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EARTH SATELLITES

presented by

12-Foot Wind Tunnel Branch
and
Flight Instrument Research Branch

I. Introduction

Although the NACA has not devoted much effort to earth satellites until recently, work with satellites will occupy increasingly larger portions of our research programs in coming years. Therefore, at this time we would like to review for you some general aspects of earth satellites which are not covered in the other demonstrations. We will discuss briefly these topics: (read title chart)

Uses of satellites

Mechanics of satellite orbits

Selection of satellite orbits

Orientation of satellites

II. Motives

A satellite in orbit can do these things: (1) It can sample the strange new environment through which it moves; (2) it can look down and see the earth as it has never been seen before; (3) it can look into the universe and record information that can never reach the earth's surface because of the intervening atmosphere. A few specific uses of earth satellites are listed on this chart (chart No. 2). Careful visual observations from different points on the earth will improve the accuracy with which geographical distances are known. Knowledge of the distribution of material inside the earth may be increased since slight gravitational variations can be calculated from irregularities in the orbit. The properties of the upper atmosphere such as density, pressure and temperature can be determined. Observations have already shown the density at an

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altitude of 140 miles to be about 10 times as great as previously estimated. The NACA has developed a special inflatable type of satellite particularly to measure air density. You will see (or have seen) one of these satellites at another demonstration today. The environment of a satellite at the edge of space, while empty by earthly standards, is teeming with energy, radiation, and fast moving particles of great variety. We can determine the frequency and size of meteors, the characteristics of solar energy and particles, and the character of radiations in the ultra-violet and X-ray regions. We have already learned from the Explorer satellites that radiation at altitudes above 600 miles may be 1000 times as great as expected. We can now obtain a detailed three-dimensional picture of the earth's magnetic and gravitational fields. By observation of the natural phenomena which cause weather, meteorologists hope they may improve long-range forecasting of weather. Satellites may serve as relay stations for world-wide communication and television. Military applications of reconnaissance satellites have also been suggested. Astronomical instruments aboard satellites cannot fail to provide new sights which have been hidden from earth-bound observers because of the earth's atmosphere. Finally, satellites are the means for many biological and medical experiments which are a necessary prelude to manned spacecraft.

These are a few of the foreseeable applications of satellites; many more will appear as the science progresses. Certainly, all implications cannot now be foreseen.

III. Orbital Mechanics

Now let's consider the mechanics of satellite orbits. First, what keeps these satellites from falling? Well, actually they are falling! We all know that the harder we throw a baseball, the farther it goes before

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falling to earth. Suppose you were above the earth's atmosphere and could throw a baseball 15,000 miles per hour. It would cross the Atlantic Ocean before falling to earth. Now if you throw it 18,000 miles per hour, what would happen? The rate at which the baseball falls would be just equal to the rate at which the earth's surface curves away from a straight line. If there is no atmosphere to slow its flight it will continue to orbit indefinitely around the earth.

The time for a satellite to travel around the earth in a circular orbit increases as the altitude of the satellite is increased as shown on this next chart. (Chart No. 3) The horizontal scale indicates distance from the center of the earth in earth radii or 4000 mile units. The vertical scale at the far left indicates time for one revolution. At the surface of the earth, the time for one orbit would be a little less than an hour and a half. Now, for example, if we quadruple the distance from the satellite to the center of the earth, the time per revolution increases 8-fold and is slightly less than 12 hours. Also shown on this chart is the variation of satellite speed with altitude, speed being indicated by this scale at the right. Again, if we quadruple the distance from the satellite to the center of the earth, we see that the speed is reduced from about 18,000 mph at the surface of the earth to about 9,000 mph. Basically, these changes in velocity and time result because gravitational attraction decreases as distance from the center of the earth increases as shown by this curve. This other scale at the left indicates the gravitational attraction in percent of its value at the surface of the earth. Note how rapidly it decreases in the immediate vicinity of the earth's surface.

We have been talking about circular orbits, but we know that all satellites launched to date travel elliptic orbits. Actually, a circle is obtained only if the direction and speed at burnout of the rocket are

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exactly right for the altitude. If either departs, the path will be an ellipse. We should add, however, that to obtain any specific elliptic orbit requires speed and direction at rocket burnout to be as accurate as for a circular orbit.

We have here a simple demonstration of some orbit characteristics. The ball represents a satellite revolving around the earth at the center of the bowl. This bowl is steeper toward the middle so the tendency of the ball to roll toward the center increases as the ball gets nearer the center in approximately the same manner as gravity increases as a satellite approaches the earth. We start the ball orbiting and with no special care, we get an ellipse. Note that maximum speed occurs when the satellite is nearest the earth and that minimum speed occurs when the satellite is farthest from the earth. As the orbit nears the earth, the time per revolution decreases. (Repeat demonstration.)

Unfortunately, we do not have time to go into the subject of orbital motion more thoroughly. However, this subject as well as the more general subject of space mechanics, is an important area of NACA research.

The next speaker is Mr. who will discuss the Selection of Satellite Orbits.

IV. Orbit Selection

In planning a satellite, selection of the orbit is important. It is helpful to consider the plane of an orbit fixed in space. We have here a globe and satellite model which will help us visualize the combined effects of satellite motion and earth rotation. We put the globe in motion and it makes one revolution in 2 minutes and 40 seconds; the satellite can also be put into motion and it will circle the globe 16 times while the globe makes one revolution. Therefore, relative motions of the globe and

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satellite represent those of an actual satellite circling the earth every hour and a half. Furthermore, the physical distance of the model satellite from the globe and the time for one revolution are in scale for a satellite at an altitude of about 175 miles. To further fix the scale of the model in your minds, I call your attention to the model of the moon suspended to your left at a distance of about 90 feet which is in scale with the globe.

First, we will simulate a typical IGY satellite launching from Cape Canaveral in a direction about 35^{o} south of east. (Start satellite from Canaveral) While the satellite is orbiting, the earth is rotating eastward and when the satellite next passes over the United States, it goes over the Southwest, about 1400 miles west of the launching site. This chart (chart No. 4) shows the same path on a map. The launch angle of 35^{o} to the equator is about the largest southern launch angle that can be used from this site and still avoid flying the early stages over Puerto Rico and South America. With this launch angle the satellite passes over portions of the earth at latitudes lower than 40^{o}. For such orbits, a string of stations has been established from Blossom Point, Maryland, to Santiago, Chile, for observing the satellites at least once each revolution.

While I have been talking, our model satellite has continued to orbit. (Turn globe stand 180^{o}). When 12 hours have elapsed since launch, we find that the satellite again passes near the launch site, but this time it is traveling from southwest to northeast.

Now, let us examine two limiting cases of orbit orientation, namely, one in which the satellite passes over both poles and one in which the orbit circles the equator. First, let us simulate an orbit passing nearly over the poles (adjust model as close to polar orbit as possible). Perhaps

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we should launch this one south from the area of Camp Cook in California so that we need not worry about the spent rocket stages falling on inhabited areas (start satellite).

A polar orbit carries the satellite over all parts of the earth, as you can see. Such orbits will be ideal for complete weather surveys, for scientific studies of the earth's magnetic field, and for military reconnaissance. Large earth coverage complicates landing at a specific site. In a polar orbit with a period of 1-1/2 hours, the opportunity to land at a specified site occurs only twice in 24 hours.

We will now show an equatorial orbit (adjust model). This provides the least earth coverage. Launching must be from the equator. The possible landing points will be in a narrow belt extending around the earth and the satellite will pass over them each time it circles the earth. This will make the recovery of a satellite from an equatorial orbit simpler than from other orbits except that landing sites on the equator are largely limited to oceans or jungles. Also, fewer ground stations will be needed to keep track of the satellite throughout its orbit.

A very interesting orbit is a circular one around the equator at an altitude of about 22,000 miles. This ball represents such a satellite at scale distance from the earth. At this altitude, the satellite would complete its circle once every 24 hours, so it would appear to hang motionless in the sky. It has been suggested that three satellites equipped as radio or television relay stations and equally spaced in such an orbit would permit world-wide broadcasts.

We have touched only a few of the factors involved in the selection of satellite orbits. However, it is apparent that we will use many different orbits to realize all the benefits available from satellites.

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The next speaker is Mr. who will discuss some of the problems of satellite orientation in space.

V. Orientation

At satellite altitudes there are essentially no aerodynamic forces. Unlike the situation with an airplane, there is very little air to produce lift, drag, or turning moments, nor is there air friction to damp out undesirable rotation of the satellite. As a result, the path of a satellite in orbit is independent of its orientation. Yet, for most satellites, some form of stability and control will be required. For example, undesirable rotations such as may be induced when the satellite is disengaged from the launching rocket must be stopped. Military and weather reconnaissance satellites must keep their scanning devices pointed earthward. Recoverable satellites must be rotated into the proper attitude for entering the atmosphere.

Satellites can be given a spinning motion during launching to provide the kind of stability possessed by spinning bullets. The effect is shown on this chart. With a proper combination of rate of spin and distribution of masses within the satellite, it would continue to point in one direction (chart No. 5) as it circles the earth.

The natural forces on a suitably designed but non-spinning satellite will tend to keep one axis pointed toward the earth, as shown on the other side of this chart. With the mass distribution indicated by the dumbbell shape, there will be minute differences in gravitational attraction on portions of the vehicle closest to and farthest from the earth. This difference in forces will tend to keep the longer axis (point) pointed toward the center of the earth. However, if such a satellite is disturbed from this stable attitude, as it might be during launching, it will

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oscillate slowly back and forth indefinitely in the manner of a frictionless pendulum.

Methods of controlling the attitude of a satellite will be required for manned flight, so let us look at some of the methods of control. We have here a chair which is free to rotate about one axis. (Demonstrate.) The revolving part represents a satellite but of course a satellite would be free to rotate in all directions and would not be hindered by bearings or air friction. Incorporating the other freedoms of motion, rolling and pitching, (indicate by hand motions) would only complicate the demonstration. (Fix chair and pilot climb aboard).

First, let us see what can be done with a simple flywheel. This bicyle wheel has been weighted with lead to provide a flywheel. The rate of rotation of the flywheel can be controlled by the crank and the plane of rotation can be controlled by the stick. To demonstrate the use of the principles of momentum to control attitude, we put the flywheel in a horizontal plane. Now as the pilot cranks up the flywheel the satellite begins to rotate in the opposite direction. There is no external force or reaction so the momentum put into the flywheel is picked up in the reverse direction by the rest of the satellite. The total momentum of the combination does not change.

Now we will see gyroscopic force used as a control. We start with the flywheel rotating in a vertical plane. By turning the plane of rotation of the freely spinning wheel, the pilot can alter his direction at will.

Small jets are another source of force for rotating space craft. The NACA has conducted both ground and flight research on such systems at its High-Speed Flight Station at Edwards Air Force Base. Controls of

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this type will be used on the X-15 research airplane when it reaches altitudes where ailerons, rudder, and elevators are no longer effective. Research conducted thus far indicates that small jets can provide the control required.

We will demonstrate this type of control. Again, the revolving portions of the stool represents the satellite. We attach a pair of nozzles pointing in opposite directions, and we give the pilot a switch to operate the valves which control the flow of gas to the nozzles. Now we ask him to turn the satellite 90° and maintain the new heading. The friction in the rotating system tends to resist the motion and makes his task easier than it will be in actual satellites. Even so, you see he has difficulty in obtaining an accurate heading.

Let's discard the human pilot and substitute automatic apparatus to control the jets. This device has an inner unit which is mounted on gimbals so it can turn freely in any direction. It contains three single-degree-of-freedom gyroscopes arranged so they keep the orientation of this unit fixed in space regardless of the motion of its support. As this device is carried to the stool, you will notice how the inner unit with the gyroscope maintains a fixed attitude regardless of rotation of the base. This device is similar to equipment used for inertial navigation of long-range airplanes, missiles, and ships. It is generally called a "stable platform".

We will now demonstrate how a stable platform can help provide satellites with stability and control of attitude. The stool again represents a satellite and again we will demonstrate with only one degree of freedom to rotate. As our satellite is rotated, the stable platform maintains its direction. Now we are connecting some wires to the jet

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control-valve switch so any rotation of the satellite relative to the stable platform will operate the same air jets our human pilot demonstrated. The stool is forceably displaced, and the air jets quickly and accurately drive it back to its original position. This illustrates one way a satellite can be maintained in a fixed attitude in space in spite of disturbances.

Next, we demonstrate how the stable platform can be used to change the orientation of a satellite. In this case, as an example, the stable platform is made to rotate at a constant rate instead of maintaining its initial heading. This is accomplished by applying electrically a constant torque to the gyroscope much in the same manner as our human pilot steered by applying a torque to his bigger gyroscope. Relative motion between the stable platform and satellite supplies an electrical signal which operates the air jets to bring the whole satellite along with the stable platform. This system may find such uses as keeping satellites carrying cameras pointing continuously earthward as they circle the earth. The satellite in this case would be driven one revolution about its own axis for each revolution it makes about the earth.

Because of the limited time we have touched only briefly on a few aspects of earth satellites. We hope our demonstrations have helped you understand some of the principles of satellites.

Thank you.

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SOME USES OF EARTH SATELLITES

- Geographical distance measurements
- Distribution of material inside the earth
- Properties of the upper atmosphere
- Meteor frequency and size
- Solar and cosmic particles and radiations
- Earth's magnetic and gravitational fields
- Weather theory and prediction
- Communication and TV relay
- Military reconnaissance
- Astronomical investigations
- Biological and medical investigations

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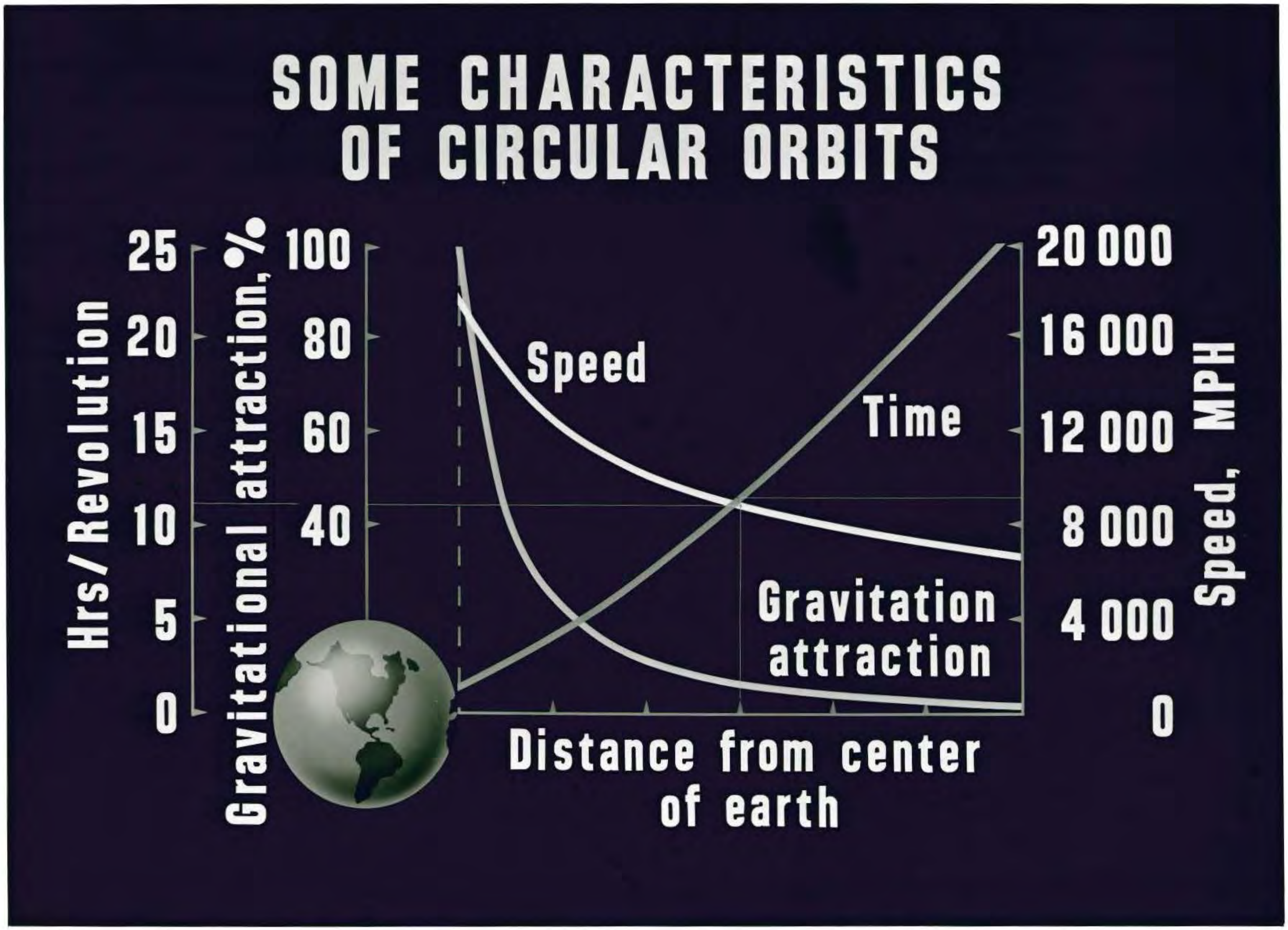

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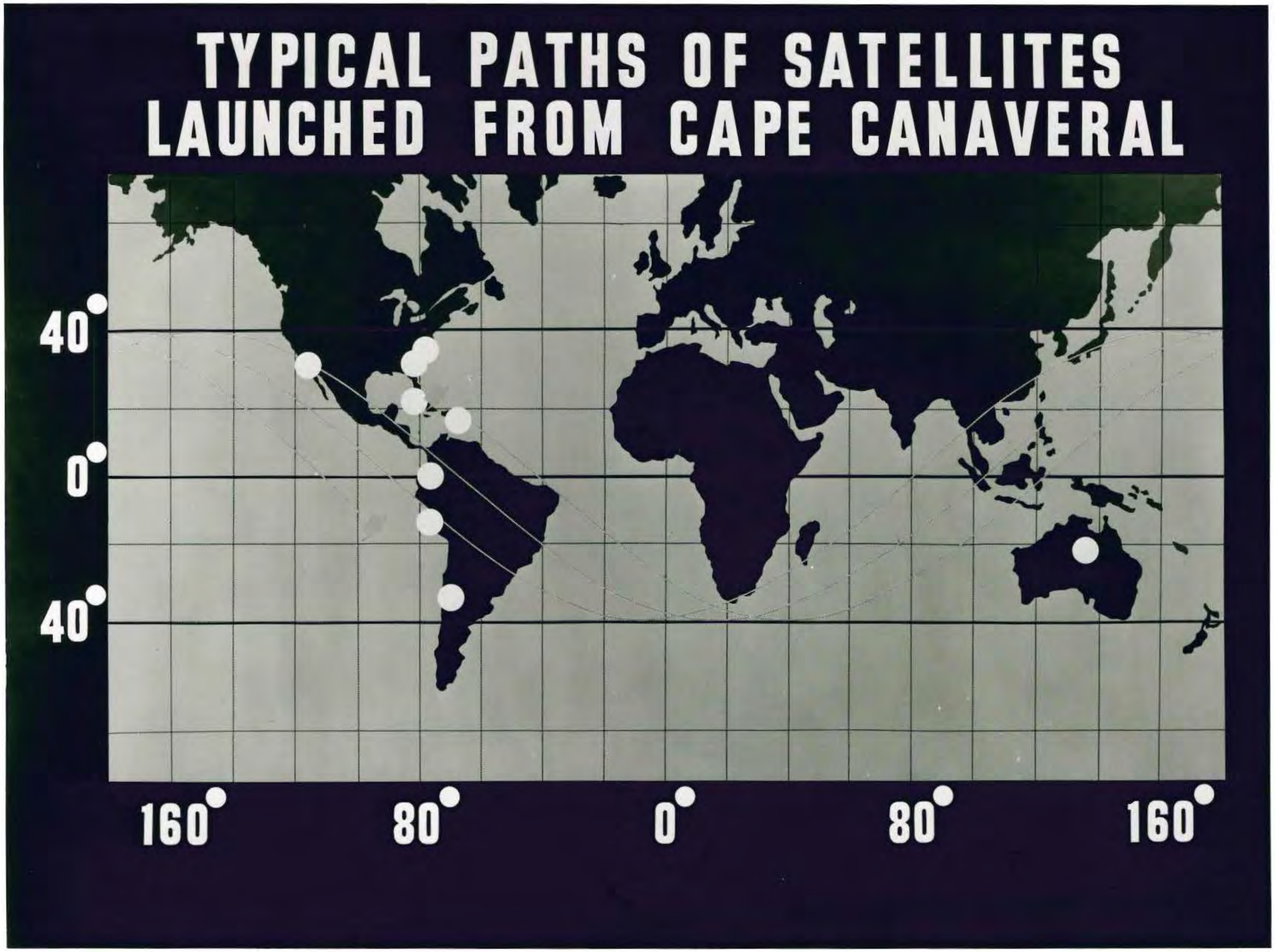

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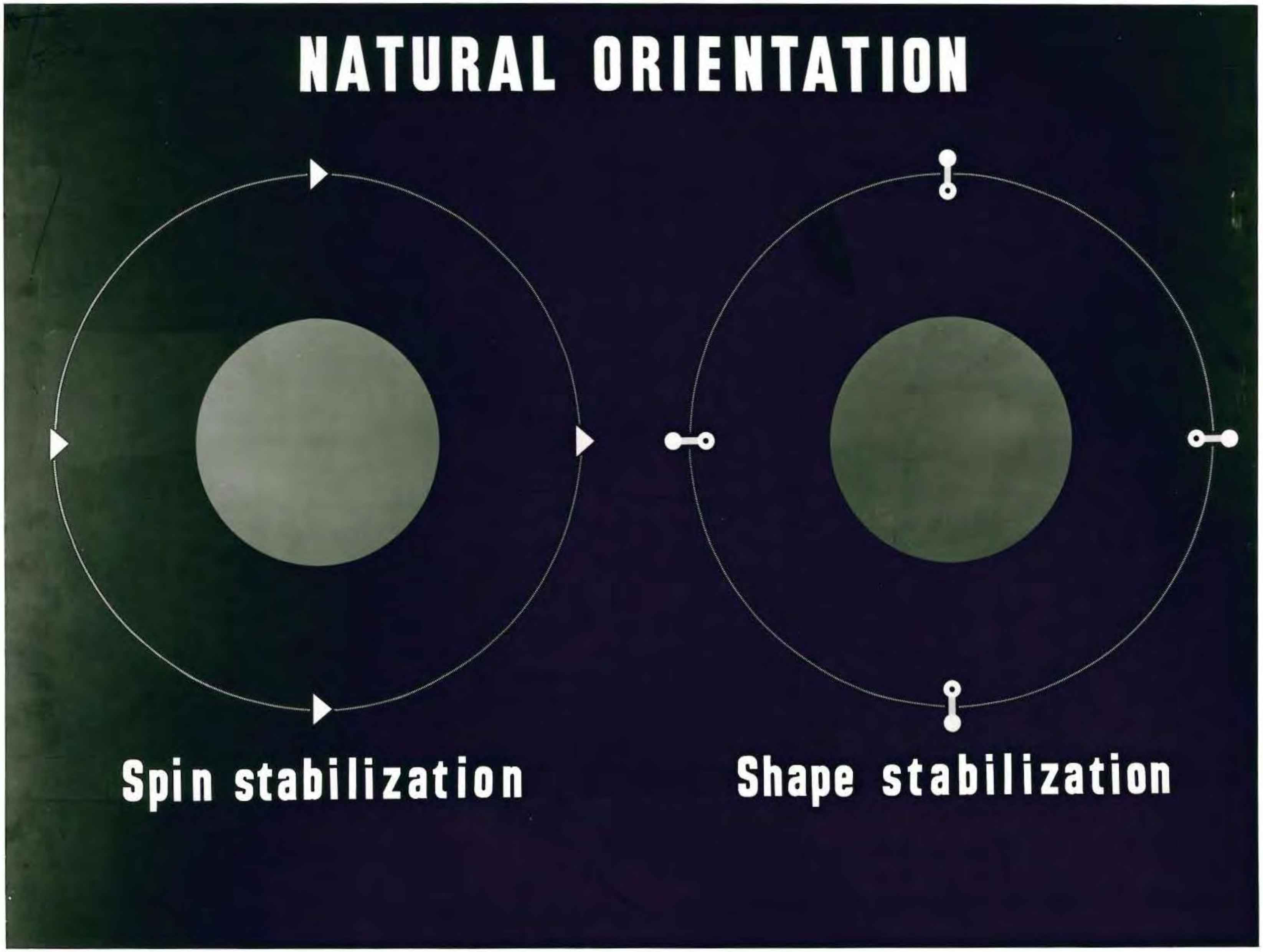

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