One college student got to live out a dream over the summer in 2009. Brandon Lojewski, a student at the University of Central Florida, earned a spot as an intern at NASA’s Kennedy Space Center in Cape Canaveral, Florida. While he’d launched his own paper rockets for school competitions beginning with a high school physics class, watching massive Delta IV and Atlas V rockets lift off gave him a whole new perspective.

“I had a headset and a computer console to click around in. The headsets have about 30 different voice channels you can tune in to and hear all the steps of the mission and any problems that are encountered,” Lojewski says. “Being ‘behind the scenes’ is really an honor because it has made me realize and appreciate the depth, size, and complexity of our nation’s space program.”

Lojewski did more than just watch launches. He helped with projects to improve the launch process. One of his projects was to design, develop, and publish what are called Iris pages for display on launch consoles. Lojewski explains that Iris pages compile telemetry measurements (measurements such as temperature and pressure) from a spacecraft and launch vehicle. Engineers then look over this data during launch countdown, liftoff, and ascent.

“Planning for a launch starts years in advance,” says Lojewski. “Every single component of the rocket is analyzed and monitored every second until the end of the mission. Some missions can even last a few decades. The stuff I am exposed to here is absolutely incredible.”
The Evolution of Rocket Technology

Over the millennia, not only the technology of rockets but also their purpose has evolved. The first rocket-like devices were more like toys, invented by Archytas and Hero, two Greek men you read about in the previous lesson. But as the sophistication of rockets grew and human beings began to understand their power, rockets changed from toys to weapons.

Today countries around the world use rockets for both military and peaceful purposes. The United States, the European Union, Russia, and others use rockets to launch humans and satellites into space. The results include an improved understanding of Earth and better communication here on the planet. But as the United States proved in 1985 and China proved in 2007—when they used missiles to destroy satellites in space—rockets may also help introduce war to space.

The Early Use of Rockets

The Chinese were, in fact, instrumental in developing rockets. They reportedly had a very rudimentary version of gunpowder in the first century. In the thirteenth century they created fireworks. They filled bamboo and leather tubes with saltpeter, sulfur, and charcoal. In 1232 the Chinese used these rockets to ward off Mongol invaders (Figure 2.1). Some historians suggest that these were the first true rockets.

Figure 2.1 In 1232 the Chinese used rockets to ward off the Mongols. Courtesy of NASA
The Chinese rockets so impressed the Mongols that the Mongols began work on their own rockets. They in their turn likely introduced Europeans to rockets. Europeans soon began introducing their own modifications. Studies by a thirteenth-century English monk named Roger Bacon improved gunpowder. His efforts increased the range of rockets. He showed he understood the uses of gunpowder and the rocket when he wrote that it “is possible with it to destroy a town or army.”

In the fifteenth century an Italian named Joanes de Fontana developed the first surface-running torpedo, which coasted on top of water and set enemy ships on fire (Figure 2.2). And in the same century Frenchman Jean Froissart discovered that launching rockets through a tube increased their accuracy. His finding led to the modern bazooka.

For a time starting around the sixteenth century, Western civilization set aside rockets in warfare and mostly shot them off for fireworks. During this lull, a German named Johann Schmidlap made a critical improvement. He invented the step rocket. As you read in the last lesson, rockets often have a first stage that launches a spacecraft to low-Earth orbit and a second stage that breaks it out of Earth’s orbit. Schmidlap gets credit for these multistage rockets because of his two-stage fireworks that flew higher than any ever had before. And Kazimierz Siemienowicz (KAH-zee-meer Sye-myeh-NOH-vich), a seventeenth-century commander in the Polish Royal Artillery, wrote about multistage rockets in a way that also laid the foundation for their development in the centuries ahead.

**Gravesande, Congreve, and Hale: The Early Rocket Scientists**

Two qualities eluded scientists in their earliest rockets: accuracy and power. Without these features commanders on the battlefield relied instead on lobbing great numbers of rockets to overwhelm their enemies. Nations resumed using rockets in a serious way in war beginning in the late eighteenth century and early nineteenth century.

Willem Gravesande was a Dutch professor in the early eighteenth century. He propelled model cars with jets of steam. Experimenters in Russia and Germany began working with rockets that had exhaust flames powerful enough to bore holes in the ground before liftoff.
Then, after the British succumbed to Indian rocket attacks in battles in 1792 and 1799, an English colonel named William Congreve began designing rockets. Congreve’s rockets could travel three miles (4.8 km). He developed different models: Some showered the enemy with shot (small metal pellets); others were incendiary rockets for burning ships and buildings. He also pioneered launching rockets from ships. You hear of his work every time you sing the National Anthem.

**LESSON 2  ■  Propulsion and Launch Vehicles**
Francis Scott Key’s lyrics that include “the rockets’ red glare” refer to Congreve rockets pounding Fort McHenry in Baltimore during the War of 1812. Still, Congreve rockets lacked accuracy.

William Hale, an Englishman, invented a stickless rocket in the middle-nineteenth century that revolutionized battle. Hale’s spin stabilizer, which eliminated the need for the long guide sticks that Congreve had used to provide stability in flight (Figure 2.4), improved that much sought-after quality: accuracy. Exhaust gases struck vanes at the rocket’s base and made it spin like a bullet. The United States used these rockets in the Mexican War of 1846–48. They also appeared in the Civil War.

More-effective breech-loading cannon (cannon loaded from the rear) with rifled barrels (cut with spiraled grooves that improve accuracy) and exploding warheads eventually caused armies to once again set rockets aside for a time. But variations of Hale’s principle are still in use today.
The Contributions of Tsiolkovsky, Goddard, and Oberth to Modern Rocket Science

Modern rocket scientists focused not only on accuracy and power but also on distance and altitude. Russian Konstantin Tsiolkovsky earned the title of “father of astronautics” for his contributions to rocketry. After nearly going deaf at age 10, he educated himself. In 1898 Tsiolkovsky suggested using rockets to travel to space. In 1903 he wrote in his most famous work, *Research Into Interplanetary Space by Means of Rocket Power*, that liquid propellant could increase how far rockets could travel. He also said that the velocity of exhaust gases determined how far and how fast a rocket would travel.

American Robert Goddard built the first liquid propellant rocket in 1926. It traveled only 41 feet (12.5 meters) but was as important to the future of spacecraft as the Wright Brothers and Kitty Hawk were to the development of aircraft in 1903. Goddard based his rocket on the theory that a stable flight could be attained by mounting the engine ahead of the fuel tanks, with the tank shielded from the flame by a metal cone. This work was instrumental in the development of the *Saturn V* Moon rocket in the 1960s.

Among other ideas, Goddard developed a gyroscope system to control his rockets as well as a parachute recovery system. This “father of modern rocketry” also demonstrated that rockets will fly in a vacuum (no air and no gas)—that they don’t need air to push them.

*Figure 2.4 A British ship launches Congreve rockets at Copenhagen in 1807.*

© Science Photo Library
Finally, Hermann Oberth of Germany wrote a book in 1923 titled *By Rocket to Space* that delved into the math of spaceflight as well as rocket designs and space stations. His book inspired many to study rockets, including a German group called the Society for Space Travel. A young German engineer named Wernher von Braun joined this society along with Oberth. The German military eventually recruited Von Braun along with many society members in the 1930s to help develop a rocket for its arsenal. The V-2 rocket was the result. It weighed 12 tons, had a range of 200 miles (300 km), flew more than 3,500 miles (5,600 km) per hour, and could carry a one-ton payload.

### The Types of Launch Vehicles

After World War II the United States and the Soviet Union seized abandoned V-2 rockets for study back home. Hundreds of Germany’s top scientists accompanied them. The United States became home to the brilliant Von Braun, who surrendered to American troops along with 500 of his fellow scientists.

Thus both the United States and the Soviet Union based their space programs on the work done in Germany with V-2 rockets. Until 1960 Von Braun and his scientists worked for the US Army. Then the US government appointed Von Braun as first director of NASA’s Marshall Space Flight Center, a position he held until 1970. Under his watch, NASA developed the *Saturn* rocket that would take man to the Moon. But the contest of rocket development between the United States and the Soviet Union first really heated up back in 1957 with the USSR’s launch of *Sputnik*.

### The R-7 Intercontinental Ballistic Missile (ICBM) That Launched the *Sputnik* Satellite

*Sputnik* launched atop the R-7, a Soviet *intercontinental ballistic missile*. An intercontinental ballistic missile (or ICBM) is a *missile designed to deliver a payload to another spot on Earth several thousand miles away*.

The R-7 is a *base rocket*. Engineers add to it upper stage rockets as needed to “build” different launch vehicles. Since the R-7 launched *Sputnik*, the Russians have launched more than 1,600 R-7-derived rockets, more than any other launch vehicle in the world.

**CHAPTER 11  Rockets and Launch Vehicles**
The R-7 consisted of a core rocket (which the Russians refer to as the second stage) surrounded by four boosters (the first stage), each shaped like a tapered cylinder. Both first and second stages ignite at launch. Each of the strap-on boosters had one engine producing tons of thrust at sea level. The four boosters separate from the core about two minutes after liftoff, leaving the core to continue firing. After the core finishes firing, additional upper stages fire to insert the payload into orbit.

**Voskhod, Soyuz, Tsiklon, and Proton: Russian Launch Vehicles**

The Russian *Voskhod* and *Soyuz* launch vehicles have relied on “R-7 plus upper stage” combinations for launches. So atop an R-7 (or a rocket developed from the R-7 design) sits an upper stage referred to as a “block.” Starting in 1963 the *Voskhod*, using an “R-7 plus Block 1” combination sent reconnaissance satellites into space.

A couple years later *Soyuz* rockets lifted off with satellite payloads on a somewhat revised version of the R-7 plus Block 1 mix. The *Soyuz* launch vehicle interestingly enough also gets credit for launching not only manned *Soyuz* spacecraft into orbit starting in 1967 but also the manned *Voskhod* 2 in 1965 as well. The Russians still use *Soyuz* today to get cosmonauts and astronauts to the International Space Station. And they continue to develop new *Soyuz* rockets.
The Soviets started using their more powerful Tsiklon-3 launch vehicle in 1977 to send weather and military satellites into orbit. They based it on their two-stage R-36 ICBM, a liquid-propellant military missile that was the first missile the United States viewed as a threat to its own ICBM arsenal. The Tsiklon could deliver about 3.5 tons (3,175 kg) into a polar orbit. To deliver that payload, it relied on a restartable third stage. The Soviets used an earlier two-stage version of Tsiklon, the Tsiklon-2, as far back as 1967 to launch high-security military payloads into space. These payloads included anti-satellite weapons and ocean reconnaissance satellites.

Russia’s largest launch vehicle in use today is Proton. Unlike Voskhod, Soyuz, and Tsiklon, the Soviets did not base Proton on one of their ballistic missiles. From the beginning stages of development, they intended to use Proton for space missions. Proton’s most basic package, the Proton-K, comprises three or four stages depending on the mission. Six engines make up the first stage, four engines make up the second, and one engine makes up the third stage. If a mission heads to deep space or geostationary orbit, it calls for a fourth stage called the Block DM, which is restartable and can carry as much as 4.9 tons (4,445 kg). In the 1970s and 1980s the Russians launched a three-stage version to send all of the parts for the Mir and Salyut stations into space. In more recent years they’ve used Proton to send such things as the module Zarya (Dawn) to the International Space Station (ISS), as they did in 1998.
**Delta, Titan, and Atlas: US Expendable Launch Vehicles (ELVs)**

The United States produces two types of launch vehicles: expendable and reusable. The country's only partially reusable launch vehicle is the space shuttle, which you read about in Chapter 7. Expendable US booster rockets—models that can be used only once—include Δelta, Titan, and Atlas (Figure 2.5).

**Delta**

The Δelta launch vehicle was America’s answer to the R-7 and Sputnik. NASA engineers purchased a dozen of the US Air Force's Thor medium-range ballistic missiles, added their own modified second stage, and called this new package Δelta. The space agency launched its first Δelta in 1960. With it, NASA has launched many weather, scientific, and communications satellites over the years.

Initially Δeltas could support a payload of only 100 pounds (45 kilograms). Over time, improvements allowed the Δelta to become NASA’s go-to spacecraft. Engineers increased thrust by adding solid rocket boosters and making room for more propellant to add burn time. A Δelta II is about 127 feet (39 meters) tall, while the Δelta IV can range from between about 206 feet (63 meters) and 235 feet (72) meters tall. Today the Δelta IV Heavy can launch a payload weighing more than 50,000 lbs (23,000 kg) into low-Earth orbit. It features three common booster cores joined together and topped with a second-stage engine.

The first space shuttle flight in 1981 seemed to spell doom for Δelta. NASA stopped placing orders, expecting that the shuttle would launch payloads the rocket had carried previously. By 1986 NASA had only three Δeltas left in its inventory. After the Challenger explosion that same year, however, President Reagan decided that space shuttles would no longer carry commercial or military payloads. Δelta was back in demand. Today these launch vehicles carry about 34 percent of all the commercial satellites in the world. The United States, Russia, Europe, and China compete for this commercial business, so Δelta plays a crucial role in winning this business for the United States.

**Titan**

Titan was another critical US expendable launch vehicle (ELV). It was the country's first two-stage ICBM, and first successfully test-launched in 1959. This liquid-propellant rocket gave the United States strategic comfort during the Cold War. And it was the first missile stored in a hardened underground silo.

Later versions achieved other firsts. Titan II was the first US launch vehicle to use fuels that could sit for long periods in the missile's fuel tanks. This meant that if war broke out between the United States and the Soviet Union, the US military could quickly launch its nuclear-armed Titans without wasting valuable time fueling them. NASA adopted Titan II to launch its two-man Gemini spacecraft for the 10 Gemini missions between 1965 and 1966 that prepared for the Apollo program.
The US Department of Defense (DoD) next requested the development of Titan III for space missions, not ICBMs. DoD needed launch vehicles to fly their intelligence-gathering satellites into space. This version launched satellites from 1966 until 1987. Meanwhile NASA turned to Titan III for numerous missions, including Viking and Voyager 1 and 2.

And the most costly rocket of all time, Titan IV—at $400 million each—propelled NASA’s Cassini and Huygens probes on their way. Titan IIIIs and IVs continued to use a liquid-propellant core but also had strapped-on solid rocket motors. Because they cost so much to operate, the United States retired its Titan rockets in 2005 in favor of the Atlas V.

**Atlas**

The Atlas rocket, like Titan, launched exploratory probes but also had a national defense mission. The United States Army Air Forces, the predecessor to the US Air Force, first ordered what would become the Atlas in 1945 after World War II’s end. The liquid-propellant rocket’s design evolved over the years, but in 1959 it became the first American ICBM.
While no longer used as an ICBM—the military phased it out in 1966 to replace it with the solid-propellant Minuteman ICBM—Atlas is still used today for a variety of other military, space, and commercial missions. And its design has not changed much in its 50-plus years. It is lightweight and can carry large payloads.

Of historic significance, NASA sent astronaut John Glenn on man's first Earth orbit in the Friendship 7 Mercury capsule in 1962 with an Atlas launch vehicle. Other Mercury missions also launched atop the Atlas.

Recent Atlas upgrades include the Atlas IIA and IIAS. They can carry large payloads, including communications satellites, weighing almost 8,500 lbs (3,856 kg), to a geostationary orbit 22,300 miles (35,888 km) above the equator.

Interestingly, the Atlas V, introduced in 2006, contains an engine built in Russia. This is an interesting development for a rocket whose initial purpose was to launch nuclear warheads against the former Soviet Union.

Courtesy of NASA/Stennis Space Center

Saturn V: Launch Vehicle for the Apollo Program

NASA needed a more powerful launch vehicle to send astronauts to the Moon. None of its previous ELVs would do. With von Braun as chief engineer, the Marshall Space Flight Center developed the Saturn V. NASA built 15 of these rockets.

In December 1968 the Apollo 8 spacecraft atop a Saturn V launched a crew into orbit around the Moon. And in July 1969, propelled by another Saturn V, the Apollo 11 crew lifted off for mankind’s first landing on the Moon. The Saturn V also launched the Skylab space station. NASA launched a smaller version of the Saturn V, called the Saturn 1B, to carry crews to Skylab in 1973 as well as for the 1975 Apollo-Soyuz docking mission. This largest and most powerful of all rockets ever launched had a first stage that alone weighed more than a space shuttle. It had three stages in all. Each of its first two stages contained five engines. And no Saturn ever failed, despite the fact that it was made up of some 3 million parts.

Star POINTS

The Saturn V rocket that sent astronauts to the Moon was as powerful as the energy created by 85 Hoover Dams.
The Space Transportation System (STS): US Reusable Launch System

As you read in Chapter 7, the space shuttle’s official name is Space Transportation System (STS). This reusable launching system relies on a combination of liquid and solid propellants. Fed by the external tank, the shuttle main engines burn liquid hydrogen and oxygen. The strap-on boosters burn solid propellant. Only the external tank isn’t reusable. After each flight, scientists retool and repair the main components of the STS for use on future flights.

The STS has many duties. It launched **Galileo**, **Magellan**, and **Ulysses**. It has taken spacecraft to orbit, performed satellite rescues, and assembled and serviced the ISS. It also carries out a wide variety of scientific missions ranging from the use of orbiting laboratories to small self-contained experiments. And it was designed to transport loads of up to 66,000 lbs (30,000 kg) into low-Earth orbit.

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**Astronaut Stephanie Wilson**

Stephanie Wilson was born in Massachusetts in 1966. She graduated from Harvard University with an engineering degree and went to work for Martin Marietta, where she worked on **Titan IV**. After two years, she went back to graduate school at the University of Texas for her master’s in aerospace engineering. When she graduated, she got a job with the Jet Propulsion Laboratory in California and worked on software development, as well as various aspects of **Galileo**.

Wilson says that she chose engineering because it offers so many career choices. “As a mechanical engineer, I could work on automobiles if the bottom fell out of aerospace. I could work building designs. I could work on city planning. I always felt like engineering was a good career move.”

NASA accepted her into the astronaut program in 1996. But before she showed up for training, she had to learn how to swim, since so much astronaut training takes place underwater. She spent her whole summer training with a coach. And it paid off. Wilson has been to space twice and took part in the Spring 2010 launch of **Discovery**. On previous missions she has traveled to the International Space Station where she performed maintenance. Her missions have also transported various astronauts to and from the ISS.

Wilson was the second African-American woman in space. Two other women—mission specialist Dottie Metcalf-Lindenburger and Japanese astronaut Naoko Yamazaki—joined Wilson and ISS flight engineer Tracy Caldwell Dyson in the first mission to feature four women aboard the same spacecraft for the first time.
Once NASA retires the space shuttle program—intended for September 2010—it plans to replace the shuttles with the *Ares I* launch vehicle for human spaceflight and the *Ares V* for cargo launches. But as of this writing in 2010 the Obama administration has dropped its support for the idea, putting the *Ares*’s future in doubt.

### The Factors and Features of a Rocket Launch

Once NASA has picked its launch vehicle based on the mission, it still has many choices to make, from where to launch it to when and how. NASA has names for each of these steps: launch sites (the “where”), launch windows (the “when”), and preparation and integration (the “how”).

#### Launch Sites

Back in Chapter 10 you read that launches from the equator can take advantage of Earth’s rotational speed of about 1,040 miles (1,675 km) per hour. This means that even though the launch vehicle is only sitting on the launch pad, it is already moving at those great speeds relative to Earth’s center. NASA applies these miles per hour to the speed needed to orbit Earth (about 17,350 mph or 28,000 km per hour). A spacecraft launched close to the equator calls for less propellant and can launch a larger vehicle than one launched farther away. But launches at the equator help only those missions that follow an orbit close to Earth’s equator.
Missions headed for a high-inclination Earth orbit (such as a North Pole to South Pole orbit) don’t benefit from an equator launch. In such a case, it is up to the launch vehicle to provide all the energy needed to reach orbit.

For interplanetary launches, a launch vehicle takes advantage not only of Earth’s rotation but also of its orbital motion about the Sun. Using these readily available sources of free power allows NASA to make up for the limited energy available from today’s launch vehicles. The launch vehicle accelerates in the direction of Earth’s orbital motion, which averages about 62,000 miles (100,000 km) per hour. This is in addition to the launch vehicle’s using Earth’s rotational speed.

Launch sites must also have a clear path downrange so the launch vehicle will not fly over populated areas, in case of accidents. Space shuttles require a landing strip with acceptable wind, weather, and lighting conditions. They also need landing sites overseas, in case of an emergency landing.

The Kennedy Space Center at Cape Canaveral, Florida, stages many East Coast launches. Others are conducted at nearby Patrick AFB. However, these sites are suitable only for low-inclination orbits (those nearer the equator). This is because major population centers underlie the trajectory required for high-inclination launches. On the West Coast, NASA launches high-inclination missions from Vandenberg Air Force Base in California. This location is suitable because the trajectory for high-inclination orbits avoids population centers.

Finally, heavy launch vehicles call for complex ground facilities. Smaller vehicles use mobile facilities. And some even launch from airplanes.

**The Launch Window**

The [launch window](#) is the specific timeframe during which a launch can take place. Many factors determine when the launch window occurs, including safety and mission objectives.

An interplanetary launch has a limited number of weeks in which it must take place. The timing of the launch window depends on Earth’s location in its orbit about the Sun and the target planet’s position in its own orbit about the Sun. The timing must permit the launch vehicle to use Earth’s orbital motion for its trajectory, while timing it to arrive at its destination when the target planet is in position. The launch window may also be constrained to a number of hours each day to take best advantage of Earth’s rotational motion.

Actual launch times must also consider how long the spacecraft needs to remain in low Earth orbit before its upper stage places it on the desired trajectory toward a target planet.

In addition, a launch that will rendezvous with another vehicle in Earth’s orbit must time its liftoff with that object’s orbital motion. This was the case with the Hubble Space Telescope repair missions.
Preparations for a Launch

NASA has an acronym that stands for launch preparations: ALTO stands for assembly, test, and launch operations. This process is very precise.

The plan requires delivery of a spacecraft’s parts to a large clean room. A clean room is a workspace with a constant temperature and humidity and low levels of contaminants such as dust. Engineers put the parts together and test them in this clean room using computer programs that are nearly identical to those used in flight.

NASA then transfers the spacecraft to an environmental test lab. Engineers place it on a shaker table and subject it to launch-like vibrations. Additionally they install it in a thermal-vacuum chamber and test its thermal properties—how it responds to extreme temperatures. The engineers make adjustments as needed in thermal blanketing to protect spacecraft from the harsh space environment.

Once complete, NASA moves the spacecraft to the launch site. Engineers seal it inside an environmentally controlled carrier, either a truck or an airplane, and carefully monitor the spacecraft during the trip.

More testing takes place at the launch site. Technicians load propellants on board and arm any pyrotechnic devices. They then mate the spacecraft to its upper stage, and finally hoist and mate it to the launch vehicle.
The Process of Launch Vehicle Integration

NASA refers to the phase of mating the spacecraft with the launch vehicle as **launch vehicle integration**. It is a long and detailed process. Engineers maintain clean-room conditions on top of the launch vehicle while they put the payload shroud in place. A **payload shroud**, also called a payload fairing, is the thin metal cover, or nose cone, that protects a spacecraft and upper stages during a launch when aerodynamic forces can batter the rocket. The shroud gives the rocket nose an aerodynamic shape (Figure 2.6). Finally they double-check that the launch will place the spacecraft on the proper trajectory so it gets where it needs to go.

About three months before launch, the engineers transfer the spacecraft and launch vehicle to the launch site. They then attach the spacecraft to a **launch vehicle adapter**, which is a physical structure used to connect a spacecraft to a launch vehicle. They place this whole package into the payload shroud, move it to the launch pad, and hoist it by crane onto the top of the launch vehicle. This final stage takes place about 10 days before liftoff. A countdown then begins.

The countdown helps everyone orchestrate the many operations needed to get everything ready. People have to perform their various tasks at very specific times during the countdown so they don’t interfere with one another. During this period, many final operations on the spacecraft take place, including removing instrument covers and other “remove before flight” items, installing arming plugs, and generally getting everything buttoned up for the big day.

Pauses in the countdown, or “holds,” are built in. These allow the launch team to target a precise launch window, and to provide a cushion of time for certain tasks and procedures without affecting the schedule. For the space shuttle countdown, built-in holds vary in length and always occur at the following times: T minus 27 hours (that is, 27 hours before liftoff), T minus 19 hours, T minus 11 hours, T minus 6 hours, T minus 3 hours, T minus 20 minutes, and T minus 9 minutes.

The final hold is always at T minus 9 minutes. It often lasts 20 minutes, although this can vary, depending on the mission. During this time, NASA officials:

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**Figure 2.6** A protective payload shroud, or payload fairing, separates from Skylab in this artist’s conception. Courtesy of NASA
• determine the final launch window
• activate the flight recorders
• conduct the final “go/no-go” launch polls and decide whether to launch.

Specialists monitor the spacecraft’s health at all times. If a problem arises, they can stop the launch. The Deep Space Network begins tracking immediately after the launch.

Despite these finely tuned procedures, launches remain too complex and dangerous for the everyday person to take part in. NASA’s goal is to find ways to make space more accessible. The space agency says that launch vehicles must be less expensive and more reliable than they are today. They also must be reusable—the agency can’t afford to throw away expensive hardware after each launch. That’s been the beauty of the reusable space shuttle program.

Engineers see a future that allows more people to travel into space and encourages commercial development as well. Some people believe these commercial companies could replace NASA in delivering astronauts to places like the International Space Station. NASA itself may eventually develop aerospace planes that will “take off from runways, fly into orbit, and land on those same runways, with operations similar to airplanes,” the agency says. It may sound like the stuff of science fiction—but it could become a reality in your lifetime.
**Lesson 2 Review**

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

1. Which people were instrumental in developing rockets?

2. Which type of rocket does the National Anthem lyric “the rockets’ red glare” refer to?

3. Who built the first liquid propellant rocket?

4. Which launch vehicle has been used more than any other since its invention in the 1950s?

5. Which is the largest launch vehicle the Russians use today?

6. Which launch vehicle was America’s answer to *Sputnik*?

7. Which ELV launched human beings to the Moon?

8. What is the Space Transportation System more commonly known as?

9. Which type of orbit doesn’t benefit from an equator launch?

10. If a launch is to rendezvous with another spacecraft, it must time which two elements?

11. What does ALTO stand for?

12. When does a countdown begin?

**APPLYING YOUR LEARNING**

13. Explain why NASA has not needed a rocket as powerful as *Saturn V* since the end of the Apollo program.