CHAPTER 1

Space Physics
Do Your Ears Pop in Space?

Is there gravity where a shuttle orbits?

Absolutely! In fact, it’s gravity that keeps the shuttle in orbit. Without gravity, it would fly into deep space and never return to Earth.

Gravity does get weaker as you travel away from the earth (or any object with mass, for that matter). The exact amount of loss is a function of this simple relationship:

\[
\frac{1}{R^2}
\]

The earth is about 4,000 statute miles (we’ll use statute miles throughout this book because that’s how most Americans think of miles) in radius from its core to its surface, where we live. (R = 1 at the earth’s surface). When standing on the earth’s surface, we say we are at “1” gravity. This relationship simply states that if you travel from the center of the earth to a distance two times the earth’s radius, or 4,000 miles above the earth (where R = 2), the gravity doesn’t drop to one half but rather to one fourth or 1/2². So, if you could climb a tower that was 4,000 miles high and could stand on a scale, it would show one fourth of your Earth weight. But shuttle astronauts don’t orbit at 4,000 miles altitude. They circle about 200 miles up. This is an R of only 1.05. According to the preceding relationship, this means a shuttle orbits in a gravity field that’s about 91% of Earth’s surface gravity. Put another way, if there were a 200-mile-high tower and you climbed to its top and weighed yourself, you would see 91% of your Earth weight. Gravity has dropped by only 9%.

Why are astronauts weightless?

From the answer to the first question, it’s obvious astronauts are not weightless because there’s no gravity. Astronauts are weightless because they are freely under the influence of gravity. The common term used to describe this condition is free fall. Let me explain. Suppose I was standing on a scale in an elevator that’s at the top of a skyscraper. I would see my weight on that scale
(160 pounds). Now, suppose someone cuts the elevator cable. What would I see on the scale in my free fall down the elevator shaft? Before you answer, think about what’s happening. The elevator floor is falling. The scale is falling. I’m falling. Everything is falling (accelerating) freely (if you ignore the effects of air friction and other types of friction). I’m no longer standing on the scale. I’m falling with it. So, it’s going to read zero. I’m weightless. Simply put, any time you are able to move freely in response to gravity—when there is nothing to restrain you from accelerating or decelerating with it—you are weightless. When you think about it, the only reason anything weighs anything on Earth is because the ground gets in the way of what gravity wants to naturally do—pull us to the center of the earth. When you stand on a scale, the weight you see is merely the equal and opposite reactions of the earth getting in the way of a fall.

Why don’t astronauts hit the ground in their free fall?

Let’s suppose there’s a skyscraper that’s 200 miles high (a typical shuttle altitude). Let’s further suppose I could shrink you down to the size of an ant and put you inside a windowless box. Now, I take that box to the top of the building and drop it over the side. Your fall would be identical to my hypothetical elevator ride. As soon as I released the box, you would be weightless, because the floor would no longer be in the way of what gravity wants to do—pull you down. In other words, the bottom of the box would be falling out from under your feet as rapidly as your body is falling. Suppose, now, instead of dropping the box, I threw it horizontally from the edge of the building. What would that ride feel like?
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Momentarily you would be pinned to the wall as my arm accelerated you; that is, you would feel g-forces, just like an astronaut feels when the engines are thrusting. But as soon as my pitching force ended, you would again be freely under the influence of gravity and would once again be weightless. Now, however, your fall wouldn't be straight down. My throw has given you a constant horizontal velocity away from the building (remember, we are assuming no sources of friction), while, at the same time, gravity is pulling you and the box downward. It's important to understand that the horizontal velocity away from the building is not affected by the downward acceleration of gravity. At any instant you are continuing to move horizontally away from the building at the exact speed you had when the box left my hand. It's just that you are also continually gaining downward speed from the pull of gravity. This combination of horizontal speed and downward acceleration results in a curved trajectory. Would you have any idea that this time, you would be falling in a curve? No. The box is windowless. All you would know is that you are weightless. Now, if I successively increased the power of my throw, I could send you into a weightless flight that would take you further and further from the building, and each time, you would have no idea what trajectory you were tracing. Suppose, however, I could throw the box at a speed of 17,300 mph. As soon as the impulse of that throw ended you would again be in weightless flight, but now the curve is flattened so much that it traces the curvature of the earth. In other words, I've thrown you into orbit. You would still be freely under the influence of gravity, just as you were when I dropped the box straight down and after each of my lower velocity pitches, but now you won't hit the ground. You're in orbit.

Is orbit speed always 17,300 mph?

No. Orbit velocity depends on orbit altitude and the mass of the planet being orbited (how much stuff it's made of). To orbit something at a low altitude, you must go faster because gravity is stronger. Similarly, the more massive an object is, the stronger
its gravity and the faster you have to go to orbit it. An orbit just above Jupiter’s clouds would require a speed of 94,300 mph, while orbit velocity just above the surface of our moon is only 3,760 mph. On a very small asteroid, orbital velocity would be even less. In fact, you might be able to find a tiny asteroid that has gravity so weak that its orbit velocity is only 50 mph. On such an object, it would be possible to play catch with yourself. You could throw a ball, watch it disappear over the horizon, and then turn around and catch it as it circled in orbit.

**What is a Vomit Comet?**

Remember, the only way you can be weightless is to be freely under the influence of gravity, and you can do that in a falling airplane. To prepare astronauts and shuttle experiments for weightlessness, the National Aeronautics and Space Administration (NASA) flies an old Boeing passenger jet on a roller coaster trajectory. At the top of each hill the pilot pushes the nose of the airplane downward. This effectively drops the floor from underneath the passengers and allows them to be freely under gravity’s influence. When this happens everything inside the jet is momentarily weightless. Unfortunately, as the nose gets too low, the pilot has to pull out of the dive, and everything in the aircraft is subsequently pinned to the floor with a force of about 1.8 g’s (nearly twice the pull of normal gravity). Then, the pilot climbs back up and repeats the maneuver. After about an hour of this roller coaster ride, you’ll understand why the plane has been nicknamed the Vomit Comet. It is a nauseating ride, and many people get air-sick.

**Besides the Vomit Comet, is there another way of duplicating weightlessness on Earth?**

Yes. Because weightlessness is a free fall, dropping something down a deep hole would also make it temporarily weightless. Believe it or not, NASA has a 430-foot-deep hole in the ground at the Lewis Research Center in Cleveland where things can be
dropped to measure their response to weightlessness. To remove the effects of air friction, which ruins perfect weightlessness, air is pumped out of the hole to create a vacuum. Experiments are then literally dropped down this hole. High-speed data collection equipment enables engineers to evaluate experiments for about 5 seconds of true weightlessness before a bed of styrofoam cushions the impact. Fortunately, NASA doesn’t drop astronauts down this hole for their training.

NASA can double the weightless test time in this hole by launching the experiment upward with compressed air from the bottom of the hole instead of dropping it from the top. While it’s not intuitively obvious that something moving upward could be as weightless as something falling downward, it is a fact. Visualize this: With a scale attached to my feet, I’m launched upward from the bottom of the hole by compressed air. After the launch impulse ends, what does the scale show? Think about it. The scale is being slowed down by the pull of gravity at exactly the same rate my body is being slowed. Therefore, I’m not standing on it. The scale and I are in a weightless free fall, except, this time, we’re moving upward. I would continue to slow down until I reached zero speed at the very top of the hole, then I would begin the fall downward. Throughout the entire flight I would be weightless because I would be freely under the influence of gravity. This is why pioneering astronaut Alan Shepard was weightless—during his first mission. He didn’t get into orbit on his first flight. It was a 15-minute “lob” out into the ocean. As soon as his Redstone rocket’s engine shut down, however, he was freely under the influence of gravity and was therefore weightless—even though the capsule was still moving away from the earth. Similarly, shuttle astronauts first experience weight-
lessness when their main engines shut down—even though they are still flying upward toward apogee (the high point of the orbit). Remember, weightlessness has nothing to do with the direction you’re moving in. It occurs whenever gravity is freely able to do what gravity wants to do—pull you. It doesn’t matter if that pull is speeding you up as you fall toward Earth or is slowing you down as you are moving away from Earth. In both cases, as long as nothing is getting in the way of that invisible pull, you’ll be weightless.

What is microgravity?

True weightlessness can never be achieved aboard the shuttle. There is always a very small force—a deceleration—produced by atmospheric drag. This force is measured in millionths of an Earth g and is referred to as microgravity. Because it’s so small, astronauts can’t feel this force.

Why do astronauts go underwater to train for spacewalks?

Many people believe we do this because we’re weightless underwater. This is not correct. Are people in submarines weightless? Of course not. Think of underwater astronauts as being in very small submarines having the shape of a space suit. Like the Navy scaman in a real submarine, they’re not weightless. So, why do we practice space walks underwater?

To understand the answer to this question, you must first understand what happens when a spacewalking astronaut tries to work on a satellite in orbit. If she is not restrained, her body will move in the opposite direction of any force she exerts. In other words, if an astronaut has
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A wrench and is trying to loosen a bolt and exerts a counter-clockwise force, the bolt will not loosen. Instead, the astronaut’s body will turn in the opposite direction—clockwise. Now, if you’re neutrally buoyant underwater (meaning you’re not sinking and not rising, just floating at the same depth), and you tried to loosen the same bolt on an underwater mock-up of the satellite, you would get the same reaction. Your body would move opposite to any force you exert. It is this effect that makes practicing underwater a good preparation for a spacewalk. Doing the work underwater shows the engineers how tools need to be designed, where handholds and foot restraints need to be placed, and it allows the astronaut to practice doing the work inside a bulky suit.

Can you weigh yourself in weightlessness?

In weightlessness it’s impossible to weigh anything, yet in some life-science experiments, changes in body weight are important research parameters. How can weight be measured? NASA makes use of Newton’s second law to record changes in weight:

\[ F = ma \]

This equation states that force (the weight you see on the bathroom scale) is equal to your mass times the acceleration (gravity). So, in space, if you could determine your mass, it would be easy to calculate how your Earth weight is varying. A special NASA device does just that. When it’s necessary to see how his Earth weight is changing, an astronaut straps his body to a chair that is accelerated along a short rail by a known spring force (F in the equation). During the motion, acceleration is measured by special electronics. Because \( F \) is known and \( a \) is measured, it’s easy to then calculate the mass of the person riding the chair. Using that mass figure and Earth’s gravity for acceleration, the same equation (\( F = ma \)) can be used to calculate a person’s Earth weight.
If a shuttle is orbiting in a circle, why does the Mission Control map show wavy lines?

The wavy lines you see on Mission Control's map are ground tracks. They show the path of the space shuttle over the ground and look like this:

![Map showing wavy lines](image)

A shuttle orbit is approximately a circle, but on a flat map it looks like a wavy line.

The lines appear wavy because of the effect of trying to project an inclined great circle (a shuttle orbit) onto a flat map.

Try this experiment. You'll need an Earth map, an Earth globe, and some rubber bands. The map and globe need to have latitude and longitude lines. Tie the rubber bands into a long chain and then tie each end of the chain together. Now you have a chain loop of rubber bands. Stretch that loop over the globe at an angle of about 45 degrees to the equator. (Make certain the loop traces a great circle, that is, its imaginary center is the center of the globe.) We'll pretend this is a shuttle orbit. Now, look at where your rubber band loop crosses the equator and record the latitude and longitude (the latitude will be zero at the equator). Go about 2 inches along your orbit (the rubber band) and, again, write down the latitude and longitude of that point. Keep doing this until you've recorded the latitude and longitude at about 2-inch segments all the way around your
orbit. Now, plot each of those points on your Earth map and connect the dots. What do you have? You have a wavy line just like that completed by Mission Control. Your rubber band is a circle, just like a shuttle orbit, but when you plot it out on a flat map, it looks like a wavy line.

**Does a shuttle orbit continually trace the same path across the earth?**

No. The shuttle orbit is fixed in space and never changes, but the Earth spins underneath it. This means the orbit passes over different spots on the earth. Let's say you are a shuttle astronaut and look out the window as you cross the equator and see Lake Victoria. (Look at a map. Lake Victoria is in the east African country of Kenya. It's a big lake and easily seen from orbit.) Ninety minutes later you are again crossing the equator over Africa, but now Lake Victoria is about 1,553 miles to the east. Some simple math explains this change in ground track. (I've ignored the minor effects of earth's precession.)

In one day (in 24 hours), the earth makes one complete 360-degree turn to the east. That means it's spinning 15 degrees per hour:

\[
360 \text{ degrees} / 24 \text{ hours} = 15 \text{ degrees per hour}
\]

At the equator, each degree is equal to 60 nautical miles (about 69 statute miles), so, every hour, something on the equator, like Lake Victoria, is going to move about 1,035 miles to the east.

\[
15 \text{ degrees} \times 69 \text{ miles per degree} = 1,035 \text{ miles (approximately)}
\]

But your orbit wasn't 1 hour. It was 1.5 hours (90 minutes). So, when you next cross the equator, Lake Victoria is going to have moved 22.5 degrees, or about 1,553 miles, eastward.

\[
22.5 \text{ degrees} \times 69 \text{ miles per degree} = 1,553 \text{ miles (approximately)}
\]
In other words, every time astronauts cross the equator, it appears they have moved about 1,553 miles to the west when, actually, their orbit hasn’t changed at all. It’s the earth that has moved. At the equator, it has spun about 1,553 miles to the east.

**Why are shuttles launched only from Florida?**

There are two reasons. One is safety. You don’t want to endanger people on the ground by launching a rocket over their heads, so we launch them over water. Also, for the shuttle, the booster rockets need to parachute into the ocean to be picked up and reused. An impact on land would destroy them. But there is also a space physics reason for launching from Florida. When you do so, you get a free ride from Mother Nature. Remember, the earth is spinning to the east. That spin represents free velocity to a rocket headed eastward into orbit.

To better understand this, let’s go back to the equator. There, everything is spinning toward the east at 1,035 mph. The trees, people, buildings, the air, the birds, everything—including a rocket on a launch pad—is traveling 1,035 mph due eastward. In other words, a rocket on an equatorial launch pad hasn’t even lifted off and it already has 1,035 mph toward its orbit speed of 17,300 mph. You would be foolish not to take advantage of this free speed and launch your rocket to the east. That’s the space physics reason why NASA launches the shuttle eastward from Florida. To do so reduces the fuel load and increases the payload weight that can be carried.

Having said this, however, the shuttle doesn’t lift off with a free 1,035 mph. Remember, that’s the earth’s spinning speed at the equator. The Kennedy Space Center isn’t on the equator. It’s at approximately 28.5 degrees north latitude, so its spinning speed is less.

To better understand this, take a look at a globe. As you move away from the equator, the circles formed by lines of latitude become smaller. Regardless of latitude, though, it still requires 24 hours to spin the complete circle. This means, the further you move away from the equator, the slower your spin-
ning speed. For example, if you were on the line of lati-
tude that's only a foot southward from the north pole, 
you would spin a circular dis-

tance of about 6 feet in 24 
hours, for a speed of about 3 
inches per hour. The latitude 
of the Kennedy Space Cen-
ter measures a circular dis-
tance only 88% of the 
equator's circle, so the 
Kennedy Space Center's spin 
speed is only 88% of the 
equator's speed, or about 911 
mph. It doesn't take a rocket scientist to figure out that it would 
be much better to build a launch site in Florida than in Maine. 

By the way, what country has a launch pad best situated to 
take advantage of Mother Nature's free spin? France. France 
built its Ariane launch pad in French Guiana, South America 
(latitude about 5 degrees). The Russians, because of the high lat-
titude of their land mass, have the least favorable launch site— 
the Baikonur Cosmodrome (east of the Aral Sea, in Kazakhstan) 
at a latitude of 45.9 degrees north.

Why does the shuttle roll after lift-off?

This is because sometimes we don't want to launch due east. 
Even though this is the best direction to maximize the free boost 
of the earth's spin, such a launch trajectory might not support the 
mission objective. This statement is best explained by example. 

If you were a scientist and had a shuttle experiment designed 
to study the ozone hole over the Antarctic, which of the orbits 
shown in the picture on page 13 would you prefer to fly? Obvi-
ously you would want the near-polar orbit—the orbit that takes 
you close to the north and south poles. Otherwise your instru-
ments would never even see the ozone hole. For the same rea-
son, if you were in the military and wanted to launch a spy satellite, you would desire the near-polar orbit. As the earth spun underneath you, you would eventually see most of the earth and have a view of all potential enemies. But what if you were launching a communication satellite? Most of these types of satellites are aimed for orbits over the equator. Clearly, in that case you would want the rocket to fly the orbit closest to the equator. Or what about rendezvousing with the Mir space station? Its orbit is tilted 51 degrees to the equator.

It’s the mission that dictates what orbit a shuttle will fly. The tilt of that orbit to the equator is called its inclination. In turn, the launch direction is dictated by this inclination. If the mission requires a high-inclination orbit (tilted toward the poles), the shuttle will launch to the northeast. If the mission requires a minimum-inclination orbit, the shuttle will fly due east.

It’s this need to vary the orbit inclination from mission to mission that makes it necessary for the shuttle to roll on its tail after lift-off. The roll aligns the shuttle’s pitch axis correctly so that when it begins to tilt (pitch) over, its nose is aimed in the right direction for its journey into orbit. Because the shuttle sits on the launch pad with its tail fin pointed south (and a shuttle will never fly south into orbit), some type of a roll is always necessary. After lift-off, if the shuttle is destined for a minimum-inclination orbit, it will roll until the tail is pointed due eastward and then begin its pitch over to aim the nose eastward. If it’s aiming for a high-inclination orbit, it will roll until the tail is pointed northeastward (parallel with the east coast of the United States) and then begin its pitch over.
You might wonder why NASA built the launch pad so the shuttle’s tail points to the south when it’s awaiting launch. Why didn’t they build it so the tail points eastward and thus minimize the need to roll? This arrangement was due to the fact that the shuttle pads weren’t originally built for the shuttle. They are converted Saturn V launch pads from the Apollo program. The conversion did not permit a tail-east shuttle launch orientation.

**How many shuttle launch pads are there?**

There are only two shuttle launch pads and both are at the Kennedy Space Center. Their designations are pads 39A and 39B. These are more than sufficient to support the shuttle launch schedule of seven or eight missions per year.

**Can the shuttle fly over the north and south poles?**

Many scientists—for example, geologists, oceanographers, and meteorologists—as well as military forces want their satellites to be able to see the entire earth’s surface. The only orbit that permits such a view is a polar orbit. Unfortunately, the shuttle cannot launch satellites into such orbits. For safety reasons, NASA will not launch the shuttle over land, so a shuttle launching into the highest possible inclination will fly northeast heading just off the coast of the United States and achieve a 62-degree inclination in the process. Higher inclinations are safely achieved by unmanned rockets flying southward over the Pacific Ocean from Vandenberg Air Force Base in California. Originally, NASA did plan for the shuttle to be launched from California into polar orbits, but after the Challenger accident, those plans were cancelled. There were two primary reasons for this cancellation. One was the fact that there were many more satellites waiting to be launched from Florida than California and NASA needed all three of the remaining shuttles to make these launches. The other reason was that California launches were going to require a much lighter solid rocket booster design. Remember, launch-
ing into polar orbits means you don’t have the earth’s free eastward rotational speed, so NASA needed a way of cutting weight from the boosters to minimize the reduction that otherwise was going to be required in payload weight. So, instead of using steel, they were going to make the boosters out of nonmetal composites similar to fiberglass. Having already experienced one tragedy as a result of a solid rocket booster failure, NASA was reluctant to take a chance on this completely new booster design. They scrubbed the plan to use the California launch site.

Can the shuttle fly around the earth’s equator?

No. A shuttle launching from the Kennedy Space Center (latitude approximately 28.5 degrees) doesn’t have enough fuel to bend its orbit southward to coincide with the equator (latitude 0 degrees). The minimum inclination it can fly is the latitude at the launch pad, or approximately 28.5 degrees latitude. This means astronauts on minimum-inclination missions won’t get to see much of the earth’s land masses. Their nadir will pass only over the area between 28.5 degrees north and south latitudes. In other words, the only part of the United States they’ll pass over will be extreme south Texas, the southern half of Florida, and Hawaii. I hate to say low-inclination orbits are boring, but, compared with high-inclination orbits, they are. Unfortunately, astronauts don’t get a choice on their inclination. As I explained earlier, it’s determined by what you’re going to do on the flight—the mission objective.

How much payload weight can the shuttle carry?

Orbit inclination also affects how much payload weight a shuttle can carry into orbit. High-inclination missions aren’t aligned with the spin of the earth, so more fuel (and less payload) has to be carried to make up for the lost free speed. NASA advertises that the shuttle can carry 59,600 pounds of payload into a minimum-inclination orbit (28.5 degrees) but only about 45,600 pounds into a high-inclination orbit (57 degrees).
Why don't space-walking astronauts fall off the shuttle?

First of all, on most spacewalks, the astronauts are tethered to the shuttle, so they can't fall off. But even if they released their tethers they still wouldn't fall or be left behind, because they are traveling in exactly the same orbit and at exactly the same speed as the shuttle.

If you have a difficult time visualizing this, try this simple experiment. The next time you're a passenger in a car, driving at highway speeds—60 mph—hold a coin toward the car's ceiling in one hand and then drop it into the palm of your other hand. During the eighth of a second or so of drop time, the car travels approximately 11 feet (60 mph is 88 feet per second). Now, ask yourself, "When the coin was released, why didn't it slam into the back window as the car moved 11 feet forward?" The answer is that nothing changed the forward speed of the coin relative to the car. As the coin fell, it gained downward speed, but nothing changed its forward speed. It and the car continued forward at 60 mph. That's exactly the reason why a spacewalker continues in orbit with the shuttle. Her forward speed relative to the orbiter remains unchanged when she releases her tether.

If there is no air in space, how can astronauts steer a shuttle?

On Earth, when a pilot wants to steer his plane, he moves the stick, which in turn moves aileron and elevator controls to change the flow of air across the wings and tail and make the aircraft point where he wants it to point. In space there is no air, so it's impossible to use aircraft-like controls to change the di-
recon a shuttle is pointed. Instead, the shuttle uses a system of 44 small rocket jets mounted in the nose and tail—the reaction control system, or RCS. These jets are pointed up, down, and sideways and are turned on and off in response to movement of the pilot’s rotational hand controller, or RHC. Suppose an astronaut is docking her space shuttle with the Russian Mir space station. As she approaches, she needs to raise the nose. She will do this by tilting back on the RHC control stick, just as an aircraft pilot would do. But now, that stick action fires downward firing rockets in the nose to rotate the nose up. This is where the term reaction comes from.

When the jet fires downward, Newton’s third law says there will be an equal and opposite reaction—equal magnitude in the opposite direction. In this case, the reaction is to raise the nose. To stop the rotation, the commander has to tilt the RHC stick forward. This will fire the upward-pointing jets in the nose and stop the movement.

Because the RCS rocket jets are in the nose and tail and because they point up, down and sideways, various jet firings can be commanded to point the shuttle (to rotate it) in any direction. Astronauts don’t have to think about what jets need to fire, because the shuttle’s computers will interpret the stick movements and fire the appropriate jets for them.

Can the shuttle change its orbit?

Moving the RHC only changes the shuttle’s attitude—its pitch, yaw, and roll. It will not change the shuttle’s orbit (its altitude or inclination). To do this, you have to change the shuttle’s speed. Large speed changes are done with the orbital maneuvering system (OMS). This system has two 6,000 pound thrust engines that can be fired only through the shuttle’s computers.

Small speed changes, and thus small orbit changes, are done by firing various combinations of RCS jets. In space talk, such burns are called translations and are done through movement of the translational hand controller (THC). This is a stick different from the RHC. The THC is a square-knobbed hand controller that can be moved up, down, left, right, and in and out. These movements
cause the appropriate RCS jets to fire and move (translate) the shuttle in the corresponding direction. In other words, an inward movement on the THC fires the aft-pointing jets and moves the shuttle forward. An upward movement of the THC fires the down-pointing jets in the nose and tail and moves the shuttle upward.

There are RHCs and THCs for the commander (the person in the front, left seat) and on the back instrument panel. The set of controls in the back are used during rendezvous and docking. The commander will float at the aft cockpit with the RHC in his right hand and the THC in his left hand and fly the shuttle while watching the target out of the back and top windows.

Before leaving this RCS discussion, I should mention that every shuttle astronaut remembers the first time she experiences an RCS jet firing. This occurs during ascent after the main liquid engines are shut down and the empty external tank is jettisoned. You want to get away from that tank so it doesn’t bang into the belly of the spacecraft and damage the heat tiles. So, after the tank is released, the autopilot fires the down-firing jets in the nose and tail to move the shuttle away. The reason I say every shuttle astronaut remembers this event is because of the noise and vibration of the RCS firing. It takes you by surprise. You’ve gotten used to everything being smooth and quiet during the last few minutes of your ascent. Then, there’s a thunk in the cockpit when the external tank is separated. For a couple seconds it’s quiet again. Then, BOOM! BOOM! BOOM! The nose jets sound like cannons. The cockpit shakes and vibrates. Welcome to the RCS.

You might wonder how you can hear the RCS jets. There’s no air in space to transmit the noise. You hear the jets because the sound is transmitted through the aluminum structure of the shuttle and into the air of the cockpit and then to your ear.

**How can satellites be parked in orbit?**

They can’t. Anything that’s stopped in space above the earth—parked—would fall straight down. Yet, the term parked in orbit is frequently used by NASA. What gives? When NASA refers to
a parked satellite, they are referring to a satellite in geostationary orbit. Objects in circular orbit 22,300 miles above the earth's equator circle the earth once every 24 hours. This means that to an observer on the ground, the satellite doesn't appear to move. It appears parked in the sky. But, correctly said, its motion is synchronous with the earth's surface movement, or geosynchronous. (More correctly, a 22,300-mile-high circular, equatorial orbit should be called geostationary, but I will use the commonly accepted term for such an orbit—geosynchronous or geosync.)

This fact of orbit mechanics—that an object in orbit at 22,300 miles above the earth appears parked—has spawned a communications revolution. It enables someone on Earth to point a satellite dish at a fixed spot in the sky and get a TV, telephone, or other communication signal from space. Think of how difficult it would be for satellite TV reception if every backyard Earth station dish had to track a moving satellite. There would be a much smaller satellite TV market because of the complexity of that tracking effort. But to track a geosynchronous satellite, a dish can be pointed once and left alone. The motion of the earth itself is doing all the tracking—it matches the satellite's motion.

Besides communication satellites, there are other users of geosync orbit. The weather pictures you see on the evening TV news come from meteorologic satellites at geosync altitude. Also, the military has missile early-warning satellites parked in geosync. These stare down at Earth with infrared eyes that can see the heat of a rocket launch and would give our leaders a warning in case of an attack.

Can geosynchronous satellites be placed anywhere above the earth?

No. The only geosynchronous orbit is 22,300 miles above the earth's equator. A satellite in an orbit tilted to the equator will always be moving relative to an observer on the ground. If the earth is spinning due east and a satellite is in an orbit that's inclined northeast-southwest, it's obviously not matching the earth's spin, so it can't appear stationary to someone on the ground. Knowing this, you can chuckle, as I do, whenever you
see a news media report or read in a novel that the United States has spy satellites parked over Lebanon or Iran or Russia. Space physics says this is impossible.

You have evidence in your own neighborhood of the fact that the only geosync satellites are above the equator. Take a look at all the satellite dishes you pass in back yards and at cable TV stations. What pointing direction do they have in common? If you’re in the northern hemisphere, they all have a southerly aim. Some may be pointed due south, others southeast, and still others southwest (it depends on what satellite they are pointed at), but (in the northern hemisphere) they all have a southerly component of aim because that’s the direction to the equator. If you are in the southern hemisphere, you would see all satellite dishes pointed in a northerly direction.

Is it possible to see an orbiting satellite from Earth with the naked eye?

Absolutely! I have seen hundreds of satellites from Earth. On rare occasions, I’ve even seen five or six satellites crossing the sky at the same instant. But they can be seen only when the sun is shining on them and it’s dark on the earth. In other words, they are only visible beginning about an hour after sunset for about a 1-hour period or about 2 hours before sunrise for a 1-hour period. During these times, like sun shining on a mountain peak while it’s still dark in the valley, the sun will shine on a satellite while it’s dark on the earth directly below. This sun glint against the black of a dark sky is frequently bright enough to be seen—and probably accounts for a number of UFO sightings.

What is the best way to watch for satellites from Earth?

First, try to get away from as much light as possible. It would have to be an exceptionally bright satellite to be seen from a city or well-
lighted suburban yard. Second, lie on a blanket or recline in a lounge. If you remain standing, you’ll get a pain in your neck. Third, do not try to use binoculars or telescopes. Remember, you are trying to detect motion and that’s very difficult to do in the narrow field of view of an optical device. Instead, let your unaided eyes roam the sky, pausing briefly for a few seconds in different areas of the heavens. If there’s a passing satellite, you’ll see it moving against the background of the stars. But spend most of your search time in the hemisphere of the sky that’s down sun, away from the setting or rising sun. You’re looking for reflected light and you’ll see this best when the satellite is presenting a whole side of illuminated surfaces to you. Fourth, don’t confuse an airplane with a satellite. Airplanes will have flashing red and white lights and might even be leaving a vapor trail or making audible noise. Satellites have no lights on them and will not leave vapor trails or make noise. The only reason they are visible is because of reflected sunlight; therefore they will always appear whitish. Also, because of the changing angle of the sun’s reflection as satellites move across the sky, they might vary in brightness, sometimes even going out for several seconds between reflections. They also usually appear to move faster than an airplane. Another difference between airplanes and satellites is that eastward orbiting spacecraft will suddenly go out and remain out as they enter the earth’s shadow, while the lights of a moving plane will remain visible all the way across the sky. Finally, don’t stare at the satellite once you see it. In darkness, our eyes have a natural blind spot at the focal point so if you stare at the satellite it’ll seem to disappear. Just scan around it.

An observer in the dark will be able to see a sunlit satellite overhead.
Can you see an orbiting space shuttle?

Unless you have seen a prediction of a shuttle passage in a newspaper or other source, it would be impossible to know you are seeing a shuttle fly over. You won’t be able to see its wings or other detail because of the distance. But it is possible to make some logical conclusions about the objects you are viewing. First, the faster they are moving, the lower their orbit. I won’t go into the orbital mechanics of this, but it’s a fact that higher orbits are slower orbits. It takes the moon a month to orbit the earth, while a shuttle takes only 90 minutes. In all cases you will be seeing satellites that are only a couple of hundred miles above the earth. It’s impossible to see anything at geosynchronous orbit with the naked eye. Second, if the object varies significantly in brightness as it travels across the sky, it’s probably a piece of space junk. Functional satellites are usually stabilized and will be less changeable in brightness because of that stability. A piece of junk will be tumbling, thus the changes in brightness. Third, notice the direction a satellite is traveling. If it’s in a high-inclination orbit—steeply tilted to the equator—then smile. There’s a good chance it’s a military satellite and it might be taking pictures of you. Most of these are in orbits that are generally north-south in direction so they can see the majority of the earth as it spins underneath. If the satellite is crossing in a generally east-west direction, it’s probably some astronomic observation science satellite (e.g., the Hubble Space Telescope) or a thrown-away rocket body used to launch a communication satellite.

For those of you interested in knowing when a space shuttle might be passing over your location, you might want to send an inquiry to this Internet address: adamod@iapc.net. This is the address for Dan Adamo, a NASA engineer who has prepared a home computer software program that shows the path of any orbiting space shuttle across the earth.

Are orbit rendezvous dangerous?

I chuckle whenever the press hyps a shuttle rendezvous with particular emphasis on the incredible speed at which the rendezvous
occurred—17,300 mph—the implication being this speed made the rendezvous exceptionally dangerous. Not so. The absolute speed of the shuttle (the 17,300 mph) has nothing to do with the danger involved. It’s the relative speed between it and the object it’s approaching that matters. As long as that relative speed (the difference in the speed of the objects) is nearly zero, a rendezvous of two spaceships traveling at 17,300 mph isn’t any more dangerous than a rendezvous of two aircraft traveling at 173 mph. In fact, some pilots would tell you that a nighttime rendezvous of two aircraft in marginal weather is a lot more stressful than an orbit rendezvous.

Are orbit rendezvous difficult?

Yes. Imagine you are the commander of a shuttle on a mission to rendezvous with the Russian Mir space station. It’s at your exact altitude and 20 miles in front of your shuttle. You need to gain on it—close that 20-mile distance—so you do what’s intuitive. You push in on your THC, firing the aft thrusters, thus increasing your speed. Everything you’ve ever done on Earth tells you this increase in forward speed will bring you closer to Mir. But in orbit, it actually has the opposite effect. Within minutes, you’ll find the distance to Mir increasing not decreasing. What’s going on? Increasing the speed of any orbiting spacecraft will raise the orbit, and, by the laws of orbit motion, higher orbits are slower orbits. So, your forward burn raises the shuttle orbit and causes it to slow down. The distance to Mir increases. To close the distance, you need to do a braking burn. This will lower the shuttle orbit and increase its orbit speed. Eventually, through a series of burns, the distance will be closed and the rendezvous completed. Only when the shuttle is within about 2 miles of a target could a commander complete a rendezvous by eyeball. Beyond this distance, the counterintuitive behavior of orbit mechanics makes him a slave to radar and computer data.