Lectures in AEROSPACE MEDICINE

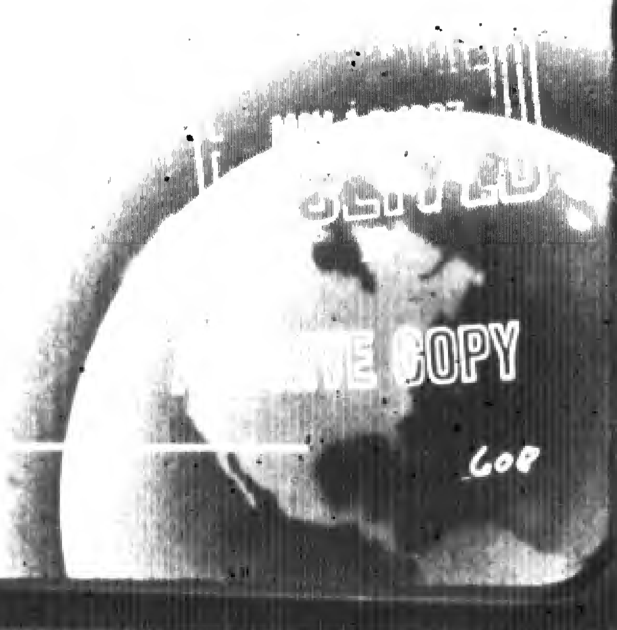
11-15 JANUARY 1960

Conducted at the

SCHOOL OF AVIATION MEDICINE

USAF AEROSPACE MEDICAL CENTER (ATC)

BROOKS AIR FORCE BASE, TEXAS



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C O N T E N T S

* Those articles marked with an asterisk (*) will be published at a later date.

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LECTURES IN AEROSPACE MEDICINE

INTRODUCTION

Presented By

Major General Otis O. Benson, Jr., USAF, MC

Commander

USAF Aerospace Medical Center (ATC)

INTRODUCTION

by

Major General Otis O. Benson, Jr., USAF, MC
Commander
USAF Aerospace Medical Center (ATC)

I feel very honored to welcome you to this series of "Aerospace Medical Lectures" at the Aerospace Medical Center. If we compare the titles of the various lectures with the topics in the courses and lectures in Aviation Medicine given some 10 years ago, we immediately recognize that there is a revolution in our medical thinking brought about by the Space Age.

In these new developments the propulsion systems to be used in human flight are replacing aerodynamics by ballistics and celestial mechanics:

1. Altitudes are being expressed by distances from the earth in miles and kilometers, not feet and meters.

2. The velocities approach those of meteorites.

3. The vehicles behave in their motion-dynamics like celestial bodies.

4. The nearest celestial bodies will unquestionably be within the reach of manned space craft.

These considerations are some of the features in the complex development of the Space Age, novel in human history, and exotic, indeed. A unique challenge to medicine as an active participant in the space program has been extended.

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Space medicine research and teaching cannot be completely separated from aeromedical research and teaching. Space medicine is quite logically an extension of aviation medicine. This is evidenced by the fact that there is a transitional stage between atmospheric flight and space flight in the form of space-equivalent flight. Our knowledge of thermal, mechanical and other stresses gained during the past 30 years in heat chambers, on centrifuges, etc., is applicable to rocket flight. Experience acquired in low pressure chamber experiments can be utilized in the creation of an artificial atmosphere in a space cabin. Submarine medicine has many contributions to make. We better understand space optics by contrasting it with atmospheric optics. An analysis of the atmospheres of other planets requires comparisons with the Earth's atmosphere. Therefore, despite the fact that certain problems encountered in space flight, namely, ionizing radiation and weightlessness, are novel, we have chosen to call this lecture series "Aerospace Medical Lectures," to cover all the aspects involved.

We dare to offer this series of Aerospace Medical Lectures because we feel that we have a modicum of both tradition and experience in these fields. The "Aero" component can be traced back to the early twenties when our predecessors at Mineola L. I. (Wilmer, Bauer, Schneider and others) started with aeromedical research. We have continued in aeromedical research here at

Brooks Air Force Base, at Randolph Field and again at Brooks and to date have graduated more than 9000 physicians in Aviation Medicine. The "Space" component in our medical activities dates back to 1949 when a special Department of Space Medicine was added to the other departments of the School. In this department basic concepts and equipment were elaborated to meet the challenge of the Space Age. Even earlier, radiobiological studies of nuclear reactions were carried out, which have given us valuable basic information to enhance our knowledge of the biological effects of space radiations.

The School, while at Randolph Air Force Base, can proudly look back upon two successful international symposia--the first in 1951 and the second in 1958--in which the medical problems involved in atmospheric flight and space flight were the topics. Logically, when the School moved back to its original site at Brooks, it adopted the name, "Aerospace Medical Center," and we feel honored to offer this lecture series on both the "Aero" and "Space" medical components in human flight. We are especially happy that a number of nationally known experts in related fields, such as physics, astrophysics, astronomy, and space technology have accepted our invitation to join the ranks of the speakers of our own staff.

I welcome all of you. First, those who came from countries abroad; then those from industry and universities and medical schools, and my colleagues from the services.

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I would feel especially happy if the material offered in these lectures would inspire you, with your knowledge and experience, to participate, experimentally, and with new ideas, in the aerospace medical research program, which is a wide-open field and has no limits. There is no question that the close cooperation of all of us, on an international basis, is mandatory to meet one of the greater challenges in human history.

I will give you a gross introduction, one to another, by telling you who comprises this distinguished audience:

Distinguished representatives from Allied Nations	23
Representatives from the MEND Program	129
Officers of the Air Force	50
Officers of the Army	13
Officers of the Navy	6
AF Reserve Officers	30
Officers of the Air National Guard	10
Representatives of the National Aeronautics and Space Agency	9
Representatives of the Aerospace Medical Association	26
Graduate Resident Students	10
Program Participants	28
Representatives from Universities, Research Foundations, and other individuals	86
Total	369

Again, my welcome to all of you and my profound thanks to the 28 lecturers, many who have come great distances.

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LECTURES IN AEROSPACE MEDICINE

BIOPHYSICS OF THE SPACE ENVIRONMENT

Presented By

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

Professor of Space Medicine - Advisor for Research

USAF Aerospace Medical Center (ATC)

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BIOPHYSICS OF THE SPACE ENVIRONMENT*

by

Hubertus Strughold, MD, PhD**

Ladies and Gentlemen: The fast development in rocketry during the past 20 years and, especially, the fantastic achievements in the penetration of space with unmanned research vehicles, such as artificial satellites, circumlunar, and interplanetary space probes, since 1957, indicate that the realization of manned space flight is in sight. This prospect has brought the realm of space, more than ever before, into the focus of scientific and public interest. Until now, for thousands of years, as long as astronomy has existed, the attention has been concentrated, essentially, upon the celestial bodies found therein. But now, with the beginning of astronautics, the so-called "empty" space itself; i.e., the space between the Earth and Moon and the neighboring planets through which the astronaut will have to travel for days, weeks, or maybe months before he reaches the target celestial body, demands our

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* Lecture presented at "Lectures in Aerospace Medicine," School of Aviation Medicine, USAF Aerospace Medical Center, Brooks Air Force Base, Texas, 11-15 January 1960.

** Professor of Space Medicine and Advisor for Research, Aerospace Medical Center, Brooks Air Force Base, Texas

attention--not only from an astrophysical point of view, but also with regard to the biomedical implications of a journey through this environment. Such an environmental study is called biophysics or ecology of space. In a broader sense we must include some dynamic gravitational aspects which have a certain biomedical significance. And this is the topic of this lecture--biophysics, or the ecology of space within our solar system, with which I have the honor to begin this series of aerospace medical lectures.

The Basic Structure of the Environment of Space Within the Solar System. Space is usually referred to as "empty space" or a vacuum. It is indeed a vacuum in the sense of the physical vacuum definition, but space is not empty. It contains pieces and particles of matter and is permeated by an enormous flux of quanta of energy. Some of them can be utilized for manned space flight--most of them, however, pose hazards and require means of protection for the occupants of space vehicles.

The basic contents of matter and energy in space are:

a. Meteorites of all sizes from large lumps of matter to micrometeorites.

b. Dust particles, neutral and electrically charged.

c. Molecules and atoms, mostly hydrogen, neutral and charged.

d. Atomic particles, such as electrons and atomic nuclei of various kinetic energy, the so-called particle rays or corpuscular rays including cosmic rays coming from the sun and the galaxies.

e. Electromagnetic radiation with the sun as the main source.

f. Magnetic field forces, and

g. Gravitational field forces.

Between most of them are interrelated influences.

The low gas density gives the environment of space the characteristics of a very hard vacuum with a pressure in the order of 10^{-14} mm. Hg. For comparison, the best vacuum obtainable in the laboratory is in the order of 10^{-10} mm. Hg.

In such a vacuum environment (Rayleigh) scattering of light is minimal with the result that the sky is dark despite a bright shining sun and, of course, this is no medium for sound propagation.

In contrast to our atmosphere, which is essentially a dense gaseous medium with mild radiations and free of meteorites, space is essentially a radiation environment in a very thinly dispersed gaseous medium, and spiced with sharp meteoric pepper.

The biomedical conclusions from this situation are that we must provide the astronaut with all the benefits and protection which we enjoy on the earth's surface under the shielding mantle of a breathable atmosphere; namely, an artificial atmosphere in a sealed cabin with a hull structure with protective capabilities concerning radiation and meteoric hazards, and of the same effectiveness, if possible, as that of our atmospheric envelope.

Such in brief is the basic picture of the environment of the solar space and of the biomedical implications for manned space flight.

Spatiography

But space is not uniform and static in its structure throughout our solar system. It shows great variations, regional and temporal, and both of these combined. The regional variations, are a function of the distance from the sun, the result of the vicinity of celestial bodies, and of their magnetic and gravitational fields, and a relic of the historical development of the solar system from a flat nebular disc. The temporal variations are caused, essentially, by fluctuations in the activity of the sun. Both of these environmental variations in space are of special biophysical importance because they are indicative of specific danger zones and of time periods of increased hazards for manned space operations, and set even definite limitations to astronautics in both respects.

This situation requires a topographical approach to the space environment after the fashion of geography, and can properly be called spatiography. The description of the planets is called planetography, of which geography (Earth), areography (Mars), and selenography are special cases. Spatiography and planetography, including the description of the sun, or heliography, are the two subdivisions of an all-embracing cosmography of the solar system. This lecture will be confined to a topographical description of the space between the celestial bodies, based on biophysics, or ecology.

A biophysical or ecological space map must include a delineation of the border between atmosphere and space. We shall, therefore, first briefly answer this question, "Where above the earth's surface does space begin?" before we discuss the regional and temporal variations of the space in our solar system.

The border between atmospheric space. According to general astrophysical assumption, the atmosphere as a material continuum extends to about 1000 km, or 600 mi. 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 manned space flight. In this respect the cessation of the atmosphere's life-supporting, life-protecting and aerodynamic functions and effects determine the border between atmosphere and space.

Without going into detail, about a dozen such functional borders between atmosphere and space, can be differentiated:

1. As low as 15 km (about 10 mi) the influx of atmospheric oxygen into the lungs comes to an end because the alveoli are filled with water vapor and carbon dioxide, issuing from the body

itself, to the full barometric pressure of 87 mm Hg. found at that altitude.

2. At nearly 20 km (12 mi) the total air pressure of 47 mm Hg. is no longer effective to keep the body fluids in the liquid state, and prevent them from boiling. (H. G. Armstrong, 1936).

3. 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.

4. At 40 km (24 mi) we are beyond the region of atmospheric absorption of cosmic rays and encounter them in their original primary form.

5. The same is true at 45 km (28 mi) with regard to the sunburn-producing ultraviolet of solar radiation, which is absorbed within the altitude range of the ozonosphere (20 to 45 km).

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

7. At about 100 km (60 mi) the rarified air ceases to scatter light, leading to the so-called "darkness of space."

8. At about the same altitude propagation of sound terminates, resulting in the "silence of space."

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

10. This is practically also the limit for aerodynamic friction heat, even for the fastest vehicle. From here on the temperature of the cabin's hull is determined exclusively by solar radiation.

11. And, finally, at about 200 km (120 mi) air resistance approaches zero. This "mechanical border" of the atmosphere (H. Haber) is its final functional limit. At this altitude the "appreciable" or effective atmosphere terminates. If atmospheric interference of this kind is absent the vehicle and its crew are weightless, provided that no further propulsion is applied.

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

We can also explain the environmental situation in this entire region by saying that with the termination of its functions the atmosphere becomes partially space equivalent at 15 km and progresses step by step to total space equivalence at 200 km.

Three of these steps on the ladder to space, in the 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 laws of celestial mechanics, unhindered by air resistance, are fully effective. It is here where true space begins. The 200 km level is the astronautical border of the atmosphere, whereas the level around 1000 km, or 600 miles, can be regarded as the astrophysical border. This concept of the functional borders between atmosphere and space, and of atmospheric space

equivalence, answers our question where space begins for manned flight. It also demonstrates that all the altitude record flights in balloons and airplanes during the past 20 years were actually flights of a highly space-equivalent type.

We now can proceed to a description of the environment of actual space. We have already touched briefly upon its basic properties and structure, and shall now concentrate upon its regional and temporal variations, the main topic of this lecture.

Beginning with material contents of larger dimensions, the meteorites vary in size from large lumps of matter to micrometeorites as small as white blood cells. Their over-all frequency distribution increases with decreasing size. Meteorites crisscross space with an average velocity of 40 km per second (25 mi/sec) at the orbital distance of the earth, whereas micrometeorites have lower velocities down to about 12 km per second (7 mi/sec). But there are noteworthy regional differences in the distribution of meteoric material and its velocity. Near the earth a space vehicle is shielded by the planet's solid body over a large solid angle. On the other hand, the earth's gravitation increases the velocity of the attracted meteorites at short distances from the earth.

Secondly, the meteoric material is essentially found in the plane of the ecliptic and therein it is specifically concentrated in the form of streams along the orbits of disintegrated comets, of which most meteorites are remnants. Their frequency may also be greater within the belt of the asteroids, a second source of meteorites.

Now, the space medical implications of meteorites are obvious. The effects of a collision with meteoric material are twofold: puncture and surface erosion. The probability of a hit by a meteorite with puncture capability has been estimated from 1 in two months to 1 in a year. Be that as it may, the occupants of a space vehicle will have to know the consequences; namely, slow or rapid decompression of the cabin's air with all the dangerous physiological effects, such as anoxia, aeroembolism, boiling of the body fluids, or ebullism. In such an emergency the "time of useful consciousness" of the crew may offer a chance to seal the leak. Also, suggestions have been made for protection in the form of self-sealing devices, and of a secondary hull (a so-called meteor bumper) surrounding the cabin to break down and disperse the colliding meteoric body into fine dust (F. Whipple).

Erosive effects of fine meteoric material on surfaces exposed to space may affect the transparency of optical surfaces, the characteristics of heat-absorbing and reflecting surfaces, and radio antennas. From data obtained in artificial satellites we have obtained some information about the impact rate of micrometeorites. For instance, 3×10^{-10} impacts per m^2/sec have been reported near the earth. In another instance 17 impacts on a sphere with a 50 cm diameter were recorded during 10 minutes time.

Material particles smaller than 0.5 micra are generally referred to as interplanetary dust. It might be "pulverized meteoric material" or of cometary origin. The movement of such timy submicronic particles is, in addition to gravitation, affected by solar radiation and, if charged, by magnetic field forces. By and large, they are concentrated like the meteorites in the plane of the ecliptic with about 1 particle in 10 cubic meters.

The distribution of interplanetary dust and micrometeorites in the ecliptic plane is dense enough to produce the so-called zodiacal light, a faint luminance within the zodiac, visible after sunset and before sunrise on a clear, moonless night. It is produced by solar light scattered by these tiny particles, which probably gives the dark sky in space a slight touch of luminance. Zodiacal light might be observed as far as the region of Jupiter.

Space also contains gas particles found in numbers of about 10 in 1 cm^3, and consisting mostly of hydrogen. In the region of the inner portion of the solar space most of them are ionized by solar ultraviolet radiation; consequently, space contains electrons. In addition, the sun continuously injects large amounts of electrons into space. The total number near the earth's orbit is about 10 to 100 electrons in 1 cm^3. Electrically charged gaseous material is called plasma. Thus, the environment of space is a very thin plasmatic medium.

An extremely important material component in space is atomic nuclei completely stripped of their electrons and moving with very high kinetic energy, some approaching the speed of light. In interplanetary space, generally, an omnidirectional flux of these corpuscular, or cosmic particle rays, is prevalent. But, again, there are regional and temporal variations.

We encounter the primary cosmic ray particles as low as 40 km (24 mi), but below this altitude they come into collision with the atmospheric molecules and are transformed into secondary and tertiary rays to which we are normally exposed. Furthermore, in the vicinity of the earth a space vehicle is protected from the primary cosmic rays from below by the shielding solid body of the earth, just as it is with meteorites.

The most remarkable regional variation of these particle rays is related to the geomagnetic field. They are channeled into the polar atmospheric regions along the magnetic force lines causing the polar lights. Over the equatorial regions they are trapped, forming a huge radiation belt consisting of two zones, discovered by means of the Explorer Satellites in 1958 by J. van Allen. The inner zone extends from about 800 km (500 mi) to 6000 km (4000 mi). It contains, in essence, trapped protons, which are produced by beta decay of cosmic ray neutrons scattered outward from the fringe regions of the atmosphere. The outer zone consists, primarily, of electrons. They come directly from the sun and are somehow deflected and then trapped by the magnetic field lines. This zone extends from 12, 000 km (8000 mi) to about 90, 000 km (60, 000 mi).

The existence of this great radiation belt poses a serious problem to manned space flight with regard to shielding and navigation, and will occupy astrophysics, space technology, and space medicine in the coming years. The same is true concerning the possible occurrence of similar radiation belts surrounding other celestial bodies, such as Venus and Mars. These localized concentrations of corpuscular radiation seem to be more important from the standpoint of radiation hazards than the more or less evenly distributed omnidirectional cosmic rays, including their heavy components. About the physical and biologic aspects of this whole complex of particle radiation see the lectures of Professor Fred Singer, who predicted the trapped particle rays, and Lt. Colonel David Simons.

The next important environmental factor in space is solar electromagnetic radiation, which includes the range from x-rays of about 10 Ångstrom, ultraviolet rays, visible rays, and infrared rays, to radio waves of more than 10 meters wave length. Since radiation varies with the inverse square of the distance from the radiating source, the variations within the solar space are enormous and differ tremendously from the values found at the earth's mean orbital distance, which we shall use again as a base line.

With regard to manned space flight, in the first place, we think about heat radiation and the temperature control of the space cabin. The temperature and heat problem in space is often misunderstood. Molecules in space may have a very high kinetic energy--in other words, a very high temperature. However, transfer of heat by conduction from these few particles upon a space vehicle is practically zero. Heat transfer by convection in space also does not occur except in cases when hot material is blown from the sun in the form of jet streams as far as into the region of the earth. Basically, heat transfer in space is achieved only by radiation.

The intensity of heat radiation (essentially infrared and visible rays) is measured by the amount of heat irradiated upon a unit of area per unit of time, and is conventionally expressed in calories per square centimeter and minute. At the top of the earth's atmosphere the value of the heat flux from the sun is roughly 2 $cal\ cm^{-2} min^{-1}$ This is called the solar constant. On the earth's surface at noon, under favorable weather conditions, thermal irradiance is never higher than two-thirds of this value, because of reflection of radiation back into space, and heat absorption by atmospheric water vapor and carbon dioxide. Using the terrestrial solar constant as a base line, thermal irradiance at the orbital distance of Venus nearly doubles, and at the mean orbital distance of Mercury it is more than six times as high. At the distance of Mars it decreases to less than one-half; at Jupiter's distance to one-twenty-seventh, and in the remote region of Pluto it drops to one-sixteen-hundredth of the terrestrial value. (Table I.)

We then immediately recognize that there is a zone in our solar system in which heat radiation is not too different from that at the earth's distance and, therefore, not so hostile to space operations. On both sides of this zone, however, it turns to extremes. We can, therefore, differentiate between an euthermal zone (from Mars to Venus) surrounded by a hyperthermal and hypothermal region.

The space medical conclusions from these extreme variations in solar thermal irradiance are obvious. It makes a great difference in cabin temperature control whether a space operation is planned into the furnace-like heat radiation condition beyond Venus, or into the sparsely irradiated environment beyond Mars or Jupiter. The temperatures measured within the shell of the Explorer and Vanguard Satellites were well within the physiologically tolerable range, around 25°C. But a space ship penetrating the intra-mercurian space would inevitably run into a kind of solar heat barrier, as symbolized by the legendary flight of Icarus.

We find a similar zonal pattern in solar light irradiation, or solar illuminance (Table I). At the top of the atmosphere solar illuminance amounts, roughly, to 140,000 lux; i.e., lumens per square meter. For comparison, on the earth's surface the value is never higher than a little over 100,000 lux. An illuminance equalling the maximal terrestrial surface value is found in space at a distance of some 20 million miles farther from the sun; that is, almost halfway to Mars. At the mean orbital distance of Mars illuminance drops to 60,000 lux; at that of Jupiter to 5,000 lux; and in the remote region of Pluto, below 100 lux. In the direction toward the sun, at the orbital distance of Venus, solar illuminance increases to 267,000 lux, and at the solar distance of Mercury, to nearly 1 million lux. Again, we might speak of a euphotic belt on both sides of the earth's orbit, surrounded by a hyperphotic and hypophotic zone.

This zonal pattern, in the photic environment of space, has significance in two respects; namely, with regard to vision and to the utilization of light in photosynthetic recycling of metabolic material in the closed ecological system of the space cabin.

Beginning with the latter, solar illuminance drops with increasing distance from the sun below the minimum required for photosynthesis, and this limit may be reached somewhere beyond Saturn. Beyond this distance a space ship would have to provide its own light energy. For this purpose a nuclear power plant would have to replace the sun.

As for vision, let us consider first the situation at our base line, the earth's mean solar distance. Solar illuminance amounts to 140,000 lux, about 40% higher than ever found on the earth's surface. But the sky in space is dark--much darker than on clear moonless nights on earth, where the so-called airglow gives the regions between the stars a light, bluish luminance. This combination of a bright sun in a black sky leads to a strange optical situation found on earth only under artificial conditions, such as searchlight effects and theatrical stage lighting. Everything that is exposed to sunlight appears extremely bright--everything in the shadow is black.

Light and shadow dominate the scenery. This photoscopic condition poses interesting problems in the field of contrast vision and retinal adaptation, and requires special attention in the design of the space cabin windows.

Looking into the sun with the naked eye may lead to retinal damage, such as retinitis solaris and retinal burns, resulting in a blind spot in the visual field (helioscotoma). Retinal lesions of this kind occur on earth frequently when a solar eclipse is observed without sufficiently smoked glasses (scotoma helioclipticum). Such retinal lesions are actually heat effects by visible rays and the neighboring near infrared rays focused by the lens of the eye upon a small area in the fovea centralis retinae and producing a thermal necrosis with a subsequent scar.

Now, outside of the earth's atmosphere and on the airless moon, the danger is much greater. Caution in this respect is indicated and eye protection by means of automatically reacting, light-absorbing glasses is a necessity. Also, a retractable light-scattering visor attached to the helmet, serving as a kind of blue sky simulator, may be useful to an astronaut on the moon. Where in space the retina burning power of the sun--which is actually a nuclear fireball of the fusion type in permanence--becomes negligible, is difficult to extrapolate from experimental data obtained on rabbits concerning similar retinal lesions caused by atomic flashes. It may be somewhere beyond Jupiter or Saturn.

Finally, a few remarks about ultraviolet rays and x-rays in space! Very little was known about the latter before space probes were available. Ultraviolet rays are probably no unsolvable problem for an astronaut at the orbital distance of the earth and farther away from the sun, because he is sufficiently protected from these rays by his vehicle and pressure suit. But I would like to mention that these rays also show regional variations. This can be deduced from their effect upon the chemistry of the planetary atmospheres insofar as they are held responsible for the transformation of the primordial reducing protoatmospheres into oxidizing atmospheres within the range of the inner planets. But even Jupiter's atmosphere shows some photochemical changes as manifested in colorations.

So much for the regional variations of the thermal, photic, and ionizing electromagnetic radiation as a function of the distance from the sun.

We get a dramatic impression of the spatial effectiveness of the sun by comparing its size as seen from the distances of the various planets. To an observer on Mercury the diameter of the solar disk would appear more than twice as large as it does to us on earth. As seen from Mars the sun has a considerably smaller apparent dimension than our moon. At the distance of Jupiter, the sun's diameter is only one-fifth as large as seen from the earth. And, at the distance of Pluto the sun would appear not larger than the Evening Star, Venus, appears to us on earth, which means that in the remote regions of our planetary system the role of our sun--as a dominating source of light and heat energy--approaches that of a common star. It takes sunlight three hours to reach Pluto, as compared with eight minutes to reach us. And, yet, solar illuminance here is still above the threshold for reading and also for color vision. But below 10 lux, which is found at about three times Pluto's distance from the sun, color discrimination becomes difficult, and from here on the colorless, dimly-lighted world of interstellar space with its pitchblack, star-studded sky begins.

The most spectacular examples to demonstrate to us the radiation effectiveness of the sun are the comets which, hibernating as icy mountains of dirt, frozen water, ammonia, and methane, (Fr. Whipple), in the remote regions of Jupiter and Pluto, come to life by displaying gigantic tails caused by solar radiation as soon as they approach closer than three astronomical units to the sun.

They demonstrate, indeed, the great diversities in the biophysical-ecological conditions an astronaut would encounter throughout the solar system, and illustrate in an impressive manner the justification, or even necessity, of a topographical study of the space environment.

Temporal variations. Now all of these regional differences in the radiation climate in our solar system are not in a steady state. Rather, they show temporal variations because of variations in the activity of the sun. The latter are frequent and occur in the form of flares and eruptions. These phenomena on the sun's surface, associated with sun spots, are characterized by intensified electromagnetic radiations, ultraviolet for instance, and by ejections of huge amounts of ray particles, such as protons and electrons. These streams of solar plasma make themselves noticeable about 20 hours later in gigantic polar lights within our atmosphere. As a result of such solar events, the radiation intensity in the upper atmospheric polar regions of the earth and in the outer radiation belt may reach, temporarily, values considerably higher than during the time of a normal, quiet sun.

As is generally known, the sun-spot cycle is of an eleven-year duration. The consideration of this time pattern may be important for scheduling manned space operations.

The gravitational situation in space. The picture of the biophysics of space would not be complete if we would not include some aspects of the gravitational situation in space, because this determines to a great extent the routes of space vehicles, and duration of their exposure to the various ecological space conditions. The gravitational situation in space has been somewhat neglected in the astronautical literature. This is the reason that there is always some confusion centered around the question, "Where does a rocket leave the gravitational field of the earth?" The forces of the geogravitational field decrease, like radiation, according to the inverse square to the distance law, but theoretically they extend to infinity. With the aid of the gravitational field concept the astronomer explains the mutual gravitational attraction of celestial bodies, perturbations of their motions, and tidal effects, like ebb and flood.

But the astronaut is additionally interested in the extension of the region within which the gravitational force of one specific celestial body is predominant. This sphere is called "sphere of gravitational influence" in the astronautical literature. We may preferably call it "sphere of predominant gravitational influence," or briefly, "gravisphere."

It seems to be advisable to differentiate between the inner gravisphere and the outer gravisphere. The inner gravisphere represents the region within which the gravitational attraction of a planet is able to hold a satellite in orbit. We can call it, therefore, the potential satellite sphere. The outer gravisphere includes that distance beyond the potential satellite sphere within which the gravitational force of a celestial body is still strong enough to cause considerable disturbances of the trajectory of a space vehicle. The inner gravisphere of the earth, or its potential satellite sphere, reaches up to 1.5 million km (1 million mi). Beyond this distance the gravitational field of the sun becomes predominant and a space vehicle becomes a satellite of the sun, or a planetoid moving from a geocentric orbit into a heliocentric orbit. Table II shows the radii of the satellite spheres of all the planets. They grow in size as a function of their mass and of the distance from the sun, because solar gravity becomes weaker with increasing distance.

The moon's gravisphere extends to 58, 000 km (36, 000 mi) from its center. When a rocket crosses this earth-moon gravitational divide it can, if properly guided in direction and controlled in velocity, become a captive or satellite of the moon.

To become an artificial satellite of the earth requires orbital velocity. This is the so-called first astronautical or cosmic velocity. The terrestrial orbital velocity near the earth's surface amounts to 8 km per second, or 18, 000 miles per hour. With increasing altitude the orbital velocity decreases and the period of revolution of the vehicle increases correspondingly. Because of the Van Allen Belt, the arena for manned satellite flight will be confined to low orbits not higher than 800 km, or 500 miles. Beyond this altitude the orbits, which we might call middle orbits up to the outer border of the great radiation belt, around 15 earth radii, are probably forbidden for prolonged manned satellite flight. In the high orbits beyond this altitude a satellite vehicle would be exposed solely to the general omnidirectional flux of cosmic rays. This shows us the close relationship between motion dynamics and ecology in space flight. Knowledge of the orbital flight characteristics also informs us how long a satellite vehicle travels through the shadow of the earth or is exposed to solar thermal and photic radiation. The shadow of the earth thins out in the form of a cone and ends at a distance of 1.4 million km, or 860,000 miles.

The same combined gravitational and ecological consideration applies to circumnavigation of the moon. The lunar circular orbital velocity near the surface is 1.6 km per second and one period of revolution takes 1 hour and 48 minutes. According to O. Ritter, a 10,000 km orbit requires 0.64 km per second and a duration of 32 hours. At 20,000 km, it takes more than three days to orbit around the moon. With reference to the moon there probably is not a radiation belt which would confine satellite flight to certain altitudes.

Now, to get to the moon requires only a little less than the terrestrial escape velocity. To escape from the earth's gravisphere requires 11.2 km per sec. (7 mi/sec). The escape velocity represents the second astronautical or cosmic velocity. To escape from the moon's gravity requires only 2.2 km per sec (1.5 mi/sec); from Mars, 5.0 km/sec (3.1 mi/sec).

So much for motion dynamics in space flight which seems to be, at first glance, somewhat too much on the astronomical and astronautical side for an aerospace medical lecture; however, knowledge of these data is necessary for the full ecological and medical stress evaluation of routes, regions, and duration of various space operations.

In summary, what we have tried to do in this discussion was to examine the physical contents of space, which are essentially meteoric materials, dust particles; energy quanta; and forces. We took special notice of the fact that they are unevenly distributed over large areas, and some of these regional differences can be used for the development of an ecological cartography of space, or spatiography.

What subdivisions are conceivable and practical from the point of view of space flight? We might differentiate between the following subdivisions, beginning with that region where the space factors first enter the environmental picture; i.e., within the atmosphere.

Atmospheric space-equivalence begins, physiologically, at 20 km (12 mi), as manifested in boiling of the body fluids.

True space begins at 200 km (120 mi), where the aerodynamically effective atmosphere terminates. From here on we can make the following subdivisions:

First, nearby space is that region within which the influence of the earth, due to its solid body, reflecting properties of its surface and cloud cover, and especially due to its magnetic field (trapping of particle rays) upon ecology of the environment, is distinctly recognizable. This is the case up to at least 15 earth radii, or 90,000 km (60,000 mi), (outer border of van Allen's radiation belt).

But the influence of the earth reaches much farther into space with regard to gravitation. The sphere of predominant gravitational influence or gravisphere represents a larger spatial unit which we might call terrestrial space or, more precisely, the terrestrial gravitational space. It extends to 1.5 million km (1 million mi). The terrestrial space is only one example of the category of planetary space. Others are the Martian, Venusian, Jovian (gravitational) space, et cetera. The gravisphere of the moon, which might be called lunar space, belongs in the same category. It extends to 58, 000 km (34, 000 mi).

From the terrestrial space or other planetary spaces a vehicle enters interplanetary space. This huge interplanetary space, with the planetary spaces combined, represents the whole gravitational territory of the sun, or solar space, which blends far beyond Pluto into interstellar space.

Ecologically, as we have seen, the solar space contains a belt within the realm of the inner planets which is not too hostile to space operations, and relatively favorable for life on the planets. This zone can be called the ecosphere in the solar system. We may assume for it an extension of some 100 million km, or 60 million miles, in both directions from the earth's orbit--that means from Venus to the region beyond Mars. This will be the operational theater for manned space flight in the first decades of the Space Age.

This subdivision of space, based on an ecological examination of possible routes through the various gravitational territories, gives us that picture of the space environment which, in terms of biophysics, is required for the development of a sound and successful space program. A biophysical spatiography of this kind refers, of course, only to the space between the celestial bodies. The ecological and gravitational conditions found on these actual astronautical targets will be discussed in another lecture of this Aerospace Medical Lecture Series.

TABLE I

SOLAR TOTAL IRRADIANCE AND ILLUMINANCE AT THE MEAN DISTANCE OF PLANETS

	Mean Solar Distance 10^6 km 10^6 mi	Mean Solar Distance in Astronomical Units (A.U.)	Total Solar Irradiance cal cm^{-2} min^{-1}	Solar Illuminance lux
Mercury	57.9 36.0	0.387	13.3	935,000
Venus	108.2 67.2	0.723	3.8	270,000
Earth	149.6 93.0	1.00	2.0	140,000
Mars	227.9 141.6	1.52	0.86	60,000
Jupiter	778.3 483.6	5.20	0.74	5,200
Saturn	1428. 887.	9.55	0.022	1,500
Uranus	2872. 1784.	19.2	0.0054	380
Neptune	4493 2792	30.1	0.0022	155
Pluto	5910 3670.	39.5	0.0013	90

TABLE II

GRAVISPHERES (POTENTIAL SATELLITE SPHERES) OF THE PLANETS AND THE MOON

Celestial Body	Radius (10^6 km)
Mercury	0.22
Venus	1.0
Earth	1.5
Mars	0.5
Jupiter	53
Saturn	65
Uranus	70
Neptune	116
Pluto	57
Moon	0.058 cislunar
	0.064 translunar

LECTURES IN AEROSPACE MEDICINE

CELESTIAL BODIES
I. THE SUN

Presented By

Dr. John W. Evans

Professor of Astronomy

Upper Air Research Observatory

Sacramento Peak Observatory

THE SUN

by
John W. Evans
Sacramento Peak Observatory

I have been invited to tell you something about my own field of intellectual adventure, the sun. I suspect that most of you already know a good deal about it, and my effort here will be to fill in some of the details that now appear likely to influence the space environment, and about which we will consequently learn a great deal more from instrumented space vehicles.

First of all let me refresh your memories on the broader general characteristics of the sun. It is a purely gaseous body, about 1.4 million km in diameter, with a mass 333,000 times that of the earth. Its energy output is about 4×10^{33} ergs/sec which is the result of the conversion of about 4 million tons of solar material per second into energy by a thermonuclear reaction. The sun rids itself of this energy primarily by electromagnetic radiation, which is distributed through the spectrum approximately according to Planck's law for a surface at a temprature near 5900°K.

The main body of the sun is opaque and has a rather sharply defined visible surface known as the photosphere, the source from which practically all the light and heat of the sun is radiated. Resting on the photosphere and visible to a height of about 10,000 km is the chromosphere, a complicated layer of transparent tenuous gas shot through with a fur of small luminous spikes known as spicules. Above the chromosphere is the transparent corona, a rather irregular faint appendage of extremely low density and high temperature, visible out to a distance of several solar diameters. Both the chromosphere and the corona emit a steady flux of radio waves, which have been observed over the frequency range from 30,000 to 15 mc/sec.

The photosphere, chromosphere and corona constitute the solar atmosphere, and are the only part of the sun accessible to observation. They all have the same chemical composition, which probably differs little from that of the solar interior. They are permanent features, always in a state of internal change but always present at all points on the solar surface.

Within the solar atmosphere a number of isolated temporary phenomena occur, much as clouds, thunderstorms, tornadoes, and the like, occur in the terrestrial atmosphere. Known collectively as "solar activity," they include the sunspots and faculae in the photosphere; the flares, plages, and spicules in the chromosphere; and the prominences and a variety of changing coronal structures in coronal space. Some of the chromosphere and coronal phenomena are associated with sudden bursts of radio emission, which often exceeds the steady background emission by factors of hundreds or thousands in the lower frequencies.

The material of the sun is a gas of neutral and ionized atoms, free electrons, and a barely detectable trace of a few of the hardiest molecules. The high temperature is sufficient to vaporize the most refractory substances, and shattering collisions reduce most molecules to their single atom constituents.

The sunspots and faculae are readily observed with a small telescope, by projecting the solar image through the eyepiece onto a shaded white card. Observations of the chromosphere and corona, however, require additional elaborate spectroscopic accessories.

In its gross energy output the sun is remarkably constant. After a study of many years, Abbot at the Smithsonian Institution concluded that there are variations of one or two percent. However, the observations are frightfully complicated by atmospheric noise in the form of variable absorption of many times this magnitude. The absorption is indistinguishable from variations in solar radiation except by methods which are valid only in a statistical sense. During the last few years the Lowell Observatory (under a contract with the Geophysics Research Directorate through the Sacramento Peak Observatory) has been looking for small variations in solar radiation in a narrow region of the spectrum by a method which reduces the uncertainties of atmospheric absorption to an exceedingly low level. They compare the brightness of the planet Uranus and Neptune with stars of known brightness. Thus the standards and the unknowns are subjected to the same atmospheric effects except for second order differentials due to differences in position between the planet and the standard star. While these small differences are quite significant they can be computed with far greater accuracy than total absorption. The Lowell observers feel confident of an accuracy of 0.3%. The results up to the present show an increase of about 2.5% in the blue radiation reflected from both Uranus and Neptune, apparently coincident with the sunspot maximum. We would unhesitatingly attribute this observation to an increase in the solar radiation were it not for the fact that Sterne at the Smithsonian Astrophysical Observatory found from a careful statistical study of the Smithsonian observations that no variations greater than 0.14% had occurred in the past 50 years. This suggests the possibility of a systematic solar influence on the reflecting powers of these two rather similar planets. The question remains unresolved, but it is clear that solar variations are small. Incidentally, in the course of their study, the Lowell observers found that all of their comparison stars were detectably variable.

Although variations in the gross energy output of the sun are small, other variations do occur, and they are unmistakably associated with the emission of the ultraviolet and corpuscular radiations which affect the earth. Chief among these is the development and decay of what we term active regions on the sun.

An active region embraces a small area of perhaps one thousandth of the solar surface, about 100,000 km in diameter, within which a wide variety of related activities occur. While these activities are individually exceedingly interesting, and have rightly received much research attention in the past, I suspect that the active regions as a whole are far more significant than the sums of their parts. I shall therefore try to discuss them from this viewpoint.

An active region is recognizable simply by the presence of the optical and radio phenomena which are a part of it. Some of these phenomena, which I shall term the static features, endure for most or all of the life of the active region, typically several solar r tations of 27 days. This class includes enormous magnetic fields of several thousand gauss, sunspots, plages, faculae, and coronal regions in which the spectral lines of Fe XIV and Fe X are greatly enhanced. These are features of every active region. In addition, several short lived transient phenomena of great violence may occur. These include the flares with accompanying coronal brightenings in the lines of Ca XV and various forms of rapidly evolving prominences, the most interesting of which are loops, surges and flare prominences. Although the distinction is not a sharp one, I divide active regions into two classes which I shall refer to as eruptive and equable active regions, according to whether they do or do not exhibit the violent transient phenomena. Either type may be associated with terrestrial disturbances, like geomagnetic storms and aurorae, which we attribute to corpuscular showers from the sun. Since the terrestrial effect appears to depend greatly on the apparent position of the region on the solar disk, rather than on some sudden outburst, we infer that the emission of corpuscles in a fairly sharply defined stream is generally an equable characteristic. It is not known, however, whether it is an invariable characteristic of all active regions, since many large conspicuous regions transit the solar disk with no terrestrial responses. Either there is no corpuscular emission, or it is confined to a beam which missed the earth.

The terrestrial disturbances attributed to ultraviolet radiation like sudden ionospheric disturbances and certain characteristic types of magnetic storms, are always associated with the transient phenomena of an eruptive region, principally flares. The association here is one to one between the terrestrial event and a specific flare, although many flares occur without any terrestrial response.

You may have noted that in listing the phenomena of an active region I mentioned the magnetic field first, I did this deliberately. Solar magnetic fields can be measured directly by means of the Zeeman splitting of certain lines in the spectrum. Over most of the sun the fields are very weak, generally less than 1 gauss, and pretty much at random in direction. However, we find small isolated areas when the fields attain thousands of gauss. These areas are invariably the centers of active regions. Although we are far from an agreed theory of how these great magnetic fields are produced at the surface of the sun, I think many solar physicists share my hunch that an active region owes its existence to the magnetic field, and its nature, equable or eruptive depends upon the nature of the field. In short, the magnetic field is the active region and all the activity we observe is induced by it. Certainly the recent studies of magnetohydrodynamics have showed decisively that a strong field exerts an overwhelming influence on the motion of material and pressure disturbances in a conducting medium like the solar atmosphere. Unfortunately the observational study of details of magnetic fields in active regions by the classical methods is very laborious, and the information now available is rather meagre. However, the Mt. Wilson Observatory has done yeoman service in keeping a long record of the magnetic character of every spot which has appeared on the sun for the past 35 years. On the basis of the Mt. Wilson observations, Bell at the Harvard College Observatory has made a statistical analysis of the association between the magnetic classification of a sunspot and the flare productivity of its active region. Such an association had been long suspected, and was definitely confirmed by Bell. She finds that sunspots with highly irregular complex fields, in which numerous positive and negative components appear side by side, are very much more likely to produce flares than spots with simple unipolar or bipolar fields. This tempts me to an obvious extrapolation. It suggests that the distinction between equable and eruptive active regions lies basically in the degree of complexity of the associated magnetic field. If this is correct it may provide a means for predicting the nature of an active region as soon as its magnetic field can be observed and classified. The verification of this idea and its usefulness depend in large measure on more expeditious methods of observation, a problem we are now working on at the Sacramento Peak Observatory.

I am sure that the sunspots themselves are quite familiar objects to all of you, so I shall not waste your time with a detailed description. The spots occur sometimes singly, but more often in groups dominated by a large pair, in fairly sharp latitude zones which vary throughout the sunspot cycle. A given cycle begins with spots at about 30° and works down to its termination with spots at 10°. A sunspot is darker than the surrounding surface simply because it is cooler. The refrigerating mechanism is not well understood, but one plausible explanation is based upon the magnetic field. Sunspots always occur in the region of greatest field strength. Here the normal convection of the surface layer of the sun should be inhibited because the transfer of material between upward and downward moving cells is rigidly restrained. This convection is the means by which energy is transferred from the solar interior to the surface, and any area in which the convection is stopped simply cools off by radiation and we have a dark sunspot.

Sunspots are often preceded and always accompanied by faculae. Although observable with an unaided telescope in white light, they are far less conspicuous than the spots themselves, and are generally visible only near the solar limb. They consist of irregular areas of slightly enhanced brightness around the spots. The faculae have received rather little attention from investigators and no one seems to care much just what they are. However, it is generally accepted that they are closely associated with the bright plages visible in monochromatic light. It is not unreasonable to suppose that faculae may be identified with the most intense portions of plages but seen at a much lower level in the solar atmosphere.

The plages themselves are quite invisible in white light. They are regions where the strong absorption lines of hydrogen or Ca II in the Fraunhofer spectrum are slightly filled in. They can be observed through a birefringent filter or spectroheliograph which isolates the light of one of these lines and rejects the rest of the spectrum. They appear then as large irregular bright regions centered around the sunspots. During the life history of any sizable spot, the area of its retinue of plages will vary greatly, but they never disappear together. Although they are probably above the visible surface or photosphere of the sun, they apparently do not extend to great heights in the overlying chromosphere, and can only rarely be identified at the limb.

One of the most interesting of the equable features is the corona. It is known from eclipse observations that the coronal light consists of monochromatic radiation in some 25 lines of highly ionized atoms, and white light from the photosphere scattered by coronal electrons. The white light spectrum contains none of the absorption lines present in the photospheric spectrum. They are completely washed out by the Doppler effect of high kinetic velocities of the electrons due to high temperature. The presence of emission lines of ions with ionization potentials as high as 800 volts confirms the high temperature and a study of the line widths and relative intensities indicates that it is between 1 and 2 million degrees.

The red and green coronal lines of Fe XIV and Fe X are the brightest in the visible spectrum, and can be observed with the aid of a coronagraph and spectrograph, provided the sky is really clear. Two stations in this country, at Climax, Colorado and Sacramento Peak, Sunspot, New Mexico, are properly equipped with both sky and instruments, and keep a daily record of the brightness of the red and green lines at all positions around the solar limb. The intensities of these lines are sure to be enhanced over active regions as long as the regions last. Indeed, the appearance of a coronal enhancement is often the first and the last remaining detectable evidence of an active region. Enhancements of the two lines usually differ in detail. The interpretation of variations in the ratio of red to green intensity is a fascinating study which I must regretfully pass over here for lack of a few hours to talk.

The white light electron corona is equally interesting and will probably turn out to be quite as significant for students of solar terrestrial and space effects as the emission lines. It is far more difficult to observe than the emission corona, since a weak polarization provides the only method for discriminating it from the overpowering scattered light of the sky and the observing instrument. The first photoelectric instrument capable of this work is now in operation at Climax, and we can count on some important results shortly. The first objective of the program is to determine whether or not the white light coronal streamers can be identified with the corpuscular showers which produce geomagnetic storms.

The transient phenomena of eruptive active regions are apparently responsible for the most spectacular terrestrial effects, and are themselves the most spectacular of solar features.

The flares are the most violent of all forms of solar activity, and are usually accompanied by some or all of the other eruptive activities of an eruptive region. They are associated with the most drastic sun-induced terrestrial effects in the form of sudden ionospheric disturbances and sudden commencement of geomagnetic storms concurrent with the flare, and long-lasting geomagnetic storms and auroree beginning a day or so later. All of these terrestrial disturbances are indicators of drastic changes in the space environment. Flares are observed optically in the monochromatic light of the hydrogen and Ca II lines and in all accessible radio frequencies. They appear as a sudden brightening of the solar surface near a sunspot group, usually two or three times as bright as the surrounding background. The brightening usually takes a few minutes, but occasionally takes place in a few seconds. After passing the peak of maximum brightness, the flare gradually fades into the background in half an hour or so. The optical phenomenon is typically accompanied by an appreciable enhancement of solar radio emission, which may be enormous in the 200 mc range, and is less pronounced but more reliable in the 3000 mc range. An interesting feature of the lower range is a pronounced time dependence of the frequency, shown in radio spectrometers. The radio enhancement appears first at the higher frequencies and gradually moves to lower frequencies in a few minutes. In the 200 mc range the radio emission originates in the corona, high above the visible surface of the sun. The lower the frequency, the higher is the level of origin. Hence the time variation of the radio spectrum of a flare is interpeted as a disturbance which starts at the visible surface and is propagated outward through the corona at a velocity of roughly 1000 km/sec. This slow moving disturbance is often accompanied by another, which goes through the same range of frequencies in less than 1/100 of the time, and should therefore represent a disturbance moving at better than 100,000 km/sec. Very few objects have been observed optically moving at 1000 or more km/sec, and we cannot definitely identify these radio bursts with anything we see. However, there have been at least three flare prominences recorded at the limb with velocities of this magnitude. They are in a class by themselves in the matter of speed, and since they have all been coincident with SID-producing flares, they are likely suspects as the source of the radio bursts.

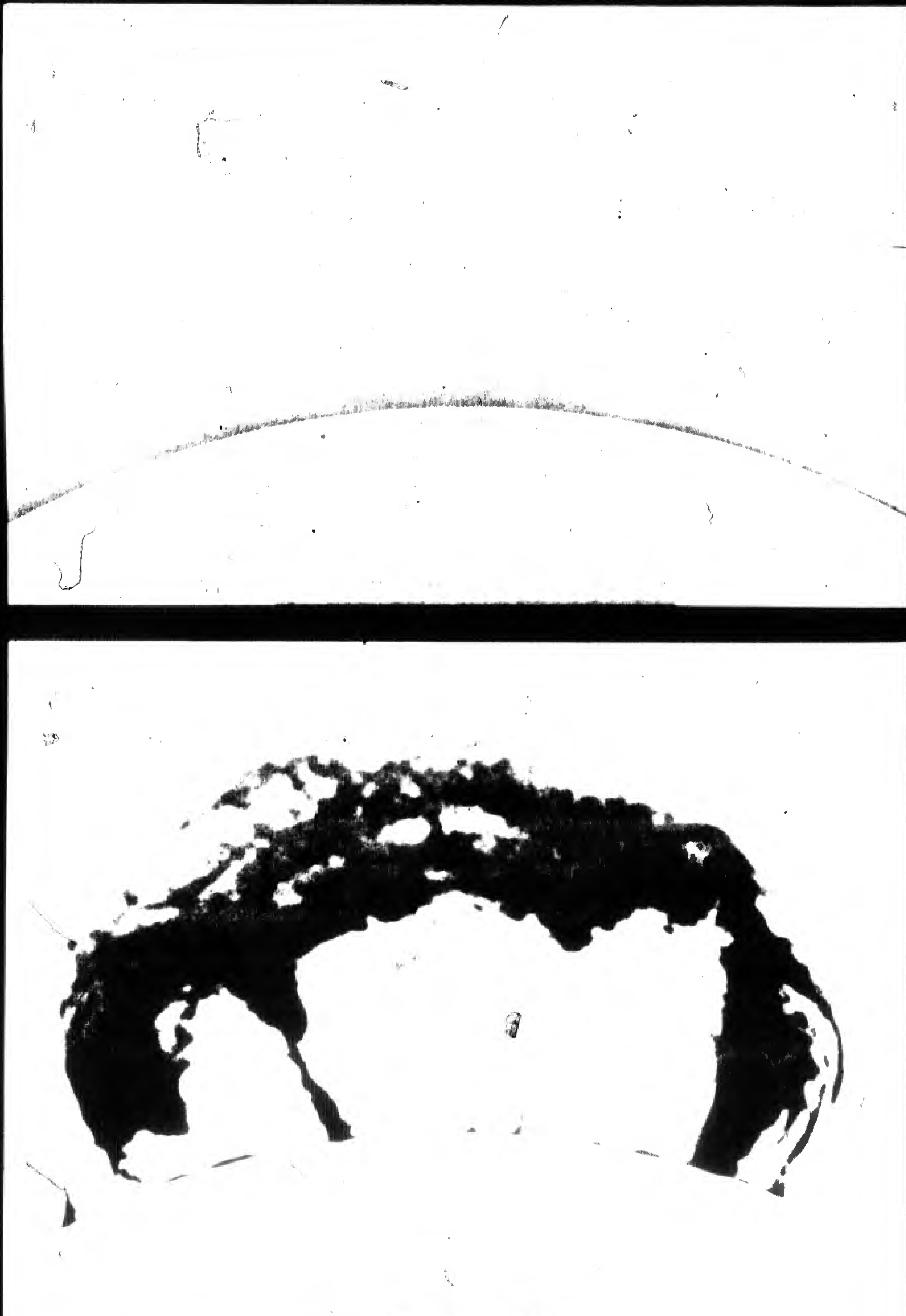
When a flare appears at the limb, the yellow line of Ca XV usually appears in the immediately overlying corona and remains for a few hours. Since the ionization potential for Ca XV is 814 volts, more than twice that for the more equable green line of Fe XIV, its presence probably signifies a small region of very high temperature above the flare. Like the flare, the yellow line is an eruptive feature, and rarely occurs without some evidence of an associated flare. Since the coronal lines can be observed only at the limb, the associated flare may be beyond the limb and unobservable because it is a comparatively low level phenomenon. However, flares are usually accompanied by surge or loop prominences, which are visible above the limb. To the best of my knowledge there have been no instances of yellow line without either an observable flare or these very distinctive prominences. I also suspect that no limb flares have been observed unaccompanied by a yellow line region if the appropriate coronal observations are available. This is equivalent to saying that yellow line corona is a part of the flare phenomenon. Because of its position in the region of origin of the radio bursts, it may reasonably be regarded as a second suspect as the source of the bursts.

I have already mentioned the flare prominences. They are distinguished from other upward moving prominences only by their enormous velocities and the fact that they are associated with SID's. In these two respects they are quite distinctive, and since in all three observed cases those characteristics appeared together, I call attention to them as a rather special type of prominence. If they are themselves the origin of the SID-producing radiation, they could be classified as flares, although the high velocity fragments are not characteristic of most flares.

The most significant of the more common active region prominences are the surges and loops. They are both quite distinct from other types and are always associated with an eruptive active region which is producing flares. A surge has the appearance of a great spike of glowing hydrogen which shoots up from the solar surface with velocities between 100 and 300 km/sec, often along a distinctly curved, highly inclined path. Having reached its full extent at a height which may be anything up to 200,000 km, the surge retracts along its original path. This decidedly non-gravitational behavior suggests motion along magnetic lines of force. While the surges originate in the solar surface and return to it, the loops appear to pour out of stationary and inexhaustible nucleus suspended high above the sun. The material streams down along two semicircular arcs which often present the appearance of an almost perfect circle resting on the surface of the sun with nucleus at the highest point. The nucleus must be the point at which coronal material condenses sufficiently for the hydrogen to become luminous, since it seems almost inconceivable that all of the material which pours out could have been there originally. Of these two types, the surges are almost invariably associated with flares, unlike the loops. The loops, on the other hand, do not appear to be directly related to flares, although their presence is a sure indicator of a highly eruptive active region which can be expected to produce flares.

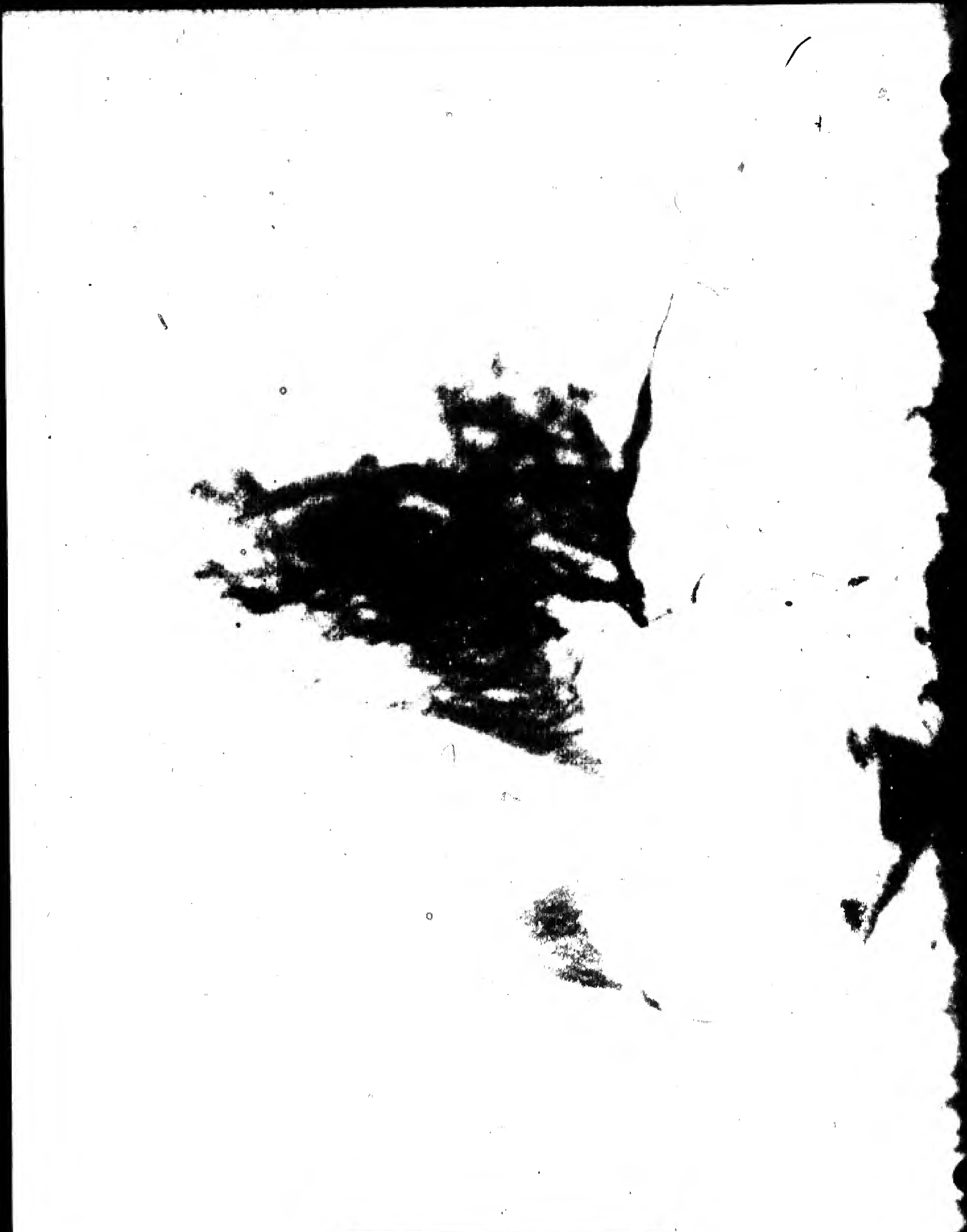
These, then, are the observable phenomena of a solar active region. The overwhelmingly dominant feature, energetically, is the magnetic field, and it is reasonable to suppose that the more spectacular activities are actually relatively trivial results of slight twitches in the field. The twitches have not yet been observed due to the difficulty of the required techniques, but such observations are now in their preliminary stages at the Sacramento Peak Observatory. Meanwhile we can only conjecture.

If this concept is correct, the emission of corpuscular streams, the ultraviolet and X radiation may also originate in the small magnetic fluctuations which simultaneously produce flares. These emissions, therefore, accompany but are not necessarily caused by flares and need not originate in a flare. We can also suspect that there may be other types of emission which have not yet been identified. So far our main dependence for a study of the short wave and corpuscular radiation from the sun has been their interactions with the ionosphere. It is clear that more direct observations from above the atmosphere can yield far more exact information on intensity, energy distribution, and point of origin of these radiations than has so far been possible. A magnificent start in this direction has been made by Tousey, Friedman, and their associates at the Naval Research Laboratory, and by Rense's group at the University of Colorado, who have made intensity measurements in the ultraviolet and X ray regions from rockets. Similarly, the studies of particle radiations around the earth by Van Allen and his associates are telling us much about the final destinies of solar corpuscular streams. However, these outstanding researches only whet our appetites for more. The field of space-borne solar research is one which promises prodigious rewards in our knowledge of the sun and solar activity, and the resulting modification of the space environment. Not only will the data lead to new information per se, but they will provide the missing link for the interpretation of reams of ground based observational data, which are at present simply an imposing and impossible mystery. For this reason solar astronomers are looking forward to a genuine break-through in the near future, which will contribute directly to their own field, and enable them to contribute their bit to knowledge of the space environment which will ultimately but inevitably become the environment of men.



Eruptive Prominence

Solar Disk in Hydrogen Light Showing Large Flare (Bright), Dark Filaments, Plages, and Sunspots



Prominence Over Entire Center

4

LECTURES IN AEROSPACE MEDICINE

THE UPPER ATMOSPHERE AS OBSERVED WITH ROCKETS AND SATELLITES

Presented By

Dr. William W. Kellogg

Head, Planetary Sciences

Engineering Division

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THE UPPER ATMOSPHERE AS OBSERVED WITH ROCKETS AND SATELLITES

by

William W. Kellogg

In 1945 the first sounding rocket, a WAC Corporal, was fired at White Sands, New Mexico, and the following year at White Sands captured German V-2 rockets began to be used to carry instruments into the upper atmosphere. The year 1946 also saw the formation of the Upper Atmosphere Rocket Research Panel, which has until recently guided the scientific program of rocket exploration in the U.S. (It is now called the Rocket and Satellite Research Panel.) In the fourteen years which have passed since the first sounding rocket the advances which have been gained in our knowledge of the upper atmosphere, above the ceiling of sounding balloons, have been phenomenal. The purpose of this brief report will be to emphasize some of the steps which have been made during the last two and-a-half years, starting roughly in July, 1958, with the beginning of the I.G.Y.

The purpose of the I.G.Y. program, broadly stated, was to study the planet Earth and its environment on a global basis. Applied to the rocket (and satellite) program, this meant extending the rocket coverage in latitude as well as altitude. Thus, during the IGY the U.S. alone fired, according to a "preliminary estimate"* 89 rockets at Ft. Churchill, Canada,.

*Hearings before the Subcommittee of the Committee on Appropriations, House of Representatives, 86th Congress, Report on the International Geophysical Year, p. 157.

20 at Pt. Mugu, Calif., 6 at White Sands and Holloman, 9 at Guam, 8 during the Pacific eclipse expedition, and 54 more from shipboard at locations from the Arctic to the Antarctic. These, plus the extensive Soviet meteorological rocket program and the more modest programs of Great Britain, Australia, Japan, and France, have given us a perspective on the upper atmosphere and the earth's radiation environment which we could not have achieved in any other way. It is estimated that in the order of one hundred more rockets have been fired since the IGY in the U.S.

Added to this have been the earth satellites and space probes, which have surveyed the radiation belt and have given invaluable data on the density in the upper atmosphere at altitudes higher than rockets can measure it.

With so much activity, it will be impossible here to do much more than touch the highlights of the results which have been obtained. There has rarely been a period in the history of any science in which such an explosive advance has been made as now in the field of upper air research.

Upper Atmosphere Meteorology

The starting point for any study of an atmosphere must be the description of its mass distribution and motion. This is what the meteorologist does as he draws his weather charts, and this is what the rocket people do when they measure pressures, densities, or temperatures, and winds in the upper atmosphere.

The expanded rocket coverage has given a better idea of how the upper atmosphere differs between White Sands (31°N. Lat.) and such locations as Ft. Churchill (58°N. Lat.), and how it changes with season and time of day. The combined observations by the Naval Research Laboratory, the Army Signal Research and Development Laboratory, and the University of Michigan, plus the report of the Soviet meteorological rocket program, give the following general picture.

There is relatively little diurnal temperature change below about 100 km, but there is a complex seasonal one. Up to 50 km, according to the Soviet rocket series, it is generally warmer in summer, colder in winter, as one would expect, with the changes following the seasonal change in solar radiation very closely (without the large lag experienced near the ground). Naturally, there are significant day-to-day fluctuations, but there is not enough "synoptic" data yet to trace these changes systematically above the level of balloons.

Above 50 km there is a reversal in this annual change, as revealed by the University of Michigan and Signal Corps rocket flights at Ft. Churchill, and it is actually warmer at 80 km during the winter than in the summer, by some 60°C. This curious phenomenon, probably due to a dynamical effect, has still to be adequately explained.

In comparing middle and high latitude results, it is revealed that in summer pressures and densities at a given altitude are about the same or a bit higher at high latitudes up to 80 or 90 km, but in winter the pressures and densities in the arctic atmosphere are lower. The day-to-day variations in winter are considerably greater at Ft. Churchill than at White Sands. Incidentally, the prevailing winds from 30 to 80 or 90 km are east in summer and strongly west in winter, as measured by the Signal Corps rocket experiments and ground-based radio observations of the drift of meteor trails, and these directions are consistent with the pressure and density distributions just mentioned.

Above 80 or 90 km the picture is somewhat different. In the ionosphere, above 90 km, the arctic atmosphere seems to draw on a heat source in addition to the sun (probably the influx of particles into the auroral zone, or a dynamic heating) and is generally warmer than at White Sands. Only during the winter nighttime, when it gets no sunlight for long periods, is it comparable. There is a marked diurnal change. This diurnal change increases with height up to 200 km and above, and at 200 km it results in density changes at Ft. Churchill which may be as much as an order of magnitude. (A note of caution here: The White Sands observations used for comparison with Ft. Churchill were mostly made several years earlier, and during a sunspot minimum, so we <u>may</u> be confusing an effect due to a solar or time change with a latitudinal change.)

At still higher levels, above 200 km, satellites have given us the best density data, based on satellite drag calculated from observations of orbital decay. This has refined our knowledge of the mean conditions, and has forced a revision of most of the earlier temperature estimates upwards. Furthermore, certain changes in density in the 200 to 600 km region with solar and geomagnetic activity have been demonstrated most dramatically by L. Jacchia, of the Smithsonian Astrophysical Observatory. Although these changes are rather complex, the most significant findings seem to be that both Vanguard I (perigee at 650 km) and Sputnik III (initial perigee at 216 km) show fluctuations in drag which are remarkably well correlated with solar activity as measured by microwave emission from the sun. Furthermore, following two of the stronger solar flares during 1958 there were strong magnetic storms in the earth's upper atmosphere, and the Sputnik III drag showed a pronounced increase a few hours after the onset of the magnetic storm. Thus, the fact that the upper atmosphere densities (and temperatures, presumably) are directly affected by solar changes has been experimentally verified for the first time.

Upper Atmosphere Composition

Since the upper atmosphere is being intermittently irradiated from a variety of sources, it is never in a state of chemical (or thermal) equilibrium. Furthermore, the vertical distribution of the various components of the atmosphere's gas is variable, and is determined by the combined action of photochemical processes, gravity, and air motion. Although theoretical work had resulted in rather good predictions about the gross composition of the upper atmosphere, recent rocket and satellite observations have given us some rather rude shocks, and several preconceptions are in the process of being revised.

In the stratosphere and mesosphere ozone and water vapor (or OH) are the most interesting variable constituents, but rockets have so far not been used extensively to study them. This is an area where some good observations were made by the Naval Research Lab. and the Applied Physics Lab. in the early days of the rocket sounding program, and it appears that there is a renewal of interest in the subject.

Somewhat higher, at about 90 km, oxygen begins to be dissociated, and some important observations of the atomic and molecular oxygen distribution have been made by the Naval Research Lab. using ultra-violet absorption techniques. At Ft. Churchill there is a seasonal change of at least 10 km in the level at which dissociation begins, as would be expected.

The distribution of the main atmospheric constituents below 90 or 100 km is fairly constant, since mixing by turbulence and large scale vertical motion is rapid. Somewhere above this level molecular diffusion becomes sufficiently fast to cause a sorting out of the heavier constituents from the lighter ones, and also a rapid vertical exchange of constituents. Rocket observations at both White Sands and Ft. Churchill by the University of Michigan (using sample recovery) and the Naval Research Laboratory (using mass spectrometers) indicate that the level at which diffusive separation begins is below 120 km, and at White Sands it may be as low as 90 km.

The ionized constituents of the ionosphere have been observed by Naval Research Lab. rockets at Ft. Churchill and by the Soviet Sputnik III. (Soviet rockets have also made such measurements, but this author is not aware of any scientific publication of results.) The significant finding by NRL was the dominance of the NO^+ ion (atomic mass 30) in the lower ionosphere, the presence of which was previously suspected on theoretical grounds by Nicolet, Friedman, and others. This ion, although a minor constituent at Lower altitudes, plays an important role in the ionization of the D- and E-regions because of its relatively low ionization potential and the ease with which ultraviolet can ionize it. Higher, in the F-region, O^+ (atomic mass 16) becomes the dominant ion. The dominant negative ion in the ionosphere over Ft. Churchill was found to be NO_2^-.

The free electron density measurements with rockets, and to a somewhat lesser extent with satellites, have provided a great deal of new insight into the structure of the ionosphere. The rocket findings which have been of great interest in this regard are:

- Measurements in the D-region, especially during polar blackout conditions.
- E-region measurements showing the detailed structure of the density profiles.
- Measurements "between the layers," which are not observable from the ground by ordinary radio techniques.

- Measurements above the F_2-region maximum, showing a relatively slow decrease of electron density with altitude.

Electrical Currents and Energetic Particles

Closely related to the electron structure of the ionosphere are the electric currents flowing there. The State University of Iowa rockoons have been able to measure these currents in the vicinity of the equatorial electrojet, and the Naval Research Lab. has measured the currents associated with a visible aurora over Ft. Churchill. There have been two few observations to generalise with any confidence, but the following results are highly significant.

- In the equatorial electrojet it now appears that there are at least two layers in which current flows.
- In the auroral zone there are currents associated with the features of a visible aurora at about 120 km, and these currents have relatively small dimensions (since the currents observed on ascent and descent of the rocket were markedly different).

Although this review will not deal specifically with radiation belt measurements, these having been discussed elsewhere at such length, those rocket measurements of auroral particles closely associated with aurorae clearly have a bearing on the physical processes in the arctic ionosphere. Both the State University of Iowa and the Naval Research Lab. have made such measurements, and the latter note that energetic electrons were detected in all aurorae penetrated by their rockets, but not outside such aurorae. Energetic protons are detected both inside and outside of aurorae, but their pattern is not at all clear.

It should be pointed out, in connection with the influx into the atmosphere of these energetic charged particles, that there are undoubtedly large variations in the intensity of this influx, apparently associated with magnetic storms. The work of the University of Minnesota group with balloons, and recently with satellites (Explorer VI), has called attention to this variation, and this is an area where much additional work is being done.

Solar Radiation

Since, as mentioned earlier, virtually every charecteristic of the upper atmosphere is affected by solar radiation, observations of the sun from above the atmosphere are an essential part of upper atmosphere physics. Of particular importance are the changes in solar ultra-violet and x-ray radiation which accompany solar flares, and these must be observed above the E-region of the ionosphere, where they are absorbed.

During the past summer at Point Arguello the Naval Research Lab. has conducted another in a series of spectacularly successful rocket firings to observe the sun, and has, according to preliminary releases, observed x-ray energies of as much as 80,000 eV (a fraction of an Angstrom). One implication of these observations is that the previous N.R.L. estimates of effective solar corona temperatures of several million degrees may now have to be revised upwards by an order of magnitude.

Other results of the N.R.L. rocket series have been:

- o Photographs of the sun's disk in the ultraviolet radiation of hydrogen, at the wavelength of the Lyman-alpha line.*
- o Observations during the October,1958, solar eclipse in the south Pacific, which indicated that considerable x-ray radiation continued to reach the earth during totality. From this it is deduced that the source of the x-radiation, as was suspected, was the corona and not the solar disk.
- o Observations during a series of rocket firings from San Nicolas Island (just off Point Arguello) in 1957 which showed a significant enhancement in x-rays from the sun during a solar flare.
- o Observations of the appreciable flux of Lyman-alpha radiation (at 1210 °A°) at night, coming from solar Lyman-alpha which was scattered by protons either in the vicinity of the earth or in interplanetary space. There were also discrete sources of Lyman-alpha in certain regions of the night sky, indicating that some distanct star systems are strong emitters of this radiation.

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*H. Friedman, The sn and the upper atmosphere, Astronautics, 4, p.20, July, 1959.

Meanwhile, an argument is continuing concerning the cause of radio blackouts and SID's. The N.R.L. group (H. Friedman et al) believes that the primary variable which causes enhancement of ionization in the D-region is solar x-rays, while the Central Radio Propagation Lab.- High Altitude Observatory school of thought (J.W. Warnick and H. Zirin) seems to favor a change in ultra-violet radiation. A third party, the University of Minnesota cosmic ray physicists (J.R. Winckler et al) have found some evidence for D-region ionization by temporary fluxes of energetic electrons during solar and magnetic storms. So this very important problem is clearly going to receive a good deal more attention before it is solved.

5

LECTURES IN AEROSPACE MEDICINE

CELESTIAL BODIES

II. Planetary Ecology (Astrobiology)

Presented By

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

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USAF Aerospace Medical Center (ATC)

PLANETARY ECOLOGY*

(ASTROBIOLOGY)

by

Hubertus Strughold, MD, PhD**

Ladies and Gentlemen: In the first lecture of this Aerospace Medical Lecture series we discussed the biophysical conditions found in the space between the planets, with special emphasis upon the regional and temporal variations. In this way we arrived at a kind of geography of space--what we called Spatiography. To a high degree the Sun is responsible for the ecological conditions encountered in interplanetary space. The planets, too, are not only under the gravitational control of the Sun, but also considerably influenced with regard to the conditions found on them, such as temperatures, light, and chemical composition of the atmospheres.

A description of the conditions on the planets with regard to life is an ecological planetography, or Planetary Ecology.

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5

Planetary Ecology (Astrobiology)
H. Strughold

Recently the term Astrobiology has come into use and is perhaps generally better understood.

This new field of science, Astrobiology, studies two questions: First, is there indigenous life on other planets? This problem has captivated the imagination of men since G. Schiaparelli in Milano, 1877, described strange features on Mars which he called canali. The discussion of life on other worlds reached its first climax in the studies and publications of Percival Lowell in Flagstaff, Arizona around 1910, followed later by noteworthy publications of other authors. The progress made in rocketry, space technology, and space medicine since the past decade, has had a catalytic effect upon the occupation with this problem, as evidenced by numerous publications and stories about visitors from Space in flying saucers, and so on. But the Space Age put another question into the foreground; namely: what kind of environment will an astronaut find on the neighboring celestial bodies with regard to himself; i.e., from the standpoint of his survival? Both of these questions will be discussed in this lecture. The atmosphere of the planets, especially their chemistry, are the key problem in both respects.

Therefore, we shall devote a considerable part of this lecture to the chemistry of the planetary atmospheres and other ecological properties.

But, in order to completely understand the chemistry of the planetary atmospheres in their present state, we must include their origin and historical development. As a paleo-astrobiological model in this respect, we shall consider the evolution of the Earth's atmosphere, about which several important publications are available. Actually, we should dig even deeper into the past, into the theories of the origin of the planets. But, due to lack of time, I would like to mention, only, that according to the theories of the past century (E. Kant, P. de Laplace), and the beginning of this century the planets originated from very hot gas clouds, or very hot solar matter; in other words, in a hot way. According to recent theories advanced during the past 25 years (F. von Weizsaecker, H. Urey, G. Kuiper), the planets formed from peripheral solar dust of relatively low temperature, or in a cold way. With the accumulation of matter their temperatures rose, secondarily, to some two thousand degrees.

In brief, the planets have gone through the following stages of development: primordial solar dust cloud--the phase of accumulation of dust particles and planetesimals, or the pre-protoplanet; the early period of the final planetary body, or the protoplanet; and the early stage of planet as it exists today. The age of the Earth is generally estimated to be four billion years, while that of the solar system about five billion years.

And now, to the evolution of the Earth's atmosphere! For this purpose let us go back about two and one-half billion years. At that time the primordial Earth, having reached a temperature of about 2000°C, was surrounded by a gigantic thick blanket of water vapor, impenetrable to the Sun's rays. At these high temperatures most of the water on earth existed in gaseous form.

When, in the course of millions of years, the Earth's surface had cooled, more and more water vapor began to condense and finally the entire water vapor contained in the air rained out. As a result, tremendous amounts of water accumulated on the Earth's surface and formed oceans of boiling water. This was the turning point from the astronomical or pregeological time to the geological time. After practically all water vapor had condensed on the Earth's surface, the Sun's rays could penetrate the remainder of the transparent gaseous envelope and touch the ground. This, then, was the hour of birth of the Earth's atmosphere--some two and one-half billions of years ago. Before this time the Earth was enveloped by a thick blanket of essentially water vapor and some gases. Now a differentiation of this hot vapor and gaseous sphere had taken place, separated into a hydrosphere and an atmosphere containing the primordial gases.

These gases of the primordial atmosphere or protoatmosphere showed a chemical composition very different from that of the present-day atmosphere. The present-day atmosphere contains, essentially, oxygen, nitrogen, and oxygen compounds such as carbon-dioxide. (Table I). It is an oxidizing atmosphere. The protoatmosphere, however, consisted mainly of hydrogen and hydrogen compounds such as methane, ammonia, and helium. It was a reducing atmosphere. It had no actual oxidizing power. Chemically, the present atmosphere is essentially an oxygen atmosphere, whereas the protoatmosphere was essentially a hydrogen atmosphere.

But soon a change took place. According to recent astrophysical theories (H. Urey, G. Kuiper), by means of photodissociation, the remaining water molecules at the border of the protoatmosphere were split into hydrogen and oxygen by ultraviolet of solar radiation. The lighter hydrogen escaped into space, and the heavier oxygen remained. With the appearance of this initial oxygen the protoatmosphere attained oxidizing power. This started a new decisive step in its development. Ammonia (NH_3) was oxidized to free nitrogen (N_2) and water, and methane (CH_4) to carbon dioxide and water. During this process of evolution the primordial atmosphere became more and more oxidized. With the appearance of chlorophyl, about one and one-half billion years ago, this process of oxidation was accelerated by the process of photosynthesis. With this, biology entered the picture of the transformation of the Earth's gaseous envelope. The oxygen, photosynthetically produced, oxidized the remaining hydrogen compounds and a surplus of oxygen accumulated to rather large amounts, such as are observed in the present-day atmosphere, or we might say neoatmosphere. This stock of atmospheric free oxygen (O_2)

amounts to 1.2 quadrillion metric tons. It has been calculated that this total amount of O_2 could be replaced, photosynthetically, by the present green vegetation on all the Earth continents within approximately 27,000 years. This demonstrates the effectiveness of photosynthesis in the oxidation and oxygenation of our atmosphere. It has, without a doubt, surpassed by far the oxygen production by photodissociation of water, aforementioned.

In this whole oxygen complex and that of carbon dioxide, we must not consider the atmosphere alone. The atmosphere is in a continuous gas exchange with the hydrosphere; that is, with the oceans, lakes and rivers, with the lithosphere; that is, the solid earth, and the biosphere, which represents the whole living world. A discussion of these interrelations, however, goes beyond the scope of this lecture.

This survey shows how complicated the task would be to obtain a clear picture of the losses and gains in the oxygen balance of our atmosphere. Drastic changes are not to be expected in the range of recorded history. For the past 150 years the oxygen content in the air has been constant.

Summarizing, we find in the historical development of terrestrial atmosphere, two basic types of atmospheres with pronounced chemical reaction tendencies and, logically, a transition stage between the two:

1. A reducing protoatmosphere with a potential but no actual oxidizing power--a non-oxidizing atmosphere. In this anoxic hydrogen atmosphere, which was found in the early phase of the protoatmosphere, organisms are hardly conceivable. If, however, organic compounds such as amino acids, etc., were produced from methane and ammonia and water by solar ultraviolet radiation or other photochemically effective rays with some CO_2 available, anoxibionts could have existed in this primitive atmosphere. These, then, would have been the protobionts on our planet.

2. A transitional stage with increasing oxidizing power. In this stage of the protoatmosphere, chemautotrops (iron-, sulphur-, ammonia-, and hydrogen-bacteria) and photoautotrophs (cholrophyl-bearing organisms of lower order) could have existed.

Large iron deposits such as those found in the area of the Great Lakes in the United States are the result of the activity of iron bacteria. These deposits are one and one-half billion years old.

3. A highly oxidized atmosphere with strong oxidizing power. This type of atmosphere, which we observe today, provided the basis for the development of higher plants, animals, and man. So much for the origin and historic evolution of the Earth's atmosphere. We must keep in mind that behind the scene of this chemical transformation as the effective agent, was and is solar radiation.

We can now proceed to our main topic: the atmospheres of the other planets and their ecological qualities.

It can be assumed that the protoatmospheres of the other planets, at about two to two and one-half billion years ago, had the same chemical composition as the protoatmosphere of Earth. Then it can be expected that they must have very different chemical properties now, since they have been exposed to different intensities of solar radiation corresponding to their respective distance from the Sun.

In the following, we shall consider the planets--not with increasing distance, as is usually done--but rather with decreasing distance from the Sun, since this sequence conforms better with the foregoing discussion concerning the chemical evolution of the terrestrial atmosphere.

Table II shows the main chemical components of the planetary atmospheres in the order of their abundance. It also shows the distances from the Sun.

Approaching the solar system from the outside, we first encounter Pluto, the outermost planet. It is assumed that its atmosphere consists of hydrogen, helium, and methane in a frozen state.

Neptune, Uranus, Saturn, and Jupiter can be considered here as a group. The atmospheres of these larger planets consist mainly of hydrogen, methane, ammonia, helium, and probably frozen water. They are reducing and reduced atmospheres with no actual oxidizing power. The similarity of this composition to that of the protoatmosphere of the Earth is striking. Apparently, escape of these light element compounds has been prevented by the strong gravitational forces of these large planets. They seem to be preserved in a frozen state because of their greater distance from the Sun.

The main constituents in the Martian atmosphere are probably nitrogen, argon, and carbon dioxide. The amount of carbon dioxide is about twice that on Earth. Water is present in very small amounts, mainly in the form of ice and vapor. This atmosphere is qualitatively similar to that of the Earth, except that it does not contain oxygen, or only traces of it. During its evolution it lost most of its atmosphere because of its low gravitational force (38% of the terrestrial value). Not only hydrogen but also oxygen might have escaped from proto-Mars. The Martian atmosphere is an oxidized atmosphere with low potential oxidizing power and perhaps a low actual oxidizing power, depending on the presence of free oxygen.

The Venusian atmosphere, too, is a completely oxidized atmosphere. It probably contains nitrogen and carbon dioxide--the latter in large amounts. The presence of free oxygen is still a matter of astronomical dispute. Proto-Venus probably lost most of its oxygen by escape, due to the high temperature caused by its proximity to the Sun. Water seems to be present, according to recent spectrographic studies made in high altitude balloon flights.

We find a type of atmosphere resembling that of Venus in volcanic fumaroles, which are little craters, where carbon dioxide has escaped from the interior of the Earth and has displaced the air on the ground because of its heavier weight. Such places are the Grotto del Cane at Puzzuoli near Naples, the Moffetten (vents in the last stages of volcanic activity) on the eastern short of Lake Laach in the Rhineland, and Death Valley on the Dieng Plateau in Java. Some lower places in this valley are barred to animal life because of their carbon dioxide enrichment of the air. Bodies of birds and mice are sometimes found in these areas; they died when they ventured into this toxic air.

Mercury has no atmosphere at all. It probably could not hold an atmosphere because of its low gravitational force, and its high temperature, due to its nearness to the Sun.

Summarizing, in the solar planetary system in its present state of development we find two basic types of atmospheres:

1. Hydrogen and hydrogen compounds containing atmospheres found on the outer planets, and

2. Oxygen and/or oxidized compounds containing atmospheres on the inner planets with three varieties:

the atmosphere of the Earth--a dense oxidized atmosphere with a high content of free oxygen,

the Venusian variety--a dense oxidized atmosphere with none, or only a small amount of free oxygen, and

the Martian variety--a thin oxidized atmosphere, also with only traces of free oxygen.

The group of the oxygen-dominated atmospheres of the inner planets form a kind of oxygen belt in the planetary system, and the Earth is the pronounced oxygen planet in this belt. The group of the hydrogen-dominated atmospheres represent a hydrogen belt. These two belts correspond exactly with the two basic phases in the historical development of the Earth's atmosphere: the hydrogen stage some two and one-half billion years ago and the present oxygen stage. Indeed, we notice the same sequence when we travel through the planetary system, beginning at its remote outer regions into those of the vicinity of the Sun:

a change from hydrogen and hydrogen compounds containing atmospheres to oxygen and/or oxidized compounds containing atmospheres. The atmospheres of the outer planets, while beyond the effective range of solar radiation, apparently have preserved their hydrogen atmospheres of the protoatmospheric stage up to the present time. Chronologically, they are all of about the same age as those of the inner planets, but younger with regard to their chemical structure which, unaffected by the Sun's radiation, still show the primordial features. They are still protoatmospheres. It is interesting to note that there is not a transitional type of atmosphere in the planetary system; this can be explained with the existence of a large spatial gap between Mars and Jupiter.

So much for the chemistry of the planetary atmospheres of the planets. They all belong to the same family of celestial bodies but revolve around the Sun at different distances and, as a result, they show a different chemistry which is ecologically significant.

Not less significant for life is the temperature of the planetary atmosphere which, too, is dependent on the solar distance. Temperatures on planets which are favorable to life are found only in certain distance range. We can call this zone biotemperature belt in the planetary system. Venus lies in the warm, or hot; Mars in the cold; and the Earth in the golden temperature middle of this biotemperature belt. The group of the outer planets, with temperatures ranging from -140°C to -250°C, lie outside of this belt of life-supporting temperatures.

In about the same area, dependent on temperature, water is found, or is conceivable, on planets in its biologically useable form; namely, in the liquid state. Shapley called this zone "liquid water belt" in the planetary system.

And, as we have seen, we can also speak of an oxygen belt in the planetary system.

With regard to the light conditions, we may also speak of a euphotic or biophotic belt. All of these belts are found at about the same distance from the Sun.

To cover all of these ecological factors we can use, for this life-favoring zone, the more general term "Ecosphere" in the planetary system, or Helio-ecosphere. This ecological belt is a relatively narrow zone and represents nor more than 5% of the whole range from the Sun to Pluto. We can use this concept for both space operations and for the celestial bodies as well. Recently it has been the subject matter of various publications with regard to other stars.

From all of these general ecological considerations it seems to follow that, besides the Earth, only Mars and perhaps Venus, may qualify as bioplanets.

On the outer planets, microorganisms, such as hydrogen bacteria, methane bacteria, etc., are conceivably just the same as in the terrestrial protoatmosphere, but the low temperature would seem to dispute this. For visiting astronauts these planets are also not very inviting because of their atmospheric chemistry.

Of the ecospheric planets, Venus, constantly and completely covered with dense clouds, probably consisting of carbon dioxide crystals, is wrapped in mystery concerning its surface features. Venus might also be too hot for astronauts, due to its nearness to the Sun and a "greenhouse" effect in its carbon dioxide-enriched atmosphere.

The Martian atmosphere is rather transparent and permits observation of the planet's surface. Because of this Mars is the favored planet in any astrobiological discussion, and I, therefore, would like to make a few remarks about this planet from the standpoint of human physiology and general biology.

An astronaut would like to know what environment he might find on Mars and what protective equipment he would need with regard to respiration. At ground level--by the way, there is no sea level on Mars--the barometric pressure is about 70 mm Hg. This pressure corresponds to an altitude of about 15 km on Earth. Barometrically, this altitude is the Mars-equivalent level in our atmosphere. Our pilots flying at altitudes of 15 km must wear a pressure suit. The same will then be required for a man on Mars, when he leaves the sealed compartment of his space ship. However, an air pressure of 70 mm Hg lies just in the critical border range in which a pressure suit and simple oxygen equipment with pressure breathing are a matter of dispute. The latter may be sufficient, especially if a space vehicle would land in the lowlands on Mars. Be that as it may, a terrestrial explorer on Mars, wearing a pressure suit or pressure breathing equipment, must always retreat after one hour or so, into the more convenient sealed cabin of the ship. In the event of a leak in the sealed compartment, or pressure suit, the astronaut would encounter the same rapid decompression effects, such as anoxia and dysbarism, as our pilots face in our stratosphere, at about 15 km. He would not, however, be endangered by ebullisms, or boiling of body fluids. This effect becomes manifest on Mars at an altitude of about 3 1/2 km, which corresponds to 20 km in our atmosphere.

Concerning other climatic conditions on Mars, the temperature, during the daytime in summer, in the equatorial regions, may reach 25°C; after sundown it drops very quickly to -45°C, and the space cabin has to provide adequate protection. Harmful effects from solar ultraviolet rays can be disregarded because the astronaut is always protected from sunburn by his respiratory equipment or by the cabin. Hazards from primary cosmic rays, too, are probably not to be expected because of the atmosphere's absorbing power. The same certainly would be true of meteorites.

The intensity of daylight on Mars is lower than on Earth, but still in physiologically desirable range. The color of the sky is probably whitish-blue (G. Kuiper), due to scattering of light by the various hazy cloud layers.

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An adaptation of the astronaut to a different day-night cycle is not necessary, since the day-night cycle on Mars is only 34 minutes longer than that on Earth. And his weight and that of his equipment will be reduced to less than one-half of the terrestrial value. This makes life easier for him and facilitates his readaptation to weight, after a long weightless journey.

So much for the ecological qualities of the Martian atmospheric environment from the standpoint of human physiology, or from an astromedical point of view.

And now to the astrobiological question, "Is there indigenous life on Mars?" -- a question of general human interest which has been under lively discussion since the discovery of green areas during the Martian Spring, and which show seasonal color variations of the kind we observe on terrestrial plants. There are three theories concerning these dark areas:

1. The organic or vegetation theory.

2. The inorganic theory, explaining them as the result of either volcanic eruptions (P. McLaughlin), or of color changes of some hydroscopic inorganic material caused by variations of the soil's humidity (S. A. Arrhenius).

3. The physiological optical theory, which explains the green color as a contrast phenomenon against the yellow-red surroundings.

In the following I shall confine myself to those theories which involve biological aspects.

Concerning the vegetation theory, we must consider some additional climatic data. On Mars the carbon dioxide pressure is twice as high as on Earth. Water, however, is very scarce. The light intensity is about 40% of that on Earth, high enough for photosynthesis.

The amplitude of the day-night temperature variations in the equatorial regions can exceed 70°C.

The maximum, minimum, and mean temperatures for the various latitudes on Mars are in an average of some 20°C to 30°C below the terrestrial values.

In general, then, the physical conditions are, in terms of botany, extremely severe with the exception of sufficient carbon dioxide, light, and suitable temperatures during the day.

Such conditions could, according to terrestrial standards, support only very hardy and cold-resistant organisms of lower order.

But we must not only consider the climate as a whole but also the so-called microclimate near, on, and below the ground, influenced by surface and subsurface features, snow coverings, hollows, caves, etc., which usually moderate the extremes of the macroclimate.

And then we must not only look upon the physical ecological side of the problem but also upon its physiological side; that is, the enormous capacity of life to adapt itself to abnormal climatic conditions. With regard to the specific environment on Mars, we should consider the possibility of adaptive phenomena, such as storing of photosynthetically produced oxygen in intercellular spaces, as we find them in plant leaves; storing of carbon dioxide in the tissue fluids; storing of water, as in our desert plants; stronger absorbing power of the plant surfaces for infrared; and a shift in the reflecting power toward blue for temperature control, as it has been found in our subarctic plants. Protection against frost could be imagined, if the Martian plants were able to produce some kind of antifreeze, such as glycerol, as a metabolic by-product. When searching for clues in this respect, in botanical literature, I found that some of our terrestrial lichens de facto contain erythrol, which belongs to the same class of chemical as glycerol.

These are some theoretical considerations. What are the results of observational and experimental studies?

Dr. William M. Sinton, Smithsonian Observatory, found recently in the Martian spectrogram strong absorption bands near 3.4 $/^{u}$, the wave length of the carbon hydrogen band. This indicates the presence of organic molecules. "It seems unlikely, however," according to Dr. Sinton, "that organic material would remain on the Martian surface without being covered by dust from storms, or being decomposed by the action of solar ultraviolet, unless they possess some regenerative power." These studies support, therefore, the Martian vegetation hypothesis. A strong regenerative power was first postulated by E. G. Oepic.

Audouin Dollfus, from the Mendon Observatory, Paris, with L. Focas, Athens, Greece, made polarimetric and photometric observations of Mars and on mixtures of dirt and plant material. Their results, too, favor the vegetation theory.

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In Russia the outstanding Mars researcher is the astronomer, G. Tikov, at the Alma Ata Observatory. He started with his studies at about the same time that Percival Lowell, in Flagstaff, Arizona, published his famous book, "Mars as an Abode of Life," in 1909. Tikov concentrated on the optical properties (reflection and absorption) of terrestrial plants, and compared them with those of the dark green areas on Mars. Similar studies of the reflection spectrum of light have been made by G. Kuiper, Chicago, published in 1949, in his book, "Plane ary Atmospheres." Whereas Kuiper concentrated on the visible spectrum, which comprises the absorption band of chlorophyl, Tikov chose the infrared portion of the spectrum and made extensive comparative studies or plants which grow under severe temperature conditions, such as those found on the Pamir Plateau in South Central Asia and in the sub-Arctic. He reported that the colder the climate, the less is the reflecting power of plants in the main heat-carrying rays from infrared to red and yellow. Optically, this means that their color is shifted to the bluish side. Ecologically, it means that they absorb more heat. Since the dark areas on Mars show a strong bluish-green tint, Tikov thinks that the plants on Mars have developed just these optical properties for adaptation to the severe Martian climate. All of these properties, manifested in the color of plants are, essentially, adaptations to the general level of the environmental temperature. On Mars, therefore, where the climate is vigorous, the plants are of blue shades. On Earth, where the climate is intermediate, the plants are green; and on Venus, where the climate is hot, the plants have orange colors--according to Tikov. He has published his findings and conclusions in two books, entitled "Astrobotany," in 1947, and "Astrobiology," in 1953. He also founded a Department of Astrobiology with an astrobotanical garden at the Alma Ata Observatory.

Another scientist, Olga W. Trovizkaja, is not so optimistic. She is of the opinion that only anarobic (very cold-resistant micro-organisms) are conceivable in the Martian climate.

So you see, the problem of the green areas on Mars is far from being solved. Especially is it difficult to explain their rapid expansion in the Martian Spring. Following the melting of the ice-caps they progress toward the equator with a speed of 10 to 15 km per day. No such growth rate is known to us in the terrestria plant kingdom, as has been emphasized by Dr. Fr. Salisbury. Perhaps one could explain it with a dormant, drooped down position of the leaves during the winter--a kind of hibernation. Then, it could be imagined that in spring they expand in a horizontal position, fully exposed to the Sun, and to the eye of the astronomer.

Compared with our Earth, the opinion has been epxressed (G. Tikov) that a terrestrial climate, which comes nearest to that on Mars, with regard to temperature, radiation and humidity, is that on the Pamir Plateau, or on the high plateau of Tibet. As previously mentioned, the air pressure conditions on Mars correspond to those in the lower region of our stratosphere. So, if you combine the climate of the Pamir Plateau, or Tibet, and the air pressure milieu of our stratosphere, you have about the environment on Mars. It is much worse than in Tibet but friendlier to life than our stratosphere because of its higher temperature during the day.

A new experimental approach in astrobiology has been made recently by examining the behavior of terrestrial microorganisms under simulated Martian conditions in Mars Chambers, in the Department of Microbiology of this School. These studies, to date, indicate that certain kinds of soil bacteria perish; others, however, not only survive but increase in numbers during exposure to certain simulated Martian atmospheric conditions.

Such experiments must be extended under simulated Venusian atmospheric conditions in Venus Chambers. All of these studies with simulated foreign environments are, of course, of great interest, not only from the standpoint of astrobiology, but also of general biological and philosophical interest insofar as in this way the struggle for existence, as conceived by Charles Darwin, is shifted from a terrestrial to a cosmic level.

With regard to all of these discussions on the possibilities of life on other planets, I would like to emphasize that they, of course, are based on terrestrial biology; i.e., on the assumption of life as we know it on Earth, with carbon as the basic structure atom. One must not, however, orthodoxically preclude the possibility of other paradoxical forms and processes of life completely unknown to us, based, for instance, on other elements than carbon--for example, silicone, as the fundamental structure atom. This would be a kind of extracarbonic biology, or parabiology, and is a matter of everybody's imagination.

TABLE I

Main components of the terrestrial protoatmosphere and present atmosphere in order of abundance

Protoatmosphere	H_2	He	Ne	H_2O	NH_3	CH_4	A
Atmosphere	N_2	O_2	H_2O	A	CO_2		

TABLE II

Chemical Components of the Planetary Atmospheres

(After S. Hess, G. Kuiper, H. Urey, G. DeVaucoulers and Fr. Whipple)

Planets	Solar Distance in Million Km	Most important atmospheric chemical components in order of abundance				
Pluto	5910	H_2	He	CH_4*		
Neptune	4493	H_2	He	CH_4	NH_3*	H_2O*
Uranus	2872	H_2	He	CH_4	NH_3*	H_2O*
Saturn	1428	H_2	He	CH_4	NH_3	H_2O*
Jupiter	778.3	H_2	He	CH_4	NH_3	H_2O*
Belt of Asteroids	--	--	--	--	--	--
Mars	227.9	N_2	A	CO_2	H_2O?	O_2?
Earth	149.6	N_2	O_2	H_2O	A	CO_2
Venus	108.2	N_2	CO_2	H_2O	O_2?	--
Mercury	57.9	--	--	--	--	--

* - Probably in frozen state only.

6

LECTURES IN AEROSPACE MEDICINE

CELESTIAL BODIES

III. Moon, Mars, Venus

Presented By

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THE MOON, MARS AND VENUS

by

Clyde W. Tombaugh

For thousands of centuries, primitive man watched the moon with curiosity. It stimulated folklore in every land. He became filled with fantastic superstitions regarding the moon's influence on his life and agricultural pursuits. It is not hard to find vestiges of it among backward people in the United States today. Because of its monthly revolution around the Earth, the moon served as a convenient time-piece for primitive peoples to schedule events.

With the invention of the telescope, a new and vast realm was opened to man's exploration. In 1610, Galileo's tiny telescope revealed craters, mountains and plains on the moon. A number of early telescopic observers engaged in making maps of the moon's surface features. As telescopes of greater power were built, better maps of the moon were compiled. Toward the end of the 19th century, the long, achromatic refractor reached its peak in optical quality and power. The amount of detail visible on the moon was so overwhelming that each lunar observer had to limit his charting to small selected areas.

However, lunar and planetary astronomers met with a serious barrier. When looking at celestial objects with magnifying powers of several hundred diameters, the disturbances in our own atmosphere are correspondingly magnified to blur the image quite appreciably. If one applies more power, he may actually see less detail than before. The moving air masses of varying refractive index above the telescope act as lenses to deviate the rays of light. If the bending were uniform, no harm would result. Such is the case in a small telescope where the aperture intercepts a narrow pencil of rays, through which the air is essentially homogeneous. But then another air mass of different refractive index passes in front of the telescope, which causes a different amount of bending. The telescopic image then shifts in position by a few seconds of arc. The eye follows the shift in position, called "excursion", almost unconsciously if the movement is slow. But the effect is disastrous to a photographic image in which the energy from a particular detail is being accumulated and stored in a particular set of emulsion grains. This is the great difficulty in photographing fine and delicate lunar and planetary detail. The eye can follow such unpredictable oscillations of image position until the frequency approaches 1/10th of one second of time. Persistence of vision then begins to hamper the eye in much the same way as the photographic plate. Unfortunately, most of the time the excursions are rapid and the observer must wait for a momentary lull of longer duration in which he is able to "glimpse" some group of very delicate markings on the disk. This requires patience and perseverance, in addition to good eye-sight. Experience will increase his skill in the perception of difficult detail, whether it be minute crater-pits and fine clefts on the moon, or the so-called canals on Mars, or the delicate festoons between the belts of Jupiter.

Seemingly, one could dodge this difficulty by taking photographs with very short exposures of the order of 1/25 second of time or less. Obviously, this would require more light, hence a larger telescope. This means a larger pencil of rays to be intercepted through the atmosphere. The larger air masses involved are less likely to be homogeneous in refractive index. Consequently a portion of the pencil is deviated in one direction, while another portion is bent in a slightly different direction. The result is a smeared image at the focus. The probability of a larger mass of homogeneous air happening along is more rare in occurrence.

In planetary photography, one needs equivalent focal lengths of 100 feet or longer to obtain sufficient scale. This means an f 50 cone for a 24-inch aperture, or f 100 for a 12-inch. These are very slow photographic systems, which require exposures from 1/2 to 2 seconds in time in photographing the moon with the most suitable emulsions through the proper filters. But, the eye sees this detail in 1/10th of a second.

In order to obtain the maximum possible resolving power, it is necessary to use as much aperture as the atmosphere will allow. Only during brief moments on the best nights, can one use mirror or lens diameters as large as 20 inches to advantage. Such apertures will yield magnifying powers up to 800 diameters. But this is the practical limit, as larger apertures and higher powers begin to show less detail. An experienced visual observer using a good 6-inch telescope with 200 power, can see as fine detail on the moon as has ever been photographed.

Reflecting telescopes are more useful for photographing over a greater range in wave-lengths because they are immune to secondary chromatic aberrations.

Unfortunately, visual observations and drawings are subject to personal error, but it is the only method to date which can record the finest detail. It is the inexperienced and fanciful observers who give rise to disagreement and confusion. Some experienced observers see well, but cannot draw well.

Several well-known investigators have advanced explanations and origins for various lunar features from their own perusal of the best lunar photographs. Some appear sound and others are untenable. If they could have had the benefit of visual telescopic acquaintance with the moon's features under superior conditions, they would have never set forth some of their interpretations in writing. On the other-hand, there have been many sharp observers with no background knowledge of physics, mathematics, geology or chemistry who have gone sadly astray. Still other investigators have made brilliant analyses of some lunar problems and foolish ones in some others. Several geologists have steadfastly refused to even consider the possibility of external origin for any of the moon's craters. In spite of over-whelming evidence such as the distribution of meteoritic iron, it is disappointing to learn that many geologists do not accept the extra-terrestrial origin of Arizona's great meteorite crater. Therefore, the audience may be prepared to understand that there is much controversy about the origin and nature of the moon's features. I have myself been rather unsettled about certain interpretations and conclusions over the past 35 years of telescopic observation and study.

It is impossible in a single lecture to review in an adequate way the history of lunar exploration and study. I make no claim to cover all of the salient facts.

Many early scholars thought that the moon was once part of the Earth, and that it was thrown off by rapid axial rotation and then pushed farther and farther from the Earth by tidal action. Dr. Kuiper thinks that the moon evolved from a separate and lesser proto-mass near the greater proto-mass that was destined to be our home. Within the past few decades, physical chemistry has greatly aided in our understanding of planetary evolution. More recently, nuclear physics and astrophysics have thrown much light on the formation of the elements and their relative abundances.

Man has long been acquainted with volcanic activity. It was natural that early ideas on the origin of the moon's craters should consider plutonic forces. I must admit that in my younger days, I was quit plutocrat myself, in more ways than one. Nasmyth and Carpenter of the Royal Observatory at Greenwich in their book, "The Moon," published in 1885, elaborately described the formation of the various aspects of the lunar craters. But they specifically stated that the lunar maria defied explanation. At this time very little was known about terrestrial impact-craters. No drillings had been made in the Barringer crater near Winslow, Arizona. The great Siberian falls in 1908 and 1947 had not yet occurred. No asteroids were known to cross the Earth's orbit. The Earth had plunged through the tail of the great Comet of 1861 without perceptible effect.

Two outstanding differences characterized the lunar craters from terrestrial volcanoes. One, the floors of the lunar craters lay thousands of feet below the general level of the moon's surface. Second, the diameters of the lunar craters far exceeded any similar features on the Earth. These perplexing features induced students of the moon to attribute the events of formation to peculiarities attending the crust-congealing stage. All such ancient scars on the Earth were erased by the many erosional cycles that followed in succession during its long geological history.

Before proceeding to a more detailed discussion of the moon's surface features, let us get acquainted with their appearance (Slide #1). The moon is just barely past full phase. The terminator (the boundary line between the moon's night and day) is just beginning to show on the moon's western edge. The sun is setting on these regions to be subjected to intense cold and darkness for two weeks. Lunar temperatures have been measured with a very sensitive thermocouple placed in the focus of a reflecting telescope. In the moon region of the equator at lunar moon, it is $+134^{o}$C., which is 64 Fehrenheit degrees above the boiling point of water at sea level pressure. By lunar sunset, the temperature drops to -50^{o}C., and must approach absolute zero before sunrise. During a total eclipse when the moon passes through the Earth's shadow (always at full moon) the temperature falls from $+134^{o}$C. to -117^{o}C. in about two hours! (a drop of 251^{o}C., or 452^{o}F.)

The large dark areas, comprising 2/5ths of the hemisphere that we normally see, are the so-called maria. Long ago, they were thought to be bodies of water, hence the Latin names. The largest is called Oceanus Procellarum. Here is the Mare Imbrium, bounded on the south-west by the greatest mountain range scarp known on the moon, the Lunar Apennines, 420 miles long. Here is Mare Serenitatis, whose western and northern fringe shares the darker material of neighboring Mare Tranquilitatis. Several conspicuous patches of very dark material are seen in Sinus Aestuum region. Near the terminator is the isolated Mare Crisium, completely enclosed by lofty mountain walls, and not too different in appearance from another class of objects known as "the mountain-walled plains" _ the largest of crater forms. The latter are lost in the glare of high angle illumination. Here is Mare Humorum, which will be shown in great detail under the lighting condition of lunar sunrise on the third slide.

Lastly, on this slide, are the curious, radial systems of bright rays. At the hubs of these systems are another brand of craters known as the "mountain ring-plains", whose characteristics differ basically from the mountain walled-plains. The king of them all is Tycho, which has the longest rays. One appears to extend along a great circle of arc to a distance of two thousand miles. But some selenographers are doubtful that the portion which crosses Mare Serenitatis really belongs to Tycho, that it may have originated from Menelaus. The grey ring around Tycho is unique, and has been the source of much speculation. Note the prominent double ray, whose components are parallel _ a striking resemblance to the double canals of Mars. The second greatest bright ray system belongs to Copernicus, which has several pairs of parallel rays. Here is the spiked system of Kepler. Here is Aristarchus, the brightest patch on the moon. On the eastern side of Mare Crisium is the bright ray system of Proclus. There are several other systems near the limb of the moon, such as Olbers to the east of Kepler. The bright ray systems are best seen under high solar illumination.

Slide #2 is a photograph taken from days before full moon. The bright ray system of Kepler is not nearly as conspicuous under a low morning sun. The shadows cast by elevations in the regions near the terminator greatly enhance the visibility of the craters. Note the ring-plain, Plato, whose floor appears to have been flooded with dark lava, which may have leaked in from the Mare Imbrium. Plato is really round, but appears oval-shaped because of foreshortening, which increases toward the limb of the moon. Note also the famous Bay of Rainbows, technically known as Sinus Iridum. The distance between the tips is 140 statute miles. Also shown is the great mountain walled-plain, Gassendi, 55 miles in diameter.

This excellent photograph (Slide#3) was taken by the late Dr. Lampland at the 80-foot cassegrain focus of the 42-inch reflector at the Lowell Observatory June 4, 1914. Gassendi existed before the formation of Mare Humorum. The floor of the crater slopes gently downward toward the mare, where its southern portion has been invaded by the lava flood. The southern rim was partially melted and buried. The ancient walled plain, Doppelmayer, 40 miles in diameter, suffered greater destruction. Relatively few craterlets were formed on the new lava surface after it congealed. Compared to the number of craters on pre-marian surfaces, it is evident that the maria formed either relatively late in the moon's history; or else, that the rate of formation was much less.

Three beautiful, concentric cracks, over 100 miles long, appear at the western side of Mare Humorum, and they indicate shrinking of the mare body of lava after congealing, with further loss of heat. The lava lens of the mare is thinnest at the edge; consequently, the fracturing logically occurs there. The great majority of cracks, known as rills or clefts, occur at the edges of the various maria. They are not found in the central areas of the maria. Other long cracks are seen in the eastern environs. Associated with several maria are adjacent local regions that are thickly strewn with hills. The sun is only about 3 degrees above the lunar horizon here, yet the shadows are quite short, denoting low elevations. The smallest hills shown here are about a mile across with heights of only 100 to 200 ft. This indicates basaltic lava, which does not pile up like silica lavas. The dark shade of the maria also is suggestive of basaltic composion. It is no mere accident that these bordering areas of low hills are associated with the maria. These hills are undoubtedly minor volcanic extrusions from the same magma reservoirs which gave birth to the maria.

Several clefts are shown on the floor of Gassendi. Much additional and finer detail can be seen visually under superb seeing conditions. The great English selenographer, Neison, shows 36 clefts on his chart of Gassendi, most of them are found on the western half of the floor. Lastly, note the very low wrinkle ridges on the Mare Crisium.

[illegible] #4 shows the Mare Nubium. Near the top is one of the greatest and longest lunar clefts. Note that it continues perfectly in the same direction on the other side of this mass of mountains. On the left is the famous Straight Wall, 60 miles in length. Not only is it a fault-fracture; it is also an escarpment. The mare side (to the right) is 800 feet lower in altitude. It divides an old pre-marian crater, the east half of which is visible only under a low sun. At last quarter phase, when the sun is shining from the right, this escarpment shows no dark shadow, but is a bright line instead, because the sun is illuminating a cliff. It is so straight that early lunar observers mistook this for an artificial work. It should be noted that both of these great clefts lie near the edge of the mare.

Just to the east of Kies, is the most outstanding example of a lunar strato-volcano. It is definitely an elevation above the surrounding mare, as can be seen from the direction of the shadow. Its base is 9 miles across, and its summit is 2000 feet high. Under visual observations, I have distinctly seen a craterlet some 3000 feet across in the center of its summit. The relatively low height ratio to the width of the base implies a gentle slope, which again is indicative of basaltic lava. Over enthusiastic proponents of the impact hypothesis claim that the craterlet at the summit is a chance hit. If this were so, there ought to be a few similar craterlets on the flanks or immediate environs, but I have seen none. It has been suggested by those who advocate that the craters found on the maria are collapsed gas bubbles, that this unusual formation is one which failed to burst. It seems doubtful to me that the low arch could sustain it from eventual collapse, especially since there would be severe jars in the moon's crust occasionally from asteroid hits. The ring-plain Bullialdus, 38 miles in diameter, is obviously a great explosion crater. On all sides the immediate environs are scarred by radial ridges and valleys.

Slide #5 is the largest walled-plain that is well presented to view on this side of the moon. It is named Clavius, 142 miles across. The floor lies 12,000 feet below the rim. Like similar neighboring formations, Magnius and Longomontanus, the rims of the walled plains protrude scarcely at all above the general level of the moon's surface. In contrast to them is Tycho, a ring-plain whose floor is also 12,000 feet below its rim, but the rim rises considerably above the general lunar surface. Dr. Alter calls Tycho a "violent explosion crater." The volume of the rim material would refill the crater. The central peak is 5,000 feet high, but lacks 7,000 feet of reaching the level of the rim. Of importance in lunar isostasy is the fact that no central peak protrudes above the general level of the moon's surface.

Slide #6 shows the southern section of the moon, but 4 days after full moon. It is the roughest region on the moon, and represents the largest section of the very old, pre-marian surface. Note the Altai

Mountains, which is a great scarp. The great ring-plain, Theophilus, 64 miles in diameter, is also an explosion crater, similar to Tycho and Copernicus. Peaks on its rim rise 14,000 to 18,000 feet above the floor. It is evident that Theophilus is more recent in origin than its neighbor Cyrillus. If you look closely, there is a remarkable long row of craterlets running from the south rim of Abulfeda toward Catherina. This example is a strong argument for volcanic origin along some fault line. But, these craterlets are holes, not elevated cones. Perhaps one may relieve the difficulty by considering these craterlets as the product of mere gas eruptions without the accompaniment of extruded magma. If we admit this, then where do we draw the line in distinguishing small impact craters from volcanic ones? Impacts from foreign bodies must inevitably pulverize the country rock. Therefore, craterlets with bright nimbi may be singled out as being of impact origin. Those craterlets not possessing a bright nimbus must be the product of volcanic de-gassing.

Slide #7 is Theophilus again on a larger scale, and further from the terminator.

Let us now review and contrast the characteristics of two great classes of craters. They probably have very different modes of origin.

Dr. Dinsmore Alter, Director Emeritus of the Griffith Observatory, has given much careful study to the moon in recent years. He has taken an excellent series of deep red and infra-red photographs of the moon with the 60-inch reflector on Mount Wilson. He lists the properties of the mountain walled-plains as follows: (Slide #8)

1. They are very shallow with respect to their diameter, as shown by their profiles, notwithstanding that the floors are many thousands of feet below the surrounding terrain.

2. They have little or no external walls.

3. They seldom have central peaks.

4. The walls are not circular, but tend toward hexagons.

5. They have diameters from 40 to 160 miles.

6. They are found only in mountainous areas. None are known to exist on the maria.

7. They resemble the maria in some ways.

8. The floors tend toward smoothness.

9. Many small craters are found on their rims, which indicate sinkings along fault lines.

10. Some exhibit numberous "ghost" rings on their floors.

11. They become inconspicuous under a high sun.

12. They have no bright-ray systems.

13. They often show definite relationships to their neighbors, such as rows of three.

In this slide, the apparent convex floor is the curvature of the moon's surface, which is 4 times greater than the Earth's because the moon's diameter is only 2,160 miles. If an observer stood in the center of the floor of Clavius, he would be unable to see the rim because the curvature would place it below his horizon.

These data indicate strongly that the typical mountain-walled plains are not due primarily to explosions either from interval or from external causes.

Some investigators advance the hypothesis that the walled plains represent the collapse of great domes raised by gas pressure. I am inclined to think that they represent the remains of enormous volcanic caldrons in the crust, caused by the twice daily high tide when the moon was rotating on its axis.

Dr. Alter lists the characteristics of the second great class of craters, known as the mountain ring-plains, which he calls the "explosion" craters.

They are: (Slide #9)

1. The explosion craters have definite external walls, as shown in their profiles.

2. Many of the explosion craters brighten very much under a high

sun (which is undoubtedly due to much pulverized debris).

3. Their rims are quite circular.

4. They are found on both the maria and the mountainous highlands.

5. Many radial lines of craterlets exist on the outer walls and surrounding areas of a number of the ring-plains. These often form numerous clefts, which tend to be radial to the great explosion, such as are found around Tycho and Copernicus.

6. Some of the outer slopes exhibit ridges and intervening valleys, which give the casual impression of having been formed by outflowing tongues of lava, such as on Aristoteles.

7. Central hills or groups of hills are common. Craterlets have been seen on the summits of many central peaks, and it seems probable that the central peaks represent the product of secondary volcanism, generated by the impact of an asteroid. It is also worthy of note, that the summits of the central peaks fall a few thousand feet short of attaining the level of the rim.

8. Those which exhibit extreme violence are the hubs of radial bright ray systems, which traverse about everything in their paths, indicating that they are among the most recent catastrophic events. Those exhibiting moderate violence have merely bright nimbi around them without the bright rays.

The evidence of extreme violence is so great that one must agree with Gilbert, Baldwin, Urey, Kuiper, LaPaz, Leonard, Nininger, and others that, at least initially, these craters have been formed by asteroidal impacts.

Since 1932, a dozen asteroids ranging from 1/2 to 2 miles in diameter have been discovered, whose orbits cross the paths of the moon and the Earth. In 1936, one of them missed the Earth by only 600,000 miles. There is the possibility that the Earth or the moon may sometime collide with some of them. Since these asteroids were discovered accidentally, the dozen known probably represent a small minority of those possessing the possibility of collision.

Slide #10 is a logarithmic graph prepared by Baldwin, showing the relationship of diameter versus depth of shell craters, bomb craters, terrestrial meteorite craters, and the lunar craters. This curve obeys Ebert's rule: That as the diameter of a crater increases, its relative depth decreases.

Slide #11 is another logarithmic graph by Baldwin, showing the relationship of diameter versus rim height. If he limited the data here to the class of ring-plains, it looks to be of the right order. Otherwise, then, the walled-plains should have clumped along an abscissa to the right of the curve between rim height log 2 to 3. But, he has none represented here.

Now let us consider further the problem of the lunar bright rays, (Full Moon) first listing their principal characteristics: (Slide #12)

1. They are exclusively associated with ring-plains and craterlets which brighten greatly under a high sun. None are associated

with mountain-walled plains. This strongly suggests that the lunar bright rays are the products of violent impacts, in which a great deal of rock was finely pulverized.

2. The ring-plain craters at the hub of the bright ray systems are the roughest and freshest-looking formations of all. That these craters represent the youngest features is further borne out by their habit of always invading older formations.

3. They are most definitely post-marian in origin, since the same rays traverse stretches of highland and maria alike.

4. There are over a hundred bright ray systems visible on this side of the moon. The majority of them issue from minute, intensely white craterlets hardly more than a mile in diameter.

5. Area for area, the bright ray systems are somewhat more numerous on the maria, which is undoubtedly due to the better contrast provided by the darker terrain.

6. The lunar bright rays do not become easily visible until a high angle of illumination is reached. However, there are some exceptions. The systems of Kepler and Aristarchus can be seen even when the hub-craters are very close to the terminator.

7. They reappear at the same phase each month.

8. In systems connected with the larger ring-plains there is a strong tendency for the longer rays to be tangent to the walls of the crater. The classic example is the long double and parallel ray running northward from Tycho over a distance of some 500 miles.

At first glance, Kepler appears to be an exception, but careful observation shows that some of the radial spokes are composed of two converging tangential rays from opposite sides of the crater.

9. The bright rays themselves show no relief above the general terrain level. They appear to be a superficial covering of finely divided material.

Many explanations have been advanced for these most curious of all lunar features. Some of the earlier lunar observers thought the rays were caused by sunlight being reflected from metal which had congealed down in the bottom of cracks. Tomkins of England suggested that they might be alkali tracts similar to those found in India. Chacornac seems to have been the first to suggest that the rays might be due to the deposition of fine white powder thrown out from craters by volcanic action upon a darker background. In 1919, airplane photographs of craters formed by exploding bombs dropped from planes led Ives to propose that the lunar rays represent material ejected by meteoritic impact rather than by volcanic action.

The fact that all of the lunar-bright ray systems emanate from bright craters with protruding rims indicate that the impact of foreign bodies is the primary cause of origin. The change of visibility of the rays with the elevation angle of the sun was simulated in an experiment performed in 1932 by Buell and Stewart in a vacant 79 foot elevator shaft. A strip of pulverized basalt was strewn with basalt pebbles. As the illuminating lamp was placed at higher angles of incidence, the shadow of each pebble shortened, allowing more area of the highly reflective rock flour to be directly illuminated.

Recently, a few theorists have argued that the lunar maria are deeply covered with dust, and that they are unfit for rocket landings. Several observational facts refute such a conclusion. Since this problem is of particular importance to immediate space efforts, it may be of interest to list the objections:

1. The visible remains of partially destroyed craters on the borders of the maria is proof that the maria were formed at a much later time in the moon's history. There are abundant indications that the maria were once bodies of fluid magma, which sought their level and congealed. Consequently, this new surface was subjected to less meteoritic erosion, in accord with the scarcity of craters on their surfaces compared to the number on the brighter highlands.

2. The bright rays possess a much greater contrast on the maria than portions of the same rays crossing the highlands. The experiment with basalt rock flour and pebbles suggests that the difference in brightness can be due to the degree of pulverization. Rock in massive form is darker.

3. Measurements of polarized light from the maria run as high as 16 per cent, compared to 8 per cent on the highlands.

4. Great clefts are found in abundance on the maria near the borders parallel to the shoreline. These appear to have resulted from contraction with further cooling after congealing. The fracturing took place near the borders where the new body of solidified magma was thinner. The fact that fractures occurred is proof of the massive character of the maria bodies. Had they been composed of deep, unconsolidated debris and dust, they would have been filled shut by the terrible moonquakes attending the impact of asteroids which produced the great post-marian ring-plain craters.

5. The craters on the maria are the freshest looking. It is on the old brighter highlands that the craters exhibit signs of deterioration. A great number of the latter are old ring-plains of duller lustre. One wonders how many old bright ray systems have been obliterated by superficial erosion from small meteorites.

The nature and composition of the lunar bright rays seem fairly well established; but the manner in which such remarkable systems were produced, is in a state of confusion. It is commonly believed that the rays were blobs of fine debris shot out radially by the force of asteroidal impact and that particles steadily dribbled down to form the ray. But it seems to me that this concept has some serious shortcomings from the standpoint of mechanics. A clump of loose debris to which a certain speed and direction has been imparted will spread out as it recedes from the point of origin, because each particle will retain its particular azimuth angle. There are examples of this kind in the southern part of Mare Imbrium, but the rays are short. Such features could be laid down only under the vacuum condition prevailing on the moon.

The long rays which retain a narrow linearity, especially those from Tycho and Olbers, are quite continuous. It is extremely difficult to see how space-borne debris could be steadily dribbled down in such a manner. It would require a great range in either the speed of the individual particles, or else in the elevation angles. Neither of these suppositions can be reconciled with such a tight confinement in azimuth. Grounds for dismissing the dribbling process appear to be substantiated in what is observed on the planet Mars. (Slide #13)

The lunar bright ray systems bear some resemblance to the oasis-canal patterns. The latter are much more difficult to see because Mars is about 200 times farther away; hence, the patterns are imperfectly seen. Indeed, only during moments of a second or less are the canals seen at all during the best nights and with telescopes of high optical quality working under the proper parameters for fine planetary detail.

This slide is a map of Mars that I compiled from hundreds of careful drawings by several skillful independent observers. I spent an entire month sifting through this material, omitting the very difficult canals which were not well confirmed among the various observers. This is the first time that the markings of Mars have been plotted on the Mollweide projection, whose properties were the best suited to portray the entire global network much as we see it in the telescope. The Mercator projection badly exaggerates the scale in high latitudes, whereas, a projection is needed to represent the higher latitude regions in somewhat of a foreshortened manner as we really view the planet.

Note the dark spots called "oases," and the radial lines issuing from them, which in most cases are arcs of great circles. There is a considerable resemblance to the great bright ray systems on the moon. Mars is just twice the diameter of the moon. Many of the canals are over 1,000 miles in length. A great many of them appear to be inter-connected, and generally emanate from the centers of the oases. Gehon II is an exception where single canals are tangent to the oasis (Slide #13), like some of the single rays from Tycho. Many of the bright rays of Copernicus connect with those of Kepler and Aristarchus. The double canals are parallel and tend to originate from the opposite sides of the oases, just as the double bright rays on the moon. There is one outstanding difference in the comparison. The oases and canals of Mars are dark; whereas, the corresponding central spots and rays on the moon are bright.

Except for the most easily seen members, the various oases and canals are visible only during the summer season of each respective hemisphere.

A series of photographs taken by Dr. E. C. Slipher at the Lowell Observatory shows what appears to be a wave of vegetational development. Curiously it proceeds from a high latitude which is the first to receive the benefit of water vapor from the polar cap. ....
Above the Fork, the area appears light like the desert areas. By mid-summer an intense greenish darkening takes place, which is hard to explain unless we ascribe it to the seasonal quickening of vegetation.

Mars is endowed with an atmosphere with a surface density of 1/12th that of our own. The transfer of about all of Mars water to the other polar region each half Martian year requires the medium of an atmosphere.

The astronomers of the 19th century thought that the dark areas on Mars were bodies of water, hence the designation as maria. Serious doubts arose when better observations revealed that the maria changed color with the seasons. In 1892, dark streaks were seen crossing the maria, which dispelled the idea of seas. Vegetation appears to be the better explanation of the maria. Lowell then thought that these areas had been the sites of oceans in past ages. But he overlooked the fact that these areas would have been sterile with a covering of salt. Neither is there the slightest vestige of a dendritic erosion pattern. Therefore, it may be inferred that Mars never had any seas of water. The shapes of the Martian maria are remarkably angular; whereas, the lunar maria are circular. What kind of origin would have produced these characteristics?

Mars is near the asteroid belt. Many of the asteroids have eccentric orbits. A dozen small asteroids have been discovered which cross the

Earth's orbit. These probably represent only a small fraction which do so. Many more undoubtedly cross the orbit of Mars. Through the ages, Mars must have been hit many times by some real crust busters. Eros is a huge irregular rock 13 miles long and 4 miles across. It swings out past the orbit of Mars about as far as it swings inside. Collision with such a body would be a fearful spectacle. Since it appears that Mars has not had water erosion to destroy old features, there must surely be scars of such encounters on its surface. The oasis-canal patterns probably are the products of such collisions. Macroscopically, igneous rock tends to be isotropic in strength, and under very sudden shock would fracture like a stone hitting a windshield. Where the fracture shocks met the surface, the rock would be shattered in long strips across the Martian landscape. Broken rock would offer a protective haven for hardy vegetation on a cold planet. This would explain why these systems on Mars are dark. In theory, fractures which pulverize material along their edges is more acceptable because fine debris could never travel very far through the Martian atmosphere.

As a planet contracts slightly through some loss of internal heat, the volume is obliged to contract slightly. Sections of the Martian crust, sheared free by intersecting fractures, can sink down thousands of feet. This provides a denser atmosphere and greater warmth over the sunken areas, making them more favorable for the growth of vegetation.

Another example is the Margaritifer Sinus (Slide #13). The dark oasis at its tip appears to be the site of the asteroid impact. It produced a crater about 40 miles across. At times, an enlarged penumbral fringe is visible, which may represent temporary vegetation on the broken rock outside of the crater rim. A hypothetical relief is portrayed along the lines AB and CD. The Margaritifer Sinus also has a lighter bar across it which indicates the site of the crustal hinge. This is a case of a mare being formed from two bounding fractures from a single impact.

What caused such a difference between the Martian and lunar maria? At present, I can offer only some speculative explanations. Since the two satellites are very small and its distance from the sun is greater, Mars would enjoy almost complete freedom from tides in the crust. The moon, on the other hand, was subjected to severe tides, especially when the moon was much closer to the Earth in the past then it is now. Before the moon's axial rotation slowed to a standstill, twice daily a huge tidal wave with a crest height of a hundred feet or more must have swept through the solid rock. This enormous friction may have melted vast quantities of rock, thereby providing reservoirs of magma for the sudden, colossal outpouring that formed the lunar maria. As the rotation slowed down the crests may have grown higher and higher until the crises of crustal collapse occurred. The mountain walled-plains may have been the cauldron pots of this crucial period. After the moon's rotation stopped, there were no more tidal waves __ only a permanent lengthening of the moon diameter toward the Earth by 3/5ths of a mile. Large scale congealing then took place. This may account for the fact that no more walled-plains were formed, as may be inferred from their total absence on the maria surface. It is also significant that the surface of Mars is not thickly covered with craters as are the old lunar highlands, which suggests the absence of walled-plains. Only the collision ring-plains may be found on Mars.

There are many other important aspects of the moon and Mars, that have not been touched upon in this discussion. The account of Mars is especially incomplete. Some of these are set forth in my articles in the January and December issues of Astronautics last year. The subject of the Moon and Mars is much too extensive for a single lecture. I have merely attempted to bring to you some new interpretations on the nature and evolution of these planetary bodies.

VENUS

Venus is a planet of mystery. It is almost the size of the Earth and comes closer than any other planet, but far less is known about it than Mars. The rotation period of Mars is known to an accuracy of one-thousandth of a second, while that of Venus is really unknown. The reason is that markings on Venus are notoriously difficult to observe.

On a few rare occasions, I have been able to see darkish stripes in the visual wave-lengths. In March of 1937, I was able to follow a dark stripe some 6,000 miles long for a few hours each day over a span of 20 days. Not the slightest movement could be detected. This would indicate a rotation period several months long; indeed, if not keeping the same face to the sun.

Infra-red photographs, to-date, have been rather fruitless. Radio observations have given repetitions of signals that have been interpreted as indicating a 22 hour period. (Next is Slide #15)

Bright stripes are easily recorded on ultra-violet photographs. They tend to be, more or less, parallel to each other and perpendicular to the terminator. This is suggestive of rapid axial rotation. But when the pattern changes suddenly to that in the second image within 24 hours, one doubts that axial rotation is the governing factor.

These images are careful drawings of the markings recorded on

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our ultra-violet photographs taken at Las Cruces, New Mexico.

In our project, ultra-violet and infra-red photographs are taken on every possible day. This slide shows the appearance of Venus in ultra-violet from 14 April to 28 June of 1959. The purpose of this patrol is to ascertain the pattern of change over a long period of time and to seek correlation with other phenomena, especially solar activity. Very few photographic patrols elsewhere have continued for more than a few weeks. Breaks in the records are very undesirable because one misses the steps in a change. Las Cruces lies in the 85 per cent sunshine belt at 3900 feet altitude, and we miss very few days. We photographed Venus through inferior conjunction with 8 degrees of the sun. A prolonged record may possibly lead to a better determination of the rotation period and the inclination of the axis.

The other method of obtaining a rotation period is by means of the Doppler principle in observations with a high dispersion spectrograph. One of the most exhaustive investigations of this kind was undertaken in 1956 by Dr. Richardson, using the powerful spectrographs at the Mount Wilson Observatory. He obtained 30 spectrograms with the slit oriented in different position angles. The extreme difficulty of this problem may be inferred from his summary of the reductions, quote:

" The velocities can be represented rather closely by a normal error curve. The mean of the 102 measures is _0.032 km/sec, corresponding to a period of 14 days, retrograde. The standard error of the mean is ±0.033. We may interpret this result in different ways:

"a. The direction of rotation is retrograde, with a period between 8 and 46 days, a statement with one chance in two of being correct.

"b. The period is longer than 14 days direct, or longer than 5 days retrograde, a statement with 16 chances in 17 of being correct.

"c. The period is longer than 7 days direct, or longer than 3.5 days retrograde, a statement with 134 chances in 135 of being correct."

It is of interest to compare these results with earlier work. V. M. Slipher, from his spectrographic measures in 1903, obtained a small retrograde velocity of rotation with a relatively large probable error. In the early 1920's, St. John and Nicholson also obtained a small retrograde equatorial velocity with a probable error of the same order. They felt it unlikely that Venus rotates in the opposite direction from the Earth and Mars. On the assumption that the rotation is really direct, they interpreted their results by saying that the chances are about 10 to 1 that the period is longer than 20 days.

Quoted from page 259 in the June 1958 issue of Publications of the Astronomical Society of the Pacific, "RADIO OBSERVATIONS OF VENUS: Radio signals of an impulsive nature, resembling those from Jupiter, have been recorded from Venus by Kraus at the Ohio State University. The radio observations were made from February to July, 1956, with April omitted, and thus overlap our spectroscopic observations. The fluctuations recur about every 13 days, and show a distribution pattern that is repeated from 1.6 to 1.85 hours earlier on successive days. Kraus believes the 13-day interval is not the true rotation period, as it seems to him unlikely the activity would be repeated by a pattern advancing a fixed amount each day. Rather he has concluded that the 13-day interval represents the beat frequency between the rotation periods of the earth and Venus, and that the probable value of the rotation period is 22 hours 17 minutes, with an uncertainty of ± 10 minutes. The radio observations do not indicate the direction of rotation.

Such a short period seems difficult to reconcile with the spectroscopic observations. A possible explanation is that the spectroscopic observations were taken in high planocentric latitudes, but this is ruled out if we accept the values for the orientation of the axis determined from the ultraviolet photographs. Also, if the rotation period were only 22 hours, the disk should be sensibly oblate, but numerous measures made when Venus was in transit across the sun have failed to reveal any evidence of polar flattening. It would seem more likely that the 13-day period is the right one, and that the daily advance of 1.6-1.85 hours arises from some local disturbance in the planet's atmosphere."

Radiometric observations for the determination of temperature have been about as futile. Pettit and Nicholson at Mount Wilson obtained values for the mean temperature of the dark side of -37°C, and -42°C. for the bright side. The night temperature before inferior conjunctions was found to be about 6 o/o lower than after, which is consistent with direct rotation and cooling at night. Strong and Sinton found a temperature of about -40°C for the dark and sunlight hemispheres, but were unable to establish the direction of rotation. The fact that the dark and sunlit hemispheres are at nearly the same temperature is a strong argument against a long rotation period, although it is difficult to set an upper limit.

However, there are some important tentative deductions which follow. The -40°C is that temperature at which all water droplets

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crystallize out into ice spicules.

Even at saturation, the amount of water vapor at this temperature is extremely small far less than the driest air over a mountain observatory, hence the difficulty of spectroscopic detection. Dunham's observations were negative. His analysis places the upper limit of water vapor in the atmosphere of Venus at 2 to 5 per cent of that above the Mount Wilson Observatory. The very small range in the temperature readings between the day and night sides of Venus, together with this critical temperature is suggestive that water is involved, which would greatly stabilize the condition.

Whatever this Venusian cloud canopy consists of, it is extremely difficult to penetrate it. All kinds of measurements can only deal with the amount of atmosphere above this level, which must be a very small fraction of the whole. The temperature values are those of the cloud surface.

The amount of carbon dioxide in the Venusian atmosphere has been observed to be abundant — of the order of a half km. or more at sea-level pressure. This implies vigorous volcanic activity, but where is the copious water vapor that attends such eruptions? Fortunately for us, the great bulk of CO_2 was removed from our atmosphere about as fast as it was supplied. Think of the consequences to life on the Earth if the CO_2 content in the thousands of feet of limestone and dolomite beds was part of the

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atmosphere and not locked up in these rocks!

Two prevailing conditions operate to remove the excess CO_2 from our atmosphere; either one by itself is insufficient. First, there must be water erosion to dissolve the salts from weathered rocks and carry them in solution to the sea. The sodium cloride or common salt is the best known one. But the important salt in this case is one of calcium. Through the medium of the oceans, the CO_2 in the atmosphere is absorbed and united with the calcium to form limestone ooze, which is laid down at the rate of about one foot in thickness per century in the more favorable places.

The large content of CO_2 in the Venusian atmosphere indicates that one of the conditions for the production of limestone is absent. Either the planet is all ocean, which would eliminate the rock-weathering process for the supply of calcium; or else, the planet's surface is all land, which is incapable of precipitating calcareous ooze.

One school of interpretation concluded that Venus was without oceans. With the slow rotation, the sunward side becomes very hot, which sets up violent winds for exchange of heat with the dark, colder side. This condition would result in a world-wide dust bowl. The swirling dust clouds prevented our seeing the surface.

In the meantime, the French Astronomer, Lyot, made some important observations of the planet's polarization. He found that only water droplets give a satisfactory representation of the variation of polarization with scattering angle on Venus. H. C. van de Hulst conjectures that small globules of quartz might exhibit similar behavior. H. Suess suggests that salts might be responsible. The latter might be caused by salt spray carried aloft.

In 1955, Menzel and Whipple published a paper, in which they made a pretty good case for H_2O clouds on Venus. Quote of a passage is as follows:

- - - "A second even more serious observational discrepancy occurs in those hypotheses requiring that the Venusian clouds be made of dust. Lyot's polarization data clearly indicate that the particles in the Venusian clouds are considerably larger than the wave-length of visual light, of the order of 2 microns in diameter or greater, and surprisingly uniform in size. There is no difficulty in reconciling these facts with the pertinent properties of water droplets. On the other hand, dust clouds from surface material would have been formed by grinding processes, and we should expect to find a large range of particle sizes present. - - - We are confronted with the difficulty that the particles in the high-level clouds of postulated dust on Venus are somewhat large for airborne dust at high altitudes.

"If Venus is completely covered with water, the air would be exceptionally free from all kinds of dust or nuclei. Consequently supercooled cumulus clouds may well be much more abundant than cirrus, on Venus." End of quote.

It is of interest to note the differences in albedo between the Earth and Venus. Recent values by Kuiper are 39 and 76 per cent, respectively. This gives a ratio of 1 to 1.9, which is almost exactly compensated by the insolation difference from the squares of their distances from the sun.

However, the large CO_2 content will greatly increase the greenhouse effect.

Radio observations with the 50-ft reflector at Naval Research Laboratory indicate that the centimeter wave length spectrum of Venus near conjunction seems very close to that of a black body with temperature about 550°K.

In any case, it must be very hot near the surface, so hot that a considerable fraction of its hydrosphere may be in vapor form, generating tremendous atmospheric pressure. This pressure, in turn, would greatly raise the boiling point and thus prevent the condition of all of the water going into vapor form. The equilibrium pressure for a temperature of 550°K is about 60 atmospheres.

Finally, on 29 November 1959, Commander Malcolm Ross, U. S.

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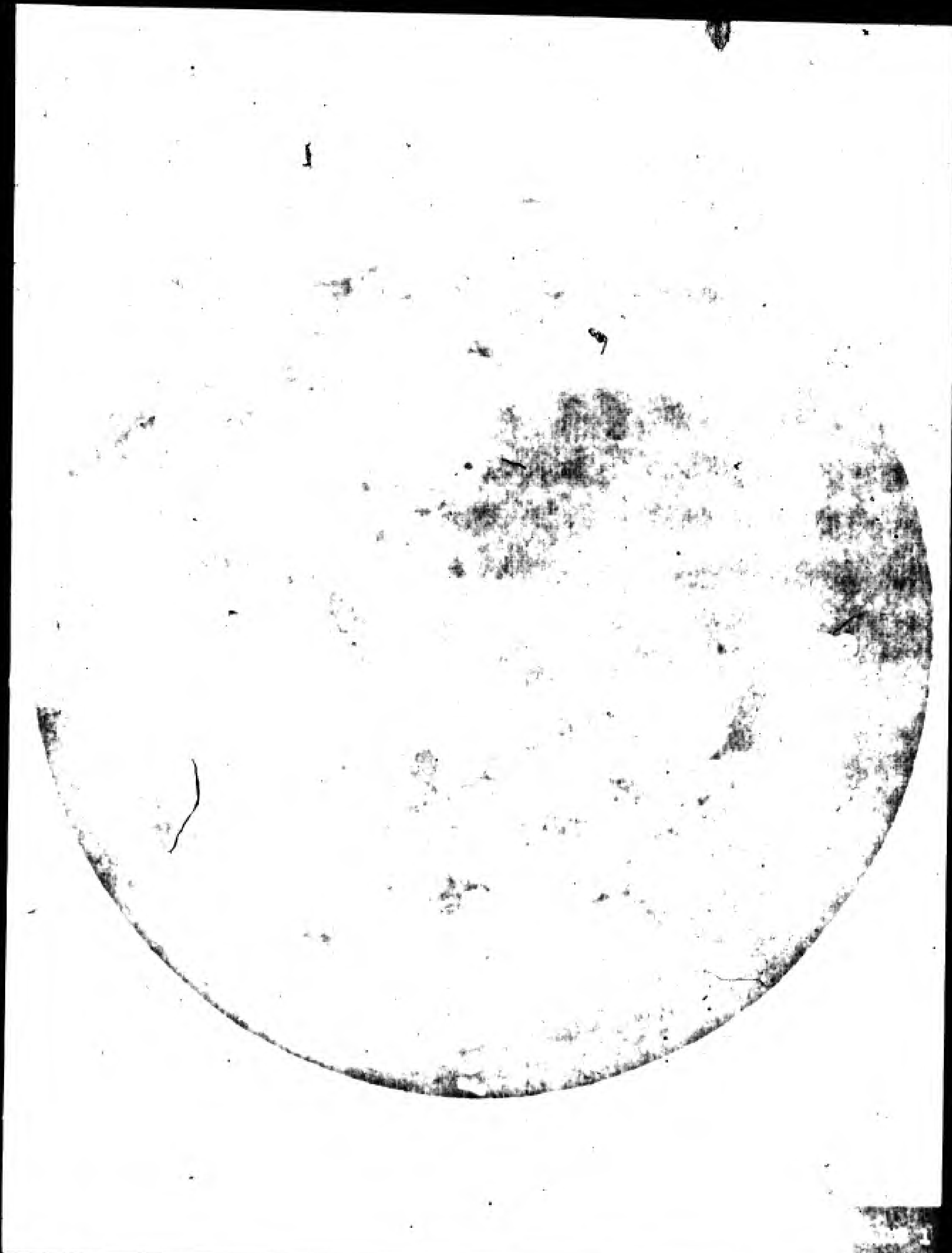
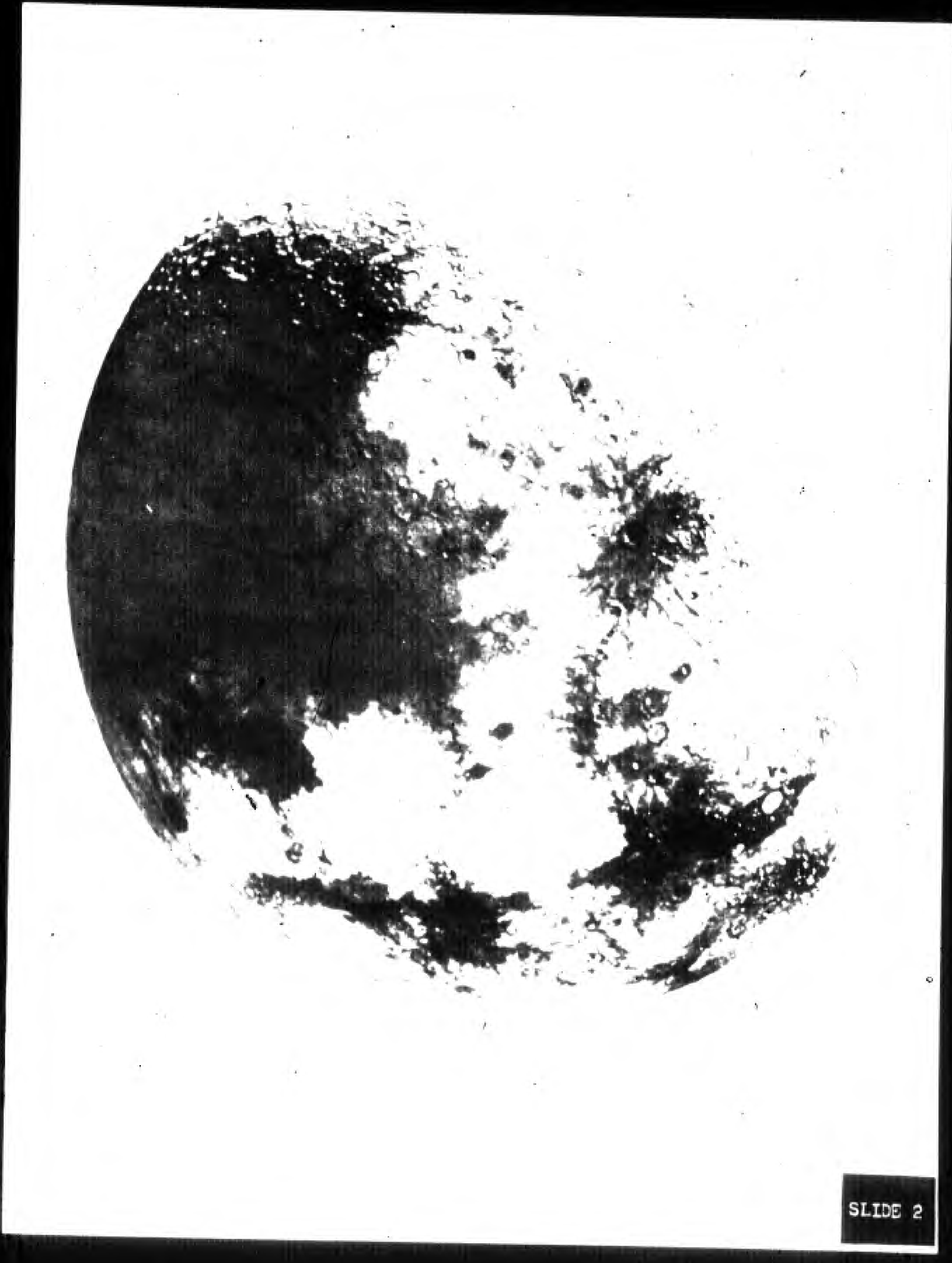
Navy, and Arthur Little ascended in a large ballon to an altitude of 81,000 feet to photograph the spectrum of Venus. With a 16-inch reflecting telescope mounted on top of the gondola, they obtained good spectrograms, in which Charles Moore found definite evidence of water vapor in the upper Venusian atmosphere.

Several years ago, a colleague of mine, Cecil Post, and I one evening saw a faint reddish light over the entire dark portion of Venus' disk. (Venus was in crescent phase then). The following night, the reddish light had vanished. We must have observed an intense aurora on the planet.

In a recent study of the spectrum of the dark side of Venus, the Russian astronomer, Kozyrev, located some 50 emission features, most of which he identified as due to the spectrum of N_2. The oxygen line at 5577 Å, which is outstanding in the terrestrial airglow and aurora, was absent in his spectra. Kozyrev found the night glow of Venus to be about 50 times that in our own ionisphere. Newkirk at Boulder, Colorado, found the radiance of the emission bands centered at 4420 Angstroms to be about 80 times that of the 5577 Angstrom line of the terrestrial airglow. It is unknown whether the emission from the dark side of Venus is of airglow or auroral character.

In view of the evidence obtained to date, Venus is not only a hidden planet; it may be a forbidden planet for manned exploration.

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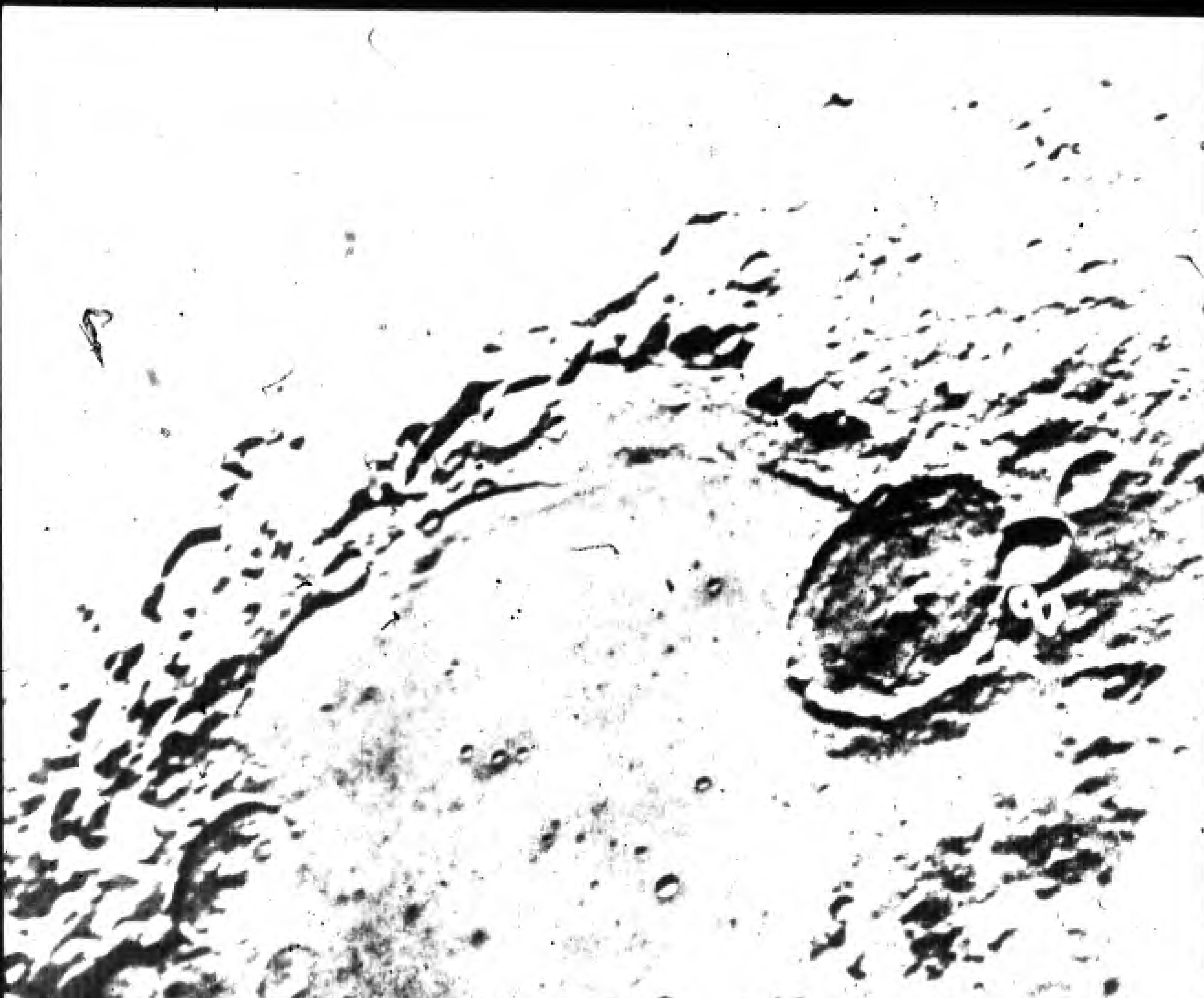

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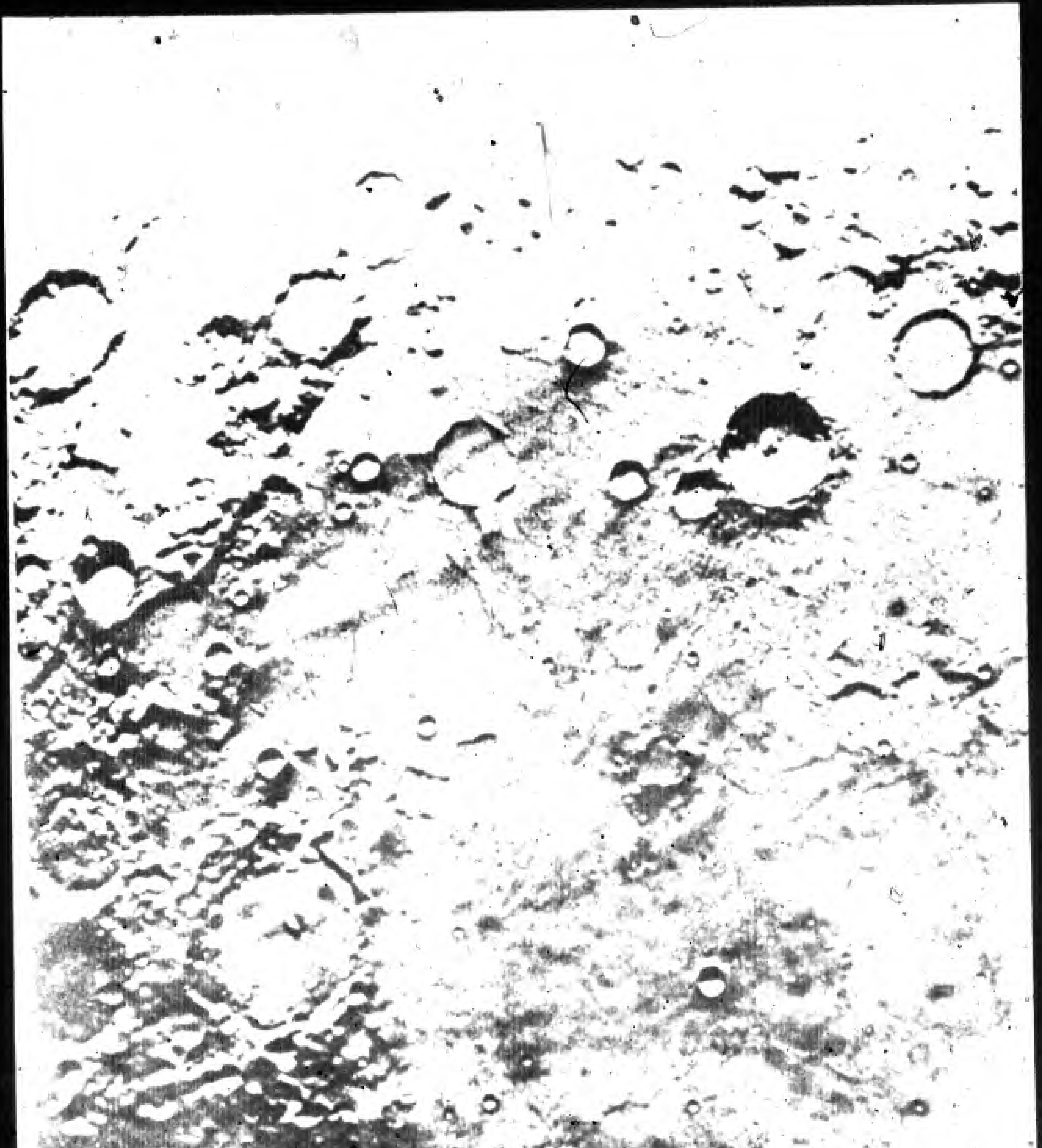

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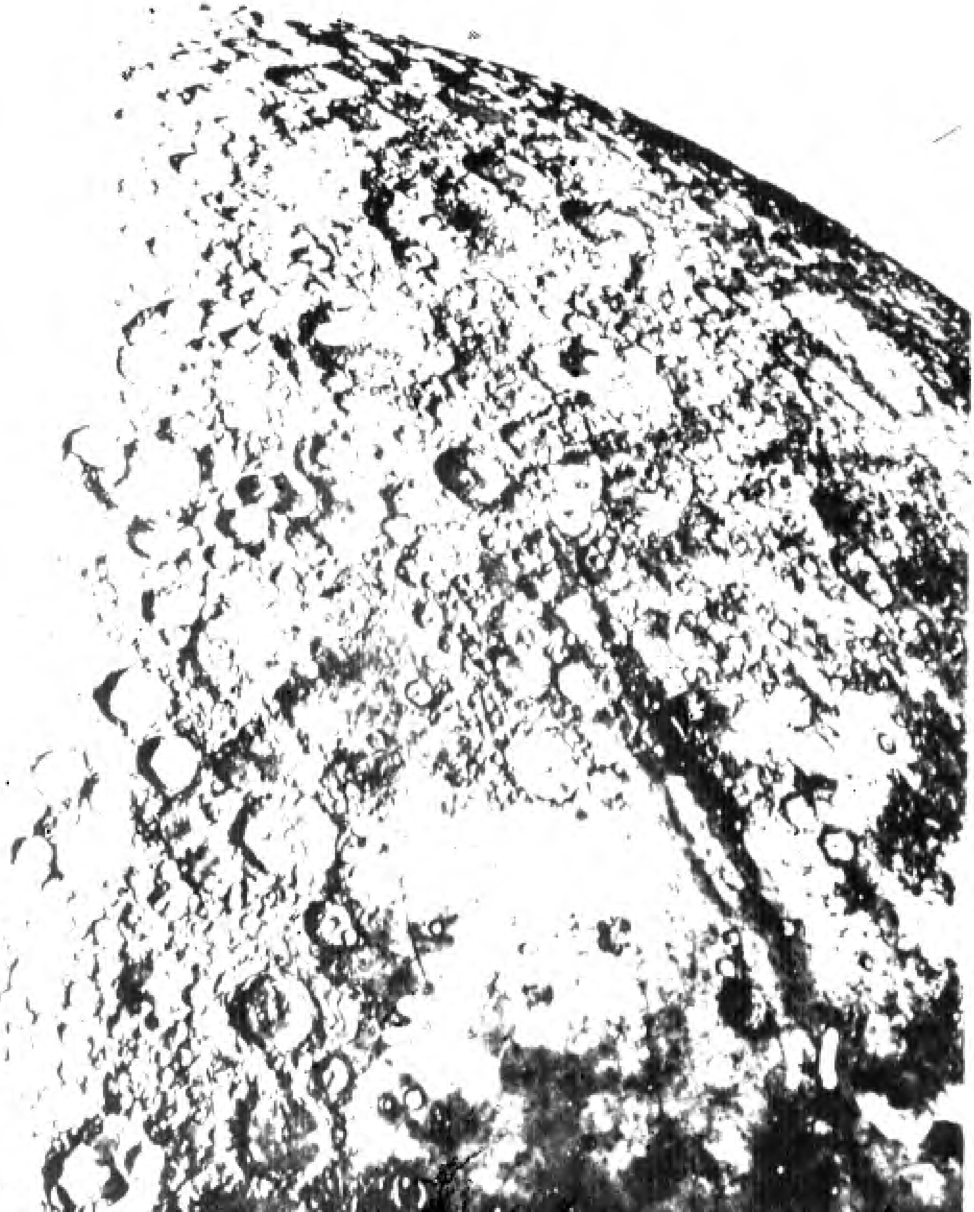

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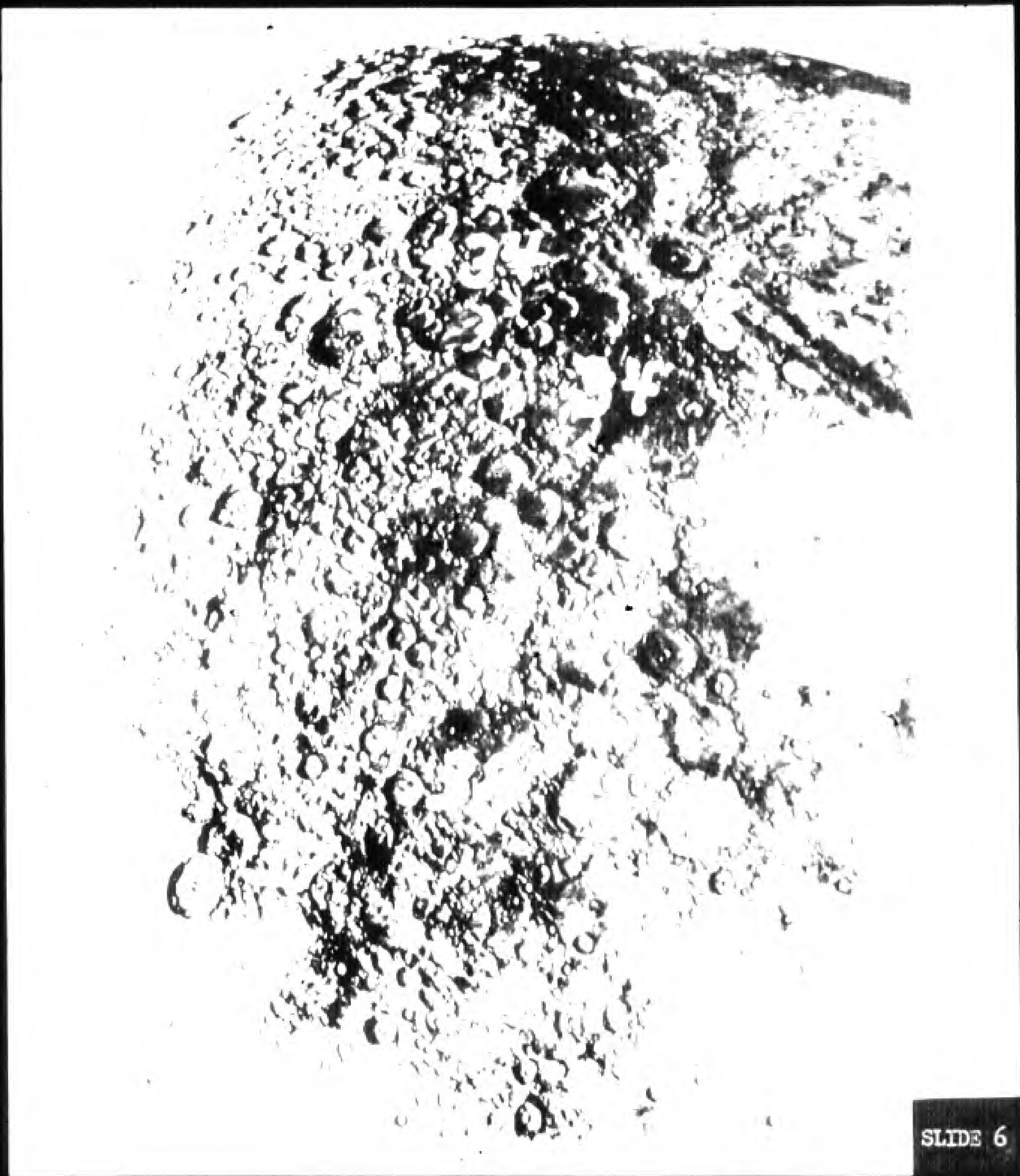

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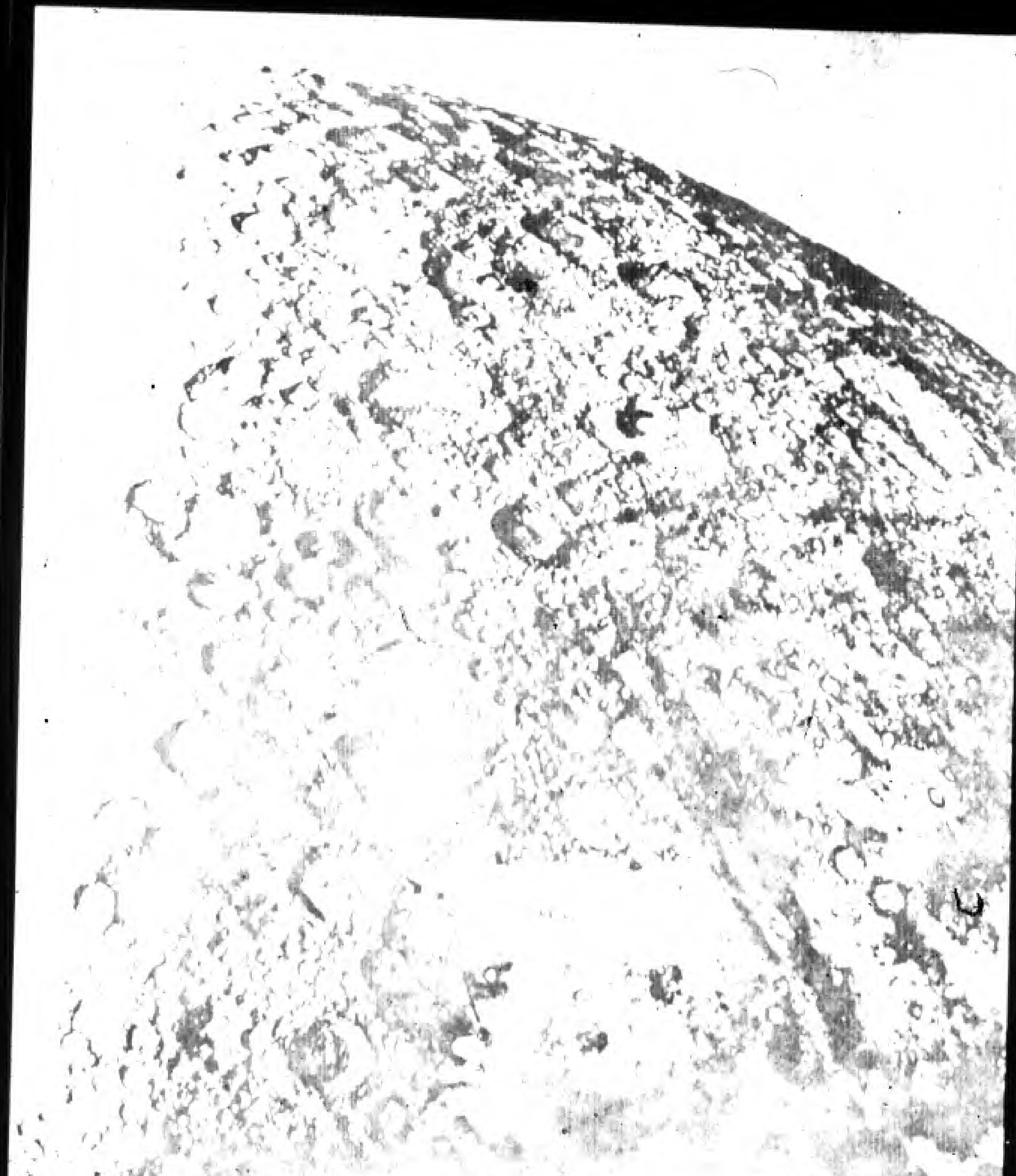
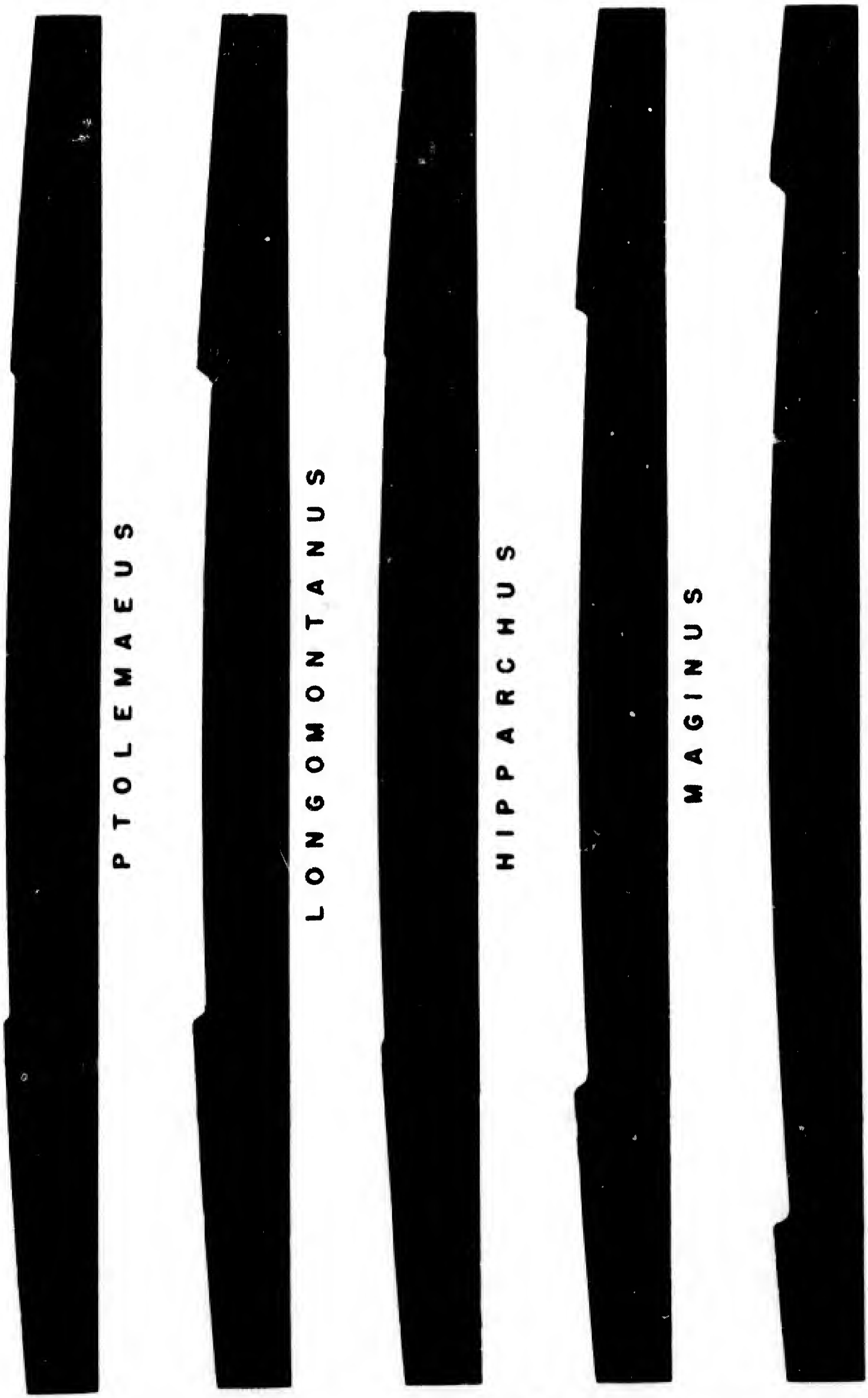
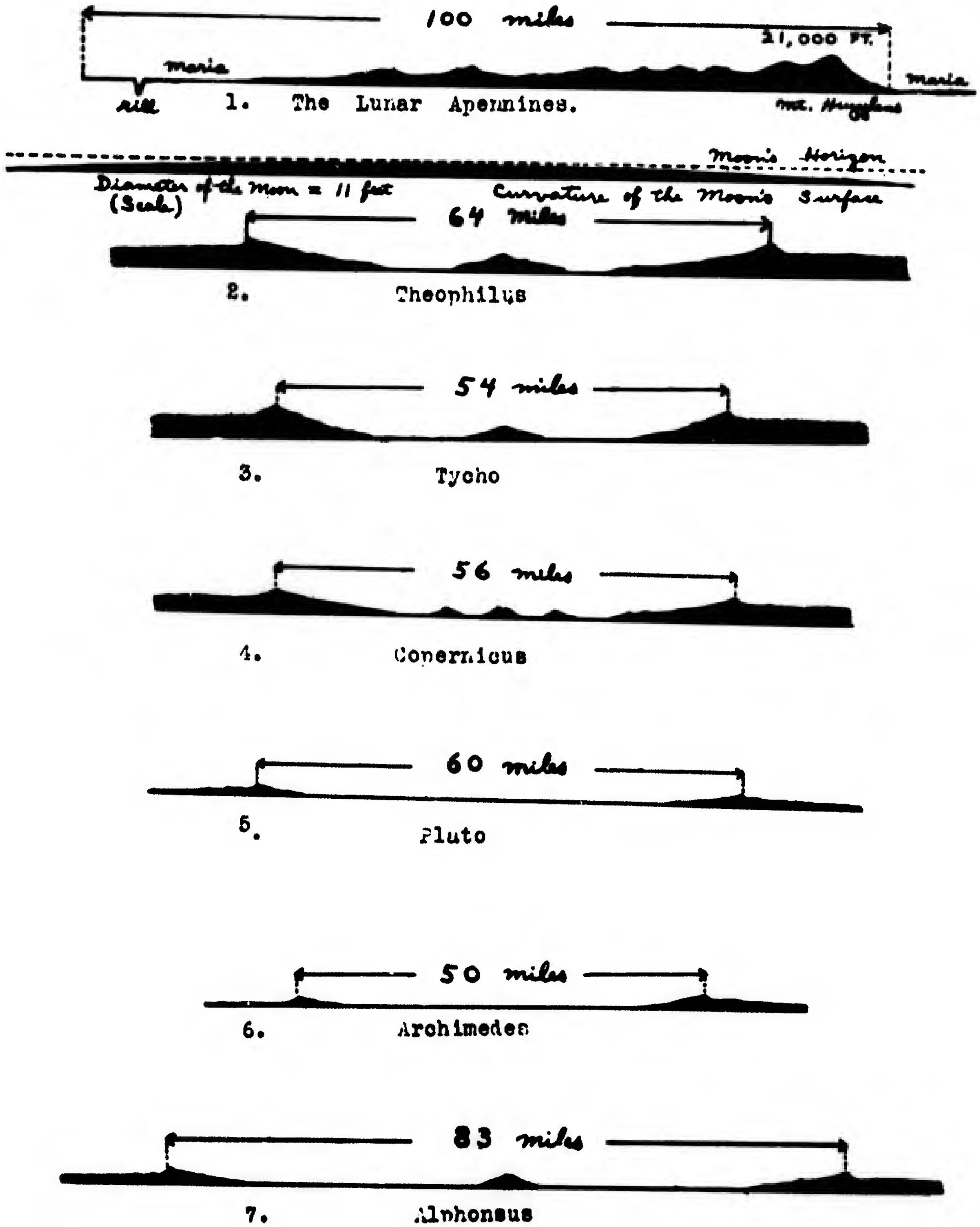




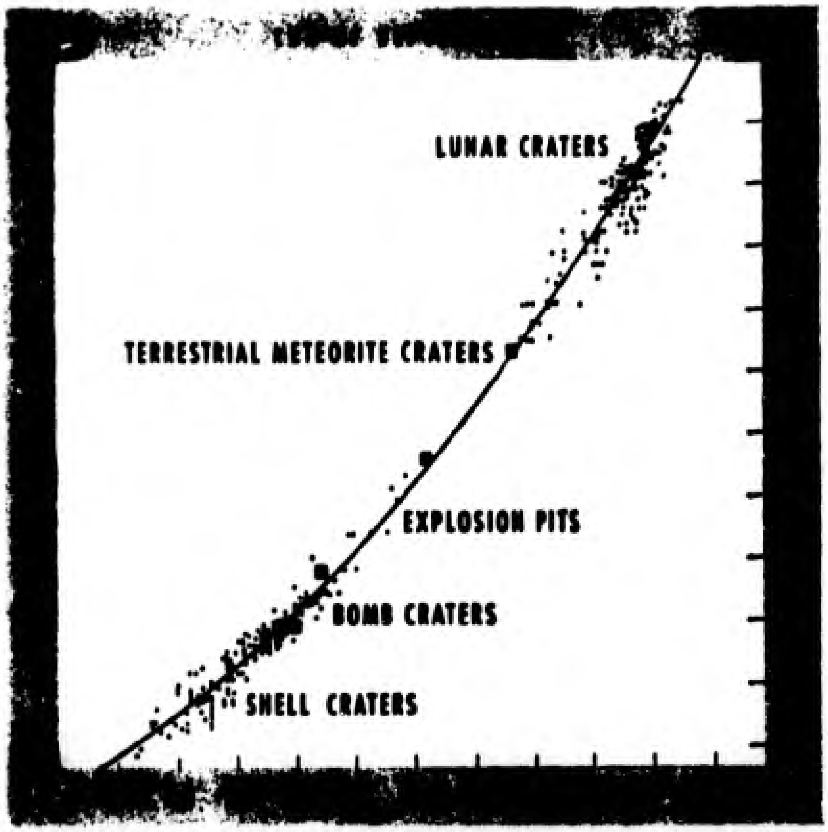
Vertical sections of some typical walled plains. SLIDE 8

LUNAR MOUNTAINS AND CRATERS SHOWN IN PROFILE

Horizontal and vertical scales are the same.

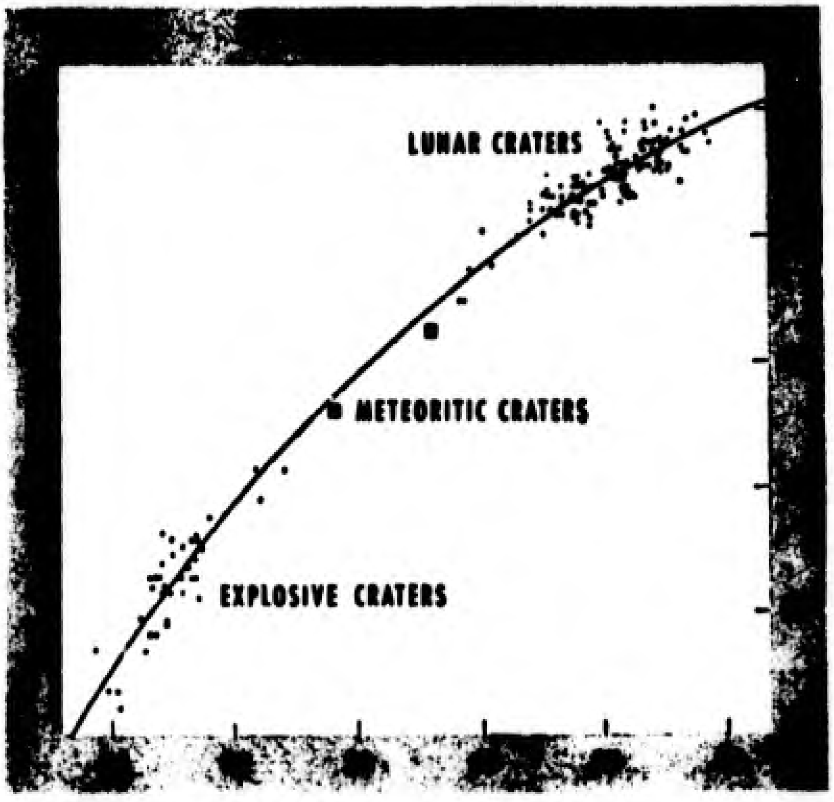


SLIDE 9



DIAMETER AND DEPTH relationships of craters on the earth and the moon follow the same curve. Logarithmic scale is used because of great difference in size between craters measured on earth and visible on the moon.

SLIDE 10



DIAMETER AND RIM HEIGHT relationships of terrestrial and lunar craters also follow the same rule. Another similarity between terrestrial explosion craters and lunar craters is that they are almost perfectly circular.

SLIDE 11

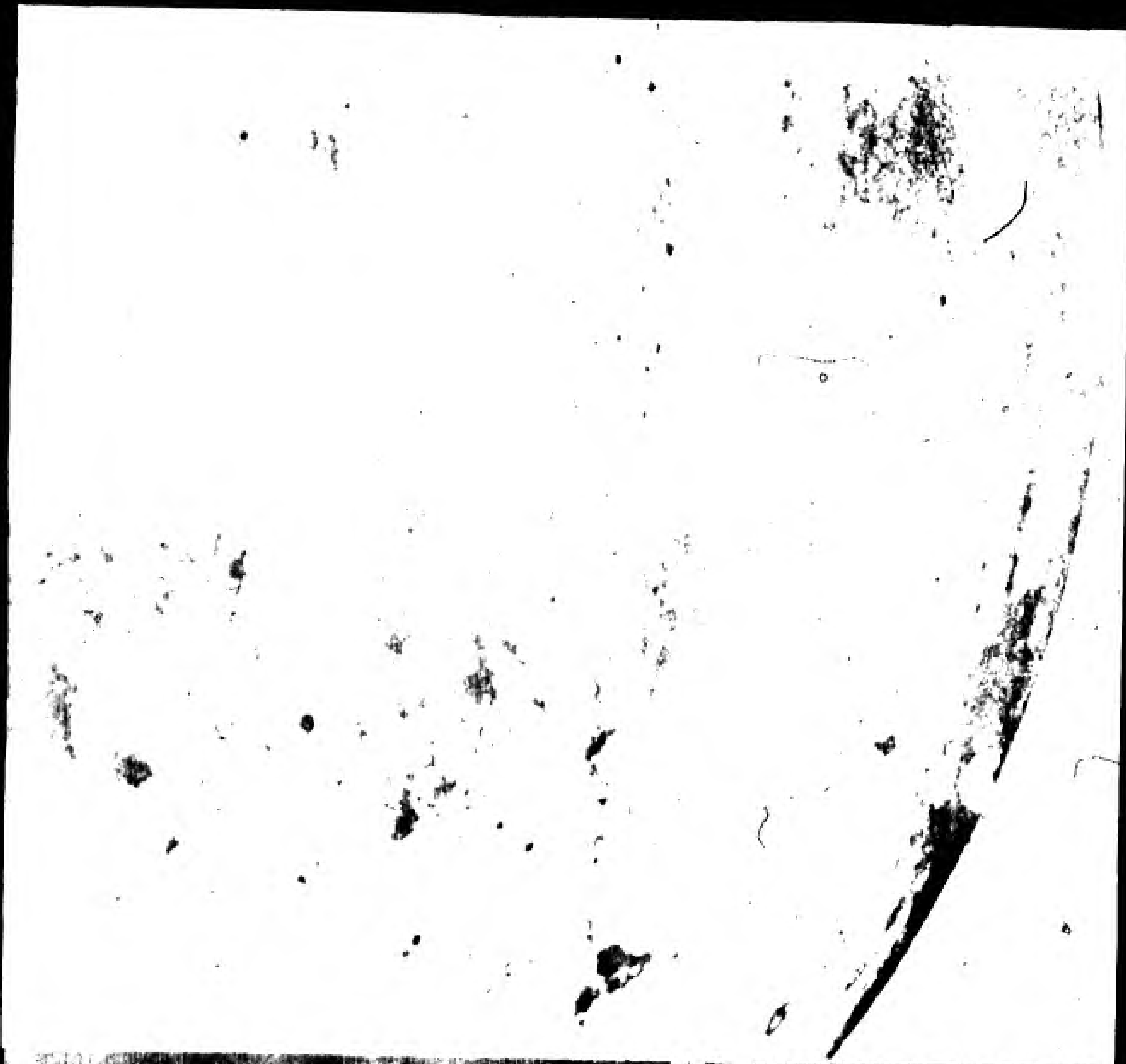
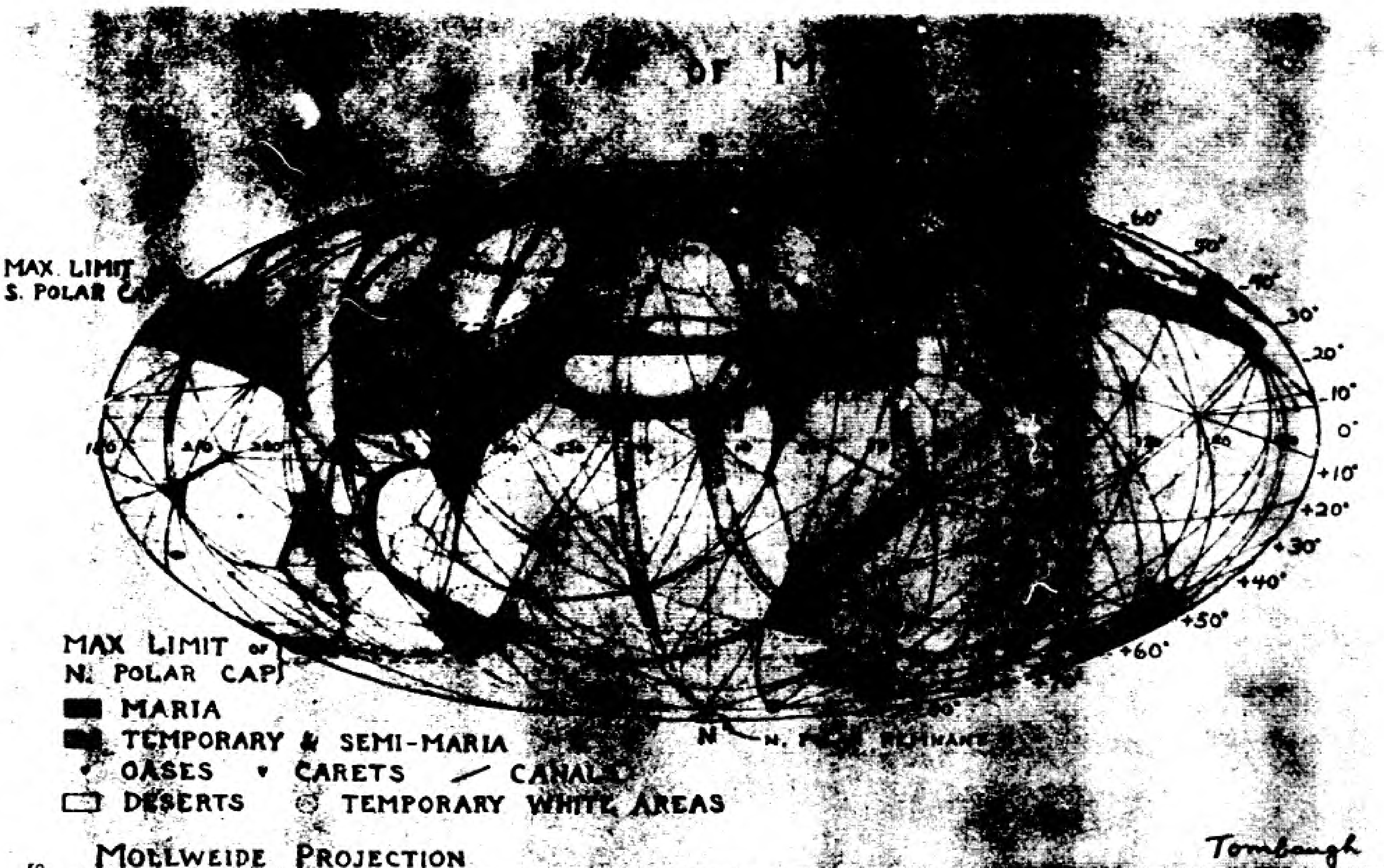


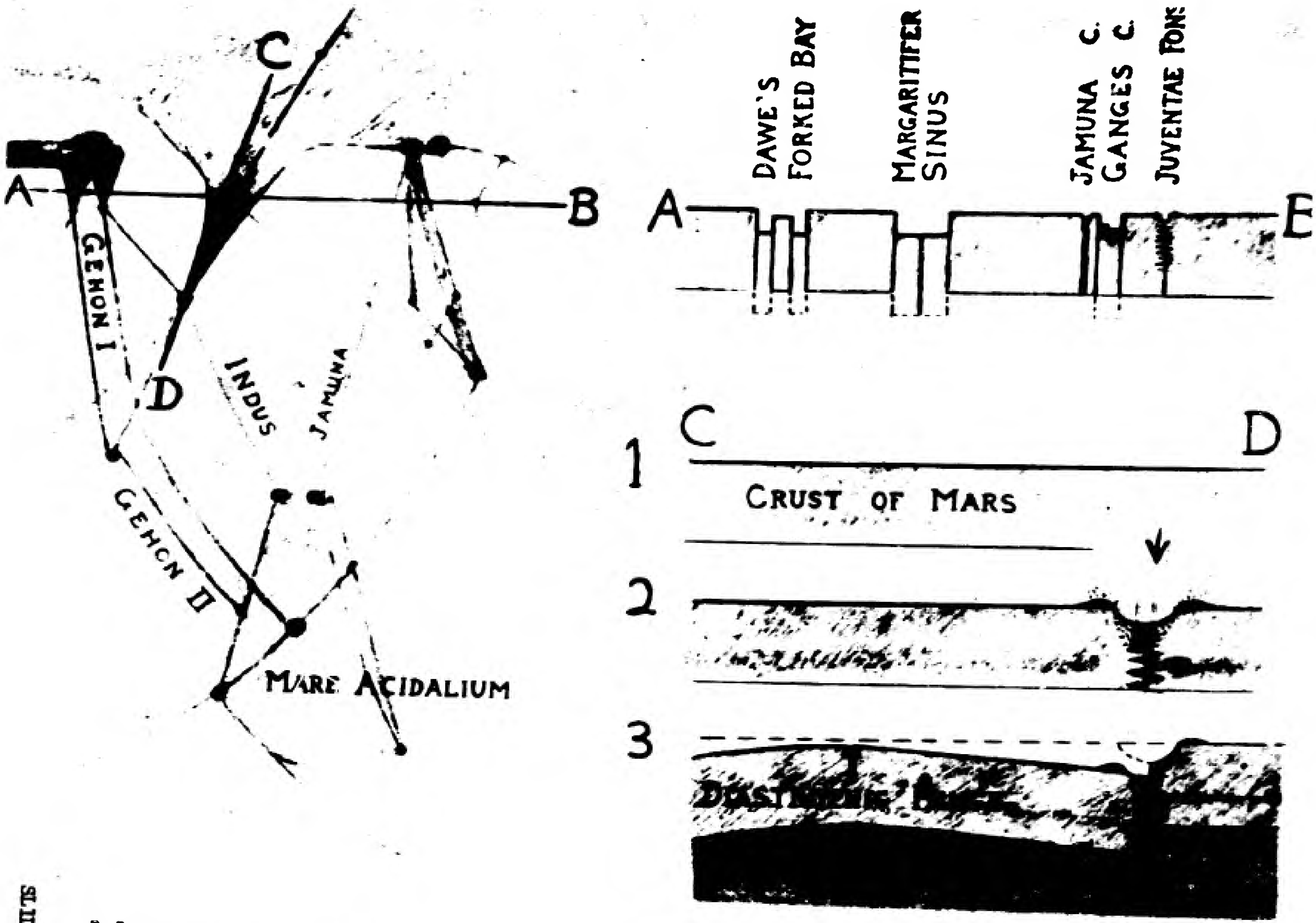
Fig. 88.—Rays.

From the craters Copernicus, left, and Kepler, right. Nearly full Moon. [illegible]



MAX. LIMIT
S. POLAR
60°
50°
40°
30°
20°
10°
0°
+10°
+20°
+30°
+40°
+50°
+60°
MAX LIMIT OF
N. POLAR CAP
MARIA
TEMPORARY & SEMI-MARIA
OASES
CARETS
CANALS
DESERTS
TEMPORARY WHITE AREAS
MOLLWEIDE PROJECTION
N
Tombaugh

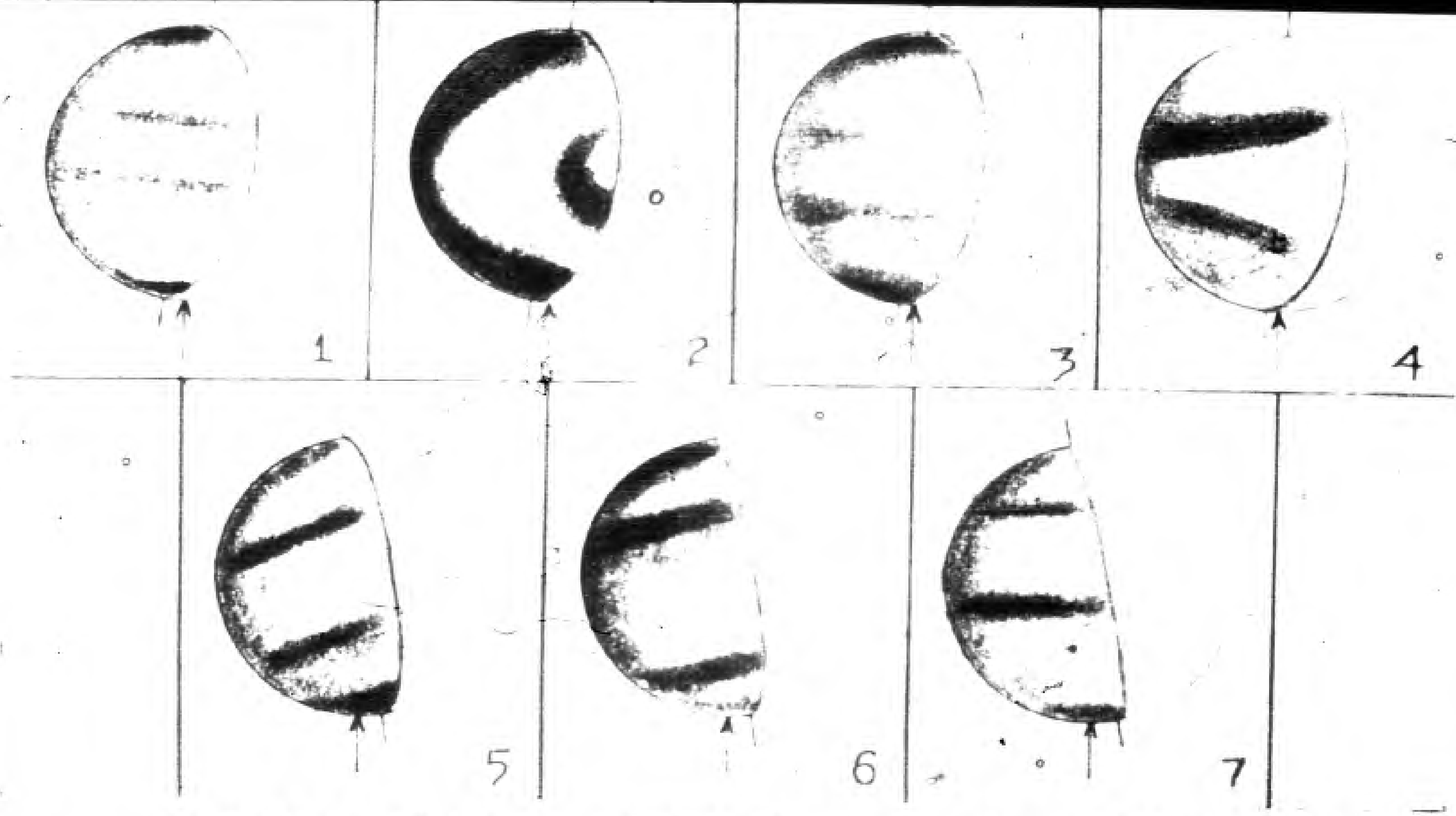
SLIDE 13



MARTIAN DIASTROPHISM & RESULTING TOPOGRAPHY

SLIDE 14

SLIDE 15



Sketches of ultra-violet photographs of Venus taken by Mr. Bradford A. Smith with a 12-inch cassegrainian reflector at Las Cruces, New Mexico. The sketches are in positive form with north at the bottom. The markings show as bright clouds. In serial order, the photographs were taken 1 May, 2 May, 5 May, 7 May, 2 June, 4 June, 8 June, 1959. The contrast has been enhanced.

LECTURES IN AEROSPACE MEDICINE

RADIATION IN SPACE

I. The Physical Picture

Presented By

Dr. S. Fred Singer

Professor of Physics

University of Maryland

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4

Effects of Interplanetary Dust and Radiation Environment on Space Vehicles

4.1 INTRODUCTION

The chapter is divided into two main parts. The first deals with *micrometeoric erosion* and with *sputtering*, the second with the effects of high-energy corpuscular radiation, including *cosmic rays* and the *radiation belt*, and with the design of appropriate radiation shielding. There is little discussion of the astrophysical and geophysical significance of these various radiations; for a more technical discussion the reader is referred to references 1, 4, 7, 17 and 18.

I wish to thank my colleagues, Professors E. J. Öpik, W. R. Webber, R. C. Wentworth, and J. B. Marion, for discussion and helpful suggestions. The research leading to this paper was supported in part by the Air Force Office of Scientific Research under Contract No. AF 18 (600)-1038.

The basic difference between the two categories lies in the speed of the incident particles, and therefore in the energy per incident atom (see Fig. 4.1). For meteors and micrometeors the energy per atom is extremely low, since their velocities rarely exceed 70 km/sec. The meteors are generally associated with speeds of 20 to 50 km/sec, and many of them come in meteor streams. Their structure is probably that of a "dust ball" (i.e., a loose assembly of dust grains), and they range in size from

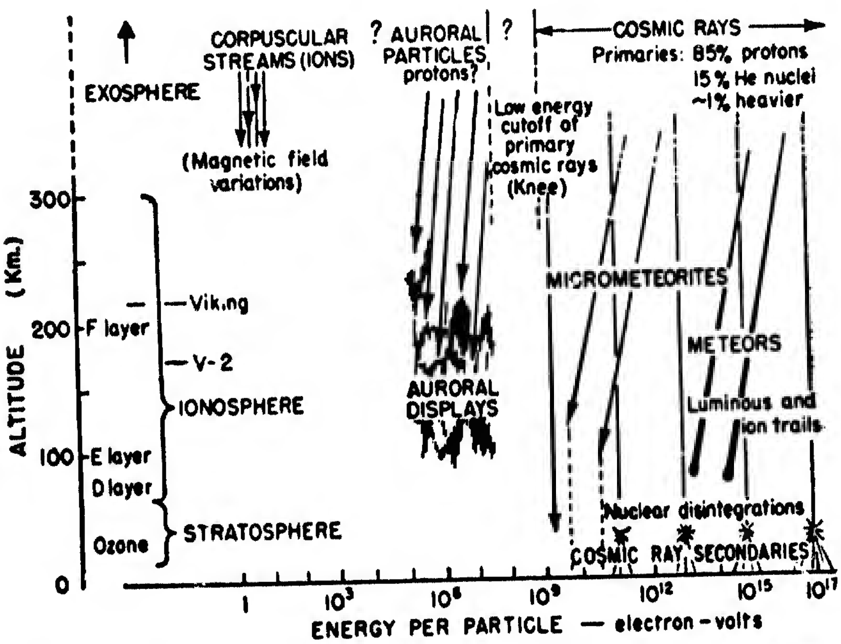

Fig. 4.1. Penetration of extraterrestrial particles into the Earth's atmosphere as a function of energy in electron volts. The radiation belt (located *outside* of the atmosphere) occupies the region 10^6 to 10^9 ev.

the order of a few centimeters down to small grains. Below about 0.035 cm the interplanetary dust (sometimes referred to as micrometeors) becomes more important. Properties of the interplanetary dust are better known, since it is subject to optical observations in the zodiacal light and in the solar dust corona. It probably consists of solid grains, and its velocity relative to the Earth may be quite low, about 12 km/sec.

As a consequence of these low velocities, interactions between the incident dust grains and the atoms in the skin of a space vehicle can be understood in terms of collisions between hard spheres. The electron shells of the atoms involved are hardly deformed in these collisions, and therefore the analysis can be carried out by simple ideas involving conservation of momentum. These considerations form the basis of

Öpik's theory of meteor craters, which should be applicable to the erosion of the skin of space vehicles under dust bombardment. However, because of the uncertainties in the theory and because of the uncertainties in the incident flux, the expected erosion cannot be accurately predicted. It is therefore desirable to measure the flux experimentally in satellites and in space probes, and to carry out, if possible, laboratory experiments to study the effects of high-velocity particle impact; some of the space-vehicle experiments and laboratory experiments are described here.

Depending on how large the dust particle flux is, the erosion due to dust may represent a serious problem for the operation of a space vehicle since it affects the properties of the surface and therefore its albedo and temperature; large meteors may produce fatal punctures of the skin, but sputtering by high-velocity atoms is probably not a serious hazard. In fact, at velocities of the order of 1000 km/sec the sputtering yield is less than at lower velocities; however, at velocities of the order of 10,000 km/sec* and higher, the energy per atom is large enough to produce effects on the atomic electrons, such as excitation or even ionization of the atoms in the skin.

Shielding at the very lowest energies is never a problem. However, as energies increase into the region of several megaelectron volts (such as are found in the low-energy portion of cosmic rays and in the radiation belt) and billion electron volts† (such as are found in cosmic rays), these atomic effects become all-important, and ionization deep within the space vehicle becomes of major concern, particularly if human occupants are involved. For example, following solar flares very high fluxes of low-energy protons in the megaelectron-volt range may be present, and the same sort of conditions exist in the radiation belt. Although ordinary shielding will stop the protons themselves, they may produce radiative effects, i.e., γ-rays, which propagate through even thicker shields. Even if these effects occur only infrequently, the high incident flux of protons will make them important, therefore stress must be placed on the design of an antiradiation shield. It is found, for example, that an outermost coating of lead may be most desirable and may reduce the production of γ-rays by these low-energy protons factors of the order of 1000 or more.

We will discuss in detail problems that arise in connection with the earth's radiation belt. There are in reality two radiation belts, which coexist in the earth's magnetic field as trapped particles: one is soft

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* The kinetic energy of an atom in electron volts is given by $5.2 \times 10^{-3} Aw^2$ where A is the atomic weight and w is expressed in kilometers per second. For a proton, therefore, 1000 km/sec corresponds to 5200 ev, 10,000 km/sec to 0.52 Mev.

† 1 Mev = 10^6 ev; 1 Bev = 10^9 ev.

and of solar origin, the other is hard and of cosmic-ray origin. The latitude and altitude distribution is different for the two types, and so is the nature of the radiation, and therefore the shielding problem. Shielding is very difficult for the hard radiation belt; large thicknesses of material (more than an inch of lead) are needed to reduce the radiation level to a tolerable value. It may therefore be more practical to reduce the radiation-belt intensities by eliminating the particles themselves through the operation of satellites that "sweep" the space around the earth by absorbing the particles that hit them.

Against high-energy primary cosmic rays (consisting of protons and heavier nuclei) shielding may be of no avail; however, the intensities involved should be small. Shields of hydrocarbons turn out to be most effective against heavy primaries by producing fragmentations, which break up the incident heavy nuclei into smaller particles; the ionization density is thereby considerably reduced, and so is the biological effectiveness.

4.2 MICROMETEOR EFFECTS

For space flight and for satellites, meteors represent one of the greatest hazards. Of all the incident radiations and particles, meteors contain the largest individual amounts of energy. For typical (visual) meteors energies range from 10^{13} ergs down to 10^7. Micrometeors are too small to produce luminous trails and have lower energies; but recalling that $1 \text{ ev} = 1.6 \times 10^{-12}$ erg, we realize that the kinetic energy of a micrometeor far exceeds that of the average cosmic ray, which is only 10 billion ev. Although cosmic rays can have energies ranging up to 10^{17} ev, their effect on matter is very different from that of meteors. The difference arises, of course, due to the vastly different mass, the mass of a cosmic ray being that of an atomic nucleus, whereas the smallest micrometeor contains on the order of 10^{10} to 10^{13} atomic nuclei. The meteors have, therefore, a correspondingly small velocity, and cosmic rays move with nearly the velocity of light. This difference in velocity implies a difference in interactions with solid material. For example, a cosmic ray will easily penetrate large thicknesses of material, and in general will lose only small amounts of energy, of the order of 2 million ev in penetrating 1 g/cm^2 of material.[2] Most of this energy is given to the electrons in a metal, but the lattice structure of the metal itself is not disturbed. These effects, of course, are self-healing because of the high conductivity of the metal. On the other hand, plastics or organic materials having complicated molecules will suffer from prolonged cosmic-ray bombardment. Also, cosmic rays can disintegrate nuclei and thus produce permanent effects.[3]

Meteors, however, because of their low velocities, typically around 20 to 50 km/sec, will penetrate only a small distance and must of necessity *give up all of their energy in this small distance.* Their specific effects, therefore, are very much greater than those of cosmic rays.

Penetration by Large Meteors

Large meteors, those having a mass of more than a milligram, can penetrate thin skins of satellites or space ships upon impact—a milligram meteor penetrating approximately 3 mm of aluminum skin. On the other hand, the much smaller and less energetic micrometeorites will not be able to penetrate a skin of this thickness, but instead will gouge out small pieces of the skin, a process very similar to sandblasting. Prolonged exposure above the atmosphere, therefore, will produce a gradual erosion of the skin; this thinning has deleterious effects, since it will eventually damage the integrity of the space ship or satellite.

Calculation of Meteoric Erosion

The problem is a threefold one. It is first necessary to derive the flux of micrometeors of different masses and different energies at the top of the atmosphere. This flux is given by the space concentration times the velocity of the particles. The data rest mainly on astronomical observations, such as observations of scattering of sunlight by interplanetary dust (which causes the solar dust corona and the zodiacal light), on observations of impacts of dust particles in high-altitude rockets, and on measurements of the accretion of such material by the earth through the study of ocean-bottom deposits. Whipple[4] has reviewed the evidence and gives an accretion of 1000 tons of meteoric material per day.

1. For the present calculation we will *assume* an incident flux of 1000 tons/day at a velocity of 50 km/sec. The incoming kinetic energy, therefore, is about 2.5×10^{-5} watt/meter^2 or 3×10^{14} ev/meter^2/sec. (For comparison, the energy input from the sun is 1400 watt/meter^2.)

2. The second step is to get information on the effect of the impact of a single high-speed (50 km/sec) particle on a metal surface. Such data are not available at present; however, as will be discussed later, they could be studied in the laboratory by accelerating particles to these high speeds and observing their impacts.

3. Finally, it is necessary to combine the data from the two sources

in order to calculate the integrated erosion effect of dust bombardment on the skin of the satellite.

Öpik's Meteor Crater Theory

In the absence of any data on the effects of dust-particle impacts, we must derive the results from theory.

Moving with a geocentric speed of at least 10 km/sec, the kinetic energy per atom in the dust particle is of the order of 100 ev. We can neglect the binding energy between atoms whose maximum value is given by the sublimation energy, approximately 2 to 9 ev for most materials. We can, therefore, consider the meteor penetrating into the metal surface as if it were a liquid until the meteor atoms have lost enough energy to be in the range of binding energies of the metal lattice.

In papers as far back as 1936 Öpik had developed a theory to explain the size and shape of meteor craters.[5] This theory can be applied also

Table 4.1 Data on Micrometeors:

Radius (cm)	Mass (g)	$N(>r)$ (cm^{-3})	Penetration Depth (cm)
2×10^{-2}	1.1×10^{-4}	1.1×10^{-17}	8×10^{-2}
10^{-2}	1.4×10^{-5}	3.8×10^{-17}	4×10^{-2}
3×10^{-3}	3.8×10^{-7}	2.3×10^{-16}	1.2×10^{-2}
10^{-3}	1.4×10^{-8}	1.4×10^{-15}	4×10^{-3}
3×10^{-4}	3.8×10^{-10}	9.5×10^{-15}	1.2×10^{-3}
10^{-4}	1.4×10^{-11}	5.5×10^{-14}	4×10^{-4}
3×10^{-5}	3.8×10^{-13}	4.7×10^{-13}	1.2×10^{-4}
10^{-5}	1.4×10^{-14}	2.2×10^{-12}	4×10^{-5}

The space concentration $N(>r)$ gives the number having a radius greater than r and is taken from the zodiacal light observations. M_0 is the absolute visual magnitude (reduced to an altitude of 100 km). The penetration and erosion is given *per* particle.

to the dust-erosion problem, since we are still dealing with dimensions that are large compared to atomic dimensions.

Under the high pressures of impact, which greatly exceed its crushing strength, the meteor flattens, leading to rather smaller penetrations than might be expected from the extrapolation of ballistic impact data. The flattening causes the generation of a lateral shock which vaporizes, pulverizes, and eventually breaks up the target material until the shock strength drops below the elastic limit of the material. The data of Table 4.1

are applicable to the impact of stony dust grains on a light metal, such as aluminum. From Öpik's theory we derive the following approximate relations for the eroded mass, M_e, in terms of the dust particle's mass, μ, and the velocity, w_0 (in km/sec):

$$\frac{M_e}{\mu} \sim 12w_0$$

With the depth of the eroded crater, approximately four times the particle's radius, r, the radius r_e, of the eroded crater is

$$r_e \sim w_0^{1/3} r$$

The flux values given in Table 4.1 are calculated from the zodiacal light dust-frequency distribution given by van de Hulst[4]

$$N\ (>r) = \frac{3.5 \times 10^{-20}}{1.6}\ (r^{-1.6})\ \text{per cm}^3$$

Flux, Penetration, and Erosion

W_0 = 20 km/sec			W_0 = 50 km/sec		
M_0	Flux ($cm^{-2}s^{-1}$)	Erosion (g)	M_0	Flux ($cm^{-2}s^{-1}$)	Erosion (g)
10.6	2.9×10^{-11}	2.5×10^{-2}	8.9	5.9×10^{-11}	6.3×10^{-2}
12.8	1.0×10^{-10}	3.2×10^{-3}	11.1	2.0×10^{-10}	8×10^{-3}
16.7	6.0×10^{-10}	2.4×10^{-2}	15.0	1.2×10^{-9}	2.2×10^{-4}
20.3	3.6×10^{-9}	3.2×10^{-6}	18.6	7.4×10^{-9}	8×10^{-6}
24.2	2.5×10^{-8}	8.7×10^{-8}	22.5	5.0×10^{-8}	2.2×10^{-7}
27.8	1.5×10^{-7}	3.2×10^{-9}	26.1	3.0×10^{-7}	8×10^{-9}
31.7	1.2×10^{-6}	8.7×10^{-11}	30.0	2.5×10^{-6}	2.2×10^{-10}
35.3	5.8×10^{-6}	3.2×10^{-12}	33.6	1.2×10^{-5}	8×10^{-12}

Flux and erosion (per particle) are calculated for two *assumed* velocities; in reality there is not much choice about the geocentric velocity of the interplanetary (zodiacal) dust which is about 12 km/sec. Taking this dust flux, the *total* erosion of the vehicle's skin is only about 10^{-5} cm per year (if uniformly distributed).

A focusing factor, f, has been introduced to allow for the enhancement of accretion because of the Earth's gravitational field; $f = 1.3$ for $w_0 = 20$ km/sec and 1.05 for $w_0 = 50$ km/sec.

With an upper limit of the dust-particle size of about 0.035 cm, the mass density (assuming solid stone) turns out to be approximately 3×10^{-21} g/cm^3 near the Earth's orbit.

The relation between particle mass, μ (in grams), velocity w (in kilometers per second), and the absolute visual magnitude (reduced to

100 km altitude) is given by Öpik[7] as

$$\log \mu = 2.47 - 1.7 \log w - 0.4M_0$$

These expressions have been combined in Table 4.1, which gives the flux and erosion per particle for two values of w_0, 20 and 50 km/sec. The penetration depth depends very little on w_0 in this range.

Laboratory Experiments on Dust Erosion

We shall now discuss the possibility of checking the impact effects in laboratory experiments, i.e., by accelerating artificial dust particles to simulate meteor dust and observing the effects of their impacts on metal surfaces. Acceleration may be accomplished electrostatically.[8] The dust particles are first charged, e.g., by allowing them to traverse a specially constructed discharge tube. The charge of the particles can be checked in various ways, and those particles that have picked up a sufficiently large charge are then accelerated further by an electric field in a linear accelerator; this has the advantage of producing velocities in the meteor range without excessive accelerating voltages. Since the dust particles move rather slowly, it should be possible to apply on the order of 100,000 v between the successive accelerating rings, switching this voltage as the particle goes along. In the experimental arrangement one can, therefore, vary the final velocity of the dust particle and, within certain limits, the size, mass, and nature of the particle as well. Of course, the target surface is completely under control so that various satellite skin materials can be tested in the laboratory. A second method under consideration in our laboratory is the acceleration of dust particles in a shock tube.

The results of these experiments will allow a better estimate of the erosion rate to be expected in the satellite experiment. Conversely, when one compares these laboratory erosion data with the actual erosion of the satellite skin measured above the atmosphere, it should be possible to obtain a more precise value of the incident flux of micrometeors.

Without waiting for the results of these laboratory experiments on dust-particle impacts, there is other evidence that can guide us in judging the effects of meteor impacts. The extensive experiments by Pugh et al.[9] and by Rinehart[10] show very clearly the effects of compression waves, tension waves, and their interactions. The energy released on the outside of the skin is propagated as a compression wave, is reflected from the inside of the skin, and could therefore lead to spalling of material, i.e., erosion on the inside of the skin.

The aim in the design of the skin, therefore, should be to reduce as much as possible the high-stress concentrations. This speaks very strongly for a use of a meteor bumper of the type suggested by Whipple,[4] which diffuses the impact.

A qualitative type of reasoning can be used to allow us to make a better decision on the type of skin material for a satellite or space station:

1. It is clear that the tensile strength of the material should be as high as possible.
2. The material should be free of sharp discontinuities, inhomogeneities, and other scattering centers which could cause local stress concentrations. Their existence might be established by sonic testing procedures.
3. Most important, the waves should be damped as rapidly as possible, as they are propagated through the skin material.
4. Also, in order to reduce the scabbing of material on the inside of the skin, an internal layer of material having very soft rubberlike properties might be advisable.

Measurement of Meteoric Dust Erosion on the Satellite Skin

The importance of *measuring* the erosion of the satellite skin due to meteoric dust impacts and sputtering is evident since the calculations give uncertain results. There are three major points of importance:

1. Measurement of the skin erosion gives a measure of the integrated effects of meteoric dust impacts and of sputtering. The results serve to establish one of the important environmental factors for satellites, and for space flight in general.
2. Meteoric dust impacts and sputtering are important in the design of more advanced satellites. For example, measurement would allow us to gage the effects of erosion on different kinds of surfaces.
3. The changes of the surface properties must be measured, since they have far-reaching effects on the optical and aerodynamic properties of the satellites, and therefore subsidiary effects on the satellite albedo and temperature. These properties are important for visual tracking and for the proper operation of the satellite instrumentation.

Radioactive Method

One of the most sensitive methods that can be used, which is at the same time most convenient for satellite applications, is the radioactive method[5] proposed by the University of Maryland group for the Vanguard satellite. Radioactive material, preferably a β-ray emitter, is applied to the satellite skin. On the interior of the skin we monitor the activity with a β-ray detector (see Fig. 4.2). As dust impacts erode the skin, some of the radioactivity will be carried away and the detector output will decrease. Hence, the erosion of the satellite skin is measured by observing the decrease in activity of a radioactive portion of the skin.

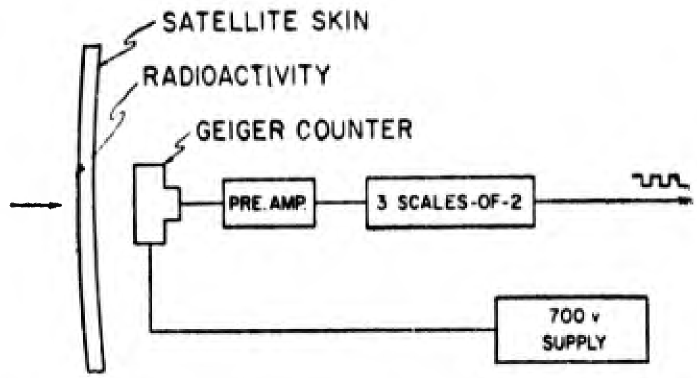

Fig. 4.2. Satellite erosion monitor. As the skin of the satellite is eroded by dust impact, the radioactivity decreases, giving a lowered counting rate in the Geiger counter.

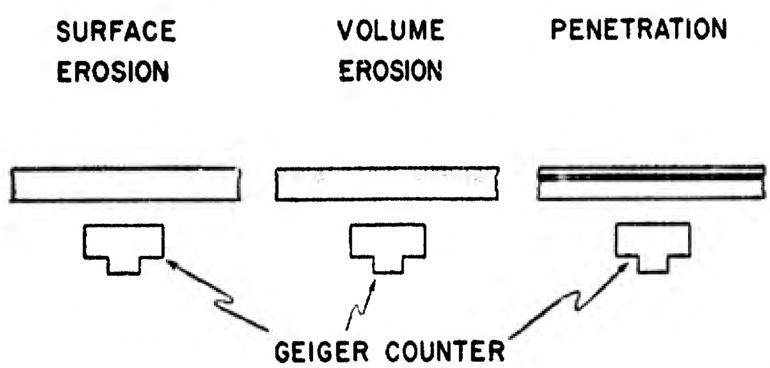

Fig. 4.3. Radioactive erosion technique. Illustrating different uses of radioactive materials. They can be used to measure surface erosion, volume erosion, and penetration.

The method lends itself to variations. For example, in Fig. 4.3 we illustrate adaptations of the radioactive erosion technique to the measurement of surface erosion, volume erosion, and penetration.

4.3 SPUTTERING

Collisions with high-velocity gas atoms can lead to sputtering of the surface of a space vehicle. Basically this is because the incident atom transmits its energy to a surface atom, which may become ejected before the lattice has communicated the energy to a larger volume.[11]

Existing data indicate that the yield, i.e., the number of sputtered atoms per incident atom, increases linearly with the energy of the bombarding atom, up to an energy of about 1500 ev.* Öpik[7] has represented the sputtering yield, ν, by an empirical relation which holds for low energies:

$$\nu = 5.3 \times 10^{-3} k_n (E - 32i)$$

Here E is the kinetic energy of the impinging atom, and i the lattice energy, both expressed in electron volts. Typical values for i are: Iron $\sim$ 4.2; stone, 3.5; aluminum $\sim$ 3.0. The value of k_n depends on the angle of incidence and ratio of atomic weights; for a large ratio $k_n \sim 0.45$. The evidence indicates that the maximum yield may be in the vicinity of 5 to 10 kev. The actual yield varies greatly with target material.*

High-energy sputtering yields have been measured and show a trend towards lower values, of the order of 1 per cent for 50-kev protons. This decrease is due to the fact that the incident atom penetrates quite deeply into the lattice. It appears, therefore, that sputtering, e.g., by fast solar corpuscules, does not present any special problem for space vehicles unless thin coatings or windows are involved.*

4.4 CORPUSCULAR RADIATION EFFECTS

The incidence of high-energy corpuscular radiation produces both atomic and nuclear effects. The latter result in an *irreversible* change in nuclei of the target material. However, in practice, the atomic effects prove to be generally more important; nuclear reactions occur so infrequently that they are important only over geological periods, e.g., in meteorites.[3]

Atomic effects are produced by energetic charged particles, which remove an electron from one of the electron shells of a target atom (the so-called ionization process) or lift an electron from a low-lying level to a high level (the so-called excitation process). The processes of ionization and excitation thus transfer energy to the atoms of the target matter, which may be tissue, metal, or perhaps a semiconductor like the transistors used in electronic equipment.† The result may be a breakdown

* These conclusions furnish only a rough guide. For a particular situation it is best to use actual experimental data (see, e.g., reference 11 as well as further publications by Wehner to appear in *Phys. Rev.* and *J. of Appl. Phys.*).

† Experiments have established that semiconductors are the components most sensitive to radiation, e.g., *p-n-p* transistors are affected by doses of about 6×10^6 roentgen.

of chemical bonds in some molecules, or formation of bonds in others; in tissue, for example, because of the preponderance of water, the main effect would be the production of H and OH radicals with a subsequent formation of H_2O_2.

These effects can be reproduced to a large extent in the laboratory.[12] They can also be expressed in terms of radiation dosages for which safe limits have been derived from experience.

A particular subclass of atomic effects, which cannot yet be studied in the laboratory and whose biological effects are imperfectly known, are the radiation effects of heavy cosmic-ray primaries.[13] They produce ionization trails dense enough to destroy the physiological functions of the cell.

Atomic effects have been dealt with in recent years from a physical and biological point of view.[14,15] The heavy primary problem is being attacked by studying the effects of long-time exposure of animal tissue at altitudes above 80,000 ft in plastic ballons.[16]

Nuclear effects, which are cumulative, are also caused by cosmic rays. It has been estimated that an exposure of one day in space is equivalent to a year's exposure at an altitude of 10,000 ft. It is believed that their biological effects are not of great importance.[3]

4.5 COSMIC RAYS

Special problems in regard to cosmic rays and other corpuscular radiations arise if we move at large distances from the Earth's surface, where the magnetic-field conditions are different from those just above the atmosphere. For cosmic rays the Earth's magnetic field provides a screen which is very effective at the equator and completely ineffective at the poles; i.e., at the equator the magnetic field near the Earth will prevent the entry of particles with energies below about 15 Bev, which constitute at least 90 per cent of the primary cosmic rays.[17] The present situation with respect to the latitude dependence of the primary cosmic rays and their individual components, such as protons, α-particles, and heavy nuclei, is given in a recent review article.[18]

This screening effect of the earth's magnetic field diminishes with altitude, and as a result we find that the primary cosmic-ray intensity at the equator rises steeply as a function of altitude (see Fig. 4.4).[3] The calculations[18,19] refer only to the *primary* radiation, i.e., particles coming directly from large distances from the earth, and either hitting the Earth or returning to "infinity." Trapped radiation, which constitutes the radiation belt, has to be calculated by different techniques, and shows a different altitude dependence, as can be seen from Fig. 4.5.

There is considerable uncertainty as to the intensity of cosmic rays at very large distances from the Earth, because of our uncertain knowledge concerning the form of the energy spectrum at very low energies (indicated in Fig. 4.4 by the absence of particles with momentum less than p_{min}). It is presently believed, however, that during periods of great

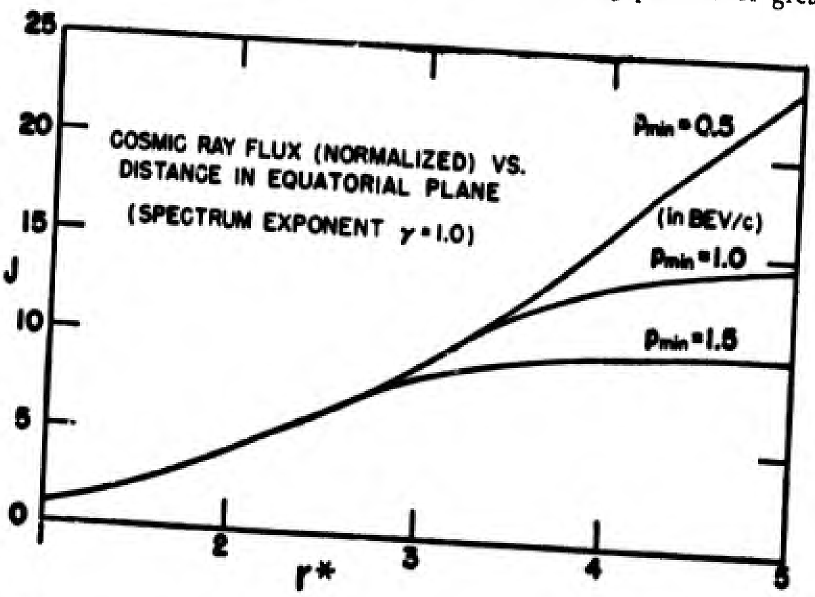

Fig. 4.4. Primary cosmic ray intensity at the equator vs. distance from the center of the Earth (from reference 19). At the geomagnetic equator the increase is due mainly to the decreased magnetic screening. Since the existence of a low-energy cutoff (as indicated by the uncertainty in the minimum momentum, p_{min}) depends on the sunspot cycle, the interplanetary intensity can vary by large factors. Note that this graph shows only the primary radiation; the radiation belt is superimposed and is many thousands of times greater.

solar activity these low-energy cosmic rays are absent, producing what is called a "knee" in the spectrum. But during quiet solar periods, i.e., in the years near the minimum of the sunspot cycle, the intensity in the low-energy region rises to very high values, and therefore the intensity of cosmic rays in interplanetary space will also rise.[18,19] It should be noted, however, that these large changes are mostly confined to the low-energy part of the cosmic radiation (below about 1 Bev).

Solar-Flare Increases of Cosmic Rays

An extremely dangerous situation is produced by the sudden cosmic-ray increases associated with some solar flares. During the past twenty

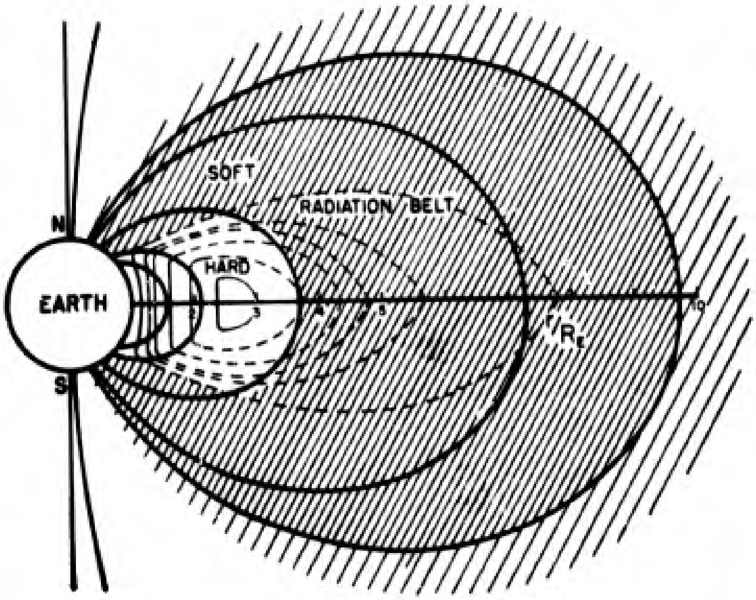

Fig. 4.5. Distribution of radiation belts around the Earth, derived from the theory in references 28 and 38. The lines emanating from the Earth indicate the lines of force of the Earth's magnetic field. The closed lines give contours of equal radiation intensity for the hard radiation belt, which is of cosmic ray origin. Its maximum is in the vicinity of 1.5 Earth radii where the radiation exposure is about 10 r per hour. Its intensity begins to increase at about 600 km (according to the theory) and may reach out as far as 10 Earth radii (40,000 miles) at the equator. Note that the regions around the poles are clear. The soft (auroral) radiation belt is indicated by cross-hatching and overlaps somewhat with the hard radiation belt at higher latitudes and greater altitudes.

years about half-a-dozen such large increases have been observed, the most recent and spectacular one during February 1956.[18] In this event, which commenced a few minutes after the eruption of a strong solar flare, the cosmic-ray intensity was observed to rise to 20-fold its normal value at sea level in many places all over the Earth. Even at the equator a rise was observed, indicating that primaries with energy greater than 15 Bev were present. From an analysis of the data at various locations, the energy spectrum of this additional radiation produced in the solar flare could be determined and was shown to be extremely steep, i.e., the number of particles increased very much more sharply towards low energies than in the normal cosmic radiation. This means that at an energy of about 1 Bev, the intensity outside the atmosphere may have been 1000 times normal, and at lower energies the intensity would be still greater. We must, therefore, reckon with the fact that the intensity in the region around $\frac{1}{2}$ Bev energy may have been of the order of

10,000 or even 100,000 particles/cm^2/sec for many hours.[20] This intensity in the absence of shielding far exceeds the usual tolerance levels (by factors of 1000); in addition, the energies of the protons are still so high that effective shielding becomes quite difficult.*

What makes the situation worse is the fact that these increases do not seem to be confined to just isolated solar flares appearing, perhaps, once every few years. A recent experimental result with specially designed equipment indicates that even small solar flares can produce cosmic-ray increases quite frequently. These increases (about 30 per cent) were observed in an experiment in which an airplane was flying near the auroral zone.[21] Again the increases followed closely after a solar flare, but were not observed at sea level, indicating that the energy of the radiation responsible for the increase was about 1 Bev or less. An interesting feature of the observation was that the increases lasted for only a few minutes and presented a quite distinct appearance. If the increases are as shortlived far from the Earth, they should not present a particularly serious radiation hazard.

During some very intense cosmic-ray increases the radiation effects may be serious even within the atmosphere, e.g., at airplane altitudes. Calculations for the February 1956 increase show[20] that the integrated exposure over the duration of the increase was 5 to 10 r at an altitude of 50,000 ft. This value may be compared with the usually accepted radiation-tolerance limits of 15 milliroentgens/day, and total dosages of 20 to 50 r (inducing sickness), 100 r (maximum lifetime dose), and 500 r (lethal).

4.6 THE EARTH'S RADIATION BELT

In order to discuss the effects of the radiation belt and the shielding problems connected with it, it will be necessary to derive its properties from a theoretical point of view, in the absence of detailed experimental data. The following discussion gives the writer's views of the properties of the radiation belt, based only on theoretical studies. The theory predicts the existence of two radiation belts around the Earth, of different origin and having widely differing properties (see Fig. 4.5 and Table 4.2).†

* It should be pointed out also that for very large particle fluxes ordinary shielding may not be sufficient. Even though the thickness of the shielding is sufficient to stop low-energy protons, their radiative effects may propagate through considerably thicker shields and must therefore be carefully considered. (See Section 4.7.)

† *Note in proof:* The existence of *two* distinct radiation belts which was explicitly proposed at the symposium (November 1958) has now been verified by experiments in Pioneer space probes (J. A. Van Allen and L. Frank, *Nature*, **183**, 430, 1959) and in Lunik rockets (S. N. Vernov et al., *Dokl. Akad. Nauk SSSR* **125**, 304, 1959).

Table 4.2 Properties of Earth's Radiation Belts

	Hard (Cosmic-Ray)[a]	Soft (Auroral)[b]
Origin	From the decay of cosmic ray albedo neutrons which come out of the Earth's atmosphere	From solar corpuscular streams with subsequent acceleration near the Earth
Nature	Protons between 10 and 400 Mev	Electrons and protons of less than 1 Mev
Shielding	Difficult to absorb and shield	Easily absorbed
Location	Equator and low latitudes Close to the Earth	Auroral latitudes Far from the Earth
Time dependence	Constant in time	Variable, increasing when sun is active

[a] From reference 28. [b] From reference 24.

It must be understood, however, that experiments will provide the ultimate guide to the design of effective shielding against the radiation-belt effects.

Summary of the Trapped Particle Theory

The theory of the motion of a low-energy charged particle in a magnetic field was first developed by Alfvén.[22] We have applied it to geophysical phenomena occurring in the Earth's magnetic field.* Over the last two years we have studied the "trapping" and "storing" of solar corpuscular radiation by the Earth's magnetic field, mainly in connection with a new theory of magnetic storms and aurora.[24] The magnetic field can be shown to be a good container, i.e., once introduced, charged particles will spiral around a line of force and remain in a certain region for a long time (uncharged particles, such as neutrons, and electromagnetic radiation cannot be trapped). In our magnetic-storm theory, solar protons and electrons drift around the axis of the earth's magnetic field, thereby producing a ring current which causes magnetic storm variations.† Also the particles are accelerated by a hydromagnetic shock-wave mechanism to high enough energies to produce the aurora.[25]

When the radiation belt was discovered by Explorer satellites instrumented by Van Allen and his colleagues, it was at first thought that it might be due to the trapped particles responsible for magnetic storms

* It is interesting to note that quite independently, and during about the same time, Alfvén's theory was applied by groups working on thermonuclear projects to the problem of the confinement of a plasma in a magnetic field, the so-called mirror machine.[23]

† *Note in proof:* Evidence for such magnetic effects of trapped radiation was found by Dolginov in the first Lunik rocket (January 1959).

and aurorae.[26] However, it seemed that this solar corpuscular radiation could not be present near the equator at low altitudes, but must be confined to high latitudes and great altitudes (see Fig. 4.5).[27] It was clear, however, that the satellites must be running into trapped and stored radiation, since only in this way could the high intensities be explained. We therefore investigated a number of injection mechanisms which could provide particles in the equatorial and low latitude region. The only *known* method found so far that shows promise is the following:[28]

Primary cosmic rays smash into the earth's atmosphere in the vicinity of 20 to 25 km and disintegrate atmospheric nuclei. Neutrons are released with energies up to several hundred Mev, many of which travel upwards (and are therefore called cosmic-ray "albedo"). Being uncharged, the neutrons travel along straight lines, right through the earth's magnetic field, out into space. But free neutrons are radioactive. A minute fraction of them (about 10^{-13}/cm, or about 1 in a million in 100 miles) change into protons while traveling through the field. These protons immediately spiral around the lines of force; a fraction having a small pitch angle are lost immediately as they get back too deep into the atmosphere, but the rest are trapped.*

The essential part of the calculation can be understood as follows: The concentration, N, of trapped particles follows from a balance between the injection rate, Q, and the rate of removal; the latter can be expressed in terms of a lifetime, T, and is found to be determined mainly by collision with atmospheric atoms and ions. Roughly then, we find

$$N(\text{per cm}^3) \sim Q(\text{per cm}^3/\text{sec}) \times T(\text{sec})$$

But the experimentally determined quantity is the flux, J, given by

$$J(\text{per cm}^2\text{-sec}) \sim N(\text{per cm}^3) \times v(\text{cm/sec})$$

A typical injection rate is 10^{-13}/cm^3-sec (for protons near 50 Mev) i.e., one particle is injected into a given cubic centimeter of space every 300,000 years. But the theoretically calculated "lifetime" is so long that the particle concentration builds up to about 10^{-7}/cm^3 at 1000 km.† With a velocity of about 10^{10} cm/sec the flux is about 1000/cm^2-sec.

The lifetime that is calculated is found to be inversely related to the atmospheric density. Since the latter decreases with altitude, the lifetime and therefore intensity of the radiation increase with altitude. The fast proton flux (in particles per centimeter^2-second-steradian) is found

* The trapping always occurs when the particle's pitch angle increases to 90 degrees and reflection takes place (see Fig. 4.6).

† The situation is analogous to a water tank that has a very tiny leak; then a small injection rate can build up a high level.

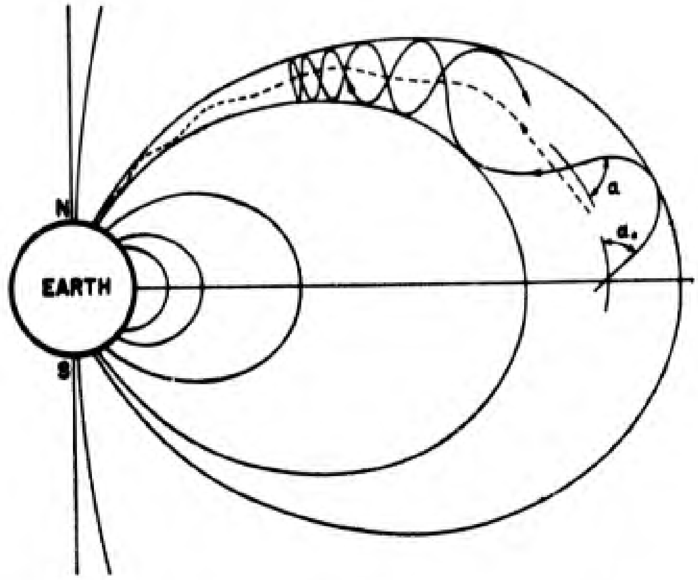

Fig. 4.6. Schematic indication of the reflection and trapping of a charged particle by the Earth's magnetic field. The particle's velocity makes a pitch angle, α_0, to the magnetic line of force in the equatorial plane. As the particle moves into a region of stronger magnetic field (lines closer together), its pitch angle increases until it reaches 90 degrees, at which point the particle is reflected and moves into the opposite hemisphere where it will again be reflected from a similar turning point. With a smaller value of α_0 the particle will approach nearer to the Earth's surface. For extremely small values of α_0 the particle can enter the Earth's atmosphere (dotted line). With $\alpha_0 = 90$ degrees the particle remains in the equatorial plane. Both soft and hard radiation-belt particles are trapped in this manner.

to vary with atmospheric density, d, as $I \sim 10^{-14}/d$ at low altitudes near the equator.[28] With a radiation-belt flux of 3000 at 1900 km given by Explorer IV[29] we can therefore derive an upper limit to the density of the atmosphere at 1900 km as 2.5×10^{-18} g cm^{-3}, i.e., an H-atom concentration of about 1.5×10^{6} cm^{-3}. Combining with density values at lower altitudes from satellite orbit data we can construct a model of the exosphere.[30] Its temperature is 1500° K. The critical level is found to be 530 km, and transition to the "outer exosphere" (where neutral hydrogen predominates) occurs at 1000 km (see Fig. 4.7).

Using these values for the atmospheric density calculated from the one observed radiation-belt point, we can now calculate also the variation of radiation intensity with altitude. For the *hard* radiation belt, a maximum is reached at the equator at about 1½ earth radii (2000 mile altitude), beyond which the intensity drops. The soft radiation-belts intensity should reach a maximum near 5 Earth radii, ultimately decreases, because the trapping properties of the field deteriorate, and it disappears when the interplanetary magnetic field takes over, probably at near 10 Earth radii. These theoretical predictions can be checked experimen-

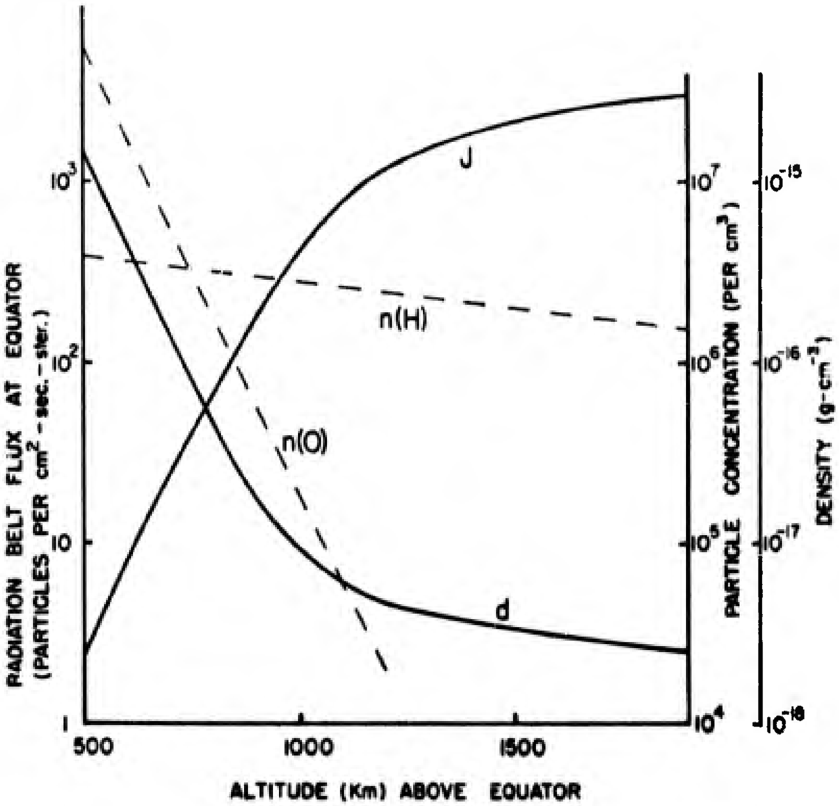

Fig. 4.7. Radiation-belt intensity and atmospheric density and composition at the equator. The atmospheric density was derived from satellite data, the low altitude values from the atmospheric drag, and a high altitude point at 1900 km from the radiation-belt intensity and the theory of reference 28. The exosphere critical level is found at 530 km; above this level collisions between atoms can be neglected and the temperature remains constant at 1500° K. Oxygen, because of its smaller scale height, falls off very rapidly with increased altitude until at about 1000 km hydrogen predominates. This region, then, we call the "outer exosphere." Using these new values for the atmospheric density, the radiation-belt intensity can be calculated as a function of altitude and is shown in the graph (from reference 30).

tally; the moon shots should give an excellent opportunity for such measurements.

The excellent agreement between the calculated radiation-belt intensity at the equator and the observed values gives support to our theory for the origin of the radiation belt. However, in our view, there are in reality two radiation belts coexisting at the same time: (1) the *hard* radiation belt, just discussed, which is of cosmic-ray origin, and can be calculated with great accuracy from cosmic-ray data and theory; and (2) in addition the *soft* radiation belt, which is of solar origin and is connected with magnetic storms and aurorae—it surrounds the hard

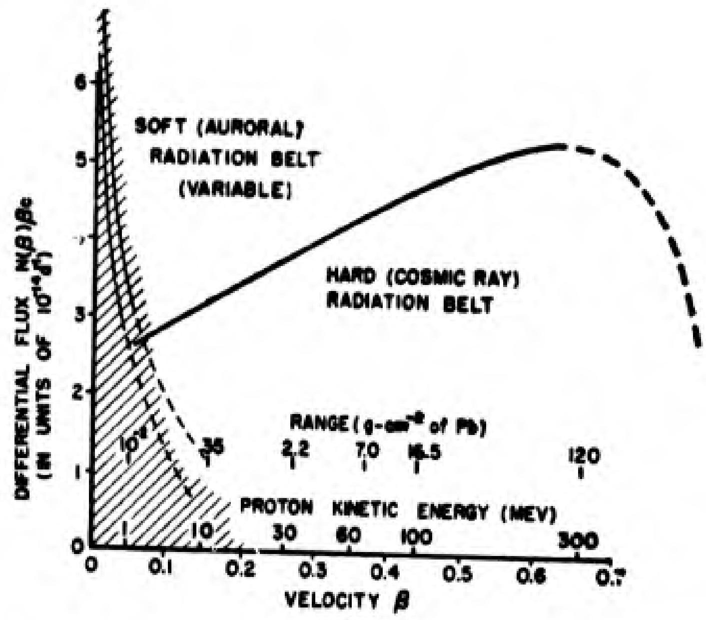

Fig. 4.8. Differential energy spectrum of the radiation-belt flux. The differential flux is shown as a function of the proton velocity, β. Note that the differential flux actually increases with β until the supply spectrum cuts off, or until the trapping properties of the magnetic field deteriorate (indicated by dash line). The corresponding kinetic energies and ranges are shown giving the thickness of lead required to stop a proton of given energy. At very low energies we find the soft radiation belt, its contribution depending on latitude, altitude, and probably time. Its uncertain variation is indicated by crosshatching. In any case its energy spectrum will fall off very steeply.

radiation belt like a halo, although there must be a region of overlap (see Fig. 4.5). As a consequence, the radiation-belt picture changes at different latitudes and different altitudes. Table 4.2 indicates schematically the properties of the hard and soft radiation belts of the Earth.

The energy spectrum to be anticipated is shown in Fig. 4.8.[28] The high-energy portion is the hard radiation belt* and the low-energy por-

* *Note in proof:* High-energy protons, some with energies extending as far as 700 Mev, have been found to exist in the inner belt (S. C. Freden and R. S. White, *Phys. Rev.* Letters **3**, 9, 1959).

tion is due to the soft radiation belt. The intensity of the soft belt will vary depending on location and time; for example, it will be absent at low altitudes near the equator and will reach a maximum in the auroral zone following intense solar activity. As a consequence of this complicated mixture of spectra, experiments with thin absorbers are likely to give inconsistent results. Since the hard radiation belt should be quite constant with time, the use of shields having a thickness of about 10 g/cm^2 or more, should give reproducible flux values.

Space Medical Implications

Reference 28 gives a calculation of the expected energy spectrum of the trapped protons which form the hard radiation belt. Energies range from less than 5 Mev to perhaps 400 Mev, with a large percentage at high energies. To screen out particles having energies less than 100 Mev requires 1 cm of lead shielding. To reduce the intensity of the highest energy protons requires about 4 cm of lead. But a 4-cm-thick shell to shield a sphere of diameter 4 m would weigh over 10,000 lb. In reference 28 the approximations introduced into the calculations are discussed; the exact theory (which is very difficult to calculate) indicates somewhat fewer high-energy protons, but even 5000 lb of lead shielding may be impractical.

Health Hazards. The protons in the radiation belt are quite equivalent to those accelerated in a cyclotron. In addition to the very high flux, they also have a high ionization density. Thus their effects will be very serious, particularly, of course, on complex molecules, such as living cells and genes, and even on long-chain molecules such as rubber. With the use of our calculated proton energy spectrum we can derive the following approximate relations: a counting rate of 1000 (particles/cm^2-sec-steradian) corresponds to an energy density of 20 ev/cm^3, to an energy flux of 0.2 erg/cm^2-sec, and to an exposure of 0.1 r/hr. Near 2000 miles, therefore, the exposure would be about 5 to 10 r in 1 hr, close to the maximum allowable dose for a whole year (5 r). A lifetime dose would therefore be accumulated after one week's operation at this level in the equatorial plane.

Clearly, manned satellite space stations operating in the radiation belt cannot be declared safe until the theoretical predictions are modified (or possibly refuted) by experiments.

Counter-Measures to the Radiation Belt

Avoidance. Operation of satellites below 400 or above 40,000 miles should give radiation levels corresponding only to the primary cosmic radiation whose altitude dependence was calculated earlier.[10] Interplanetary launchings may best be carried out near the poles since the theory indicates that the polar regions are clear of the hard radiation belt. In the auroral region, of course, we would still have the soft radiation belt, but it presents no particular shielding problem.

Shielding. As discussed before, heavy shields may be required, ranging as high as 40 g/cm², which may be impractical for many applications. For the soft radiation belt, however, the structure of the space vehicle may be sufficient to provide the necessary shielding. Therefore our counter-measures need be directed only against the hard radiation belt.

The theory of trapped particles shows that they spiral mainly at right angles to the line of force and are therefore incident mainly perpendicular to the line of force. (In fact, the line of force defines the axis of a double cone which is clear of incident particles.*) Therefore, a shielding ring (rather than a shell) may be sufficient, giving a weight-saving of perhaps a factor of 10. On the other hand, it will be necessary to keep the shielding ring's axis aligned with the line of force.

"Space Sweeper." Perhaps the most radical suggestion for overcoming the radiation belt is to construct a satellite whose purpose it is to "sweep out" a channel in the radiation belt, i.e., to remove the protons by absorbing those that hit it.[31] This scheme may work, because the injection rate for the hard protons is so small.† It requires, however, satellites of very large area (and therefore mass) distributed throughout the radiation belt. The cross-sectional area, A_c, of the swept-out channel is determined by the radius of curvature, ρ, of the protons in the Earth's magnetic field, B, and is therefore quite large. At a distance r from the Earth's center we find[31]

$$A_c = (r \cdot \Delta\lambda) \cdot \rho = r \frac{H_0}{2r} \cdot \frac{Mc^2\beta}{300B}$$

where $\Delta\lambda$, the effective latitude interval is proportional to the scale height, H_0, and $Mc^2\beta$ is the proton momentum in electron volts ($Mc^2 =$ 931 Mev). Thus, at an altitude of 4000 mi above the equator, the cross-sectional area of the swept-out channel for protons of about 150 Mev is in the neighborhood of 4×10^{15} cm² (over 100,000 sq miles). The effective removal rate of the particles, however, is given by the cross-sectional area of the satellite. Therefore, the number of particles removed depends on the product of satellite area, A_s and operating time,

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* As a consequence, a directional detector will observe a flux value which depends on its angle to the line of force, and therefore on vehicle's orientation, its spinning or tumbling.

† In our analogy this amounts to making a large hole in the water tank, and waiting until the level goes down.

T_D. The fractional reduction in intensity, $\delta J/J$, is given very roughly by the number of particles absorbed divided by the total number of particles in the volume affected. The former is simply $JA_sT_D = NvA_sT_D$, and the latter is $N \times 2\pi r A_c$. Hence,

$$\frac{\delta J}{J} = \frac{v}{2\pi r A_c} A_s T_D$$

In our specific example, assuming an intensity reduction of 50 per cent, the product A_sT_D turns out to be about 10^{15} cm²sec. Thus, the operating time would be about one year if the sweeper satellite had a radius of about 30 meters, or about one month if twelve such sweeper satellites were used.

It is an interesting consequence of this theory that the sweeping time is independent of the proton energy to a first approximation, but that the satellite in a given time sweeps up a larger *volume* of the higher energy particles, which is of course very desirable.

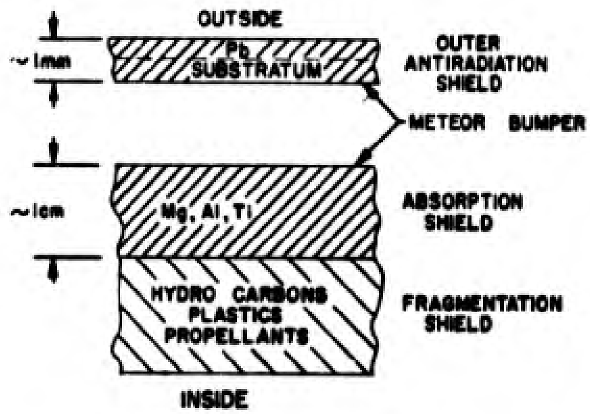

Fig. 4.9. An optimum radiation-shield design based on the presence of a large flux of low energy protons. The outermost layer of lead reduces the radiative processes by these protons by introducing a high Coulomb barrier. This outer skin can be spaced from the inner structural skin using the meteor bumper design suggested by Whipple. The skin of the vehicle itself is made of low Z material to reduce the radiation from electrons; also low Z materials have a higher stopping power per gram per centimeter² than, e.g., lead. The inner layer of hydrogenous material (fuel, propellants, plastic, water, etc.) serves to fragment heavy primaries of the cosmic radiation and thus reduce their biological effectiveness.

4.7 RADIATION SHIELDING

The design of an optimum (i.e., minimum-weight) shield is quite an involved problem. It is necessary of course to know (1) the types, energies, and intensities of the radiations, and (2) the specific effects they produce in various materials.

The discussion below indicates how we arrive at the composite shield shown in Fig. 4.9.

Categories of Radiation

1. Electrons with energy less than 0.5 Mev (occurring in auroral radiation).
2. Electrons with energy greater than 0.5 Mev (possibly in radiation belt).
3. Protons with energy less than 0.5 Mev (auroral radiation).
4. Protons with *E* of 0.5 to 5 Mev (auroral and hard radiation belt).
5. Protons with *E* of 5 to 500 Mev (radiation belt and produced in small solar flares).
6. Protons with *E* greater than 500 Mev (primary cosmic rays).
7. Heavy nuclei with *E* greater than 500 Mev (primary cosmic rays).
8. γ-rays of 0.5 to 5 Mev (of bremsstrahlung and nuclear origin).

Specific Effects

1. Range. For electrons and protons the range (measured in grams per centimeter^2) is fairly well defined and given in Tables 4.3 and 4.4.

Table 4.3 Range and Energy Loss of Protons (in Aluminum and Lead)[2]

Residual Range (g/cm^2)		Kinetic Energy (Mev)	Momentum (Mev/c)	Energy Loss (Mev/g-cm^{-2})	
Al[a]	Pb[a]			Al	Pb
1.3×10^{-3}	—	0.5	31	295	—
3.6×10^{-3}	1×10^{-2}	1	43	185	~70
2.15×10^{-2}	5×10^{-2}	3	75	84	37
6.9×10^{-2}	1.5×10^{-1}	6	106	51	24
1.7×10^{-1}	3.5×10^{-1}	10	137	34	17
1.17	2.2	30	239	14.5	8.2
4.05	7.9	60	341	8.4	5.0
10.0	16.5	100	444	5.8	3.5
65	120	300	808	2.95	1.7
195[b]	310[b]	600	1220	2.10	1.32
400[b]	620[b]	1000	1690	1.80	1.17

[a] The density of Al is 2.7 g/cm^3 and that of Pb is 11.3 g/cm^3.

[b] These values exceed the range corresponding to nuclear interactions.

Table 4.4 Range and Energy Loss of Electrons (in Aluminum)[2]

Residual Range (g cm²)	Energy (Mev)	Momentum (Mev c)	Energy Loss (Mev/g-cm⁻²)
2.5×10^{-4}	0.01	0.101	>20
8×10^{-4}	0.02	0.144	13.8
1.7×10^{-3}	0.03	0.177	9.6
2.8×10^{-3}	0.04	0.206	7.8
4.1×10^{-3}	0.05	0.232	6.8
1.4×10^{-2}	0.10	0.335	4.2
4.4×10^{-2}	0.20	0.494	2.85
8.6×10^{-2}	0.30	0.630	2.35
1.3×10^{-1}	0.40	0.754	2.10
1.7×10^{-1}	0.50	0.986	2.02
4.2×10^{-1}	1.00	1.42	1.80
9×10^{-1}	2.00	2.46	1.85
1.4	3.00	3.47	1.95
1.8	4.00	4.48	2.00
2.1	5.00	5.49	2.05

Table 4.5 Absorption Coefficient of Gamma Rays in Aluminum and Lead[33]

Energy in units of (Mev)	Energy (electron masses)	Al α_T (cm⁻¹)	Pb[a] α_{ph}	Pb[a] α_c	Pb[a] α_{pp}	Pb[a] α_T (cm⁻¹)
0.150	0.29	0.35	≫1	1.19	0	≫1
0.300	0.59	0.26	>1	0.9	0	>2
0.500	0.98	0.22	0.9	0.75	0	∼1.65
0.700	1.4	0.18	0.4	0.67	0	1.07
1	2.0	0.16	0.21	0.57	∼0	0.78
2	3.9	0.11	0.06	0.41	0.05	0.52
3	5.9	0.09	0.04	0.32	0.11	0.47
4	7.8	0.08	0.02	0.26	0.15	0.43
5	9.8	0.06	0.01	0.22	0.24	0.47
6	11.7	0.05	∼0	0.20	0.30	0.50
7	13.7	0.04	—	0.17	0.35	0.52
8	15.6	0.04	—	0.15	0.41	0.56
9	17.6	0.04	—	0.14	0.45	0.59
10	19.6	0.04	—	0.13	0.48	0.61

[a] For Pb we give the total as well as the partial absorption coefficients for photoionization, Compton scattering, and pair production.

NNN 41

For γ-rays, absorption is exponential, i.e., intensity falls off as $e^{-x/\alpha}$ where α is given in Table 4.5.

2. Ionization density: This is given in Tables 4.1 and 4.2, for electrons and protons (or energy loss dE/dx per g/cm^2). To a good approximation, $dE/dx \propto Z^2/\beta^2$. For protons in the Mev range, $dE/dx \sim E^{-0.55}$.

Shielding thick enough to exceed the ionization range can protect reasonably completely against categories 1 and 3, less well against 2 and 8. Shielding may not be too practical against 5, 7, and especially 6. The choice of the best shielding material is governed by physical laws and by practical design: low-Z material (aluminum) for 1, 2, 3, 5, 6, and especially 7 (see below under "Fragmentation"); high-Z (e.g., lead) for 8. Only for 4 is a sophisticated design indicated, since in spite of a thick shield protons can make their effects felt by radiative processes which create γ-rays. Even though their yield is small, about 10^{-4} to 10^{-10}, they become important if the number of particles is large and if the γ-ray energy is high. The most important γ-ray processes are: bremsstrahlung, K-shell x-rays, Coulomb excitation, and nuclear reactions, e.g., of the $(p\,\gamma)$ type. Of these processes only the last one is exothermic, i.e., capable of giving a γ-ray whose energy exceeds that of the primary proton. As will be shown, the best protection is obtained from an outermost coating with a material of high atomic number, Z.

3. Bremsstrahlung. This occurs when the incident particle is accelerated in the Coulomb field of a nucleus or of an atomic electron. For an incident electron the bremsstrahlung cross section is larger by a factor 10^6 to 10^7 as compared to a proton, because of the much smaller mass of an electron. For high-energy protons incident on targets of high Z, the radiation is mostly of the electric dipole type, with the differential cross section given by[42]

$$d\sigma_{E1} = 1.225 \times 10^{-8} Z^2 \left(\frac{1}{4}\right) f_{E1}(\xi)\,\frac{dE_\gamma}{E_p E_\gamma}\ \text{barns}$$

A barn, the usual unit for nuclear cross sections, is 10^{-24} cm^2. E_γ is the γ-energy. E_p is the proton energy (in Mev). We find f from Table 4.6. A typical yield for 4-Mev protons on tungsten is 100 counts per μcoulomb. Note the strong dependence on Z.

4. Nuclear γ-rays. This process is important for protons with $E > 0.5$ Mev; they can be absorbed by the target nucleus (of charge Z) to form a compound nucleus which later emits an energetic γ-ray. The critical proton energy is given by the Coulomb barrier, E_B, which is[34]

$$E_B \sim ZA_2^{-1/3} \sim 0.8Z^{2/3}\ \text{Mev}$$

Below E_B the cross section drops rapidly (see Table 4.7). But because of resonances, large yields are sometimes produced below the Coulomb

Table 4.6 Coulomb Excitation Factors[32]

γ-ray energy = 200 kev

E_p (Mev)	$\xi = 1.3\ E^{3/2}$	$f_{E1}(\xi)$	$f_{E2}(\xi)$
1	1.30	0.022	~0.008
2	0.459	4.7	0.32
3	0.250	19.4	0.66
4	0.163	37	0.80
5	0.116	52	0.84
6	0.088	~66	0.86
7	0.070	~77	0.88
8	0.058	~85	0.88
9	0.048	90–100	0.88
10	0.041	~100	0.88
20	0.014	≫100	0.88
30	0.008		0.88
50	0.004		0.88
100	—		0.88

barrier. Resonance locations and widths are tabulated in references 35 and 36. It is clear, therefore, that in order to avoid nuclear γ-rays (which in some cases can have energies up to 17 Mev!) one must go to an initial shielding layer of high Z. The same requirement also holds for the effects 5 and 6 below.

Table 4.7 Cross Sections (in Barns) for Compound Nucleus Formation[32]

E/E_B	Z of Target Nucleus 20	50	90
0.2	4×10^{-4}	—	—
0.3	5×10^{-3}	6×10^{-5}	—
0.4	3×10^{-2}	2×10^{-3}	8×10^{-5}
0.5	8×10^{-2}	1×10^{-2}	2×10^{-3}
0.6		6×10^{-2}	2×10^{-2}
0.7			6×10^{-2}

5. X-rays from *K*-shell of target atom. In heavy target atoms the x-ray energy is about 50 to 100 kev. The cross section (for protons) is given by

$$\sigma_K \cong \left(\frac{E_{\text{Mev}}}{A_1}\right)^4 \left(\frac{36}{Z}\right)^{12} \cong E^4_{\text{Mev}} \left(\frac{36}{Z}\right)^{12} \text{ barn}$$

6. Coulomb excitation. This is probably the most important source of γ-rays from protons with energy below E_B. The Coulomb field of the passing proton can excite collective oscillations in the target nucleus, which then radiates. For a typical case of a target nucleus with $Z = 50$, $A = 120$, and excitation energy $\Delta E' = 200$ kev, σ for an electric dipole ($E1$) transition increases from 1 to 10 millibarns, and for an electric quadrupole ($E2$) transition from 10^{-2} to 1 millibarn as the proton energy varies from 1 to 3 Mev. In practice, however, only the $E2$ transition is important, and in some target nuclei it may exceed the theoretical values above by a factor of 100 because of collective action. Thus, one may get a thick target γ-ray yield of 10^{-7} for a 2-Mev proton (protons give highest yield because they have the longest range). The exact expression for the $E2$ cross section with a proton projectile is[32]

$$\sigma_{E2} = 4.8\left(1 + \frac{1}{A_2}\right)^{-2} \frac{1}{Z^2} (E - \Delta E') f_{E2} \cdot B \text{ barns}$$

In using the expression we note again the Z^{-2} factor; the dependence of σ_{E2} on E is mainly through f_{E2} (ξ) (see Table 4.6).

In order to design the least "active" shield we should select a material with the highest possible atomic number, Z, in order to obtain the maximum Coulomb barrier. Lead not only satisfies this condition, but in addition has negligible Coulomb excitation. The most abundant isotope $_{24}Pb^{128}$ has a doubly closed shell and is therefore very inactive as far as

Table 4.8 γ-Ray Energy and Intensity from Coulomb Excitation[32]

Target Nucleus	γ-ray Energy, $\Delta E'$	B
$_{22}Ti^{46}$	890	0.15
$_{24}Cr^{53}$	155	0.015
$_{26}Fe^{56}$	854	0.10
$_{28}Ni^{58}$	1450	0.1
$_{29}Cu^{65}$	1150	0.027
$_{47}Ag^{107}$	419	0.28
$_{47}Ag^{109}$	412	0.31
$_{73}Ta^{181}$	309	0.57
$_{74}W$	295	0.27
$_{76}Os^{188}$	202	
$_{77}Ir^{191}$	356	0.8
$_{77}Ir^{193}$	368	0.3
$_{78}Pt^{195}$	240	0.48
$_{78}Pt^{196}$	360	1.3
$_{79}Au^{197}$	580	0.42
$_{92}U^{238}$	45	0.13
$_{92}U^{235}$	103	0.6

Coulomb γ-rays are concerned. On the other hand, it has an appreciable cross section for the process (p, xn) when the energy of the incident protons is in the region around 20 to 80 Mev.[37] Clearly to be avoided as the outermost layer are titanium, iron (steel), nickel, and copper. As can be seen from Table 4.8 these materials will radiate high-energy Coulomb excitation γ-rays.

7. Fragmentation. For deeper shielding against categories 5, 6, and 7, a low-Z material is preferred for three reasons: It has (1) higher stopping power per gram per centimeter^2 (but its lower density may increase the shielding weight), (2) low probability for generating cosmic-ray cascade showers, and (3) highest probability on a weight basis for fragmenting of heavy cosmic-ray primaries, especially if the material contains much hydrogen (fuels, water, or plastics).[3]

Final Radiation-Shield Design

Based on the foregoing discussion we can design an optimum radiation shield if we know what radiations are prese[illegible]. In the absence of category 8 but in the presence of cosmic rays, radiat[illegible] belt, and perhaps large low-energy cosmic-ray fluxes from solar flares, the shield shown in Fig. 4.9 would be optimum on a weight basis. The outermost layer should be made of lead, possibly evaporated on a substratum that also has little possibility for Coulomb excitation, such as tin. It may be desirable to separate this antiradiation shield from the skin of the space vehicle, thus providing a meteor bumper. The skin of the vehicle could be made of a low-Z material such as aluminum, magnesium, or titanium, that provides shielding by ionization loss for protons and electrons, and gives structural strength. An inner layer of hydrocarbons can then effectively stop or fragment, depending on its thickness, a certain fraction of the primary cosmic rays.

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8

LECTURES IN AEROSPACE MEDICINE

RADIATION IN SPACE

II. Biological Effects

Presented By

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RADIATION IN SPACE: II. BIOLOGICAL EFFECTS

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INTRODUCTION

The previous section presented the physical nature of space radiations which can be divided into: galactic cosmic rays, solar cosmic rays, and planetary radiation belts(1). Figure 1 pictures the distribution of these three space radiations.

The biological effects of space radiations can be interpreted in terms of two physical models, a diffuse birdshot model and a rifle bullet model.

Radiation produced by gamma rays, electrons, and the nuclei of light elements can be compared to birdshot in the sense that it produces a spray of ionization scattered throughout tissue. Birdshot radiation produces isolated ionizating events rarely related to each other in time and space considered on a scale of atomic dimensions.

The atomic nuclei of heavy elements between carbon and iron observed only in the first type of space radiation, compare to rifle bullets. The heavy nuclei, like bullets, produce their

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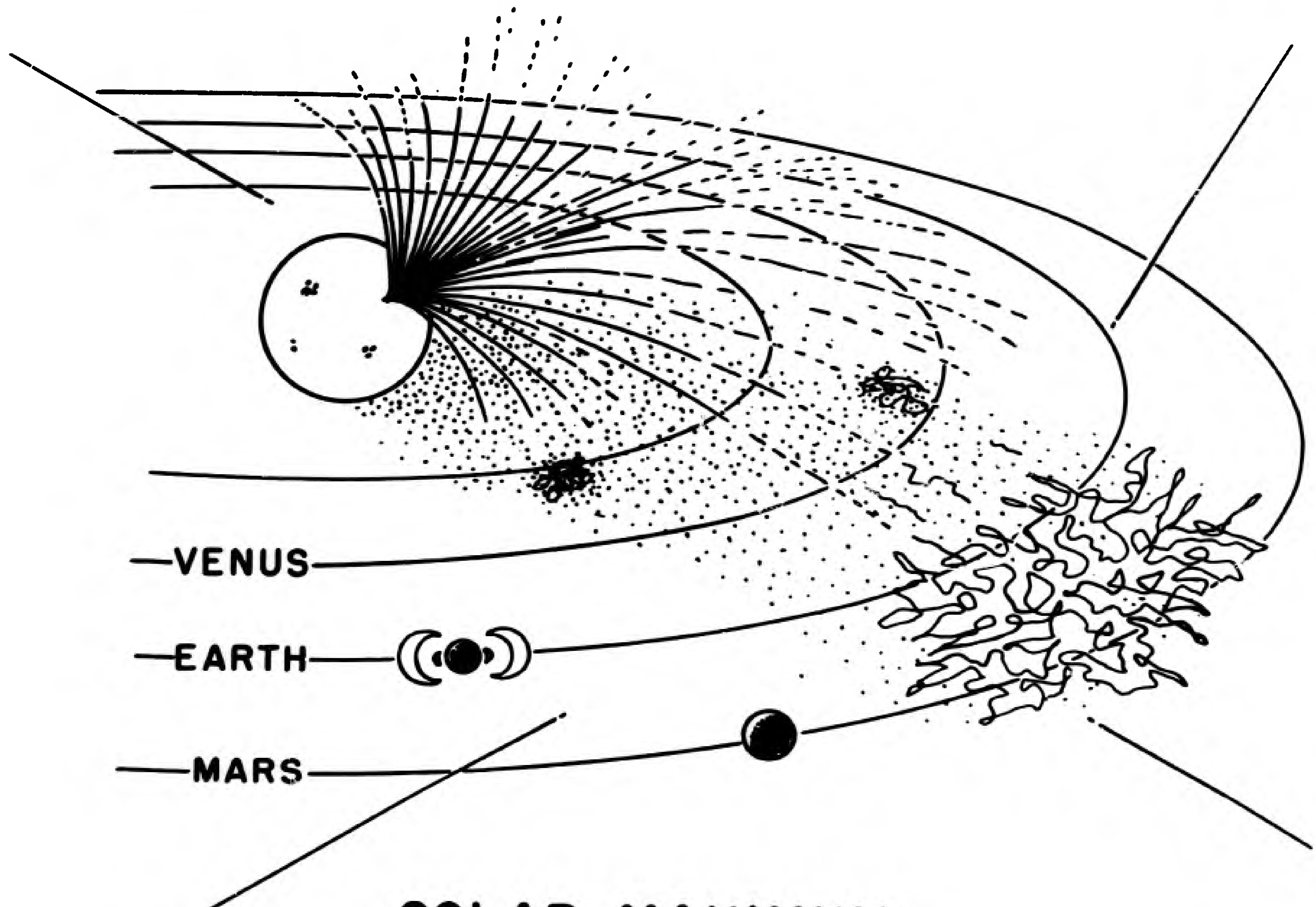
damage along a circumscribed path in a very short period of time. These nuclear bullets suddenly create a path of ionization so dense that, effectively, ionizing events occur simultaneously among a path o of adjacent molecules and atoms. The resultant interaction of products of ionization (track effects) are observed along the path of all kinds of high energy nuclear particles. The scattered ionizing events of the birdshot type radiation are so widely separated in space and time they rarely produce comparable chemical and biological reactions. The spray of secondary radiation produced by the collision or spallation of primary galactic cosmic ray particles is characterized by the birdshot model. In composition and energy this secondary galactic radiation is comparable to solar cosmic rays and planetary radiation zone radiations.

The second category of space radiations, solar cosmic rays, includes intense streams of x-rays, electrons and protons ejected from the sun at irregular intervals. If these relatively low energy solar radiations are confined to nuclei lighter than Helium, as many physicists suspect, they will produce their biological effects chiefly in terms of the birdshot model.

The planetary radiation (Van Allen) belts, composed of electrons and protons, constitute the third type of space radiation. They produce a birdshot radiation pattern.



SOLAR MAXIMUM

Figure 1. Galactic cosmic ray particles traverse the solar system from interstellar space. The sun ejects solar cosmic rays which permeate the solar system. Planetary radiation belts are charged particles trapped in magnetic fields surrounding a planetary body.

Dose concepts based on total ion production and total energy absorption such as rep (roentgen equivalent physical) and rad are applicable to birdshot types of radiation. Likewise, derivative concepts such as rbe (relative biological effectiveness) are useful in that context. However, these concepts lose much of their meaning when applied to the exposure of an organism to track-producing (rifle bullet) radiation. The reasons for this will be considered in more detail later.

A track-forming particle produces its effects in a microscopic portion of a specific tissue in one discrete event. Hence, exposure is more meaningfully expressed in terms of the number of particles penetrating a given area or volume of tissue per unit time. Under quiescent conditinns Yagoda observed approximately 30 heavy primary thin-downs per cc of tissue per day (2).

Figure 2 presents the energy relationships among the various radiations occurring naturally in space and the corresponding radiations produced by laboratory sources. The electrons comprising the soft(outer) radiation zone (3) have a maximum energy of a few Mev (million electron volts). The protons comprising the hard (inner) zone have energies reaching several hundred Mev. The protons and electrons ejected from the sun have reached the earth with energies of 30 or 40 Bev. The positively charged galactic primaries arrive with energies encompassing 10 orders of magniture of energy. Ninety percent of these primaries arrive with an energy of 15 Bev per amu (atomic mass unit) or less. Of the galactic primaries, the

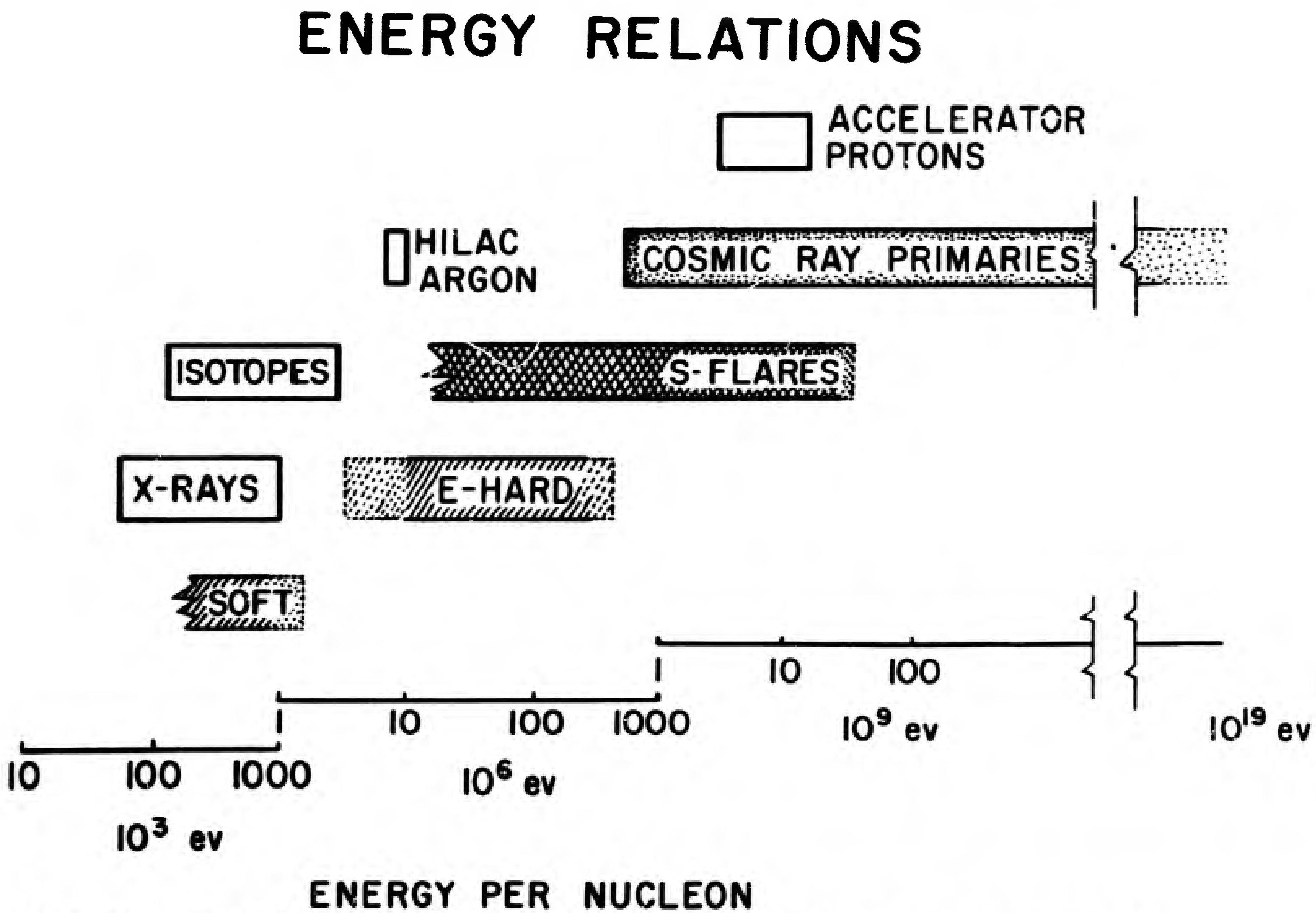


Figure 2. Energy Relationships of Ambient Space and Laboratory Produced Radiations. The hatched bars represent the range of energy characteristic of the soft (outer), and hard (inner) earth radiation zones. The cross hatched bar represents the energy distribution of particles ejected from the sun as solar cosmic rays. The stipled bar indicates the energy range of galactic cosmic ray primaries. The open bars represent the energy of radiations produced by laboratory sources. Heavy ion linear accelerators (HILAC) can accelerate nuclei as heavy as argon to an energy of 10 Mev/atomic mass unit. Synchro cyclotrons canproduce electrons and protons of 20 Bev.

heavy nuclei (carbon or heavier) arriving with energy less than a few Bev/amu are of greatest biological concern and interest.

The health hazard to be expected from exposure to the birdshot type of radiation in space can be evaluated in terms of the known effects of exposure to x-rays, protons, electrons, etc. of comparable energy. The observed effects resulting from these radiations produced by atomic sources are directly applicable.

The health hazard to space radiation may be considered either on a military acute hazard basis or on an industrially acceptable hazard basis. Langham (4) has argued eloquently for considering acute space radiation exposure on a basis comparable to the other acute hazards of space flight such as meteor impact, rapid decompression, engineering failure, etc. On this basis, an acute exposure to 100 r would be acceptable since it can be expected to produce only trivial clinical symptoms (5).

By contrast, relatively little is known of the biological effects to be expected from the tracks of dense ionization produced by the relatively low energy bullet-like heavy primary portion of the primary galactic cosmic radiation spectrum. Primary particles of less than approximately one Bev per amu terminate by thin-down. Particles of higher energy terminate by nuclear collision producing stars or spallation products (spray of secondary radiation). For ions larger than argon (calcium to iron) the dense radiation produced in the terminal portion of the thin-down tracks can be observed only in space.

The contrast between the ionization pattern produced by an iron nucleus thin-down (Figure 3) and the spray of radiation produced by a relativistic iron nucleus collision (Figure 4) graphically illustrates the physical difference between bullet and birdshot radiation. These two figures are photographs at the same magnification of the paths produced in nuclear track plate emulsion. The thicker, denser path produced by the low energy terminating thin-down particle contrasts to the less dense path of ionization produced by the high energy relativistic primary particle. After star formation the ionization of the high energy particle becomes much more diffuse (less concentrated per cc of tissue irradiated).

The space radiation pattern to which an astronaut in a space ship would be exposed when traveling beyond the earth's atmosphere can be related to the radiation pattern observed between 100,000 and 150,000 feet of altitude. The absorption effects of a given space ship's hull and of the atmosphere above a given altitude in this region are comparable. The two can be equated to a first approximation by expressing both in terms of the number of grams per square centimeter of absorber through which the ambient space radiation must pass. Figure 5 illustrates how incoming primary galactic cosmic ray particles react with the atmosphere between altitudes of 150,000 and 75,000 feet. The 1.5 grams per cm^2 of air remaining above 150,000 feet (corresponding to a hull thickness of $\frac{1}{4}$ inch of aluminum) has little effect on the high energy galactic cosmic ray

Figure 3. (thindown) Terminal portion of galactic cosmic ray primary thindown track produced by a nucleus approximately the weight of iron. Track observed and photographed in Ilford G-5 nuclear emulsion by Dr. Herman Yagoda, AFCRC.

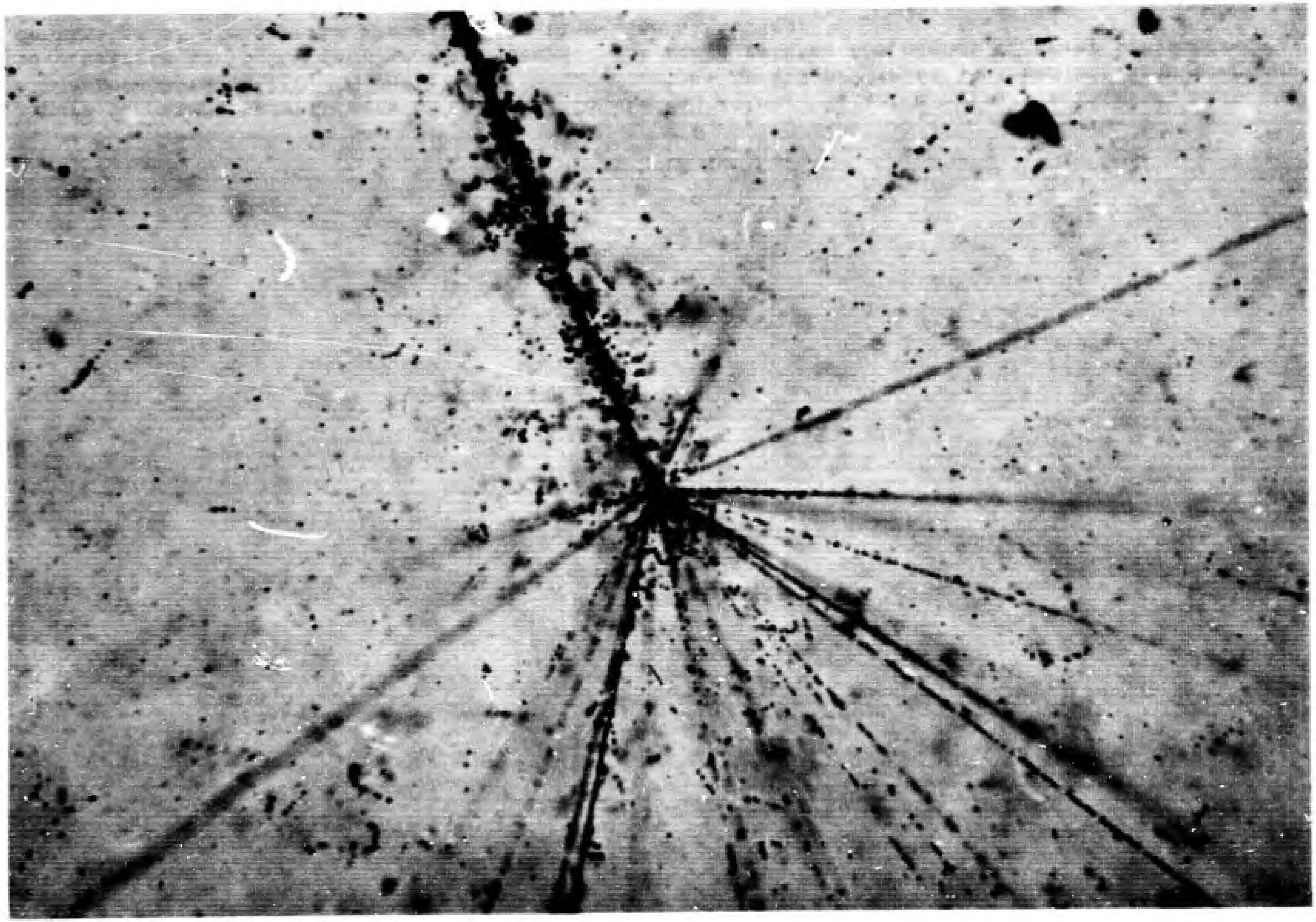


Figure 4. (Star) Star producing spray of secondary radiation following collision of descending galactic cosmic ray primary approximately the weight of iron. Primary collided with a heavy nucleus possibly silver or bromine in Ilford G-5 nuclear emulsion. Event observed and photographed by Dr. Herman Yagoda, AFCRC.

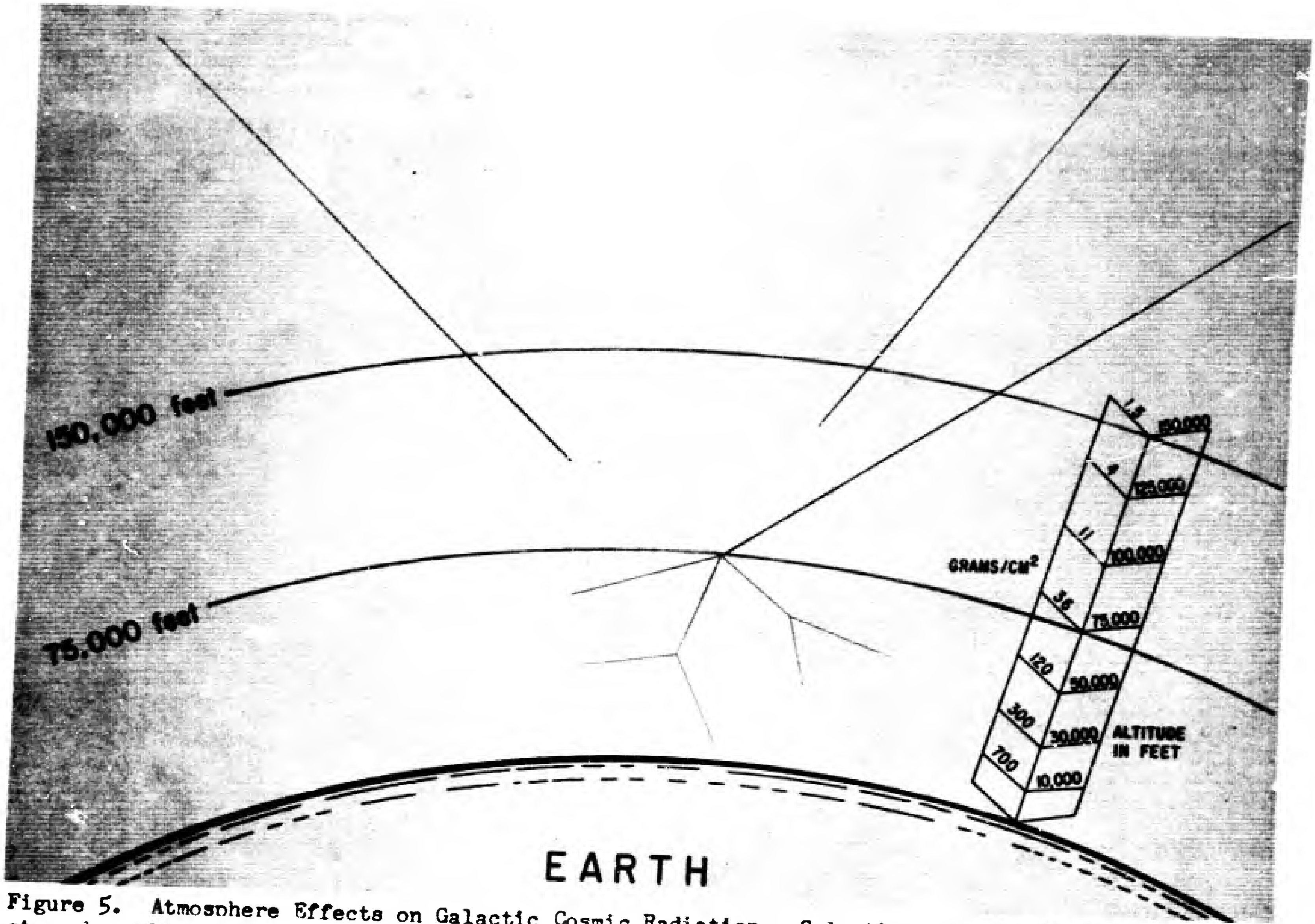


Figure 5. Atmosphere Effects on Galactic Cosmic Radiation. Galactic primaries interact with the atmosphere between 150,000 and 75,000 feet. Practically all primaries that had sufficient energy to penetrate to 75,000 feet produced stars. The scale relates the number of grams per square centimeter of atmospheric absorption to tape-line altitudes.

primaries. The 36 gms/cm^2 of absorbing atmosphere remaining above 75,000 feet corresponding to a hull thickness of 5.2 inches of aluminum. In this much absorber the energy of the original galactic particles has either been dissipated by ionization (thin-down) or it has been widely scattered as spallation products following a star-producing nuclear collision. An intermediate value between $\frac{1}{4}$" and 5.2 inches of aluminum seems reasonable for the total thickness of a space ship cabin hull.

Heavy ion linear accelerators (HILAC) can reproduce only the terminal low energy segment of the tracks produced by medium and light nuclei. These 10 Mev/amu HILAC particles can penetrate a maximum depth of several cells in tissue. Primaries in space approaching 1 Bev per nucleon energy can penetrate 20 to 100 cm of tissue. The remainder of this paper will be concerned chiefly with the theoretical and observed biological effects from exposure to track producing heavy primary type radiation.

TRACK EFFECTS

Comparison of Figures 4 and 5 reveals graphically the marked difference in radiation intensity per unit volume of tissue between a heavy primary thin-down and a star. The region of intense ionization (more than 10^4 ion pairs per micron of path length) along the track of an iron thin-down particle extends through a distance of 1 centimeter in tissue.

The effects observable as the result of traversal by a heavy primary cosmic ray particle can be divided into four stages. First, a purely physical stage lasting approximately 10^{-13} (less than a millionth of a millionth of a second), a physio-chemical stage lasting approximately 10^{-11} second, a purely chemical phase lasting approximately 10^{-6} second, and finally a biological phase which may extend over many generations (6).

Figure 3 illustrates the result of the physical stage as it occurs in nuclear emulsion. Part of the energy of the original particle is transferred to the material through which it passes in two ways: it ionizes atoms and molecules and it excites them, temporarily placing them in a higher energy state. Both mechanisms affect the sensitized emulsion of nuclear track plates.

The physio-chemical stage follows instantly. Now the primary products undergo transforming reactions. The ions collide with each other and with normal molecules forming new molecules or molecular fragments. The excited molecules either spontaneously dissociate to become ions or dispose of their energy as heat retaining their identity. The net result of this stage is a group of newly formed molecules which may or may not be different from those originally present, and chemically unstable species or molecular fragments frequently called free radicals.

At this point the third (chemical) stage follows. The newly formed molecules and free radicals react chemically with each other, the molecules previously present, and the milieu in which the reactions occurred. The highly reactive free radicals frequently disrupt nearby stable molecular groups creating biologically harmful products.

The fourth stage represents the reaction of a biological system to the foreign chemical substances. The biological reaction will be determined by the effect of these substances on the structure and function of the cells in which the products have been formed, the structure and function of the tissue formed by these cells, and the importance and function of this tissue to the total economy of the organism and its descendants.

It thus becomes clear that the biological effect produced by a heavy primary cosmic ray particle depends entirely on where it occurs in the body. Dose terminology for track-producing radiation that expresses the number and kinds of tracks produced, indicates far more clearly the nature and types of biological damage to be expected than a system which describes only the total ionization without regard to its configuration. To evaluate the hazard from track producing space radiation it is necessary to know the nature and extent of the damage produced in those cells and tissues which suffer critical irreplaceable damage.

An understanding of this problem can be approached from two research points of view: 1) The mechanisms whereby effects are mediated from the physical through physio-chemical to the chemical stage can be elucidated through exposure of simple biological materials to laboratory generated radiations; 2) The observable biological effects produced by track-producing radiation can be observed in complex organisms. The research effort encompassed by the Bioastronautics Branch of the School of Aviation Medicine includes both approaches. Exposures using microbeam x-rays and heavy Ion Linear Accelerators extend knowledge of basic radiobiological mechanisms. Informatinn now available provides only a hazy indication of how these mechanisms exert their ultimate biological effects on living organisms. Flight experiments exposing biological materials to heavy primary radiation in space identify effects produced by specific heavy primaries. There is now a large gap between the two approaches but research in the next 5 to 10 years should see several examples of its closure.

The chemical stage of irradiation by a track producing particle would logically be quite sensitive to the presence of water and oxygen. The interaction of molecular radicals with oxygen radicals of atomic oxygen and ozone will produce more reactive chemical compounds than would form in the absence of oxygen (7). Chase (8) has observed a significant increase in the sensitivity of pigment cells radiation damage by x-rays in the presence of increased oxygen tensions. A similar effect has been observed (9) on balloon flights.

BIOLOGICAL EFFECTS OF TRACK PRODUCING IONIZING PARTICLES

The first approach to the total problem, examination of radiobiological mechanisms, is being pursued by a group of scientists under the direction of Dr. Ernest Pollard of Yale University. Utilizing the HILAC there, they have studied the inactivation of dried enzymes by 10 Mev fluorine, oxygen, and carbon nuclei (10). Observed cross sections for inactivation of dried trypsin and Beta-galactosidase enzymes correlated well with theoretical calculations based on the application of target theory. The trypsin target radius of 19 angstrom units (corresponding to an equivalent molecular weight of 22,400) agrees closely with the physio-chemical molecular weight determination of 23,000. These results clearly indicate that in this dried biological material the effective "track" or spread in the path of ionization and excitation corresponds closely to its calculated physical dimensions. This has been demonstrated for dried biological material only. By contrast experiments with "wet" vegetative cells and higher forms of actively metabolizing tissues (e.g. the mouse experiments) indicate a much higher sensitivity to track effects. The enzyme studies confirm that even in dry biological materials a single ionization along a track produces inactivation of a single molecule. For the densely ionizing heavy primaries this means a continuous series of altered molecules along the path of the particle.

The second approach observes the nature and severity of biological effects produced by high energy nuclear particles. This approach includes two types of experiments. Biological specimens exposed to ambient space radiation can be evaluated on a non-specific basis to detect any general change as a result of exposure. The other approach is to monitor individual heavy particles identifying exactly what identifiable portion of the biological material is exposed to what kind of nucleus of what energy. The latter approach provides a better opportunity of understanding the biological effect in terms of the physical exposure characteristic of heavy primary particles.

Three experiments explored the non-specific approach. In 1955 two Macaque monkeys were exposed for 63 hours above an altitude of 90,000 feet on serial balloon flights (11). The performance of these animals was compared with two ground control animals. They were examined for loss of memory or performance ability for previously learned tasks, loss of ability to learn new tasks, and general health characteristics such as appetite, weight loss, personality changes, etc. No significant difference was detected between the exposed animals and the ground control animals.

A second experiment involved the exposure of 85 white mice above an altitude of 90,000 feet for 16 hours, also in 1955 (12). Immediately after flight an equal number of control animals were exposed to exactly the same environmental conditions that the exposed mice had experienced during flight. The two groups were followed until they died of "natural" causes. Each mouse was autopsied to determine its cause of death. The colony death rate was closely followed through their two year life span following flight. There was no clearly significant difference in the death rate between the two groups. This was a small group of mice, a short exposure or at a minimal altitude. However, the experiment was conducted very carefully and conscienciously. There was a suggestion of an increased incidence of mammary tumors but the significance of this was statistically marginal.

The third experiment involved 50 dry radish seeds exposed above 82,000 feet for a total of 250 hours (13). Evaluation of their development following flight revealed no significant change in germination rate or any abnormality in the appearance of the germinated plants compared to ground controls. Calculations indicated that 10 percent of the seeds had experienced a heavy primary thin-down within the germinal area.

This negative picture changes when we look at the specific effects produced by individual heavy primary particles (the second type of biological effect experiment). Figure 6 illustrates one of the most impressive effects observed to date. A streak of gray hairs appeared on the left flank of this mouse following exposure above 90,000 feet in 24 hours (14). This phenomenon has been observed on other mice.

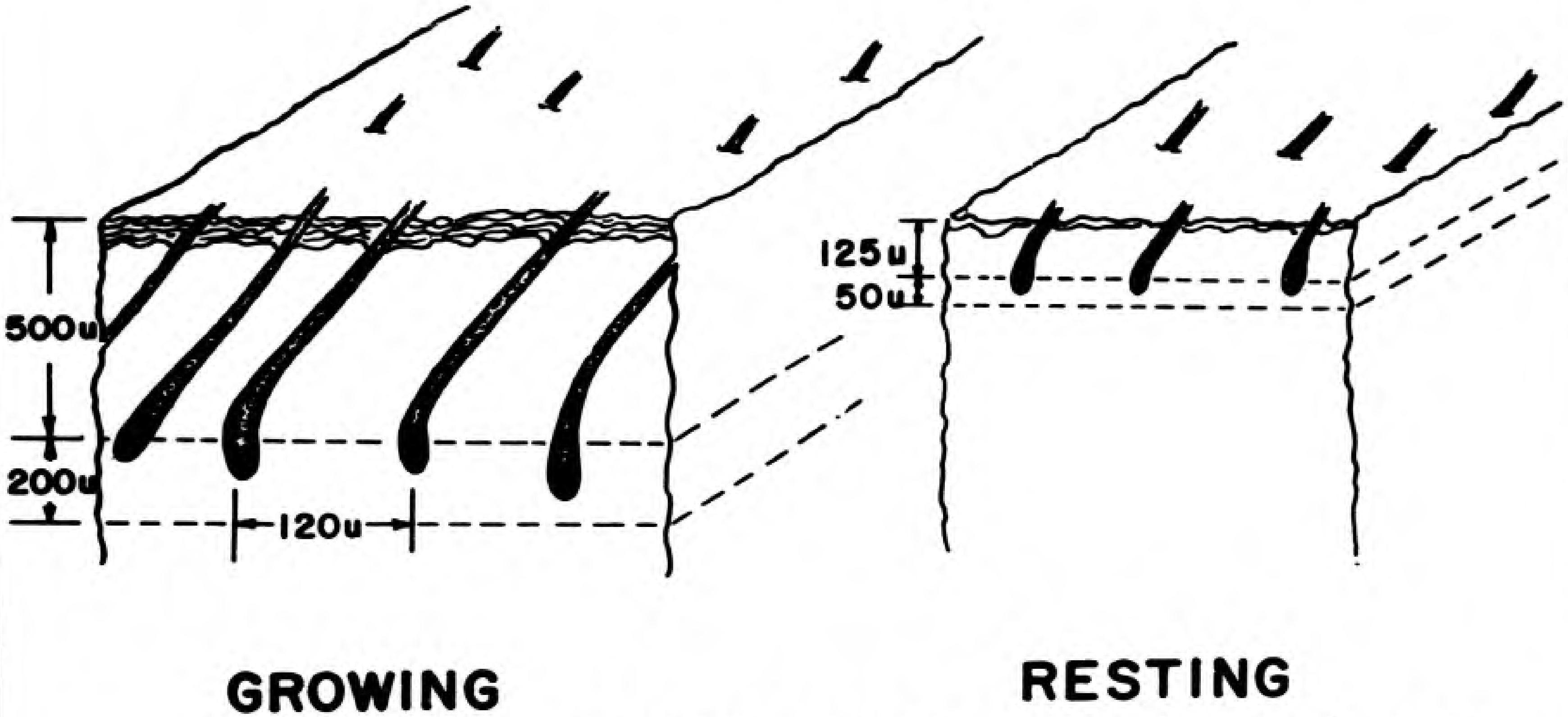
Figure 6. Streak of gray hairs occurring on left rump of C-57 black mouse following exposure to heavy primary cosmic radiation. Photograph courtesy of Brown University.

Dr. Hermann Chase of Brown University has conducted numerous x-ray experiments to study graying of the hair of C-57 black mice. He has found that exposure to less than approximately 100 Rep (roentgen equivalent physical) will produce no noticeable graying effect. Dose levels between 100 and 1000 Rep produce an increasing incidence of graying until, at approximately 1000 Rep levels, the entire exposed area produces gray hairs.

Each hair follicle contains a group of several sensitive pigment cells (melenophores) which pigment the hair as it grows from the follicle. The average distance (Figure 7) between hair follicles in black mice is approximately 120 microns. The minimum effective diameter of the track that has produced the observed series of unpigmented hair follicles (Figure 8) is 30 to 100 microns. The physical diameter of a heavy primary track which includes a radiation intensity of 100 r is only a few microns (15). The observed biologically effective track width exceeds the theoretical path width many times. The explanation apparently involves unidentified mechanisms operating in the chemical and/or biological stages.

The subject of the Manhigh II balloon flight of 1957 remained above 90,000 feet for 16 hours. Nuclear emulsion pellicles were taped on several areas of the body to monitor heavy primary thin-downs which might produce gray hairs such as those observed on C-57 black mice. After flight the plates showed (16) an exposure

Figure 7. **MOUSE HAIRS**



Schematic of follicle pattern observed over dorsum of C-57 black mice showing the separation and range of depth of follicles within the skin. (from data by Chase)

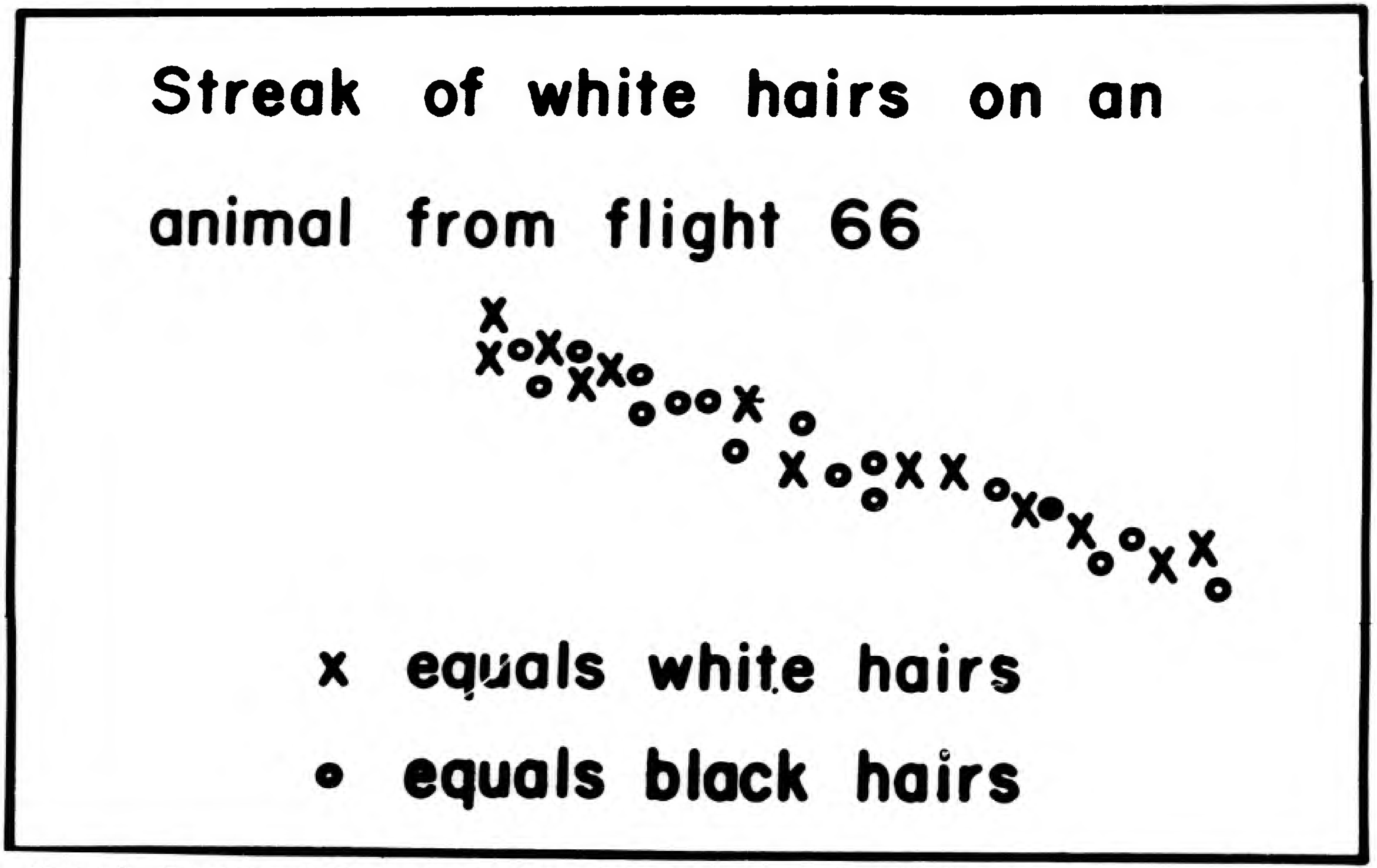


Figure 8. Schematic of streak of white hairs following exposure above 90,000 feet.

rate of only half that which had been observed 4 years earlier during solar minimum. All thin-downs of primary particles heavier than neon were recorded and correlated with the appearance of gray hairs. Only a few hairs turned gray in the monitored areas following flight. It is interesting to note that the gray hairs observed on the arms within a few months following flight were the first to appear in these areas. No additional gray hairs have been observed on the arms since this one crop that appeared over two years ago. This result is consistent with the graying effect observed in mice.

Each specific tissue: e.g. cutaneous cells, brain cells, and reproductive cells, has unique response characteristics to radiation. Unless some specific monitoring technique is employed to unambiguously identify exactly what kind of primary particle causes a specific tissue reaction, a clear knowledge of the effects of the various portions of the radiation spectrum will be extremely difficult to realize.

One of the prime objectives of the Bioastronautics Branch of the School of Aviation Medicine is the development of a workable monitoring technique for identifying exactly which cells were irradiated by what kind of primary particle.

Figure 9 illustrates the technique being developed based on the original concept of Dr. Herman Yogoda of the Air Force Cambridge Research Center. Nuclear emulsion is poured on both

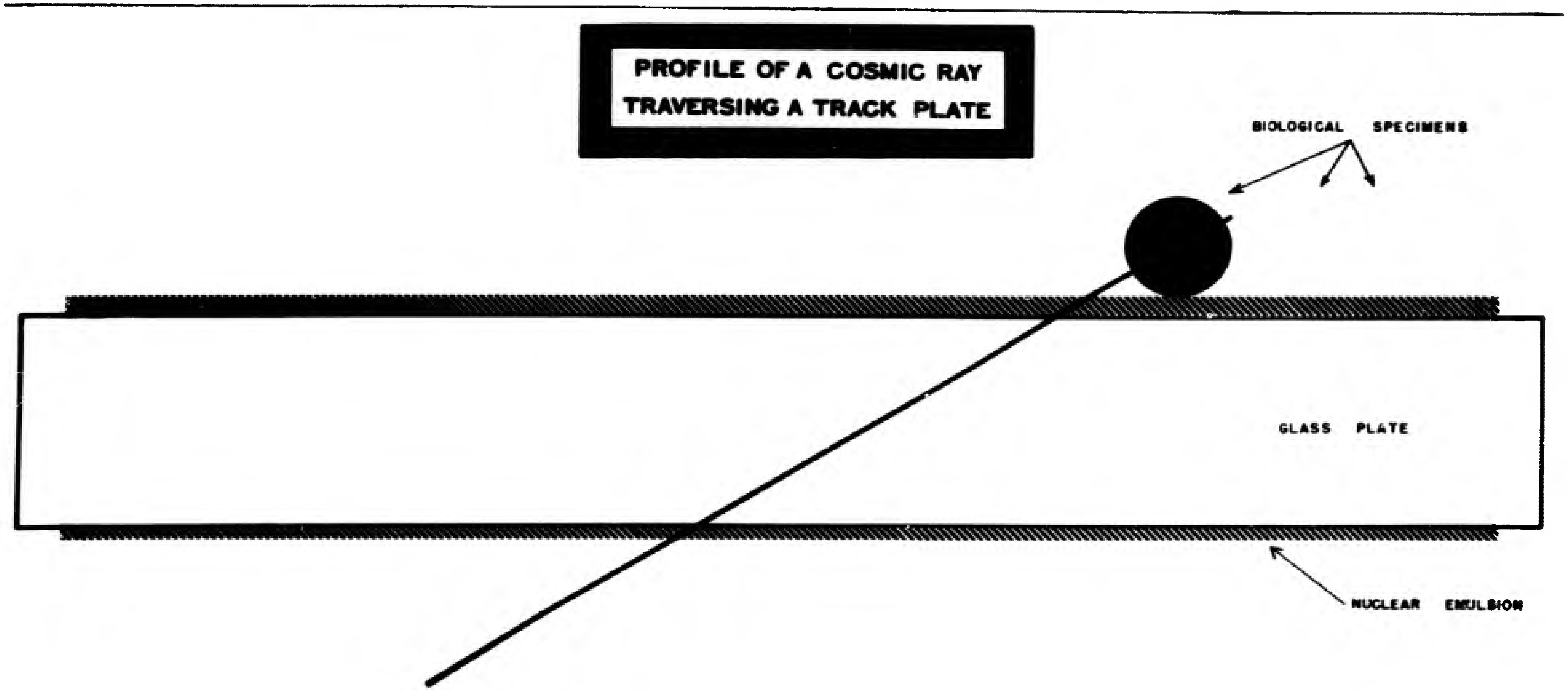


Figure 9. Schematic of track plate monitoring system illustrating the extrapolation of the path of a heavy primary particle through the emulsion to the biological specimen oriented above the track plate.

sides of a glass plate. The biological specimen is firmly attached and oriented with regard to the track plate in a known position above one layer of emulsion. When a primary particle traverses the total assembly the exact path of the primary particle can be extrapolated from the nuclear emulsion to establish accurately what part of the monitored biological specimen was exposed. This technique was originated to monitor guinea pig brains, through the interest and efforts of Dr. Herman Yagoda.

During this past year experiments monitored in this fashion include Neurospora (a bread mould), rat nerve cells in tissue culture, and insect eggs. Only preliminary results have been obtained to date. The technique looks very promising.

The question of the sensitivity of nerve tissue to heavy primary cosmic radiation has been studied by Dr. Webb Haymaker, Armed Forces Institute of Pathology, Washington, D. C. In collaboration with Dr. Herman Yagoda, Dr. Haymaker prepared six guinea pigs using nuclear track plates to monitor the specific occurrence of individual primary cosmic ray particles (9). In April 1957 six animals were exposed from South St. Paul, Minnesota above 100,000 feet for four hours. Figure 10 shows that one track and one lesion correlated, a second track had no corresponding lesion and there was one lesion without a track. The second track may have terminated in cutaneous or skull tissues. Since the flat track plates did not preclude the

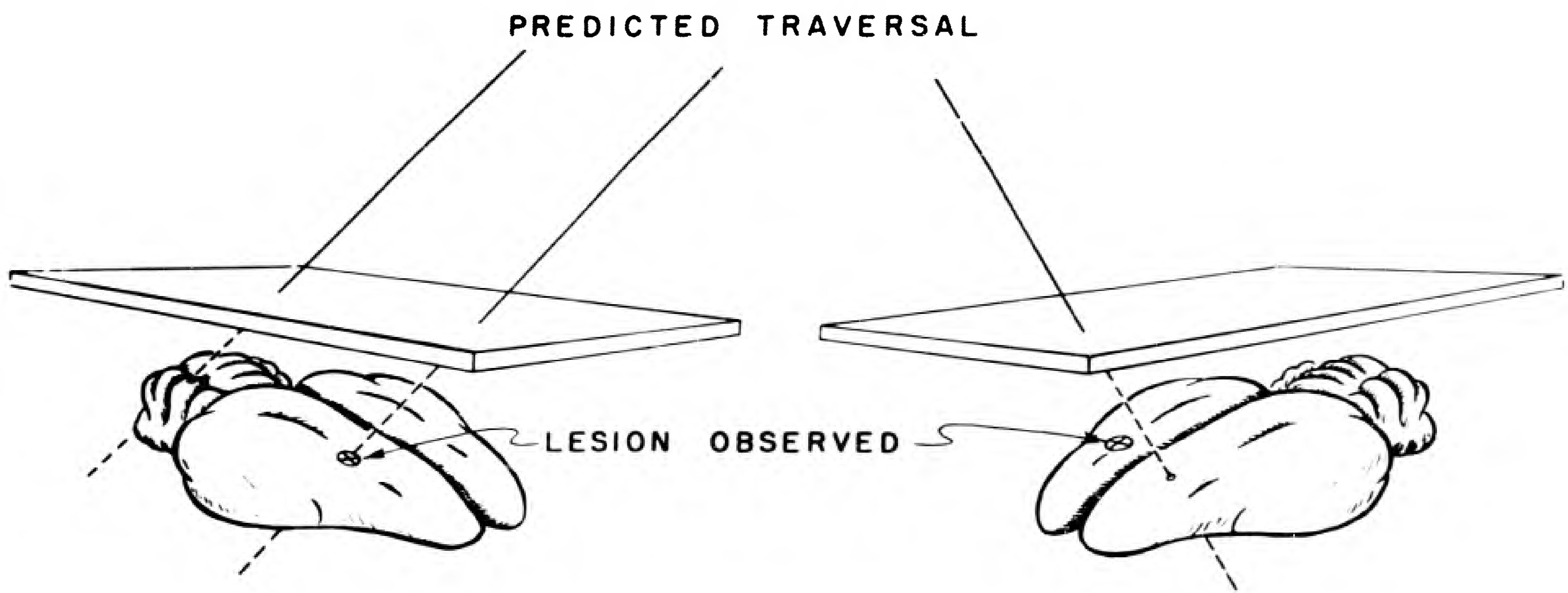


Figure 10. MONITORED GUINEA PIG BRAINS

the entrance of unrecorded heavy primaries from the side of the animals head the lesion with no identified track can be accounted for. The lesions observed were approximately 1000 microns long and from 110 to 440 microns in diameter. The total lesion presented a spongy appearance. The nerve cells were necrotic and their nuclei had begun to enlarge as if due to focal ischemia (17).

In a subsequent study (18), the significance of beam size in producing brain lesions was examined using 22.5 Mev deuteron beam from a 60 inch cyclotron at the Brookhaven National Laboratory. The threshold dose required to produce radiogenic lesions in mouse brain increased from 30,000 Rad with a beam 1,000 microns in diameter to 1,100,000 Rad with a beam only 25 microns in diameter. This clearly suggests that a beam as narrow as the effective path of a primary particle is less damaging than a corresponding dose of radiation spread over a wider area. The time scale, however, is of a different magnitude so that no direct conclusions may be drawn concerning track effects. In this study total exposure times ranged between approximately 1 to 20 seconds compared to cosmic ray track exposures lasting only a micro micro second.

Progress reports submitted by Dr. Herman B. Chase describing research conducted under Air Force contract as part of the Bioastronautics Branch cosmic radiation program describe recent results. In collaboration with Dr. Cornelius Tobias of Donner Laboratory, he exposed the C-57 black mice to neon particles accelerated to 10 Mev per amu in the HILAC at Berkeley, California. One centimeter areas of skin developed hyperplasia and hyperkeratosis of the epidermis and swelling of the dermis following exposures as low as 700 RAD (19) an effect not observed with comparable doses of x-rays. Exposure through a micro-beam aperture produced a remarkable effect, the subsequent total loss of cutis muscle in the area of exposure. The muscle disappears completely, quickly, and is not replaced. With larger apertures there is damage to the cutis muscle but not the same clean permanent loss of the exposed sector. This work is continuing.

The high altitude flight genetic studies using Neurospora crassa appear promising. The problem of identifying the spores which have suffered mutation as compared to normal spores is greatly simplified by selecting a back mutation system. An adenineless Neurospora mutant which has suffered a radiation induced back mutation to wild type will stand out as a sole center of growth in a culture prepared on adenine-free media. Dr. A. Gib DeBusk is also conducting experiments under Air Force contract utilizing track plate monitoring. This experiment is arranged as illustrated in Figure 11. By imbedding the Neurospora in a filter paper carrier attached firmly to a monitoring nuclear

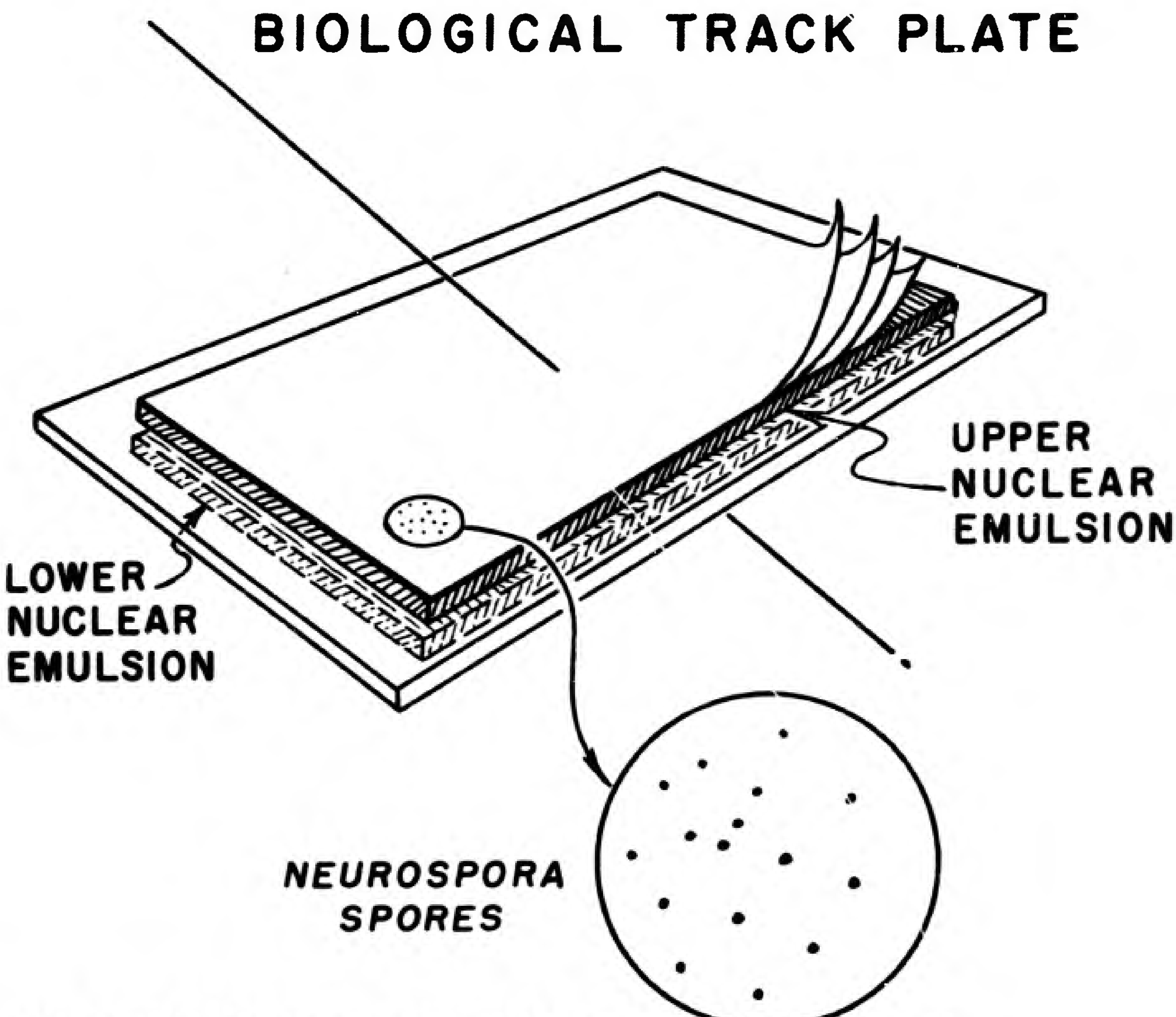


Figure 11. Schematic of technique used to monitor Neurospora experiments conducted by Dr. A. Gib DeBusk of Florida University. From top to bottom the preparation consists of layers of paper saturated with Neurospora spores, nuclear track plate emulsion, a glass plate supporting the nuclear emulsions, and the lower nuclear track plate emulsion.

track plate it is possible to correlate back mutant Neurospora spores with heavy primary traversals. This technique has been successfully employed on several flights in the past few months. It has been possible to correlate a locus of back mutation with the specific primary particle that produced it.

Dr. Wilson Stone, employing the same type of material, is conducting experiments in which the spores are carried on the track plates in an entirely different configuration.

SUMMARY AND CONCLUSIONS

Biological effects of space radiations are considered in three categories: planetary (Van Allen) radiation zones, solar cosmic radiation, and galactic cosmic radiation. The heavy primaries uniquely characteristic of primary galactic cosmic radiation produce bullet-like tracks in contrast to the bird-shot distribution of the other space radiations.

The absence of any biological experiments exposed directly to either planetary radiation zones or solar cosmic radiation permit conclusions based only on theoretical considerations. The inner (high energy proton) planetary radiation belt appears to pose a serious hazard if a satellite orbit were established at the altitude of its central region. Singer has proposed several methods for significantly reducing the radiation intensity in this region. A total of approximately 10 roentgens was presented as the dose to be expected while passing through this region on an interplanetary space mission. This dose appears trivial compared to the other hazards that must be faced during interplanetary flight. Polar exit would avoid exposure to this type of radiation.

The outer (low energy electron) planetary radiation belts contain electrons in considerable numbers at energies above 13 Mev. This is sufficient energy to produce bremsstrahlung (x-rays) that can penetrate 5 grams per centimeter of lead. The intensity of this belt varies markedly with time and may be virtually absent during periods of low solar activity. The hazards posed during periods of high solar activity will be dependent upon the thickness of the space ship hull and the intensity of electrons in this zone and their energy.

Solar radiations during periods of solar flares and active unipolar magnetic regions may be a major, if not catastrophic, radiation hazard. More data are needed concerning the energy spectrum and charge distribution of particles present beyond the atmosphere during solar flares of various intensities. Until then, the full significance of, and requirements for, shielding from these birdshot radiation hazards remain unsolved.

The bullet-like tracks produced by primary cosmic radiation becomes of concern only above 75,000 feet. The track effects experienced from this radiation are identified in four stages: physical, physiochemical, chemical and biological.

The physical and physiochemical mechanisms identified by Pollard correlate well with physical models in dry material. Extension of research examining in more detail the physical and physiochemical mechanisms of track effects using this approach appears very promising.

The effects observed in biological specimens exposed to track producing high energy particles were examined in three non-specific experiments. The negative results observed from these experiments indicate there is no serious health hazard to be anticipated from exposure lasting approximately every 24-hours to galactic cosmic radiations in the vicinity of the earth's orbit.

A series of experiments in which individual primary particles were monitored to identify the specific biological effects reveal unique radiobiological phenomena. The occurrence streaks and clumps of grey hair observed in mice exposed at high altitude correlate with the track plate monitored experiment on the subject of the Manhigh II flight. Lesions observed in guinea pig brains suggest that central nervous system tissue may be susceptible to bullet-like radiation pattern of heavy primaries. Observations on black mice exposed to the HILAC beam by Chase and Tobias demonstrate unique cutaneous tissue changes. Positive results on high altitude exposures of Neurospora material for evaluation of genetic changes confirm the expectation that individual tissues will show characteristic response patterns to track producing radiation.

These positive results warn that the hazard of exposure to galactic cosmic radiation for periods of a week or more in the regions of space well beyond the earth's orbit are undetermined.

The total radiation hazard picture in Space looks hopeful, but dependent upon the resolution of a number of gaps in our knowledge of the physical exposure present and completion confirmatory biological experiments in Space.

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LECTURES IN AEROSPACE MEDICINE

SPACE PROPULSION SYSTEMS

Presented By

Dr. Walter R. Dornberger

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In the two years since Sputnik I was launched, there have been profound changes in our attitude as well as our concepts regarding space flight. This is as true of space propulsion concepts as it is of other aspects of the problem. Forms of space propulsion that were previously brushed aside as visionary or impractical are now the subject of intensive study and experiment. To one who has viewed the development of propulsion of heavier-than-air devices from its inception, the exponential increase in the rate of development is truly remarkable. The reciprocating piston internal combustion engine, which made powered flight possible in 1903, underwent steady development and refinement for 40 years without being seriously challenged by any other form of propulsion. However, under the pressure of increased power and speed requirement, born of World War II, gas turbine development suddenly increased. By the end of 1945, the piston engine was obsolete as a military powerplant and its place was taken by the turbo-jet. The turbo-jet has made it possible to almost quadruple the speed of military aircraft in the last 15 years. Nevertheless, while the turbo-jet is just now replacing the piston engine for civilian aircraft, it is already facing obsolescence in the military field. Even more remarkable is the history of the ram-jet. Regarded as the most promising successor to the turbo-jet 15 years ago, it is now already obsolescent, although it has never yet powered a man-carrying aircraft. The requirements for more and more speed have reached the limit of capability of air-breathing engines. The future, it would seem, belongs to the rocket engine.

The rocket engine, however, is not just a new type of engine. It is a whole class of engines, ranging all the way from the simple "4th of July" powder rocket to the wonderously complex giants that power the Intercontinental Ballistic Missile and our present satellites and space probes. It is basically different from the air-breathing engine because it does not require air either as a working fluid or as a source of oxygen to burn the fuel. It is a completely self-contained propulsion system. The rocket engine is also, certainly, the oldest concept of jet propulsion. Its use in unmanned military weapons dates back over 700 years. However, as a power source for manned vehicles, its development has lagged far behind other forms of propulsion, and only in the last 25 years has it been the subject of serious scientific study and development. There are many reasons for this lag, of which I will mention two. First, the scientific principles by which engines of any kind could be rationally designed have been known for less than 100 years, and much of the technology is of much more recent origin. Secondly, when the principles of jet propulsion were understood, it became obvious that the rocket engine had a tremendous appetite for fuel in comparison with air-breathing engines. Since there was no requirement for long range ballistic missiles or space vehicles, the superior fuel economy of air-breathing engines was the deciding factor in their favor, and they were developed intensively while the rocket engine was almost completely neglected. Requirements have, however, changed, and it is now clear that for the extreme high speeds and extra-atmosphere environments now being explored, the rocket engine is the only possible propulsion system. As a result, we are witnessing at the present time intensive development of chemically-fueled rockets of thrusts ranging from a few pounds to well over a million pounds. At the same time, exploratory work is under way on advanced nuclear-powered, electric-powered, and solar-powered rockets to propel long-range space vehicles of the future.

In order to discuss rocket engines of the present and future in an intelligent manner, we should first review some basic principles. We are all aware, of course, that a rocket engine produces forward thrust by ejecting a stream of high temperature gas rearward at high velocity. The essential elements of a rocket engine are (1) a source of heat, (2) a source of working fluid, and (3) a nozzle to expand the working fluid into a high velocity jet. The basic equations are, first, the momentum equation:

$$F = \frac{\dot{W}\ v_e}{g} \qquad (1)$$

where F = thrust (lb.), $\dot{W}$ = flow rate of working fluid (lb/sec),

v_e = exhaust velocity (ft/sec), and g = acceleration of gravity,

32.2 ft/sec^2.

From this equation, we can readily obtain the specific impulse, I_{sp}, which is the thrust produced per unit of working fluid consumed per unit of time. This is simply:

$$I_{sp} = \frac{F}{\dot{W}} = \frac{v_e}{g} \text{ , seconds} \qquad (2)$$

Now the exhaust velocity is related to the heat content or "enthalpy" of the working fluid by an energy conservation equation known as Bernoulli's Theorem:

$$h_c - h_e = \frac{v_e^2}{2gJ} \qquad (3)$$

where h_c and h_e are the enthalpies of the working fluid in the combustion chamber and exhaust respectively, BTU/lb, and J = mechanical equivalent of heat, 778 ft-lb/BTU. From this equation, we find that the jet velocity is

$$v_e = 223.7 \sqrt{h_c - h_e}$$

$$= 223.7 \sqrt{h_c \left(1 - \frac{h_e}{h_c}\right)}$$

$$= 223.7 \sqrt{h_c \cdot \eta} \qquad (4)$$

and $$I_{sp} = 6.94 \sqrt{h_c \cdot \eta} \qquad (5)$$

where $\eta = 1 - h_e/h_c$, the thermal efficiency of the exhaust nozzle. The thermal efficiency turns out to be related to the pressure ratio across the nozzle by the equation:

$$\eta = 1 - \left(\frac{P_e}{P_c}\right)^{R/C_p} \qquad (6)$$

where P_c and P_e are the pressures of the working fluid in chamber and exhaust respectively, R is the universal gas constant, and C_p is the molar specific heat of the working fluid.

Equations (5) and (6) tell us everything we need to know about chemical rockets. To obtain maximum specific impulse, we want a working fluid with the maximum possible heat content and the minimum possible pressure ratio. In a chemical rocket, a chemical reaction produces both the heat and the working fluid (i.e., combustion products). In a nuclear or solar powered rocket, the source of heat is separate from the working fluid, and it is important in this type of rocket to know how much power is needed to produce a given thrust and a given specific impulse. For this we need one more equation which we can derive from our basic equations:

$$P = 0.0218 \frac{F \cdot I_{sp}}{\eta}, \text{ Kilowatts} \qquad (7)$$

where P is the power supplied to the working fluid.

This completes our review of fundamentals; let us now look at specific cases. We shall first consider the chemical rocket, which represents the present state-of-the-art, and which we may expect to be with us for some time to come. The chemical rocket has a definitely limited specific impulse, as we shall see shortly. However, it has two outstanding advantages over more exotic propulsion devices; its relative mechanical simplicity, and its high thrust-to-weight ratio.

Engineers and chemists have, for years, been reviewing thousands of chemical compounds as possible rocket propellants and the search still continues. To the outside observer this must seem like a waste of time; time that could be spent more profitably by selecting one combination and developing safe, reliable and efficient rocket engines with it. Unfortunately, it appears that the time when two engineers can agree on a propellant combination is still a long way off, and this indecision is as prevalent among our customers as it is within the rocket industry. The choice for any particular mission is the result of compromises among several important requirements, and as yet there is no ideal universal propellant. Theoretically, however, if we are looking for the ultimate in specific impulse, the picture is pretty clear (see Figure 1). The most energetic chemical reaction producing all gaseous combustion products is the reaction of hydrogen with fluorine. The combustion product from this reaction, hydrogen fluoride, is also an excellent working fluid, having a low molar specific heat and good chemical stability. The hydrogen - oxygen reaction produces nearly as much energy, but the combustion product is not as good as a working fluid and the theoretical performance is consequently lower. There are several chemical reactions producing more energy than these, notably the light metal oxidation reactions. Of these, however, only the boron - fluorine reaction produces gaseous combustion products. The others produce solid products which cannot be used alone in a rocket engine, but must be diluted with a gas in order to be used effectively. In spite of their higher energy, none of these chemicals have theoretical performance equal to either hydrogen - fluorine or hydrogen - oxygen. One other chemical propellant deserves special mention, however. If it were possible to stabilize liquid hydrogen in its atomic or free radical form rather than its normal molecular form (H_2), the recombination energy when it reverted to H_2 would be over 15 times that of the hydrogen - fluorine reaction. Even a ten percent solution of atomic hydrogen in normal hydrogen would be a sensational chemical

BASIC ROCKET PROPULSION EQUATIONS

Momentum: $I_{sp} = \frac{F}{\dot{w}} = \frac{v_e}{g}$, seconds

Energy: $I_{sp} = 6.94 \sqrt{h_c \cdot \eta}$

where h_c = heat content of working fluid, BTU/lb

η = expansion efficiency

Effect of pressure ratio on efficiency:

$$\eta = 1 - \left(\frac{P_e}{P_c}\right)^{R/C_p}$$

where R = universal gas constant

C_p = molar specific heat

Propulsion Power Requirement:

$$P = 0.0218 \frac{F \cdot I_{sp}}{\eta}, \text{ Kilowatts}$$

FIGURE 1
Basic Rocket Propulsion Equations

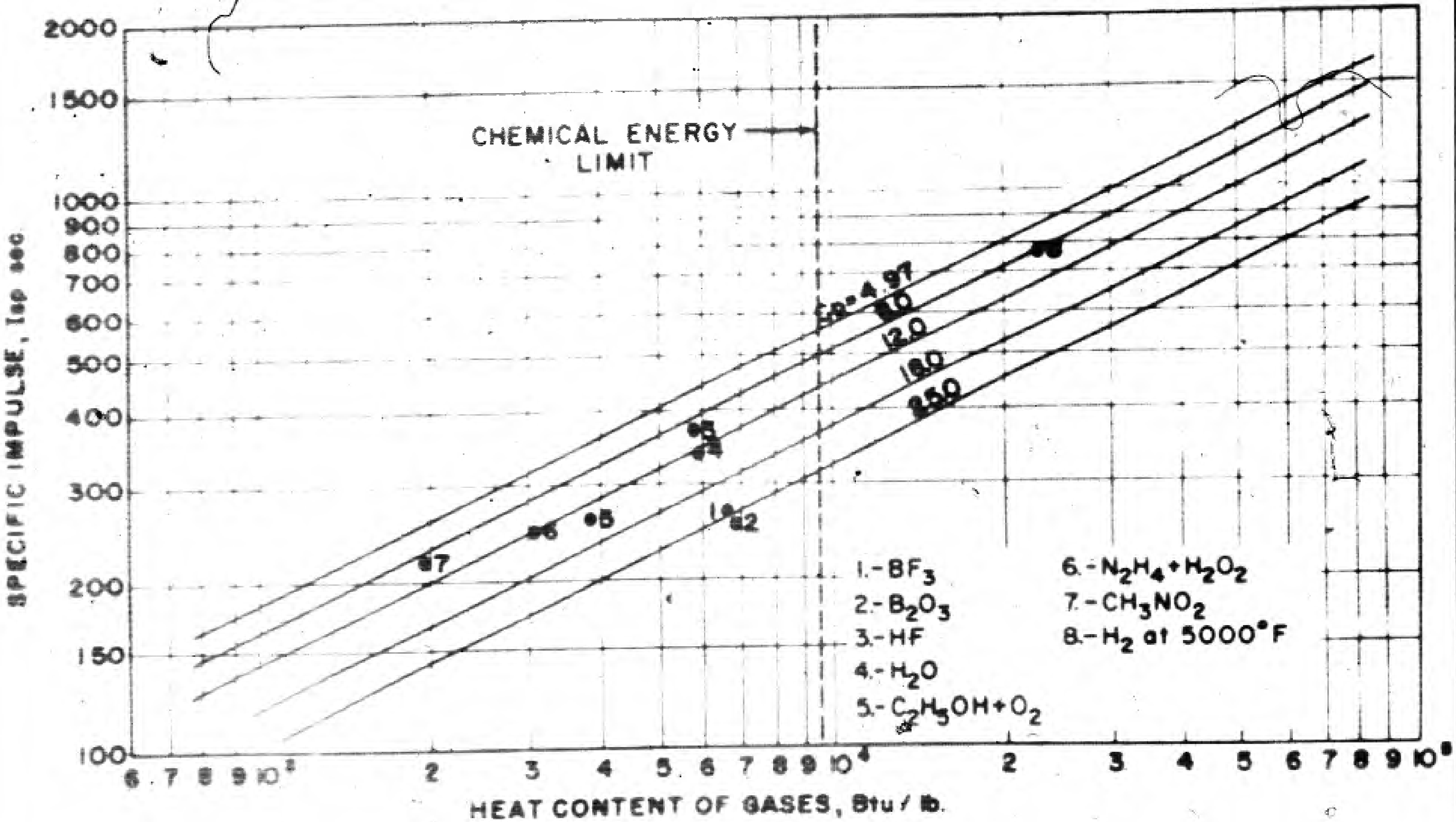


FIGURE 2

Relation Between Specific Impulse and Propellant Energy propellant - if it were possible to make it. This intriguing possibility led the Defense Department to sponsor, two years ago, an intensive free-radical research program under the direction of the National Bureau of Standards. Many interesting and useful discoveries have come from this program, but unfortunately no free radicals have been produced in anywhere near enough concentration to be of interest as rocket propellants. It thus seems probable that the hydrogen - fluorine combination will remain as the ultimate chemical propellant system.

Why not concentrate all rocket engine development on the hydrogen - fluorine system? Well, after working with liquid fluorine at Bell Aircraft for over 3 years, and with the hydrogen - fluorine combination for almost a year, we are inclined to echo "Why not?" We are convinced that the fears about the toxicity and reactivity of fluorine are greatly exaggerated. We have handled over 50,000 pounds of liquid fluorine without any serious mishaps, without any personnel injuries, and, most significant, without any damage to vegetation or livestock in surrounding areas. Granted that both liquid fluorine and liquid hydrogen require special handling techniques, we are satisfied that these techniques can easily be mastered. Furthermore, we have had notable success in building rocket engine components that have operated reliably at 96% of the theoretical performance of this combination. However, lest we be carried away by our own enthusiasm, we should recognize that there are shortcomings to this system which make it impractical for a number of applications.

The most serious problem associated with the use of liquid fluorine, liquid hydrogen, and even liquid oxygen is that they are all cryogenic fluids; that is, they can be kept as liquids only at temperatures far below normal ambient temperature. Liquid hydrogen presents the greatest difficulties in this respect. Its normal boiling point is -423°F, only 37 degrees above absolute zero, a temperature at which all other materials except helium are frozen. Furthermore, liquid hydrogen has an extremely low density, which means that very large insulated tanks are needed to carry it. These tanks add to the weight of the propulsion system; hence partially overcome the advantage of high performance. It is generally recognized in the rocket industry that <u>any</u> cryogenic propellant is practical only for pre-scheduled missions. Consider, for example, the problems associated with filling one of our current space rockets which uses liquid oxygen and kerosene as propellants. Two hours before scheduled launch time, the hoses are attached between the rocket oxidizer tank and the liquid oxygen supply vessel. Liquid oxygen is pumped into the rocket, but for the first 15 minutes it boils off as fast as it is pumped in, since the tank has to be cooled down to liquid oxygen temperature. After this pre-cooling is accomplished, filling proceeds and the tank is filled in about an hour. Boil-off of the liquid oxygen still occurs, as heat leaks into the tank through the walls and through various pipes and connections. The hoses are thus left connected until just before launching, so that the tanks can be "topped-off" at the last minute. If, for some reason, the launching time is delayed, complications may set in. As the surrounding structure continues to be cooled by the liquid oxygen, moisture freezes out on the exposed metal parts, adding hundreds of pounds to the launching weight of the rocket. Hydraulic oil freezes in the lines, inactivating the controls. Even the fuel may freeze. The result of all this is that if the launching is delayed more than a few minutes, it may be necessary to empty out all of the liquid oxygen, thaw out the vehicle, and start all over again. Careful checking and rechecking of systems may eliminate most of these aborted launchings, and indeed such occurrences are now the exception rather than the rule. Nevertheless, it is obvious that a lot of problems would be eliminated if we had storable propellants that could be put into the tanks and left for long periods of time without further attention. This very important factor has led to the current rivalry between liquid and solid propellants, as well as to continuing search for improved propellants of both types. Storable propellants can, of course, be either liquids or solids. They are chemical compounds or mixtures of chemical compounds, and performance is sacrificed in order to get desired physical properties. This sacrifice in performance is considerable. The best storable propellant combination under development today, nitrogen tetroxide and hydrazine, has a theoretical specific impulse of only 257 seconds, compared with 364 seconds for the hydrogen - fluorine system. In fact, the best operational storable propellant combination, red fuming nitric acid (RFNA) and uns-dimethylhydrazine (UDMH), has a theoretical performance of only 240 seconds, while the best operational solid propellant is only 225 seconds. These figures are for sea level performance at a chamber pressure of 300 pounds per square inch. It is possible to improve performance of any of these systems considerably by increasing chamber pressure and by taking advantage of the low ambient pressure at high altitudes. Thus it is possible to achieve a delivered specific impulse of over 270 seconds with the RFNA-UDMH combination at 100,000 feet altitude, using a large expansion ratio nozzle. There is, nevertheless, a great deal of room for improvement in the performance of storable propellants, and chemists are hard at work trying to synthesize new chemical compounds of improved performance.

Very little attention has been given to date to the space environment and its effect on storable propellants. Since rocket engines may be used for orbital adjustment and attitude control as well as for launching, they may be exposed to the space environment for considerable periods. Of particular concern is the effect of exposure to the radiation belts. Strong particulate radiation may dissociate or even explode some chemical compounds. This

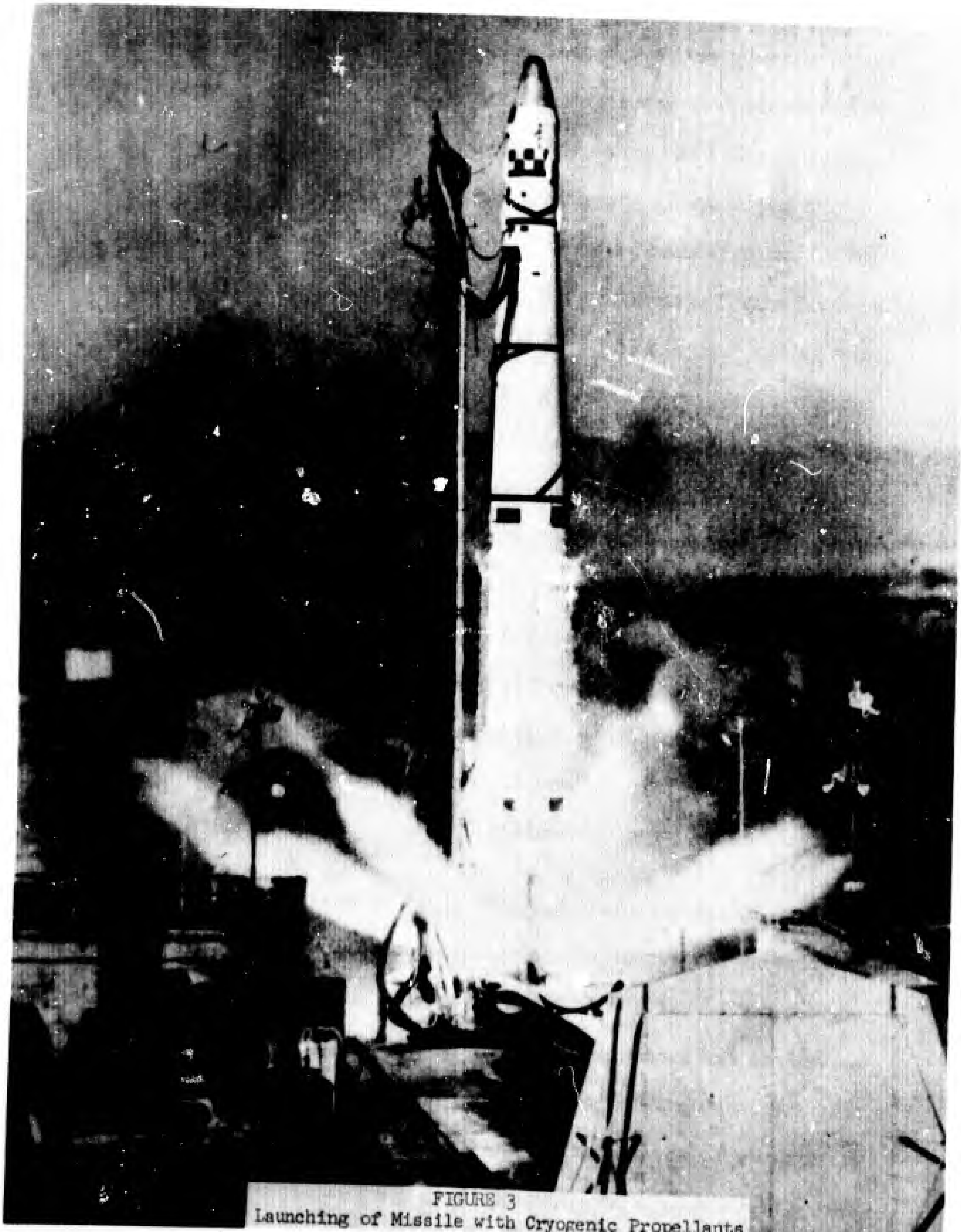


FIGURE 3
Launching of Missile with Cryogenic Propellants

COMPARISON OF PROPELLANT PERFORMANCE

Propellant Combination	Specific Impulse*, seconds
Liquid H_2 - Liquid F_2	364
Nitrogen tetroxide - hydrazine	257
RFNA-UDMH	240
Ammonium perchorate-rubber (solid)	225
Hydrogen peroxide	140

*Sea level performance, 300 psia chamber pressure

FIGURE 4
Comparison of Propellant Performance

subject deserves much further study.

The development of rocket engines is not simply a matter of selecting the right propellants. A great deal of work is also being done in the fields of combustion, heat transfer, fluid flow, and materials research. The design and development of thrust chambers, injectors, pumps, gas generators, valves, controls, and propellant tanks has occupied the greatest part of our efforts in past years. We have now, within the limitations imposed by the propellants we use, developed propulsion systems that are efficient, simple and reliable.

The next slide shows the final stage of Lockheed's "Agena" satellite which uses a modern storable liquid propellant rocket engine built by Bell Aircraft. The propellants used are RFNA and UDMH. This engine has achieved 100 percent reliability in service - eight successful firings in eight attempts. The large expansion ratio nozzle of the thrust chamber can be seen extending out at the right end of the satellite. A detailed interior view of this engine would, unfortunately, be classified "Confidential", so we cannot show it here. However, the next slide, which is a sales picture of a liquid propulsion system, will illustrate the main details of a high-altitude propulsion stage. This is a pressure-fed system, in which stored helium gas is used to push the propellants into the thrust chamber. The thrust chamber uses regenerative cooling - the

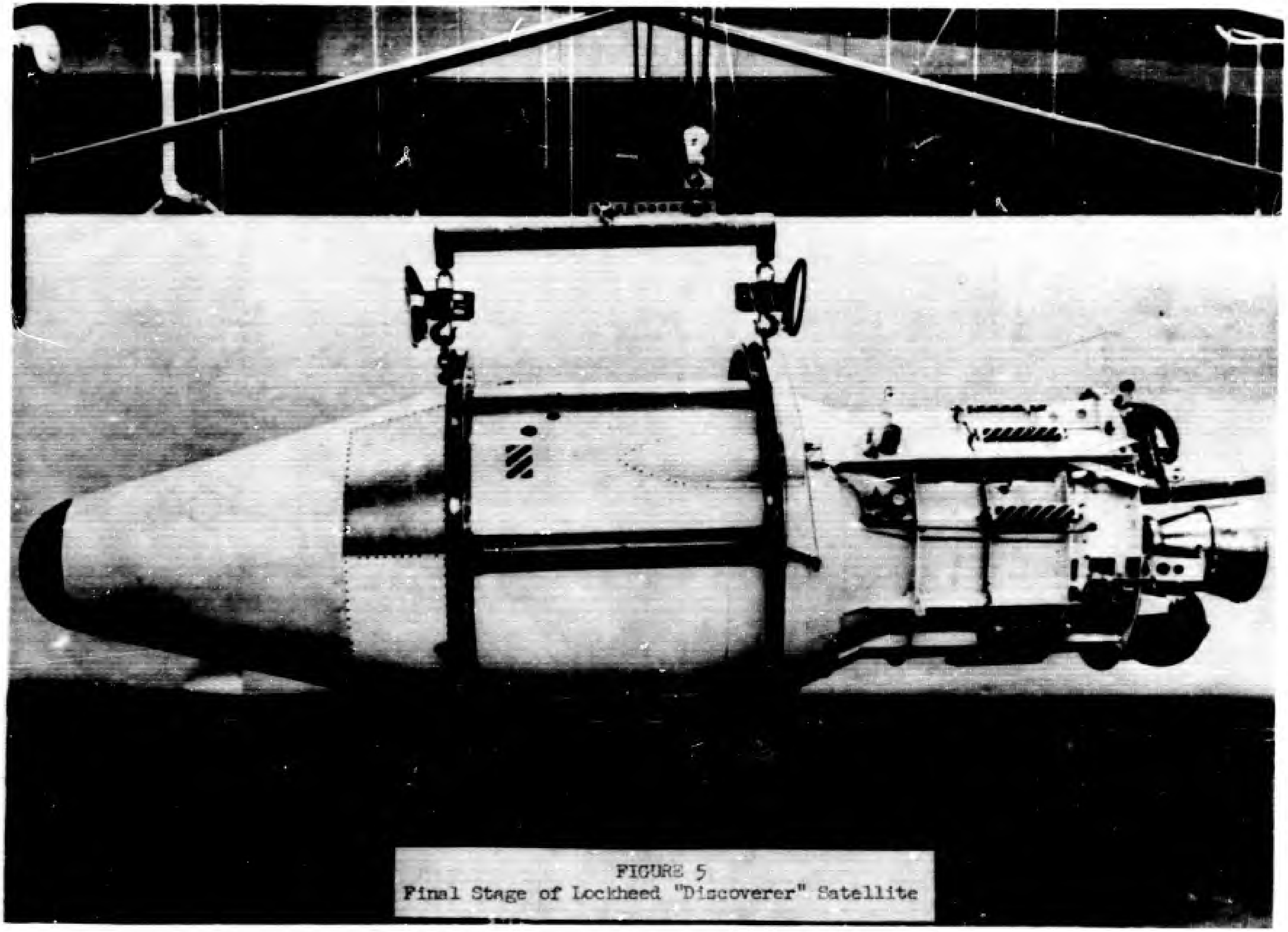


FIGURE 5
Final Stage of Lockheed "Discoverer" Satellite

FIGURE 1
High Altitude Rocket Power Plant

HIGH-ALTITUDE ROCKET POWER PLANT

fuel circulates through the walls before entering the combustion chamber through the injector. There is no ignition system, as the propellants ignite spontaneously on contact. The thrust chamber is gimbal-mounted so that the direction of thrust can be changed as required by the guidance system. The propellant tanks are spherical for minimum space utilization, and the helium passes through a heat exchanger on the rocket nozzle to warm and expand it before it enters the propellant tanks. The fixed weight of a propulsion system such as this can be less than 10 percent of the weight of propellant it carries, which is an important factor in achieving high stage velocity or high payload capacity.

The next slide shows several small altitude control rockets which operate on hydrogen peroxide decomposition. The thrust of these rockets varies from one to 24 pounds. They can be operated on and off at the direction of the pilot.

The next slide is a drawing of a typical solid propellant rocket engine. As you can see, it is a very simple device, mechanically, consisting of a pressure vessel or case, a solid propellant grain, an igniter, and an expansion nozzle. Modern solid propellant rockets all use case-bonded internal burning grains as shown here. This protects the case from the heat of the burning propellant and makes possible very light weight case construction. The nozzle cannot be protected in this way, and since it cannot be cooled

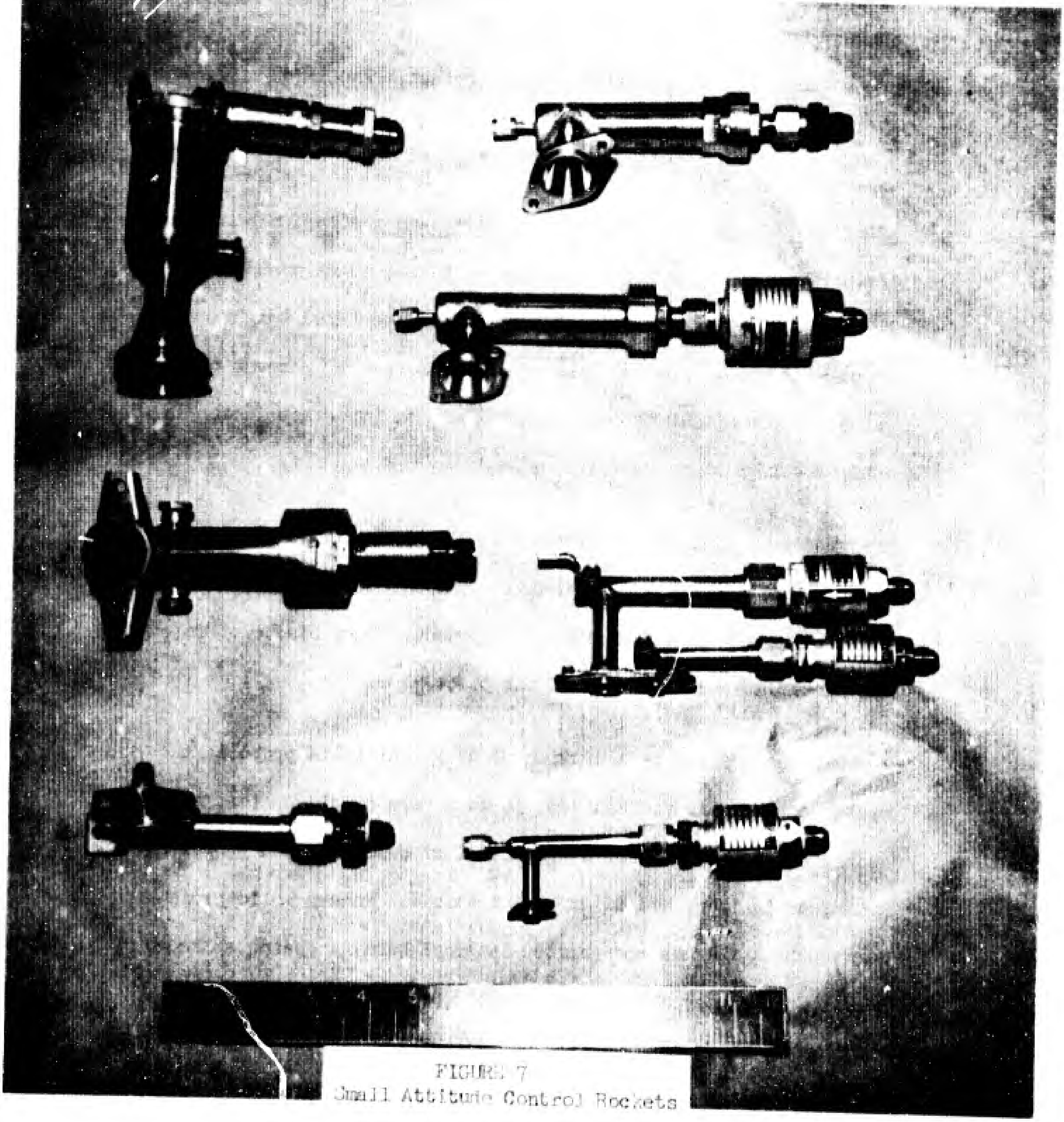


FIGURE 7
Small Attitude Control Rockets

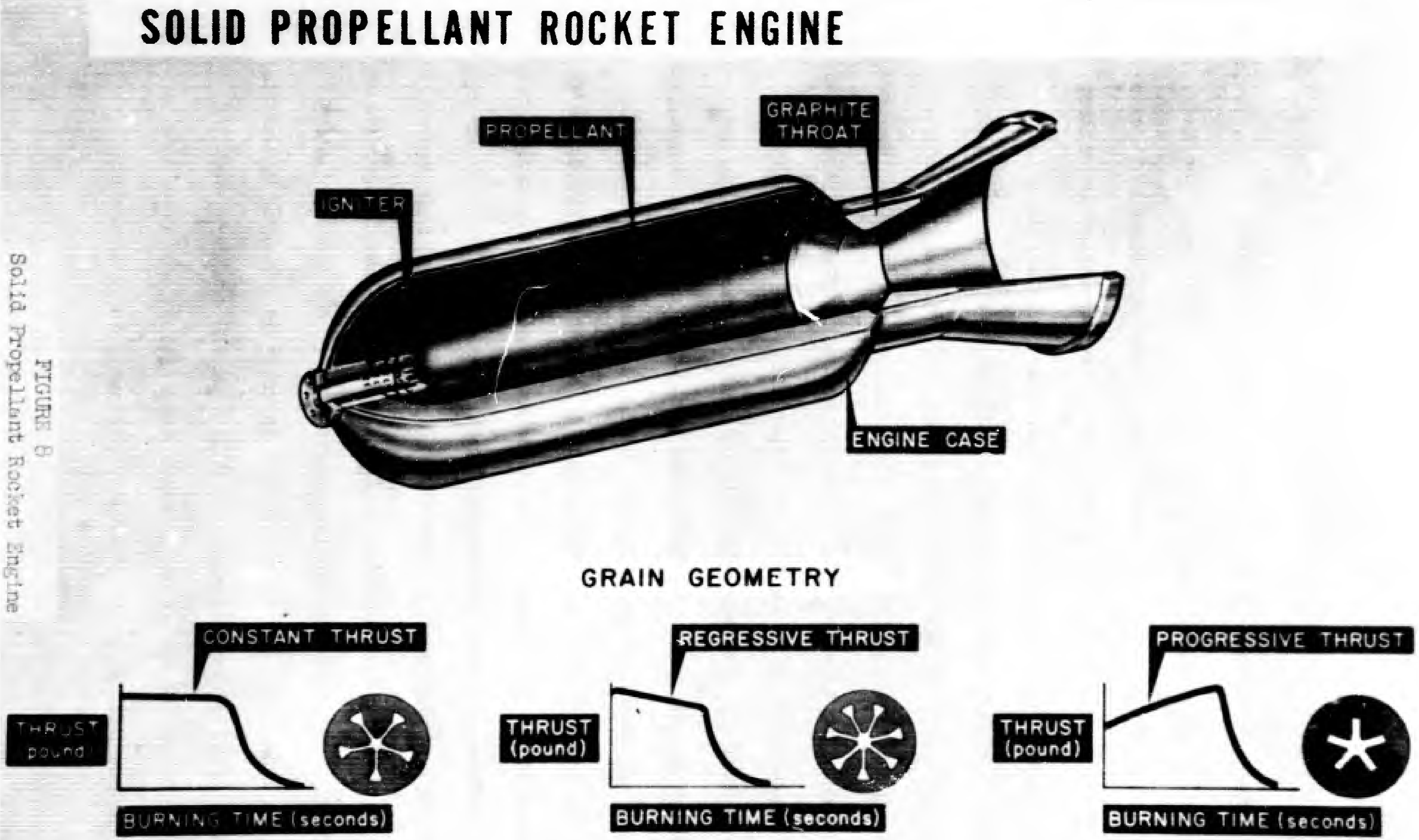


FIGURE 8
Solid Propellant Rocket Engine

either, it must be made of a high temperature resistant material.

The great advantage of the solid propellant rocket engine is its simplicity and ease of handling in comparison with liquid engines. Solid rockets have also achieved an excellent past record of reliability, and this record has been used to good advantage in selling solid rockets for high performance and long range missions that have in the past been restricted to liquids. We agree that solid propellant rockets have their place, and that the present intense development efforts will expand their usefulness. However, we take issue with the argument that the solid rocket is more reliable than the liquid because it is simpler. Simplicity and reliability are not necessarily related. The long outstanding record of the reciprocating piston engine is sufficient proof that a complex mechanical device can have high reliability. A much better case can be made for the argument that the reliability of any engine is decreased by increasing its performance. The reliability record of solid propellant rockets has been established with rockets of relatively small size and low performance. There is no assurance that this record can be maintained when higher combustion temperatures, longer firing durations, and bigger propellant grains are used. Now, I don't mean to imply that the liquid rocket industry is standing by waiting for the solid rocket companies to fail. On the contrary, we expect them to be increasingly stiff competition, and if we are to stay in business ourselves we must constantly improve our own products. Like our competitors, we are seeking to achieve higher thrust, higher specific impulse, higher thrust-to-weight ratio, minimum size and weight, maximum reliability, and ease of handling and servicing.

Now, as I mentioned earlier, there is a definite limit to the specific impulse that can be achieved with any chemical propulsion system. With the development of the hydrogen-fluorine propellant combination we will have reached that limit. However, the requirements of space flight demand more and more performance, beyond what chemical systems can provide. For the future, we must go to nuclear energy or possibly solar energy. Nuclear reactions produce far more energy than chemical reactions. To put it in engineering terms, the fission of uranium 235 produces about 20 billion BTU per pound, and the fusion of deuterium produces about 38 billion BTU per pound. Compare this with less than 6000 BTU per pound for the hydrogen-fluorine reaction. This vast source of energy should make a lot of things possible, but the problem is how to harness it. The temperatures produced by nuclear reactions, if not diluted, run into the hundreds of millions of degrees. At these temperatures, all construction materials have long since become gases and containment by any solid boundary is impossible. Obviously, then, a diluted reaction must be used. For the uranium fission reaction, this can readily be done, as witnessed by the many types of power reactors now in service or under development. Thus, with a few exceptions, the advanced propulsion schemes now under serious study employ a fission reactor as the primary power source, and either direct heat transfer or electric conversion to transfer the heat to the working fluid.

The simplest of all nuclear powered rockets is the gas-cooled reactor currently being developed under the ROVER program. The initial test version of this rocket is aptly named "Kiwi" after an Australian bird that cannot fly. A schematic of the gas-cooled reactor is shown in the next slide. The rocket looks much like a conventional thrust chamber, having a convergent-divergent expansion nozzle and cooling passages in the walls. In place of the combustion chamber is a solid fueled, carbon moderated, fission reactor. Liquid hydrogen is the working fluid. It passes under pressure through the cooling passages of the nozzle and into the reactor where it absorbs heat until its temperature approaches 5000° F. It then expands through the nozzle as a conventional rocket propellant. Hydrogen can absorb about 21,000 BTU per pound in being heated to 5000° F. This is sufficient to give a specific impulse of 750 seconds at 300 pounds per square inch pressure, sea level; a very worthwhile improvement over chemical rockets. It is also very nearly the limiting performance that can be expected from a direct heat transfer device, as the reactor temperature is near the upper limit for any known refractory materials. The requirements for the nuclear reactor are quite impressive. In equation 7,

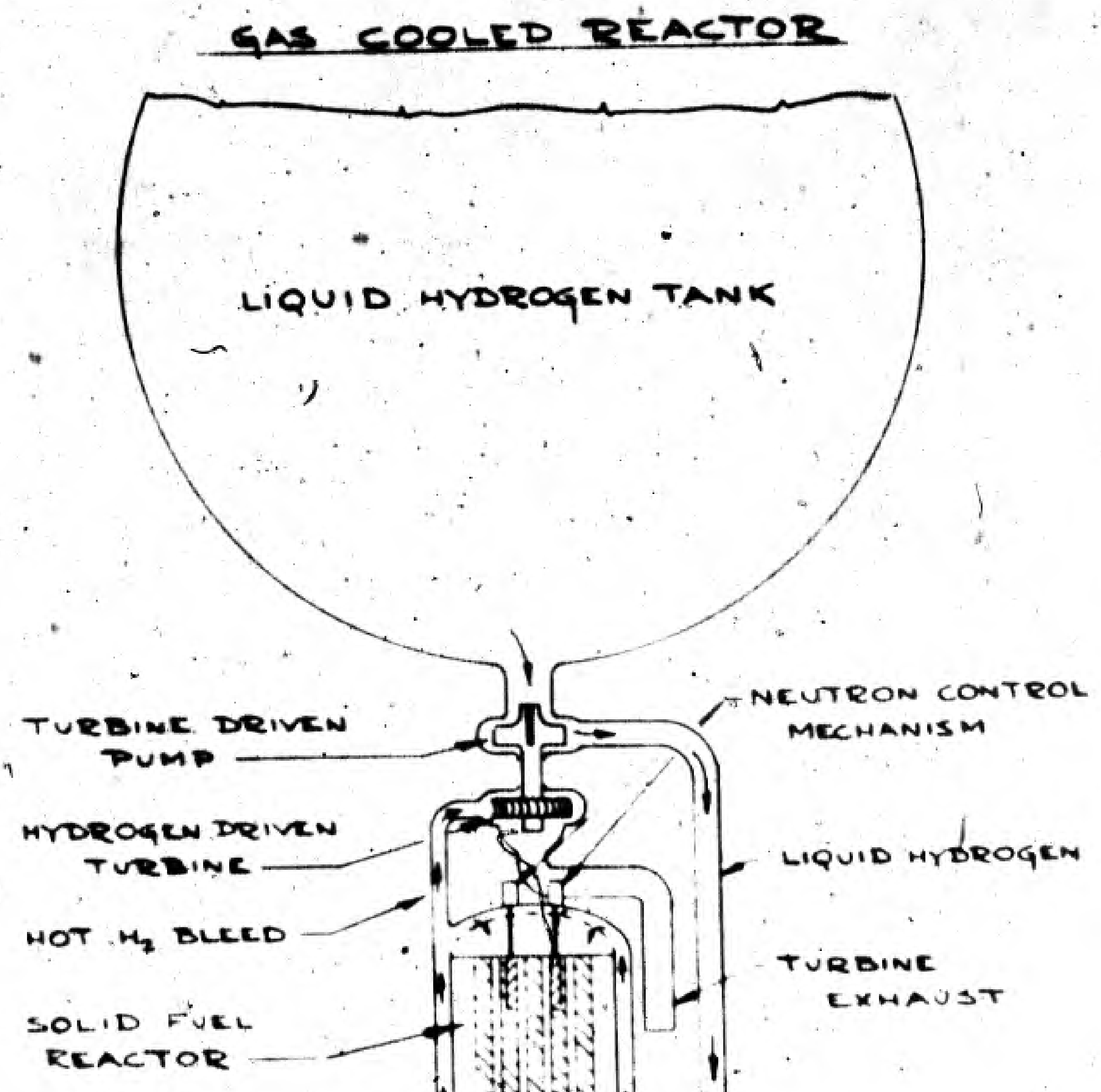


FIGURE 9
Gas-Cooled Reactor

which we showed at the beginning of this paper, the power supplied to the working fluid was found to be proportional to thrust times specific impulse divided by expansion efficiency. For a thrust of 100,000 pounds (a modest requirement for a booster rocket) the power output of the reactor works out to be 2,800,000 KW. The weight of the reactor must be less than 20,000 pounds if it is to be able to lift itself from the ground and have any margin left for payload. Hence the specific output of the reactor, including necessary shielding, must be at least 150 KW per pound. This is a tremendous advancement over nuclear reactors as generally known to the public, but there is no reason to believe that it cannot be done. Several other things about this reactor bear considering. It has been noted that if the reactor is to run at full output until all of the hydrogen has been exhausted, the residual radioactivity will cause it to "burn up" even if promptly shut down. Hence, if the booster is to be recovered intact, an excess supply of hydrogen must be carried for cooling after shut down. There are both economic and safety reasons for wanting to recover this booster. The investment in the nuclear fuel alone may be several million dollars. Furthermore, the core of the reactor will be highly radioactive and, if allowed to burn up, will scatter radioactive debris over a wide area. For the same reason, a malfunction after takeoff could have grave consequences to surrounding areas. Although it is theoretically quite feasible to build a nuclear powered booster rocket of this type, safety considerations may rule it out in favor of chemically powered boosters of lower performance and much larger thrust.

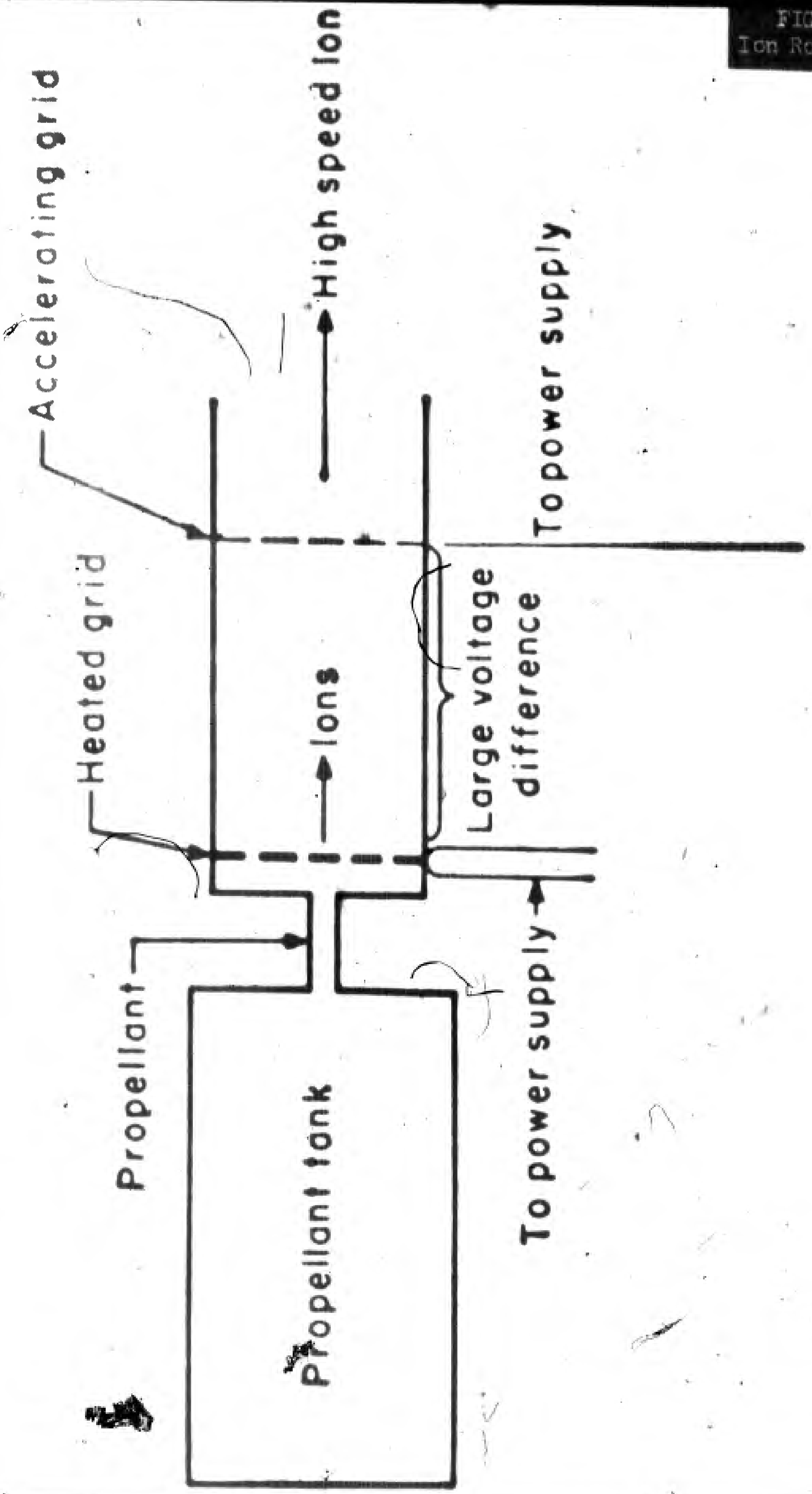
Nuclear power plants are more favored for inter-orbital propulsion missions than for ground-launched boosters. Once a vehicle is in orbit, a propulsion system no longer has to produce the high thrusts necessary to overcome gravity, and modest accelerations of one-tenth or even one-hundredth "G" is sufficient for most missions. In the space environment, however, we can consider another source of energy that may be more convenient to use, namely, solar energy. At the earth's orbit, we can collect 1 KW of solar energy for each 7.7 square feet of heating area. This heat could be focused by a parabolic mirror onto a boiler which would heat hydrogen. With hydrogen as a working fluid, exhausting into a vacuum, we can achieve a specific impulse of about 1000 seconds. A reflector 216 square feet in area is theoretically required to produce one pound of thrust. The reflector could be a spherical balloon, silvered on 1/2 of its surface. This appears to be a simple and not unreasonable method of producing low thrust in orbit.

For specific impulse of several thousand seconds, such as would be required for interplanetary exploration, the limits of the direct heat transfer rocket are exceeded and a more sophisticated approach is needed. The schemes that are under current study all use a nuclear reactor to produce electric energy. This energy is then imparted to a working fluid, accelerating the latter to extremely high velocity. Three types of electric propulsion device may be considered. The Arc Jet uses a high-current confined arc to heat the working fluid to a very high temperature, about 50,000° K. The working fluid can be used to cool the electrodes. At this high temperature, all chemical bonds in the gas are broken, and the gas becomes an electrically conducting "plasma". Although highly ionized, the gas is still neutral, containing the same number of positive charges as negative charges. In the Arc Jet, the hot plasma is allowed to expand through a nozzle as in a conventional rocket. Using hydrogen as a working fluid, a specific impulse of about 4000 seconds is possible. The power requirement, however, is about 200 KW per pound of thrust. A more sophisticated device is the Plasma Jet, more correctly referred to as the electromagnetic accelerator. In this device, the working fluid is ionized (by an arc or by a radio-frequency field generator) at a moderate temperature and low pressure. The plasma then flows into a strong magnetic field, and a continuous current is passed through it at right angles to the field. This produces a motor force at right angles to both current and field, accelerating the plasma to a high velocity. A very high jet velocity can be produced in this way without any parts of the ionizer or accelerator being subjected to high temperatures. Although almost any value of specific impulse can be obtained with this device, the practical limit appears to be 10,000 - 20,000 seconds. The power requirement is 500 - 1000 KW per pound of thrust. The thrust/weight ratio of this device is very low, about 1/1000, leading to very small accelerations.

The <u>Ion Rocket</u> (shown in the next slide) is similar in principle to the Plasma Jet, but uses electrostatic acceleration. The working fluid is ionized, and then the electrons are drawn off, leaving a positively charged plasma. The electrons are then pumped by a high voltage generator to the cathode, an annular electrode which strongly attracts the positive ions, causing them to accelerate to a high velocity. When the positive ions pass through the hole in the center of the cathode, they pick up electrons and leave the accelerator as a neutral plasma. The theoretical performance of the Ion Rocket is about the same as that of the Plasma Jet, as are the power requirements and the thrust/weight ratio. Both devices operate at low pressure and require vacuum chambers for sea level testing. The Plasma Jet is a low voltage, high current device and uses a low molecular weight working fluid, such as hydrogen. In contrast, the Ion Rocket is a high voltage device and works best with a heavy working fluid. Cesium has been favored because of its high atomic weight and its ease of ionization.

Although much interesting theoretical and experimental work has been done on arc jets, plasma jets, and ion rockets, the most

FIGURE 10
Ion Rocket Engine



important part, the power source, has been somewhat neglected. Current concepts of electric power generation fail when we consider the requirements of electric propulsion devices. The most efficient thermal electric power plants being built today (i.e., steam turbines) require at least 3 KW of thermal energy to produce 1 KW of electric energy. The remaining 2 KW is rejected to a condenser. Our nuclear power source must then produce 1500 - 3000 KW thermal per pound of thrust produced; and some way must be found to dispose of the 1000 - 2000 KW not needed. There is not nearly enough working fluid available to absorb the waste heat, and the only other means of disposal is by radiation. The radiant condenser may well prove to be the heaviest component of the propulsion system. A major breakthrough in the conversion of nuclear energy to electric energy is needed before electric propulsion systems of practical size and weight can be built.

The next step beyond electric propulsion is the thermonuclear rocket. At the present time, we cannot visualize the physical configuration of a thermonuclear rocket at all, but it is of interest to consider its potential performance. If we use equation (5) to calculate the specific impulse, using a heat of fusion for deuterium of 38 billion BTU per pound, we calculate a specific impulse of 950,000 seconds. The temperature of this reaction is a fantastic 30 billion degrees F. By diluting with 1000 parts of inert gas, we can reduce the temperature to "only" 30 million degrees F and still achieve a specific impulse of 30,000 seconds. There is little more that we can say about thermonuclear rockets at this time. However, we can mention that the experts of Project Sherwood predict that it will be 20 years or more before controlled thermonuclear reactors are developed; so we still have plenty of time to work out the mechanical details.

We cannot leave the subject of advanced propulsion systems without mentioning the Photon Rocket, a device which produces thrust by radiation pressure. The photon rocket has been called by some authors "the ultimate goal in rocket propulsion". Actually, it is more correct to say that it is the ultimate in waste of energy. The interest in photon rockets stems, of course, from the high theoretical specific impulse of 30 million seconds. This figure is sheer nonsense, however, as it could only be achieved by complete conversion of mass into energy. The power required to produce a pound of thrust by radiation pressure is 1.3 million kilowatts, or a thousand times that of the electric propulsion devices we discussed previously. A nuclear reactor could be built to furnish this power, but the reactor could then produce 30 times as much thrust as the photon rocket by exhausting its own waste fission products. If the power were supplied by solar energy, then a reflector of 10 million square feet area (or two-thirds of a mile in diameter) would be required to collect enough energy to produce a pound of thrust. The photon rocket can thus be dismissed as a completely impractical idea.

In summary, we have discussed the present state-of-the-art in chemical rockets, and have looked into the future of nuclear powered and solar powered thermal and electric rockets. The advanced propulsion devices can achieve high specific impulse that is unattainable by chemical rockets. However, all of these schemes require relatively large and heavy power sources. For nuclear rockets, we must make heroic efforts to reduce the size and weight of the nuclear power source in order to achieve practical goals.

We will undoubtedly have nuclear rockets for space flight, but we will also continue to have chemically powered rockets for launching of space vehicles. With the rapidly expanding effort in space flight, the future of both nuclear and chemical systems seems assured.

10

SPACE FLIGHT DYNAMICS

Increased "G"

by

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The area of increased "G" in space flight dynamics has opened a new era of acceleration studies on the physiological reactions of man and his tolerance to these forces. I can vividly remember just four years ago that there were some investigators who saw little future for those of us who were involved in increased acceleration studies. Yet, at that very time we were engaged in design and fabrication of the "sarcophagus" for underwater acceleration studies on the human centrifuge at the Aeromedical Laboratory at WADC, and also an oscillator for investigating the effects of epicyclic G forces on man. We shall see how these, and other devices, play an important role in today's and tomorrow's acceleration studies. I would like to talk today about some of the recent studies being made in the field of acceleration, their application to current and projected problems, the problems we face with instrumentation and end points, and my opinion of the future in this field.

There are four fundamental factors that are essential to any discussion of increased accelerations. They are:

1. Magnitude - or peak G.
2. Duration - or exposure time.
3. Rate of Onset - or rate of application of G.
4. Position - or body orientation to the G vector.

Keeping in mind these four variables and that each one has an almost infinite number of points, it becomes apparent that to define man's tolerance or limit to increased G for all possibilities is an impossibility. The investigators have, and will continue to limit themselves to those areas which are applicable to present or future operations, using factual findings and experience whenever possible and intelligent judgment to extrapolate answers for the design engineer when the acceleration problem falls outside investigated areas.

An example of this is the curve by Henry, Edelberg, and Hessberg developed for the HIAD (Handbook of Instructions for Aircraft Designers) which delineates the limits of human tolerance to escape. (Fig. I.) This curve uses points established by Stapp [1] on his sled experiments, Henry and coworkers on the centrifuge, the operational reports of actual ejections, and judgment.
It is interesting to note that Mr. George Smith, the North American Aviation test pilot, who ejected at approximately Mach 1 at 6500 feet MSL, falls in the area of probable injury on this curve. Though seriously injured from acceleration loads and windblast, he lived by virtue of several fortuitous circumstances and immediate, excellent medical care.

Today's acceleration problems, and tomorrow's, generated by manned missile systems, can be defined as follows:

A. Simple - Linear

1. Long duration 2 seconds
2. Short duration 2 seconds (abrupt or impact)

LIMITS OF HUMAN TOLERANCE FOR ESCAPE SYSTEMS

(ASSUMING TRANSVERSE G IN A STABLE SYSTEM)

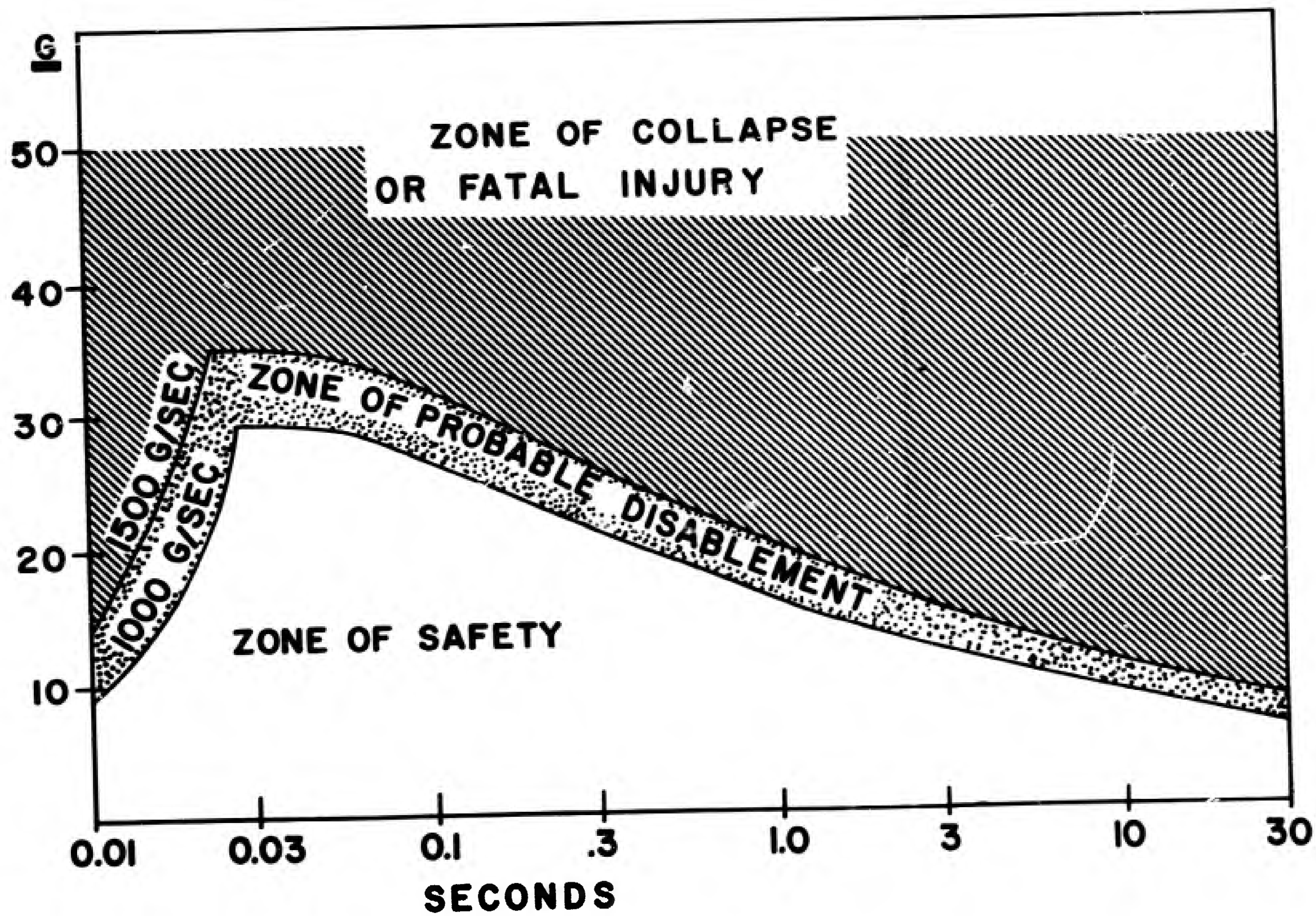

FIGURE 1

B. Simple - Non-Linear

1. Epicyclic - Long or Short
2. Vibratory - " "
3. Oscillatory - " "
4. Centripetal - " "
5. Angular - " "

C. Complex

1. Combinations of B above.
2. Any of B above superimposed on A above.

Using the classic description of manned space flight, i.e., launch (boost), orbit, reentry, recovery, and landing, we can identify acceleration problems with these operational functions. Launch or boost phase poses problems in simple linear, long duration acceleration. (Emergency situations during boost carry over into complex accelerations.) Liquid rocket systems provide launch curves similar to those investigated by Preston-Thomas and Henry [2] in 1954 which proved that man can tolerate them but his ability for motor performance is markedly impaired.

An area of interest yet to be investigated is the effect of the rapid dropoff of acceleration (rate of offset) as the stages stop burning. This is a controversial issue in that some feel this is no problem, and others wonder whether it is or not. It seems only logical to me that if rate of onset is a problem, that the very rapid dropoff of acceleration following burn out of the booster should be equally as much of a problem. This area has not been investigated to date, and can only be simulated on high speed rocket sleds on a long track considering all existing facilities. Human centrifuge capacities do not permit the rapid rates of onset and offset required. Track tests require sacrificing total time of exposure while achieving the rates of onset and offset. A circular track is the final answer for attaining both acceleration factors in the same experimental situation. (Spin stabilization which has been vetoed successfully to date by the Aerospace Medicine Researchers would bring in an area of complex rotational, epicyclic, acceleration superimposed in a simple linear long duration G field.)

Solid fuel boosters will give low acceleration loads for long periods of time. Miller [3] and coworkers investigated this in 1957-58 and showed that 3G for one hour is within man's capability, provided head movement is minimal. Hardy [4] and coworkers at Johnsville have completed 2G for 24 hours. Both of these studies provide acceleration time histories far in excess of escape velocity. What has been said here is, if the engineers could provide long duration, low thrust, man could travel into space in comfort, acceleratively speaking.

The orbit phase has two acceleration areas of great interest; the subgravity (Zero "G") which will be discussed by Major Hawkins immediately following this presentation, and the proposed methods of providing a partial gravitational environment in orbit. The latter poses problems of long duration centripetal (rotational) acceleration. The major acceleration problems generated by this approach fall into vestibular stimulation and sensory illusions. Graybiel[5] and coworkers at USN SAM, Pensacola, are presently engaged in investigating this and associated acceleration problems in the "disorientation device" and the closed room built at the hub of the centrifuge.

Reentry of a high drag system gives rise to oscillatory G's in a linear high G field of several seconds duration (more than 2). These could become vibratory in nature if the frequency increases and the characteristics become sinusoidal.

Recovery (parachute opening) and landing result in abrupt accelerations. Formerly, little concern was given to the rate of onset, but recently space vehicle systems, both in second and third stage boost, and upon landing impact of high drag systems, have projected rates of application of G in the range from 4,000 to 8,000 G/sec., and peak G's from 40-60G.

The Aeromedical Field Laboratory has initiated a "rate of onset" study on the "Daisy Decelerator." We calculate rate of onset as a function of time to peak G. The table below summarizes the work to date on human subjects, seated rearward facing, being investigated by Beeding [6] and coworkers.

	G		Rate of Onset	
No. human exposures	Sled	Subject	Sled	Subject
6	17	22	1400	900
6	18	25	2500	1000
5	17	26	3800	1100
*1	40	83	2000	3800

Note the consistency in the higher G's experienced by the subject versus the sled G's. This is always constant due to the elasticity of the human structure. Even though the accelerometer is strapped as tightly as possible over the sternum there is override recorded from this accelerometer. The reverse is true for rate of onset as the elasticity, therefore travel, of the human is greater, extending the time factor, thereby lowering rate of onset.

Captain Beeding's exposure of April 1958 is presented for contrast. Although it was not a part of the present program it provides invaluable information as to trent expected, and an upper limit, below which we can investigate with some degree of safety to

*Data from Captain Beeding's "Daisy Decelerator" run, April 1958.

6

the human volunteers. Captain Beeding [7] experienced a pronounced drop in blood pressure, increased pulse, and syncope for about three minutes post run. He was hospitalized for 3 days with pain and spasm in the region of L_3, and anorexia. No x-ray evidence of skeletal injury in the lumbar region was found. The anorexia may have been due to contusions of the greater curvature of the stomach which was found on pathological examination following similar exposure of black bears.

This brings us to the problem of instrumentation and end points. There has been an international committee formed to try and establish a standard end point or points for centrifuge acceleration experimentation. After two years they are nearer their goal, but are not yet fully in accord. At least they have end points to argue over. (Loss of peripheral vision, loss of central vision, black out, dyspnea or apnea, A-V pressure drop, etc.) In abrupt acceleration, we have not as yet determined anything more subtle than syncope or shock-like syndrome. There are three reasons for this. First, there has been relatively limited study done in the field of impact accelerations. Second, the usual exposure time is .02 to .05 seconds, and third, physiological instrumentation demonstrates nothing that warns of impending syncope. Maybe we are measuring the wrong parameters, (i.e., EKG, blood pressure, pulse, and respiration) or more likely, we are not yet aware of the right parameter to measure which could be a neurophysiological, endocrinological, or biochemical factor. We, as physicians, don't ordinarily think of anything happening in the human body in four hundredths of a second that we could measure, but I'm convinced we must. Needless to say, we place great emphasis on the pre and post run studies and are continuing to improve our instrumentation during exposure. We hope to find a better end point and are planning a study incorporating psychomotor performance as a possible subtle indication of human tolerance limit in abrupt acceleration.

Earlier I said we'd look at some of the problem areas of the future. I foresee three that may require far more investigation than has or can be presently studied.

First is the area of complex or multiple accelerations. We have very limited capability, facility-wise, in this area. The Navy human centrifuge at Johnsville, Pa. and the angular acelerator (Disorientation Device) at the USN, School of Aviation Medicine, Pensacola, are the only two devices with more than one degree of freedom, I know of, that are used for human experimentation. We need to investigate the buffeting (oscillating) that occurs during reentry simultaneously with linear deceleration. The vibrations that occur during boost acceleration cannot be studied simultaneously because we do not have a facility for human investigations capable of simultating these conditions. We have no real knowledge of the summating or cancelling factors that may be discovered when facilities are available. It will take new and very expensive facilities to investigate these problem areas associated with space age acceleration.

Secondly, I am concerned about man's physiological reaction in going from increased G to zero G as he is inserted into orbit. What may well be much more severe will be his reentry, after from three hours to months or years, he goes from a well established physiologically stabilized zero G state to a 5 - 10 G deceleration. Von Beckh [8] has reported on going from plus to zero G and zero to plus G. Exposure times were short, 40-60 seconds acceleration and 15-25 seconds of zero G, yet I feel he has indicated a possible trend that requires further investigation. This will have to wait until the Aerospace Medical Researchers are provided satellites for their investigations. Then the necessary exposure times will be available for sound research investigations.

The third is the high impact that can so earily result on a misjudgment of retrothrust on a planetary or lunar landing. The slightest miscalculation can result in high impact G forces. Recent emphasis on water for G protection deserves further study. The underwater acceleration studies accomplished by Boudurant [9] and coworkers in the "Sarcophagus" on the centrifuge at AML, Wright-Patterson AFB, Ohio in 1957-58, proved that mobility was unimpaired during G loads up to 12 G's, and that at lower G levels, 6-8 G, exposure time was greatly increased. Flanagan-Gray [10] and coworkers on the Navy Centrifuge, Johnsville, Pa. have demonstrated about a fourfold increase in protection against positive G from underwater acceleration studies.

Underwater abrupt deceleration studies by Zabosowski and Blackshear from the Aeromedical Field Laboratory at Holloman AFB, are just beginning on the 35,000 ft. long track. The only two runs to date, which were in December 1959, only serve to emphasize that water is far from a proven panacea for acceleration. The Navy Acceleration Laboratory and the Aeromedical Field Laboratory are wrestling with this new problem, and are finding unsuspected results that were not predictable. This only means we must proceed with greater caution than anticipated.

I have attempted to cover the major facets of increased acceleration in Aerospace Medicine. I am sure I have left no doubt in your minds that there is a tremendous workload facing those of us studying this area. The problems are new, complex, and challenging. We shall continue to provide answers and/or protection in anticipation of man's determined desire to forever want to fly farther, faster, and higher.

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LECTURES IN AEROSPACE MEDICINE

SPACE FLIGHT DYNAMICS

II. Zero "G"

Presented By

Major Willard R. Hawkins

Biodynamics Branch

School of Aviation Medicine

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II. ZERO GRAVITY

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Ladies and gentlemen, Colonel Hessberg has just discussed the effects of high "g" forces on man--forces which may very well be experienced by astronauts in the launching and re-entry phases of space flight. I would like to complete this picture by bridging the gap from the time of burn-out of the rocket to the time of re-entry and discuss the weightless state or zero-gravity phase of space flight.

Background:

The problem of weightlessness is a very interesting one, and perhaps the strangest problem man will face in space operations. It is definitely a unique situation--a condition never before experienced by man except for brief periods in free fall, as when diving off a diving board. But in space flight, weightlessness will be the rule, except when interrupted for brief periods by accelerative forces introduced to change the direction or velocity of the space craft, or when the inter-gravisphere[8] of another planetary body is entered.

It is not known just how this new situation will affect man's psychophysiological behavior and orientation. Here we have a human individual who has spent his entire life under the influence of the gravitational attraction of the earth. And now, suddenly, he is going to be called upon to adapt, or make out, in some way in a strange, new environment.

His orientation and state of equilibrium are dependent upon a group of special sensors called mechanoreceptors, which include primarily the otolith organs, the pressure sense, the muscle sense, the posture sense, and the eyes. At rest or in motion these special sense organs respond to external stimuli or forces constantly acting on man, furnishing detailed messages to the brain about the state of tension, position, and support of the body. In the weightless state the exteroceptive function of the pressure sense and muscle sense will be lost and the exteroceptive function, "par excellence, the eye" (photoreceptor), will take over.[7]

The term weightlessness implies the absence of weight, but to appreciate the full significance of this state we should have a clear understanding of the definition of weight. Haber has stated that the term, as generally used, implies that it is "a constant for each particular body, and this definition conveys the idea of weight being a characteristic physical property of a body comparable to its mass, geometric dimensions and shape, density, etc."[3] This applies only under such conditions as an object of specific mass resting on a supporting surface, such as a table, or moving at a constant velocity relative to the center of the force of gravity.

In reality, we become aware of weight due to the fact that there is a supporting medium pushing back against the body with a force equal to the gravitational force attracting the body toward the center of the earth. Thus, in brief, three factors are responsible for weight; gravity, inertial force, and supporting (or external) forces. And if the supporting force is lost, the body is in a state of zero-gravity or weightlessness. Actually, these two terms mean the same thing; but we use the term weightlessness to denote the psychophysiological condition of the individual, and we use the term zero-gravity to denote the physical condition.

A question frequently asked is, "Where do we encounter this weightless state?" We know that the force of gravity decreases with the inverse square of the distance from the center of the earth (fig. 1). The earth's gravitational attraction will, thus, always be acting on man, even though the intensity of the force will drop to very low values until man enters the graviational influence of another planetary body, such as the Moon, the Sun, or Mars. As he approaches closer to this new body, the force of attraction will increase. But the gradual reduction in weight in this manner could be achieved only if it were possible to support a man in a static state far removed from any planet.

Once the space vehicle is in orbit above the effective limits of the atmosphere, however, the situation is quite different. The space craft and occupants will be in a state of free fall, owing to the continuous accelerative force of gravity pulling it toward the center of the earth. However, it does not fall back into the atmosphere or to the surface of the earth if orbital velocity is maintained because of the resultant of the tangential inertial and centrifugal forces which exactly counterbalance the force of gravity (fig. 2). When this state of equilibrium is reached, all elastic forces acting in or on the surface of the body vanish and the craft and crew are weightless.

History:

The appreciation of this problem is not a new one and certainly not of recent origin. Doctor Strughold in 1928, while flying in Germany with Ritter von Graim, a fighter pilot of World War I, first pointed out man's tendency to over-shoot when reaching for an object in a subgravity state. During World War II, Professor H. von Diringshofen observed the occurrence of weightlessness in experimental flights. In 1946 Gauer and Haber, then research scientists at the Aeromedical Center in Heidelberg, Germany, stimulated by the fabulous advance of rocketry, hypothesized that our perceptual pattern which provides information about the mechanical forces acting on and within the body would be altered decisively in the state of zero-gravity.

Several physiologists have predicted deterioration of the autonomic nervous system and disturbances of muscular coordination.

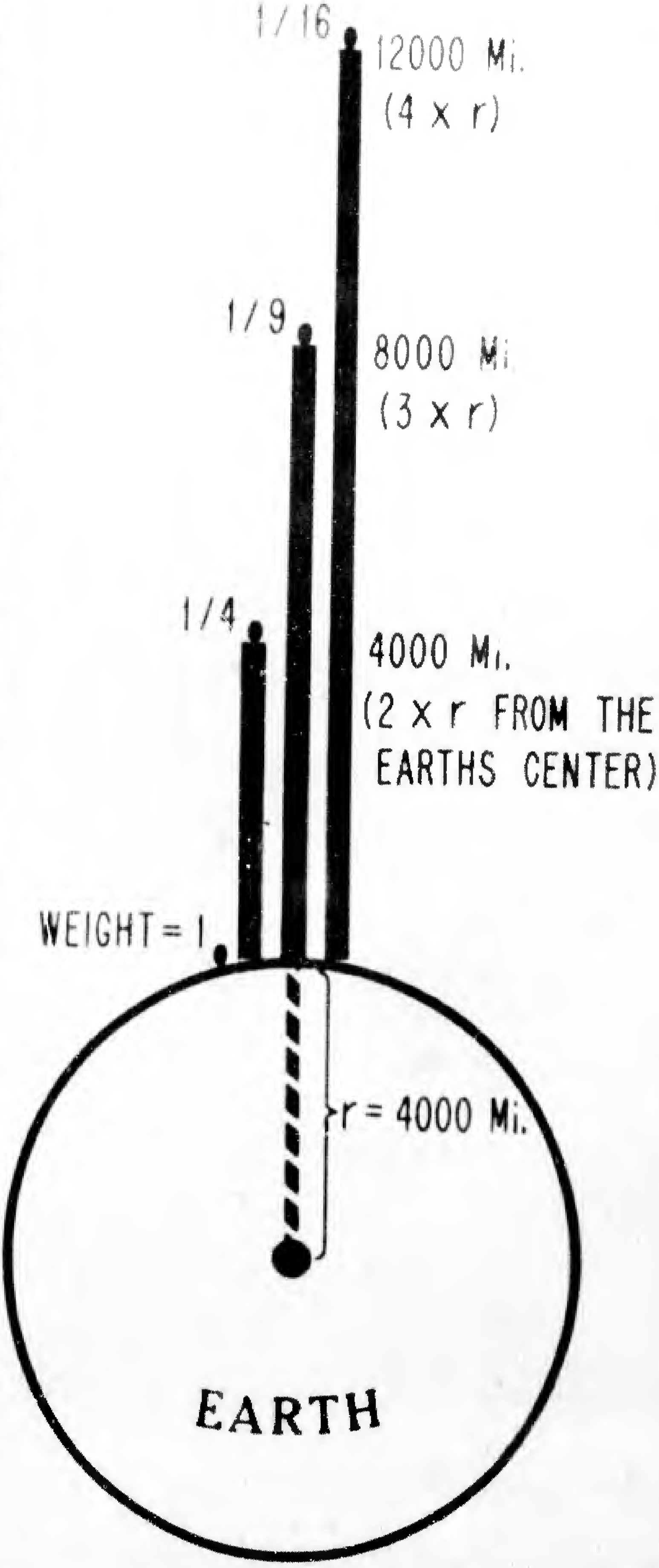


FIGURE 1

The Force of Gravity Decreases with the Inverse Square of the Distance from the Center of the Earth.

FIGURE 2

The Centrifugal Force Exactly Counterbalance the Gravitational Force.

Others contradict vigorously, however, assuming that we can do without the proper stimulation of the senses during weightlessness. One even predicted death due to failure of the circulatory system.

Methods of Studying Weightlessness:

All this convinced the authorities of the Air Force very early that weightlessness is a problem that must be investigated. However, it was immediately realized that the problem of weightlessness is one with which it is extremely difficult to come to grips. Unlike most of the characteristics of future space flight, it cannot be simulated in a laboratory on the ground.

Several methods of producing weightlessness have been used by investigators in the past. These include the use of elevators, free fall towers, (or subgravity towers) and ships (fig. 3). The principle of all such methods is based upon the realization of the state of vertical free fall. In all of these methods, however, the time of weightlessness amounted to not more than a few seconds, for very quickly the body's weight is restored because of the support afforded by the strong frictional forces from the air.

The duration of weightlessness can be extended, however, at flight altitudes in high-performance jet aircraft. The airplane is flown through a Keplerian trajectory, an ellipse, which closely resembles a parabola as long as the vertical distance traveled is small as compared to the earth's radius. The minimum stalling and maximum permissible speeds of the aircraft, and thus, the speed of and angle of entry into the parabola, are the primary factors that determine the duration of weightlessness. The details of the technique of producing the gravity-free state by this means have been reported elsewhere [3, 5, & 12]; but in summary, the vertical velocity of the aircraft is constantly changing while the horizontal velocity remains constant (fig. 4). The vertical component is rapidly lost at the rate of 981 centimeters per second per second (32.2 feet per second per second) during the ascending line of the parabola, reaching zero velocity at the apex, and then increasing by 32.2 feet per second per second during the descending part of the trajectory. When this is done, the apex of the parabola and the center of the earth become foci of the ellipse.

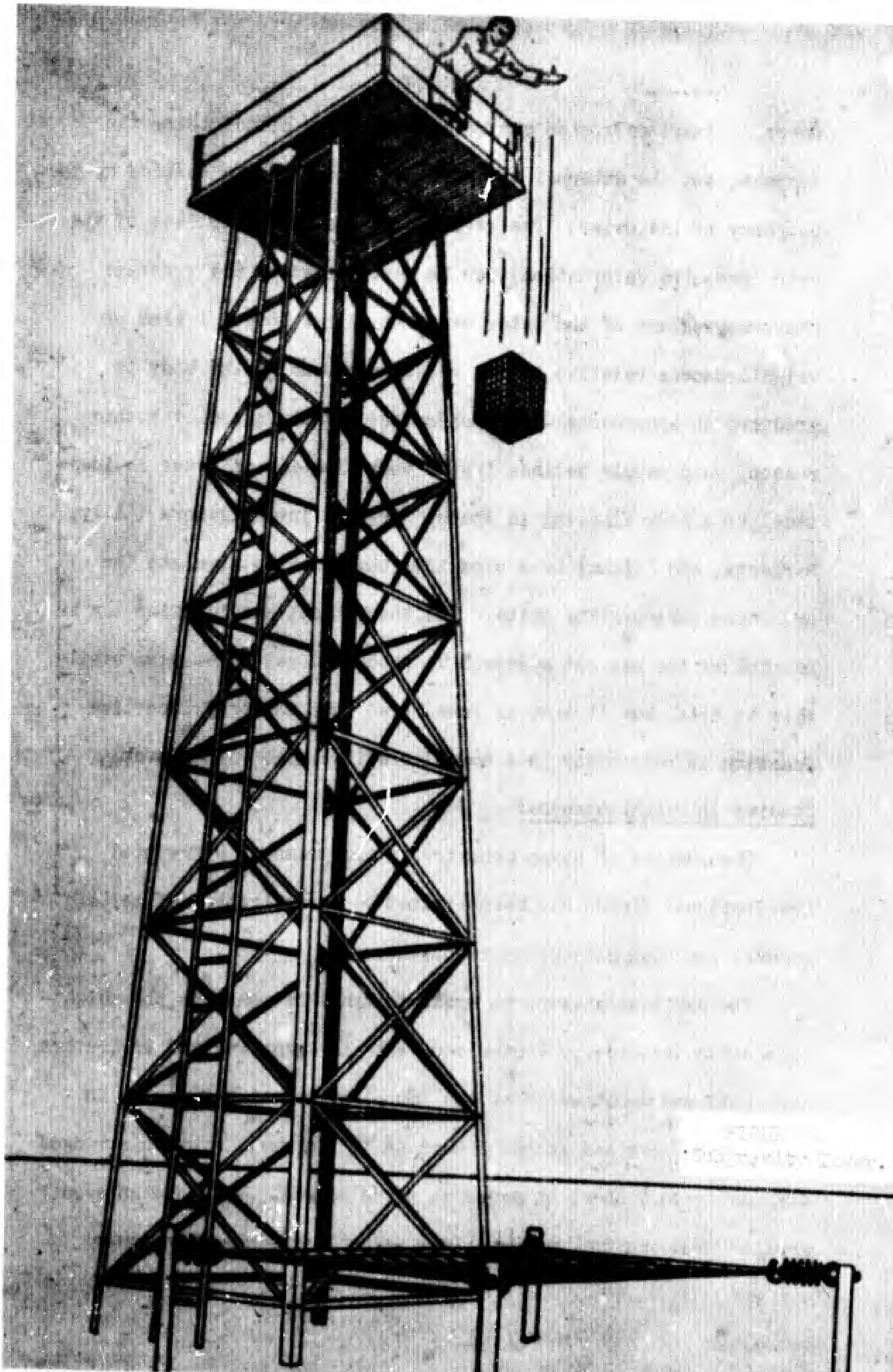
In this manner 30 to 40 seconds of null gravity have been produced in the F-94C Starfire aircraft (fig. 5). The School of Aviation Medicine is now using the F-100F aircraft which produces 50 to 60 seconds of weightlessness (fig. 6). As vehicles of higher speeds and higher altitude capability are available, zero-gravity of longer duration can be expected; but, as can be seen in figure 7, the duration of weightlessness actually has not increased appreciably. Therefore, we may have actually reached the limits of capability of our present-day high-performance jet aircraft, and as Colonel Hessberg mentioned a moment ago, the next step may obviously be the bio-satellite for medical studies.

Of the various other methods that have been used to study this state, one that deserves special mention is immersion in water. Visual reference can be eliminated by blindfolding the subject, and the external (supporting) forces can be reduced by the buoyancy of the water. The response of the exteroceptives of the skin (pressure deformation) can be neutralized by the constant uniform pressure of the water over the entire body. A kind of weightlessness relative to the medium surrounding the body is produced in accordance with Archimedes' principle and, for this reason, many people believe that a body floating in water is identical to a body floating in space. Several investigators (Lilly, Margaria, and Knight) have used this technique to simulate the prolonged zero-gravity state. The theoretical similarities may be helpful as the nearest approach to prolonged weightlessness available to date, but it must be remembered that the proprioceptive function is responding to a normal gravitational environment.

Studies in Weightlessness:

Observation of human behavior in the presence of reduced gravitational fields has been limited to investigation of certain general psychophysiological reactions.

The earliest attempt to evaluate man's response to the weightless state was made by Doctor von Beckh in Argentina and by Doctors Strughold and Gerathewold at the School of Aviation Medicine in 1953. von Beckh had subjects mark an "X" in small squares arranged diagonally on a sheet of paper at arm's length. He found an even greater tendency to overshoot in a weightless state when these



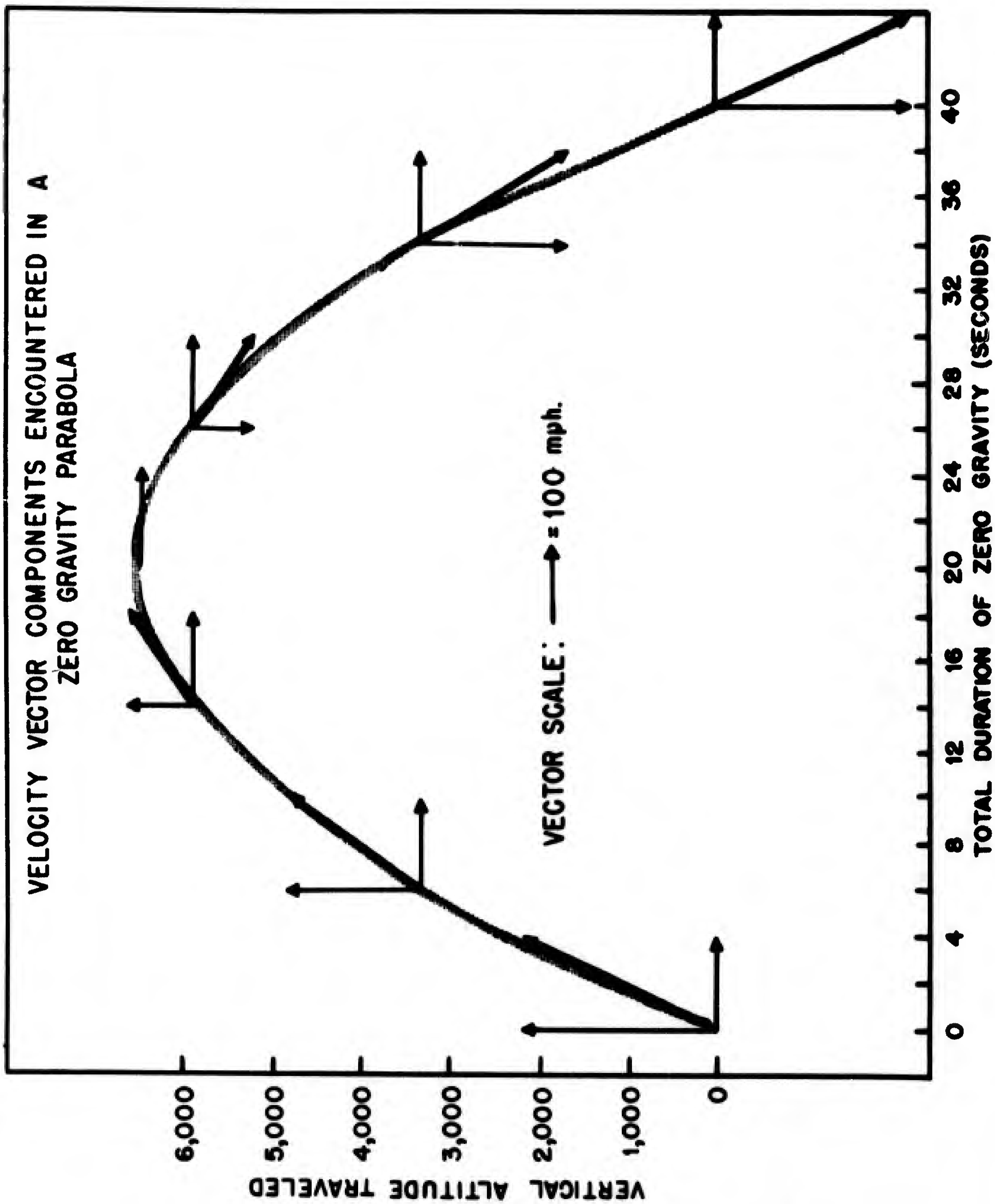


FIGURE 4
Velocity Vector Components Encountered in a Zerogravity Parabola.

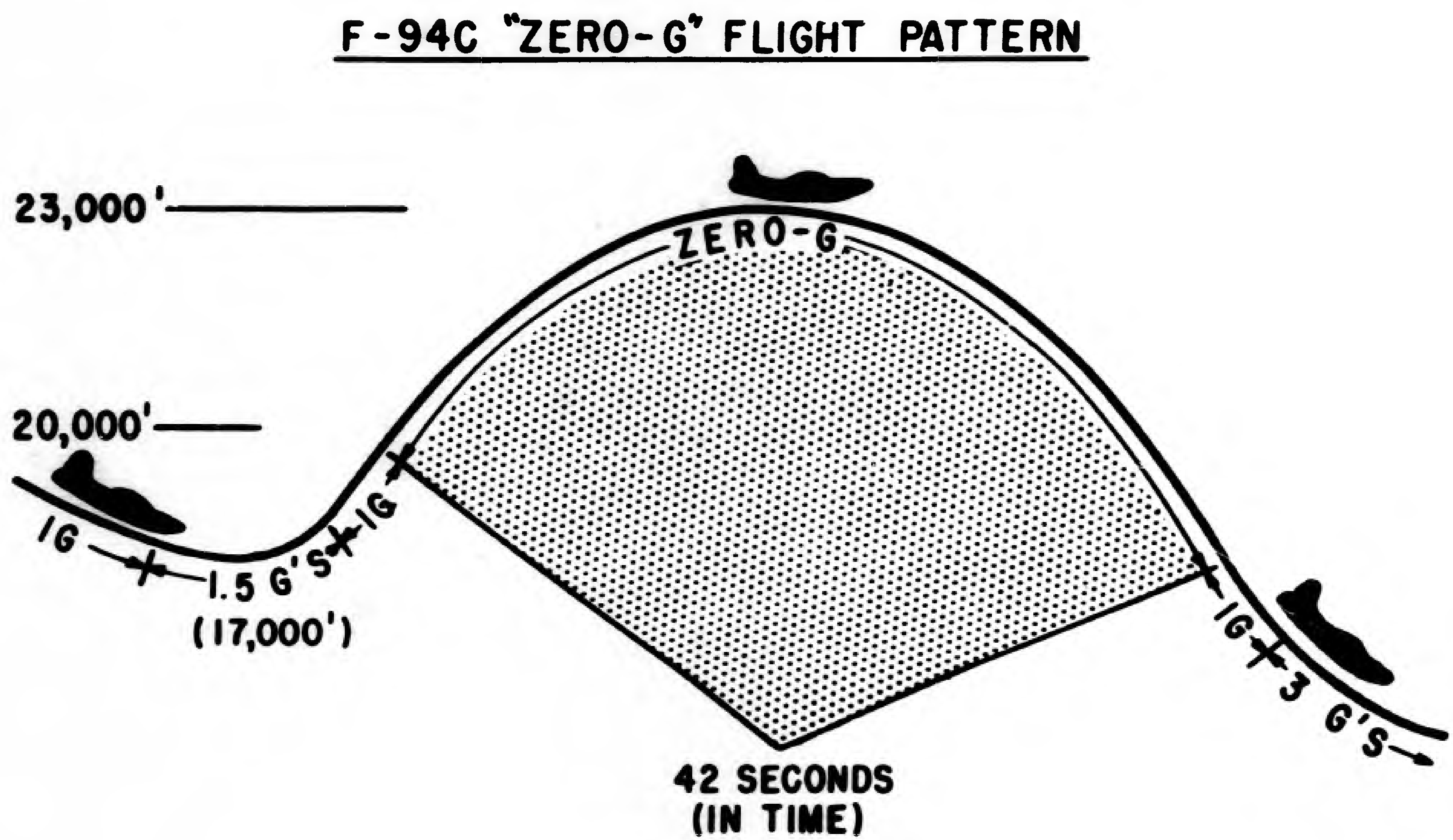


FIGURE 5
F-94 Zerogravity Flight Pattern.

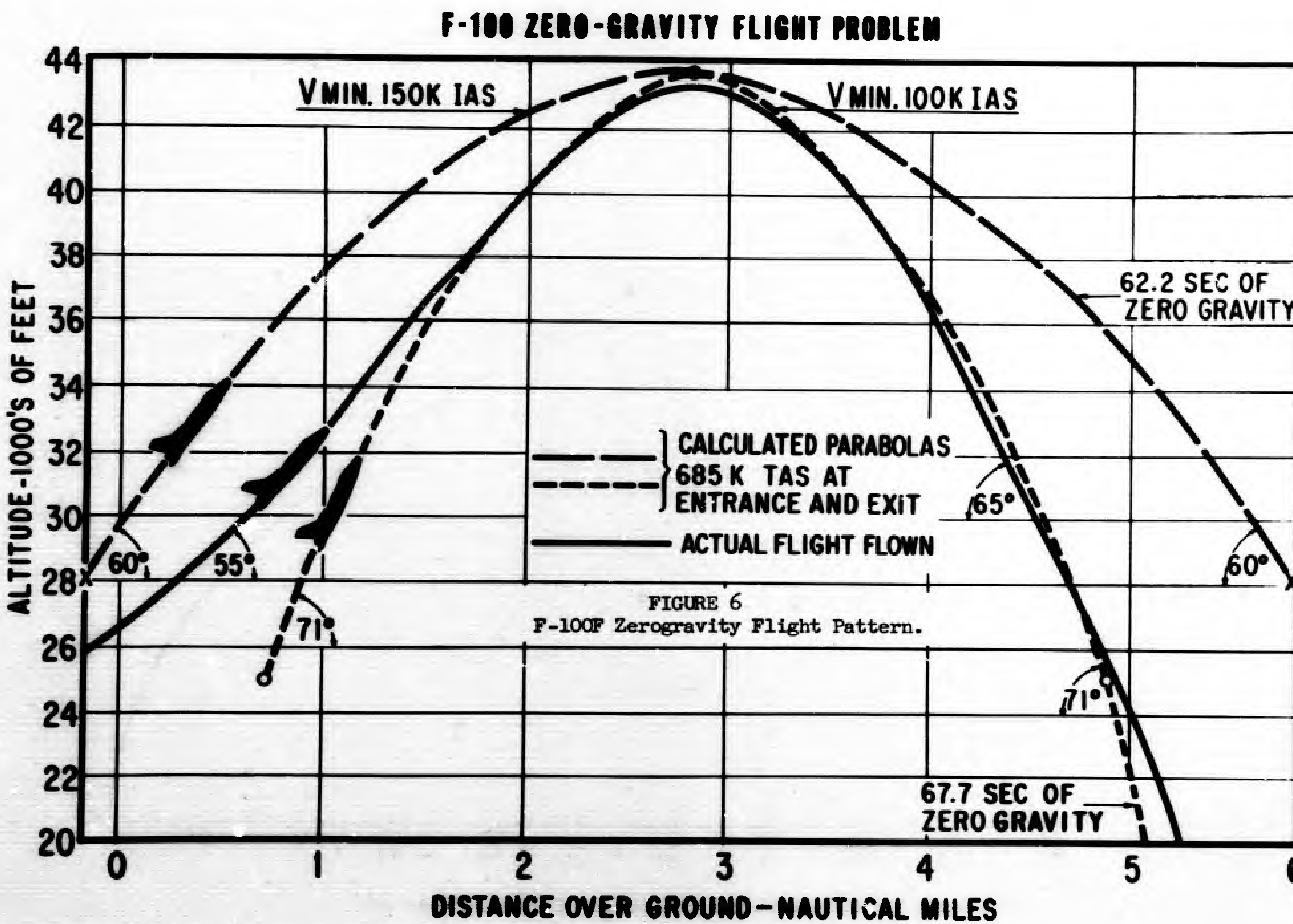


FIGURE 6
F-100F Zerogravity Flight Pattern.

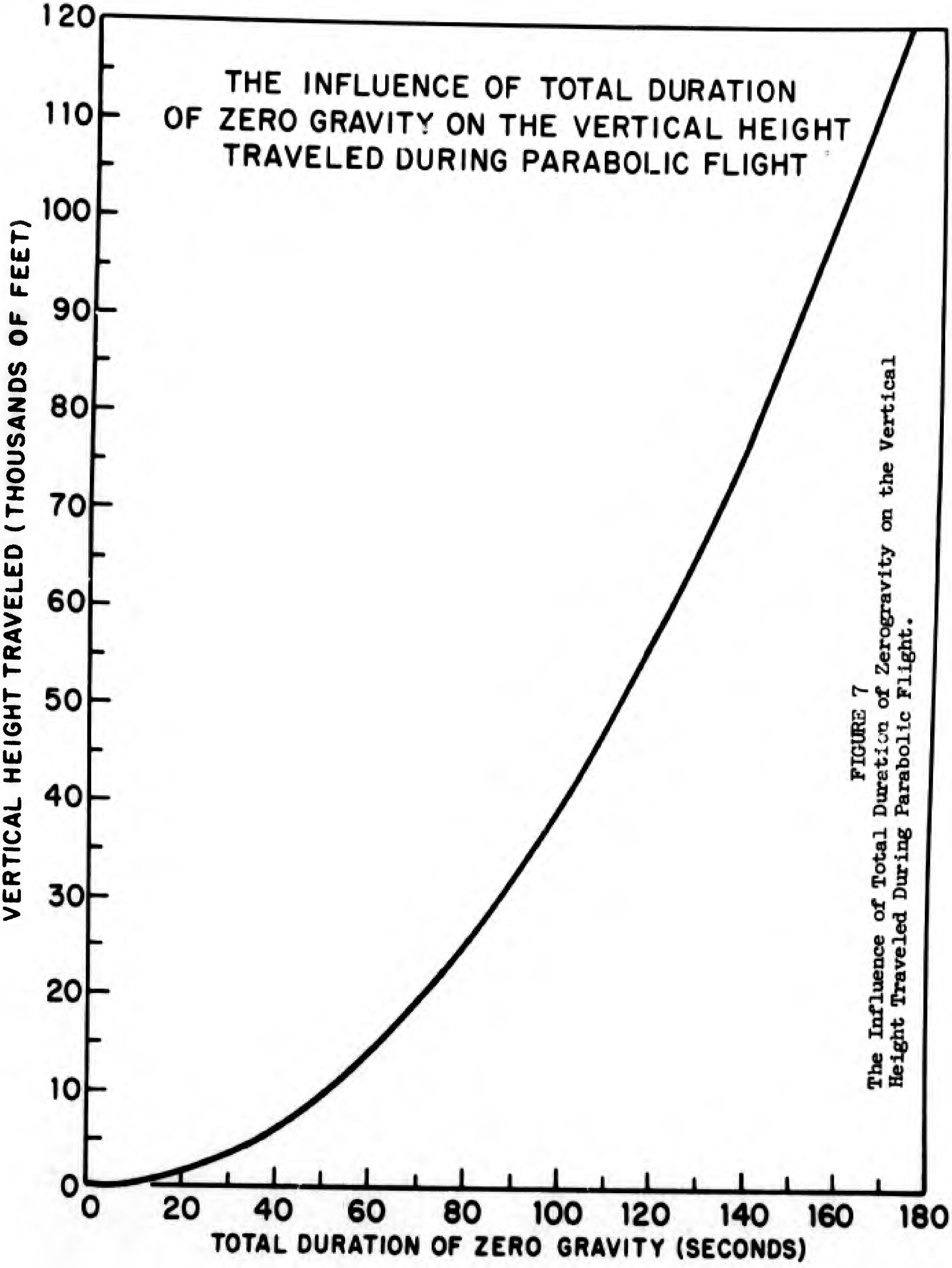


FIGURE 7
The Influence of Total Duration of Zerogravity on the Vertical Height Traveled During Parabolic Flight.

subjects were blindfolded.[9] Strughold and Gerathewold confirmed these findings with their subjects using a stylus to hit a bull's eye target on the instrument panel of a T-33 aircraft.[4] All subjects did seem to improve, however, on subsequent trials; this indicates that man may readily adapt to the weightless state and learn to compensate for the altered reflex pattern (stimulus-response ratio) of movement.

Another area of concern has been vision. In this new and strange environment of space, the future astronaut must depend more and more, or entirely, on the eyes for orientation. Once weightless, the exteroceptive function of the mechanoreceptors (i.e., otolith organ and the pressoreceptors of the skin) can no longer provide man with information about his position and movements in space.

One very interesting contribution concerning optical illusion during the weightless state was made by Gerathewold. A visual after-image was induced in 15 subjects during straight and level flight by having each subject concentrate on the bright point light source for about 20 seconds. The subjects were then flown through a zero-gravity maneuver with the head still and the eyes closed. In all cases the after-image seemed to move from the central visual field in the direction of the changing "g" force. With increased "g's" action on the subject during the pull-up following the dive, the light image would move down. It would then pass through the center and localize in the upper visual field as the force of gravity was neutralized.[2]

Other investigators (Schock and von Beckh) have observed the same pattern under similar studies. Such misplacement of the apparent position of objects in space flight could present difficulties and the astronauts may have to learn to compensate for this if normal visual orientation is not restored after prolonged exposure to zero-gravity. There is no evidence, however, that this is a true ocular aberration, due to ocular nystagmus or cyclotorsion of the eyeball. From all indications it is due to the response of the otolith to the super-gravity and zero-gravity state. This would certainly coincide with the subjective responses reported by subjects who have flown in zero-gravity with eyes closed. There is a predominant feeling of rotating upward and backward but never getting anywhere.

Following these early approaches and studies, a number of very basic and vital physiologic functions have been studied in the weightless state by the School of Aviation Medicine. These include such areas as: (1) mechanics of nourishment and deglutition of solids and liquids; (2) initiation of micturition in the weightless state; (3) disorientation; (4) circulation time studies; and (5) neuromuscular reflex patterns. I have a film which goes back to the very early studies of weightlessness here at the School which I would like to show you at this time. You will notice that the subjects have no difficulty reaching for objects floating in the weightless state.

[16 mm Film -- Studies in Weightlessness]

In this early study a piece of dry ice was sealed in a jar of water to provide a constant source of bubbles which you see rising to the top of the jar. The jar was mounted at one end of a board facing a movie camera mounted at the other end. The entire assembly was dropped from the top of a building using the principle mentioned earlier--a vertical free-fall situation. During the drop you can see the bubbles tend to coalesce and remain suspended in the medium. This is a problem of fluid dynamics which the engineers and propulsion people are most interested in at the present time.

In the next series of pictures you can see a profile of the parabola as the F-94C Starfire actually flies through this maneuver. Throughout the trajectory the ship is weightless. Until recently the pilots used a golf ball as an aid in flying these maneuvers. They would make their corrections in speed and altitude so as to float the golf ball in front of them at all times. However, the F-100F's we are now using are completely instrumented with accelerometers in the three principal axes. And this information is presented to the pilot which enables him to fly the parabolas more accurately and more consistently.

Drinking from an open container such as a water glass will definitely be a problem. Although it was realized that such attempts would be exceedingly messy, many of the ramifications had not been anticipated. Even in the process of very slowly lifting the glass to the face or tipping it sufficiently upward and rearward, acceleration was imparted to the fluid to cause it to leave the container as an amoeboid mass and envelop the face. The fluid flowed into the nasal passages, frequently entering the sinuses, as the subjects attempted to breath. Choking--virtually a sense of drowning--was a common occurrence (fig. 8). I think we can conclude from these studies that any water aboard the space craft will have to be in an enclosed system under a driving force in order to be able to handle it.

The final series of the film shows a bowl of goldfish that were flown in several zero-gravity flights. Watch the movements of the fish as they go from a one "g" condition into the weightless state. The "g" meter mounted on top of the bowl will help you identify the "g" field. The fish seem quite disturbed by the 2 ½ "g's" during the pull-up, whereas in the weightless state they are more relaxed. They seem a little confused as if trying to determine which direction is up. Actually, as you can see, it doesn't seem to make any difference to them. Some are upside down, while others are swimming on their sides. The bowl was sealed to try to eliminate the effects of pressure changes. As you know, the air bladder of the carp fish responds to changes in pressure and the fish derives some orientation clues in this manner.

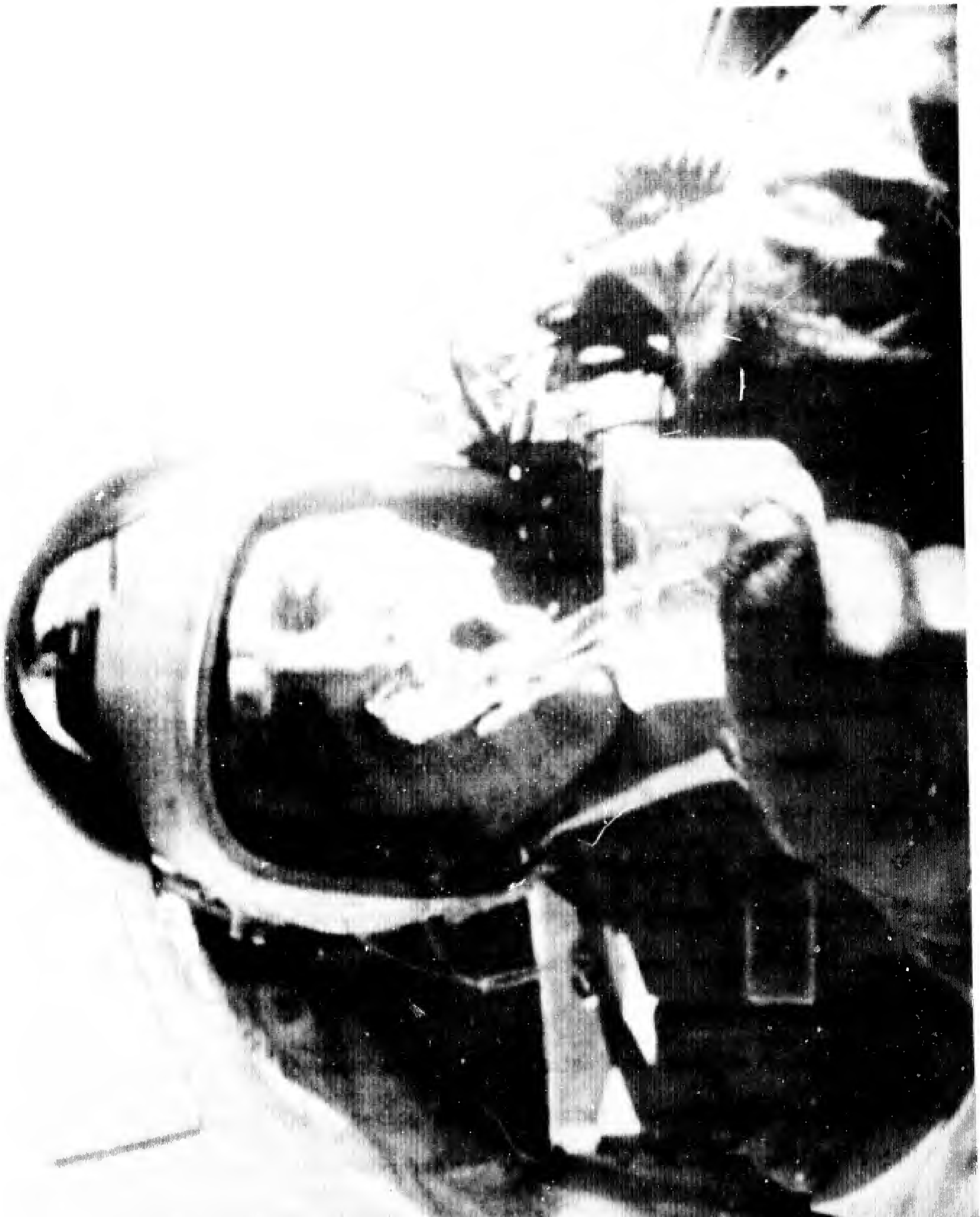


Figure [illegible]

Subject Attempting to Drink Water from an Open Container While in the Weightless State.

There is one particular study I would like to bring to your attention. I think the findings are quite significant. A number of subjects were flown in an experiment designed to study the problem of micturition in zero-gravity. The subjects were instructed to drink a glass of water every 15 minutes for two hours prior to flight and to refrain from voiding until they were in the weightless state. This was to assure that the urinary bladder would be distended at the time of the experiment, and many subjects complained of relatively severe discomfort.

Most of the individuals were able to initiate micturition in the weightless state. But the most outstanding finding of the study was that most of the subjects experienced a definite decrease in urinary urgency during one or more of these brief exposures to weightlessness. Several subjects became nauseated after beginning micturition or after emptying their bladders, and these probably reflect the effect of a "vagal shower" phenomenon commonly observed by urologists. Some reported that once micturition had been initiated in zero-gravity they were unable, without visual reference, to detect the usual pressure clues indicating that urination was being accomplished.

Although no firm conclusion concerning man's ability to void in weightlessness should be drawn from experiments utilizing the brief exposure technique, perhaps a few inferences can be made. The inhibitory effect may have been due to derived behavioral patterns, psychologic factors such as anxiety, apprehension, or diversion of attention induced by a new and exciting environment which completely nullified the vesical contractions. However, there should be another explanation since the majority of these subjects were experienced in jet flying. It seems reasonable to assume that the weight of the fluid pressing against the floor of the bladder may be responsible for perception of bladder fullness. This would mean that the primary sensory zone for this awareness must be sought in the trigone of the bladder rather than in the stretch receptors located within the wall of the urinary bladder.[11]

What does this actually mean as far as future space flights are concerned? If this is true, crew members may become preoccupied and neglect to attempt micturition except at long intervals. It would then be necessary to establish a rigid schedule for the elimination of body wastes to prevent severe stretching of the vesical wall which could lead to atrophy of the muscles, possible rupture of the urinary bladder, and extravasation of urine.

Actual physiological measurements in zero-gravity have been quite limited until recently. The early work of Doctor Henry in 1951 is well known. He conducted the first animal experiments in the V_2 and Aerobee rockets. Heart rate, arterial and venous blood pressures, and respiration rate were successfully telemetered throughout a 3-minute weightless flight.[6] In the same year Doctor Ballinger was able to obtain similar physiological measurements from human subjects during 15 seconds of weightlessness in a modified F-80E aircraft during parabolic trajectories.[1] No significant changes were noted by either investigator.

A little later, Doctor von Beckh reported three-lead ECG, galvanic skin response, and respiration rate during pre- and post-weightless acceleration studies. He found that the blackout period caused by the high "g" exposure lasted longer when the recovery period occurred in the weightless state. He also noted that the heart rate continued fluctuating up and down for a certain period that was not evident when the accelerative period was followed by a normal one "g" state.[10]

Last month (December 1959) after a year of intensive development and aircraft instrumentation, a team from the School of Aviation Medicine in cooperation with NASA and Air Force Test Center personnel conducted a zero-gravity training program for the Project Mercury Astronauts.

The seven astronauts were given four flights each in our F-100F aircraft. Three to four 60-second zero-gravity parabolas were flown per flight--giving each astronaut a total of 12 to 15 minutes of weightless experience.

A systematic program was followed and three instrumented flights per day were achieved on schedule using the aircraft seen in figure 9. Actually, this was no small accomplishment. Each subject was completely instrumented for three lead ECG, respiration, and blood pressure. The ECG electrodes were placed on the chest and below the umbilicus. This unconventional location was used to eliminate the muscle action potential interfearance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caused by moving the arms. A strain gauge was placed on the forearm to pick up the pulse wave for the blood pressure determination and figure 10 shows the completely instrumented subject with the blood pressure cuff in place. The subject was then connected in the aircraft to a seat pack unit (fig. 11) that was developed by the School of Aviation Medicine with technical assistance by personnel from the Air Force Flight Test Center.

This work was originally started by Doctor Ray Ware and Mr. Robert M. Adams of the Department of Physiology. It has subsequently been carried on by Doctor Roman and Captain Young of the Department of Space Medicine. The entire unit is completely automatic and the subject has no responsibility for its operation. The astronauts reported that they were completely unaware of the instrumentation and were quite comfortable throughout the flight.

The data was telemetered to a ground receiving station for direct monitoring of the flight and was simultaneously recorded on board the aircraft using a 14-channel oscillograph.

A final report of the data analysis is not available at this time, but figures 12 and 13 are presented simply to show the quality of tracings that were obtained during actual flight. The three principal axes of acceleration and altitude were simultaneously recorded with the subject's physiological responses. We did lose some channels at times during flight

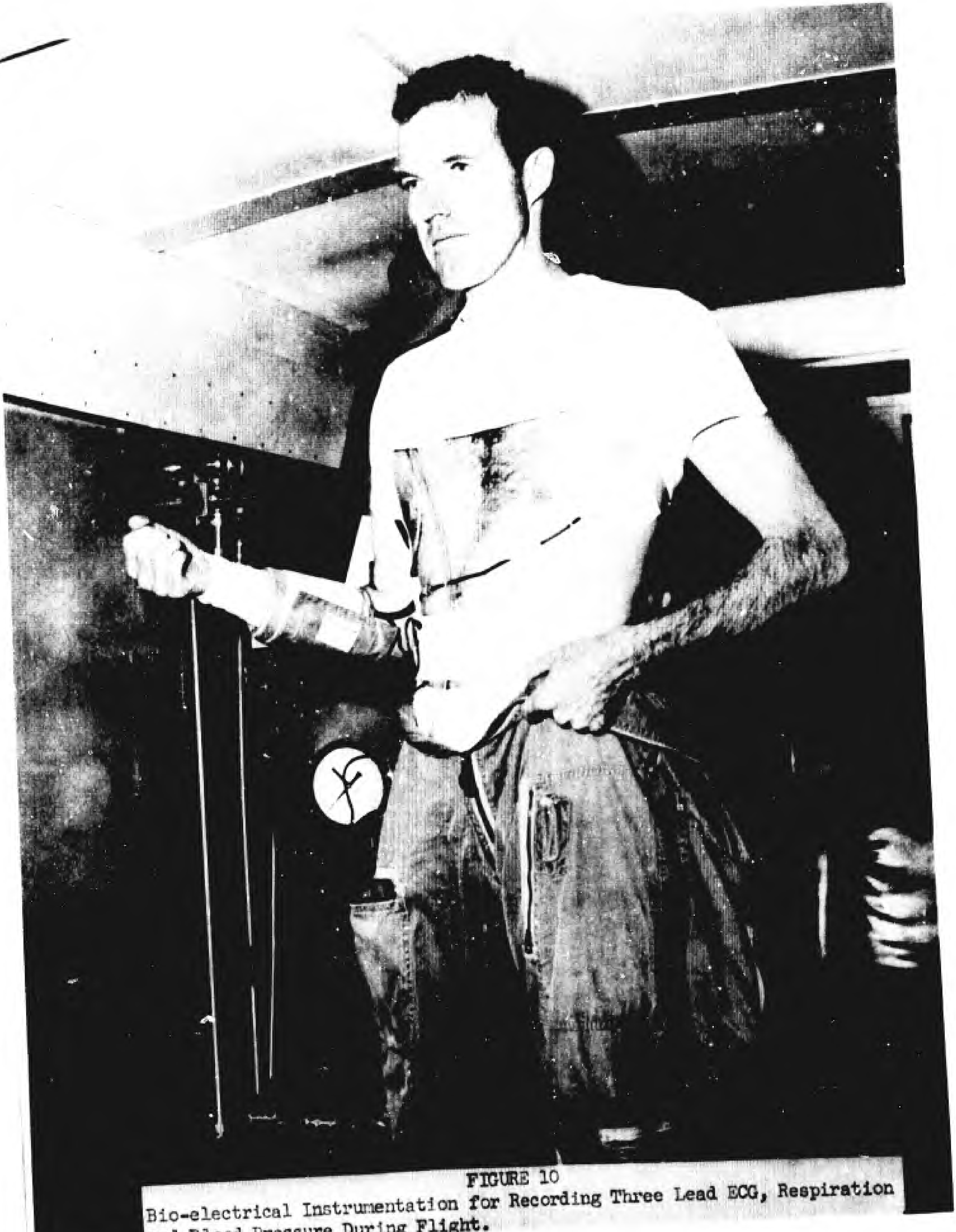
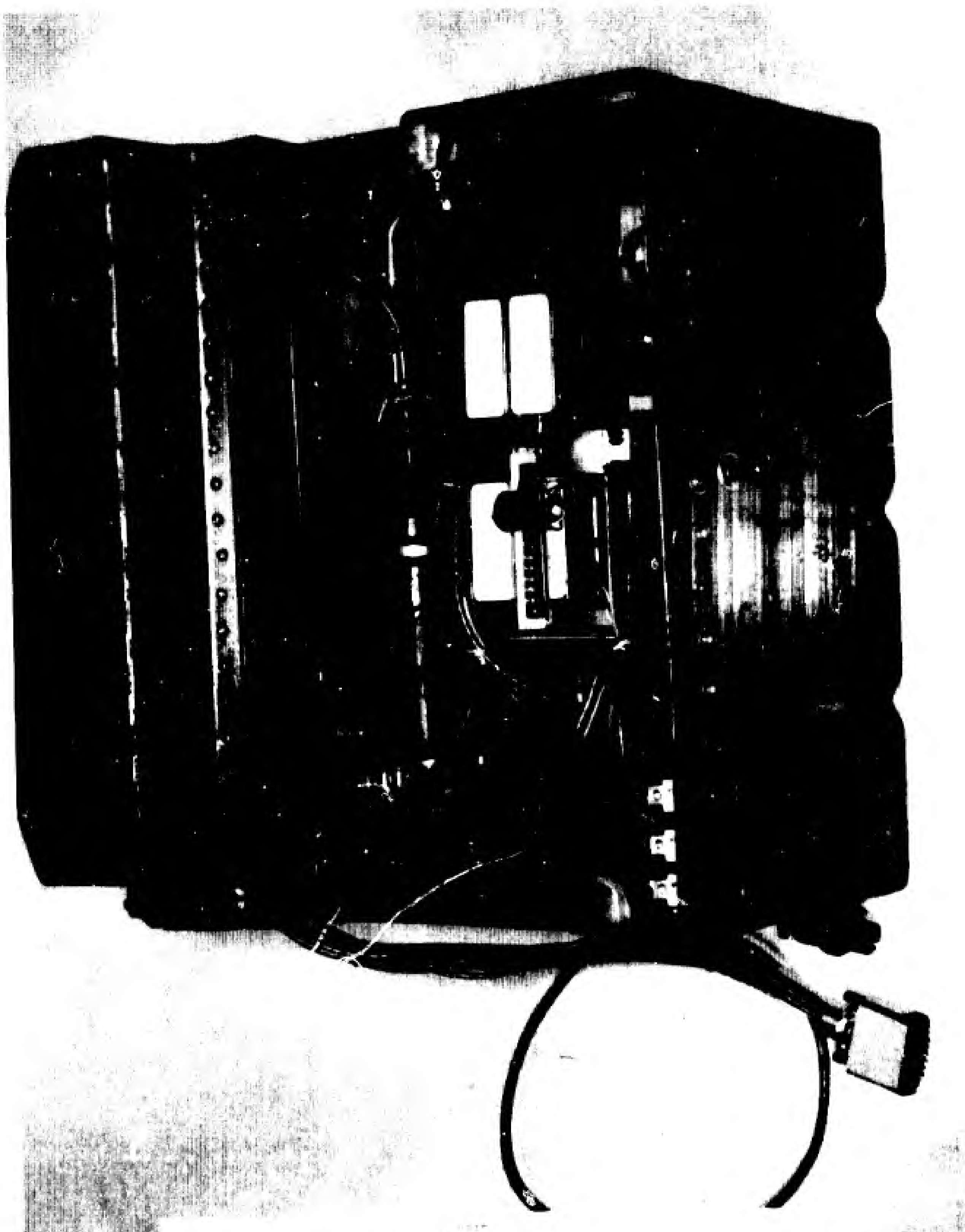


FIGURE 10
Bio-electrical Instrumentation for Recording Three Lead ECG, Respiration and Blood Pressure During Flight.



The [illegible] Seat Pac [illegible]

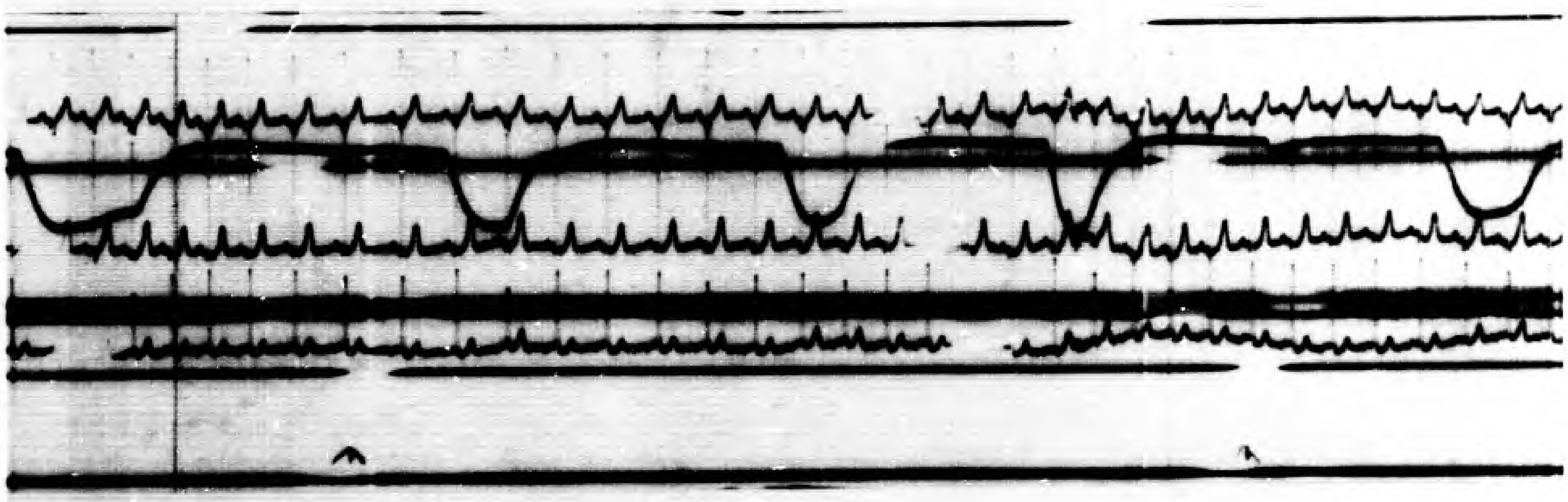
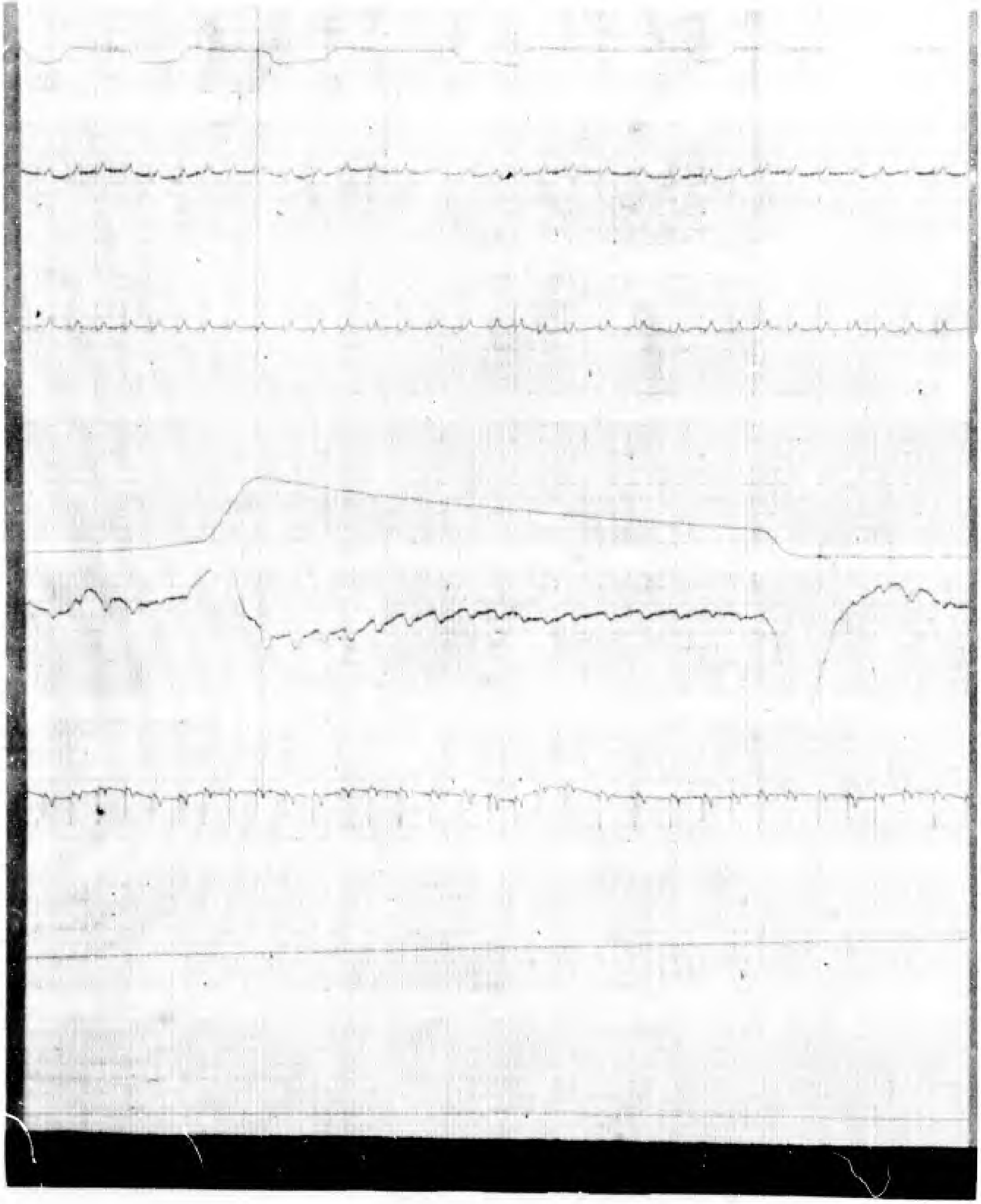


FIGURE 12

Oscillograph Record Obtained During Flight. Tracing from Top to Bottom are: (1) Lead I ECG; (2) Respiration; (3) Reference Line; (4) Lead II ECG; (5) Forward Axes Acceleration; (6) Vertical Axes Acceleration; (7) Lead III ECG; (8) Zerogravity Base Line; and (9) Reference Line.

FIGURE 13

Telemetered Data. Tracings from Top to Bottom are: (1) Respiration; (2) Lead I ECG; (3) Lead II ECG; (4) Blood Pressure Cuff; (5) Pulse Wave; (6) Lead III ECG; and (7) Vertical Axes Acceleration.



due to electronic failures but fortunately the data were not always lost on both recording systems at the same time.

Figure 12 is a sample of the on-board oscillograph record and figure 13 is a strip of the unfiltered telemetered data obtained by direct readout at the receiving station. The pressure in the blood pressure cuff (the middle tracing, fig. 13) can be seen to build up to about 200 mm Hg pressure which is then released slowly. This is all accomplished automatically and is repeated at one-minute intervals. The systolic pressure can be read in the pulse wave tracing (the fifth tracing from the top, fig. 13) as the arterial blood returns to the lower arm. This is obtained by the strain gauge placed on the skin surface beneath the cuff. Respiration (the top tracing, fig. 13) is obtained by the use of a thermocouple placed in the oxygen hose and is a direct measurement of inspiration.

Summary and Conclusions:

The consequences of the effects of zero-gravity must be considered seriously. We must consider the phenomenon of weightlessness as a medical problem even though today the duration of each exposure is still very short. This new environmental factor will greatly gain importance in the not too distant future. Too, the effects of prolonged weightlessness in orbital flight is of much concern to the engineer. Free floating objects, hardware, protective equipment, and the loss of convection, which depends on density-gravity relationships, are just some of his problems.

But aside from the future application in space flight, the study of zero-gravity has an immediate bearing on operational flying. Therefore, there are three main areas of research and programming with respect to weightlessness in the Air Force today: (1) the medical, which is concerned with the general medical aspects of well-being of the weightless individual and the intactness of his physiological functions; (2) the psychological; and (3) the operational.

In summary, I would just like to emphasize that the final answers will come only when we have a man in space, in the weightless state for prolonged periods of days or weeks. However, this does not preclude our using every available means open to us today to study this state and determine what the potential problems are in order that we may forestall any serious consequences that might otherwise occur.

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12

*LECTURES IN AEROSPACE MEDICINE

CABIN ATMOSPHERES

I. Metabolic Requirements

Presented By

Dr. Hans G. Clamann

Professor of Biophysics

School of Aviation Medicine

* This article will be published at a later date.

13

CABIN ATMOSPHERES:

THEIR PHYSICAL AND CHEMICAL CONTROL

BY

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13 JANUARY 1960

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CABIN ATMOSPHERES

Of the immense space occupied by the solar system, only that tiny shell surrounding the earth has the gaseous composition that is required by man. When man travels away from the earth, he must take with him a small part of this shell as an artificial atmosphere. Further, he must continually examine his gaseous environment, and when it is found to have become imperfect, he must treat it with the proper chemical and physical means in order to repair it.

On earth, these essential procedures are carried out with energy from the sun and with the aid of an infinite number of catalysts, each of exquisite form for accomplishing its work. The subject of this paper is to point out and discuss some simple procedures which the astronaut might utilize as temporary substitutes for this complex natural process.

I. Oxygen

A. Control: Once an oxygen partial pressure has been selected for the artificial atmosphere, oxygen must be supplied at a suitable rate in order to maintain that pressure. This rate of supply is of course equal to the rate at which oxygen is used by the crew and by any oxygen using equipment within the sealed environment. The rate of utilization is certainly not a constant value, especially for crews consisting of only one or two men. The rate for an individual is very likely to fluctuate by as much as twofold during a 24 hour cycle. If one adds to this the difficulty of predicting man's oxygen utilization rate for tasks as yet undefined, it becomes obvious that, for most efficient use, the oxygen supply must be keyed rather closely to the cabin oxygen partial pressure.

In cabin atmospheres containing a significant amount of gas other than oxygen, an oxygen analyzer is required to monitor the oxygen pressure and to control the oxygen supply so that a suitable pressure is maintained. Such an analyzer will take its toll in weight volume, power, and maintenance requirements.

There is, however, a way to avoid the requirement for a specific oxygen sensor. This is simply to omit all "inert" gases from the artificial atmosphere. In this situation the total pressure becomes a fair approximation of oxygen partial pressure. The only difference between total pressure and oxygen pressure would be the pressure of water vapor plus the carbon dioxide partial pressure. Under an ideal situation these two pressures, water vapor and carbon dioxide, would only amount to 10 or 20 mm Hg.

It is conceivable, however, that these two pressures together could amount to as much as 70 or 80 mm Hg. and that the total pressure, which might be set at say 190 mm Hg (or one-fourth atmosphere), would be far from the oxygen partial pressure. Although the ambient oxygen pressure in this situation might drop to a level ordinarily considered suboptimal, there is a curious relationship between ambient and alveolar oxygen pressures, as they are affected by ambient carbon dioxide and water vapor, which is rather startling.

Figure 1 is a plot of the ambient oxygen partial pressure against the total pressure of the artificial atmosphere. The alveolar oxygen, carbon dioxide, and water vapor pressures and the respiratory quotient were assigned the values indicated. The effect of the third variable, ambient water vapor pressure, is depicted by the several curves as the pressure assumes successive values of 0, 10, 30, and 47 mm Hg. The left most extreme of each curve is connected by a vertical straight line and is the situation where no inert gas such as nitrogen is present. It is seen that as the ambient water vapor replaces up to 47 mm Hg. of ambient oxygen, the total pressure required to maintain a normal alveolar pressure does not shift from the constant value of 187 mm Hg.

Figure 2 shows that a somewhat analagous situation obtains when ambient carbon dioxide is permitted to vary. The nearly vertical solid line at the left contains the terminal points of each curve and relates ambient oxygen pressure, in atmospheres free of inert gas, to the total pressure. The large positive slope of this solid line would indicate that ambient CO_2 could nearly quantitatively replace small amounts of ambient oxygen while alveolar oxygen pressure remains constant.

AMBIENT OXYGEN REQUIRED TO MAINTAIN ALVEOLAR OXYGEN TENSION

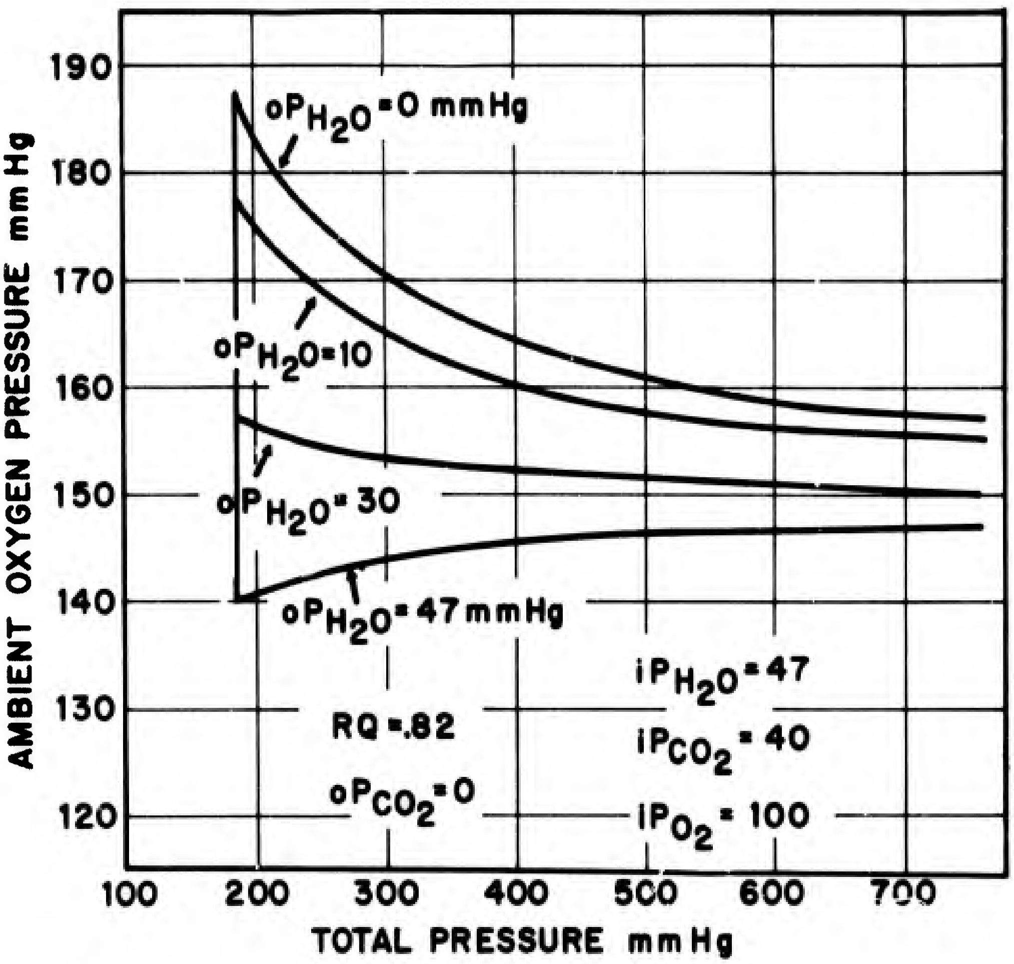

FIGURE 1

AMBIENT OXYGEN REQUIRED TO MAINTAIN ALVEOLAR OXYGEN TENSION

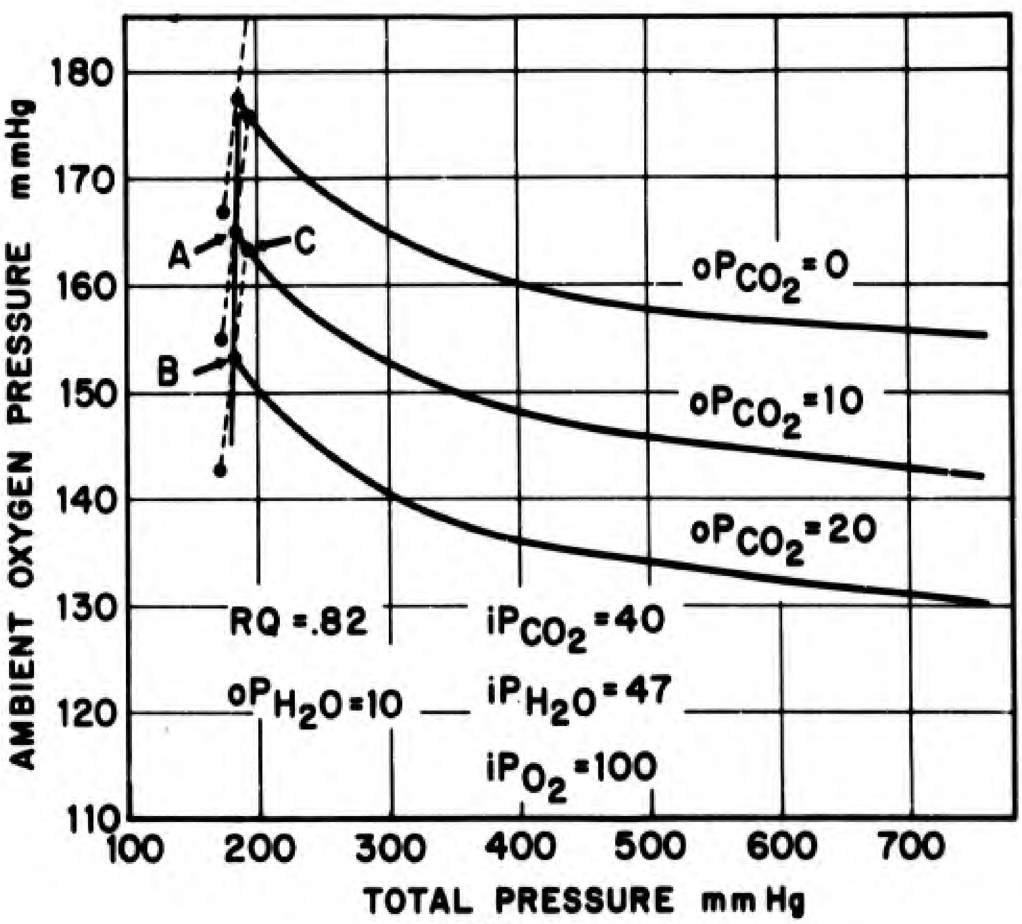

FIGURE 2

This is only true of course as long as alveolar CO_2 remains fixed. If the alveolar CO_2 rises (as is the usual case) or falls, the relationship between ambient oxygen and total pressure will be indicated by points on the dotted lines. For example, in atmospheres free of inert gases, point A indicates the coordinates for $oP_{CO_2} = 10$ and $iP_{CO_2} = 40$; point B : $oP_{CO_2} = 20$, $iP_{CO_2} = 40$; and point C : $oP_{CO_2} = 20$, $iP_{CO_2} = 50$. Because physiologic response achieves a partial correction of alveolar CO_2 tension, the actual conditions while breathing gas with increased CO_2 content would generally be represented by some point between B and C.

These considerations then indicate that in artificial atmospheres free of inert gasses--so-called "pure oxygen" atmospheres--a total pressure monitor would be a minimally sufficient assessment of the oxygen available to the alveoli.

B. Oxygen Storage: Oxygen may be stored in several ways: as a highly compressed gas; as a liquid; or chemically bound. It is necessary to consider each means of supply with respect to several characteristics in order to select the best system for a given mission. The characteristics of particular concern are weight, volume, safety, system by-products and secondary uses, heat change during oxygen liberation, and any free energy requirements.

Compressed gases include oxygen, nitrogen, helium, and of course any mixtures of these. Preformed mixtures of two gases would require that the ratio of the two required supply rates is a predictable constant. Probably the only situation where this would obtain would be in systems with a high loss by leakage--a situation generally to be avoided in space missions.

Weight may be conserved by increasing the gas pressure within the containing vessel; however, as this is done the weight of the vessel will increase. For a given vessel design there will be a mixímum pressure, above which the ratio of gas weight to vessel weight will decrease. It would not be advantageous from the standpoint of weight conservation to increase the pressure above that point. There has been recent development of "super-pressure" vessels in the range of 6,000 psi but for purposes of comparison, figures for the more standard 3000 psi vessels were used here.

Historically, it is interesting to note that early balloon ascensions in a sealed gondola, reported by Auguste Piccard[1] in 1933, utilized a liquid oxygen source. Now, liquid oxygen storage systems are in wide use by the Air Force. This is primarily due to the very significant weight advantage for these systems.

The rate at which gaseous oxygen is formed from the liquid reservoir is governed by the rate of heat transfer to the liquid. Because it is not possible to reduce heat transfer to zero, each particular bottle design will have a minimum rate at which oxygen will vaporize. This minimum amount of evaporation is in the neighborhood of a few percent per day in the best of present equipment. For example, the evaporation loss from the three 25 liter bottles in the School of Aviation Medicine 2-man Space Cabin Simulator is about two pounds per bottle per day or 3.2 percent of capacity per day. The important point is that this is the minimum rate of oxygen escape and is independent of whether it is used or not. And further, this rate of evaporation determines a maximum flight duration, beyond which liquid could not serve as the oxygen source. For instance, if the evaporative loss were reduced to one percent, the maximum flight duration with liquid oxygen would be 100 days. Design of the containers should be improved until evaporative loss is an absolute minimum while at the same time large capacity and low weight are maintained.

It is possible to supply mixtures of liquid oxygen and nitrogen in the same container. Indeed this was done in 1934 by Stevens and Anderson[2] who used 45 percent oxygen--55 percent nitrogen on their balloon flights. However, liquid nitrogen, having a higher vapor pressure than oxygen, will evaporate more rapidly and gradually increase the oxygen content in the vessel. In the Stevens-Anderson flight, this was not a problem apparently because flash evaporation of the liquid was made to occur so that proportionate amounts of nitrogen and oxygen were used. Flash evaporation would only be permitted when gas requirements are above minimum evaporative rate, and since gas requirements on prolonged space flights would likely be about equal to minimum evaporative rate, nitrogen-oxygen mixtures would not be suitable.

Of the several chemical sources of oxygen, some have been in use for many years, and their possible use in space flight must be looked at closely. In general the total weight per pound of oxygen supplied by these sources is less favorable than for liquid oxygen. But several of these compounds can do more than just supply oxygen. Therefore, in order to adequately compare these various oxygen sources, a "weight credit" must be given for any secondary tasks performed.

Ninety percent hydrogen peroxide, when catalytically decomposed, will supply oxygen at the rate of one pound per 2.36 pounds of original material[3]. The remaining 1.36 pounds is water (or rather steam at 300°F) and might be utilizable in some cabin environmental system where human waste is not recycled. The heat released in the reaction is 2,820 Btu per pound of oxygen. The large energy release would provide an auxillary power source. Perhaps the biggest drawback to this material is the problem of removing the water vapor from the oxygen.

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Potassium superoxide[3], a chemical developed by the Mine Safety Appliance Company, has perhaps even more promise. It has been used for many years in a personal breathing canister for the supply of oxygen. The reactions that occur no doubt are complex, but a practical test of the chemical, for use in an enclosed space occupied by human subjects, has been carried out at the MSA Research Corporation by Mr. Robert Bovard, et al[4]. According to their report (page 6 can No. 3), 12.2 mols of the superoxide absorbed 6.6 mols of water from the atmosphere, released nine mols of oxygen, and absorbed 5.6 mols of carbon dioxide. This would be approximately equivalent to the three reactions:

$$2\ KO_2 + H_2O \longrightarrow 2\ KOH + 1.5\ O_2$$

$$2\ KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

$$K_2CO_3 + 1.5\ H_2O \longrightarrow K_2CO_3 \cdot 1.5\ H_2O + 1.5\ O_2$$

Sum: $$2K O_2 + 1.5\ H_2O + CO_2 \longrightarrow K_2CO_3 \cdot 1.5\ H_2O + 1.5\ O_2$$

Here the theoretical molar ratio of KO_2 : water : oxygen : carbon dioxide in the overall reaction is 2:1.5:1.5:1. In the practical test the ratio was about 2:1.1 : 1.5 :.9. In this very interesting report the authors point out several ways whereby the overall behavior might be modified to meet more adequately a particular need.

It is interesting to derive a ratio for water, oxygen, and carbon dioxide as they are metabolized by man (Table I).

TABLE I

Molar Ratios of Reactants

	KO_2		H_2O		O_2		CO_2
KO_2 Theoretical	2	:	1.5	:	1.5	:	1
KO_2 Actual	2	:	1.1	:	1.5	:	.9
Man	X	:	2	:	1.5	:	1.3

A subject that does not perspire noticeably will lose about 55 mols of water vapor to the air; use about 27 mols of oxygen with moderate exercise; and release about 23 mols of carbon dioxide per day. These are then in a ratio of X : 2 : 1.5 : 1.3, but this ratio is certainly quite variable; especially the water vapor production may go higher with heat loads. The inequality of the superoxide and human performance ratios and especially the variability of the latter would indicate a requirement for accessory equipment to handle part of the water vapor and carbon dioxide loads. Nevertheless, this chemical seems very promising--at least for certain special functions.

The possibility exists of reducing the weight of superoxide systems by selecting a metal with a lower equivalent weight than potassium. According to Bovard[5], sodium superoxide has been prepared in small amounts and behaves similar to potassium superoxide. Also calcium superoxide has been prepared in trace amounts but apparently has not undergone sufficient test. The weight of a sodium superoxide system would be about 80 percent of one using the potassium compound--an apparently significant saving for use in space missions.

Sodium chlorate, in the form of candles, has been tested rather extensively as an oxygen source[3,5]. It has been used in high altitude breathing masks as well as in the closed environment of submarines.

Oxygen is released by thermal decomposition, approximately according to the reaction:

$$x\ NaClO_3 + y\ Fe \longrightarrow x\ NaCl + y\ FeO + ZO_2$$

The candles also contain barium peroxide, to inhibit formation of chlorine, and fiberglass for structural strength. After the decomposition is initiated at one end of the candle, usually by a percussion type fuse, the candle burns uniformly to the other end, evolving 555 kilocalories per Kilogram of oxygen.

Once the reaction is begun, the rate of oxygen liberation cannot be controlled and is determined by the size of the candle. Diameters of 20 inches with nearly 10 pounds of oxygen per inch of length are possible.

Figure 3, taken from Dryden et al, relates the efficiency of several oxygen sources to the amount of oxygen to be supplied; that is, to the weight of empty equipment. It is seen that for small oxygen requirements as in a personal breathing apparatus, chemical oxygen sources are most advantageous.

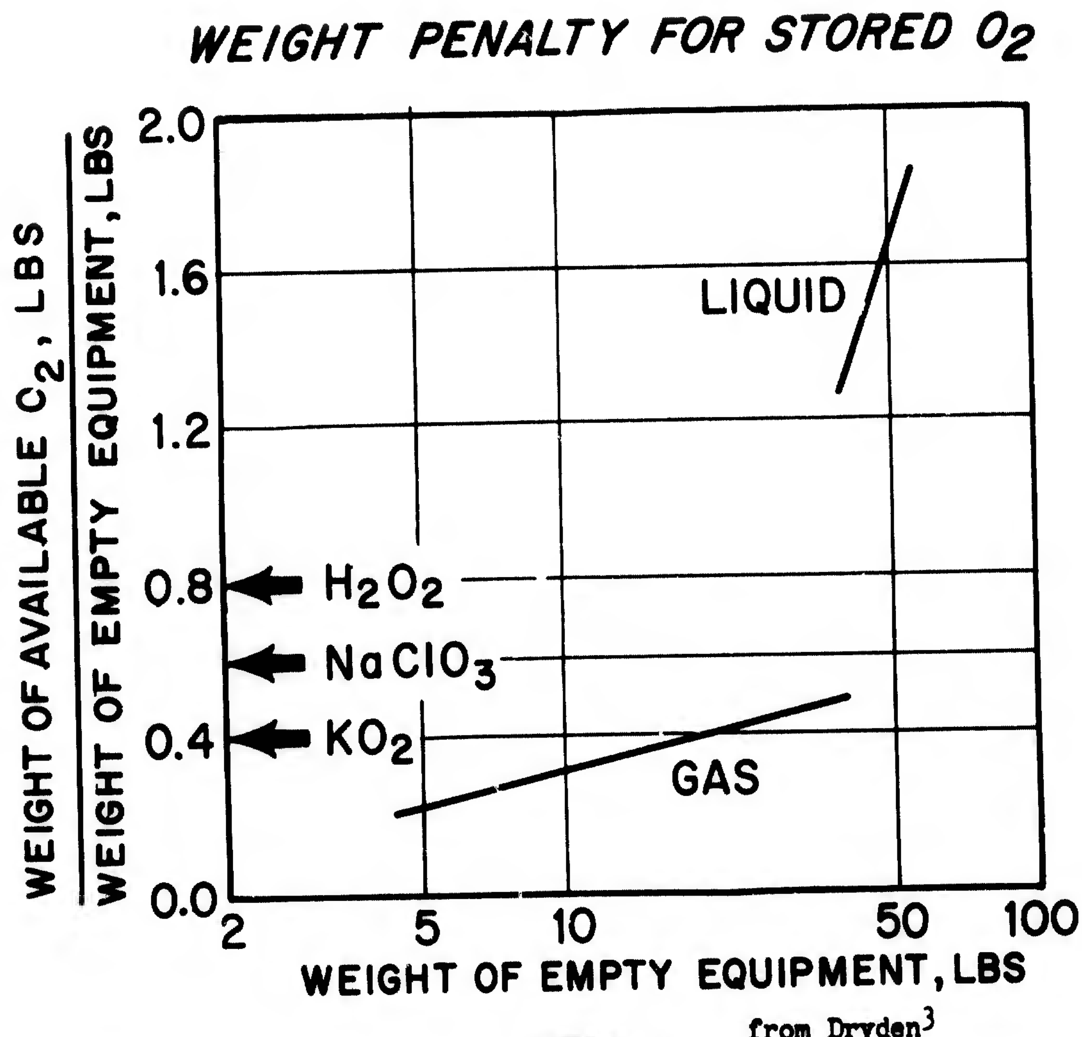
WEIGHT PENALTY FOR STORED O2
WEIGHT OF AVAILABLE C2, LBS
WEIGHT OF EMPTY EQUIPMENT, LBS
2.0
1.6
1.2
0.8
0.4
0.0
LIQUID
H2O2
NaClO3
KO2
GAS
2
5
10
50
100
WEIGHT OF EMPTY EQUIPMENT, LBS
from Dryden3

FIGURE 3

Other considerations would probably dictate which of the chemicals would be most useful.

Table II lists the five main oxygen sources mentioned thus far and gives their weight, volume and heat evolution per 900 grams of oxygen released. Also the by-products and secondary uses of each system are listed in separate columns. Although liquid oxygen would seem to have a clear lead, the evaporative loss limits its use to shorter missions. Also the secondary uses of some of the chemicals may make them superior for some applications.

TABLE II

Stored Oxygen Sources

Source	Kilos / 900 gmO_2	ft^3 / 900 gmO_2	Kcal / 900 gmO_2	System by Products	Secondary Uses
Gas	2.7	.128	.-15	Containers	
Liquid	1.4	.064	-64	Containers	Refriger-ant
H_2O_2	2.6	.050**	1,400	H_2O	Power, H_2O 1.36# H_2O/# O_2 Supply
$NaClO_3$	2.7	.074	500	NaCl	Heat Source
KO_2	5.0*	.20	500***	K_2CO_3	Dehumidi-fier CO_2 absorber Odor re-mover

* Without blower
** Without equipment
*** Approximate

C. <u>Oxygen Regeneration</u>: There are two other chemicals which would be readily available within the sealed cabin and which could be made to yield oxygen. These are carbon dioxide and water. Carbon dioxide is produced at a rate such that 80 to 90 percent of man's oxygen supply could come from this source. The water that is produced in metabolic oxidations, on the other hand, could supply about 40 to 45 percent of the required oxygen. If both carbon dioxide and water were tapped for their full oxygen content, gaseous oxygen would accumulate on the space station or be available for other uses at the rate of 200 to 300 grams per man per day. Biologic processes for utilizing these materials are beyond the scope of this presentation; however, a few comments should be made on possible physical processes.

The replacing of the more usual oxygen sources, such as liquid oxygen, with an apparatus capable of generating oxygen from waste material within the space cabin changes the logistics in three ways:

1) It omits oxygen stores and equipment
2) It adds oxygen regeneration apparatus
3) It adds an additional power requirement.

The take-off weight of oxygen stores will be essentially proportional to flight duration, whereas the weight of oxygen regeneration equipment may be nearly independent of flight duration. The weight cost of conventional power storage would make regenerative systems prohibitive. For example, about 125 pounds of storage batteries would be required to supply 900 grams of oxygen (one days supply for one man) by electrolysis of water. Therefore, regenerative systems depend on the utilization of solar energy or on the development of suitable atomic energy sources. With the hope that such power sources will become available, we may look at the possibilities for physical extraction of oxygen from carbon dioxide and water.

Laboratory data exist which show that water can be produced by chemical reduction of carbon dioxide with hydrogen[6,7]. This can be accomplished by passing these two gasses at 1 atmosphere pressure over a nickel catalyst at 300°C. The exit gas is a mixture of carbon dioxide, hydrogen, methane, a trace of carbon monoxide, and about 50 percent water. By studying the effects of temperature, pressure and catalyst on the reaction, the resulting mixture might very likely be improved, but even the above products would seem acceptable. The water could be separated by cooling and oxygen recovered by electrolysis. The hydrogen from the water would not be a waste product but would be recycled in the apparatus to chemically reduce more carbon dioxide. Such a process could produce 80 to 90 percent of man's oxygen requirement and by electrolyzing an extra 100 ml of water--much less than a subject produces--all of the oxygen requirements could be met.

Such a system seems very promising. Three of the four main steps could be accomplished almost entirely by means of thermal control. Carbon dioxide could be separated from the cabin's oxygen atmosphere by cooling; chemical reduction of the carbon dioxide by addition of hydrogen and heat in the presence of a catalyst; and water separation by cooling. The fourth main step in the process, the breakdown of water, could be most easily accomplished by means of electrical energy.

The production of oxygen from water is a much more thoroughly developed process. Since the necessary apparatus would be at hand with a minimum of research, a more thorough analysis of the logistics is possible. A basic assumption for such a consideration is that an otherwise useless by-product of man's metabolism--water--would serve as the raw material. The rate of this water production is directly proportional to the metabolic rate. It depends also, to a slight extent, on the type of food oxidized, being slightly higher per kilocalorie for carbohydrates than for fats. On an ordinary diet it amounts to about .14 grams per kilocalorie or about 400 grams (22 mols) per day. This water will contain 40-45 percent as much oxygen as was used in metabolic oxidations. The question then is "What are the logistic effects of replacing 40 percent of the oxygen stores with oxygen produced electrolytically?"

An interesting report by G. W. Work[8] describes the design of a nickel-cadmium gas generating cell with potassium hydroxide solution as the electrolyte. During discharge of the cell, hydrogen gas is formed which could be vented overboard or used in a CO_2 reduction apparatus. During charge gas ous oxygen is formed. For continuous production of oxygen, these cells are operated in pairs with one charging while the other discharges. Using the data given in the report, it would appear that 40 percent of man's oxygen supply (or about 8.6 cubic feet per day) would require 390 grams of water per day and .358 amperes at 275 volts for 98.5 watts of power. The weight and volume requirements for this apparatus, exclusive of power supply, would be 6.7 kilograms and 3500 cubic centimeters, respectively. The weight of liquid oxygen and system that must be placed on board at time of take-off in order to supply this 40 percent of a man's requirements would be .56 kilograms times the flight duration in days. From this it can be calculated that, for operations longer than 12 days duration, water electrolysis would have a logistic advantage (power requirements being omitted) over liquid oxygen.

Of course any of these physical means to obtain oxygen from carbon dioxide or water assume that food will be provided from stores . And conversely, the utilization of either the metabolic water or the carbon dioxide would prevent the production of food in the sealed environment by plants. However, until plant technology for space application becomes sufficiently advanced, and even following that time for certain missions, physical systems must be developed to their highest efficiency.

II. Carbon Dioxide

A. Control: This metabolic end product will be added to the sealed cabin atmosphere at the rate of about 23 mols per occupant per 24 hours. The above figure is based on a 3000 kilocalorie diet but is directly proportioned to the caloric output. Because of this, the rate of carbon dioxide production will easily vary over a two to three fold range as the subject changes from a condition of sleep to one of increased physical activity. Of course as the number of subjects in the environment increases, and their duty hours are staggered the rate of CO_2 production will tend to become more constant throughout a twenty-four hour period.

The rate of carbon dioxide production is also influenced to some extent by the diet (Figure 4). Oxidation of carbohydrates produces about 18 percent more CO_2 per kilocalorie than oxidation of fats.

The partial pressure of carbon dioxide must be kept at low levels in order to avoid toxic symptoms. The rate of partial pressure build-up is directly proportional to the rate of production and inversely proportional to the cabin volume and carbon dioxide removal rate. As a rule of thumb, the carbon dioxide partial pressure will increase in the absence of CO_2

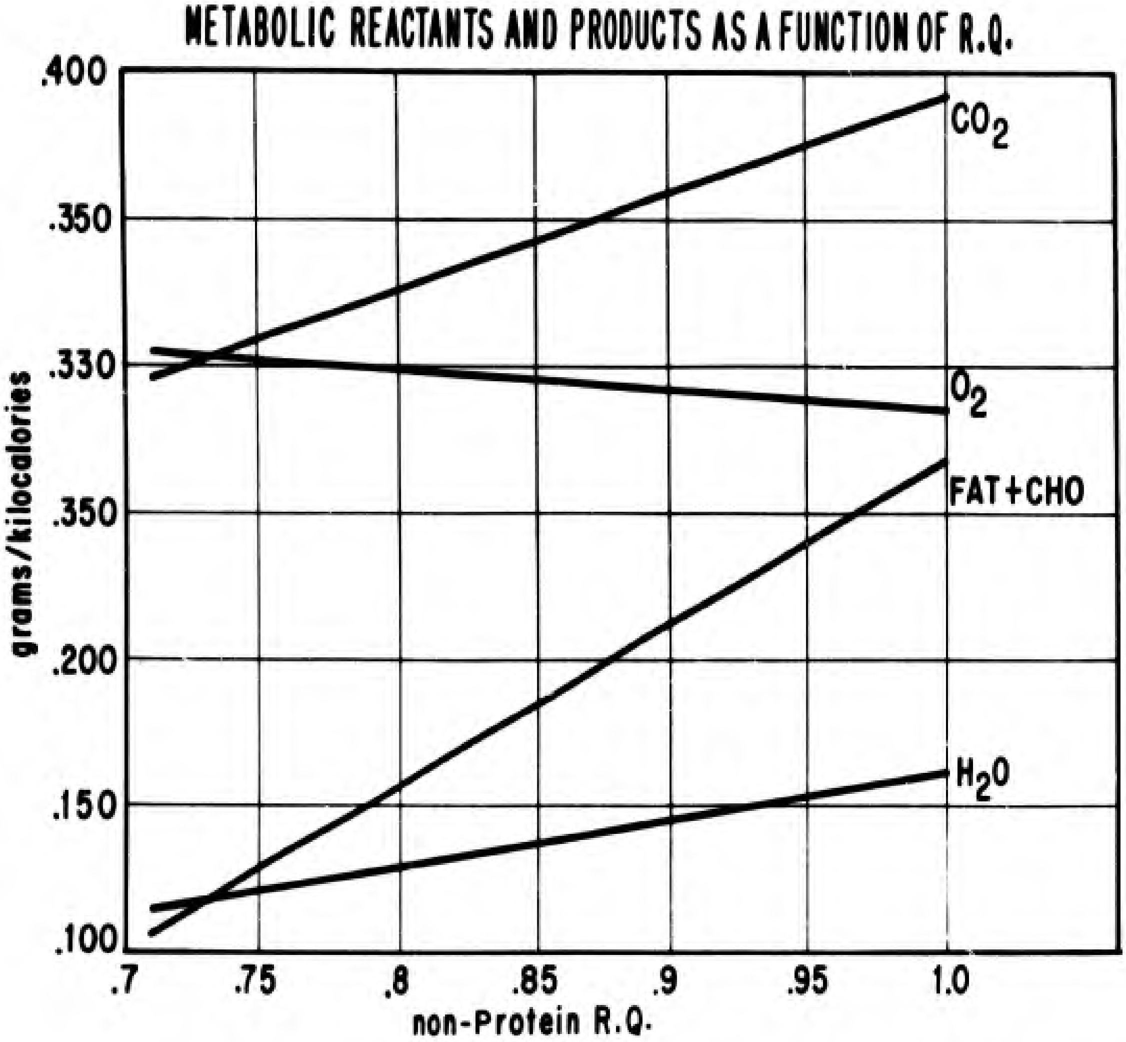
METABOLIC REACTANTS AND PRODUCTS AS A FUNCTION OF R.Q.
.400
.350
.330
.350
.200
.150
.100
grams/kilocalories
CO2
O2
FAT+CHO
H2O
.7
.75
.8
.85
.9
.95
1.0
non-Protein R.Q.

Figure 4

removal, at the rate of about seven mm Hg. per active occupant in 100 cubic feet of cabin volume. It will increase at about half this rate during sleep. The increase in CO_2 pressure could be roughly estimated by the formula:

$$\Delta P_{CO_2}(\text{mm Hg/Hr}) = \frac{7 \times \text{no. active men} + 3.5 \times \text{no. sleeping men}}{\text{Hundreds of cu ft in cabin}}$$

This indicates that a CO_2 absorbing system must not be omitted for longer than about two hours of operation for cabin volumes of 100 cubic feet per man.

Means of monitoring the carbon dioxide partial pressure will probably be required as a check on the CO_2 removal system and to permit maximum efficiency in the system. For use in space, an analyzer with ruggedness, and the least maintenance and power requirement would be desireable. Considerable accuracy could be sacrificed if necessary to meet these other needs.

B. Carbon dioxide removal: An acceptable CO_2 level in the atmosphere can be maintained in a number of ways. Probably the simplest would be to flush out the cabin with a continuous stream of oxygen. In order for this process to be most efficient from the standpoint of oxygen cost, the mol fraction of CO_2 in the atmosphere should be at the highest acceptable level. Suppose CO_2 and oxygen pressures are fixed at 10 mm Hg. and 170 mm Hg. respectively. In order for 23 mols of CO_2 per day to be lost in exit gas, 17 times this amount or 391 mols of oxygen would exit. This amounts to 12.5 kilograms of oxygen or

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to 20 kilograms of liquid oxygen plus equipment. A secondary effect of this flushing would be to remove water vapor--about 380 grams per day in this example, if cabin water vapor partial pressure were kept at 10 mm Hg. This is one-half to one-third of the total water vapor produced daily. Even if credit is given for this secondary task, the expenditure of 20 kilograms per 24 hours per subject for atmosphere purification is several fold below the efficiency of other systems.

Other ways for ridding the atmosphere of CO_2 use means to concentrate the carbon dioxide at one site to the relative exclusion of oxygen. The main ways of concentrating or capturing the CO_2 that might be applicable in space are as follows:

a) Chemical absorption by reacting the CO_2 with a metal oxide or hydroxide. For simulated space flights and balloon flights this method has been most widely used.

b) Physical adsorption of CO_2.

c) Solidification of CO_2 by cooling.

d) Filtering CO_2 from the atmosphere by means of physical or chemical filters.

In all of these methods the concentrating mechanism will eventually become saturated and, in this condition, useless. At that point the usual procedure is to set the spent chemical aside and use fresh material. An alternate mode of operation would be to regenerate the spent chemicals in some manner.

Regeneration is generally not easily accomplished with metal hydroxides, but on the other hand, their high capacity makes them most suitable for non-regenerative systems.

Table III lists three chemicals which have been used extensively as non-regenerative CO_2 absorbers.

TABLE III

CO_2 Adsorbing Agents

	Kilos / 1000 grams CO_2	Kilo H_2O Evolved / 1000 grams CO_2	Remarks
LiOH	1.35	+.300	dusts
Baralyme	3.68	+.378	non-dusting
KO_2	3.58	-.500	O_2 source

These materials are generally used in rather coarse granular form packed in columns or beds. The cabin air is forced through the beds at such a rate that essentially all of the CO_2 is removed and so that pressure drop across the bed is optimized with respect to power requirements. It generally works out that the rate of CO_2 absorption required dictates the bed cross section area.

Several factors may influence the effectiveness of the chemical. Temperature can be quite important as seen by the fact that Lithium hydroxide acts well at low temperatures whereas potassium superoxide requires heat to rapidly initiate the reaction. Water vapor has been periodically rediscovered as a requirement for reactions between CO_2 and alkalis[9].

However, since water vapor will cause lithium hydroxide to form the less active mono-hydrate, data relating the effect of humidity on the CO_2 uptake might be very useful. A report by Hougen and Marshall[10] presents an excellent theoretical consideration of adsorption in granular beds.

From Table III it is seen that lithium hydroxide is lightest for a given amount of CO_2 absorbed. This substance is available in 2-4 mesh, highly porous granules from the Lithium Corporation of America. The small amount of dust encountered can be handled satisfactorily in canister systems by using thin glass wool filters though more elaborate filters have been suggested[11]. With these simple filters, there has been no complaints of irritating dust in the cabin and no detectable increase in the plasma lithium level. However, with very prolonged use and with sufficiently rough handling, more extensive measures might be required to control dusting.

An interesting method which does away with any dust problem, has recently been developed here at the School by Major Cloid Green. In this method, a report of which is in progress, the lithium is held within a sintered metal container which permits CO_2 free access by diffusion. This also reduces considerably the requirements for an air blower.

Baralyme, while less advantageous weightwise, has other properties which highly recommend it[3]. It is in granular form, is essentially dust free, and has a high resistance to crushing. The commercial product, available from Thomas A. Edison Industries, is apparently primarily a mixture of barium hydroxide and calcium hydroxide with an indicating agent added.

Potassium superoxide was mentioned earlier as a possible oxygen source. From Table III it is seen to be about as efficient, weightwise, as Baralyme, for CO_2 absorption. In further contrast to the other two absorbers listed in the table, potassium superoxide does not evolve water vapor, but actually absorbs it.

With the other ways of handling CO_2 (physical adsorption, change of state, and filtration), continuous or discontinuous removal of CO_2 for regenerating the system is essential. There are two means of regenerating spent CO_2 absorbers that are readily available in space. These are thermal energy and vacuum. Elevating the temperature of spent absorbers will generally cause release of CO_2 which in turn could be used or discharged into space. Even more simple operationally would be to expose the spent absorber to the vacuum of space without necessarily elevating the temperature. For some absorbers, however, a combination of the two methods would be required.

Activated charcoal has been mentioned as a possible means to physically adsorb CO_2[12]. Although little data is available the capacity would undoubtedly be quite low and its usefulness would depend entirely on regeneration. It could be visualized as being operated as a number of adsorbing units with some desorbing to space while others are exposed to the cabin atmosphere.

Removing CO_2 by changing its physical state to a solid was suggested many years ago by Oberth. Ross[13] proposed that the cabin air be circulated through a series of tubes outside the space ship to permit cooling by thermal radiation. The operation of such a system could be interrupted at intervals to permit the accumulated CO_2 to vaporize overboard. Vaporization could be enhanced by orienting a radiation absorbing surface of the coils toward the sun.

Fenno[14] has suggested that CO_2 could be removed from the cabin atmosphere by utilizing materials such as a thin rubber dam which has greater permeability to CO_2 than to oxygen. Such a scheme is intriguing indeed but apparently no theoretical analysis has been accomplished.

III. Water Vapor

Of the multitude of contaminants that man's body will add to the artificial atmosphere, water vapor will be quantitatively the greatest, the most variable in amount, and equal to any in its possible hazards. The rate of water vapor production, as well as the optimal humidity, is closely tied to the subject's heat exchange by means of radiation and conduction. Under ordinary conditions a man produces about 1000 grams or

55 mols of water vapor daily and this figure will be used for purposes of comparison.

There are three different means to assess relative humidity which might very well be applied to sealed environments[15]. The simple hygrometer consists primarily of a hygroscopic material, such as wood, paper, silk, or animal membranes, which changes its physical shape with variations in humidity. It has the advantage of being direct reading and maintenance free. The wet bulb-dry bulb temperatures may be used with a few precautions. The apparatus consists essentially of two thermometers or thermocouples, one of which is covered by a moistened wick and exposed to an airdraft. The readings require reference to special curves drawn for the particular atmospheric pressure. An electric hygrometer (as produced by American Instrument Company, Inc.) is also available and has as its sensing element a hygroscopic film which changes resistance with changes in humidity. This instrument should easily lend itself to telemetry.

Humidity may be controlled by circulating the air through beds of water absorbing materials[3]. The better of these substances are listed in Table IV with figures indicating the kilograms of material required per 1000 grams of water.

Magnesium perchlorate has the highest capacity of any of the absorbers. Further it can be regenerated at 275°C and 1 mm Hg. pressure--conditions likely attainable in outer space. However, because the material is a strong oxidizing agent,

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organic vapors could produce a fire hazard.

Calcium sulfate is commercially available with an indicator as Drierite. It can produce a very low humidity--comparable to magnesium perchlorate--but has less capacity.

TABLE IV

Dehumidifying Agents

	Kilos / 100 grams H_2O	Remarks
$Mg(ClO_4)_2$ (Anhydrone)	2. to 3.1	Oxidizing Agent
$CaSO_4$ (Drierite)	10.	Indicating
LiCl	4.7	(Estimate)
Silica Gel	6.6 to 20.	Absorbing
KO_2	7.16	Oxygen Source

The first three agents in the Table capture water vapor by chemically combining as the hydrate. Silica Gel[15], on the other hand, physically adsorbs water vapor and has a rather low capacity. It may be regenerated, however. The commercial product, represented by formula as SiO_2xH_2O and containing 5 to 7 percent water, is a hard glassy granular material with highly porous structure. The name gel simply refers to its physical state at one step in its manufacture.

Potassium superoxide again shows up surprisingly well on a weight basis.

Another means of controlling humidity is to cool the air below the dewpoint causing precipitation of the water. The droplets of water entrained in the air stream may be captured in the weightless state by passing the air through a vinyl absorbent. The absorbent can be kept sufficiently dry by periodically compressing it, mechanically forcing the water into a container. The means for cooling could be much simpler than for freezing out CO_2 because such low temperatures are not required. One method achieves cooling by permitting water to vaporize into the vacuum of space. The cooling coils previously mentioned for carbon dioxide would be equally applicable to water vapor.

IV. Other Contaminants

A multitude of atmospheric contaminants besides CO_2 and water vapor will undoubtedly be present in various concentrations[16]. Three noxious gases present in intestinal gas are listed in Table V. The approximate times it would take each of these gases to become a hazard were calculated by Taylor[17] and are based on the assumption of one occupant per 100 cubic feet of cabin volume and no cabin leakage. Even the excellent leak rate of 1 percent of the cabin volume per day should theoretically prevent any hazard from these agents.

TABLE V*

Noxious Gases From Intestine

Substance	MAC	Effect	Time
H_2S	20 ppm	Nausea, tears	420 days
H_2	4.1%	Explosive	124 days
CH_4	5.3%	Explosive	166 days

*From Taylor, Ellis R., Physical and Physiological Data for Bioastronautics

There are many volatile organic compounds produced by man and his bacterial associates. The identity of these and their effects on man is an interesting research area. Control of these contaminants can probably be achieved by a combination of outboard leakage, oxidation as may occur in a superoxide canister or at a hot surface, and adsorption as on activated charcoal. A freeze-out method could also be used. Charcoal plus about 11 cubic feet (STP) per day of inadvertant leakage have been chiefly used in the one-man SAM Sealed Cabin. Additionally there are various surfaces at high temperature which may have been of benefit. Bacterial action in the excrement was controlled with Timsen-Air, a granular material consisting 90 percent of a quarternary ammonium salt. Di-isobutyl Phenoxy Ammonium Chloride Monohydrate. For runs up to eight days duration these means appear adequate. The amount of activated charcoal required depends not only on how much vapor is produced but also on how low the concentration is to be kept. The report of Dryden, et al, suggests about 180 grams of charcoal per man per day.

V. Conclusion

From the foregoing remarks it can be appreciated that daily weight requirements for atmosphere control would vary over a wide range depending on the various components selected. In Table VI, two simple, entirely non-regenerative systems are summarized. They are designed to handle one subject's average daily turnover which is assumed to be: 900 grams of oxygen, 1000 grams each of CO_2 and water vapor and the usual contaminants. The weight of the blowers and their power requirement would be somewhat greater for the number 2 system but these weights were omitted in both cases. In a short term personal breathing canister using KO_2, an air blower would not be needed at all.

It is seen that both systems add up to about 8 kilograms or 18 pounds per man per day. Either system might be used for flights of days and weeks duration but because of other considerations the superoxide system would be more suitable for short term and personal use.

TABLE VI

Atmosphere Control Systems

Component	Kilos/man/day No. 1	No. 2
LOX + Containers	1.4	
KO_2 + Containers		5.0
LiOH	1.35	.4
$Mg(ClO_4)_2$ [for man]	2.5	1.3
$Mg(ClO_4)_2$ [for LiOH]	.75	.2
Charcoal	.2	.2
Other Containers	2.4	1.0
Total	8.6	8.1

As space technology advances and single operations lasting weeks or months occur, atmosphere regenerating (or recycling) apparatus must be available to replace such simple, non-regenerative systems as outlined above. Because of their capability of producing food, biological regenerative systems are the ultimate--certainly for large and permanent extraterrestrial bases. However, for operations of intermediate size, it is felt that physicochemical regenerative systems should be developed. Their chief advantages would be that much fewer man-hours would be required to operate them and that their power requirement would be significantly less.

DMK/mbn

13 Jan 1960

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By: Daniel M. Keller, Capt. USAF (MC) Dept of Space Medicine, School of Aviation Medicine USAF, Aerospace Medical Center (ATC), Brooks Air Force Base, Texas

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14

LECTURES IN AEROSPACE MEDICINE

SPACE LOGISTICS

I. Food, Water, Waste

Presented By

Dr. Billy E. Welch

Chief, Space Ecology Branch

School of Aviation Medicine

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FOOD, WATER AND WASTE FOR MAN IN SPACE

by

*B. E. WELCH, Ph.D.

During the course of the lectures presented in this survey on Aerospace Medicine, you have heard various distinguished experts talk on rather exotic topics of Celestial Bodies, Radiations in Space, Propulsion Systems, Acceleration, Zero Gravity and Cabin Atmospheric Requirements and Control. It will be our purpose for this hour to perhaps, at least figuratively, bring our feet back to earth and talk on some of the more prosaic problems of space flight, i.e., the problems of supplying man with food and water and of removing the liquid and solid waste material that is generated. I call these some of the more prosaic problems, which may or may not be true. This is debatable. One thing that is not in doubt, however, is the importance of adequately solving these problems before we can launch man into space missions of extended duration.

This morning, therefore, I would like to discuss with you man's requirements for food and water, the logistics involved in supplying these requirements, some possibilities of handling the waste products generated and the type of system that has been designed for use in the SAM two-man space cabin simulator.

*Chief, Space Ecology Branch, Dept of Space Medicine, School of Aviation Medicine, USAF Aerospace Medical Center (ATC, Brooks AFB, Texas

When we consider man's requirements for food and water, we must, of necessity, establish our ground rules and state our assumptions. Therefore, let us say that we are considering that the space mission we are planning for will be one of extended duration, i.e., months with an environmental control system of such a degree of sophistication and reliability that the occupant or occupants of such a vehicle will be maintained in the comfort zone as far as oxygen, temperature, pressure, relative humidity and carbon dioxide are concerned.

This then simplifies our problems somewhat and makes further guesswork into the actual caloric requirements fairly easy and straight forward. Estimates have normally placed the caloric requirement of man in a space situation at about 3,000 kilogram calories/day.[1, 2] This should be adequate to sustain the astronaut during a long space voyage, provided the essential amino acids, vitamins and minerals are present. It should be pointed out, however, that this 3,000 kilocalories does represent only an estimate. This requirement can be influenced by several factors, (Slide 1) among them being the basal metabolic rate (BMR), physical work load, psychologic stress, specific dynamic action (SDA) of foods, to mention a few. Of the factors mentioned, the BMR accounts for roughly 50 per cent of the 3,000 kilocalorie requirement, and of course, can be estimated fairly closely or determined very accurately for a given individual. The effect of the SDA as an

FACTORS RELATED TO ENERGY REQUIREMENTS

Basal Metabolic Rate

Physical Work

Psychological Stress

Temperature

Specific Dynamic Action (SDA)

Slide 1

energy source is dependent on the type of foods consumed, but in any case represents only a small percentage of the total daily requirement. This leaves then, two major indefinite factors influencing the astronaut's energy requirements---physical work and psychological stress. The impact that these two items might have on the energy requirement of the astronaut is difficult to predict. Unfortunately, we have very few bits of information concerning the energy cost of performing given tasks while in a weightless condition.

We can simulate the rather confined situation, however and measure man's energy requirements in that type of environment. Granted, it will not be precise, but it will provide good groundwork data in this field. Likewise, we are limited to simulation in the case of the effect of psychological stress on man's energy requirements. This should not be as big an unknown though, since we can expect that this form of stress will not have as great an impact on energy requirements as will physical work.

As we mentioned earlier, the dietary regimen of the astronaut should provide an ample amount of essential amino acids, vitamins and minerals. The amino acids are particularly important, as well as the minerals, though for somewhat different reasons. The vitamins are less important since we could supplement them for less than one gram per day.

Now, let us turn our attention to the requirement for water. Next to the body's need for oxygen, we could probably place water as the most important requirement of the human. Under ordinary conditions, (Slide 2) the body loses some two to three liters of water per day, (3) which must be replaced. This water is lost mainly through the kidney---some 1 to 15 liters here. In addition, about 100 cc per day is lost in the feces. Loss through the lungs and by insensible perspiration amounts to another 900 cc per day, making the total loss again, between 2-3 liters. Of course, if sensible perspiration occurs, then the total water loss will increase, thereby increasing the body's requirements. The water to replace that lost by the body comes primarily in the form of pre-formed water, either taken as liquid or that present in the foods. In addition, on a 3,000 kilocalorie diet, there will be some 300-350 cc/day of metabolic water formed. This amount is rather insignificant, but as we will see later, might be extremely important.

It is well and good to talk about 3,000 kilocalories/man/day and two to three liters of water/man/day, but what does this actually mean when you consider weights and volumes? It has been suggested that the average person currently requires on the order of seven pounds of food (including edible, inedible, and that lost in preparation) and the materials used to package the foods. (4) In addition, a variety of support equipment is required, such as a

WATER BALANCE

Input	Output
Liquid Water	Urine
Preformed Water in Foods	Feces
Metabolic Water	Lungs
	Insensible Perspiration
	Sensible Perspiration

Slide 2

refrigerator, stove, dishes, eating utensils, pots and pans, etc. Obviously, if we considered a space mission of say, some six months duration with a crew of three, we could hardly live as wastefully as we do at home. Of course, the first thing that can be done and is done is to eliminate the need for refrigeration facilities and, with the exception of a hot cup, eliminate the need for a stove. This is done by using canned foods, but creates one big problem in the disposal of the cans and other waste that remains. This type food was utilized in the 7-day flights that have been conducted here at the School of Aviation Medicine.[(5)] The food and containers for these 7-day periods had a total weight of 50 pounds and occupied 1.1 cubic feet of storage space. A sample menu is given in Slide 3. An average of 2,400 kilocalories per day was prepacked for each subject, which appeared to be adequate for this situation---at least adequate as far as the man was concerned. From the logistic point of view, this is still woefully inadequate. What then represents the next biggest advance that can be taken to minimize the weight and volume of stored food? If we can assume that the water supply will be recycled, dehydrated foods appear to offer much promise.[(6)] For example, dehydrated foods would weigh about 2 to 3 pounds per man per day, including container weights. In addition, the foods often can be rehydrated in the same container that they are packed in. Also, the foods can be pre-cooked so that a minimum amount of time has to be allocated for food preparation. In the next slide (Slide 4), we have graphically shown the comparison

SAMPLE MENU - 7 DAY FLIGHT*

Mixed Nuts

Raisins

Shoestring Potatoes

Boned Turkey

Green Beans

Fruit Cocktail

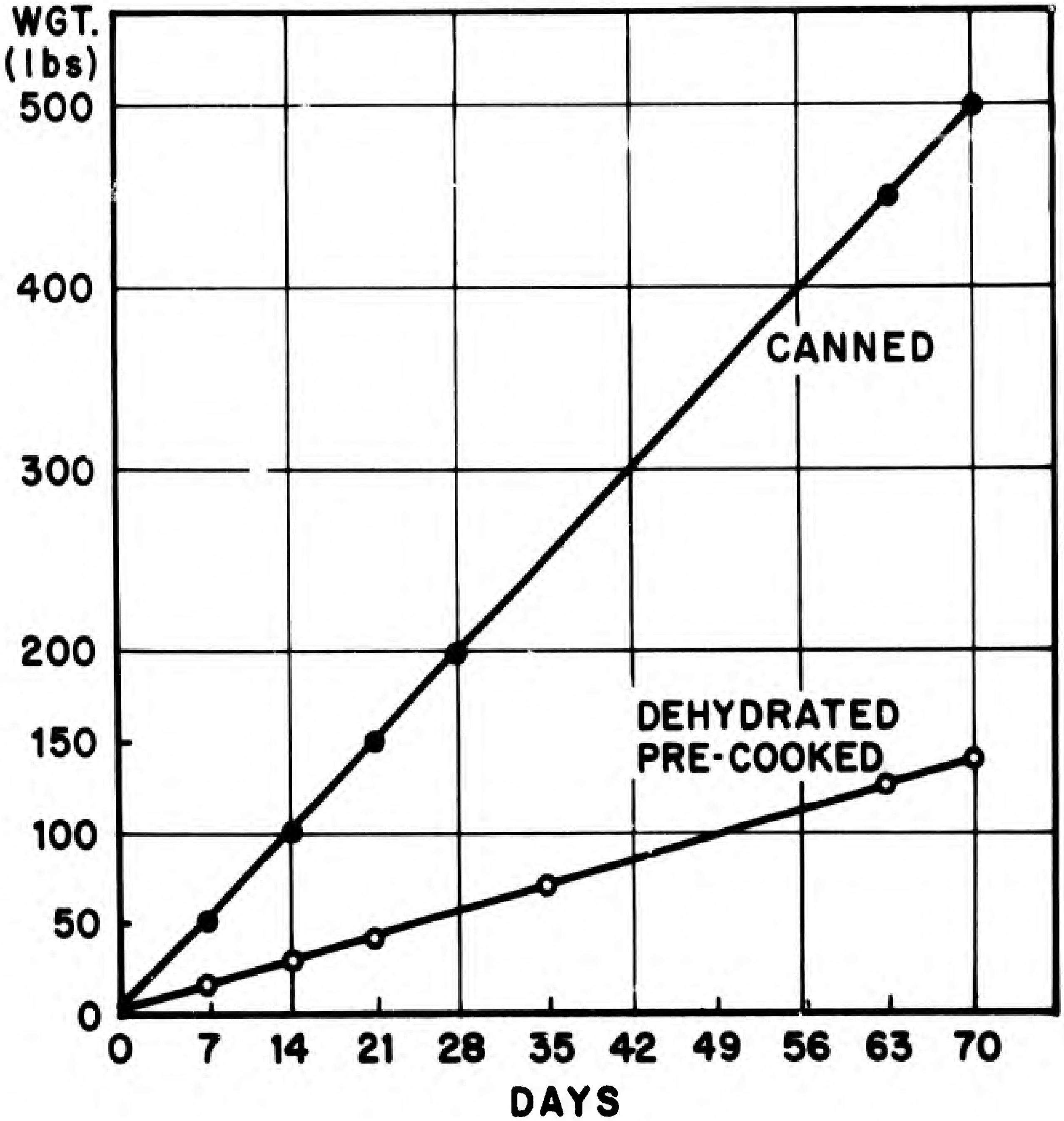
Fruit Juice

Coffee, Salt, Pepper, Sugar, Gum, Candy

*Approximately 2400 kilocalories

Slide 3

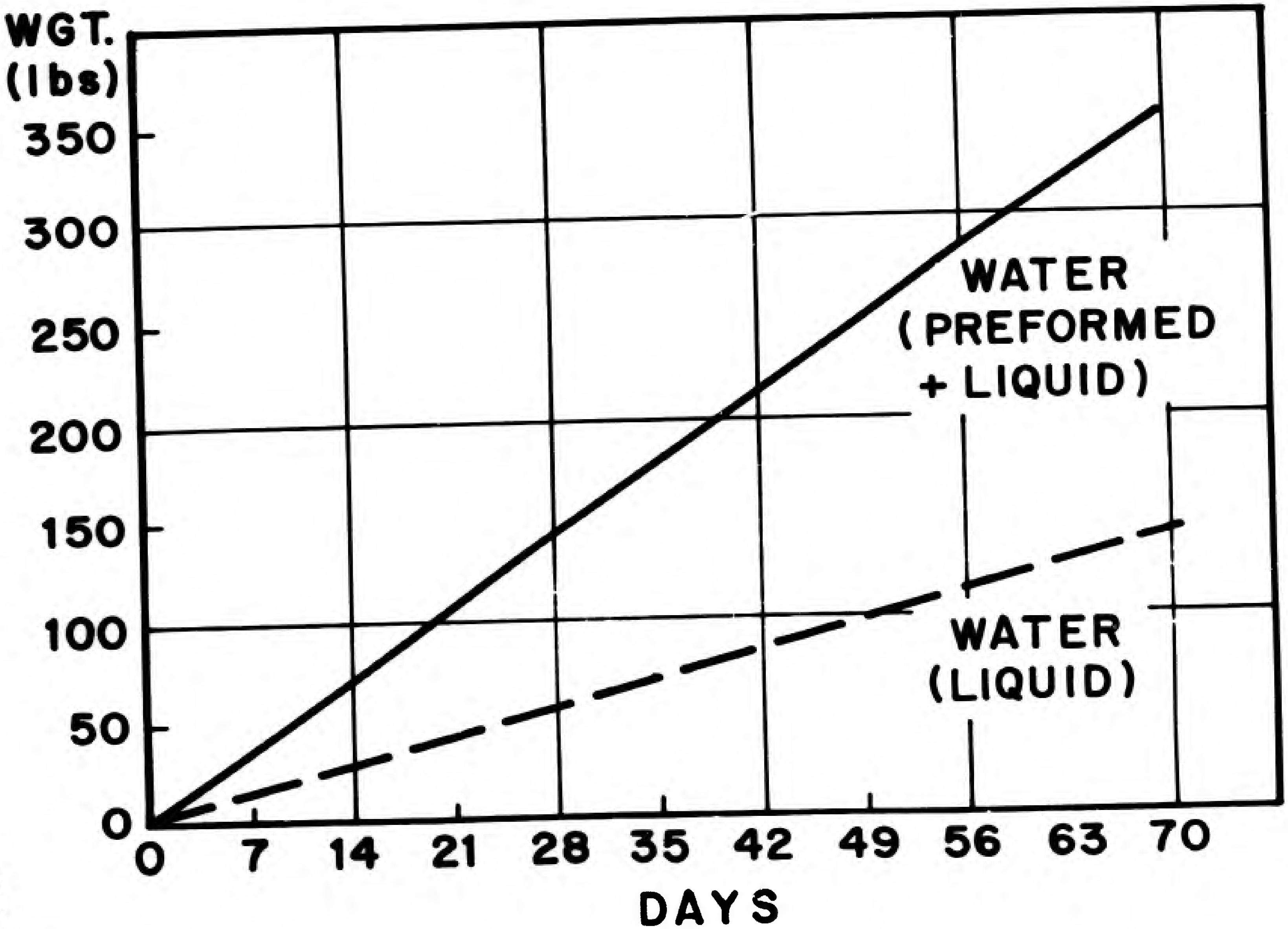
CANNED FOOD vs DEHYDRATED FOOD



of food weight, using canned foods similar to those previously utilized here in 7-day flights in comparison to pre-cooked dehydrated foods. Various people have also proposed concentrated, semi-solid foods that could be packaged in tubes[7] and consumed directly without any preparation or at least, with heating only. These foods will undoubtedly be easier to consume in a zero gravity environment than, say, dehydrated foods. The problems of rehydrating foods in a zero gravity environment might be a little ticklish, as well as subsequent ingestion after rehydration. I believe that this merely points up the necessity of a modified "weapons system" approach to the problem of food selection---i.e., the necessity of considering foods not only from the standpoint of nutritional adequacy, but also from the psychological impact it might have on the occupant and the ease with which it can be prepared and eaten.

Let us consider next the problem of water supply. The requirement, as we mentioned previously will be in the area of 2 to 3 liters per man per day or 4.5 to 6.6 pounds (Slide 5). This does not mean that we need that many pounds of liquid water per day, since the water preformed in foods normally accounts for a large portion of our daily requirement. The daily requirement for liquid water will vary with the type of food that is used, with dehydrated food requiring more liquid water per day than normal type food. There does not, however, appear to be any

MAN'S METABOLIC WATER REQUIREMENT

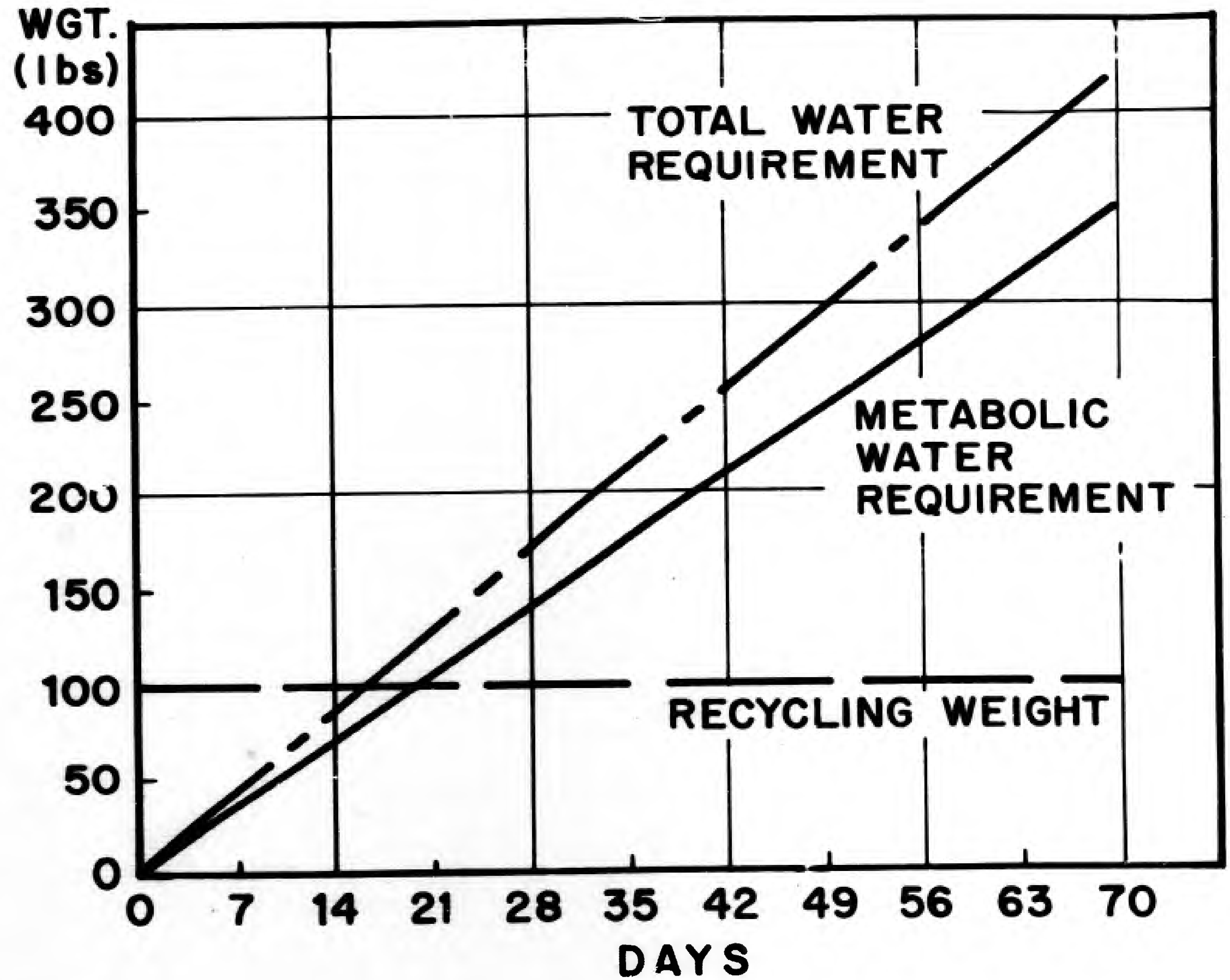


SLIDE 5

appreciable difference in the total requirement of a man consuming normal or rehydrated foods. From the standpoint of logistics, it will be necessary to recycle water in the space vehicle on extended missions. Otherwise, the advantage incurred by utilizing dehydrated foods would disappear and we would have to add additional weight to the food weight, the amount depending upon the duration of the mission. Slide 6 shows the weight savings affected by recycling water, bringing to mind the concurrent effect of utilizing dehydrated foods. Also, since any recycling system will be less than 100 per cent efficient, the metabolic water formed will serve to maintain the supply of recyclable water at a relatively constant level.

Now, assuming we have been successful in getting the food weight down to some two pounds/man/day and can recycle the water without too much difficulty, does this end our problems in this general area? Unfortunately, no, since the human body does not ingest these constituents without producing waste materials. (Slide 7) The body produces, on the average, some 125 to 150 grams of fecal material and approximately 1 to 1.5 liters of urine. As we noted previously, there is also about 0.9 liters of water per day lost through the lungs and through the skin. What can be done to recover this water? We have mentioned recycling systems earlier in our discussion as if to indicate that there is no difficulty in this area at all. This is not exactly true, but much progress has been made in this area. Probably less research has been done toward solving the

EFFECT OF RECYCLING WATER



SLIDE 6

SUMMARY OF WASTES

Liquids	Solids
Urine	Feces
Water Vapor	Containers
Wash Water	Food Wastes
Food Preparation	

Slide 7

problem of feces disposal. Let us consider first, then, the problem of removal and/or storage of fecal material.

Fecal material has a composition of approximately 75 per cent water and 25 per cent dry solids. The more important products present in fecal material,[(8)] which must be considered if you try to incorporate feces back into some sort of regenerative systems, are given in Slide 8. Currently, the basic problem related to fecal material appears to be one of handling and storage. Since the dehydrated fecal material amounts to some 25 to 30 grams per man per day, the amount of usable elements is small in relation to the problems posed by their re-use. For example, if the cabin atmosphere is at reduced pressure, outgassing of the fecal material may be anticipated, requiring the rapid transfer to a closed system so that the gases do not enter the atmosphere of the occupied closed space. In addition, the water content of fecal material is predominately bound water, indicating that this source of water should probably be considered only in the case of emergency. Ingram, of New York University,[(8)] has suggested that fecal material be stored and proposes to use heat followed by freezing or even freezing alone to inactivate the material and permit its storage at -20°C or lower. (Slide 9) He further estimated that the cubage required for storage of the fecal material would not exceed 0.02 cubic feet per day. The weight, volume and power penalty of the equipment required to preserve fecal material in this fashion is

COMPOSITION OF FECES

Indole	Hydrogen
Skatole	Carbon Dioxide
Paracresol	Peptone
Hydrogen Sulfide	Peptides
Methane	Ammonia
Methymercaptan	Mucus
Fats	Starch
Tissue Remnants	Bacteria

Slide 8

SOLID WASTE DISPOSAL TECHNIQUES

Storage

Expulsion

Bacteriological

Incineration

Slide 9

not known. It does offer one advantage however, in that the equipment could also be utilized for food storage, providing the astronauts with a bit of variety in the diet, if necessary. Other techniques that could be employed to remove solid waste would include the use of the vacuum of outer space for dehydration of feces prior to storage. Of course, people have also proposed expelling feces from the vehicle but this has inherent disadvantages. Some of these are the creation of artificial meteorites,[(1)] possible influence of the momentum (mass x velocity) of the ejected material on the vehicle's course, and possible interference with visual observations that might be made by the expelling vehicle or subsequent ones. Another idea that has been proposed is to place the waste material in a small rocket and fire this on a course so that it would subsequently enter the earth's atmosphere and burn up. Undoubtedly, refrigeration offers us a bit more. But, what if ejection of waste material is not adequate, or what if we do not wish to or cannot freeze it? We could establish a regular sewage disposal system, using such treatment practices as the activated sludge process or the trickling filter process. Both of these, however, require the establishment and maintenance of a culture of a complex of microorganisms requiring both bacteria and protozoa. Another approach that appears to be feasible is the use of incineration to remove the solid waste material. This is the approach that has been used in the SAM two-man space cabin simulator and we will defer discussion on this point for a few moments and describe the overall system at that time.

The problems involved in recycling the water supply in a space vehicle are many. First of all, the water must be collected. This will not be too difficult in the case of urine and water used for washing and cleaning. However, it will be somewhat more difficult in the case of that water lost through the lungs and the skin. The main problem in this respect appears to be the complicating factor of gravity or rather the lack thereof. At any rate, what sort of a liquid do we have to purify. Slide 10 shows the typical composition of human urine,[9] which contains only 4 per cent total solids, with urea constituting 50 per cent of that amount. If we dilute this with wash water and insensible perspiration, we will add to this a few additional solids in the form of electrolytes and possibly detergents. Hawkins[10] has summarized the various techniques that might be utilized in the purification of liquid wastes. Some of these techniques are shown on the next slide. (Slide 11) Distillation has been looked upon with favor by many people, though this one process, by itself, does not appear to be adequate to supply potable water. The urine must be acidified to minimize foaming and the carry-over of volatile amines. In addition, simple distillation is rather expensive from a power requirement point-of-view. This power requirement could be lessened somewhat by the use of evaporative distillation, though it would

COMPOSITION OF URINE

Constituent	Percent In Urine
Water	96
Urea	2
Creatinine	0.15
Sulphate	0.18
Phosphate	0.27
Uric Acid	0.05
Potassium	0.15
Chloride	0.6
Sodium	0.35
Ammonia	0.04

Slide 10

LIQUID WASTE PURIFICATION TECHNIQUES

Distillation

Evaporative Distillation

Electro-osmosis

Chemical

Freezing

Lyophilization

Slide 11

still be, according to Hawkins, on the order of 2.8 kilowatt-hours/day to distill 4 liters of waste liquid.

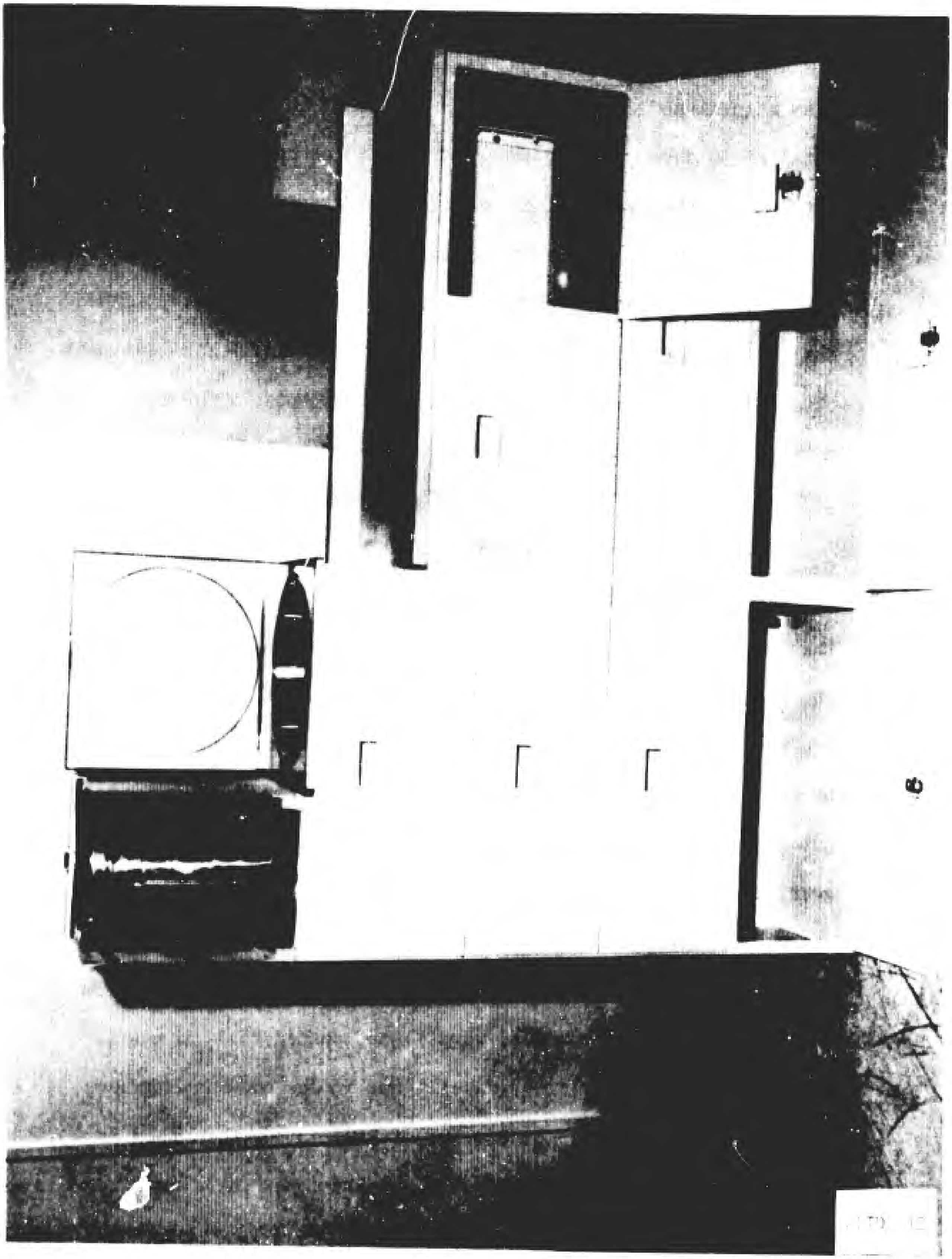
Electro-osmosis has been considered and is felt to have much promise. Other techniques involving the electrolysis of water might also be employed, however, most of these become inefficient with the passage of time. The neutralized ions accumulate at the electrically charged plate and impede the flow of ions through the solution. Chemical methods, such as precipitation, adsorption and ion exchange also have been examined. It is felt that of these, the ion exchange technique is the only one which offers promise. The weight of such a system might get to be prohibitive, depending upon what can be done to extend the life of the resin.

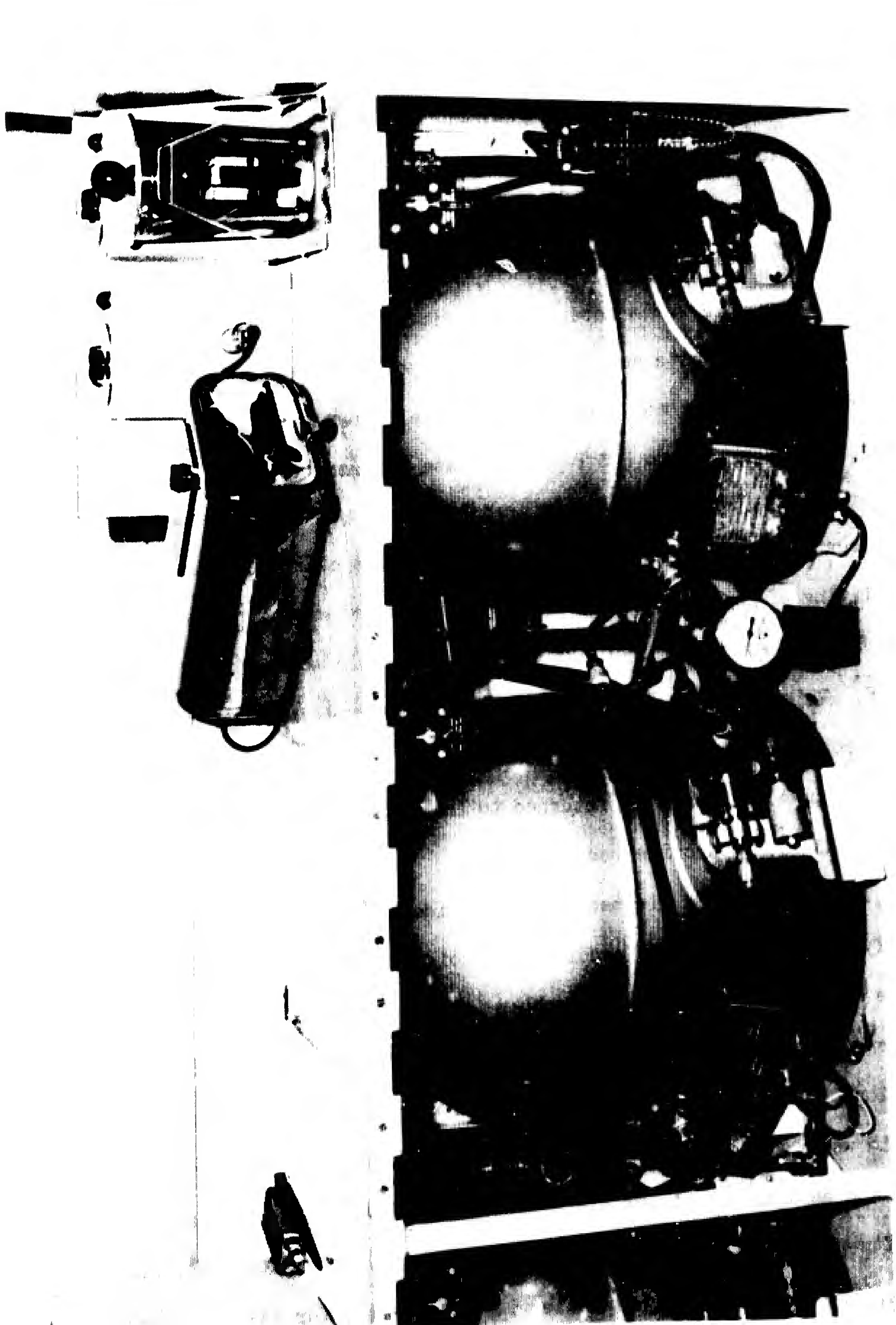
The possibility of simple freezing has also been considered by Hawkins and discarded, since the temperature of the solution would have to continuously lowered as pure water was removed and the ion concentration concurrently increased.

An additional technique has been investigated by Sendroy and Collison.(11) These investigators compared acid distillation followed by treatment with activated carbon to freeze-drying followed by treatment with activated carbon. They found that the freeze-drying or lyophilization technique was superior, giving almost complete recovery of the original water content of the urine.

In addition to chemical analyses of this urine, the authors also maintained 12 young male rats on the purified urine for a total of 30 days, with no untoward effects as measured by growth rate, gross observation, and pathological examination at the end of the experiment. The authors pointed out that this work was primarily a laboratory experiment which, in some respects, ignored the engineering principles and particular practicalities that must be observed before any given technique is acceptable for use. However, this is the type of experimentation that must precede the practical design of any waste purification system.

I would like to take a few minutes now and describe the food storage and waste disposal facilities that are incorporated in the SAM two-man space cabin simulator. First, we will describe the facilities for food storage and preparation. Slide 12 shows you the total space available for storage of everything required by two men for a 30-day "flight." This includes not only food, but also what clothing will be necessary, towels, personal hygiene gear, first-aid kit, emergency oxygen supply, etc. You can see, therefore, that storage space is at somewhat of a premium, even though in comparison to actual space vehicles, it might be rather commodious. If, for example, we utilized canned foods in much the same fashion as in the 7-day flights in the one-man chamber, the space available for the storage of items other than food is only some 2.5 to 3.0 cubic feet or, the area shown here in Slide 13.





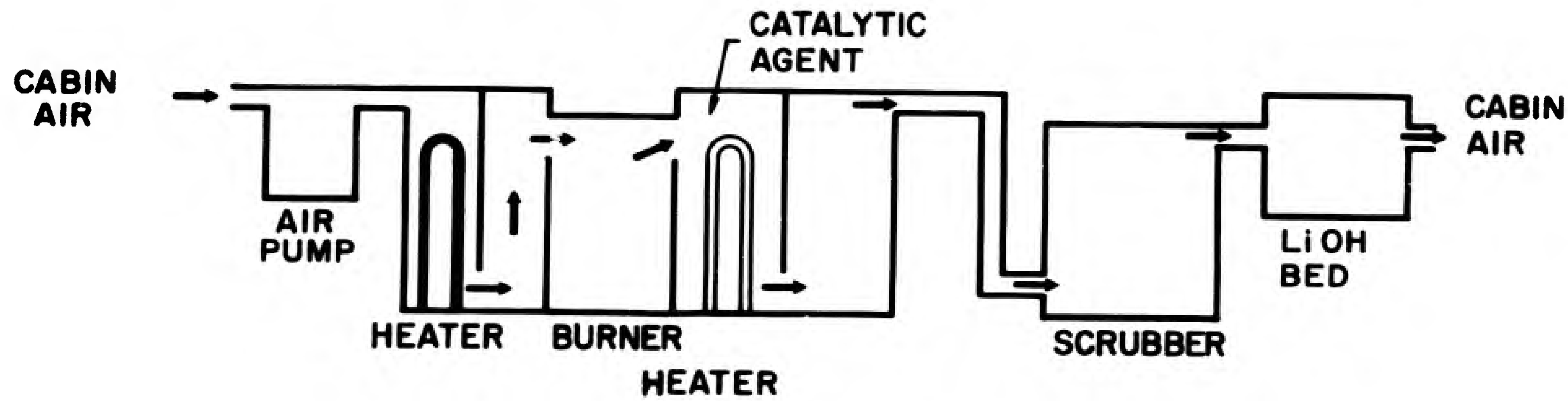
SLIDE 13

Food preparation is limited to a hot cup and a small (10" x 6" x 3½") electrical baker. Since there are no refrigeration facilities and since the equipment and time available for food preparation will be minimal, pre-cooked and preserved foods are essential.

Solid organic waste material is disposed of in an incinerator (Slide 14). The waste material (feces, paper, food waste) is placed in a polyethylene bag and put in the burner. The temperature is first raised to 400°F to dehydrate the material and prevent splattering. The temperature is then raised to 900°F to reduce all the organic material to a residue of ashes. The effluent gases, consisting of carbon dioxide, carbon monoxide and organic vapors are passed through a bed of silica gel and hopcalite maintained at 900°F. This completes the oxidation of the gases to carbon dioxide. After cooling and filtering the exhaust gases by passing through a water scrubber, the gas is returned to the cabin through the baralyme or lithium hydroxide beds.

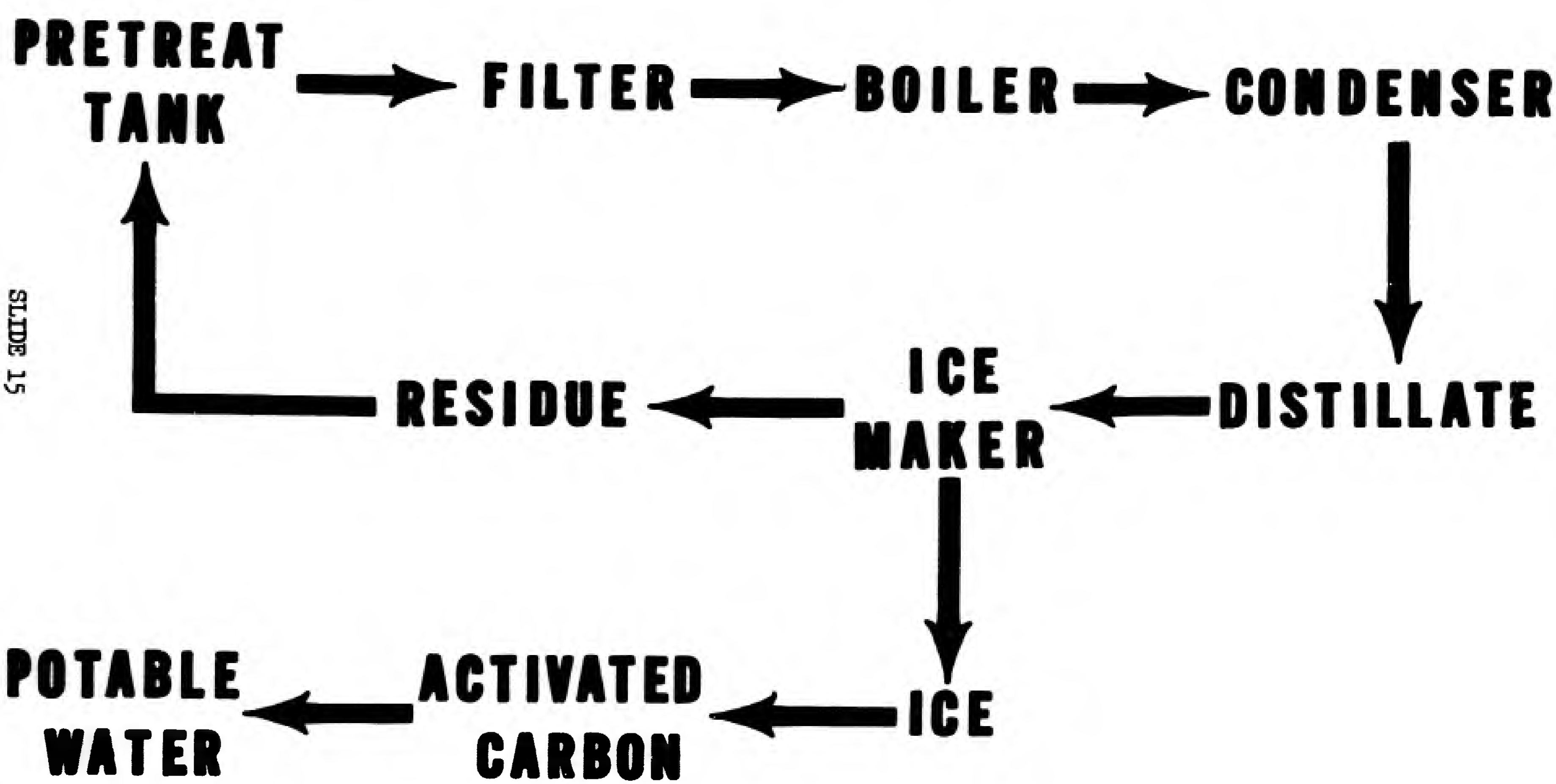
The liquid waste disposal system (Slide 15) is designed to purify water from the air conditioning coil, lavatory wash water, urine and the waste disposal scrubber tank mentioned earlier. The system makes use of several of the principles described in the section of our discussion covering liquid waste disposal. The liquid waste is collected in a pre-treatment tank where sulphuric acid and an anti-foam agent are added to the liquid. It is then gravity-fed into a filter tank and then into the boiler for distillation. The vapor leaving the boiler is super-heated for flash

SOLID WASTE DISPOSAL SYSTEM



SLIDE 14

LIQUID WASTE DISPOSAL SYSTEM



SLIDE 15

sterilization before it enters the condenser. The condensate is transferred to an ice maker which contains a paddle, which is slowly rotated by a small motor during the freezing process. When the hollow ice cylinder builds up to the desired thickness, the increased torque on the paddle operates a clutch device and actuates a microswitch. This turns off the motor and lights a console light telling the occupants of the cabin that the ice is frozen. The ice is then flushed and allowed to melt over an activated carbon filter. This system then, utilizes not only distillation, but also freezing and treatment with activated carbon. The end result is potable water. This system then, has applied engineering principles to laboratory procedures, resulting in a workable unit. Perhaps our next step should be to try to simplify the system and try to apply practically additional laboratory procedures, particularly seeking out those that might be useful in the zero-gravity situation that might prevail in a space vehicle.

Before concluding our discussion this morning, there is one rather vast area that should be mentioned at this time. This is the area that encompasses the concept of a closed ecological system, in which the supply of food and water and the removal of waste material are even more closely enmeshed than in the systems we have mentioned earlier. In a truly closed system, of course, all molecules entering the body eventually are excreted, purified by some means and then re-used. For example, the solid materials removed from urine might be utilized in a photosynthetic gas exchanger, or the raw urine and fecal material might form the basis for a medium designed to grow algae or broad-leafed plants. This type of system appears to be a necessity for extremely long duration missions or perhaps, lunar colonies and will be discussed further by Colonel Campbell in his talk on Friday.

In summary, let us say that there is a problem in supplying man with food and fluid and in removing the waste material he generates. We could say that any of the techniques mentioned are the answer, but that would not be true. The system, or systems, that will be utilized will vary from mission to mission, depending upon the purpose of the mission, duration, etc. It does appear, however, that in systems utilizing recycled water, dehydrated, pre-cooked food offer much promise from the logistic, physiologic, psychologic and crew-time standpoint.

The two-man space cabin simulator will afford an excellent research tool to help us obtain information along this line, as well as to obtain more data about the composition of various waste materials under different dietary regimens. It does not represent the ultimate in this respect, but it does signify a big second step in the right direction.

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15

LECTURES IN AEROSPACE MEDICINE

SPACE LOGISTICS

II. Biosynthetic Gas Exchanges

Presented By

Dr. Jack Myers

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University of Texas

SPACE LOGISTICS. II BIOSYNTHETIC GAS EXCHANGES

by

Dr. Jack Myers

The preceding speakers have considered the human requirements and the logistics of provision for these requirements in a sealed cabin. I shall continue in this same vein but with attention focused specifically upon the possibilities and limitations of a biological management of the logistics.

It is clear that for short periods of space flight the human requirements can best be met by what I shall call an expendable system -- by consumption of required materials and absorption or accumulation of waste products. It is also clear that for very long periods of space flights, a regenerative system will be needed--one in which the material turnover of the human is balanced by reconversion of his waste products into usuable input requirements. The breakpoint in time at which a regenerative system becomes preferable is not now definable. Furthermore, it is my thesis that a regenerative system is not an all-or-none proposition.

To a biologist, the regenerative system is a closed ecological system. The model is the total biological world in which foods, exchanged gases, and excreta are balanced by the action of many organisms to give a materially closed system driven by light energy input alone. An attack on our problem can be phrased as an attempt to approach such a balanced system in a small space by proper selection of organism and conditions --- to miniaturize the balance of the biological world.

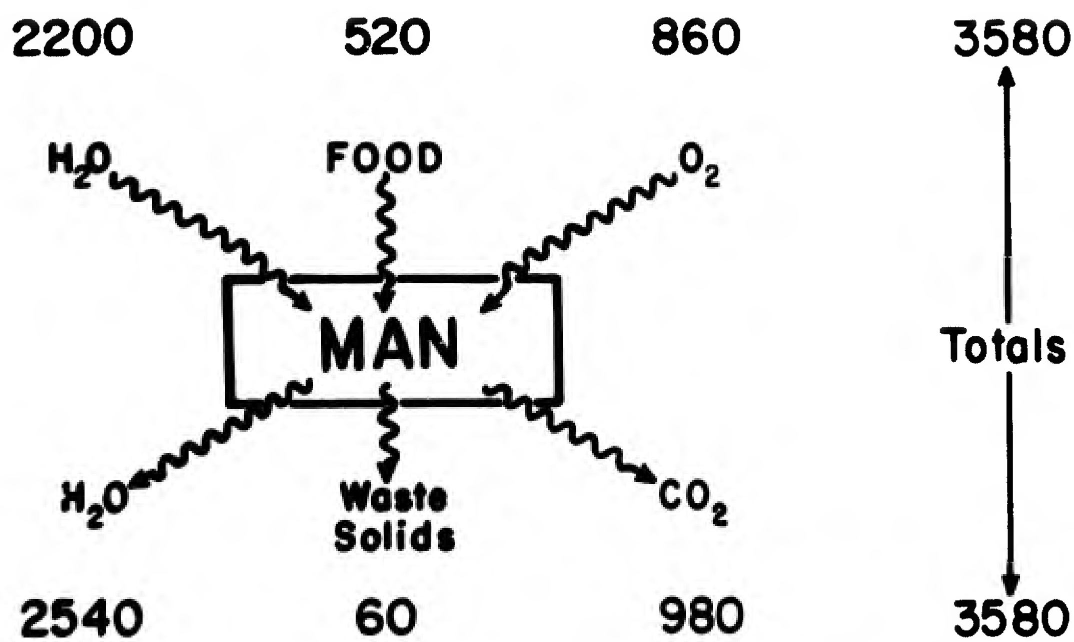
We should pause to consider that even our model in the total biological world is not a perfect one, that steady-state conditions are not perfectly achieved. There is good evidence that the carbon dioxide content of the atmosphere has not remained constant but has shown cyclic variations over long time periods and is now slowly increasing. It is apparent that the structure of plant and animal species has not remained constant but has been changed markedly by man's activities in historic times superimposed on a slowed evolutionary development. And as man has entrenched himself as a dominant biological species, he has developed problems of human relations which are not at all stable. Whatever our problems in creating a closed ecological system in the confinement of a space vessel propelled far out into space--and these really are staggering--I think that they may be solved sooner than we shall solve the unbalancing problems of politics and human relations of our own ecosphere.

The important idea is that in a space vessel a closed and perfectly balanced ecological system is a limit or ideal case which we may attempt to approach but which we should not expect to achieve. A rational attack is to examine the metabolic requirements of the human, discussed by Dr. Clamann and consider the problems in order of importance (Fig. 1). For example, the very large turnover of water is clearly the first order problem. The second order problem lies in balancing the gas exchange, which is closely associated with the energy demand of the human. This has major importance, not only because of mass of exchanged gas but also because of the additional weight requirements in storing oxygen and absorbing carbon dioxide in an expendable system. My attention, therefore, will be centered upon the gas exchange problem.

We have one piece of machinery of known reliability in converting carbon dioxide into oxygen. This is chloroplast of the green plant which makes the conversion incidental to its synthesis of carbohydrate in photosynthesis. The chloroplast is a piece of biochemical machinery elegant in its organization which has been developed by organic evolution, indeed by trial and error method, but by strict criteria of competitive selection and over time measured in millions of years.

We have larned a great deal about the stepwise events which go on in this machinery. It is proper to expect that in the distant future we may learn to reproduce and improve upon the photochemistry of the chloroplast. In the immediate future, our rational approach is to learn to select and manage the machinery in order to best accomplish the purpose at hand.

In any given plant, photosynthesis is meshed into a total metabolism the business of which is to produce the



Human turnover in gm./day

FIGURE 1

total materials of the plant. In studying the process of photosynthesis, we naturally use various tricks which are reasonably effective over short experiments in minimizing the effects of other metabolic processes. However, we have had no success----in spite of considerable effort---in isolating the photochemical machinery in such a way as to keep it working successfully all by itself for long time periods measured in days. So we cannot use the data describing photosynthesis *per se* to predict performance of any total plant over long time periods. We must rely on the total or over-all metabolism and gas exchange of the plant which may be at considerable variance with the simple equation of photosynthesis itself. Fortunately, there is a wide range in the choice of plants which we may use.

I shall now make the proposition that the requirements of a closed ecological system (including man) clearly dictate a unicellular algae as the principal kind of plant to be chosen. There are several compelling reasons. The algae are microorganism unspecialized in structure and reproductive mechanism, loaded with photosynthetic machinery, and with the highest intrinsic rates of growth and photosynthesis found in the plant kingdom. They are easily managed. They have a favorable and adjustable CO_2/O_2 exchange ratio as noted below. And they are high in protein and lipid and low in the crude fiber or cellulose, not digestible by the human, which makes up the bulk of higher plants.

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All of the above considerations have led to the study of the possibility of what we may call an algal photosynthetic gas exchanger. For the past several years, my laboratory and a laboratory here at the School of Aviation Medicine have been studying the machine-like characteristics of a photosynthetic gas exchanger using the alga Chlorella. We know that it can be made to work reliably for time periods measured in weeks. It can be powered by light within most of the visible spectrum (400-680 mu) at a maximum efficiency of about 19%.

The business of the algal cell is the production of more algal cells, accomplished in Chlorella with a conservation of organic materials such that 90 to 95% of the carbon taken up as carbon dioxide is recoverable in the cells produced. A technically useful consequence is that over-all metabolism may be estimated from an elementary analysis of the cells produced as illustrated in Table I. Over-all metabolism is reduced to an equation giving stoichiometric relations between oxygen and cells produced and carbon dioxide and nitrogen source used. Note for example that the production of one gram dry weight of cells is attended by production of about one liter of oxygen. Chlorella and many other algae will use also other nitrogen sources with characteristic and different values of the CO_2/O_2 exchange quotient. For example, with Chlorella, nitrate gives a lower quotient of about 0.73; Ammonia gives a higher quotient of about C.90. This is an obvious technical advantage to the problem of balancing the RQ of the human. Estimate of performance of a photosynthetic gas exchanger can be made by the above procedure with two qualifications affecting precision. First, elementary analyses on algal cells are obtained with some difficulty and are not always of high precision. Secondly, the equation is written as noted for 100% recovery as compared to the 90-95% recovery commonly observed for Chlorella.

We have conducted a reasonably successful pilot or demonstration experiment in operation of a small and very incomplete microcosm. Two small mice were contained in a glass vessel with a supply of food and water. The alga Chlorella ellipsoidea was grown in liquid suspension in a separate chamber illuminated by tungsten and fluorescent lamps. Air was recirculated between the mouse and algal chambers by a leak-proof pump. Total gas volume of the system was about 10 liters recirculated at 520 liters per day. The complete system was operated satisfactorily for about one month and could have been continued longer. Rather complete data were obtained for the last 17 days of the experiment.

There are several levels of criteria by which performance may be judged. The first is: were the mice maintained happily? There were. However, this is only a presumptive criterion. Probably some 20 high school students have managed such an experiment at Science Fairs and by this criterion considered their results entirely satisfactory. The difficulty is that even a small leak in a recirculated gas system will make performance look very much better than it actually is. A second criterion is whether gas concentrations were maintained constant. In our experiment, carbon dioxide was maintained at a rather steady low level of 0.5 to 1.0%. Oxygen increased from 21 to 25% as a result of a small mismatch between the CO_2/O_2 quotients of the mice and alga. A third criterion is whether the production rate of the algal chamber really matches the expected metabolic turnover of the mice. In our experiment, the algal chamber, maintained on a daily regimen of partial harvest and replacement with fresh nutrient medium gave a steady production rate of 1.45 gm./day while compared reasonably but not precisely to an estimated 1.7 liter/day oxygen demand measured separately for the mice.

The experiment brings to attention the problem of balancing of the CO_2/O_2 exchange quotient. It is readily shown algebraically that a mismatch of 1% between the CO_2/O_2 quotient of the animal and that of the plant leads to an accumulation or loss of 1% of the animal oxygen demand per day. It appears likely that advantage must be taken of the possibility of control of the quotient by choice of nitrogen source as previously discussed. (In this connection, it should be noted that in higher plants with a predominantly carbohydrate synthesis the CO_2/O_2 quotient is unfavorably high and not subject to any range of control.)

Our experiment was no more than a simple demonstration and we are proceeding to repeat the experiment with more elaborate instrumentation in search for a more precise description of its characteristics. However, in principle, only one feature needs to be added to make it mimic usable conditions.

The algae need to be removed from the harvested algal suspension and salts and fixed nitrogen added to the clarified media so that it may be recycled. If this is achieved and water of the human also recycled, net conversions of the "closed" portion of the system, as extrapolated to the human, could be diagramed as shown in Fig. 2. The excess metabolic water of the human is used metabolically by the algae. The input requirements have been reduced to 520 gm. food for the human, 140 gm. of salts and urea for the algae. The output accumulation has been reduced to 60 gm. of solids excreted by the human and 600 gm. of algal product.

You will see that a third stage toward complete closing of the system might be accomplished by reuse of urea and other human excretion products by the algae and by at least partial use of the algae as food for the human. For both of these conversions we have at least partial experimental evidence of feasibility. The extent to which we can profitably carry a regeneration system depends on the relative cost (in space and weight) of processing equipment as compared to the cost of expendable materials.

Having examined the possibilities, it is only proper that we also consider the limitations. There is no doubt whatever that a photosynthetic gas exchanger can be made to work. The question is whether the technical problems can be solved in the sense of reducing weight, space, and power requirements to feasible values. Actually, the question is not now answerable since actual development to the hardware stage has only begun. However, we can look at some of the recognizable problems.

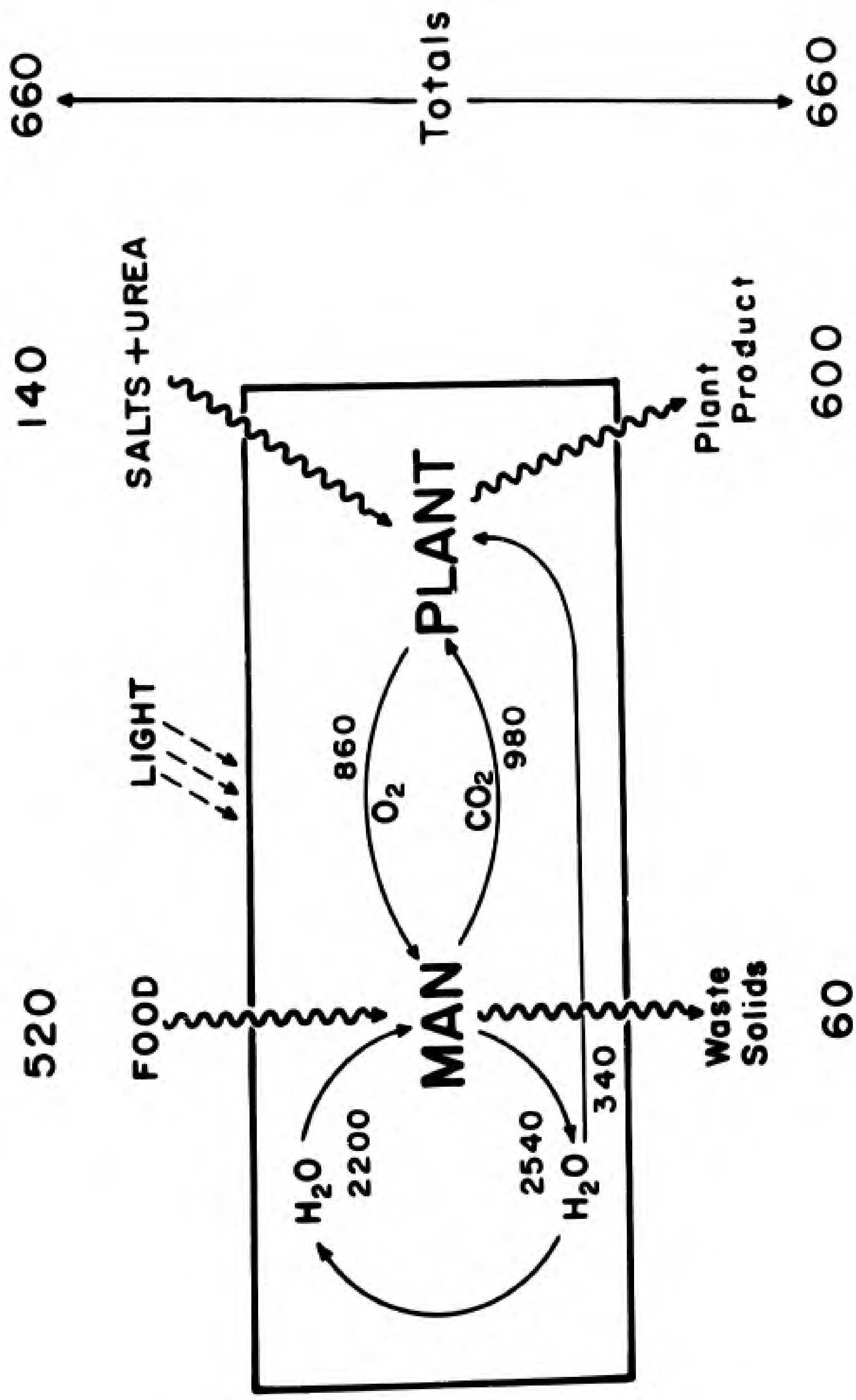

FIGURE 2
An Ecological System Closed or Regenerative for Water and Gas Exchange.

First we may ask about the working quantity of algae needed to sustain a man. At a human demand of 600 liters oxygen per day, we must produce about 600 gm. dry weight of algae per day. What illuminated and working quantity do we need to produce 600 gm/day? Several factors enter into the answer. First, there is the specific growth rate, the first order reaction rate or interest rate at which alga grows. For the Chlorella ellipsoidea which we used at 25° C the specific growth rate is about 2.0 per day or a simple interest rate of 200% per day. For several algae such as Chlorella 71105 at 39° C can produce 600 gm. dry weight per day, with an oxygen production sufficient to support a man. However, we cannot expect to practically achieve such figures. Actually, the specific growth rate, for any cell of an algal culture, varies with light intensity in a fashion as a saturation curve such as Fig. 3. The figures for maximum specific growth rate which I quoted are light-saturated values on the plateau of the curve and are seen for a whole culture only if all cells are light-saturated.

Now, if we have any regard at all for minimum power requirement and efficient use of light, we cannot afford to maintain all cells of a culture at light saturation. We could not do so without wasting light not absorbed by the algae. And the very fact of light saturation means that the algae are limited by enzymatic processes, not by their photochemistry; they are wasting much of the light which they absorb. Actually, maximum efficiency of light utilization by a culture is attained only if no cell in the culture is ever light-saturated. For these reasons, I consider it only

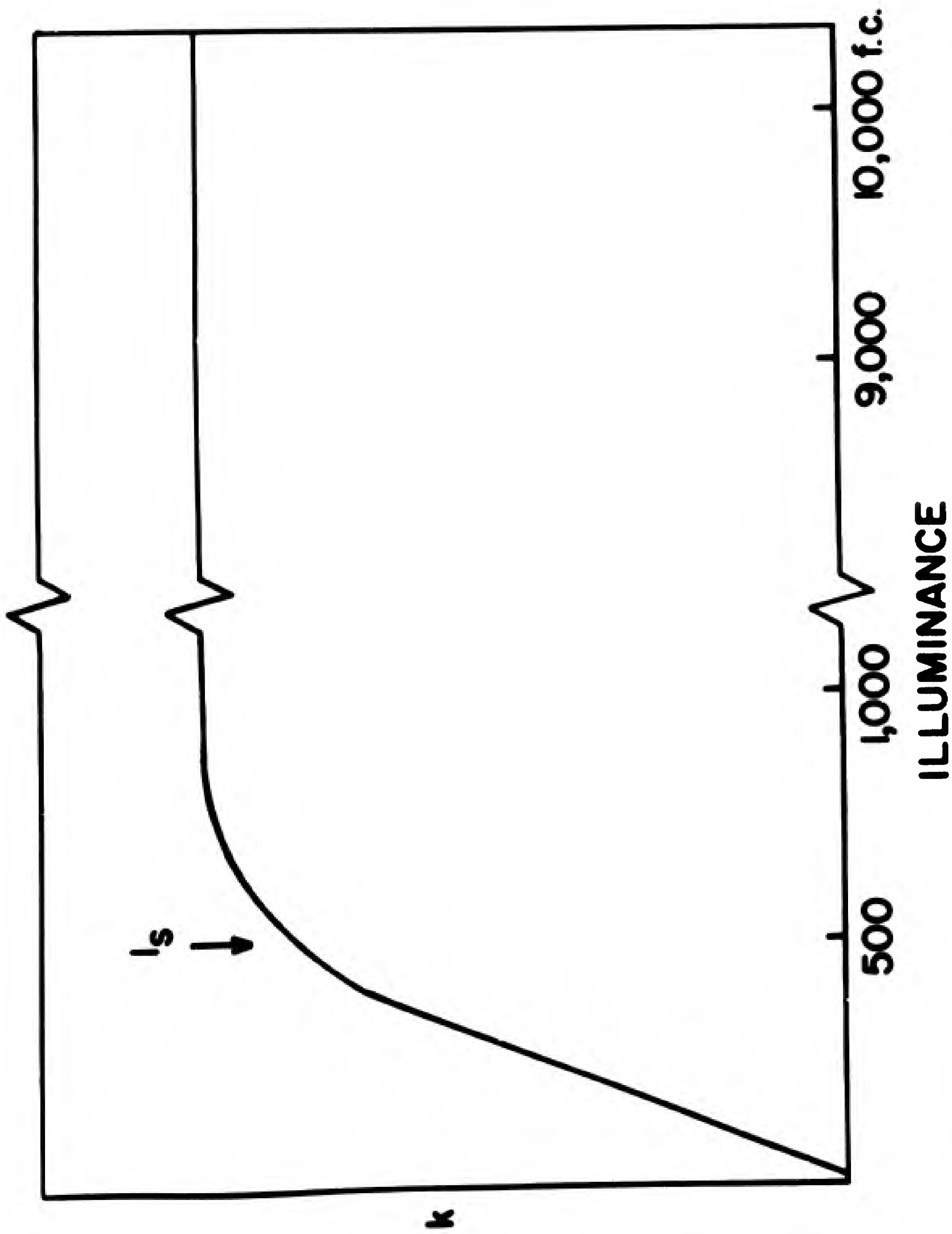

FIGURE 3

Typical Response of Specific Growth Rate K of an Alga to Light Intensity. I_s Designates an Approximate Value of the Point of Light Saturation.

good sense to make calculations for about 1/2 of the maximum growth rate. In short, even for low temperature algae (which we can now handle most reliably) certainly 600 gm. dry weight will support one man.

What estimates can we make for power requirements? Our maximum efficiency of about 19% is a very respectable efficiency. Oxygen, as a kind of sound money currency of metabolism, has a value of a little less than 5 kilocalorics per liter. So a production of 600 liters of oxygen per day by an algal suspension working at maximum efficiency will require about 15,000 kcal/day of light energy input. Now, the question is whether we elect to use artifical or Solar illumination. For artificial illumination, our best sources now available have a 20% efficiency for the electrical to visible light conversion. This leads to a minimum input electrical power requirement of 75,000 kcal/day or about 5 HP/man, a figure even more formidable if one considers the attendant problem of heat dissipation.

Solar illumination is an obviously attractive and likely solution but it is not a complete bargain. A difficulty of sunlight is its very high illuminance of something like 10,000 foot candles on the earth's surface. From many attempts at algal culture under diurnal solar illumination maximum practical figures are something like 20 gm. of algae/meter^2-day. And for very small size experiments in my own laboratory, we have found an estimated maximum yield of 70 gm./meter^2-day under continuous equivalent sunlight. The latter figure leads to a minimum requirement of about 9 square meters of illuminated surface of algal culture per man which is again a formidable figure.

Development to the hardware stage is a problem in illumination engineering. Light absorption by an algal suspension is very high. Even a 1/2 inch layer of a 1% suspension is almost opaque. The design problem is to spread the algal suspension in a very thin layer over a large area illuminated at low surface intensity.

Perhaps even more severe a problem than that of hardware design is a rather meager background of basic knowledge of the physiology and biochemistry of the algae. It has been only about 20 years since the practical possibilities of the algae were first given serious consideration. There are relatively few laboratories now concerned and a marked shortage of trained personnel.

My lecture has been designed to examine with you the possibilities and limitations of a biosynthetic approach to the logistics of supporting man in space. Since the subject could not be covered exhaustively in limited time, I have considered only some of the salient issues. Let me conclude with a take-home summary.

We have available in the green plant an elegant piece of machinery by which we can accomplish a regenerative provision of the gas exchange of the human in a closed system. We find the plant machinery best adapted to our needs in the unicellular algae. By additional processing, partly by physical and chemical means and by introduction of other organisms, we have available reasonable methods of achieving an approach to a completely regenerative or closed ecological system.

At the same time, we are still a long way from successful development to a hardware stage. In terms of space, weight, and power requirements, we anticipate really formidable problems, as viewed by our present technology. However formidable these problems appear, they cannot be held as deterrents to a soberly planned and vigorously pursued attack.

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LECTURES IN AEROSPACE MEDICINE

TOXICITY OF CHEMICALS

Presented By

Dr. Vernon Montgomery

Chief, Experimental Toxicology

School of Aviation Medicine

TOXICITY OF CHEMICALS

Vernon Montgomery, Jr., M.D., Ph.D.
Johnie L. Reeves, Captain, USAF(VC)

In the preparation of this lecture, we have assumed that an audience of mixed disciplines such as this has little or no knowledge of the biological effects of high energy fuels and their oxidizers. Therefore, we shall present a rather broad outline of the toxicological problems inherent in the use of these chemicals.

At the outset, it is important to note that some of the high energy fuels and their oxidizers are extremely potent poisons in comparison with the usual aviation fuels or even with the combustion products of conventional fuels. For example, the United States Air Force threshold limit values (1) for octane and its most hazardous combustion product, carbon monoxide, are 500 and 100 P.P.M., respectively. With this as a point of reference, let us compare the threshold limit values for diborane and hydrazine, two respectably high energy fuels. The values for such fuels are 0.1 and 1.0 P.P.M., respectively. Such a crude comparison shows that the toxicity of propulsion chemicals may be 100 to 1000 times as toxic as carbon monoxide, which currently kills about as many people per year as all other toxic substances combined. Certainly the high energy fuels pose a problem in extreme toxicity.

Table I

U.S. AIR FORCE

THRESHOLD LIMIT VALUES

FUEL OR PRODUCT	P.P.M.
CONVENTIONAL	
Octane	500
Carbon Monoxide	100
HIGH ENERGY FUEL	
Diborane	0.1
Hydrazine	1

What is the possible scope of this toxicological problem? At the present time, we are prone to think of the high energy fuels only in terms of rocket propulsion at a few launching sites widely scattered over the earth's surface--not a problem of very broad concern. If, however, we are to avoid underestimating the potential health hazard problem of the so-called rocket fuels, we might be wiser to view these chemicals in a broader context. The first commercial production of petroleum products was begun in this country in 1859. Figure 1 illustrates the change that has occurred in the rate of petroleum production since that time (2). Note that after a relatively inactive period of 40 years, the production and, therefore, the use has accelerated considerably. If the same data is plotted as the logarithm of petroleum

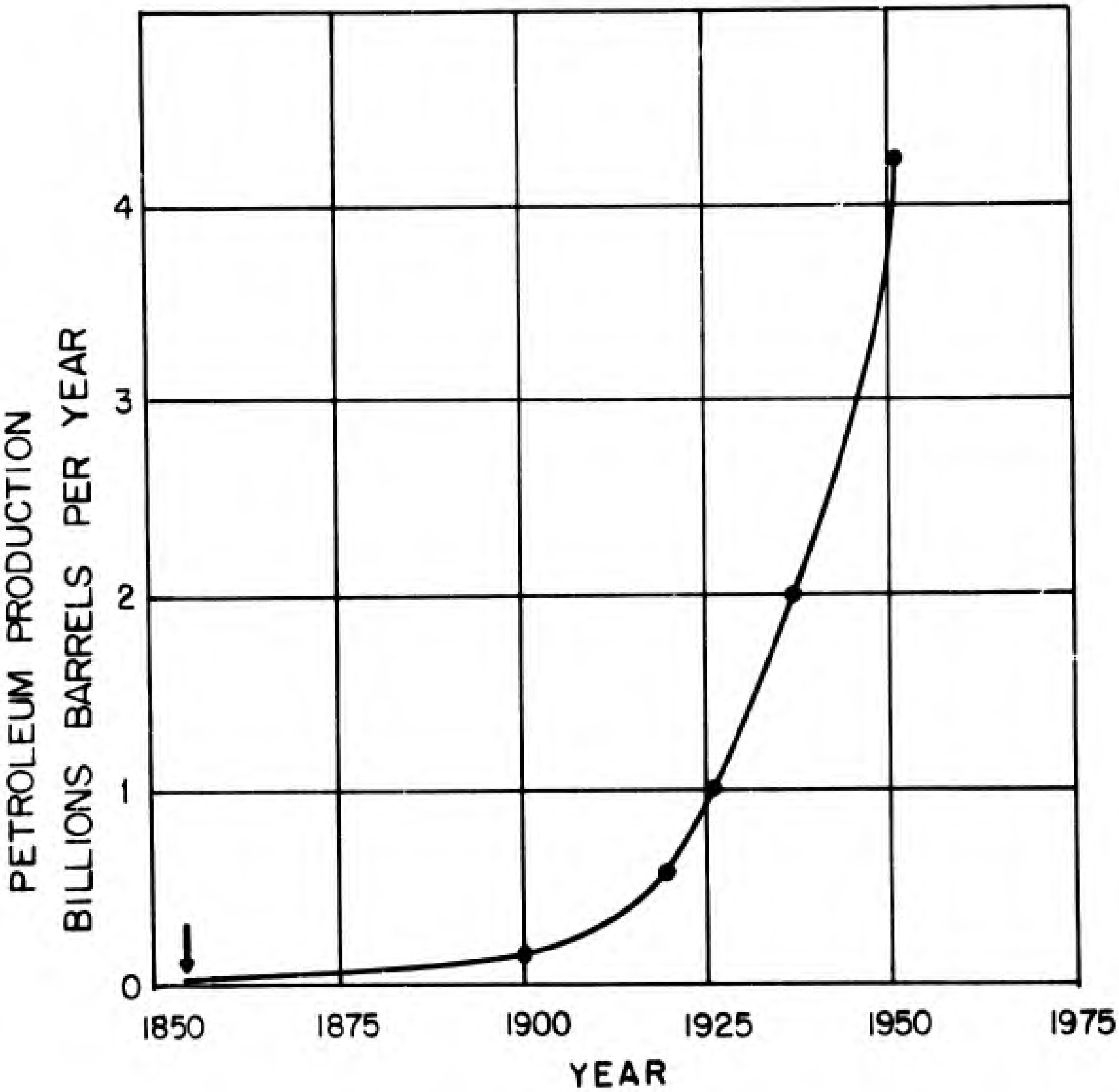


Figure 1. The change in rate of world petroleum production during the last one hundred years.

production, the relationship is linear. The point we wish to make is that although the originally envisioned uses of petroleum products are very different from current uses, the rate of growth of total world production has continued as a simple exponential function. It does not seem out of the realm of possibility that the use of certain high energy fuels will broaden also. Should this happen, and should their later use have a growth curve similar to that of petroleum products, it is apparent that the extreme toxicity of these chemicals would no longer be of practical concern to only a few missile men or research biologists, but rather it would then pose a serious, large scale health hazard problem. At the present time, it is impossible to extrapolate with certainty into the future and to predict the magnitude of the problem which high energy fuels will present to the biologist. Fortunately, the biologist is not expected to play such a role. It is important, however, for us to recognize a potential health hazard, to assume that the problem will be great, and to begin the accumulation of basic information before the problem gets out of hand.

With these thoughts concerning the scope of our problem, let us turn to the nature of rocket fuels. To the biologist, one of the most troublesome features of rocket fuels is their chemical heterogeneity. Where does he start a systematic study of biological effects? Table II is a partial list of fuels selected merely to give an indication of the variety of chemical

Table II

CURRENT HIGH ENERGY FUELS

Hydrogen	Benzene	Xylidene
Lithium	Methyl Alcohol	Nitromethane
Methane	Ethyl Alcohol	Propyl Nitrate
Ethane	Isopropyl Alcohol	Acetylene
Propane	Methylamine	Lithium Hydride
Heptane	Fthylamine	Borohydride
Octane	Aniline	Ammonia
Ethylene	Toluidine	Hydrazine

substances which fall in the category of high energy fuels. Contained in this list we see elemental fuels such as hydrogen and lithium. There are also some familiar hydrocarbons; the alkane series from methane through octane is almost complete; the alkanes are represented by ethylene, and benzene is a representative of the aromatic series. Alcohols are also common fuels. The primary alcohol series receives representation from methanol, ethanol and isopropanol. There are also amines of various types such as methylamine, ethylamine, aniline, toluidine, and xylidene. There are members of the nitro, nitrated, and acetylenic hydrocarbons. In addition, there are hydrides of lithium, boron, and nitrogen as well as other more complex compounds containing these elements.

The oxidizers presented in Table III do not present as imposing an array as do the fuels. There are elemental substances and their allotropes such as fluorine, oxygen, and ozone, and strong oxidizing acids such as nitric and sulfuric, in various stages of purity. There are also the more exotic oxidizers such as chlorine trifluoride and nitrogen tetroxide.

Table III

CURRENT OXIDIZERS FOR
HIGH ENERGY FUELS

Fluorine	Sulfuric Acid
Ozone	Chlorine Trifluoride
Oxygen	Nitrogen Tetroxide
Nitric Acid	

An idea of the pattern of composition of the current high energy fuels and their oxidizers can be obtained from the periodic table. Table IV is a portion of the periodic table of elements

Table IV

PERIODIC TABLE

Metals

GROUP	I	II		III	IV	V	VI	VII	0
PERIOD I	H 1							H 1	He 2
PERIOD II	Li 3	Be 4		B 5	C 6	N 7	O 8	F 9	Ne 10
PERIOD III	Na 11	Mg 12	TRANSITION METALS	Al 13	Si 14	P 15	S 16	Cl 17	A 18
SUBGROUPS	1A	IIA	IIIA _ _ _ _ _ _ _ IIB	IIB	IVB	VB	VIB	VIIB	0

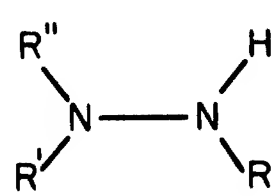
which includes only those periods and groups of importance to the present discussion. In this table, hydrogen has been placed in both group I and group VII. The atomic numbers of the elements which have been used or which are under consideration as components of high energy fuels are 1, 3, 4, 5, 6, 7, 12 and 13. Note that these are the elements of groups I, II, III, IV, and V. The atomic numbers of the elements of oxidizers are 1, 7, 8, 9, 16, and 17 and are found in groups V, VI, and VII. To the best of our knowledge, none of the group 0 elements, the rare gases, has been incorporated into the fuel or oxidizer systems. We can further limit the present, and possibly the future, high energy compounds by looking at the periods involved. Hydrogen is the only element of period I with which we are concerned. All of the period II elements of groups I through VII are involved either as fuels or oxidizers. Four of the elements of period III are of some importance as fuels or oxidizers. At the present time, elements of period IV and above are not used.

In summary, the fuels of primary current concern are elemental hydrogen and lithium, and hydrides (or hydrogen substituted radicles) of lithium, boron, carbon, and nitrogen. It is fortunate that so few elements must be dealt with, but still the multiplicity of compounds that can be made from these few elements is great.

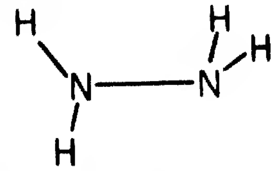
It would seem reasonable that as experience is gained, the variety of high energy fuels would become smaller. A reasonable first guess as to the nature of these hypothetical compounds is that they will be relatively small molecules. The elements composing the compounds will be light and consist primarily of the first three periods of the first five groups of the periodic table.

It is left for the research biologist to anticipate, insofar as possible, the types of compounds to which the living organism may be exposed, and to investigate the biological effects of this contact. The ultimate goal of the research biologist, regardless of his subspecialty, is to describe biological actions in terms of known physical and chemical actions. This goal is seldom achieved even when the desire is to describe how a given chemical causes an isolated biological effect. It is even more difficult to describe precisely how a given chemical kills a higher organism. However, when one desires to determine the biomechanism of chemical toxicity, it is usually helpful to have an understanding of the in vitro reactions of the chemical in question.

We should like now to discuss certain aspects of the chemistry of one group of high energy fuels—the hydrazines. The structural formula for this group of compounds is usually written as



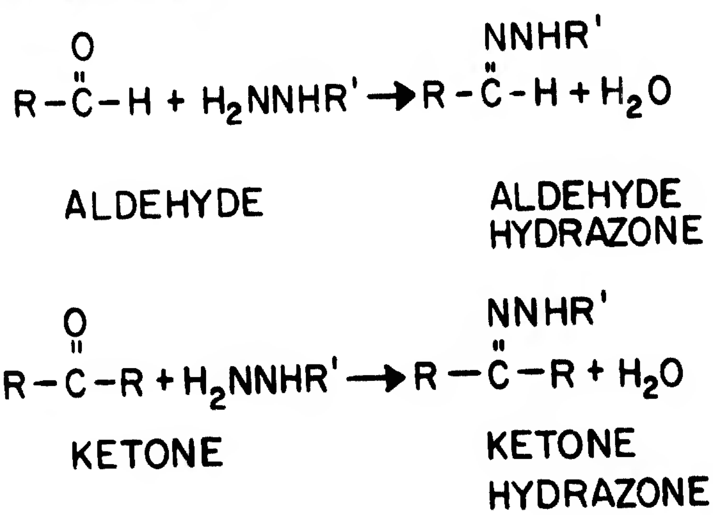
although a more nearly correct steric formula for the present compound H_2NNH_2 is probably (3),



The molecule is not symmetrical.

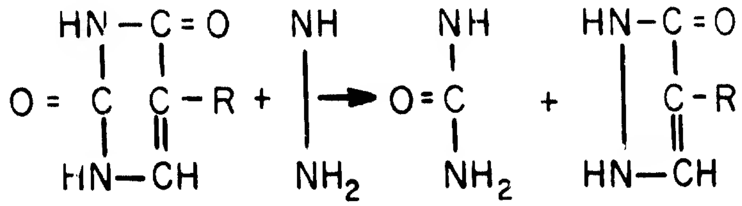
The R's on the general formula may be the same or different. The hydrazines of interest as high energy fuels today are hydrazine, methyl hydrazine, symmetrical dimethyl hydrazine, and more importantly, unsymmetrical dimethyl hydrazine. The molecule is said to be unsymmetrical when the two methyl groups are on the same nitrogen atom.

There are several types of reactions that hydrazine undergoes <u>in vitro</u> with compounds of a class known to exist in the body. Therefore, certain of these reactions may occur in the body and may be of importance in an explanation of the biomechanism of toxicity. Hydrazine is particularly reactive toward the carbonyl group of aldehydes and ketones. The general reactions may be written as shown below:



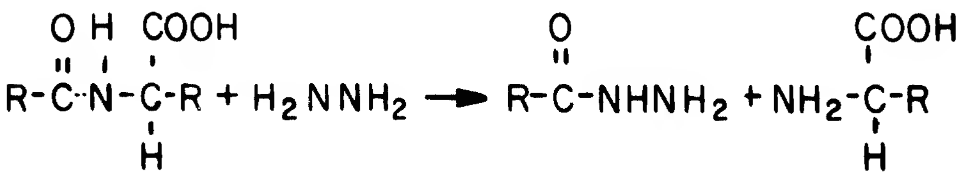
Some of the potential biological candidates for aldehydic reactions which exist in the body are: glyceraldehyde, 3-phosphoglyceraldehyde, acetaldehyde, glyocylate, folinic acid, and pyridoxal phosphate. Some potential candidates for ketonic reactions are: dihydroxy acetone phosphate, acetyladenylic acid, oxalosuccinic acid, alpha keto glutaric acid, succinyl Co A, ascorbic acid, riboflavin, pantothenic acid, vitamin K, etc.

Another type of chemical reaction which may be of considerable importance is that of hydrazine with the pyrimidine ring, as shown below:



Some candidates for this reaction in the body are: uracil, thymine, riboflavin, and biotin.

Hydrazine also reacts with the peptide linkage on one end of polypeptide molecules.



Candidates for this kind of reaction are body proteins, including such important compounds as insulin.

This partial listing of known and suspected reactions serves to illustrate the magnitude of the problem of assigning their relative importance in the overall deleterious effect on the animal. Additionally, the toxicity of hydrazine and its derivatives vary with the route of administration, the species studied, and the nature of the individual compound. It is not important, for this lecture, to delve into these details at any length, but it may be of some aid to show the rank order of toxicities of several of the compounds by several routes of administration.

Rothberg and Cope (4) have shown the intravenous toxicity for rabbits to be:

$$MHz > Hz > SDMHz > UDMHz$$

where MH is methylhydrazine, HZ is hydrazine, SDMH is symmetrical dimethylhydrazine, and UDMH is the unsymmetrical dimethyl isomer. The same ranking of toxicity held for skin application to guinea pigs. With skin application in rabbits, they found no distinction between the first two:

$$Hz = MHz > SDMHz > UDMHz$$

Toxicity is also exhibited by the inhalation route; however, the relative toxicities of the hydrazine derivatives administered by this route is not clear.

The symptomatology of acute toxicity, regardless of route of administration, consists of hyperpnea, vomiting, convulsions, coma and death (5). With chronic exposure, there is anorexia, weight loss, vomiting, tremors, and weakness (6).

The pathology exhibited by animals exposed to the hydrazines varies also with the compound, the route of administration, and the level of exposure. Large intravenous doses cause rapid death during convulsions and no remarkable pathology. Smaller doses administered subcutaneously over several days lead to gross liver damage.

Probably the best study of the pathological effects of hydrazine was made by Wells (7) in the early 1900's. He used hydrazine and phosphorus to damage livers in order to learn something of the development of the pathological picture of hepatic damage. He found that the toxic effects of hydrazine differed from those of phosphorus in several important respects. Hydrazine attacked only the parenchymal cells of the liver; whereas phosphorus attacked all types of cells of nearly all organs. Hydrazine affected the cells in the center of the lobule first; whereas phosphorus shows its first effects in the peripheral cells. Too, hydrazine had its primary effect on the cytoplasm with little damage to the nucleus. The final picture described by him was one of gross fatty infiltration. Hydrazine produced no other organ pathology except for an occasional area of focal necrosis of the renal tubules.

Moderately high levels of hydrazine in the atmosphere lead to an inflammatory reaction of trachea and bronchi, accompanied by patchy areas of atelectasis and peripheral emphysema. With lower concentrations in the atmosphere, there may be little or no pulmonary pathology, but a striking fatty degeneration of the liver is still noted (6). Hydrazine applied to the skin or eyes gives a deep burn which, in the case of the cornea, may be permanent. Methylation seems to decrease the local effects. For example, MH does not produce ulceration but does nevertheless cause local damage as indicated by the appearance of swelling and blanching at the site of application. The addition of two methyl groups, as in UDMH and SDMH, on the other hand, produce toxicity with no evidence of local damage to the skin even though systemic pathology results.(4).

In summary, the most striking pathology produced by hydrazine is fatty metamorphosis of the liver. This occurs with all routes of administration if the animal does not die acutely. Local irritant effects may be seen in the eyes, skin and respiratory apparatus.

It would seem from the symptomatology and the pathological findings that there are three distinct mechanisms which need to be explained. The first is the local irritant effect of hydrazine. You will recall that local application of hydrazine to the skin causes ulceration. This has been explained by the known lytic activity of hydrazine on the carboxy end amino acids of polypeptides, and the formation of short chain alkaline metaproteins (8). Alkaline metaproteins are soluble, and hence may partially explain the soft, deep burns that are seen with hydrazine contact. You will also recall, however, that methyl hydrazine causes only slight erythema when applied to the skin and that the dimethyl hydrazines cause no damage at all. If the pulmonary effects of hydrazine are also of an irritant nature similar to that seen with direct skin contact, one would anticipate scant pulmonary pathology as a result of inhalation of vapors of the methyl and dimethyl derivatives.

The mechanism underlying liver damage is another one not yet exhaustively explained. Studies of the hepatotoxic effects of hydrazine have a rather long history. Hydrazine, as well as chloroform, phosphorus, and hepatectomy, has been used as a tool to elucidate the function of the liver. Underhill (9) reported that subcutaneous injection of hydrazine sulfate caused a marked lowering of the blood sugar. In a later communication, Underhill and Fine (10) found that hydrazine exposure caused the animal's R.Q. to shift toward 1. They concluded from this that the hypoglycemic effect was the result of increased utilization of carbohydrate.

Certainly a shift to an R.Q. of 1 is not sufficient evidence on which to conclude the presence of an absolute increase in carbohydrate utilization. In fact, the work of Bodansky (11) seems to indicate that hydrazine treatment impairs the dog's ability to metabolize glucose. This worker studied the effect of hydrazine injection on the glucose, levulose and galactose tolerance curves. Figure 2 shows, by the solid line, the change in blood glucose following an intravenous injection of glucose into a dog before hydrazine treatment. The dashed line shows the change in blood glucose following the intravenous administration of the same glucose load after the dog had been pretreated with hydrazine sulfate. It is readily apparent that there has been a decrease in the animal's tolerance to a load of sugar as a result of hydrazine treatment. A higher peak of glucose is achieved and is maintained over a long period of time. The levulose and galactose curves are similarly distorted.

Treatment with hydrazine certainly has a remarkable effect on the body's ability to handle hexose, but from present knowledge it is difficult to make a clear-cut analysis of the functional alterations that produce the effect. The decrease in tolerance to glucose has been attributed to a direct effect of hydrazine on the liver. In view of the extensive damage to the liver that occurs following hydrazine, this is a likely

GLUCOSE TOLERANCE OF A DOG BEFORE (o—o—o) AND AFTER (o----o----o) RECEIVING HYDRAZINE SULFATE SUBCUTANEOUSLY

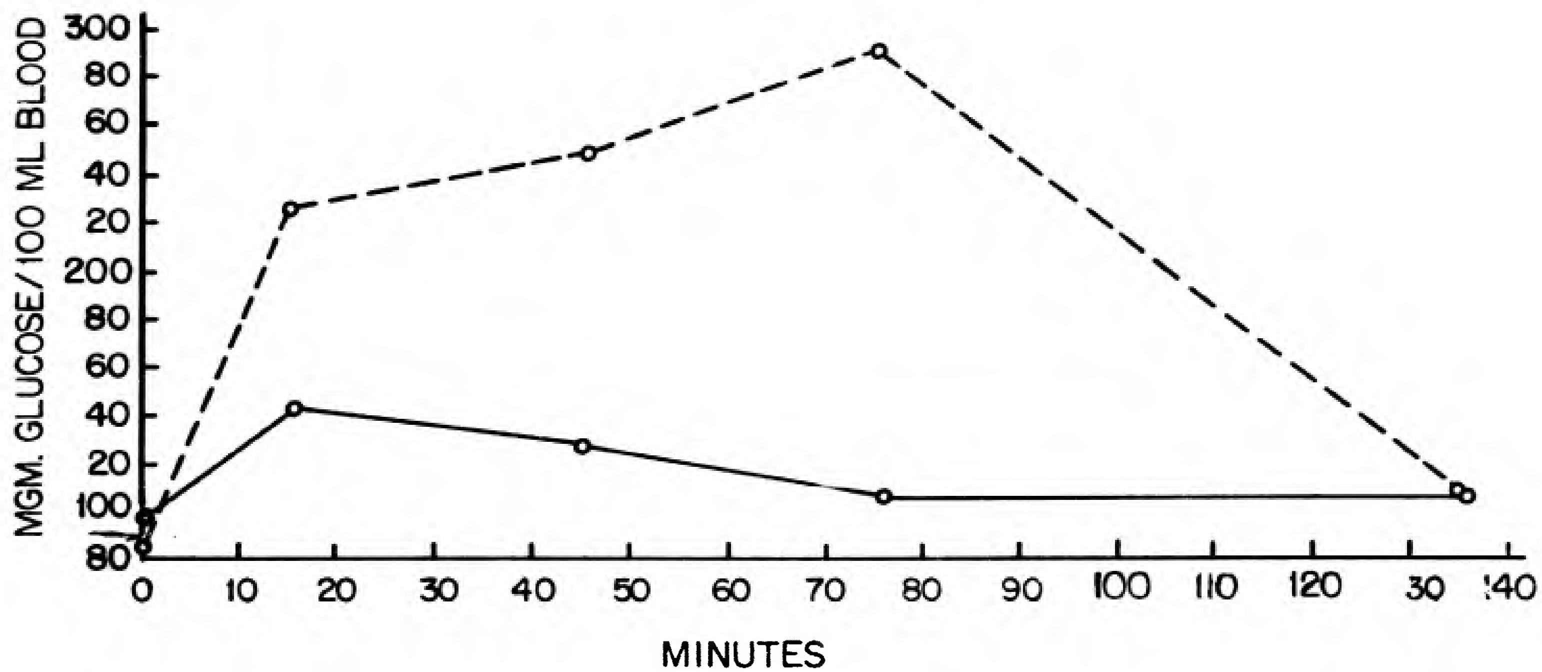


Figure 2. Shows the effect of hydrazine treatment on the dog's response to an intravenously administered glucose load. Zero time is the time of glucose injection.

explanation, but one must remember that hormonal dysfunction could give similar effects.

An alteration in amino acid metabolism has also been found to result from hydrazine treatment. Lewis and Izume (12) found that injection of hydrazine sulfate led to an increased concentration of total amino acids in the blood. In addition, they found that hydrazine impaired the ability of the animal to clear the blood of an amino acid load. Injection of glycine into normal rabbits caused an abrupt rise in total amino acid concentration of the order of 15 mg./100 cc., followed by a steady decline and a return to normal within 9 hours of the injection. Hydrazine treated animals showed the same abrupt rise in amino acid nitrogen, but there was no tendency toward a decline even 12 hours after the glycine injection.

Another indication of a disturbance of protein metabolism induced by hydrazine is the elevation of blood ammonia (13). Speck (14) has made some enzymatic observations that may be of importance as a partial explanation of this observation. He found that ATP was necessary for the rapid reaction between glutamate and ammonia to yield glutamine and ADP. This reaction was catalyzed by glutaminase of pigeon liver. He found also that hydrazine or hydroxylamine could substitute for ammonia to form other glutamyl compounds. Addition of hydrazine in the presence of ammonia caused a decrease in the rate of ammonia utilization. McKennis (15) has confirmed the observation of the enzymatically catalyzed reaction between hydrazine and glutamic acid to yield a compound he calls gamma glutamyl hydrazide. He found that acetone dried powder from rabbit liver, rabbit kidney and hog kidney were also active in catalyzing this synthesis. McKennis was also able to show that glutamine and hydrazine could be catalytically reacted by glutamine transferase to form gamma glutamylhydrazide. These enzymatic reactions shall be referred to again as we discuss the third mechanism in need of explanation; the convulsogenic effects of hydrazine.

In the early experiments with hydrazine, it was noted that the experimental animals often exhibited convulsions. This was usually attributed to the hypoglycemia that occurs. There are several lines of evidence that seem to indicate hypoglycemia is not the primary cause of these convulsions with either hydrazine or its derivatives. As was noted earlier, hydrazine poisoned animals show a decreased glucose tolerance curve. However, injections of glucose into hydrazinized animals do not eliminate the convulsions. There is another possible mechanism which is more attractive at the present time. Before specifically stating this possible mechanism, some background material must be described. Recently, Roberts and

Frankel (16) have found a decarboxylase enzyme which catalyzes the conversion of glutamate to gamma aminobuteric acid (GABA)with the release of carbon dioxide. This enzyme is in very high concentration in the brain and in lower concentration in the liver. The activity of this decarboxylase depends on the presence of the coenzyme, pyridoxal phosphate. Grundfest (17) has interpreted certain electrophysiological change of the cortex as indicating that GABA blocks excitatory synapses in the brain, and therefore may represent an inhibitory substance in the nervous system. Pyridoxine deficiency has been shown to cause convulsions (18) and has led to the hypothesis (19) that the convulsions are due specifically to the absence of the coenzyme needed for the synthesis of GABA. Semicarbazide and hydroxylamine cause convulsions in experimental animals (19). Both of these agents are similar in structure and chemical reactivity to hydrazine. All three are powerful carboxyl trapping agents. Wingo and Awapara (20) have shown that the decarboxylase activity could be inhibited by semicarbazide. It is thought that semicarbazide blocks the formation of GABA by its combination with the aldehyde moiety of the coenzyme. Finally, it has been shown that treatment of animals with pyridoxamine prevents the occurrence of convulsions produced by semicarbazide and even isonicotinic acid hydrazide (21).

In view of these findings, it does not seem unreasonable to propose the following biomechanism for the convulsogenic effects of hydrazine. Hydrazine reacts with the carboxyl group of pyridoxal or pyridoxal phosphate. The compound formed does not serve as the coenzyme for decarboxylation of glutamate to GABA. Absence of GABA then released the excitatory neurons of the cortex to full activity, thus causing generalized convulsive seizures. There are a number of gaps in the above proposed mechanism, but it has the desirable quality of being approached experimentally.

In summarizing this lecture, we should like to once again point out that there are a number of exceedingly toxic substances of great economic or military interest which, because of their experimental nature or excessive cost, are of practical interest today to only a few scientific disciplines. Some of the high energy propellants serve as examples. However, the probability that many of these compounds will come into widespread use in the future makes imperative an understanding of fundamental biological mechanisms involved in their toxicity. As an example of the magnitude of the work awaiting the research biologist, one class of compounds which has been rather extensively studied has been reviewed. Even in the case of this group, the hydrazine derivatives, one is still left with many biochemical reactions to investigate, many gross effects to explain; in short, many hypotheses to formulate and to test.

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17

LECTURES IN AEROSPACE MEDICINE

MEDICAL PROBLEMS AT LAUNCH SITES

Presented By

Colonel George M. Knauf

Surgeon

Air Force Missile Test Center

Patrick AFB, Florida

MEDICAL PROBLEMS AT AN R & D LAUNCH SITE

by

Colonel George M. Knauf, USAF, MC

The purpose of this discussion this morning is to point out some of the areas of general interest in the launching of missile weapon systems and to attempt to highlight certain aspects of such operations which are of particular interest from a medical point of view.

In order to take full advantage of the data acquired to date in the process of testing missiles at Cape Canaveral, it is proposed to limit this discussion to the Research and Development type of missile launching. One can readily imagine that these R & D operations entail many problems which will not be allowed to remain problem areas by the time a missile has reached its initial operational capability and is turned over to our troops for tactical or strategic employment. The program of missile testing includes the identification of such problems and, where possible, their solution, prior to completion of the test phase in the development of a missile weapon system.

It would appear that if we are to fully understand the significance of these test operations we must first know a bit about the Air Force Missile Test Center and its operation. Patrick Air Force Base in Florida is the home of the Air Force Missile Test Center, which is the organization which operates the Atlantic Missile Range. The Atlantic Missile Range is the free world's largest outdoor testing laboratory. If not the largest such laboratory, it is most certainly the longest--- stretching some 6000 miles down into the South Atlantic. Cape Canaveral is Station Number One of this Atlantic Missile Range. At Cape Canaveral we neither design nor build missiles. We simply launch them. Here we operate an enormous proving ground to which we welcome any responsible agency with a missile for testing. All three military services utilize the facilities of the Atlantic Missile Range, and, of course, the National Space Agency has now joined our Cape Canaveral family.

Some general observations on our activities may help to fill in this picture. In general, the missiles we receive are unknown quantities. Their flight performance has never before been explored. It is true that certain tests are completed prior to the arrival of some missiles at Cape Canaveral, but not those tests which involve release of the missile for flight. When we release a missile at Cape Canaveral and permit it to rise from its launcher, we are probing for the first time the flight performance characteristics of that missile. Of course, we must be prepared for all eventualities. Anything might happen and, as you can imagine, it frequently does. Of necessity our safety program must be elaborate and in some areas redundant. Certainly, many of the precautions we are forced to employ will never be required at an operational missile base. They are made necessary by the fact that we have no guidance to help us to identify in advance any untoward behavior characteristics peculiar to a given missile.

Today most of our missiles use liquid oxygen as an oxidizer and one of the hydrocarbons as a fuel. For this reason we have no serious toxicological problems of an exotic or bizarre nature. A great deal is known about the materials we use. From time to time we hear some comment concerning the use of the hydrazines. The toxicology of the hydrazines has been well known for the past 25 or 30 years. The fact that we use them in missiles today has not changed their toxicological properties. The quantities we use and, to some degree, the manner in which we use them, have created a need for the development of certain handling technics in the interest of safety but, even here, these new technics are built around well established industrial medical experience. In essence, there do not appear to be any true medical problems associated with missile launch operations which can not be solved by the application of traditional rules of sound industrial medical practice.

The quantities of fuel and oxidizer required to launch one of our major missiles give rise to certain medical problems. One of our Intermediate Range Ballistic Missiles comes to mind as an example. Such a missile in a normal 1500 mile flight will use as much as 7000 gallons of liquid oxygen and as much as 4000 gallons of a hydrocarbon fuel. These two materials must be pumped into the combustion chamber of the missile, in exactly the right proportions, at a rate of perhaps 85 gallons per second. One immediately senses the pressures required to accomplish the delivery of these chemicals at such a rate. These pressures constitute still another area of potential medical concern. Then, too, there are temperature problems to be dealt with. In order to maintain liquid oxygen in its liquid state, this material must be stored and transferred at minus 297 degrees F. One can readily perceive the frostbite problems incident to the handling of this oxidizer.

Pressures up to 6000 PSI coupled with temperatures as low as minus 320 degrees F. certainly set the stage for disaster. When these characteristics are evaluated in terms of the quantities of material used, the challenge to our medical ingenuity becomes a formidable one. We make our own liquid oxygen at Cape Canaveral. It is interesting to note that we may make and use as much as 75 tons of liquid oxygen in a single day's operation. All of this is, of course, complicated by the fact that our operations must be placed in the hands of non-technical personnel. The need for safety education in such a situation is apparent. At Cape Canaveral we permit no compromise with safety. Our people are thoroughly trained in all aspects of a safe operation and this state of safety discipline maintained by regular and frequent refresher sessions. Each man is taught to consider himself as a safety team of one. Only in this way have we been able to continue to live safely with these steadily growing members of the missile family.

Now let's meet the missile family. I will attempt to point out the characteristics of the individual members of the family since each one has a certain place in the total picture.

First, the THOR----- This is an Intermediate Range Ballistic Missile developed by the Air Force and having a range of about 1500 miles. It is a single stage, single engine, liquid propellant missile which is now operational and in the hands of the troops.

Next the JUPITER----- An Intermediate Range Ballistic Missile developed by the Army and having a range of about 1500 miles. It is a single stage, single engine, liquid propellant missile which has also been brought to a state of operational readiness. This is the only one of the family with any significant level of bioastronautical experience, having carried Able and Baker on their now historic space adventure.

Then the BOMARC----- This is a surface-to-air missile designed to intercept hostile aircraft approaching our shores. This missile operational and is in the process of being deployed to key positions in our national defense structure. It is interesting to note that while launched from a test stand at Cape Canaveral, the actual launching exercise is being carried out at Kingston, New York, some 1500 miles distant. The format for these test launches is as follows: The missile is erected in an operational enclosure at Cape Canaveral and readied for launch. A radio controlled aircraft is dispatched from Patrick Air Force Base to take up a course off shore over the Atlantic

Ocean. This aircraft is located by our coastal radar installations and its position, course, altitude and speed determined. This information is fed into a computer at a defense control center at Kingston, New York where the computer translates this radar data into guidance information for the missile. This guidance information is relayed automatically to the guidance system of the missile in Florida and, at the appropriate time, the missile is launched to seek out the target aircraft miles away over the ocean. Cameras in the nose of the aircraft accurately document the success of the test. We have been able to launch two such missiles in a period of 11 seconds.

Another important member of the family is the POLARIS----- This is an Intermediate Range Ballistic Missile developed by the Navy and having a range of about 1500 miles. It is unique in that it is designed for launch from either surface vessels or submarines. The POLARIS is a two stage, solid propellant missile.

Then we have the REDSTONE----- This is one of our earliest missiles. It was developed by the Army and has a range of about 300 miles. It is currently in the hands of our troops. This missile appears to be destined for a prominent role in the training of our Astronauts as they are made ready for their first venture into space.

Finally, we come to the big fellows---the Intercontinental Ballistic Missiles. First is the ATLAS. This is an Air Force developed missile having a range of about 5500 miles. It employs two booster engines to assist its main engine at launch and uses liquid propellant. The ATLAS is now operational and has been selected to boost the Mercury Manned Capsule into an earth circling orbit.

The other member of the ICBM family is the TITAN. This is the newest member of the missile family. It was developed by the Air Force and has a range of about 5500 miles. It is a two stage, twin engine, liquid propellant missile.

To complete the picture of our missile family we must add the SNARK. This is an aerodynamic missile, developed by the Air Force and having a range in excess of 5000 miles. It employs rocket boosters for launching but as soon as it has attained an adequate velocity its own ram-jet propulsion system takes over and the rocket boosters are discarded. This missile contains a unique guidance system which makes it possible for it to return to Cape Canaveral and land on a skid strip, bringing back a photographic record of its travels.

So much for the individual members of the missile family. It might be of some assistance in outlining the medical areas of concern at Cape Canaveral were we to trace the progress of a missile from its arrival up to and including its launch down the South Atlantic.

Most of our missiles are flown to us from the factory using transport type aircraft. They arrive on specially built trailers and are taken to an assembly hangar where they undergo a complete and exhaustive check-out of all of their component systems. When this check-out is completed and it has been established that all is in good order, the missile is taken to the launch complex. Here it is erected in a launch tower or gantry. This structure is peculiar to an R & D launch operation. It is designed to permit technicians to have access to all levels of the missile. Such a device is essential to permit the adjustments and instrumentation checks so important in a development program. With these tasks completed, preparations are made for launch. The fuel tanks are filled to a pre-determined level and the liquid oxygen tanks filled to a level which takes into account the losses of LOX which will result from volatilization in our warm Florida climate. The many incidental tasks such as placing explosive ordnance, igniters and destruct packages are accomplished. During all of this time the blockhouse crew have been proceeding with a methodical, step by step check of all elements of this complex system. This count-down consumes many hours. Tension builds up and the signs of fatigue begin to appear. After the test conductor is assured that all is in readiness for launch, the word is passed to clear the pad. LOX tanks are topped off, the vents closed and all personnel retire either to the blockhouse or a safety road-block. The service tower is withdrawn to a safe location. If the flight path of the missile is clear of shipping and aircraft, and if all range stations are ready to perform their tracking and data acquisition tasks, the missile is finally launched.

The end product of all of this is a flight report. This report, about the size of a metropolitan telephone directory, contains a complete summary of all of the data connected with the check-out, countdown, launch and flight of that specific missile. From an analysis of this data is derived the information necessary to proceed with the development and refinement of the weapon system.

As has been pointed out, there are no new or startling medical problems incident to the launching of even our largest missiles. We have found it necessary to take certain steps to develop a state of readiness to meet emergencies that might arise during launch preparations. We have developed a group of "Missile Sitters." Realizing that during fueling operations the level of accident probability is at its peak, we dispatch a medical team with an ambulance to stand by on the launch pad to render such assistance as may be required. Being supplied with two-way radio equipment, this team functions as a medical out-post as well, keeping our main dispensary crew informed on the progress of the launch preparation. This is accomplished through our medical communications center in the dispensary. This center is in constant communication with all essential elements associated with the launch, the blockhouse, Central Control and our out-post medical unit. They also exercise control over our rescue team positioned outside the main dispensary. This rescue team is made up of support personnel, plumbers, electricians, steamfitters, carpenters, drawn on a voluntary basis from the shops in the vicinity of the dispensary. These personnel are selected because their place of employment, being remote from the launch site, offers some assurance of their availability when needed. These volunteers have been given an intensive course of training in first aid and rescue operations by our medical department. Frequent disaster drills serve to maintain their proficiency. The rescue team assembles 30 minutes prior to each launch of a major missile. They are led by an experienced rescue chief who directs them to a disaster in a small pick-up truck which has been modified to carry rescue equipment, medical supplies and protective clothing for the rescue crew.

These things, then, make up the Cape Canaveral story. Let's take a close look at this operation in an effort to identify the areas which give us reason for medical concern. In this way we will be able to point out the situations which have given rise to our present system of safety discipline. Perhaps we can justify to you the great lengths we go to in an effort to protect our people.

First the chemicals used in our operations. As explained earlier, there are no new or bizarre problems of a toxicological nature induced by missiles. The quantities used cause handling concern particularly in the case of liquid oxygen, hydrogen peroxide and unsymmetrical dimethyl hydrazine. While used in smaller quantities, white and red fuming nitric acid give cause for concern by their nature. This situation is aggravated when the storage and transfer of this material is accomplished adjacent to a second or third stage of a missile on the top working platform of a gantry, over the heads of a hundred or more technicians busy on the levels below.

Virtually all missiles employ certain items of explosive ordnance--It must be borne in mind that each missile launched on a test flight is equipped with two destructive explosive charges placed aboard to enable the Range Safety Officer to instantly destroy the missile, should it deviate from its programmed flight path and threaten life or property. Most missiles include some explosive ordnance such as explosive bolts to effect stage separation or to accomplish some other in-flight task. All of these devices have an inherent element of danger to our people by their very nature.

Temperatures vary widely in the various facets of a missile launch operation. These vary from the minus 297 degrees F. of the liquid oxygen as it is transferred from the storage tanks in a missile, to the 6000 degrees to 7000 degrees F. temperatures developed in the flame deflector at the base of each missile as the engine is brought up to full thrust.

Pressures pose a real threat to personnel during all pre-launch activities. These pressures may reach a level as high as 6000 PSI in some of the systems. The greatest cause for concern here stems from the fact that much of this activity takes place before personnel leave the pad area. In this way the degree of hazard is augmented by reason of the numbers of people so exposed.

Noise has not to date posed any real problem. The average missile today does not produce in excess of 150 db of notice. Most of this is to be found in the low frequency portion of the spectrum where physiological effect is somewhat lessened. Of greatest importance is the fact that when this level of noise is developed all personnel are either well protected inside of the blockhouse or have withdrawn to the safety road block, at least a half-mile removed from the launch point.

Blast is just now beginning to give us cause for concern. Until recently the size and nature of our missiles has been such that, when we had a pad failure, we experienced a quick burn of the fuel and oxidizer with little damage to the surrounding structures. Of recent date we have learned that as our missiles grow in size and complexity, they have also acquired the capability to give rise to a rather severe first order detonation, in the event there is a propulsion system failure at the time of launch. Then, too, this situation is complicated by the basic format of a missile launch. All ballistic missiles are launched in a vertical position. During the first phase of their flight they are under the control of a guidance system similar to an auto-pilot. After the missile has flown long enough to reach an appropriate altitude and velocity its internal guidance system takes over and turns it to take up its flight trajectory. This, of course, means that for some period of time immediately after launch the missile is directly overhead. Failure during this phase results in the missile impacting on or near the launch complex where a first order detonation could have serious consequences.

Personnel make up the final and most significant source of medical concern. As explained earlier, we go to great lengths to educate our people in the ways to live with missiles safely. In spite of this it is estimated that between 25% and 40% of missile failures are the result of some sort of human error. These human errors may be the product of fatigue or stress during a prolonged countdown. More often, however, our concern is with the rugged individualist who takes unnecessary chances in spite of his safety training. Despite all of our effort, we still must deal with the individual who rests a flatladder against the curved ice covered surface of a missile, who handles an ice covered LOX line with bare hands, who extracts loose tools from his pockets with these frosted hands, with no thought for his fellow workers going about their duties at the foot of his ladder. This last, the tool dropped from overhead, is still the greatest source of disabling injuries in our missile test program. We still find the individual who carelessly exposes himself to the vapors venting from a LOX tank only to find that this "steam" can cause a severe frost bite.

Of course we have missile mishaps. We are engaged in a program of testing developmental systems. By their nature these weapons are in reality enormous firecrackers. When one considers that one ICBM is made up of some 330,000 parts it is not remarkable that in the course of such a test program we find one once in a while that fails to achieve it's test objective and destroys itself or is destroyed by the Range Safety Officer because it threatens life or property. Such destruction has a significant potential for the production of a disaster of great magnitude, particularly when one realizes that we employ about 8000 people on Cape Canaveral.

It is when these factors are considered that our safety record takes on real significance. We have reason to feel that our program of safety education and safety discipline, together with a policy that there will be no compromise with safety, has really paid big dividends. We have been launching missiles at Cape Canaveral for about eight years. In those eight years of firing untried and untested missiles we have had two deaths. One was a mandane elevator accident of a type which might occur in any location where an elevator might require repairs. The other death was the result of a fall from a ladder to the concrete floor of a hangar. Neither can be said to have resulted from a work situation peculiar to missile operations.

We have established beyond any reasonable doubt that, if the physical and chemical properties of the materials in use are understood, if proper precautions are employed, and if personnel are trained to recognize and appreciate the hazardous situations encountered, missile operations can be conducted at a level of personnel safety in consonance with sound industrial medical practice in any industry as complex and as diverse.

18

LECTURES IN AEROSPACE MEDICINE

PSYCHO-PHYSIOLOGICAL PROBLEMS OF MANNED SPACE VEHICLES

Presented By

George T. Hauty, Ph.D.

Professor of Experimental Psychology

School of Aviation Medicine

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PSYCHOPHYSIOLOGICAL PROBLEMS IN MANNED SPACE VEHICLES

George T. Hauty*

In the best interests of both brevity and comprehension, I would like to confine my discussion this morning to the two problems that have received most of our attention and, consequently, for which we have the most data to report.

The first problem is that of day-night cycling or, as termed in the current literature of biological rhythms, circadian periodicity. Our practical interests are occasioned by the readily apparent fact that periodicity of this sort acts as a fundamental limitation whenever man is incorporated as an integral component in space systems designed for extended operations. In short, man must sleep and, because of this, he represents in relation to such a system a distinctly unique component. Interestingly enough, we do not have nor do we find in the literature a great deal of systematically obtained information relevant to this problem. Hence, our basic interests are concerned with the modifiability of circadian periodicity. That is, to what degree of change can the human organism adjust without loss of functional integrity?

To date, our investigations of this problem have consisted of 7-day flights in the 1-man space cabin simulator. During these,

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the subjects are confined to a rather unusual environment characterized by an impoverishment of normal circadian cues and committed to an 8-hour rather than the normal 24-hour day.

This space cabin simulator has been described in detail in an earlier report (2). Certain characteristics deserve specific mention. The space allowed the subject is approximately 50 cubic feet. Figure 1 illustrates how limited this amount of space actually is.

See Figure 1

During his rest period, the subject can arrange a bunk beneath the operator system and, if he is not too tall, stretch out to his full length. As the flight continues, moreover, allowable space becomes

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See Figure 2

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even more limited. The picture shown by this slide was taken at the end of a 7-day flight and, as can be seen, garbage becomes a problem. The amount of condensate, for example, that can be collected in 7 days is quite surprising.

In addition to these restrictions of mobility, the subject is also denied visual contact with the external surrounds. Further, whatever external noise may be transmitted by connecting pipe lines is considered to be effectively damped by a constant internal noise level of approximately 84 db. Finally, the interior of the cabin is constantly illuminated at a high level which serves a dual purpose: removal of a predominant circadian cue and the operation of

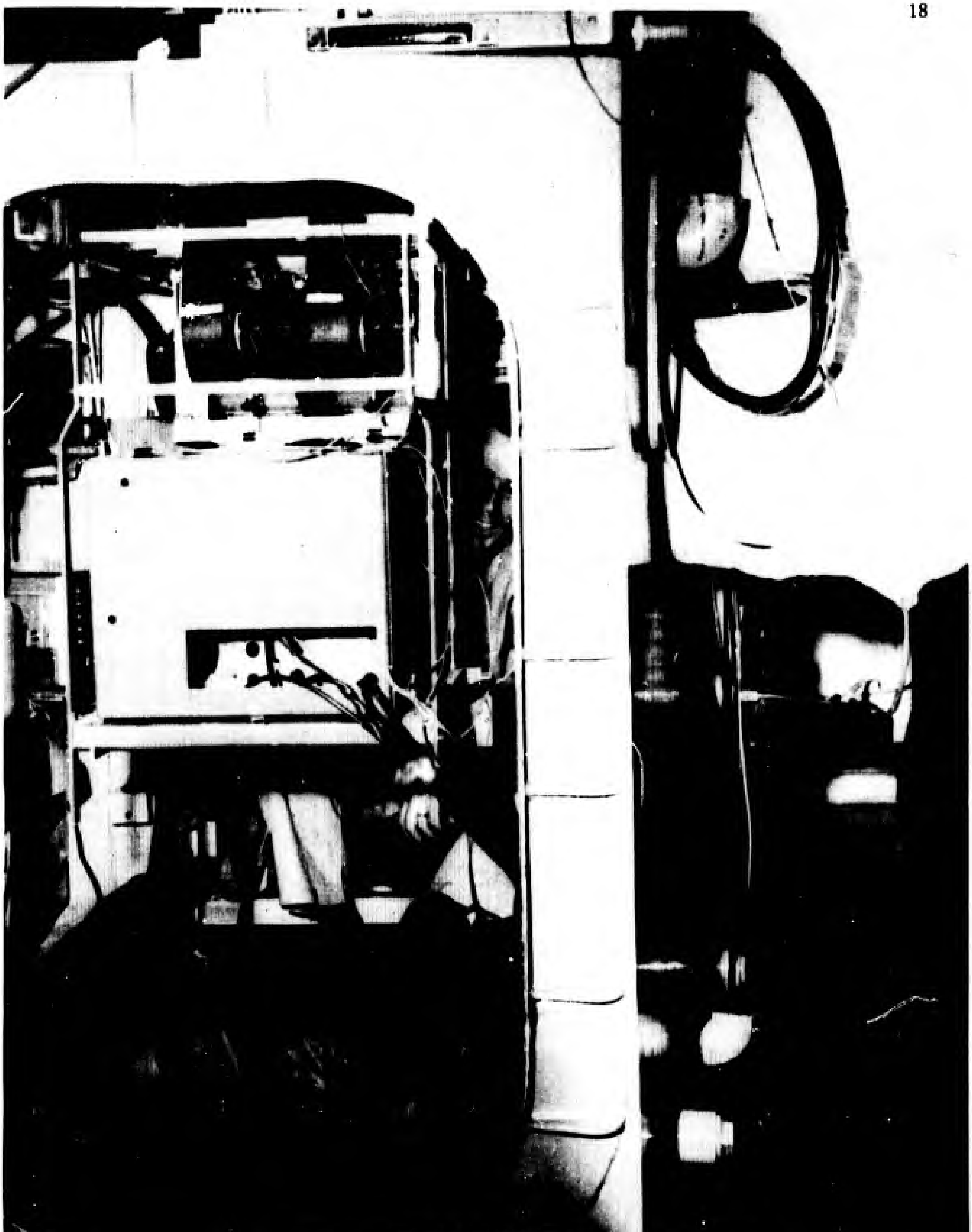

FIGURE 1
Interior of SAM 1-Man Space Cabin Simulator.

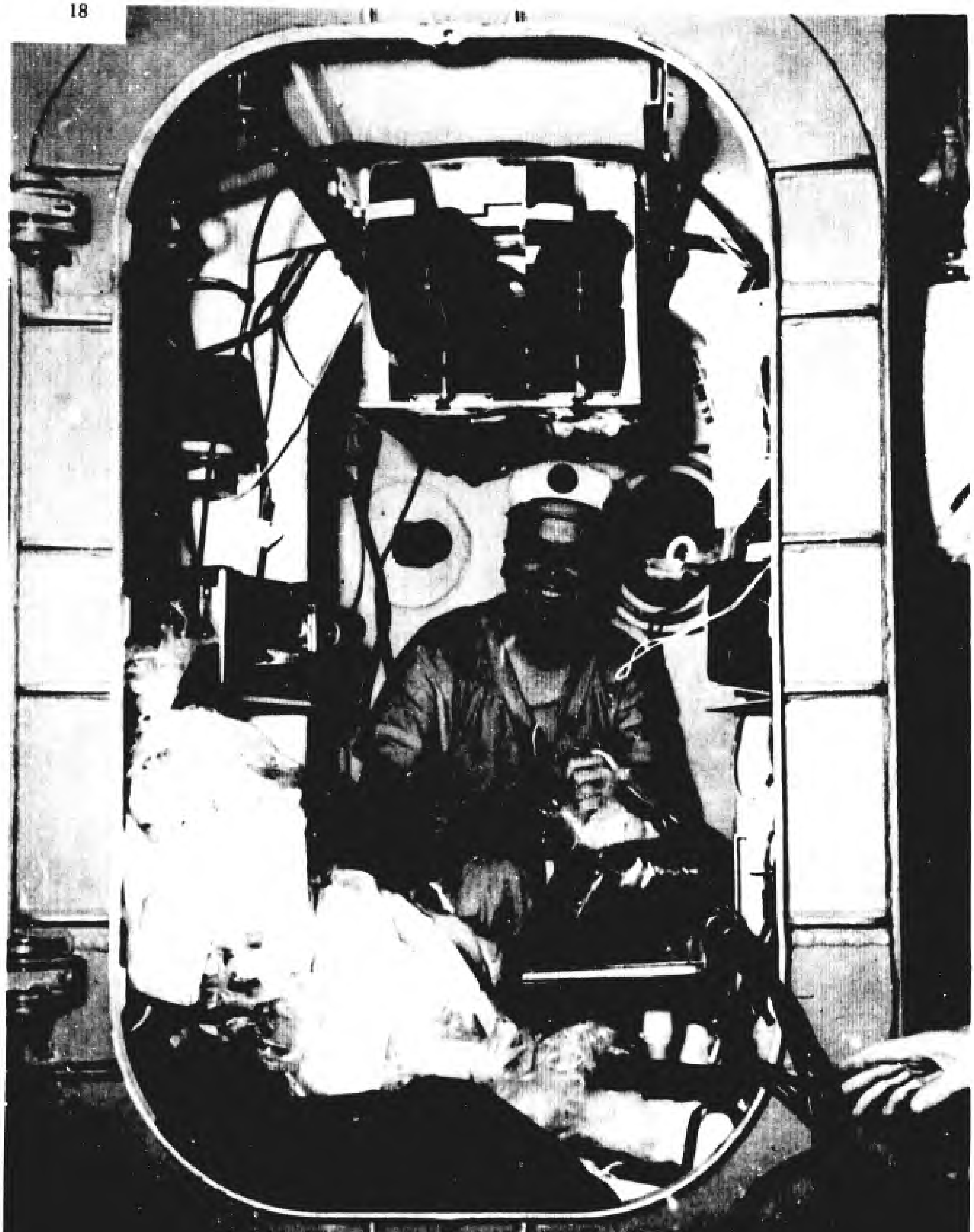

FIGURE 7
Waste Accumulation During a 7-day Flight.

the closed circuit television which permits a constant visual observation of the subject.

Following one week of physical, psychiatric, and psychological evaluation, the subject was given two days of intensive pre-flight indoctrination. On the morning of the third day, the subject entered the chamber to begin his 7-day flight. Throughout this entire flight, the attempt was made to maintain environmental conditions at constant levels. Cabin pressure and the partial pressure of oxygen were maintained at approximately 380 mm. Hg., and 150 mm. Hg., respectively. Partial pressure of CO_2 was maintained below 5 mm. Hg., temperature at approximately 86^{o}F, and relative humidity at 45%. In addition to denial of visual access to the outside, radio silence was maintained throughout the flight by the ground personnel. However, the subject did have the capability of verbally reporting to the ground crews any information he desired to convey. Hourly recordings were made of cabin temperatures, humidity, pressure, partial pressures of oxygen and carbon dioxide, and of heart and respiratory rates during the 7-day period. In addition, ground observers were permitted to maintain logs of the subject's activities and other significant events by means of the closed circuit television system already mentioned.

The diagram in Figure 3 presents, on the left, the day-night cycle

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See Figure 3

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to which all of the subjects were accustomed and, on the right, the 8-hour day to which the subjects were committed throughout the entire

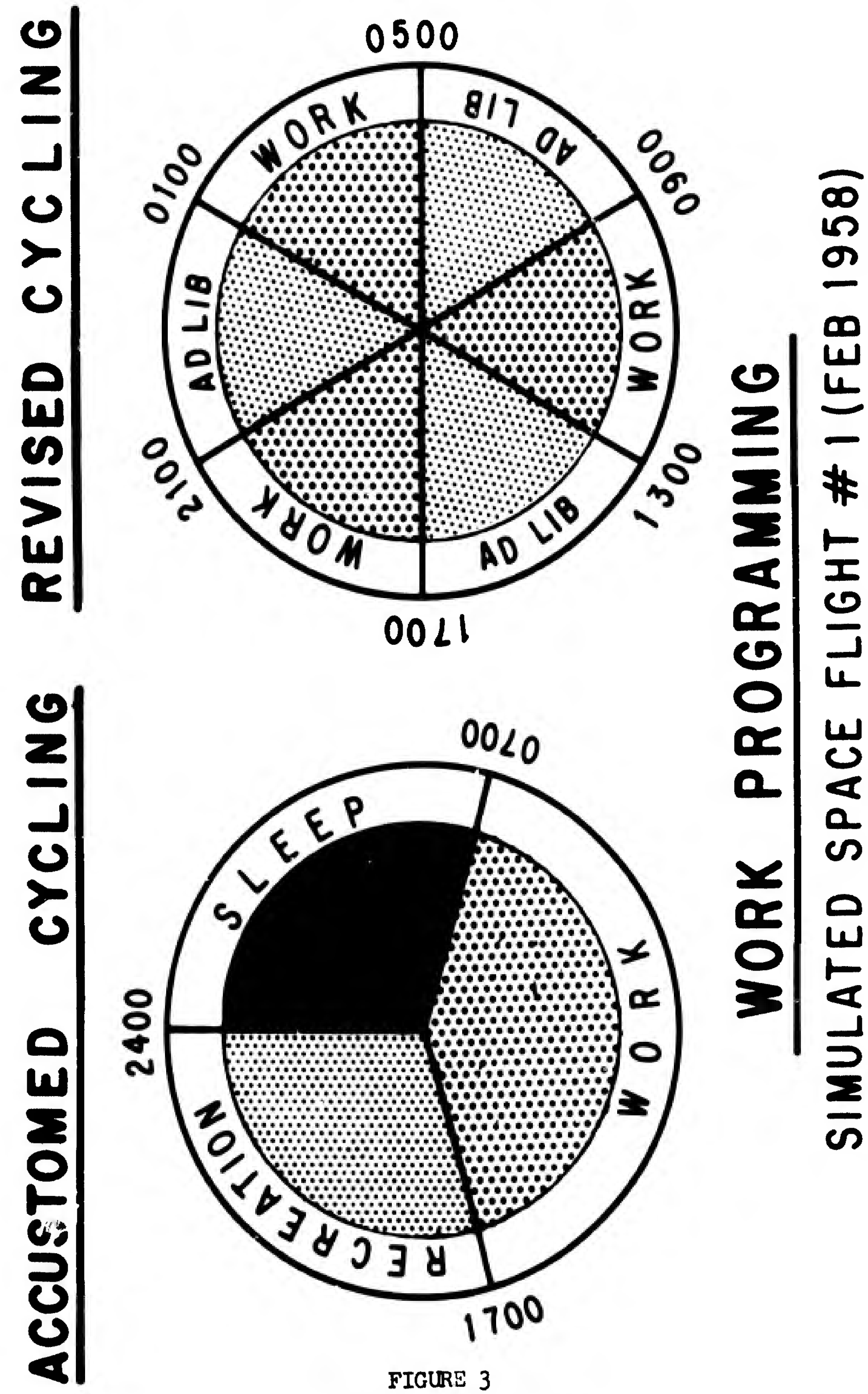


FIGURE 3
Work - Rest Cycles.

duration of the flight. It can be seen that the 8-hour day consisted of four hours of work followed by four hours of rest. It will be noted further that what is shown as the third work period of a 24-hour day occupies that portion of the 24-hour day which the subjects normally devote to sleep.

The work required of the subject was provided by a second independent closed circuit television system which permitted the presentation of his operator tasks. The display monitor and its associated control console are shown in Figure 4. The tasks

See Figure 4

required of the subject involved the functions of spatial discrimination, perceptual judgment, vigilance, and problem solving. The proficiency with which the subject executed these functions was electrically recorded in terms of time; that is, time required to solve a problem, detect the departure of an indicator from null position, etc., and also in terms of the errors committed. The panel of lights and switches seen at the left of the operator system is the command panel which obviates the necessity of verbal communication between subject and ground crew personnel for a flight of this duration.

The first 7-day flight was made, using as the subject, a young airman of mature emotionality, high intelligence, and who typically was extremely well-poised in unusual situations. Previously, this individual had participated as a subject in our early zero gravity

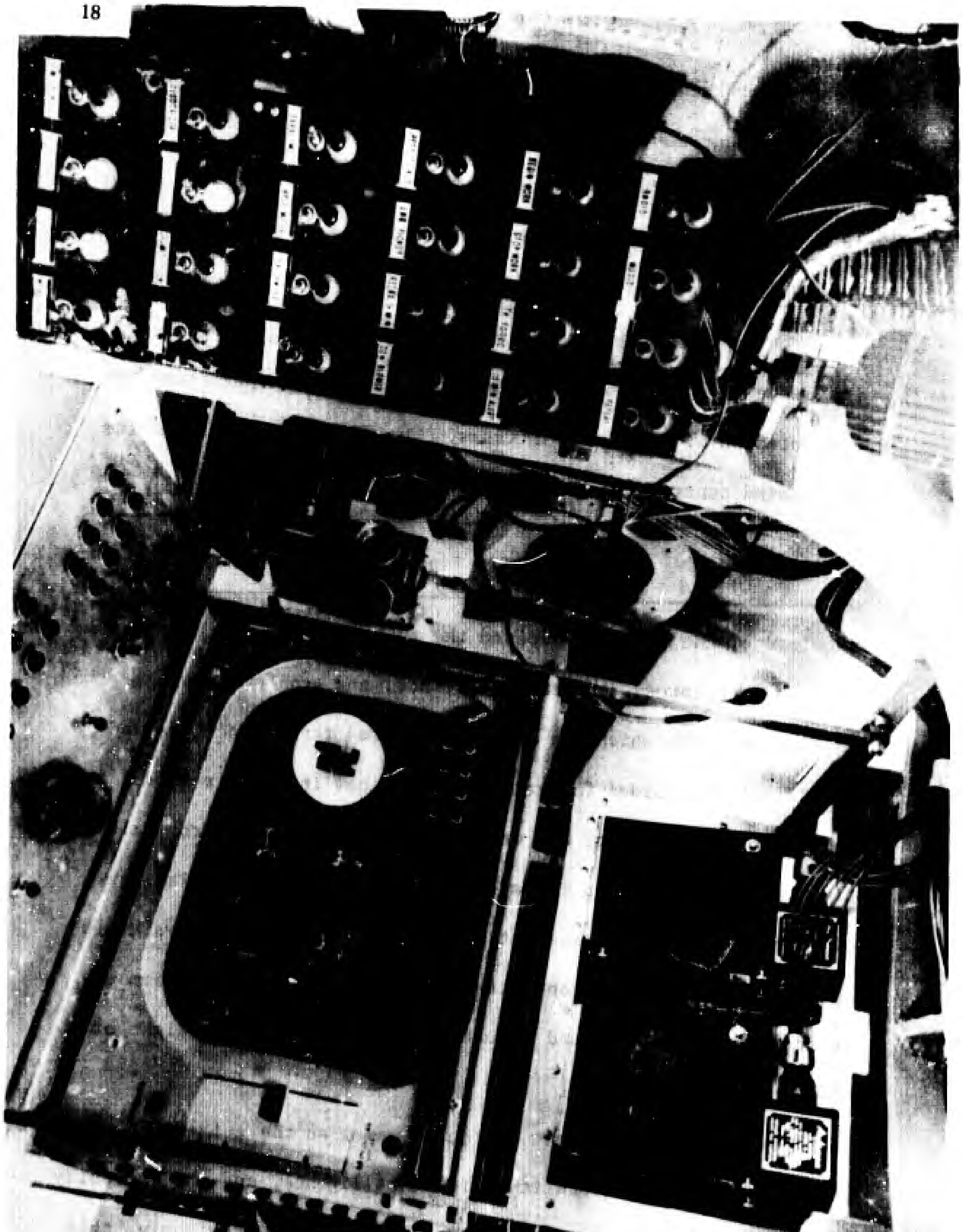


FIGURE 4
Operator System and Command Panel.

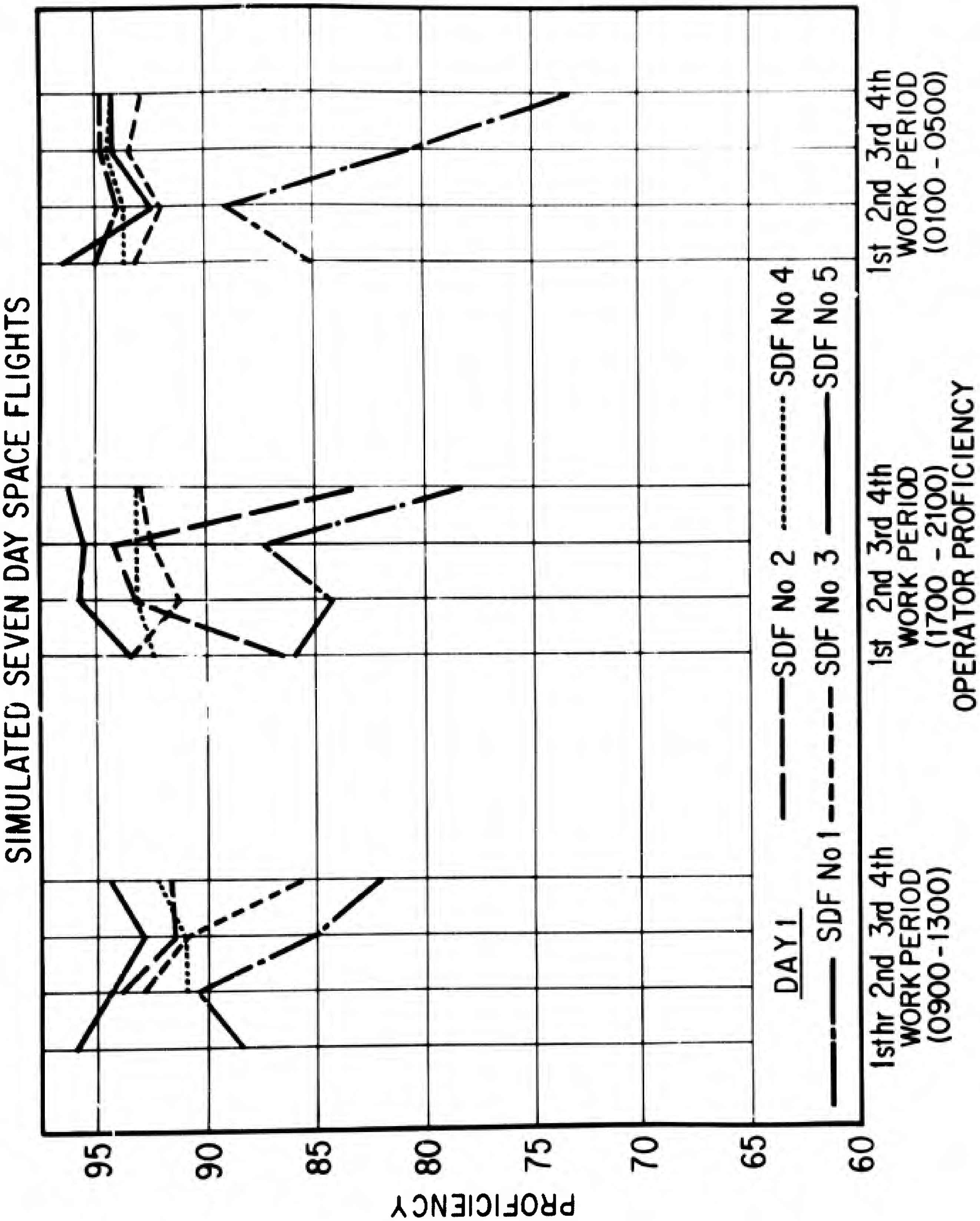
flights. His performance and conduct during these were largely responsible for our decision to use him as our first subject. This was a fortunate decision, but not because of our preconceptions. As it turned out, this subject did not adjust to the 8-hour day which admittedly does represent a drastic revision of a normal 24-hour physiological day. Fatigue accumulated as the flight continued and, as a consequence, his proficiency as an operator deteriorated to extremely low levels. Following an intensive debriefing of the subject and a review of the flight and its events, the decision was made to secure future subjects from a specific parent population. Fortunately, we were afforded access to precisely the population that we had in mind. This was a squadron of highly selected pilots with long-term experience in flying jet aircraft on prolonged missions. We have made four additional flights under conditions comparable to the flight just described and have used as subjects volunteers from the population just described. The results are quite interesting.

Figure 5 presents the levels of proficiency attained by each

See Figure 5

subject for each hour of work during each of the three work periods of the first day of flight. The lower-most curve for each of these periods of work is that of the first subject. I think it will be agreed that these curves and their rank ordering represent what typically would have been predicted. That is to say, for each

FIGURE 5
Hourly Mean Proficiency Attained by Each Subject During the First Day of Flight.



subsequent work period, level of proficiency exhibits progressive reduction and the rate of decrement occurring within the work period becomes increasingly greater.

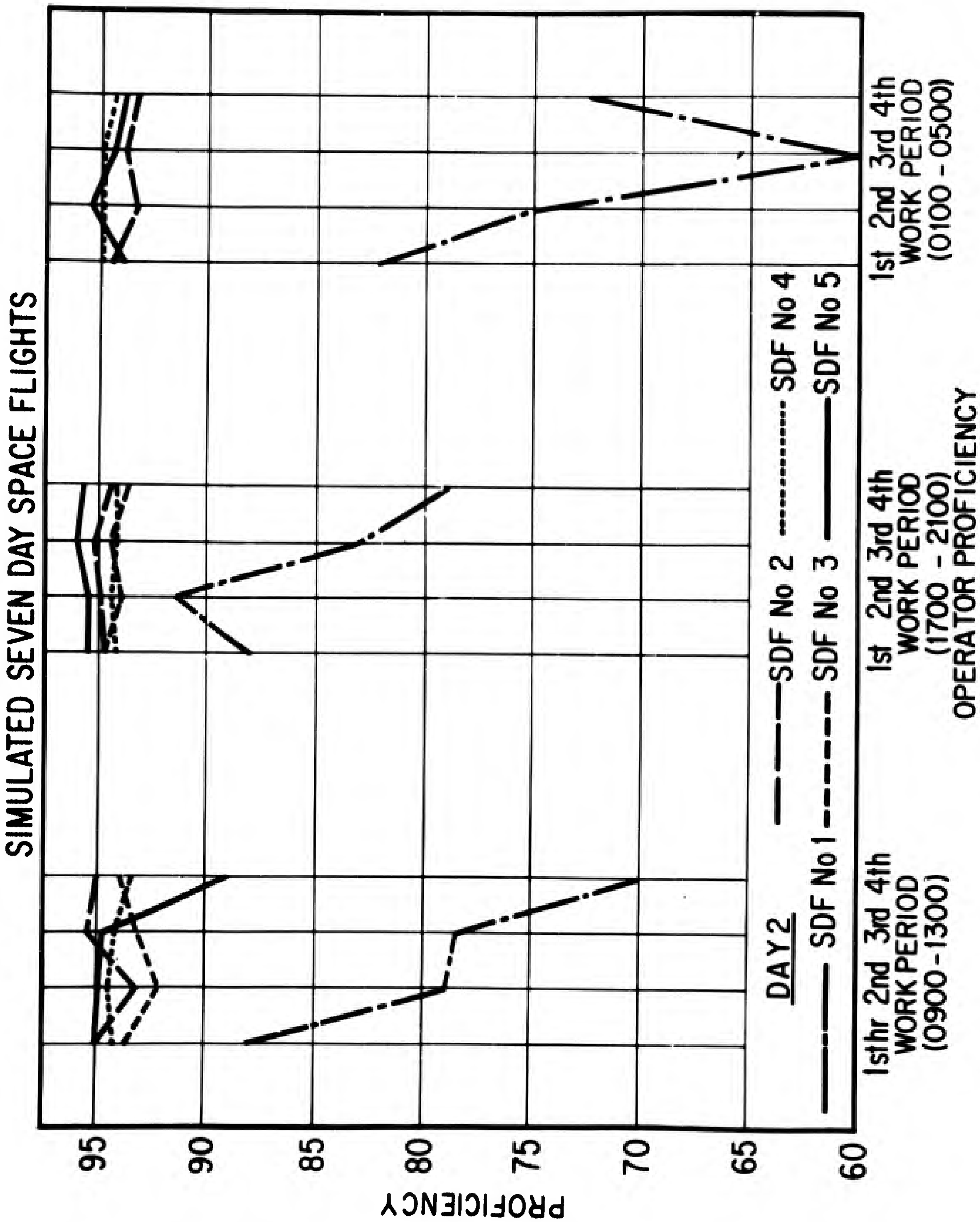
In direct contrast to these curves are those of the pilot subjects. Following the first two work periods during which a good deal of time is spent rearranging stores and equipment, these subjects finally attain a surprisingly high level of proficiency throughout the entire third period of work. One example of the consequences of the arrangements or rearrangements illustrates the efficiency of these particular subjects. Whenever the emergency signal was given, the subject was required to pick up his walk-around oxygen bottle and mask and begin breathing from this source as quickly as possible. In the case of the pilot subjects, there was no need for the subject to look around for the purpose of finding his emergency oxygen supply. He simply reached down without looking, picked up the bottle, and completed his emergency procedures. The first subject, on the other hand, took much longer because frequently he would have to hunt for his emergency oxygen system and, having located it, be required to clear a path to it.

Figure 6 reveals the increasing proficiency deterioration charac-

See Figure 6

teristic of the first subject and the remarkable degree of consistency or reliability with which the pilot subjects maintained their high levels of proficiency throughout the second day of flight. It should

FIGURE 6
Hourly Mean Proficiency Attained by Each Subject During the Second Day of Flight.



be mentioned at this point that the levels of proficiency characteristic of these pilot subjects may be regarded as ceiling levels; that is, these levels are about as high as can be attained.

A continuation of the observed contrast during the third day of flight is revealed by Figure 7. Also revealed, in the case of the

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See Figure 7

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first subject, is a phase alteration which began during the previous day. On the first day of flight, this subject was most proficient during the first period of work, 0900-1300 hours. Now his highest level is achieved during the second work period, 1700-2100 hours. During this particular work period, the second work period of the third day, the proficiency differences between the first subject and the pilot subjects was of least extent. During the following work period, however, discrepancy in proficiency between the first and the other subjects resumes its characteristic magnitude.

The alteration in phase, occurring for the first subject on Day 3, is seen in Figure 8 to be continued for the fourth day of flight. This

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See Figure 8

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alteration actually was maintained throughout the remainder of the flight. Finally, the next slide is shown not only for purposes of demonstrating the extreme contrast between the subjects, but also to indicate the extremely small degree of variation in proficiency

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See Figure 9

FIGURE 7

Hourly Mean Proficiency Attained by Each Subject During the Third Day of Flight.

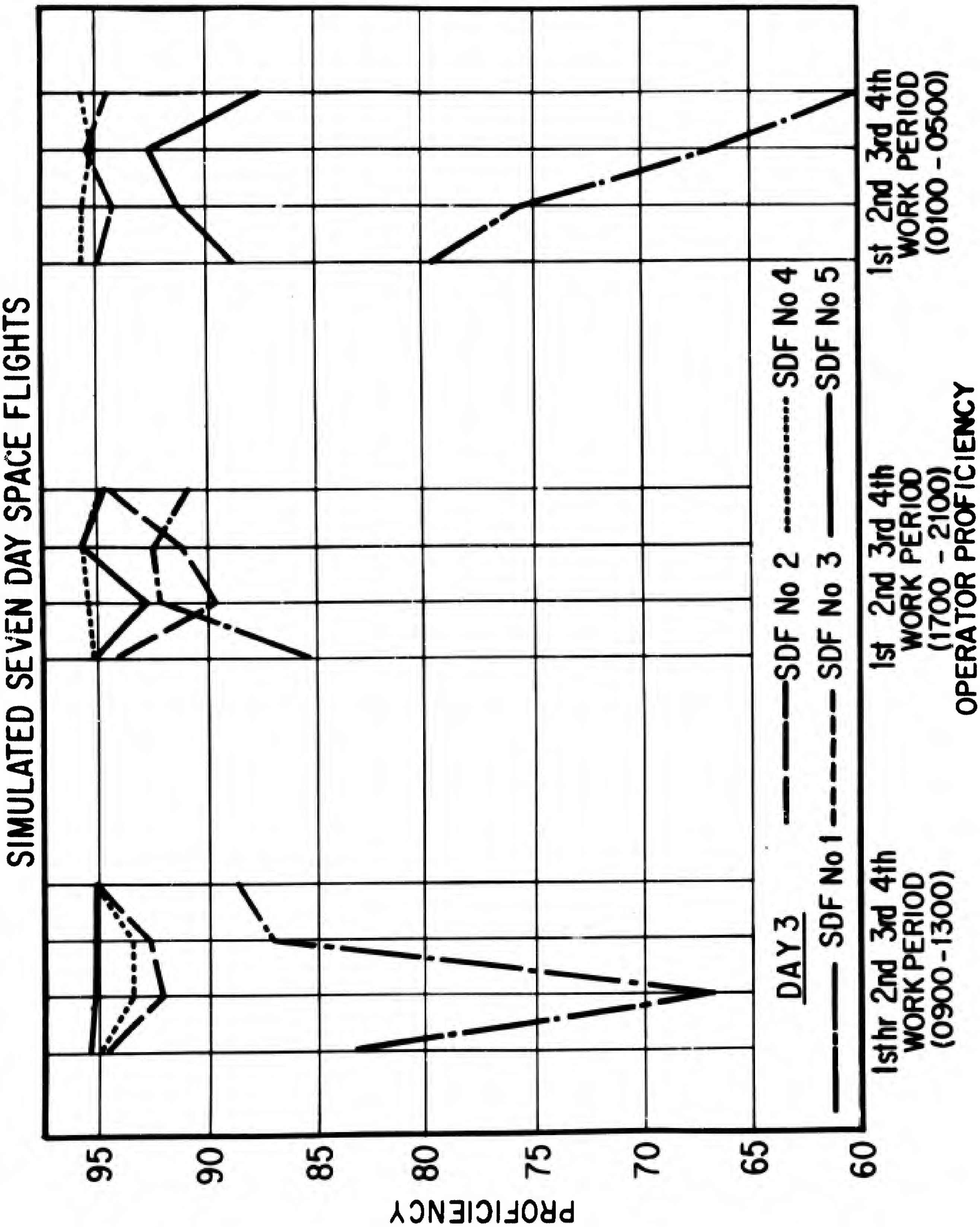


FIGURE 8

Hourly Mean Proficiency Attained by Each Subject During the Fourth Day of Flight.

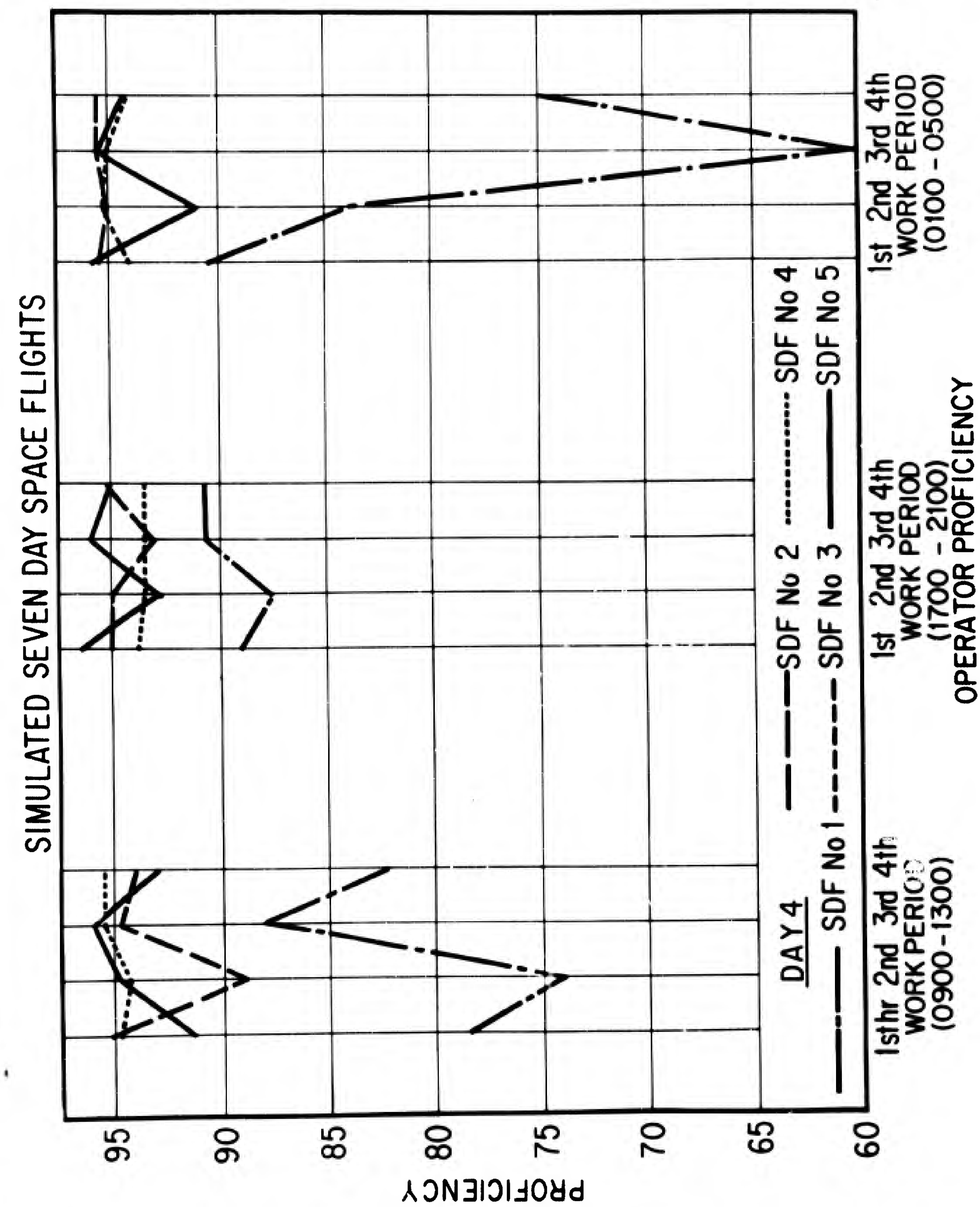
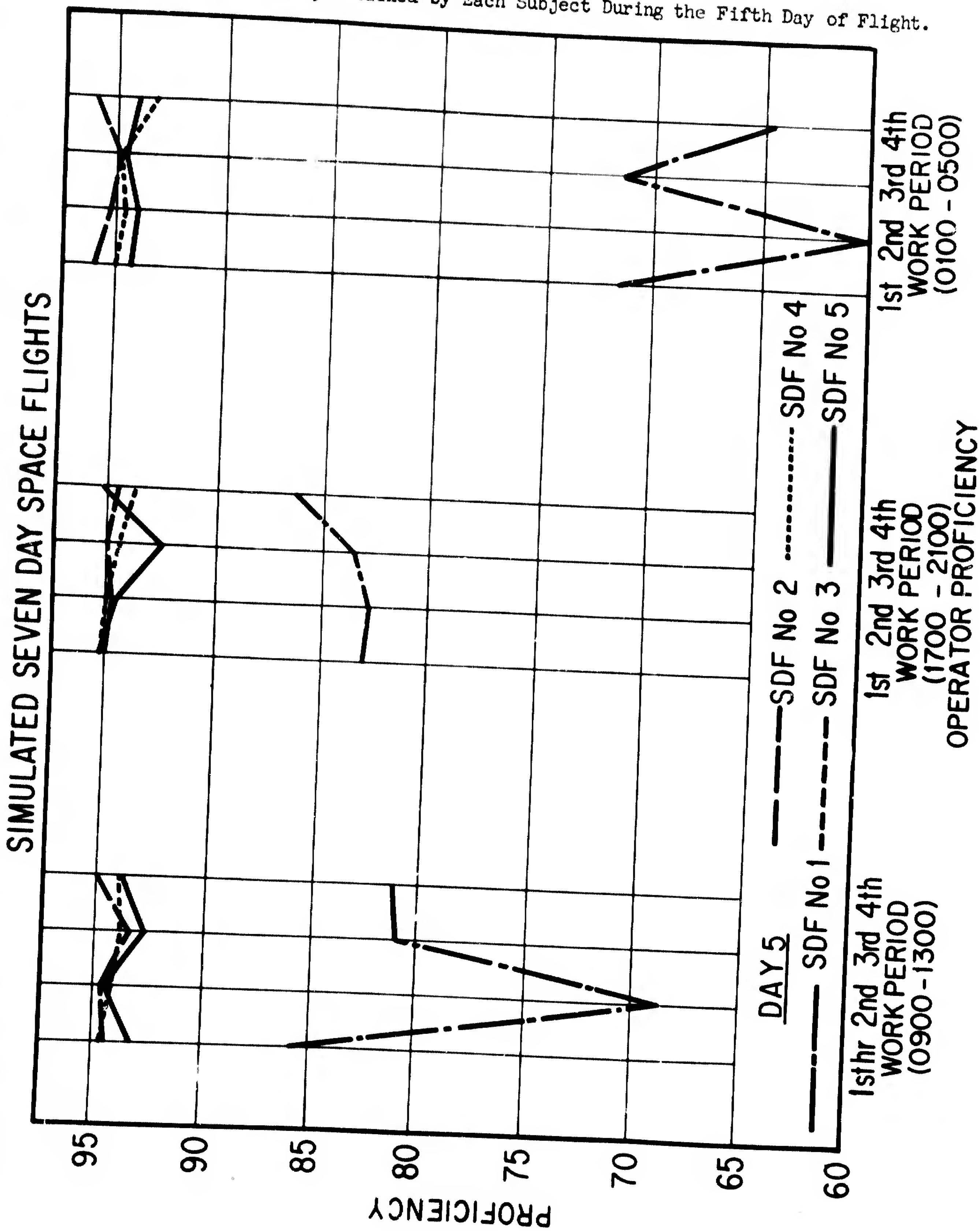


FIGURE 9

Hourly Mean Proficiency Attained by Each Subject During the Fifth Day of Flight.



existing between the three pilot subjects on the fifth day of their flight. It should be mentioned, however belatedly, that one of the flights had to be aborted on the second day because of a fire which broke out within the chamber. It should also be mentioned, hurriedly, that the pilot subject suffered no harm or ill effects.

The slides presenting the levels of proficiency achieved by these subjects during the remaining two days of their flight (2) need not be shown because they merely reveal a continuation of what already has been seen.

On the basis of these curves, it would seem that the pilot subjects did adjust, at least to a substantial degree, to the 8-hour day to which they were committed. Further, in their debriefings, other evidence was obtained which seemed to indicate near or complete adjustment. For example, the normal temporal reference of night and day was lost for two of the subjects. These subjects began to think entirely in terms of four on--four off. They would look at their watch, see that it was 12:00 o'clock, and would not know, unless they looked at their running calendar of work periods and days, whether local time was high noon or midnight.

Observations such as these and the plotting of proficiency means, unfortunately, do not yield definitive information. Accordingly, we are submitting the data, operator proficiency, heart, and respiration rates to additional analyses at the present time. What we will obtain will be autocorrelograms which will reveal for the data mentioned the occurrence of periodicity and, in addition, periodograms which will reveal the period and amplitude of any given periodic function. This work has not been completed to date; however, we can summarize that which has been completed. In the case of the first subject and for the measured function of proficiency, the autocorrelogram confirms, as would be expected, the conclusion that would be drawn following an inspection of the mean proficiency curves which we have already seen. That is to say, proficiency of this subject displays a definite circadian periodicity. The autocorrelograms for the pilot subjects, on the other hand, present far less evidence of clear-cut circadian periodicity. However, before one can arrive at any conclusion concerning these latter subjects, it will be necessary to examine the periodograms which, as has been mentioned, will give the indication of period and, equally important, the amplitude of whatever phasic or periodic function is characteristic of these subjects.

At any rate on the basis of this additional evidence, it appears even more reasonable to conclude that certain of the subjects did adjust most effectively to a drastic revision of their accustomed 24-hour day indicating that under the conditions of the investigation circadian periodicity may be far less restrictive than originally thought.

Why this greater adjustment occurred for some of the subjects, as compared to others, is not known. It is quite likely that one important reason might be attributed to the fact that these particular pilot subjects represent products of an extremely long-term and highly valid process of selection. In this sense, then, they are unique to a general population. Coupled with this is the possibility that long-term exposure to the conditions of their tactical missions may have conditioned certain relevant but at present unknown factors which may be responsible for greater adjustibility. In this connection, mention should be made of work done recently in Holland. Here, Dr. van Loon (3) studied the circadian periodicity of body temperature of three industrial workers over a 14-week period. This period covered one day-shift week, followed by a change to nightshift work, and then a change back to dayshift work. The finding which I should like to single out is that the changes in work shifts elicited individual variation seemingly as great as those that we have seen this morning. "One worker presented an almost immediate switch-over in either direction. For the second one, the process took some days. The third man never obtained a complete regularity in the night-shift pattern." (p. 302) It might also be said and just as properly that the motivation of these subjects may have been even higher than the high level of motivation characteristic of the first subject, and that this might have accounted for the observed differences. Finally, of course, it is quite probable that all of these factors contribute to the differences noted.

More recently, we have made two additional 7-day flights using as subjects volunteers drawn from the previously mentioned population of highly selected pilots. The conditions were comparable with those of the preceding flights save for one exception--the 8-hour day consisted of five hours of work followed by three hours of rest and this was maintained throughout the entire duration of the flight. The following figures, 10 - 16, present the mean proficiency for all

See Figures 10, 11, 12, 13, 14, 15, 16

tasks that was attained by each of the two subjects during each tour of work. A gross inspection of these curves reveals an interesting difference between these two subjects or, more specifically, in their ability to adjust to the 8 hour but substantially more demanding day. The first subject maintained a high and surprisingly constant level of proficiency during the first two days of flight. But on the fifth and seventh days, his proficiency evidences considerable deterioration which progressed in a manner contradictory to effective adjustment. On the other hand, following the first day of flight which clearly reveals the effects of circadian periodicity, the second subject appears to have achieved greater success in adjusting to the 5:3 work-rest ratio and this was continued up to and including the seventh day of flight. This subject, in fact, stated during his debriefing that he could have continued on with additional days of flight had he been required to. Our present plans, therefore, are to make additional 7-day flights of even more demanding 8-hour days; that is, increasing the work period to six hours, and decreasing the rest or <u>ad lib</u> period, to two hours. We suspect that it will be this ratio of work to sleep that will be the tolerance load, as it were, for this highly specific population of pilots.

Practical implications of data such as these require brief treatment. As we come to understand more fully any biological function,

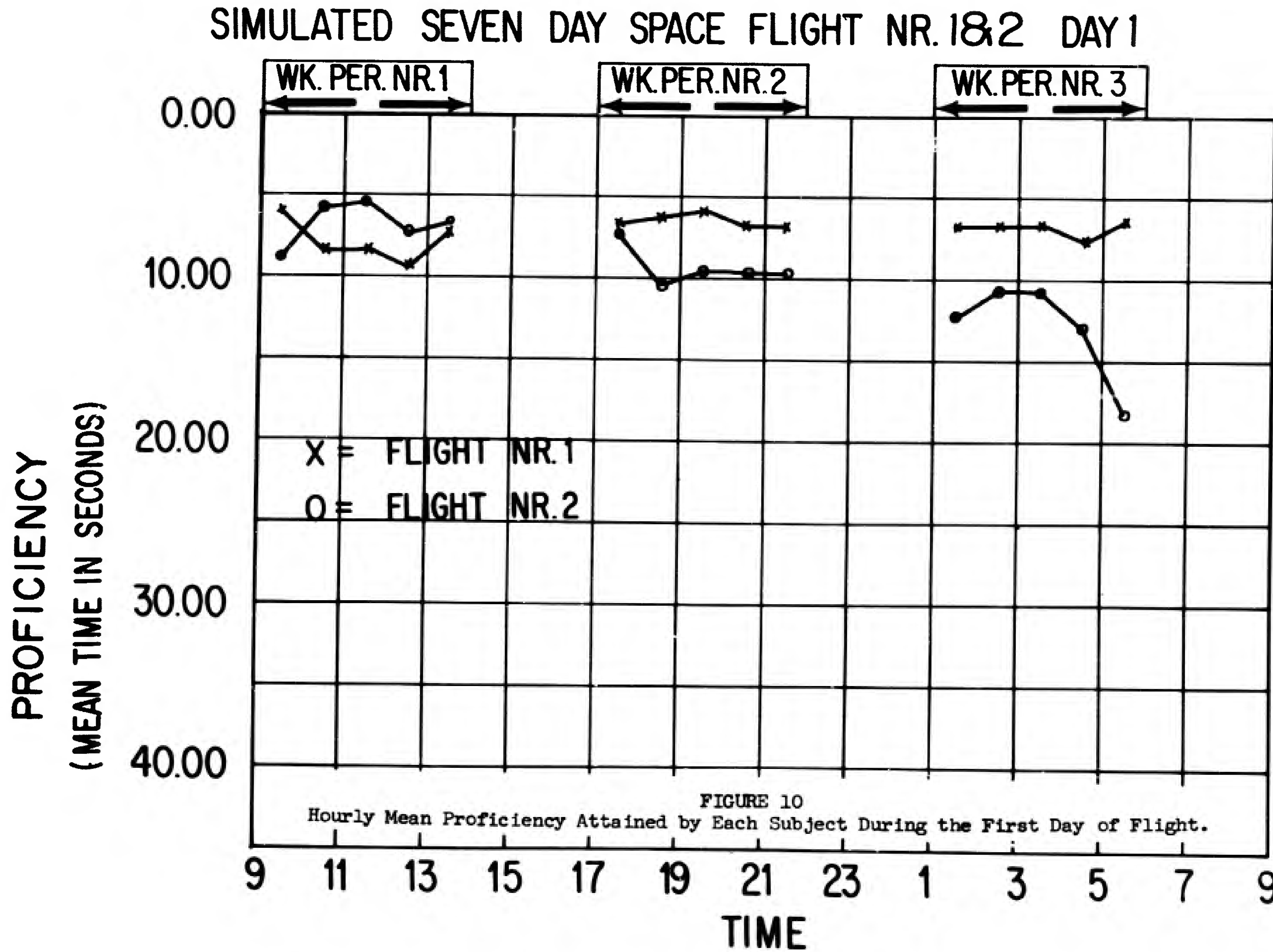


FIGURE 10
Hourly Mean Proficiency Attained by Each Subject During the First Day of Flight.

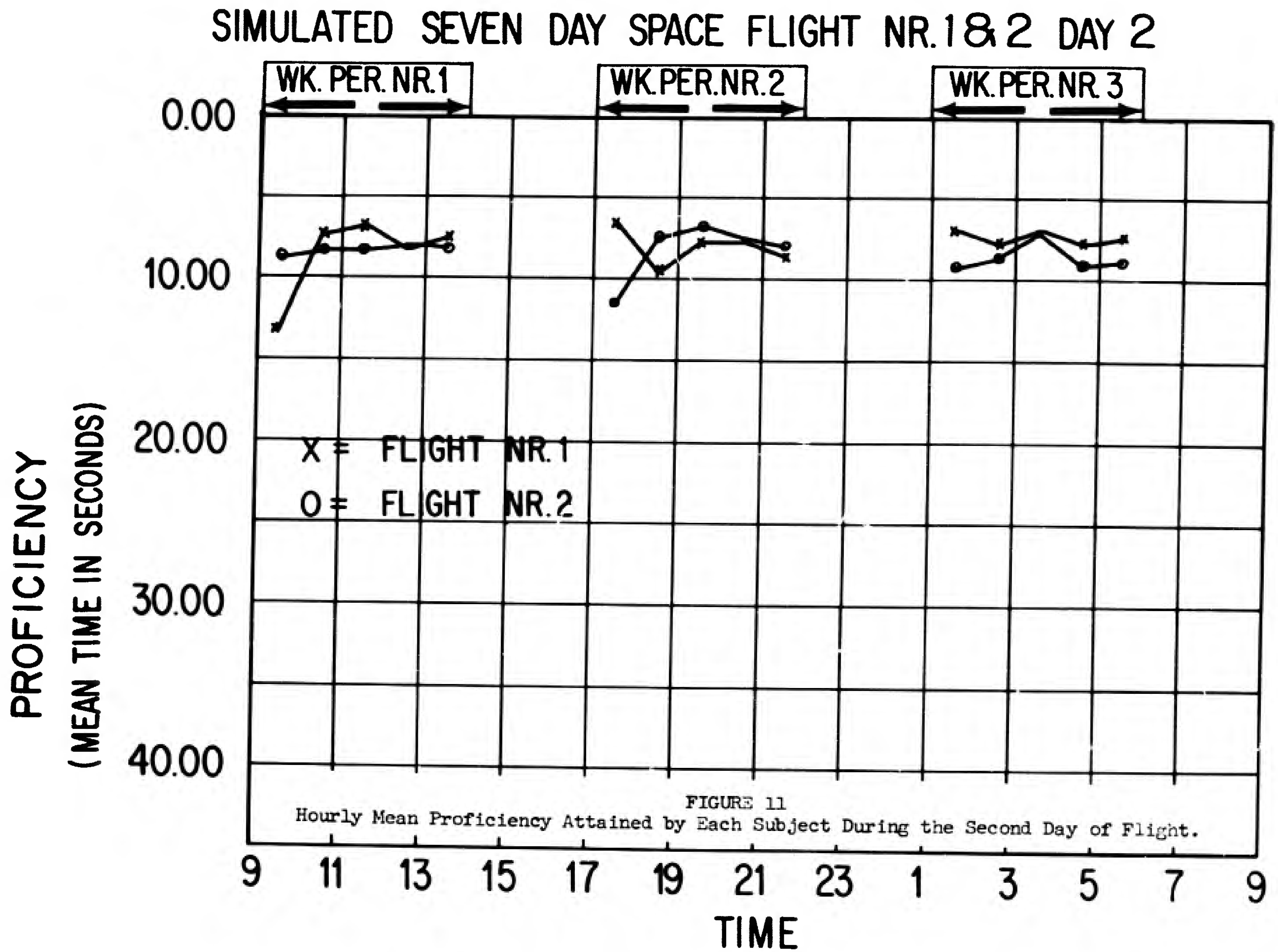


FIGURE 11
Hourly Mean Proficiency Attained by Each Subject During the Second Day of Flight.

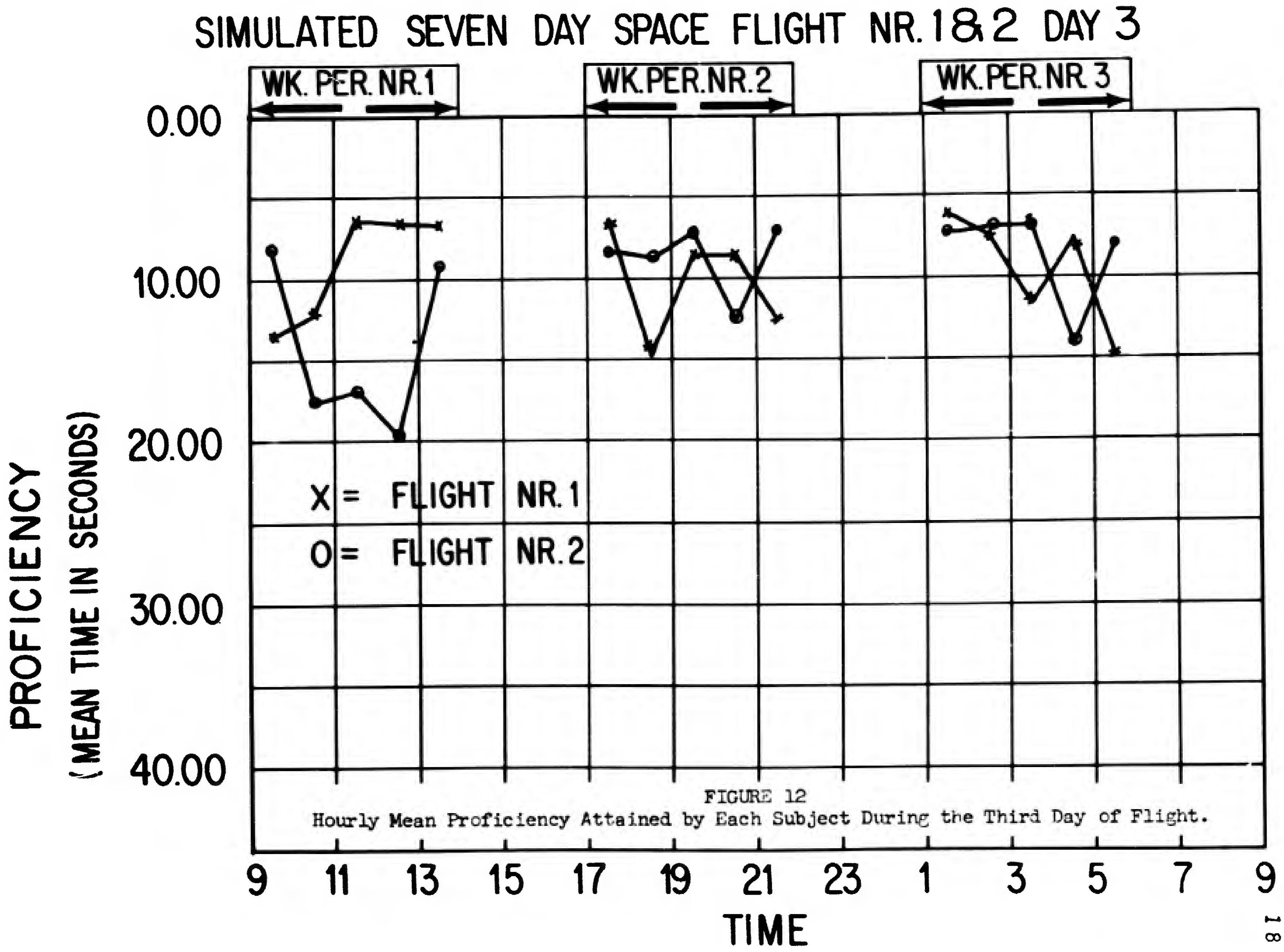


FIGURE 12
Hourly Mean Proficiency Attained by Each Subject During the Third Day of Flight.

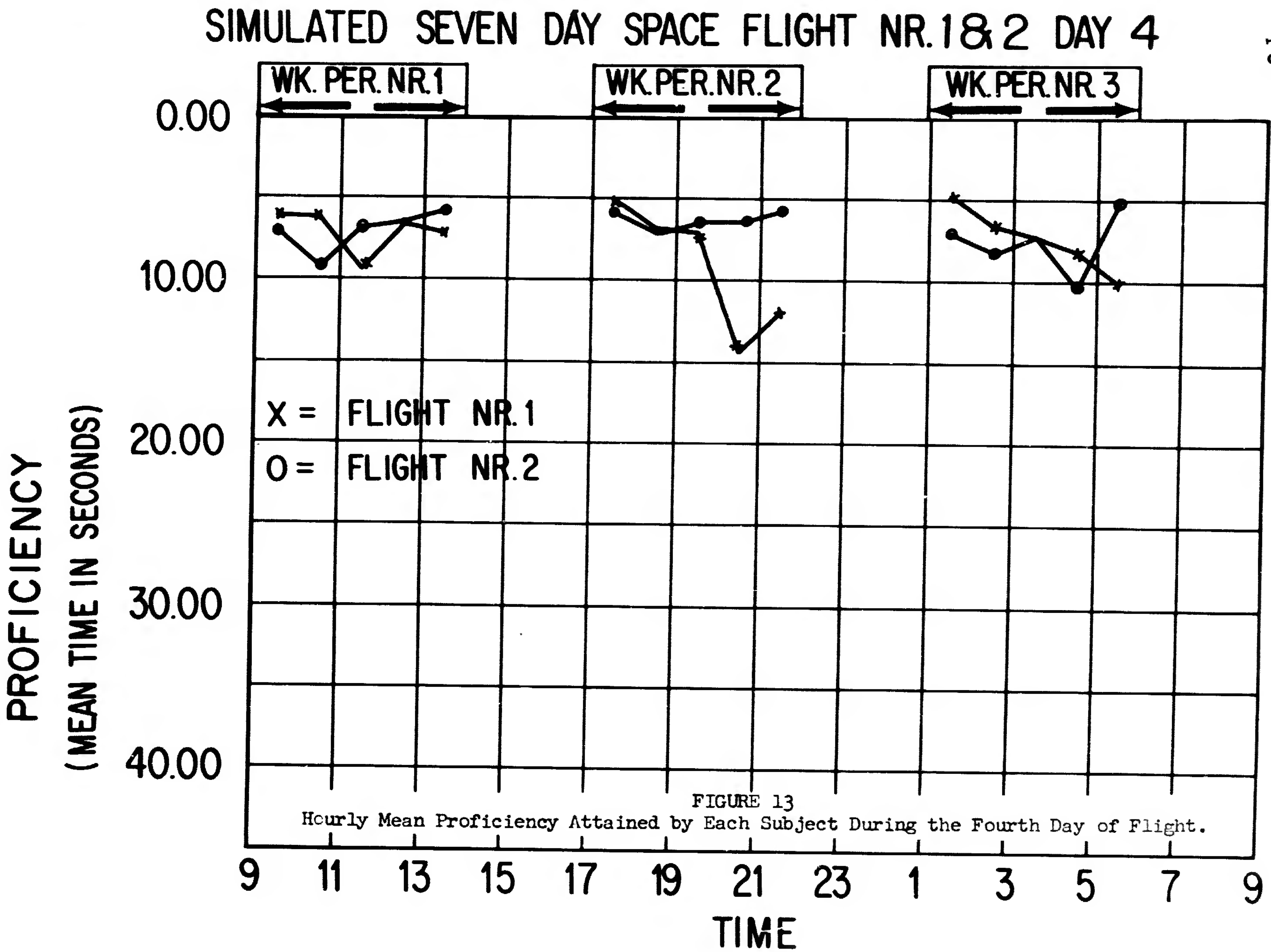


FIGURE 13
Hourly Mean Proficiency Attained by Each Subject During the Fourth Day of Flight.

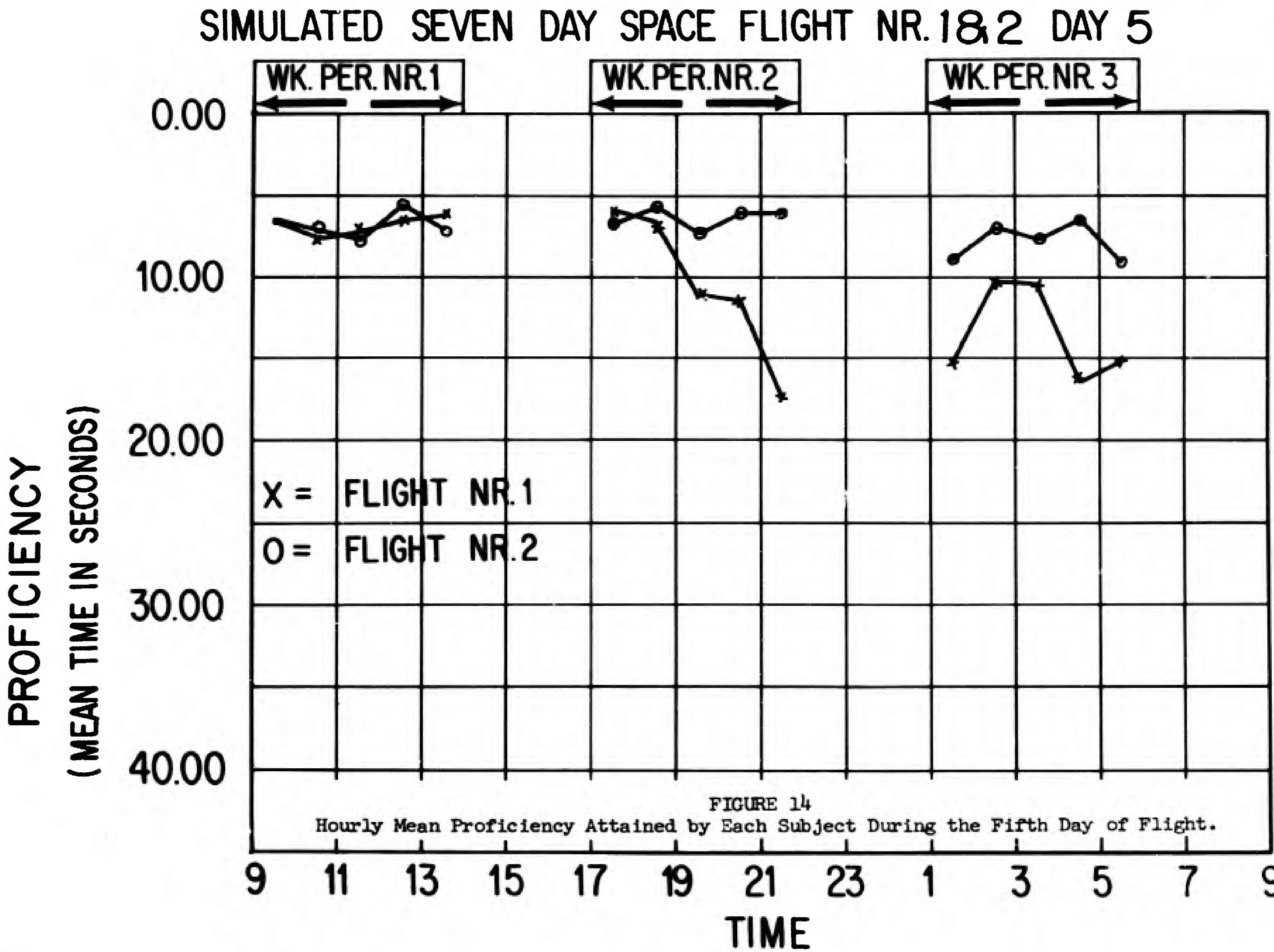


FIGURE 14
Hourly Mean Proficiency Attained by Each Subject During the Fifth Day of Flight.

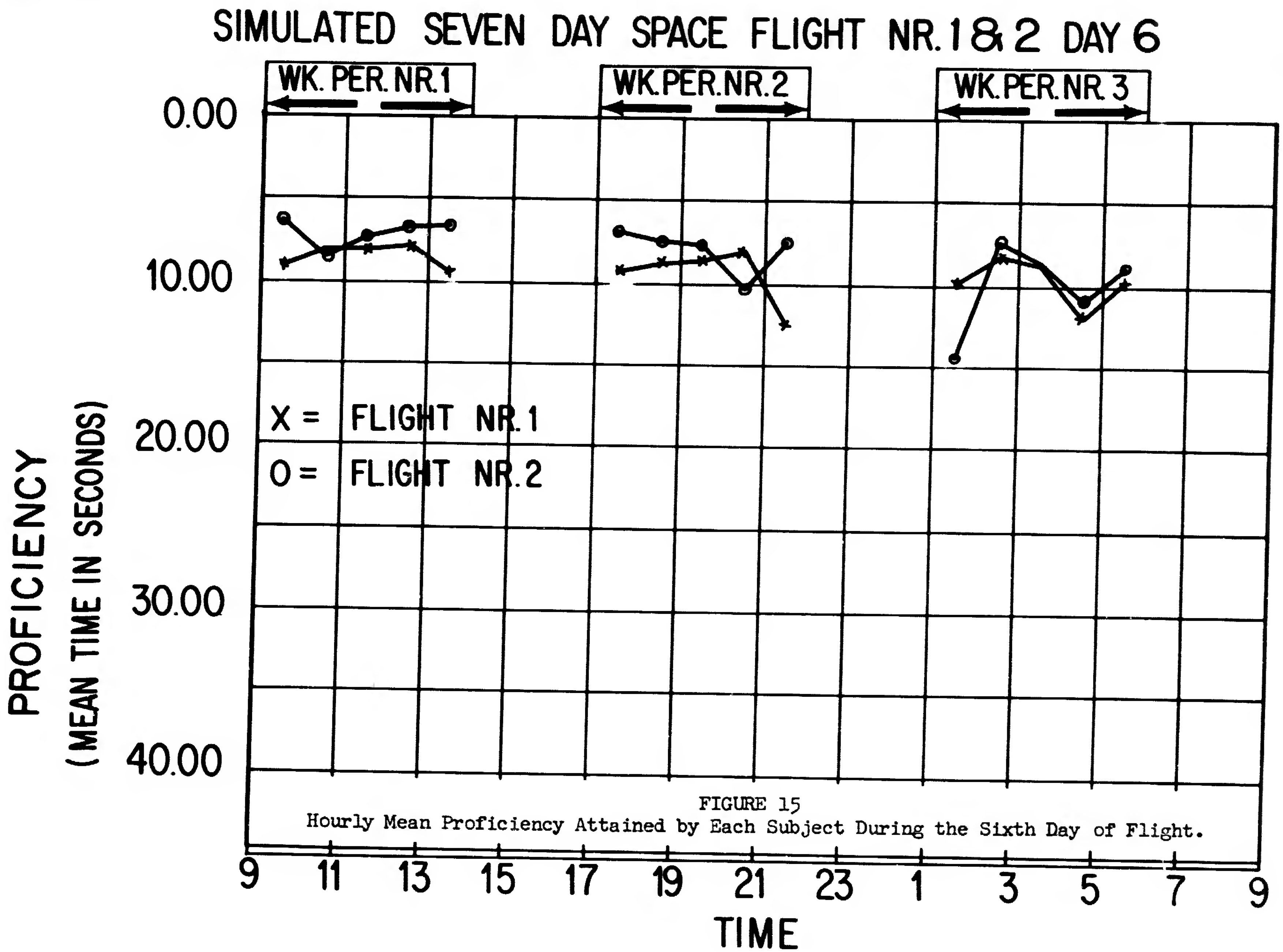


FIGURE 15
Hourly Mean Proficiency Attained by Each Subject During the Sixth Day of Flight.

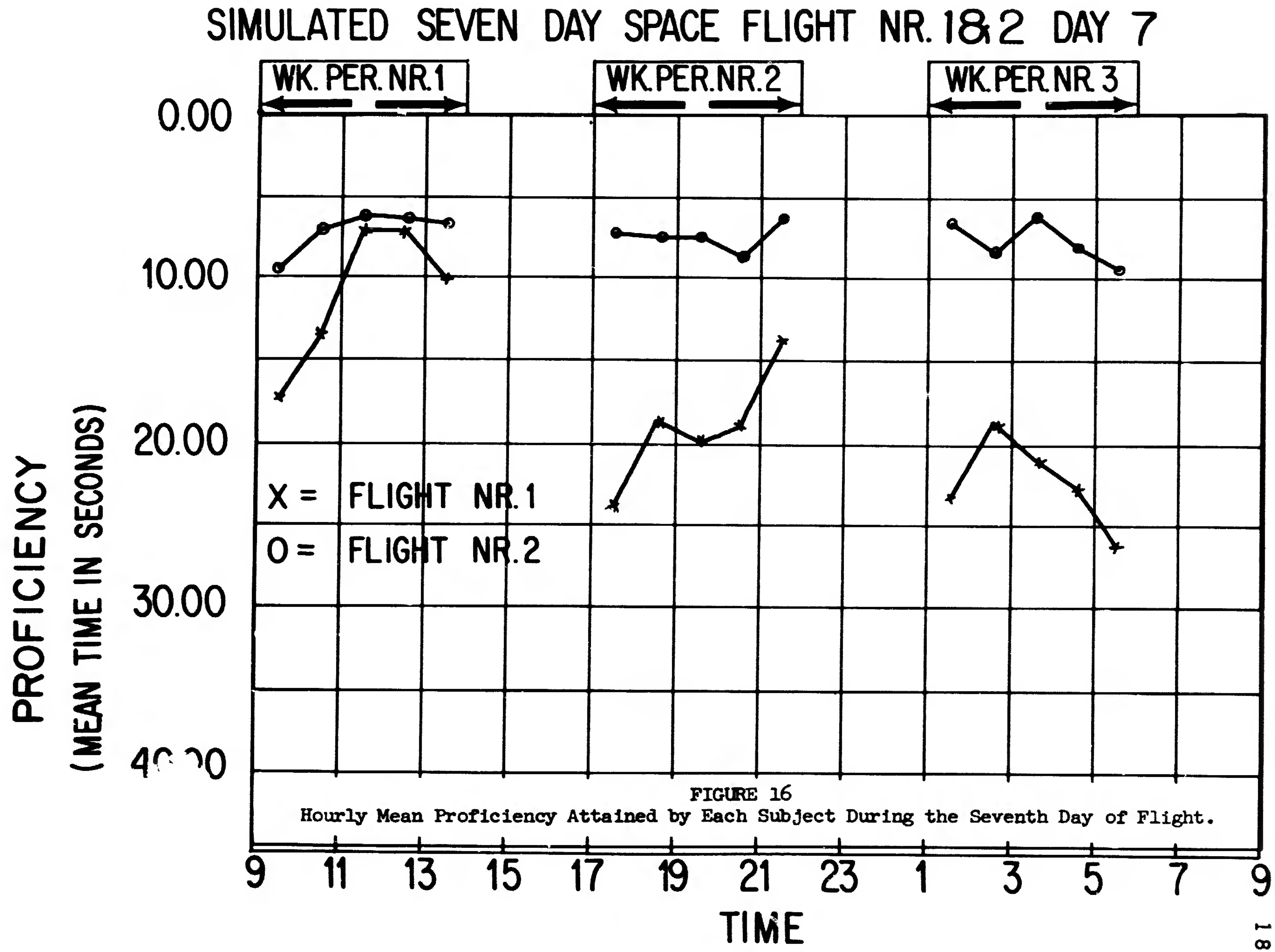


FIGURE 16
Hourly Mean Proficiency Attained by Each Subject During the Seventh Day of Flight.

we can, through manipulation of the organism, relevant conditions, and necessary requirements, mitigate the limitations manifested by the function concerned.

The second problem is that which is popularly termed "sensory deprivation." Early work in this general problem area was generated by interest in the effects of an impoverished sensory environment; specifically, what psychological changes occur as a result of severely reducing the normal input of sensory events typically impinging upon the human organism. In certain of these artifically contrived environments, changes did occur and often with bizarre expression, frank hallucinatory behavior in fact, which ranged from simple to extremely complex forms and in the degree and persistence of reality with which the hallucinatory event was perceived by the subject. Earlier, our interest in the matter was no more than academic. Later, however, a study was completed here at the School. (1) This particular study was not to explore sensory deprivation; instead, it was designed to appraise the restorative effect of d-amphetamine on operator proficiency following 24 consecutive hours of work at a complex operator system. What we discovered was that we had manufactured conditions conducive to an extreme degree of deprivation of sensory experiences. We had required highly motivated subjects to monitor or fixate a small perceptual field of work for an extremely prolonged period of time. As a consequence of this requirement and as time continued, the subjects, in effect, deprive themselves of the ambient sensory events making up the entirely normal sensory environment to which they were committed. Our amazement can be better appreciated if I read extracts from some of the reports made by the subjects following their unusual experience. One subject reports:

> "The instrument panel phased in rhythmically various colors which were subsequently withdrawn after a brief period. Colors such as vivid cocoa brown, beige with abstract blue-green lines throughout, pink, black, dark blue, were perceived at one time or another. These colors would appear to represent the complimentary colors involved in the actual color of the instrument panel /which was black/. At approximately 5:30 A.M., my shoes appeared to be a very bleached color. It was my impression that they had been switched with my own on a recent leave. After the experiment terminated, this bleached color was also perceived toward a navy blue coat. It was not recognized as my own because of the latter shade."

As this particular subject stated, he did not recognize his own coat; in fact, very stoutly denied that the one navy blue coat hanging on the rack was his, and would not take it home. Another subject reports:

> "Toward the end of the 30-hour period, I seemed to be in relatively good shape, reasonably alert...so I was striving with the very best of my ability to increase and maintain a high level of proficiency. Suddenly, the instrument panel began to melt, very slowly at first, progressively faster within a few seconds or minutes, until, finally, my instrument panel was actually perceived to be dripping on the floor. This induced a surprising degree of panic because I was trying to increase my proficiency while having to cope with indicators which I could not read because they were melting, dripping on the floor."

Finally, a third subject:

> "At 11:00 A.M., I began to slow down and experienced a rather frightening illusion. The walls about me appeared to be sloping down to a conical, bottomless pit. I felt as if the instrument panel and I were falling into this pit. Several seconds later, all was normal."

These results made us considerably more interested in sensory deprivation because in manned space operations the operator will be subjected not only to an impoverished sensory environment, but also in any advanced weapons systems he will be required to monitor displays for what may be prolonged periods of time.

Our initial approach to the problem has been of the following nature: four non-pilot subjects, made well acquainted with the likely occurrence and nature of such bizarre or aberrant experiences, were then committed to simulated space flights designed to generate such experiences. These flights were then followed by four comparable flights made by subjects from our select pilot population but who received no prior notice or instructions concerning aberrant behavior likely to be experienced.

Prior to these simulated flights, subject was given instructions and training on the operation and control of the life support systems required for prolonged simulated flight, practice with the operator system, and briefed on the nature of the flight profile. Essentially, the flight consisted of two phases: 6 hours of simulated pad time followed by a simulated flight of 30 hours duration. In the case of the former, subject entered the chamber at either 0800 or 2400 hours and, with the exception of occasional check-outs of instruments and procedures, devoted most of the 6 hours to sleep, reading, or rest. Immediately following this, ascent was made to a simulated 18 M feet altitude and subject was committed to the activated operator system.

The pertinent requirements and conditions of the flight itself were as follows: first, subject was required to perform the tasks provided by the operator system for the entire duration of the flight. Remaining awake was to be exclusively his problem in that no attempt would be made by the ground crews to awaken him. Secondly, at 90 minute intervals which were to be timed by subject, a Transit Report was required. This consisted of verbally reporting chamber temperature, oral temperature, hygrometer reading, and any comments which subject might wish and was initially encouraged to volunteer. The amount of time permitted for such reporting was 10 minutes. With the exception of these reports, radio silence was to have been maintained by ground crews. Failures did occur but only when seriously stressful experiences necessitated reassuring support. Thirdly, visual contact with external surrounds was denied subject and external noise was considered to have been effectively damped by a constant internal noise. As for the other environmental conditions, chamber pressure, as has been mentioned, was maintained at about 380 mm. Hg., partial pressure of O_2 at 150 mm. Hg., temperature below 90°F, and relative humidity below 65%. Since the CO_2 absorbent (lithium hydroxide) was held to a minimum weight (3 lbs.), partial pressure of CO_2 increased gradually as the flight continued. When, after 15-20 hours of flight, the level reached 20-25 mm. Hg., subject was signalled to insert the spare canister of absorbent in the flow system. Finally, the food stored in the chamber was of minimal amount, approximately 940 calories and

350 grams, but nutritious and quite acceptable to the subject. Amount of potable water was 2 liters.

The results to be discussed will be those of, first, the non-pilot and lastly of the pilot population.

During the early half of his simulated pad time, Subject A appeared extremely restless. He would read for several minutes, then arrange stores and equipment within the chamber, listen to music, rearrange again, empty the first-aid kit and replace the items, etc. Finally, at 0400 hours, he tried to sleep but with little success. At 0447, he was engaged in rearrangements. At 0600, ascent was begun.

Considering the duration of flight, imposed work requirements, minimal amount of food, and the other conditions inherent in the chamber, the performance of this subject was of a surprisingly high level. In addition to the obvious effects induced by these conditions were other effects which may have attenuated his capability as the flight progressed. These were the aberrations reported during flight and in greater detail during debriefing. Typical of these are the following extracts of the flight transcription:

> "This is SAM cabin, Terrella 10, date is 8 Feb 59, time is 1825 hours. I've evidently confused the issue a little bit more. I must have given up my 7th pass (Transit Report) at 1800 hours instead of 1830--I'm sure I gave it but I'm not absolutely certain; things are beginning to get a little bit queerish in here now--I'm seeing shadows that aren't there, I'm sure, and I'm beginning to see gremlins on the face of this work panel from time to time. And don't be alarmed if you see me laughing at them now and then--that's all--over and out."

Later, at midnight:

> "This is Terrella 10--Space Cabin to Ground--do you read me? I'm tired. I went through some real flying zero gravity there awhile ago. You ought to stand in this thing on your head for awhile. Do you hear me any better now? I was just talking about some hallucinations I was going through. I really experienced something similar to zero gravity."

During his debriefing, these particular experiences were related in considerable detail. When they occurred, the subject felt himself to be suspended in space within the chamber as though he were weightless, which, in fact, he had previously experienced when serving as a subject in zero gravity investigations. The point of interest, however, is this. During one of these periods when he was "floatint about," he heard the click of the solenoid which automatically activated the camera. This, he reported, pleased him immensely <u>at the time</u> because on the roll of film there would be one frame that would "<u>prove</u>" to all of us that he actually was "floating about."

At 0430 hours, subject made his Transit Report and then was asked:

O - Are you seeing anything else in the way of gremlins?

S - Oh, I've seen a good many of the most comical faces on these guages that you ever saw. I drew a picture of one of them.

O - When do they appear?

S - Well, I could be sitting here off in a daze and then I'll try to focus on the guage and try to read it but I cannot get the reading off the guage because of the face on it. I can't determine between the face and the guage reading. Right now, I can see two beautiful faces--both the same faces on the upper two guages and two different types on the bottom two guages.

O - Are they talking to you?

S - No, they look like wooden puppet heads--not moving--
they're rigid and on the guages, and the more you
imagine it, the more perfect they become. I could
pretty well draw them from memory probably tomorrow--
just how this thing looks. I've seen a lot of shadows
along in the cabin--I don't know how to explain.

One particular type of aberration which was regarded by subject as having interfered with his execution of the operator tasks was that of size distortion. These were persistent and, for the most part, entailed his hands and feet. At times, the former would appear to him to be as large as the control console and, consequently, he experienced difficulty in operating specific controls. Finally, he found it necessary at one point to leave his tasks unattended for several minutes so that he could crawl under the operator system to explore the frightening "12 foot deep" hole which had opened up in the chamber floor.

Subject B entered the chamber at 0800 hours and, during the subsequent 6 hours of simulated pad time, conducted himself in a manner typical of the other subjects as is revealed by the following extracts from the observer's protocol:

0840 .... S is sitting quietly--slumped in his seat--reading.

1100 .... S is sitting quietly--reading.

1250 .... S is slumped down in seat--eating.

1336 .... S has thermometer in mouth.

1341 .... Thermometer out--S is writing in log.

At 1400 hours, ascent began and the operator system was activated. Six minutes later, subject reported difficulty in obtaining good definition in the televised picture of the display console of the operator system. "...It's still hard to pick those meters up. It's not like it was yesterday /indoctrination flight/. It's not as clear but that doesn't make much difference, the meters are pretty hard to pick up." At this point, the above televised presentation was viewed by one of the observers through a peephole and judged to be of normal quality.

1410 .... S places sign in front of camera (camera televising his image to ground station monitors). "I can't get the meters to look right."

1413 .... S still adjusting focus--appears perturbed.

1419 .... S removed sunglasses--has cap pulled low shading eyes--has glum look.

1425 .... S replaces sunglasses--has right knee propped up--facial expression of pouting.

1428 .... S takes off sunglasses--puts on regular glasses.

1500 .... End of first hour--S has been somewhat restless--continually moving about in seat--removing sunglasses and replacing with regular glasses--appears to be settling down now.

At 1530, subject made his Transit Report:

"Time is 1530 hours--relative humidity is 42 percent--cabin temperature is 83°F--body temperature is 98.6," and then volunteered: "I don't know if it is my eyes or the monitor--I can see the lights /signals/ now but I can't see where they are. Can't figure it out. I can see it but I can't make out the letters real good unless I get it /the monitor/ close to me. I have to get it almost on top of me to make out what the letters say." When asked about his eyes, subject reported:

"They don't hurt but it makes a haze--sort of mixes up the letters--blurry."

Subject continued to report visual difficulty so was instructed to lean back, close his eyes, and rest. He complied accordingly but 10 minutes later picked up the microphone to report: "I've got to get out of here--this blur in my eyes--I can't take it anymore."

Descent was begun at once and when subject emerged from the chamber, he immediately requested a private talk with the author. Once in the recovery room, S asked if he could be taken to a psychiatrist right away so that he could "...find out if I'm any good at all or just what's wrong with me." He then stated that his eyes hadn't really bothered him--that was just an "excuse." The "real reason" was that the walls were closing in on him.

Subject C entered the chamber at 0030 hours and dozed for the greater part of the 5½ hours of simulated pad time. Throughout the early half of the subsequent flight, his spirits were excellent as judged from facial expression and the jocularity of his Transit Reports.

At the end of the 22nd hour of flight (0405 hours), the operator system was deactivated by the observer because subject suddenly shouted:

> "...it's real hot, tell them to pull it out. The TV set. It's still on. The TV set--it's turning all brown--the one sitting right in front of mee--right in my face. Better turn it off in a hurry--it's getting hot as hell!"

And, then, held a blanket up to protect his face. The observer quickly uncovered the chamber port to view the TV monitor and, upon discovering nothing unusual, reactivated the system and proceeded to allay subject's anxiety. He was not at all successful.

> "...I don't think I want to be in here with it, to be honest with you. That brown spot is still in front of it. It seems twice as hot as it was before. I'd pull it out, I really would. Maybe those television guys know more about it, but I'd pull it out. I really think the thing to do, if we had another TV set, maybe lower the thing /descend/ and get the other TV set, but why don't you go ahead and turn this thing off and call the boss man. I'd hate to have this thing catch on fire in front of me--it's brown--about 3/4ths of it has turned brown. The picture is not good either--it would be pretty hard to see anything with it that way....Is there another one down there? Why don't you have those guys pull this damn thing out....I don't like to sit here facing it. Couldn't we get one up fast to bring in here? A TV set would do it, wouldn't it? I'd just as soon stay in and finish this 3 day run if we could get another TV set. I'd hate to come out now and get another one of these things later on. I'll tell you, I sure don't want to go on with this television situation, I don't believe. I'm pretty skeptical with this thing sitting here in front of me. Is one of those television boys here? What do they say about it?"

The system was deactivated again and the television technician attempted to explain to subject that the monitor was functioning properly and, moreover, what subject thought was happening could not possibly occur, particularly since the monitor had been modified for operation at high altitude. This explanation also failed to achieve the desired effect, so the observer inquired if subject wanted to abort the flight.

> S - "Listen--this is the way I feel about it--but I volunteered for this thing. I didn't volunteer to sit in front of this thing or tube that turns black in a matter of seconds and got hot as heck. Now, unless somebody can tell me what made it do it, because it is going to do the same damn thing over again, darned if I'm going to sit here in front of that thing. Seems to me if we could get hold of another set, I'd like

to go on with this flight, but I'm sure dead set against volunteering to sit in front of that thing. I'd hate to abort the flight as much as anybody, but I'm not about to sit in front of that thing if it is about to explode--I don't know what they do, but if you can't fix it, the same thing is going to happen again. That would be just poor sense."

O - You don't want to continue the flight?

S - I'd like to continue the flight but I don't want to sit in front of the tube unless you all can find out what is wrong with it and fix it. I want to go on with the flight, in fact, I want to go on with it more than anybody because I've spent all this time in here, but I think it would be kind of foolish to do that....I think there's got to be something wrong. If you all can find out what it is, maybe it won't hurt to come down. Ask the Colonel, maybe they can fix this in a hurry."

Later, subject asked how he could disconnect the monitor.

O - ...Anytime you want to turn the set off, just turn the switch and it will turn the power off on the outside--we will turn the set back on for you, and if you get worried, all you have to do is just reach up there and turn the set off.

S - Ask those guys just one thing. Will these tubes explode?

O - They will not explode....I feel that under the circumstances we'd better not turn the set back on. You can just sit back and relax.

S - No, ask them what happens to them. If they don't explode, I'm not too much afraid of a fire because there's not much to burn here, but what I am worried about is the thing exploding. See, I'm only about a foot away from that thing, facing it right in the eye.

O - ...We're not going to turn this thing on for awhile.

S - Okay. What are you going to do? See if you can find anything wrong out there.

O - We've checked and can't find any difficulty--you just go ahead and relax--we're not going to turn this thing on.

For the next half hour, subject rested until 0455, at which time he shaved, combed his hair, and engaged in a variety of minor activities. At 0555, after having been given sufficient reassurance, subject agreed to resume work at the operator task and the system was reactivated.

0605 .... S is working well--looks very alert.

0700 .... S is still working well.

0810 .... S is chewing gum and working intently--looks through the top of his glasses at the TV monitor.

0820 .... S has removed his glasses several times--looks around--peers over the top of them.

0833 .... S picked up mike and held it as if he were going to talk into it--however, he made no comment.

0835 .... Removed glasses--stared intently for a few seconds--looks kind of wild-eyed.

0843 .... S is peering over top of glasses.

0857 .... S is speaking into the mike--wants observer to look into porthole--states that he now knows why the monitor turned brown.

At 0902 hours, subject was informed that descent had begun and continue at a very slow rate until ground level was reached at 1200 as was planned. He was informed further that:

O - This is ground. Do you have any further questions? This is the last contact we will make with you. We are going to stop all contact. We are going to get back on our schedule /of radio silence and transit reporting/ as originally set up, okay?

S - Okay, fine. I'll keep working.

Eight minutes later, subject was highly agitated.

S - Hey....We are back on the ground, aren't we? I was going to show....something before we took this puzzle off the screen. He probably thinks I'm nuts or something because I called him out here this morning, that's when I was trying to figure out what was happening. Look in the back window by the screen, will you? Well, I think what happened is whoever was taking the picture...something got real hot causing the fumes to go up around the paper, etc., and I thought there was a fire here in the TV camera--it still looks like it--I wanted to show it to him so he wouldn't think I was crazy or something, but with the picture on here it's here, and I bet you with that picture off of there you can't see a thing on that screen, and I was about half scared to death when I saw that. Okay. Come back here to the screen, I want to show you. It's just soot or something--a burned place--you can see it by looking in the back here.

O - Okay, later....

S - No, no--hey, I'm telling you this screen here is perfect. I agree with you. There's nothing wrong with the screen. It's over there where they're showing it--you've got to look, I'm not kidding, you haven't seen this back here. I'm not psycho. I know you think I am. If you'll come back to the back window here, it's fuzzy yet--but it was like that--you could see the heat coming up from it....

O - What I want you to do is to describe everything--anything you see--for the duration of the flight.

S - Well, look, I'm not going to do anymore work. Now look, you're worrying me to death now because I know you probably think I'm psycho or something here.

O - We will discuss all this when the flight is over.

S - Well, look, come back here because it is here now, no kidding. It's got to be. I'll tell you where it isn't. It isn't in the center where the little matching diagrams are. That's...it wasn't on the screen when I saw it in there. But in between...it's not there--it's just up in this area. Can you see that? That's what had me fooled before and I could see the heat fumes. You can see the heat fumes a little bit now. That's what had me scared to death. I thought it was the screen, the gases in the picture tube, something was wrong with it, and I was so darn

> sleepy this morning I was trying to work the puzzle and I saw that and it scared me. But nothing is wrong with me, my goodness, I'm okay. This flight didn't do anything to me. That's the truth. If you come back here you can see it now--the way it was before, it was even worse than that, but it was the focus. I thought it was going away, but it was the way I had it focused, but it isn't in the middle part.

From this point on, subject ignored the operator task. His heart rate which had ranged from 80-88 at the outset of the flight was now 120. From time to time, he attempted to reestablish verbal contact.

"Could I please come on down and talk to you all?

"I've been here for 3 days--I'm awfully tired in here. Could I please come down to the ground? I also have to go to the john and I can't go in here very easily."

By 0957 hours, reestablishment of verbal contact was necessitated by the seemingly severely depressed state of subject.

S - Can I come down now?

O - Well, we've got two hours to go here, don't you want to finish it up on schedule?

S - Yes, but if you or somebody wants to talk about hallucinations, I sure want to get that over with because it worries me.

O - Well, as soon as you get out, we'll have a cup of coffee and we'll go over this thing and discuss it. Do you feel that you can go ahead in there and complete the work cycle?

S - I'll tell you. Unless it's important for reports, I feel real miserable in here thinking about it. No kidding, I'd sure rather come on out.

O - Well, this is important. Now, then, if....

S - Well, I don't really feel like it--I just don't feel like it.

O - Well, how about then we ignore the work program and you just sit back, close your eyes and relax while we continue the descent and termination of the flight.

S - Can I come on out of here? No kidding. I feel miserable here. I just couldn't stay in here. Really.

O - We'll bring you down a little faster. We'll get you out of there as soon as we can.

S - I'd sure appreciate it.

O - All right. Now what I want you to do is--I want you to be very careful about your ears. Okay, now here we go....

O - The time is now 1010--1500 feet altitude. We're almost back to ground level. We can see subject is already getting ready to crawl out of the chamber. His heart rate is now up to 130 beats per minute.

Subject emerged with a weak, fixed grin and was brought to the recovery room for his debriefing.

Several points concerning the experiences of this subject must be reemphasized. Prior to his flight, he had been made well aware of the probable occurrence and nature of the aberrant behavior that he might experience. Nevertheless, when he did perceive the television monitor turning brown, he did not regard this as an illusory event. He accepted it as being real which was reinforced by his natural apprehension of fire hazard. Further, this reality persisted for two or more hours which had the effect of prolonging his highly disturbed stat . Later, a great deal of confusion was introduced when he began to determine in his mind just what had happened to him. And when it appeared to him that he really wasn't certain what had happened to him and, furthermore, that the ground personnel might be having some doubts concerning his functional integrity, he became even more disturbed and had to be taken out of the chamber. The net effect of all of the foregoing was to render ineffectual an otherwise completely normal, healthy, and highly effectual young man.

Subject D entered the chamber at 0800 hours and, after checking out instruments, dozed for about 3 hours of the simulated pad time period. Ascent was begun at 1400.

From 0100 to 0600 hours, subject appeared quite sleepy but by continually resorting to extraneous activity, such as singing, snacking, exercise, etc., he was able to remain awake. For the next 4 hours or so, he appeared to be considerably more alert. During this period, he recorded the following in his log:

0630 .... 11th pass. BT-98°, RH 63%, CT-80°. If you are looking for hallucinations--the bottom meter could be a kitten or a human--but it's really a meter!

0800 .... 12th passover. BT-98.5°, RH-65%, CT-80°. Was hallucinating some, i.e., top and bottom meters resembled Indian faces--white marks on top resembled chief--gone now.

0930 .... 13th passover. BT-98.6°, RH-58%, CT-80°. I feel pretty good now--not rested, but not sleepy either. I think I am doing quite well on the work panel /operator task/ now.

1100 .... 14th pass. BT-98°, RH-53%, CT-80°. Meters still look like faces once in awhile, but that's all.

1230 .... 15th pass. BT-97.9°, RH-50%, CT-81°. Having to keep moving to keep from going to sleep. This next 7½ hours will be rough. When I get a real fixed stare, I see a wooden man made out of two meters.

By 1300 hours, subject was extremely sleepy and would doze for 10-40 second periods. Upon awakening, he would slap himself to remain awake. Finally, at 1446 hours, subject fell asleep and remained so for 30 minutes. He awoke spontaneously and, upon seeing the signals on the operator display console, attempted to resume the operator task. For several minutes, his efforts were completely ineffectual due to his extreme confusion. Ten minutes later, still somewhat confused, subject missed his Transit Report. From this point until the termination of flight, subject alternated between short periods of grogginess and alertness achieved by activities designed to keep him alert.

Only one additional point of information was obtained from the debriefing of this subject. He professed to have no recollection of having ever fallen asleep and when told that he had done so frequently, he was then asked to estimate what his longest period of sleep might have been. He replied that it could not have been more than several seconds.

In comparison, the experiences reported by the four pilot subjects were far less dramatic and only two of these subjects reported what may be considered significant events.

Subject A reported:

O - How about this vertigo now you mentioned yesterday. Will you explain that?

S - Well, I'm sitting there and I'm about half asleep and I'm trying to fight this sleepiness, and your eyeballs want to go this way and you know you're sitting straight and level and you can't look outside and I just had the impression several times like I had vertigo. You'd be up in this attitude or that attitude and you can't look outside at that thing and you have no visual horizon, not even an artificial horizon. I've had vertigo flying instrument conditions. Usually all I do is, when I do get it, is level the wings up and look down between my legs and just about 1 - 2, like that and then come back up to the instruments and then I'm all right.

Subject B reported:

S - ...As I told you before, figures--after I'd been on the panel for awhile there were all kinds of figures come out on the instruments. I could make out the shapes of different things.

O - Such as?

S - Oh, your dialed instruments. You can see a face or--it isn't looking at the dials and seeing it. It's the whole thing going together on you and making one. I don't know how to explain it--it's real funny. Also, on my radar pattern, I don't see things there but I lose my presentation every now and then, if I get to staring at it too long after I've been in there awhile. The only thing I get is a black and white contrast rather than having the clear presentation of a figure as it comes out, but if I move around the room and look away from it, I can look back and I have my presentation again, but if I start staring at it, it seems to have a black and white contrast. It all won't be anything particularly. I can line up the two contrasts and make them look alike but I don't have a figure to work with. It might be weird, maybe it's just me being able to stare at things and make them distort themselves, but I can do it.

O - Did this occur during the first part or the last part?

S - It's always after I've been in there looking at it a long time before it ever occurs.

O - About how long, very roughly?

S - Oh, the last time I don't think it happened until I'd been in there three or four days, but this built me up to the panel. This time I don't think it started happening until this morning on me, it started distorting as I'd stare at it and come up with unusual shapes and things, but I can always get rid of it just by looking away, work at another portion of the panel or something and come back to that portion. The lights never bothered me. Where the light portions are, these are always just lights and there's no subterfuge with them, but some of these other things, there can get to be some weird looking change, especially those meters. It always seems like I get a figure out of them right around the dial itself. This time, for some reason, don't ask me why, it looked like it might be some type of African savage all painted up around it's face and forehead where would be the needle in the outline of the things, and it fit right in real fine.

O - Well, then, from what you say, I judge that this does not bother you particularly.

S - No, in fact, the last time I was over here was the first time it had ever happened to me and I guess it's a certain fatigue factor. I don't know what it is. Maybe it's my vivid imagination, of which I have one, or maybe I do this unconsciously. Normally, when I see a pattern of some type, I try to make something out of it in my own mind. Maybe subconsciously I go ahead and make something out of these, but I realize it and it doesn't interfere with my work. It gets irritating at times though. I'm sitting there and looking at it and I thought it would be so much nicer and clearer if I could forget these things are there and get rid of them. And I can, I can look away and come back at them and they're clear and then after I'd stare at them awhile the damn things would come right back up again.

O - Well, did this persist through this afternoon?

S - Uh huh, oh, yes, it would persist as long as I'm--after I've been staring at them for a long time. It's never happened in an airplane....

Because of the small samples we will have to run additional flights before we can answer fully the questions which we set out to explore What does seem to be indicated, thus far, is what might have been predicted. In contrast to the normal sensory environment characteristic of the early fatigue study, the impoverished sensory environment of the Space Cabin Simulator resulted, additively or synergistically, in aberrant behavior that was more disturbing to the subjects. This would seem to indicate the necessity of repeatedly exposing astronaut candidates to such simulated conditions prior to their flights.

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AEROSPACE EMERGENCY

AND ESCAPE PROCEDURES

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INTRODUCTION

During the course of man's existence, and as a direct result of his technical ingenuity, the roads on land were traveled at increasing speed once the wheel was invented and supplied with motive power; the sea lanes were traveled faster once the floating body was discovered and imparted a thrust device; the air routes were opened by the balloon and the supporting wing with their elementary propulsion systems. Today, man is seeking to create a fourth type of locomotion that will separate him from his terrestrial habitat and enable him to navigate in the near vacuum of interplanetary space. The venture will expose him to an environment which is alien and hostile to his physiological and psychological requirements. Moreover, the human organism has changed but little during its known existence and certainly cannot be expected to vary on a time scale compatible with technological developments. [4] Adaptation can therefore be expected to make only small contributions to survival. Further, if man were to wander unprepared into the void of space, exposure to cosmic radiation, bombardment by meteorites, and extreme pressure differentials would surely reduce the adventurer to a state of "space debris." Successful penetration of this new frontier will depend on space ship duplication, or at least approximation, of the many protective functions of the earth's atmospheric shield.

The manifold requirements attendant to such a program are clearly indicated by the scope of the many research and development programs now in being which have as their combined objective the solution of problem areas which are unique to the space venture. The total program, while still in its infancy, has a multitude of facets. Some, well defined, will be served by extension of current practices, while others will require advancing the state-of-the-art for solution; still others are anticipated vaguely or are wholly unknown.

It is unwise to become completely divorced from total program objectives and thus ignore the related effects of the many facets. Certainly that is not intended here, where the subject will be limited to emergency and escape procedures applicable to the various phases of a representative aerospace mission.

INITIAL CONSIDERATIONS

Fundamental to the problem of incorporating emergency and escape equipment in any vehicle of locomotion is a definition and careful analysis of conditions under which the vehicle will be operating. Particular emphasis has been placed on development of personnel protection and emergency escape equipment for flight crew members as the performance of the air vehicles has been progressively improved.

During the early phases of flight, the hazards involved were primarily attributed to potential energy associated with elevation above the terrain. A malfunction of the machine which resulted in uncontrolled flight required that the responsibility for crew transportation from altitude be transferred to a parachute. Increased speeds inhibited the "over-the-side" procedure for crew and airplane separation and thus generated a requirement for the ballistically propelled ejection seat. Still greater extension of the performance envelope required that attention be directed toward control of force systems during dissipation of the energy levels imposed on the escape device by a high velocity airstream. Figures 1 and 2 are indicative of the progress that has been made in attenuating deceleration forces by the addition of effective aerodynamic stabilization devices and maintenance of a desirable drag-weight ratio for the escape system.

Flights in areas of low ambient pressure necessitated the addition of pressure protection for the escape system occupant. A pressure suit worn on the crew member's person was the initial approach and is incorporated in currently operational systems. The more sophisticated devices proposed and currently under development for advanced manned weapon systems effect a transfer of responsibility for occupant environmental protection from protective personal equipment to the mechanics of the escape system.

Human Limitations

Prior to an assessment of escape requirements and provisions, it would be well to review at least the fundamental limitations of the unprotected human body. The physiological effects of varying energy levels are sensitive to either magnitude of change or rate-of-change, and in many cases a combination of both. The limits of human tolerance to the many important variables are not completely defined, although there are accepted criteria which may be utilized as a guide in equipment design.

Figure 3 is a graphic presentation of acceleration versus time tolerance for various directions of force applications.[7] This parameter is of particular importance during all phases of the emergency escape sequence including escape system propulsion, deceleration, recovery, and ground contact. It is further instrumental in establishing thrust-time histories for primary propulsion of rocket boosted vehicles. Optimum-performance booster programming does not necessarily contribute a physiologically acceptable acceleration profile and may require alteration to effect a condition within tolerance.

Figure 4 indicates time of useful consciousness after exposure to reduced atmospheric pressure levels.[11] Limits in this area establish countermeasures which can be expected of the occupant or of the mechanical system, the automaticity which should be designed into personal equipment, and the location and operation of escape system controls.

Figure 5 is an indication of time tolerance to extremes of the thermal environment and will dictate necessary protection from transient heat pulses. The data are for nude exposures with pulse slopes ranging from 15 to 100 degrees per minute. The dotted line is an approximation of downward trend of maximum tolerable temperatures as rate of change decreases. For comparison an isolated example of the effect of properly selected clothing is included.[9]

INTRA-ATMOSPHERIC VEHICLE

A paramount consideration for escape systems under development for intra-atmospheric vehicles is the accomplishment of safe emergency egress, throughout the airplane's performance envelope, by utilizing a secondary transportation mode to effect immediate separation. Undelayed escape is rendered both practicable and necessary by the qualities of the medium through which the aircraft moves: practicable because atmospheric density and a strong gravity field assure a positive return in haste by a simple escape device to a physiologically compatible environment; necessary because this same air density can extend an initial emergency by supporting combustion or by producing disintegrating forces.

The encapsulated ejection seat (Figure 6) incorporated in the B-70 Air Vehicle is representative of intra-atmospheric escape systems which satisfy the twin criteria of shirtsleeve occupancy and immediate abandonment. This capsule is characterized by:

a. Crew seating facilities which afford unrestricted mobility, vision and comfort during normal operation of the air vehicle (Figure 7).

b. Establishment and maintenance of an emergency inhabitable environment while in the air vehicle and after ejection without the necessity for personal equipment. This is accomplished by utilizing the pressure vessel capability of the basic shell with its movable door segments and seals positioned along the mating edges. The two doors are normally stowed along the capsule upper and lower contours and are rotated into position to complete the encapsulation (Figure 8). The capsule internal atmosphere is supplied by high pressure oxygen-enriched gas, while pressure regulators establish flow rates commensurate with conditions at time of closure and during descent.

c. Control of acceleration magnitude, direction, duration and rate-of-onset by providing proper propulsion force vectors and aerodynamic stability at all points in the performance range, encompassing high dynamic pressures as well as free fall from altitude. In order to achieve the desired stability, the aerodynamic properties of the basic shell are supplemented by drag and lift devices properly oriented relative to the capsule-man center of gravity.

d. Recovery throughout and somewhat beyond the parent vehicle's performance capability, including on-the-runway conditions. Capsule propulsion by a ballistic-rocket catapult satisfies the composite requirements of empennage clearance during high speed flight and an altitude increment that insures parachute inflation during ground rolls at low speed (Figure 9) and approaching zero velocity.

e. Acceptable terminal rate of descent with attenuation of ground impact loads, provided by an automatically actuated and sequenced recovery system (Figures 10 and 11). Maximum reliability is maintained by a fixed time sequence with an aneroid override. A time delay of three seconds permits a velocity decay from maximum airplane performance to speeds at which parachute opening loads are tolerable. Proper design of the main parachute canopy, in this case an extended-skirt configuration, limits oscillations and descent velocity to permit effective use of an energy-absorbing device, an air-filled bag, for dissipation of attendant kinetic energy.

f. Enhancement of post-landing survival by offering shelter and flotation. The capsule shell and door furnish a rigid structural cabin, while the ability of the capsule to assume and maintain an upright attitude in water and to permit door opening during flotation is augmented by pneumatically deployed cells.

Indicative of recent advances in the art of emergency escape is the ability of this encapsulated seat to effect safe egress at airspeeds exceeding Mach 3.0 and altitudes to 120,000 feet.

SUB-ORBITAL RESEARCH VEHICLE

The advent of research vehicles operating on the fringes of space and projecting into the era of the true space vehicle, requires a reevaluation of escape system design philosophy with respect to hazard potential and methodology of counteraction.

The rocket powered X-15 research airplane is an early example of the revised concepts in escape provisions. A detailed study of accident potential was conducted by analyzing maximum-effort mission profiles, sub-dividing these into phases or stages. The resulting breakdown included: (1) Prelaunch, (2) Launch and light-off, (3) Burning, (4) Coasting, (5) Re-entry, (6) Glide, (7) Approach, and (8) Landing.

Flight conditions and air vehicle malfunctions that would necessitate abandoning the airplane were established and, utilizing time of exposure as a weighing factor, their probability of occurrence was determined for each mission stage. Pursuing the analysis a step further, one is able to determine the distribution of accident potential as a function of mission progress. The mission profile being presented as a Mach number-altitude relationship, it is possible to identify a probable escape envelope that would contain a majority of the accident potential. Specifically, the conclusion contributed by the study is that 98 per cent of the accident potential for an X-15 maximum mission is included in an envelope bounded by Mach 4.0, a pressure altitude of 120,000 feet, and an incompressible dynamic pressure of 1500 pounds per square foot (Figure 12).

A conventional emergency escape system of the ejection seat-pressure suit configuration is optimum for this particular application.[5] The two percent of accident potential which is not included in the aforementioned criteria is attributed to conditions which could best be countered by continued occupation of the primary vehicle. Aerodynamic overheat during re-entry, for example, could be more effectively alleviated by exhausting the cooling capability of the ventilation system and the structural heat sink characteristics of the airplane prior to abandonment.

Summarizing, the emergency and escape procedure for the X-15 indicates a deviation from previously applied escape system design philosophy in that immediate evacuation throughout the performance envelope is not considered optimum.

ORBITING VEHICLES

The configuration of earth orbiting vehicles (Figure 13) will vary from a wingless, basically uncontrollable capsule describing a purely ballistic flight path, to a winged, maneuverable vehicle, not significantly different in appearance from conventional intra-atmospheric aircraft. The former will be used for early research as a probing medium. As initial-stage propulsion systems are developed which will suit the winged vehicles, there will be a transition to this type craft. The latter are less restrictive because of their capability to fly a more nearly optimum re-entry flight profile and thus improve acceleration patterns, minimize aerodynamic heating, and offer greater flexibility in the choice of a landing area.

Flights of earth orbiting vehicles have certain physical characteristics and are governed by a common sequence of events. A representative mission may be defined and major mission phases and attendant hazards noted (Figure 14).

The extremely large growth factor that exists between useful load in orbit and launch gross weight (approximate ratio 1:200) is a vivid indication of the importance of weight economy. It is readily apparent that single-purpose elements must be minimized lest cumulative weight and costs for the total vehicle extend beyond feasible limits.

Escape During Launch and Boost

On the pad in the ready-to-launch configuration, the space vehicle, due to its high energy content, imparts the initial and acute problem in crew survival. Close proximity to the large amounts of highly combustible, corrosive and toxic fuels for the rocket boosters is in itself a hazardous venture. Subsequent to launch, propulsion malfunctions which result in fire, explosion, and thrust termination have historically occurred very early in flight, permitting the vehicle to fall back from very low altitudes. The period encompassing pre-launch through boost phases is therefore a critical escape area and is characterized by situations which occur rapidly without warning, and require immediate separation of the occupant from the dangerous environment.

Primary considerations in providing a launch pad escape capability are:

(1) Method of detecting and reacting to an emergency situation.

(2) Separation characteristics between escape device and parent vehicle.

(3) Post-separation recovery.

Personal responsibilities which will affect the pilot's positon and activities prior to and during launch will determine the degree of automation or remote control which should be incorporated in the ejection control system. The crew should be in position for escape sequence initiation by whatever control input is deemed most desirable.

Certainly one method of initiating escape procedure will be by action of the vehicle occupant. And, too, the ground safety observer, by direct observation and monitoring of instrumentation, will be in a position to decide on the necessity for a direct control input to the escape system, not for mere communication to the pilot. With caution, it may be said that the additional alternative for sequence initiation is a sensing circuit that will monitor vehicle performance and react to abnormalities that could generate a catastrophic condition. Such a circuit should be limited in its use to those conditions under which successful escape is enhanced by elimination of the time required for an observer to detect and react to an indication of impending emergency. It would be unwise to have the circuit active under conditions wherein an unwanted operation would place the occupant in a more hazardous environment than is maintained by the parent vehicle.

Removal of the occupant from the danger area of the launch pad may be accomplished by alternate means, depending on vehicle type. Figure 15 is representative of an off-the-pad trajectory for a wingless condiguration. It is noted the entire occupied vehicle is utilized as the escape device. It is true that a "capsule within a capsule" approach is an alternative and would result in a much reduced mass requiring separation from the launch pad. This would, however, require duplication of propulsion and recovery systems and incorporation of hatch jettison and ejection guidance components. Requirements of this condition are primarily rapid separation, sufficient altitude to permit parachute inflation, and horizontal displacement to a safe distance from the launch pad. In providing impulse requirements for effecting the separation, maximum use should be made of energy sources whose primary function is orbit disturbance and attitude control. Although undesirable from the standpoint of reliability, propulsion requirements for emergency escape may require programming as a function of flight conditions in order to gain maximum effectiveness on the pad and yet attain adequate separation during boost without exceeding human tolerance limits. Since the parachute system incorporated for post-orbiting final stage recovery should be used for recovery during mission aborts, the relatively large canopy size and lengthy deployment time under zero-airspeed initial conditions requires that a large altitude increment be provided. In consideration that the kinetic energy associated with parachute descent must be dissipated in a manner which will limit landing forces to tolerable magnitude, a force attenuation device such as an air bag or cushion of frangible material is effective by virture of extending the period of contact deceleration.

Pre-launch escape from a winged vehicle is different only by the character of the components which are removed. A winged vehicle will inherently exhibit a greater mass; consequently, projection under the influence of its own propulsion system probably will not satisfy the urgency of the situation. A minimum-mass ejection normal to the vehicle launch attitude will provide a maximum lateral separation during the least time duration. A representative trajectory is indicated by Figure 16.

During the boost phase of the mission, the escape problem is, in many respects, parallel to that for high performance aircraft with an intra-atmospheric flight regime. While the underlying reasons for initiating escape may not be common to conventional flight, the mechanics of the launch procedure are complicated only by the superimposition of relatively high linear accelerations imparted by the booster in gaining velocity most efficiently. Booster malfunctions resulting in thrust termination or imminent explosion, and guidance errors which would ultimately result in a flight condition from which recovery is not possible, are basic reasons for mission abort.[6]

With a wingless vehicle the procedure for recovery is single in nature and involves capsule separation and parachute recovery. Figure 17 is a typical sequence during maximum "q" flight. Operation of the parachute system is aneroid-time-controlled as it is for all modes of recovery, independent of initial conditions.

Procedures for mission abort during boost of a winged vehicle will vary according to cause. For example, anticipated trajectory perturbations resulting from guidance or propulsion errors which would require discontinuing the flight would dictate the least demanding procedure: thrust termination and booster jettison, with the return flight of the final stage vehicle under the influence of its own propulsion system. The more stringent requirement associated with impending explosion indicates a minimum mass ejection with divergent flight path.

Orbit Emergencies

During orbit or near-orbit flight conditions, if escape becomes mandatory, the complexity of the procedure increases with distance from the earth. The magnitude of emergency and probability of occurrence, however, are significantly reduced, while the hazards lend themselves to countermeasures associated with occupancy of the final stage vehicle. Divorcement from the parent vehicle would require a duplication of that vehicle's re-entry capability by the escape device, an impractical solution as evidenced by payload/gross weight relationships.

For control of the limited hazard potential which is contributed by this mission phase, attention is concentrated on parent vehicle reliability and integrity. Isolation of energy requirements for orbit insertion, orbit transfer, or initiating and controlling re-entry will minimize the effects of a propulsion malfunction. While reduction of the complexity of vehicle structure and quantity of exit and observation apertures will minimize the possibility of loss of inhabitable environment due to excessive leakage, the responsibility for emergency environmental control rests primarily with personal protective clothing and equipment.

Re-Entry

During the re-entry mission phase, conditions which may degrade or sacrifice optimum vehicle performance can best be alleviated by consuming the environmental control capability of the basic vehicle. As in the launch-pad condition for a wingless craft, a capsule within a capsule is possible; however, the secondary capsule would necessarily include a re-entry capability. The inherent weight and complexity of this approach may be utilized more efficiently if applied to the primary capsule.

With respect to the winged vehicle, the heat sink characteristics of the primary structure and the increased weight/drag ratio for peak force reduction should be fully exploited. If the vehicle is rendered incapable of controlled flight and normal landing, crew ejection under reduced flight conditions (Mach 4.0 and 120,000 feet or less) is resolved to equivalence with boost phase escape.

Post-Landing Survival

The final phase of a successful escape procedure is fulfilled by survival on the ground until rescue. Post-landing survival is dependent basically upon two inter-related factors: (1) provision of sufficient sustenance and (2) minimization of time awaiting rescue.

The wingless vehicle is somewhat more versatile in the first area, particularly in integrated flotation capability. With respect to retrieval time, it is assumed the orbiting vehicle will be under constant surveillance by ground monitoring stations. Accurate tracking during all flight phases will contribute a probable impact area and permit an early dispatch of rescue craft, while on-board communications facilities should be provided for use by the occupant after landing to permit precise location. The use of electronic and visual contact aids is depicted by Figure 18.

The second parameter, rescue time, is served best by the winged vehicle which, as shown by Figure 19, exhibits considerable latitude in selection of a landing site, including the probability of return to a pre-selected site or of landing or achieving escape at an alternate site with equivalent climatic and topographic conditions, a feature which has a decided influence on post-landing procedures.

Crew sustenance requirements, while awaiting rescue, must be provided aboard the vehicle. Limited food supplies should be included along with accouterments for use by the crew in supplementing the supply of rations should rescue time be extended. Equipment so required, in addition to clothing for post-landing environmental protection, may be minimized by an analysis of the topography included in the projections of the orbital path on the earth's surface. Figure 20, for example, depicts an essentially equatorial orbit passing over approximately a 4:1 water/land ratio, with an average water temperature of 70°F. It would be inefficient in this circumstance to include arctic survival gear. Contrarily, emphasis should be placed on fishing equipment, water desalting, capsule flotation, and visual contact aids usable at sea. The weight economy realized by providing survival gear compatible with probable requirements will increase the likelihood of total mission success even though the requirements for all post-landing climatic and topographic conditions have not been satisfied.

EXTRA-ORBITAL OPERATIONS

If the discussion of earth orbital and sub-orbital flight conditions is extended to include cis-lunar and interplanetary travel, the tendency is to generate more questions than answers. There are a variety of opinions reflected in proposed concepts, each including considerable conjecture on the part of the proponent.

For emergencies of less than catastrophic proportions resulting in disintegration of the craft, certainly initial effort should be directed toward vehicle repair. Loss of the inhabitable environment because of cabin penetration by a meteorite is included in this category, although more likely is a loss resulting from a defective pressure vessel seal or element of secondary structure such as a port or window. The pressurized area of the vehicle should be compartmented with these eventualities as considerations. A centrally located emergency air lock that is readily accessible from all compartments will provide a crew retreat while making preparations for necessary repairs, while a designated portion of the crew should be on standby in protective clothing at all times, ready to function as a rescue team for the balance of the personnel.

Rendering of the oxygen regenerative system, the closed ecological system, or the navigation and communication equipment inoperative will create an emergency situation with the same ultimate effect but of less immediate consequence. As in the case of decompression, reviving normal functions must be the primary mode of survival.

Under conditions wherein successful repair of malfunctioning equipment is not possible, the crew will find itself temporarily at the mercy of the near infinity of space. It has been proposed that a "life boat" for survival while awaiting pick-up might best satisfy requirements. Such a device would be most useful in the improbable circumstance that it were imperative that the primary craft be abandoned; otherwise the emergency life support systems of the "life boat" could be employed effectively while enjoying the residual usefulness of primary vehicle components. In any event, dispatch of a rescue vehicle from earth or a satellite station, and navigation to a point of intercept with the derelict vessel, will require an effort of considerable magnitude in at least the early stages of space exploration.

Unnecessary complications obviously should be avoided. It follows, too, that the most satisfactory solution will be that which will counter the majority of eventualities.

For exploratory effort, pending verification of total mission reliability, it appears best to apply the basic philosophy of duality to mission planning.[1] Redundancy is impractical when applied to individual craft since the duplication of systems is for the single purpose of emergency provisions and makes no further contribution to the mission. If, however, the parallel system is in the form of a total vehicle, it is "paying-its-way" as it were by providing transportation for additional payload. The net effect on crew safety will be equivalent to increased reliability of a mechanical system through duality.

The approach will require proper implementation. Siamese vehicles will not satisfy the intent since both would be vulnerable to the same explosion and penetration by meteorites of the same cloud or by other space debris. The craft should describe flight paths separated by a safe distance but close enough to lend mutual aid in a relatively short time and without navigating a complex intercept course. A constant communications link should be maintained, including monitoring of mutual flight conditions and course. The procedure would further enhance crew safety by mutual aid in prevention of potential emergencies.

Effecting a rescue from or imparting aid to a stricken vehicle from a sister ship should not be an overly complex procedure. Both craft will nevertheless require minimal provisions for accommodating the extra crew during the emergency return or, under favorable circumstances, the completion of the mission.

The method is not without inherent disadvantages, the foremost probably being logistics, but it does appear that vehicle duality in mission planning will contribute an optimum in crew safety and ultimately a minimum cost through increased probability of mission success.

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CONCLUSION

The potentialities of human flight are undergoing a radical change, having been accelerated by the rapid and successful developments in rocketry since World War II. Inherent characteristics of the rocket which result in dynamic and chemical independence of an external medium have contributed a propulsion device which opens to the flyer the "vertical frontier." [8]

Successful penetration of this new frontier will depend on space ship duplication, or at least approximation, of the natural habitat of man. The use of a mechanical substitute for natural provision of requirements for sustaining life will inevitably generate the necessity for minimal standby equipment to assure a safe emergency environment.

For early probing missions of relatively short duration and in the immediate vicinity of the earth, extension of current techniques will best satisfy the requirements of emergency and escape procedures. An alteration in basic escape philosophy will be applied in that separation from the primary vehicle throughout the performance spectrum is not optimum. Emergency situations which occur during extra-atmospheric flight will constitute a minority of the hazard potential and their nature will dictate continued occupation of the parent vehicle.

Intra-atmospheric emergencies occurring during launch, boost, reentry, and recovery will essentially parallel those attendant to superperformance aircraft such as the X-15 and B-70, whose development is already solving space age problems and producing much technology of direct applicability to putting man safely in space. The exact escape procedure and system configuration will be dependent on vehicle type, varying from total vehicle separation and recovery for a wingless craft to a fly-down or minimum-mass ejection for the winged craft.

Inter-planetary operations with extended mission duration should be planned on a parallel vehicle approach. Mutual aid during multiple vehicle operations offers a maximum in crew safety while simultaneously increasing the probability of mission success since the "duplicate" vehicles are transporting additional payload.

The ultimate conclusion is that from a standpoint of ethics, the philosophy of democracy and ordinary realism, a man or crew on an exploration will not be sent into space by our nation without a high probability of a safe journey and safe recovery. [2]

POSTSCRIPT

During the introduction to this discussion of aerospace emergency and escape procedures, little attention was directed toward the basic question, "Why Man in Space?"

The more technical interpretation of requirements to accomplish a given objective indicates that for extended missions there is a rapidly diverging relationship that exists between manned and instrumented space vehicles (Figure 17). Levels of reliability necessary to insure a high probability of success for prolonged flights dictate that on-board data sensors and computers be basically "archaic", the term in this context indicating evolution beyond experimental status and exhibiting a recorded history of reliable operation. Man is far superior to instrumentation in this respect.

As expressed by General Donald Flickinger,[3] many objectives may be offered depending upon what particular aspect of national interest and philosophy is being expressed. One may say that it is to satisfy man's inherent curiosity about the celestial bodies which are the last frontier for him to conquer and explore. From a political standpoint, repeated safe returns of space travelers will enhance national prestige. Certainly a case can be made for putting man in space to further scientific knowledge. From the Air Force standpoint, there is the objective of an improved capability to maintain and safeguard the security and integrity of our nation. The aim is to develop a manned space-vehicle system in which the unique capabilities of the human component can be exploited toward greater net military effectiveness than could be realized from an unmanned space-traversing system.

In the same vein, General Thomas White[10] concludes that despite all the efforts of industry and the genius of science, certain limits are automatically imposed where the machine is involved. A machine cannot think nor can it reason. Man must operate in space, employing his logic, his common sense, and his good judgment as he encounters the unexpected and the unknown. In the event of military operations in space, man's presence and ability to perform in space could spell the difference between defeat and victory. His on-the-spot judgment and selectivity will be necessary not only for purposes of scientific research, but to ensure national survival.

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Figure 1

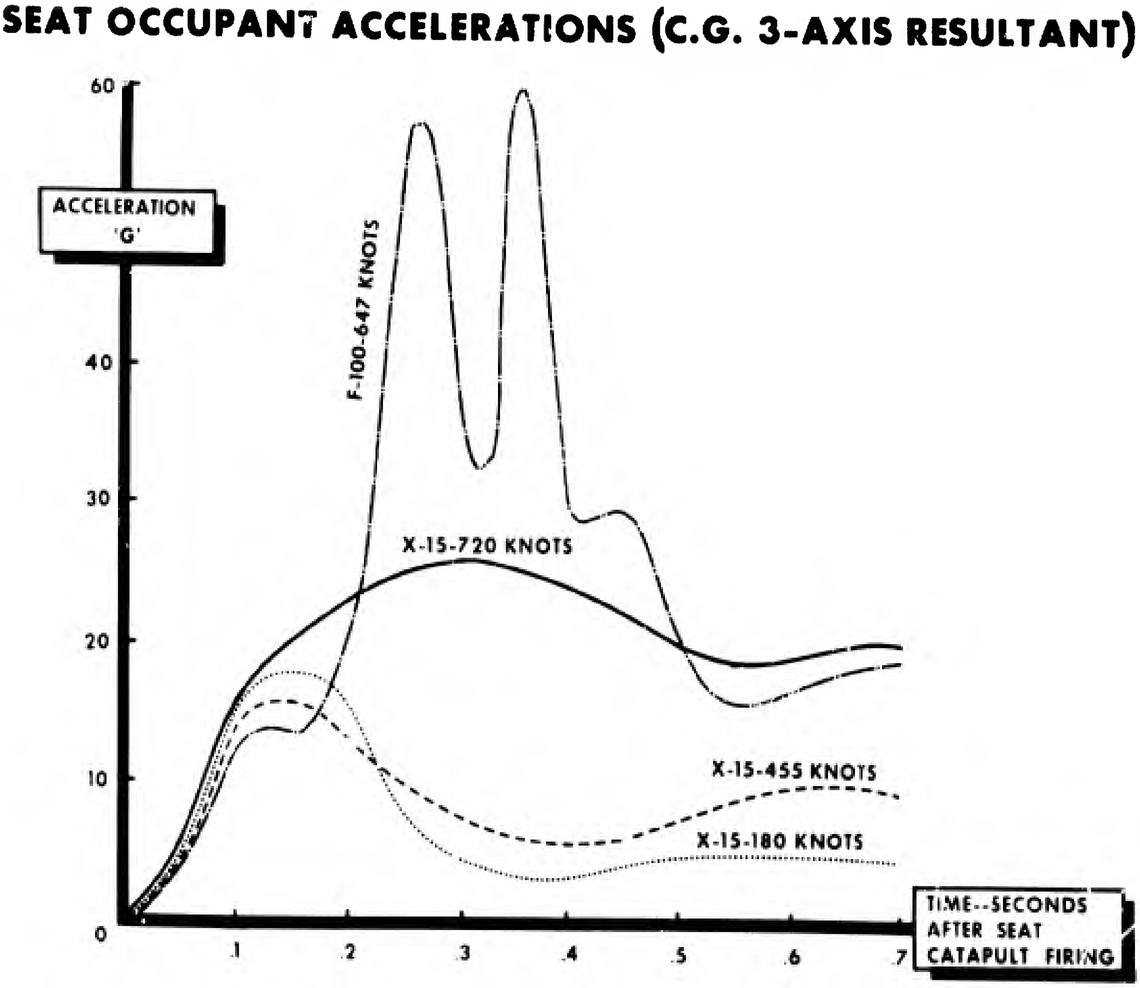

Figure 2

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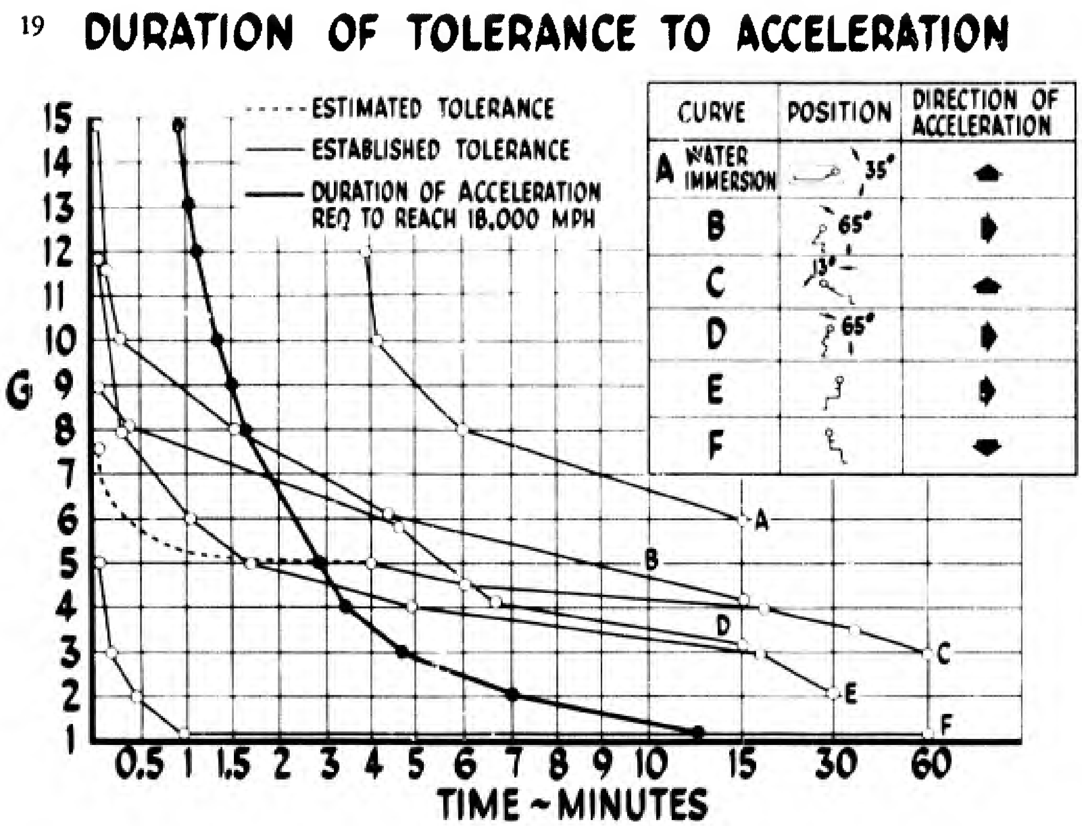

Figure 3

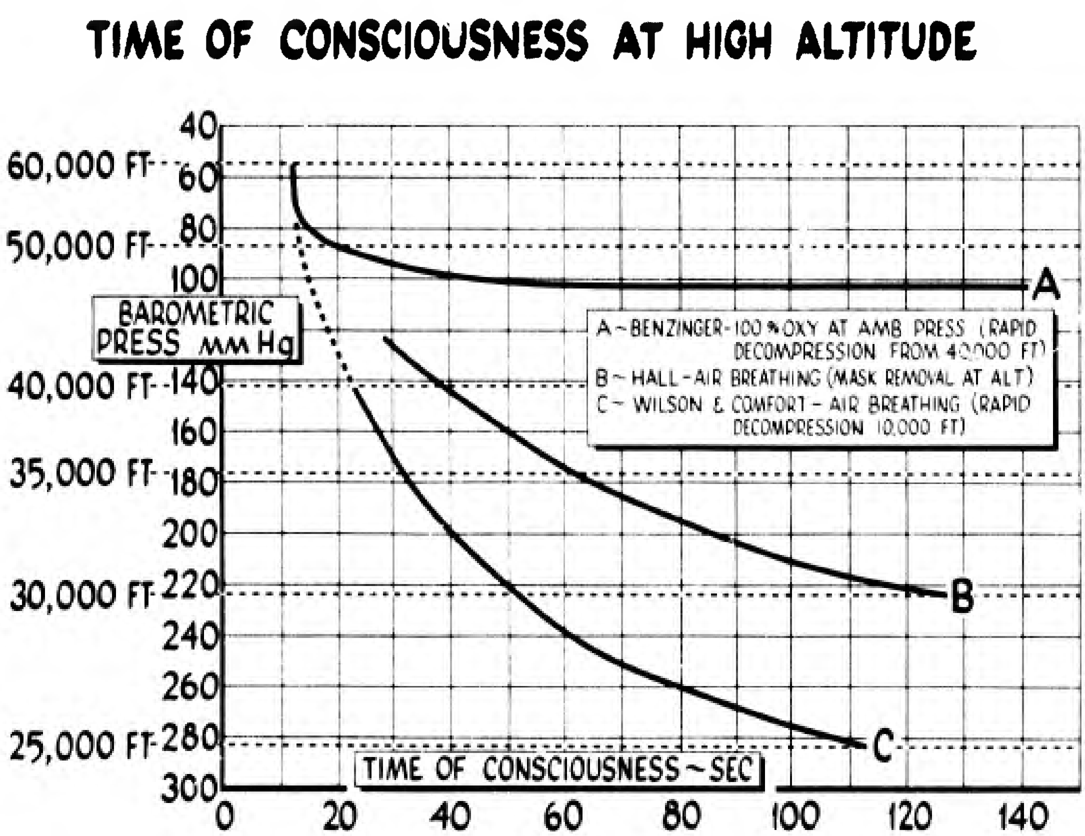

Figure 4

TOLERANCE TO HEAT PULSE

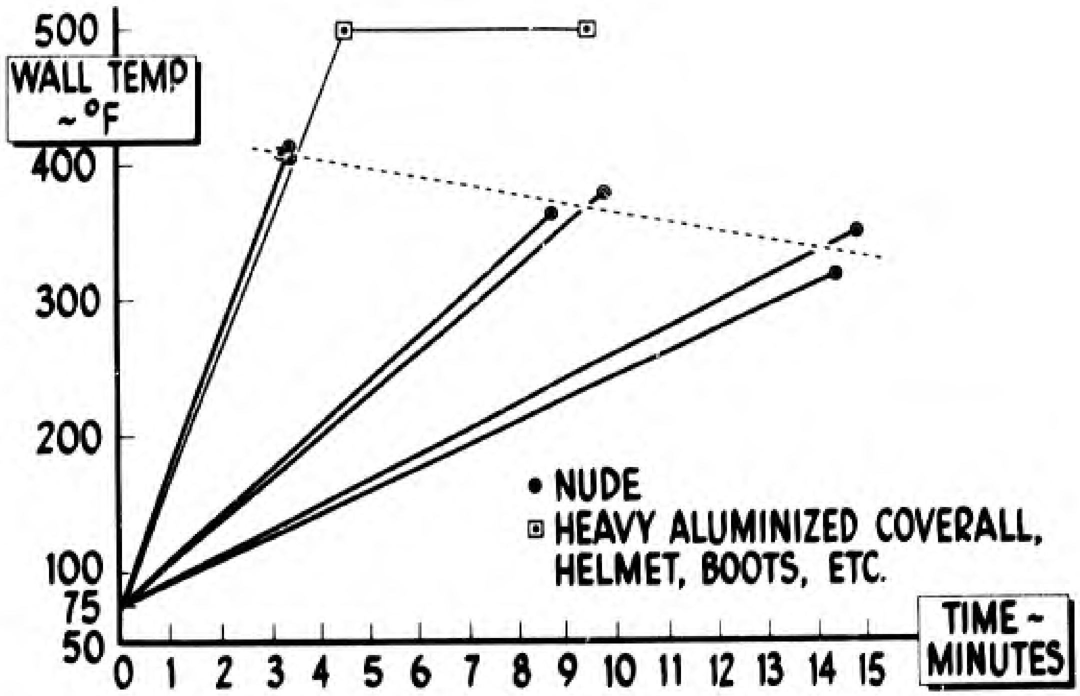

Figure 5

ENCAPSULATED EJECTION SEAT OPEN

Figure 6

SEAT OPERATION

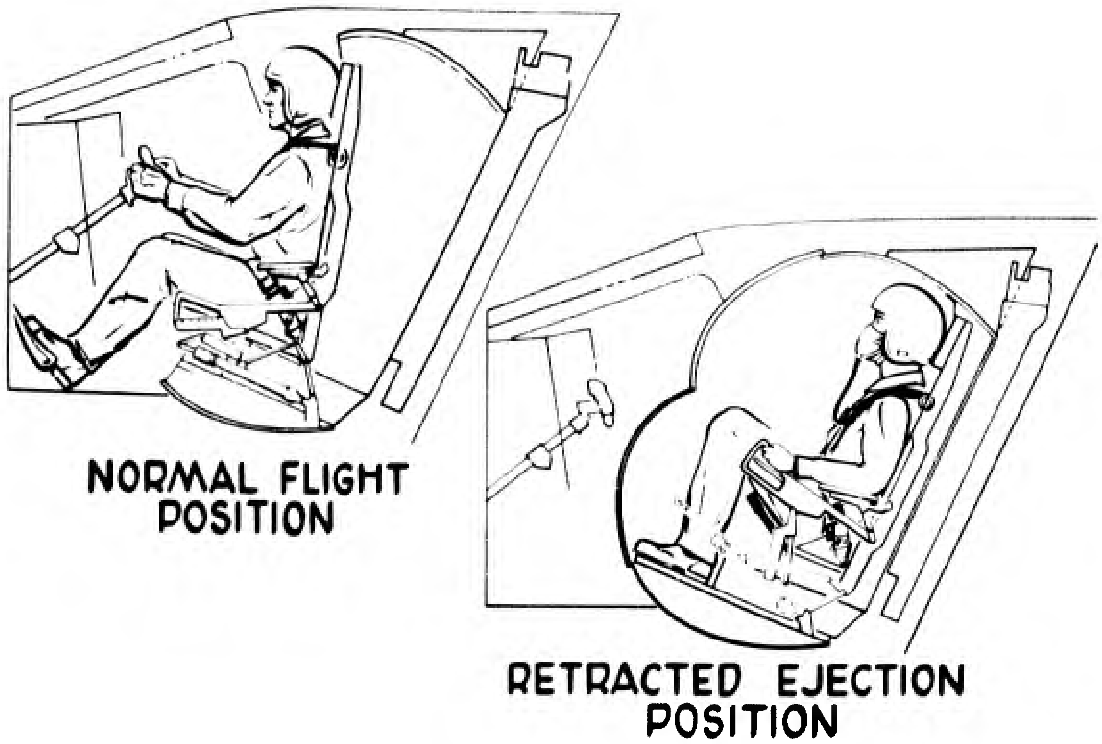

Figure 7

ENCAPSULATED EJECTION SEAT CLOSED

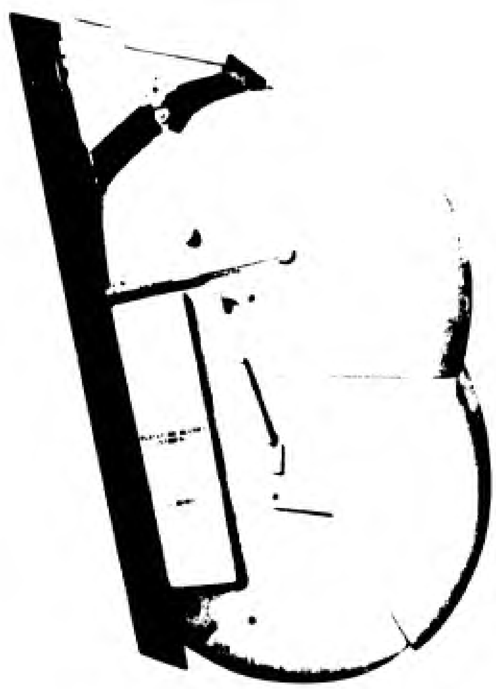

Figure 8

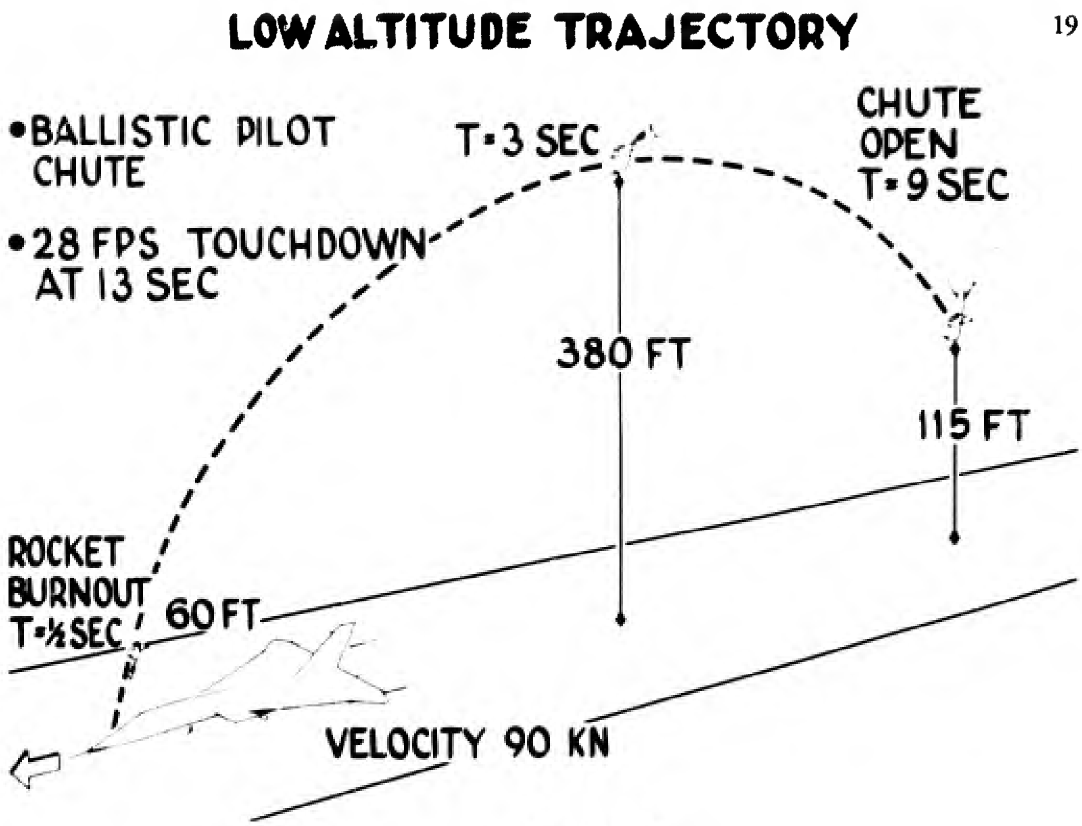

Figure 9

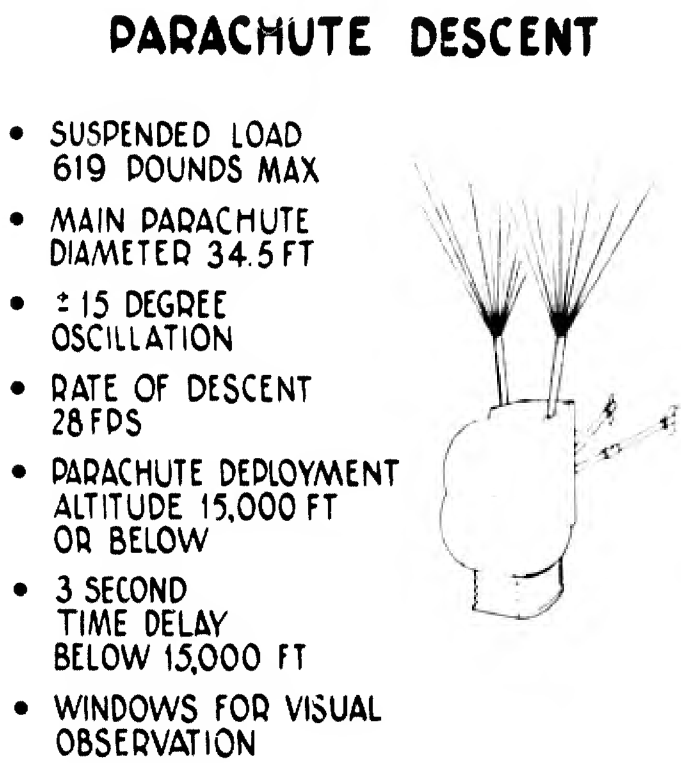

Figure 10

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ENCAPSULATED SEAT - RECOVERY

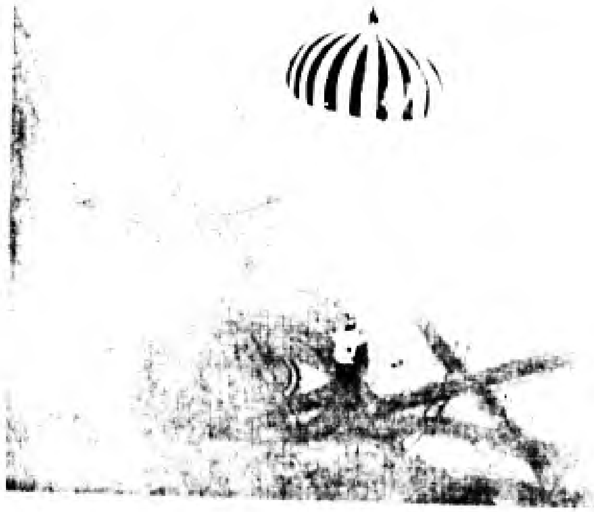


Figure 11

ANALYSIS OF X-15 ACCIDENT POTENTIAL

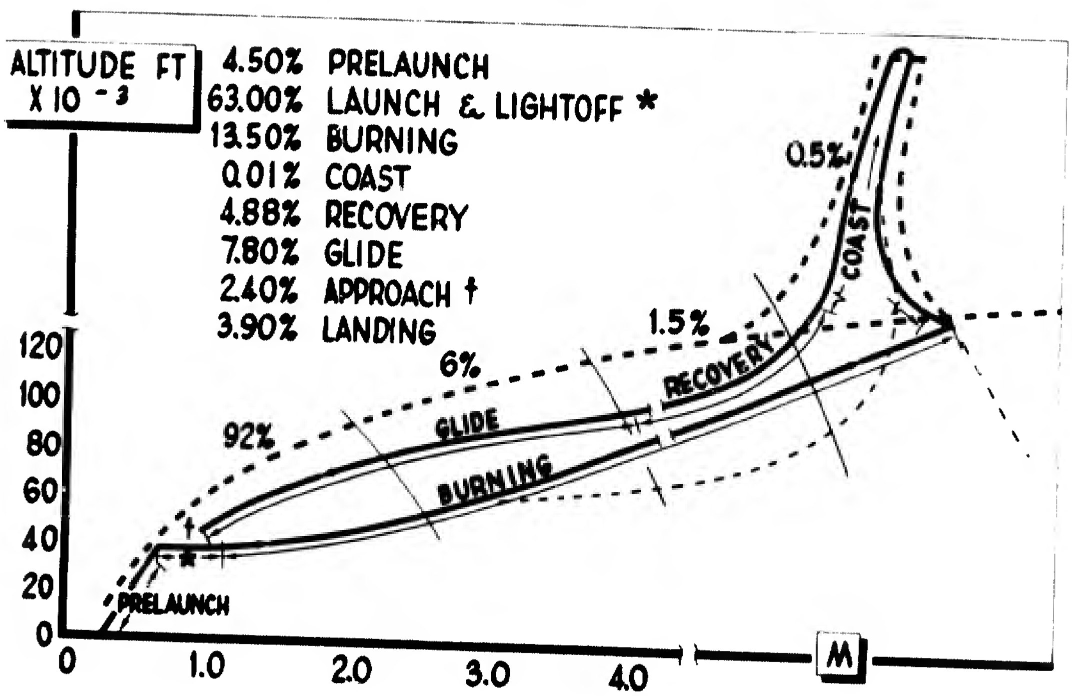


Figure 12

ORBITING VEHICLE CONFIGURATION

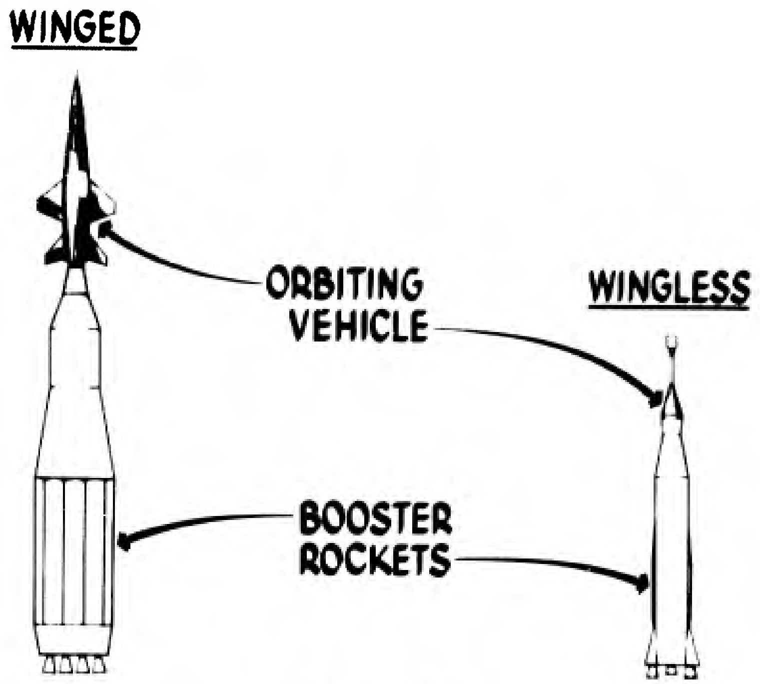
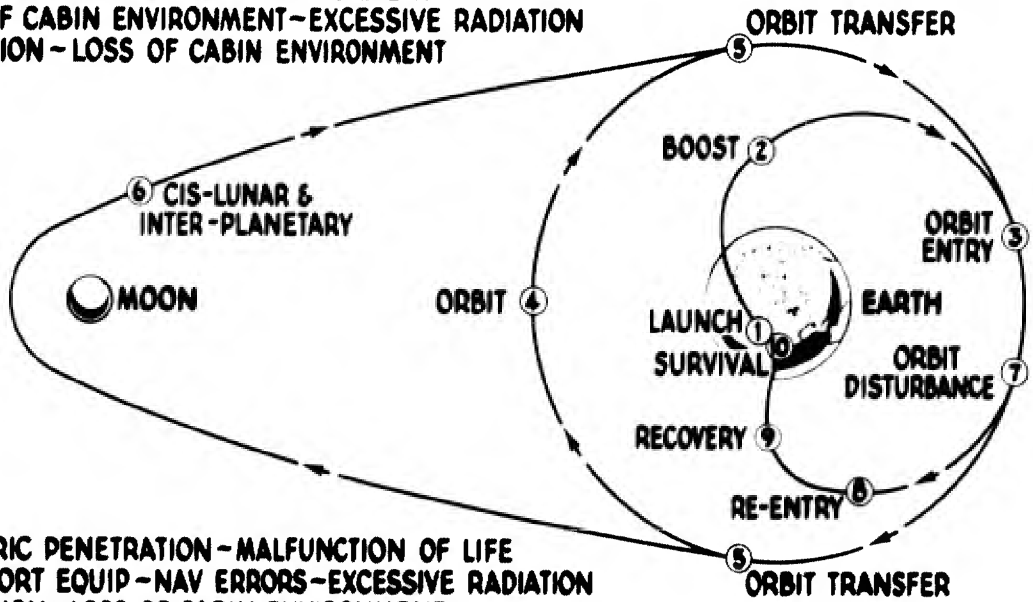


Figure 13

MISSION PHASE & HAZARDS

1. EXPLOSION – CONTAMINATION BY FUEL – THRUST TERMINATION
2. THRUST TERMINATION – EXPLOSION – GUIDANCE ERRORS
3. EXPLOSION – LOSS OF CABIN ENVIRONMENT
4. LOSS OF CABIN ENVIRONMENT – EXCESSIVE RADIATION
5. EXPLOSION – LOSS OF CABIN ENVIRONMENT



6. METEORIC PENETRATION – MALFUNCTION OF LIFE SUPPORT EQUIP – NAV ERRORS – EXCESSIVE RADIATION
7. EXPLOSION – LOSS OF CABIN ENVIRONMENT
8. AERODYNAMIC OVERHEAT – EXCESSIVE "G" – NO ATTITUDE CONTROL
9. PARACHUTE MALFUNCTION
10. INCAPACITATION – SEVERE CLIMATIC CONDITIONS – ABSENCE OF SUSTENANCE REQUIREMENTS

Figure 14

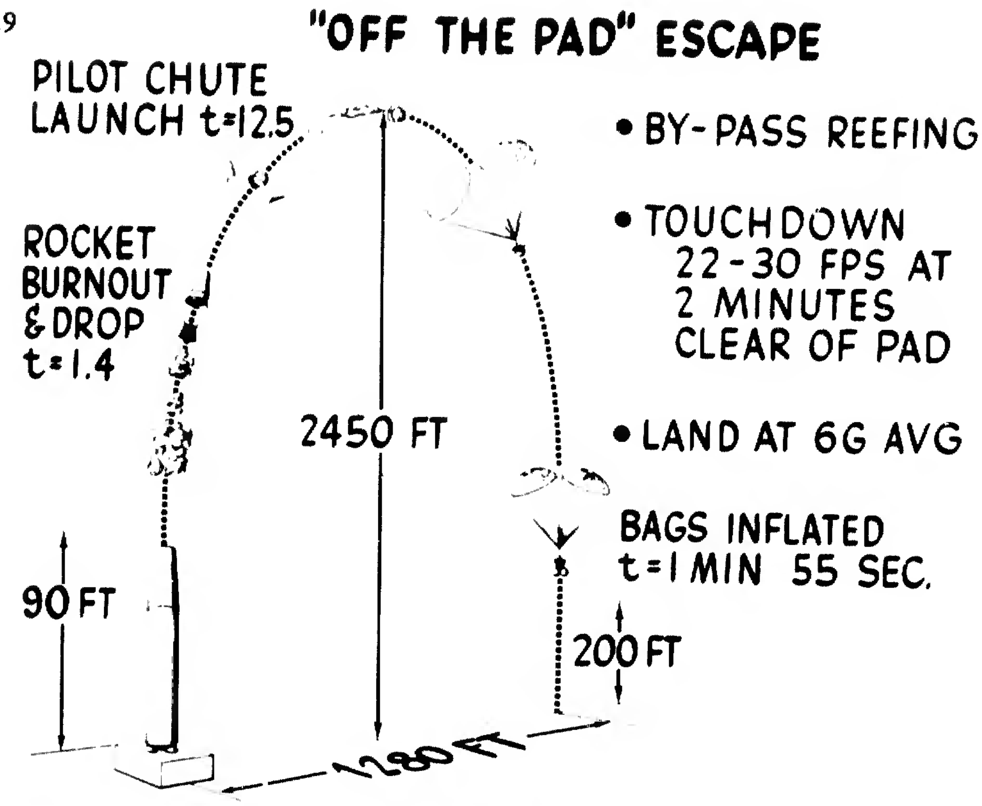


Figure 15

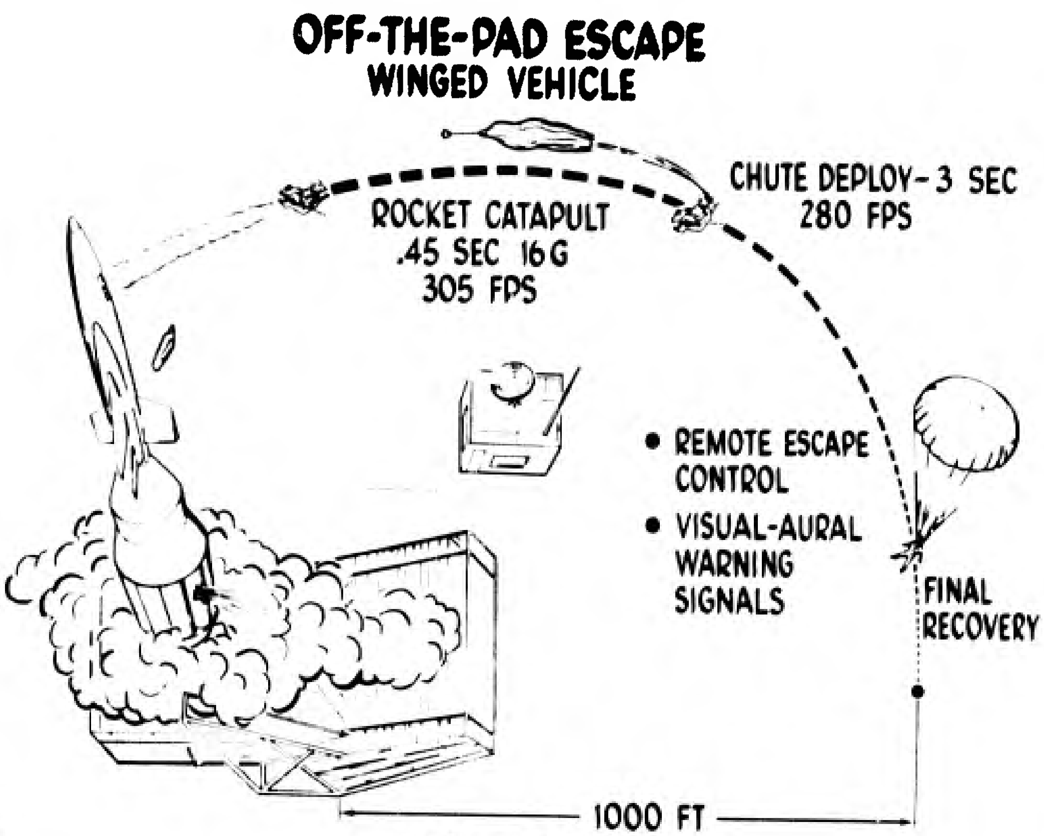


Figure 16

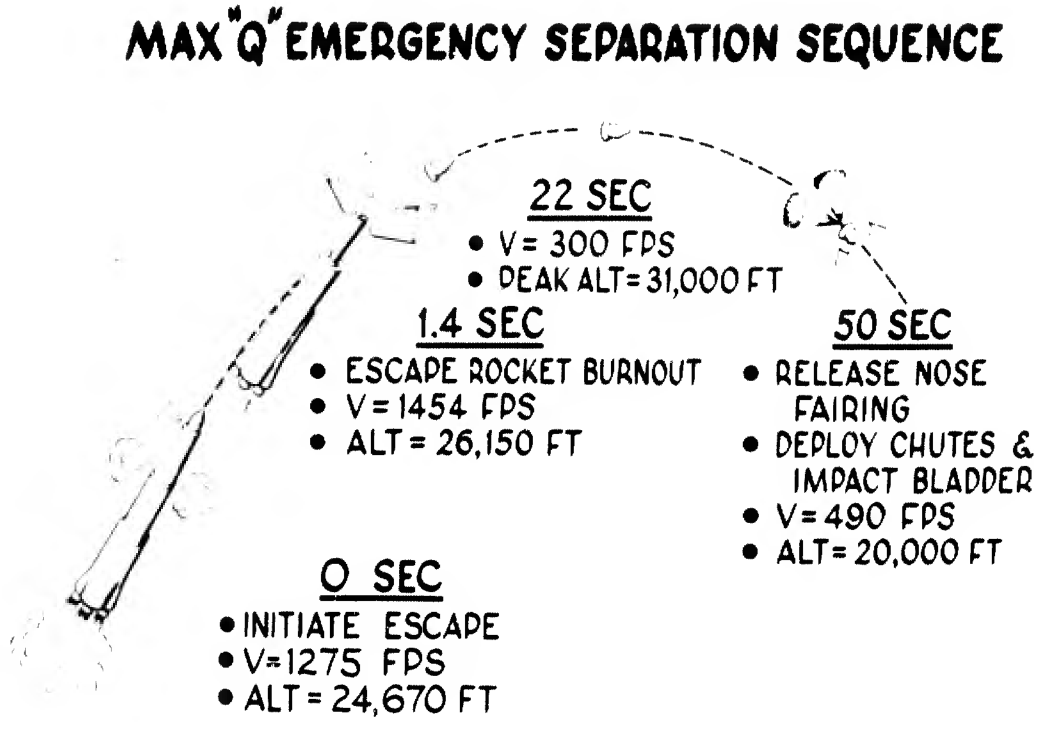


Figure 17

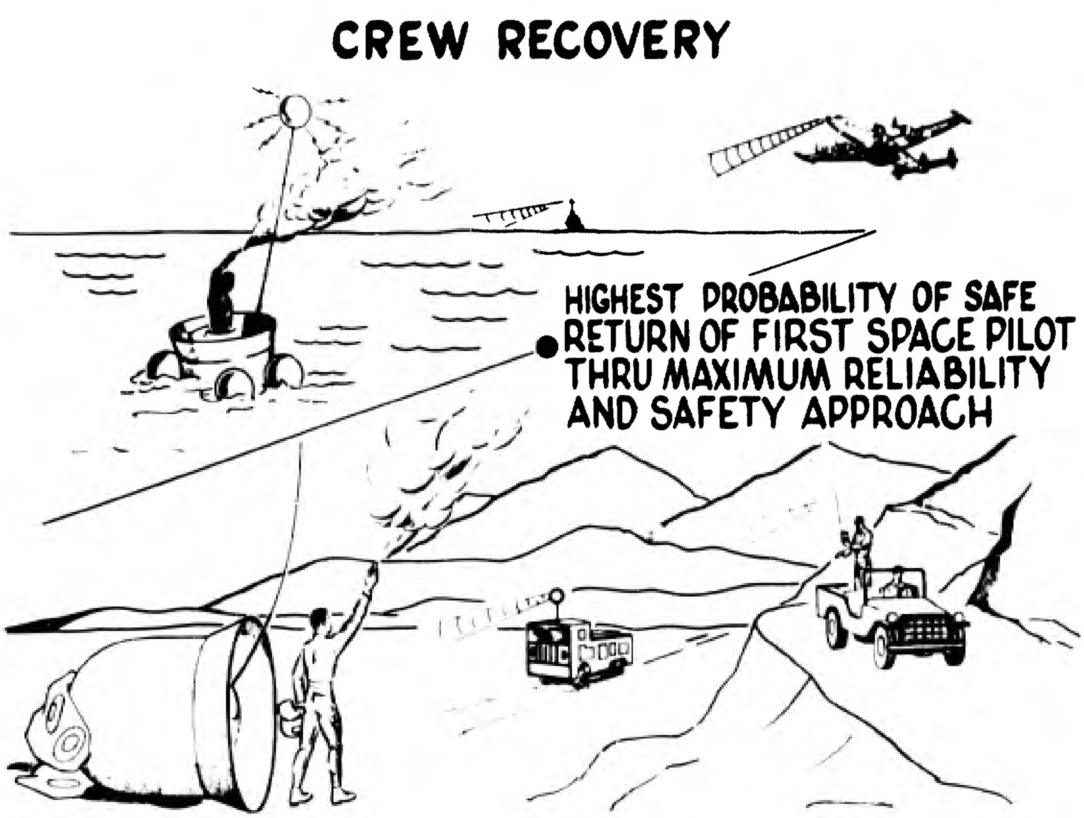


Figure 18

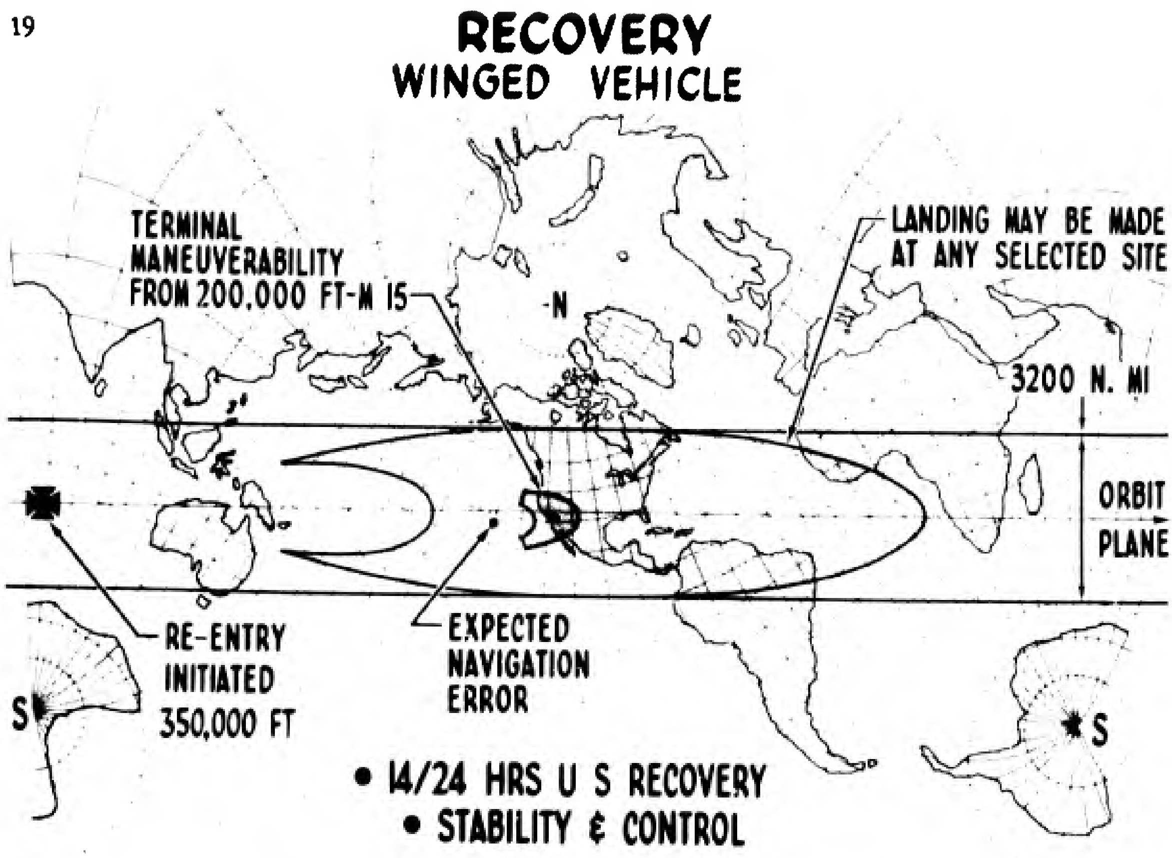


Figure 19

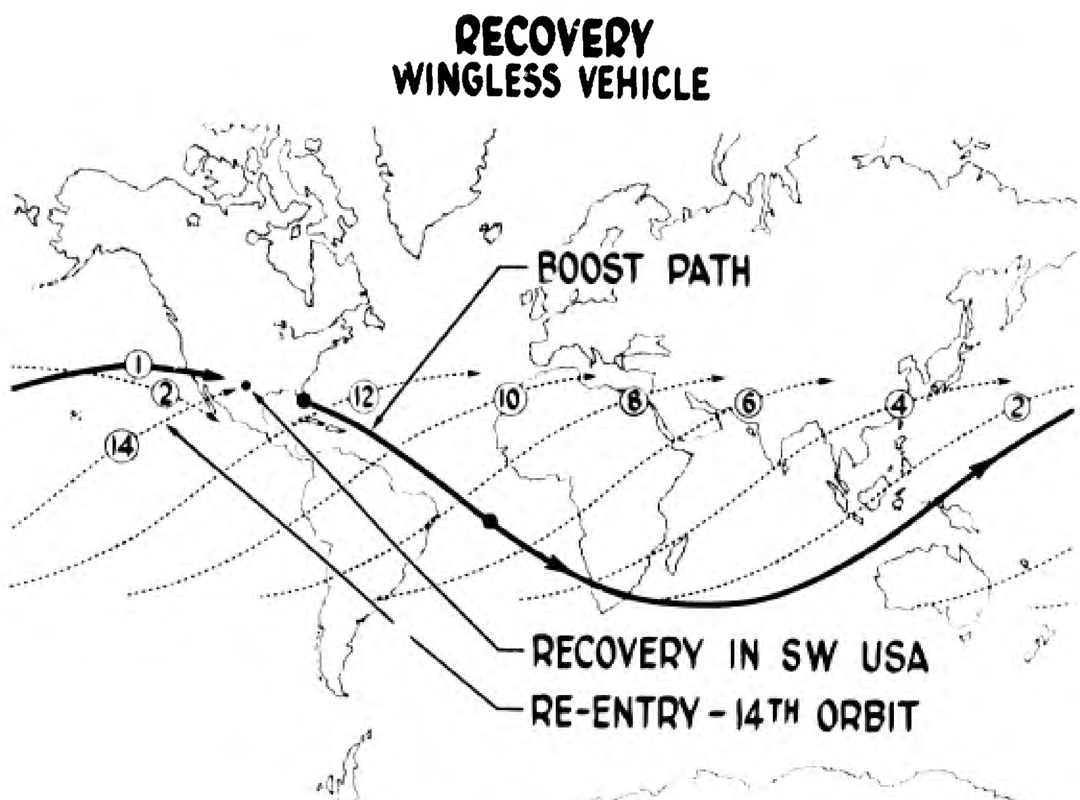


Figure 20

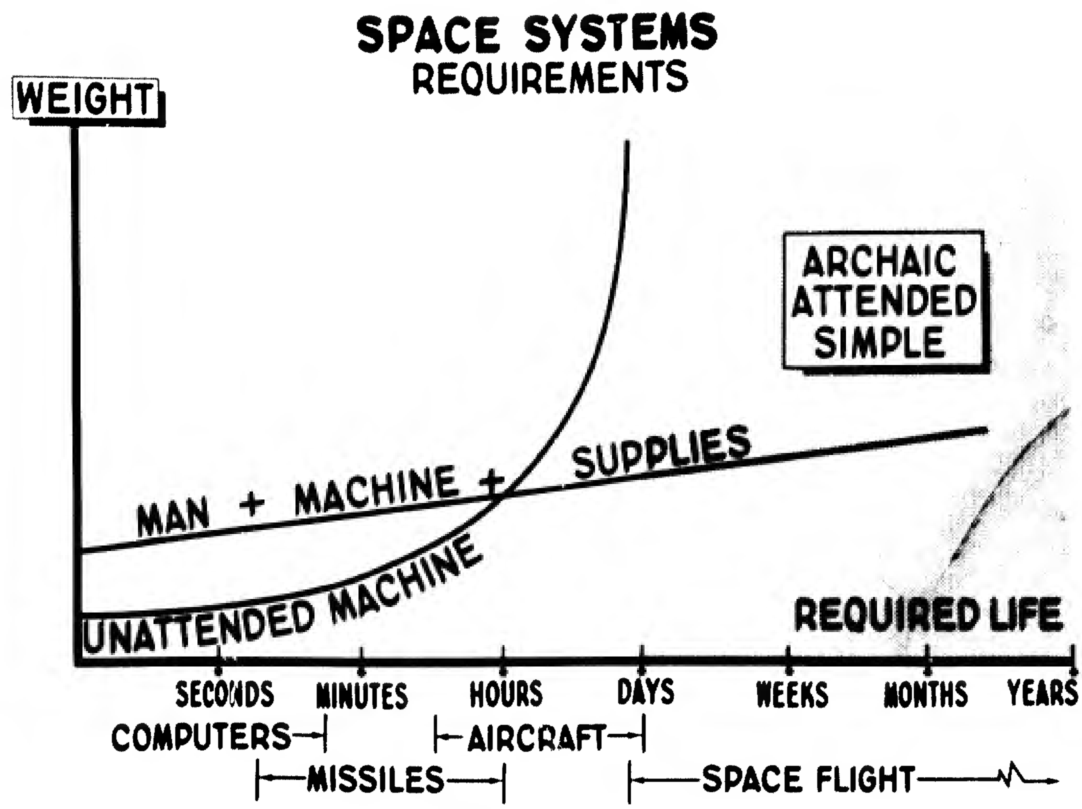

SPACE SYSTEMS
REQUIREMENTS
WEIGHT
ARCHAIC
ATTENDED
SIMPLE
MAN + MACHINE + SUPPLIES
UNATTENDED MACHINE
REQUIRED LIFE
SECONDS
MINUTES
HOURS
DAYS
WEEKS
MONTHS
YEARS
COMPUTERS
AIRCRAFT
MISSILES
SPACE FLIGHT

Figure 21

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LECTURES IN AEROSPACE MEDICINE

PRESENT AND FUTURE PERSONAL EQUIPMENT

Presented By

Lieutenant Colonel Stanley White

Aeromedical Consulting Staff

Langley Research Center

Langley Field, Virginia

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I shall try to continue the line of thought begun by Mr. Hegenwald, and I hope to integrate the ideas presented during the week so that we can view the total area of personal equipment. Now if I can do this, we will have accomplished the following: (1) a very serious consideration of the concept of personal equipment; (2) a study to see how it is related to the space vehicle; and (3) a review of problems that we have already encountered in the operation of such vehicles as the X-15 and Mercury capsule, and if I may be allowed to use my jaundiced eye, I should like to look ahead at the vehicle of the future.

Let us now turn to my first objective--to decide whether or not the common concept of personal equipment is really a legitimate one in light of present-day events. The first thing that strikes you as you begin to study the area of personal equipment is that an item of personal equipment ordinarily comes into the inventory because it was needed for some emergency; then as time goes on, you find that instead of its being used for an emergency (or one-time use), it is incorporated for the more routine events. I would like to cite about three examples:

1. Mr. Hegenwald pointed that the escape originally was accomplished with a personal parachute and the over-the-side bailout. As escape became more difficult, we had to include

the ejection seat along with the personal parachute; then the stabilized seat and the personal parachute; the stabilized seat and the seat parachute: and finally the pod-capsular involvement, as described by Mr. Hegenwald.

2. To solve the problem of environment, we began with the oxygen mask; the pressure cabin evolved, followed by combinations of pressure cabin and mask. The pressure cabin and pressure suit were then combined; developed, then, was the capsule for escape with its own kind of environment inside; and, finally, we are developing sealed cabins with a closed environment.

3. Recalling Dr. Hessberg's presentation the other day, we proceed the same way in regard to acceleration. The pilot of the old dive bomber used the yell, the grunt, and the elbow in the abdomen or other gimmicks to help him tolerate the g's. Then in the inventory came the anti-g suit. If you review the history of the anti-g suit, you will remember two things: you had to be on some kind of a special mission that made you afraid the airplane would outlast you; and also you were considered somewhat "chicken" at heart if you wore the first anti-g suits. But as time went on, the g-suit became a standard part of the inventory of personal equipment. The next innovation was the

tilting of seats along with wearing anti-g suits. Now we are talking about horizontal couches and orienting the g's so as to take advantage of the transverse g's.

Development of other emergency and survival gear follows the same basic pattern, starting with the simple form to meet an emergency, and becoming more involved in the actual system as we progress. There are certain things we can learn, I believe, from these examples, and they are the following: Each step was developed one at a time and for a specific purpose, and I should like to call your attention to the fact that only very recently have you seen any attempt at collaboration. It was always that the g-suit man worked in his closet, the seat-man worked in his closet, and the twain never met until it was almost too late; the man using the equipment was the ultimate sufferer. With each step, use of the equipment became less related to the purely emergency situation, as I said before. With each step, it became more difficult to identify the equipment as truly a personal equipment item. It moved toward a total-system concept and each change in the sequence has produced some change in the operational approach that was, in turn, reflected in the vehicle and the vehicle handling, the vehicle flight plan, the approach to checking out the vehicle, etc.

Simultaneous with each step was the increased demand for a higher mental and physical performance by the man if he was accomplishing his flight successfully. Obviously, when you think in terms of all the variables which have occurred, the old concept of what you wear on your back as personal equipment is probably very antiquated. So I should like to propose that we lay to rest the former concept of personal equipment and come up with some new term--personal support if you wish, or some other appropriate term.

Taking personal support as an optional term, I would suggest that it be defined as follows: It should include all of the equipment, procedures, operational concepts which support man in both routine and emergency conditions, and the equipment needed to measure or indicate his performance or his status. Now this is a very general and all-encompassing definition. I would like to add a postscript and say that if you are thinking of using this definition in a didactic way, you must daily re-evaluate it to see if it, too, will become obsolete. In other words, I think the definition can be the "albatross" around your neck unless you keep it flexible with increasing demands.

With the working definition in mind, let us turn to the direct areas of support which we can identify for specific consideration for present and future vehicle design. We now have the X-15 and the Mercury project to consider. It becomes important for the human support engineers (whether of biological or engineering disciplines or the physical sciences) to think together about the problem of supporting the vehicle. I have divided the task roughly into ten areas (Figures 1 and 2). I would like to group them in logical categories, to allow you to organize your thinking; but keep in mind that no item is isolated from the rest; the items make up a complete system; they are not listed in order of magnitude, importance, or priority. Keeping a concept of the integrated idea, remember that each influences the others.

I think we have had a very good review of acceleration, deceleration, and weightlessness this week. I wish to treat acoustic energy as an entity because it includes both sound and vibration. The third area includes atmosphere, temperature, and humidity, which I should like to group together because I think they interplay in such a way that they cannot be separated. Decompression is a problem which involves an interplay of specific kinds of hardware as well as biologic effects on the man; although it overlaps some of the other areas and is usually the result of some of the other factors, it is of such great importance

BIOLOGICAL AREAS

1. ACCELERATION, DECELERATION, WEIGHTLESSNESS*
2. ACOUSTIC ENERGIES (SOUND AND VIBRATION)
3. ATMOSPHERE, TEMPERATURE, HUMIDITY
4. DECOMPRESSION
5. RADIATION

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FIGURE 1

BIOLOGICAL AREAS

6. WORK CAPACITY AND PHYSICAL FATIGUE*

7. ORIENTATION*

8. DAY-NIGHT CYCLES

9. HYGIENE, ILLNESSES

10. DIET, WASTE HANDLING

NASA

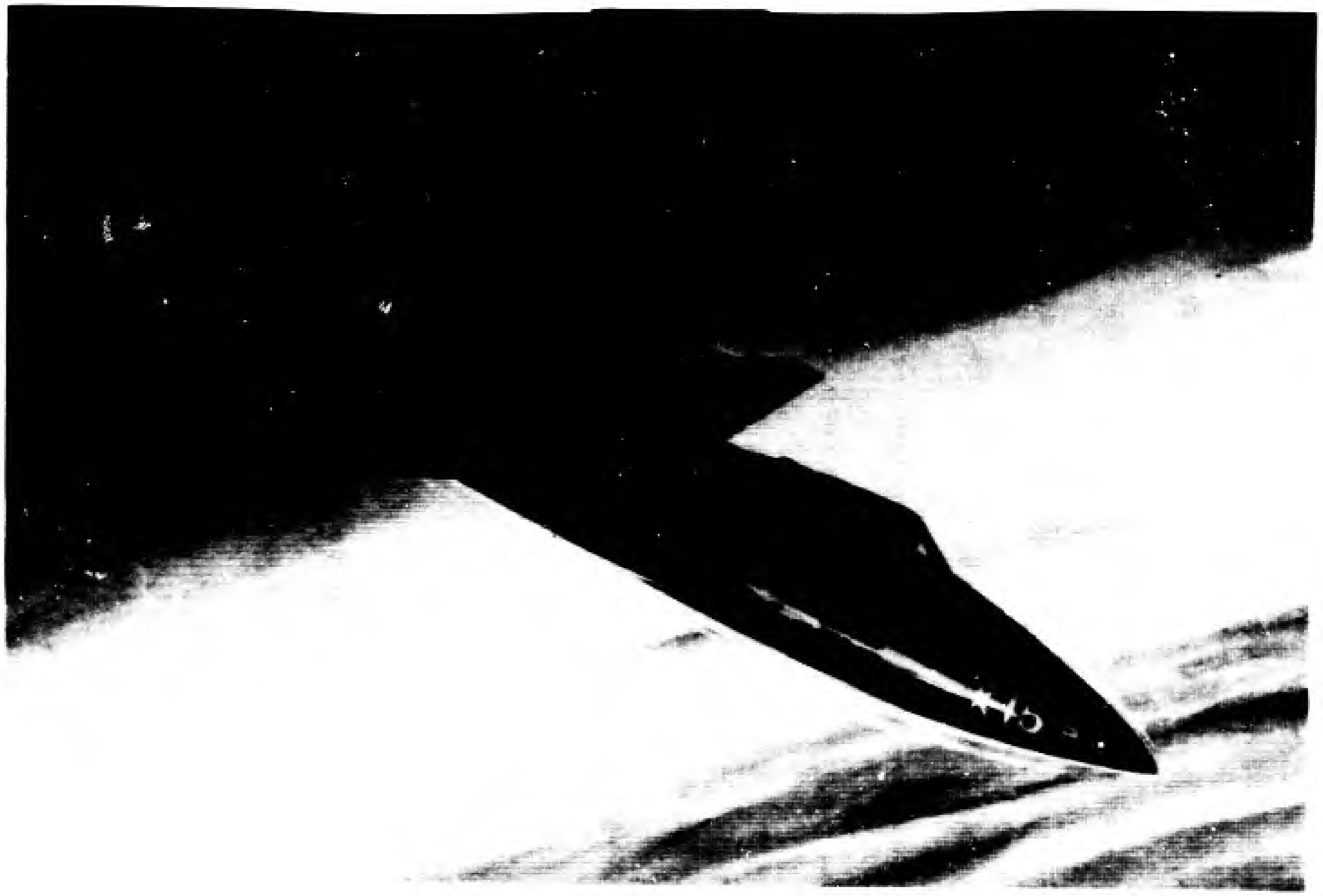
FIGURE 2

to the outcome of the mission that it should be emphasized in the early planning. We have had a good review of radiation, but I should like to put a different slant on it in terms of organizing our human or biological approach to the problem in future systems.

The areas named in figure 2 concern the more mundane happenings to or about the man, but they must be considered when we plan the vehicle. Under work capacity and physical fatigue I include such things as station lay-out, the job that you expect the man to do, keeping in mind always that the individual has a rather comprehensive complex job which always seems to increase--never decrease--per man. I mention orientation separately although it could be combined with work and physical fatigue and related to crew station lay-out. It takes on new importance, however, in vehicles which may not have conventional earth orientation. You heard about day-night cycles this morning, and it is an operational problem. An area that has not been talked about very much thus far, and one that will become of increasing importance, is hygiene and illness as far as people in future vehicles are concerned. The area of diet and waste handling was discussed this morning; I think diet other than for just nutrition can be of use in space flight.

Keeping in mind these ten biological areas and the fact that they interplay in the development of new vehicles, we will discuss the problems related to some of the vehicles that we are dealing with today. Now I would like, again, to emphasize that the X-15 is a success not only as a vehicle to enable us to probe outside the more mundane aeronautical parameters and to begin probing the space equipment areas mentioned by Dr. Strughold, but it makes us realize that we really have to start making decisions. Now these decisions can take several forms. I will refresh your mind on the X-15 (Figure 3). You say, "Well, now, the X-15 is a short-time flight vehicle; it's not going out very far as far as the geography to be covered, etc. As to a lot of those biological areas that I would very quickly say, 'No sweat.'" This is true, but in plans for the use of this vehicle, some decision was made regarding each biological area. As for diet, for example, you might say, "Well, my goodness, he's going to be gone so long--why worry about diet?" I do know that in the planning of the X-15 (i.e., the original planning of the operational concept), the diet pre-flight was considered very seriously, not only as to the nutrition, but also the water-electrolyte balance as far as the man would be concerned if he had to land involuntarily

X-15

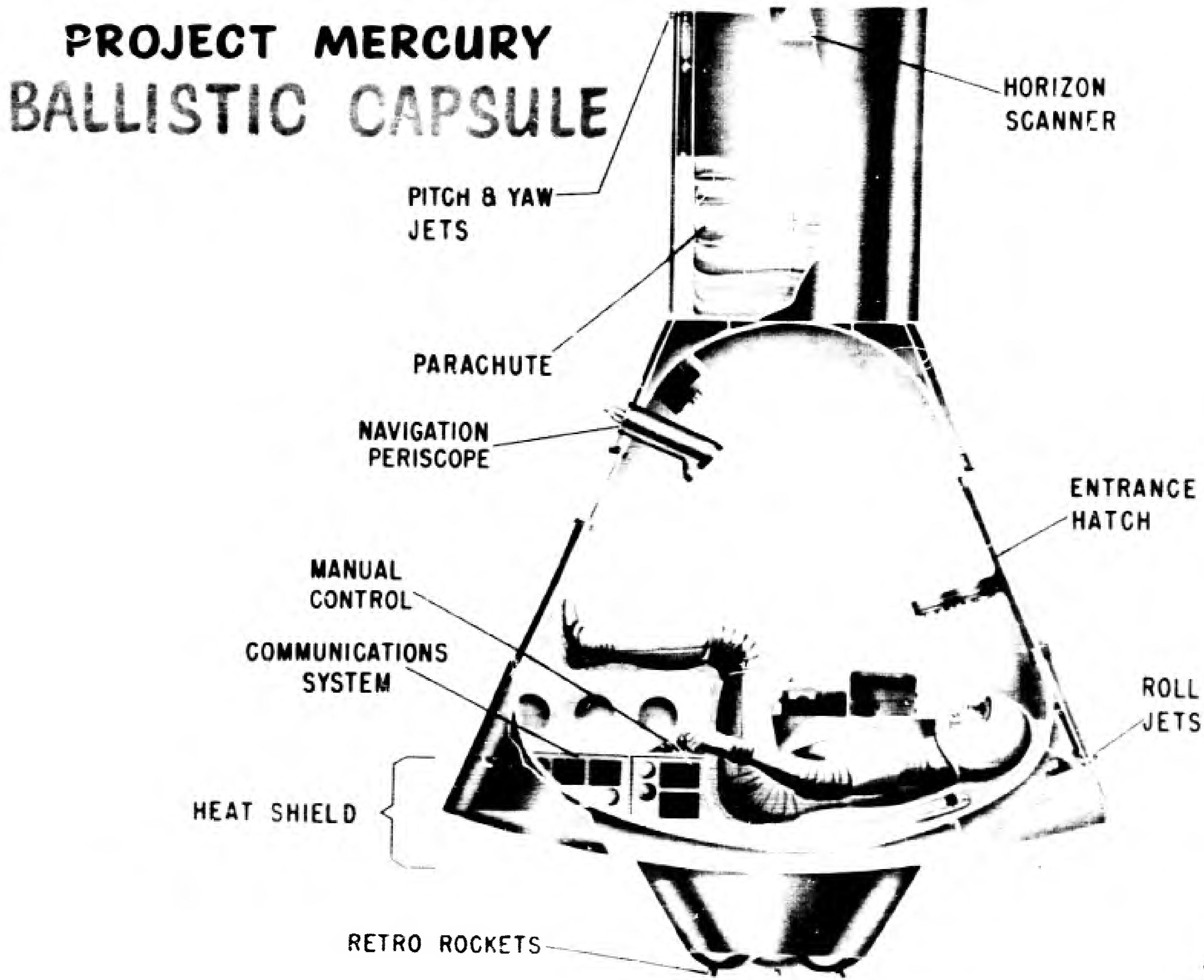


NASA

FIGURE 3

and could not be picked up as soon as expected. If you could see some of the terrain that the X-15 expects to fly over--I have heard that even the jack rabbits carry knapsacks there!

The Mercury capsule (Figure 4) is the one referred to as the wingless vehicle under development as the first attempt at truly around-the-earth orbital flight as far as the United States is concerned. Project Mercury has made it necessary to discuss the biological problems of putting man in space and evaluating his capability of living and working under space conditions. Both the Mercury and the X-15 introduce the requirement (mentioned by Mr. Hegenwald) that crewmen must stay with the vehicle. It would be impossible to have a man jump over the side of the X-15, traveling at maximum speed. Unless the man carried his own oblation helmet, or something of equivalent size, he would have a devil of a time landing on the surface of the arth. In the orbital vehicle of the Mercury type shown here, to step out over the side of the capsule would mean death unless the astronaut carries his own retrorockets system and also wears the oblation helmet. Therefore, it is essential that he stay with the vehicle and bring it down again; in other words, "punch the button" for return home whenever the emergency demands it.


PROJECT MERCURY
BALLISTIC CAPSULE
PITCH & YAW JETS
PARACHUTE
NAVIGATION PERISCOPE
MANUAL CONTROL
COMMUNICATIONS SYSTEM
HEAT SHIELD
RETRO ROCKETS
HORIZON SCANNER
ENTRANCE HATCH
ROLL JETS

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The first item on my biological list is acceleration, deceleration, and weightlessness. As related to the X-15 type of vehicle, I think Mr. Hegenwald has covered the subject very well as to the kind of acceleration patterns we will encounter. By the manner of ejecting the seat in the event the man has to leave the vehicle and by programming the acceleration forces that he will experience during landing (and incidentally the man can program these), we have been able to keep the acceleration forces on the X-15 down to something we have dealt with pretty well in the past. It has been demonstrated repeatedly by use of the dynamic centrifuge simulation of the Navy Johnsville Centrifuge, that the man can, in effect, not only tolerate the g's as far as survival is concerned, but even more important, he can tolerate the g's in a functional manner. This brought about, I think, a new concept in acceleration study, that of the dynamic centrifuge. As for weightlessness, the X-15 programs will get into the neighborhood of four- to five-minute periods; this is about four or five times that which we have been able to experience to date with the F-100F, as discussed by Major Hawkins the other day. Weightlessness does not seem to be an insurmountable problem; the Russian experience with Laika, the mouse experience with Mia, the Army-Navy animal flights on the ballistic missile, and the flight made by Sam on the Little Joe project all demonstrated that the animals took the kinds of acceleration, the weightless periods, and the re-entry accelerations quite well. We also expect to show by additional animal flights that man has the same capacity--in other words, to demonstrate that the X-15 forty-five-minute period is not really an insurmountable problem for the man.

Now in Mercury we have become more involved as far as acceleration is concerned. First of all, the man is, as has been pointed out, going to be lying in a couch; he will be exposed to g's which exceed those normally expected from the X-15. In fact, the normal launch g-loads will be in the neighborhood of 7 to 9, and by putting him in the transverse plane so that the forces are actually going through the chest-back parameter, we have found that the man is able to tolerate them quite well. Secondly, during the emergency flights--in the event that we have an emergency re-entry, as was pointed out by Mr. Hegenwald--we can pretty well control the accelerations between 12 and 20. It has been demonstrated on the centrifuges that man can tolerate these accelerations although he loses his capacity to perform at the extremes of this level. As mentioned earlier, we expect to use landing bags to try to top-limit the acceleration so that when the man hits the ground or lands in the water, the bags will absorb the energy beyond a certain point; and we have set 20 g's as the maximum.

I will show you the approach used by the Mercury capsule in handling the acceleration problem (Figure 5). Keep in mind that the large end will hit the ground first. The man is lying on his back, in the ideal position, as demonstrated by the multiple studies both at Navy Centrifuge and at WADC. In this position, he can take the g's in the transverse manner; we have added crushable materials to the bottom side of the couch. They are aluminum crush blocks of special foil that allow us--in the event the landing bags fail to offset the g's--to avoid exceeding around 40 g's during the landing impact. Thus, although it would be a very rough ride if he hit land, we think the man would live even though he did not have the bags inflated.

Now, you may see what this couch looks like (Figure 6). This is the man in his couch; this is a foamed, tailored couch, and as you can see by the smile on the man's face, he is obviously contented. This was one of the experimental couches we tested on the centrifuge in determining the angles, the contour, how much contouring is needed. One new idea that came out of this program was to make the couch, as you see here, B-88

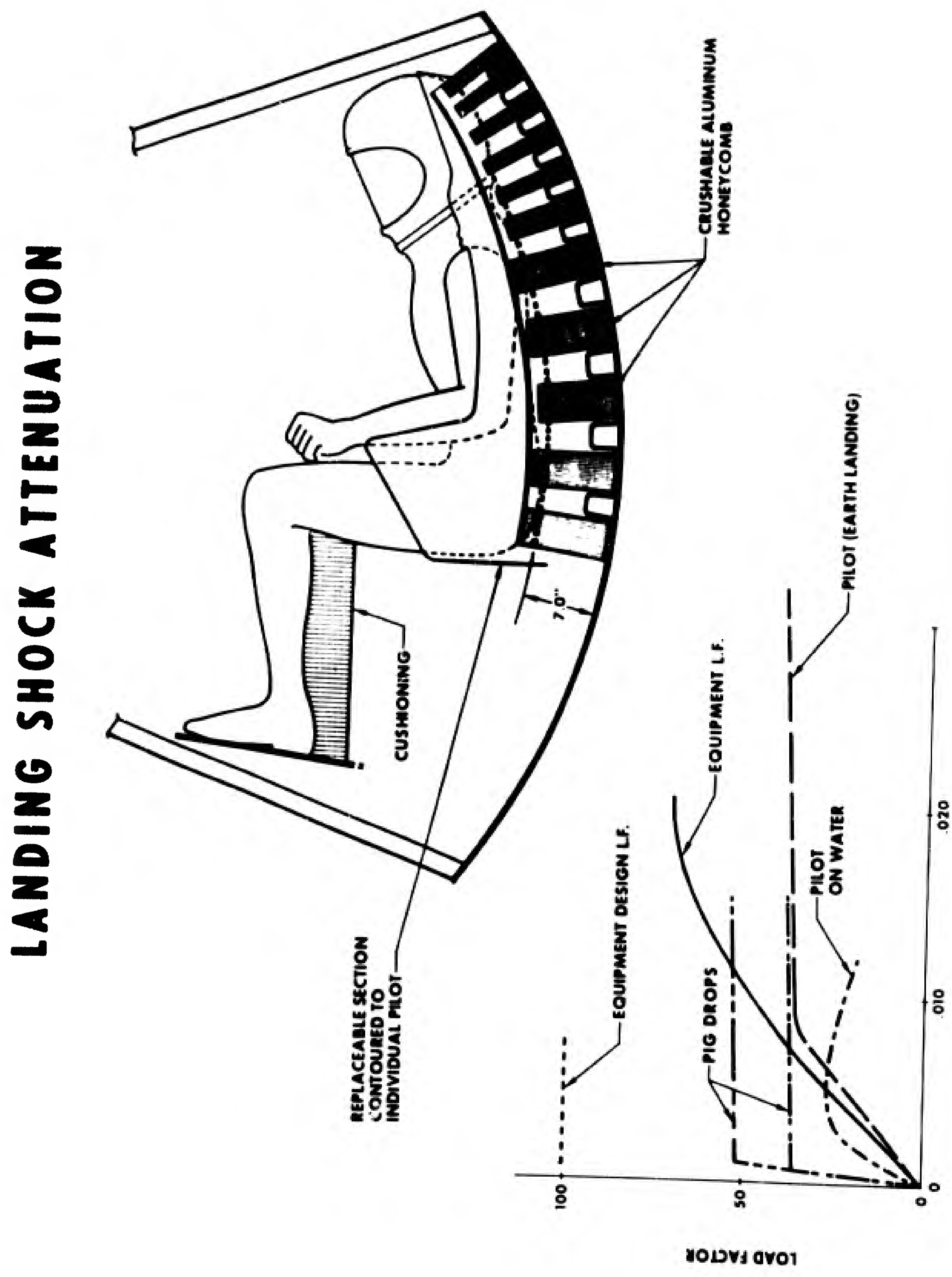
LANDING SHOCK ATTENUATION
CRUSHABLE ALUMINUM HONEYCOMB
CUSHIONING
7.0"
REPLACEABLE SECTION CONTOURED TO INDIVIDUAL PILOT
EQUIPMENT DESIGN L.F.
PIG DROPS
EQUIPMENT L.F.
PILOT ON WATER
PILOT (EARTH LANDING)
LOAD FACTOR
100
50
0
0
.010
.020
TIME-SECONDS

FIGURE 5

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FIGURE 6

actually come up beyond the mid-axillary line and support the chest so that, when the man takes the load of g's on impact, he is not flattened out against the back as we saw in the pictures of Captain Beatty. We think we went too far in this; we think that not so much protection is required. In this way, we attack the system approach problem by getting the man out of the deep grooves in the couch and giving him more mobility; because when he is immersed in this groove, he has to fight the couch all the time when he gets ready to do movements. We have the best couch for g forces, but not such a good couch for mobility; so a compromise must be made.

In training the astronaut, we let him experience weightlessness for four or five minutes, maybe a little longer; we next jump to three orbits of roughly one and one-half hours each. Now this is a relatively large jump in the learning curve on weightlessness. As you know, we have been fighting desperately over the last several years to achieve a second at a time. We are, therefore, interested in simulating weightlessness, as much as possible, by using aircraft; this is the reason the boys were out at Edwards flying the F-100F. Dr. Douglas will discuss this more in detail tomorrow. In addition to this, we will use animals to learn more of man's capacity for performance during weightless flight. Our animal of choice, the chimpanzee, has been selected for two reasons: we want to observe the effects of his breathing and generating CO_2 during weightless flight; and the chimpanzee can be trained to perform tasks which should give us a better understanding of what man can do under similar conditions.

As for future systems, I was very much encouraged to hear Dr. Hessberg say the water-immersion technique must undergo some changes before we can put it in the vehicle. We have heard a lot about water-immersion, but it has not seemed feasible from an operational point of view. We thought we were a small voice in a large wilderness and were not being heard, but I see that something has happened to make people agree that there is a lot to be done before water-immersion can be considered the ultimate answer. We think that it would be far better to design vehicles which will lower the g-forces--to put the man back in the system under his normal environment--than continue to saddle him with vehicle boosters and vehicles which by their very design push him toward his tolerance limits. We would rather think in terms of the tolerance being set at some level where the man is a full voting member in the vehicle. I think the astronauts will go along with this, too.

Now, as we consider the space vehicle of the future, as far as accelerations are concerned, we think that the kinds of accelerations will be roughly the same types that we have already dealt with. The problem of disorientation, which was described earlier by Dr. Hessberg in relation to the spinning vehicle, is a very serious one. We should think a long time before we saddle the people with the necessity of putting artificial gravity into a vehicle. Mechanically, this is a good-sized problem and, in addition, it would present problems in keeping the man oriented. I think we should look one step ahead: if we decide we must have aritificial gravity, we should carefully determine exactly how much we need so that the vehicle would spin a minimum number of revolutions, because again the magnitude of the problem of the man adjusting goes up almost directly with the number of rpm's.

Let us turn now to our acoustical energy, which is too often passed off as unimportant. I like to think of acoustical energy as overlapping several other problems. One problem is communications, an extremely essential thing. You will remember Colonel Knauf's films today, showing the failure of some of the missiles. If I were an astronaut lying at the top of a missile, I would certainly like to get the message in a hurry if things were not going well. So communications during this part of the flight, and actually during the entire flight, are very, very essential. Acoustical energy can be both harmful and helpful in this regard.

Related to the problems of acoustics and vibration is that of fatigue. In industry we know that men who are supposed to "torque that nut" cannot do it under noisy environments very reliably for a long time. If we can avoid fatigue by either damping or eliminating vibration, we will have a much more efficient astronaut for the critical jobs we are expecting him to do. A problem being studied by use of the vertical accelerator at Wright Field concerns critical frequencies and body tissues. When we learned that there are critical frequencies for the specific organ masses in the body, we went back and started checking missiles for these frequencies. No critical frequencies have been found in the boosters that we have at this time.

Of equal importance is the problem of distraction caused by noise. With someone pinging away with a high-pitched fan or another annoying noise, you cannot concentrate on navigation. A good example of this was Scotty Crossfield's experience in the X-15; the striking of his helmet against the canopy during vibration caused a buzzing sound. He thought something serious was happening until his level-headedness and experience helped him to identify the source of the sound. In the Mercury we have a rather noisy environment. We can expect, until we have demonstrated otherwise, noise levels of 120 to 130 db. We have considered designing the helmet so as to obtain at least 20 db attenuation.

To improve the communications system, speech clipping will be accomplished together with restriction of amplitude; the frequency will range from 300 to 3000 cps, and amplitude will be reduced by 12 db. By doing this, the voice comes through much clearer, you clip out a lot of the extraneous information or noise that hinders rather than helps in the problem of communication. In addition to this we are using a voice-over-noise ratio of 6 db which has been satisfactory through the critical first phase of launch. I think it should also be kept in mind that vibration contributes to failure of components. When you see the component hodge-podge inside most of the new vehicles and realize that much of the electronic equipment requires pressurization just as man does, you will know that the friends in the capsule with you are many--so many, in fact, that it will soon be difficult to tuck the man inside.

These items all have their own origin as far as materials are concerned, and with vibration, failure and by-products of the running of this machinery, we get into the new area of toxicity. We have used for years the maximum allowable concentration, which is a very useful number for industry; but I would like to caution you that this is based on exposure during an eight-hour day, and the man is allowed to recover from his toxic exposure during the rest of the day. When we put these by-products in the cockpit of vehicles, the man will, for a longer period of time, have no respite from whatever the agents are.

Let us turn to atmosphere, temperature, and humidity. Now that we are going into a new era of environment approach, I should like to call your attention to a series of items which have originated or have come out of this new parameter of environmental provision inside the vehicle now that we have discarded the idea of the old oxygen mask. You can make a system of the environmental type a very complex one. The equipment is available to do this, but remember whenever you do this, the problems of trying to validate the reliability are increased manyfold. A prime requisite then, is not to over-design complexity into your system. As Mr. Hegenwald said earlier, be conservative in your provision or allowances; do not be stingy, but avoid complexity at all costs. You must consider whether requirements for the vehicle and for man can be met by a single system or if you have to go to a dual system. You must consider such things as interplay of toxicity, the ranges of temperature in the equipment bay, and the ranges of temperature in the man compartment. I wish to emphasize that this is a vital system. Those of us who have been around operational bases for the old aircraft are well aware that many airplanes were flown when the pressure cabin did not work. We remember the reports out of Korea that just because the pressure seals around the cabin were out, the airplane was not grounded if the mission called for it. The new concept of sealed cabins is that the system can cause an abort of the vehicle; the flight does not go unless it is working. Also, if future vehicles are going to require man to be in and out of the vehicle either to repair or to do observations or other tasks, two systems aboard may be necessary to take care of the dual requirements. If this happens, try to use both systems in routine operations. Nothing is more uncertain than a system that has not been used for six months. If you use it daily, you know its idiosyncracies and its performance characteristics; you are in a better position to know whether or not you can rely on it.

I wish to call your attention to the problems of failure of such an environmental system during a flight. As these vehicles move out and away from the earth, first in orbital and then, I presume, into more advanced types of flight, either to or around the moon or some other celestial body, it is not easy to turn and go home at any point in the flight. I mentioned earlier the problem of a crash re-entry. In the X-15, in which we have a short-flight characteristic, we can solve the problem of cabin pressurization by the use of nitrogen. The cabin atmosphere will be 100% nitrogen. This requires the man to wear a suit to avoid exposure to the nitrogen atmosphere. The pressure in the cabin has been set at 3.5 psi. This would normally make you worry about dysbarism; since the flight is short, however, we can obviate this concern by simple pre-breathing, or at least moderate the symptoms by pre-breathing. The systems used in the X-15 are an extension of the oxygen system presently used in aircraft out on the line, except that the man wears the full pressure suit to back up cabin pressurization. A problem would arise if the man should become ill and must vomit; if he opened the face place to vomit, the atmosphere of 100% nitrogen would make it difficult for him to survive.

The Mercury represents the first attempt to create in the space vehicle type a sealed cabin. A gas purification system was put aboard (Figure 7). Air is sucked from the cabin, through a fan compressor, through a heat exchanged to handle the heat loads that will be generated by the equipment aboard the vehicle. The heat exchanger uses evaporation of water as its mode of drive lowers the temperature and brings cooler air back into the cabin. Again I emphasize that we try to keep this simple. You notice that the suit control unit is a separate entity, and the man is actually hooked to it. Figure 8 shows that the suit unit is more complex than the cabin system. You see that air is pulled out of the helmet into a debris trap; this prevents dust particles or vomitus from fouling up the system. The air is re-dosed with oxygen through a demand type of system which is a high psi unit; it again goes through the compressor and then through a series of re-purifications--through the odor absorber using charcoal, lithium hydroxide absorber of CO_2, a heat exchanger using water evaporation, and then a condenser for the humidity; the heat exchanger reduces the temperature (through the dew point). Droplets of water are

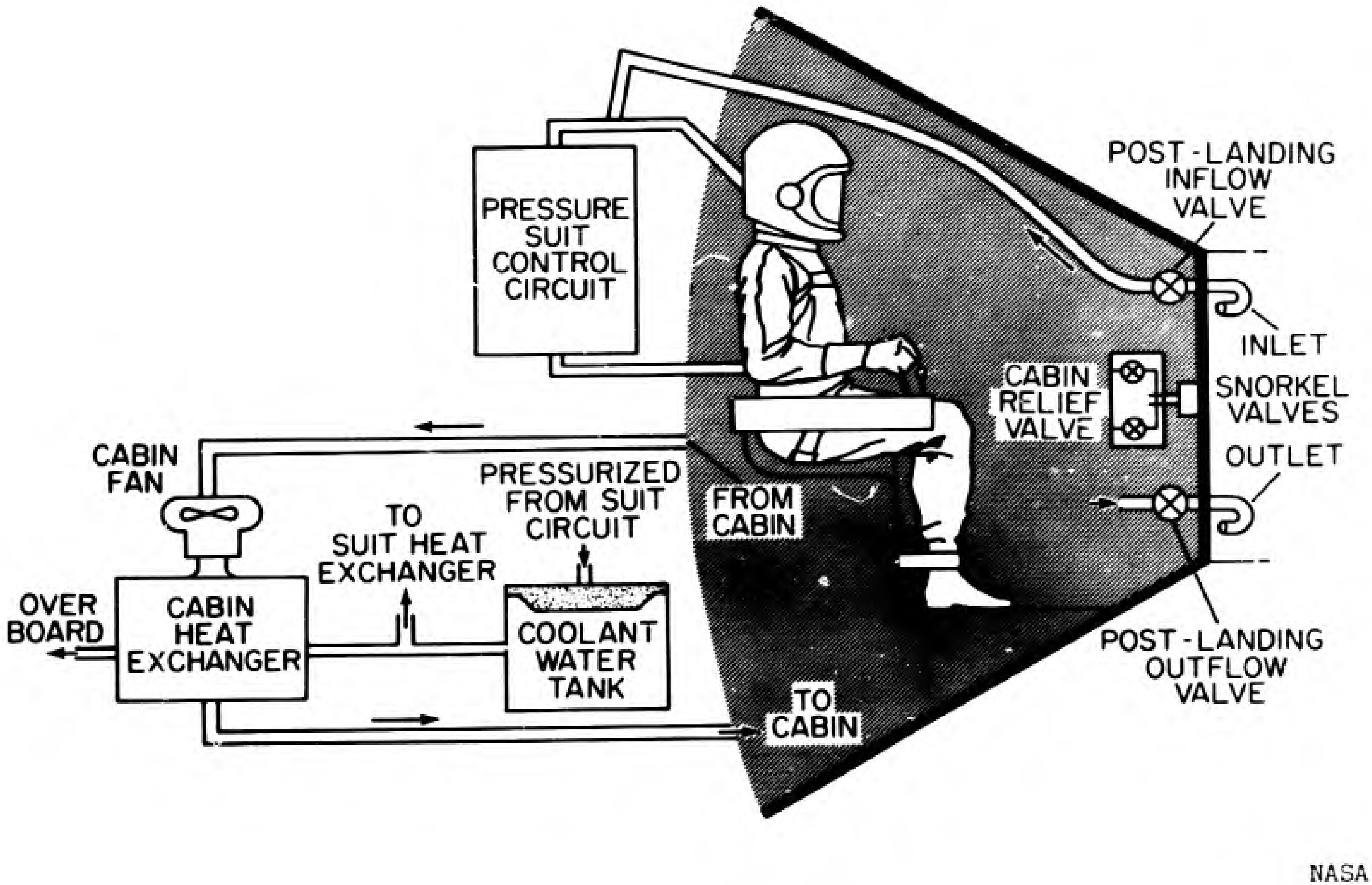

FIGURE 7 - Cabin air control system.

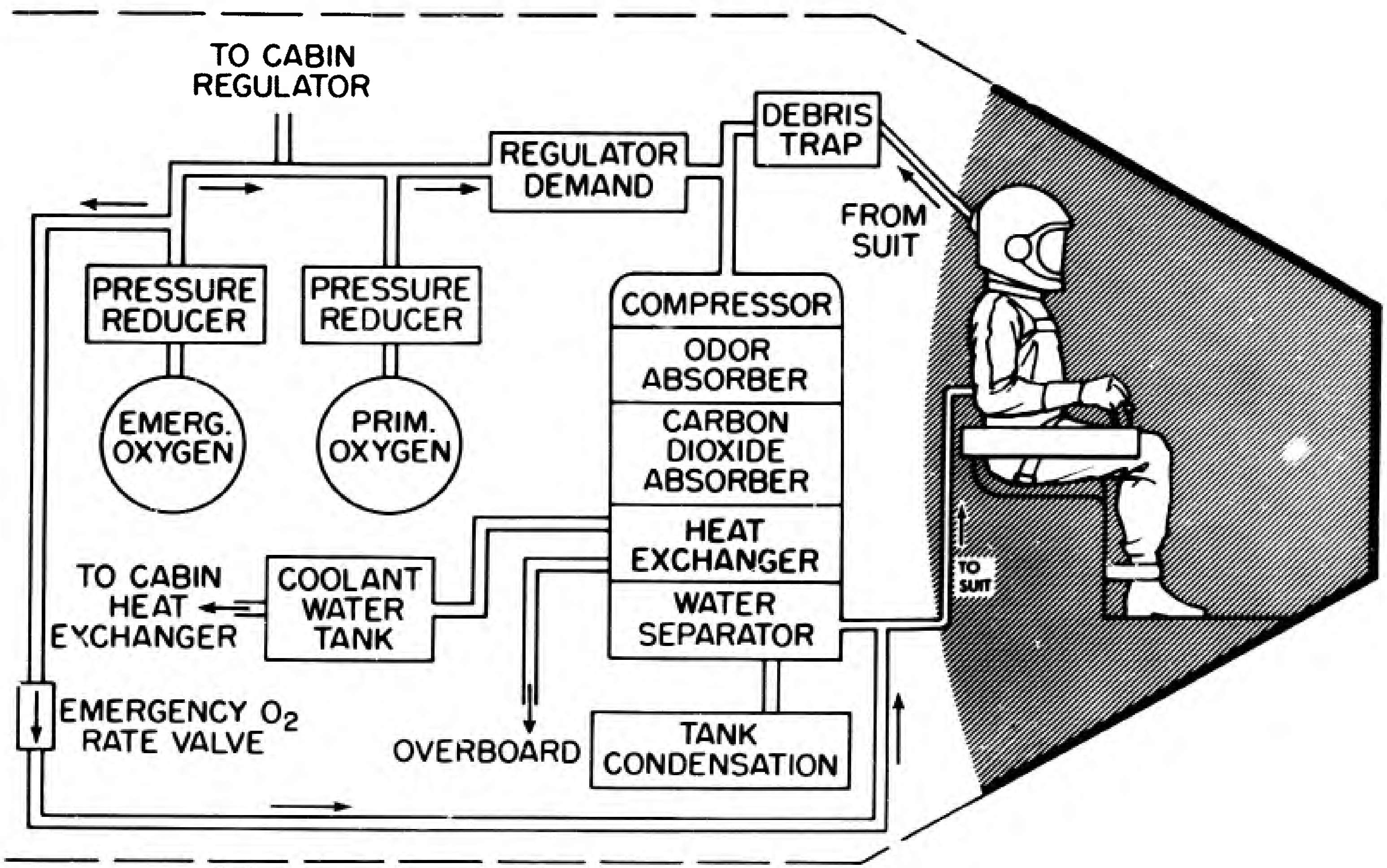

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FIGURE 8 - Pressure suit control system.

impaled on a vinyl sponge; the sponge is squeezed periodically and the excess water collected in a condensate tank. After this, the air, now reprocessed and ready for a man, is brought back, distributed by a ventilation system over the body of the man where it is warmed; evaporative cooling takes place over the body surface; the man breathes oxygen, and the air is processed again. In the event this system fails, we have a simple by-pass system; this is a minimum flow oxygen line which comes in, flows out and back out through the demand regulator and provides a constant flow of oxygen for the individual.

The problem of toxicology in the cabin is solved by isolating the man, or at least giving him the capability of isolating himself. In the event of a fire, he stays inside the suit, puts out the fire, shuts off the circuit or whatever is burning, then repressurizes the cabin after he has things under control.

I was very happy to hear earlier this week that systems other than the algae will be used in the immediate future. The development of an alage system will probably not be expedient for five to ten years. Presuming that we want to accomplish more than just the Mercury flight in the meantime, some other system must fill the gap. The use of algae presents too many problems not yet solved: the respiratory quotient, whether or not biological nutrition can be handled, the handling of wastes, and the problem mentioned in the question session yesterday of producing oxygen at the required rate with the presence of radiation hazards. I think the problems are all solvable, but we want to do a lot of study before we commit ourselves to the system. I think that there are many chemical systems which will give us the intermediate capability required.

The problem of decompression has led to new problems of manufacture and maintenance. First of all, since this is a system which can cause an abort and its failure in flight would be serious, factors to prevent this must be considered in designing the vehicle equipment. The original concept has to be very good. New rigid quality control must be established. New standards for maintenance must be established by those who do checkouts and flight preparation. The technical ability of personnel must be at a much higher level. We must be sure that the system at all levels, from the original concept of design right down to the actual flight, is handled by the best people rather than the man who is very cognizant of the use of the eight-pound sledge and the large crescent wrench. New concepts of instrumentation and checkout of the capsule are essential. Among the essential new points is the leak rate we have set on the Mercury capsule: 500 cc's per minute is the leak rate from the total capsule. It is hard to think in these terms when you consider the leak rates that present-day aircraft have.

As for biological radiation studies, I want to put in a plea for bringing together in one spot the total effort that is going on throughout this country in this area. I have divided this study into six areas (Figure 9). First is the study of the Van Allen bands. This means more than measuring just the physical data; we must know the biological effects of these bands. We must demonstrate by actual flights through these bands that the biological effects can actually be measured. I would like to be sure that both quiescent (and this is nonsolar flare activity) and solar flare activity be spelled out. This would assure us that we truly have the parameters or the outside areas identified in our study of the problems presented by Van Allen bands.

The second item concerns space radiation. On this subject we have had very good discussions and the best summaries I have heard. I want to emphasize that biological effects must be determined; more is required than just the physical

STG 325

BIOLOGICAL RADIATION STUDIES

A. STUDY OF VAN ALLEN BANDS
   1. PHYSICAL BIOLOGICAL EFFECTS
   2. QUIESCENT, SOLAR FLARE

B. STUDY OF SPACE RADIATION
   1. PHYSICAL, BIOLOGICAL EFFECTS
   2. QUIESCENT, SOLAR FLARE

C. STUDY OF RADIATION ON NUCLEAR POWER UNITS
   1. PHYSICAL, BIOLOGICAL EFFECTS

D. CORRELATION OF EFFECTS

E. ESTABLISHMENT OF RADIATION DOSAGE

F. DESIGN AND OPERATIONAL INFORMATION

NASA B-38-1 WHITE 1/60

FIGURE 9

measurements. We want to be sure that we are not going to get fluxes or changes that are related to quiescent or solar flare activity.

A new area being discussed concerns the use of nuclear power units or other nuclear units that will be used aboard the vehicles, either for propulsion or for power. Again, the same rule holds; we want not only the physical measurements, but also the biological effects that can be expected. It is most important, then, that we bring these three areas together and correlate the physical and biological measurements that result as they interplay. Again this is a system concept.

We must solve the problem as to what dosages we will allow our space traveler to accept. AEC dosages for the people working in industry have been established, but do those dosages hold for the kind of operation we are going to do? Other questions arise: Does the man make one flight and is then retired? Or should he make multiple flights and thus take advantage of the experience gained by the previous one?

I think we should accept the advice of experts in this field. Having attained information on design, dosage, physical measurements, biological effects, and dosage, we proceed to operational design and operational information. If you tell us that we have a problem of radiation, we can handle it in several ways. We can use shielding, which is very heavy and bulky if lead is used, or we can use the equipment aboard to help in shielding. The problem might be minimized by planning where to go through the bands or how long to stay in them. You remember the kidney-bean-shaped deployment of the bands; if we go out through the edges of the bands by traversing them in an oblique manner rather than flying straight through, we will take a longer time to go through, but can thereby control our dosage rates.

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LECTURES IN AEROSPACE MEDICINE

SELECTION AND TRAINING OF SPACE CREWS

Presented By

Lieutenant Colonel William K. Douglas

National Aeronautics and Space Administration

Space Task Group

Langley Field, Virginia

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SELECTION AND TRAINING OF ASTRONAUTS

by

Lt Col William K. Douglas, USAF, MC, NASA

When it comes time to select a person to do a job, the first thing one customarily sets down is the nature of the job. In selecting pilots to fly in combat we first studied combat. At least, we eventually studied combat. Originally, I am told, almost any one was acceptable for pilot training. I speak here of the pre-World War I era. As time progressed those who had the authority to say "No" became aware of the fact that some people could not be considered adaptable to aeronautics. About the time this realization came to the conscious level I am sure some one asked the medics to come up with selection criteria. Presumably then, this pioneer took a look at flying and made some effort to determine what the pilot had to see; thus establishing the criteria for vision. Next he might have looked at what the pilot had to hear, and possibly came up with the criteria for hearing. Some time along the line it was realized that the pilot had to know a few things also, so his intelligence was estimated and more criteria were established. In some such a manner we finally arrived at a thick volume of regulations which make selection of a pilot today a relatively simple procedure.

Now when it comes to the selection of an astronaut we are at a certain disadvantage. We really don't know what the pilot has to do. We can delineate fairly well what we would like for him to do and set our criteria by this rather artificial standard. This is all brought about by the fact that we can't really examine the job. We can postulate and hope that we are accurate in our postulations. This is essentially what has been done in the case of the Mercury Astronauts. One other thing will give us some clues as to what the astronaut must be fit to do, and this is the vehicle itself. Dr. White has reviewed the anatomy and physiology of the Mercury capsule in some detail so in my future remarks, I will assume you are familiar with the machine the Astronaut must fly. The use of the word "fly" in this instance was by design and choice; not by accident, for the Mercury astronaut will, in fact, fly the capsule to a limited degree.

Let us then examine the typical Mercury orbital mission. After several days of preparation the astronaut is finally dressed in his full pressure suit a few hours prior to launch time. Then, after the inevitable delays he will be taken out to the launch pad where he will be placed into the capsule and strapped tightly into his form fitting couch. This will occur approximately two hours before launch. After all straps are secure, the lid to the entrance hatch will be secured with 140 nuts, bolts, and screws. The capsule checkout procedure takes only about 30 minutes so for approximately one hour he will have to sit secure in his capsule waiting only for T minus zero, or a sudden emergency abort signal which will send him, 3 seconds later, 2500 feet into the air with an accelerative force lasting slightly over one second and peaking at about 20-G. This will be quite a jolt. If all goes well and there is no necessity for abort, the Atlas will accelerate to a peak of 8-G in a little over two minutes. At this time staging occurs and the acceleration drops abruptly to one G, but builds up to 9-G by sustainer burn-out. The capsule with its contents is then abruptly weightless. As soon as separation from the sustainer occurs, the autopilot will, in about 5 seconds, stabilize the capsule, and then rotate it 180° in the yaw axis and also 35° base up in the pitch axis so that the capsule is, placed in the retro-fire position. This is to assure that retrofiring can occur at the soonest possible moment to avoid landing on the continent of Africa if full orbital velocity or programmed orbit parameters have not been obtained.

Up to this point the astronaut has taken no active part in the flight, that is; if all goes well. During this phase, however, he has a crucial passive role to play. For his own safety he must monitor those instruments and indicator lights on the panel which indicate proper function of the rocket or which may indicate mal-function. The pilot's left hand will always be on the abort handle and he can fire the escape rockets at any time after the Atlas has ascended two inches off the launching platform. This inability to abort prior to lift-off is a pad-safety feature, but it does insert another element of uncertainty and dependency into the pilot's mind. From lift off to insertion into orbit the pilot must be alert and prepared to manually operate a number of vital procedures which ordinarily would be taken care of by the automatic system. These include activation of the cabin oxygen purge bottles, escape tower jettison 15 seconds after staging, and capsule separation from sustainer, if these events do not take place automatically. At insertion the pilot must be prepared to manually orient the capsule for retro-firing if this is not accomplished due to malfunction of the automatic stabilization control system. After stabilization in orbit the pilot must maneuver the capsule in various axes if he is to make purposeful observations of the earth and sky. This brings us to the operation of the attitude controls. The control actuating device in the Mercury capsule is a far cry from the conventional stick and rudder pedals. The single control handle is placed on the pilots right side and controls the capsule in all three axes. The handle itself is shaped very much like the hand grip on a conventional control stick, but here the similarity ends. The axis of rotation is not about a point at the base of a non-existent control stick but is configured into the center of rotation of the three major motions about the wrist joint. Pitch is controlled by radial and ulnar deviation of the wrist; yaw is controlled by flexion and extention of the wrist; and roll is controlled by supination and pronation. To further complicate matters one recalls that there is no aerodynamic damping in the vacuum of space, so once the capsule is started into motion by a control movement, it will continue in that movement, and at the same rate until an equal and opposite control force is applied to stop the motion. Another factor enters here; in aircraft coordinated control movements are the rule, in this device they are the exception. In the positioning of the capsule for retro-firing the pilot first rotates the capsule 180° in the yaw axis, then he pitches up to 35°. Due to control cross coupling and gyros with only two degrees of freedom the customary coordinated control movements cannot be made.

With the capsule now safely in orbit the pilot assumes a more active role in the mission. He will be expected to perform a great number of tasks, not the least of which is making periodic and frequent reports to ground tracking stations. He will relay vital instrument readings to confirm data telemetered to ground stations. He will have to monitor carefully such factors as cabin pressure, pO_2, pCO_2, and oxygen tank pressure, since he may be the first to detect that these are reaching dangerous values, and he is the only one who can take corrective action if this should occur. There is no automatic faceplate on his suit, and in the event of a rapid decompression from any cause, or even worse possibly a relatively slow decompression (taking as long as 15 minutes for example) the pilot must get his face piece closed and quickly analyze the situation to determine what corrective action is called for. This action may even be voluntary, immediate initiation of the retrofire sequence for return from orbit. It is hoped that the pilot will be astute enough, and calm enough, to make careful analysis of his predicament so as to avoid re-entry at such a point which would result in his landing in other than one of the primary or secondary recovery areas. If the emergency is so great that immediate re-entry is indicated, then, of course, this must be accomplished and the pilot must, then, be prepared to survive on land or water any place between about 40° north latitude and 40° south latitude. While in orbit the pilot will also be called upon to make a variety of scientific observations. He will be asked to observe such natural phenomena as cloud cover, auroral displays and possibly certain naked eye astronomical observations. He will also be asked to note carefully his own body sensations, the presence or absence of illusionary phenomena, and any variations from his normal earth-bound subjective sensations. The capsule has a relatively elaborate navigational system in the form of an earth viewing periscope. The center of the field of this periscope gives an earth view with a "magnification" of 0.7. This presents a 19 degree view of the earth's surface in the inner 5 inches of the periscope's field. Outside of this 5 inch circle is presented a view of the earth from horizon to horizon. Actually the viewing angle of the periscope is slightly more than 180°. With this periscope, and with the aid of strip maps, time clocks, and other navigational aids the pilot will be required to perform such navigational problems as may be presented to him in advance of the flight. This might include such tasks as determining the time over various easily recognizable geographical landmarks; "terrestrial" navigation if you will. Of course, he cannot alter either his speed or his heading, but his ability to perform such realistic tasks as these will give us some insight into the more complex navigational problems of future space flights. This terrestrial navigation system also serves as a backup to the pilot's instruments. He is being trained to use his periscope as an orienting and stabilizing instrument in the event of failure of the more elaborate system.

Shortly prior to the completion of the third orbit the capsule and its occupant will be prepared for re-entry. Even though re-orientation of the capsule will be accomplished automatically, the pilot will have to be prepared to perform this function in the event of system failure. Again, the capsule must be oriented with its broad base forward and elevated at an angle of 35°. This position must be attained prior to reaching the predetermined point where the retro rockets are to be fired. If the capsule is out of allignment beyond specified limits a locking device prohibits firing of the retro rockets. There are three of rockets allignod so that their thrust will be directed through the center of gravity of the capsule. Each rocket fires for 10 seconds but each is fired 5 seconds after its predecessor. This has been termod "ripple firing." Since the exact location of the center of gravity cannot be predicted, or rather, it is subject to change depending on such factors as fuel consumption, oxygen consumption and so forth, there may be some thrust misallignment with the resultant alterations in the attitude of the vehicle. This may impose another guidance task on the astronaut. After retro-firing the capsule is oriented into the re-entry attitude which is a base down angle of 1.5°. As the atmosphere is entered aerodynamic forces build up to cause oscillations in the attitude of the capsule. These are of such magnitude that the capsule attitude cannot be accurately maintained by the reaction jets. However, it will still be necessary to apply counteracting control forces to prevent the rate of oscillation from building up beyond unacceptable limits. At about 10 M' a ribbon parachute is deployed which lowers the capsule to the surface with an impact velocity of 30 feet/sec. Here again the pilot must monitor the automatic system, and be prepared to manually activate the parachute. Then to evaluate the status of primary chute and if non-satisfactory, jettison the primary chute and deploy the secondary chute. At this point there are two courses of action open to the astronaut. One, he may remain in the capsule until it is lifted aboard a recovery vessel, or he may immediately vacate the capsule and board his life raft. In practice he will probably not do the latter unless the capsule is leaking water. He will probably remain in the capsule until located by helicopter or surface vessel at which time he will climb out and be picked up by the helicopter or the ship. Even at this time his mission is not complete. He still must submit to an extensive de-briefing which will include a thorough physical examination as well as innumerable questions concerning his observations while in orbit. In fact, these first few men will undoubtedly be subject to careful study and scrutiny for the remainder of their lives.

To review briefly, then, let us look at a gross outline of the various things required of the pilot.

1. COMMUNICATE WITH GROUND ACTIVITIES
2. MAKE SCIENTIFIC OBSERVATIONS
3. MONITOR ONBOARD EQUIPMENT
4. CONTROL CAPSULE ATTITUDE
5. NAVIGATE AND FIRE RETROROCKETS (POSSIBLE)
6. INITIATE EMERGENCY PROCEDURES
7. ACTIVATE ESCAPE SYSTEM IF REQUIRED
8. DEPLOY LANDING PARACHUTE IF REQUIRED

As these activities are analyzed, and as they are broken down into their individual sub-tasks, it becomes quite apparent that the best suited type of person for this job is an experienced pilot, even further he should be a combination scientist and pilot. A man who is accustomed to acting quickly and correctly in emergency situations; a man who is used to working without help from others, but who nevertheless can readily and easily work with others. It is clear that the job itself dictates many of the requirements for this man but there are a few other items which must be given consideration. One of these less obvious factors is that of the requirement for procuring a standard biological subject. We are basically concerned with only one thing in Project Mercury, and that is the demonstration of our sincere and profound belief that man can exist and function effectively in a space environment. Further, we must show that he can withstand the stresses associated with putting him there and with getting him back safely. To demonstrate this contention it is necessary to use as a subject a more or less standard man. By this is not meant average, the relationship of the "standard" man to the "average" man is similar to that which exists between the Western quarter horse and the mustang. There is also the thoroughbred, but he has a rather restricted use and is in reality quite fragile. We must select standard men, as our first voyagers into space. This is true for more reasons than meet the eye. Obviously, if a standard man can inhabit space, then probably the rest of us also can. Likewise, he will probably live to a ripe old age, and be functional longer than most men, thus, these pioneers will, it is devoutly hoped, be around for years to come and will probably form the nucleus of future advanced space operations.

With these factors in mind then, let us review the selection criteria as established by White, Augerson, and their colleagues in October 1958:

CRITERIA USED IN PILOT SELECTION

1. AGE - LESS THAN 40
2. HEIGHT - LESS THAN 5'11"
3. EXCELLENT PHYSICAL CONDITION
4. BACHELOR'S DEGREE
5. GRADUATE OF A TEST PILOT SCHOOL

6. 1500 HOURS FLYING TIME

7. QUALIFIED JET PILOT

The age limit is admittedly a rather arbitrary one, however, it was felt that up to this age one retains much of the resilience of youth, and has not yet acquired the rigidity of age. The earlier comment regarding the desirability of retaining these people actively engaged in space flight pursuits must be borne in mind. No lower age limit was established, but it is interesting to note that the youngest of the seven selected men is 32 years of age. The oldest is 38. This mid-thirty span of age results not from design or choice, but from the fact that once one has lived long enough to fulfill all of the other requirements one is in his mid-thirtys. (The mean age of the seven is 35). The height limitation of 5'11" was dictated, in the main, by the size of the capsule. Although the greatest exterior diameter of the capsule is slightly over six feet; the greatest internal diameter available for the man is less than five feet. The interior is so crowded with equipment that even a 5 foot eleven inch man has a difficult time folding himself into the remaining space allocated to the man. Actually the critical dimensions as far as the man is concerned is the eye-to-rump distance. The eye position is the one fixed and invariable point in the capsule, and this is dictated by the location of the exit pupil or image of the periscope. This point is not alterable. With the pilot's eye fixed at the image plane of the periscope (which, incidentally is optically similar to a telescopic sight for a sporting rifle, i.e., the eye sees the image at a relatively great distance from the ocular lens itself) the remainder of the body can be placed as convenience dictates, within certain rather liberal limits. Long legs can be folded, sacrificing only comfort, but the eye to buttocks length can be altered only by bowing the back, and this is undesirable from the standpoint of impact shock as well as comfort.

The many and varied stresses of the Mercury mission, from the accelerations of launch to those of re-entry and impact on the surface of the ocean with the added possible necessity for survival on the open sea, and the remote possibility of the necessity for survival on some remote land mass dictated the requirement for excellent physical condition. The foregoing is obvious, but what is less apparent, but equally important as justification for and healthfulness is a factor related to that mentioned previously in connection with the standard man philosophy. Another vital reason for good health is the fact that the astronaut might not take his first ride until from two to three years after he was selected. It is vital that he survive this three year period in good health from a purely economic standpoint. The onset of sudden illness or physical incapacity any time during the training period would be most unfortunate. At this point the general philosophy of selection deviates somewhat from the aim of fitting the man to his immediate job. Also one must bear in mind the medico-legal aspect of selection. It is important to record existing traits, or departures from normal physiology prior to exposure to any agent which might result in, or aggravate the abnormality. For this reason sperm counts and other seemingly unrelated procedures were accomplished during the physical examination. Although not specifically mentioned in the slide, mental and emotional health is understood to be included in the broad general heading of "excellent physical condition." The psychological make-up of the astronaut must be one of great rarity in our society. He must be a man who can work as a member of a group for a long period of time, contributing his share and accepting the contributions of others with grace and confidence. Then he must, quite suddenly, become a lone wolf; completely self-sufficient and self-confident. Although he will have radio communication with ground stations, and have the best advice of experts available to him on request, the orbiting astronaut must, in the truest sense of the word, be a man who thinks for himself. A high order of intelligence is a must, and into this category falls the requirement for a Bachelor's degree. Not that this is, in itself, proof of intelligence, but more because it gives a fundamental background of knowledge and strong evidence of educability. A glance at the pilot requirements is proof enough of the necessity for intelligence and educability.

The most controversial of the requirements have been those which dictated that the astronaut be a graduate of a test pilot school, be a qualified jet pilot, and that he possess a minimum of 1500 hours flying time.

Many have asked, "Why a pilot, and especially why a test pilot?" The basic philosophy here is that founded on the premis that space flight is in reality nothing drastically new, foreign or different, but it is instead, the logical and proper extension of flight within the borders of the atmosphere. Man progresses in the profession of flying by going faster, further and higher. The Mercury vehicle is the most advanced flight craft that this country has developed. If some liberty is allowed in the application of the word "flight" one can say that this machine is the first non-aerodynamic flight vehicle developed in this country. It is then only fitting and proper that it be test flown by men who are experts in the field of test flying. The Mercury capsule is manuverable as has been pointed out. It differs from earlier generations of vehicles in that manuevers do not result in a change in the flight path. This difference, however does not alter the fact that it is still an instrument of flight in the broadest sense of the word.

The intent here is not to leave the impression that the selection of the Mercury Astronauts was accomplished solely and entirely by the medical profession. Such was certainly not the case. This effort was a joint one, participants being the medical group and the aeronautical engineers of the National Aeronautics and Space Administration. Each group learned from the other, and each contributed to the four phases of selection, namely: estimation of the tast characteristics; establishment of criteria; application of testing procedures; and finally the analysis of the test results or "selection" in the restricted sense. Determination of each candidate's engineering background and his fund of knowledge in the technical fields was an important responsibility of the engineering group. After the medical selection was completed and the field of candidates reduced to workable levels, the engineering panel performed the final selection based on technical aspects and the abilities of the medically acceptable candidates that this method worked, and worked so very well, speaks for the mutual confidence and the esteem with which each of these groups regards the other. Here too widely separated scientific disciplines work together with a minimum of misunderstanding and a maximum of faith.

In summary then our astronaut plays many roles in Project Mercury; he is a subject in a biomedical experiment, he is a test pilot-engineer for a momentous advance in the field of flight and finally, he is a scientist conducting a pioneering investigation. Selecting a man to fill all of these roles is a formidable task. I am confident that those directly concerned with the selection program were successful beyond all expectations. The several military and civilian institutions that cooperated in this effort are due great praise and sincere congratulations.

In the case of training astronauts, one is faced with a problem similar to that faced in selection. Namely, what are we training him for? Again, we must analyze the job, and make some effort to reach a logical description of the task. We are faced with yet another problem, and that is that there is quite a dearth of experienced instructors. In spite of these handicaps, an extensive and vigorous training program has been developed. The broad general areas of coverage are illustrated by the next slide:

ASTRONAUT TRAINING PROGRAM

1. EDUCATION IN ASTRONAUTICS AND SPACE BIOLOGY
2. PARTICIPATION IN MERCURY DEVELOPMENT PLAN
3. CONDITIONING FOR SPACE FLIGHT
4. TRAINING IN OPERATION OF MERCURY VEHICLE
5. FAMILIARIZATION WITH GROUND OPERATIONS
6. AVIATION FLIGHT TRAINED

The first item on the slide, education an astronautics and space biology has been, in the main, a classroom activity. Early in the program the men were introduced to basic orbital physics, the principles of rocketry and other similar types of subjects. They have attended lectures in human anatomy and physiology, as well as many informal sessions on the various elements of biology which have particular significance to the training program. These are given concurrently with the training exercise. For example, the physiology of the body's response to acceleration is discussed both formally and informally during training periods on the centrifuge. One interesting laboratory procedure in aviation physiology was undertaken at the Bethesda Medical Research Laboratory under the supervision of Dr. Benzinger. Here each of the men was placed into the human calorimiter and various physiological measurements were made. During this experience the men gained insight into the mechanism of heat balance and temperature regulation. As a part of the same program they were placed in a sealed chamber in which the carbon dioxide concentration could be varied at will. As a result of this practical experience as well as the preceeding lectures the astronauts now have an excellent understanding of that aspect of respiratory physiology. They are also familiar with their own individual response to increased partial pressure of carbon dioxide. This information could be life saving in the event of failure of the life support system.

Time is so short, and the training demands on the astronauts are so great, that it is patently impossible to require them to participate in single purpose efforts. An example of this has already been mentioned. That is, education in the physiology of acceleration while training on the centrifuge. There is yet another purpose served by most of the training exercises; this is the collection of physiological data on these gentlemen. This data is utilized in design of the capsule, in establishment of operational procedures, and will soon be used in training of the many medical monitors required to man the monitoring stations scattered along the orbital path of the capsule. Various bits of biological data are being collected so that before any man goes into orbit we will be able to simulate completely the information telemetered to the monitoring stations. For example, we will have recorded on magnetic tape electrocardiograms taken while the pilot is undergoing the identical g-profile of the launch on the centrifuge. We can then splice in recorded EKGS taken on the same man in the weightless state, and follow this with EKGs obtained on the centrifuge while simulating re-entry. Voice recordings have also been taken at the same times. We will soon have temperatures and respiratory traces obtained in the same manner. Admittedly the training of ground monitors is not the topic of today's presentation, but this serves to illustrate the goals of the training program.

Let us turn, now, to the second item in the training program, namely PARTICIPATION IN MERCURY DEVELOPMENT PLAN. This also has been alluded to earlier where it was shown that talent in engineering was a necessary requirement for an astronaut. This too serves a dual purpose. NASA recaps the benefits of the men's knowledge, and the men themselves gain confidence in their machine and consequently function more skill-fully in their role as pilots of the Mercury capsule. Each man has been assigned a specific area of responsibility which is in line with his own background and experience. These areas of responsibility include: The Life Support System, Cockpit Design, The Atlas Booster, The Redstone Booster, Communications, Recovery, and others. Each man learns as much about his own assigned field as he can by reading, inspection of the hardware, consultation with engineers and manufacturers, and by participation as a functioning member of the development team. The knowledge he gains in his own field is brought back to the home base and distributed to the remainder of the group. In this manner the man himself becomes an expert in his field and the rest of the group become profoundly knowledgeable.

CONDITIONING FOR SPACE FLIGHT is also included in many of the other activities in which these men are engaged. At the outset of the program consideration was given to the establishment of a formal exercise program conducted in a manner similar to that practiced by athletic teams. After careful consideration this approach to physical conditioning was abandoned for several reasons. The most compelling argument against a formal program was that the men were felt to be intelligent adults who would realize the importance of physical conditioning and would establish for themselves a program which would fit each individual's needs. This supposition has turned out to be correct. Each man has developed a physical conditioning program of his own. Some of them run a specified distance each day, others swim, and another engages in various types of strenuous activities, embracing running, handball, squash, and swimming. Also, the activity practiced is largely dependent on the season of the year. In spring and summer skin diving and water skiing predominate. In the colder months handball and squash are the most popular. Those who engage primarily in running engage in this activity rain or shine, regardless of the season. Running seems to be the most popular of all forms of physical conditioning. This is possibly because it requires so little in the way of special equipment. A pair of tennis shoes and gym shorts can even be carried on trips to allow continued participation while away from home. In the winter the only additional item of equipment required is a warm-up suit. Skin diving has many characteristics which particularly recommend it for this training program. First of all, it is a vigorous sport which can be quite fatiguing. Secondly, it probably does provide training in orientation with dimished gravitational cues. It is not my intention to imply that submersion simulates the gravity-free state. It probably does simulate a weightless state, but it is my feeling that there is a distinct difference between the gravity-free state and the weightless state. When submerged and hydrostatically in balance one is practically weightless, but one is still in a gravity field of one g, and this attraction still acts upon the otolyth organs. There is a distinct difference the subjective sensations of balanced submersion and that of the gravity free state as produced in flying the Keplerian trajectory. This difference is definite but is indescribable, at least I am unable to verbally differentiate between the two sensations. Underwater swimming was introduced into the training program to provide exercise, to facilitate orientation skill, and to provide a modicum of water familiarity. In view of the fact that each flight of the capsule will terminate in water it was felt advisable to assure that the pilot would be completely familiar with the water environment. In this same regard two related programs will soon be started. One is training in escape from the capsule in water. An escape trainer in the form of a capsule mockup will soon be available at Langley AFB. This trainer will be placed in a water tank and the astronaut will practice exiting from the tower, (or apex of the cone-shaped capsule), and from the side hatch. Later on this year the Astronauts will visit Pensacola, Florida, where they will practice open sea survival under the supervision of the US Navy.

One cannot deny that experiences on the human centrifuge at Johnsville, Pennsylvania are also physically stress-full. Here too is a program designed to condition the astronaut for space flight. During the training program which took place during August 1959 three categories of centrifuge runs were experienced. These were the acceleration profiles of a normal Atlas boosted Mercury mission; various types of aborted Atlas missions, and Normal Mercury Redstone missions. The runs were all made with the subject in a recumbent position experiencing positive or negative transverse Gs. The gondola was equipped with a mock-up of the Mercury panel with functioning instruments and a sequence panel. The three axis side arm controller was utilized and the gondola was "flown" on a closed loop system utilizing the computer to orient the capsule according to the control movements, and also to direct the attitude and rate indicating instruments. The normal Atlas missions subjected the astronaut to acceleration peaks of between eight and nine g with quite slow onset rates. The same was true of the Redstone flights but with peak g's in the neighborhood of five. The abort missions resulted in higher g loadings such as might be experienced if it became necessary to abort the mission prior to insertion into orbit. In this circumstance the re-entry angle is much steeper thus higher peak g's are reached, and the on-set rates are higher. The astronauts experienced peak g's of 11, 14, 16, and 18 g. The onset rates in these abort situations are more rapid; in the 18 g situation, for example, the peak is reached in about 15 seconds and the decay takes an equal period of time. The most stressfull runs of all are those which simulate aborts at low altitude when the escape rockets are fired. In this case the escape rocket imparts a sudden added thrust to that already provided by the booster rocket. This added thrust is to carry the capsule away from the booster and to one side. As soon as the escape rocket stops burning aerodynamic braking slows the capsule down immediately. Subjectively the pilot feels a sudden surge of acceleration which lasts only an extremely short period of time and tends to force him into the couch; this is immediately followed by a g-reversal which throws him into the restraining harness. The time periods involved could not be simulated on the Johnsville centrifuge but the g-magnitudes could and were simulated. These were termed the "tumble" runs because the gondola was tumbled while in the g field. The subjects experienced g reversals of from +3 to -3; +5 to -5; and +7 to -7 g's. The actual reversal took two seconds to go from full positive to full negative g. 22

The description of the centrifuge experiments leads us on into the next major grouping of the training program; TRAINING IN OPERATION OF THE MERCURY VEHICLE. The centrifuge is only one of several simulators which have or will be used in the Mercury program. The next slide Lists the more significant and sophisticated of these:

FLIGHT TRAINERS AND SIMULATORS

1. CLOSED LOOP ANALOG STATIC SIMULATOR
2. ORBITAL ATTITUDE SIMULATOR
3. CREW PROCEDURES TRAINER
4. CENTRIFUGE (CLOSED LOOP SIMULATION)
5. ENVIRONMENTAL SIMULATOR
6. WEIGHTLESS FLIGHT.

The first of these simulators, the CLOSED LOOP ANALOG STATIC SIMULATOR is a device constructed from the computer circuitry of a conventional F-100 flight simulator. This trainer is composed of a recumbent molded couch with the attitude and rate instruments of the Mercury capsule presented to the pilot and with the three axis controller in its relative position. Movements of the controller are sensed by potentiometers and fed into the computer. The computer in turns feeds appropriate readings into the instruments. Various control problems such as reorientation of the capsule for retrofiring, firing of the retro rockets, and re-entry aerodynamic forces can be introduced into the circuitry by the computer. The pilot is expected to fly these various problems. His excellence in this regard can be estimated by analysis of control records which are maintained in strip chart form.

The AIR-BEARING ORBITAL ATTITUDE SIMULATOR is an ingenious device constructed by personnel at the Space Task Group, Langley AFB. It takes advantage of the principle of air lubrication to provide a horizontal platform which rests on an almost frictionless ball and socket joint. On top of this delicately balanced platform is placed a couch, a Mercury controller, an optical viewing system and a system of air jets which operate in response to the movements of the controller. The pilot sees, through the optical sighting system, a view of the earth similar to that which he will see through his periscope in the capsule. By manipulation of the controller he can practice orientation of the capsule through the use of the periscope alone without resort to the instruments. This may become necessary in the event of instrument failure.

The CREW PROCEDURES TRAINER is a more sophisticated device combining the functions of the previously described static simulator and a mock-up of the capsule itself. This device will also make use of complicated analog computer equipment, and will resemble more closely the well known flight simulators in that it will be identical to the capsule in its interior configuration, and will provide a realistic setting for the astronaut to practice flying his machine.

The CENTRIFUGE has already been described at some length. It is necessary to mention here only that there will be additional training exercises on the Navy's human centrifuge in the future. The forthcoming exercises will emphasize the normal mission control problem and g-stresses. A much more sophisticated gondola interior will be available. This will include a functioning instrument panel almost identical to that in the capsule; and individually molded couch which will be identical to that in the capsule, and most important of all the actual pressure environment of the capsule will be simulated. The gondola will be evacuated to five psi, and the pilot will wear his pressure suit breathing 100% oxygen..

An Environmental Simulator is presently being constructed and will soon be in place at the Navy Aircrew Equipment Laboratory in Philadelphia, Pa. This trainer is essentially a Mercury capsule placed in an altitude chamber. In this case, however, all parameters of the environment with the exception of the gravitational field will be simulated. The capsule will contain the definitive life support system. Heaters will be installed in the capsule to simulate the heat load produced by the electronic equipment. Lamps and heaters will be installed to simulate wall temperatures predicted to occur during re-entry, and ventilating air temperature and humidity will also be controllable to match that expected in the real mission. The pilot will ride through various missions in his suit and have the opportunity to practice manipulation of temperatures just as he will have in the capsule. In the actual flight the pilot will have to exercise some discretion in the use of his environmental controls. Certain emergencies will call for closing the face piece and dumping cabin pressure, other circumstances might dictate that he accept some degree of discomfort as far as temperature is concerned in order to conserve his coolant water supply. All of these circumstances, both normal procedures, and emergencies will be simulated in this device.

The astronauts will have the opportunity before their rocket flight to experience WEIGHTLESS FLIGHT on several occasions. They have already flown in the School of Aviation Medicine's F-100's for periods of weightlessness of approximately sixty seconds. During these flights they performed psychomotor tasks, and practiced eating and drinking. They were instructed in the method of flying the zero-g parabolas and allowed to fly several of them themselves. During these flights certain physiological data was both tememetered to a ground station and recorded on board the aircraft. This data included a three lead electrocardiogram, respiratory rate and depth and blood pressure. Voice recordings were made during zero-g and during one g. Part of the group has also experienced weightlessness in the C-131 aircraft. This aircraft allows the subject to practice locomotion in its large cargo compartment. In the future all of the men will be given the opportunity of riding in this aircraft. It appears at present that the problems of orientation are much more severe in the C-131 than in the F-100, because of the fact that in the fighter aircraft one obtains clues from the pressure of the restraint harness. These clues are not available to the subject when floating in mid air at some distance from floor, ceiling and walls.

One final training device must be mentioned; this is the Redstone rocket itself. Sometime prior to the orbital flight the capsule will be placed on a Redstone rocket and fired from Cape Canaveral down the Atlantic Missile range. This flight will reach altitudes in excess of 100 miles and a distance of roughly 150 miles. It will provide in the neighborhood of 5 minutes of weightlessness. This experience will constitute a trial of the man and the equipment. It is truly a training exercise of the first magnitude. In this case however everyone from the astronaut to the medical monitors will have an opportunity to practice for the orbital shot.

* LECTURES IN AEROSPACE MEDICINE

RESEARCH PROGRAMS

I. Biosatellites

Presented By

Dr. Hans G. Clamann

Professor of Biophysics

School of Aviation Medicine

* This article will be published at a later date.

PROBLEMS OF LUNAR COLONIZATION*

By

Paul A. Campbell, Colonel, USAF, MC**

* Given as a part of "Lectures in Aerospace Medicine," School of Aviation Medicine, USAF Aerospace Medical Center, Brooks Air Force Base, Texas, 11-15 January 1960.

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NOTE: The contents of this manuscript reflect the personal views of the author and are not to be construed as a statement of official Air Force policy.

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Problems of Lunar Colonization--
Col Paul A. Campbell

The Moon, Nature's Space Station, our nearest and most inspiring celestial neighbor, probably, within the framework of propulsion systems of the near future, offers man his most suitable touchdown point for space travel. Its location and some of its physical attributes may some day make it the crossroad for interplanetary and, later, more extended space travel. Its location away from the Earth's gravitational pull and its absence of a frictional atmosphere decrease take-off fuel requirements and thus qualify it as a staging or refueling depot, similar in function to that served by Hawaii, the Azores, Iceland, and Newfoundland, in present day transoceanic travel, or possibly is more comparable to Ascension Island in the early days of World War II. In spite of its beauty, the sonnets which have been written about it, the goddesses Diana, Selene, Cynthia, Phoebe, and others, who represent the Moon in mythology, it presents an environment extremely hostile to man and his machines. On Earth we have, at times, felt the polar regions, the mountain peaks, such as Everest, the deserts and the Bad Lands were hostile. However, if most of the really hostile elements of each were assembled to harass man the resulting environment would be heavenly as compared with the Moon.

For this presentation we must assume (and most of us do) that man can get to the Moon and that he reaches his new environment with the proper logistical support (which is complex in itself) and a reliable means of return. To demonstrate the complexity let us first look at the Earth-Moon relationship. (Figure 1.)

Basic astronomy tells us the Moon rotates about the Earth in an elliptical orbit each 27 1/3 days, presenting at all times approximately the same face. Thus the days are 13-plus Earth days in length and the nights are the same. As some libration due to slight changes in the relative Moon-Earth relation takes place, some 6/10 of its surface has been observed through the ages. With the photographic image of the far side taken by the Soviet Lunik III, the general condition of that face is beginning to unfold.

The distance to the Moon varies. At apogee--the greatest distance--it is some 252,948 miles away. At perigee it is 221,593 miles, with the mean roughly 240,000 miles. This is only 1 1/3 light seconds, an infinitesimally small number as compared with distances in terms of light years, of which our more optimistic space voyagers speak at times. The lunar bound vehicle must leave the Earth's environment at escape velocity of approximately 7 miles per second and proceed through the Van Allen radiation belts (Figure 2.) if the art of shielding against radiation or repulsion of the particles has reached a state of the art which will allow man to be protected to

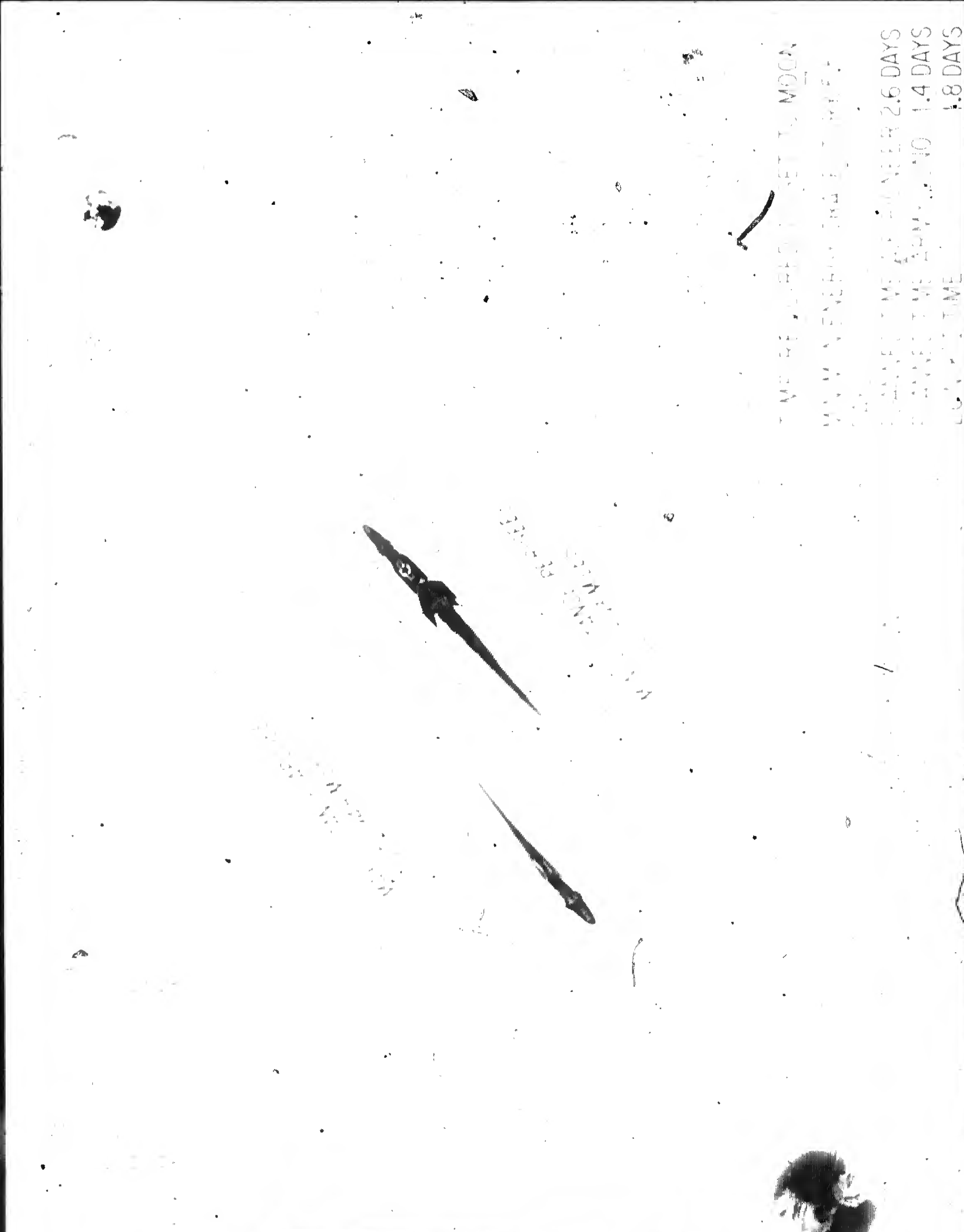
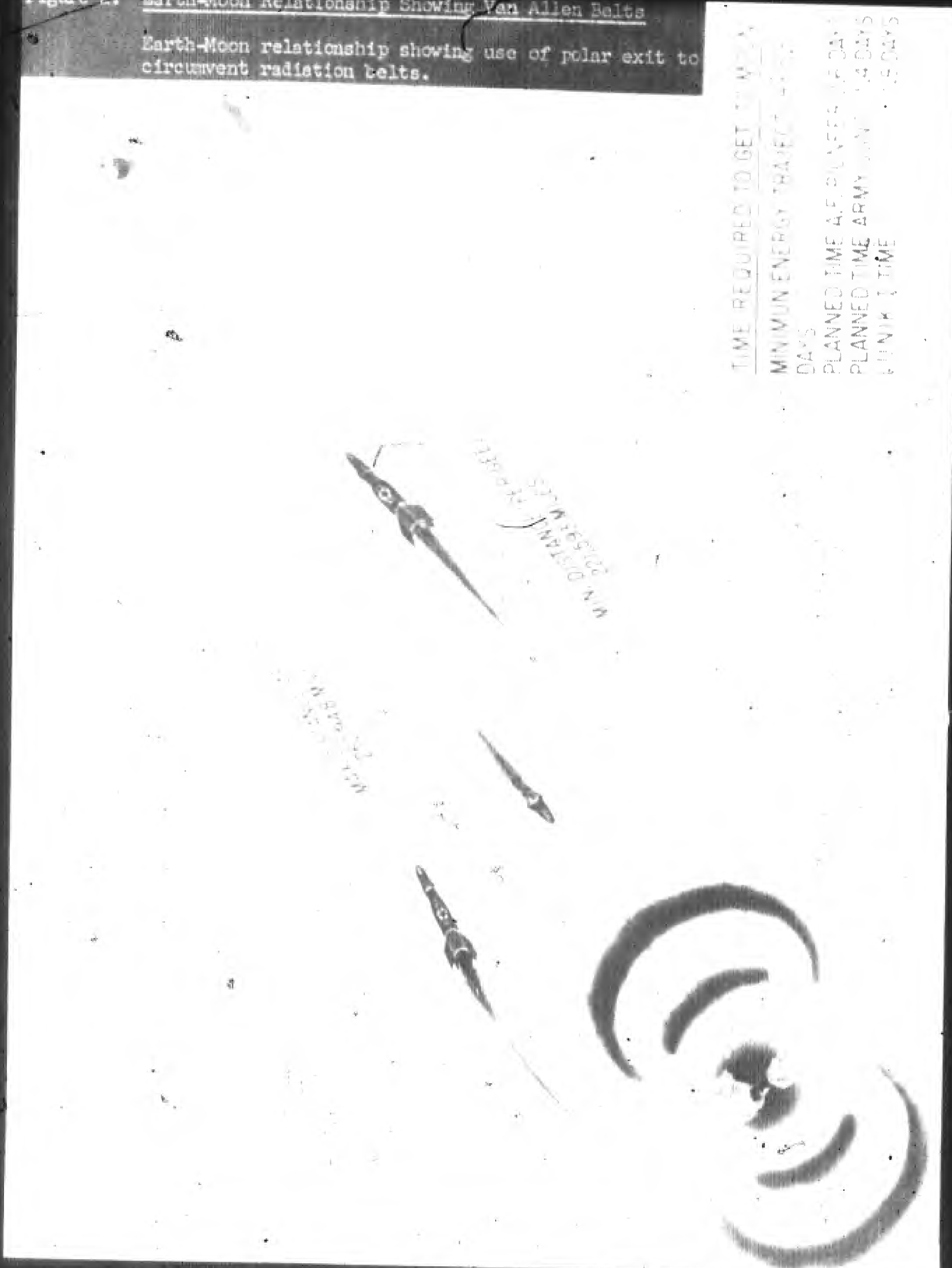


Figure 1. Earth-Moon Relationship

Figure 2. Earth-Moon Relationship Showing Van Allen Belts

Earth-Moon relationship showing use of polar exit to circumvent radiation belts.



a tolerable degree. If the state of the art is insufficient to protect him through the Van Allen Belts, then the polar corridors or some compromise will have to be used. Using the polar corridors will probably require new concepts of guidance and a longer trip, if the G-tolerances are to be acceptable. More fuel will undoubtedly also be required.

Homer Newell,[1] in a very recent article appearing in Aviation Week of December 21, 1959, states that it is the belief of both the Soviet scientists and our own that rapid traverse of the belts, which will be required by escape velocity, will decrease exposure time to a level at which the radiation hazard will probably not be serious.

The art of getting there followed by safe landing and return I shall, however, gleefully brush away as an engineering problem.

Some day our children or our children's children may, in their schools, study selenography--the Moon science which corresponds to the geography of the Earth. They may also study various other aspects of the Moon, such as its physiography. Possibly their studies will be considered superficial. However, much of their information will be more specific than ours of today. In spite of many extreme difficulties our present-day selenographers with their Earth-based remote instruments have given us an unbelievable amount of information, although several key items must await man's landing on the Moon, or a degree of sophistication in probing or telemetering, which we do not have at this time.

The selenographers teach us the Mcon is approximately 2,163 miles in diameter. (Figure 3.) Its origin remains controversial. The more recent consensus seems to point to its origin at about the same era as that of the Earth, possibly as a part of a dual Earth-Moon system. Thus the time seems to have been of the order of 3 1/2 to 5 1/2 billion years ago. The most prominent features on the lunar surface are the maria, which in the past ages were so named because they were thought to resemble seas, although are now known to be perfectly dry. The other prominent features are the mountains with their valleys and craters. The mountains are in ranges, for the most part, some peaks reaching altitudes in the neighborhood of 30,000 feet. The maria are dark plains--one at least--Mare Imbrium--reaching a diameter of the order of 700 miles. Probably the most interesting of the surface features are the craters which pock-mark large areas. These resemble, superficially at least, caldera. Again, their origin has been food for heated arguments among the selenologists of the past, some dogmatically defending a position that both the craters and the maria are the results of

Figure 4. Selenography

Diagram showing selenographic relationships. This diagram points out the more important land marks on the Earth side of the Moon, showing approximate dimensions.

asteroidal or meteoritic collisions during the bygone ages, with subsequent explosions following penetration of the surface. Others are just as dogmatic in their defense of the volcanic theory. Then there are straddlers who believe both are factors. According to the laws of chance the straddlers are usually right.

Most of the experts agree that the surface is covered by dust, although they disagree on the thickness of the dust. The dust was probably produced by forces of erosion much different than those on Earth. On Earth the erosive forces are primarily water, winds, tides, chemical effects, and gravity; whereas on the Moon, water and wind are absent. Thus on the Moon the erosive processes are probably based upon extreme temperature changes, collisions with meteoritic material, the effects of vacuum (sublimation), of gravity, as well as those of cosmic and solar radiations, including unattenuated ultraviolet light.

Many of the problems of a lunar visit stem from its almost total lack of atmosphere. (Figure 4.) As is well known, one of the Earth's most precious heritages is its benevolent atmosphere. It is this gaseous envelope upon which we must depend for such indispensable life-supporting substances as oxygen, water vapor, carbon dioxide, and nitrogen. It is this same envelope which protects us by its mass

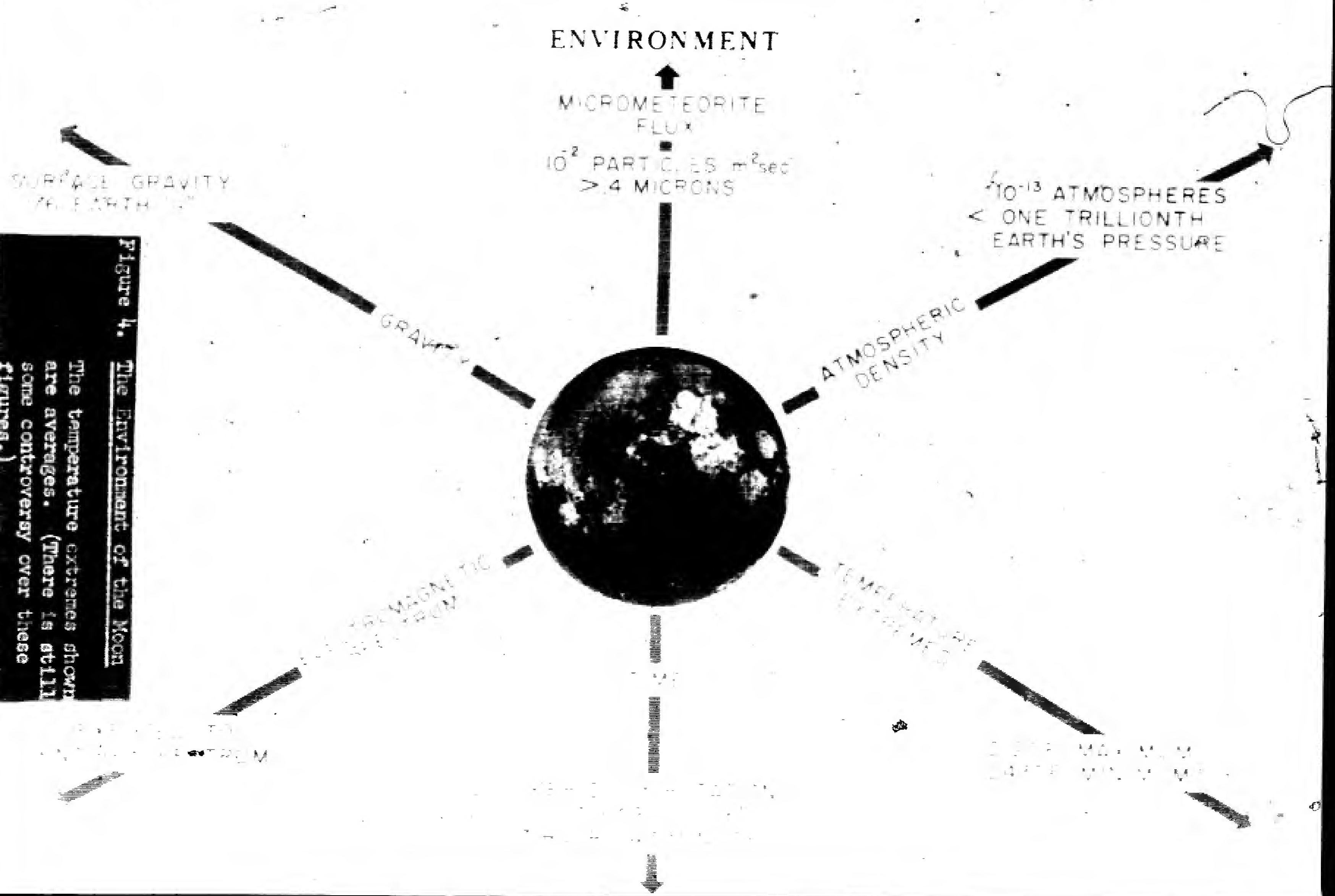


Figure 4. <u>The Environment of the Moon</u>

The temperature extremes shown are averages. (There is still some controversy over these figures.)

and chemistry from the more destructive portions of the ultraviolet spectrum, from the more undesirable portions of the infrared spectrum, from practically all of the primary particles of cosmic radiation, and from meteoritic material. It is this same envelope which gives us the life-supporting pressure which we require for physiological function. It is this same atmosphere which makes plant life possible through recirculation of water, the compounds of nitrogen, and other nutrients. It is this same atmosphere which conducts the sound of our voices, conducts heat and disperses light, thus decreasing glare and attenuating what must be disturbing light contrasts.

As previously stated, the Moon, ostensibly, has no atmosphere. Because of its small mass (only 1/80 that of the Earth) its gravitational forces have been unable to hold the substances required by man for his life support. Thus there is no oxygen, water vapor, carbon dioxide, or nitrogen to support his life functions, to protect him or to pressurize him.

According to Kuiper, [2] the lunar atmosphere (based upon data from observations of distant radio sources occulted by the Moon) has a density of approximately 10^{-13}, a tenth of a trillionth of that of the terrestrial atmosphere. This would correspond to an altitude of 300 miles above the Earth, some twelve times as high as man has ever been. This residual tenuous envelope is probably composed of argon and krypton. The aerodynamic qualities of the atmosphere, as well as the supportive and protective qualities, thus are completely negligible; in fact, about as near to zero, functionally, one can get. Thus the surface of the Moon is completely naked in its exposure to the bombardment of the rubble of space and the energies of the entire electromagnetic spectrum.

Among the most serious effects of absence of a functional atmosphere is the resultant temperature extremes and the rapidity of temperature variation. (Figure 5.) Pettit and Nicholson,[3] as early as the late 1920's, made a study demonstrating the distribution of temperatures on the surface exposed to the direct solar rays to reach values as high as 273°F at the sub-solar point. From this point the temperature dropped as the limbs were approached, reaching 252°F at half the radius, 216°F at 3/4 the radius, 171°F at 9/10 the radius, and 153°F at the limb. During the eclipse of June 14, 1927, Pettit [4] made a series of consecutive measurements of an area about 1/15 of the lunar diameter from the limb. (Figure 6.) These measurements showed the temperature to fall from 156°F to -81°F during the first hour of the partial shadow. For the following 2 3/4 hours of total shadow the temperatures dropped on down to -186°F.

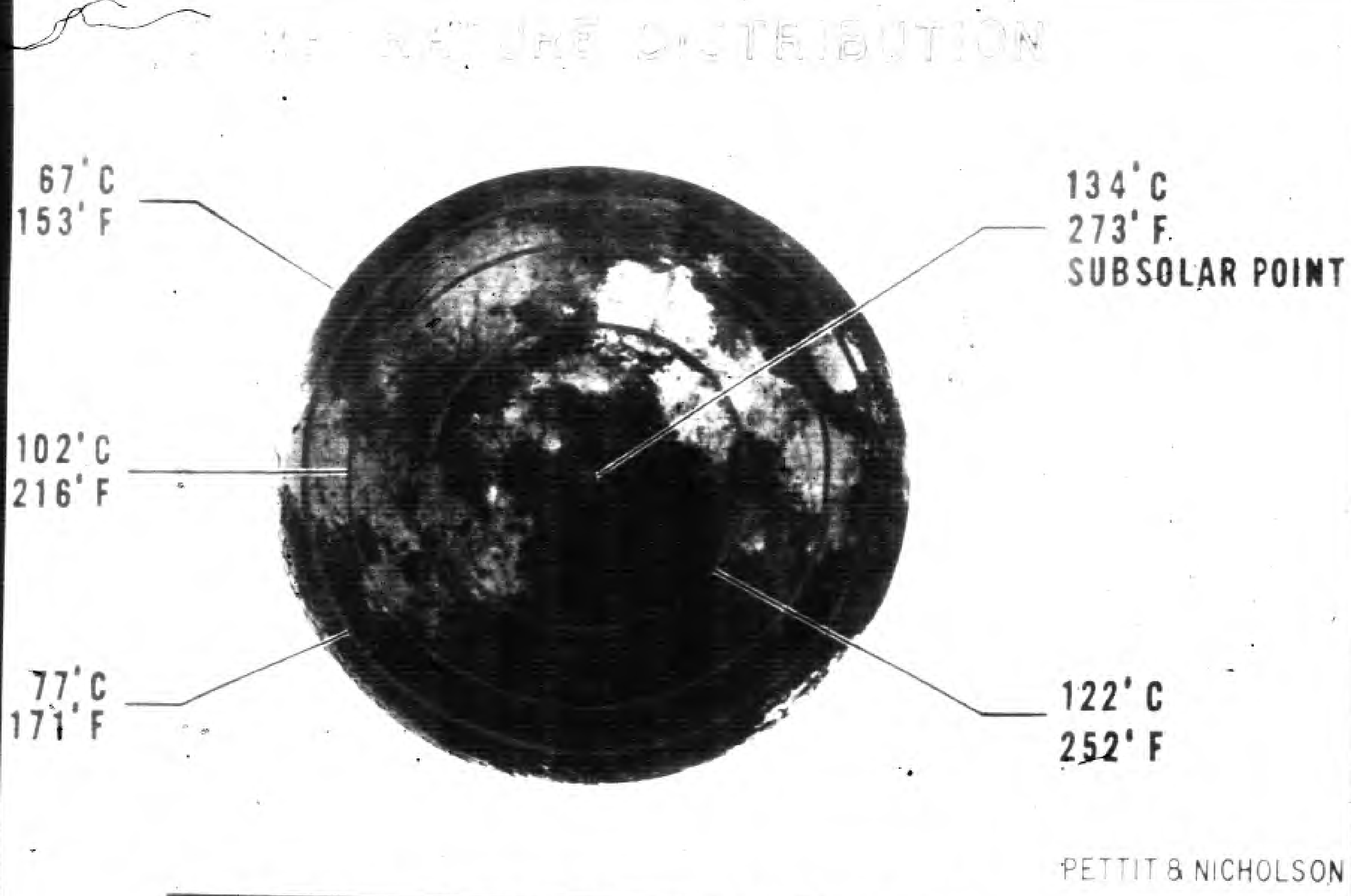


Figure 5. Pettit and Nicholson Measurements of the Temperatures of Various areas of the Face of the Moon Visible from the Earth

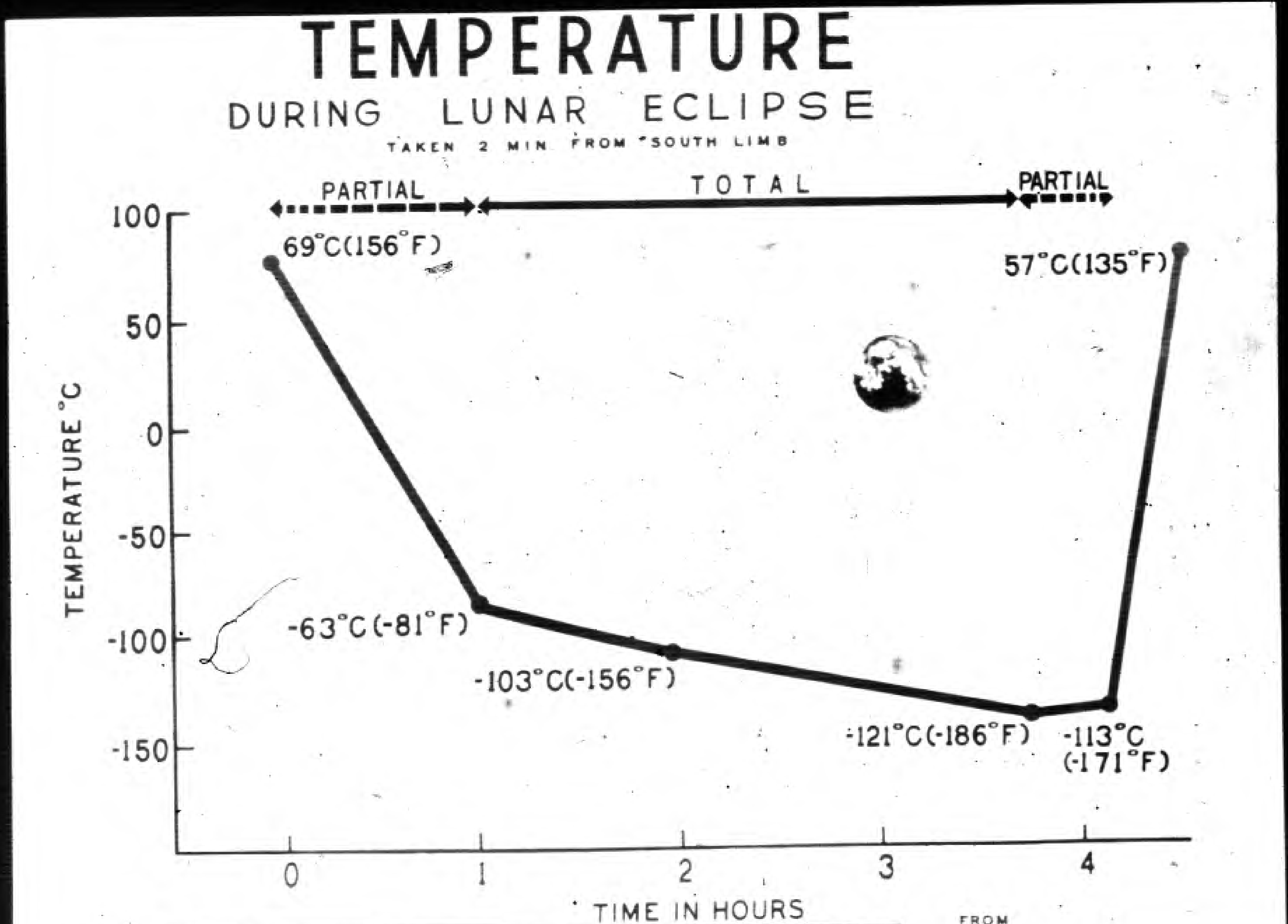


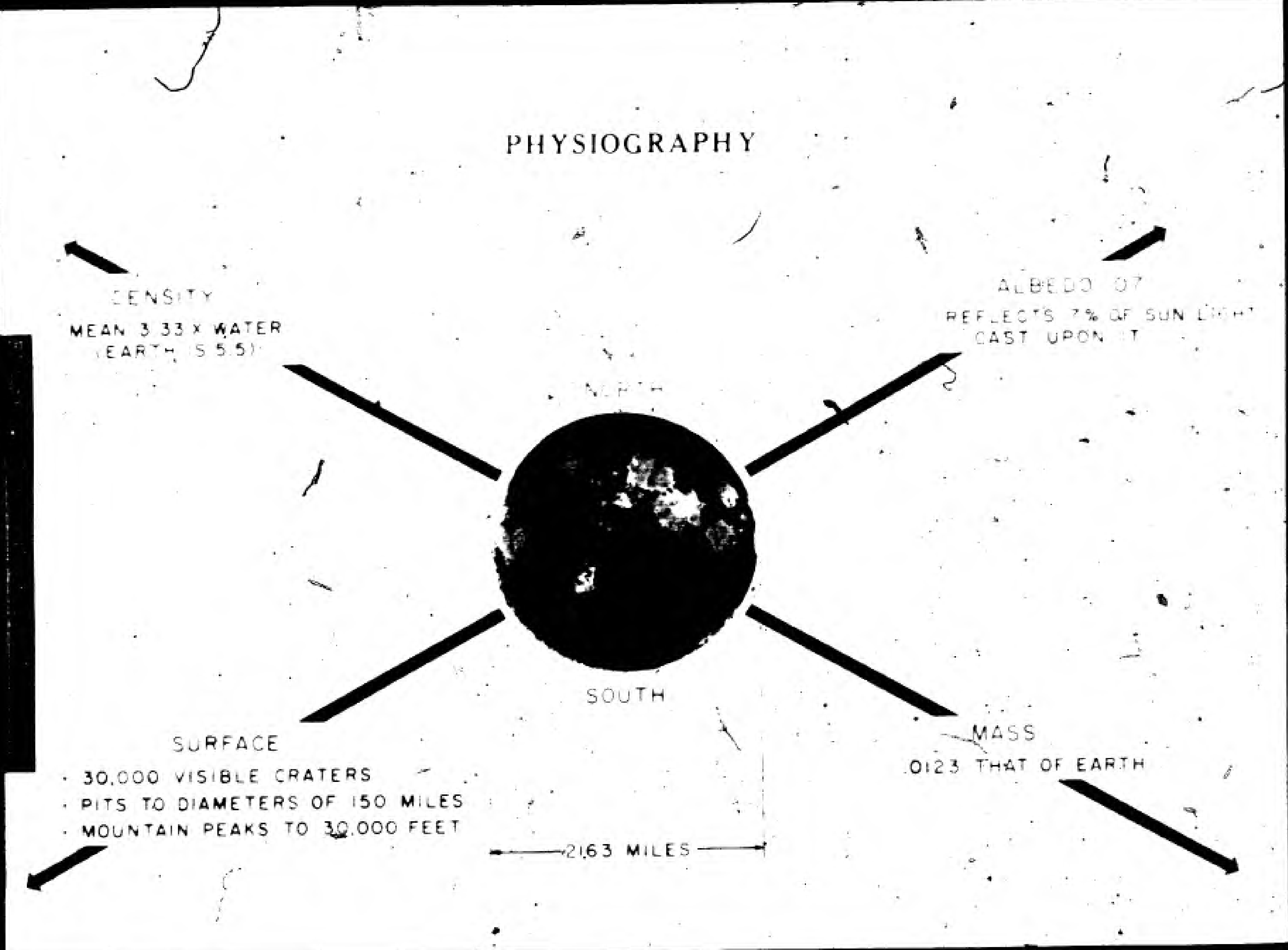
Figure 6. Pettit's Measurements of Temperatures on the Earth's Face of the Moon During Eclipse

During return of the partial phase the temperature went up to -171°F, and after the shadow was dissipated, went quickly on up to 135°F, where it remained.

Everyone recognizes the horrible qualities of these surface temperatures, yet a man's body, or his clothing, or a different material might show values considerably different. Shade of any sort must bring about violent temperature changes. Many types of reflectors and filters have been suggested. Certainly something of the type must be used. The most acceptable suggestion, however, seems to be that of underground dwellings. Many investigators feel the dust is not very thick and probably acts as an insulator. Thus underground shelters burrowed into the rock or subsoil of the Moon could conceivably result in temperatures not too different from that in caves found on Earth. H. C. Urey[5] recently stated that the temperature a meter below the surface remains continuously at -30°C. This is quite cold but during the lunar day the temperature upstairs could be tapped. Some feel Urey's figures are too low.

The same type of protection would probably be quite effective as insulation against micrometeoritic dust whose flux is probably similar to that at the top of the Earth's atmosphere, a value of 10^{-2} particles per square meter per second, having diameters greater than .4 microns[6]. This flux is sufficient to penetrate 0.01 inches of stainless steel at a rate of about 4 particles per square meter per day.

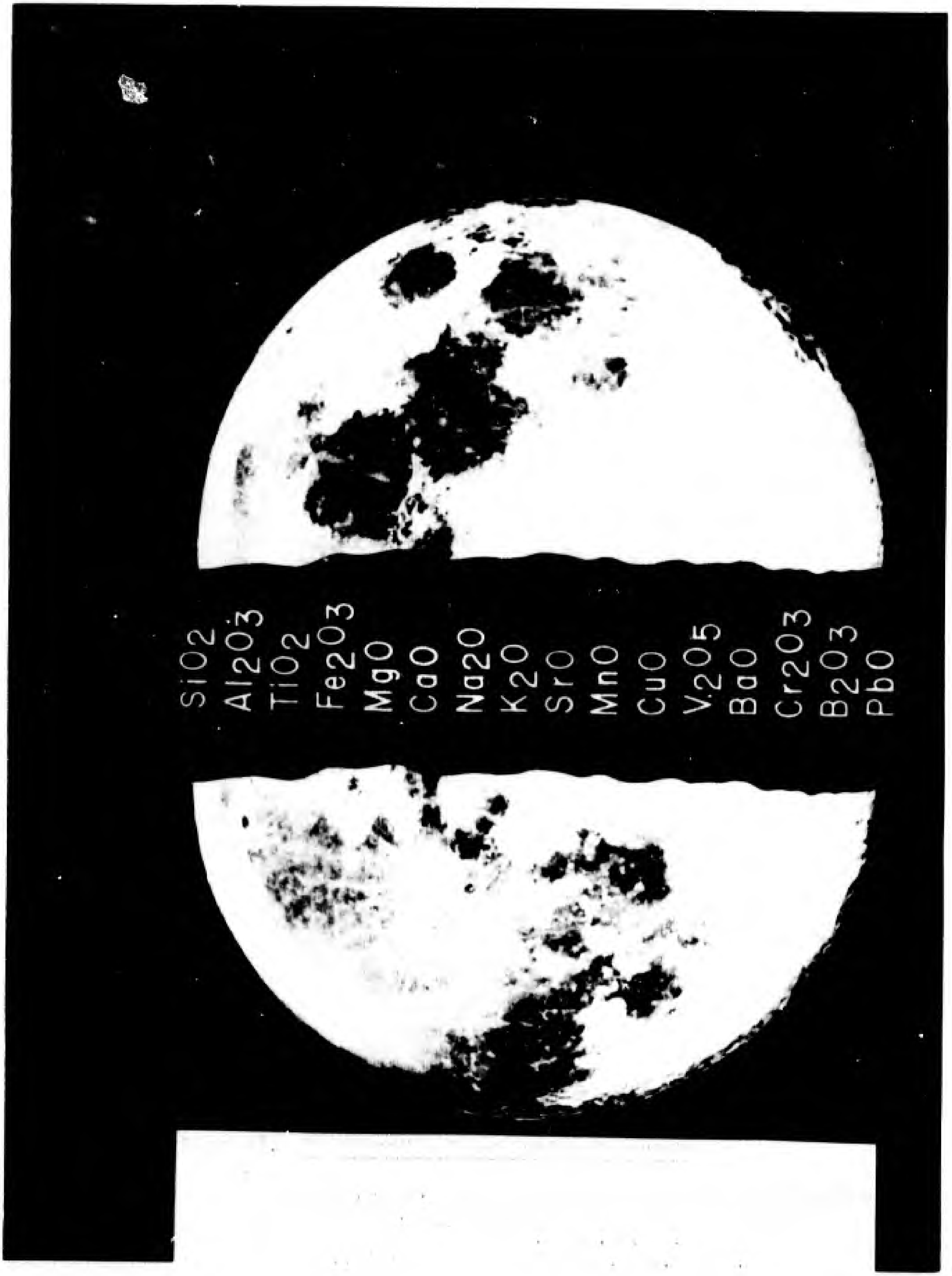
Such protection should also furnish acceptable shielding against the radiant energies of space which bombard the surface of the Moon with forces unattenuated by an atmosphere and probably unattenuated by shielding afforded by an electromagnetic envelope, such as we have about our Earth. Such a shield repels or traps most of the primary cosmic particles, as well as the particles from solar flares. The Moon, apparently, has no appreciable electromagnetic envelope, although that is a situation which requires more knowledge. (Figure 7.) Much of the evidence for absence of electromagnetic shielding is based upon the density of the structure of the Moon. This density is 3.33 x that of water, as compared with the 5.5. x water density of the Earth. According to many, such a density would largely preclude an appreciable iron-nickel core such as that of the Earth upon which our circumterrestrial magnetic shield depends. Again, according to Newell's[1] article, Soviet measurements made by Lunik II as it plunged to the surface of the Moon, demonstrated the magnetic field to be no greater than 50 gamma.


PHYSIOGRAPHY
DENSITY
MEAN 3.33 x WATER
(EARTH IS 5.5)
ALBEDO .07
REFLECTS 7% OF SUN LIGHT
CAST UPON IT
NORTH
SOUTH
SURFACE
· 30,000 VISIBLE CRATERS
· PITS TO DIAMETERS OF 150 MILES
· MOUNTAIN PEAKS TO 30,000 FEET
2163 MILES
MASS
.0123 THAT OF EARTH

Thus it would seem reasonable that an expedition arriving on the Moon should go underground at the earliest possible moment for assembly of their base. Logistically they will be unable to carry burrowing machines which could cut out into the crust quickly and effectively. An Answer would be the location of an acceptable cave-like structure for touchdown in its vicinity. Caves formed through water erosion seem precluded; however, it would be difficult to imagine a surface of some 14,000,000 square miles without cave-like shelters, especially in view of the large number of caldera, crevasses, etc. Thus it is my feeling that considerable effort should be expended to locate such natural shelters telescopically, or through early reconnoiterring circumlunar flights, manned or unmanned. Many of the logistic problems and human problems could be solved by the disclosure of an acceptable natural shelter near a landing site. Spent portions of the vehicle not utilizable for the return trip, and construction elements carried, would then have to be assembled in the cave as quickly as possible.

By this time it is certainly apparent that the major problem involved in a manned expedition to the Moon is one of logistics. If enough weight and volume could be lifted to the Moon and safely landed in the proper place, then only organization and expert labor would be required. Given enough means for protection, sufficient supplies to meet vital needs, and sufficient means for construction, a small colony could be established and maintained. Such payloads, guidance and other required capabilities are, to understate the situation, exorbitant. Living off the land, to an appreciable degree, is impossible. Thus the compromise is that of lifting essential elements packaged within the framework of minimum weight and minimum volume, followed by conservation through minimum utilization, recycling, etc., and through the multiple use of everything which can have more than one function. The occupants of the colony must then supplement their existence by utilizing the materials they may find, wherever and whenever possible. Energies in the form of heat, light, vacuum gradients, etc., are there in overwhelming abundance. Their harnessing is the problem. The 1/6 G-situation reduces workload. The soil of the Moon is thought by many to be similar to the crust of the Earth, if proper allowance is made for long-time unattenuated exposure to the situations we have described, and for the practical nonexistence of atmosphere and surface water. Thus there may be a possibility of recovering oxygen from the oxides of the crust. Possibly there is a source of hydrogen and possibly there is some water in combination with the material of the rocks. (Figure 8.) The problem, then, is recovery of the material in useable form. A study of the recovery of the needed materials from the rock of the crust of our Earth, using the unattenuated energies of space, whenever possible, should be an important research field. The studies of Dr. Jack Green[7] of the California Research Corporation, and his colleagues, are notable in this field.

There is much, therefore, to be learned here on Earth before man on the Moon can be a reality. Man on the Moon can be a reality only through the accumulation of bits and pieces of knowledge through interdisciplinary effort. Some bits and pieces from the human factor point of view could result from a simulator which has been considered here at the Aerospace Medical Center, and which it might be worthwhile to roughly describe. It would make use of our present two-man simulator as the vehicle for a partially simulated flight to the Moon. It would require that the two-man simulator be capable of movement into a vacuum chamber wherein as much as possible of the environment of space could be simulated. The occupants at the end of the stipulated time of the journey could then exit through locks into a bubble colony capable of closing as much as possible of the ecological loop. Simulated return to Earth would


SiO2
Al2O3
TiO2
Fe2O3
MgO
CaO
Na2O
K2O
SrO
MnO
CuO
V2O5
BaO
Cr2O3
B2O3
PbO

be a reversal of the original trip. Only through such a beginning can one isolate some of the problems and develop solutions. As is well known to all in space research, the solution of each generation of problems brings forth an entirely new and often unsuspected generation of new problems.

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LECTURES IN AEROSPACE MEDICINE

RESEARCH PROGRAMS

III. Future Problems

Presented By

Colonel John E. Pickering

Director of Medical Research

School of Aviation Medicine

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FUTURE RESEARCH

by

John E. Pickering, Colonel, USAF

Gentlemen, we have seen over the past two years a tremendous growth in our National Bio-Space effort. Nearly every institution and industrial organization has some facet of a space medicine research effort. Additionally, practically everyone in this audience has a personal interest in space research or is a member of one or more space committees. Yet with all of this, we are still without a central coordinated Space Biology research team. Programs are being pursued on a near individual basis without benefit, in many instances, of advice and experience of interested and knowledgeable people. As a consequence we are in fact diluting our national talent to such an extent that the future does not hold much more hope for real success and understanding than the past, and a record of the past is not one of sound and rigorous scientific achievement. From limited personal participation, a reflection into the old Manhatten District concept suggests one method whereby a singularly unique national effort provided the vehicle for a fruitful realization of an objective, wherein the available scientific talent did in fact concentrate their abilities and efforts to the timely solution of a tremendous challenge in the conquest of the unknown. The result was the Nuclear Age, its applications both in peaceful utilization and as a deterrent to world aggression. Seemingly there is a parallelism in today's challenge -- the peaceful and deterrent utilization of space. This being true I submit to you that the first step in future research is the implementation of a similar singular scientific effort.

Continuing then in this same trend, I feel that space research holds the same unknowns as did nuclear research of the past two decades. In the former instance one concept was developed that permitted a degree of standardization to the primary objective - a source of power with varied application; weapons, heat, and propulsion. The point I would like to emphasize was standardization with reasonable flexibility yet sufficiently rigorous in design until reliability became prime, until sufficient reproducible data was obtained to enhance scientific judgment.

If we carefully analyze the past two years of our space effort of data gathering the most discouraging factor is in the development of a standardized space probing system that will permit reasonable reliability. When will we be able to successfully count on launching, orbiting and recalling three out of four of our Bio-scientific experiments as we can in our weapons program? This is vital because without this reproducible data the many problems about which we are still speculating cannot be thoroughly analyzed, understood or applied to furnish guidelines for future programs. Today each biomedical research shot, vehicular system, payload, and trajector is different from the other and in the long run it is a significant deterrent to a unified program. Furthermore, it is inconsistent with ever realizing standardization of maximum data gathering equipment. At this point I would simply like to say each of us as scientists accepts this approach simply as a means of getting something done and of making some small contribution. But is it the most fruitful approach when superimposed on the clock of time and the ledger of dollars? I think not. A standardized biomedical vehicle of reasonable payload and volume would materially enhance research!

Tomorrow's research, the research we will do in the future, is the probing of the unknown - the physical and the biological unknown. These past two years of concerted space effort may be likened to the voyage of Columbus proving the unknown for a path to the far East. Instead of realizing his primary objective, a straight line route - something got in his way - America! and it appears that similarly in the conquest of space the same paradox has occurred.

The first U. S. satellite, carrying a Geiger counter for cosmic ray measurements, discovered in actuality a new belt of radiation. Many times more intense than the known cosmic ray intensities. So intense in fact that the counters were saturated. Subsequent experiments have shown this radiation to extend from a few hundred miles to more than ten thousand miles above the earth seemingly following the contours of the earth's magnetic field. In addition, solar flares, mentioned earlier by Dr. Singer, present an even greater problem. Even though tremendous personal efforts have gone into acquiring all possible data from limited flights, the nature and source of these radiations are still speculative. Yet herein may be one of the rigid limitations to maximal space reconnaisance and manned space travel. Because this radiation is in regions which appear to be of significant importance in military reconnaisance, weather pattern observations, radio reflection layers, and gravitational irregularities, it becomes exceedingly important if photographic plates, electronic instruments or man for that matter are to be affected by this radiation. We do know that radiation can penetrate and effect matter; it has the ability to produce significant changes which in the case of biological systems can produce illness and even death. Considerable knowledge exists concerning the effects of ionizing radiation as it may apply to defining maximum permissible limits of radiation exposure both from acute and chronic studies, but the radiation spectra has been limited to weapons radiation or laboratory sources of neutron, gamma, x-ray, alpha, or beta origin at energy levels well below those predicted as occurring in the Van Allen belt and solar flares. True, dosage vs effect criteria can be established for these sources for guidelines to future probing, but what are the specific effects of high energy protons and electrons. Will they produce similar end points of concern - cataracts, leukemia, shortening of life span and genetic changes - most likely yes - but what is the dose effect, the energy effect? Is there a relative biological effect significantly different from present ideas concerning the neutron? To date we can define a fairly accurate threshold dose for these effects so far as time post-radiation permits yet the actual experiments that need to be done can't be done without space probing. Laboratory particles, identical in physical make up aren't available so the first question is only answerable by conjecture at the present time.

First approximations, however, can and must be done within our present facilities so to this end it appears logical to use particle accelerators as proton sources to demonstrate a degree of biological change vs dose. Our approach, because of limited beam geometry, is by comparative changes in tissue cultures after exposure to neutrons, protons, and/or gamma rays. Simultaneously dosimetric methods for biological surveillance are being developed for the biological dose is the one of interest here. Is there a tissue equivalent material for monitoring protons? I don't know, but if not, such a device is sorely needed. In summary, if we are interested in more than just projecting man through the belts or during times of minimum solar activity, which can undoubtedly be done from a radiation hazard point of view, particularly if we accept 50 to 100 rad is acceptable, then refined measurements must be made.

If nuclear power is to be a source of propulsion, the reactor type and history will contribute to the problem of radiation protection particularly in terms of shadow shield requirement against primary radiation. If ceramic reactors are found to be the most feasible then fission product debris and activation must be considered from the point of inhalation and ingestion. We must carefully define maximum permissible levels in terms of body burden from several of the prominent isotopes. This is certainly of extreme concern in the event of accidents at or near launch facilities particularly if destruction were required during early times. Extensive work must be done in the area before systems are engineered for man.

Since one of our objectives is to ultimately employ manned space craft, progression in research can come from animal work on various species mice, monkey, man, paralleling advanced vehicle research from supersonic aircraft to rocket-powered vehicles of the X-15 and projected Dyna Soar configurations. Accomplishments to date have for the most part satisfied primary objectives in that animals have been successfully flown in ballistic profiles and recovered alive. Additionally some photographic, physiological, performance and environmental data have been obtained; yet one must admit that it has been limited and all too frequently tailored to a payload in the piggy back concept. As a result compromises have, of necessity, accrued at the sacrifice of sophistication in both data gathering and reduction. If reasonable payloads were assigned, one could more readily design equipment of a standardized nature so that here, too, reliability and flexibility could be increased. Furthermore, miniaturized equipment to record EEG, ECG, G.S.R., BP, respiration and skin temperature would be proof-tested for implementation in manned projects wherein one cannot deny the desire for complete technical competence. This miniaturization of instruments will also find tremendous applications in other clinical medical research, i.e., O_2 sensor vs an hypoxia warning device.

One large step in animal research remains yet to be done, a successful injection into orbit and subsequent recovery of live biological specimens. For some long time a program has been underway to complete this phase of work, but the translation of laboratory instrumentation into flight hardware of limited weight and volume capable of functioning for extended mission times has been underestimated in its complexity, i.e., feeder mechanism, operation, air conditioning equipment, physiological sensors, electrode implantation, programming sequences, etc. In addition accurate physical and biological data required to engineer a safe system has been at the low end of the learning curve. The result, significant postponements in the program. I might refer to thermal profile data that is vital to capsule design in support of live specimens. As presently configured, support is questionable. For it will be translated to the F-100's, 102's, KC-135's, X-15 and Mercury flights to monitor man in some critical phase of the given flight profile.

While in the area of inflight biomedical instrumentation a real challenge is in the area of rapid reduction of physiological data so that decisions can be rendered at the required time and not after the fact. This, I believe is evident when one sees the data accumulated from the recent weightless parabolas flown for and with the Mercury Astronauts and the medical officers assigned to their training program. The volume of information is staggering and the results far from meaningful interpretation at this time.

This does not negate aircraft research but does in actuality point up an area for additional bio-instrumentation in gathering physiological and psychological data. Time extension of the near weightless state is approaching maximal limits with the F-100F aircraft, (50-60 secs.) yet even within these limits much additional data can be recorded and telemetered. Likewise the suggestion to utilize large jet aircraft, KC-135, as near weightless laboratories, while limited in the time trajectory, will permit greater facility for work. The large bay area of the KC-135 affords an opportunity to evaluate man's responses to this new environmental condition in a manner not possible in fighter type aircraft. A medical observer could be present to personally observe reactions, make tests and physiological measurements by conventional laboratory methods using standard laboratory equipment. It is conceivable that treadmill and tilttable work could be included; furthermore, fluoroscopy during barium swallow may reveal interesting results. These tools then may in part be the stepping stones for refined monitors for future research vehicles of the X-15 Dyna Soar class.

It would be erroneous on my part to create in your minds that research can only be done in the flight items of missilry or aircraft, on the contrary the bulk of our biomedical knowledge will for some long time still come from laboratories and simulators confined to earth.

By necessity, man will be an integral component in certain systems designed for extended space operations. Together with the other major components then, he will be subjected to extensive and systematic testing for reliability determinations. The need for such testing is occasioned not so much by a lack of information on the interactions of these inherent limitations with the conditions man will experience in space. You have heard a presentation enumerating these conditions peculiar to a closed ecological system in space and the relevant human limitations found to date. These are confinement, detachment, sensory deprivation, weightlessness, habitability, physiological day-night cycling, and fatigue.

Full utilization of the two-man simulator is one way by which refined answers can be obtained to these problems. The extension of the 7 and 10 day sealed cabin experiments to time periods of thirty days with utilization of dual subjects will ensure valid predictions of these limitations or degradative effects. In a like manner measures can be assessed for the efficacy of attenuating these deterimental effects through studies on pre-exposure training, programming of functions, improved information displays, and the use of drugs.

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Concomitant with these psycho-physiological studies, the intra-cabin environment to meet the climatic, respiratory, and nutritional requirements of the astronauts in terms of economic logistics comes into focus. The crucial point here is the time factor, that is, the duration of the flight. In this regard there are two feasible methods for providing the respiratory and nutritional necessities.

The first is accomplished by replacing 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 in experiments carried out in space cabin simulators. It was also the method in space-equivalent balloon flights of the Navy and Air Force. As a result, the duration of keeping a man alive and alert in a sealed cabin can now be expressed better in weeks than of days. Therefore, nearby space and deep-space flights, 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. The introduction of new exotic absorbents for carbon dioxide and humidity may also improve the time limitation. It seems, however, that a more refined physicochemical system will be required for the regeneration of the intra-cabin environment for more extensive flights involving circumlunar missions as well as deep-space penetrations approximating one or two months. Beyond these times, however, we must resort to recycling of all the vital bioelements like oxygen, carbon, and nitrogen in the same manner as observed in nature in the process of photosynthesis. Here we are dealing with a true closed ecologic system. This is the method for interplanetary and planetary missions. Although far from operational, intensive efforts have been made in studies on algae, more and more effective strains have been found, not only to recycle the gaseous components of metabolism, but also the fluid and semifluid waste products.

In the future of planetary travel, it appears a surety that lunar explorations will be of first priority. This will require programs of instrumentation to study, explore, and investigate the lunar environment, the surface, and interior as it may affect survival. The program will begin with unmanned reconnaissance, proceed to circumlunar flights and manned exploration of limited scope, and may conclude with colonization. Specific objectives are studies of the physical nature and characteristics of lunar surface material, determination of the presence and composition of a possible atmosphere, seismic investigations of the interior-properties of the moon, and the placing of scientific instruments and finally, scientific observations on the moon.

The program objectives may include further the continuous improvement of specifications and requirements for the development of propulsion techniques, vehicle systems, and equipment, for the conduct of exploratory missions; supporting research and development in related areas such as data transmission, mapping, structures, and sustaining systems for eventual habitation of the moon. As you heard yesterday this requires inspiration and perspiration but may I add a plea for organization and standardization.

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LECTURES IN AEROSPACE MEDICINE

SUMMATION

Presented By

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

Professor of Space Medicine - Advisor for Research

USAF Aerospace Medical Center (ATC)

SUMMATION*

by

HUBERTUS STRUGHOLD, MD, PhD**

Ladies and Gentlemen: I have the honor of giving you a brief summation. It is, of course, an impossible task to summarize what has been discussed; this would not do justice to the excellent papers presented. I would like to confine myself to some remarks about the progress and prospects on our Vertical Frontier, which were reflected in the lectures.

Ten years ago Aviation Medicine, or Aeromedicine, which, as General Benson pointed out in his introduction, cannot be completely separated from Space Medicine, had already reached its climax, but Space Medicine at that time was more or less a nebulous affair. Today, as we have seen in this lecture series, considerable progress has been made in this field. During the same time important advances have been made in space technology, astrophysics, and astronomy, as evidenced in the pertinent lectures given in this course.

*Presented at the Aerospace Medical Lectures, USAF Aerospace Medical Center, Brooks AFB, Texas, 15 January 1950

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25 Summation
H. Strughold

These are some new steps and aspects in space medical dev' ' ·pment and related fields:

The recent recordings in sounding rockets and artificial satellites about the density, temperature and pressure in the upper atmosphere and the fringe zone of space have provided valuable material for the establishment of a new standard atmosphere with a new pressure and altitude table for use in aeronautics and ballistics.

Beyond the effective atmosphere, because space is essentially a radiation environment, we need now in astronautics an analogon to the pressure altitude tables; namely, a solar distance irradiance table. Such a table for solar thermal irradiance and illuminance for the whole range from Mercury to Pluto has been published in a research report of this Center.

In atmospheric flight we deal essentially with the atmosphere and, of course, with the Earth's gravity. In space flight concerning motion dynamics we deal exclusively with gravitation and accelerations. For a better understanding of the gravitational situation in space we need, in addition to the gravitational field concept and the gravitational pit or crater concept, the sphere concept which subdivides space into gravitational territories, or gravispheres.

For the first time the magnetic field of the Earth enters the picture of Aerospace Medical considerations, but not in the sense that the magnetic forces could affect in any way an astronaut-- the magnetic field forces are too weak. But the magnetic field becomes indirectly important by its trapping functions concerning particle rays forming a giant radiation belt over the central latitudes around the Earth and perhaps around Venus and Mars. All of these features and variations in the space environment require an extension of our geographical thinking into space, the development of a space map, or spatiography, which indicates specific danger zones and times of increased hazards.

New in the history of medicine is the development of a completely sealed environment. Already the development of life-supporting systems in sealed cabins has progressed to a stage that we can easily keep a man alive over a period of several weeks.

For space operations of longer durations physical recycling and biological recycling of metabolic material are urgent problems in present and future research.

25 Summation
H. Strughold

Studies in space cabin simulators include the reaction of man to confinement and isolation. Considerable progress has been made in this field.

Up to now the day-night cycle has been an exlusive subject matter for biologists. Now in an environment such as space, where there is no day or night, the study of the best pattern of a day-night cycle under space flight situations is a main topic. The day-night cycle plays even an important role in today's fast atmospheric jet flight, which is especially interesting to watch when high-level diplomatic people make trips around the world.

Concerning multiples of G in the biodynamic pattern, we can resort to the many experiments which have been made on centrifuges and rocket-powered sleds during the past 30 years.

The state of weightlessness is a novel environmental situation; but here, too, we are quite well informed about short time states of weightlessness. We might know more about longer exposures to weightlessness within the next few years.

With this I come to the problem of extended flight operations, such as flight to the Moon or Mars. Astronomy has accumulated a large amount of new observational material for medical and biological evaluations. On the Moon, space with all of its properties and ingredients, immediately touches the ground. A Moonbase, therefore, requires an airtight compartment--that is, of course, a delicate situation for the occupants. On Venus we might run into a Hell of an environment; but Venusian probes might record a more attractive situation below the cloud cover. The old warrior god of Mars probably will show a more peaceful attitude for coexistence with terrestrial invaders. But the atmosphere he has to offer does not represent the substrate for a second Earth. However, temporary Martian bases for exploratory purposes are not beyond space medical thinking.

The interplanetary space projects, based on present propulsion systems, involve considerable durations. These methods permit minimum-energy trajectories to other celestial bodies. This fact finds its expression in the term "coasting" or "passive phase" of the trajectory. A flight to the Moon and return in this way is a matter of less than a week. This would probably not pose insurmountable medical problems. A flight to Mars, however, requires a time of more than eight months. This is what space technology presently can offer. Experiments made in space cabin simulators indicate that flights of such durations in a sealed cabin, under the conditions of confinement and isolation, might meet with the greatest difficulties. They arise essentially from the necessity to recycle the environment and from the psycho-physiological nature of the human creature. It seems to be necessary to shorten the duration of planetary missions. This, of course, would mean a change from a minimum-energy orbit to a minimum-time orbit, which would require more effective propulsion methods, possibly applying continuous slight acceleration. This should almost be regarded as a physician's prescription to astronautics. In this way a compromise concerning the flight duration may be found--possible from the standpoint of space technology, and acceptable from the viewpoint of space medicine.

Constant slight accelerations, of course, lead to very high speed, ultimately approaching that of light. But not every speed the engineer likes to choose is permissable from a medical point of view because extreme speeds change the environment for the vehicle and crew. The collision energy of meteorites and dust particles will become higher for a space vehicle. In rushing through the omnidirectional flux of cosmic rays their energy level of impact upon the vehicle increases. At a velocity range close to that of the speed of light we would observe the Doppler Effect in the electromagnetic spectrum insofar as in the direction to a star infrared will become visible and visible light will turn into ultraviolet and x-rays for the space travelers. Looking back to a star, he would experience the reverse. This shows that velocity in higher fractions of the speed of light becomes a limiting factor by its effect upon the environment related to a space vehicle and its occupants. Time dilation associated with sublight speed is often discussed as a phenomenon favorable to extended space flight, such as interstellar flight. However, flight of interstellar dimensions is presently not conceivable essentially for the aforementioned reasons, and the operational range will almost with certainty, at least for this century or so, be confined to the celestial bodies of our home solar system. But even this more modest goal, even if confined to the neighboring celestial bodies Moon, Venus, and Mars, will be one of the greatest achievements in human history. And, there is no question that Medicine in its aerospace studies will play in these cosmic efforts, in close cooperation with astrophysics and space technology, an important--in fact, a decisive--role.

Space flight within our solar system is full-fledged, three dimensional flight centered around the vertical, or third, dimension. The medical problems involved put medicine, so-to-speak, in the third dimension. The strange problems that would be encountered in the subspeed of light, interstellar flight, puts medicine in the fourth dimension.

Our lectures this week were essentially concerned with interplanetary flight, and if they have made some contribution to the advancement on the vertical frontier this would be the greatest reward for us.

In the name of the Aerospace Medical Center, I thank the speakers for their excellent papers, and all of you for your attention. This lecture series will probably not be the last one of its kind, and we hope to see you all again.