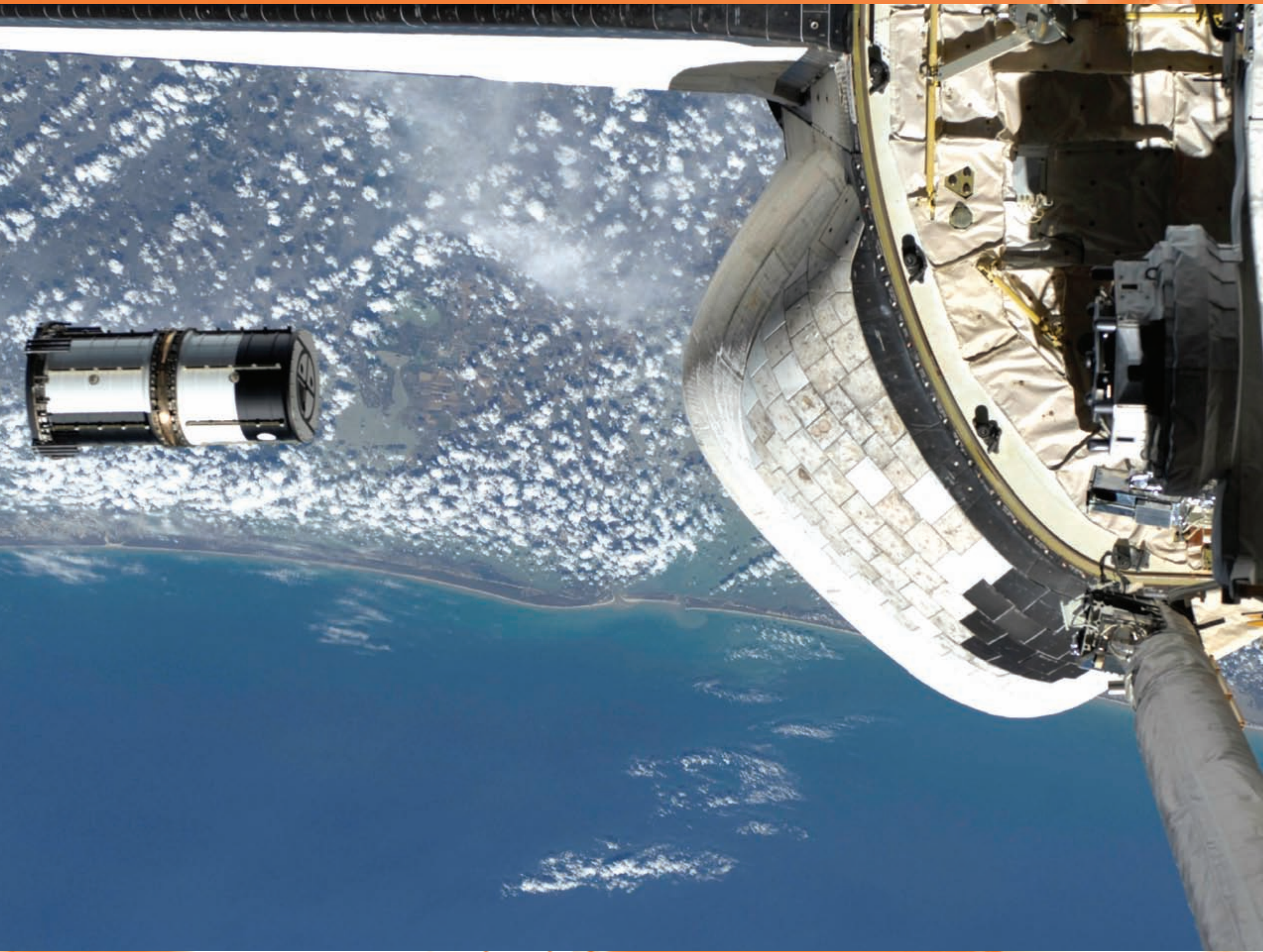
CHAPTER 10



STS-127 crew members release the Atmospheric Neutral Density Experiment 2 (*at left*). This experiment consists of two spherical micro-satellites, which will measure the density and composition of the low-Earth orbit atmosphere.
Courtesy of NASA

Orbits and Trajectories

Chapter Outline

"We are gliding across the world in total silence, with absolute smoothness; a motion of stately grace which makes me feel godlike as I stand erect in my sideways chariot, cruising the night sky."

Michael Collins, Carrying the Fire: An Astronaut's Journey

LESSON 1 Orbits and How They Work

Quick Write

Can science fiction contribute to scientific progress? What other science-fiction writers can you think of who foresaw important scientific discoveries and inventions?

Learn About

- how orbits work
- different types of orbits used for different purposes

Sir Arthur C. Clarke, who lived from 1917 to 2008, was a famous British science fiction writer and futurist. Perhaps his most famous book was *2001: A Space Odyssey*. Director Stanley Kubrick made it into a popular movie, which was released in 1968. One of the film's most memorable characters is the renegade computer, HAL, which tries to take over the spacecraft and kills several astronauts before the surviving crew member can subdue it. Clarke later wrote three additional novels involving several of the same characters.

Like many of the best science-fiction writers, Clarke was a practical thinker. In 1945 he published an article in *Wireless World* calling for a system of relay satellites in geostationary orbit around the Earth. He thought these satellites would be useful for telecommunications around the world. Remember that at that time, no country had even launched a satellite. Clarke was not the first or only person to come up with the idea, but his article helped popularize it. Today some people refer to geosynchronous orbit as "Clarke orbit."

How Orbits Work

You've been reading about different orbits throughout this book. But think a minute about what an orbit is. It's a regular, repeating path that one object in space takes around another object. The Moon and man-made satellites orbit the Earth. The Earth and the other planets orbit the Sun, along with asteroids, dwarf planets, and comets. Most of these objects orbit along or close to an imaginary flat surface astronomers call the ecliptic plane, which you read about in Chapter 9.

In Chapter 1 you read about Johannes Kepler's discovery that the planets' orbits are elliptical, or oval-shaped. This is true of many satellites' orbits, too. Satellites are not always the same distance from Earth during their orbits. In Chapter 2 you read that *perigee* is when a satellite is closest to Earth. *Apogee* is when an object is at its farthest distance from Earth.

Vocabulary

- orbital velocity
- inclination
- geosynchronous Earth orbit
- Sun-synchronous orbit
- low-Earth orbit
- high-Earth orbit
- medium-Earth orbit

Momentum and Gravitational Force

To place a satellite into orbit, scientists must deal with Sir Isaac Newton's law of gravity, which you studied in Chapter 1. If it weren't for gravity, a satellite launched into space would keep right on going away from Earth in accordance with Newton's first law of motion: An object in motion will stay in motion unless something pushes or pulls it. But gravity pulls the object back to Earth. An orbit is the constant struggle between the momentum of the object in a straight line, and gravity pulling the orbiting object back toward the body it circles.

In previous chapters you learned about various missions to space, including the Pioneer missions of the mid-twentieth century. *Pioneer 1* and *Pioneer* 2 both failed, in large part, because their momentum wasn't enough to escape Earth's gravity and propel them to the Moon. (*Pioneer 1* did return some useful data about Earth, however.) In 2009 a NASA satellite launched to study global warming. But it was too heavy and failed to escape Earth's gravity. It crashed in the Antarctic Ocean less than 48 hours after takeoff from California.

A Saturn 1B takes off for a Skylab mission in 1973.

Courtesy of NASA

A space shuttle must rocket out of Earth's atmosphere to reach orbit. Yet the shuttle can't travel so far beyond Earth's atmosphere that gravity can't hold it in orbit around the planet. When momentum and gravity are balanced, a satellite is always falling into the planet. But because it's moving "sideways" fast enough, it never hits the planet.

Escape Velocity

Escape velocity—which you read about in Chapter 4—is the speed an object must reach to overcome a body's gravity and leave its orbit. Because a body's size and mass determine its gravitational pull, escape velocity differs from planet to planet, moon to moon, and asteroid to asteroid.

The location and direction from which scientists launch a satellite or spacecraft is also important. For instance, the closer an object is to the Earth's equator, the more speed it gains from the Earth's own rotation—assuming it's launched eastward. This is because the planet's surface rotates fastest at the equator. The surface rotation speed slows down the farther you get from the equator, until it's almost at a standstill at the poles. A satellite launched in a different direction does not gain this advantage, and one launched toward the west needs more velocity to overcome the rotation.

The additional miles per hour that engineers gain by launching from near the equator helps them propel rockets and their payloads into space. That's one reason the European Space Agency maintains a spaceport in Latin America in French Guiana, about 300 miles (500 km) from the equator.

To reach escape velocity, engineers must decide how much thrust to apply to a launch vehicle. They can't have too little, but, depending on their destination, they can't have too much, either.

Figure 1.1 In this artist's conception, a GOES satellite orbits some 22,000 miles (35,000 km) above Earth. Once a spacecraft achieves orbit, it must reach a certain orbital velocity—the speed an object must maintain to stay in orbit.
Courtesy of NOAA

As NASA International Space Station science officer Ed Lu wrote during his *Expedition 7* mission on how to reach orbit: "[A] lot of speed and initially a little bit of aiming to make sure you don't hit the ground. . . ." And if you get these factors right along with getting high enough to be out of Earth's atmosphere, "[Y]ou will just keep going round and round the planet."

Star POINTS
The escape velocity for an object from the Earth is seven miles (11.3 km) a second.

Orbital Velocity

Once a spacecraft achieves orbit, it must reach a certain orbital velocity—*the speed an object must maintain to stay in orbit*. This velocity differs, depending on how high up in orbit a spacecraft or satellite is. For example, NASA says that at 150 miles (242 km) above Earth, a spacecraft must travel about 17,000 miles (27,000 km) per hour—far less than full escape velocity.

The closer an object is to Earth, the faster it needs to travel to remain in orbit. This is because the closer an object is to Earth, the stronger Earth's gravity is pulling downward on it. The faster an object travels, the more it "rejects" the gravitational pull. As Newton reasoned more than 300 years ago, Earth's gravity pulls much less on the Moon than it does on objects in closer orbit. So the higher a spacecraft climbs from Earth, the slower it can travel and still resist gravity (Figure 1.1).

Orbital Period

The amount of time a satellite takes to orbit Earth—its orbital period—changes dramatically depending on how far above Earth it is. The closer to Earth, the stronger gravity's pull, with the result being a faster orbital period. Here are three examples for comparison:

1. NASA's Aqua satellite orbits Earth in 99 minutes from 437 miles (705 km)
2. A weather satellite orbits in 23 hours, 56 minutes, from 26,141 miles (42,164 km)
3. The Moon orbits Earth in 28 days from 238,329 miles (384,403 km).

How Height, Eccentricity, and Inclination Affect an Orbit

Many factors affect orbiting satellites. Height, as you've read, determines the speed required for a satellite to remain in orbit. But an orbit's shape and angle will affect what path a satellite will take and, therefore, determine what it sees and reports back to Earth.

The elliptical orbits of satellites come in different degrees. As you read in Chapter 1, *eccentricity* is the term scientists use to refer to an orbit's shape. A low-eccentricity orbiting object is one flying in a more-round, less-oval path. A circular orbit has an eccentricity of zero. A highly eccentric orbit is close to 1 (but never reaches it).

Inclination is *the angle an orbit takes as it circles the Earth*, especially as it relates to the equator. If an orbit is directly over the equator, it has a zero inclination. An object that revolves or orbits north to south (and then south to north) has a 90-degree inclination.

The $856 million Solar Dynamics Observatory, launched in 2010 for a five-year mission, tells scientists more about the Sun and how it impacts space weather. It flies in a geosynchronous orbit around Earth. Satellites fly in orbits with varying eccentricities and inclinations.

Courtesy of NASA

Different Types of Orbits Used for Different Purposes

Scientists not only consider speed and gravity when planning launches, they also must choose from many types of orbits. The kind of orbit they pick depends on the mission.

Some satellites maintain station over the same spot on Earth's equator. Others circle from North Pole to South Pole and back again. Spacecraft also enter a low-, medium-, or high-Earth orbit, again determined by the mission's purpose.

Geosynchronous Earth Orbit (GEO)

Satellites that seem to be attached to some location on Earth are in geosynchronous Earth orbit (GEO). Geosynchronous orbit is *an orbit around a planet or moon that places the satellite in the same place in the sky over a particular point on the surface each day*. An object in geosynchronous orbit appears to remain still all day long, but in reality it orbits at a speed equal to the Earth's rotation. So it remains fixed over the same spot at all times. When a geosynchronous orbit is over Earth's equator, it's called a *geostationary orbit*.

Geostationary Operational Environmental Satellites (GOES)

Satellites in geostationary orbit—such as Geostationary Operational Environmental Satellites (GOES)—fly very high above the Earth in the equatorial plane. GOES orbit at approximately 21,700 miles (35,000 km) high. Scientists place GOES this high so the satellites can travel slowly enough to make only one orbit a day, just as the Earth makes one revolution per day (Figure 1.2).

Since GOES and other geostationary satellites stay above a fixed spot on Earth's surface, they watch continuously for the atmospheric triggers of severe weather such as tornadoes, flash floods, hailstorms, and hurricanes. When these conditions develop, the GOES monitor the storms and track their movements. They also provide general weather monitoring to provide data for daily weather forecasts.

Figure 1.2 GOES fly very high above the Earth in the equatorial plane.
Courtesy of NOAA

These satellites provide scientists with consistent, long-term observations, 24 hours a day, seven days a week. They monitor fast-breaking storms across "Tornado Alley" (a region in the heart of the United States often hit hard by tornadoes) as well as tropical storms in the Atlantic and Pacific Oceans. Scientists also use the satellite information to monitor coral reefs, fires, and volcanic ash. Monitoring the Earth from space helps scientists better understand how the Earth works.

Data from GOES satellites also help meteorologists estimate rainfall during thunderstorms and hurricanes for flash flood warnings. Such data also help them make snowfall projections, and issue winter storm warnings and spring snowmelt advisories. Satellite sensors also detect ice fields and map the movements of sea and lake ice. They help track icebergs that threaten shipping—like the one that sank the *Titanic* in 1912.

Polar-Orbiting Operational Environmental Satellites (POES)

While GOES are high-flying orbiters, Polar-orbiting Operational Environmental Satellites (POES) fly lower and closer to the Earth. This means they have a much faster orbital period. In fact, they monitor the poles and circle the Earth once every 100 minutes. Combining the data from three POES over a six-hour period allows scientists to compile an image covering nearly every inch on Earth.

POES also pass over the same latitudes at the same times each day. This way scientists can more easily note any changing conditions on the ground.

These polar orbits are Sun-synchronous orbits. A Sun-synchronous orbit is *an orbit coordinated with Earth's rotation so that the satellite always crosses the equator at the*

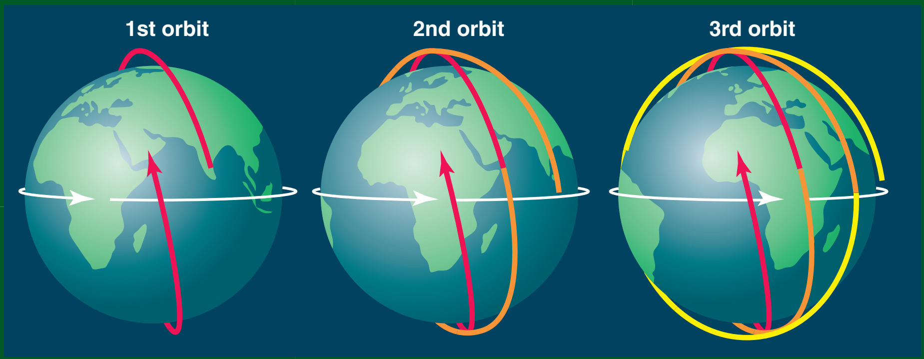


Figure 1.3 A Sun-synchronous orbit crosses over the equator at approximately the same local time each day (and night). This orbit allows consistent scientific observations with the angle between the Sun and the Earth's surface remaining relatively constant. These illustrations show three consecutive orbits of a Sun-synchronous satellite with an equatorial crossing time of 1:30 pm. The satellite's most recent orbit is indicated by the red line, while older orbits are orange and yellow.

Courtesy of Earth Observatory, NASA

POES and You

You and your neighbors benefit from POES satellites, particularly if you're planning on flying, boating, fishing, or farming. More than 50 percent of the US public uses the three-to-five day forecasts issued by the Weather Service to plan business or pleasure activities. These are based on POES data. And your local governments use the information from these satellites to plan expansion and to monitor growth. Finally, search-and-rescue equipment on board the satellites has helped save more than 24,000 lives.

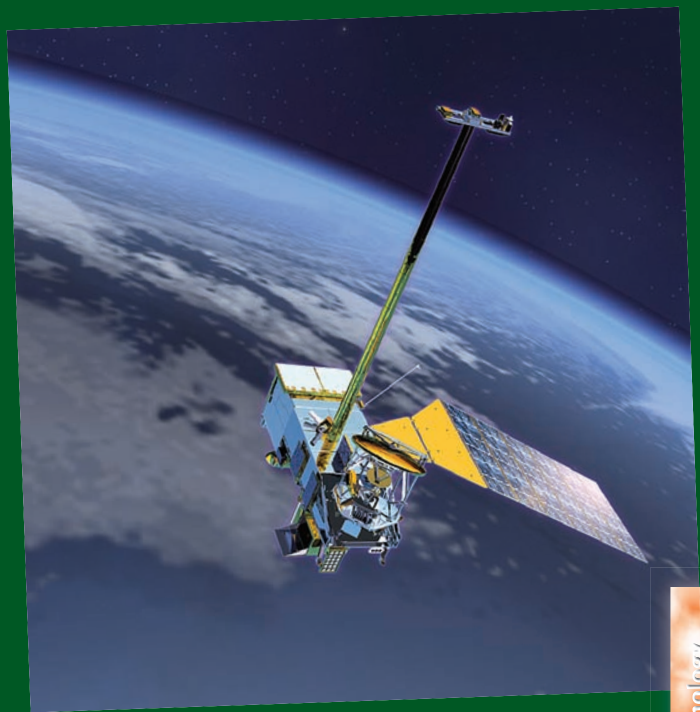
The military benefits from the satellites as well, tactically and strategically. As a result, the military takes advantage of good weather conditions to maneuver, and exercises caution when the weather is bad.

same local time on Earth. The orbital planes of these satellites rotate one degree a day because the Earth bulges at its equator. This bulge exerts extra gravitational pull on the satellites as they pass overhead and gradually rotates the satellites' orbital planes. As a rule, a Sun-synchronous satellite's orbital plane will complete one full rotation about Earth's axis in one year's time due to this force of gravity (Figure 1.3).

POES see everything from environmental conditions to real-time weather. They provide global coverage of the Earth's weather, atmosphere, oceans, land, and near-space environment. NASA and the National Oceanic and Atmospheric Administration (NOAA) share responsibility for these satellites, as they do for GOES. But NOAA operates them.

The POES system monitors the entire planet and provides information for long-range weather and climate forecasts. The data gathered by these satellites saves lives by allowing more-efficient disaster planning and faster response times to severe weather conditions, such as tornadoes and floods.

These satellites also collect a large amount of specific information about the Earth's surface, as well as atmospheric and space environmental measurements. This lets scientists and forecasters monitor and predict weather patterns with greater speed and accuracy.



POES fly lower and closer to Earth than satellites in geostationary orbit.

Courtesy of NOAA

Low-Earth Orbit (LEO)

POES usually travel in a low-Earth orbit—*an orbit up to about 1,240 miles (2,000 km) above the Earth*. This area is the easiest to get to when orbiting the Earth.

The International Space Station and space shuttles travel in this zone as well. A complete revolution in low-Earth orbit can take as little as 90 minutes.

If it were possible to drive to the International Space Station in low-Earth orbit, it would take you only a few hours to get there. It's only about 250 miles (400 km) high. By comparison, a geosynchronous high-Earth orbit—*an orbit at an altitude of about 22,300 miles (35,900 km)*—begins about one-tenth of the way from the Earth to the Moon.

A medium-Earth orbit is *one with an altitude of about 12,400 miles (20,000 km)*. Satellites in this orbit take about 12 hours to orbit the Earth. Such an orbit is outside Earth's atmosphere and very stable. Radios across the globe can receive signals from satellites at this altitude. Along with the orbit's stability, this makes it ideal for navigation satellites, although such satellites have used both higher and lower orbits.

Of course, once engineers and scientists have decided which orbit to use for a mission, they have to get the spacecraft there. For manned and some research flights, they have to get it back as well. Maneuvering into space and in space is a lot more complicated than driving a car or even flying a plane. The next lesson will examine some of the challenges.

CHECK POINTS

Lesson 1 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. Give an example of what can happen when the speed of an object racing toward space is not balanced properly with Earth's gravity.
2. To determine escape velocity, what must engineers decide?
3. What is the orbital velocity needed to stay 150 miles above the Earth?
4. When an orbit is directly over the equator, what inclination does it have?
5. What is a geostationary orbit?
6. Why do scientists place GOES high above Earth?
7. What advantage do scientists gain by having POES pass over the same latitudes at the same times each day?
8. What is low-Earth orbit?

APPLYING YOUR LEARNING

9. Why do engineers like to launch satellites from near the equator?