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AT the Manila Observatory, visitors ask many questions which bear on the appearance, motions, uses, tracking and kinds of satellites. A summary of their questions and of our answers may help others towards a clearer notion of this new phenomenon added to the heavens.

APPEARANCE

What does a satellite look like?

An artificial satellite, in general, is so far away and so small that when it is seen it resembles nothing better than a moving star, sometimes a bright star (namely, one of zero or first magnitude) and sometimes a weak faint star (one of fifth magnitude). Many objects taken by the uninitiated for satellites are not such. A satellite cannot be seen in the daytime just as stars cannot be seen in the daytime. Balloons in the daytime, Venus in the twilight, airplanes, jet exhausts at night, even weather balloons with a small light in them, and finally stars peeping out from behind fast moving clouds—have all been mistaken for satellites, especially before it is known that the satellite shines with reflected sunlight,[1] and before it

[1] It is said that Sputnik III is not metal-colored (aluminum) nor is it white nor any neutral color. The Japanese reported that it was somewhat reddish, hence we suspect that the Russians may have painted it red.

is realized that a satellite goes in a uniform direction with an almost undeterrible urgency.

LAWS OF MOTION

What keeps a satellite up?

"What goes up comes down," so the popular notion has it. The story of Newton's falling apple is familiar. He realized that there are gravity forces, yet he also knew of centrifugal forces. An object in motion tends to move in a straight line unless acted upon by an outside force. The satellite is given a very high speed (approximately 18,000 miles per hour) which tries to shoot the satellite off at a tangent to a curved orbital path, but the earth pulls the satellite with just enough force to counteract this tendency. The satellite's tendency to fly off into space is exactly balanced by its tendency to fall towards the earth, and so it does neither but remains suspended in between.

What keeps a satellite in motion?

Once the satellite has been given a motion, it is better to ask what can stop it, for it is just like a frictionless machine, and keeps on without any more fuel than what was necessary to set it in motion. It is coasting or "free wheeling." But there is some friction up where the satellite moves, and eventually the satellite loses energy and falls to the earth.

Then the satellite gradually loses speed?

Strange to say, the satellite gradually loses total energy but gains in speed. There is total energy which consists of potential energy or energy of position and of kinetic energy or energy of motion. The satellite coasts in towards the earth and loses more energy of position by so doing than it gains energy of motion. Because there is more gravitational force when the satellite is closer to the earth, there has to be a greater speed to counteract gravitational force by centrifugal force.

If the satellite moves faster closer to the earth, does it vary in speed even in making one revolution about the earth?

The satellite follows quite definite laws known as Kepler's laws (See Figure 1). If it travels in a circular orbit, it remains almost constant in speed in one revolution about the earth. But if it travels in an elliptical orbit, it travels at such a speed that the product of the length of a line from the center of the earth to the satellite by the component of its velocity perpendicular to this line is constant. The longer the line is, the slower the velocity.

What are the meanings of some of the terms used, such as perigee, apogee, nodal crossing, ellipse?

Perigee is the place of closest approach of the satellite path to the earth, whereas apogee is the place of greatest distance from the earth. A node is an intersection point of the plane in which the orbit lies, with the plane of the earth's equator. If the satellite passes the equator going north, the point of crossing is called the ascending node, and if going south, the descending node. An ellipse is a path, inside which are two points (foci); the total distance from one point out to any part of the path and back again to the other point is always the same. The earth's center is at one of these points.

TRACKING

How can one tell when a satellite is going to appear overhead?

There is a great deal to understand before very accurate predictions of a satellite passage can be made, but first approximations can be made with a very limited amount of information and a minimum understanding of the motions of a satellite. There always has to be some information given, such as the time at which the satellite passed over a certain section of the world. Crudely, it may be imagined that the satellite's motion is confined to a ring fixed in space, while the earth revolves under or inside the ring with an angular motion of 360 degrees in 24 hours, or 15 degrees per hour. Thus, to an observer on the earth, the orbit of the satellite seems to move or rotate

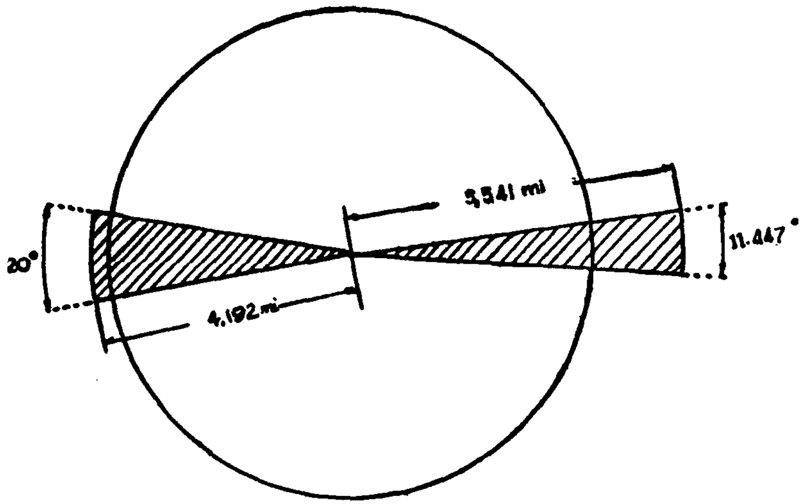

Fig. 1. Kepler's LAW OF AREAS

"The line joining a body and its center of revolution sweeps over equal areas in equal times."

Then, any two segments of an orbit are equal in area when the one with the longer radius covers a correspondingly lesser number of degrees of the circumference.

The radius of the orbit of Explorer I, at perigee, is 4,192 miles; at apogee the radius is 5,541 miles. The area of the segment at perigee covering 20 degrees of the circumference is equal to that at apogee with longer radius covering only 11.447 degree of the circumference.

Although the areal velocities are equal, the linear velocity is necessarily greater at perigee than at apogee.

Circle represents the earth. Computations by Dr. R.A. Thorson, Manila.

Explorer I:
perigee: 229 miles
apogee: 1578 miles
period: 114.7 minutes
approximate circumference of the orbit: 30,869.36 miles

about the outside of the earth to the west at 15 degrees per hour, because actually the earth is rotating inside the orbit at 15 degrees per hour to the east. Hence, if the orbit is over London at a certain time, it will be over New York five hours later and over the Philippines thirteen hours after it is over New York. However, there are other considerations. Though the orbit may be over us at a certain time, the satellite in the orbit may be at the opposite side of the earth at that time, and it will take another fifty minutes approximately before it will appear on our side of the earth. By that time the earth will have moved 12 1/2 degrees (one degree every four minutes) and the orbit will then be 12 1/2 degrees to the west of us when the satellite comes by. We would see it in the western sky, if the time happened to be enough before sunrise or after sunset that stars could be seen, but not so much that the satellite would no longer be in sunlight.

Then, can the satellite be in sunlight when we on earth are in darkness?

Just as a high cloud can be in sunlight when the sun has already set for us on earth, so the satellite can be in sunlight when we are in the shadow of the earth.

What are some further complications in satellite tracking?

There is the motion of precession, which means that the orbit is not stationary in space, but itself rotates backwards three or four degrees per day. By backwards is meant to the west if the satellite's motion in its orbit has always a component to the east. All the satellites, thus far have been launched to move towards the east. The bulge of the earth at the equator tries to tip the satellite's orbit or line the orbit up with the equatorial plane, but because the satellite is in motion, the pull has its effect when the satellite is already in a different part of the orbit from where the pull was exerted. The net effect is to rotate the orbit. Because of the rotation of the earth (360 degrees per year) around the sun, an extra one degree per day of apparent precession is added to the satellite's orbit.

Why have satellites been launched towards the east?

The earth rotates to the east, and this direction gives a free boost of about 1000 miles per hour to the satellite.

Are there further complications in the satellite's motion?

The chief additional motion is in the shifting of the low point of the orbit, the motion of the perigee. This shifts about the orbit so that sometimes the low point of the satellite occurs when the satellite is over the northern half of the world and at other times over the southern half of the world. This point moves about 6 degrees per day in the same direction as the satellite moves in the case of the American satellites and about ½ a degree per day in the opposite direction for the Russian satellites. All motions of the satellites depend on the inclination of the orbit with the equatorial plane. The satellites also wobble up and down from the path of a perfect ellipse twice and three times per revolution. These motions can be mathematically expressed,[2] but even the mathematicians are stumped by the fact that the Russian satellites enter the thicker atmosphere at perigee sometimes broadside on and sometimes end on. The unpredictable friction throws their calculations off by a considerable amount.

Are we to understand that the Russian satellites tumbled end over end, whereas the American satellites do not?

The Russian cylindrical satellites revolved end over end about 8 times per minute. The American Explorer satellites have been given a spin like that of a rifle bullet of about 500 revolutions per minute so that they always point to the same place in the universe.

Then would we always see the American "Explorer" satellites the same way?

At one point on the earth, they would be seen broadside on and because they always pointed to a fixed part of the

[2] Staff of the Royal Aircraft Establishment at Farnborough, "Observations on the Orbit of the First Russian Earth Satellite" *Nature* 180 No. 4593 (9 November 1957) 939.

heavens, ninety degrees away on the earth, they would be seen endwise.

What effect would the tumbling of the Russian Sputnik II have on its dog passenger?

The dog would experience a centrifugal force of about 1/40 the force of gravity on earth. Colonel Stapp has survived a force of 20 times the force of gravity.

What contribution has the Philippines made in helping to track the satellite?

Visual sightings have numbered seventeen at the Manila Observatory of the Jesuit Fathers at Baguio for Sputnik I and Sputnik II. The carrier of Sputnik I was seen three successive evenings preceding the day of its fiery death. The scientists of the World Center for visual observations were very interested in the Baguio data. As far as possible the exact position of the satellite in the sky to the nearest degree and the time to the second when the satellite was at that position were sent to the tracking center at the Smithsonian Observatory in the United States. For timing, radio signals with wire recorders and electrical impulses fed to the seismograph recorders were used. Other entities in the Philippines have tracking equipment. Mr. Hans Arber at Pasay City has seven wide-angled telescopes and a trained group of boy scouts for spotting satellites. The Weather Bureau's astronomy section at Diliman in Quezon City is similarly set up with a dozen telescopes under Mr. Ricardo Cruz, coordinator for Philippine Moonwatch teams. But the most spectacular sighting was made by Father Clement Risacher S.J., once head of the chemistry department of Boston College and now a missionary in Bukidnon. He made an unexpected contribution to the world's knowledge of what probably happens when a rocket satellite reenters the atmosphere. On the plain of Kisalon in Mindanao at 5 a.m. 27 October 1957 he saw a rocket-like object, red and trailing fire. It shot off a section to the front (probably the nose cone) then broke into two parts, burst into red flames and disintegrated while running along parallel to the earth. Nearby villagers were awakened by the loud noise of its disintegration.

Do you think Fr. Risacher, on 27 October 1957, saw one of the Russian failures?

Because its general direction relative to Sputnik I was exactly the same as that of Sputnik II launched a week later, this seems plausible.

Has anyone ever witnessed the re-entry of a satellite into the earth's atmosphere?

Father Risacher again, appears to have seen it in May of this year. He describes it as follows: On Saturday, 17 May 1958 at about 8:15 p.m., he saw coming out of the western sky in a direction towards the NNE a very bright silvery bluish round body, giving off sharp rays all around, more brilliant than Venus. It seemed to rise and fall as it sped along its course twice, before it disappeared from view behind Paliapan Mountain Head in Bukidnon.

We wondered what this could be. It was of course right after the Russian launching of Sputnik III. It was going in the proper direction, for all Russian satellites go towards either the NNE or the SSE, since they are launched at 65 degrees to the equatorial plane. The apparent bouncing up and down had us puzzled, until we remembered that the Russian method of re-entry into the atmosphere is a skip method, by which they use little fin-like wings to ease the satellite into the atmosphere gradually so that it planes in. If the fins were just a little badly proportioned or if the speed were just a little off, the satellite would come in, then rise and take off for a brief space into rarer air, until it should fall into thicker air, all the time going forward at a very high speed. Thus, what Father Risacher saw may have been this very process.

Is there not very sophisticated and expensive equipment devoted to satellite tracking?

There are $100,000 telescopes, with f/1 focal ratios, almost two-foot apertures and very wide fields of 30 degrees devoted to satellite tracking.[3] Also there are equally expensive radio tracking stations which can extract the information being sent from the satellites, and pinpoint their location to a small fraction of a degree and a hundredth, even to a thousandth of a second. Clark Field, for several months had a radio station, called a "minitrack" system, which listened in on the American Explorer I.

Then, are further observations and visual sightings of value?

The ionosphere distorts radio signals, so that the satellite is not always where radio observations would have it to be. Also, the casings or empty rockets or carriers have no radios. Visual observations and radar are the only methods of sighting these. Sometimes a satellite can get lost or might never have been properly located, so that the complicated mechanism of the high powered telescopes cannot be directed to pick up the trail of the satellite. Clouds may prevent an observation in one part of the earth, whereas a small observing post not so well equipped may make a valuable and needed observation. The ideal amateur "Moonwatch" team has enough small telescopes to set up a fence across the sky, through which the statellite cannot escape undetected.

SOME DIFFERENCES IN SATELLITES

Why did the Russians choose a different orbit than the Americans chose?

The American satellites do not travel over Russian territory. The amount of the earth covered depends on the angle of the orbital plane with the equatorial plane. This angle remains constant throughout the lifetime of the satellite. If a satellite were launched pointing at the North Pole, its angle of inclination to the equatorial plane would be 90 degrees,

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[3] F. L. Whipple and J. A. Hynek "Observations of Satellite I" *Scientific American* 197 No. 6 (December 1957) 37.

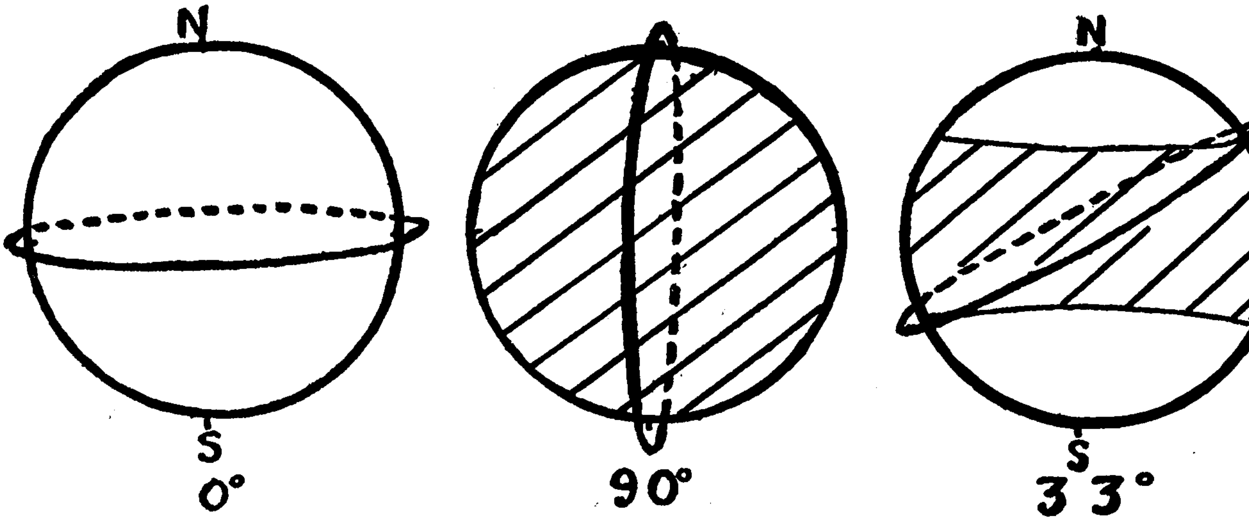

Fig. 2. Various angles of inclination of satellite orbit with equatorial plane. Hatched areas on the earth are portions covered by the satellite.

and the orbit would cover the whole earth. (See Figure 2). If a satellite were launched parallel to the equator at the equator, the angle of inclination of the orbital plane to the equatorial plane would be zero degrees, and the satellite would cover no portion of the earth except directly over the equator. The Russian satellites were so launched that the angle of inclination to the equator was 65 degrees and they covered every portion of the earth from 65 degrees N. latitude to 65 degrees S. latitude. The American satellites, launched to cross the equator at 33 degrees, cover the earth from 33 degrees N. latitude to 33 degrees S. latitude. There have been some limitations, because of populated islands close by the launching site in the angles the American could choose. A smaller angle of inclination also limits the task of tracking to a smaller area of the earth. Some future satellites of the Americans have, however, been planned to cover more of the earth's surface.

How did Sputnik II differ from Sputnik I?

There was really not such a great difference in the sizes, nor in the fuel required to put them into orbit, when it is recalled that the chief difference was in the separation of the last rocket stage, called the carrier, from the load. The combined weight of carrier and load was comparable in the case of the Sputniks. Sputnik II's carrier and the dog-carrying compartment were never separated. Most people saw the carrier of Sputnik I and not the two-foot sphere. The American Explorers are of the Sputnik II type, whereas the Vanguards and also Sputnik III are of the Sputnik I type as far as separation of the last stage is concerned. The linear dimensions of Sputnik II were about six times those of the first Explorers. This makes the volume of Sputnik II about 200 times that of the first Explorers.

USES

Of what use is a satellite?

Already, much valuable data has been collected and some tentative results of importance can be shown. In the region

100 miles above us, the atmosphere has been found to be about seven times denser than less reliable methods had previously given. Calculations[4] based on the changes of orbit of the first Russian Sputnik have shown that at 240 miles the earth's atmosphere is 40 times denser than was previously estimated. Even so, the atmosphere is extremely thin. 240 miles up, its density is one ten billionth of its density at sea level.

Satellites have found that cosmic rays and meteorites are not too dangerous for space travel to be feasible. It has been found that temperature inside a satellite can be kept comfortable, even though temperatures on the outside of the satellite vary hundreds of degrees Fahrenheit.

Satellites have aided in precise mapping of the world. The "minitrack" personnel at Clark Field have placed the Philippine Islands to the northeast of its previously calculated position. Data has been collected for very precise calculations of the shape of the earth, especially of the equatorial bulge, for this affects the precession of satellite orbits. Anomalies in the density of the earth, over the Pacific ocean or over the Himalayas are reflected in the motion of the satellites. Much data on the ion layers and density in the electrified upper atmosphere has been collected in the reception particularly of the 20 megacycle radio signals from the Russian satellites. The ionosphere affects the Russian 20 megacycle signal much more than the American 108 megacycle signal. Values of the magnetic field of the earth at high altitude can be calculated from the Faraday rotation of radio signals coming from satellites.

You have mentioned some of the present accomplishments of satellites. What of the future?

Obviously, much of this is secret, yet there can be no limit placed on the imagination of possible uses for satellites. They can be equipped as observation posts, with television, radar, infra red cameras and other equipment for taking pic-

[4] R. Jastrow and I. Harris in *Science* 127 (28 February 1958) cited in *Science News Letter* 73 No. 11 (15 March 1958) 168 ("Atmosphere Denser than Thought").

tures of every part of the world, relaying information on cloud and weather conditions. They can be used as radio and television relay stations, as carriers of telegraph messages through all parts of the world; to pick up a message at London, for example, which can be extracted, with proper triggering frequencies, at New Delhi, India. Their possibilities as astronomical observatories would thrill any astronomer. Present satellites are but the forerunners of space ships which will investigate the moon, then Mars and/or Venus and finally the more remote planets.

Is there a chance of reaching the nearer stars?

It is not possible in a lifetime, even at the greatest speeds possible, close to the speed of light, to reach any but the nearest stars. A round trip to the nearest (Alpha Centauri) would take nine years at the speed of light. Of course, stars are intensely hot and only planets of stars could be visited, anyway. Unless the life span of man can be enormously prolonged, investigation of possible rational life on the planets of other stars than our sun would seem to be reserved as one of the activities of our glorified bodies.