THE EARTH SATELLITE PROGRAM

How, when, where and why the United States will begin its first scientific observations of outer space

by W. H. PICKERING
Director, Jet Propulsion Laboratory

THE IDEA OF SPACE TRAVEL has become so popular since the war, particularly with the younger generation, that I am afraid that when we actually get around to flying the first satellite, there is going to be a sense of anti-climax. This first satellite is not going to be a particularly spectacular object from the point of view of the general public. It will be just barely visible to the naked eye perhaps a few times a month. It will be quite hard to detect and I am sure the small fry are going to wonder what all the excitement is about.

On the other hand, if we really consider the problem, it is a fantastic engineering task to put any object into an orbit around the earth. Furthermore, such an object will necessarily have a great scientific significance. It is the beginning of scientific observations of outer space.

The earth satellite program of the United States is a part of the International Geophysical Year program. During the period from July, 1957, to December, 1958, there will be a concerted effort on the part of most of the nations of the earth to gather data of geophysical interest. The scope of the program covers most of the scientific disciplines. Among the more highly publicized programs, there are, for example, the Arctic and Antarctic expeditions, which will involve many nations, and the rocket experiments which will be made at several places for upper atmosphere observations.

The international committee which is coordinating the IGY program—the so-called CSAGI committee—recommended in October of 1954 that a satellite program would be of extreme value as part of the IGY activity. In July of last year, the President announced that the United States would indeed fly a satellite as part of our contribution to the IGY program. Since then, the Russians have announced that they also will fly a satellite.

The program for the United States has been established by giving the Department of Defense the responsibility for putting the satellite FOB on orbit. This, of course, is the largest engineering problem; it involves application of large rocket techniques developed over the past ten years. The President has stated that each of the services will contribute to this effort, but the primary responsibility has been given to the Navy. The Naval Research Laboratory has set up what is now known as Project Vanguard.

The scientific part of the program is being coordinated by the National Academy of Sciences, which is responsible for the whole IGY scientific work on the part of the United States. There has been established a U. S. National Committee with Dr. J. Kaplan of UCLA as Chairman. This committee carries out the IGY program through a series of technical panels, one of which is the Technical Panel on the Earth Satellite Program.

In order to get a feeling for some of the numbers involved in the satellite problem, let us consider some freshman physics.

Suppose the satellite is in a circular orbit above the surface of the earth. The velocity required is obtained by equating the centrifugal force to the gravitational force. Numerically we find that for an altitude of 300 miles we need a velocity of just over 25,000 feet/second.

As the altitude increases, the required velocity will decrease; however, the total energy required to take an object from the surface into the orbit will, of course, go up. The total energy, adding the potential and kinetic energies, is a fairly slowly varying function of altitude. At 300 miles it works out at about 11,000,000 ft. lbs. per pound of mass of the object—which is a lot of energy.

The exact height at which one might like to fly a satellite will be determined by the amount of energy available and, secondly, by the desired life of the satellite. The life is limited by the fact that the satellite is not flying in a perfect vacuum, and the residual trace of atmosphere at these altitudes will slow it down, so that the object will eventually lose energy to the extent that it will spiral into the earth and be burned up as it enters the dense atmosphere. An altitude of 300 miles is predicted to give a lifetime which will be measured in weeks or months. There is considerable uncertainty as to the actual density of the atmosphere at these altitudes, and so the prediction of lifetime is uncertain, but the best estimates say that at 300 miles it will be at least several weeks. It may be as long as a year.

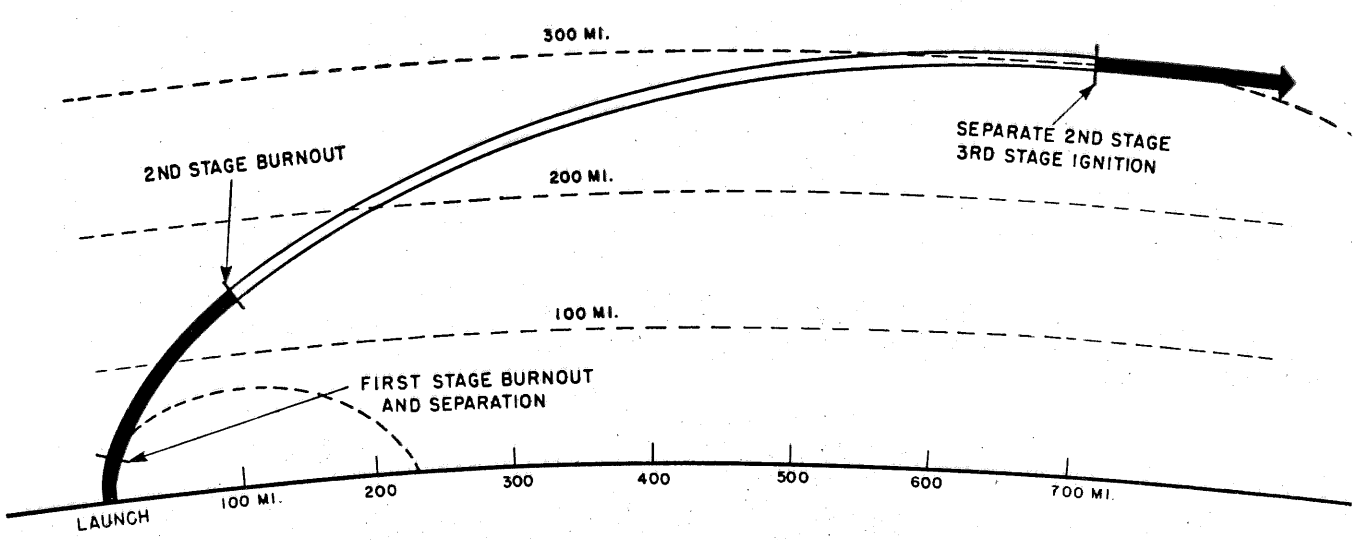
In order to actually place an object in an orbit, it will be necessary to give it more energy than that required for a circular orbit. In this case, the orbit will become elliptical, and, assuming that we launch the object from an altitude of 300 miles in a horizontal direction, the launching point will be the perigee of the ellipse. The altitude of the apogee will depend upon the magnitude of the excess velocity imparted to the object. The expectation is that the Vanguard satellite orbit will be an ellipse which is about 200 miles high at the closest approach and about 800 miles at the apogee.

The period for a circular orbit can be easily calculated from the velocity and the radius of the orbit. For the 300-mile altitude this works out to be about 94 minutes to go around the earth.

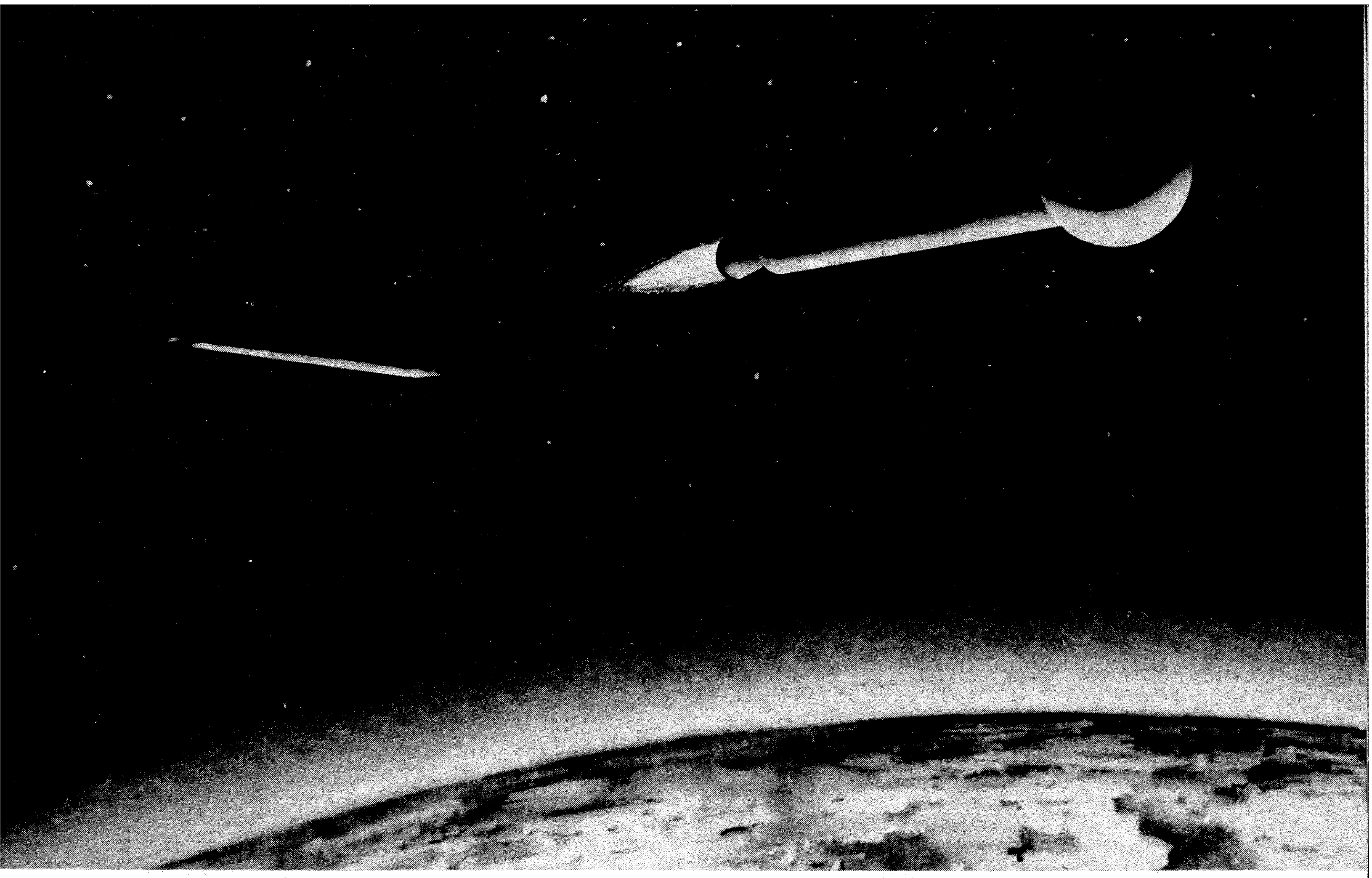
It is interesting to ask: At what altitude would the period become 24 hours? In this case, the object would remain apparently at rest over the launching area. This turns out to be a height of about 5.6 times the earth's radius.

As a practical consideration, if we plan to launch this satellite vehicle, we might just as well take advantage of the fact that the earth is rotating toward the east with a velocity which amounts to 1500 ft/sec at the equator. Therefore, one would like to launch the object from the equator and towards the east. Fortunately, the United States has a long-range proving ground in Florida with a firing line towards the east, and all the necessary facilities to help with launching. Firing directly east from this site would give an additional velocity due to the earth's rotation, of about 1300 ft/sec. The launching direction finally selected will probably be inclined somewhat to the south of east so that the plane of the orbit will intersect the plane of the equator at an angle between 35 and 40 degrees.

Finally, considering the question of accuracy of the direction of launching, we have two problems. The first is the azimuth accuracy which will determine the plane of the orbit. The required accuracy will depend on the location of observing stations, but presumably accuracy of a few degrees would be acceptable. The second problem is the elevation accuracy. This will determine the perigee altitude. If the launching is accurately horizontal, the launching altitude is the perigee altitude. Any other launching angle will lower the perigee. If the direction deviates as much as 1.5 degrees, then the perigee will drop about 100 miles. This means, then, that the accuracy of launching must be somewhere of the order of one degree. So, to sum up, we must



The launching trajectory of the Project Vanguard satellite.



The three-stage rocket is shown here just as the second and third stages are separating. At the end of burning of the third stage, the ball—which is the actual satellite object—will be separated from the rocket by a spring-ejection device.

take our satellite object to an altitude of 300 miles and launch it with a velocity of 5 miles a second in a specified direction with an accuracy of about one degree.

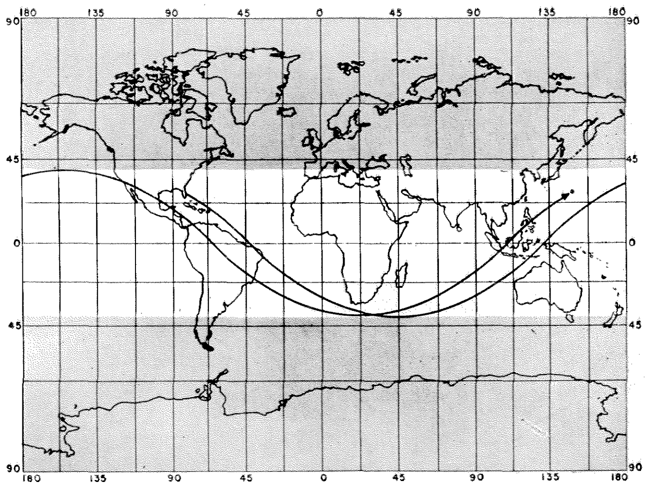
Project Vanguard will consist of a three-stage rocket, the first stage having some similarities to the Viking rocket, the second stage having some similarities to the Aerobee rocket, and the third stage being a solid propellant rocket.

The type of trajectory which will be flown is indicated in the diagram on page 14. The first stage will take the satellite up to about 40 miles and then combustion is complete and the first stage will drop off. At this time the velocity is about 5,000 ft/sec. The second stage will take over and carry it up to about 140 miles with a velocity of 16,000 ft/sec. At this time combustion is complete but the second stage is left attached to the third stage, and together they will coast up to a 300 mile altitude. At the 300 mile altitude, when the object is pointing in the correct direction, the third stage is ignited and off it goes on its orbit. The second stage, of course, is separated and will drop back to earth about 1,000 or 2,000 miles away from the launching site.

Separation between the second and third stages might look something like the picture above, where I have indicated the third stage as having a ball, which is the actual satellite object, attached to the forward end. Of course, in the earlier parts of the flight, this must be covered with some sort of wind shield or stream lining to protect it as it goes through the atmosphere. At the end of burning of the third stage, one will want to separate the ball from the rocket, and this can be accomplished by some sort of simple spring-ejection device.

For something with which to compare this performance, I might note that the present official altitude record is held by the so-called Bumper-Wac rocket, which was a V-2 with a JPL-developed Wac Corporal on the front end. This Bumper-Wac reached an altitude of approximately 250 miles. One can calculate that it required a velocity of about 9,000 ft/sec so that there is a considerable increment from this 9,000 ft/sec to the 25,000 ft/sec needed for the satellite.

The problem of keeping the rocket on its trajectory is a very critical one. Guidance is obviously going to be necessary during the whole combustion process. It is proposed, however, that none of the rockets possess fins or any aerodynamic surfaces to guide them, but that since most of the flight has to be in a vacuum, it be guided by swiveling the rocket motor in each of the first two



The white strip on this map shows the regions of the earth that will be swept over by the satellite's orbit.

stages. In the final stage, since there is a solid propellant motor, the simplest thing is just to give it a spin to maintain its orientation.

The first stage will use liquid oxygen with some kind of alcohol-type fuel; the second stage will be nitric acid with unsymmetrical di-methyl hydrazine as a fuel; and the third stage will be a solid propellant. The exact sizes of these rockets have not been announced, but the general indication is that the first stage is somewhat larger than the present Viking rocket. The present Viking is a rocket weighing about 11,000 or 12,000 pounds, built by the Glenn L. Martin Company for the Naval Research Laboratory as a high-altitude sounding rocket used for research purposes. The Aerobee, which is a prototype of the second stage, likewise has been developed by the Aerojet Corporation as a high-altitude sounding rocket. The size of the satellite object has been announced as weighing about 20 pounds and probably having a diameter of about 30 inches.

The satellite orbit

Suppose that the satellite is launched at an angle of about 40 degrees with the equator. The map above indicates the regions of the earth which will be swept over by the orbit. As time goes on, all that region of the earth lying between ±40 degrees latitude will be covered by the trajectory. Interestingly enough, the object will come over Pasadena—or very close to it—on its first time around. The first chance to get a good look at it will be when it comes back over the southern part of the United States on its first time around. The observations made from this area will be very important in establishing the orbit.

It is interesting to consider the question of visual observations. At any given point, the time that the object is above the horizon is very short. If it goes over the zenith, the time will be of the order of 9 minutes from horizon to horizon—and, by the way, it will rise in the West and set in the East. There will be no question of distinguishing it from the other heavenly bodies. However, an object only 30 inches in diameter is not going to be very conspicuous, and indeed the only hope of seeing it will be when the sun is shining on the object and you, as the observer, are in darkness underneath it—which means that you will have to see it just after sunset or before sunrise.

This means that from the point of view of optical tracking there is going to be a very limited chance that you will see it on any given revolution, because you will have to be at the right place at the right time with the proper seeing conditions. So that for optical observations, it will be necessary to establish stations at carefully selected sites and to set the correct launching time.

For example, if one launched it from Florida in such a way as to obtain good observations from Pasadena, then the passage over Pasadena would have to occur just before local sunrise or just after local sunset. This, then, will determine the launching time in Florida. Given optimum observing conditions, it is calculated that this 30-inch object will be about as visible as a 6th magnitude star, which is about the limit of visibility. If you have some relatively low-powered binoculars and you know where to look, you should be able to locate it.

Observations could be of two types, either optical or radio. There will be a radio transmitter aboard the satellite which will put out a weak signal. Radio direction-finding will then give a rough position of the object, and optical observations, a considerably more precise orbit. The advantage of the radio is that it can be detected every time it comes within the vicinity of a receiving station. Therefore, there will be a network of both radio and optical stations established, and indeed it is expected that amateurs will be invited to contribute to this network.

When the satellite is actually launched, there will be announcement of the approximate orbit and of the approximate time that the satellite will be passing various points on the earth's surface. It is hoped that both radio amateurs and amateur astronomers will be organized to collect data and to channel it in to the central data analysis points.

Data from orbital measurements

Supposing that a precise orbit of the satellite is obtained, the question one might ask is: What kind of information can be deduced from such knowledge? In other words, is it possible to obtain useful data from what one might call external measurements? Four useful areas of investigation are: air density along the path; variations in the shape of the earth; anomalies in the distribution of matter within the earth; and precise knowledge of relative location of points on the earth's surface.

There is considerable interest in the density of the atmosphere at these altitudes. It is of the general order of magnitude of 10^{-15} gms/cc, which by all ordinary standards is an excellent vacuum; but from the astrophysical point of view, one would like to know just how the density does vary with altitude in this region. This small density of perhaps 10^{-15} gms/cc will exert a small drag on the object. If we say the drag force is proportional to the frontal area, the square of the velocity and the density, then we can calculate a loss of energy and of velocity per revolution. For a 30-inch sphere weighing 20 pounds, at 200 miles altitude, the period will change by about .04 seconds per revolution. This means, then, that if we are going to use the satellite to enable us to calculate air densities, we must have a very precise orbit, and we need a very careful analysis of the orbital data. In order to obtain data on the density as a function of altitude, the path must be analyzed as the object gradually spirals down into the dense atmosphere.

The shape of the earth

The next thing I have indicated is the shape of the earth. We know that in a broad sense the earth is an oblate spheroid. This fact will cause the plane of the orbit to precess around the axis of the earth with a period of about 50 days. Again, if we have the precise orbit, we can calculate back to obtain information on the actual shape of the earth.

We know that the earth is not a perfectly symmetrical sphere as far as the distribution of matter within the earth is concerned. The variations of G as we go over the continents and over the oceans imply that there are differing amounts of matter between the surface and the center. Therefore, again, we have the possibility of learning something about the symmetry of the earth.

A surveying problem

The final problem that I have indicated is the surveying problem. If we consider the problem of locating an island some distance off the coast of a continental mass, this can be done by measuring the latitude and longitude of the two points. But in order to do this, one has to use the local vertical, and one wonders if the local vertical is indeed the direction to the center of the earth. With a satellite it becomes possible to put an observing site both on the island and on the continental mass to observe the satellite, and then by simple trigonometry to obtain the separation between the two. Likewise, if the orbital parameters are known precisely, the path of the satellite can be used to survey the observing station.

Thus it appears that, even with data from the satellite restricted to observations from the ground, a wealth of useful information will be obtained, provided only that the object can be tracked visually.

The next problem is to measure various quantities at this 300 mile altitude. This poses a new problem because the only way to get data back is by radio. The satellite will never be recovered. As time goes on and it slows down, it will re-enter the atmosphere and burn up. So, all the data must be presented in a form which can be sent down to the earth by radio. Since radio receiving sites can be located in only a few limited areas, the information will have to be stored in the satellite in some fashion until it is over a receiving site, and then a transmitter at the receiving site will have to interrogate the satellite concerning the data. Unfortunately this will call for some fairly complicated telemetering techniques to go into the satellite. Therefore the types of measurements which can be made will be fairly limited; at least, in the small satellites. The total payload is 20 pounds and that has to include all the structure.

Internal measurements

Suitable internal measurements might include the following. First, one might measure the temperature of the satellite object itself. This temperature will be determined by the radiation balance—the radiation falling on the object and the re-radiation from the object. Knowing something about the infrared characteristics of the surface of the satellite, and knowing what we do about the solar radiation, we can hope to establish a balance that will keep the instrumentation of the satellite at a fairly uniform temperature. However, there will be fluctuations as it goes around the earth and behind the shadow of the earth. The temperature will not go very low during this period because of re-radiation from the earth, although there is considerable question as to just what this re-radiation from the earth actually consists of; and this measurement should add to our knowledge of this particular quantity —the albedo of the earth.

A second measurement could be a pressure measurement. From the point of view of the instrumentation which is carried in the satellite, it will almost certainly be desirable to make it pressure tight. If the satellite is bombarded by small meteorites, these will make holes through the skin and the internal pressure will be lost. By observing the pressure, as a function of time, we can obtain information on the probability of collision with the small meteorites.

Environmental factors

These first two measurements will be made on the first satellite objects for instrumentation purposes, if for nothing else, because future satellites with more elaborate instrumentation aboard will require information about the environmental conditions on the satellite. The pressure and temperature measurements describe the most important environmental factors.

Another class of measurement is that of radiation. We know that all the radiation observed here at the surface has been filtered through the atmosphere and absorbed by the atmosphere. The atmosphere is actually opaque to radiations of many wave lengths. Now, by balloon measurements and by high altitude sounding rocket measurements, direct measurements of the radiation at high altitudes have been obtained, but these earlier types of measurements are limited because of the fact that the measurement is made at one particular point in space and one particular point in time.

In the case of a rocket—for example, a sounding rocket going up to altitudes of the order of 100 miles—the time spent outside of the atmosphere is measured in seconds. Balloons stay up for longer periods of time, but will not reach such high altitudes. The satellite, on the other hand, is up for an indefinitely long time and at higher altitudes than have been attained before.

Cosmic radiation

Of the kind of measurements we can make which utilize these facts, one possible measurement is the intensity of the primary cosmic radiation. There is a great deal of interest in the variation of cosmic rays as a function of latitude, longitude and time. The satellite is particularly useful because of the fact that it sweeps over large areas of the earth's surface in a short period of time. From the cosmic ray point of view, one would prefer to have the orbit going over the poles rather than in an equatorial direction, but the inclined orbit which is planned should provide exceedingly interesting data. Perhaps some later satellite will go over the poles.

Another measurement is that of the intensity of the Lyman alpha line. The Lyman alpha radiation from the sun lies in the far ultra-violet with a wave length of about 1200 angstroms. There is considerable interest in just what the intensity of this radiation actually is. Measurements have been made from sounding rockets; however, the sounding rocket measurements suffer from the disadvantage that they make a single observation on the condition of the sun as it happens to exist at the time. It is believed that the Lyman alpha intensity from the sun varies over very wide ranges and one would like very much to observe the changes in this radiation as the sun goes through some sort of disturbed condition.

Disturbances on the sun

Here again, the continued series of observations possible from the satellite over a period of weeks provides an opportunity for finding the sun in a disturbed condition and therefore obtaining the required information. We may note in passing that the period of the geophysical year was chosen as a period in which the sun would be most disturbed, so that there would be a better chance of catching such conditions.

In addition to the types of measurements which I have indicated here, a wide variety of additional measurements have been proposed. Some 30 papers were presented at a scientific meeting held at the University of Michigan in January of this year. There were some duplications, but many new ideas were presented. Among these I will mention just two.

Magnetic measurements

One was the problem of magnetic measurements. We know that the magnetic field of the earth arises partly from currents inside the earth and partly from currents above the surface. We believe that the contribution arising from currents flowing above the surface may be due to currents in the ionosphere, but the so-called Stormer ring current which is several earth radii above the surface of the earth may also contribute. It would be of considerable interest to know whether this ring current actually exists, and to get some idea of the relative contributions of the ionosphere and the ring system. We need to make measurements, then, above the ionosphere, and if we could measure the disturbances in the magnetic field, then we could obtain these data. In practice, this looks like a very complicated experiment because it requires measurements of small fluctuations in the magnetic field. Furthermore, the observing site is wandering all over the globe, and so observations have to be corrected for local conditions. It is a discouraging experiment but one which would have a lot of scientific interest.

Meteoritic dust

Another experiment is a further investigation of meteoritic dust or micro-meteorites. One might ask, Is the surface of the satellite being eroded by bombardment with some sort of cosmic dust? One proposal is that the satellite should start out with a polished surface which has a certain apparent brightness. As time goes on, will that brightness change, and if so, will the change be due to a change in the condition of the surface brought about by meteoric dust? Alternatively, another proposal has been made: Suppose the surface is coated, in some areas at least, with a certain amount of radio-active material? Then if the surface is being eroded, this material would be worn off, and by measurements of changes in the radioactivity, one could determine how much has been worn off.

The precise experiments which will be carried in the early satellite flights have not yet been established, but it is clear that already a large number of possibilities exist, and it is to be expected that within the year and a half before the first satellite is flown, many more experiments will be under consideration.

The Technical Panel on the Earth Satellite Program has an interesting task ahead of it to formulate the best possible scientific program. The earth satellite program has stirred the imagination of scientists and public alike. It will be a spectacular demonstration of the potentialities of modern technology and the first real step towards the conquest of space.