Space Travel : A Symposium

Introduction

By Colonel Paul A. Campbell, USAF (MC), *Chairman*

Many of us here today are of the opinion that extra atmospheric flight—space flight, if you please—is now entering the realm of the feasible. We have on our program today a group of experts representing various disciplines. Their contributions toward our goal can be questioned by no one. They have been asked to discuss the present state of the art in their line of endeavor, problems which are soluble and those which are extra-atmospheric flight. Possibly that will insoluble, and if they can—within the framework of security—make predictions.

I am certain one of these problems will be to attain agreement as to what constitutes be answered today.

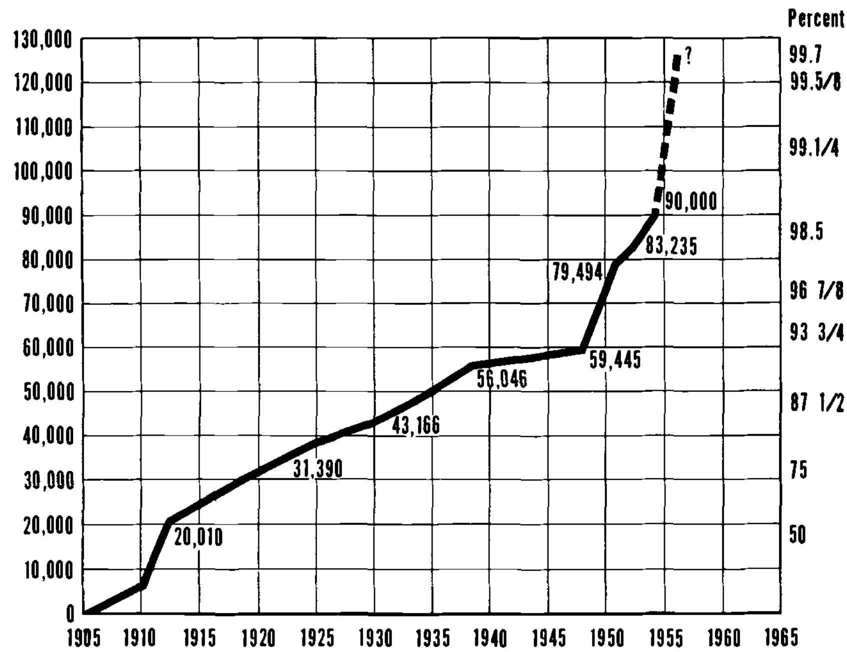

Fig. 1. Graph showing man's altitude achievements plotted chronologically by years and the percentage of atmosphere penetrated. The broken line represents unconfirmed records reported in the press.

To start off, I would like to show two diagrams (Figs. 1 and 2) showing evidence of man's approach toward space. The first is the time-worn graph of altitude achievement plotted chronologically. Note the break-through produced by the advent of rocket propulsion. The dotted lines represent that portion of the achievements which have been reported at times in various news media but have never been confirmed.

This symposium was presented on May 8, 1957 at the 28th annual meeting of the Aero Medical Association, Denver, Colorado.

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The second diagram represents the same chronological graph of altitude achievements but plotted in terms of per cent of mass of atmosphere penetrated. Note the

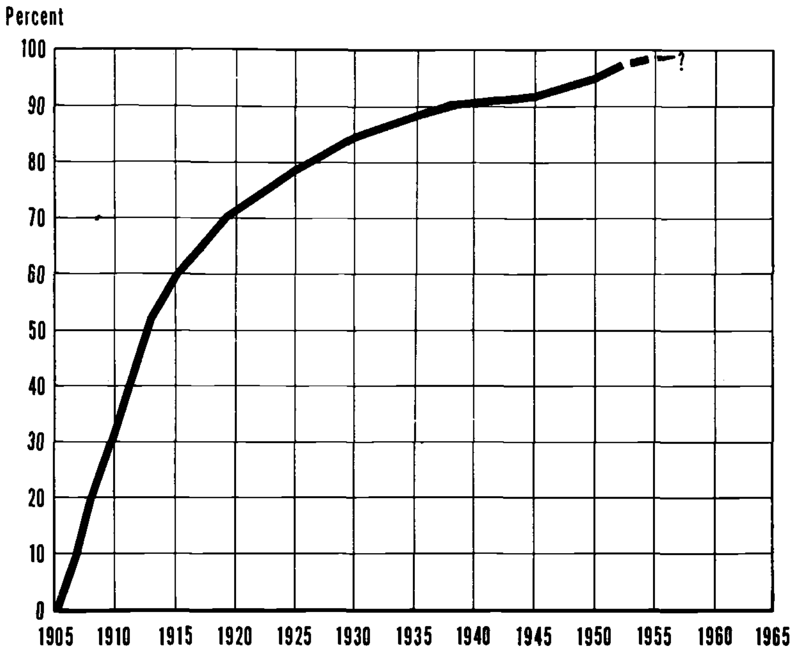

Fig. 2. The penetration of the atmosphere plotted according to year of achievement. The broken line represents unconfirmed records reported in the press.

smooth asymptotic progress, and also that the sudden break represented by advent of rocket propulsion has ironed out. Note, please, that the most rapid progress if one uses this parameter took place in the early days of aviation. That is a little deflationary. However, we shall hear many of the answers today from the members of our symposium.

Konrad K. Dannenberg, director, Technical Liaison Group, Army Ballistic Missiles Agency, will tell us how the "Propulsion Engineer Views Space Travel."

Professor Walter Orr Roberts, High Altitude Observatory, of the University of Colorado, will discuss "The Astronomer's Views."

Dr. Heinz Haber of the University of California, Los Angeles, will comment on "The Astrophysicist's Views."

Scott Crossfield, test pilot for North American Aviation, Los Angeles, will set us straight on some of the quite serious human problems.

Commander George W. Hoover, USN, Office of Naval Research, Washington, D. C., has chosen the subject, "What Instrumentation Will Be Required."

A. M. Mayo, chief equipment and safety research engineer of the Douglas Aircraft Company, El Segundo, California, will cover survival aspects of space travel.

Dr. John P. Hagen, Naval Research Laboratory, Washington, D. C., will describe the space travel implication of the Vanguard project.*

As a fitting conclusion of this series of discussions, Dr. Hubertus Strughold of the School of Aviation Medicine, Randolph Air Force Base, Texas, will discuss the question, "What are the Possibilities of an Inhabitable Extra-Terrestrial Environment Reachable from the Earth?"

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*Dr. Hagen was not present to read the report included in this symposium—EDITOR.

The Propulsion Engineer's Views

By Konrad K. Dannenberg

The purpose of this presentation is to analyze the status of existing propulsion systems and their usefulness for extra-atmospheric flight. First, a definition of the extra-atmospheric portion of flight would be in place. Ninety-nine per cent of the total air is contained within a 50-mile shell, and this coincides with the upper border of the stratosphere. However, there is still noticeable air resistance at this altitude especially on high speed bodies, such as meteors and rocket ships. Not until 120 miles are exceeded is the atmosphere so thin that it no longer offers detectable resistance to a traveling object, thus defining the minimum altitude of manned space flight for short-lived satellites.

The region beyond 120 miles is called the exosphere. It has been demonstrated that rockets can move through it at great speeds. The lower border of the exosphere was reached by high altitude firings of single-stage V-2 rockets in Germany in 1944 and in the United States in 1948. More recently a Viking rocket rose to approximately 160 miles. A Wac Corporal launched as a second-stage from a V-2, reached a peak altitude of 250 miles in 1949, thus traveling well within the exosphere. Newspapers late in 1956 reported another flight of a multi-stage rocket. Unconfirmed reports claimed a peak altitude of about 600 miles which would then extend well into the upper regions of the exosphere. The precise borders of this outer atmospheric layer are unknown at present. It simply "thins out" until there are no nitrogen or oxygen molecules left. It is believed by many to extend up to 700 or 800 miles.

Propulsion units, for all practical purposes, encounter physical conditions of extra-atmospheric flight when traveling through the exosphere. It should be noted that air molecules at the 250 mile peak altitude of the Wac Corporal are so rare that there was less air than is present in the best vacuum tubes. Today's knowledge can provide man with the transportation to venture into space *right now.*

Mr. Dannenberg is director of the technical liaison group of the U. S. Army Ballistic Missile Agency, Redstone Arsenal, Alabama.

STATE OF THE ART

Calculations have shown that conventional power plants can do the job. New power sources should presently be viewed as possible improvements but are not a necessity. Today's designs for solar and nuclear power generators are very heavy and, therefore, inefficient. It is generally expected that a 21-pound satellite will take to its orbit in late 1957 or early 1958. Improved designs will permit several hundred pounds to be thrown into the orbit and should follow shortly. In the early 1960s we should be able to accelerate several thousand pounds to a velocity which would permit any desired orbit, the altitudes of which will be determined by the satellite's specific mission.

For example, as an assembly point for manned space ships, Dr. von Braun proposes a celestial route 1,075 miles above the earth. Such a satellite would complete a trip around the earth every two hours, which is desirable for observational purposes. It would orbit well beyond the atmosphere, and would provide an excellent stepping stone for further progress into space. Vehicles taking off from such a satellite to go to the moon and to neighboring planets would need only small power plants because the weight of the ship does not need to be lifted off the earth's surface. Thrust ratings lower than the ship's weight are normal. It can, therefore, be said that once propulsion problems of manned spaceships to extra-atmospheric orbits have been solved, there should be no major obstacle hindering the propulsion engineer to step into lunar space, or even into the adjacent interplanetary space of our two neighboring planets.

ENERGY PROBLEMS

The vast difference in energy level between the earth's surface and space creates the primary problem. To leave the gravity field of the earth permanently with an escape velocity of 7 miles per second would require 14.9 Kcal/g, whereas to orbit at an altitude of 140 miles at a circular velocity of almost 5 miles per second only 7.6 Kcal/g. would be required. Energy levels presently of interest are in this span. We have a number of fuels which yield the desired amount of energy; however, they have to be used with oxygen or another oxidizer. This in turn cuts approximately in half the yield per gram of mass. Furthermore, we must package our propellants in containers, and must add instrumentation and a pilot's compartment. This requires additional fuel quantities to fulfill the energy needs. Such a problem could be solved by the "staging" of our ships. The total chemical energy of the first stage could thus be converted into stored kinetic energy, and from this mass with an originally higher energy level, we could start our second stage. This in turn will add by its combustion of propellants to the energy level of the remaining mass. Because this process can be repeated as often as necessary available chemical propulsion units are able to meet our energy requirements.

For travel to the outer planets, energy requirements cannot be met by chemical propellants. Expected improvements will not change the situation much. Obtainable combustion chamber temperatures offer difficulties at about 3000° C. (5400° F.) at 500 psi chamber pressure. A limit is presently anticipated around 4000° C. (7200° F.) and 1,000 psi chamber pressure due to heat transfer and material strength problems. Use of atomic reactors to heat working fluids does not improve this situation. The desired propulsion system for outer space and interstellar flight is therefore an atomic rocket which will convert energy directly into thrust, yielding a million times the amount obtained with present fluids or propellants.

However, as stated before, today's conventional propellant combinations are adequate, if one is willing to limit travel to the adjacent interplanetary space.

SPECIFIC IMPULSE

The "specific impulse" tells us how much thrust is obtained while consuming one pound of propellant per second. A high specific impulse is, therefore, desirable because it results in a smaller rocket having the same operational capabilities. However, the specific impulse is not the only criteria for the desirability of a propellant. High density, for instance, permits one to carry the same amount of energy in a smaller propellant and tank package. Very dense propellants may even result in decreased dimensions and weight of the rocket engines. Therefore, the product of specific impulse "Isp" and the bulk density "d" of both propellants is often used for comparison. The "ideal" fuel, hydrogen, looks very poor when judged from this point of view; whereas, combinations containing fluorine and fluorine compounds perform excellently.

Here are a few comparative figures quoted for a 300 psi chamber pressure with 1 *atm* nozzle exit pressure:

	Isp	*d*	*Isp.d*
V-2 Propellants: LOX—75% Alcohol	234	0.98	230
IRBM Propellants: LOX—Kerosene	249	1.02	254
"Ideal" Propellants: LOX—Hydrogen	345	0.23	79
Proposed Propellants: *RF Nitric Acid-Hydrazine	242	1.25	302
Possible Propellants: *Fluorine-Hydrazine	300	1.07	321

*Hypergolical propellant combination.

In any case, the final choice can be made from a great variety of propellant combinations, some having extensive test and operational experience, others possessing outstanding performance but with unknown characteristics of operational behavior. Dr. von Braun for logistic reasons favors nitric acid and hydrazine as the most promising propellant for a large satellite project which could be implemented today.

LOGISTICS

Propellant logistics pose the greatest individual problem. Continuously ferrying supply rockets will devour huge quantities of propellants; the storage depot at the space station must be stocked, and a sizeable amount must be used during pre-flight testing, training and test flights with crew and relief personnel. Thus, propellant needs will be tremendous. The problem should not only be analyzed from the desire for a minimum sized rocket, but also from the overall economy of the venture which may be an overriding viewpoint.

The problem can possibly be reduced by the use of nuclear power at the launching site to provide, among other things, energy for the manufacture of propellants. The fuel and oxidizer may therefore be chosen on grounds that they can be manufactured at the site from air and from water. This may determine preference even over propellants of higher energy output. Such a combination would be nitric acid-hydrazine; propellants like fluorine would be at a disadvantage. To team atomic energy and rocket propulsion in this fashion appears presently much more realistic than the direct use of nuclear power plants in the vehicle, especially for first stages.

HARDWARE

The powerplants of passenger-carrying space ships can be much smaller in thrust output than the commuting ferry rockets as outlined earlier. Therefore, no great difficulties in design, construction and operation of chemical space ships are expected after the much larger units for the flight to and from the space station have been accomplished. "Staging" of all ships to the space station will be required. Engine throttling permits limitation of acceleration values to tolerable loads. If desired for economy, recovery of the exhausted portions of the lower stages can be accomplished. Much experience will be accumulated from further perfection of existing automatic and manned vehicles for high altitude flight. This in turn will lead to further advances and eventually to the manned orbiter.

Published design proposals normally provide a large number of smaller engines to meet the requirements for a high total thrust. This does not necessarily decrease the system reliability. In fact, I would at any time prefer to fly with a large number of well proven, and extensively tested IRBM engines rather than with a newly developed single engine which has never flown and which has undergone only rudimentary testing. The engines of these vehicles will be swiveled for programmed flight control. They will be mounted in such a manner that missile roll can be compensated. The high ratio between the combustion chamber pressure and the ambient condition of zero pressure will permit low combustion chamber pressures and thereby light-weight engines, which still would yield excellent specific impulses. The exhaust nozzles will be designed for high expansion ratios. No severe cooling problems are expected because the expanding gases will cool down to such an extent that use of uncooled nozzle ends is intended.

Highest emphasis will be placed on reliability. Thorough testing of all components, of the engine sub-assembly, and of the assembled missile will be scheduled. Most tests do not necessarily have to be made at the launching site, but may be performed at the contractor's manufacturing plant or at a proving ground at home. A captive firing at the launching site just prior to take-off may be desired and could be arranged. It can be of short duration, but the used propellant portion should be replenished before take-off. Existing methods of in-line and test-site inspection will have to be improved greatly. In fact, existing difficulties in rocket systems occur essentially in the smaller components, which do not always get the same attention as the large items; thus, we now have more difficulties with heat exchangers, pipe lines, control valves and pressure regulators than we have with other often less understood and more complicated systems such as turbo pumps, combustion chambers, and injectors. It will be the mission of American industry to overcome these difficulties by better and more efficient inspection and by improved methods of production and product evaluation. This mission will be complicated by the need for redesign of propulsion systems, as well as of the guidance and control systems, for full automation. The pilots will not have the necessary time and capability to fulfill these functions and will have to depend upon mechanized automatic control for the entire ship during the propelled flight. The human response time is too long to perform the necessary maneuvers with the required precision and accuracy. Furthermore, acceleration and the events of the flight put man under such physical and mental stresses that he cannot be relied upon. The handicaps are just too great. We are, consequently, back again to space flight's worst bottleneck—man himself.

As a plain and earth-bound propulsion engineer and not as a co-pilot of the ship, I see no difficulties of a magnitude which would prevent the initiation of a venture into space immediately with good assurance of success. Forthcoming results of existing missile and satellite programs will yield invaluable information towards the final solution. We've come a long way, and I am convinced that once men unite their knowledge and combine their efforts toward the progress of science and technology, nothing can permanently stand against them.

The Astronomer's Views

By Walter Orr Roberts, Ph.D.

Our symposium today signalizes that an age old dream of the astronomer nears reality. The science of rocketry has, at last, brought the realistic prospect of exploring far into space with telescopes, photoelectric devices, and other measuring instruments that will telemeter their findings back to earth. The chance to probe directly into the hidden facts of nearby space is exciting fare for the astrophysicist.

My view of the prospects for space travel by living persons is less sanguine. I see only an outside possibility of some limited flights into the first few hundreds of miles of space for perhaps a few hardy souls. Except for this I doubt that human space travel is for our generation, however fascinating it may be in science fiction. Nor do I think this will be much loss. I, for one, wouldn't want to spend forty years of my life getting to a nearby star where there is perhaps one chance in a million of finding a planet like earth. If I did make it, and there *were* a suitable planet, it would probably be a dusty, windy desert, like Mars, or a steaming jungle, rather than just the right blend of temperate climate.

Even if I could travel at the improbably fast speed of 50 million miles an hour—round the world in about one second—it would still take me forty years or so to reach the nearest star if no worse fate befell me in the meanwhile. And even within the solar system where the time for travel is relatively short, and the over-all prospects brighter, the problems are many and look difficult to surmount. In short, I'm frankly pessimistic about space travel for humans.

Here is where my pessimism ends, however. Important mysteries of space can be solved with the rockets and satellites on today's blueprints if we plan imaginatively. The wealth of rocket data already available about the upper atmosphere, cosmic rays, the aurora, and the ionosphere is but a taste of what we can learn. Pointing the way are the brilliant researches of groups like the Naval Research Laboratory teams headed by Tousey, Newell, and Friedman and Chubb, or the work of Van Allen and his colleagues at State University of Iowa, to name but a few of the many. We are indeed at the threshold of an era of space physics.

The years ahead will see us breaching the protective shield of the ozone layer and penetrating regularly into the D, E, and F regions of the ionosphere some 50, 65, and 150 miles overhead. There we shall find, I believe, clues to the true atmospheric chemistry and physics of the layers we rely on for long distance radio communications. Going beyond, we shall find, possibly, new facts of the primary cosmic rays unaffected by atmospheric collisions, data on spatial magnetic fields, and measures of the tempera-

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tures of the tenuous but highly significant gaseous layers, in and above the ionosphere. Indeed, we are very likely to get the first realistic census of the true space density of meteors, the debris of space on which may conceivably depend such things as worldwide tendencies in rainfall.

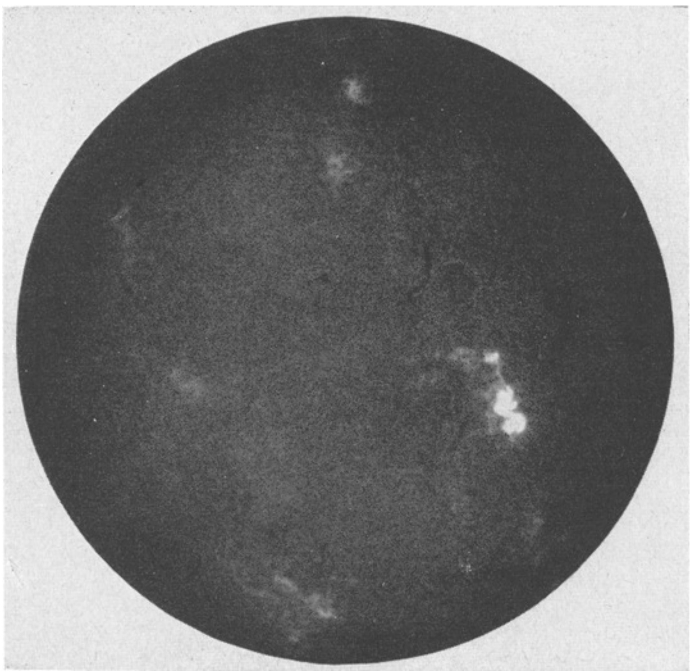

Fig.1. A large solar flare that rose to maximum in five minutes. Such a sudden brightening on the surface of the sun is often accompanied by an immediate fadeout of short wave radio communication on the sunlit half of the earth. This flare was photographed in the light of hydrogen at the Sacramento Peak Observatory on February 29, 1956.

But to a solar astronomer the greatest challenge of all is the prospect of looking at the sun with a freedom impossible for the earth-bound. To understand this challenge, let's look for a moment at the basic facts about the sun. The sun is a gaseous sphere about 864,000 miles in diameter. The weight of the successive layers of gas compress the central gases to a density ten times that of steel. To support this weight the central temperature rises to tens of millions of degrees. Deep in this core thermonuclear processes slowly transform the sun's prime constituent, hydrogen, to helium and thus to the energy ultimately radiated as sunlight. This visible solar light is given off at such a constant rate that despite determined efforts no significant variations have ever been observed. We know that variations, if they exist, are a small part of 1 per cent.

In contrast to this steady emission, the sun probably sends out a multitude of radiations in non-visible wave lengths, many of them highly variable both in intensity and duration. Because of the opacity of the earth's atmosphere to these radiations, our knowledge of them is almost entirely indirect. From 100 Å to 900 Å, for example, we do not even have reliable guesses of what the solar emission looks like. Those in the wave lengths from 1 to 1500 Å are of particular interest because of their suspected influence on the earth's atmosphere. All of these short wave emissions must originate in sources far from thermodynamic equilibrium. Their behavior makes the solar atmosphere a fascinating laboratory

Fig. 2. A large eruptive prominence seen at the edge of the solar disk showing material being ejected into space at high velocity. Photographed in the light of hydrogen at the Climax observing station of the High Altitude Observatory of the University of Colorado on March 5, 1953.

for study of the physics of hot gases at low pressures, high velocities of ionized gases in magnetic fields, and non-equilibrim radiation physics.

At the surface of the sun, also, are found challenging astrophysical problems. Dark sunspots form like vortices, cooler areas in the warmer surrounding surface. Associated to one degree or another with the sunspots are the many other phenomena of the sun's changeable atmosphere, the prominences, corona, chromosphere, faculae, plages, flares, filaments, spicules, granulation. And each of these varies with its own characteristic time and size scale.

At one end of the time scale are the explosive solar flares, sudden brightenings on the sun's face, that rise in seconds or minutes to multimillion square mile regions of dense hot gases with temperatures that may reach 5×10^6 degrees (Fig. 1). At the other end of the time scale are the brilliant quiescent prominences, suspended clouds of the solar atmosphere, sometimes visible for months (Fig. 2).

With many of these solar features there are believed to be emissions of different sorts. For example, the flares are thought to emit powerful x-rays and ultraviolet emanations that change the ionization of the lower ionospheric regions, and produce abrupt radio fadeouts. Other regions of the sun, far less well defined, are suspected of ejecting electrified particles that travel in a day or two from sun to earth with a speed of about a thousand miles a second. Some particle streams appear in a steady continuous flow; others arrive in irregular spurts. There is evidence that these particles produce the aurora and the magnetic storms. But this is still hypothetical. Even more speculative is the possibility that some of these solar emissions are responsible for upper atmopheric heating that may have far reaching effects on the location of the jet stream and on world-wide weather patterns. But there are intriguing suggestions that this is so!

Another interesting possibility is that the earth moves in the outer reaches of the sun's very tenuous atmosphere and that there is actually heating of the earth's own outer atmosphere through thermal conduction resulting from the million degree corona of the sun. We now know also that the sun emits radio waves from several meters to a few millimeters wave length, that vary greatly from day to day, hour to hour, and even second to second. It does not seem probable that research efforts now underway may reveal terrestrial effects from these radio waves. But solar-terrestrial research is full of surprises.

Space exploration offers us the chance to study all the emanations from the sun before their energy is spent in modifying the earth's atmosphere. I will regard the earth-satellite program a success if just once it brings us a life history of the x-ray and ultraviolet emanations from the sun at the time of a solar flare. The techniques are all available today, and it seems that even a light load-carrying satellite could carry the necessary photocells, amplifiers, and telemetering equipment. Great ingenuity and expense is still needed, and it will be easy to become impatient. But rewarding goals beckon and the techniques lie within our grasp.

Lifetimes of research into sun-earth relationships lie ahead. Solar effects on earth physics are being found in meteorology, ionospheric physics, geomagnetism, airglow, auroral physics, upper atmospheric physics. and in many other fields of geophysics. So promising is this field that we have recently created at the University of Colorado a new program of graduate study. Mindful that the sun is a star, and that other astronomical bodies may also affect the earth, we have labelled our new program "astro-geophysics." The astro-geophysical potentialities of space flight with unmanned vehicles carrying scientific instruments represent one of the great research opportunities of our century.

The Astrophysicist's Views

By Heinz Haber, Ph.D.

The interest of the astrophysicist in space flight is twofold. First, he is justified in expecting that observations of cosmic factors outside the contaminating blanket of the earth's atmosphere will result in important new data of great benefit to the advance of astrophysics. Second, he can put his specialty at the service of space technology by supplying data to engineers and space surgeons for the design of space vehicles and protective devices.

This is not the place to discuss possible research projects in the field of astrophysics which could be initiated as soon as unmanned or manned space vehicles become operational. It appears more important at this time to consider those areas of astrophysics that can and will contribute toward the successful design and operation of such vehicles. Perhaps the most important contribution of astrophysics will result from an analysis of the field of radiation existing in the proximity of the earth and how this field of radiation relates to the surface temperature of a body exposed to it. This paper confines itself to a discussion of this problem and to its possible solution by laboratory experimentation.

RADIATION TEMPERATURE EQUILIBRIUM

If a body is exposed to a field of radiation in a complete vacuum, its temperature will be determined solely by the exchange of radiation between the surface of the body on the one side, and the radiation sources contained in a solid angle of 360° on the other. Since the body is assumed to be in a vacuum no medium is present that would transfer heat to or from the body. Under these conditions the body's temperature will approach asymptotically a certain value T_e at which temperature the amount of radiative energy received by the body equals the amount radiated away by the body. This state is called "radiation equilibrium," and the temperature T_e itself is designated by "equilibrium temperature."

It follows that the equilibrium temperature of the body will be determined by the law of Boltzmann. Referring to a body in extraterrestrial space, two major radiation sources must be considered, namely, the sun and the earth, while the background of space including the other celestial bodies is considered as a radiation sink with the temperature of O° Kelvin. Furthermore, the body is assumed to have a temperature comparable to or only slightly greater than that of the earth, while the temperature of the sun's surface is taken as 6,000° Kelvin. Under these conditions it follows from the laws of black-body radiation that the body and the earth radiate preponderately at wavelengths greater than 3μ, while the bulk of solar radiation (more than 99 per cent) lies in the wavelength region smaller than 3μ.

On the basis of the above assumptions Buettner[1] has derived an equation which permits the calculation of equilibrium temperatures of various surface materials and configurations of bodies in space under

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idealized conditions. Using his equation Buettner[2] has calculated the equilibrium temperatures of a plane body of infinite dimensions which was assumed to be perfectly insulated thermally from the rear.

TABLE I. EQUILIBRIUM TEMPERATURES (IN DEGREES C.) OF A PLANE BODY OF INFINITE DIMENSIONS INSULATED THERMALLY FROM THE REAR

Surface	*Sun*	*Plate faces*	
		Sunlit Earth	*Dark Earth*
White	— 51	— 13	— 29
Black	122	68	— 29
Aluminum	428	295	— 29

Assuming a black (lampblack), a white (magnesium oxide), and a polished aluminum surface, Buettner obtained equilibrium temperatures for the plate facing perpendicularly the sun, the sunlit earth, and the dark side of the earth, respectively. His results, in Table I, show that aluminum surfaces attain extremely high equilibrium temperatures as soon as solar radiation is involved, either directly or reflected from the earth. The same holds for other metal surfaces with steel assuming somewhat lower, and nickel somewhat higher. temperatures than aluminum. These high equilibrium temperatures occur because metals are very poor radiators in the long wavelength band comprising the maximum of the Planck curve for moderate temperatures. Even though highly polished metal surfaces may reflect as much as 90 to 95 per cent of the incoming solar radiation, their emissivity at lower temperatures is so low that equilibrium temperature is reached only at higher values. This particular property of metals is exemplified by the high temperatures assumed by chromium parts of cars parked in the sun. A white surface, however, assumes fairly low equilibrium temperatures.

A rocket missile or a satellite will be exposed to changing periods of exposure to full sunlight as it enters or leaves the earth's shadow. Buettner[1] has also given equations that describe the asymptotic approach of the temperature towards the final equilibrium temperature T_e which, however, may sometimes not be reached if the heat capacity per unit area of the body's surface is large in relation to the time of exposure to "day" or "night." Even though Buettner's results can be taken only as an approximation of equilibrium temperatures to be expected for actual space vehicles, they seem to point out that untreated metal surfaces will probably be unsuited as surface coverings because of their extremely high surface temperatures T_e. The outer metal skin of the artificial satellite (project Vanguard) will receive a special treatment in order to maintain moderate operational temperatures in its orbit. The coating will consist of this multi-layer metal and metal oxide sandwich: a 0.00005 inch thick gold plating applied to the actual metal shell; upon the gold plate is vacuum evaporated a layer of chromium; on this layer of chromium will be deposited a thin layer of silicon monoxide which in turn will bear a thin aluminum coating. On the aluminum will be deposited a silicon monoxide layer of such a thickness so as to give the desired radiative emissivity. It is hoped that this surface treatment will result in an operational temperature of the satellite compatible with its transistor instrumentation inside.

CASES OF RADIATION EQUILIBRIA

In the denser layers of the atmosphere the surface temperature of a vehicle is chiefly determined by the exchange of heat between its hull and the ambient air. With increased altitudes the heat transfer between the vehicle and the atmosphere decreases and finally ceases. Owing to adiabatic and friction heating, the process of heat exchange between the outer hull of the vehicle and the air is dependent on the vehicle's velocity. For a body at rest in relation to the ambient air the conditions of pure radiation equilibrium are practically fulfilled at an altitude of about thirty miles. With increasing velocities of the body these conditions will be fulfilled only at increasingly greater altitudes. For the maximum operational speeds anticipated (i.e., orbital velocity of about five miles per second) conditions of radiation equilibrium are found at altitudes in excess of about 150 miles. This range lies in the presumable operational area of intercontinental missiles and satellite vehicles. An intercontinental missile will enter the critical range above 150 miles only after it has been heated by aerodynamic stagnation and friction prevalent during the powered ascent. Its temperature will then seek its equilibrium level which will depend upon the position of the sun, the duration of its free flight, its spin and wobbling movements, if any, the nature of its surface, and its thermal capacity per unit area.

Fig. 1. Vacuum chamber deveolped by Litton Industries capable of simulating altitude of 150 miles.

A satellite vehicle generally will be subjected to repeated exposures to sunlight and to the earth's shadow. Each "day" and "night" of a satellite operating within the altitude range between 200 and 800 miles will last approximately forty-five to forty-eight minutes. During each revolution, parts of the satellite will face the sun, the sunlit earth, the dark earth, and free spac.e Rotation of the satellite will introduce a further parameter. If the satellite Orbit is arranged so as to coincide with the plane of the earth's terminator (the great circle dividing the earth into its sunlit and its dark hemisphere), the vehicle will be always illuminated by the sun, at least for the duration of several weeks. Special radiation conditions will prevail for missiles and satellites if additional solar radiation is received through specular reflection from broad areas of ocean surface. From these conditions the following practical cases of radiation equilibria can be compiled:

ICBM ascending into day
ICBM ascending into night
ICBM non-rotating
ICBM rotating and/or wobbling
ICBM under specular reflection
Satellite in eclipsing orbit
Satellite in terminator orbit
Satellite non-rotating
Satellite rotating
Satellite under specular reflection

All these cases, of course, must be permutated with different geometrical configurations, surface materials, and thermal capacities.

SIMULATION OF SPACE CONDITIONS

Theoretical treatment of the problem of equilibrium temperatures in space is rendered difficult and involved because of the large number of parameters entering the problem. For these reasons an experimental study in the laboratory appears highly desirable. To do this a properly equipped facility must be available for simulating the various conditions and properties of space. The following factors must be simulated: (1) a vacuum; (2) solar radiation; (3) radiation of the sunlit earth; (4) radiation of the dark earth; and (5) radiation characteristics of free space.

Fig. 2. Pressure suit with vapor cover, developed by Litton Industries, designed for use in experimental vacuum chamber.

Vacuum.—To simulate the vacuum conditions of space a large evacuated chamber representing the air density conditions equivalent to an altitude of 150 miles is necessary. A chamber meeting these specifications has recently been developed and built by Litton Industries,[3] Beverly Hills, California. The present facility consists of a cylindrical steel shell, 12 feet long on the inside with a diameter of 8 feet. (Fig. 1) The pumps are specified to evacuate the chamber to a minimum pressure of the order of 10^{-6} mm. Hg. The chamber is designed to admit a human operator equipped with a pressure suit. (Fig. 2) The suit which was designed by Hansen and his associate of Litton Industries, is equipped with leads for oxygen pressure, water, humidity, and temperature control. The gloves of the suit are so designed that the operator is able to execute fairly delicate manual tasks. Litton Industries plans the construction of a larger chamber equipped with an air lock through which the pressure-suited operator can enter and leave without the necessity of recompressing the main chamber. The Litton facility more than adequately fulfils the conditions of vacuum for experimentation in the field of radiation equilibria. In addition it has the advantage of the presence of a human operator who can monitor and modify the experimentation.

Solar Radiation.—The spectral distribution of solar radiation closely approximates that of a black body having a temperature of 6,000° K.[5] The peak of the continuous spectrum of the sun lies around the wave length of 470 mμ. Specifically, for three arbitrarily subdivided regions of the solar spectrum—ultraviolet, visible, and infrared—the distribution of solar energy is as follows: UV (0 — 400 mμ) : V (400 — 740 mμ) : IR ($>$ 740 mμ) = 9 : 45 : 46. Because of the absorption of ultraviolet radiation by atmospheric ozone and oxygen, the percentages at sea level are changed to the following approximate ratio: UV : V : IR = 7 : 45 : 46. Because the region critical for radiation equilibria lies above the actual atmosphere, the extra-terrestrial values have to be used. The absorption of solar radiation caused by ionospheric layers that lie above the operational region of missiles and satellites is confined to the extreme short-wave ultraviolet, and comprises less than 0.1 per cent of solar radiation under conditions of normal solar activity.

A first good approximation of solar energy can be obtained from the radiation emitted by a carbon arc which includes the radiation from both the plasma and the solid ends of the positive crater. The peak temperature of a normal carbon arc is 4,470° C., i.e., the vaporization temperature of pure carbon. This temperature, of course, is lower than that of the sun's photosphere with the result that the above ratio is shifted in favor of infrared radiation and an appreciable depletion of ultraviolet radiation. However, the spectral absorptivity of most metals in the visible and the near ultraviolet is rather flat, so that an ordinary carbon arc of sufficient energy can be expected to produce a fairly equivalent effect on test bodies so far as spectral distribution is concerned. Application of water cell filters will probably be sufficient to approach the spectral distribution of solar radiation.

Even though atmospheric absorption falsifies the spectral distribution of solar radiation, the sun can be considered as a radiation source for the experiments. In this case a beam of sunlight, made stationary by means of a coelostat, can be focused on the test object. A proper convergence of the beam can be chosen to correct for the loss of solar energy in passing the optical system consisting of mirrors and filters so that the energy flux recevied by the test object is equal to one solar constant (2 gcal per cm^2 and minute).

Radiation from the Sunlit Earth.—According to Fritz[4] the radiation emitted by the sunlit earth has the following spectral distribution (see above for arbitrary divisions): UV : V IR = 4.5 : 39.0 : 12.6. Since about 91 per cent of the radiation reflected by the sunlit earth is reflected and scattered by clouds and the free atmosphere, the color temperature of the reflected light is higher than that of original sunlight. Accordingly, the infrared part of the reflected sunlight is sharply depleted in favor of the visible part. In order to simulate this spectral distribution, radiation from a carbon arc or from the sun must be filtered by water cells and color filters. If a parallel beam of radiation is directed at the test object, its energy flux must be adjusted to correspond to 35 per cent (albedo of the earth) of one solar constant. This energy flux then corresponds to the radiation emitted by the sunlit earth covering a solid angle of 180° as is always the case for operational altitudes of missiles and satellites. Any excess light from artificial or natural light sources representing solar and terrestrial radiation (sunlit earth) must be allowed to fall into a baffled black radiation sink. Specular reflection from the oceans raises the influx of radiation energy upon the test object by an amount of up to 10 per cent. Even though the spectral distribution of sunlight reflected by the ocean surface differs slightly from that of original sunlight, specular reflection can be simulated without introducing an appreciable error by adding 10 per cent to the flux from the carbon arc (or sunlight) representing the radiation from the sunlit earth.

Radiation from the Dark Earth.—In order to simulate the long-wave heat radiation emitted by the dark earth the test object must be located in the center of a blackened hemisperical dish having a sufficienly large radius. The surface of the dish must be kept at such a temperature that the bolometrically measured radiation flux received by the test object is equal to about 15 per cent of one solar constant.

Characteristics of Free Space.—The radiation sink representing free space will pose a few problems. Previous discussions with Hansen have resulted in the following suggestion: The sink might best be constructed by a system of staggered radiation baffles consisting of thin copper plates covered with a layer of dull lampblack. The baffles themselves bear a system of copper tubing soldered to them which conduct a flow of liquid air. In the absence of air and, consequently, humidity inside the chamber such a radiation sink appears to be entirely feasible; no condensation will occur on the plates and tubing destroying their radiative properties of a black body at very low temperatures. The radiation sink will cover the second half of the full solid angle around the test object which is not covered by the hemispherical dish representing the earth.

PARAMETERS OF EXPERIMENTATION

From the foregoing a set of parameters and their logical permutations for conducting individual experiments can be derived. They fall into the following categories:

GEOMETRY

Circular disk
Square and rectangular plate
Cylinder
Cone
Sphere
Wire

SURFACE

Metals and alloys of different textures: high polish, smooth, rough, heat-treated
Paints
Dull Black
Sandwiches
Ceramics
Non-uniform
Abraded (micro-meteorite effects)

HEAT CAPACITY

Thickness of hull
Materials of different specific heat
Test bodies of different size
Evacuated bodies
Air-filled bodies

MOTION

Stationary
Rotating at varying periods and axial positions

INITIAL TEMPERATURE

Aerodynamic heating
Long-term exposures to space conditions

TIME

Exposures equivalent to:
ICBM ascending into day
ICBM ascending into night
Satellite in eclipsing orbit
Satellite in terminator orbit

A facility of the kind described above can be operated similar to wind tunnel operations. A proper permutation of all important experimental parameters will provide a set of extremely valuable data on the problem of radiation equilibrium temperatures. It would be an important contribution of astrophysics to intercontinental missiles, flight at highest altitudes, and unmanned and manned satellites.

ACKNOWLEDGMENT

The author wishes to express his gratitude to Mr. Siegfried Hansen and Mr. Richard Roche of Litton Industries for many valuable discussions and suggestions.

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A Test Pilot's Viewpoint

BY A. SCOTT CROSSFIELD, M.S.

The test pilot in his business permits no flights of fancy, but is personally directly and vitally concerned with all the subjects discussed at this meeting wherein they apply to aviation. The word "test" here implies early or developmental efforts toward extra-atmospheric flight. "To test" requires a specific purpose in mind and in design and, therefore, to escape the meandering of lack of definition, let me select a case to discuss. The following observations, while not necessarily original, are a personal responsibility. Let's assume a virgin engineering effort to construct a chemically powered rocket ship to attain, orbital velocity at altitudes of se-

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veral hundreds of miles and be repeatedly recoverable. First considerations then appear to be:

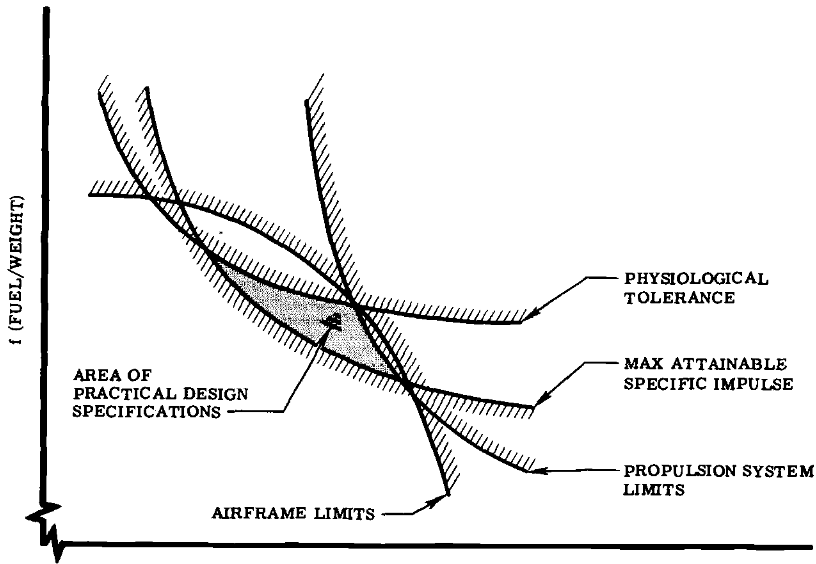

Fig. 1. Orbital vehicle design practicality.

1. What is the requirement . . . that is, what are we seeking to establish . . . and why. Satisfying that this venture has a purpose, then:
2. It certainly involves consideration of economy of time, manpower, money, resources, and perhaps defense requirements as influencing factors upon the degree of the effort.
3. Are reliability considerations or risk acceptance in the required mechanisms involved in the proposal to help to further determine the extent of the effort?
4. The elimination of exotic approaches that have little subsequent use for practical and useful development.

The above four considerations almost necessarily define a manned vehicle. Also, thoughtful analysis of the four considerations reveals one very important absolutism: Tyrannical authority of design decision and responsibility must be vested in one source to attain uncluttered objective results in this venture.

The subject case, intended to be powered by a chemical rocket engine and with the afore-mentioned performance requirements, designs itself. Referring to Figure 1, with some function of fuel-to-weight ratio as the ordinate and some function of thrust as the abscissa, several basic things need to be satisfied. By analysis of the design, materials, and fabrication capabilities, we can define an airframe practicality boundary somewhat as shown, which is a function of size, loads, temperatures, et cetera. The engines and fuel systems are affected by the same considerations, and a practical propulsion system boundary may appear as shown. A requirement for power recovery upon return to earth would lower both of these curves relative to the level permitted by aerodynamic recovery alone.

Like the airframe and propulsion system, the pilot has load limits. A physiologic tolerance to accelerations of thrust, lift, and drag will define a boundary perhaps as shown. These three curves bound an area with the axes within which the subject vehicle can be successfully constructed. However, as shown, maximum attainable specific impulse will rule out a lower bounded area that moves down and to the left as specifics are increased. A design and manufacturing capability to build this vehicle exists only when the four boundaries enclose a point or define an area within which the physical characteristics of the machine lie. Therefore, there seems to be little question that our ability timewise to solve such a problem as this rests with our determination of the degree of simplicity of approach that we can accept consideration three above.

What does all this mean to the pilot? One fact becomes outstanding if it is urgent to construct such a machine at the earliest possible time: Use of the pilot to close out the control loop of the internal mechanisms, as well as the mission, in lieu of gross automaticity, becomes mandatory. What then is the concern of the pilot? Let's look at some observations by area; possibly—or probably—they are controversial.

PHYSIOLOGIC CONSIDERATIONS

Basic and measurable are accelerations, temperatures, pressures, breathing requirements, moisture control requirements, and waste disposal requirements. All of these yield to engineering solutions at hand.

Subtle and unmeasurable, or at least unpredictable, are effects of radiation, zero G, visual and orientation disturbances. Meteorite collision might be included here as a physiologic hazard. No conclusive evidence yet exists that any of these are real problems in a limiting sense.

PROPULSION

We know that we will require extreme performance engines, exotic fuels, high specifics, high chamber pressures, and very high thrusts, at least in the early exit phases. To the pilot, this means critical engine control requirements and fuel handling, and allotment. Furthermore, he requires adequate information from engine and fuel system instrumentation for alternative action should it be necessary. The pilot is also concerned with recognition of, and alternative action to be taken for, problems such as those arising from main and auxiliary engine exhaust attenuation at zero nozzle back-pressures. These may give rise to radiation and local vehicle environmental problems. There is vital pilot concern over the maintenance of fuel and pump suppression pressures and alternative controls if getting out of the orbit is deemed desirable. Probably, in the propulsion section, should be included the pilot concern for internal exchange in heat for man and equipment environmental control, and, if necessary, the managing and allotment of stored heat sources.

NAVIGATION AND COMMUNICATION

Here the pilot's first concern is accurate knowledge and prediction of the vehicle's path in space with reference to some datum. Will the ship be beclouded with a visually and electronically opaque ionized exhaust product atmosphere which permits no outside contact? Can he see or hear electronically through the ionosphere? If not, will reliance solely upon inertial guidance be required and, if so, what are alternative methods? In this discussion, continual reference to alternatives stems from the notion that a pilot is always in control until he runs out of alternatives or . . . into the ground.

INSTRUMENTATION

There is a fashionable concept that is in grave error. This is the treatment of pilot presentation and instrumentation in a broad sense. It is felt very strongly that pilot instrumentation, like the proper parts of any mechanical assembly of thoughtful design, is uniquely determined by the vehicle, its mission, time allowables, internal mechanics, and pilot experience.

There is another and related fashionable concept that is open to question. This is the idea of not giving the pilot quantitative, real physical information. The red light-green light idiot's delight may well prove the undoing of any advanced performance endeavor.

SURVIVAL

Two philosophies (a word used here to cover a lack of systematized factual information) are about at a standoff here. One approach devotes major attention to analysis of the occurrence and prevention of danger, and to airframe recoverability to restricted escapable regions in case danger does arise. The other approach devotes major attention to the "abandon ship immediately" idea. Of course, as in all black and white arguments, the gray area in the middle probably is the more defensible and probably more acceptable to a large number of pilots.

In the subject orbital vehicle, there are two serious doubts. First, that accidents requiring abandonment can occur at extreme or even moderate altitudes because of the absence of fire and explosion hazard and lack of structural loads, and, second, that the pilot is any better off in a life boat than he was in the original vehicle because if the latter has failed the former must be a better spaceship, and the question is raised that perhaps he should have taken the life boat in the first place. One opinion is that the basic uncompromised integrity of the basic uncompromised vehicle is the predominant source of safety and survival.

STABILITY AND CONTROL

As with all other airships, this beginner's spaceship will succeed or fail upon its stability and control characteristics during launching, exit, orbiting, re-entry, recovery, and landing. Of all of the problem areas, this one of stability and control of the craft and its internal mechanisms is the most difficult to solve. The pilot is vitally concerned with the inherent stability of all that he controls, but is directly and immediately concerned with his control situation. For control, he requires: (1) information based upon a plan, instruments, and ground reference monitoring; (2) decisions based upon a plan, a planned change in plan, alternative control capability, and analysis of known information; and (3) a control method which may be pilot-mechanical, electro-hydro-mechanical, or push-button-mechanical which includes the wide area of gross automaticity probably correctly termed pilot-push-button-electronic-electro-hydro-mechanical.

Practice and experience demand that all electrical, hydraulic, and pneumatic control functions of a primary nature require complete duality, with the associated priority and "fail-safe" characteristics, for reliability. Therefore, in an early effort such as proposed here, wherever reasonable, pilot-mechanical methods are highly attracitve. Thus, still following the original thesis, this then allows the pilot to assume the major role in closing the control loop and to retain control over his fate.

The degree of acceptability of the foregoing observations is subject to one very important operational concept. If the mission can be made reversible, that is, if the pilot can change his plans at any time and abort a planned mission and return to earth to try again, then much greater latitude is afforded.

The thing that appears to precipitate from all of this is that the pilot's problems are not those of capability, environment, or physiological stress, but as usual, are assessed to be in the area of system and subsystem reliability and control. Therefore, based upon the original thesis of an early virgin effort, one pilot would prefer a sound, severely objective design with which to establish the ground rules for the elaborate developments to follow.

Instrumentation for Space Flight

By Commander George W. Hoover, USN

The success or failure of flight into space, either manned or unmanned, will depend not only on the performance of the engine and the vehicle itself, but equally upon the instrumentation. The success of the instrumentation will only be assured, not by modifying present aircraft instrumentation, but rather by treating the problem as a

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completely new art. The general requirements for space instrumentation are that all components must be absolutely reliable, extremely simple and lightweight, completely automatic and, in the case of the manned vehicle, provide presentation capable of being interpreted with no possibility for error.

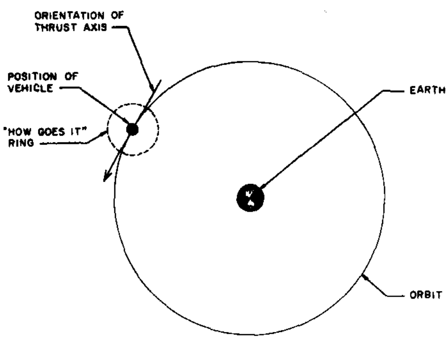

Fig. 1. Drawing showing how position of space ship might be displayed as part of the total situation.

Space instrumentation can be divided into two general categories: research instrumentation, and control "instrumentation." Both types will eventually be needed in all vehicles, whether manned or unmanned. Let us talk first about unmanned vehicles and then proceed to the manned ships.

The first satellites will of necessity primarily contain research instrumentation. Here the successful gathering of data is dependent upon the reliability of the information gathering sensors and the telemetering transmitters. Failure of any of these components will render the flight useless except for data which can be gained only from visual tracking. Because of the critical limits in weight, every ounce must be shaved off the instrumentation in order to obtain the maximum amount of experimental data.

As the satellite grows larger with the development of better rockets, more and more instruments can be employed but weight and reliability will still be at a premium because the need for remote guidance will become necessary, at least until the satellite has reached its orbit. Such data will permit the ground controller to make corrections due to errors in the total system and place the satellite into many different orbits.

It is conceivable that with the proper information being telemetered back to earth it will be possible to construct large observation satellites by placing the necessary components into the same orbit, one at a time, and then guide them by ground control to connect with each other, thus forming much more effective stations. In order to do this however, an integrated instrument display must be developed which will in a sense put the controller's eye into the nose of each component. Such a system will be the test bed and operational flight trainer for the more sophisticated manned vehicle. The unmanned observatories will not only give us an early space platform for observing the the earth and for gathering astronomical data, but will tell us what we will need in order to control and maneuver a manned space ship.

Although the space ship will be inherently automatic, the pilot being a human being must be made aware of the total situation at all times. It will be necessary to provide information concerning time, orientation, velocity, altitude, flight path, power, fuel management, and ship condition.

Time will be of extreme importance to the pilot and will include local time, for determining the boundary time limits between take-off and landing. Sidereal time will be necessary for determining the position of the orbit. Orbital time will be required to determine perigee and apogee, "how goes it" information, and for rendezvous in the orbit. Elapsed time will be necessary in order to calculate flight duration and fuel management.

One way of displaying orbital time might be to show "how goes it" information by a ring around the ship's position in order to show actual position relative to intended position (Fig. 1). The instrumentation required for orientation must include an answer to the question, "Which way is Up", and with respect to what? Orbiting the earth will require knowing a vertical radially from the earth, and azimuth as a function of the initial orbit. A change in axis orientation will be required to change the orbit.

Changes in thrust when tangential to the orbit will increase or decrease the radius of the orbit. However, any change in elevation will change the size and shape of the

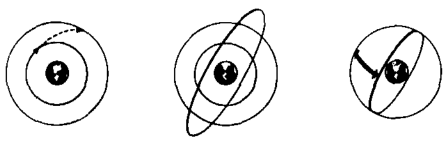

Fig. 2 Drawing showing the result of applying thrust in the space ship traveling in an orbit around the earth.

orbit, and any change in azimuth will cause a geographical change in the orbit. So it can be seen (Fig. 2) that accurate orientation of the thrust axis will be mandatory. In addition to orientation, the problem of position will be most important to the space pilot. A continuous check on orbital position and transition into and out of the orbit will be required. Maintaining position in the orbit will be relatively simple, requiring an application of thrust or negative thrust along with orientation of the thrust axis. Determining position during interplanetary operation, however, will be a much more complex problem because of shifting from orbit to orbit. Celestial fixes and inertial systems will probably provide data to the computers to solve the orbital technique required.

A great deal of effort has gone into research to determine the proper display for orientation as well as other data for ordinary aircraft. Final decisions have not been reached as to how this information will be displayed. The problem of velocity is really three-fold, namely: how to measure it, how to indicate it, and how to use it. A new method of measurement or perhaps several will be required when operating in space. Celestial references, ionization, Doppler, and inertial references are all possibilities. The displays will undoubtedly be a function of each mode of flight and will be shown as actual velocity relative to a desirable velocity. Numerical values may be used but more likely velocity will be shown as per cent orbital rate of ascent or descent, and reentry velocity. At any rate, all velocities will be shown relative to the earth, altitude, or orbit.

Altitude, measurements and display will be interesting but difficult to solve (Fig. 3)

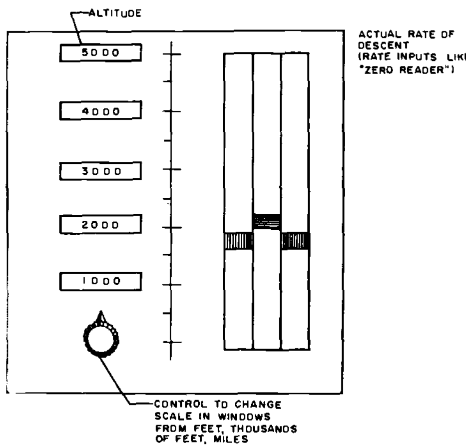

Fig. 3 Schema of instrumentation for displaying velocity of space ship.

The problem will consist of determining how to measure altitude, how to indicate it, and altitude with respect to what. Then ascending or descending the measurement will probably be in feet and thousands of feet. When orbiting, altitude will probably be measured in miles from the object about which the ship is orbiting. When actually shifting orbits, altitude will become distance and thus will resolve into a function of navigation in three dimensions.

Power and fuel management (Fig. 4) will be fairly simple to handle but will require positive indication because rate of fuel consumption will be critical. Fuel remaining and fuel flow will be necessary but the real requirements will be for fuel available taking into account all possible losses as well as fuel consumption. Power could be measured as thrust and indicated as per cent of power available.

Ship condition divides into several problems: temperature, pressurization, meteorite hits, radioactivity, and engine condition. Means must be provided to measure the skin temperature of the vehicle accurately both during the flight, where solar radiation or lack of same will be a problem, and during re-entry where the rise will occur from skin friction. In addition, a temperature rise due to impact of solid particles

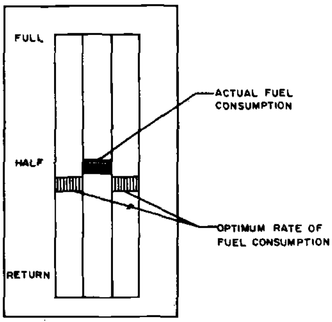

Fig. 4. Schema of instrumentation for displaying fuel management data of space ship.

in space will complicate the problem.

Pressurization will be constantly under surveillance and will require, not only indications of the condition of each compartment, but an automatic damage control. Some type of trend indication will be a must in order to permit the occupants either to vacate the damaged area or don a space suit. Radioactivity of the ship will have to be indicated because it appears certain that the vehicle will be under constant bombardment of cosmic rays and other forms of radiation. In the unmanned satellites, instrumentation for this problem will be a research tool but in the manned ship they will definitely be required for control.

Meteorite hits will be a part of the temperature problem as well as of those related to pressurization and damage control. Engine conditions will need instrumentation to keep a constant check on the operation of the power source and will require displays not only of the condition but command displays to indicate the action required to prevent damage or loss of power source.

The development of instrumentation for space ships must be considered just as important as the engine, the control, and the ship itself. All space flights will be instrument flights, and the success of these flights will be directly proportional to the ability of the crew to read and interpret the necessary information. An interesting observation about space flight is that in an airplane a pilot is always worried to a degree about spinning in. In the space ship he'll be more worried about "spinning out."

Some Survival Aspects of Space Travel

By Alfred M. Mayo

In a space craft as in aircraft the overall objectives must command first attention. Survival problems resulting from space environment will be so severe however, that a larger percentage of total space craft design time is likely to be spent in their solution than in airborne craft. Aside from short flights around the moon or nearby space excursions, it seems likely that the trips even to planets in our own solar system would involve a substantial period of time. A trip around the sun in fact has been a commonly proposed method of reaching the sister planets in our own solar system.

The design of crew compartments will be dictated by the requirements of human operators not significantly different in basic physical and mental capabilities from those of the pilots of present aircraft. The need for information to be gathered from very great distance to provide time for a human crew member to think and act is emphasized in Figure 1. It is evident from the distance involved that survival will depend increasingly on the reliability and accuracy of high speed automatic control systems. Automatic controls will be needed as greatly for actuation of safety equipment and

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environmental control of the crew quarters as in control of the craft and its propulsion and power systems. A major problem will be that of suitably linking the human operator to his "automatic" systems. As in every man-machine system decision making control must be retained for the human brain. An intermediate computer can undoubtedly be used to link sensed information to both "automatic" systems and display for the operator.

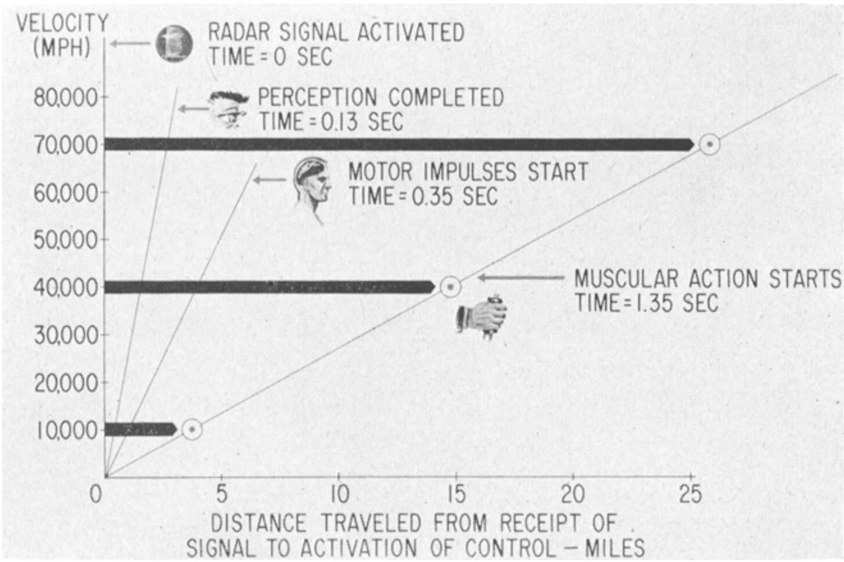

Fig. 1. Relation of speed of space ship to time required for pilot response.

Hermetically sealed crew quarters to provide a livable earth environment in space will be a prime survival requirement. The time of flight will tend to be sufficiently great that total regenerative air, water and food cycles are likely to be the only practical answer to this survival problem. Suitable control of air pressure and composition might be approached by a combination of stored materials possibly in a solid chemical state together with a system which can reconvert water and other excreted body gases to their original state. The immediate possibility of utilizing sunlight and the action of chlorophyll in green plant life has occurred to many people. Another, in which more precise control and less uncertainty with respect to health problems of living algae or other plants, might grow out of intensified research in the area of synthetic photosynthesis. The need to provide reliable automatic controls with suitable standby systems can hardly be overemphasized.

The reconversion of liquid and food waste products to useful nutrients that are psychologically satisfactory might also be approached by the use of secondary living organisms in the same manner as in nature. The desire for a system subject to more positive control and greater overall reliability might well dictate the expenditure of great effort to provide a regenerative chemical cycle not dependent on the art of keeping biological specimens healthy, happy and productive.

The evident need to protect against loss of vital materials through a leak or from structural damage will undoubtedly dictate the considerations of extensive compartmentation and automatically controlled air locks as a means of isolating damaged compartments. Pressure-suited emergency crew members may be able to make repairs and return damaged compartments to use, after a minimum loss of vital gases. The need for such compartmentation and repair facilities might be emphasized by considerations of the possible effects of meteor showers.

Newer estimates indicate an increase over past data in the probable numbers of meteor particles of potentially dangerous size. In addition to compartmentation, it is also likely that added emphasis in the design of the structure and skin will be needed to provide penetration resistance to meteors of a larger size than previously considered statistically important. The large amount of kinetic energy per unit mass of meteor particles indicates that an explosive type of impact with a surface is likely. Accordingly Whipple has suggested a relatively thin outer or buffer skin to effect that explosion. The smaller particles could then be absorbed by a larger mass of primary material. Self-sealing substances on the inner skin surface might also help to reduce the importance of the smaller penetrating meteors. A rapidly applicable mechanical seal might also be needed to seal larger holes quickly.

Temperature control will undoubtedly require specialized attention. For free space flight it is likely that large heat radiating surfaces will be needed. Waste heat from powered equipment could be transferred to these surfaces by an intermediate fluid. The resulting radiant refrigeration system would then be roughly comparable in intermediate stages to some present low temperature refrigeration systems. Similar surfaces could be used to collect solar heat and by reverse cycle operation provide energy to the chemical and mechanized systems during periods when large amounts of power are not being dissipated within the craft. The orientation of the radiation surfaces with respect to the sun would determine whether they added or removed heat from the system. For free space travel there is then a rather direct though complex engineering approach to the problem of temperature control. During re-entry in a craft not utilizing retro-thrust or contained fuel to dissipate its high kinetic and potential energy, much aerodynamic and thermodynamic study will be needed. The craft would need to operate long enough in the thin outer boundaries of the atmosphere with a high enough surface temperature to allow these very large amounts of energy to be dissipated entirely by radiation and molecular rebound.

A substantial amount of data with respect to human tolerance to acceleration as a function of time and acceleration (Fig. 2) and an increasing understanding of the effects of rate of change of acceleration on the human body are available. It should then be possible to configure a space craft so that the accelerations encountered under controlled take off conditions need not be a serious survival problem.

The relative lack of knowledge as to the exact psychologic and resulting physiologic problems of the gravity free or weightless state of free space flight probably should not cause excessive concern. The engineer should be able to provide nearly any specified value of artificial weight by rotating the craft about its own center of gravity. The configuration of course would need to be such that the resulting cabin spaces would be oriented in a usable direction with respect to such rotation. Considerable inconveniences might be expected if the normal ceiling of the compartment were to be oriented such that it were usable only as a floor.

The problems of surviving the effects of a wide variety of solar and cosmic radiation are still not thoroughly defined. Physicists and biologists are confident that shielding against the lower energy solar radiations will not be too difficult. No practical approach utilizing a reasonable weight of shielding or deflecting material has yet been advanced to protect against the effects of very high energy cosmic particles. With the ionizing paths of such particles still increasing after penetrating a foot of solid lead, mass shielding does not appear practical.

Proposed methods of generating a sufficiently extensive and powerful electromagnetic force field indicate an even less promising approach. Practical methods of utilizing the reduced secondary emission effect of low atomic weight materials in shielding still remain to be advanced. This avenue may prove interesting. The inherent capability of a complex biological organism to tolerate and/or repair damage along the paths of penetration of individual cosmic particles on a statistical basis appears to be the only present practical reason for hope. Available physical and biological data are not extensive enough for categoric statements that tolerance to the cosmic radiations, existing in space is practical for extended times. On the other hand, competent physicists and biologists are showing considerable optimism on the basis of the data available.

Careful consideration must be given to a proper balance of the fundamental moral, morale and economic factors to provide escape equipment justifiably on the basis of the total purpose of the craft involved. Certain of the space craft escape requirements are merely extensions of those which need to be met in aircraft. Others are unique and a function of space itself. In order to outline some of the problems involved, it might be well to consider three phases of space flight. These are: (1) Take-off through an atmosphere and against gravity; (2) free space flight; and (3) landing involving re-entry through an atmosphere.

During the initial part of the take-off phase, failure of the control system or a major power plant malfunction could impose escape requirements not too radically different from those of a high performance aircraft. The requirement to separate cleanly a suitably stabilized section and to provide controlled deceleration to solve the primary G time tolerance of the crew would not materially differ from that of a very high performance aircraft. A separate crew section of high structural and environmental integrity might also aid in the solution of problems pertaining to fire, power plant malfunction and structural failure during the take-off phase. Such a device if properly isolated might even be useful in certain types of explosions where the build-up of pressure might be slow and the initial violence limited. A number of different types of acceleration control devices varying from a winged escape vehicle to parachute decelerated systems or combinations of both suggest possible solutions to this portion of the problem.

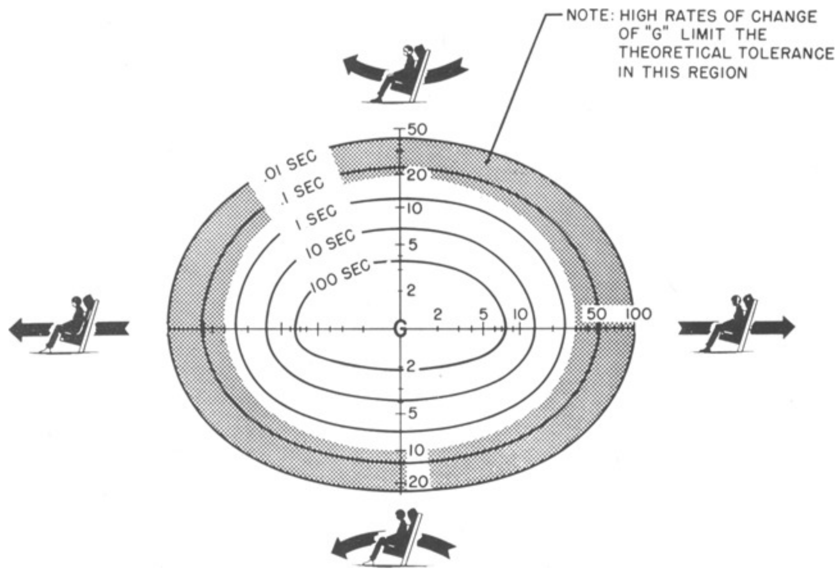

Fig. 2. Human tolerance to acceleration as a function of time and acceleration.

As the craft moves into free space and power is no longer needed to maintain velocity, a new set of problems and requirements present themselves. Many of these problems are concerned with providing an adequate human environment and are just as real a safety consideration during normal flight as in a properly configured escape section. Since both the mother craft and any escape device will continue to travel indefinitely at constant velocity in space, it is evident that the average time for rescue after separation must be assumed to be relatively large. Additionally the problem of sending distress and rescue messages, and that of providing directions to rescue forces would not only be of paramount importance, but in all probability will present a problem not easily solved. The basic unfriendliness of the free space environment coupled with the probable substantial times of waiting for rescue dictate the need for adequate air, water and food provisions. These problems in themselves might well determine a minimum practical size for the free space escape vehicle. The case of a crew successfully separating itself from a dangerously damaged mother craft only to be lost in space to starve or die from exhaustion of environmental control facilities would be a not unlikely situation if very careful consideration is not given to the need for adequate emergency communication, locating and rescue procedures.

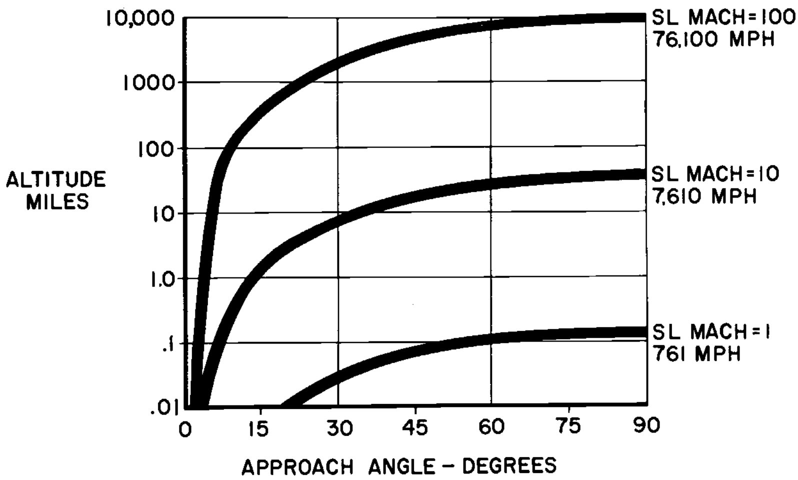

Fig. 3. Tolerable deceleration distance vs. approach angle.

During the re-entry and landing phases of flight, the hazards of possible instability and induced accelerations from air drag would be added to the environmental problem. Additionally if it were necessary to re-enter an atmosphere without retro-thrust equipment, the escape craft must have suitable aerodynamic and heat resisting characteristics. Both the extreme kinetic energy of high velocity and the high potential energy of gravitational attraction must be dissipated as radiant heat or molecular rebound. This presents a problem of allowing a very high surface temperature for a relatively prolonged period of time. It further requires an aerodynamic and drag configuration capable of precisely controlling a craft within the fringes of a relatively thin atmosphere until sufficient slow down is effected and energy dissipated. The deceleration problem is further emphasized by Figure 3 which shows minimum distances versus speed and angles that are required for survival as a function of available deceleration and time data. For example if a man were traveling at Mach 1 in a 90° sea level dive, his physical tolerance to acceleration for the required time would make it necessary to utilize approximately .12 miles of distance to slow him down without killing him. Similarly if he were travelling toward the earth at Mach 100, or approximately 76,000 miles per hour, a distance of the order of magnitude of 10,000 miles would be required to slow him down within his acceleration tolerance limit.

In order to achieve satisfactory performance and economic compromise without sacrificing the escape potential, it appears evident that major use must be made of portions of normal crew stations in order that excessive penalty to the overall craft will not make impractical the provisions of escape capability. The requirements for extended times of survival coupled with the temperature aerodynamic and acceleration problems of re-entry indicate that the size of any useful separable portion of a large space craft would need to be sufficiently large to store the provisions necessary for survival.

Many difficult problems in nearly every branch of science remain to be solved if a reasonable survival potential is to be generated for man in space flight. The boundless curiosity of men of science has already provided paths toward the solution to some of these problems and new data are being gathered and organized to provide solution to others. So much remains to be done that much time will be required unless a substantial increase in the amount of effort is provided.

The Vanguard Project

By John P. Hagen, Ph.D.

The earth satellite program, while designed as a scientific experiment in the International Geophysical Year, may serve also as man's first venture into space travel. As you now know, space vehicles will travel in orbits about the earth, moon, a planet or the sun. The least difficult of these to effect is the trip around the earth, or the earth satellite. I say the least difficult because even this first step is not easy with present day techniques. Let me first describe the Vanguard launching vehicle, its trajectory and the planned orbit for the earth satellite program.

The first consideration in choosing limits placed upon the orbit is that of atmospheric drag. Even in the sparse outer regions of our atmosphere the low density gases will remove energy from the rapidly moving satellite, causing the orbit eventually to collapse. Since the density increases exponentially as height decreases, the rate of losing energy increases and hence the rate of decay of the orbit. Based on our rocket-gained knowledge of the atmosphere, it is felt that if a 21.5 pounds, 20-inch sphere in a satellite orbit approaches closer than 300 miles to the earth's surface, the lifetime may be

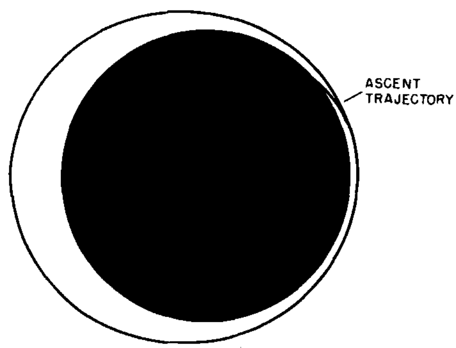

Fig. 1. Plan view of orbit with 200 mile perigee and 1400 mile apogee.

less than two weeks. At the other extreme it is desired to have the satellite get no further away than about 1500 miles. The actual orbit (Fig. 1) will be an ellipse with the earth's center at one focus. The launching will be so designed that if successful the closest approach of the satellite will be 200 miles and the greatest separation 1500 miles. To put a satellite in such an orbit re-

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quires a launching vehicle that can lift it against the gravitational attraction of the earth some 300 miles, and then accelerate it to a velocity of about 25,000 feet per second, or 4.6 miles per second. At the same time the controls of attitude of the rocket must be precise so that the launching will be nearly parallel to the earth.

All this requires a finely designed vehicle and, with present day fuels, one with three stages (Fig. 2). The Vanguard launching vehicle is being constructed for the Navy under prime contract with the Martin Company. It is 72 feet long, four feet in diameter at its base and weighs 22,000 pounds. The first-stage, far the largest of the three, is powered by a General Electric engine having a thrust of 27,000 pounds. The engine is on gimbals and it is by engine deflection that the rocket is steered in its course. The second-stage, made by Aerojet General Corporation, is initially attached to the nose of the first, and also is powered by a gimballed rocket-motor burning liquid propellants. Buried in the nose of the second-stage and protected by a disposable nose cone is the third-stage. This is the smallest of the three and burns a solid propellant. Mounted on the nose of the third-stage is the satellite pay load. After the end

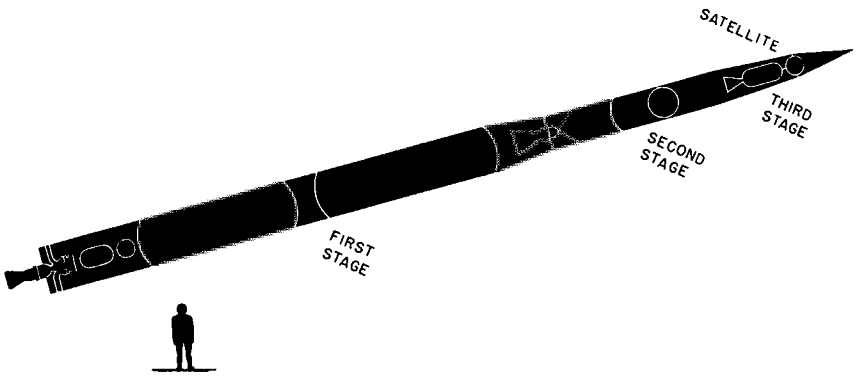

Fig. 2. Schema of the Vanguard launching vehicle.

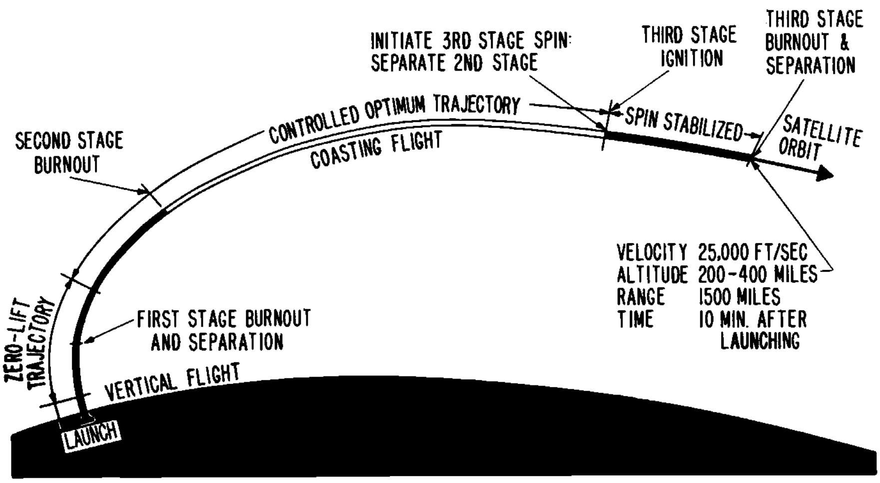

Fig. 3. Planned trajectory of the Vanguard launching vehicle.

of burning of the last stage the satellite will be separated from the empty casing.

The rocket will be launched at the Air Force Missile Test Center in Florida. The azimuth of launch will be somewhat south of east so that the plane of the orbit will be inclined to the equator some 35°. The planned trajectory is shown in Figure 3. After ignition of the first-stage motor the rocket will rise vertically and then be programmed over toward the south east. As it rises through the atmosphere it will tilt more and more toward the horizontal. After first-stage burnout, the empty casing of the first-stage will be discarded and the second-stage ignited. After second-stage burnout the velocity will be up to 50 per cent of final velocity and the second-third-stage combination, having discarded the nose cone, will coast for several minutes. During the coasting period the rocket will gain altitude to 300 miles when it is about 900 miles out from the launching point. The complete guidance mechanism is in the second-stage and during this period it will control the attitude of the second-stage and point it in a direction parallel to the surface of the earth so that when the third-stage is spun up and ignited it will "shoot" out of the second-stage casing much like a shell out of a rifle. At the end of third-stage burning, if all works well, the third-stage casing and the satellite will have a velocity somewhat in excess of 4.6 miles per second. If this occurs and the direction is proper, the satellite will be in a stable orbit and space flight will have been achieved.

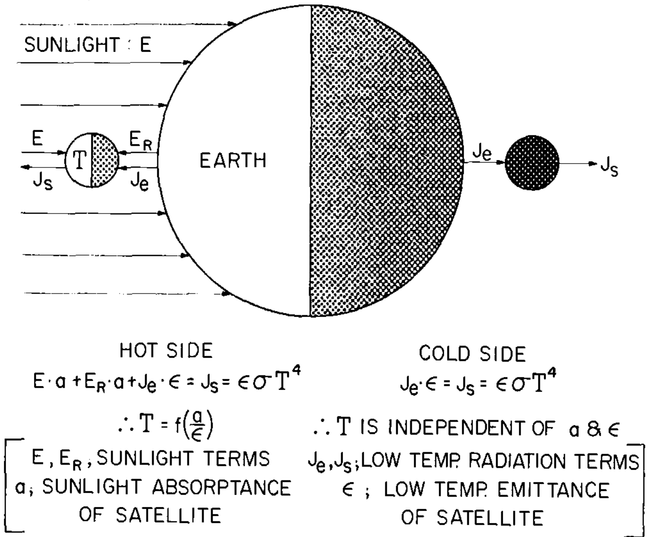

Fig. 4. Diagram showing the flow of heat in and out of the satellite.

One of the early experiments to be carried out in the earth satellite is designed to measure the environmental factors in the satellite itself and in the space through which the satellite moves. It is the results of these measurements which can aid in the design of future space vehicles. Once the vehicle is beyond the protective atmosphere of the earth it will be exposed to high energy radiation and to collisions with meteoric particles from which we are normally protected by absorption in the atmosphere. The vehicle for long periods, will be in full sun-absorbing heat. The only means for keeping temperatures in the vehicle within bounds is to control the infrared emission of the outer surface because the vehicle can lose heat only through radiation.

The environmental experiments include thermistors attached to the shell and to the inner structure to measure the temperature at these points, thus determining (1) the distribution of heat within the satellite, (2) the effectiveness of the measures taken to insulate the electronics, and (3) the effectiveness of the surface coatings in radiating away heat. The flow of heat in and out of the satellite is shown in Figure 4. Here it is clear that the controlling factor in the temperature of the satellite will be infrared emission. In recognition of this, the surface of the satellite will be highly polished aluminum coated with silicon monoxide (SiO). This material (Fig. 5) has the property of being transparent in the visible and opaque in the infrared, thus permitting control of the infrared emissivity through control of the coating.

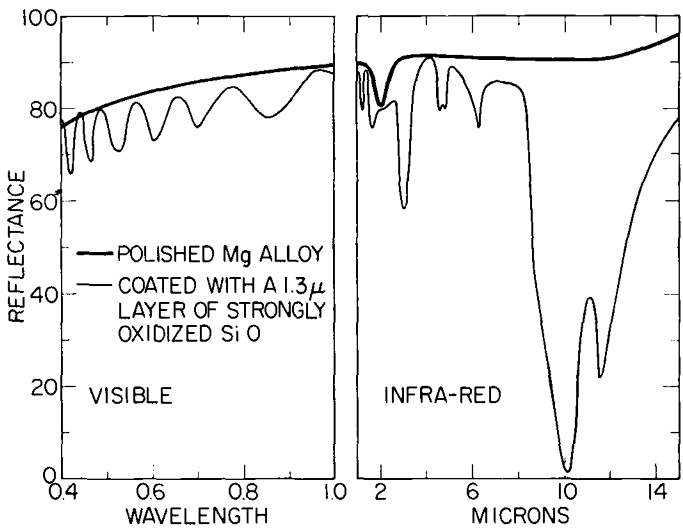

Fig. 5. Reflectance of coating material as a function of wave length.

Another environmental experiment is that of measuring the rate of erosion of exposed surface. The vehicle will be moving at a high velocity of 4.6 miles per second, and will have numerous collisions with meteoric material, much of it finely divided particles. The surface will also be bombarded by ionized molecules of the atmosphere. Both of these actions can cause erosion. A thin metallic coating on a glass plate will be used to measure this effect through the change in resistance of the strip as it wears away. Another way to detect collisions with micrometeorites is being used. Small, sensitive microphones are attached to the inner surface of the shell and will record the "ping" as each particle strikes the surface. For the more rare occasions when a larger particle is encountered and penetration of the skin may occur, pressure zones are attached to the skin and can register the occasion where they are first punctured. Optical and radar measurements of meteors are not sufficiently sensitive to detect the smaller particles which yet may have sufficient energy to puncture the satellite skin. Extrapolation from counts of the larger particles show that the 20-inch satellite has a probability of puncture of once every couple of weeks.

The scientific experiment to be carried in the first satellite attempt will measure the intensity of solar ultraviolet in the region of Lyman. Knowledge of this intensity has great significance for our interpretation of the nature of our outer atmosphere. It will also be of importance to future space flight because the solar ultraviolet will be the most intense high energy radiation to which material will be subjected in space.

The most penetrating of all radiation that will be encountered will be that of the primary cosmic rays. There is a scientific experiment, designed by the State University of Iowa, planned for an early satellite attempt to measure cosmic ray intensity. The primary cosmic rays contain a small percentage of the heavier nuclei. These particles due to their greater mass are much more capable of producing ionization and hence can be more damaging to the human body. Project Vanguard can contribute to future space flight by taking the first step in placing a vehicle in space and by determining the ambient conditions in which a space vehicle must operate.

The Possibilities of an Inhabitable Extraterrestrial Environment Reachable from the Earth

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

The problem of life on other worlds is a subject which captivates the imagination of mankind tremendously. Not until it was recognized by Copernicus in 1543 that the earth is not the center of the universe but rather only one of the members of the planetary family of the solar system, could such thoughts arise in the human mind. There are two technical events that have had a catalytic effect upon man's occupation with this question: the invention of the telescope some 350 years ago, which has brought the celestial bodies closer to us optically, and recently, the successful development of the rocket which possesses the potentialities of bringing us closer to them physically. Not only has the older question of the existence of indigenous life on other planets come anew into the focus of scientific and general public interest, but in addition, with the development of space operations, this question is posed: Are there planets in the solar system that offer an environment of such kind that an astronaut from the earth—the species homo sapiens terrestris—could land there and stay there for some time at least?

We get an answer to both of these points very quickly by projecting the specifications of the environment required, from the standpoint of human physiology and of general terrestrial biology, against the physical planetary data offered in the astronomical literature.

Such a study can be called planetary ecology. For the science which particularly studies the possibility of indigenous life on the planets the terms "astrobiology" and "astrobotany" are in use. With regard to this latter problem this discussion will consider only the kind of life known to us, based on carbon as the structure atom and on oxygen as the energy liberation atom.

Table I shows a list of certain ecological factors indispensable for the existence of life such as: the presence of an atmosphere and a hydrosphere, or *water* in its liquid state, a biologically suitable temperature, carbon dioxide which is, in addition to water, the raw material for photosynthesis in green vegetation, and finally, oxygen, the key element in the biological energy liberation. The table further shows, by use of the marks + and — whether or not these ecological factors are found on the planets of our solar system. By screening the planets in this way, only Mars and Venus remain as bioplanets or conceivable bioplanets. And these planets are found in neighboring orbits near the sun only. The decisive factor responsible for this zonation of the planets with life-favoring conditions is the intensity of solar radiation

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which decreases with the inverse square of the distance from the sun. The difference in the radiation intensities to which the planets are exposed, and have been exposed since their protoplanetary stage, are therefore tremendous.

TABLE I. THE PLANETS AND SOME OF THE ECOLOGICAL NECESSITIES FOR LIFE

Planets	Atmosphere	Hydrosphere	Bio-Temperature	Carbon Dioxide	Oxygen
Mercury	–	–	–	–	–
Venus	+	(+)	+	+	(+)
Earth	+	+	+	+	+
Mars	+	(+)	+	+	(+)
Jupiter	+	(–)	–	–	–
Saturn	+	(–)	–	–	–
Uranus	+	(–)	–	–	–
Neptune	+	(–)	–	–	–
Pluto	+	(–)	–	–	–

+ present, (+) probably present in small amounts.
– not present, (–) present in frozen state.

We get a dramatic picture of this by considering the size of the sun as seen at the distances of the various planetary orbits (Fig. 1). To an observer on Mercury the diameter of the solar disk would appear more than twice the size it does to us on earth. As seen from Mars, the sun would have 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 no larger than the evening star Venus appears to us on earth. This means that in the more remote portions of our planetary system, the role of the sun, as dominating source of light and heat energy, fades into that of a common star. If there were people on Pluto, these Plutonians would not even know the concept of a sun. This consideration makes it quite clear why life-supporting planets are conceivable only in a certain zone within the planetary system.

More in detail, the visible section of the solar radiation spectrum presents a narrow zone of physiologically desirable planetary illumination, a kind of "euphotic belt" surrounded by dysphotic (hyperphotic and hypophotic) regions. With this we have added a new ecological factor not mentioned in Table I, namely, light. The infrared portion of solar radiation, as the main carrier of heat energy, is apparently effective in providing biologically acceptable temperatures on planets only in the range from Venus to Mars, which justifies our speaking of a "biotemperature belt" in the planetary system. The occurrence of water in this same zone represents a kind of "liquid water belt" in the planetary system.[5]

Finally a zonal distribution is evidenced in the chemical composition of the planetary atmospheres. On the inner planets we find atmospheres containing oxygen, and such oxygen compound as carbon dioxoide, while the atmospheres of the outer planets contain hydrogen and such hydrogen compounds as methane and ammonia. Originally about two and one-half billion years ago, the atmospheres of all the planets were basically hydrogen and reduced atmospheres. This protoatmospheric composition dominated by hydrogen has been transformed in the course of many millions of years into one of oxygen and oxidized compounds by the effect of ultraviolet of solar radiation, but only on the planets relatively near the sun, namely on Venus, earth and Mars. These planets, therefore, form a kind of atmospheric "oxygen belt" in the planetary system. The atmospheres of the outer planets, moving beyond the effective reach of ultraviolet solar radiation, are still protoatmospheres preserved in a frozen state. They form a "hydrogen belt" of the primordial brand in the planetary system. But Jupiter, nearest to the sun in this outer belt, shows some indication of photo-chemical reactions in the upper atmospheric regions, manifested in green and reddish colorations, which have recently been interpreted by Rice[4] as caused by free radicals of methane and ammonia in a frozen state.

In summary, this general ecological consideration leads us to the assumption of specific life favoring ecological belts in the planetary system such as an euphotic belt, biotemperature belt, liquid water belt, and oxygen belt. Because all of these belts are found in about the same region, they are therefore parts of a "general life zone" which we might call "ecosphere" in the solar planetary system and which is confined to the orbital range from Venus to Mars. (Fig. 2) This is the zone on the planets in which the kind of life now predominant on earth is conceivable. On the planets in the hydrogen belt, micro-organisms such as hydrogen-, ammonia-, methane-, and iron-bacteria, are conceivable; these are the kind which probably populated the earth during its protoplanet stage some two billion years ago and which we still find today in the pores of the soil and other poorly aerated spaces. However, the low temperature on the outer, so to speak, permafrost planets excludes the possibility of life in the hydrogen belt. The sun's radiation in this region apparently has not been sufficiently effective to change the atmospheric environment on these planets into a biologic climate.

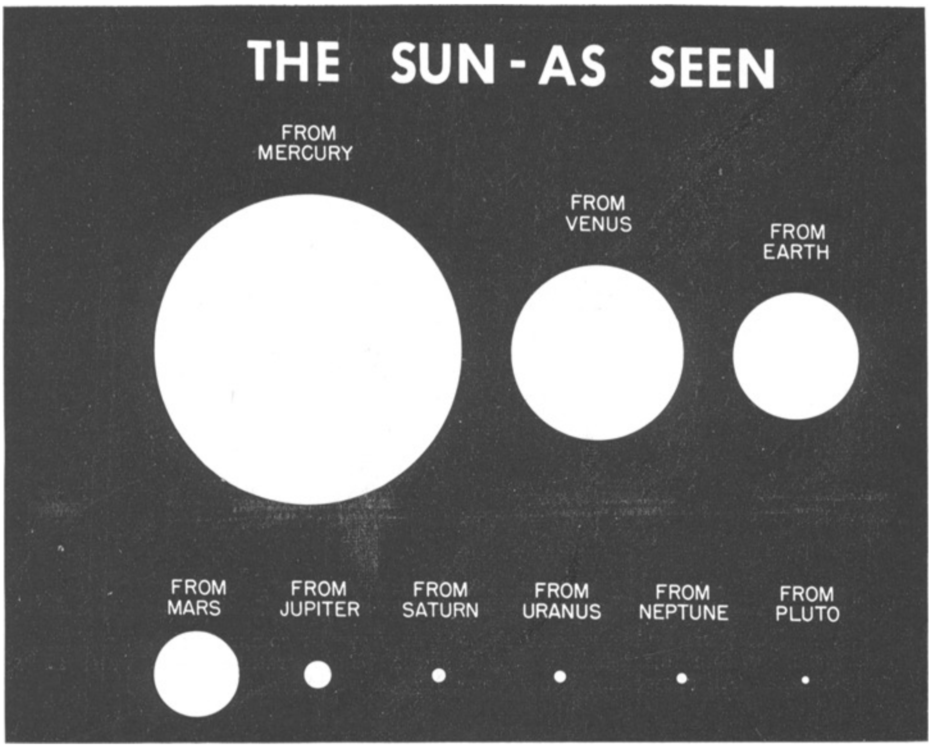

Fig. 1. Size of the sun as seen from the orbital distances of the various planets.

For all of these reasons, it would be ecologically impracticable to extend space operations beyond the well irradiated ecosphere to the outer planets with their hydrogen, methane and ammonia saturated atmospheres, and their arctic temperatures and surrounding midnight sun light conditions. But even the two ecologically acceptable planets, Venus and Mars, pose considerable medical problems. Because of lack of time, I will omit a discussion of Venus, whose surface features are wrapped in mystery by dense clouds of carbon dioxide, and shall concentrate upon Mars. Of primary interest to the astronaut will be the question of the kind of atmospheric environment he would find there from the standpoint of human physiology, especially what protective measures he would have to take concerning respiration.

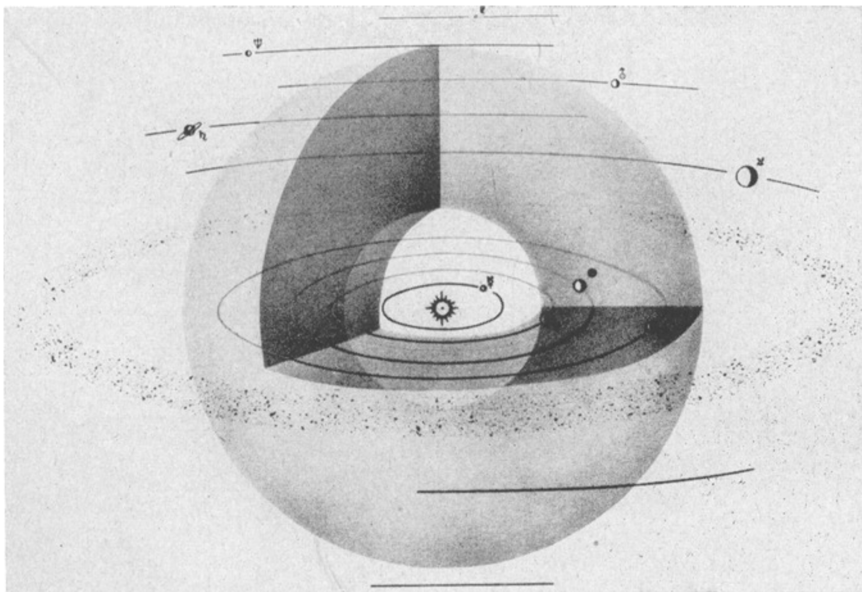

Fig. 2. Ecosphere or life zone of the planetary system comprising Venus, Earth, and Mars. Within this sphere lie the euphotic, biotemperature, liquid water and oxygen belts. All are essential to support life as we know it.

Atmospheric entry will pose fewer aerodynamic, aerothermodynamic and pertinent physiological difficulties than are encountered in the terrestrial atmosphere because of the lower air density. The most likely chemical composition according to de Vaucouleurs[7] is as follows: 98.5 per cent nitrogen, 1.20 per cent argon, 0.25 per cent carbon dioxide, and oxygen $<$ 0.12 volume per cent. The barometric pressure at ground level (there is, by the way no sea level on Mars because of the absence of open bodies of water) is about 70 mm. Hg. or 95 millibar. This pressure corresponds to an altitude of 55,000 feet in our atmosphere (Fig. 3). Barometrically, this altitude is the Mars equivalent level in our atmosphere. The oxygen pressure at ground level is probably lower than it is in our stratosphere.

Pilots flying at altitudes above 55,000 feet must wear pressure suits. The same would be required for an astronaut on Mars when he leaves the sealed compartment of his space ship. However, an air pressure of 70 mm. Hg. lies just within the critical border range in which a pressure suit, or simple oxygen equipment with pressure breathing, are a matter of dispute. Oxygen equipment with pressure breathing may be sufficient for shorter periods of time. Balke,[9] after spending six weeks at a height of 14,800 feet at Morococca, Peru, for acclimitization purposes, was able to withstand an altitude of 58,000 feet in a low pressure chamber for three minutes with pressure breathing only. A certain altitude adaptation of the astronaut can be expected if the air pressure in the sealed cabin is kept at a pressure of half an atmosphere during the trip. Be that as it may, a terrestrial explorer on Mars, wearing a pressure suit or pressure breathing device must always retreat, after an hour or hours depending on the efficiency of the equipment, into the more convenient sealed compartment of the ship, which should have its landing place in the lowlands because, with regard to the respiration equipment, every milimeter of Mercury of air pressure counts. Such a depressed area, for instance, is the Trivium Charontis, a dark greenish patch several thousand feet below the level of the surrounding desert.

In the event of a leak in the sealed compartment or in the pressure suit, the astronaut would encounter the same rapid decompression effects including anoxia and aeroembolism as the pilots do in our atmospheric region at about 50,000 to 55,000 feet. He would not, however, be endangered by "ebullism" a new term[8] for the so-called "boiling" of body fluids. This effect becomes manifest on Mars at an altitude of 13,000 feet which corresponds to 63,000 feet in our atmosphere. These are the essential points which must be considered in insuring physiological air and oxygen pressure for an astronaut. A factor which might facilitate the oxygen requirement and the mobility of the astronaut is the relatively low gravity on Mars, which is 38 per cent of that on earth.

The temperature in summer during the day in the equatorial regions may reach 25°C. After sundown when the temperature drops very quickly to —45°C., the space cabin must provide adequate protection. Harmful effects from solar ultraviolet rays can be disregarded. Even if they were not sufficiently filtered out by the martian atmosphere, the skin of the astronaut is always protected from sunburn by the respiratory equipment or by the cabin. Health hazards from primary cosmic rays are probably not to be expected because of the atmosphere's absorbing power. The same certainly would be true concerning meteorites.

The intensity of day light on Mars is lower than on earth but still in physiologically desirable limits. The color of the sky is probably whitish blue[2] due to scattering of light by the various hazy cloud layers. It might be that under this umbrella

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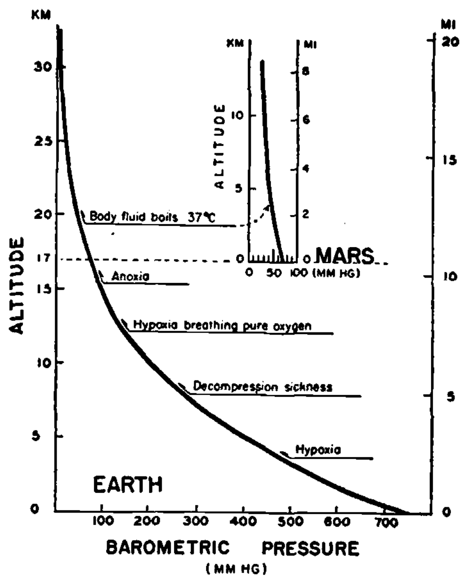

Fig. 3. Mars equivalent altitudes within the earth atmosphere. The altitudes and air pressures of the martian atmosphere are projected onto those of the earth. The curve shows points at which certain physiologic effects of decreasing air pressure are observed.

of whitish haze the sun would be invisible. Finally, an adaptation of the astronaut to a different day-night cycle is not necessary because the day-night cycle on Mars is only thirty-four minutes longer than that on earth. Such are the climatic environmental conditions that a terrestrial explorer probably will find on Mars from the standpoint of human physiology or, in other words, with regard to himself. A strange "second earth"!

Of particular interest for a terrestrial explorer on Mars will be the question: Does indigenous life exist on the planet itself? With this we touch upon the much discussed dark green areas in the equatorial regions which show seasonal color changes and therefore have been interpreted as vegetation. Will the astronaut find that this is correct or will he find instead volcanic ash[3] or some hygroscopic inorganic material?[1] Recent spectroscopic studies seem to support the martian vegetation theory. The physical conditions are extremely severe with the exception of sufficient amounts of carbon dioxide and light. Such conditions, especially the extreme day-night temperature variations, according to terrestrial standards could support only very hardy and cold resistant plants. We must, however, consider not only the climate as a whole but also the so-called microclimate near, on, and below the ground influenced by surface and sub-surface features, snow coverings, hollows, and caves which usually moderate the extremes of the macroclimate. Then there 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 specific structures and properties of the plants for storing water, carbon dioxide and photo-synthetically produced oxygen. Such phenomena are well known in terrestrial biology. Strong absorbing power of the plant surfaces are infrared and reflecting power for blue could be imagined as a means for temperature control and protection against ultraviolet, respectively, if the latter is necessary. The pronounced bluish tint of the green areas on Mars might offer a hint in this respect. Protection against frost might be possible if the martian plants were able to develop some kind of antifreeze such as glycerol. We know that even terrestrial animal cells can survive temperatures as low as —70°C. when placed in glycerol solutions.

The opinion has been expressed by Tikhoff[6] that a terrestrial climate which comes nearest to that on Mars with regard to temperature, radiation and humidity is that found on the Pamir plateau, a high mountain desert in Central West Asia, or that on the high plateau of Tibet. As previously mentioned, the air pressure conditions on Mars correspond to those in the lower region of our own stratosphere. So if we combine the microclimate of the Pamir plateau or Tibet with the macro-climatic air pressure milieu of the lower stratosphere, we have an approximation of the environment on Mars. It is more severe than on the Pamir plateau but friendlier to life than our stratosphere because of its higher temperature during the day.

Such is the picture that can presently be drawn of an extraterrestrial environment most probably reachable from the earth. Whether or not this earthly conception corresponds to the martian reality, is a question that will probably remain open until a successful space operation to the green and red planet has been achieved. Until then, it will remain a common meeting place for discussion for astronomers, biologists, botanists and physiologists—in fact, for everybody.

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