities, but now both man and machine depend on each other in a kind of symbiosis, as manifested by a manned spacecraft. All these relationships between life sciences and technology are demonstrated by the terms such as biotechnology, bioengineering, anthropotechnology, anthropometrics, bionics, bioastronautics, and space medicine. It is important that those working on one side of this interface get acquainted with some of the problems on the other side, and vice versa. In the following I shall discuss certain basic medical and physiological concepts within my professional aerospace medical field which are important for the engineer to know; namely

1. The human body as a self-regulating system,
2. The physiological time regulator, or physiological clock,
3. The human eye as sensor in the exploration of space, and
4. Biological fuel cells.

It is certainly a great pleasure and an honor to have been invited to speak at this Seminar, at this progressive University of Texas.

Now, to the first topic! As you know, the whole living world on Earth is divided into three subdivisions: air inhabitants, water inhabitants, and amphibians. Man--*homo sapiens terrestris*--is a homeothermic, oxygen-breathing air inhabitant. His sleep and wakefulness time pattern is synchronized with a dark-light period of 24 hours, and statokinetically he is adapted to the Earth's standard gravitational force of 1 G. But he is an air inhabitant only with regard to his body as a whole; his basic elements of life, the cells (billions in number), live in a watery environment, the intercellular fluid called the fluid matrix of the cells. His metabolic processes are regulated in such a way as to keep the physical properties and chemical composition,

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such as the water balance, salt, and sugar content, ion concentration, and temperature of this "milieu interne" (Claude Bernard, 1860), in any external environment nearly constant, a tendency termed "homeostasis" (W. B. Cannon, 1929).

Homeostasis is a precondition for man's health, well-being, and intact sensomotoric and intellectual activities. If one of the physical or chemical components of the external environment deviates from the normal, but is still above the physiologically required minimum or below the permissible maximum, the human body reacts with coordinated effective compensatory or defensive responses, such as changes of metabolic rate by muscular action, respiratory, cardiovascular, and hematological reactions, and changes in perspiration. Deviations beyond these two ecological "cardinal points" have rapidly deleterious effects upon the cells, particularly the brain cells, and as a result the psychophysiological functions deteriorate. Maintenance of a nearly steady state of the body's "fluid matrix" is the function of the autonomic nervous and endocrine systems, governed by a control center in the thalamus and hypothalamus of the diencephalon, or interbrain. Homeostasis is a fundamental feature in the physiology of the human body and offers a very useful basis for a medical study of man in relation to any environment, or for a medicoecological analysis of the fitness of an environment for man. It is very useful in studies of extreme climatic conditions such as those found in the arctic, tropic, and high altitudes. This is particularly true concerning the hostile, natural environments on other celestial bodies, and the artificial environs required in spacecraft, space suits, and in lunar and planetary stations.

Beginning with the Earth's atmosphere, the lower 4 to 5 km are the physiological zone to which the human body can adapt itself, as proved by the life in the high plateaus in Peru and Tibet; above this altitude the compensatory reactions become insufficient and the situation becomes subcritical, until above 7 km it is critical--all caused by oxygen deficiency. At 20 km the air pressure is too low to keep the body fluids at 37°C in the fluid state and prevent them from boiling. This is supercritical and vacuum-equivalent, or space-equivalent. For protection oxygen equipment, pressure suits, and pressurized cabins have been developed. Up to about 25 km the ambient atmosphere can be used for the pressurization of aircraft cabins. Above this level an artificial atmosphere with a suitable pressure has to be provided, as in a spacecraft.

In manned space flight and on a manned landing mission to the Moon and Mars, we deal with a very demanding, high-level, homeostatic creature, the astronaut, on the one hand, and very low-level to zero-level ecological environments on the other. These environmental conditions lie either far below the ecophysiological minimum or far beyond the maximum tolerance level. A man suddenly exposed to such an external medium would immediately experience complete oxygen deficiency, or

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anoxia, and boiling of the body fluids (ebullism). His "time of useful consciousness" would last 10 to 15 seconds, and the survival time reserve maximally 4 minutes, as recent experiments with chimpanzees indicate. The solution for survival in space and on the Moon and Mars for terrestrials, therefore, is a closed ecological system with adequate life-supporting and protecting subsystems to meet the respective requirements of man as a homeostatic system. This is a combined task for the technological and life sciences.

Without going into detail, these are some of the physiological requirements:

The oxygen pressure should be kept at the normal terrestrial level, i.e., around 160 mm Hg, or about 200 millibar. Temporary variations in the range of 160 ± 40 mm Hg would be medically acceptable. It would keep the oxygen pressure of the alveolar air, which is the intermediate between the ambient air and the blood in the capillaries of the lungs, at a physiologically required level. The permissible maximum CO_2 pressure is about 5 mm Hg. A two-gas atmosphere is preferable to a one-gas atmosphere of pure oxygen. The natural diluent in a two-gas atmosphere is nitrogen; however, it could be replaced by helium for certain reasons. The total barometric pressure does not need to be 1 atm, or 1000 millibar. One-half atm would be even better for technological reasons and for the preparation of extravehicular excursions. A temperature of $20^\circ \pm 4^\circ\text{C}$, with humidity of $50\% \pm 20\%$ would be in a comfortable range. The regeneration of the artificial atmosphere and waste products and the control of contaminants, too, is a vitally important task of bioengineering. The ambient climatic milieu of the astronauts in their ecosystems has to be kept in the physiological tolerance range within which the regulatory system of the human body can maintain homeostasis of its interior milieu, the intercellular body fluid.

In a broader sense all of this is a kind of artificial homeostasis. Clinical examples in this respect are the application of artificial heart pumps, electric pacemaker for the heart, and artificial kidney. This clinical medical area concerned with artificial homeostasis will become increasingly an important field of cooperation between medicine and engineering, and this was one of the reasons for me to discuss here the concept of homeostasis.

Another basic property in the physiological nature of the human body which shows a tendency to near constancy and which is actually integrated in the homeostatic system is the sleep and wakefulness cycle or rhythm. Rhythmicity is a basic characteristic in the nonliving cosmos, as manifested in the rotation of the galaxies, revolution and rotation of the stars, revolution and rotation of the planets and their moons, vibration of the molecules and atoms, and the orbiting of the electrons around the atomic nucleus. Rhythmicity is the rule in the universe, in the microcosmos and the macrocosmos, and it is

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therefore not surprising that rhythmicity is also a dominant feature in the process of life. Many of the biological rhythms are endogenous, but in the course of phylogeny have become influenced by, and synchronized with, external environmental, rhythmically occurring factors. One of the most impressive of this category is the alternation of sleep and wakefulness. This physiological cycle is closely associated with the physical cycle of day and night, caused by the Earth's axial rotation in the powerful electromagnetic radiation field of the Sun. It is therefore called the Physiological Day-Night Cycle or circadian cycle (from "circa" and "dies" = about one day). (Halberg, 1964). This cycle, always a focal topic in biorhythmology; has recently attracted increased attention in aeronautics and astronautics. The most conspicuous features of the circadian cycle are the phases of sleep and wakefulness or activity, but there are many more rhythmic changes behind the visible scene.

For instance, the electroencephalogram shows a decrease of the 10 cycles per second (alpha waves) down to three or two during sleep. At the same time there is a considerable relaxation in tonus of the skeletal muscles. This indicates a lower metabolic rate, which is reflected in a slowing down of the respiration and heart rate during the night. In contrast, activity of the intestinal tract is increased during this time, and there are also daily maxima and minima in the functions of the kidneys and of the endocrine glands. Generally, the sympathetic division of the autonomic nervous system predominates during the day and the parasympathetic division, during the night.

It is, of course, not surprising that the blood, as a kind of mirror, reflects the picture of the overall activities of the body in the form of day-night variations in its chemical and morphological constituents.

All of these variations around the homeostatic baseline on an organ-, cellular-, and molecular-level, harmoniously integrated into a functional circadian system, with the thalamus as the coordinating center, repeat themselves with clocklike regularity within the temporal frame of 24 hours, so that the cycle researchers speak of a "metabolic clock" or a "physiological clock." An easily recognizable indicator of this physiological clock is the body's temperature, with a maximum in the late afternoon and a minimum in the early morning.

Concerning the activity period, most of the higher-developed living beings are "light active" in contrast to "dark active," such as nocturnal animals. In both types the effective time cue is the change in illumination and temperature at sunrise and sunset.

In man, as in numerous animal species, the circadian cycle is firmly established as a vital endogenous feature.

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Of interest is the development of the circadian cycle with age. Babies in the first 10 to 20 weeks show more than one cycle per day; they are polycyclic, as indicated by their sleep and feeding habits. They act like nocturnal and diurnal animals, such as owls and larks. Thereafter, they gradually become monocyclic and light-active, and act only like a lark. But the typical day-night temperature curve develops only in the second year, after they have learned to walk. They then have reached the state of rhythmically controlled homeostasis.

The normal physiological time requirement for sleep, or the normal sleep dosage, is about 8 hours every 24 hours, found in those people who are not under community, social, or professional pressure. The stability of this cycle is demonstrated by three facts:

1. It is impossible to break this cycle by ignoring sleep completely over a number of days; this would lead to neurotic disturbances. From history it is known that Napoleon I, Emperor of France, and Frederick the Great, King of Prussia, tried to demonstrate that sleep is just a bad habit. After two nights without sleep they had to capitulate to Morpheus, the more powerful god of sleep and dreams.
2. The duration of this cycle can be shortened to 18 hours or extended to 28 hours. Going beyond this minimum and maximum would lead to confusion of the circadian system.
3. A shift in the phase of the cycle cannot be achieved instantly; rather it requires a certain amount of time for readjustment. This is a familiar problem in work shifts in factories, mines, and hospitals; on ship watches, and in astronomical observatories. In these cases the individual changes the time of his activities but stays in his home time zone. With the development of fast-moving surface vehicles, and especially since the advent of the airplane, a phase shift of the day-night cycle takes place by a change in the time zone. The geographic time difference is 4 minutes per one meridian, or 1 hour or one time zone per fifteen meridians, making a total of twenty-four time zones (Fig. 1).

Within the higher range of the first aeronautical speed, namely, subsonic speed, and with the second aeronautical speed, supersonic speed, a half dozen time zones and more can be crossed within a few hours.

As statistical observations in long-distance flights have shown, the majority of people are sensitive to this phase shift and experience some physiological discomfort. They become hungry, get sleepy, or are awake at the wrong time. It should be emphasized that this condition is not a disease; it is merely a phase shift between the temporal physiological requirements of the body and the local geographic situation and professional and social requirements at the new place; but this can be significant in many respects.

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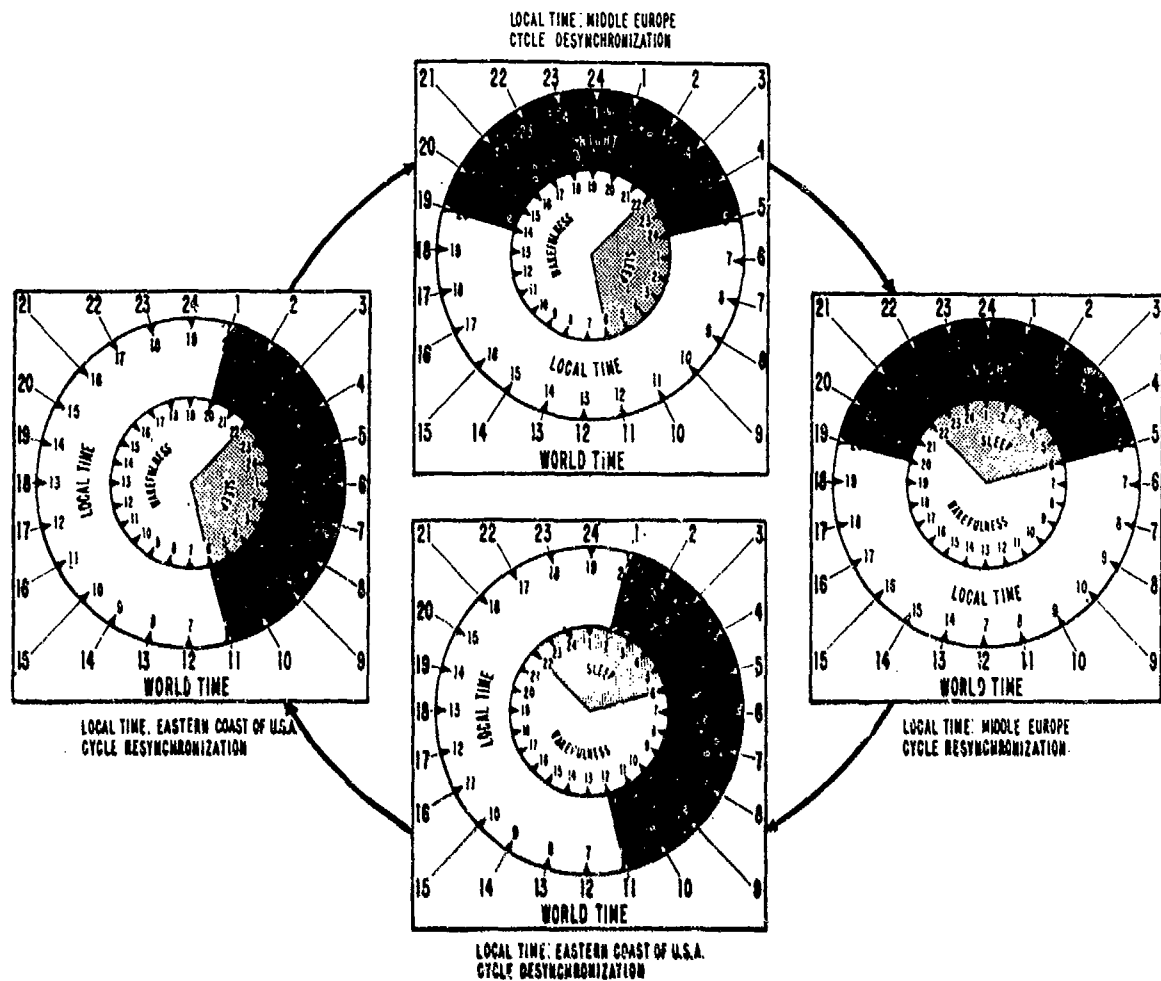


Figure 1. Phase shift of the circadian cycle. The outer area of the squares shows Greenwich Time (universal time). The outer larger circle gives the local geographic time, and the smaller inner circle gives the physiological time. The black section of the outer circle indicates night, and the shaded section of the inner circle indicates the normal time of sleep. The diagrams present the behavior of the physiological clock after a flight from the East Coast of the United States to Middle Europe and return. The left diagram shows the physical and physiological day-night cycle in New York or Washington, D.C. The upper diagram shows the geographic time change by six hours on arrival in Europe. The physiological day-night cycle is still the same. About a week later it is again in tune with the physical day-night cycle, or resynchronized, as shown in the diagram on the right. Reading the figure from right to lower center and left demonstrates the physical and physiological cycles after a trip from Middle Europe to the East Coast of the United States.

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Professionally, circadian cycle desynchronization may have some significance for international conferences. The morning hours, during the first few days after long-distance, eastbound flights, and the late afternoon hours after westbound flights, are not the best times for important negotiations. During these days, the individual who has crossed a number of time zones may be in a somewhat handicapped position due to his desynchronotic condition. It has also been observed that actors, athletes, and last, but not least, race horses were not at their intellectual or physical best the first few days after arriving from a region four or more time zones away.

The problem of cycle desynchrony is especially important for those who for occupational reasons have to cross and recross a number of time zones several times a month. Pilots on long-distance air routes are in this category: their physiological clock requires special attention. There are also medical aspects concerning diagnosis and treatment of patients who arrive from distant time zones, I might add.

The question therefore arises: What can be done to prevent undesirable physiological consequences of a phase shift in the day-night cycle after long-distance flights? There are several means of avoiding desynchronization:

First, a traveler could fly to his destination several days in advance, so that he will be adjusted to the new local time (post-flight local preadaptation).

Second, a synchronization of the physiological with the physical day-night cycle can be attained by presetting the physiological clock; i.e., by adopting gradually, several days in advance of the trip, a sleep and wakefulness pattern which corresponds to the physical day-night cycle of the place of destination (preflight adaptation, or preflight synchronization).

Third, the use of mild pharmaceuticals given at the proper time might accelerate, as a kind of synchronizer, the physiological adjustment to the new local geographic day-night cycle.

The aforementioned measures for synchronization of the day-night cycles are useful and applicable in case the traveler remains at the place of destination for several days; however, the jet age has facilitated the entire matter insofar as it is now possible to fly to a distant place and back in one day; for instance, from Los Angeles to New York, and return. In this case, the trip is an intradiurnal matter and should not cause any inconvenience, especially if the speed is supersonic, which makes possible a round trip, for instance, from Washington, D.C. to the capital cities of Europe, within one day. So much about air travel.

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In orbital space flight within the relative radiation-safe altitude range from 200 to 800 kilometers below the Van Allen Radiation belt, the orbital periods last from 80 to 130 minutes. Maximally about 30% of this time--depending upon the orbit's inclination--is satellite night, or Earth-shadow time. The external, photoscotic cycle is not longer than one-tenth of the day-night cycle on Earth.

In interplanetary space flight the astronauts are beyond the reach of the Earth's full shadow, or umbra. Here is constant sunshine and a velvet black sky, or day and night at the same time, so to speak.

But in this unearthly environment of near and deep space with short contrast-rich photic periodicities, or with no photic periodicities at all, the astronaut still is bound to his inborn temporal pattern of sleep, rest, and activity. The behavior of his physiological clock is still basically dictated by his physiological nature as a terrestrial creature.

Fortunately, sleeping under weightless conditions seems to pose no particular problems. All of our astronauts and the Russian cosmonauts had a sound sleep when the radio noise level was kept in proper relation to the silence of space. Astronaut Cooper, for instance, stated that he slept perhaps a little more soundly than on Earth, and the Russian cosmonaut Titov reported that he slept like a baby. In case that two astronauts are in a spaceship, it has been found desirable that they sleep at the same time to avoid any noise. In case of a crew of more than two, a shift in the sleep and activity cycle will be required, and one of the astronauts has to be kept synchronized with the time zone of the Manned Spacecraft Control Center for radio communication reasons.

On the Moon, the physiological sleep and activity cycle will be completely independent of the physical or selenographic day-night cycle, which is 27 terrestrial days in length. This photic environment does not provide a time cue comparable to the 24-hour dark-light cycle on Earth.

On the most attractive postlunar astronautical target--the red planet Mars--the day-night cycle is only 37 minutes longer than that on Earth. Solar illuminance on the Martian surface at noon may reach one-third of that on Earth. Thus, the temporal dark-light alternation on Mars offers a time cue familiar to terrestrial visitors for their physiologic sleep-activity cycle, and consequently there should be no difficulties in this respect in a Martian station.

The question arises--what has bioengineering to do with the day-night cycle? First of all, it might intrigue the engineers to see that the human body not only represents a self-regulating, homeostatic

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system but also a self-regulating, cyclostatic system. Moreover, there are some close engineering relations. Sleep can be induced electrically. This so-called electro-sleep, however, cannot replace the natural sleep, but it can be used to induce natural sleep. Second, the state of sleep can be checked by recording the action currents of the brain--the electroencephalogram. This method is now applied by means of telemetry in manned orbital space flight.

And, finally, it is up to the bioengineers to make it anthropometrically comfortable for the astronauts in their space cabins or stations so that they will have sound, undisturbed sleep in order to be alert and fresh for their activities, particularly for the exploration of space.

This brings us to the next topic I want to discuss, namely, the exploratory function of vision or of the human eye in space. The superiority of the sensors of the human retina in the range from 3800 to 8000 Angstrom compared with technologic sensors is one of the reasons for the justification, or even necessity, for manned landing missions to the Moon and Mars. In addition, vision plays a vital role in rendezvous and docking operations of a spacecraft. Further, its function is dominant in coordination with the labyrinthine organ and the peripheral mechano-receptors in statokinetics, as during walking on the Earth, the Moon, and during extravehicular activities in space.

Astronauts will never see the scenery around the ship or station with the naked eye; they will always look through windows or visors. If these consist of 2 layers of transparent material, about 10% to 15% of the light does not reach the retina; this is the amount of light reflected by their four surfaces.

Solar illuminance at the Earth-Moon distance from the Sun is 140,000 lux (lumen per m²); only 100,000 lux reaches maximally the Earth's surface because of reflection, scattering, and absorption of light by the atmosphere. In space and on the airless Moon about 120,000 lux might be the illuminance level behind the windows and visors; for the glass-protected eyes of the astronauts solar illuminance is then, still considerably higher than maximally at the bottom of the Earth's atmosphere for the naked eye. Furthermore, the glasses do not change the color as atmospheric scattering and absorption do, and the stars seen from space and from the Moon do not twinkle.

Looking directly into the Sun for a number of seconds is not advisable because this can cause a retinal burn resulting in a blind spot in the visual field (helioscotoma). It is not ultraviolet but heat radiation that causes such a retinal injury, which is the same as eclipse blindness (scotoma helioeclipticum); but even a glance at the Sun affects the sensitivity of the eye for minutes. The use of instant photoreactive glasses should reduce these disturbing blinding effects.

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For observational tasks certain ophthalmological items are of special interest.

First, the human eye can be made 200,000 times more sensitive by complete dark adaptation, by closing the eyes for 20 minutes. (Wearing Roentgen glasses, as the x-ray doctors do, might be useful, too, to preserve dark adaptation.)

Second, the light-adapted eye is more sensitive to yellow-green and the dark-adapted eye to bluish-green.

The space researcher must have some knowledge of the minimum perceptible--that means the smallest spot one can perceive, and the minimum separable--the smallest distance between two spots allowing visual separation.

Furthermore, they must take into account the differences between subjective perception and objective reality, as manifested in brightness contrasts, in color contrast effects, misjudgment of object size, in other words, visual illusion. So much about the visual sensors.

In conclusion, I should like to make a brief observation about a power equipment used in the space vehicles of the Gemini project, which has some kind of an analog in biology. I have in mind the fuel cells. The idea for this electricity-producing device, which is based on oxidation of hydrogen with water as by-product, goes back to the last century. In its early models it was called "gas battery." Now, in the modern version, termed fuel cells, they will play an increasingly important role in extended flights in space stations and flights to the Moon or Mars.

But there are also interesting biological representatives and precursors of the fuel cells: the hydrogen bacteria, originating more than two billion years ago in the hydrogen-rich protoatmosphere and still found today in the pores of the soil; they oxidize hydrogen to water, but the energy liberated in the reaction which includes electric processes is used for growth; and, second, the electric eel (*Electrophorus electricus*), living in the Amazon River. It carries columns of more than 10,000 electric cells on each side which enable it to paralyze its prey by an electric shock like a blitz. This fish specializes in electricity as the main product. The reaction in question is probably based on oxidation of carbohydrates. Developments are going on to use hydrocarbon instead of hydrogen in fuel cells. I think comparative study of inorganic and organic fuel cells is a fascinating and promising field of research in bionics.

It is interesting to note that in a broader sense all of our activity cells, such as those of the heart muscles, the motoric muscles, and the brain cells are actually fuel cells; they oxidize,

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of course, instead of hydrogen, carbohydrates in which process also electricity is produced, as indicated by the electromyogram, electrocardiogram, and the electroencephalogram. There is another important difference. In all of these physiological activity cells, electricity is only a by-product; in the chemical fuel cells and the electric eel it is the main product.

Those researchers exploring the electro-physiology of the heart and the brain, some 50 years ago, would probably never have dreamed that their findings and recording methods would be used some day to control the health, activities, and sleep of astronauts orbiting the near-Earth space. This shows that basic research which might first appear to be a matter of pure science may find sometime, somewhere, and somehow a very useful application.

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RECENT ASTRONOMICAL DISCOVERIES AND
THE MARTIAN LIFE THEORY*

Hubertus Strughold, M.D., Ph.D.

I would like to make a few remarks about the extent to which the recent discoveries of Earth-based astronomy and of rocket astronomy by means of Mariner IV might affect the Martian Life Theories, and about some open questions.

1. According to one analysis of the radio occultation measurements of Mariner IV, the reddish area named Electris might be 5 km higher than the dark region, Mare Acidalium. This would confirm the generally accepted opinion that the reddish areas are highlands and the dark regions are lowlands.

2. The dark areas, according to most observers, show seasonal color changes from dark gray to bluish-green, to brown, and back to dark, a possible indication of vegetation on Mars. But to some observers they appear always to be dark gray. This latter can be accepted only if the observers have normal color vision, as determined by medical examination. The final answer in this color dispute might come from color photographs during fly-by missions.

3. The earlier estimations of the atmospheric pressure at ground level, based on spectrographic studies, ranged 85 to 10 millibar. The occultation experiment of Mariner IV suggests a pressure of 10 to 5 millibar. This would mean that the ground level air pressure is not 10 times, as it was formerly believed, but rather 100 times lower than the barometric pressure of the Earth's atmosphere, and equivalent to an altitude of 30 km and not to 16 km. Could microorganisms survive such low pressure? Recent experiments in space simulators have shown that bacteria and particularly spores are resistant even to a vacuum. The same has been observed in actual space on bacteria in packages attached to the outside of space vehicles.

4. Recent spectroscopic studies indicate that the carbon dioxide concentration in the Martian air might be 10 times as high as on Earth. This would even be of advantage for the growth of green vegetation, since increased carbon dioxide in this pressure range promotes photosynthesis. Beyond 22 mm Hg, it has an inhibiting effect upon this process.

*Presented at the Third Texas and Southwestern Astronomers Neighborhood Meeting, The University of Texas, Austin, Texas, 4 Mar 1967.

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5. Very recently methane has been detected in the Martian atmosphere and interpreted as an indication of the presence of organic soil material. In geobiology anaerobic bacteria convert decomposed organic compounds via fermentation to methane. This "marsh gas," produced by these "methane bacteria" in oxygen-free environments such as at the bottom muds of ponds, upon rising to the surface into the atmosphere, is then oxidized by aerobic bacteria. This latter process cannot be expected in the absence of oxygen on Mars, but "methane fermentation" is certainly conceivable.

6. With regard to temperature, I would like to mention only that during most of the daytime in the lower latitudes in summer the surface temperature is ecologically adequate, but at night it drops always and everywhere far below the freezing point of water. But we know bacteria and spores that survive temperatures close to absolute zero. Thus, Mars biology during the daytime in spring and summer would be a moderate euthermal one, but the cold nights would always turn it into cryobiology. However, locally there might be exceptions in the form of perma-warm spots on the Martian surface similar to those found on Earth, as for instance on Mt. Wrangell in Alaska, in Wyoming, Greenland, Iceland, and New Zealand. There are no reasons why similar perma-warm spots should not exist on Mars which would not have the extreme low temperatures during the night and, therefore, would have a higher ecological potential. Scanning the surface with infrared sensors by future Martian orbiters may answer this question.

7. The low density of a 10 millibar pressure atmosphere might not provide effective protection from harmful solar ultraviolet and x-rays. it is now argued. But we must remember that the intensity of solar irradiance at Mars' solar distance is less than half of that at the Earth's distance; furthermore, a certain amount of these rays is certainly absorbed within the Martian atmosphere. From biological research it is of course well known that ultraviolet rays, particularly in the range from 2500 to 2800 Angstrom, are indeed very destructive to most terrestrial microorganisms. For this reason, they are used to sterilize food and even lunar and planetary probes to prevent contamination; but there are various degrees of resistance to ultraviolet and x-rays. It has been reported in the bacteriological literature that certain microorganisms are even stimulated in growth when exposed to low-intensity ultraviolet and x-rays. And, finally, some microorganisms, plants, and animals are less susceptible to ionizing radiation under hypoxic and hypothermal conditions. This is particularly interesting with regard to Mars where there is practically no atmospheric oxygen and a much lower temperature range.

8. Energetic particle rays of solar and galactic origin are considered as possible adverse factors to life on Mars since they can reach unhindered its atmosphere because of the absence of a magnetospheric shield. But because of the greater distance from the Sun the influx of solar particle rays is certainly lower and the so-called microenvironment in caves, craters, and fissures might offer effective protection.

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Considering all of the physical, chemical, and biological factors and their interrelations, and particularly the fantastic adaptability of life to adverse conditions, we must come to the conclusion that the occurrence of life on Mars is still more in the realm of probability than of possibility. Some of the new findings of Mariner IV and of modern Earth-based astronomy are more hostile to life, but others are more favorable.

SOLVED AND UNSOLVED PROBLEMS IN AEROSPACE
MEDICINE--INTERNATIONAL STATUS, 1967*

Hubertus Strughold, M.D., Ph.D.

After the subsonic and supersonic flight phase in aeronautics in man's fast advance on the "vertical frontier," the first milestone in astronautics is already behind us with the achievement of numerous orbital flights, with a record duration of 14 days in near-Earth space. Rendezvous-docking operations and fantastic extravehicular excursions have been successfully performed. Now, preparations are underway for longer orbital flight durations and for manned lunar and planetary landing missions.

This is the time to look back at the problems that have been solved and at those that are still open in manned orbital flight, and to make extrapolations from the medical experiences in near-Earth space with respect to the long-range flights to neighboring celestial bodies. In this respect, we are now in the fortunate position to make use of a rich source of physical environmental data gained by means of space-bound rocket astronomy such as automated space probes, lunar orbiters and landers, and planetary fly-bys; and, last but not least, of the remarkable progress made in modern Earth-based optical, radio-, ultraviolet-, and x-ray astronomy.

It is, of course, impossible to present in 1 hour an overall review of the solved and still unsolved problems. Therefore, I would like to confine myself to certain freely selected timely topics, with emphasis upon the environmental medical aspects of the Earth, space, the Moon, and Mars, or the ecophysiological factors along the line from Aerospace Medicine to Lunar and Mars Medicine.

Beginning with the Earth's environment, some distinct altitude levels are of special medical and flight operational interest. They can be summarized as follows:

First, the atmosphere:

0-700 km--extension of the inner atmosphere

700-5,000 km--extension of the outer atmosphere, or exosphere

*Presented during the visit of Lt. Gen. Richard L. Bohannon, Surgeon General, USAF, with his distinguished guests, the Allied Air Surgeons General, 6 Apr 1967.

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At 4 km--threshold of subcritical hypoxia

At 7 km--critical hypoxia

At 20 km--boiling of body fluids, or ebullism (Armstrong line)

50-80 km--limit for aerodynamic navigation (von Karman line)

100 km--official demarkation line between atmosphere and space
(Federation International Aeronautique, Geneva, 1964)

150-200 km--border of the aerodynamically effective, or sensible
atmosphere

At 20 km the atmosphere attains the characteristics of partial space equivalence, which widens to total space equivalence at the border of the sensible atmosphere.

The circumterrestrial environment includes two fields of forces:

1. the magnetosphere is the background force of the Van Allen radiation belts. On its Sun-directed side the magnetosphere, with its boundary, the magnetopause, is compressed by solar plasma wind to about 10 Earth radii, and on the opposite side it is elongated in the form of a tail reaching far beyond the Moon (magnetic tail).

2. the gravisphere (the region within which the Earth can hold a satellite in orbit) extends to 1.5 million km. Up to several times this distance, its gravitation field is still influential, as manifested in its effect upon the velocity and direction of space vehicles (gravipause). The Moon's gravisphere extends to about 60,000 km. So much about our present knowledge of the gross morphology of the physical environmental (atmospheric, magnetic, and gravic) profile of the Earth.

In contrast to the radically changing physical environment along the vertical frontier, the physiological "milieu interne" (Claude Bernard, 1860) of the human body has the tendency to constancy, or homeostasis, a concept advanced by W. B. Cannon, Boston, in 1929. The human body tends to keep the physical properties and chemical composition (temperature, oxygen, salt, ion concentration, etc.) of its internal milieu (i.e., intercellular, or interstitial fluid, called fluid matrix) in any external environment nearly constant.

Whereas, with regard to his surrounding environment, man is an air inhabitant, his basic living units, the cells--trillions in number--are water inhabitants, just the same as the microorganisms in the physically rather constant deep sea. His internal intercellular ocean, amounting to about 12 liters, connected via the moving blood and lymph streams

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with the moist surfaces of the lungs and kidneys, has to be kept in a nearly steady state, a precondition for man's health, well-being, and intact sensorimotoric and intellectual activities.

If one of the physical or chemical components of the external environment deviates from the normal, but is still above the physiologically required minimum or below the permissible maximum, the human body reacts effectively with coordinated compensatory or defensive responses (changes of metabolic rate by muscular action; respiratory, cardiovascular, and renal reactions; perspiration). Deviations beyond these two ecological "cardinal points" lead to pathological effects upon the cells, particularly the brain cells, and as a result the psychophysiological functions deteriorate. Maintenance of a nearly steady state of the body's fluid matrix is the function of autonomic and endocrine systems, governed by a control center in the thalamus and subthalamus of the diencephalon, or interbrain. This makes the human body a self-regulating system, but only within certain limits.

I have referred to this fundamental physiological phenomenon, homeostasis, because it is an ideal departure point for a medical study of the human body in relation to any environment, or for an ecophysiological analysis of the "fitness of an environment" for man. Application of this concept is now particularly useful with regard to the natural environments beyond the life-supporting regions of the Earth's atmosphere, in space, and with regard to the artificial environs in spaceships, space suits, and in lunar and planetary stations.

During the past 10 years considerable progress in research has been made concerning the kind of atmosphere for spacecabins, such as two-gas atmospheres with nitrogen, helium, neon, or argon as a diluent of oxygen; one-gas atmosphere (pure oxygen), its toxicity and fire hazards; chemical and biological regeneration of the air; prevention of chemical and biological contamination; decompression prior to egress for extravehicular activities; survival time of chimpanzees after sudden exposure to vacuum conditions; etc. In addition to these experiments on man and animals in spacecabin simulators, lasting many weeks, practical experiences have been gained in actual manned space flight up to a 14-day record duration. Principally, the environment in a spacecraft should be as terrestrial as possible, and this applies particularly to the atmosphere which should be a two-gas atmosphere, especially for long-range operations.

A leak of the spacecabin can endanger the homeostatic system of the occupants. One possible cause, often considered in the literature, could be a hit by a meteoroid with puncture capability; but the situation in this respect, at least in circumterrestrial space flight, looks better today than had been expected 10 years ago in the presatellite time. Most of the meteoroid material in near-Earth space is of cometary

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origin, and this kind, according to Fred Whipple, is soft "fluffy stuff," neither as frequent nor as violent as had been feared earlier. But recently the temperature of the nucleus of a comet, Ikeya-Seki, has been measured by means of infrared sensors; it increased from 371°C at a distance of 74 million km from the Sun to 649°C when the comet came within 32 million km of the Sun. On its return, the temperature dropped back to 371°C . This high temperature at the perihelion has been interpreted as an indication that comets consist not only of dirt and snow but also of some metallic material. We can expect more information on this question when automated space probes fly through the tail of a comet, collect and analyze its material, and send the data back to Earth. An opportunity for such an on-the-spot exploration by a cometary tail probe will come when Halley's Comet returns in 1985. Be that as it may, during the total manned-space-flight time, no macro-meteoritic incident has occurred; and, so far, four extravehicular excursions have been made without even micrometeoritic interference. Moreover, it might be interesting to note that up to now four manned spacecraft have been in orbit at the time when the Earth crosses yearly the orbit of a permanent meteor stream. But stream meteoroids are also occasionally concentrated in the form of a meteor swarm. When the Earth passes through such a swarm--which is a rare event--we see the spectacle of a meteor shower, as in 1933, 1946, and 1966.

All in all, the situation concerning meteoroid hazards at the Earth's solar distance is no longer considered of first-rate concern. But this rosy picture might be somewhat dimmed by the possibility of a spacecraft colliding with the stone and iron meteoroids of asteroidal origin in extended space operations to Mars and beyond, near the belt of the asteroids where they should be more numerous.

Protection against puncture by using "meteor bumpers" (Fred Whipple), including self-sealing devices, therefore will remain the concern of the engineers and the space doctors.

Concerning micrometeoroids, preventive measures have to be taken against corrosion effects on windows and communication equipment, particularly on long-duration flights. Satellites such as Pegasus and Gemini XII-Agena, by means of micrometeorite collection packages, have already provided important information about the distribution of micrometeoroids in near-Earth space.

Turning to another space environmental factor, energetic particle rays, what is their hazard potential as we see it today? In manned orbital flights in circumterrestrial space between 50 degrees North and South Latitude, the radiation dose absorbed has been maximally less than 1 millirad per hour, or about 15 millirads per day, as recorded in both the Gemini flights and the Russian flights. Thus, in low orbits we can look upon the radiation problem with no particular concern. This is different in high orbits, i.e., above 800 km, within the Van Allen

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radiation belts, where we must reckon with up to 5 rads per hour in the inner belt around 3,000 km, and with 10 millirads per hour in the outer belt around 18,000 km. These belts, therefore, are "off limits" for space flights of the orbital type. In deep space beyond the magnetosphere, the dose rate might be several rads per month. Such is the particle radiation climate for the astronauts during the time of a quiet Sun, if the absorbing power of the cabin's wall is equivalent to 1 cm of steel. There are other more optimistic and pessimistic estimations; be that as it may, the intracabin radiation dose can still be reduced by heavier shielding.

Concerning a proton outburst after a solar flare, astronauts orbiting in near-Earth space and constantly in communication with the Earth-based Solar Flare Prediction Center, will have more than 10 hours to take protective measures. Extravehicular excursions are, of course, not advisable for several days after a solar flare. With increasing distance from the Sun, as en route to Mars, the proton streams become gradually less vicious. In near-Mars space there is no effective magnetosphere to trap particle rays, according to Mariner IV. There are, therefore, no restrictions from a Van Allen-type radiation belt for selecting the altitude for a parking orbit. The same is true about circumlunar flights, according to recordings of lunar orbiters.

With regard to electromagnetic radiation, I would like to confine myself to its visible section as an environmental factor. In circumterrestrial orbital flights, the photic environment includes a variety of components: sunshine intensity, 140,000 lux; earthshine, several lux; moonshine, about 0.5 lux; and the Earth's shadow--all to some extent overlapping and encountered by the astronauts within the short orbital period of 90 to 130 minutes. This is certainly in sharp contrast to the 10-times-longer regular light and darkness cycle of 24 hours on Earth, with which our physiological sleep and wakefulness cycle is synchronized. This circadian cycle is another basic property in the physiological nature of the human body; it shows a tendency to near constancy and is actually integrated in the homeostatic system insofar as the changes in metabolic rate, oxygen consumption, activity of the exocrine and endocrine glands, and temperature fluctuate around their homeostatic baselines.

This physiological circadian cycle is firmly established in man and can be shortened only to about 18 hours and extended to 28 hours. Man is, so to speak, cyclostatic. Preservation of this physiological cyclostasis, i.e., alternation of sleep and activity within nearly the inherited time frame, is a precondition for man's health and performance capability. Astronauts, therefore, have to follow the dictate (or better, tick-tock) of their physiological clock by a well-regulated sleep and activity regime.

Fortunately, sleeping under weightless conditions in space flight seems to pose no particular problems. All of our astronauts and the

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Russian cosmonauts had a sound sleep in the silence of space when noise was kept at a low level. When two astronauts are in a spaceship, it has been found desirable that they sleep at the same time, as has been arranged for the last Gemini flights. In case of a crew of more than two, a shift in the sleep and activity cycles will be required, and one of the astronauts has to be kept synchronized with the time zone of the Manned Spacecraft Control Center for communication reasons.

The Moon's day-night cycle of 27 terrestrial days does not provide a time cue for the physiological clock of the occupants of a station. Their sleep regime has to be arranged independently of the lunar photic environment. Nevertheless, since the lower gravity on the Moon might probably cause fewer sleep-interrupting body movements than experienced on Earth, due to the so-called pressure points, the sleep might be more refreshing in the gravitational arms of Luna, the Goddess of Night.

On Mars the day-night cycle is only 37 minutes longer than on Earth and offers, therefore, a time cue familiar to terrestrial visitors for their physiologic sleep-activity regime.

Basically, then, there are no particular problems concerning the physiological clock for space travelers; probably less than encountered by air travelers who, after crossing a half-dozen time zones, are for several days desynchronized.

In all medical aspects of space flight, the duration plays an important role. What might be the time limits in this respect? A flight to the Moon is no problem since this takes only about 3 days. But a flight to Mars, based on an economic (minimum-energy) trajectory, lasts more than 8 months. This is the simplest method for unmanned, automated planetary probes such as the Mariner IV.

But is such a long duration also acceptable for a manned planetary mission? To get a realistic judgment in this respect, we must consider the whole complexity of life of the mission crew, a team of perhaps six or more, living in a cramped, closed ecological world with its own economy and autonomy. Their activities include power control, navigation, exploration, telecommunication, control of the life-support system, hygiene, and housekeeping. Weightlessness complicates some of these activities; others are facilitated.

The astronauts, after some 20 hours of flight, should be in a state of "relatively stable adaptation to weightlessness," as has been concluded from the medical observations in orbital flight. Anthropometric comfort, appropriate exercise, and a well-regulated sleep regime might enable them to endure space flight in the order of months. Artificial gravity might not be required. Be that as it may, it is medically

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advisable, if not even a requirement, to base a flight plan to Mars on a high-energy trajectory (which would shorten the duration of the minimum-energy trajectory of about 8 months to 30% to 20% of this time), which can be achieved by nuclear propulsion.

In addition to the man-machine-intracabin environment complex, the external space environment also must be taken into account. A shorter time reduces the possibility of meteoritic incidents and of radiation hazards after solar flares.

In brief, a minimum in time and an optimum in comfort is the medical prescription in order to achieve a maximum of success of any manned planetary landing mission. Of course, astronauts with week-long experiences in orbital flight and the space medical "practitioners" who have controlled these flights will have a decisive voice in this respect.

In case of long-range space operations, as for instance a flight to Mars, preflight prophylactic surgical measures, in addition to preventive dentistry, must be considered. Appendectomy would certainly be advisable and even cholecystectomy unless more advanced diagnostic methods can prove that the astronaut is free of negative gallbladder stones (not visible in present-day x-ray examinations).

The human body is a self-regulating system not only with regard to its vegetative functions, but also with regard to its sensory motoric functions, or statokinetics. This is particularly interesting concerning extravehicular activities, the most fascinating achievement in manned space flight. I would like to make a few comments about the sensorimotoric control of equilibrium and orientation during walking under reduced gravity down to zero G.

The sense organs involved in these functions are: the eye, the labyrinthine (otoliths, semicircular ducts), and extra-labyrinthine peripheral mechanoreceptors. Usually the labyrinthine organ is in the center of the discussion about this threefold equilibrium control system, or "orientation trias." I, therefore, would like to confine myself to the extra-labyrinthine mechanical senses. They are the muscle sense, the pressure sense, and the posture sense, with their well-known receptors. Responding to mechanical stimuli such as pressure, tension, stretching, etc., they control sensorically to a great extent position and movement of the body and its parts by coordinating the required muscular reactions, as indicated by the electromyogram.

First, let us assume a man of 70 kg mass, or 70 kilopond (=70 kg weight), walks on the Earth's surface with its 1-G condition. The pressure upon the mechanoreceptors in the soles of his feet and, particularly, the muscle tension provide adequate stimulation for the

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coordination of the flexors and extensors; moreover, during walking upstairs and downstairs or on a rough surface, the increased and abruptly changed muscular tension produces supporting or correcting proprioceptive muscle reflexes.

On the Moon a 70-kg man has a weight of 12 kilopond. This might still produce enough gravitational stimulation for the mechanoreceptors in the legs. But keeping balance during walking might be facilitated by increased weight for the astronaut--by his carrying, in addition to the life-support equipment, some 30 kilopond of material, maybe Moon pebbles, in pockets around his waist or shoulders. This would increase the tension in the extensor muscles of the legs and might even trigger proprioceptive reflex support, and thus should make walking on the Moon's pebble-covered surface safer. It would make the stimulation of the peripheral mechanoreceptors more Earth-gravity equivalent. Of course, it would not affect the otoliths. (By the way, similar measures are used by aquanauts when walking on the bottom of the sea). This is the method of walking on the Moon I suggested at the Symposium of the Lunar International Laboratory Committee of the International Academy of Astronautics in Madrid, 1966.

In contrast to this method of walking, R. Margeria, Milano, suggested at the same meeting that advantage of the Moon's low gravity should be taken by jumping. This might be acceptable if the surface is smooth; but, on a rough surface if the "Moonhoppers" should lose their balance and hit the ground, they might risk a leak in the pressure suit. Thus, the increased-weight method might be generally safer.

Furthermore, a one-man rocket propulsion device, too, seems to be very useful on the Moon; in the personal control of this system, the peripheral mechanoreceptors, in addition to the otoliths and eye, play an important role.

Interestingly, there is an analog to this device in the animal kingdom. The Medusa of the phylum Coelenterata swims by taking water slowly into a cavity through an opening and by expelling it again by a fast contraction. This is an individual water-propulsion device which has been in existence for some 300-million years.

Back to the space age; during the zero-g extravehicular activities in space, orientation and balance depend exclusively upon vision and the proprioceptive perceptions of the peripheral mechanoreceptors. The important role of the latter is indicated by the fact that the astronauts feel better oriented when they touch a handrail on the spaceship, which gives them additionally some exteroceptive perceptions. By the way, when the Russian cosmonaut G. Titov had some dizziness in his Vostok ship, he felt immediately better when he pressed his buttocks against his seat. This is a kind of space analog to "flying by the seat of the pants" in an aircraft.

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On Mars, with a gravity of 0.38 G, there should be no balance difficulty in walking around outside the station to explore its surface mysteries.

In this respect, I would like to make a few concluding remarks about what we have learned from the recent discoveries of Mariner IV and from modern Earth-based astronomy for Mars biology and Mars medicine, particularly how they might affect the Martian Life theories. In terms of planetary analogy and terrestrial biology, this can be summarized as follows:

First, concerning the relief of the Martian surface, the generally accepted opinion is that the reddish areas are highlands and the dark regions are lowlands. This seems to be confirmed by the radio occultation measurements of Mariner IV, according to which a certain reddish area named Electris is 5 km higher than a dark region called Mare Acidalium.

The dark areas, according to most observers, show seasonal color changes from dark to bluish green, to yellow gold, to brown, and back to dark, which is interpreted as an indication of green vegetation on Mars. But to some observers they appear always to be dark gray. This can be accepted only if these observers have medically examined normal color vision.

The bluish-green color is also considered by some to be a visual-contrast phenomenon against the ocher-reddish surroundings. Visual-contrast effects certainly occur, especially if the areas are small, but the bluish-green coloration of large areas such as the Syrtis Major is in all probability real. This is supported by the observation of Clyde Tombaugh, according to whom certain areas occasionally look dark when others look green, despite the fact that both are surrounded by reddish areas. The final answer in this color dispute might come from color photographs made by future fly-by probes. But green or not green, it is not decisive for life "to be or not to be" on Mars.

Fifty years ago, Sv. Arrhenius advanced the theory that the dark areas are salt beds of dried-out oceans, which respond to changes in atmospheric humidity, and concluded that "Mars is indubitably a dead world." But in the Dead Sea, which is an extraordinarily salty medium, numerous species of microorganisms (algae and bacteria, etc.) flourish abundantly, as reported recently. The Dead Sea, therefore, is not so dead after all, as it was believed. And the Red Planet might not be so dead, as well.

The dark areas have also been explained as being deposits of volcanic ash blown by the prevailing winds, and the color changes have been attributed to reactions to seasonal variations in humidity, or in radiation. This, of course, does not exclude the possibility of life,

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because terrestrial bacteria--lichens and mosses--can grow on lava. Actually, bacteria can grow on practically any material, even in oil wells and jet fuel containers, as indicated by the new bacteriological branch, petroleum bacteriology.

Concerning the atmosphere, the earlier estimations of its pressure at ground level, based on spectrographic studies, ranged from 85 to 10 mb. The occultation experiment of Mariner IV suggests a pressure of 10 to 5 mb. Could microorganisms survive such low pressure? Recent experiments in space-environmental simulators and in containers carried outside a spacecraft have shown that bacteria and particularly spores are resistant even to a vacuum.

Oxygen so far has not been detected in the Martian atmosphere. This does not exclude life, as proven by the occurrence of various types of anaerobic bacteria on Earth. Anoxybiosis might be the Martian way of life if no organisms exist there capable of producing their own oxygen by means of some kind of photosynthesis. This process requires carbon dioxide and water as raw material.

Recent spectroscopic studies indicate that the carbon dioxide pressure in the Martian air might amount to 3 mb, i.e., 10 times as high as on Earth. This would even be of advantage for the growth of green vegetation, since carbon dioxide in this pressure range increases photosynthesis. Beyond 22 mm Hg it has an inhibiting effect upon this process.

Water vapor has been detected in the Martian atmosphere, but is extremely scarce, only about 1/1000 of the mean humidity of the terrestrial atmosphere. If the barometric pressure is below 7.5 mb, this is below the "triple point" of water, i.e., H_2O can exist only in the state of vapor and ice. But in the lowlands of Mars, the air pressure might be around 10 mb; in this case it could occur also in the liquid state in the soil. The "wave of darkening" moving from pole to pole in spring is an indication of soil moistening. Water is decisive for the existence of life. But some terrestrial microorganisms can survive long periods of complete desiccation; they would not be destroyed by seasonal periods of extreme dryness of the Martian surface. Hydroecologically, the situation on Mars is severe but not to the extent that it is prohibitive to life of the low-level terrestrial type. Moreover, there might be subsurface ice layers which could increase the soil's humidity locally. They are considered to be remnants of ancient oceans, now covered by some 100-m-thick layer of solidified dust. This theory, advanced in 1910 by Professor Bauman in Zurich, later somewhat forgotten but recently revived, is very attractive if combined with two other concepts.

In 1937, P.A.M. Dirac advanced the hypothesis that the gravitational constant has decreased slightly during the life of the solar system and continues to decrease. This has led to an expansion of the Earth, causing "tension cracks," or fissures, on land and at the bottom of oceans, as recently described by R. H. Dicke and P. Jordan who both

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confirmed Dirac's first generally not-accepted theory. The splitting of the two giant original supercontinents, Gondwanaland and Laurasia, about 1 billion years ago into several secondary continents, now widely separated by a continental drift (A. Wegener), is attributed to this gravitational phenomenon.

It is logical to assume that on Mars, too, this gravitational decrease has caused similar effects, namely, volume expansion and tension cracks, after it had cooled off at the end of its proto-planetary phase and had reached a temperature equilibrium. And meteoritic impacts in addition to volcanic Marsquakes could have triggered fissures of tremendous lengths, particularly in a crust of different layers, including a subsurface ice layer. This threefold environmental combination--subsurface ice layer, tension expansion due to gravitational decrease, and meteoritic impacts--might well have been the mechanism behind the scene of the dark spots called oases and the dark linear marking radiating from the dark spots over enormous distances. A subsurface ice table, or hydrocryosphere, would increase the humidity locally, i.e., in and around the meteoritic impact craters and in and along the fissures, making them ecologically more suitable for the growth of vegetation. Actually, it might be the soil's humidity and vegetation that make these areographic surface features visible to Earth-based optical astronomy in the first place.

To conclude this water dispute, if there should be native life on Mars, this would not be conceivable if there had not been ancient open waters for its origin.

The Martian surface temperature in summer is for about 5 hours each day ecologically adequate, and it can reach a maximum of 30°C, but all the other times it remains below the freezing point of water; it drops to a minimum of -60°C, a condition which appears particularly prohibitive to life. But we know of bacteria and spores that survive temperatures close to absolute zero; furthermore, it has been found recently that the terrestrial bacterium Aerobacter zerogenes survives when experimentally exposed to a diurnal freeze-thaw cycle. Generally, then, a biology of Mars during its cold nights turns always into cryobiology. However, locally there might be exceptions in the form of perma-warm spots on the surface similar to those on Earth, as for instance in Alaska, Wyoming, Iceland, and New Zealand. There is no reason in terms of planetary analogy why similar perma-warm spots should not exist on Mars, possibly above dormant volcanos, which would not have the low night temperatures and therefore would have a higher ecological potential. Scanning the surface with heat sensors by future automated Martian orbiters may answer this question.

The low density of a 10-mb pressure atmosphere might not provide effective protection from harmful solar ultraviolet and x-rays, it is argued. But, first of all, the intensity of solar irradiance at Mars'

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distance from the Sun is less than half of that at the Earth's solar distance; furthermore, a certain amount of these rays is certainly absorbed within the atmosphere. It is, of course, well known that ultraviolet rays, particularly in the range from 2500 to 2800 Angstrom, are indeed very destructive to most terrestrial microorganisms. For this reason they are used for sterilization of food and even of lunar and planetary probes to prevent contamination. But there are various degrees of resistance to ultraviolet and x-rays; certain microorganisms are even stimulated in growth when exposed to low-intensity ultraviolet and x-rays. And, finally, some microorganisms, plants, and animals are less susceptible to ionizing radiation under hypoxic and hypothermal conditions. This is particularly interesting with regard to Mars with its oxygen-free atmosphere and low temperature.

Finally, energetic particle rays of solar and galactic origin are considered as possible adverse factors to life on Mars because they can reach its atmosphere unhindered by a magnetospheric shield. But because of the greater distance from the Sun, the influx of particle rays of solar origin is certainly lower; and the so-called microenvironment provided by caves, craters, and fissures might offer effective protection.

Considering all of the physical, chemical, and biological factors and their interrelations, and particularly the adaptability of life to adverse conditions, we must come to the conclusion that the occurrence of life on Mars is more in the realm of probability than of possibility. Some of the findings of Mariner IV and of modern Earth-based astronomy are more hostile to life, but others are more favorable. In the years ahead, life-detecting instruments onboard unmanned landers will be sent to Mars for acquisition and analysis of soil samples and for transmitting the data back to Earth; but the final and more detailed answer concerning a Martian biosphere might come from a manned Mars-landing mission. If the answer is no life on Mars, this would give the explorers a unique opportunity to study the chemistry of a virgin planet of the terrestrial group. If the answer is yes, then we would be interested to know if the Martian life is similar to that on Earth, based on carbon biology, or of a completely different kind unknown to us. Be this as it may, it would broaden our present Earth-related Cenozoicum into a universal spectrum, the Cosmozoicum.

With regard to Mars medicine involved in a manned Mars-landing mission, I would like to mention only that if the barometric pressure on the Martian surface is 10 mb, boiling of the body fluids of terrestrial visitors, suddenly exposed to this environment, would occur at the surface and not at an altitude of 5 km, corresponding to the earlier assumed pressure of 85 mb. Barometrically this means, in terms of human physiology, that the atmospheric environment is partially space-equivalent immediately on the surface. The atmosphere offers certainly some protection from ionizing electromagnetic and particle radiation and

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micrometeoroids, and if there are ice layers below the surface, this would help to solve some of the logistic problems. All in all, a manned Mars-landing mission is medically conceivable if, as emphasized earlier, time reduction of the interplanetary journey can be achieved.

In conclusion, the achievements in man's advance on the vertical frontier so far have been spectacular, and will be even more fantastic in the years ahead; nevertheless, in its medical aspects we must be realistic and keep common "horse sense" in our extrapolations for long-range manned missions. After all, a horse, Pegasus (the winged horse of Apollo), was the first to roam around high in the sky in ancient mythology.

BIOLOGICAL "FUEL CELLS"*
(From the Electric Fish to Man)

Hubertus Strughold, M.D., Ph.D.

During the past few years the term "fuel cell" has become more and more known to the public. It entered the language from outer space, so to speak, because fuel cells were used as electricity-producing devices in manned space flight. A "fuel cell electric generator system" was required in addition to the conventional chemical batteries to meet the objectives of the long-duration missions of the Gemini Program, as reported at the Gemini Mid-Program Conference of NASA, 1966, by P. Miglicco, R. Cohen, and J. Deming (13). Oxygen and hydrogen as chemical reactants and ion-exchange membranes are the characteristic instrumental features, and electricity and water are the products of this technological power source.

There is--in a broader sense--an interesting analog to these two characteristics of the technological electric fuel cell in the biological world, namely, in the activity cells of plants, animals, and man. Their function is accompanied by electric action currents--bioelectricity. In this paper I would like to elaborate on the similarities and differences in electrogeneration between technological fuel cells and living cells, and on the functional significance of the bioelectric action currents, particularly in the human body; furthermore, on the contributions that their recordings have made to our knowledge of the physiology of the human body and to the progress in medicine, as well as to the safety of man in his advance into space.

For a better understanding of the comparison of the living cells with the technological fuel cells, we must look back into paleontology down to the Archeozoic Era of the Earth's history, some three billion years ago. During that time the protoatmosphere of the Earth contained essentially hydrogen (H_2), helium (He), methane (CH_4), ammonia (NH_3), and water (H_2O). Later small amounts of oxygen appeared, produced by photodissociation of water molecules by solar ultraviolet radiation. During this still predominantly hydrogen era in our atmosphere's history, a type of bacteria, Hydrogenomonas, or hydrogen bacteria, learned to use this photolytically produced oxygen to oxidize hydrogen. The product of this reaction is energy and water, according to the formula:



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The energy is used for growth. This process of building up organic material, called anabolism, involves some electric processes but only on a minimal, not measurable, scale.

During the atmospheric hydrogen time, another bacterium appeared that derived its energy for growth from oxidation of methane: Methanomonas methanica. Hydrogen bacteria and methane bacteria are still found today, for instance, in the pores of the soil and in swamps where the required gases, hydrogen and methane (marsh gas), are present, produced from decomposed organic material by anaerobic bacteria.

In the Paleozoic Era hydrogen gradually disappeared from the atmosphere by escape into space, whereas its oxygen content rapidly increased due to photosynthetic action of green plants (algae), thereby initiating the oxygen era in our atmosphere's history. The multicellular organisms which appeared obtained their energy essentially by oxidation of carbohydrates to carbon dioxide and water. The function of all their activity cells, as we know them today, is accompanied by the production principally of heat energy and electricity; but the amount of the latter is minimal.

Electric phenomena became more and more apparent with the evolution of special organ systems, such as the muscular and nervous system. Here the electric action currents play an important role insofar as they initiate and harmonically coordinate the activities of these systems. Since the early days of electrophysiology, a variety of instruments have been developed to record these currents. Their application in manned space flight has made it necessary to make them simpler, more sensitive, and comfortable. This, of course, is also a valuable "space benefit" for hospitals in the diagnostic and therapeutic control of patients.

Turning now to the various organ systems, the contraction of the muscle cell, or muscle fiber, is accompanied by electric currents. This was first observed by Luigi Galvani (1786) and Alessandro Volta (1794), on frog muscles. Around the beginning of this century, nerve-muscle preparations of the frog became for many years the main research tool from which much of our knowledge in electrophysiology has been gained. Even the terms "isometric" and "isotonic," now common words in exercise technique, were coined in this fruitful frog period of physiology.

During the muscle contraction itself, chemical energy of the nutrients is transformed by oxidation into mechanical energy and heat energy, not electricity; actually, the observed electric current precedes the contraction. The electric potential stems from a difference in electrolyte (ion) concentration above and below the membrane that covers the muscle and the attached nerve endplate. Nerve impulses initiate a wave of depolarization across the muscle fiber, manifested in the recorded action current, causing the contraction. The electromyogram of our voluntary muscles during movement shows 30 to 100 electric action currents per second. Electromyography has contributed tremendously to our knowledge about the coordination of the muscles during movement of our body and the limbs. It has made it possible to record the respiratory muscle

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movements under all kinds of stresses and under the conditions of space flight. In clinical medicine it has provided a new means for studying neuromuscular disorders such as muscular dystrophy and paralysis after poliomyelitis and stroke, and for determining improvement after treatment, etc. With reference to the motoric eye muscles, we speak of the electrooculogram, which serves as an important diagnostic indicator in ophthalmology.

The electric potential in the voluntary muscles of man and animals is rather low and is only in the order of magnitude of millivolts. But there are animals in which, during their evolution, muscle cells in certain regions of the body have been transformed into specific electric organs capable of producing electric potentials up to 300 volts--the electric fish (1). They are real "bioelectric generators." The electric eel, Electrophorus electricus, found in the Amazon River, has on each side of its body more than 10,000 electric platelike cells, enabling it to discharge electricity in a brief series of pulsations of sufficient voltage to strike and paralyze its prey or a fisherman, like a blitz. There are other electric fish such as the stargazer (Astroscopus), (eastern part of the U.S.A.), the Malapterurus (Nile River), and the Torpedo marmorata (Mediterranean Sea). Of the latter, Aristotle, 2300 years ago, wrote in his History of Animals, "The Torpedo narcotizes the creatures it wants to catch, overpowering them by the strength of shock that is resident in its body. ...It is known to cause a numbness even in human beings." (The Greek word "torpedo" means numbness and numbfish). Today, the electric shock in a controlled form is used for psychiatric treatment of, for instance, schizophrenia, for narcosis (electronarcosis), or anesthesia (electroanesthesia), and for inducing sleep (electrosleep).

The kind of chemical process behind the action of the electric-fish organ is still not completely understood; but in all probability, different ion concentrations on the lower and upper surface of the electric cellular plates are involved. These units are piled one upon the other, forming hundreds of separate piles--a remarkable resemblance to the stacks of some two dozen cells in the two sections of the technological fuel cells (13).

The electric-fish organs represent a developmental climax in bioelectricity, which is one of the various subdivisions of bionics (12, 15, 17). This new and fast-developing biotechnological field explores what technology can learn from biology. But in this discussion I would like to confine myself, more or less, to basic human electrophysiology and its application on Earth and in space.

The best known electrogram is that of the heart--the electrocardiogram (ECG), manifested in a distinct pattern of action currents. The electric potential during the excitation phase of the heartbeat amounts to about 40 millivolt. Electrocardiography has become an indispensable diagnostic method for the heart specialist; it has made it even possible

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to check the heartbeat of a fetus in the uterus capsule. Moreover, the telemetric recording of the electrocardiogram of the astronauts in their space capsule has provided the space doctors at the control centers on Earth invaluable data concerning the effects of space flight, particularly the effects of increased G forces during landing and reentry, of weightlessness, and the stresses associated with extravehicular activities (2, 4, 5, 8, 11, 14). Electrocardiography has been employed earlier in laboratory experiments on centrifuges which have given us basic cardiovascular data about the tolerance of high G forces in various body positions, which later have been very useful to secure the safety of and provide some comfort for the astronauts during atmospheric reentry (5, 6, 16).

Finally, in 1924, it was found by H. Berger (3), that the human brain also produces electric action currents of various frequencies in different regions, known as the electroencephalogram (EEG). Fifty years earlier fluctuations of the cerebral electric potential were observed on rabbits and monkeys by R. Caton (7). There are several theories (metabolic, neuronal, and others) about the processes behind these spontaneous cerebral electric rhythms (6).

Of special interest is the behavior of the predominant frequency, namely the alpha waves, under various conditions. During the state of wakefulness, for instance, the oscillation frequency of the alpha waves amounts to 9 to 13 per second; during deep sleep it drops to 2 or 3 per second (9). But an exciting dream, or a nightmare, leads to a burst of electric currents. The EEG unquestionably is the most sensitive index to measure the state of alertness and the depth of sleep. Thus, man's physiological circadian cycle--the sleep-and-activity cycle, which is synchronized with the Earth's physical day-night cycle--is reflected in the brain's electric activity cycle. The alpha waves are, so to speak, the electric tick-tock of the "physiological clock," or more specifically, the "head clock." The EEG, therefore, can be used to check the time it takes a desynchronized air traveler, after crossing some six or more time zones, to become synchronized with the local day-night cycle of the place of destination. This could have some significance if a not-yet-resynchronized participant of an important international meeting confers with other participants who could stay in their time zone; in the first few days he might be somewhat sleepy and thus would have a lower brain wave frequency at the wrong time.

The electroencephalogram unquestionably has given us an important means to study the activities of the whole brain and the specific functions of its parts. It serves as a means to test hypnotic drugs and to check anesthesia. Alcohol, for instance, causes higher voltage and lower frequency waves. Neurologists use the electroencephalograph, or brain wave machine, to locate lesions, tumors, inflammations, hemorrhages, etc., and to analyze epilepsy and other pathological conditions (6). The EEG has already been sent from continent to continent via communication satellite for clinical consultation purposes between hospitals.

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This is an example of medical "teleservice" (G. H. Stoner). Electroencephalography has brought about a new research approach in the science of the mind: electropsychology, which looks into possible relationships between brain electricity and level of consciousness, behavior, and personality.

During manned orbital flights, the physicians in charge of the medical control of the operations had the opportunity to observe the electroencephalograms of the astronauts, televised to the control centers, and watch on the screen their states of alertness and fatigue and their periods of sleep and wakefulness, or their physiological clock, which--in an environment without day and night--has to be kept more or less within the time pattern of the terrestrial circadian cycle (4, 5).

If the oxygen partial pressure in the atmosphere drops below the required physiological minimum, this shows up in a decrease of the oscillation frequency of the electroencephalogram, according to laboratory experiments (10) just the same as decreased oxygen supply leads to a failure of the technological fuel cells. The eye's retina, which is an anatomic extension of the brain, also shows electric action currents (electroretinogram), which already have been widely used in studies of the visual sense.

In conclusion, the human body is a highly sophisticated, low-voltage bioelectric system. A comparison of its cellular units, trillions in numbers, with the technological electrical fuel cells is suitable and inspiring; despite some differences, it shows, in a broader sense, distinct similarities in structure and function, which are reflected also in a common terminology. It offers, therefore, some interesting aspects for both technology and life sciences as a stimulus for future basic and applied research.

Originally, the electric potential of the biological activity cells, as manifested in the electromyogram, electrocardiogram, and electroencephalogram, was used in basic research as a source for better understanding of the cellular processes and of the physiological functions of the organ systems. Very soon these electrograms found applications as important diagnostic and therapeutic methods in clinical medicine; but the discoverers of these various bioelectric phenomena, and the inventors of the respective recording instruments, probably never dreamed that some day these would be used to monitor, by means of telemetry, the various physiological functions of astronauts orbiting in space. This should remind us that in the so-called directed scientific research, such as that connected with aeronautics and astronautics, we should look back even to the pioneer discoveries in basic undirected research. We learn from this that we should never discard the future practical potential of any discoveries which might seem, at first glance, rather academic and unrelated to anything. Someday, somehow, and somewhere they might find some specific application; we have witnessed this, particularly in space flight, which has been and will be even more in the future, followed by a "fallout" for general use on Earth. There is no question

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that the utilization of the bioelectric phenomena in space medicine has already paid off for the benefit of Earth-based medicine. This, of course, also has tremendous commercial implications.

REFERENCES

1. Amberson, W., and D. C. Smith. Outline of physiology. New York: F. S. Crofts & Co., 1939.
2. Bedwell, T. C., Jr., and H. Strughold (eds.). Bioastronautics and the exploration of space. Aerospace Medical Division, Brooks AFB, Tex., 1964.
3. Berger, H. Uber das Elektrenkephalogramm des Menschen. Arch Psychiatr 87:527-570 (1929).
4. Berry, C. A. Man's response to a new environment including weightlessness: Gemini biomedical results. XVII International Congress of the International Astronautical Federation, Madrid, Spain. Oct 1966.
5. Berry, C. A. Project Gemini medical aspects. Ch. 29 in Ref. 2.
6. Brazier, M. A. B. The electrical activity of the nervous system. New York: The Macmillan Company, 1960.
7. Caton, R. The electric current of the brain. Br Med J 2:278 (1875).
8. Gazenko, O. Medical investigations on space ships Vostok and Voskhod. Ch. 18 in Ref. 2.
9. Kleitman, N. Sleep and wakefulness. Chicago: Chicago University Press, 1963.
10. Kornmuller, A. E., F. Palme, and H. Strughold. Uber Veranderungen der Gehirnaktionsstromme im akuten Sauerstoffmangel. Luftfahrtmedizin, Vol. 5, pp. 161-183. Berlin: Verlag von Julius Springer, 1941.
11. Lamb, L. E. Circulatory aspects of manned space flight. Ch. 17 in Ref. 2.
12. Marteka, V. Bionics. Philadelphia: Lipincott, 1965.
13. Miglicco, P., R. Cohen, and J. Deming. Electrical power and sequential systems. In Gemini Mid-Program Conference, Part I, Ch. 5. NASA, Houston, Tex., 23-25 Feb 1966.

BIOLOGICAL "FUEL CELLS"

14. Minners, H. A., S. C. White, and W. K. Douglas. Aeromedical studies. A. Clinical medical observations. In Results of the second U.S. manned orbital space flight. May 24, 1962. U.S. Government Printing Office, 1962.
15. Oestreicher, H. S. Aspects of bionics. Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, Brooks AFB, Tex., Feb 1967.
16. Torphy, D. E., S. D. Leverett, Jr., and L. E. Lamb. Cardiac arrhythmias occurring during acceleration. *Aerosp Med* 37:52-58 (1966).
17. Wells, R. Bionics, nature's ways for man's machines. New York: Dodd, Mead & Co., 1966.

THE SECRETARIES' LANGUAGE AND ART
IN THE SPACE AGE*

Hubertus Strughold, M.D., Ph.D.

I feel very honored and pleased to have been invited to speak to you today at your luncheon. I have chosen as my topic, "The Secretaries' language and Art in the Space Age."

We are in a fast-changing world. Never before in the history of mankind have we seen so many changes in all kinds of life, induced by the atomic age and, particularly, by the space age. This is noticeably reflected in the language, and since the knowledge of and versatility in language is one of the secretaries' most important qualities, I would like to talk to you today about certain aspects of their language and art, with special reference to the space age; and I feel somewhat qualified to discuss this matter since I have had 7 secretaries during the past 32 years, the time of my contact with the development of Aviation Medicine and Space Medicine.

But we should look back even deeper into the history. As you all know, a fantastic progress in physical science, technology, biology, and medicine has been made during the past 100 years. I would like to start with the discovery of bacteria by Pasteur, in Paris, and Robert Koch, in Berlin, in the 1870's; then I would like to mention the discovery of the x-ray by Wilhelm Roentgen, in Wuerzburg, which has revolutionized clinical diagnostic methods in medicine. With the Wright Brothers' first flight in 1903, aviation came into the picture and, as a consequence, aviation medicine was founded with the establishment of the first Air Service Medical Research Laboratory at Hazelhurst in Mineola 50 years ago, the predecessor of the School of Aviation Medicine. In the decade from 1920 to 1930 we got a detailed insight into the structure of the atom; in 1939 the splitting of the atom uranium started the atomic age, or the nuclear age. In 1937 the sonic barrier was broken by Chuck Yeager, which extended subsonic flight into supersonic flight; and 10 years ago, with the first man-made satellite in orbit, the space age began. In biology and medicine new electric recording devices such as the electrocardiograph and electroencephalograph, new methods in anesthesia, and the development of antibiotics represent real breakthroughs.

*Presented at the Luncheon of the AMS Secretaries, Brooks AFB, Texas, 27 Sept 1967.

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This, by and large, is the spectrum of important discoveries and inventions during the past 100 years, climaxed by "man's advance on the vertical frontier" manifested in manned orbital space flight and in the close-up exploration of the Moon, Mars, and Venus by automated lunar and planetary probes. This development has had a profound effect upon our language in general, and upon the language of secretaries in particular. If a secretary of 50 years ago read a paper typed by a secretary of today, she would be confused and would probably feel she were on another planet. Most of the new terms with which the secretaries of the space age are, or should be, acquainted are based on Latin and Greek. This is important because in this way the terms are better understood internationally.

Now, I would like to cite a few examples of the space terminology, or glossary:

Astronautics--which literally means "flight to the stars"--was coined in Paris in 1929 and now it is used internationally for all the activities in space.

The Russians use the terms Cosmonautics and Cosmonauts. But this is not a Russian term, because the word cosmos goes back to the ancient Greeks, and it was used in a book in the 16th Century by Thomas Muentzer, in Stuttgart, with the title Cosmography, in which he described the geography of Europe, North Africa, parts of Asia, and a few areas on this continent. At that time the designation cosmos included only the known countries on Earth; today we know more about the surface features on the Moon and Mars than was known in the 16th Century about this new continent and the eastern part of Asia. Actually, the word "cosmos" means jewel, and it was used by the early ancient Greeks for the stars, which they thought were jewels distributed over the ceiling of a velvet black dome. Today the word "cosmos" is applied in the same sense as the term universe.

I should mention also that the word cosmetics, an area of activities of secretaries, too, is derived from the word "cosmos"; its purpose is to make the face of a lady look like a jewel, or like a glowing star.

If we like to emphasize the human life factors involved in space operations, bioastronautics and biocosmonautics are the logical terms. The medical aspects of flight have led to the terms aviation medicine or aeromedicine, space medicine, or both combined, to aerospace medicine. Lunar medicine, which deals with the medical evaluation of the environment on the Moon, already plays an important role in the construction of a Lunar International Laboratory, and Mars Medicine and Venus Medicine also appear on the scientific horizon. All of these medical studies, together with terrestrial environmental medicine, are subdivisions of

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an all-embracing cosmic medicine. Biology, the science of life as we know it on Earth, has been extended into astrobiology which looks for life on Mars and Venus. Such seems to be the development in the next 50 years. A girl now in kindergarten who will become a secretary in space research will be a witness of this extraterrestrial or "out of this world" development in science and bioscience.

After these general terms, let's take a look at some specific terms of the space language. The word orbit, for instance, means the pathway of a natural or manmade satellite moving around a celestial body. Ten years ago in lectures one had to explain the meaning of an orbit; today, everybody knows what an orbit is. He hears this word for days on the radio when a rocket has been launched. It even has become a slang expression. For instance, if somebody in a bar has had three highballs or Martinis, he is said to be high in orbit. And, I remember a very amusing cartoon in which a secretary was sitting in a corner of an office taking dictation from her boss, who had the habit of walking around the table while dictating. At one point during the dictation the secretary interrupted him, asking, "Excuse me, what did you say during your last orbit?"

The word rendezvous, so far used for a date of a couple, is now commonly known as the word for a close approach of orbiting space vehicles. The occupants of these vehicles experience for the first time what is called earthshine, a novel space addition to sunshine and moonshine observed on Earth.

The astronauts in orbit are weightless. To counteract some of the effects of zero gravity and of inactivity in the cramped space capsule, they need exercise. This has made very popular two kinds of exercise: isotonic and isometric. In the latter we increase only the tension of the muscles without moving them. It is also applied on patients during bedrest. Even now there are popular books on isometric exercise, but it is not so well known that these two terms, isometric and isotonic, were coined around 1900 as the result of physiological experiments on frog muscles. For secretaries it might be a good idea to perform some isometric exercise or calisthenics occasionally for a few minutes. No one else will notice this exercise.

An important part in the secretarial work is making telephone calls, which in this modern time can reach transatlantic and transpacific distances. A modern secretary knows that the Earth is subdivided into 24 time zones. When it is, for instance, noon in Texas it is midnight in Korea and Vietnam, or 8 hours earlier at the Air Force Headquarters in Wiesbaden, Germany. A secretary of this modern era of communication (which was the topic discussed by Colonel Robert Martindale at your last monthly luncheon) knows the proper time to put in a telephone call to a distant location having a different office time.

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This time factor is also of interest in another respect. If her boss has just returned from Europe or from Manila, the up-to-date secretary knows that during the first few days he may be somewhat sleepy in the early morning hours or late afternoon hours, respectively, and consequently will make important appointments with visitors accordingly. She has to take into consideration the behavior of the physiological clock of her boss after long-distance flights. The "tick-tock" of his body's clock may be ahead or behind the "ding-dong" of the office clock.

So far, I have talked only about the mental activities of the secretary, consisting of checking bulletins, reports, papers, and editing them, and recording telephone calls. The physical activities of the secretary, in addition to sitting on a chair about 90 percent of the 8-hour duty day and working essentially with her arms and fingers on the typewriter and notebook, require an energy of about 2400 Calories per day. This is practically the same as an astronaut needs when in orbit. Every housewife uses daily the term Calories, but as a secretary you know its exact scientific definition--it is the heat required to increase the temperature of one liter of water by one degree Centigrade. This leads us to a brief consideration of the units of measure with which a secretary of today has to be familiar.

Conventionally, in the United States the several hundred-year-old English System of units of measures is in general use. Some of its units are based on human body measurements, such as the foot and yard. (Yard is derived from girdle.) They are easily understood, but do not have an exact scientific basis. Some 180 years ago the French, using the Earth as standard, introduced the meter, which is one-ten-millionth of the distance from the Equator to the North Pole. This Metric System--the meter, kilogram, and liter--is now used by more than 90% of the world population. In the United States it was made legal by an Act of Congress in 1866 and is used today in practically all fields of science, such as physics, chemistry, biology, medicine, and pharmacy. The general current trend is definitely in the direction of the Metric System. As you know, 3 years ago the Aerospace Medical Division issued a regulation that all scientific papers must use the Metric System, which is now called SI (Système International d'Unités). This International System is also more and more used in technology and by industrial companies because most of these have subsidiaries in foreign countries using the metric system. It is, therefore, important that secretaries get accustomed to this international system of units. It is my belief that in the United States the inch/pound system will have disappeared within 5 years. A young secretary 10 years from now probably will not understand today's written papers based on the English System alone.

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The same is true concerning the measurement of temperatures in Fahrenheit, which will be replaced by Centigrade. This development is especially important with regard to man's advance into space, to the Moon and planets, and with regard to future international cooperation in this field.

Now, I will make a few remarks about the various languages. English has become, and will be even more so, the world language in science and diplomacy. In the latter field it already has replaced the French language. Because of the world leading role of the United States, secretaries therefore will have to understand, in addition to English, a second language such as Spanish, German, and French. This is already clearly evident in the requirements of big business companies in New York and other cities which hire preferably bilingual secretaries, and since at the present time they cannot get enough of them in the United States, there is an influx of "two tongue" (bilingual) secretaries from England into the United States. In addition to their native language, they speak one or two of the continental languages. In sending letters to foreign countries, a bilingual secretary is also able to substitute words which have a different meaning in those countries.

Finally, I want to talk about mechanization of secretarial work. The computer is occasionally called the competitor of the secretary. No doubt it has brought a fantastic progress in calculating, evaluating, predicting, memorizing, and storing data in all areas of administration-- personnel, materiel, finance, management--and scientific research and development. A computer can handle data en masse in a shorter time than one hundred secretaries. The method of the computer, which is occasionally called "electronic brain," is based on programmed automation. This is comparable with the reflex functions of the autonomic nervous system, programmed and controlled by our midbrain. But computers have not the thinking capacity of the upper brain, or cerebral cortex. As an example: Some time ago I calculated the size of Texas in square kilometers from its well-known size in square miles, found in textbooks. To be on the safe side, I gave the square mile figure to a mathematician who used the computer technique and got in less than a minute a value several square kilometers larger than my head-calculated value. The reason: The computer did not know that a small area of land west of the Rio Grande, near El Paso, had been returned to Mexico one year earlier. This shows, despite the fact that a computer is irreplaceable in modern technology and medicine, that it has not the human thinking and decision-making capability and creativity. Consequently, a secretary cannot and never will be replaced by a computer. For a computer everything has to be programmed, but a secretary works out a program for herself. Furthermore, in addition to the absence of an upper brain equivalent, a computer has no charm.

UNORTHODOXIES AND CONTROVERSIES IN PLANETARY
AND SPACE SCIENCE*

Hubertus Strughold, M.D., Ph.D.

I feel very honored to have been invited to speak at the Banquet of this Working Group on Extraterrestrial Resources. It is a great privilege, but it is also very difficult to select a suitable topic before this august audience of experts in the field of geology, selenology, and planetology. After some thinking, I decided to talk about "Unorthodoxies and Controversies in Planetary and Space Science;" that means, theories which are not in accord with present generally accepted ones, but which should not be ignored, because they might be correct after all.

In the following, I would like to discuss some freely selected examples of unorthodoxies and controversies with special reference to the life sciences.

To begin with, I would like to refer first to a theory proposed in 1937 by Professor P.A.M. Dirac in London, Nobel Prize Winner in Physics. He suggested that Newton's constant of gravitation is actually not a constant, but has decreased slightly during the lifetime of the solar system and continues to decrease in correlation with the expanding universe. This idea was not accepted in physical science; and when, 2 years ago, I had the opportunity to talk personally with Professor Dirac about his theory, he emphasized that most of the physicists are hostile to it. But 5 years ago Professor R. H. Dicke, physicist at Cornell University, came to the same conclusion; and, at about the same time, Pascual Jordan, physicist at the University of Hamburg, published several papers in favor of Dirac's theory. By the way, Professor Jordan has accepted an invitation to discuss this topic at the Fourth International Symposium on Bioastronautics and the Exploration of Space next June here in San Antonio. This symposium is sponsored by the Aerospace Medical Division, Brooks Air Force Base, and organized by the Southwest Research Institute in San Antonio, Texas.

The acceptance of Dirac's theory leads to interesting aspects. Generally, it is assumed that the Earth is contracting like a "shrinking apple." This probably was the case during the time when the proto-Earth cooled off from a much higher temperature. But after it had reached a

*Presented at the Banquet of the Working Group on Extraterrestrial Resources, St. Anthony Hotel, San Antonio, Tex., 19 Feb 1968.

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temperature equilibrium, about 1 billion years ago, the decrease of the gravitational constant might have become the dominant factor in shaping the surface of the Earth by causing the opposite of shrinking, namely, an expansion. It has been calculated that the radius of our globe during the past half billion years has increased by 37 meters and its circumference by 600 km. This tendency to expand has led and still leads to tension cracks in its crust. This explains why the primordial supercontinents, Gondwanaland and Laurasia, were split into a number of secondary continents, which then drifted apart (continental drift). Formerly, the African continent was connected with the South American continent and the North American continent; Greenland and Iceland were part of the Eurasian continent. The islands off the east and west coasts of the United States and Canada have been split off from the continent by tension cracks; and, there are numerous faults in the continents, such as the Andreas Fault in California.

Recently explorers in oceanography have discovered fissures several thousand kilometers long at the bottom of the Atlantic and the Pacific Oceans. They, too, have been interpreted as expansion tension cracks. Thus the Earth can no longer be compared with a shrinking apple, but rather seems to be an expanding planetary body. This tendency to expand may be a factor to make earthquakes produced by volcanic activities more destructive. The effect of the gravitational decrease upon our planet's surface, reflected by its subdivision into continents and oceans, has tremendously influenced the evolution of the Earth's biosphere. But, this phenomenon of gravitational decrease is not restricted to our planet; it includes the whole universe. However, I would like to confine myself to our local universe, the solar system, and specifically to that planet with its surface best known to us: namely, Mars.

In contrast to Earth, Mars has a stony solid surface with no open waters. Mars formerly had oceans, but it has lost most of the water molecules by escape into space due to its lower gravity. This is the generally accepted orthodox theory. But around 1910, Professor Baumann, Zurich, Switzerland, suggested that parts of the Martian ancient oceans are now frozen and covered with dust which has become solidified in the course of millions of years. In Dr. Urey's book The Planets, 1952, H. E. Suess, at that time at the University of Chicago, is quoted as stating that "substantial quantities of water may be buried under dust and never become volatile at the low temperature of parts of the planet." As you know, the average temperature on Mars is about 15°C lower than that on Earth. This somewhat forgotten unorthodox frozen-ocean theory has been recently revived and developed in more detail by Dr. V. D. Davidov, a young astronomer at the Sternberg Astronomical Institute in Moscow. He theorizes that there may be a subsurface ice layer 500 meters thick in the equatorial regions now covered by about a 100-meter-thick layer of solidified dust. He even expressed the opinion that beneath this frozen conglomerate, or "cryosphere," as he

called it, water might be found in the liquid state due to an increase of temperature in the interior of Mars.

If we combine this unorthodox hypothesis of the existence of a hydrocryosphere below the surface of Mars with Dirac's unorthodox theory of the gravitational constant, we get an interesting picture. The gravitational decrease would cause on Mars, too, a volume expansion with tension cracks. Their appearance might be triggered by the impact of meteorites and asteroids and should produce fissures of tremendous length in a crust of not uniform composition. This threefold environmental combination--planetary volume expansion, subsurface ice layer, and meteoroid impacts--might well be the mechanism behind the scene of the dark spots called oases and the dark linear markings, or canali, which generally originate in the dark spots and radiate over tremendous distances.

The existence of a subsurface ice and water table on Mars would increase the humidity locally; namely, in and around the meteoritic impact craters and along the fissures, making them more suitable ecologically for the growth of vegetation. Actually, it might be the soil's humidity and vegetation that make these areographic surface features visible to Earth-based optical astronomy in the first place.

The theory of the existence of a subsurface hydrocryosphere on Mars is unorthodox, but there are some astronomical arguments and indications that speak for it. For instance, without such a subsurface ice table, all the water molecules might have disappeared into space in the course of millions of years, according to the Russian astronomer Barabashov. Furthermore, when cracks in this kind of crust occur, caused by Marsquakes, water may reach the surface and produce localized giant clouds and white streaks of fog; such clouds, visible for days, have been described by P. Lowell and E. C. Slipher. White spots glittering like ice have been observed in the equatorial regions by the Japanese astronomer, T. Saheki, Tokyo.

How does this combination of theories look in the light of the Mariner IV pictures? Their initial interpretation was that the visible Martian surface is extremely old and that neither a dense atmosphere nor oceans have been present on the planet since the cratered surface was formed. But later evaluations of Mariner IV photographs considered the surface of Mars to be only 300 to 500 million years old and led to the statement that: "The crater density on Mars no longer precludes the possibility that liquid water and a denser atmosphere were present on Mars during the first 3.5 billion years of its existence." Thus, the ancient ocean theory might be correct after all, and it might be that some 300 million years ago Mars, after it had lost most of its water into space, entered a permanent ice age; the remaining frozen waters in the course of millions of years became covered with a deep layer of dust that became solidified, and was bombarded by numerous asteroidal

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meteoroids, starting some 300 million years ago with the disruption of Planet X, the matrix planet of the asteroids. And, this might be the history of the features on the Green and Red Planet as we see it today.

Now, I would like to go a little more into detail about some controversies concerning life on Mars. The dark areas, according to most observers, show seasonal color changes from dark to bluish green, to yellow gold, to brown, and back to dark, which is interpreted as an indication of green vegetation on Mars. But to some observers these regions always appear to be dark gray. This can be accepted only if these observers have normal color vision, confirmed by an ophthalmologist. As you know, 7% of the males are color defective.

The bluish-green color is also interpreted as a visual-contrast phenomenon against the ochre-reddish surroundings. Visual-contrast effects certainly occur, especially if the areas are small; but the bluish-green coloration of large areas, such as Syrtis Major which has the size and shape of Texas, is in all probability real. This is also supported by the observation of Clyde Tombaugh, according to whom certain areas occasionally look dark when others look green, despite the fact that both are surrounded by reddish areas. The final answer in this color dispute might come from color photographs made by future fly-by probes. But, of course, green or not green is not decisive for life "to be or not to be" on Mars.

Fifty years ago in Stockholm, Sv. Arrhenius advanced the theory that the dark areas are salt beds of dried-out oceans, and concluded that "Mars is indubitably a dead world." But on Earth, in Palestine the Dead Sea, which is an extremely salty medium, was for thousands of years considered to be without life (thus its name). Recently, however, numerous species of microorganisms, bacteria, and algae have been detected therein. The Dead Sea, therefore, is not so dead at all, as it was believed, and the Red Planet, Mars, might also not be so dead.

Recent spectroscopic studies indicate that carbon dioxide pressure in the Martian air might amount to 3 mb; that means 10 times as high as on Earth. The opinion has been expressed that this would exclude life; but, actually, it would be even an advantage for the growth of green vegetation because carbon dioxide in this pressure range increases photosynthesis; beyond 22 mm Hg it has an inhibiting effect on this process.

The low density of a 10-mb pressure atmosphere, as revealed by Mariner IV, might not provide effective protection from harmful solar ultraviolet and x-rays, it has been argued. But, first of all, the intensity of solar irradiation at Mars' distance from the Sun is less than one-half of that at the Earth's solar distance. Furthermore, a certain amount of these rays is certainly absorbed within the atmosphere. It is, of course, well known that ultraviolet rays, particularly in the range from 2500 to 2800 Angstrom, are indeed very destructive to

most terrestrial microorganisms. For this reason they are used for sterilization of food and of lunar and planetary probes to prevent interplanetary contamination. But there are various degrees of resistance to ultraviolet and x-rays. Moreover, certain microorganisms are even stimulated in growth when exposed to low-intensity ultraviolet and x-rays, as has been found in bacteriological experiments around 1930.

The temperature on the Martian surface during the night is always and everywhere below the freezing point of water. This is considered to be particularly prohibitive for life; but experiments in Mars environmental simulators have shown that many organisms survive the freeze/thaw cycle for some time. If there is a Mars biology, then during the night it is always a cryobiology; that means a low-temperature biology.

All in all, the question of life on the Martian surface is still more a matter of probability than possibility. And if there is life on the Martian surface, then a precondition for it would have been the existence of open waters for its origin and development. Furthermore, if there is a water table below the ice layer, as mentioned earlier, this water table could be a second habitat for life based on chemosynthesis. This, of course, sounds ultra-unorthodox; but on Earth the water of the geysers contains microorganisms, and there are microbes even in oil wells--which has led to the establishment of a new branch of bacteriology called petroleum bacteriology.

Finally, I would like to touch upon some controversial points concerning human physiology in space flight. In all space medical discussions, the duration of the flight plays an important role. What might be the time limit in this respect? A flight to the Moon is no problem since this takes only about 3 days, but a flight to Mars based on a minimum-energy trajectory lasts more than 8 months. This is, of course, the simplest and most economic method for unmanned automated planetary probes, such as Mariner IV.

But is such a long duration also acceptable for a manned planetary mission? To get a realistic judgment in this aspect, we must consider the whole complexity of life of the mission crew--a team of perhaps six or more, living in a cramped, closed ecological world with its own economy and autonomy. The activities of this "capsule society," as S. B. Sells calls it, include power control, navigation, exploration, telecommunication, control of the life-support system, hygiene, and housekeeping. Weightlessness complicates some of these activities; others are facilitated.

The astronauts, after some 20 hours of flight, should be in a state of "relatively stable adaptation to weightlessness," as has been concluded from the medical observations in orbital flight. Anthropometric comfort, appropriate exercise, and a well-regulated sleep-duty regime

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might enable them to endure space flight in the order of months. Artificial gravity might not be required. Be that as it may, it seems to me advisable, if not even a requirement, to base a flight plan to Mars on a high-energy trajectory to shorten the duration of the minimum-energy trajectory of about 8 months to 30% to 20% of this time, which can be achieved by novel methods of propulsion.

In addition to the man-machine-intracabin environment complex, the external space environment also must be taken into account. A shorter time reduces the possibility of meteoritic incidents and the radiation hazards after solar flares.

In brief, a minimum in time and an optimum in comfort is the medical prescription in order to achieve a maximum of success of any manned planetary-landing mission. Of course, astronauts with week-long experiences in orbital flight and the space medical "practitioners" who have controlled these flights will have a decisive voice in this respect.

In case of long-range manned space operations (as, for instance, a flight to Mars), preflight prophylactic surgical measures, in addition to preventive dentistry, must be considered. Appendectomy and even cholecystectomy would certainly be advisable, the latter only if there is some doubt that the astronaut is completely free of positive and negative gallbladder stones.

This, in my opinion, makes sense. But the suggestion to transform astronauts into cyborgs (astronauts with artificial organs), which hit the headlines of the press some 10 years ago and might be revived since the successful transplantation of organs, will probably remain a matter of wild imagination; for it is not the task of space bio-engineering to artificially adapt the human body to the extraterrestrial environment. It is our aim, rather, to make the extraterrestrial environment artificially as physiological as possible, which is the challenging task of the Working Group on Extraterrestrial Resources.

The present main object of your Working Group is the Moon. I would like to finish this discussion with a brief remark about the controversial question: How should selenonauts, the Moon explorers, walk on the Moon? At the meeting of the Lunar International Laboratory Committee in Madrid, 1966, Professor Margeria, Milano, suggested that they should take advantage of the Moon's low gravity by jumping some 5 meters, like grasshoppers. This might be acceptable if the surface is smooth; but on a rough surface if the "Moonhoppers" would lose their balance and hit the ground, they might risk a leak in the pressure suit. In contrast, at the same meeting, I suggested increasing the weight of the selenonauts by their carrying, in addition to the life-support equipment, some 30 kilopond of material, maybe Moon pebbles, in pockets around their waist or shoulders. This would increase stimulation of the peripheral mechanoreceptors in the skin and

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muscles of the leg, and would help them to keep their balance. It would make the stimulation of these mechanoreceptors more Earth-gravity equivalent. It would, of course, not affect the otolith apparatus. There are some more controversies in space medicine, lunar and Mars medicine, and Mars biology which will be a stimulus for further theorization and experimentation.

In conclusion, the technologic and scientific achievements in man's advance on the vertical frontier so far have been spectacular and will be even more fantastic in the years ahead. Nevertheless, in its medical aspects we must be realistic and keep common "horse sense," particularly in our extrapolations for long-range manned missions such as a flight to Mars. After all, a horse, Pegasus (the winged horse of Apollo), was the first to roam around high in the sky in ancient mythology, or astromythology.

ON THE ROAD TO "METRICATION"*

Hubertus Strughold, M.D., Ph.D.

I consider it a great privilege and pleasure to have been invited by your Chairman, Mr. Goetzke, to talk to you at this, your San Antonio Zero Defects Area Council Luncheon Meeting.

I have chosen to talk about the Systems of Units of Measures which, at present, is a very timely topic and particularly suitable for a meeting like yours, because the units of measures play a very important role in many Zero Defects efforts. Having grown up in metric atmosphere, I, personally, am conditioned to the use of the Metric System, and hope that all other systems will soon disappear completely from our planet. But apart from this my subjective attitude, I shall try in the following to draw an objective picture based on facts.

The two systems in question are the older English and the younger Metric System, formerly called the French System. The English System is based partly on anatomical dimensions of the human body, as indicated by the foot, the inch, and the yard. (The yard is derived from the length of man's girdle.) They are easily understood but do not have an exact scientific basis. Some 180 years ago France, using the dimension of the Earth as standard, introduced the meter, which is one-ten-millionth of the distance from the Equator to the North Pole. In 1960, the Metric System, with its three basic units, the meter, kilogram, and liter, has been extended into what is now called the Système International d'Unités, or in short SI, according to a decision of the Conference Generale des Poids et Mesures, in Geneva, Switzerland, which is responsible for the control of the standards of measurements on an international basis. This International System includes, in addition to the three basic units, so-called derived units, such as the volt, ampere, watt, calorie.

In this space age, the world has become too small for two different systems. Actually, 90% of the world's population already uses the Metric System, and in the United State it is dominant in all fields of natural science, such as physics, chemistry, astronomy, biology, and others. Recently the journal American Scientist (56:2, 1968) published a paper "Metrication in Scientific Journals," by the Royal Society Conference of Editors, London, which has been taking a leading part in promoting the metric system in the United Kingdom. In this article it made two recommendations: "(1) That the system of units known as SI should be adopted in all scientific and technical journals; and (2) That, in order

*Presented at the San Antonio Zero Defects Area Council Luncheon, Brooks AFB Officers Club, 24 Sept 1968.

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to keep to a minimum the difficulties that will inevitably arise during the period of transition, the changeover should be effected as quickly as possible." A similar trend is noticeable in the United States scientific journals. But the English System is still used in daily life, in intracontinental business, many industries; in traffic on the ground and in air and space travel. In intercontinental trade, however, the Metric System has come more and more into use.

The educated younger generation in the United States is definitely in favor of a changeover. In a question-and-answer television interview, held here in San Antonio six years ago, after I had made some statements in favor of the Metric System, ten students of one of the San Antonio universities were asked their opinions. Seven of them were in favor of an immediate introduction of the Metric System; two were for a gradual changeover, and only one, an older retired officer, was against it. I think this attitude also reflects that of the students of other universities through this country. The teachers at public schools, too, are definitely metric minded. As an example: when, in the early sixties, during a luncheon speech before some 1200 members of the Texas Women Teachers' Association in the City Auditorium of Austin, I mentioned the necessity of educating the pupils in the Metric System, my talk was interrupted by a standing ovation.

The mentality of the "man on the street" and of the housewife is usually mentioned as the greatest obstacle. But today the man on the street, fascinated by so many exciting achievements in near-Earth space flight, the coming flight to the Moon, and life on Mars, has become more or less a "man on the Milky Way;" and one should also not underestimate the versatility and adaptability of the brain of the housewives. They will go through this transition period just as easily as the European women did some decades ago, and they will become just as well accustomed to a metrification of their body configuration. It is argued that heavy industry, particularly the auto industry, will never give up the English System; but it is interesting to note that the Ford Company, in Detroit, has recently published a brochure with the title, "Ford and the Metric System." This company has factories in about 12 foreign countries which are all in the Metric camp. The photo industry, because all its cameras and films are metric, or millimetric, enjoys a big international business. All this indicates that the units of measures have become an economic problem. A two-system situation is particularly an obstacle to the formation of the so-called Common markets in Europe and in this hemisphere.

After these general remarks, I should like to make a few observations with regard to my specialty--medicine and biology--and some related scientific fields, as seen nationally and internationally.

It is interesting to note that despite the fact the English System is based on the anatomy of the human body, as mentioned earlier, medical

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biological research does not use it any more. In clinical medicine, too, blood transfusions and intravenous nutrition are given in terms of cubic centimeters. Blood pressure is measured in millimeters of mercury and no longer in inches of water. In surgery, the size of tumors and scars, of gallbladder stones and kidney stones, is expressed in centimeters. The laboratories in hospitals, in their hematological and urological tests, use the cubic centimeter, and the x-ray pictures are analyzed in centimeter dimensions. Microscopic histology, epidemiology, and bacteriology operate in the range of millimeters and microns. The thermal unit in metabolic research is the calorie, a derived metric unit. Housewives talk about calories, concerning food and weight. The pharmaceutical industry sells the drugs in the units of grams and milligrams, and enjoys a big international business.

All in all, medicine and biology and related branches have advanced farther to the metric side than most people realize. In this respect, it is interesting to note that Australia decided several years ago to introduce the use of the Metric System in all of its hospitals at a certain date. Recently the same has been done in Canada.

In aviation and space medicine, here at the Aerospace Medical Division, Brooks AFB, according to a directive signed by General Bedwell in 1964, we use the Metric System in research, teaching, and publications. The lectures in the various courses particularly require this, since these are also attended by medical officers of the Air Forces of the NATO and SEATO countries.

A main topic of aerospace medicine is the physics and chemistry of the atmosphere. Data tables concerning air pressure and altitude are found in the book: The U.S. Standard Atmosphere, 1952. They are based on feet and P.S.I. (pressure per square inch), and cover the range up to 300,000 feet. For six years the new U.S. Standard Atmosphere, 1962 has been available, based on the meter and millibar, and extending up to 700 kilometers. This book is published by the U.S. Government Printing Office, Washington, D.C., under the sponsorship of NASA, the Air Force, and the U.S. Weather Bureau. As the official demarcation line between atmosphere and space has been declared the 100 kilometer level by the Federation Aeronautique Internationale in Geneva, all speed and altitude records have to be submitted in metrics to this organization for official international recognition.

Solar heat radiation is expressed in calories per square centimeter and min. Solar light radiation or illuminance was formerly measured in foot candle (1 lumen per square foot), but now in the internationally accepted unit of lux or meter candle (1 lumen per square meter).

Today we very often hear mentioned the international cooperation in the exploration of space. In this respect I should like to mention only one example: The International Academy of Astronautics has, among others,

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a Lunar International Laboratory Committee, consisting of about a dozen scientific and technological representatives from seven countries. I am a member of the Committee of Medicine and Biology. It is logical and natural that in the discussions at its meetings, which during the past several years were held in Stockholm, Paris, Varna, Madrid, Athens, Prague, and next month in New York, all attendees speak the same language as it pertains to the units of measures.

In conclusion, the American way of life is becoming metric. The changeover does not require a revolution--it will be simply a gradual but directed and programmed evolution. It seems that the transition from the old, colonial to the new international system will take up speed in the coming years.

During the past years, several Congressmen (including Miller of California, Gonzales and White of Texas, and Fulton of Pennsylvania) have shown particular interest in the introduction of the Metric System in the United States. As you remember, on August 15th this year, President Lyndon B. Johnson signed a bill (H.R. 3186) introduced by Congressman G. P. Miller for the study of the feasibility of the introduction of the Metric System. This Bill, in the decades ahead, will be considered an important historical document in line with the first one enacted by the Congress in 1866, to make the Metric System legal and optional.

I hope that the Texas Legislators will form the avant garde on the road to metrication. After all, the size of Texas expressed in the old colonial system amounts to only 267,339 mi²; but in the Metric System it is 672,403 km². This certainly sounds more in line with the Texan way of thinking.

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Hubertus Strughold, M.D., Ph.D.

In the historical development of astronautics we can differentiate several phases which, to a certain extent, overlap.

First is the mythological phase of the ancient times. I should like to mention only Pegasus, the winged horse of Apollo, and Astraea, the daughter of Zeus or Jupiter, who during the Golden Age disappeared from the Earth into space, which means that in mythology the female was the first astronaut. Nike, the daughter of Apollo, was portrayed with wings. Atlas, carrying the Earth on his shoulder, symbolized the gravitational force. The best-known story is that of Icarus who, against the good advice of his father, Daedalus, flew too close to the Sun and ran into heat problems. Furthermore, Elias ascended into Heaven in a chariot of fire with four horsepower. Then, Odin roamed through the northern skies of Europe on an eight-footed horse surrounded by Thunder and Blitz. His son was Thor, the God of the Universe. Some of these names have now been given to rockets, space vehicles, and space mission projects. We might call this mythological era of riding and flying in the air and space, "astromythology" or "cosmomythology."

The second phase is the science-fiction phase, manifested in writings and beginning with the Greek Plutarchos and the Roman Ovidius Naso and continuing to the present day.

The third phase can be classified as the science-vision phase, with Jules Verne as its initiator. His books fertilized the fantasy of science-fiction writers, but they were also the matrix for the fourth phase--the theoretical-scientific phase, associated with the names of Tsilkovsky and Hermann Oberth. This phase overlapped with the operational-technological approach of Robert Goddard in the 1920's in which rocket flight of the ballistic type for the first time came to realization. In the same category of activities were those of the W. Dornberger and Wernher von Braun groups in Peenemuende in the early 1930's.

With the first satellite on 4 October 1957, the development of the ballistic flight trajectory advanced to the Kepler regime of celestial mechanics, in the form of technologically controlled celestial mechanics or applied celestial mechanics, which is the operational mode in astronautics.

*Lecture presented to the Bioastronautics for Aerospace Research Pilots, Brooks AFB, Tex, 1970.

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The whole developmental picture of astronautics, with aeronautics as background, as we see it today, can be illustrated by a family tree of aircraft, rockets, and space vehicles. This tree has three fundamental roots: Physicochemical sciences, technology, and life sciences, such as medicine. The latter's task, of course, was and is to safeguard manned space flight. Manned space flight was preceded by a brief dog and monkey phase remembered by the names of Baker, Sam, and Enos. Dogs and monkeys are still in the space business via biosatellites; other animals may join them. But the horse, so eminent in astromythology, probably will never become a Hippo-astronaut, but its prime mythical role should always remind us to keep common "horse sense" in manned space flight programming.

Now, concerning our topic, Pioneer Developments in Space Medicine, or in a broader sense Aerospace Medicine, I should like to concentrate upon some crucial environmental problems and on space flight dynamics including some personal contacts with these developments and some stories and events which are not found in books.

In the environmental area, oxygen pressure and barometric pressure play a decisive role. The first book about high altitude effects based on oxygen deficiency was published in 1590 by the Spaniard, Jose de Acosta, describing the life in the Andes of Peru. His book, Historia Natural y Moral de las Indias, made him the pioneer in the field of altitude sickness and, so to speak, the Earth-bound Columbus of the "vertical frontier." But oxygen, itself, was not known at his time. From the time of the Greeks throughout the Middle Ages, they called this mysterious energy-producing agent in the air "pneuma" or "phlogiston" and "igneo-aerial spirit." Finally, around 1800, Priestly, in England, and Scheele, in Sweden, discovered the element oxygen and its property as fire substance, and Lavoisier, Paris, recognized its function in respiration and called it the "life substance" and "element of life." Around 1870, Paul Bert in Paris started the experimental era of barometric and oxygen pressure research, and even before this time, a number of balloonists, including doctors, studied oxygen deficiency in high altitudes up to 10 km and also the means of protection by breathing oxygen; to mention only Pilatre de Rosier, 1783, Croce-Spinelli, Sivel and Tissendier, 1875, Glasher and Coxwell (1862), von Schroetter, and Boynton.

The balloon was the first means to study high altitude effects above the mountains. In 1928, when I gave my first lectures on flight physiology, I, too, made a flight in a hydrogen balloon to get some material about the strength of the muscles, patellar reflex, sensitivity of the skin, respiration, and pulse at high altitudes. The balloon ascended to an altitude of 4,500 meters, and after a brief stop it landed in East Bavaria in a tree. But I saved all the experimental material and two bottles of champagne and, by the way, it could have been worse; that is, if we had flown only 10 kilometers further we would have been shot down by the Czechoslovakian border guards, just as it is today.

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In addition to the balloon research at that time--in the 1920's--in the newly developing field of aviation medicine, we had to rely to a great extent on the studies which had been made in high mountain physiology by such people as Mosso--Italy; Loevy--Austria; Joseph Barcroft--England; and E. C. Schneider--United States, who had a high altitude laboratory on Pike's Peak; but it was expected that soon passenger planes would fly much higher than the Rocky Mountains or the Alps.

The logical device to study extreme oxygen deficiency was the low-pressure chamber or high-altitude chamber. These studies, as you know, have laid the groundwork for what we know concerning oxygen deficiency in extreme high altitude flights, and means of protection by oxygen equipment and pressure suits. An Air Service Research Laboratory with the first low-pressure chamber was built in Mineola, 1918, and the first pioneer experiments were carried out by Dr. Bauer. This chamber is here at Brooks Air Force Base. At the end of the 1920's similar low-pressure chambers came into operation in England, Germany, France, Italy, and Holland.

Soon the question arose: What happens if suddenly oxygen breathing is interrupted? This led to the concept of the "time of useful consciousness," conceived by Harry Armstrong in the middle 1930's. I made similar studies in Berlin and used the term "time reserve," which is used in Europe, South America, and Russia, because it is better understood internationally, and because "the time of useful consciousness" translated in different languages leads to different meanings.

Closely related to this problem is the physiological effect of rapid decompression, which was studied extensively at Wright-Patterson Air Force Base by Colonel Sweeney, and by a colleague of mine in Berlin, Dr. Hans Clamann, now Chief of Bioastronautics here at the School of Aerospace Medicine. In addition to hypoxia, decompression can lead to two phenomena: aeroembolism, and "boiling of body fluids" or ebullism.

The first paper on aeroembolism--which means the formation of nitrogen bubbles in the blood, leading to pain called "bends," was published in 1929 by a Holland physiologist named Youngblood, Professor of Physiology at the University of Utrecht. This paper can be considered a classic, and describes the symptoms and causes, as well as the prevention of such events. "Bends," as you know, still are undergoing continuous studies because they can be a disturbing factor in space flight during the preparation for extravehicular activities.

Boiling of body fluids was first described and systematically studied on warmblooded animals around 1935 by Captain Harry Armstrong, Wright Field, who later became Air Surgeon General. But as early as in the 17th Century, Robert Boyle noticed this when he observed bubbles in the eye of a viper in a vacuum jar. Later, the boiling of body fluids was studied with regard to its true nature and called "ebullism" by Captain Julian Ward, my co-worker in the Department of Space Medicine, School of Aviation Medicine, Randolph

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Field, in the early 1950's. The occurrence of boiling of body fluids as a function of air pressure represents an important demarkation line in the atmosphere. Pressure physiologically, this altitude level at about 20 km, can be considered as the beginning of space equivalence in our atmosphere. It requires the same antivacuum protection as in free space: The Armstrong Line will play, also, an important role in the future when mass transportation in supersonic aircraft will become routine.

Another important space-equivalent level or functional border within the atmosphere is the region above which we cannot pressurize an airplane from the outside air. The reasons are of a technological, thermodynamical and toxicological nature. Above this level, which lies around 25 km, any cabin has to be pressurized from within. In 1953, I submitted a project to the Research Council of the School of Aviation Medicine to build what we called at that time a sealed cabin. One year later, we had the first sealed cabin for the study of artificial atmospheres and their maintenance within physiologically acceptable limits. When, a little later the cabin was renamed "Space Cabin Simulator," the interest of the scientists and volunteers suddenly increased. The first experiments lasted 8 hours; then 24 hours; and, then in 1958, the Airman Farrell experiment of 8 days hit the newspaper headlines. This experiment attracted great interest everywhere, including Washington, D.C., and the Majority Leader of the Senate, Lyndon B. Johnson, was present when we opened the cabin. When Airman Farrell came out of the cabin the Senator, who certainly was the first high-level politician with a sensitive nose for the space potentialities, congratulated him in the name of the Nation; the Commander of the School, Otis O. Benson, Jr., did the same in the name of the School of Aviation Medicine, and I had the pleasure of congratulating him in the name of the new discipline of space medicine. A press conference concluded this event at Randolph Field, but it did not end there. Three weeks later, the Commander of the School, General Benson, Airman Farrell, and I were invited by the Majority Leader of the Senate to a luncheon with Mrs. Lyndon Johnson, as the hostess, in the Caucus Room of the Senate on Capitol Hill. Invited were more than 100 VIPs, including the Secretary of Defense, Mr. McElroy. During the luncheon, the Senator asked me to give a brief talk about the problems of space medicine and the significance of this experiment. I did not need to tell a joke, as usually is done at the beginning of speeches, because I created some amusement when I addressed him as "Minority Leader." All smiled, including him. The luncheon was followed by a thirty-minute discussion, and it is my feeling that this invitation made the field of space medicine, developed "deep in the heart of Texas," suddenly acceptable to the highest governmental levels on Capitol Hill.

By the way, the steak which was served at this luncheon was in the shape of Texas, and usually when I tell this story I say it was so large that I could eat only the Panhandle.

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There is no question that this space cabin simulator of the Air Force was the first in the United States, and now they are found all over the country. As mentioned before, the main purpose of these chambers is to study the physiological qualities of artificial atmospheres and the methods to control them. The question arose, should we use a two-gas atmosphere or one consisting of just pure oxygen? The studies of the physiological tolerability of pure oxygen date back to the late 1930's when Captain Behnke from the Navy made extensive experiments in this respect. At the same time, Dr. Clamann did the same in my Institute in Berlin, and generally it was agreed upon that a pressure of about 300 mm Hg is the tolerable maximum for several days. Again, it is not so well-known that Jules Verne wrote a novel about the effect of oxygen in a book called Doctor Ox's Experiment, around 1880, shortly after Paul Bert started his barometric pressure experiments. This book has been published for the first time in the United States three years ago, and there are some very interesting points in it which envisioned some of the actual effects of oxygen breathing. I had the honor to write an epilogue in this book about our present knowledge of the effects of oxygen, based on our experiences in clinical medicine, aviation medicine, and space medicine.

As you know, in the Mercury and Gemini capsules, pure oxygen has been used, essentially due to concessions to technology. In 1956, I published a paper in Jet Propulsion entitled "Medical Problems in Orbital Space Flight." In this paper, and later in a chapter in Armstrong's textbook, Aerospace Medicine, 1961, I suggested a two-gas atmosphere--oxygen and nitrogen--and this is exactly what the Russians have used in their space vehicles. A two-gas atmosphere diminishes fire hazards, and nitrogen is the natural diluent of oxygen to which life on Earth has become accustomed during its evolution. Of course, experiments with other inert gases, such as helium and neon, are necessary in order not to overlook any other preferable possibility under certain conditions. As you know, helium will be used in the Manned Orbiting Laboratory (MOL).

Basically, the artificially created and maintained microenvironment in the closed ecological systems in stations in space, in research laboratories on the Moon or Mars, has to be a replica of the terrestrial atmospheric environment. Any extraterrestrial station, therefore, is in many respects, except gravity, a little Earth or "Terrella," designed to provide a comfortable ecophysiological milieu inside and protection from hazards from the outside. The latter refer to meteoroids and particle radiation.

Generally, the picture of meteoritic hazards in circumterrestrial space flight looks brighter today than had been expected 15 years ago, according to recordings by satellites. Fred Whipple believes that most of the meteoroid material of cometary origin is soft "fluffy stuff," neither as frequent nor as violent as had been feared. During the total space flight time, now amounting to 2500 hours, no meteoroid incident has occurred and, so far, four extravehicular excursions have been made without micrometeoritic interference. Moreover, it might be interesting to

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note that Vostok III and Vostok IV, with the cosmonauts Andrian Nicolayev and Pavel Popovich, were orbiting in 1962 at the time when the Earth crossed the orbit of the permanent Perseid meteor stream, which annually occurs around the 12th of August. Other permanent meteor stream crossing dates of the Earth are around December 13th (Geminid stream), December 22nd (Ursid stream), April 21st, etc., and this was just the time when Borman and Lovell and W. Schirra and Stafford were in orbit. In brief, the situation concerning meteoroid hazards is considered no longer alarming; at least at the Earth's solar distance; but this rosy picture might be somewhat dimmed by the thorny possibility of collisions with meteoroids of noncometary origin, with puncture capabilities in extended space operations to Mars and beyond, into the neighborhood of the belt of the asteroids. Furthermore, stream meteoroids are also occasionally concentrated in the form of a meteor swarm. When the Earth moves through such a swarm--which is a rare event--we see the spectacle of a meteor shower such as that in 1933, 1946, and 1966. All in all, protective devices against puncture such as meteor bumpers, suggested as early as 1951 by Fred Whipple, will remain the concern of bioengineers. Corrosion effects by micrometeoroids on long-duration flights cannot be ignored. Satellites such as the Pegasus and others are providing us continuously with more information in this respect.

In the paper just mentioned, I had chosen an orbital altitude of 500 km (300 mi) because the environment here is real space and yet the vehicle is still close to the sensible atmosphere. However, for reasons which cannot be discussed, I could not use this altitude and was requested to select a much, much higher altitude. For matters of convenience, I then chose the two-hour orbit which, as you know, is found at an altitude of 2,000 km (1,300 mi). This was wrong, because, according to our present knowledge, space vehicles at that orbital altitude would move in the Van Allen radiation belt. But, the existence of this belt was not known before 1958. Since radiation hazards play an important role in the environment of space, I would like to include at this point a brief story of how I ran into it--that means, into the news of its discovery. The existence of such a belt was suggested by Dr. Fred Singer as early as 1956, and in 1958 was actually recorded by a U.S. satellite. I was lucky to be present when Dr. James Van Allen disclosed his findings at a press conference in the lecture room of the National Academy of Science on Pennsylvania Avenue in Washington, D.C., on 8 May 1958. That morning I arrived in Washington for the purpose of a hearing before the Congress. When I arrived in my hotel I saw a headline in the Washington papers--"Huge Radiation Belt Around the Earth, Deadly to Space Travel." The paper said that there would be a press conference at the National Academy of Science Building in which details of the discovery would be revealed. I took a taxi to the NAS building and attended the press conference. I stayed in the background in the last row to avoid questions as to implications of this discovery in terms of manned space flight. Dr. Van Allen, who was introduced by Dr. Richard Porter, former President of the ARS, drew a sketch of the magnetic field on the blackboard and also some outlines of the radiation belt. There is no question that this was the most important discovery during the international geophysical

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year (IGY), and still is. Dr. Porter, in his introduction, mentioned that it was the academic custom to report important findings in physics or astronomy first at the annual meetings of the respective professional societies, but that this discovery was so important for everyone concerned with space research, and things were moving so fast, that it was decided to take the unusual step of announcing this matter first at a press conference.

It was indeed a prudent decision, which I understood better later. The Russians were very close on the heels of American scientists in this field, and if it had not been revealed as early as possible, the Van Allen radiation belt might have another name today, probably Vernoff belt. At the end of the press conference I had lunch with Dr. Van Allen and I got the first typewritten report on the radiation belt. When I got back to Randolph Field a few days later, I got a number of phone calls asking me if this was the end of man's ambition to go into space and, consequently, the end of space medicine. I answered that the radiation belt was certainly a matter of serious concern, but that there would be ways and means to get around the hazard. In other words--where there is a will, there is a way.

So--what is the actual particle ray situation as we see it today? Below the inner Van Allen belt, in orbits up to about 800 km, radiation hazards seem to be insignificant during the time of a quiet Sun.

The radiation dose absorbed in orbital flights by our astronauts and the Russian cosmonauts has been an average of 15 millirads per day. This is far below the medically permissible dose of 100 to 180 rads. Thus, in low orbits, with doses a little less than 1 millirad per hour, we can look upon the radiation problem with no particular concern. This is different with high orbits; i.e., above 800 km, within the Van Allen radiation belts, where we must reckon with up to 5 rads per hour in the inner belt around 3,000 km, and in the outer belt around 18,000 km, with 10 millirads per hour. These belts, therefore, are "off limits" for space flights of the orbital type. About 10 millirads per hour can be assumed for the auroral regions of the Earth's atmosphere. This is of interest concerning flights in polar orbits. In deep space beyond the magnetosphere, the dose rate that will be received by the occupants of a spaceship might be in the order of 1 to 3 rads per month. Such is the particle radiation climate for the astronauts, if we assume an absorbing power of the cabin's wall equivalent to a thickness of 1 cm of steel. There are other estimations with a trend to a more optimistic or pessimistic view; be that as it may, the space physician's prescription should be: Avoid the dangerous radiation belts for orbital flights. For escape velocity operations such as a flight to the Moon or Mars, the medical advice is to dash through these belts in several hours, and take the tolerable risk of absorbing 5 to 10 rads per hour; or, escape through the safer polar regions.

The pioneer discovery of cosmic rays goes back to the year of 1908. At that time Victor Hess in Switzerland made a balloon flight and discovered

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an increase of particle radiations with increased altitude. Before this time their occurrence in the lower atmosphere was known, but it was thought that they came from radioactive material of the Earth's crust. But now it was realized that most of those cosmic rays came from the Sun and the stars. This was the beginning of a scientific field now called space radiobiology.

So much about environmental problems. Now, a few minutes about biodynamics, which has to deal with a broad gravitational spectrum from multiples of 1 G to zero G.

In the 1930's Aviation Medicine became interested in increased G up to 4-5 G. Space Medicine, dealing with rocket propulsion, had to give answers concerning tolerability up to 15 G. The outstanding pioneer in this field is Colonel P. Stapp due to his experiments on the rocket-powered sleds at Holloman Air Force Base. Even Titov in his book, I Am Eagle, acknowledges that "the Russian cosmonauts have the greatest admiration for the heroic experiments of USAF Colonel Stapp." Experiments on centrifuges dating back to the mid-1930's and performed at Wright Field, Pensacola, Johnstown, Mayo Clinic, Berlin, and Holloman have provided the medical knowledge of the effects of high G forces and how to make them better tolerable. This certainly has been a blessing in advance for the astronauts for the launching period and especially for the "baptism of fire" during atmospheric reentry.

Dynamic weightlessness entered the sphere of medical interest 15 years ago, manifested in theoretical papers and experiments. Colonel Henry studied the reactions of mice and monkeys in suborbital rocket flights in 1950 to 1954. And the theoretical paper entitled "Possible Methods to Produce Weightlessness," by Dr. Fritz Haber, member of the Department of Space Medicine, 1951, triggered the well-known parabolic flight maneuvers carried out to the thousands by Major Stallings, Dr. Gerathewohl, at Randolph AFB, and Dr. Ballinger at Wright-Patterson AFB. The experiments included drinking, eating, swallowing, and urination. The now well-known squeeze bottle was conceived and developed as the results of these flights. Also, sensomotoric tests were performed and the behavior of cats under weightlessness was studied. Today parabolic flights, as you know, are still flown essentially for the purpose of familiarization with weightlessness or indoctrination. But the experimental approach to zero gravity is now essentially a matter of orbital flight in which the astronauts for longer periods of time can observe its effects and test the countermeasures, such as exercise programmed for them by the space physicians on the ground.

There are still other space medical topics with some historical background, such as vision of the pilot in aircraft flight and in space and eye protection, sleep and activity cycle or the circadian cycle of the physiological clock. You will hear about them in other lectures.

I would like to conclude this lecture with a few remarks about pioneer work in basic sciences. An interesting field in this respect is the discovery

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of electric phenomena associated with physiological process, such as the contractions of the motoric muscles, heart muscle, and the activities of the brain cells. The pertinent electrograms, namely the electromyogram, electrocardiogram, and electroencephalogram, first were used for a better understanding of the cellular process as such. Later they found important diagnostic methods in clinical medicine, but the discoverer of these various electrograms and the inventors of the respective recording instruments probably never dreamed that some day they would be used to monitor by means of telemetry, or better, biotelemetry, the various physiological functions of astronauts in space, or that electrograms would be transmitted from hospital to hospital over intercontinental distances via communication satellites for diagnostic and consultation purposes.

This should remind us that in the so-called directed scientific research, we should look back even to the pioneer discoveries in basic undirected research. We learn from this that we should never discard the future practical potential of any discoveries which might seem, at first glance, rather academic and unrelated to anything. Someday, somehow, and somewhere they might find some specific application, as we have witnessed this, particularly in Aeronautics and Astronautics.

THE SLEEP AND ACTIVITY CYCLE
IN THE MARS INTERNATIONAL LABORATORY (MIL)*

Hubertus Strughold, M.D., Ph.D.

A vitally important precondition for the health and exploratory efficiency of the occupants of a future Mars International Laboratory (MIL) will be a proper time regulation of sleep and activity. This sleep and activity rhythm is synchronized with the light and dark cycle in the Earth's rotation period of 24 hours (circadian rhythm) during which time about 7 to 9 hours are spent in sleep, which is required for energy restoration. This is an inborn or endogenous rhythm in the body of Homo sapiens terrestris and shows a certain degree of stability (rhythmostasis). When it is changed by flights across time zones, the shift of the circadian rhythm takes a certain time for adaptation to a new time zone (1 hour per day (Colonel William K. Douglas)).

The experiences in astronautics (in near Earth space and on the Moon) during the past 10 years have contributed considerably to our knowledge of the nature and behavior of man's body clock, which can be defined as a psychoneurohormonal system.

On Mars the day/night cycle is only 37 minutes longer than that on Earth. Thus the dark/light cycle offers a Zeitgeber sequence for entraining sleep and wakefulness which is very familiar to terrestrial visitors. In this connection I would like to mention an interesting and somewhat amazing point. As has been found recently in sleep laboratories (J. Aschoff), the circadian rhythm of man under constant light or dark conditions with no contact with the outside is not exactly 24 hours but about 24 1/2 hours. This is indeed more in line with the 24 hours and 37 min day/night cycle on Mars. In science fiction this might be explained that our ancestors have been the green Martians and that we inherited the circadian rhythm of their body clock. But actually according to some sleep researchers the gravitational effect of the Moon might be responsible for it. But it might also be that the rotation of the Earth some 20,000 years ago had been somewhat slower. Be that as it may, the red planet poses no circadian cycle problems for terrestrial visitors; furthermore, after insertion of the Marsship into a circummartian orbit its occupants could easily synchronize their circadian rhythm with the time zone of the selected landing place.

*Presented at the MIL Panel meeting during the Congress of the International Academy of Astronautics in Baku, USSR, 7-13 Oct 1973.

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How good might be the sleep on Mars? This question has to do with gravity. Under the terrestrial gravity of 1 G people change their positions slightly about 15 times during an 8-hour sleep, which prevents compression anemia of the same skin areas. The visitors on Mars with a gravity of 0.38 G might show fewer of these occasionally sleep-interrupting body movements which could be recorded by means of a hynograph or actograph.

Furthermore, during sleep the parasympathicus is dominant which slows down a number of vegetative body functions. Interestingly, according to V. V. Parin and O. Gazenko, the same is the case during the state of weightlessness. This coincidence speaks for a better sleep during weightlessness. Because of the lower gravitational milieu on Mars, we might also, at least to some degree, expect a good and sound sleep in MIL, maybe even better than on Earth.

THE RHYTHMOSTAT IN THE HUMAN BODY*
(In the Jet and Space Age)

Hubertus Strughold, M.D., Ph.D.

A fundamental phenomenon in the universe is the occurrence of cycles, or rhythms. These can be defined as repetitions of situations, events, and levels of activity in regular intervals or periods of time. Almost all processes in the universe are cyclic, as manifested in:

1. rotation of the galaxies, i.e., the revolution of the stars around the center of the galaxies;
2. the 11-year maximal activity cycle of the Sun and its rotational period of about 25 terrestrial days;
3. rotation of the planets and their moons around their axis;
4. revolution of both planets and their moons around their primaries;
5. periodic tidal effects associated with these movements;
6. regular reappearance of certain comets,
7. regular occurrence of meteor showers; and
8. the orbitlike movement of the electrons around the atomic nucleus.

Cyclicity, or rhythmicity, is the rule in the Universe--in the dimensions of the macrocosmos and of the microcosmos of the nonliving world. It is therefore not surprising that cycles are also a dominant characteristic in the living world. In fact, practically all processes of life on Earth show rhythms in the levels of activity, the study of which has become a very attractive research area in a new branch of biology called biorhythmology or chronobiology.

There are basically two types of biorhythms. One is caused by and dependent upon external environmental cycles; this type is an exogenous biological rhythm, i.e., produced by outside or external stimuli. But most biorhythms originated independently as an inherent internal property

*Lecture to the Southwest Research Institute, Chapter of Sigma Xi, 24 Oct 1974.

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of life, and have become, in the course of evolution, influenced by and synchronized with external physical rhythmically recurring factors of the nonliving world. These are the endogenous biological rhythms, i.e., originated from inside stimuli. Only the physical cycles within the solar system can influence both of these types of life cycles on Earth.

To begin with the longest cycle, the 11-year cycle of maximal solar activity not only affects the Earth's ionosphere but also the lower atmosphere, resulting in more rainy weather which increases the growth rate of plants. The circannual cycle of seasons is reflected in the growth, color, leaf development, blossom time, etc., of plants, and in the hibernation, aestivation, migration, mating, and reproduction time of animals. The next shorter cycle--the new-Moon/full-Moon cycle--of nearly 1 month's duration has a distinct effect upon nocturnal animals. The most impressive rhythm in the biological world is the one associated with the Earth's axial rotation in the electromagnetic radiation field of the Sun--the light-and-darkness cycle, or the day-night cycle. This biological rhythm of a period of about 24 hours, manifested in rest or sleep and activity, is called circadian rhythm (Fr. Halberg). There is still a shorter environmental cycle, the 6-hour alternation of high tide and low tide, to which the rest-and-activity cycle of the seashore animals is adapted. So much about the multitude of rhythms in the living world on Earth or in its biosphere.

In the course of evolution most of these biological rhythms have become an ingrained property of the living world; they continue to occur even if the external physical cycles, with which they are normally synchronized, are drastically changed or even completely removed. A logical term for this tendency of life to keep its rhythms constant, or better, nearly constant, would be "rhythmostasis" ("stasis" = tendency toward maintenance of stability) and the apparatus which regulates this could be named rhythmostat.* Life is dynamic not static, but the periodicity of its rhythms is static.

Rhythmostasis would be an analog to the concept of homeostasis advanced by W. B. Cannon, 1929, which means that the human body has the tendency to keep the physical and chemical properties of its internal milieu--the intercellular body fluid--in a nearly steady state. Rhythmostasis is a life characteristic within the frame of homeostasis.

The concept of rhythmostasis is applicable to most of the aforementioned biological rhythms. It is especially instructive and useful with regard to the circadian rhythm, particularly in these days of long-distance air travel, in which the physical day-night cycle changes with the geographic time zones in a matter of hours, and of manned space flight, in which the familiar light-dark cycle does not exist at all.

*For more detail see chapter 3 in "Your Body Clock," published by Charles Scribner's Sons, New York, 1971.

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In the following, we shall consider the human circadian rhythm in the perspective of rhythmostasis, or of the rhythmostat, in more detail and in reference to the modern technology of transport by jets and rockets. A familiar term used in this respect is the "biological clock." The concept of rhythmostat provides a more scientific picture of the biological clock. Both terms will be used in the following discussion.

First, let's take a brief look at the nature of this timing device inside our body and at the phases of the circadian cycle--wakefulness and sleep.

During the state of wakefulness via sensory receptors, we become aware or conscious of the outside world and of some processes inside our body.

During sleep we are not aware of the outside surroundings. There are four different stages in the depths of sleep: light sleep, moderate sleep, near deep, and deep sleep. Light sleep and moderate sleep are the phases of dreams and rapid eye movements (REM). Concerning the length of sleep, in addition to the 6 to 8 hours of nightly sleep, many people enjoy a short afternoon nap which could be called minisleep. Furthermore, after a night with not enough sleep, sleep seizures occasionally occur that last only several seconds and are therefore called microsleep. A deeper insight into the levels of sleep and wakefulness has been gained by recording the electric activity of the brain.

During the state of wakefulness the electroencephalogram shows one dominant frequency of "brain waves" of about nine to thirteen oscillations per second and of about 50 millivolts (alpha waves). During deep sleep their frequency decreases to two or three per second and the voltage increases (delta waves). A dream or nightmare causes bursts of more frequent and violent oscillations.

Sleep and activity are the most conspicuous signs of the circadian cycle. But there are many more rhythmic changes behind the visible scene, such as a decrease in metabolic rate, respiration, heart rate, blood pressure, and temperature. The activity of the digestive system increases during the night, but in contrast, the elimination system (kidneys and bladder) is more active during the daytime.

Blood analysis reveals the picture of the whole complex on the body's activities in day-night variations in its cellular and chemical constituents.

With regard to the latter, the hormone secretion of the endocrine glands is of special significance because they play an important role in the control of the circadian rhythm. Adrenalin production by the medulla of the adrenal gland starts to increase after 4:00 a.m. and shows a peak around 8:00 a.m. and another one around 2:00 p.m.; in this way the body gets mobilized via the sympathetic for the activity requirements of the

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day. Day-night fluctuations are also found in the activities of other endocrine glands, including those of sex. All of these endocrinal functions are coordinated by the pituitary gland--hypophysis.

This "master gland" is closely connected by nerve fibers with the hypothalamus of the midbrain, the central station of the autonomic nervous system, which with its sympathetic and parasympathetic divisions, controls all vegetative activities of the human body.

All of these periodic variations on an organic, cellular, and molecular level repeat themselves with a clocklike regularity within the temporal frame of nearly 24 hours. Such is the picture of the "physiologic clock," or rhythmostat. It is a neurohormonal system, or since psychological conditions can also affect its function, it is a psychoneurohormonal system.

At this point I would like to mention that the pituitary gland also produces the growth hormone somatotrophine, but only during sleep, essentially during deep sleep. This is particularly important for children. It is therefore very good that the daylight saving time for the winter has been abolished. If we had this situation for a number of years, the coming generation of adults would be shorter. (This would be particularly bad for Texans.)

For the adult, the normal physiological time requirement for sleep, or the duration of sleep, is about 6 to 8 hours every 24 hours, plus a brief afternoon nap, as found in those people who are not under community, social, or professional pressure. As a measure of sleep, the concept of the amount (quantity) of sleep, which is the product of duration and depth of sleep, has been suggested. But there is at present no unit to measure the sleep amount similarly as we measure the metabolic requirements in calories. Be that as it may, within the time frame of 24 hours, man needs a certain amount of sleep for energy restoration and revitalization. This must be regarded as a biological law.

Even tissue cells show a day-night cycle as manifested in higher cell-division rate during sleep. There is one exception--cancer cells. These, it has been found, always multiply at an erratic rampant rate (circadian anarchy) and no longer conform with the normal rhythmicity of the surrounding tissue. As has been reported, x-ray treatment can bring back the tumor cells into a normal circadian order of activity.

The stability of the circadian cycle, or the rhythmstatic nature of man, is evidenced by the following facts:

1. It is impossible to break this cycle by ignoring sleep for a number of days; this leads to neurotic disorders, as proven by numerous sleep-deprivation experiments in sleep laboratories.

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2. The duration of the circadian rhythm can be shortened to 18 hours and extended to 28 hours by exposing the individual to artificial light-dark cycles; the physiological clock accepts these durations by adaptation.

3. The sleep-wakefulness cycle continues in its nearly circadian pattern in constant light or dark environments, as observed on inhabitants of the subpolar twilight zones and on animals kept under similar constant conditions in the laboratory.

4. A shift in the phases of the circadian cycle is possible, but it requires a certain time for readjustment. This is a familiar problem in work time shifts in some industries, communications and transportation services, fire and police departments, hospitals, military service, astronomical observatories, astronautical tracking stations, on ships, etc. Individuals involved in these activities feel some inconvenience for a number of days after they change their duty hours. There are, of course, differences in the sensitivity to a phase shift. Some, but only a few, people can sleep at any time, in any place, and under any conditions, but the great majority are more or less sensitive in this respect.

These four points definitely illustrate the basic rhythmstatic nature of the human body. In the just-mentioned examples of work time shift, the individual stays in his home time zone. With the development of fast-moving surface vehicles and especially the advent of the airplane, a new way of phase shift of the day-night cycle is experienced by millions of people; namely, by time zone changes via travel, particularly by air.

Within the higher range of subsonic speed and in supersonic speed, about half a dozen time zones are crossed in 6 hours or less. This exposes a traveler in a very short time to a day-night cycle different from that at the point of departure, and, consequently, different from the physiological day-night cycle to which his body is adjusted. This results in a phase shift between the geographic and physiological cycle. Flight in an easterly direction advances, in a westerly direction delays, the cycle.

This unaccustomed relation of the internal time of the traveler to the local geographic time is called desynchronization, or desynchrony, and it may take him several days to a week to get adapted to the local time where the trip terminates, or until the two cycles, physical and physiological, are resynchronized.

As statistical studies in long-distance flights have shown, the majority of people are sensitive to this travel-produced phase shift, and experience some discomfort for several days. They become hungry, get sleepy, or are awake at the wrong time with regard to the new local time. Their "head clock" and "stomach clock" and elimination system

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are confused. Such is, in brief, the picture of the circadian "phase-shift syndrome," or jet lag.

After transcontinental flights in the U.S.A., this condition lasts 3 to 4 days; after trans-Atlantic flights, 5 to 6 days. When crossing 12 time zones, which leads to a complete reversal of the day-night cycle, resynchronization may take 10 to 12 days. As a general rule, most travelers adjust to a new circadian cycle at a rate of nearly 1 hour per day (Colonel W. K. Douglas). Some people feel more easily adjusted after eastbound flights, others after westbound flights, and some when returning to their home time zone with its familiar climate and social order. There are, of course, also some people who are not particularly sensitive at all.

It must be emphasized that the psychophysiologic effect of cycle desynchronization, or more in line with medical language, desynchronosis, is not a pathologic condition; it is merely a time disharmony concerning what the body's physiological internal milieu expects from the physical and social external milieu at the new locale, and vice versa. But this time disharmony is significant in many respects.

Circadian cycle desynchronization can have some significance concerning political summit meetings, diplomatic missions, emergency sessions of the United Nations, international scientific congresses, Olympic Games, etc. During the first few days of such events, the participants who had to cross a number of time zones may be temporarily in a somewhat handicapped position due to their desynchronotic condition.

The problem of circadian cycle desynchrony is especially important for those whose occupation involves time zone changes. Pilots of long-distance air routes, and the stewardesses as well, are in this category. A too-frequent shift of their circadian cycle causes fatigue and requires special attention; this is well recognized and taken care of by the pilot associations and the medical directors of the airlines and the medical officers of the Air Force.

What can be done to avoid the state of desynchronization of the circadian cycle on a certain occasion which requires full alertness after long-distance flights? There are several ways and means to achieve this and to be synchronized with the local time of the destination of the journey at the right time.

1. Preflight adaptation or synchronization--Beginning 3 to 5 days before departure, go to sleep every evening 1 hour earlier before a flight in an easterly direction and 1 hour later in a westerly direction.
2. Postflight local preadaptation--Flying to the distant place several days in advance of a certain event or meeting.
3. Preadaptation by stopovers during the flight. This was first introduced by the former White House physician, Major General Walter R. Tkach.

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Each of these three methods--preflight, postflight, and inflight preadaptation--should be effective to keep the traveler alert during the whole day of his engagement.

A traveler who cannot afford the time for preadaptation must know that the morning hours during the first days after long-distance east-bound flights, and the later afternoon hours after westbound flights, are not proper times for important discussions and decisions.

Finally, controlled mild medication might help to accelerate the physiological adjustment to the new local time. All of these are not necessarily of concern for vacation travelers.

The flying speed of birds is in the same range as that of surface vehicles. From a comparative physiological point of view, it is interesting to note that the long-distance migrating birds such as cranes, geese, ducks, and swallows on their seasonal north-south flyways, stay within the range of two to three time zones. The long-distance champion migrator, the Arctic tern, crosses about five to six time zones on its 16,000-km (11,000 mile) flyway to the Antarctic. But these birds do not make more than 100 to 500 km per day; they stop frequently for food and rest in forests and on islands and coastlines, and in this way get adapted to a different time zone. All this indicates that fast crossing of a larger number of time zones without stopovers is "not for the birds." The same should be recommended for diplomats concerning their rhythmstats.

Beyond the time zones, in the environment of Space--with no day-night cycle, but with a variety of photic conditions such as Sunshine, Moonshine, Earthshine, and shadows--orbiting astronauts have to follow the dictate of their body clock. They usually keep their time in tune with the time of the control center on Earth. The sleep durations of the astronauts of the Skylab lasted around 6 to 7 hours. This helped keep the spacemen in good condition.

On the flight trajectory to the Moon and back, simultaneous sleep of the three-man teams of the Apollo projects proved itself very efficient.

On the Moon itself the light-dark cycle lasts 27 terrestrial days. This photic environment does not provide a "time cue" comparable to sunrise and sunset within 24 hours on Earth. The selenonauts must arrange in a future lunar station the sleep and activity regime according to their georhythmstatic nature.

On the most attractive postlunar astronautical target--the Red Planet, Mars--the day-night cycle is only 37 minutes longer than that on Earth. Thus, the temporal day-night alternation on Mars offers a time indicator familiar to terrestrial visitors for their sleep-and-activity rhythm, and, consequently, there should be no difficulties in this respect in a future Martian station, especially since the circadian rhythm of man, kept in isolation without touch with time, is nearly 30 minutes longer

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than the actual terrestrial day-night cycle of 24 hours. Some chronobiologists consider this as an influence of the Moon. It is also possible that some 10,000-20,000 years ago the rotation of the Earth might have been somewhat slower. For science fiction it would offer a welcome indication that our ancestors had come in flying saucers from Mars and that the *Homo sapiens terrestris* has kept the inherited Martian day-night rhythm in his body up to the present day.

All in all, the biological clock, manifested in circadian sleep and activity with rhythmstatic tendency, will always play an important role in the maintenance of health and performance capability of man on Earth, in air travel, and in his conquest of space.

And in this connection I wish you all, wherever you come from, a long-lasting, happy tick-tock of your rhythmstatic body clock.

SEMANTICS FOR POETRY IN THE SPACE AGE*

Hubertus Strughold, M.D., Ph.D.

I feel very honored to have been invited by Dr. Stella Woodall, the President of our local Poetry Society, to speak to you at this seminar here in San Antonio, the City of the Sun. As my topic I have chosen the original derivation and meaning of words, or "Semantics for Poetry in the Space Age."

Semantics is the scientific branch of linguistics that deals with history, development, and changes of words. It is derived from the Greek "semainein" - to show.

The human language is the reflector of the thinking center of the brain. Poetry, then, can be considered as a kind of reflecting mirror, rotating in cycles or rhythms and showing rhymes in verses. This can be accepted as the psychophysiological analysis of poetry, or of the mirror of your poetic mind.

The words in poems have the meaning of the present, or of the time at which the poems were produced. But they reveal much more if we trace the words back to their ancient origin. The words of the English language, for instance, are up to 70% of Anglo-Saxon origin and 30% of ancient Latin and Greek origin.

There are, of course, in the United States names of numerous persons, things, locations, etc., the origin of which would be attractive for poetry. But in the following we shall confine ourselves to some new terms of our recent time which is marked by the Space Age.

In fact, I shall emphasize particularly the new Space-related terminology which includes modern environmental science, technology, medicine, and biology. It has become, since the realization of manned orbital flight and the fantastic first step on the Moon, part of the common language. It is therefore logical that poetry also joins the Space Age more and more, which would lift the space-devoted poetry to "astropoetry" or "cosmopoetry," comparable to the liftoff of a rocket into space. Astropoets will have, in the coming Space shuttles, a unique opportunity to fly beyond the atmosphere into near-Earth space and experience personally the wonder of the universe of which our home planet is only a minute, but vital, part.

*Presented at the Poetry Seminar in San Antonio, Texas, 3 Oct 1975.

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Now we turn to the topic of this presentation, "Semantics for Poetry." First, a few semantic remarks about the name of this society: Poetry has its roots in the ancient Greek verb "poiein," which means to create or to compose. A poet is a composer. The Greek term for poetry was "poietria," which entered also the Roman or Latin language as "poetria." The present English word "poem" was originally "poiema" in Greek and "poema" in Latin. The adjective "poetic" was "poietikos" in Greek and "poeticus" in Latin.

The predominant and decisive features of poems are the verses and rhymes. The word "verse" is derived from the Latin verb "vertere"--to turn--or more specifically from the substantive "versus"--which means turning line. The word "rhyme" has its origin in the Anglo-Saxon's word "rim," which comes from the old French "rime" and, originally, from the Latin "rhythmus" and Greek "rhein"--to flow: regular occurrence. Another characteristic term in poetry is meter, derived from the Greek "metron"--measure. It measures the systematic arrangement of rhythms in verses.

So much about semantics of the structure of poetry itself. And now to some subjects and terms for poetry in special reference to the Space Age.

Let's begin with a look high into the sky and deep into linguistics' past. The word "sky" is derived from the Anglo-Saxon "sceo," which means a cloud. Maybe, several thousand years ago, the sky was more a cloudcover than it is today. At night, in the cloudless sky, we see thousands of stars. The name for these distant Sunlike celestial bodies in Anglo-Saxon regions was "steorra"; in medieval English, "sterre"; and in German, "stern." The Latin word for star is "stella"; its derivation from sterre is hypothetical.

Our home star is the Sun. This word is derived from the Gothic "sunno." In ancient times this light- and heat-providing celestial miracle was venerated as a god--Sungod.

The present annual ritual Sun dances of the American Indians, such as the Sioux and the Navajo, remind us of this mythological belief.

The first day of the week is appropriately named after the Sun: "Sunday" (German "Sonntag"). The Sun is, in fact, the fountain of energy for life, which is reflected by many poems and also romantic songs; for instance, "You Are the Sunshine of My Life." The Greek name for the Sungod is "Helios." A large satellite named "Helios" is presently in orbit for exploration of the Sun. The Roman's name for the Sun was "Sol"; this term today is used in all Latin countries. Eight orbiting solar observatories (OSOs) are now in space for the study of the physics of the Sun and its radiation. Solar energy has already entered the common language, since this source of energy will in the next 10 years substitute 20% of all conventional energy sources; for instance, in air-conditioning buildings and in producing electricity by solar cells. "Solar" will

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become a house word, as has already the term "energy," which is derived from the Greek "energeia"--in work, or to do work.

In ancient times some of the stars were considered as wandering stars. The Greeks therefore called them "planetes," derived from "planasthai"--to wander. The planets move in specific pathways around the Sun, called "orbits." Orbit comes from the Latin "orbis" which means circle. The term "orbit" has been used for a long time in astronomy, and since artificial satellites are circling, or orbiting, around the Earth, it has become a popular word in astronautics and even in the vocabulary of the average man.

It even has become a slang expression. For instance, if somebody in a bar has had too many highballs, he is said to be "high in orbit." And I remember a very amusing cartoon in which a secretary was sitting in a corner of an office taking dictation from her boss who had the habit of walking around the table while dictating. At one point during the dictation the secretary interrupted him, asking, "Excuse me, what did you say during your last orbit?"

The members of the solar planetary system have been named after some of the mythological Greek and Roman deities. The planet (Mercury) closest to the Sun has been named after the Roman god "Mercury," the god of trade, peace, and prosperity. "Venus" was the goddess of love and of the spring season. The Roman goddess "Terra" became the name of Mother Earth. Our second planetary neighbor was dedicated to "Mars," the god of war and agriculture. The next and largest planet received the name "Jupiter," the Roman counterpart of Zeus, the king of the gods. "Saturn" was the god of planting and harvest. "Uranus," from the Greek "Ouranos," was the personification of the sky and the heavens. The Roman "Neptune" was the god of the sea, and the farthest planet in the solar system was named by its discoverer, the astronomer Clyde Tombaugh, for "Pluto," the Greek god of hell.

For poets and writers it might be interesting to remember that almost all the days of the week are also named after some mythological gods, except Monday. I have already mentioned the first day of the week--Sunday, the day of the Sungod.

Monday has the same root as the word "month," namely, the Anglo-Saxon "mona" or "mena." It means to measure, namely, the time. For the Anglo-Saxons, thousands of years ago, the Moon was the time indicator from new Moon to full Moon and back to new Moon, about 27 days--a time range they called "month." Because of the preeminence of this time-keeper in the sky, they gave also one day of the week the name Monday. Tuesday is the day devoted to Zeus, the Greek god of all the gods: Zeus-day. Wednesday is the day of the Teutonic god of war and magic, Wodan: Wodanaday. Thursday is the day of Wodan's son, Thor, the god of thunder: Thoraday. Friday is the day of Freya, or Freia, the goddess of love and marriage. Saturday is the day of Saturn, the Roman god of planting and harvest: Saturn's Day.

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Now back to our home planet, Earth, with its life-supporting atmosphere. The most important chemical element in our surrounding air is oxygen, the element of life. But oxygen was not known before the 17th Century. From the time of the Greeks and throughout the Middle Ages, this mysterious energy-producing agent in the air was called "pneuma," the breath of life; or "phlogiston," inflaming or burning element; or "igneo-aerial spirit," fire-air spirit. Leonardo da Vinci in the 15th Century was the first to state that the air contains two gases. Finally, in the years 1774-1777, scientists in England, Sweden, and France independently discovered this new element and recognized its property as "fire substance" and "life substance." In 1776, Lavoisier of Paris coined the word "oxygen."

In the coming Bicentennial, it would be very appropriate to celebrate the 200-year jubilee of the discovery of oxygen as "the" element of life. Its discovery, as already mentioned, was made in foreign countries. But the research in the U.S.A. in the last century has made tremendous contributions to the application of oxygen in technology, and particularly in medicine and aviation and space flight. Oxygen therapy has been a lifesaver for millions of patients. Oxygen should be an attractive topic for poetry. After all, without oxygen on Earth there would not be poets, only anaerobic bacteria as on Mars. Behind the screen of oxygen is the Sun, because in the course of millions of years the original hydrogen atmosphere on Earth has been transformed essentially via photosynthesis by green plants into the present-day pleasant oxygen atmosphere. In this respect, the Sun and the plants deserve special recognition in poetry.

The Sun produces on the rotating Earth a cycle of light and darkness or a day-night cycle, with which our body clock--with its two phases of sleep and wakefulness--is in tune, or synchronized. This physiological circadian rhythm is vital for the body's health and vigilance. (Circadian = circa-dies = around 1 day.) Our body clock is regulated by a rhythmostat. Its study is the topic of a new branch of biology called "chronobiology" or "rhythmobiology." A flight by plane across time zones leads to desynchronization of the body's clock, or jetlag, and it takes (according to the rule proposed by Colonel William Douglas, Vice Commander of the Aerospace Medical Division, Brooks Air Force Base, Texas--the first physician of the Mercury astronauts) about 1 hour per day to become adapted to, or synchronized with, the new time zone. This is a matter of special interest for traveling diplomats. In Space, there is no day-night cycle. Astronauts, therefore, keep their body clock synchronized with the time of their Space flight-control center on Earth. At this point, I wish all you attendants of this seminar a long-lasting happy tick-tock of your body clock.

By the way, the circadian rhythm of people, kept in sleep laboratories without any contact with the time, is not exactly 24 hours--the rotational period of the Earth; it is about 30 minutes longer, the same as that of Mars. For science-fiction writers, this might be a welcome indication that our ancestors many thousand years ago came in flying saucers from.

SEMANTICS FOR POETRY IN THE SPACE AGE

Mars and have kept the Martian circadian rhythm on Earth up to the present time. Actually, it might be that the rotational period of the Earth several thousand years ago was somewhat longer.

As you know, two automated spacecraft called "Viking" are presently on the way to Mars, to land and to explore the possible existence of lower forms of life (Micromartians) and send the data back to Earth. If the answer is "yes," this would be the news of the century and a highlight of the Bicentennial. It would extend terrestrial biology into cosmobiology.

In conclusion, I would like to make a few remarks about the term "astronaut," which was the background of this discussion. "Astronautics" means flight to the stars; it was coined in Paris in 1929 and now is used internationally.

"Astro" is derived from the Greek "Astraea," the goddess of justice and purity, and the daughter of Zeus. After the Golden Age, when violence appeared on Earth, she abandoned her home planet and went far into Space and became the star constellation "Virgo." Thus, in mythology, a female was the first astronaut, or astronautess.

The Russians use the terms "Cosmonautics" and "Cosmonauts." But this is not a Russian term, because the word "cosmos" goes back to the ancient Greeks. It was used in a book in the 16th Century by Thomas Muentzer in Stuttgart, Germany, entitled Cosmography, in which he described the geography of Europe, North Africa, parts of Asia, and a few areas on this continent. At that time the designation "cosmos" included only the known countries on Earth; today we know more about the surface features on the Moon and Mars than was known in the 16th Century about this new continent and the eastern part of Asia. Actually the word "cosmos" means jewel, and it was used by the early ancient Greeks for the stars, which they thought were jewels distributed over the ceiling of a velvet black dome. Today the word "cosmos" is used in the same sense as the term "universe."

I should mention also that the word "cosmetics," an area of activities of ladies, too, is derived from the word "cosmos"; its purpose is to make the face of a lady look like a jewel or like a glowing star.

All of this semantic material I've had the pleasure to present here at this splendid seminar of poetry is not only important for the English language but also for two-tongue, or bilingual, and multilingual poets.

I would like to conclude this lecture with a closely related story about a very famous Space-oriented person and with the semantics of his name, Walt Disney.

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In September 1957 I had the honor to meet him during a trip to Europe on the oceanliner, Queen Mary. Every evening after dinner, during a brief walk around the deck, we had a Space talk. He was very enthusiastic about man's advance on the vertical frontier, as predicted in science fiction and science vision, and I had to tell him about the research in the Department of Space Medicine of the School of Aviation Medicine, Randolph Field, Texas.

At the last evening he said, "I am now 54 years old; I have seen during my lifetime so many inventions and discoveries that if somebody tells me that, during my still-coming lifetime, somebody flies to the Moon - darned, I believe it." Fourteen days later the first Sputnik was in Space. Walt Disney lived about 10 more years and died in 1966. He had not seen the flight to the Moon, but he saw the preparation of the Apollo Moon project.

Before we said goodbye on the ship I asked him about the meaning of his name. He told me that his ancestors had lived at the Bay D'Isney on the North Sea in Flanders. From this location they got their name. After the D'Isneys had immigrated to Chicago, they were always asked, "How do you spell your name?" To make it easier, his father changed his name by contraction of D'Isney to Disney. Such is the semantics of the famous name, Disney.

THE SUN.
THE FOUNTAIN OF ENERGY FOR LIFE*

Hubertus Strughold, M.D., Ph.D.

The Sun in Ancient Mythology. In ancient times the Sun as the dominant luminous celestial body in the sky was venerated as one of the highest deities. The Persians adored their Sungod under the name Mithra. The Egyptian Sungod was Ra, the god of light and purity. The Pharaohs were considered descendants of this deity.

The Greeks identified the Sun with Helios and the Romans with Sol. This Latin word, or derivations of it, is found in many languages; for instance, Soleil (French), Sole (Italian), Sol (Spanish), Sol (Swedish), Solntse (Russian), Sun (English), Sonne (German), Zon (Dutch) are derived from the ancient Gothic word Sunno.

The Sungod of the Incas in Peru was Inti.

The American Indians of the Great Plains (such as the Sioux, the Navajo, and other tribes) had once every year in early summer a 4-day long ritual Sun dance festival, with songs devoted to the Sun.

Japan (called "Nippon," which means the Land of the Rising Sun) has the picture of the Sun on its national flag.

Many nations pay tribute to the Sun by colorful solar pictures on their stamps.

The first day of the week is dedicated to the Sun--Sunday (Sonntag).

Sunshine is an attractive topic in romantic poems and songs; for instance, "You Are the Sunshine in My Life."

All this illustrates the impact of the Sun upon the human mind. The reason for solar worship was the ancient peoples' awareness of the beneficial qualities of light and heat and also the fear that someday their Sungod might disappear and leave them in darkness. This fear was sometimes triggered by a solar eclipse.

After this mythological aspect of the solar miracle, let's turn to the physical facts about the Sun as a "fountain of energy for life." (By the way, the word energy is derived from the Greek "en ergia," which means

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"in work," or defined in modern terminology, the capacity or power of doing work.)

Solar Science. Our Sun is a gigantic celestial spherical body with a diameter of 1,390,000 km, 109 times that of the Earth. Its heat and light energy production is based on nuclear reactions, namely on fusion of hydrogen into helium, the same as in a hydrogen bomb. This results in extremely high temperature inside and outside the Sun, and in the emission of tremendous radiation into all directions of space.

Our knowledge gained in solar science since Galileo's time by Earth-bound astronomical observatories has been tremendously extended by space-bound astronomical observatories such as Orbiting Solar Observatories (OSO). Six of these scientific OSO's satellites equipped with sophisticated recording equipment have been launched in the years 1962-1971 in the United States. Another more recent solar probe is the Helios Satellite, a combined project of NASA and Germany which revolves around and close to the Sun to record solar activity. So far, Helios A (launched in 1975) and Helios B (1976) are in orbit.

The temperature deep in the interior near the core of the Sun is in the order of 14 million degrees C (25 million degrees F), and on the surface it amounts to 6,000 degrees C. In addition to darker sunspots on the surface, there are numerous bright patches (called "faculae") that are brighter and hotter than the surrounding regions. "Facula" (Latin) means torch. If the Sun were a lightbulb, one could rate it at thirty-eight million billion billion watts. For comparison, the heat production of the human body is equivalent to that of a 70-watt lightbulb.

Solar radiation consists of two kinds: particle radiation (such as protons, neutrons, and electrons); and electromagnetic radiation. In the following we shall concentrate essentially on the latter because it is the one particularly associated with life. But before we discuss this main topic, I would like to make a few remarks about particle rays.

Particle rays in their original form in space probably consist of up to 79% protons or hydrogen nuclei, 20% alpha particles or helium nuclei, and 1% heavier atoms up to iron. These so-called primary particles can be of solar or galactic origin. The latter can possess a very high kinetic energy, which they probably have acquired by accelerations in magnetic fields between the galaxies, star clusters, and cosmic clouds.

When these primary particle rays enter the denser regions of the Earth's atmosphere, they lose their original powerful form in collisions with the air's atoms or their nuclei. This takes place between 20 to 40 km. The collision products or secondary rays (protons, electrons, neutrons, mesons, and gamma rays), which penetrate the lower layers of the atmosphere, are less powerful than the primaries, but powerful enough to penetrate 100 meters into the waters. Thus, at sea level and up to 20 km, we are exposed only to these secondary and tertiary particle rays.

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During daytime we are hit essentially by solar particle rays; during the night, by galactic cosmic rays. An area of the size of the palm of your hand is hit about 50 times and the tip of your nose about two times per minute. We are used to this drizzle of particle rays; maybe we need it as a kind of cosmic stimulant. In this connection, it should be noted that according to Professor Eugster of Zurich, seed of barley kept in the Symplon tunnel at the bottom of a 2500-meter-high Alpine mountain (Monte Leone) did not grow so well as those kept under normal radiation condition on the Earth's surface. Cosmic rays cannot penetrate a mountain.

People do not feel the impact of cosmic rays. But about 20 hours after a solar flare, they do feel it in the form of irritation on scars. There is also a beneficial effect of solar particle rays. An increase of their penetration into the atmosphere triggers rain. Since this happens especially during the time of maximal solar activity, the tree rings are larger every eleven years during the maximum of the solar activity cycle.

In contrast to the particle ray situation at the Earth's surface, an orbiting space vehicle is exposed exclusively to the more powerful bombardment of the original primaries. Here we are beyond the protecting shield of the atmosphere. The wall of the spaceship has to provide some protection. The radiation dose absorbed in manned orbital flights (Skylab) has been less than 1 millirad per hour or about 15 millirad per day. The same has been observed during the flight to and on the airless Moon. This daily dose is 10 times less than that absorbed during single abdominal x-ray picture taking. Thus, in orbital space flights, with doses of a little less than 1 millirad per hour, we can look upon the radiation problem with no particular concern.

In deep space, as en route to Mars, the dose rate received by the occupants of a spaceship might be in the order of 1 rad per month. Such is the particle radiation climate for the astronauts, if the absorbing power of the spaceship's wall is equivalent to a steel plate of 1 cm thickness.

The solar electromagnetic spectrum includes gamma rays, x-rays, ultraviolet, visible, infrared rays, and radio waves. Of special interest for us here are the visible rays, heat-producing infrared rays and ultraviolet rays as prominent beneficial and potential detrimental ecological factors in our environment. The tremendous intensity of solar radiation at or near the Sun's surface decreases with the inverse square of the distance. At the orbital distance of the Earth the total solar irradiance amounts to 2.01 cal/cm²/min and the light intensity to 140,000 lux. This is called the solar constant, the radiation standard at the distance of the Earth orbit. Using this as the baseline 1 of the irradiance intensity, at the Venus solar distance it increases to 1.91 and at Mercury to 6.67. At Mars' orbital distance it decreased to 0.861, at Jupiter to 0.0369, and at Pluto to 0.00064.

There is a zonal belt within the space of the planetary system where solar irradiance is or can be ecologically beneficial to life. It reaches

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up to Venus and Mars. Beyond Venus, as seen from the Earth, it is too hot and beyond Mars too cold. The Earth is orbiting in the most comfortable middle of this belt, which we may call the ecosphere in the planetary system of the Sun, or helioecosphere. You remember the ancient saga that Icarus, against the advice of his father Daedalus, flew too close to the Sun and ran into heat problems; his wings melted away.

Indirect and Direct Ecological Effects of the Sun. After this general survey we shall consider the Sun as an indirect and direct provider of energy for life on earth! In order to get a complete picture we have to take a look into the past upon the evolution of our home planet Terra.

In the earliest developmental stages of the Earth some three billion years ago its primary atmosphere, or protoatmosphere, consisted mainly of hydrogen (H_2) and hydrogen compounds such as methane (CH_4) and ammonia (NH_3) with some helium (He) and water vapor (H_2O) but with no free oxygen (O_2), the element of life. Gradually, in the course of millions of years, this original hydrogen atmosphere was changed into an oxygen atmosphere, thanks to the Sun, via two processes:

First, water vapor molecules in the higher regions of the protoatmosphere were split into hydrogen and oxygen by the ultraviolet of solar radiation, a process called photodissociation. Most of the lighter hydrogen molecules disappeared from the Earth's gravisphere into space. The heavier oxygen, however, remained. The accumulation of this initial oxygen started a distinct change in the atmospheric chemical composition. The ammonia was oxidized to free nitrogen (N_2) and methane to carbon dioxide and water.

In this way, in the course of millions of years, the protoatmosphere became more and more oxidized. With the appearance of chlorophyll-bearing primitive plants, such as algae, about $2\frac{1}{2}$ billion years ago, this process of oxidation was accelerated by photosynthetic activity. Oxygen produced in this biologic way oxidized the remaining bulk of the hydrogen compounds and even a surplus of free oxygen accumulated in rather large amounts such as are found in the present-day atmosphere. This stock of atmospheric free oxygen (O_2) is estimated to be around 1.2 quadrillion (10^{15}) metric tons. The effectiveness of photosynthesis in the oxidation and oxygenation of our atmosphere has, without a doubt, exceeded by far the oxygen production by photodissociation or photolysis. We must keep in mind the effective agent behind this chemical atmospheric transformation was, and is, the Sun.

With the appearance of atmospheric oxygen an ozone layer at an altitude between 25-45 km came into existence by two effects of solar ultraviolet rays. Ozone (O_3) was and still is produced by hard ultraviolet rays around 2000 Å. At the same time O_3 is destroyed by soft ultraviolet rays (2100-3000 Å). In this way an equilibrium between formation and destruction of O_3 is reached and the ultraviolet rays are absorbed and do not enter the lower region of the atmosphere except a certain amount of soft ultraviolet rays. These are the rays that can cause sunburn on people's skin, when exposed too long to sunshine. Thus the Sun is indirectly the protector from one section of its radiation.

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Origin of Life. The early evolution of our atmosphere leads us automatically to the question of the origin of life. According to theories proposed by the Russian scientist Oparin, Urey in California, and Haldane in England, the building blocks of primitive life were produced by the effect of ultraviolet solar radiation and/or lightning upon the methane, ammonia, and water of the protoatmosphere in the form of amino acids, the components of proteins. These formed a kind of nutritional broth in the upper layers of the oceans that was the matrix material from which the first living cells originated during the Archeozoicum some $2\frac{1}{2}$ to 3 billion years ago. In 1951 Stanley Miller in California, in fact, was able to reproduce this process experimentally by subjecting a mixture of water, ammonia, and methane to ultraviolet rays or electrical discharges. Later in similar modified experiments by other exobiologists, various organic molecules have been synthesized. All this has strengthened the theory that such photochemical reactions have occurred as a natural process in the primordial atmosphere.

The Sun also has provided us with tremendous amounts of fossil fuels such as oil, natural gas, and coal. These energy-rich gases, fluids, and solid materials have been formed from plants of many kinds, which flourished under a shining Sun in swampy lands and shallow bodies of water several hundred million years ago. Because of some severe climate changes in large regions, they died and decayed and the leftover debris have been transformed into the just-mentioned fossil fuels. Photosynthesis, of course, was behind the growth of the botanical matrix of the fossil fuels. Thus the Sun indirectly provided us with the energy in natural gas, petroleum, and coal.

Now back to the present. Solar rays in the range of infrared provide over most of the globe a warm climate with a seasonal cycle. On a sunny day at noon in the middle latitudes the heat received on the Earth's surface amounts to $1 \text{ cal/cm}^2/\text{minute}$ (half of the radiation intensity in near Earth space is absorbed or reflected by the atmosphere). (1 cal or gcal is the heat unit required to increase the temperature of 1 cm^3 of water by 1 degree centigrade.)

The solar heat evaporates water from the oceans and lakes. In the higher cooler regions of the atmosphere the water vapor forms clouds and some of the water falls down on land as rain and snow and eventually returns in rivers to the sea. Thus without the Sun, most of the land on Earth would consist of cold dry deserts.

The combination of the Sun's visible radiation plus the Earth's rotation is the astronomical mechanism for the terrestrial day-night cycle, the photoecological background for the circadian rhythms of the biological clock in plants, animals, and man. Its exploration has become an important new biological branch: chronobiology or biorhythmology. The Sun provides the light or photic environment for man's activity cycle.

Sunshine is also used for medical treatment of skin diseases, such as psoriasis. This is called heliotherapy.

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As mentioned earlier, overexposure to sunshine can cause sunburn, which is controllable; but the damage by looking directly into the Sun is irreparable. The Sun's heat rays focused by the eye's lens upon the retina can cause a small spot or retinal burn. It frequently occurs during a solar eclipse.

I got such a retinal burn or eclipse blindness in 1910 when I observed a total solar eclipse with an insufficiently smoked glass. Fortunately, I used only one eye. Forty years later I published a paper about retinal burn. This injury is a direct detrimental effect of the Sun that has to be avoided by all means.

Solar Energy Artificially Provided. Solar heat radiation sets the air of the rotating Earth in movement, thus producing all kinds of wind everywhere and in various directions. This Sun-generated wind power is utilized essentially by two devices: sailboats and windmills.

Sailboats, which use wind as a driving force, have been in existence for 5,000 years and were first used by the Persians. This method is mentioned by Homer in the Odyssey, in which he states that Calypso brought Odysseus "a web of cloth to make him sail." In the middle ages more powerful sailboats or sailships had been developed. They enabled Christopher Columbus to venture to the new Continent in 1492 and Vasco da Gama to open the sea route to India in 1497-1499. In the eighteenth century the sailship had gradually been replaced by the steamship and motorship. Today sailboats are only for sport and pleasure.

For centuries wind power has been used by means of windmills, to pump water, grind grain, and saw wood, particularly in Europe. But in this century wind power has been more and more replaced by fuel power. However, at the present time of the increased energy need, the windmill in a more modernized form is coming back, and it is even used to generate electricity. Of course, the amount of this kind of energy production is small compared with that of fossil fuel resources. But there are two advantages: windmills do not pollute the air and wind is not localized in certain regions or nations as fossil fuels are. Wind is a global power and last, but not least, wind energy does not cost a thing! It is indirectly a gift from the Sun.

Recently an energy expert suggested that electricity-producing windmills should be built in certain windy areas in the United States, such as New England, Lake Erie, and Michigan. They could provide 20% of all the electricity required in these regions.

Recently NASA and the National Science Foundation (NSF) have announced the award of contracts to two industrial firms for preliminary design of very large wind energy mills for generating electricity. Its rotor vanes would be approximately 21 m in diameter and each windmill could produce enough electricity to supply 100 to 200 homes.

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In recent years a direct approach to collect solar heat energy is on the way by building a solar house or Solarchitecture house.

In 1974 numerous individuals in the United States were heating their homes by solar energy. The Sun's heat is taken up by flat rooftop collectors consisting of black metal sheets. The collector is covered by two transparent glasses or plastic plates. The black sheet absorbs the heat and transfers it to fluids within pipes. The warm air or water is then circulated throughout the house. In summer the house can be kept cool by blocking the Sun's rays by isolation plates. There is a great variety in the Solarchitecture of houses. They could come more and more in use in the United States within 5 to 10 years between the latitudes 45°N and 45°S.

In this connection, I would like to mention an extraordinary example of solar heating in the animal world. In contrast to warmblooded animals which are able to produce sufficient natural body heat on their own, cold-blooded members of the animal kingdom depend more on the surrounding environmental temperature.

One reptile that was better off to take advantage of solar heat was the dinosaur, Dimetrodon grandis, which 200 million years ago roamed the country of what is now Texas. Along its back the dinosaur developed a sail-like skinfold which was kept in upright position by bony spines; it looked from a distance like a sailboat. According to C. D. Bramwell and P. B. Fellgett, physicists from Reading University in England, Dimetrodon could use its sail as a natural solar heating device. They calculated that by turning sideways to the Sun the dinosaur could raise its body temperature from 26° to 32°C in 80 minutes, something that would require about 205 minutes to do without the sail. They also mentioned that Dimetrodon could shut off the blood vessels to and in the sail and prevent excessive heat loss in the coolness of the nights. Another sail-bearing Dinosaur was the Edaphosaurus.

Very exciting and promising are the photovoltaic cells or solar cells, which convert solar light into electricity and were developed by Bell Telephone Laboratories in 1954. A solar cell consists of two silicon plates of the size 1 x 2 square cm, to which some material such as phosphorus and boron is attached. The electricity level is, of course, very low and for this reason numerous solar cells are needed to produce a practical amount of electricity. Since 1954 about 600 unmanned satellites have been equipped with 20,000 solar cells each.

Weather and telecommunications satellites (Tiros, Interstell, Nimbus, Telstar, etc.) have their outer surface or panels literally covered with thousands of silicon solar cells, some of which are always facing the Sun and generating the power needed to operate their radio and television equipment and to charge batteries. Space vehicles intended to transmit signals over vast distances (Mariners) employ more than 40,000 cells mounted on panels that can be folded into the launch rocket and then deployed when the desired course has been attained.

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A fantastic useful fallout from space is presently provided by the Application Technology Satellite (A.T.S.6), a synchronous satellite which was launched in 1974. It is now over Alaska and, in addition to communication, it serves education and particularly health care for people in isolated areas where there are no local physicians. This miraculous satellite, in connection with specific equipment and antennas on Earth, makes it possible to diagnose a remote patient's condition via two-way television and voice link between doctor and patient.

This out-of-the-sky health care called Telemedicine and the educational telecasts are a real breakthrough on the space frontier according to the rocket pioneer Werner von Braun, now vice president of the Fairchild Company which has built the A.T.S.6. In the background of the function of this satellite is the Sun, because the electric power is provided by 21,600 solar cells distributed over two huge curved solar panels.

Manned spacecraft such as the Apollo ships and the Skylabs also carried thousands of solar cells on solar panels. Recently Dr. Peter Glaser of Arthur D. Little, Inc., Cambridge, Mass., suggested that millions of solar cells should be placed on a huge synchronous satellite surrounded by reflecting mirrors. The electricity produced in this way would be transmitted to antennas on earth by a beam of microwaves and reconverted to electricity. Such a gigantic satellite solar power station (SSPS), 16 square km (10 square miles large), exposed to the Sun nearly 24 hours a day would produce the electricity for 10 million people. Of course, to bring all this equipment up into space would require a number of rocket launchings which would be too expensive, but in the future maybe space shuttles which go into operation in 1980 can do the job.

This concludes my discussion about the futurama of solar energy. Some of the proposed potential collectors of this celestial energy might seem to be more or less science fiction, but actually it is technological science vision, just the same as was the prediction of a manned flight to the Moon decades before this unbelievable achievement. There is no question, at the Tricentennial 2076 the energy economy will be more sunshine oriented than now at the Bicentennial.

I hope this speech has given you a detailed overall picture of the Sun as a fountain of energy for life. Texas with San Antonio, the City of the Sun, is the proper solar state for research and development in this field. I remember when Lyndon B. Johnson, then Senator, was invited to dedicate the new Aerospace Medical Center, Brooks Air Force Base, San Antonio, November 14, 1957, he stated in his speech that "to come here to this city where the Sun spends the winter, I just couldn't resist it."

THE SUN: THE FOUNTAIN OF ENERGY FOR LIFE

BIBLIOGRAPHY

1. Clark, W. Energy for survival. Garden City, New York: Anchor Press/Doubleday, 1974.
2. Gibson, E. G. The quiet Sun. Washington: National Aeronautics and Space Administration, 1973.
3. Sky and Telescope, An Orbiting Solar Power Station, Apr 1975.
4. Solar heating equipment. Popular Science, Mar 1975.
5. Solar cells. NASA Facts. S-6/3-68. Washington: National Aeronautics and Space Administration, 1968.
6. Strughold, H. Your body clock. New York: Charles Scribner's Sons, 1971.
7. Strughold, H., and O. L. Ritter. Solar irradiance from Mercury to Pluto. Aerosp Med 31:127-130 (1960).
8. Strughold, H., and O. L. Pitter. Oxygen production during the evolution of the Earth's atmosphere. Aerosp Med 33:275-278 (1962).
9. Sun, wind and Earth: Energy sources for tomorrow? 1975 Yearbook of Science and the Future, Encyclopaedia Britannica, Inc.
10. von Braun, W. Lighting up the Earth's dark corners with TV from the sky. Popular Science, Mar 1975.

THE EARTH'S ATMOSPHERE

Physical and Chemical Definitions and Data

Hubertus Strughold, M.D., Ph.D.

<u>Total mass</u>	= 5.2×10^{15} metric tons
<u>Atmospheric extension</u>	= 700 kilometers (420 miles) above the Earth's surface
<u>Density (d) of a gas</u>	= mass per unit volume (g/cm^3 or g/m^3)
<u>Free path of molecules</u>	= path the molecules travel between collision with other molecules
<u>Pressure (p)</u>	= force per unit area
<u>Units of measure for air pressure</u>	= grams per square centimeter (g/cm^2) pounds per square inch (psi) mm Hg bar and millibar
<u>Air pressure at sea level</u>	= 1000 millibar = 760 mm Hg = 14.7 psi

Main chemical composition of the atmosphere at sea level

Nitrogen (N_2)	78.09 vol percent
Oxygen (O_2)	20.95
Argon	0.93
Carbon dioxide	0.03

Partial pressure of oxygen at normal sea level air pressure

$$p_{\text{O}_2} = \frac{21}{100} \times 760 = 160 \text{ mm Hg}$$

Homogeneous atmosphere

= Total atmosphere compressed to standard pressure and temperature condition (SPT). Height of homogeneous atmosphere = 7991 meters or about 4.8 miles.

Decisive for the atmosphere's physical and chemical properties is solar radiation causing thermal, dynamical, chemical, electrical, and light effects.

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Two kinds of radiation:

1. electromagnetic
2. corpuscular

Solar electromagnetic spectrum extends from the soft x-rays to radio waves of about 100 meters.

Particle or corpuscular rays consist of electrons, positrons, mesons, protons, neutrons, alpha particles and nuclei of heavier atoms. They are of solar and galactic origin. Particle rays with energies of 1 billion electron volt (B.E.V.) and higher are called cosmic rays.

Solar electromagnetic radiation when absorbed by the atmosphere causes three kinds of photochemical reactions:

- | | |
|--------------------------|---|
| <u>Photoexcitation</u> | = electrons are lifted to higher orbits and return under emission of light to their original orbits. Effective rays: short ultraviolet and particle radiation. Atmospheric range: from top of atmosphere down to 80 km (50 miles). Examples: night airglow, polar lights. |
| <u>Photoionization</u> | = electrons are knocked out of molecules or atoms, which become positively charged or ions. Effective rays: short ultraviolet down to 1000 Angstrom. Atmospheric range: down to 75 km (45 miles) (Ionosphere) |
| <u>Photodissociation</u> | = molecules are split into smaller molecules or into atoms. Effective rays: 2100 to 3000 Angstrom. Atmospheric range: down to 20 km (12 miles). |

The thermal and photochemical effects of solar radiations are responsible for the atmosphere's stratification.

THE EARTH'S ATMOSPHERE: PHYSICAL AND CHEMICAL DEFINITIONS AND DATA

Atmospheric Strata and Their Altitude Range

	Spheres	Layers	Approximate height (in km)
OUTER E R E I N N E R A T M O S P H E R E	Exosphere		5000 700
	Ionosphere	Atomic layer F - layers E - layers D - layers	200+ 140-200 85-140 80-85
	Stratosphere	Upper mixing layer Warm layer Isothermal layer	50-80 35-50 11-35
	Troposphere	Tropopause Advection layer Ground layer Bottom layer	8-11 2-8 2 m - 2 km 0 - 2 meters

COMPENDIUM OF AEROSPACE MEDICINE

Important Medical and Flight Operational Levels Within the Atmosphere

At 4 km -- beginning of subcritical hypoxia

At 7 km -- critical hypoxia

At 20 km -- boiling of body fluids, or ebullism
(Armstrong Line)

From 50 to 80 km -- the limit for aerodynamic navigation
(von Karman Line)

100 km -- the official demarkation line between atmosphere
and space
(Federation International Aeronautique, Geneva, 1964.)

150 to 200 km -- border of the sensible atmosphere

The environment in circumterrestrial space includes two fields
of forces:

1. the magnetosphere, with its boundary the magnetopause as the background force of the Van Allen radiation belts. On its Sun-directed side the magnetosphere is compressed by solar wind to about 10 Earth radii, and on the opposite side it is elongated in the form of a comet-like tail reaching far beyond the Moon (magnetic tail).

2. the inner gravisphere, i.e., the region within which the Earth can hold a satellite in orbit, extends to 1.5 million km. Up to several times this distance its gravitational field is still dominant over that of the Sun, as manifested in its influence upon the velocity and direction of space vehicles (outer gravisphere, or gravipause). The Moon's (inner) gravisphere extends to about 60,000 km.

SPATIOGRAPHY:
ASTRONAUTICAL ASPECT

Hubertus Strughold, M.D., Ph.D.

Never before in its history has the imagination of mankind been captivated so much by the concept of space as today, following the rapid progress in rocketry. It is used in a great variety of versions such as near space, outer space, deep space, free space, interplanetary space, cosmic space, blue yonder, and so on. But space is an immensely vast area even within our solar system. From the standpoint of astronautics, and especially of space medicine or bioastronautics, we need a specification of just what is meant by these terms topographically and environmentally.

Just as the traveler on the Earth's surface uses the science of geography for his orientation concerning distance, climate, etc., to be encountered on his journey, so does the astronaut need a topographical and environmental description of space--a kind of spatioigraphy for orientation, navigation, the designation of the various kinds of space operations, and the estimation of the medical problems involved. At first glance, it may seem strange to draw borderlines or demarcation lines for subdividing an environment distinguished by emptiness; there are, however, several possibilities.

First, the question arises "Where does space begin?" This is the title of a paper published by the writer with H. Haber, K. Buettner, and F. Haber in 1951, in which the concept of the functional borders between atmosphere and space was introduced. In this publication, it was shown that the various atmospheric functions for manned flight come to an end at various altitudes, some even within the lower regions of the stratosphere. The final functional limit of the atmosphere is found at a height of 120 to 140 miles where the atmosphere aerodynamically terminates, though it continues as a material medium up to 600 miles. Expressed in another way, the atmosphere begins to become partially space equivalent at about 10 miles and progresses to total space equivalence at about 120 to 140 miles, as far as the atmospheric functions are concerned. There the laws of aerodynamics lose their meaning (except for objects of enormous velocity) and those of astrodynamics become fully effective. This is the dividing line between space-equivalent flight and true space operations, or between the aerodynamically effective air space and free space. Such is the picture concerning the border between atmosphere and space as seen from the standpoint of space medicine.

Now, what are the possibilities of subdividing, for astronautical purposes, the regions beyond this border--the vast extra-atmospheric void of our solar system?

COMPENDIUM OF AEROSPACE MEDICINE

First, we can use as demarcation lines the orbital distances of the Moon and the planets. Then we speak of cislunar space, translunar space, cismartian, and transmartian space, etc., as Krafft Ehrlicke has suggested (cislunar--on this side; translunar--beyond).

Of special interest from the standpoint of navigation is the gravitational situation in space. The gravitational field of the Earth, as of every other body, extends of course to infinity. But for the astronaut, the sphere of predominant gravitational attraction is of most importance. It might be practical to call these gravitational control zones, briefly, gravispheres. The gravisphere of the Earth extends to about 1 million miles. This is the arena in which satellites are conceivable. Escape velocity thrusts a vehicle eventually out of the Earth's gravisphere into the gravitational control zones of other celestial bodies. Thus we arrive at an astronautical subdivision of space based on the extension of the gravitational territories of the various celestial bodies.

Of practical and vital importance to the astronaut are differences in the environmental conditions of space itself. To begin with, the space environment in the vicinity of celestial bodies is different from that in free interplanetary space. It shows some peculiarities caused by the mere presence of their solid bodies, by optical properties of their surfaces, and by forces originating in these bodies and extending into space.

In the vicinity of the Earth, for instance, on one side we are protected by the solid body of our globe itself from cosmic rays and meteorites just as we are protected in the lee of a house against rain, hail, or wind. Other peculiarities of the space environment in the vicinity of the Earth are the shadow of the Earth and the Earth's own and reflected radiation, which pose special visual problems and influence the heat balance of a space vehicle.

The forces which cause special regional environmental differences in the space near the Earth are those of the geomagnetic field. The magnetic field of the Earth strongly influences the influx of corpuscular rays of solar and cosmic origin by channeling them into the polar regions. The density distribution of these ray particles in adjacent space in fact shows considerable variations with the Earth's latitudes.

For all these reasons, the space in the vicinity of the Earth is somewhat different from open interplanetary space. To emphasize these differences, Krafft Ehrlicke has introduced the concept of the "terrestrial space" and assumes for it an extension of 1 Earth radius, or 4,000 miles, where they dominate the picture. "Circumterrestrial space" might be another suitable designation. For this region, within which the Earth's influence upon the ecological qualities of space is distinctly recognizable, it might be advisable to use the term "near space," and for the region beyond, the term "deep space" or "outer space."

SPATIOGRAPHY: ASTRONAUTICAL ASPECT

But this outer space again shows environmental differences in the various parts of our solar system. These are based on variations in the intensity of solar radiation as a function of the distance from the Sun.

A vehicle in the neighborhood of Venus receives about fifty times as much heat per unit of surface area each minute as a vehicle in the area of Jupiter. This is an important factor in the climate control within the space cabin. A vehicle fitted for a trip to Venus is not equipped for an excursion to Jupiter, just as an expedition outfitted to hunt alligators in the jungles of the Amazon could not be sent to hunt polar bears in the Arctic. Any vehicle entering the Mercurian space would finally run into a kind of solar heat barrier.

With respect to visible radiation, or light, the sky in space is dark everywhere. However, the illumination received from the Sun varies considerably. In the orbit of Mercury it amounts to almost 80,000 foot candles while at the remote distance of Pluto, it is only 8 foot candles.

Finally, the ultraviolet range of solar radiation, which is chemically very active, has strongly influenced environmental conditions on the planets. This is shown by the division of their atmospheres into an inner oxygen belt and an outer hydrogen belt. The first includes Venus, the Earth, and Mars. The second comprises the planets from Jupiter to Pluto. Spatiographic ecology then, covers two areas: The ecology of space itself, and the ecology of the planets or planetary ecology.

For manned space operations there seems to be, at least for the time being and in the near future, a limited area in the solar system with regard to the ecological conditions of space itself and the planets, a kind of ecosphere as a function of the distance from the Sun and the resulting radiation intensities. This sphere includes the region from Venus to Mars.

We get a dramatic impression of the radiation intensiveness of the Sun in both respects by comparing the size of the Sun as seen from the various planets. For instance, from the distance of Pluto the Sun would not appear larger than the evening star, Venus, appears to us on Earth.

For hundreds of years, astronomers have been mapping the stars, measuring their distances, and defining their motions. The astronomer performs these magical feats from afar while he sits behind his telescope in a well-tempered observatory, surrounded by the fresh air of Texas or the California mountains. By contrast, the astronaut leaves the life-supporting air of our planet, Terra, and ventures far into space itself in his little Terrella. He has to know where he is going, into what physical environment. He needs indeed as guidance a "geography of space," or spatiography, based essentially on ecological considerations concerning space itself and the planets.

BIBLIOGRAPHY

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Published approximately 60 papers, co-authored a textbook, Principles of Aviation Medicine, and an atlas on aviation medicine. in Germany, from 1924-1944.

Publications in the United States in 1930 and from 1949-1968:

1. Strughold, H. A cinematographic study of systolic and diastolic heart size with special reference to the effects of anoxemia. Am J Physiol, No. 94, July-Sep 1930.
2. Strughold, H. The mechanical threshold of the cornea-reflex of the usual laboratory animals. Am J Physiol, No. 94, July-Sep 1930.
3. Armstrong, H., H. Haber, and H. Strughold. Aeromedical problems of space travel. J Aviat Med 20:383-417 (1949).
4. Strughold, H. The human time factor in flight. I. The latent period of optical perception and its significance in high speed flying. J Aviat Med 20:300 (1949) and USAF School of Aviation Medicine Unnumbered Proj. Rpt., Jan 1951.
5. Strughold, H. Life on Mars in view of physiological principles. USAF School of Aviation Medicine Special Rpt., Mar 1950.
6. Strughold, H. The human time factor in flight. II. Chains of latencies in vision. USAF School of Aviation Medicine Special Rpt., Nov 1950 and in J Aviat Med 22:100-108 (1951).
7. Strughold, H. Investigations on the usefulness of contact lenses in flight. I. The sensibility of cornea and conjunctiva of the human eye. USAF School of Aviation Medicine Proj. Rpt. No. 21-24-006, No. 1, May 1951.
8. Strughold, H., H. Haber, K. Buettner, and F. Haber. Where does space begin? Functional concept of the boundaries between atmosphere and space. J Aviat Med 22:342-349 (1951).
9. Strughold, H. Physiological considerations on the possibility of life under extraterrestrial conditions. In John P. Marbarger (ed.). Space medicine. Illinois: The University of Illinois Press, 1951.

10. Strughold, H. Basic environmental problems relating man and the highest regions of the atmosphere as seen by the biologist, ch. II. In C. S. White and O. O. Benson, Jr. (eds.). Physics and medicine of the upper atmosphere. New Mexico: University of New Mexico Press, Albuquerque, 1952.
11. Strughold, H. Ecological aspects of planetary atmospheres with special reference to Mars. J Aviat Med 23:130-140 (1952).
12. Haber, F., and H. Strughold. Physik und Physiologie des Drucksturzes im Weltraum. Weltraumfahrt 1952, Heft 4. Frankfurt Am Main.
13. Strughold, H. From aviation medicine to space medicine. J Aviat Med 23:315-318 and 329 (1952).
14. Strughold, H. Physiological day-night cycle in global flights. J Aviat Med 23:464-473 (1952), and the USAF School of Aviation Medicine Special Rpt., Oct 1952.
15. Strughold, H. The green and red planet: A physiological study of the possibility of life on Mars. New Mexico: University of New Mexico Press, 1953.
16. Strughold, H. Comparative ecological study of the chemistry of planetary atmospheres. J Aviat Med 24:393-399 and 464 (1953).
17. Gerathewohl, S. J., and H. Strughold. Motoric responses of the eyes when exposed to light flashes of high intensities and short duration. J Aviat Med 24:200-208 (1953).
18. Strughold, H. The sensitivity of cornea and conjunctiva of the human eye and the use of contact lenses. Am J Optom 30:625-630 (1953).
19. Gerathewohl, S. J., and H. Strughold. Time consumption of eye movements and high speed flying. J Aviat Med 25:38-45 (1954).
20. Strughold, H. Atmospheric space equivalence. J Aviat Med, 25:420-424 (1954) and The Air Power Historian, Vol V, No. 1, pp. 31-37, Jan 1958.
21. Strughold, H. Hypoxia, hypoxidosia, hypoxidation, hibernation, apparent death, and suspended animation. J Aviat Med 25:113-122 (1954) and USAF School of Aviation Medicine Rpt. No. 56-14, Sep 1955.
22. Strughold, H. Space equivalent conditions within the Earth's Atmosphere: Physiological aspects. Astronautica Acta 1:32-40 (1955).
23. Strughold, H. Living room in space. In Medical problems of space flight. Special Rpt. Reprinted from Winter 1954 Issue of Instructors Journal, a publication of ATC, Aug 1955.

BIBLIOGRAPHY

24. Strughold, H. Weltraumaequivalente Bedingungen Innerhalb der Erdatmosphäre, Weltraumfahrt, Heft 1, 1955.
25. Strughold, H. The ecosphere of the Sun. J Aviat Med 26:323-328 (1955).
26. Strughold, H. Physiologic day-night cycle after long distance flights. International Record of Medicine and General Practice Clinics. MD Publications, Inc., Vol. 168, No. 9, 1955.
27. Strughold, H. The USAF experimental sealed cabin. J Aviat Med 27:50-52, 745-748 and 756 (1956).
28. Strughold, H. A simple classification of the present and future stages of manned flight. J Aviat Med 27:328-331 (1956).
29. Strughold, H. The oxygen belt in the planetary system. J Astronautical Sci, Vol. III, No. 2, Summer 1956.
30. Strughold, H. Engineering for physiological requirements, Orbital and Satellite Vehicles, Vol. 2, Ch. 19, Special Summer Program, MIT, Cambridge, Mass., Aug 1956.
31. Strughold, H. Medical problems involved in orbital space flight. Am Rocket Soc J 26:745-748, 756, 788 (1956).
32. Strughold, H. The ecosphere in the solar planetary system. Proc. VII Internat Astronautical Congress, Rome, Italy, Sep 1956.
33. Haymaker, W., and H. Strughold. Atmospheric hypoxidoses. In Handbook of Neuropathology. Munich, Germany: J. Springer Printing Co., 1956.
34. Strughold, H. Space medicine and allied topics. England: The Artemis Press, Ltd., London, 1956.
35. Gerathewohl, S. J., H. Strughold, and W. F. Taylor. The oculomotoric pattern of circular eye movements during increased speed of rotation. USAF School of Aviation Medicine Rpt. 56-33, Apr 1956, and J Exper Psychol 53(4):249-256 (1957).
36. Strughold, H. The ecosphere in the solar planetary system. Astronautica Acta, Vol. II, 1957.
37. Strughold, H. The possibilities of an inhabitable extraterrestrial environment reachable from the Earth. J Aviat Med 28:507-512 (1957).

COMPENDIUM OF AEROSPACE MEDICINE

38. Gerathewohl, S. J., H. Strughold, and H. D. Stallings. Sensomotor performance during weightlessness: Eye-hand coordination. *J Aviat Med* 28:7-12 (1957).
39. Strughold, H. Medicine at work: Health in the heavens. *JAMA* 164(7): 765-769 (1957).
40. Strughold, H. Geographie des Weltenraumes: Spatiographie. *Weltraumfahrt*, 8-9, 1957-1958.
41. Strughold, H. Der Mensch im Weltraum. *Weltraumfahrt*, 8-9, 1957-1958.
42. Strughold, H. General review of problems common to the fields of astronomy and biology. *Publications of the Astronomical Soc. of the Pacific*. Vol. 70, No. 412, pp. 43-50, Feb 1958.
43. Strughold, H. Interrelations of space medicine with other fields of science. *Aeronautical Engineering Review*, Vol. 17, No. 4, Apr 1958.
44. Strughold, H. Introduction. *Vistas in astronautics*, p. 281, New York: Pergamon Press, 1958.
45. Strughold, H. Definitions and subdivisions of space: Bioastronautical aspect. *Proc. First Colloquium on the Law of Outer Space*, The Hague, 1958, Springer-Verlag, Wien, 1959.
46. Strughold, H. Space medicine. The new physician, pp. 9 and 10, Apr 1958.
47. Kooistra, J. A., Jr., R. B. Mitchell, and H. Strughold. The behavior of microorganisms under simulated Martian environmental conditions. *Publications of the Astronomical Soc. of the Pacific*, Vol. 70, No. 412, Feb 1958.
48. Strughold, H. From aviation medicine to space medicine. *Air Univ. Quarterly Review*, Summer 1958, Vol. X, No. 2, pp. 7-16; and in K. F. Gantz (ed.). *Man in space*, ch. 2. New York: Duell, Sloan and Pearce, 1959.
49. Strughold, H. Basic factors in manned space operations. *Air Univ. Quarterly Review*, Summer 1958, Vol. X, No. 2, pp. 29-46; and in K. F. Gantz (ed.), *Man in space*, ch. 3. New York: Duell, Sloan and Pearce, 1959.
50. Strughold, H. Space medicine of the next decade as viewed by a physician and physiologist. *U.S. Armed Forces Med J* X(4):397-405 (1959) and the *USAF Medical Service Digest* X(3):16-20 (1959).

BIBLIOGRAPHY

51. Strughold, H. Exotic atmospheres on earth. J Aviat Med 30:311-314 (1959).
52. Strughold, H., and O. O. Benson, Jr. Medical progress, space medical research. N Engl J Med 261:494-502 (1959).
53. Strughold, H., and O. L. Ritter. The gravitational environment in space, ch. 8, pp. 134-143. In O. O. Benson, Jr., and H. Strughold (eds.). Physics and medicine of the atmosphere and space. New York: John Wiley & Sons, Inc., 1960.
54. Strughold, H. The challenge of medicine in the space age. Today's Health, Mar 1960.
55. Strughold, H. The human eye in space (physiologic aspect). Astronautica Acta, Vol. 5, 1960, Springer-Verlag, L. R. Maxwell & Co., Ltd., London, Paris, New York.
56. Strughold, H. Interplanetary spaceflight from the viewpoint of the physician, ch. 42, pp. 622-634. In O. O. Benson, Jr., and H. Strughold (eds.). Physics and medicine of the atmosphere and space. New York: John Wiley & Sons, Inc., 1960.
57. Strughold, H. The photic environment in space and on the neighboring celestial bodies. 2d Int. Symposium on Submarine and Space Medicine, Karolinska Institutet, Stockholm, Sweden, 18-19 Aug 1960.
58. Strughold, H. Celestial bodies. II. Planetary ecology (astrobiology). In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1960.
59. Strughold, H. Summation. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1960.
60. Strughold, H., and O. L. Ritter. Solar irradiance from Mercury to Pluto. Aerospace Med 31(12):127-130 (1960) and USAF School of Aviation Medicine Rpt. 60-39, 1960.
61. Strughold, H., and O. L. Ritter. Eye hazards and protection in space. Aerospace Med 31:670-673 (1960).
62. Strughold, H. An introduction to astrobiology. Astronautics 5:20-21 (1960).
63. Strughold, H. Space medicine and astrobiology. Proc. XIth Internat. Astronautical Congress, pp. 671-687, Stockholm, 1960.
64. Strughold, H., and O. L. Ritter. Orbital characteristics of Earth and Moon satellites as a basis for space medical studies. Aerospace Med 32:422-424 (1961).

COMPENDIUM OF AEROSPACE MEDICINE

65. Strughold, H. Space medicine, ch. 31. In H. G. Armstrong (ed.). Aerospace medicine. Baltimore: The Williams & Wilkins Co., 1961.
66. Strughold, H. Planetary atmospheres, ch. 32. In H. G. Armstrong (ed.). Aerospace medicine. Baltimore: The Williams & Wilkins Co., 1961.
67. Strughold, H. Biophysics of the environment. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1961.
68. Strughold, H. Sensory-physiological aspects of the space flight situation. In B. E. Flaherty (ed.). Psychophysiological aspects of space flight. New York: Columbia University Press, 1961.
69. Strughold, H. Space energies: Summation. In P. A. Campbell (ed.). Medical and biological aspects of the energies of space. New York: Columbia University Press, 1961.
70. Strughold, H., and O. L. Ritter. Planetary gravispheres. *Astronautics* 7(1):26-27, 38 (1962).
71. Strughold, H., and O. L. Ritter. Oxygen production during the evolution of the Earth's atmosphere. *Aerospace Med* 33:275-278 (1962).
72. Strughold, H. How bioastronautics looks at the Moon. *J Mississippi State Med Assn*, III(9):397-403 (1962).
73. Strughold, H. The principle of the "Internal Atmosphere;" Geobiological and astrobiological aspects. *Aerospace Med* 33:851-854 (1962).
74. Strughold, H. Day-night cycling in atmospheric flight, space flight and on other celestial bodies. *Ann NY Acad Sci* 98(4):1100-1115 (1962).
75. Strughold, H. The ecological profile of the Moon. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1962.
76. Strughold, H. The conditions facing life on Mars. *Space Science*, Vol. XI, No. 7, 1962.
77. Strughold, H. The role of medicine in the space age. *USAF JAG Bulletin*, Nov-Dec 1962.
78. Strughold, H. The ecological profile of Mars: Bioastronautical aspect. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1963.
79. Strughold, H. The physiological clock in aeronautics and astronautics. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1963.

BIBLIOGRAPHY

80. Strughold, H. The mission of space medicine. In Grolier's Encyclopedia (Year Book 1963).
81. Strughold, H. Manned spaceflight. The Americana Annual (1963).
82. Ritter, O. L., and H. Strughold. Seeing planets from space. Astronautics and Aerospace Engineering, July 1963.
83. Strughold, H. Epilogue to Dr. Ox's experiment by Jules Verne. New York: The Macmillan Co., 1963.
84. Strughold, H. The ecological profile of Mars: Bioastronautical aspect. In G. W. Morgenthauer (ed.). Exploration of Mars, Vol. 15, Advances in the Astronautical Sciences. North Hollywood, California: Western Periodicals Co., 1963.
85. Strughold, H. Space medicine beyond the Moon. Texas State J of Med 59(12):1162-1172 (1963).
86. Strughold, H. Air and space travel. In The torch, Vol. XXXVII, Jan 1964.
87. Strughold, H. Manned space flight. The Americana Annual (1964).
88. Strughold, H. Discussion of paper by Mary Ellen Avery, M.D., "Adaptations at birth: Some analogies to space travel." J Am Med Wom Assoc 19(2):124-125 (1964).
89. Strughold, H. The solved and unsolved medical problems of manned space flight. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, 1964.
90. Strughold, H. Ist Mars mit Eis bedeckt? Int Sci Tech 11-12 (1964).
91. Bedwell, T. C., Jr., and H. Strughold (eds.). Bioastronautics and the Exploration of Space. Aerospace Medical Division (AFSC), Brooks AFB, Texas. Nov 1964.
92. Strughold, H. From outer space--Advances for medicine, ch. 12. In Lillian Levy (ed.). Space: Its impact on man and society. New York: W. W. Norton & Co., Inc, 1964.
93. Strughold, H. A subsurface marine biosphere on Mars? Astronautics & Aeronautics 3(7):82-86 (1965).
94. Strughold, H. Foreword. In A. M. Nowitzky (author). Spacecraft sterilization techniques and equipment. Boulder, Colo.: Johnson Publishing Co., 1965.

COMPENDIUM OF AEROSPACE MEDICINE

95. Strughold, H. Foreword. In P. A. Campbell (author). Earthman, spaceman, universal man? New York: Pageant Press, Inc., 1965.
96. Strughold, H. A new look at Mars - Medico-biological aspects. TRW Space Log, pp. 2-13. Winter 1965-66.
97. Strughold, H. The physiological clock in aeronautics and astronautics. Ann NY Acad Sci 134:413-422 (1965).
98. Strughold, H. Cycle Physiologique Jour-et-Nuit. Article for Encyclopedie de L'Espace. France, 1966.
99. Strughold, H. A new look at Mars. Spaceflight 8(9):302-306 (1966).
100. Strughold, H., and O. L. Ritter. Characteristics of parking orbits in circummartian space. Aerospace Med 38(2):127-128 (1967).
101. Strughold, H. Solved and unsolved space medical problems. In Lectures in Aerospace Medicine, USAF School of Aerospace Medicine, Brooks AFB, Texas, Feb 1967.
102. Strughold, H. Biological "fuel cells" - from the electric fish to man. In Proc. 13th Annual Meeting of the American Astronautical Society, Dallas, Texas, 1-3 May 1967. (Microfilm).
103. Strughold, H. Lunar medicine, pp. 113-121. Proc. 2d Lunar Internat. Laboratory Symposium (LIL), Life sciences research and lunar medicine, Madrid, 1966.
104. Strughold, H. Synopsis of Martian life theories. Adv Space Sci Tech 9:105-122 (1967).
105. Strughold, H. The clock inside your body, in the perspective of modern technology. The Natl Assoc of Doctors in the United States Journal, Vol. 4, No. 1, Apr 1968.
106. Strughold, H. Circadian rhythms: Aerospace medical aspects, ch. 4, pp. 47-55. In Hugh W. Randel (ed.). Aerospace medicine. Baltimore: The Williams & Wilkins Co., 1971.
107. Strughold, H. The physiological clock across time zones and beyond. Air Univ Review XIX (5):28-33 (1968).
108. Strughold, H. Bioelectro energetics: Fuel cell aspect. AGARD Bionics Symposium, Brussels, Belgium, 18-20 Sept 1968.
109. Strughold, H. Mars: Biological aspect. New horizons. 1968.

BIBLIOGRAPHY

110. Strughold, H. Unorthodoxies and controversies in planetary and space science. Presented at banquet of the Working Group on Extraterrestrial Resources, San Antonio, Texas, 19 Feb 1968. (Published in a NASA Report.)
111. Strughold, H. Planetary environmental medicine (Mars). Proc. 4th Internat. Symposium on Bioastronautics and the Exploration of Space, San Antonio, Texas, 24-27 June 1968.

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