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Document II-4

Document title: R.M. Salter, "Engineering Techniques in Relation to Human Travel at Upper Altitudes," *Physics and Medicine of the Upper Atmosphere: A Study of the Aeropause* (Albuquerque: University of New Mexico Press, 1952), pp. 480-487.

Few scientists and engineers outside of the narrow field of rocketry took human space travel seriously until the mid- to late 1950s. Many felt that it was little more than science fiction fantasy unworthy of serious study; they frowned upon their peers who devoted time and effort to such a frivolous topic. Robert Salter's article was most likely the first serious treatment in American academic and engineering circles of the problems of human spaceflight.

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Introduction

The subject now under consideration is the current and predicted status of engineering techniques related to the travel of man in the upper atmosphere. In other words, we are to discuss the "how" and "when" of manned space flight. The "why" of human participation in such a venture should also be examined since it is not immediately obvious that we cannot always substitute electronic equipment in place of a pilot.

In order to correlate properly the various data available it is necessary to distinguish between physical limitations, those imposed by actual physical laws (or absolute limits), and purely engineering constraints. Quite often an operation is said to be impractical when actually it is only infeasible on the basis of current engineering techniques. On the other hand, physical considerations usually furnish a clear-cut indication that the particular problem in question either can or cannot be solved. This is not a completely rigorous limitation, since some phases of physics, notably nuclear physics, are currently in a rather fluid state so that our ideas may change in the future.

Thus on the basis of the laws of motion, etc., as we now know them, the various allowable regimes of operation in the aeropause can be enumerated. It can be said that, without the employment of a rather unique release of nuclear energy, certain modes and areas of space travel must be excluded. For example, long-duration flights at 50 mi altitude would be excluded. On the other hand, it now appears that a large portion of space travel of interest can be accomplished with present-day types of propulsion and energy sources! The day for successful interplanetary travel awaits only the decision of man to provide the [481] prodigious and concerted effort required. It might be mentioned in passing that nuclear fuels are not necessary to such an operation and that the basic techniques required have been known for centuries. It is pertinent to note, for instance, that a two-stage rocket was successfully tried in 1855—nearly a hundred years ago.

Regimes of Flight in the Aeropause

Some of the first questions to be answered are, "how high," "how fast," and "how long" can flight be sustained in the upper atmosphere? Emphasis must be given the last item if a pilot is carried in the vehicle. Obviously, other than for the purposes of physiological experimentation or establishing a record, one would not conceive of a manned sounding rocket. Here, there is not time or need to supplant electronic equipment for making observations. However, in cases where flight duration is of sufficient length that electronic reliability is a problem, where computer operations (such as having adequate "memory" included) are too complex, and, in particular, where judgment in unforeseen circumstances is needed—then the participation of man will be required. It may be seen that the first two requisites are limited only by prevailing engineering development, while the last is clearly a basic constraint.

The employment of pilots in supersonic rocket planes and in balloons is an example of present approaches to the problem, and has been covered in previous papers. In the case of air-borne vehicles (those using forward motion to derive lift from the atmosphere) we must consider duration of flights as well as altitude. It is convenient to subdivide this class of vehicles into those using rocket engines and those using air-breathing power plants. This latter type is represented by the various jet propelled aircraft and missiles. In order to fly at very high altitudes it is necessary for such a vehicle to operate at supersonic speeds, not only to provide sufficient lift but also for adequate thrust. At an altitude of 20 mi (32.2 km), for example, the required Mach number for a ramjet is over 5 and the resultant incoming air has a stagnation temperature of the order of 2000° F. Since energy must be imparted to this air at higher temperatures it may be seen that a present engineering limitation on suitable fuels and materials is approached. This is particularly true with the use of nuclear heating. Thus the air-breathing vehicle is limited in altitude. As for duration, a nuclear ramjet might be capable of cruising for indefinite periods around the earth and comprises a very interesting possibility for travel in the near aeropause.

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Physics and Medicine of the Upper Atmosphere

With rocket vehicles, higher altitudes can be attained. At 50 mi (80.6 km) and at a near-satellite speed of 4 mi/sec a vehicle can support its weight in gliding. However, in the region of 20 to 100 miles (32.2 to 160.9 km), flights with propulsion that can be envisioned at the present time will be of short duration (an hour or so) and less than a revolution about the earth. In this altitude region, the justification for incorporating a pilot is doubtful.

The gliding trajectory mentioned above naturally leads us to a satellite. The feasibility of establishing a vehicle in a stable orbit around the earth has been theoretically demonstrated both here and abroad. Placing the vehicle in the direction of the instantaneous tangent to the earth at the proper speed will result in a circular orbit. At 150 mi (241.4 km) altitude nearly 5 mi/sec is needed; at 500 mi (804.6 km) this speed is a little slower at about $4\frac{1}{2}$ mi/sec. At 150 mi the duration would be of a day or so, drag slowing the vehicle down. At 500 mi, it is estimated that several decades would elapse before a satellite would come down of its own accord.

It is apparent that automatic operation of complicated scientific observational equipment is a tenuous proposition for long periods of time. The temptation for employing a human observer on a one-way basis is ever present, and it is probable that a number of volunteers willing to devote their lives to science could be obtained. However, it is physically possible to bring a satellite back without a great additional source of power.

This is not easy and would require considerable development in control equipment. In launching a satellite, a long, coasting (elliptical) trajectory is indicated, with a small additional kick provided to pull it into orbit. This same kick in reverse will put the vehicle back into the original ballistic flight path, but the vehicle might burn on the way down. By using a carefully selected and maintained gliding trajectory it is believed possible to enter the atmosphere without disastrous skin temperatures and high landing speeds. In fact, terminal speeds slightly over sonic are indicated, at which point parts of the vehicle could be landed with parachutes.

The main problem, then, of the returnable satellite is that it requires a very accurate control during the descent phase—automatic programmed control at the least, and possibly the continuously computed variety.

The satellite, especially a returnable one, is important as a step in the direction of interplanetary space travel. The principle of orbiting [483] about a given planet will undoubtedly be incorporated in future vehicle operations. For example, computations have shown that the establishment of an elliptical orbital path about the earth and moon will require not appreciably more energy than that of a low-altitude satellite—in fact, the energy required is less than that needed to establish a circular orbit at 6400 mi (10,299.9 km) height.

To escape from the earth's gravitational field, a velocity of 40 percent more than the low-altitude satellite or about 7 mi/sec is required. By properly timing the trajectory it should be possible to arrive at a near planet in a reasonable length of time. Some additional control thrust will probably be required to allow the vehicle to be captured by this planet as a satellite. At this point the vehicles can elect to land, or return to earth by orbital escape at the proper time.

Motivating Techniques Required

It is apparent from the foregoing that, as more complicated operations are visualized, an effectively greater thrust impulse is necessary for a given vehicle. Staging is one expedient, and an important one, for effecting space travel. However, if it requires a million pounds take-off weight to put 10,000 pounds on a distant planet, it will take a billion pounds initial weight for a round trip (to a planet of similar gravitational pull and return). This is the weight of ten battleships. This condition prevails if all the fuel must be carried with the vehicle.

Instead of multiplying stages the vehicle might carry a pilot plant for making its own fuel for the return voyage. This would, say, double the pay load and thus only double the gross weight.

The launching of a one-way space vehicle is felt to be possible with highly developed structural techniques and chemical fuels. What gains, then, can be made with the use of nuclear fuels?

Two possibilities exist with nuclear energy, using the fission particles directly, and degrading the energy into heat for increasing the momentum of a secondary fuel. At first sight the direct use of fission fragments and neutrons seems attractive. However, at the vehicle speeds where most of the thrust force is expended, many orders of magnitude greater energy release is required for the direct employment of fission particles to attain a given thrust than is needed for sufficient heating of a secondary fuel. This is because the mass of the particles is so small. One can consider the "dilution" of the particle momentum with inert particles of greater mass. The energy required is proportional to mV^2 , [484] while the momentum change for thrust is proportional to mV^2 if the velocity of the particle is greatly different from that of the vehicle,²⁹⁸ the low-mass, high-energy propellant is inefficient. (In the above discussion it has been assumed that it is possible to direct the fission particles rearward, which, in itself, is unrealistic considering the tremendous amount of heat generated in an absorbing chamber designed for such purposes.)

It is, of course, well known that such orders of energy production are probably physically realizable, but to accommodate such an energy release in a vehicle is beyond the scope of present engineering thinking.

On the other hand, the use of a nuclear reactor to heat a secondary propellant does not impose a large strain on the imagination. The impulse for a given energy release is roughly proportional to the square roots of the temperatures and to the inverse of the atomic weights of the propellant components. Thus the ability to use hydrogen or methane alone, and/or higher temperatures, indicates possibilities for nuclear propulsion. However, it is not immediately apparent that an improvement over a chemical-fuel system will result or, if so, that the amount of improvement will be significant.

Engineering Limitations

We have explored, in a qualitative fashion, the allowable regimes of upper atmosphere flight from the standpoint of that which is physically conceivable. How much then is realizable on the basis of engineering? In other words, if say, a satellite vehicle can be

²⁹⁸ The optimum velocity of the particle is approximately twice that of the vehicle. For particle speeds significantly greater than vehicle speeds the propulsive efficiency is proportional to V_v/V_p .

theoretically predicated, do we have the practical engineering know-how to implement such a venture?

The tentative answer to this question is yes. As a result of war-instigated research we have V2 rockets and microwave radio techniques. Even in 1945 a satellite vehicle could have been built in a "quick and dirty" fashion by staging, and by such crude expedients as clustering existing rocket motors together to form a single power plant. Since then power plants with improved fuel combinations and of a larger size, better materials for certain applications such as titanium metal, and exploratory research in the near upper atmosphere have tended to guarantee even greater success for such a program.

[485] The fact that a satellite has not been practical in a strict military sense has retarded its development in favor of guided missiles. On the other hand, the continual improvements of techniques in propulsion, aerodynamics, structures, and electronics have been brought about by missile programs.

It is on the subject of electronics that we shall dwell for the moment. Approximately half of the effort in the V2 development was expended in the simple radio control that established this vehicle on its relatively short-range ballistic trajectory. With this in mind, it is not hard to extrapolate to the difficulties involved in guiding a long-range missile over a complicated trajectory or in placing a satellite in its orbit. As was mentioned previously, this was one of the considerations in favor of having a pilot in a rocket plane for supersonic flight research. Ever-increasing needs for more complex control equipment call for better electronics. This, in turn, requires special consideration of the electron tubes themselves, which, for a particular application, went through the following interesting stages of evolution.

Initial forms of radio-detection devices included the crystal detector and the triode. Subsequent tube development resulted in more and more complex elements within the tube and in multipurpose tubes. With the recent upsurge of electronic application in microwave radio and in digital computers (or electronic brains) it has become apparent that many simple and reliable diodes and triodes are to be preferred for such circuits. Further exploitation in this direction has centered interest on the semiconductor or transistor, and the equivalents to both diodes and triodes have been made in this form. What is a transistor? It is just an improvement of the old cat-whisker-crystal affair used in the early radio sets. This cycle aptly illustrates an underlying precept of development. As Boss Kettering says, "the ultimate solution to a problem is usually the simplest." Another way of stating this is, "If it's complicated, it's wrong."

The transistor consists of a simple blob of material the size of a lead-pencil eraser (or smaller) with several wires leading to it. Its power requirements may be as small as one-hundredth that of an equivalent electron tube. The reliability of the transistor also probably will be considerably better. In short, it has been heralded as the forerunner of the coming electronic age, where many of man's more menial tasks will be replaced by computer controls.

In the actual construction of an upper-atmosphere vehicle many unforeseen problems undoubtedly will arise. Usually, if a wide gap [486] exists between the physical and engineering limits on a device, then a large number of possible solutions exist. In the early days of aircraft, for example, many weird configurations evolved. As research in piston-engine types progressed it became apparent that monoplanes with thin wings were needed. Eventually a physical limit of 500 mph was approached since the additional power required resulted in a larger engine-cooling drag that offset the benefits of increased engine size. Thus, considerable work and careful design were required to reach this limiting speed.

By analogy, it may be said that we are still in the Curtiss biplane stage of rocketry, and such considerations as accessibility of instruments for ground testing frequently predominate. A good example of such freedom may be found in a recent news release, "Newsmen who recently attended the firing of a rocket asked why the rocket was exactly 32 inches in diameter. After a long technical explanation involving the ratio of length to diameter and

effects of air drag on a large projectile, the engineer concluded, "Besides, it so happened that the metal plate we were able to obtain made a cylinder exactly 32 inches across."

Summary

Past experience has shown that most advances in the field of human endeavor are not made as a result of some completely new and different concept, but rather by skillful day-to-day improvement of existing technology. This does not mean that intelligence is not required. On the contrary, the human mind is quite capable of solving multi-parameter problems, an operation which is usually termed ingenuity. Very often a design created on the back of an old envelope is perfectly suitable (it can also be completely wrong).

The continuing development of computing machinery has resulted in powerful tools for rapid, simultaneous solution of problems of many variables. However, it should be emphasized that the machines themselves do not possess intelligence. It is quite embarrassing, for example, to find that solutions are insensitive to a given parameter and upon subsequent investigation find that this factor did not belong in the problem in the first place.

There is, and will be, no substitute for sound and thoughtful planning and direction of research. The middle road between the no-stone-left-unturned school and the advocates of the "brilliant hunch" type of investigation will afford the most fruitful course of action.

[487] Just how long before space travel is accomplished cannot be predicted accurately since a very large weighing factor must be assessed to man's own incentives and decisions. If it became necessary to our very existence to conduct interplanetary flights tomorrow, the development period required would be materially shortened—probably within our lifetime. Without such an impetus it may be many generations before such a program is attempted. Let us recall that 50 years ago most of the mechanics of a complete rocket vehicle were known.

To recapitulate, most of the components comprising an upper-atmosphere vehicle probably will be refinements of existing rocket devices. Rather than having an appreciable increase in rocket-plane altitude, the next step probably will be a satellite, with a returnable version used for manned flights. Considerable improvement in electronics from the standpoint of reliability, weight, and power consumption is indicated. The transistor may pave the way toward this end. Many of the more complex operations in the development of rocket vehicles, as well as within the vehicle itself, will be implemented by self-sustaining computers. In the final analysis, though, man himself, with his ability to use judgment and his physical limitations, will provide the key to space flight.

Document II-5

Document title: A.V. Grosse, The Research Institute of Temple University, to Donald A. Quarles, Assistant Secretary of Defense for Research and Development, "Report on the Present Status of the Satellite Problem," August 25, 1953, pp. 2-7.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

In 1952, President Truman requested Aristid V. Grosse, a physicist at Temple University who had worked on the Manhattan Project, to study the "satellite problem." Major General Kenneth D. Nichols, formerly deputy for Lieutenant General Leslie R. Groves on the Manhattan Project, arranged Grosse's meetings with space scientists at Huntsville, particularly Wernher von Braun. The report was finished after Truman left office; it was delivered to Donald Quarles, the new Assistant Secretary of Defense for R&D under President Eisenhower, on September 24, 1953. Quarles later became a major advocate of the use of space for military purposes. Another copy of the report was sent to Dr. John R. Dunning,

dean of the School of Engineering, Columbia University. Dunning discussed it with President Eisenhower, and the report contributed to the initiation of Project Vanguard. Grosse's report represents the first time that the potential propaganda consequences of a Soviet first launch of a satellite were reported directly to top levels of the government.

[2] The Present Status of the Satellite Problem

A satellite is a man-made or artificial moon which will rotate around the earth beyond the furthestmost extent of its atmosphere, for many years or indefinitely. After it has once reached its orbital velocity the centrifugal force of its motion is held in exact balance by the gravitational attraction of the earth; thus the satellite once on its orbit around the earth *does not require* any additional power to keep it there. Usually altitudes of 300 to 1000 miles above the earth's surface are considered.

As an example, at an altitude of 346 miles above sea level the time necessary for the satellite to travel once around the earth, i.e. its period of revolution, will be exactly 96 minutes or 15 revolutions per day. Its orbital velocity will then be 4.71 miles per second. Similarly, a satellite at an altitude of 1037 miles above sea level will have a period of revolution of exactly 120 minutes or 12 revolutions per day and a velocity of 4.37 miles per second.

The satellite could be made to travel over the surface of the earth in a wavy line so that in the course of a few successive days most of the North American continent, Europe, Africa and Asia, could be observed from it.

It could be made visible to the naked eye, under clear atmospheric conditions, at dawn and at dusk as a bright fast moving star.

The technical problem of creating a satellite should logically be divided into the two following steps:

1. The unmanned satellite and
2. The manned satellite.

[3] The accomplishment of the first step, in the opinion of even the most skeptical engineers, is possible with the present know-how and engineering knowledge. Since it is not manned by human beings it would not require any essentially new research and development.

A satellite of about 30 feet in length would require the stepping up of the German V-2 rocket by a take-off weight factor of 6-7. This would require essentially the addition of a third large stage to the present well known two stage rockets such as the WAC Corporal mounted on a V-2, which reached an altitude of 250 miles at the White Sands Proving Grounds in February 1949. A design for such a large stage was already on the drawing boards of Dr. von Braun and his associates in Peenemünde, Germany, in 1945. This German project "A-9 + A-10" was designed for transatlantic bombing of the United States. The A-9 stage was a slightly enlarged V-2 (take-off weight 16.3 metric tons vs. 12.8 tons of the V-2) whereas the A-10 stage had a take-off weight of 69 metric tons. Such a three stage rocket would use conventional fuels giving a specific thrust of 220-240 seconds (for example, liquid oxygen + ethyl alcohol 75%, water 25% = 239 seconds, red fuming nitric acid + aniline = 221 seconds). Conventional combustion chambers, pumps, tanks, ignition devices, etc., could be used.

Research scientists have recently demonstrated that much larger specific thrusts can be realized. For example, a liquid fluorine-liquid hydrogen rocket motor can generate a thrust of about 380 seconds. This would permit the use of a much smaller rocket to achieve satellite velocity. However, the engineers feel that this advantage is offset by the necessity of doing a lot of additional research and development in order to bring the high thrust rocket motors and their accessories to [4] the same stage of reliability and smoothness of operation as the conventional rockets. All of this new development would thus cause a loss in time. This would be unwise because it is felt by all engineers that the present rocket fuels and motors will be able to do the satellite job.

The second step or a satellite manned by human beings is decidedly a much more difficult problem. Ultimately, if solved, it would mean the beginning of man's conquest of

interstellar space and would have infinite possibilities for the human race. The solution of this problem, however, involves overcoming all the obstacles in the way of man's existence in the vacuum of outer space. It means the overcoming of the absence of a gravitational field on the functions of the human body and the effects of cosmic radiation on it. Although all of these problems have a possibility of ultimate solution, it would require at least a 20-fold expense of human effort, money and time, as compared to Step 1, coupled with an inestimable amount of human ingenuity and invention.

It is felt that the accomplishment of the first step would help solve many of the problems of the second. This writer feels that probably after the successful launching of the first unmanned satellite, a number of such unmanned satellites will be in existence at various altitudes above the surface of the earth, for various purposes. It is thus felt that at this time the main effort should be directed toward solving the unmanned satellite problem.

The value of an unmanned satellite would fall into the following categories.

a) **Scientific** — with proper electronic and telemetering equipment and devices it would enable us to obtain valuable scientific information regarding the various physical conditions existing in outer space. [5] The satellite would need a concentrated source of energy, which should be *light in weight* and should produce *power for a number of years*. It is considered that such a power plant could be produced by using alpha-active radioactive substances of an average life of a few years in concentrated form, if the appropriate resources of the Atomic Energy Commission could be mobilized.

b) **Military** — again, with the equipment referred to above coupled with televising devices, a satellite station could be a valuable observation post.

c) **Psychological** — with appropriate signaling or broadcasting devices such a satellite could develop into a highly effective sky messenger of the free world.

In the opinion of this writer the last item, i.e., the psychological effect, would be considered of utmost value by the members of the Soviet Politbureau. They would recognize that in the case of atomic and hydrogen bombs the people of the belligerent countries would be subjected to their effects only after the die of World War III is already cast. On the other hand, the satellite would have the enormous advantage of influencing the minds of millions of people the world over during the so-called period of "cold war" or during the peace years *preceding* a possible World War III. In the countries of Asia, where the star gazer since time immemorial has been influencing his countrymen, the spectacle of a man-made satellite would make a profound impression on the minds of the people. The Soviet Union has demonstrated that it has been able to develop the atomic bomb and recently to follow that up with the accomplishment of a thermonuclear reaction on August 12, 1953, [6] as confirmed by the Chairman of the U.S. Atomic Energy Commission, Admiral L. Strauss, much faster than had been generally expected by our scientists and engineers. The building of an unmanned satellite would be a feat of much smaller magnitude than the construction of an atomic bomb since all the basic information was available to the Germans at the end of World War II and is since known both to this country and to the Soviet Union. Furthermore, the industrial plant necessary for the construction of a satellite is much simpler and is now being developed for the guided missiles programs in both countries.

In the Soviet Union the construction of a satellite would amount to only a fraction of the cost in this country, a) because of the use of cheap or slave labor; b) no necessity for great safety precautions, and c) no need for tracking the satellite in the early stages of its flight.

Since the Soviet Union has been following us in the atomic and hydrogen bomb developments, it should not be excluded that the Politbureau might like to take the *lead* in the development of a satellite. They may also decide to dispense with a lot of the complicated instrumentation that we would consider necessary to put into our satellite to accomplish the main purpose, namely, of putting a visible satellite into the heavens first. If the Soviet Union should accomplish this ahead of us it would be a serious blow to the technical and engineering prestige of America the world over. It would be used by Soviet propaganda for all it is worth. Of course, the probable reaction of the American people to a

Soviet satellite circling about 300 miles above Washington, New York, Chicago and Los Angeles, would have to be considered.

At the present time our engineering efforts in this field are limited in scope and distributed over various government agencies. It [7] is recommended as a first step in solving the satellite problem that a small but effective committee be set up composed of our top engineers and scientists in the rocket field, with representatives of the Defense and State Departments. This Committee should report to the top levels of our government and should have for its use and evaluation, all data available to our government and industry on this subject. It should report in detail as to what steps should be taken to launch a satellite successfully into outer space and to estimate the cost and time required for such a development. It is felt that if such a committee were in existence and a definite decision taken by our government regarding the construction of a satellite, that it would fire the enthusiasm and imagination of our engineers and scientists and effectively increase our success in the whole field of rockets and guided missiles.

Document II-6

Document title: J.E. Lipp and R.M. Salter, "Project Feed Back Summary Report," *The Rand Corporation, R-262, Volume II, March, 1954, pp. 50-60. The figures have been omitted from this document.*

Source: Archives, *The Rand Corporation, Santa Monica, California.*

In November 1950, Rand recommended to Air Force headquarters that it pursue further advanced research on satellite reconnaissance. Two Rand reports, including "The Utility of a Satellite Vehicle for Reconnaissance" [II-3], were completed in April 1951 and were enthusiastically received by the Air Force. Some members of the Air Force recognized the valuable role that satellites could play in providing strategic reconnaissance of areas not reachable by other means. As a result, the Air Research and Development Command authorized Rand to make specific recommendations on a satellite reconnaissance system. Project Feed Back involved hundreds of scientists and engineers from Rand and a host of subcontractors. Its results were presented to the Air Force on March 1, 1954, and became the basis for the first military satellite program. Many of its specific proposals, such as the use of television transmission of reconnaissance images, were not adopted until many years later. The section of the report dealing with "television payload equipment" is still classified. Volume I of this report has not been cleared for public release. In this excerpt from Volume II, the report discusses the scanning technique that was the basis for obtaining useful data from Earth orbit. The figures have been omitted.

[50]

Scanning

The scanning problem arises for an obvious reason. The limited size and resolving power of the Image Orthicon result in each picture's being able to contain only a finite number of bits of information. Elsewhere in this report it is shown that in order to keep the time between successive views of a particular ground area to a reasonable value, the television optical system must cover a strip extending for 200 mi on each side of the flight line. If this area were to be covered by a single picture, about 1 in. on a side, the scale would then be 1:25,000,000; if the spot size of the scanning beam in the camera tube could be kept down to 0.001 in, the image projected on the ground by the optical system would be 2100 ft in diameter. Anything much smaller than a mile in its principal dimension would be difficult to detect.

At the scale of 1:500,000, one picture is about 8 mi on a side. A strip 400 mi wide will require fifty pictures to cover it. This number of pictures must be transmitted in the time it

takes the satellite to move forward 8 mi (1.68 sec), requiring a frame rate of about thirty per second, which is present commercial practice. At this scale, a spot 0.001 in. in diameter will cover a circle on the ground approximately 40 ft in diameter. Two television lines are equivalent to one optical line of resolution, and an object, to have a high probability of detection, must be covered by about two optical resolution lines. This gives, in the present case, a limiting object size of somewhere between 150 ft and 200 ft, approximately the size of bombing aircraft—hence the gain realized by the complication of the addition of a scanning system.

Because the Image Orthicon is an integrating device, it requires a finite exposure time during which the image must remain fixed on the photocathode. If it were not for this, the scanning problem would be reduced to the simple one of two cameras viewing the ground by reflection in continuously rotating mirrors. Two cameras would be required to eliminate the "dead time," i.e., the time during which the mirror into which each camera is looking would be [51] returned to its initial position to start a new sweep. But scanning in the direction of the line of flight is affected by the vehicle's motion. From the standpoint of reliability and long life, intermittent mechanisms which have been proposed for the projection of motion pictures from continuously moving film are applicable. A few of those suggested in Ref. 24 may be difficult to fabricate, but they can be used successfully here, because many of the restrictions imposed by their application to theater projectors do not occur (e.g., the f number and back focal length, in particular, present no problems).

The most promising arrangement that has been investigated is the one proposed by RCA in their study of the problem. It consists of a number of mirror pairs mounted on the periphery of a continuously rotating wheel; each mirror pair deflects a ray through a fixed angle in a plane perpendicular to their line of intersection, independently of any rotation of the mirror pair about any line parallel to their line of intersection. In Fig. 29, M_1 and M_2 are two plane mirrors perpendicular to the plane of the paper, and I is their line of intersection. If the two mirrors rotate slightly, as a unit, the change of deviation of the ray produced by reflection in the first mirror is of the same magnitude and opposite sense as that produced by the second mirror, leaving the deviation produced by the pair of mirrors unchanged. The deviation of the pair depends, therefore, only on the angle between them. RCA's device is shown in Figs. 30 and 31. For a scale of 1:500,000, an altitude of 300 mi, and a strip 200-mi wide on each side of the line of flight, the rotating drum will have eighteen pairs of mirrors, each pair equally spaced around the periphery.

This drum, whose axis is parallel to the direction of motion of the vehicle, rotates at a speed of 38.5 revolutions per minute in a clockwise direction as shown. Since there are eighteen equally spaced pairs of mirrors on the drum, the mirror pairs are spaced 20 deg apart. Both television cameras are spaced 90 deg apart as in Fig. 31. This means that at the instant that camera "A" is viewing a ground scene through a mirror pair, camera "B" is viewing the transition point between two successive mirror pairs. The sequence of ground scenes scanned is shown in Fig. 32.

Lateral image immobilization is achieved during the entire time that a pair, or part of a pair, of mirrors is in line with the optical axis of the camera. Except [52] for a short interval during which the image is recorded, a composite picture of two successive segments is seen because of vignetting effects. The situation perhaps can be explained better by describing the direction of view of one of the cameras. As the drum rotates, a scene, completely stationary except for the image motion caused by the forward motion of the vehicle (the lateral scanning introduces no image motion), can be observed for a period of time depending on the mirror size. The next scene will then be picked up and will start to blend with the first scene, both remaining completely immobilized. At some point, only the second scene will be observed; then the entire cycle will be repeated for adjacent fields of view.

Such a sequence is demonstrated by Fig. 33. The ordinate in this diagram is comparable to the intensity of illumination on the photocathode due to the fields of view indicated by the numbers above each peak, which can be made to correspond to the num-

bered fields shown in Fig. 31. RCA's proposal to avoid the resulting confusion of images is to "pulse" the image section of the Image [53] Orthicon. That is, the accelerating potential will be applied to the photoelectrons liberated by the optical image on the photocathode only during that part of exposure on, say, field 3, when the light from fields 1 and 5 is less than some minimum value, say 5 percent of full aperture. It should be noted that because the output of both cameras is to be transmitted over the same carrier wave and received on the same device, it is important that they be accurately interdigitated timewise. The curves in Fig. 33 represent the case where the dimensions of the mirror pairs are such that the full-aperture condition obtains only instantaneously. As the size of the mirrors is increased, the full-aperture exposure time increases and the exposure curves, shown in Fig. 34, develop [54] flat tops and bottoms. From the point of view of the most efficient time use, the optimum is reached when the exposure time is one-fourth of the frame frequency for both cameras; the exposure curve has the form shown in Fig. 34 for the camera on one side of the mirror drum.

Starting with field 2 (Fig. 34), full aperture is reached at the abscissa value of 1.5 and is maintained until 2.5. During this time the accelerating potential is applied and a charge image is built up on the target plate in the Image Orthicon. From 2.5 to 3.5 the image-stage voltage is shut off and the scanning beam discharges the image on the target plate. In this same interval (2.5 to 3.5) the camera on the other side of the mirror drum is being exposed. At 3.5 a new exposure is started in the first camera at the same time that the picture in the second camera is being scanned and transmitted. In this way there is always one and only one picture being exposed. There is no "dead time" for the transmitter.

[55] The price that must be paid for this more efficient use of transmitter and exposure time is, of course, weight and bulk—the scanning drum must be larger. Variation of the drum radius with the percentage of the exposure time occurring at full aperture is shown in Fig. 35.

To get the resolving power being discussed, any motion of the image, during the exposure, that can be predicted must be eliminated. Such an image motion is one that is due to the high forward velocity of the vehicle—roughly 25,000 ft/sec. At an exposure time 0.001 sec, the image of the photocathode projected on the ground by the camera lens will move 25 ft, a barely tolerable amount. If the scanning mirror dimensions are chosen so that one-quarter of the frame time is available for exposure, the exposure time at 25 frames/sec will be 0.01 sec and the image motion during this time will be 250 ft, requiring some sort of image-motion compensation.

Here again the type of mechanism devised for the projection of motion pictures from continuously moving film can be used, but there is such a small motion, in terms of percentage of frame height (at most 1000 ft out of 8 mi), [56] to be corrected that, in RCA's opinion, it can be handled (electrically) by scanning in the image stage of the camera tube. All that is required is the addition of a coil above the image stage and one below the image stage, the plane of the coils being parallel to the axis of the tube. These coils can be energized by a "saw toothed" oscillator whose frequency is equal to the frame frequency. As the optical image moves on the photocathode, the photoelectrons liberated by a (moving) point in the image can be brought to a focus at a fixed spot on the target plate where the charge accumulates. RCA workers say that a motion of 5 percent of the frame height is easily corrected in this way, whereas 10 percent is possible to correct, but very difficult. Since the motion in this instance is around 2 percent, it should not be difficult to correct.

The problem of obtaining reconnaissance data is essentially that of typifying various ground-target scenes with patterns of bits varying in intensity. The number of bits in a given period of time determines the bandwidth, or the information rate, of the system. Here, information rates of perhaps three times those of standard television systems have been considered, i.e., bandwidths of about 8 Mc. It is obvious that all components in the television system should be compatible with regard to bandwidth.

A bandwidth corresponding to the above frame rate in tube resolution is about $6\frac{1}{2}$ Mc. It is expected that a slightly higher bandwidth may be employed in the surround-

ing circuitry of the television camera tube so that no unnecessary degradation of signal will be introduced. Bandwidths of the order of 9 Mc have been employed in the simulation television setup for the photographs used in Vol. I of this report. However, the use of these bandwidths is not standard studio practice because the standard-tube studio television is limited by FCC regulations to about $3\frac{1}{2}$ Mc. Otto Schade, of RCA, has used bandwidths up to 20 Mc in some experimental television equipment, particularly for circuits surrounding the $4\frac{1}{2}$ -in. Image Orthicon camera tube.

The next component encountered by the television signal is the magnetic-tape recording system. Magnetic-tape recorders for the purpose of recording video signals have already been investigated and brought to a primitive stage of development.

A magnetic-tape recorder (Fig. 36) will be similar in many respects to the home audio-tape recorder except that it will handle much more information in a given length of time. Two reels, one for feeding the tape and one for winding it, are needed; also, the tape passes over a capstan and several other pulleys. Heads for recording information magnetically on the tape are provided, both [57] for recording and for playing back the information into recording heads, and for taking the information in playback.

An RCA video recording system was exhibited recently. It consists in using either a single track for the video signal, the black-and-white system, or a color system having three tracks on the tape. Tape speed is 30 ft/sec.

Bing Crosby Enterprises have a system using a somewhat slower tape speed. In their device, the black-and-white television is recorded with a number of tracks on the tape.

[58] Both systems are designed for standard studio bandwidths and will have to be increased by a factor of two or three in order to be compatible with the bandwidth proposed for the Feed Back system. Personnel of both RCA and Bing Crosby Enterprises have expressed the opinion that within the development period allotted for Feed Back, such a recording system can be developed.

A suitable tape is one having a cellulose acetate plastic base of 0.0017-in. thickness, similar to the one developed by Minnesota Mining and Manufacturing Company. Lubricating methods developed by them are believed to be adequate. The magnetic surface of the tape is an iron oxide coating of 0.0005-in. thickness, which is impregnated on the plastic base. It is believed that the tape cannot be run continuously over the capstans for a year's period. Even if the tape itself can be made to withstand this length of service, it is probable that the magnetic heads will be worn down because tape has characteristics not too different from those of crocus cloth. Any system assumed for the present report allows for intermittent operation and includes motors for starting and stopping the reels every time a recording or a playback is made. In fact, it is probable that the system will be started in one direction for recording and played back in the opposite direction. Discussion of the programming of the record playback magnetic-tape storage may be found under "Communication Link," page 85.

Next, in its progress through the television equipment, the signal encounters a modulator and transmitter unit. These components must have at least the 8-Mc bandwidth postulated for the other units in a television chain. Engineering of the equipment will be fairly straightforward.

The transmitter in the vehicle will be a frequency-modulated oscillator operating in the X-band and having a power output of about 10 watts. Center frequency of the transmission will be controlled by reference to a very stable high-Q resonant cavity. However, there is some difficulty in obtaining an output transmitting tube capable of transmitting at the megacycle frequency required and also having a year's life capability at reasonable power requirements.

In earlier work it was assumed that 10,000 Mc would be used for the transmission signal. However, RCA believes that 7500 Mc is a more appropriate figure, and this frequency will give a greater capability in transmission through heavy rainstorms. A frequency that is too low will require more power input in the transmitter; therefore, the 7500-Mc frequency is a compromise. RCA has recommended that the output stage be a frequency-modulated magnetron with a 20-watt output for reasonably low power consumption.

However, at present, magnetrons have not been developed to have a year's life, the longest, perhaps, being a month. It is probable (but not certain) that the life length of the [59] magnetron can be improved. Also, it is possible that traveling-wave tubes will be developed to a state of refinement that will allow them to be considered for use as the Feed Back transmitting tubes.

For the example selected here, which discussed informally with RCA, two klystrons developing a total of 5 watts have been used. (A larger antenna compensates for the reduction in output from the 20 watts stated above.) These tubes now have a reliability compatible with Feed Back requirements (over 10,000-hr lifetime in one reported instance). Previously, use of the klystron was not felt possible because power requirements of this tube are quite high. However, in putting together the various parts of the over-all Feed Back system, it became apparent that the 400-watt input required by the klystrons (compared with a tenth as much power required by the magnetron) was not dominant in the total payload power requirement.

Payload power requirements are already in the realm of several kilowatts, so that once a reactor is selected for the auxiliary powerplant, a $\frac{1}{2}$ kw more power can be obtained for about 25 lb additional radiator weight.

A transmitting antenna with a diameter of about $3\frac{1}{2}$ ft is needed for the 5-watt klystron systems. A 20 watt magnetron, on the other hand, requires only a 1-ft-diameter antenna. By placing the antennas in the locations shown on the vehicle drawing (see Fig. 1), it should be possible to enclose, within the vehicle, antennas several feet in diameter, despite their attendant complexity and weight for this particular component.

RCA has proposed an antenna system consisting of two separate paraboloid dishes: one dish receives the 3000-Mc signal and thus is able to track the ground station by means of a conical scan, and the other, the transmitting dish, is slaved to follow the receiving dish by means of a servomechanism.

Rotating parts, such as the antennas, and also the mirror wheel for the optical system, are assumed to be counterbalanced by devices of comparable moment of inertia rotating in the opposite direction.

The antenna system is to be mounted just below the throat of the secondstage rocket motor, so that upon separation of stages it will be exposed to the atmosphere and will be allowed ample freedom to scan not only directly below the vehicle, but to the horizon as well.

Approximately three video stages of amplification will be necessary between the camera equipment and the output tube. It is estimated that about 300 watts will be required to operate the transmitter circuits, exclusive of the tube requirements. The temperature of the compartment which houses the electronic [60] equipment must be regulated to within about 10° C of a desired value, and this eliminates the need for an automatic-frequency control circuit.

A tracking command receiver will also be included in the television system. It will be a simple superheterodyne type with a bandwidth sufficient to accommodate the doppler shifts due to vehicle velocity plus an information bandwidth a few kilocycles wide, which is sufficient to permit transfer of all needed command information for the most extensive case in a period of less than 1 min.

The purpose of this receiver is to receive command information from the ground, particularly to set up the scanning, recording, playback, and transmitting operation for successive passes of the vehicle. Commands will be transmitted in the form of Baudot types of symbols and will be recorded on the rotating drum of the programmer, in accordance with the present sequence arrangement, which is capable of erasing and changing all of the drum information in a period of 1 min or less. At the conclusion of each command cycle, the program drum will be played back to the ground through the data transmitter and will be checked for accuracy against the transmitted commands.

Also included in the operation is the programmer just mentioned. The programmer will probably operate in a manner very similar to that of a timer on an automatic washing machine; i.e., it will consist in a linear sequence of operations. Because successive

programs differ only in variations of the length of time (including 0) that operations can take place, the required programmer is inherently simple. More comments on the ground-to-vehicle link and programming will be found under "Communication Link," page 85.

Results of RCA's investigations up to the present time are given in their various progress reports....

Document II-7

Document title: Wernher von Braun, "A Minimum Satellite Vehicle: Based on components available from missile developments of the Army Ordnance Corps," September 15, 1954.

Source: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, D.C.

On June 23, 1954, Frederick C. Durant III, former president of the American Rocket Society and then current president of the International Astronautical Federation, called Wernher von Braun at the Redstone Arsenal and invited him to a meeting two days later in Washington, D.C., at the Office of Naval Research. At this meeting, plans were discussed for developing a satellite program using already existing rocket components. Further meetings followed at which the Army gave tentative approval, provided that the cost was not too great and the plan did not interfere with missile development. Von Braun's secret report, submitted to the Army in September, summarized what he had said at the earlier meetings. This proposal became the Army's candidate for an IGY satellite project, which was later abandoned in favor of Project Vanguard.

[1]

1. Summary.

a. The realization of a relatively inexpensive Minimum Satellite Vehicle with a payload of 5 lb. is possible with components available from weapons development of the Army Ordnance Corps. Such components have reached an advanced development stage and are expected to attain a sufficient degree of reliability by 1956, to warrant their use in a satellite vehicle.

b. In view of the launching and tracking problems of a satellite vehicle it is suggested to establish a joint Army-Navy-Air Force Minimum Satellite Vehicle Project. Office of Naval Research, endeavoring to establish a Minimum Satellite Vehicle Project, has expressed definite interest in the proposal laid down in this memorandum.

c. While the feasibility of a Minimum Satellite Vehicle based on existing Ordnance Corps hardware may be considered as firmly established, further theoretical investigations, particularly on the tracking and "lifetime" aspects, are necessary. It is suggested to authorize such studies to the tune of approximately \$100,000 for the present fiscal year. Office of Naval Research representatives have indicated their willingness to financially support such studies.

2. Introduction.

a. A satellite vehicle circling the earth would be of enormous value to science, especially upper atmosphere, meteorological and radiological research. Up to now any satellite project has been considered an extremely expensive undertaking, and a matter of more than 10 years even if an all-out effort were made. This memorandum proposes to show that, by limiting the payload of a first Minimum Satellite Vehicle to approximately 5 lb, such a project is feasible with presently available missile hardware, and that despite its payload limitations, such a Minimum Satellite Vehicle Project would be a worthwhile initial step.

b. The Office of Naval Research, Washington, D.C., has expressed its desire to support a Minimum Satellite Vehicle Project. On 25 June 1954 a meeting was held at ONR during which the desirability of action toward a Minimum Satellite Vehicle was discussed. Various proposals on how such a project could materialize in the near future were discussed. At the end of the meeting all participants agreed that the most promising approach to a Minimum Satellite Vehicle was a 4-stage missile, using a REDSTONE missile as first stage, and a cluster of LOKI rockets for the three upper stages.

c. The justification of the artificial satellite was summarized as follows:

(1) Upper air research. Due to the stay time of a Satellite Vehicle in outer space (several days or even months) a tremendous wealth of information, particularly about primary solar radiation effects on weather and radio communications [2] can be obtained with *one* firing. Considering the large number of balloon and rocket ascents presently conducted to gather such information, an instrumented satellite vehicle would be a very worthwhile investment.

(2) A rocket capable of carrying the weight of such data collection equipment into an orbit is still many years off. If payload requirements are drastically reduced, orbital speed can be reached with a proper combination of existing equipment. Such an experiment could serve to solve the problems of tracking and orbital stability and would be a logical first step.

(3) The establishment of a man-made satellite, no matter how humble, would be a scientific achievement of tremendous impact. Since it is a project that could be realized within a few years with rocket and guided missile experience available *now*, it is only logical to assume that other countries could do the same. It would be a blow to U. S. prestige if we did not do it first.

d. On 3 August 1954 Commander Wright and Lt. Commander Hoover of the Office of Naval Research visited Redstone Arsenal and discussed the possibilities of Army participation in a joint Army-Navy-Air Force satellite project with Brig. Gen. H. N. Toftoy and Dr. W. von Braun.

3. Description of the Minimum Satellite Vehicle.

The proposed Minimum Satellite Vehicle is a 4-stage rocket consisting of the REDSTONE Missile as 1st stage (or booster), and a three stage missile of clusters of the solid propellant rocket LOKI IIA with the following staging:

2nd Stage:	Cluster of 24 LOKI IIA rockets
3rd Stage:	Cluster of 6 LOKI IIA rockets
4th Stage:	(attaining satellite speed): 1 LOKI IIA rocket with 5 lb payload.

a. Description of REDSTONE Missile, used as 1st stage (or booster).

(1) REDSTONE Missiles #27 and #29 for re-entry studies.

The present REDSTONE R&D program provides that missiles #27 and #29 will be used, among other test purposes, for the study of the re-entry problem of a ballistic 400 to 600 N. Mi.-missile. These two missiles are normal REDSTONE missiles with a few minor modifications. The [3] usual 6900-lb payload (simulated by a concrete filling in the nose section during R & D launchings) is utilized for additional propellants. Thus the burning time is increased from 110 sec to 132.4 sec. The additional propellants are accommodated in an extra-long tank section. For this purpose the length of the cylindrical midsection of the missile is extended by 62 in. (This constitutes a minor change since it does not involve any changes in tooling.) The standard steel warhead hull is replaced by a lightweight aluminum hull for the guidance equipment. A special "re-entry nose" of about 24 in. base diameter and 500 lb. weight, carried in the missile's top, is separated from the missile after cut-off. Both missile and "re-entry nose" attain an altitude of approximately 265 statute miles. Fall into the atmosphere from this altitude duplicates the conditions during

re-entry of a ballistic missile of a range from 400 to 600 N. Mi. The "nose cones" of missiles #27 and # 29 will carry telemeter equipment.

(2) **REDSTONE as 1st Stage of Minimum Satellite Vehicle.**

In the proposed Minimum Satellite Vehicle the 500-lb. "re-entry nose" is replaced by a three stage LOKI cluster of similar total weight. Thus, after successful firing of missile #27 and #29 a proven design of a booster is available that can be directly applied for the Minimum Satellite Vehicle.

b. Description of LOKI Cluster.

LOKI is an unguided, anti-aircraft, solid rocket developed under the auspices of Redstone Arsenal for the Ordnance Corps. LOKI I is presently in production in quantity (59,000 rounds on order). LOKI IIA, an advanced version, is scheduled to soon replace LOKI I production.

The LOKI clusters for the upper stages of the proposed Minimum Satellite Vehicle are obtained by bundling LOKI IIA rockets. With a payload of 5 lb, a particularly favorable staging combination consists of

24 LOKI's as first stage of the cluster (Satellite Vehicle's second stage)

6 LOKI's in the second stage of the cluster (Satellite Vehicle's third stage)

1 LOKI's in the third stage of the cluster (Satellite Vehicle's fourth and final stage).

This combination has been arrived at by comparison of more than 50 different payload and bundling combinations.

[4] Two arrangements of the total LOKI cluster (Satellite Vehicle's 2nd, 3rd and 4th stage) are shown.... It can be seen that both designs provide for a telescoped arrangement of the LOKI's. The total LOKI cluster is carried in a zero launcher. The zero launcher can be rotated about a king-pin mounted on ball bearings.

c. Description of Operation.

(1) The proposed Minimum Satellite Vehicle can be launched with standard REDSTONE launching equipment according to established REDSTONE procedure. The modified nose station contains standard REDSTONE guidance and control equipment. In order to obtain the necessary high accuracy in aiming of the LOKI cluster, the standard air-bearing type stabilized platform of the REDSTONE will be used as guidance head. The LOKI cluster and its zero launcher is brought to rotation at 1800 rpm prior to launching of the entire vehicle by means of an electromotor driven from ground power supply. The rotational speed is maintained during the REDSTONE boost phase from on-missile power supply. (The possible disturbing influence of gyroscopic effects on the REDSTONE missile control during the tilting program have been studied and were found negligible.)

(2) After REDSTONE cut-off (at about 55 miles altitude) the nose station is separated from the booster. The nose section's orientation in space is now controlled by the standard REDSTONE spatial attitude control system, which consists of 8 small compressed-air jet nozzles. The tilting program in the guidance head, which determines the reference axes for the desired attitude, continues to run after nose section separation. Due to the absence of corodynamic forces at the altitudes involved, the tilt program, with the aid of the compressed air nozzles, now rotate the nose section into such an attitude, that, by arrival at the apex of its trajectory, it will be parallel to the surface of the earth. The gyroscopic effect of the rotating LOKI cluster will thereby be utilized in such manner that the correcting moments created by the air jets will cause the nose section to "process" into the desired attitude. The summit of the nose section's trajectory is reached at an altitude of approximately 186 statute miles.

(3) The first LOKI stage is ignited at the summit point, which is determined accurately by the REDSTONE guidance system in order to avoid a vertical component of the

trajectory. Each LOKI stage has a burning time of 1.9 sec. The launching of the two successive stages is initiated with time switches set at intervals of about 2.5 sec.

[5] The velocities reached by the stages are:

+	REDSTONE nose section at summit	4298 ft/sec
+	rotation of earth at equator	<u>1519 ft/sec</u>
		5817 ft/sec
+	2nd stage (24 LOKIs)	6283 ft/sec
+	3rd stage (6 LOKIs)	7152 ft/sec
+	4th stage (1 LOKI plus 5 lb payload "Satellite")	<u>6972 ft/sec</u>
+	Total satellite velocity	26224 ft/sec

(4) The satellite thus reaches a velocity *exceeding* the circular velocity of 25368 ft/sec at 186 miles altitude by 856 ft/sec. The satellite therefore enters an *elliptical* orbit around the earth with the following characteristics:

	<u>perigee</u>	<u>apogee</u>
For 0° deviation from horizontal flight path of 4th stage	186 mi (300 km)	819 mi (1318 km)
For 1.6° deviation from horizontal flight path of 4th stage	155 mi (250 km)	850 mi (1368 km)

(5) Suppose, now, that the 5-lb payload of the 4th (satellite)-stage has the shape of a sphere of 20 in. diameter. The lifetime of such a spherical satellite has been determined on the basis of data of the upper atmosphere as adopted by the Upper Atmosphere Research Panel. For the two orbits listed in the foregoing paragraph the lifetimes were found to be 360 days (for perigee at 186 mi altitude) and 90 days (for the perigee at 155 mi altitude). Within these lifetimes the elliptical orbits gradually change to circular orbits at (approximately) perigee altitude due to aero-dynamic drag. The circular orbit then rapidly converts into a spiral path toward the earth, and the satellite is finally destroyed by aerodynamic heating like a meteor.

(6) The Minimum Satellite Vehicle can be tracked by optical means. For details see chapters 4.e. and 4.f.

4. Discussion of Main Problems.

a. REDSTONE Missile.

The REDSTONE missile is being developed as a ground support weapon for a payload of 6900 lbs. As of this date, 4 missiles have been launched, [6] 3 of which were successful.... The R&D program provides that missiles #27 and #29 will be equipped with enlarged tanks and used for re-entry studies. Launching of those two missiles is scheduled for Spring of 1956. This particular version of the REDSTONE is suited for the booster for the proposed Minimum Satellite Vehicle without changes. It is obvious that a high degree of reliability is a prerequisite for the REDSTONE's application for a satellite project. Thus the R&D program of the REDSTONE as a weapon will in no way be affected by the proposal presented herein. Its successful completion is rather a prerequisite for the Minimum Satellite Vehicle.

b. Cluster LOKIs.

LOKI is an anti-aircraft solid propellant rocket developed for the Ordnance Corps. LOKI I is presently in production (Production cost less than \$100.00 per missile).... The highest performance is obtained by the improved LOKI IIA type, which is scheduled for production soon. Performance data of LOKI IIA are summarized in the following table:

Weight of rocket hardware	5 lb
Weight of propellant	17.3 lb
Total weight	22.3 lb
Specific impulse	219 sec
Combustion chamber head pressure	1320 psi
Thrust	2000 lb
Burning time	1.9 sec

The Air Research and Development Command has initiated a program for the development of a "Hypersonic Test Vehicle" (HTV). This vehicle is a two-stage solid rocket, using a cluster of 7 LOKIs in the first, and a cluster of 4 LOKIs in the second stage.... The first four rounds have been contracted with Aerophysics Development Corporation, Pacific Palisades, California, and will be fired in late 1954, starting about eight weeks from this writing. Firings will be at White Sands Proving Ground.

In view of Redstone Arsenal's great concern with the problem of re-entry of ballistic missiles of extended ranges, supporting research funds for FY 1955 and FY 1956 have been requested for the purpose of expanding this Air Force-sponsored program. Such a joint Army-Air Force program is expected to furnish, at minimum expense, vitally needed data on heat transfer, and behavior of structures and material, at Mach numbers from 8 to 13.

[7] The Hypersonic Test Vehicle may be considered a natural forerunner of the three-stage LOKI cluster for the proposed Minimum Satellite Vehicle. But here again, the Satellite Vehicle Project could never delay the development of the Hypersonic Test Vehicle, since success with the HTV is a prerequisite for the former.

c. Accuracy of launching LOKI cluster from REDSTONE nose.

An important problem is the accuracy of aiming the REDSTONE nose section with its LOKI cluster into the horizontal direction at the summit of the first stage trajectory. This becomes evident by comparing the lifetime of the two orbits described in chapter 3.c.(5). The standard spatial attitude control of the REDSTONE missile nose necessitates at least two blasts of the control jets for the correction of an angular deviation of any of the three missile axes: one blast to turn the missile to the zero position and another one to stop it in this position. In reality the zero position can be approached only after repeated application of control jets, because of oscillations around the zero position (poor damping). This spatial attitude control method, therefore, keeps the missile axis continuously and slowly oscillating around the desired zero position. While this is entirely adequate for the standard REDSTONE trajectory, it constitutes a severe handicap for the launching of the LOKI's at the apex of the first-stage trajectory.

The proposed pre-rotation of the zero launcher with its LOKI cluster at 1800 rpm has the effect that launcher and LOKI cluster are gyro-stabilized as long as no external forces are applied. But their joint longitudinal axis can be precessed into any desired direction by applying a force perpendicular to the desired angular direction of movement. The turning of the axis stops, if the applied force stops. It is evident that this method avoids those undesirable oscillations around the desired firing direction of the LOKIs and results in a higher accuracy of the aiming of the cluster. The pre-rotation of the LOKI cluster launcher has the additional and important advantage, that it minimizes the error introduced by inaccuracies in the alignment of the LOKI bundles, of their thrust axis, ignition delays, differences in burning times, and possible torques caused in the rockets

leaving the zero launcher. A preliminary analysis indicates that by using the pre-rotation method the total error angle built up during the burning time of the three-stage LOKI cluster may be kept well under 1 degree, which, according to the figures listed in chapter 3.c.(5) is adequate for an extended orbital lifetime of the uppermost stage. The exact magnitude of such error angles will be known after a number of Hypersonic Test Vehicles have been launched.

d. A stepping stone: Very high altitude firing of the Minimum Satellite Vehicle.

As an intermediate step toward a Minimum Satellite Vehicle it is suggested to launch a missile, consisting of a REDSTONE as a booster, and a LOKI cluster as upper stages, from the REDSTONE launching site at [8] Patrick Air Force Base, in a nearly vertical trajectory (approximately 2 degrees). This missile would consist of a REDSTONE (with enlarged tanks) and a cluster of 24-6-1 LOKIs, and would reach an altitude of 6400 miles (almost two earth radii!). The purpose of this firing would be to test the combination of REDSTONE booster and spinning LOKI cluster during the REDSTONE flight phase, the technique of pre-rotation of the LOKI launcher, and the launching of the LOKI bundle. Such a near-vertical firing would permit accurate tracking from take-off all the way to, and including, the uppermost stage of the LOKI cluster, and the deviations of the latter's trajectory from the flight path tangent at REDSTONE cut-off. Additional data could be telemetered if desired. The velocities reached by the various stages would be

1st stage (REDSTONE)	7900 ft/sec
2nd stage	14150 ft/sec
3rd stage	21300 ft/sec
4th stage	28300 ft/sec

Such an experiment would involve no dangers from the standpoint of flight safety. The REDSTONE booster would drop into the ocean at a range of about 110 N. Mi. (the same range as anticipated for re-entry missiles #27 and #29). The upper stages would never reach the earth surface again but burn up like meteors upon re-entering the atmosphere. Since LOKI rockets are made of aluminum, re-entry temperatures are sufficient to melt and even vaporize the falling rockets.

e. Selection of orbit for the Minimum Satellite Vehicle.

The selection of a suitable orbit for the Minimum Satellite Vehicle is closely linked to the problem of tracking and the number of tracking stations required. As a result of the combined effects of orbital motion and earth's rotation, any orbit inclined to the equatorial plane leads over a vast portion of the earth's surface and the Minimum Satellite Vehicle may thus be visible from many regions on earth. From the "propaganda" angle, this may be desirable, but it may also entail less desirable political problems. From the scientific aspect the main disadvantage of an inclined orbit lies in the fact that it is impossible to set up a sufficient number of tracking stations to "keep an eye" on the Minimum Satellite Vehicle. It must be kept in mind that the Minimum Satellite Vehicle is of limited lifetime because it is still affected by drag in the uppermost layers of the atmosphere. This means that the coordinates of the elliptical path change slightly with each revolution. Such slight changes, on the other hand, offer an ideal opportunity to determine the atmospheric density at altitudes from 150 to 800 miles.

Effective tracking requires that the Satellite passes repeatedly over the same station or stations. Therefore, an orbit in the equatorial [9] plane is most advantageous. In order to reduce the logistic problem of the firing preparations and launching, the Minimum Satellite Vehicle could be launched from the Navy's experimental guided missile ship USS "Norton Sound." In addition to the reasons mentioned before, the equatorial plane offers the great advantage that a velocity gain of 1519 ft/sec is obtained due to the rotation of the earth, if the satellite vehicle is launched in an eastern direction.

f. Visibility of Minimum Satellite Vehicle in the orbit.

Another prerequisite for successful tracking is sufficient light for optical tracking instruments. The simplest method to provide sufficient illumination and contrast would be to observe the Satellite shortly before dawn or shortly after sunset. The Satellite, illuminated by sunlight, would then be visible as a fast-moving star against a relatively dark sky. A study of this possibility indicates that, in order to obtain a brightness equivalent to that of a star of first magnitude (e.g. "Capella"), the object would have to be at least 20 feet in diameter. In principle, it appears quite feasible to provide a reflecting surface of this size even within the payload limitation of 5 lb. A particularly simple solution would be a balloon, carried aloft collapsed in the fourth stage's nose, and inflated with Helium after the orbit has been attained. However, it is likely that such a balloon would soon be punctured by cosmic dust particles and become ineffective as a light reflector. Therefore, some kite-like structure may be better suited.

Unfortunately, the conditions for visibility by a tracking station are severely restricted by the (unpredictable) deviations from the desired orbit caused by lack of accurate cut-off velocity control and possible cut-off tangent dispersions of the uppermost stage, as well as uncertainty of upper atmosphere density. Tracking at dusk and dawn will, therefore, be a rather haphazardous endeavor and should be supplemented by an active light source in the uppermost stage. Such possibilities have been discussed with Mr. E.P. Martz, Jr., Chief Optical Systems Section, Flight Determination Laboratory, White Sands Proving Ground. Mr. Martz has suggested to equip the Minimum Satellite Vehicle's uppermost stage with a gaseous discharge tube actuated by solar storage cells utilizing the solar radiation during the sunlit portion of flight and re-emitting as a flashing light during the night. He believes that use of solar storage batteries such as developed by Bell Telephone and by Wright Field are promising. It appears probable that such a light source, adequate for instrument tracking for a period exceeding one month, can be built within the payload limitation of 5 lb. Further studies will be required to determine whether the light flashes can be made bright enough for visibility with the naked eye.

Further methods discussed to improve optical visibility of the satellite vehicle include painting of the uppermost stage with fluorescent paint (brightness could be doubled because ultraviolet light is [10] converted into visible light) and luminescent paint (will absorb sunlight during the day and omit light during the night). There is also a faint possibility for the successful use of chemical smoke trails, such as used in tracking of solid rockets. (It has to be further investigated whether this method is suited to a Satellite.) Chemical flares or shaped charges may also be feasible. Another possibility would utilize solar or artificially induced fluorescence of sodium, mercury or other metallic vapors. (The fluorescence of such vapors is greatly increased by the high ultra-violet radiation from the sun in the vacuum of outer space.) Finally, use of fluorescence of solid mediums has been discussed. (The solid mediums would be activated by small electric current and additionally by solar radiation and radioactive substances.)

For ground tracking stations, normal meteor tracking cameras appear to be best suited. Such equipment is available at White Sands Proving Ground.

5. Acknowledgements.

This report has been based on detail studies prepared by:

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Redstone Arsenal, Huntsville, Alabama.

6. References.

a. "Observing the weather from a satellite vehicle", lecture presented at the American Museum - Hayden Planetarium, May 4, 1954 by Harry Wexler, Chief, Scientific Services Division, U.S. Department of Commerce, Weather Bureau.

b. "Minimum Orbital Unmanned Satellite of the Earth (MOUSE)" for Astrophysical Research. Lecture presented at the American Museum - Hayden Planetarium, May 4, 1954 by Dr. Fred S. Singer, Professor, Dept. of Physics, University of Maryland.

Document II-8

Document title: "On the Utility of an Artificial Unmanned Earth Satellite: A Proposal to the National Science Foundation, Prepared by the ARS Space Flight Committee, November 24, 1954," *Jet Propulsion*, 25 (February 1955): 71-78. [Copyright American Rocket Society (now American Institute of Aeronautics and Astronautics), 1955. Used with permission.]

In 1934, the American Interplanetary Society, one of the earliest U.S. advocates of spaceflight, had changed its name to the American Rocket Society (ARS) to improve its technical legitimacy. In 1953, the ARS invited Alan T. Waterman, director of the National Science Foundation (NSF), to attend a meeting of the society's Space Flight Committee. Soon after, the committee issued a confidential report calling for the NSF to study "the utility of an unmanned satellite vehicle to science, commerce and industry, and national defense." This report was followed in 1954 by a formal proposal, "On the Utility of an Artificial Unmanned Earth Satellite." It was partly because of advocacy groups such as the ARS that satellites were put on the government's scientific agenda.

[71]

Introduction

This is a proposal to the National Science Foundation that the Foundation sponsor a study of the utility of an unmanned, earth-satellite vehicle. The proposal is made by the American Rocket Society in the normal exercise of its functions.¹ The role of the Society in this matter is made clear by the following policy statement adopted by the Board of Directors: "The American Rocket Society should act as a 'catalyst' and should promote interest and sound public and professional thinking on the subject of space flight. It should not attempt to evaluate the merits of individual proposals or undertake work on the subject of its own accord. It should, however, encourage such activity on the part of other organizations."

It is apparent, then, that the Society cannot undertake to make the study. It can, however, serve the National Science Foundation in a number of ways, and believes it is doing so in bringing this subject to the Foundation's attention. Should the Foundation elect to sponsor the study the Society could assist by encouraging scientists and engineers both inside and outside the Society to participate. The Society would be willing to perform any other service within its functions and abilities to assist the National Science Foundation in implementing this proposal.

1. The American Rocket Society is a professional engineering and scientific organization devoted to the encouragement of research and development of jet and rocket propulsion devices and their application to problems of transportation and communication. It is actively concerned with various technical aspects of space flight, and at the present time is also interested in military applications of the reaction principle.

Background

The proposal was prepared by a Space Flight Committee appointed by the President of the Society. The Committee decided that the study of the utility of an unmanned, earth satellite would be one of the most important steps that could be taken immediately to advance the cause of space flight, and that this step would also increase the country's scientific knowledge and, indirectly, promote its defense.

Why an unmanned, earth satellite? Although many satellite proposals have been put forward, the small, unmanned satellite is the only one for which feasibility can now be shown. This opinion is held by many responsible engineers and scientists involved in rocket and guided-missile work and in upper-atmosphere research. At any rate, most of these people agree that the unmanned earth satellite would be the first step toward more ambitious undertakings. It is felt generally that, although the satellite vehicle has yet to be built, the components, i.e., power plants, airframes, stabilization systems, etc., are either available or under development in conjunction with the nation's guided-missile effort. Furthermore, the country now has nine years of experience in the techniques of instrumenting high-altitude sounding rockets, which techniques would have application to the earth satellite.

Why study utility? Although many claims have been made for the utility of a satellite vehicle and many uses have been proposed, the subject has not been thoroughly investigated by a responsible organization and, at present, does not rest upon a firm foundation. On the other hand, enough is known about possible useful purposes so that most cases are readily amenable to study, and, if such a study were made, reasonably positive conclusions could be drawn. Because of recent advances in guided missiles, the cost of producing a small, unmanned satellite is probably not the mammoth sum that was at one time considered necessary. Nevertheless, the creation of even a small satellite is still a major undertaking and will require a sizable amount of money. It is important that there be justification for the expenditure of this money. The Society feels that to create a satellite merely for the purpose of saying it has been done would not justify the cost. Rather, the satellite should serve useful purposes—purposes which can command the respect of the officials who sponsor it, the scientists and engineers who produce it, and the community who pays for it. The Society feels, therefore, that the study of utility is one of the most important tasks to be accomplished prior to creation of a satellite.

It was apparent to the Committee in its early deliberations that the subject of utility could not be entirely divorced from feasibility, and that some concept of feasibility would have to be assumed. This was done not to be restrictive, but to provide a frame of reference from which those considering utility could proceed. It was assumed that it would be feasible to establish a small payload in an orbit, the difficulty increasing with the size of the payload, and that means could be provided for communicating information from the satellite to the surface of the earth. With this concept in mind, various fields of utility were suggested as follows:

Astronomy and Astrophysics. A satellite could overcome some of the limitations on observations made through the earth's atmosphere.

Biology. Of early importance would be the effects of outer space radiations on living cells.

Communication. A satellite might provide a broad-band transoceanic communication link. A future possibility is that of obtaining continental coverage when the satellite is used as a relay station for radio or television broadcasts.

Geodesy (including Navigation and Mapping). The size and shape of the earth, the intensity of its gravitational field, and other geodetic constants might be determined more accurately. Practical benefits to navigation at sea and mapping over large distances would ensue.

Geophysics (including Meteorology). The study of incoming radiation and its effect upon the earth's atmosphere might lead eventually to better methods of long-range weather prediction.

Experiments Arising from Unusual Environment. The characteristics of the environment (weightlessness, high vacuum, temperature extremes, etc.) will suggest experiments that could not be performed elsewhere.

This list is by no means complete—it is probable that the study would reveal other fields of equal or greater utility.

In order to provide a preliminary sampling of opinion, the committee asked a number of scientists (chosen at random from those known to Committee members) to give brief summaries of their opinions on the utility of an unmanned, satellite vehicle. These papers are presented as appendixes to this proposal and include the following: (A) "Astronomical [72] Observation from a Satellite," by Ira S. Bowen; (B) "Biological Experimentation with an Unmanned Temporary Satellite," by Hermann J. Schaefer; (C) "The Satellite Vehicle and Physics of the Earth's Upper Atmosphere," by Homer E. Newell, Jr.; (D) "Comments Concerning Meteorological Interests in an Orbiting, Unmanned Space Vehicle," by Eugene Bollay; (E) "The Geodetic Significance of an Artificial Satellite," by John O'Keefe; (F) "Orbital Radio Relays," by John R. Pierce.

Recommendation

In view of the facts cited, it is proposed that the National Science Foundation sponsor a study of the utility of an artificial, unmanned earth satellite.

ANDREW G. HALEY, *President*
MILTON W. ROSEN, *Chairman*,
Space Flight Committee

COMMITTEE MEMBERSHIP: Harry J. Archer; William J. Barr; B. L. Dorman; Andrew G. Haley; Kenneth H. Jacobs; Chester M. McCloskey; Keith K. McDaniel; William P. Munger; James R. Patton, Jr.; Richard W. Porter; Darrell C. Romick; Milton W. Rosen; Michael J. Samek; Howard S. Seifert; Willis Sprattling, Jr.; Kurt R. Stehling; and Ivan E. Tuhy.

Appendix A Astronomical Observations from a Satellite

IRA S. BOWEN
Mount Wilson and Palomar Observatories

The following comments are an expansion of a conversation held by H. S. Seifert with Dr. Ira S. Bowen, Director of the Mount Wilson and Palomar Observatories. The ideas herein originated with Dr. Bowen and have been reviewed by him for accuracy.

Astronomical observations through the Earth's atmosphere are at present limited by three factors: (a) The resolution of detail is degraded at least tenfold by atmospheric turbulence (poor seeing). (b) Exposure time, and hence limiting star magnitude, is curtailed by fogging due to light scattered in the atmosphere. (c) Certain radiations, i.e., regions of the spectrum, are completely absorbed in the atmosphere. Thus, if optical equipment equivalent to that now available at the surface could be placed outside the atmosphere, much additional information in the form of planetary detail, new, remote, or faint objects, and short wave-length spectra would be obtained. This information would be of great interest and value to astronomers and to the sciences generally. The ideal situation would be to place the 200-in. telescope and its accessories on a firm platform such as the moon.

Since optical equipment projected into an orbit on a man-made satellite will be riding on a small and relatively unsteady base, certain practical limits and difficulties will be found, as follows:

Angular Resolution. The best optical resolution which the atmosphere will permit, on days of optimum seeing, which occur only a few times yearly, is of the order of $1/4$ to $1/2$ sec of arc. The 200-in. telescope would permit a theoretical resolving power of 0.025 sec of arc, and a 20-in. to 40-in. telescope would permit a resolving power of 0.25 to 0.125 sec

of arc, if free from atmospheric effects and geometric distortions. Thus in order to make use of the transparency of space and secure more detail than can be seen from the ground, an automatic satellite orienting and guiding system would be needed which was stable to an accuracy lying between 0.10 and 0.01 sec of arc.

Limiting Magnitude. Because of night sky light scattered by the atmosphere, objects fainter than a certain limiting magnitude cannot be distinguished from the general background fog. In the case of the 200-in. telescope, exposures longer than half an hour are, for this reason, not useful. In order to record objects of the same faintness, as can be done with the 200-in., a telescope of reasonable size for transport on a satellite, say 30 in., would require an exposure time of 10 to 24 hours. Since the orbital period is of the order of $1\frac{1}{4}$ hours, of which less than half is spent in the Earth's shadow, a mechanism would be required for shielding the telescope and camera during the sunlit periods while maintaining precise orientation.

Short Wave-Length Spectra. By the use of sounding rockets equipped with sun-following servos, it has been possible to photograph solar spectra down to 1200 Å with low resolution. The long exposures required for high-resolution solar and stellar spectra in this wave-length region cannot be obtained during the few minutes or even seconds of high-altitude flight time typical of sounding rockets. Adequately high resolution could be obtained from a spectrograph using light collected with a 12-in. mirror for detailed spectra of the brighter stars, with exposures of several hours. Since the physical dimensions of the equipment are not large and the orientation tolerances are less strict than for telescopic images, a spectrograph would probably be simpler than a telescope to get into proper working order.

Telemetering of Data. If one assumes that a photographic plate cannot be recovered from a satellite, certain problems arise. Any data collected must be capable of being translated into a radio or optical signal and relayed to the ground. The photographic plate has the fundamental advantage that photons are registered simultaneously in all resolvable parts of the spectrum or image. Thus shortening required exposure time. While electronic photon counters exist which equal or excel the sensitivity of the photographic plate, they can collect energy from only one part of the spectrum or image at a time, thus increasing the required exposure time.

A possible technique might be worked out in which plates are exposed and developed automatically (after the manner of the Polaroid-Land Camera), after which the fixed image could be scanned and transmitted sequentially when convenient by a photo-electronic system. Thus the stored data might be held and relayed by a transponder activated from the earth's surface only when the satellite was within radio range of a particular ground station, thus eliminating the need for a dozen or more ground telemetering stations spaced around the equator.

Appendix B

Biological Experimentation with an Unmanned Temporary Satellite

HERMANN J. SCHAEFER
U.S. Naval School of Aviation Medicine

If humans are to fly in the regions at the upper end of and outside the atmosphere, an "artificial environment" has to be provided which maintains full or near sea-level values of the various physical conditions. Whereas this task can be handled, though with considerable technical expenditure, for most of the factors involved, two novel phenomena develop in vehicles moving outside the atmosphere which cannot be compensated very easily. These are the heavy components of the primary cosmic radiation and the state of weightlessness. The technical means of restoring normalcy with regard to these conditions, though theoretically available, imply prohibitive measures with regard to weight and power. The only way out is to study the effects of both influences on the human organism with the aim in mind that a tolerance can be established which does not impose too severe

limitations upon the flight of humans in extra-atmospheric regions.

In the discussion of the usefulness of a small artificial satellite for the conquest of space, the question has been put [73] whether biological experiments could be performed in such a vehicle for gaining information as to the two aforementioned problems. The artificial satellite, in this discussion, is conceived as an unmanned and rather small vehicle which will stay in the orbit a limited time only, a few weeks at the most. A further limitation is that preferably all experiments are to be carried out by preset servomechanisms and telemetered recording. This would by-pass the complex and difficult task of recovery.

It should be pointed out from the very beginning that the last-mentioned condition imposes serious restrictions on any biological cosmic-ray experimentation to the degree where it seems questionable whether useful experiments can be designed at all. Exposure to the heavy components of the primary cosmic radiation belongs to the category of so-called long-dosage long-term irradiations which are characterized by slowly developing, initially inconspicuous, but insidious tissue damage. The peculiar feature about this exposure hazard is that a total ionization dosage which nominally remains well within the permissible limits of the official international definition is actually administered in an extremely uneven distribution. As a consequence of it, a small number of cells of the exposed tissue receive ionization dosages up to 10^5 times larger than the average total ionization dosage. It is already well established experimentally that such "heavy nuclei hits" produce severe local radiation injury in the cellular structure of living tissue. No information, however, is available on how many of such hits can be administered to the mammalian organism before a general reaction, i.e., manifest radiation injury, develops.

A conclusive answer to the latter question requires exposure of test animals over an extended period of time. Rocket or balloon flights are entirely inadequate for this purpose, the former because of the short duration, and the latter because of the too low altitude. The study of the radiation effects of the genuinely primary cosmic radiation in regions entirely outside the atmosphere, with exposure times of many days, is of fundamental value for both basic research in radiobiology and the development of high altitude flight. Experiments carried out in an artificial satellite would contribute greatly toward a solution of this problem and would be incomparably more effective than any balloon or rocket flight can ever be.

There are a multitude of radiation effects on living tissue which lend themselves to experiments of the type under consideration. Local radiation injury from heavy nuclei hits has been demonstrated recently very conspicuously in skin tissue of mice. This reaction, however, requires that the animals be recovered alive. Other reactions exist which are of similar sensitivity, but could be tested even if the animal were killed while recovering it as long as the latter is not heavily disfigured or burned. An essential prerequisite for all these reactions is a meticulous autoptic and microscopic examination. That means that recovery of the animals is indispensable. It is suggested, therefore, that the problem of recovery be included in the project from the onset if investigation of biological cosmic-ray effects is contemplated at all.

The discussion of the biological effects of the primary cosmic radiation would be incomplete without mentioning a question which actually concerns the physicist. This question pertains to the fragmentary knowledge of the frequency and the mass spectrum of super-heavy nuclei. Heretofore, iron (Fe) was considered the heaviest regularly occurring component of the heavy spectrum. However, heavier nuclei have been recorded on rare occasions, but no statistics have been established thus far with regard to frequency and mass spectrum. Recordings over extended periods of time in the regions clear of the atmosphere would rapidly accumulate data on these giant nuclei. Such measurements, in contradistinction to actual animal experimentation, could be carried out exclusively by telemetering. As a matter of fact, J. Van Allen has already developed the tools for this type of measurement. His pulse ionization chamber has proved a sensitive and reliable instrument for analyzing the heavy nuclei spectrum and has been repeatedly and successfully used for heavy nuclei recordings at extreme altitudes with rocket balloon tandems. A modification of his method for use in an artificial satellite should be comparatively easy.

The other novel environmental condition to be encountered in orbital travel outside the atmosphere is weightlessness. Present-day knowledge as to its physiological effects is scarce. The state of weightlessness or, as it is also called, the gravity-free state, can be produced artificially in a freely falling elevator car, in the warheads of rockets in unpowered flights outside the atmosphere, and in the powered flights of high-speed aircraft by steering along a free trajectory. The rocket method is most effective and can produce the state of weightlessness for a period of a few minutes. It cannot be used for humans at the present state of development. Second in effectiveness is the trajectory flight of high-speed aircraft. Its present limit stays at a longest duration of about 30 sec. It can and has been applied to humans. No physiological disturbances or incapacitation effects have been so far reported. The same statement holds for animal experiments with mice and monkeys in rockets. Considering the short exposure time of both vehicles, these findings cannot be considered as conclusive evidence that such disturbances will not develop eventually.

In an animal capsule carried by an artificial satellite this problem could be more thoroughly studied and the success of the experiment would not necessarily depend upon the recovery of the animals. A few telemetering channels, reserved for relaying breath and pulse frequencies, would provide interesting information. Telemetering of the locomotion of the animals could also be valuable.

It must be admitted, of course, that the more severe effects of weightlessness of long duration on humans are likely to develop along the psychophysiological line originating from disorientation. Animal experimentation, therefore, can be of limited value only, though some disorientation studies have been successfully performed with mice in a rocket flight.

Evaluating the entire situation on a comparative basis, it must be said that the cosmic-ray problem certainly bears the higher practical importance as well as scientific interest. It should weigh heavily in any debate on the justification of the costs involved in a satellite project, and this all the more since it is closely related and can be combined with research problems concerning the pure physics of cosmic radiation on which paramount importance rests with regard to gaining knowledge of the nuclear forces.

Appendix C **The Satellite Vehicle and Physics of the Earth's Upper Atmosphere**

HOMER E. NEWELL, JR.
Naval Research Laboratory

The purpose of the present note is to consider the usefulness of the satellite vehicle for scientific research and to point to a few important experiments which might be done with such a vehicle.

The gas particles, ions, and radiations of the earth's atmosphere act, react, and interact to produce phenomena which are still not fully understood, such as the ionosphere, the aurora, and fluctuations in the earth's magnetic field. In an effort to explain these things a host of researches have been undertaken throughout the past half century; and the effort continues to grow.

Fundamental to the research of the atmosphere has been and is the question of energy. The complex and confusing happenings in the atmosphere are simply a manifestation of [74] an influx of energy from outer space. A detailed knowledge of the nature and magnitudes of the energies concerned would go a long way toward solving some of the important problems. But it is right here that the observer on the ground runs into basic difficulties. The incoming energy in which he has the greatest interest is that which is absorbed at high altitude. The experimenter is, therefore, prevented from observing it in its original form. This leaves many a theorist to speculate on one of the most important ingredients of his theory.

A space station at sufficiently great altitude, say a thousand kilometers or more, would enable the physicist to monitor the energy influx into the earth's atmosphere. A primary

carrier of such energy would be electromagnetic radiation from the sun, measurements of which would be of as much interest to the solar physicist as to the geophysicist. Energy is also brought in by particles such as cosmic rays, meteors, and micrometeorites. Because of their extremely high particle energies, the cosmic rays have an important place in current nuclear research. They produce a small but important ionization in the lower atmosphere, but probably have a negligible effect upon the upper atmosphere. Lower energy particles from the sun are believed to cause the aurora, and, in fact, protons have been observed moving downward in auroral displays. It also appears as though such particle radiations may play a significant part in the formation of the ionosphere, particularly the F-region. At the moment the question is wide open and is an important one. Finally, for the sake of completeness, perhaps one ought to mention stellar light, although to the upper-air physicist the corresponding energies are entirely negligible in comparison with those found in solar light.

At the present time rockets are being devoted to an intensive study of the various radiations listed in the preceding paragraph. The rockets permit the experimenter not only to observe and measure the radiations, but also to determine the altitudes at which the different radiations have their effect. The rockets are, however, one-shot affairs, and furnish only a matter of minutes in which to observe. They are not convenient for making a large number of measurements over an extended period of time. It is here that the satellite would be of considerable value. Equipment carried in such a vehicle could be used to measure a specific radiation over long intervals of time.

Arrays of geiger counters could be used to monitor the influx of cosmic rays. By using counters with varying amounts of material to be penetrated by the rays, it would be possible on the low energy side to count the particles in a number of low energy bands. These would perhaps be the simplest cosmic ray experiments to be done. With a little more complication, proportional counters and low efficiency geiger counters could be employed to determine the charges on the particles observed. If the satellite station were made to encircle the earth in a geomagnetic meridian plane, the earth's magnetic field could be used as a rigidity spectrometer, just as is done now in balloon and rocket-borne experiments. By comparing observations made at different geomagnetic latitudes, the low energy end of the cosmic ray spectrum could be studied in detail.

Counters with very thin windows could be used to study auroral particles, which are of several orders of magnitude lower energy than what are commonly termed cosmic rays. As a matter of fact, it may well be that incoming particles will be found to fill out a continuous spectrum of energies between the kilo-electron volts now associated with auroral particles and the billions of electron volts found in the cosmic rays. If so, it will be of considerable interest to observe and study these particles.

Photon counters with various fillings and windows, and photomultiplier tubes, are now used in rockets to study different bands of solar electromagnetic radiation from the visible wave lengths down into the x-ray regions. Present techniques would be adaptable to observations from a satellite station. Such observations would permit a study of the fluctuations over extended periods of time in the different wave-length bands. These fluctuations are connected with solar activity and give rise to distinct effects in the earth's atmosphere. Variations in the near ultra-violet, for example, cause changes in the distribution of ozone in the atmosphere and perhaps have an effect upon weather. Variations in the far ultra-violet and x-rays have a pronounced effect upon the ionosphere, and much more data are required to understand these effects.

The magnitude of the influence of meteors, especially of micrometeors, upon the earth's atmosphere is not yet fully known. Of late there is some tendency to ascribe considerable significance to the role of the micrometeors in the ionization of the higher ionospheric layers. At present, radar and radio techniques are the primary ones in the study of these particles, but methods are being worked out for rocket studies. For example, a very thin sheet of metal used as a resistive element in a circuit would be one means of detecting micrometeors. The particle, upon striking the sheet, would produce a tiny puncture, giving rise to a small but observable pulse. Such a sheet could be used similarly as one plate of

a condenser. These rocket techniques, when developed, could also be used in a satellite observatory.

The foregoing experiments are of interest to the upper-air and solar physicist. It seems clear that known techniques, such as those suggested, could be used to carry out the various experiments. Familiar telemetering methods, such as those now used in rocket studies, could be adapted. But, there will be, of course, peculiar experimental difficulties to overcome. A number of these difficulties are already quite plain, although there may be some that are not now apparent.

One of the foremost problems is that of power. It has already been pointed out that a chief advantage of a satellite platform would be the possibility of making continuing observations over long periods of time, such as throughout a given year. The longer the period which could be covered the more satisfying would be the experiment. But to make the various measurements would require energy, which, presumably, would be stored in batteries. Associated with each 50 watt-hours of such stored energy would be something like one pound of battery mass. Including the operation of transmitting measured data, the satellite experiment would probably use energy at the rate of at least 20 watts. Assuming that the mass limitations in an early satellite vehicle would be on the order of 100 lb. this would preclude continuous operation over anything even approaching a year. To surmount this obstacle one would probably resort to periodic operation, to low current components like transistors, and to the use of the sun's light for the recharging of batteries. In this last connection, one may note the recent announcement by the Bell Telephone Laboratories of a solar device, consisting of thin silicon strips with an even thinner covering of boron, which could produce about 50 watts per square yard of exposed surface. The equipment could be turned on and off periodically by some low power timing device, or by radio means from a ground recording station. The latter method might be the preferable one, since it would permit turning on the equipment whenever ground-based observations showed the existence of unusual solar, ionospheric, or cosmic ray activity.

A second problem would be that of temperature. If the satellite were to present the same side always toward the sun, that side would become intolerably hot. By having that station rotate, however, enough of the energy absorbed at any spot on the satellite's surface could be reradiated into outer space to keep the temperature of the station and its equipment at an admissible level. This procedure would, however, introduce some difficulties into the basic experiment. Some omnidirectional arrangement of sensing elements would be required in order to make the experiment independent of the station's orientation. For the high energy cosmic ray [75] experiments, this could be done with crossed counters. In the case of low energy particles and solar ultra-violet light and x-rays, requiring counters with special windows, banks of counters might be the answer. A number of counters connected in parallel could encircle the satellite so as to present a window on every side.

The weightlessness of everything in the satellite might present some vexing problems. Thus, gassing of the batteries used is no cause for concern on the earth, where the bubbles simply rise in the liquid and pass off harmlessly. But in a nonrotating satellite station, the gas bubbles would not rise.

Remaining right where they form, they would cause the electrolyte to foam and fizz, like a bottle of soda. In a rotating satellite the centrifugal force field due to the station's rotation might provide the answer to such problems as this.

The satellite would be giving off gases continuously from the surfaces exposed to space. Also, in the near-vacuum surrounding the station, the metal structure of the satellite would evaporate slowly. Such effects would make it extremely difficult, if not impossible, to measure the original material content of the space in the neighborhood of the vehicle. Hence, although of great interest, such measurements are not suggested at the present time for a satellite experiment.

Appendix D Comments Concerning Meteorological Interests in an Orbiting Unmanned Space Vehicle

EUGENE BOLLAY
North American Weather Consultants

In view of the fact that unmanned, orbiting space vehicles appear to be feasible with our present engineering knowledge, it would seem appropriate to comment briefly on measurements one might desire to make of meteorological interest in space.

Our present concepts in meteorology revolve largely around the solar balance and the resulting fluid dynamic consequences. Such consequences are produced by heating a gaseous mixture, such as the earth's atmosphere, unevenly under various roughness conditions. A large scientific effort has been made in connection with these hydrodynamic considerations, in contrast to studying the initiating impulse—the solar radiation phenomena.

It would seem that a space-observing platform would be ideally suited for collecting direct solar measurements as well as indirect solar relationships such as magnetic storm activity, etc.

Another item to analyze from a space station is a census of meteoric dust. The recent correlation by Dr. Bowen in Australia of meteoric dust and rainfall deserves rather intense and careful research.

The saying that one does not see the forest because of the trees may be rather appropriate to this problem. On earth we are engulfed in numerous meteorological details which mask or have masked rather completely the initiating circumstances which may become evident from observations in space. Connection of the theories of the General Circulation of the Atmosphere to direct solar influences is still lacking. Information from space may provide data for the solution of this challenging problem.

Appendix E The Geodetic Significance of an Artificial Satellite

JOHN O'KEEFE
Army Map Service

I. Purpose and Scope

This report is intended to indicate the extent of the usefulness of a small artificial satellite, weighing only a few pounds, in finding out more about the size and shape of the earth, the intensity of its gravitational field, and certain other related constants.

II. Illumination

Most of the possible applications of the satellite would depend on detecting its presence either by visible light or by radar. The latter application falls outside the scope of the present paper, which would be chiefly concerned with the application of visible light. The first question is, then, how the satellite could be illuminated with sufficient brilliance to be observed.

A. Sunlight

Assuming that the satellite were to consist of a hollow aluminum sphere, 8 ft in diameter, such as could be produced by inflating a foil, it would have a surface brightness somewhat greater than that of the moon. The ratio of the total brightness would then be the ratio of the apparent surface area. At a distance of 250 miles, an 8-ft sphere would have a surface area of 1.1×10^{11} square radians. The moon has a surface area of 1.31×10^4 square radians or 1.2×10^7 times as great. The full moon is of -12 magnitude; the above ratio in brightness corresponds to approximately 17.7 magnitudes. The higher reflectivity of

aluminum as compared with lunar surface is compensated for by the fact that the moon has been taken as full while the satellite will be in a partial phase. Thus the object would have a brilliance of a star of magnitude 5.7, barely visible to the naked eye at night in a clear sky. It would not be visible by day even with a large telescope. Also, it would not be visible even in a large telescope when in the shadow of the earth, since its surface brightness would then be less than that of the fully eclipsed moon. It would be visible only between the end of twilight and the time when it passed into the earth's shadow; the interval might be as little as 15'. From the end of nautical twilight to the entrance into the earth's shadow there would be an interval of about 2^m. The interval could be very considerably increased by setting up an orbit which would parallel the line between night and day over the earth.

B. Intrinsic Illumination

1. Evidently the illumination could be somewhat prolonged by making use of a fluorescent coating which could store up solar radiation, and so continue to shine for some time after the sun's light was cut off. This process would not give any more light than direct illumination; but it might produce a longer storage.

2. There is also the possibility of radiant paint. The order of brightness to be expected here is perhaps less than for a fluorescent coating, and considerably less than that for direct illumination.

3. No method of installing a lamp appears to be promising, from the point of view of fuel required to maintain the lamp for more than a few hours.

C. Illumination of a Retrodirective Reflector by a Searchlight

1. There exist some 60-in. searchlights, which yield 800,000,000 candles on the axis. At 250 miles, or 400 kilometers, this corresponds to

$$\frac{8 \times 10^8}{(4 \times 10^5)^2} = 0.5 \times 10^2 \text{ lumens}/(\text{meter})^2$$

2. During World War II, the army developed some glass trihedral reflectors. These have the property of returning light over the same path as that along which the light came to them, with a spread of about 12 in. The effective area of the [76] ordinary trihedral reflectors is such that one would receive about 2.5×10^9 lumens, and throw it back in a solid angle of approximately 1.16×10^9 square radians, thus yielding 2.16×10^9 candles on the axis of the returning beam, or, on the ground:

$$\frac{2.16 \times 10^9}{(4 \times 10^5)^2} = 1.35 \times 10^8 \text{ lumens}/\text{sq meter}$$

According to the fundamental measurements of Fabry, a first-magnitude star yields 8.3×10^7 lumens/sq meter; hence we should require ten searchlights and six trihedral reflectors to arrive at this amount. To take care of the various aspects of the missile, it might be best to have 72 trihedral reflectors distributed six each on the faces of a regular dodecahedron in order to have adequate returned light in all aspects. There would be a loss of one to three magnitudes from atmospheric absorption in each direction, depending upon the altitude; thus the satellite would appear as an object between the third and seventh magnitudes.

III. Conclusions on Observability

Balancing the disadvantages of irregular motion against the advantages of approximately known position and speed, it appears likely that objects of the 14th magnitude could be observed. On the other hand, we have seen that an object of the 4th magnitude

could be produced; there is thus a margin of 10 magnitudes, or a safety factor of 10,000. If the satellite is imagined to be at 1000 miles instead of 250 miles, the brightness is reduced by a factor of 4² or 256; there is still a safety factor of 40. However, since the searchlights will cause the sky to appear very bright in the direction in which they are pointed, this margin of safety may turn out to be insufficient. We conclude that at 250 miles the satellite should be an easy object; at 1000 miles it may be a difficult object.

IV. Applications

In studying the applications to geodesy of such a satellite, it will undoubtedly be necessary to proceed by successive approximations, since the geodetic data now available are not adequate to permit the calculation of an accurate orbit. For example, it is believed that the present values for the latitudes and longitudes of points in Europe may be inconsistent with the American system of latitudes and longitudes by several hundred feet. For an object at a distance of 500 miles, this would imply discrepancies of the order of one minute of arc between European and American observations, under certain circumstances. Again, the International figure of the earth may be in error by as much as one part in 20,000; this would lead to a discrepancy of 10 sec per revolution between the position calculated from observations of the linear speed and the actual position; for a 2-hr orbit this would amount to 2 min per day. The problem is thus actually a problem of an overwhelming flood of basic information. It follows that it would be difficult to solve for one element at a time; it is necessary to solve simultaneously for several different elements. The following attempt to sort out the results does not correspond, therefore, to the chronological order in which results would be obtained, except roughly.

A. Determination of Relative Positions Between Continents

1. Simultaneous observations on a satellite missile from two independent triangulation systems would seem to fix their relative positions by a modification of the method now being employed for flare triangulation. A missile at a height of 1000 miles would be easily visible from points 2000 miles away. If the missile were set to follow a track around the earth's equator, the countries in which it would be easily visible would be chiefly those between latitude 30° North and latitude 30° South. In the case of a missile fired at some angle to the equator, this difficulty would disappear; on the other hand, there would be a problem of keeping track of the missile.

2. Assuming an angular accuracy of 5 sec in position, and a precision of 0^s.01 in the timing, the accuracy of positioning between independent continental systems would be of the order of 125 ft in each coordinate. Thus it is evident that a correction through a missile would be advantageous.

B. Calculation of g

From observations on the satellite made from a single country, it should be possible to obtain the absolute value of the acceleration of gravity, averaged over a large extent of terrain. Ordinary pendulum gravity measurements do not give absolute values of gravity; instead, the pendulum or the gravity meter is brought to a standard point whose gravity is assumed; and comparisons are made by differential methods. From a freely moving missile, on the other hand, the acceleration of gravity could be directly measured in absolute terms. Best of all, the gravity so measured would represent the average value over a considerable area. At present, such a value, which is required for large-scale geodetic studies, is attainable only by laboriously measuring the values at many points, and then averaging; even when this has been done, there is a danger that the mountainous areas are underrepresented, so that systematic errors are created.

C. Calculation of the Earth's Semimajor Axis a

It appears to be possible to calculate the earth's semimajor axis from considerations relating to the earth's linear surface velocity. It may at first sight seem surprising that it is

not possible to state with extreme accuracy the speed with which we move around the earth's axis. The angular speed is, of course, very well known. By definition, the earth turns on its axis one full revolution in one sidereal day. The speed of the observer in meters per second due to this rotation could be calculated with great precision if we knew exactly how far he is from the earth's axis. This quantity, however, depends on the earth's semimajor axis a and its flattening f . Of these, f if known with a precision which is adequate for the purpose under discussion; the chief uncertainty arises from the value of a .

V. Conclusions

It appears that the setting up of a satellite capable of being observed by theodolites and the like is an engineering possibility and that it would yield results of high geodetic value. If it could be accurately observed, most of the principal problems of geodesy could be attacked successfully.

Appendix F Orbital Radio Relays

JOHN R. PIERCE

1. Introduction

Following the announcement last year that the American Telephone and Telegraph Company and the British Post Office have jointly undertaken the construction of a 36-channel two-way submarine telephone cable across the Atlantic at a cost of 35 million dollars, it is natural, at least for a person who is a complete amateur in such matters, to speculate about further developments in trans-oceanic communication, even into the far future.

Would a channel 30 times as wide, which would accommodate 1080 phone conversations or one television signal, be worth 30×35 million dollars—that is, a billion dollars? Will someone spend this much trying to make a broad-band channel to Europe? The idea is of course absurd. At the present, there is no commercial demand which would justify such a channel. By the time there is, surely some technical solution to the problem will be sought which does not involve multiplying the cost of the present cable in proportion to the bandwidth.

It is conceivable that such a solution could come about [77] through further development in the field of cables; but a very difficult step must be taken to multiply the channel capacity by 30 or more. In the meantime, other means for obtaining a broad-band channel to Europe have been considered, including routes largely across land rather than across water.

A route from Labrador or Baffin Island to Greenland, around the coast of Greenland, thence to Iceland and via the Faroe Islands to Scotland traverses much nasty country by land and still leaves gaps of several hundred miles by sea. These gaps might conceivably be spanned by radio, using very high power. Perhaps it may be possible to make undersea television cables which would span gaps of a few hundred miles before such cables can be made to span thousands of miles. Even granting the success of a difficult radio link or a broad-band cable, both terrain and climate make this indirect route difficult and unappealing.

A route from Alaska across the Bering Strait to Siberia, and thence overland to Europe is conceivable, but it is difficult and indirect and it has other disadvantages which need not be mentioned.

Radio relay along a continual chain of planes crossing the Atlantic has been proposed. While this is certainly technically feasible, in good weather at least, it seems strange either as a long-range or a short-range solution.

Another "solution" has been proposed to the problem of trans-oceanic communication; that is, relaying by means of a satellite revolving about the earth above the atmosphere. I do not believe that many engineers doubt that it will eventually be possible to put a satellite up and into place, nor to supply it with small amounts of power for long periods and to exercise some sort of radio control over it. However, there is no unclassified information to tell us how long it will be before we could put up a satellite or what it might cost to do so, and there may not even be classified information on the subject. Thus, while I am here considering some aspect of trans-oceanic communication via a satellite, I have nothing at all to say about the over-all feasibility of such communication, which must depend on the feasibility of the satellite itself.

Fortunately, there is a good deal else to be said about the matter. For instance, I have spoken of *trans-oceanic* communication only, and I have a reason for this. We now have trans-continental television circuits. The announced cost of the American Telephone and Telegraph Company's trans-continental TD2 microwave system was 40 million dollars. This is only 5 million dollars more than the 35 million for the 36-channel transatlantic cable; and yet the TD2 system provides a number of television channels in both directions, as well as many telephone channels. Perhaps even more important in an overland system, it provides facilities for dropping and adding channels along the route. Without such flexibility, an overland system would be almost useless.

Some types of satellite relay systems would provide communication only between selected points. These would lack the flexibility required for overland service. Further, there is little reason to believe that a satellite relay could compete with present microwave radio relay or coaxial cable in cost. Present facilities are very satisfactory, so that there is little incentive to replace them with some difficult alternative system, even if it could do the same job. Thus, satellite radio relay seems attractive only for spanning oceans.

Two different sorts of satellite radio repeaters suggest themselves. One consists of enough spheres in relatively near orbits so that one of them is always in sight at the transmitting and receiving locations. The sphere isotropically scatters the transmitted signal, so one has merely to point the transmitter and receiver antennas at it to complete the path. Another system uses a plane mirror or an active repeater with a 24-hr orbital period, located directly above the equator at a radius of around 26,000 miles or an altitude of about 22,000 miles. Such a satellite would be visible to within 9° of the poles, that is, in all inhabited latitudes. If it were not for the perturbations of the orbit by the moon and the sun, it could stay fixed relative to the surface of the earth, and large fixed antennas could be used on earth. However, it appears that perturbation of the orbit would be large enough to necessitate steerable antennas on earth and orientation of the satellite antennas or the reflector by remote control.

Even disregarding problems concerned with the making and placing of the satellites, would such satellite relay systems or any satellite relay system be feasible in other respects? To decide this we must consider two sorts of problems: problems of microwave communication, and problems lying in the field of celestial mechanics, concerned with the orbit and orientation of a satellite.

(In his full paper, to appear in a future issue of *Jet Propulsion*, Dr. Pierce proceeds to develop mathematically the power requirements for several types of relays, and he analyzes briefly a few of the orientation and orbit problems.)

2. Summary and Discussion

The best we can do is try to state some sort of conclusions concerning the sorts of systems which have been described.... All of these are for a 5-mc video channel provided by an 8-digit binary pulse code modulation system and a wave of 10 cm. The diameter of the antennas on earth is assumed to be 250 ft.

The great advantages of the passive repeaters over active repeaters are potential channel capacity and flexibility. Once in place, passive repeaters could be used to provide an

almost unlimited number of two-way channels between various points at various wave lengths. They would also allow for modifications and improvements in the ground equipment without changes in the repeater.

Spheres, which reflect isotropically, are the most flexible of passive repeaters, because they allow transmission between any two points in sight of them. Moreover, with spheres there is no problem of the angular orientation of the repeaters.

For a 24-hour "fixed" repeater and a 1000-ft sphere, the power required is 10 megawatts, and this seems excessive. However, suppose 10 spheres, each 100 ft in diam, circled the earth above the equator at a fairly low altitude. At low altitudes, one or more would always be in sight. The path length would be only about a tenth that for the 24-hr orbit, and the power required would be around 100 kw, which seems quite feasible.

A plane mirror returns much more power than does a sphere of the same diameter. A 100-ft mirror at an altitude of 22,000 miles would call for a transmitter power of about 20 kw, which again is by no means unreasonable.

The great problem in connection with a plane mirror is that of position and orientation. If it were not for the perturbation caused by the moon and sun, the position and orientation of the mirror could be preserved automatically by a proper [78] disposition of masses attached to the mirror and by the use of damping.

However, as perturbations of position and orientation will be too large to be tolerated, the orientation of the mirror would have to be adjusted by moving masses through radio control. The power required would be small, perhaps less than that required for an active repeater. The advantage of channel capacity would be preserved.

The plane mirror suffers a considerable limitation compared with the sphere, however. If it really hung fixed in the sky, it would provide communication between any point in sight of its face and another particular corresponding point. However, because perturbation by the sun and moon will cause it to wander about in the sky so that the orientation of the mirror must be adjusted to maintain a path between two particular points, a plane mirror can actually be used only to provide channels (and a large number of channels on different frequencies) between two particular points.

The chief disadvantage, then, of the passive repeater is that the power required on the ground is large—though probably attainable.

The attractive feature of an active repeater is the small power required and the small antennas needed at the repeater, as well as the small power required at the ground. The small antennas would have a comparatively small directivity. This, coupled with the fact that for a given angular or positional shift, the beam from a radiator shifts only half as far as the beam from a reflector, makes the orientation problem considerably easier in the case of an active repeater. However, there still is an orientation problem, in contrast to the case of a sphere used as a passive repeater.

The chief disadvantage of the active repeater, aside from disadvantages of power supply and life, is that it provides only the number and sort of channels that are built into it. Once it is in place, its channel capacity cannot be substantially increased by anything done on the ground, although some gain might be made by an increase in transmitter power and receiver sensitivity and by a modification of the nature of the signal.

In conclusion, one can say that, disregarding the feasibility of constructing and placing satellites, it seems reasonably possible to achieve broad-band trans-oceanic communication using satellite repeaters with any one of three general types of repeater: spheres at low altitudes, or a plane reflector or an active repeater in a 24-hr orbit (at an altitude of around 22,000 miles).

At this point, some information from astronomers about orbits and from rocket men about constructing and placing satellites would be decidedly welcome.