Aerospace Micro-Lesson

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

The Voyager Missions

Forty years ago this month, on August 20, 1977, Voyager 2 was launched from Cape Canaveral in Florida. Its companion spacecraft, Voyager 1, launched two weeks later, on September 5. Voyager 1 flew past Jupiter on March 5, 1979 and Saturn on November 12, 1980. The slower-moving Voyager 2 reached Jupiter on July 9, 1979 and Saturn on August 25, 1981. Taking advantage of a very unusual alignment of the outer planets, Voyager 2 went on to Uranus, reaching it on January 24, 1986, and Neptune, which it flew past on August 25, 1989. (The dates given are those of the spacecraft's closest approaches to the planets.) The two spacecraft are now leaving the Solar System and starting to fly into interstellar space.

Next Generation Science Standards (NGSS):

- Discipline: Earth and Space Sciences.
- Crosscutting Concept: Scale, proportion, and quantity.
- Science & Engineering Practice: Obtaining, evaluating, and communicating information.

Grades K-2

NGSS: Earth's Place in the Universe: Use observations of the sun, moon, and stars to describe patterns that can be predicted.

In 1977, the United States launched two spacecraft to the outer planets of the Solar System. Their primary mission was to explore the planets Jupiter and Saturn. They discovered many new facts about the planets such as how complicated the rings of Saturn are and that Jupiter's moon Io has active volcanoes (which makes it very different from our own moon). Voyager 2 has also taken a look at Uranus and Neptune, and holds the record as the only spacecraft to have visited those planets. In 1998 Voyager 1 passed the Pioneer 10 to become the most distant human-made object in space.

The Voyagers were launched aboard Titan-Centaur rockets. Here is a photo of the Voyager 2 launch and the Voyager 1 launch. A funny thing about these explorers is that Voyager 2 actually launched first! It makes their names seem a bit confusing, doesn't it? Even though it launched later, Voyager 1 has managed to pick up some speed on its path through the solar system and head out toward deep space ahead of Voyager 2. Along the way Voyager 1 visited the asteroid belt, Saturn, and did a special study of Saturn's moon Titan. It has also taken what NASA calls a "family portrait" of our solar system's planets.

GRADES K-2 (CONTINUED)

Both Voyager 1 and Voyager 2 have accomplished many scientific observations and have a lot more to do as they journey onward.

Suggested Activity: Create your own family portrait of our solar system. Discuss the order the planets are generally in beginning with the sun and moving outward. You may wish to point out the inner planets and outer planets and their positions relative to the asteroid belt. You could also have students positions themselves as the various planets and have two students follow the paths of Voyager 1 and 2 through the solar system. To give you an idea of the relative positions, "The Planets Today" has an excellent interactive video showing the trajectories the Voyager spacecraft followed.

GRADES 3-5

NGSS: Waves and Their Applications in Technologies for Information Transfer: Generate and compare multiple solutions that use patterns to transfer information.

Forty years ago, in August and September 1977, the United States launched two Voyager spacecraft towards the outer Solar System. Their mission was to fly by the planets Jupiter and Saturn, taking pictures of the planets and measuring the environment around them. There are a few reasons for sending two spacecraft instead of just one.

To begin with, building a second copy of something is much cheaper than building the first one. Once you have figured out how to build something, you don't have to figure it out again; all you need to do is the actual building. While building a spacecraft is never cheap, designing one is also very expensive.

The second reason is that things break. Space is a very hostile environment and it is difficult to design things to work out there. If you have two spacecraft going somewhere and one of them breaks, the other one will still most likely make it there and do what it is supposed to do.

Finally, two sets of data are much more reliable than depending on just one. Science is built on repeatable observations. Having two sets of pictures or measurements gives scientists a much better idea of the object or conditions they are observing. Many times, the first spacecraft will discover something and then scientists can make adjustments so the second spacecraft gets a better look at the discovery.

GRADES 3-5 (CONTINUED)

Both Voyager spacecraft carry a golden phonograph record. It is a 12-inch disk of gold-plated copper that looks like a vinyl record (or a giant CD). On this disk are greetings from Earth to any life that might be encountered during their journeys. Dr. Carl Sagan helped select images and sounds to include on the record with the help of a committee. Along with greetings in fifty-five Earth languages, there are also pieces of music from different eras and cultures, and written messages from President Carter of the U.S.A. and U.N. Secretary General Waldheim. There are a cartridge and needle to play the record and directions on how to do so (in picture form).

The earlier spacecraft Pioneer 10 and 11 had small metal plaques on them with information about where and when they were launched, in case space explorers found them someday. Including the golden record was an upgrade and allowed the Voyagers to carry more information that could be seen and heard. You can visit these links to explore the contents of the record: Sounds of Earth, Music from Earth, Greetings from Earth, and Scenes from Earth.

Suggested Activity: If you were collecting information to place on board an exploratory spacecraft for other life forms to find, what would you include? Explain what images, sounds, or other types of information you would choose. Why did you pick those particular things to share? How would you store them on the spacecraft? What medium would you use (another record, a CD, an MP3 file, etc.)? Bear in mind that anybody who finds what you are sending will have no previous knowledge of anything about you, your language, or even your five senses.

GRADES 6-8

NGSS: Earth's Place in the Universe: Analyze and interpret data to determine scale properties of objects in the solar system.

To say that the Voyager missions revolutionized our understanding of the outer planets is an understatement. Before the Voyager spacecraft, Pioneer 10 and Pioneer 11 had flown past Jupiter and Saturn, measuring the environment and sending back photographs, but the instruments on the Voyager spacecraft were considerably more sophisticated. You can see an example of this by comparing a picture of Jupiter taken by Pioneer 10 with a similar picture taken by Voyager 1.

GRADES 6-8 (CONTINUED)

The missions to Jupiter also changed the view of Jupiter's moons from small dots of light to worlds in their own right. While the Pioneer missions sent back fuzzy photographs of the Galilean moons, the Voyager spacecraft showed details never seen before. Suddenly the four moons were worlds of ice and Io was the most volcanically active body in the Solar System.

Voyager 2's visits to Uranus and Neptune were even more revolutionary. No spacecraft had ever visited those planets before and none has been there since. The visits were not part of the original plan, although the people who planned the missions and designed the spacecraft certainly thought about it. There was no guarantee when the spacecraft was launched that it would survive the trip to Jupiter and Saturn. It was only as it approached Saturn that the people planning the mission decided to make it fly past Uranus and Neptune. The spacecraft discovered Uranus to be relatively featureless. Neptune was expected to be similar, but surprised scientists with its Great Dark Spot, similar to Jupiter's Great Red Spot but much smaller.

Besides increasing humanity's knowledge of the outer Solar System, the Voyager missions also gave us a new perspective on our own Earth. Shortly after launch, Voyager 1 turned its camera back towards the Earth and took the first picture of the complete Earth and Moon in one frame. Years later, it turned its cameras back again and recorded what has now known as the "Pale Blue Dot" image, showing the Earth as a small point in the vast void of space. This was a new mission; nobody had thought of it when the spacecraft was being designed or launched. Astronomers have known since the days of Ptolemy that the distance to the stars is virtually infinite relative to the size of the earth, but seeing it in a picture brings home the point.

While the Voyager spacecraft passed their last planets many years ago, they are still active and are sending data back to Earth. Voyager 1 has left the Solar System and is now in interstellar space; Voyager 2 is in the transition region, called the "heliosheath," and will soon follow. They are still measuring the medium around them and transmitting their measurements back to the Earth.

The limiting factor on the Voyager spacecraft is their ability to generate electricity. Because they are so far from the Sun, they cannot use solar panels. Instead, they are powered by three "radioisotope thermal generators," or RTGs. The RTGs contain small amounts of radioactive material whose decay generates heat, which is then converted to electricity. As the

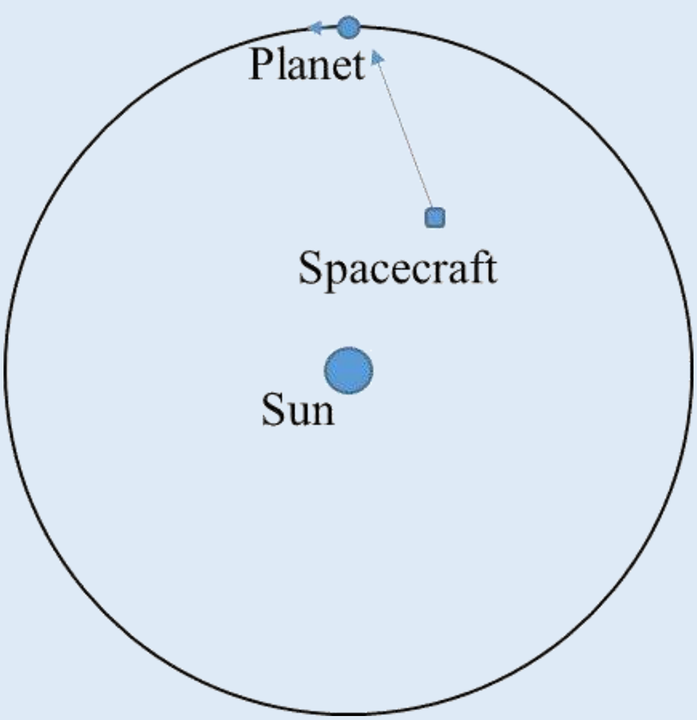
GRADES 6-8 (CONTINUED)

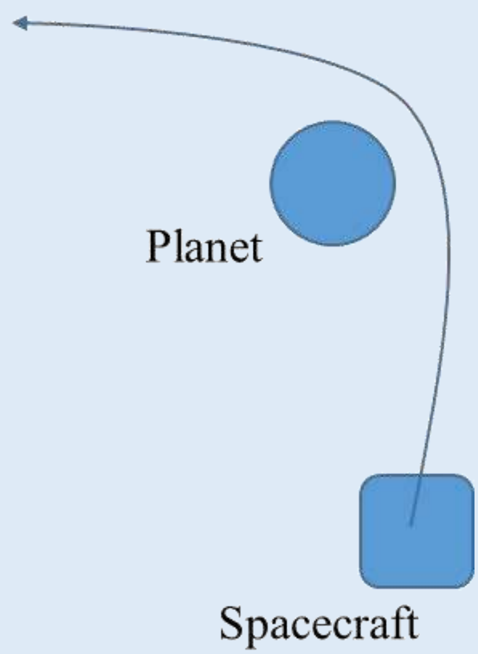
radioactive material decays, though, it is used up and the spacecraft has less and less electricity to power itself. The cameras and other instruments that were useful only for studying planets have been turned off already; as the levels of electricity decrease other instruments will be turned off. Scientists expect the entire spacecraft to fall silent around the year 2025. For a more details on this, you may wish to visit the Spacecraft Lifetime article from NASA.

GRADES 9-12

NGSS: Earth's Place in the Universe: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

The Voyager spacecraft were the third and fourth missions to use a "gravity assist" to move from one planet to another. (Mariner 10, launched in 1973 to Venus and then Mercury, was the first to use the technique.) With a gravity assist, a spacecraft uses a planet's gravity and forward motion in its orbit around the Sun to increase or decrease its own speed. At first blush, one would think that the laws of conservation of energy and momentum would prevent this from happening, but it does work. You can illustrate it using the pictures at the bottom of this page.





GRADES 9-12 (CONTINUED)

Begin by drawing the planet in its orbit around the Sun with the spacecraft approaching the planet from the sunward side. Something like the left-hand figure on the previous page will work. Then draw a zoomed-in diagram of the spacecraft flying past a "stationary" planet (like the figure on the right), passing "behind" the planet (to the right in the diagram) and finishing the encounter flying towards the left in the diagram. In this zoomed-in diagram, the spacecraft and planet obey the laws of conservation of momentum and of energy; as the spacecraft's velocity vector shifts from a "just right of twelve o'clock" direction to a "nine o'clock" direction, the planet's velocity vector shifts to the right and downward. Given the relative masses of the spacecraft and the planet, the change in the planet's velocity is not noticeable. (You may want to compare the mass of a Voyager spacecraft, which is about 700 Kg, with the mass of Jupiter, which is about 1.9×10^{27} Kg.)

Now add the planet's velocity vector from the left-hand diagram to the velocity vectors in the right-hand diagram. The spacecraft's velocity vector before it reaches the planet will shift from "after twelve o'clock" to its pre-encounter "eleven o'clock" direction as seen in the left-hand diagram. The planet's velocity will change from being essentially zero to having its orbital velocity around the Sun. And the spacecraft's velocity vector after it leaves the planet will have the planet's speed added onto it. Thus the spacecraft will have picked up a good bit of speed from the planet, slowing down the planet by an imperceptible amount in the process.

Two things are necessary for a gravity assist to be successful. The first is a very good navigation system. A spacecraft trajectory that comes closer to the planet will be deflected more; a trajectory the does not come as close to the planet will be deflected less. The difference in the deflection for a given change in point of closest approach depends on the mass of the planet and the speed of the spacecraft. In addition, a spacecraft trajectory that comes in "below" or "above" the plane of the planet's orbit will be deflected "up" or "down" relative to that plane; the change in the spacecraft's velocity vector is centered on the center of the planet. An error in direction coming out of the gravity assist of a thousandth of a degree will result in the spacecraft being 17 miles off course after it has flown another million miles (you can calculate this by converting the angle to radians and multiplying by the distance flown). Since Jupiter and Saturn were several hundreds of millions of miles apart when the Voyager spacecraft visited them, one can appreciate the need for good navigation. The actual gravity assists did not need quite such exacting precision as the spacecraft performed midcourse corrections, but still one needs good navigation for the technique to work.

GRADES 9-12 (CONTINUED)

The second requirement for a successful gravity assist is that the spacecraft's next target be in the right place at all. Between Jupiter's orbital period of 12 years, Saturn's orbital period of 29 years, Uranus' period of 84 years, and Neptune's period of 165 years, the alignment of the outer planets that made the Voyager missions possible happens only during a single three-year "window" every 175 years. The "Grand Tour" that the Voyager spacecraft carried out would not be possible now and will not be possible again until about the year 2150.

"The Planets Today" has an excellent interactive video showing the trajectories of the Voyager spacecraft and their gravity assists. It gives some idea—though not a complete one—of just how difficult the "game of cosmic billiards" was.

The movie "The Martian" refers to lots of real science. In particular, the maneuver that Rich Purnell suggests has the crew of the Hermes get a gravity assist to their velocity in a similar manner.

Sixty Years Ago in the Space Race:

August 21: The Soviets successfully launched an R-7 rocket on their fourth try. It went 840 miles high and 4,000 miles downrange.