A Pictorial History of Rockets

The mighty space rockets of today are the result of more than 2,000 years of invention, experimentation, and discovery. First by observation and inspiration and then by methodical research, the foundations for modern rocketry were laid.

Building upon the experience of two millennia, new rockets will expand human presence in space back to the Moon, to Mars and the asteroids, and beyond. These new rockets will be versatile. They will support Earth orbital missions, such as the International Space Station, and off-world missions millions of kilometers from home. Already, travel to the stars is possible. Robot spacecraft are on their way into interstellar space as you read this. Someday, they will be followed by human explorers.

Often lost in the shadows of time, early rocket pioneers “pushed the envelope” by creating rocket-propelled devices for land, sea, air, and space. When the scientific principles governing motion were discovered, rockets graduated from toys and novelties to serious devices for commerce, war, travel, and research. This work led to many of the most amazing discoveries of our time.

The vignettes that follow provide a small sampling of stories from the history of rockets. They form a rocket time line that includes critical developments and interesting sidelines. In some cases, one story leads to another, and in others, the stories are interesting diversions from the path. They portray the inspirations that ultimately led to us taking our first steps into outer space. NASA’s new Space Launch System (SLS), commercial launch systems, and the rockets that follow owe much of their success to the accomplishments presented here.

Steam, Sparks, Explosions, and Flight

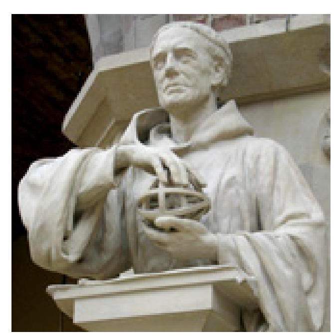
Archytas, 428 to 347 B.C.
Archytas, a Greek philosopher, mathematician, and astronomer was said to have constructed and flown a small bird-shaped device that was propelled by a jet of steam or compressed air. The 'bird' may have been suspended by a wire or mounted at the end of a bar that revolved around some sort of pivot. This was the first reported device to use rocket propulsion.

Hero Engine, c. A.D. 10 to 70
Though not a rocket, the main principle behind rocket (and jet) propulsion was employed in a steam engine invented by Hero of Alexandria. The exact appearance of Hero's engine is not known, but it consisted of some sort of copper vessel heated by a fire beneath. Water in the vessel turned into steam and traveled up two tubes to a hollow sphere that was free to rotate. Two L-shaped tubes from the sphere allowed the steam to escape in jets of gas. The sphere rotated rapidly in the opposite direction of the jets. The Hero engine was seen as an amusing toy, and its potential was not realized for a thousand years.

Chinese Fire Arrows, A.D. 1232
The origins of gunpowder are not clear, but the Chinese reportedly had a rudimentary form of it in the first century, A.D. A mixture of saltpeter, sulfur, and charcoal dust produced colorful sparks and smoke when ignited. The powder was used to make fireworks. Tubes of bamboo and leather, closed off at one end, were packed with gunpowder. Depending upon how the powder was packed and the size of the opening, a fountain of sparks or a bang would result when the powder was ignited. It is likely that some fireworks skittered about because of the thrust produced from the gases escaping the open end. Thus the rocket was born. By 1232, these primitive rockets were attached to arrows and used to repel Mongol invaders in the battle of Kai-keng.

Roger Bacon, c. 1214 to c. 1292
A monk, Bacon wrote about gunpowder in his *The Epistola Fratris R. Baconis, de secretis operibus artis et naturase et nullitate magiae*:
"We can, with saltpeter and other substances, compose artificially a fire that can be launched over long distances....By only using a very small quantity of this material much light can be created accompanied by a horrible fracas. It is possible with it to destroy a town or an army...."

Bacon is thought to have developed improved gunpowder formulas that greatly increased the mixture's power.

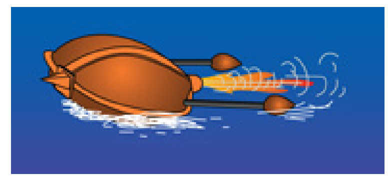


Wan Hu, Sixteenth Century

According to legend Wan Hu, a Chinese stargazer and local official living sometime around the middle of the Ming dynasty, dreamed of spaceflight. He constructed a chair and attached 47 gunpowder rockets to its base. In some versions of the story, his chair also had kite wings. On launch day, 47 assistants rushed up and simultaneously lit the fuses of all the rockets. A huge explosion followed. When the smoke cleared, Wan Hu was gone. Some have suggested Wan Hu actually made it into space, and you can see him as the "Man in the Moon." Regardless of the actual end, Wan Hu had the right idea—use rockets to travel into space.

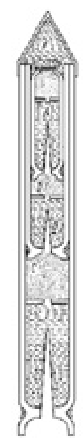
Rockets Go to War

For centuries to come, rockets competed with cannons as the weapon of choice for war. Each technological development moved one or the other system into or out of favor. Cannons were more accurate. Rockets could be fired more quickly. Breech-loading cannons speeded up the firing. Rocket fins increased accuracy. Cannons had greater range. Rockets had greater range. And so on. Invention abounded. Invented by Joanes de Fontana of Italy (1420), a surface-running rocket torpedo was supposed to set enemy ships on fire.



Kazimierz Siemienowicz, c. 1600 to c. 1651

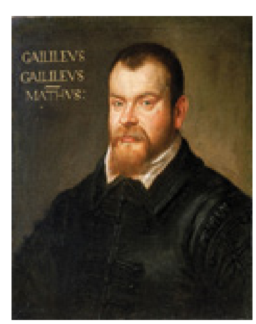
Kazimierz Siemienowicz, a Polish-Lithuanian commander in the Polish Royal Artillery, was an expert in the fields of artillery and rocketry. He wrote a manuscript on rocketry that was partially published before his death. In *Artis Magnae Artilleriae pars prima*, he published a design for multistage rockets that was to become a fundamental rocket technology for rockets heading for outer space. Siemienowicz also proposed batteries for military rocket launching and delta-wing stabilizers to replace the guiding rods currently in use with military rockets. It was rumored that Siemienowicz was killed by members of guilds that were opposed to him publishing their secrets, and they hid or destroyed the remaining parts of his manuscript.



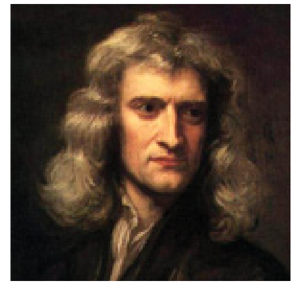
The Birth of Rocket Science

Galileo Galilei, 1564 to 1642

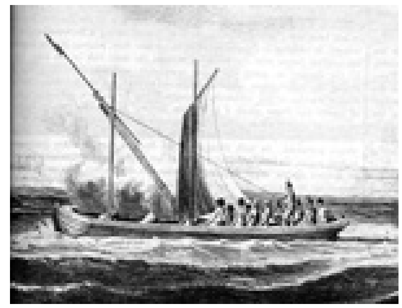
In addition to his many other accomplishments, this Italian astronomer and mathematician rekindled the spirit of scientific experimentation and challenged old beliefs relating to mass and gravity. He proved that an object in motion does not need the continuous application of force to keep moving. He called this property of matter, which causes it to resist changes in velocity, "inertia." Inertia is one of the fundamental properties that Isaac Newton would later incorporate into his laws of motion.



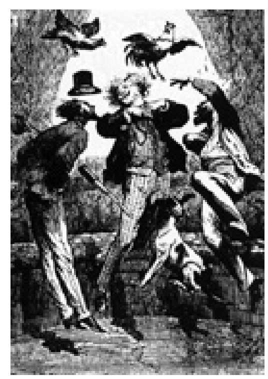
Newton's Laws of Motion, 1642 to 1727
English scientist Sir Isaac Newton condensed all rocket science into three elegant scientific laws. Published in *Philosophiae Naturalis Principia Mathematica* his laws, previously understood intuitively by early rocketeers, provided the foundation for all modern rocket science. (The "Rocket Principles" chapter focuses on these laws and the "Practical Rocketry" chapter demonstrates the applications of these laws.)



Colonel William Congreve, 1772 to 1828
Following stunning rocket barrages against the British by the forces of Tippoo Sultaun of India, William Congreve took charge of British military rocket companies. Some of his designs had operational ranges of 6,000 yards. He created both case-shot rockets that sprayed the enemy with carbine balls and incendiary rockets for burning ships and buildings. He invented launching rockets from ships. The phrase "by the rocket's red glare," coined by Francis Scott Key during the War of 1812, referred to British-launched Congreve rockets.

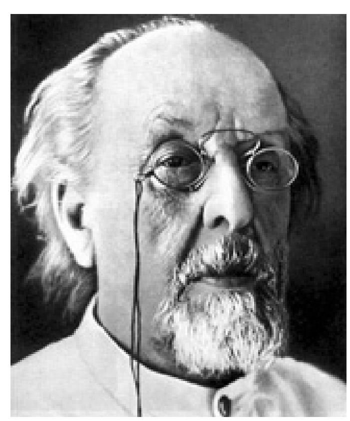


Jules Verne, 1828 to 1905
The dream of traveling through space was brought to life by French science fiction writer Jules Verne. In his *De la Terre á la Lune*, Verne used a giant cannon to fire a manned projectile at the Moon. Although not a rocket, the projectile had some interesting parallels with the future Apollo Moon program. It was called the Columbiad and contained a crew of three. It was fired at the Moon from Florida. The *Apollo 11* capsule was named *Columbia*, contained a crew of three, and was launched from Florida. Verne correctly described how the crew would feel "weightless" on their voyage. Of course, the crew would not have survived the initial acceleration of the cannon firing. Nevertheless, Verne, an early space exploration visionary, fired the imaginations of many would-be rocketeers and future astronauts.



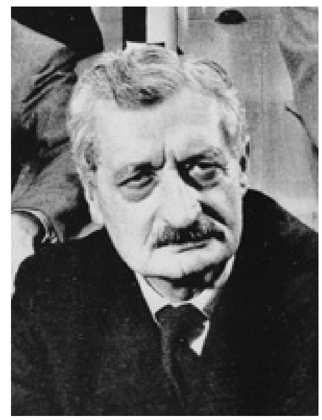
Modern Rocket Pioneers

Konstantin E. Tsiolkovski, 1857 to 1935
Konstantin Tsiolkovski was a teacher, theorist, and astronautics pioneer. Son of a Polish forester who emigrated to Russia, he wrote and taught extensively about human space travel and is considered the father of cosmonautics and human spaceflight. Tsiolkovski advocated liquid propellant rocket engines, orbital space stations, solar energy, and colonization of the Solar System. His most famous work, "Research into Interplanetary Space by Means of Rocket Power," was published in 1903, the same year the Wright brothers achieved powered and controlled airplane flight. His rocket equation, based on Newton's second law of motion, relates rocket engine exhaust velocity to the change in velocity of the vehicle itself.



Robert H. Goddard, 1882 to 1945
American college professor and scientist Robert Goddard built and flew the world's first liquid propellant rocket on March 16, 1926. Its flight, though unimpressive (it climbed only 12.5 meters), was the forerunner of the Saturn V Moon rocket 43 years later. At the request of local townsfolk, Goddard moved his experiments from Auburn, Massachusetts, to the deserts around Roswell, New Mexico. There he continued his experiments and developed a gyroscope system to control his rockets in flight, instrumentation payload compartments, and parachute recovery systems. He is often referred to as the "father of modern rocketry."

Hermann Oberth, 1894 to 1989
Hermann Oberth, a Romanian by birth and a naturalized German citizen, became fascinated by the works of Jules Verne and devoted his life to promoting space travel. His dissertation for the University of Heidelberg, rejected for being too speculative, became the basis for his book *Die Rakete zu den Planetanraumen* (By Rocket to Space). The book explained the mathematics of spaceflight and proposed practical rocket designs and space stations. This and other books inspired a generation of rocketeers. Rocket societies sprang up around the world, including the German Verein fur Raumschiffart (Society for Space Travel) that led to the development of the V2 rocket.

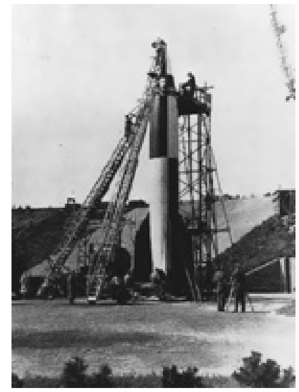


Rocket Experimenters, Early Twentieth Century
In the 1920s and 1930s, leading up to World War II, amateur rocketeers and scientists worldwide attempted to use rockets on airplanes, racing cars, boats, bicycles with wings, throw lines for rescuing sailors from sinking ships, mail delivery vehicles for off-shore islands, and anything else they could dream up. Though there were many failures, experience taught the experimenters how to make their rockets more powerful and more reliable.

World War II

Flying Bombs
The necessities of war led to massive technological improvements in aeronautics and rocketry. Almost overnight, rockets graduated from novelties and dream flying machines to sophisticated weapons of destruction. Rockets propelled nearly unstoppable German fighter planes and Japanese Kamikaze pilots with bombs into ships. War would never be the same again.

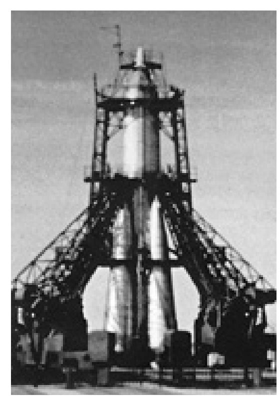
Vergeltungswaffe 2 - V2
In the late 1930s, the German Verein fur Raumschiffart Society for Space Travel evolved into the team that built and flew the most advanced rocket for the time, the V2. On the shores of the Baltic Sea, the team, under the directorship of Wernher von Braun, created a rocket powered by alcohol and liquid oxygen. With a range of 200 miles and a maximum altitude of 55 miles, the V2 could deliver a 1-ton explosive warhead to the heart of London without warning. Thousands of V2s were built, but they entered the war too late to affect the outcome.



The Space Age Begins

Bumper Project
At the conclusion of the war in Europe, 300 trainloads of V2 rockets and parts were captured and shipped to the United States along with the majority of the principal designers, who decided beforehand to surrender to American troops. The V2 became the basis of the intercontinental ballistic missile development program and led directly to the manned space program. Employing one of the captured V2 rockets with a WAC Corporal rocket (named for the Women's Army Corps) at its top, the initial launch of a "Bumper-WAC" took place on May 13, 1948. During six flights, the largest two-stage rocket launched to date in the United States eventually reached an altitude of almost 400 kilometers (250 miles).

The World's First Artificial Satellite
At the conclusion of World War II, the United States and the Soviet Union engaged in a race for space. The Soviet Union won the first round by launching its *Sputnik I* satellite on October 4, 1957. The satellite had a spherical design with four antenna. It weighed 83.6 kilograms (184.3 pounds). Two months later, the 508.3-kilogram (1,118.26-pound) *Sputnik II* reached space with a living passenger. Laika, a small dog, orbited Earth for a few hours. Although she died in space, she led the way for all humans that followed.



Explorer 1
The United States entered the satellite-launching business on January 31, 1958 with the successful launch of *Explorer 1*. The satellite was launched atop the Juno 1, a modified Jupiter-C booster. Though much smaller than the *Sputniks*, only 13.93 kilograms (30.66 pounds)—*Explorer 1*'s Geiger counter made the first important discovery about the space environment. *Explorer 1* detected around Earth what would later be called the Van Allen Radiation Belts.

X-15

Between 1959 and 1968, the X-15 experimental aircraft flew to the edge of space. In 199 flights, the air-launched rocket plane broke many flight records, including speed (7,274 kph or 4,520 mph) and altitude records (108 kilometers or 67 miles). Test flights established important parameters for attitude control in space and reentry angles. Neil Armstrong, the first American to step on the Moon, was one of twelve X-15 pilots.

Yuri Gagarin Goes Into Orbit

On April 12, 1961, space became the domain of humans with the launch of cosmonaut Yuri Gagarin. His spaceflight lasted 1 hour and 48 minutes. During that time, Gagarin orbited Earth one time inside his *Vostok 1* space capsule, reaching a maximum altitude of 315 kilometers (196 miles). Upon reentry, Gagarin ejected himself from the capsule at an altitude of 6,100 meters (20,000 feet) and parachuted safely to the ground.

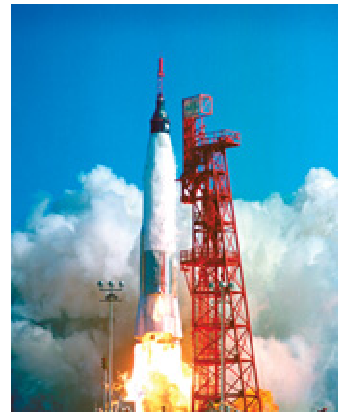
Freedom 7

On May 5, 1961, American astronaut Alan Shepherd, Jr., lifted off from Cape Canaveral, Florida, inside his *Freedom 7* Mercury space capsule, which sat atop a Redstone rocket. The rocket did not have enough power to send the craft into orbit, and Shepherd made a suborbital flight reaching 187 kilometers (116 miles) before his capsule returned to Earth in an ocean splashdown 15 minutes 22 seconds later.

Moon Rocket

Just days after Alan Shepard's flight, President John F. Kennedy addressed a joint session of Congress and challenged America to send an American to the Moon and return him safely before the end of the decade. Although it was a shockingly bold announcement, some of the steps to accomplish this mission were already underway. NASA had begun work on components of a rocket capable of a round trip lunar flight. By the next year, the rocket was named the Saturn V. It would be 110.6 meters or 363 feet tall, dwarfing all previous rockets. The Saturn V would consist of three stages, a capsule with a small propulsion unit for the return trip, and a two-stage lunar lander.

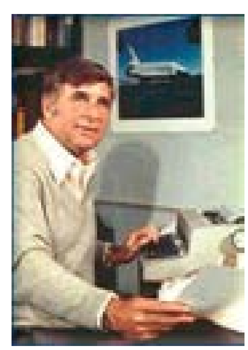
Glenn Orbits Earth
On February 20, 1962, riding on a more powerful missile, the Atlas, astronaut John H. Glenn, Jr., became the first American to go into orbit. Glenn's flight achieved parity with the Soviet program. Glenn orbited Earth three times for a total of 4 hours and 55 minutes in space. A sensor switch led to an early return. The sensor indicated that the Mercury capsule heat shield was loose, but the shield was later determined to be firmly in place during flight. The sensor was faulty. The last of the six Mercury flights took place on May 15, 1963, with astronaut Gordon Cooper remaining in space for nearly a day and a half.



Preparing for the Moon
Project Gemini followed the Mercury missions. The *Gemini* space capsule, riding on top of a Titan missile, contained two astronauts. During missions lasting up to 14 days, *Gemini* astronauts pioneered spacewalking, spacecraft rendezvous, and docking procedures. Important spacecraft systems, needed for the coming Moon flights, were evaluated. Ten *Gemini* missions were flown during 1965 and 1966. The Titan rocket, initially created as an intercontinental ballistic missile, went on to carry the *Viking* spacecraft to Mars and the *Voyager* spacecraft to the outer solar system in the 1970s.

Dr. Wernher von Braun
One of the leading figures in the development of pre-war Germany's rocket program and the development of the V2 missile, von Braun (1912-1977) became a leading proponent of America's space program. He entered the United States after the war and became a naturalized citizen. He worked on the development of intercontinental ballistic missiles and led the development team that launched *Explorer 1*. Dr. von Braun was the chief architect and engineer of the Saturn V Moon rocket. His popular writings and collaboration with Disney on a "Tomorrowland" TV series did much to inspire the next generation of rocket scientists and astronauts.

Gene Roddenberry
Gene Roddenberry (1921-1991), a distinguished World War II bomber pilot and commercial pilot, began his writing career penning stories about flying. He began writing for television and developed a concept for a "western" series set among the stars. For three years (1966–1968), the *Star Trek* series explored a wide range of scientific and social issues as humans traveled across the galaxy. The series became so popular that the first space shuttle orbiter test vehicle was named *Enterprise* after the star ship *Enterprise*. The original show spawned several companion series and a string of movies. Roddenberry, a visionary, inspired a generation of space travelers.



“One Small Step...”
At 10:56 p.m. EDT, July 20, 1969, American astronaut Neil Armstrong set foot on the Moon. It was the first time in history that humans had touched another world. He was followed to the surface by Edwin “Buzz” Aldrin, Jr. A third astronaut, Michael Collins, remained in lunar orbit in the *Apollo* capsule. The *Apollo 11* mission was the first of six Moon landings extending to the end of 1972. The astronauts’ spacecraft, the lunar module, consisted of a descent and an ascent stage. The descent stage had four legs and a powerful rocket engine to slow the craft for landing on the Moon. After surface explorations, the upper part of the lander lifted off, using its own rocket engine, and rendezvoused with the *Apollo* capsule for the return to Earth.

Skylab
Using a modified third stage of the Saturn V rocket, the United States finally launched its first space station, called *Skylab,* into Earth orbit in 1973. Rather than engines and fuel tanks, the interior of the third stage was fitted with living quarters and laboratories for three astronauts on extended stays in space. Solar panels provided electric power. Due to a problem during launch, one of the large panels was lost. Nevertheless, three crews of astronauts called *Skylab* home until 1974. The last crew remained in space 84 days.

Smaller Saturn
The Saturn V rocket was capable of launching 117,900 kilograms (260,000 pounds) into low Earth orbit and 40,800 kilograms (90,000 pounds) to the Moon. For some *Apollo* missions, though, a smaller Saturn was called for. The Saturn IB was 68 meters (224 feet) tall and required a scaffold platform nicknamed the “milk stool” to be placed on the pad designed for Saturn V rockets. This enabled the Saturn IB to match up with swing arms from the launch structure. The Saturn IB carried some of the early *Apollo* test missions, the three crews for *Skylab*, and the American crew for the 1975 historic *Apollo-Soyuz* mission, linking astronauts and cosmonauts in orbit.

Orbits and Probes

Deep Space
The Titan rockets (1959–2005), used for launching the *Gemini* missions, found wide use in launching unmanned payloads. Upgraded versions of Titans lofted heavy satellites into Earth orbit and propelled important spacecraft to other planets. The *Viking* missions to Mars and the *Voyager* missions to the outer planets and interstellar space are among its credits.

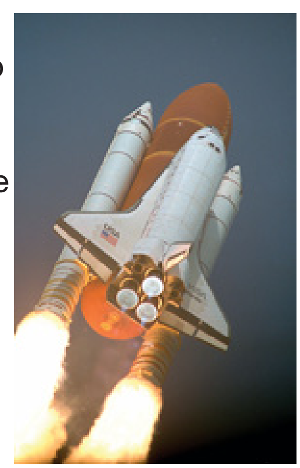
Sounding Rockets
Although rockets have generally gotten larger and more powerful, there are many reasons for flying smaller rockets. The Canadian–designed Black Brant sounding rocket has been flying since 1961 and has successfully completed over 800 flights carrying small payloads such as cameras, instruments, and microgravity experiments.
The Black Brant's reliability and low cost has made it a favorite of researchers. The biggest multistage Black Brants have payload capacities of about 100 kilograms (220 pounds) and can reach altitudes of up to 900 kilometers (560 miles).

Delta Family
With roots going back to the early 1960s, the American Delta rocket is one of the most versatile of the commercial and military payload launch rockets. Delta has many configurations, including multiple stages and heavy-lift strap-on boosters that increase payload capacity to high orbits. The Delta family has logged more than 325 launches, with a success rate exceeding 95 percent.

Atlas
Like the Delta rocket, the Atlas has deep roots. Now in its fifth major configuration, the Atlas was created as a missile in the 1950s. It was adapted to carry John Glenn and three other Mercury astronauts to space and has since been used for many commercial, scientific, and military satellite launches and interplanetary missions. The Atlas V rocket (shown) is the latest in the series.

Pegasus
Like the mythological creature, the Pegasus launch vehicle is winged. Lifted to about 12,000 meters it is then air-launched from under the wing of a carrier aircraft. This arrangement keeps launch costs low for small orbital payloads.

Thirty Years
The space shuttle was a new concept for carrying crews and payloads into low Earth orbit. It consisted of a central external tank surrounded by two solid rocket boosters and a winged orbiter. Only the orbiter, a spacecraft/airplane/space truck, actually reached orbit. It was designed to be reusable as were the solid rocket boosters. A new external tank was needed for each mission. Inside a cavernous payload bay were science laboratories, space probes, telescopes, or Earth-sensing systems. Many shuttle payloads consisted of components for the International Space Station. At the end of a shuttle mission, the orbiter reentered Earth's atmosphere and glided to an unpowered landing on a runway. The first space shuttle flight took place in 1981 and the last of its 135 missions concluded in 2011.



The Space Launch System and a New Era of Commercial Space Fight

The Space Launch System

A new and different kind of rocket is needed as NASA prepares to extend its mission beyond low-Earth orbit and out into the solar system. The Space Launch System (SLS) will be used for Earth orbital flights and long-range missions to places like asteroids or Mars and its moons. The SLS rocket will be the most powerful launch vehicle in history and it is being developed in two phases:

- Heritage hardware (components from previous rockets) is being used to build a heavy-lift rocket for development testing from 2017 to 2021. It will lift up to 70 metric tons of payload. This rocket will make two lunar flybys carrying an Orion spacecraft, the second with a crew.
- The advanced SLS rocket will lift up to 130 metric tons including equipment, cargo, scientific experiments, and/or the Orion spacecraft into deep space.

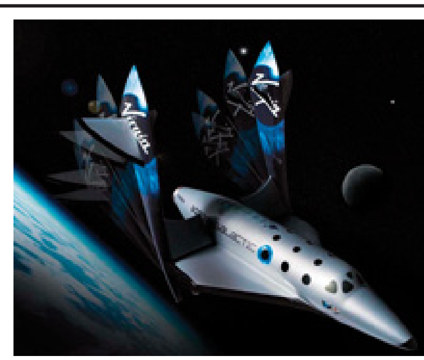
The Dragon and the Falcon

The Dragon is the first orbital spacecraft launched and recovered by a private company. As one of several private endeavors under NASA's Commercial Orbital Transportation Services program, Dragon was developed by Space Exploration Technologies, or SpaceX. It is an automomous spacecraft that will deliver to and return payloads and crew from the International Space Station. It will ride on Falcon rockets also built by SpaceX. The Falcon is a family of rockets to meet different mission requirements. The Falcon Heavy is expected to be able to lift 53,000 kilograms to low-Earth orbit, making it the most powerful U.S. rocket after NASA's SLS rockets.

Dream Chaser

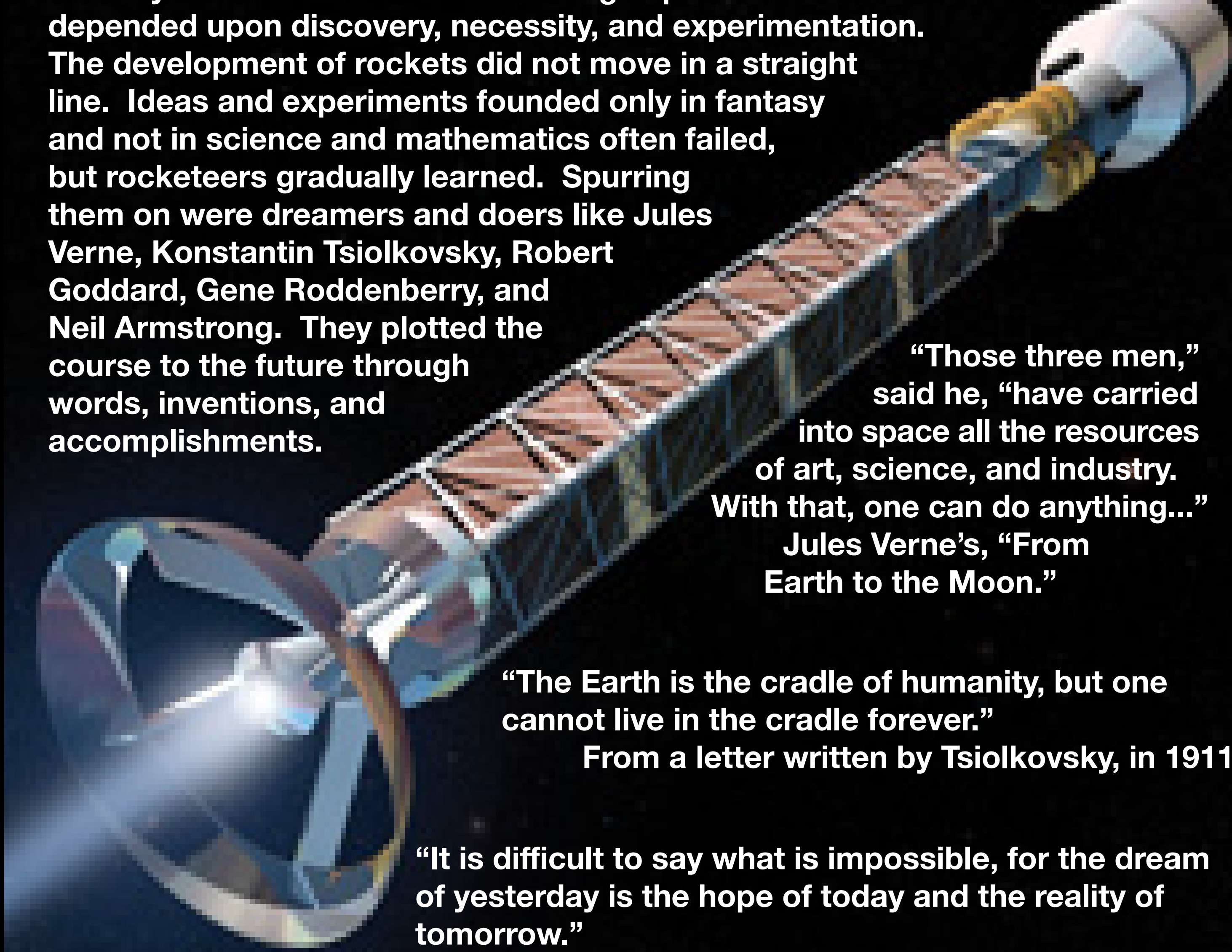
Sierra Nevada Corporation is working with NASA to develop a commercial spacecraft for transporting crew and cargo to and from the ISS. At first look, the spacecraft called the Dream Chaser, appears to be a small space shuttle but it is really a lifting body. It's shape is based on NASA's HL-20. Lifting bodies are aircraft with minimal or no wings that get their lift from the shape of their fuselage. Shaped something like a boat, the Dream Chaser will be launched at the top of a rocket (in place of a nose cone), carry up to seven people to the ISS, and will land back on Earth as an airplane. Dream Chaser is expected to be a safe, reliable, and cost effective way of transporting crew to low-Earth orbit.

Space Tourism



On October 4, 2004, SpaceShipOne, became the first private space vehicle to climb above an altitude of 100 kilometers (62 miles) twice in a fourteen-day period. Air launched by a mother ship, SpaceShipOne crossed the acknowledged boundary of Earth's atmosphere and space. Virgin Galactic is offering suborbital flights to tourists and to researchers. SpaceShipTwo flights will originate from Spaceport America, located in southern New Mexico. Soon, spaceflight will belong to all.

And Beyond?



Beginning more than 2,000 years ago, rockets evolved from toys into complex machines capable of amazing flights. Rockets are still the only means of travel to and through space. Their evolution depended upon discovery, necessity, and experimentation. The development of rockets did not move in a straight line. Ideas and experiments founded only in fantasy and not in science and mathematics often failed, but rocketeers gradually learned. Spurring them on were dreamers and doers like Jules Verne, Konstantin Tsiolkovsky, Robert Goddard, Gene Roddenberry, and Neil Armstrong. They plotted the course to the future through words, inventions, and accomplishments.

"Those three men," said he, "have carried into space all the resources of art, science, and industry. With that, one can do anything..."
Jules Verne's, "From Earth to the Moon."

"The Earth is the cradle of humanity, but one cannot live in the cradle forever."
From a letter written by Tsiolkovsky, in 1911.

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."
Goddard's high school graduation oration, "On Taking Things for Granted", June 1904.

"...to seek out new life, new civilizations. To boldly go where no man has gone before."
Star Trek television series opening theme.

" That's one step for (a) man; one giant leap for mankind."
Neil Armstrong on the Moon.

Who will be the dreamers and doers of tomorrow? Where will they take us?