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Up, Up, and Away

by James J. Secosky, Bloomfield Central School
and George Musser, Astronomical Society of the Pacific

Want to take a tour of space? Then just flip around the channels on cable TV. Weather Channel forecasts, CNN newscasts, ESPN sportscasts: They all depend on satellites in Earth orbit. Or call your friends on Mauritius, Madagascar, or Maui: A satellite will relay your voice. Worried about the ozone hole over Antarctica or mass graves in Bosnia? Orbital outposts are keeping watch. The challenge these days is finding something that *doesn't* involve satellites in one way or other.

And satellites are just one perk of the Space Age. Farther afield, robotic space probes have examined all the planets except Pluto, leading to a revolution in the Earth sciences -- from studies of plate tectonics to models of global warming -- now that scientists can compare our world to its planetary siblings. Over 300 people from 26 countries have gone into space, including the 24 astronauts who went on or near the Moon. Who knows how many will go in the next hundred years?

In short, space travel has become a part of our lives. But what goes on behind the scenes? It turns out that satellites and spaceships depend on some of the most basic concepts of physics. So space travel isn't just fun to think about; it is a firm grounding in many of the principles that govern our world and our universe.

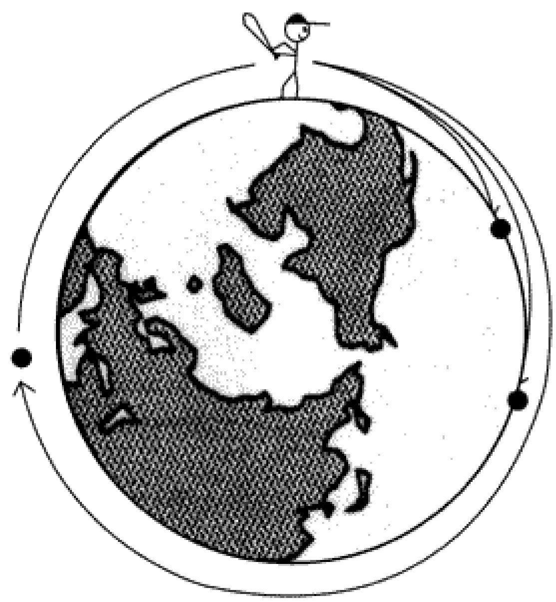
5...4...3...2...1...

The science of space travel takes off with Newton's third law of motion: *To every action there is always opposed an equal reaction.* This is why rockets ascend. The action of the hot exhaust gases rushing out the rocket engines creates an equal but opposite reaction, which pushes the vehicle forward. The higher the velocity or mass of the exhaust gases, the greater the thrust. Rockets do *not* move because they are pushing against ground or air. After all, they function in the vacuum of space where there is nothing to push against.

The same Newton's third law applies when you stand on a skateboard or rollerblades and throw a basketball: The board or blades roll in the direction opposite the way you're throwing. The harder you throw the ball or the heavier the ball is, the faster you'll roll backwards.

Following liftoff, the rocket climbs nearly straight up in order to get out of the thickest part of the atmosphere. It reaches an altitude (200 kilometers, or 120 miles) where the air is so thin that there is little atmospheric drag. Once above the bulk of the atmosphere, the rocket turns onto its side and accelerates to 28,000 kilometers per hour (17,400 miles per hour). The horizontal speed is crucial. It ensures that the rocket will keep moving forward while gravity pulls it down. If the speed were any lower, the rocket would crash into the ground somewhere.

In this sense, launching a rocket is like hitting a baseball. A lightly hit ball might drop near second base; a harder hit ball would go deep into the outfield; a home run would fly over the fence. If you hit the baseball hard enough, it would fly over the fence, over the parking lot, over the highway, over the harbor, over the Atlantic Ocean, Africa, the Indian Ocean, the Pacific Ocean -- right back over the ball park again, over the parking lot, over the highway, and so on, and so on. You would have hit that ball into orbit (see diagram). The ball would always be falling toward the ground, but would have enough forward momentum to keep it from ever reaching the ground. With no forces except gravity, the ball would stay in orbit forever (see activity). (In practice, a small amount of atmosphere is still present even at 200 kilometers, so every satellite will eventually slow down and fall to Earth.)



Going, going, gone. During a 1960 baseball game between the New York Yankees and Detroit Tigers, Mickey Mantle knocked a home run out of Briggs Stadium. According to *Guinness*, it was the longest home run ever: 643 feet (196 meters). In principle, if The Mick had swung his bat a bit faster -- 150 times faster -- he could have hit the ball into orbit. (In practice, air resistance would have melted the ball, shrapnel from the shattered bat would have killed the infielders, and Mantle would have sat out the rest of the season with severe shoulder injuries.) Orbits are just like the flight path of a ball. The Earth's gravity pulls the ball down while the ball's initial velocity carries it forward. The higher the initial velocity, the farther the ball can go before hitting the ground. At a high enough initial velocity, the ball can go all the way around the world -- and that's what we call an *orbit.*

Like the orbiting baseball, a satellite or space shuttle is always falling toward the ground -- but always missing it. Since it is falling, everything in it is falling; the sensation of weightlessness, or zero-*g*, results. People seem to love the feeling. They'll even pay to experience it: skydiving, bungee jumping, trampoline jumping, roller-coaster rides, Free Fall or Demon Drop rides.

Life in Orbit

Just because astronauts are weightless does *not* mean there is no gravity in space. Indeed, the force of gravity keeps the Moon in orbit around the Earth and the planets in orbit around the Sun. Weightlessness simply means that astronauts are in the free fall of orbital motion. Skydivers and bungee jumpers also feel weightless, but who would deny that gravity is pulling on them?

To get astronauts used to weightlessness, NASA takes them for a ride on a KC-134 airplane. Like a flying roller coaster, the KC-134 goes into a steep dive that produces 30 to 40 seconds of weightlessness. All the weightless scenes in the movie "Apollo 13'' were filmed aboard such an aircraft. Astronauts also simulate working in space while underwater in large tanks.

Despite these preparations, it takes astronauts a while to get used to the strange condition of weightlessness. When entering orbit, they do not immediately float up to the ceiling. As Newton's first law of motion says, a force is required to get people or objects moving. In zero-*g*, objects stay where they are put, until a force is applied to them. You could leave a pencil hanging in mid-air and pick it up later. If astronauts find themselves sitting in the middle of the cabin, too far to push off a wall, they're stuck until another astronaut comes to push them into motion.

Sometimes objects in orbit are disturbed by forces that we don't normally think about on Earth. Weightless water, for example, curls up into a sphere because of its internal cohesion forces --the same forces that cause beads to form on a newly waxed car. Astronauts have to drink using special straws. The straws close when not in use; otherwise the liquid would continue to squirt out the straw even when the astronaut was not sucking on it.

As much as we curse weight on Earth, weightlessness can cause physiological problems for astronauts in orbit. Half of all astronauts suffer motion sickness in the first few days. Some vomit. Space flights lasting months weaken people's muscles and bones. The body reckons it no longer needs the extra strength, breaks down the muscles and bones, and excretes the chemicals via the kidneys. The same thing happens on Earth when people are confined to bed; those of us who have had to wear a cast know how weak the limb becomes. Exercise counteracts this breakdown of the body.

Up, Up, and Away

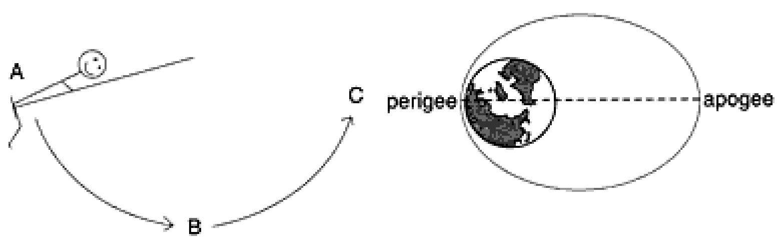
Hooking Up

Many human space flights involve a meeting, or rendezvous, with another spacecraft, such as the docking of the space shuttle with the *Mir* space station (see sidebar). During the rendezvous maneuvers, the astronauts must change their orbit to match the orbit of the spacecraft they'd like to visit. And changing orbits can be counterintuitive.

Firing the rocket engines ultimately makes an orbiting spaceship go *slower*. The reason is that the engines move the ship into a higher orbit -- which is a slower orbit, because gravity is weaker. Satellites in low orbit experience a stronger pull of gravity and therefore move faster. At an altitude of 200 kilometers (120 miles), a satellite zips by at 28,000 kilometers per hour, completing one orbit every 90 minutes.

At an altitude of 35,800 kilometers (22,200 miles), a satellite travels at a more modest 11,100 kilometers per hour, completing one orbit every 24 hours. It keeps pace with the Earth's rotation. Such an orbit, termed a *geostationary* or a *geosynchronous* orbit, is used for weather and communications satellites that need to hang over one point on the Earth's surface. At an altitude of 390,000 kilometers (242,000 miles), our natural satellite -- the Moon -- orbits at 3,600 kilometers per hour and completes one orbit every 28 days.

For each altitude, there is a unique velocity that a satellite must have in order to keep to a circular orbit. If the rocket engines force the satellite to go faster or slower than this velocity, the satellite goes into an elliptical orbit. A satellite in an elliptical orbit keeps changing its distance from Earth (see diagram). Its closest point to Earth is called the *perigee*; its most distant point, the *apogee*. As the satellite's altitude changes, so does its speed.

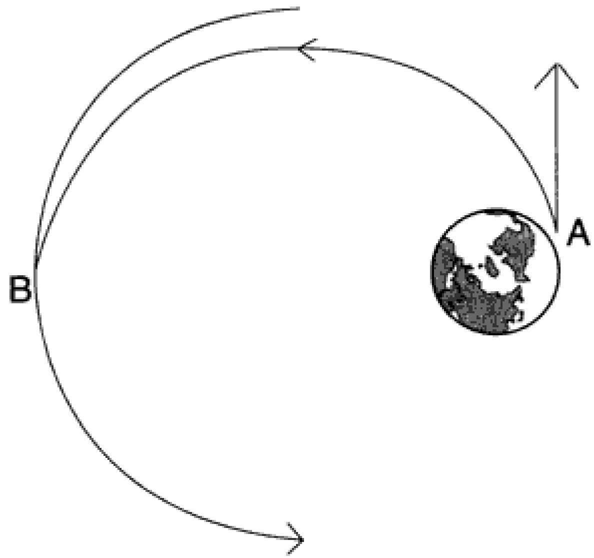


Swingin' at the Savoy. Unless you're a daredevil, you swing back and forth in an arc -- exchanging height for momentum, and then vice versa. At the top of the arc ('A'), your swing comes to a halt and reverses direction. As you swing downward, gravity causes your speed to build up, reaching a maximum at the bottom of the arc ('B'). As you swing back upwards, you slow down and eventually reach the top of the arc ('C'). A satellite in an elliptical orbit moves the same way for the same reason. At its farthest point from Earth (apogee), the satellite stops moving away from Earth and starts moving downward. As the satellite descends, it accelerates, reaching a maximum speed at its closest point to Earth (perigee). As the satellite ascends, it slows down until it reaches apogee again.

The satellite moves fastest at perigee and slowest at apogee. The speed varies just as the speed of a child on a swing (see diagram). Near the top of the swing arc, the swing is going slow; at the bottom, it goes very fast. At the bottom, the swing's inertia carries it upward; as the swing climbs, its speed decreases; at the top, gravity brings the swing back down. Likewise, a satellite goes faster when near Earth (perigee) and slower when farther away (apogee).

Almost all satellites start off in elliptical orbits because it is difficult to get the launch speed just right for a circular orbit. To shift the satellite into a circular orbit, the mission controllers fire the rocket engines once the satellite is above the atmosphere. The space shuttle regularly does this with an "OMS burn'' 46 minutes into the flight. The OMS burn ensures that the shuttle moves at exactly the right speed for a circular orbit at the desired altitude.

To get from one circular orbit to another, a satellite must first go into an elliptical orbit. There are many elliptical orbits that will do the trick, but the one that takes the least effort is called a *Hohmann transfer* orbit. Suppose you want to move your communications satellite from a low orbit into a geosynchronous orbit at 35,800 kilometers (see figure). The first step is to increase the velocity by firing the rockets. This boosts the satellite into an elliptical orbit with an apogee of 35,800 kilometers. The second step is to fire the rockets again, just as the satellite reaches apogee. This second burn changes the elliptical orbit into a circular one.



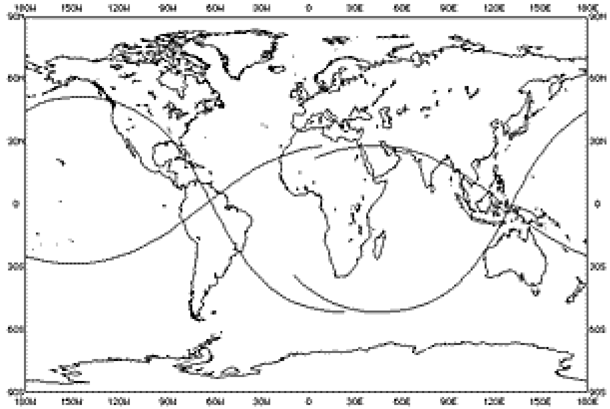
Give me a transfer. Boosting a communications satellite from low Earth orbit into geosynchronous orbit is a two-step procedure. First, fire the rockets to increase the satellite's speed from 28,000 to 36,900 kilometers per hour ('A'). This puts the satellite on an elliptical orbit, known as a *Hohmann transfer.* The perigee of the new elliptical orbit is the altitude of the low orbit; the apogee is the altitude of the geosynchronous orbit. The satellite will move outward on its new orbit, slowing down as it goes. When the satellite reaches its apogee, it is moving at 5,800 kilometers per hour. At this point, fire the rockets again to increase the speed to 11,100 kilometers per hour ('B'). This puts the satellite into a circular orbit at that altitude.

When astronauts use Hohmann transfers to rendezvous with another spacecraft, they must time the transfer precisely so that they will arrive in their new orbit at the place where the other spacecraft will be.

Inclined to Agree

The altitude and circularity of the orbit are not the only things that must match before two spacecraft can meet. The craft must have orbits with the same inclination.

When the first astronauts went into orbit, most people wondered why the ground path displayed on a world map made a strange up-and-down looping pattern (see map). We all had assumed the orbit would be directly above the equator. In actuality, nearly all orbits are inclined to the equator. Usually the angle of inclination equals the latitude of the launch site: 28.5 degrees for the Kennedy Space Center in Florida (see activity). This means that the space shuttle generally goes 28.5 degrees to the north and 28.5 degrees to the south. NASA sometimes uses orbits with greater than 28.5 degrees of inclination, but those orbits are less efficient.



Ground traces of *Mir* and *Hubble.* This map show the points on Earth immediately below these two satellites. The tracks change over the course of a day; this map shows them on April 20, 1996 from 9 to 10:45 p.m. Pacific time. *Mir* completes one orbit every 92 minutes 26 seconds and reaches latitudes between 51.65 degrees north and 51.65 degrees south. *Hubble* orbits once every 96 minutes 35 seconds and reaches latitudes lower than 28.47 degrees. Map generated by "OrbiTrack'' version 2.1.4 with NASA orbital elements set 795.
Click here for a larger version of this image.

Currently, the United States, Russia, Canada, Europe, and Japan are building a space station (see image). In an orbit inclined 51.6 degrees to the equator, the station will be easy for the Russians to reach, since their launch site -- the Baikonur Cosmodrome in Kazakhstan -- is at a high latitude. But the American shuttles will have a harder time. Because the shuttle will require extra fuel to reach the station, it will be unable carry as much payload as it could to a less inclined orbit.

The International Space Station. It doesn't quite live up to "2001: A Space Odyssey,'' but it's a start. Like a high-tech Habitrail, the station will consist of interlocking modules from the United States, Canada, Europe, and Russia. If all goes as planned, six people will live on board -- conducting all sorts of scientific and engineering experiments and, space buffs hope, demonstrating that people can live for long times in space. Assembly is due to start in November 1997 and finish in June 2002. Artwork courtesy of NASA Johnson Space Center.

On the other hand, low-latitude launches have an important advantage. When the shuttle blasts off due east from Kennedy, it receives a free boost of 1,465 kilometers per hour (908 miles per hour) because Earth is rotating. People use the same principle when they run forward while throwing a ball. The ball gets the speed that you're running at, in addition to the velocity that your arm imparts.

A launch pad nearer the equator, such as the European Space Agency's Kourou launch site in French Guiana, is even better. A point on the equator is already moving east at 1,670 kilometers per hour (1,035 miles per hour). Remember that Earth turns on its axis once in 24 hours. Since Earth is 40,080 kilometers (24,850 miles) around, a point on the equator must go 40,080 kilometers in 24 hours. Launch sites at higher latitudes go slower because the distance around is not as great as it is at the equator.

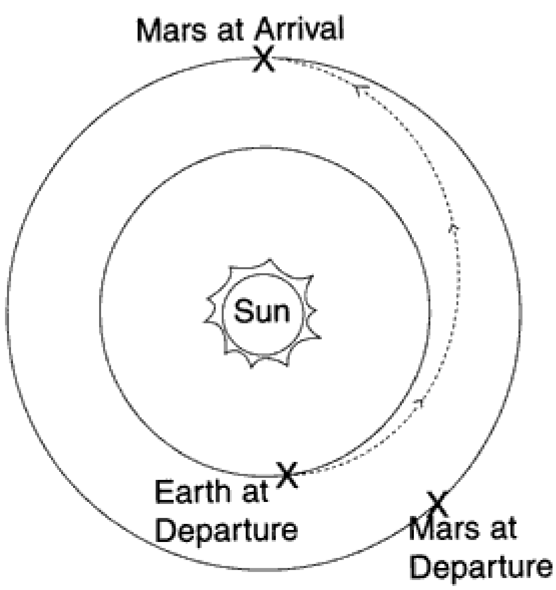
Up, Up, and Away

To the Red Planet

With this knowledge of orbits, we are ready to plan a trip to Mars. Mapping out the path involves several facts:

- We must know the length of the planet's year, its orbital speed, and its exact position. The spacecraft must be aimed not to the planet, but to where the planet will be nine months in the future.
- We must also choose a time when Mars is close to the Earth; these opportunities, or *launch windows*, occur every two years.
- Our Earth travels around the Sun at a faster speed than Mars does. The spacecraft will already have the 107,000 kilometers per hour (66,500 miles per hour) speed of Earth, whereas Mars moves at only 86,900 kilometers per hour (53,900 miles per hour). To allow for this, mission planners must launch the spacecraft when Mars is ahead of Earth in its orbit. Then the spacecraft will catch up to Mars because of the higher velocity provided by Earth.
- The spacecraft must break free of the Earth's gravity. This requires a speed, known as the *escape velocity*, of at least 40,300 kilometers per hour (25,000 miles per hour) with respect to Earth. At a lesser speed, the craft would go into a highly elliptical orbit around Earth. Once the craft breaks out of orbit around Earth, it goes into orbit around the Sun.

The Hohmann transfer orbit from Earth to Mars is very curved (see diagram) because the 107,000 kilometers per hour of the Earth's orbital motion about the Sun combines with 41,200 kilometers per hour imparted by the rocket engines. In a similar fashion, a bomb dropped from a plane makes a curved path due to the speed of the plane and the gravity of Earth. Moving in a straight path from Earth to Mars would take an enormous amount of fuel.



Come take a trip around Mars. To get to Mars, first launch yourself into orbit around Earth.

Then fire your rockets in the same direction that Earth is moving around the Sun. A speed of about 42,000 kilometers per hour will be enough to escape the Earth's gravity and, when added to the Earth's orbital speed around the Sun, put the spacecraft on a Hohmann transfer orbit to the Red Planet. If you time it right, you'll arrive at the orbit of Mars when the planet is there. At that point, fire the rockets to match your speed to that of Mars. By the way, when you get there, send us a postcard.

Eight months after launch, the spacecraft arrives at Mars, where it must slow down enough to be captured by the martian gravity. The escape velocity of Mars is 18,000 kilometers per hour (11,000 miles per hour), a good deal slower than the escape velocity of Earth, because gravity on Mars is weaker (see table). In the past, Mars-bound space probes have gone into Mars orbit by firing retrorockets to slow down.

Engineers are now working on a technique that does not require a retrorocket. Called *aerocapture* or *aerobraking*, the technique aims the craft into the planet's outer atmosphere to slow it down by atmospheric drag. This technique was shown in the movie "2010'' when the Russian spaceship *Leonov* went into Jupiter orbit. In fall 1994, mission controllers used aerobraking to circularize the orbit of the Venus probe *Magellan*. Relieved of the need to carry rocket fuel, an aerobraked probe could instead carry twice the payload. Aerocapture might prove dangerous for a manned Mars mission, though, for it would suddenly subject the astronauts to 6 to 8 *g*s after they had spent months in zero-*g*. Six to 8 *g*s would cause a 150-pound astronauts to weigh 900 to 1,200 pounds.

Thanks for the Lift

Another technique that cuts down on the need for rockets is the *gravity assist*. This uses a planet's gravity and orbital motion to fling a spacecraft in a new direction and at a higher speed. As the spacecraft approaches the planet, it speeds up; after it passes the planet, it slows down. If the planet were sitting still, the process would be symmetrical; the spacecraft would leave with the same speed it had when it came in. Only the direction of the spacecraft would change.

But because the planet is orbiting the Sun, the process is not symmetrical. If mission controllers choose the right approach path, the space probe can have a net gain or loss of speed. The most famous gravity assist sent *Voyager 2* from Jupiter to Saturn, Uranus, and Neptune. With each flyby, the path of *Voyager* was bent and its speed was increased in the direction of the planet's motion. The *Galileo* probe [see "Here Is My Journey's End,'' *The Universe in the Classroom*, Fall 1995] swung by Venus once and Earth twice to gain the momentum to reach Jupiter.

The only problems with gravity assists are that they increase the flight time and require waiting for the planets to be lined up in the proper configuration. *Voyager* made its journey from Earth to Jupiter in just under two years without an assist; *Galileo* took a little over six years using the assists.

Perhaps one day humans, too, will fly to the planets -- and beyond. But the farther a craft must go, the more problems it will encounter. To escape the Sun's gravity, a starship launched from Earth would have to go at 152,000 kilometers per hour (94,000 miles per hour). Even at that respectable speed, the stars would seem impossibly distant. Stars lie at distances measured in *light-years*. A light-year is the distance that light travels in one year -- about 9.6 trillion kilometers (5.9 trillion miles). At the above velocity, it would take 30,000 years to reach the nearest star.

Increasing the speed would require special, as-yet- undeveloped types of rocket engine to minimize the amount of fuel the starship would need to carry. By accelerating at 1 *g* for several months, a starship could make it to the nearest star and back in 30 years. But for this journey, even a "Star Trek''-style antimatter engine would consume 40,000 tons of fuel per ton of payload. The odds seem insurmountable, but remember that just a half century ago, few people seriously thought that we could visit space at all.

JAMES J. SECOSKY is a science teacher at Bloomfield Central School in Bloomfield, N.Y. He used to teach a summer course for kids, "How to Drive the Space Shuttle.'' For more information on space travel, an excellent resource is Thomas Damon's *Introduction to Space*, published by Krieger Publishing.

How Fast Do You Have to Go?

Speed is the essential ingredient in space travel. If you can go fast enough, you can orbit a planet or escape from it. The velocity required to put a satellite into a circular orbit depends on two things: the mass of the body around which the satellite orbits and the distance of the satellite from the center of the body. Because planets have different masses and sizes, satellites orbit them at different speeds.

The first column in this table gives the velocity of a satellite in low orbit -- that is, an orbit near to the surface of the body. This is the highest speed a satellite of that body can have; farther away, a satellite orbits at a slower speed. The second column gives the escape velocity. Any rocket launched from the surface with this velocity will break free of the body's gravity altogether. Do you notice anything about the two columns of numbers?

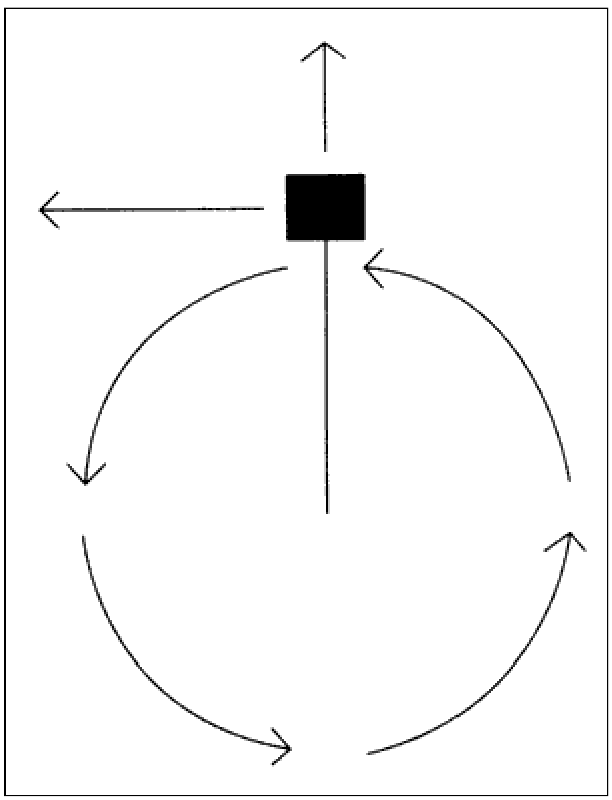
Body	Velocity of satellite in low orbit (km/hr)	Escape velocity from surface (km/hr)
Sun	1,570,000	2,220,000
Mercury	7,080	10,000
Venus	21,900	31,000
Earth	28,500	40,300
Moon	6,100	8,640
Mars	12,700	18,000
Asteroid (typical)	71	101
Jupiter	58,200	82,400
Saturn	23,000	32,600
Uranus	19,800	28,000
Neptune	28,000	39,600
Pluto	1,020	1,440

Up, Up, and Away

An Orbit in Your Hand

A nice model for orbital motion is a rubber stopper tied to a string. Swing it overhead. Compare its speed while changing the length of the string.

The string represents the inward force of gravity. When you let go of the string, the stopper will fly off in the direction it was moving when released (see diagram). This demonstrates Newton's first law of motion: *A body moves at a constant speed in a straight line unless a net force acts upon it*. While you were swinging the stopper overhead, the force exerted by the string caused the stopper to move in a circle. When you let go, the stopper moved off in a straight line.



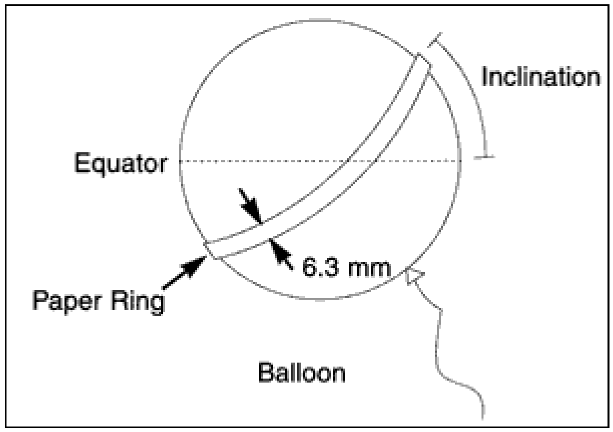
For more details on this activity, see the ASP's *The Universe at Your Fingertips* resource notebook, activity C-5.

Orbital Inclination

This activity requires a small round balloon, a metric ruler, paper, a marker, scissors, and a protractor. Blow up the balloon to about 20 centimeters (8 inches) in diameter. Use the marker to draw a circle around its middle representing the equator. Cut a paper ring about 6 millimeters (a quarter-inch) wide to just fit around the balloon's equator. Fit the ring around the equator and then change its inclination from 0 degrees (equatorial orbit used by geosynchronous satellites) to 28.5 degrees (space shuttle orbit) to 51.6 degrees (space station orbit) to 90 degrees (polar orbit used by spy satellites).

Orbital Ornithology

by Rob Landis, Space Telescope Science Institute



For most folks, the space program means a program on television or a space capsule in a museum. But did you know you can witness space travel from your own backyard?

With so many satellites now in orbit, it is likely that you have seen an artificial satellite zipping across the night sky. As orbiting spacecraft have grown in size, their visibility has increased. The Russian *Mir* space station, the American space shuttle, and the *Hubble Space Telescope* are large enough and bright enough to be spotted easily.

Perhaps the most conspicuous space bird is the *Mir*. The station is about 19 by 26 meters (63 by 85 feet) and orbits at an altitude of 300 to 400 kilometers. During favorable passes, it shines at zero magnitude and has occasionally and suddenly brightened to -3.5, brighter than any star and as bright as Venus. Because *Mir*'s orbit is inclined 51.6 degrees to the equator, it sweeps out latitudes between 51.6 degrees north and 51.6 degrees south -- making it visible, at least in principle, to observers lower than about 65 degrees latitude. *Hubble*, whose orbit is inclined 28.5 degrees to the equator, can only be seen in and near the tropics.

In December 1997, the first pieces of the International Space Station will be launched into an orbital inclination of 51.6 degrees. As assembly of the station continues through 2002, the station will grow ever bigger and brighter.

Finding Space Birds

Three basic rules can help the fledgling bird watcher:

- Look for large satellites under the right conditions of illumination.
- Observe around twilight. This is the most favorable time to see a satellite: The Sun has set for the observer on the ground, but not yet for the satellite high above. The sky is dark, while the satellite remains bright.
- Look in the right place at the right time. I have used two computer programs that calculate the locations of satellites: "SpaceBirds'' for the IBM and "OrbiTrack'' for the Macintosh. The "Voyager II'' desktop planetarium program, available through the ASP catalog, can also track satellites. Other programs include "MacSat'' (Mac), "BirdDog'' (IBM), "STSOrbit'' (IBM), and "WinOrbit'' (IBM). Many of these programs are available on the World Wide Web at:
  http://www.amsat.org/amsat/ftpsoft.html
  http://www.jpl.nasa.gov/archive/software.html
  http://spacelink.msfc.nasa.gov/Instructional.Materials/Software/

  The software requires a data file with the "orbital elements'' for each satellite. These elements, a mathematical description of the space bird's orbit, are computed by the U.S. Space Command and are available on the World Wide Web at:
  http://ssl.berkeley.edu/isi_www/satpasses.html
  http://spacelink.msfc.nasa.gov/Instructional.Materials/Software/Tracking.Elements/

Observing Tips

Roger Mansfield of the Astronomical Data Service has four helpful observing hints to bear in mind:

- Be certain to have the exact time. The National Bureau of Standards operates a talking clock at 303-499-7111 and, for those with world-band radios, at 5 and 10 megahertz. The recording provides you with UTC, or Coordinated Universal Time, also called Greenwich Mean Time. If you're on Eastern Standard Time, subtract 5 hours from UTC; for Central Standard Time subtract 6 hours; Mountain Standard Time, 7 hours; Pacific Standard Time, 8 hours.

- Get to your observing site early. Find the constellations and bright stars that the satellite will pass through or near. If the sky is hazy or cloudy and you cannot see the stars, then you won't see the satellite either. If the Moon is bright, finding the satellite will be challenging.
- Bring along a planisphere (star chart), red flashlight, and binoculars. A planisphere with the predicted path of the satellite across the sky penciled in can be a great help for beginning birders. To draw the path, plot the positions given by the computer program.
- Prepare for acquisition. You should be looking exactly where the satellite is due to appear. If you miss the satellite at the first possible acquisition point, try again along the sky trace at another point.

Becoming a space ornithologist requires skill and patience. You may need to look at your watch, the star chart, and the night sky several times in rapid succession without losing your night vision (the reason for the red flashlight). Familiarity with the night sky can help enormously. With a little experience, you can look up and see the shuttle or space station with their human cargoes, silently drifting amongst the stars.

ROB LANDIS is the program coordinator of the Project to Re-Engineer Space Telescope Observing at the Space Telescope Science Institute in Baltimore. As the human link between *Hubble* and astronomers, Landis is responsible for the development and implementation of observing programs. His email address is landis@stsci.edu. For more information on space bird watching, visit http://learn.jpl.nasa.gov/spotsat.htm.

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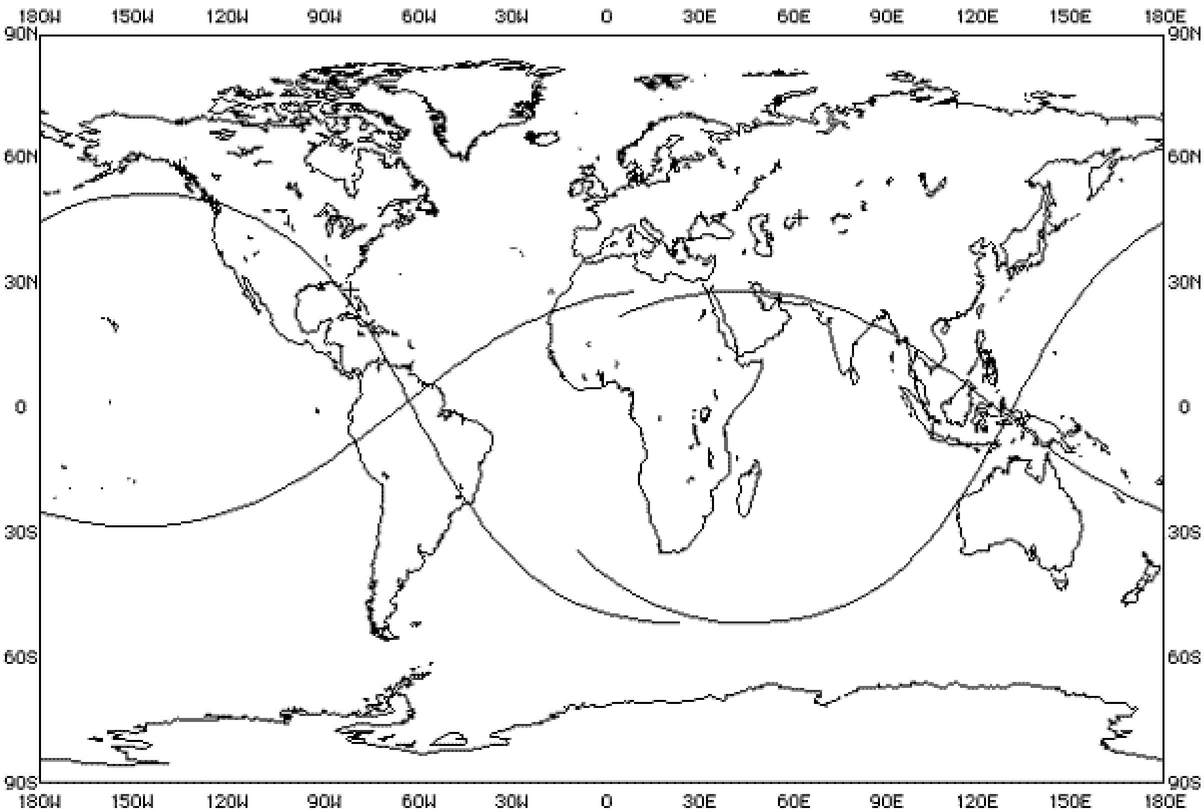

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