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# Space rockets

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Conquering space was probably the greatest technological achievement of the 20th century. Space rockets put men on the Moon, launched satellites that sent back dramatic pictures of Earth, and gave people an understanding of the Universe they could never have gained from [telescopes](http://www.explainthatstuff.com/spacetelescopes.html) trained on the sky. Since Sputnik, the first satellite, was launched into space in 1957, several thousand successful space missions have now been flown. What are rockets and how do they work? Let's take a closer look!

Photo: An Atlas Centaur rocket launches an Intelsat space satellite in 1991. Picture courtesy of [NASA Kennedy Space Center (NASA-KSC)](http://images.ksc.nasa.gov/).

## Who invented space rockets?

Chinese inventors made rockets possible when they invented gunpowder c.700–800CE; the first rockets were actually [firework](http://www.explainthatstuff.com/howfireworkswork.html) missiles used by the Chinese in 1232CE to defend the city of Kaifeng against a Mongolian invasion. Space rockets owe just as much to US physicist [Robert Hutchings Goddard](http://en.wikipedia.org/wiki/Robert_H._Goddard) (1882–1945), "the father of modern rocketry," who pioneered many rocket science techniques during the early 20th century. German scientists also played an important role, notably with a rocket-propelled missile called the V-2, which was used to devastating effect in World War II. Intense rivalry between the United States and the Soviet Union saw the Russians putting Sputnik into space in 1957, but American astronauts were the first to land on the Moon in 1969, propelled by a Saturn-V rocket. Today, rockets are still the cheapest way of putting [satellites](http://www.explainthatstuff.com/satellites.html) into space. Over half of all commercial satellites are now launched from French Guiana by the European Ariane rocket.

Photo: The father of modern rocketry, Robert Hutchings Goddard, pictured in November 1925 with one of his [inventions](http://www.explainthatstuff.com/inventors-and-inventions.html), the double-acting rocket engine. Goddard first got the idea of traveling into space as a teenager, after climbing a cherry tree in his family's garden: "I imagined how wonderful it would be to make some device which had even the possibility of ascending to Mars..." His many inventions included powering rockets with liquid fuels and constructing rockets with multiple stages—two fundamentally important ideas used in virtually every successful space rocket launched to date. Picture courtesy of [Great Images in NASA](http://grin.hq.nasa.gov/ABSTRACTS/GPN-2002-000139.html).

## How rockets work

It's a common mistake to think that rockets work by "pushing back against the air"—and it's easy to see that this is a mistake when you remember that there's no air in space to push against. Space is literally that: empty space! How, then, do rockets work?

Like jet [airplanes](http://www.explainthatstuff.com/howplaneswork.html), space rockets work on a principle called action and reaction (another name for Newton's [third law of motion](http://www.explainthatstuff.com/motion.html)). The massive force (action) generated by hot gases firing backward from a rocket's engines produces an equal force (reaction) that pushes the rocket forward through space. Most of the fuel on-board a rocket is used in the first few minutes of the mission to achieve an escape velocity of at least 25,000 mph (7 miles per second or 40,000 km/h)—the speed a rocket must theoretically attain to escape Earth's gravity.

"Escape velocity" suggests a rocket must be going that fast at launch or it won't escape from Earth, but that's a little bit misleading, for several reasons. First, it would be more correct to refer to "escape speed," since the direction of the rocket (which is what the word velocity really implies) isn't all that relevant and will constantly change as the rocket curves up into space. (You can read more about the difference between speed and velocity in our article on [motion](http://www.explainthatstuff.com/motion.html)). Second, escape velocity is really about [energy](http://www.explainthatstuff.com/energy.html), not velocity or speed. To escape from Earth, a rocket must do work against the force of gravity as it travels over a distance. When we say a rocket has escape velocity, we really mean it has at least enough kinetic energy to escape the pull of Earth's gravity completely. Finally, a rocket doesn't get all its kinetic energy in one big dollop at the start of its voyage: it gets further injections of energy by burning fuel as it goes. Quibbles aside, "escape velocity" is a quick and easy shorthand that helps us understand one basic point: a huge amount of energy is needed to get anything up into space. (You can read a much more detailed explanation in the Wikipedia article on [escape velocity](http://en.wikipedia.org/wiki/Escape_velocity).)

Photo: Test firing the Space Shuttle's main engine. Picture courtesy of [Great Images in NASA](http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-000543.html).

## How rocket engines work

Like the gunpowder missiles of ancient China, solid-fuel rocket engines are little more than giant [fireworks](http://www.explainthatstuff.com/howfireworkswork.html). Although they are very powerful, they cannot be switched off or controlled in any way, so they are typically used only during liftoff. The solid-rocket boosters (SRBs) used on spacecraft like the Space Shuttle are examples of rockets that work this way.

Unlike airplane [jet engines](http://www.explainthatstuff.com/jetengine.html), which take in air as they fly through the sky, space rockets have to carry their own oxygen supplies (oxidizers) with them because there is no air in space. Liquid-fuel engines [pump](http://www.explainthatstuff.com/pumpcompressor.html) liquid hydrogen (the fuel) and liquid oxygen (the oxidizer) into a combustion chamber at the bottom of the rocket, burn the mixture (which is called the propellant, because it propels the rocket), and allow the hot exhaust to escape through a jet nozzle to produce thrust. The oxygen and hydrogen burn at a very high temperature, which makes the engine more efficient and powerful. However, before combustion, both substances are stored at extremely low temperatures to keep them liquid. This ensures more fuel can be stored than if gases were used. The low temperature also cools the nozzle to protect it from the heat generated during liftoff. Unlike solid-fuel engines, liquid-fuel engines can be switched on and off during flight using [valves](http://www.explainthatstuff.com/valves.html).

Artwork: How a space rocket works: Liquid hydrogen (the fuel) from one tank is mixed with liquid oxygen (the oxidizer) from a separate tank using pumps and valves to control the flow. The oxidizer and fuel mix and burn in the combustion chamber, making a hot blast of exhaust gas that propels the rocket. The payload (the cargo—such as a satellite) occupies a relatively small proportion of the rocket's total volume in the nose-cone at the top.

## A typical rocket: the Atlas Centaur

Photo: An early Atlas rocket photographed in 1963. Picture courtesy of [Great Images in NASA](http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-000998.html).

One of the most successful space rockets ever developed is the [Atlas](http://en.wikipedia.org/wiki/Atlas_(rocket_family)), produced by the Lockheed Martin company. Atlas rockets have launched over 100 unmanned space missions, including voyages to the Moon, the Pioneer missions that flew past Jupiter and Venus, and the Voyager space probe that landed on Mars. NASA's first Atlas rocket took off from Cape Canaveral, Florida, on June 11, 1957. The latest version, Atlas V, has been used from late 2001 as a launch vehicle for government and commercial satellites and is expected to remain in use until at least 2020.

One version of Atlas, known as the Atlas Centaur rocket, illustrates the basic idea of how a rocket works very well. It's called the Atlas Centaur because the lower stage (a section of the rocket used for part of the flight) called Atlas is joined to an upper stage called Centaur. The rocket's payload (cargo), typically a spacecraft or satellite, rides on top of the Centaur stage and is protected from heat and vibration by a nose cone called the payload fairing.

### How Atlas launches a satellite

The Atlas and Centaur stages power the rocket through different points of its mission. The massive Atlas stage helps the rocket escape Earth's gravity and pushes it into orbit. Later, the smaller Centaur stage puts the payload satellite into orbit before separating and returning to Earth.

1. Liftoff: The Atlas stage powers the rocket with a two-chamber booster engine (operational during liftoff only), a sustainer engine (operational from liftoff until all fuel is exhausted), and four solid rocket boosters (SRBs). The Atlas stage contains 343,000 lbs (156,000 kg) of liquid fuel.
2. SRBs jettisoned: The solid rocket boosters are used to increase thrust during the first two minutes of the flight and are jettisoned when their fuel supply is exhausted.
3. Booster engine jettisoned: The booster engine cuts off and is jettisoned by releasing 10 pneumatic (air-operated) latches.
4. Payload fairing jettisoned: [spring](http://www.explainthatstuff.com/how-springs-work.html)-operated thrusters jettison the protective payload faring once the rocket has cleared Earth's atmosphere.
5. Atlas and Centaur separate: As the rocket near its orbit, the Atlas and Centaur stages separate and the Atlas stage is jettisoned.
6. Centaur moves into orbit: Centaur's twin engines give it the precise altitude and velocity it needs to launch the satellite.
7. Satellite is launched: Centaur separates from the satellite. The satellite continues in orbit, while Centaur positions itself for a return to Earth.

## The Space Shuttle: the rocket that kept coming back!

The development of NASA's reusable space-plane, the Space Shuttle, launched a whole new age of space exploration. Previous spacecraft had lasted only for one mission, but the Shuttle, which took off like a rocket and flew back like a plane, could be reused up to 100 times. Between its maiden flight in 1981, and its final voyage in 2011, the Shuttle made 135 missions, successfully launching and repairing numerous [satellites](http://www.explainthatstuff.com/satellites.html) and the Hubble Space Telescope, and playing a major role in assembling the International Space Station. Now it's retired, we bid it a very fond farewell. So long Space Shuttle!

Photo: Relaunch of Space Shuttle (mission STS-26) in 1988. Picture courtesy of [Great Images in NASA](http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001870.html) (follow this link for a bigger version of this picture).

### How did the Shuttle work?

The main component of the Shuttle was a spacecraft about two thirds the size of a 747 [airplane](http://www.explainthatstuff.com/howplaneswork.html) ("Jumbo Jet") called the orbiter. This was launched by two solid rocket boosters (SRBs) fixed to its underside, which burned solid fuel inside them. In between the SRBs, a giant external tank (ET) fed around 528,000 gallons (2 million liters) of liquid fuel to the orbiter's three engines. This vast amount of fuel was needed to accelerate the Shuttle to a speed of roughly 17,500 mph (28,000 km/h) to reach an orbit of 190–330 miles (304–528 km) above Earth. During liftoff, the Shuttle's main engines burned fuel so quickly that they could drain a family-sized [swimming](http://www.explainthatstuff.com/swimming-science.html) pool in just 25 seconds! Each orbiter cost roughly $2 billion to build and each Shuttle mission cost roughly $450 million.

Photo: Cutaway of the Space Shuttle orbiter. Picture courtesy of [NASA Marshall Space Flight Center (NASA-MSFC)](http://mix.msfc.nasa.gov/). Browse the [hi-resolution](http://mix.msfc.nasa.gov/IMAGES/HIGH/0102619.jpg) version of this image.

### Life in the Shuttle

Each Space Shuttle mission lasted up to two weeks, so the orbiter needed a comfortable-but-compact, two-story living area. On the top level were the pilot's seats and cockpit controls. A ladder led down to a large sleeping area, galley kitchen, storage lockers, gym—and a vacuum toilet that worked even in space. The astronauts ate their food with metal knives and forks held to metal trays with [magnets](http://www.explainthatstuff.com/magnetism.html); this stopped them floating away in the Shuttle's near-zero gravity.

### Shuttle missions

Space Shuttle missions often made headline news around the world. The maiden voyage on April 12, 1981, confirmed the Shuttle could successfully return from space. Another notable flight in April 1984 involved astronauts repairing a crippled satellite in the Shuttle's cargo bay before returning it successfully to space. Two years later, the orbiter Challenger exploded shortly after takeoff killing all seven crew members. Flights resumed in late 1988 and the Hubble Space Telescope was launched in 1990. Disaster struck again in February 2003, when the Space Shuttle Columbia was destroyed as it returned to Earth. The final Shuttle voyage launched on July 8, 2011, after which the four remaining orbiters were retired to science and aviation museums spread across the United States.

### From takeoff to landing

During a typical one-week voyage, the Shuttle launched from its base at Kennedy Space Center (KSC), Florida, and carried out its mission several hundred miles above Earth's surface. When the mission was complete, it returned to Earth's atmosphere and made an unpowered landing, like a glider, either at KSC or at Edwards Air Force Base in California. At 15,000 ft (4572 m) long, the Edwards landing strip is roughly twice the length of a typical airport runway.

### Reentry

The Shuttle's unique feature was its ability to venture into space and return to Earth intact. The main problem with this, however, was that friction would heat up the orbiter to nearly 1927°C (3500°F) as it passed into Earth's atmosphere, so it was coated with about 20,000 [heat](http://www.explainthatstuff.com/heat.html)-resistant [ceramic](http://www.explainthatstuff.com/ceramics.html) "tiles" (refractory [bricks](http://www.explainthatstuff.com/bricks.html)) to stop it burning up on reentry. A tough material called reinforced carbon-carbon was used in the tiles on the wing edges, the nose, and other areas where temperatures could exceed 1260°C (2300°F). Black high-purity silica tiles 1–5 inches (2.5–12.7 cm) thick were individually cemented to the underside of the orbiter to protect it from temperatures of 649–1260°C (1200–2300°F). Less heat reached the upper surface of the craft, so it was protected either by white tiles or by a blanket made from a silica composite.

### There and back—in seven easy steps!

1. At liftoff, three engines on the orbiter burned liquid fuel from the large brown tank underneath. Two SRBs either side burned solid fuel and made over 70 per cent of the liftoff thrust. Together, these five engines produced some 7.3 million pounds of thrust—150 times as much as a single Jumbo Jet engine! During this part of the flight, the temperature inside the Shuttle's engine was two thirds as hot as the surface of the Sun.
2. Two minutes later and 32 miles (48 km) into the sky, the empty SRBs were detached.
3. When the Shuttle reached its orbit, the ET was detached and burned up on its way back to Earth.
4. A typical mission lasted 4–7 days.
5. Once the mission was over, the orbiter flew backward for the first part of its descent.
6. As the orbiter turned, its nose was raised so its heat-resistant undercarriage met Earth's atmosphere first.
7. During descent, the orbiter slowed from 28,000 km/h (17,500 mph) to 350 km/h (220 mph) and a [parachute](http://www.explainthatstuff.com/how-parachutes-work.html) brought it completely to rest as it touched down to land.

Photo: Above right: Returning to Earth and landing safely was always the hardest part of a Space Shuttle mission. This is Space Shuttle Endeavour, landing in 2002. Photo courtesy of [NASA Dryden Flight Research Center (NASA-DFRC)](http://www.dfrc.nasa.gov/gallery/%20).

### Inside the Shuttle cargo bay

At 60 ft (18.3 m) long and 15 ft (4.6 m) wide, the orbiter's cargo bay was big enough to hold a a satellite or a couple of trucks parked side by side. It contained a variety of sensors and scientific instruments and a 50 ft (15 m) grabber arm, used for launching and retrieving satellites. The reflective inside doors of the cargo bay doubled up as heat shields to protect the cargo from solar radiation.

The Shuttle could not launch a satellite directly into geostationary orbit (a fixed orbit over a certain place on Earth). Instead, it spun the satellite slowly out of the cargo bay. When the satellite was clear, its own rocket motors would fire and power it into position.

Photo: Astronaut Bruce McCandless walking above the cargo bay of the Space Shuttle (mission STS-41B) in 1984. Picture courtesy of [Great Images in NASA](http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001075.html) (follow this link for a bigger version of this picture).