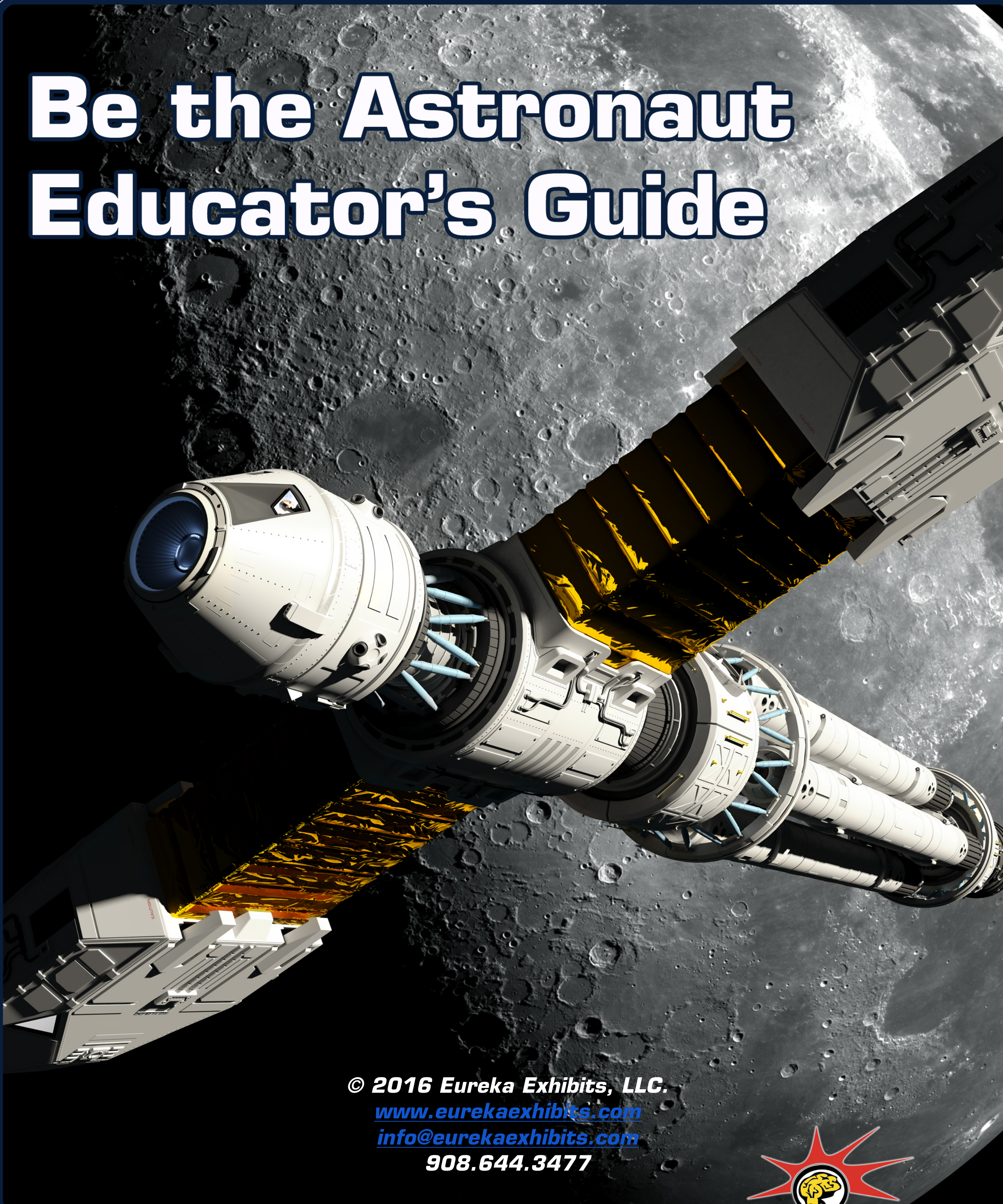
Be the Astronaut Educator's Guide



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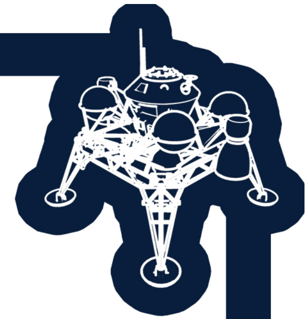

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How to use this Guide:

This is exhibit is not like any exhibit you have visited before and, for some teachers and parents, it may not be immediately apparent just *where* some of the educational lessons and information reside – because they exist in the exhibit's *virtual* space rather than its physical space… but ask one of your kids, they'll help explain it to you.

Just as with *any* video game, like it or not, the players are *learning* and without a natural understanding of this medium is can be difficult for some to realize this. With *Be the Astronaut* we take great care to examine just what it is that players are learning and to try and make the desired educational materials such an integral part of the ability to successfully play the game that not only is the education achieved – it is achieved in a manner that is not always apparent to the visitor. If the educational aspects were too apparent they would be rejected – no one likes being forced to learn, no one likes educational messages that are clumsily attached as a prerequisite to the real fun. The education in *Be the Astronaut* is baked into the core of the experience and attempts to give visitors and instinctual understanding and relationship with its subject matter – the principles of physics and motion that govern *all* of spaceflight.

At the back of this guide are a selection of Lesson Plans and Activities created by NASA and selected for their relationship to the content and experiences presented in the exhibit.

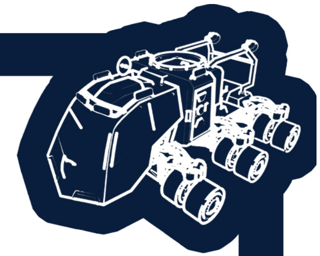


Exhibit Summary

Be the Astronaut is a world-class exhibit experience that teaches STEM-based content via a fusion of state-of-the art video game technology and traditional exhibitry.

The focus of the exhibit is on the concepts common to all space flight and so uses the narrative of a possible future space mission, as opposed to any particular historic mission, as the framework to communicate these ideas.

The medium of the video game, as exemplified here by the system of games and simulations that make up the core of the *Be the Astronaut* exhibit, speaks powerfully to children and adults. The reason video games are so compelling is precisely because they are a fun way to learn. In most video games, the learning is trivial – How many coins do you need for an extra life? How far does this laser rifle shoot? – But in our games the learning is real and integral to gameplay. The best games balance the possibility of failing with the reward of achievement and the satisfaction of success.

In the exhibit, visitors learn about the challenges and excitement of spaceflight – then apply that knowledge as they fly the spaceships, pilot the landers, and drive the rovers, in a thrilling narrative adventure to Earth orbit, the Moon, Mars, Ceres, and Jupiter.

Each course is divided into separate missions. For example, the Moon Course is divided into three missions: fly to the Moon, land on the Moon, and drive on the Moon in a rover.

Each mission – in the Moon Course or any other course – is one cycle through three visually distinct station-types: NAV, SCI, and then FLY. This is covered in the main document below.

A magnetic 'Astronaut ID' card tracks visitors' progress, allowing them to proceed through the exhibit's adventure at their own pace – and even over multiple visits.

EUREKA EXHIBITS holds scientific integrity at the highest level. All spacecraft in *Be the Astronaut* were designed with assistance and oversight from advisors at NASA Langley Research Facility. Wherever possible, the exhibit uses 1:1 simulations derived from actual NASA data, from sources such as LRO LOLA and MRO MOLA and HiRISE.

Advisory Panel

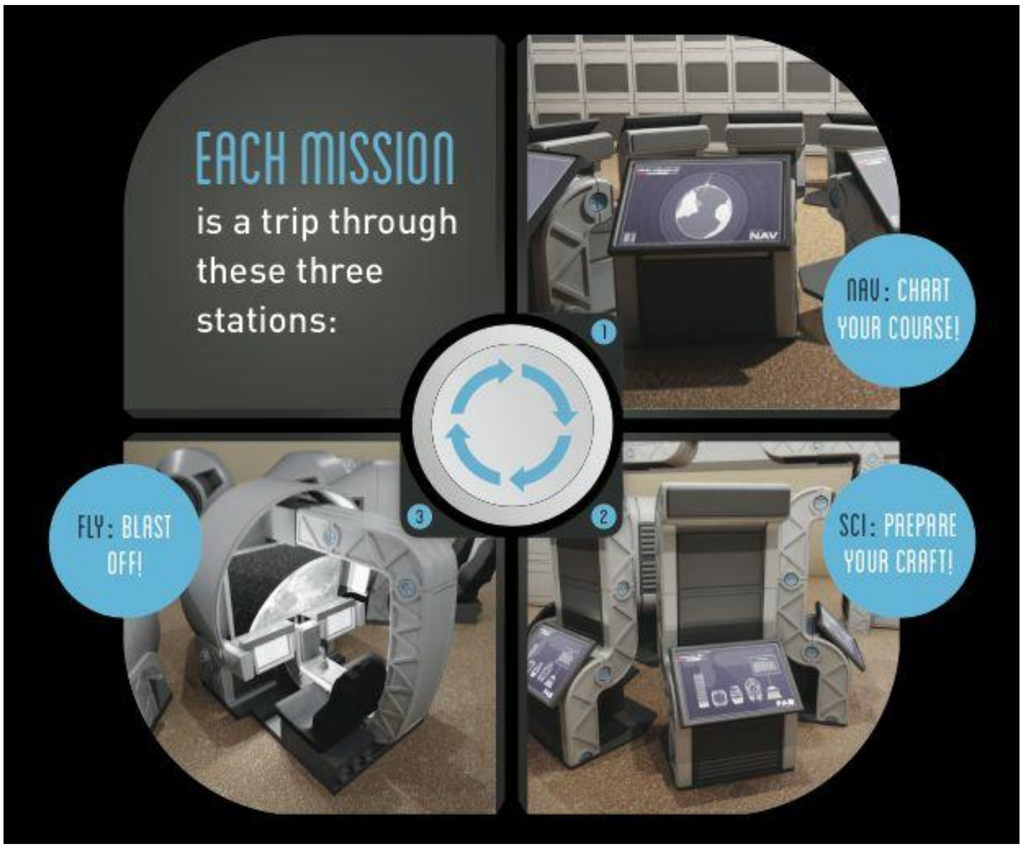
To maintain the educational integrity of the exhibition, *Be the Astronaut* has been developed with the ongoing collaboration of our distinguished advisory panel. We sought advisors within related fields who care about humanity's future in space and who would like to help inspire visitors. Our advisory panel includes:

- Dr. Steven P. Sandford, *Director of the Space Technology & Exploration Group, NASA Langley Research Center*
- Daniel D. Mazanek, *Senior Space Systems Engineer, NASA Langley Research Center*
- Alicia Dwyer Cianciolo, *Aerospace Engineer, NASA Langley Research Center. Member of the Entry, Descent and Landing Team - Mars Curiosity Rover*
- Dr. Charles Behre, *Chief Engineer & Lead Scientist, Excelis-ITT, GPS Navigation & Satellite Systems*
- David S. Portree, *Science Journalist, WIRED Magazine*
- Hardy Spire, *Senior Producer CNN*
- Dr. John Hutchinson, *Director of the Structure & Motion Lab, University of London*
- Kathleen Kelly, *Managing Director, Digital Delivery, Ogilvy & Mather*
- Josh Kessler, *Project Manager, COSI-Columbus*
- Dr. Edwin Z. Crues, *Simulation and Graphics branch (ER7) of the Software, Robotics and Simulation Division (ER), NASA Johnson Space Center Engineering Directorate.*

This document includes storyboards, screen captures, and concept art that guided the development process. It highlights the educational concepts and gameplay elements of *Be the Astronaut*.

Exhibit Structure

To create flow across the museum floor, each mission is one trip through the exhibit's three station-types: NAV, then SCI, then FLY. A magnetic card tracks each visitor's progress.



Each of these three station-types is expanded upon below.

NAV Stations

Each mission starts at a NAV station.

NAV is short for Celestial Navigation. This touchscreen station teaches core concepts of astronomy and physics. It's also a 2D dry run of the 3D FLY station content. The visual style is reminiscent of a vector-graphic test simulation and is meant to suggest a planning stage.

Each NAV station is constructed from (1) J-form module and (1) touch-screen monitor, and is clearly marked 'NAV.' NAV and SCI stations are entirely different heights.

SCI Stations

The second stop of every mission is at a SCI station.

SCI is short for Science and Technology. This touchscreen station teaches about the machines that make space travel possible, about the science of astronomy, and about the methods that keep people healthy in the harsh conditions of space. The visual style is that of an infographic rendered in multi-colored wire-frame.

The game is designed to introduce concepts and elements that inform the experience visitors are about to have in the FLY station. For example, when visitors launch into orbit in a rocket, powering on the fuel or oxidizer pumps is invested with more meaning because they have already been exposed to the basic components of a rocket engine.

Each of the curved metallic SCI stations is 6' tall, constructed from (3) J-form modules and (1) touch-screen monitor, and clearly marked 'SCI.'

FLY Stations

The FLY station is the exciting capstone to each mission.

This simulator module is where you fly the spacecraft on the flight path you just designed. Visual, sound and lighting effects immerse the user in piloting their craft.

Each FLY station is like a self-contained cockpit, with (2) command seats, (2) secondary touch-screens, (1) joystick, and (1) main view-screen so large it encompasses your entire field of vision.


FLY

Course & Mission Summary

In *Be the Astronaut*, visitors select any of the courses below, and then complete each of its missions.

EARTH COURSE

- **Mission 1:** Launch in a rocket from the Earth's surface into orbit.

MOON COURSE

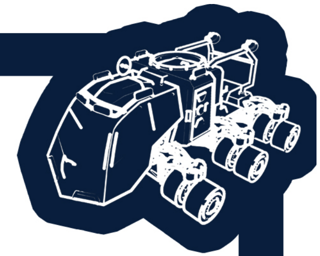
- **Mission 1:** Fly an interplanetary spaceship across the translunar gulf and perform an insertion burn into orbit around the Moon.
- **Mission 2:** Pilot a lander safely to the Moon's surface.
- **Mission 3:** Drive a rover on the Moon, into the depths of the Whipple Crater.

MARS COURSE

- **Mission 1:** Fly an interplanetary spaceship towards Mars and rendezvous with a much-needed refueling tank.
- **Mission 2:** Pilot an aeroshell lander through a fiery descent and land in a canyon on Mars.
- **Mission 3:** Drive a rover on Mars, through the Labyrinth of Night.

JUPITER COURSE

- **Mission 1:** Fly an interplanetary spaceship towards Ceres (in the Asteroid Belt) and use the robotic arm to grapple and berth a new fuel tank.
- **Mission 2:** Perform an insertion burn into orbit around Ceres and pilot a lander to its surface.
- **Mission 3:** Drive a rover on Ceres.
- **Mission 4:** Fly from Ceres to Jupiter.



The Laws that Govern Spaceflight

The concepts of planetary motion were developed by Johannes Kepler over 300 years ago in order to understand the positions and motions of objects in our solar system. Isaac Newton later explained why Kepler's laws worked, by showing they depend on gravity. In the 20th Century, Albert Einstein posed an explanation of how gravitation works in his general theory of relativity.

In any solar system, the motions of objects, be they planets, comets, spaceships, are orbits gravitationally tied to a star. These same principles govern the movements of any object in space and they will govern your exhibit experience too. If you want to fly your spacecraft well, you will need to put these laws into action!

Newton's Laws:

Newton's First Law: An object at rest remains at rest, an object in motion remains in motion, unless acted upon by another force. A spaceship in space needs to apply no force to keep moving at the same speed. It will keep moving forever with no propulsion because there is no friction in the vacuum of space.

The First Law therefore describes how any object moves when no force acts on it.

Newton's Second Law: The more mass an object has, the more force you need to apply to make it accelerate or change direction. You can add a great amount of force quickly or a small amount of force over a long period of time but the total amount of force to reach a certain speed is the same.

The Second Law therefore describes how force and acceleration are related.

Newton's Third Law: Every action has an equal and opposite reaction. When a spaceship fires its rocket the exhaust gas shoots out the back, pushing against the ship, the exhaust and the spaceship move in opposite directions.

The Third Law therefore means that exerting any force results in an equal force in the opposing direction.

Kepler's Laws:

Kepler's First Law: A planet's orbit around the sun is not a perfect circle: it's an ellipse – a stretched circle – with the center of the sun at one focus.

Kepler's First Law therefore describes the shape of an orbit.

Kepler's Second Law: The speed at which a planet orbits depends on its distance from the sun. The closer a planet is to the sun, the more the sun's gravity pulls on it, and the faster it moves. The further away from the sun you get, the weaker the Sun's gravity becomes and the slower planets move.

Kepler's Second law therefore describes how an object's speed can vary along its orbit.

Kepler's Third Law: The further a planet is from the Sun the slower it will travel and the larger its orbital path will be. The larger a planet's orbit, the longer it will take to follow along it.

Kepler's Third Law therefore compares how objects in orbits of different size move.

Sidebar
Johannes Kepler was a German astronomer and mathematician who lived from 1571 to 1630. He is best known for developing the laws of planetary motion describing the movement of the planets around the sun. His work provided some of the foundation for the work of:

Sir Isaac Newton (1642-1726) who was an English physicist and mathematician, one of the most influential scientists of all time and who created the laws of motion and universal gravitation which proved Kepler's earlier work to be true and that enable us to accurately describe the path of any object moving through space.

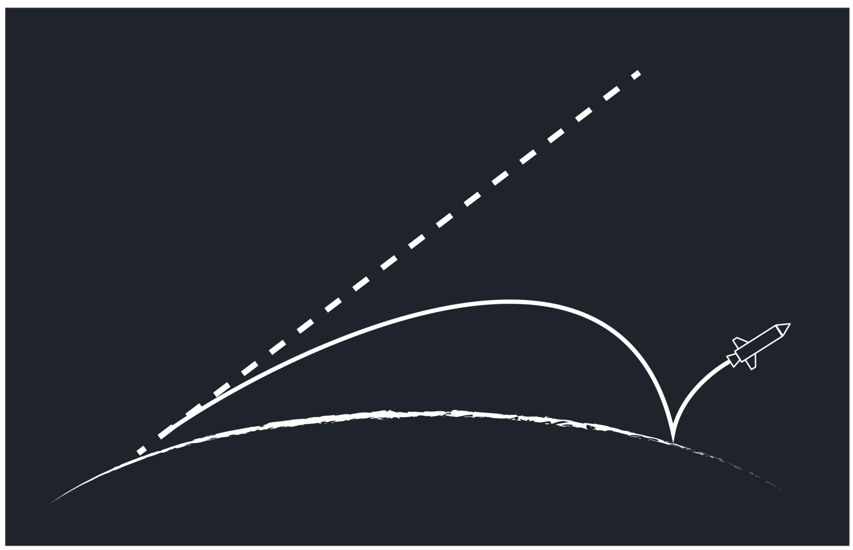
Albert Einstein (1879-1955) was a German-American physicist who, among other things, developed his principle of general relativity that took Newton's laws and helped to make them more accurate so they could perfectly predict the movement of objects.

Gravity

What is Gravity?

The force holding us to Earth is called gravity. It's why apples fall from trees – and why we don't all float up into space. To overcome it, you have to apply force

If it were not for the force of gravity, the rocket would follow a straight path. This is called the Law of Inertia (Newton's First Law), which says that a body in motion will remain in motion in a straight line unless acted upon by another force.



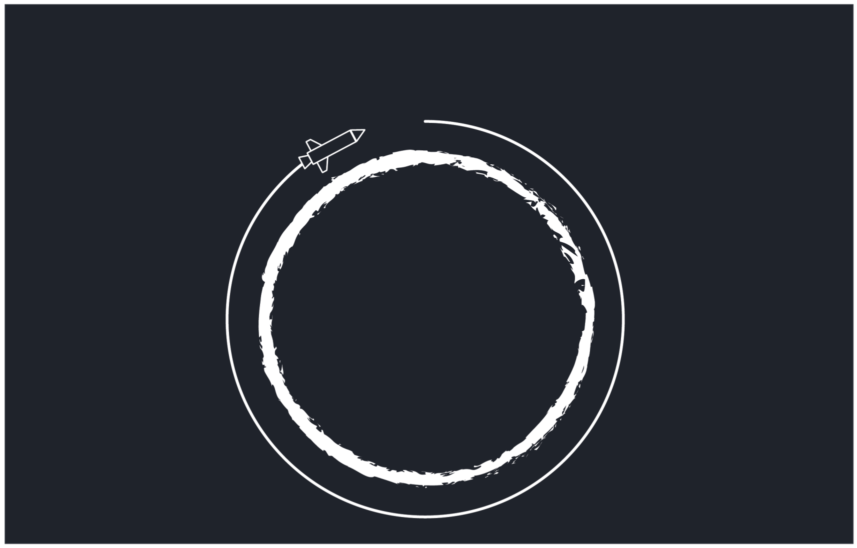
Gravity bends the rocket's path into a curve. Newton's Law of Gravitation states that bodies in space are attracted to each other with a force that depends on their mass and the distance between them. A more massive object exerts more gravity, but a less massive object that was closer would exert more force.

These two laws, Inertia and Gravitation, control the path of any object, in space. The rocket tries to travel in a straight line in response to the Law of Inertia but the force of gravity pulls on it and bends its path into a curve.

Any object launched from the Earth, be it a ball thrown in the air or a rocket launched into the air, will curve back and be pulled down to the surface – unless you launch it with enough force.

The faster an object moves, the more horizontal distance it covers as it is pulled down by gravity. An orbiting spaceship is moving so fast that the curve of its path matches the curve of the Earth.

The spaceship continues to fall but constantly misses the Earth!



When exploring in the NAV Stations - watch how the force of gravity pulls at your rocket and bends its path into a curve.

The two principles discussed here make orbital motion possible. The law of inertia keeps things moving while the law of gravitation bends an objects path into a curve that goes around the source of gravity (the sun, a planet, moon, asteroid, etc.). These same laws keep the moon circling the earth, and the earth spinning around the sun.

These principles are at work in all of the exhibit stations and understanding them will help you to better control your virtual spacecraft!

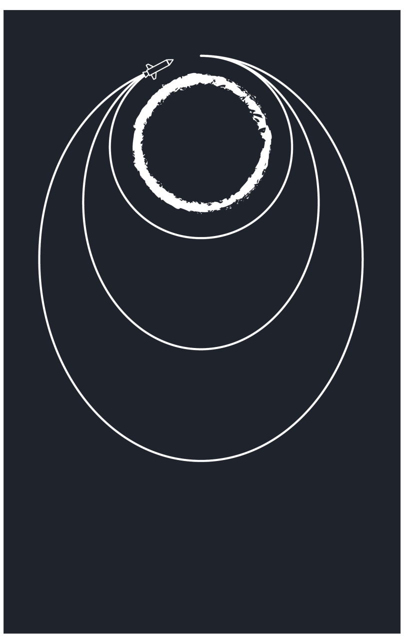
Orbits

What is an orbit and how do you achieve it?
We've all heard of satellites or spaceships being 'in orbit' around the Earth.

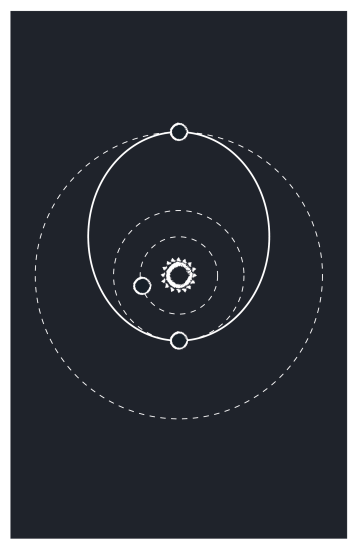
An orbit is the curved path of an object around another celestial body, like a star or planet. All planets – like Earth, Mars, and Jupiter – orbit the sun. Moons and other satellites orbit the planets.

Remember that it is not your vertical speed that gets a rocket to orbit; it's the horizontal (or tangential)! Rockets go up to get out of the thickest part of Earth's atmosphere (and to avoid running into buildings or mountains) but if a rocket simply went straight up and shut off its engines, it would fall right back down. It is horizontal speed – and lots of it – that gets a spaceship to orbit.

Changing orbits to travel from one world to another:



You can change the shape of an orbit by increasing your speed, moving you farther away from the Earth.



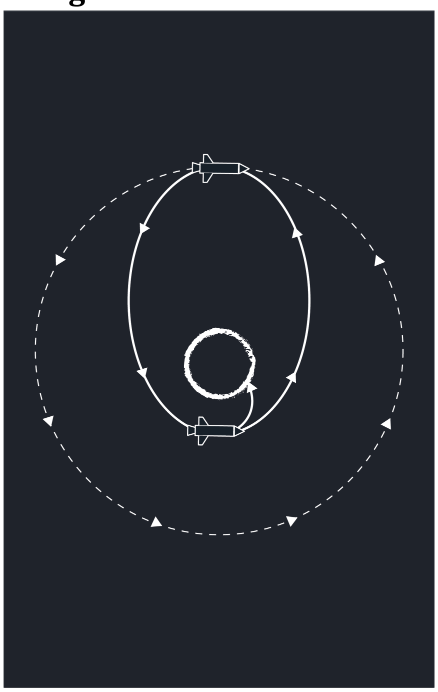
You slow as you climb and will eventually fall back towards the earth. As you fall back your speed increases.

You will shoot around the Earth and climb back to that high point. Your orbit is now an ellipse.

Elliptical orbits can be used to travel from the Earth to the Moon – and beyond.

A flight path to the Moon is an ellipse that stretches from the orbit of Earth all the way to the Moon. Traveling to other worlds like Mars is much the same – only it is an elliptical orbit around the sun whose high point intersects the orbit of Mars and whose low point intersects the orbit of Earth.

Using orbits to land:



To begin your landing from a circular parking orbit you need to alter the shape of your orbit into an ellipse that will stretch from the highest point at the parking orbit to the lowest point where you will begin descent.

If you did nothing, the spaceship would continue to follow its elliptical orbit, back up to the high point and around and down again to the low point. If, however, you fire your rockets at that low point and bleed off enough speed you will be grabbed by gravity and pulled down towards the surface.

Sidebar

You are more familiar with orbits than you realize. When you throw a ball, you are actually putting it into *orbit*! It is not an orbital flight that lasts very long. The ball tries to follow a straight line due to inertia but because you are not able to throw a ball with enough force to overcome gravity the ball's orbital path curves down to intersect the ground.

The laws that control the path of the ball are the same ones that control the flight of a spacecraft or the moons and planets in their orbits.

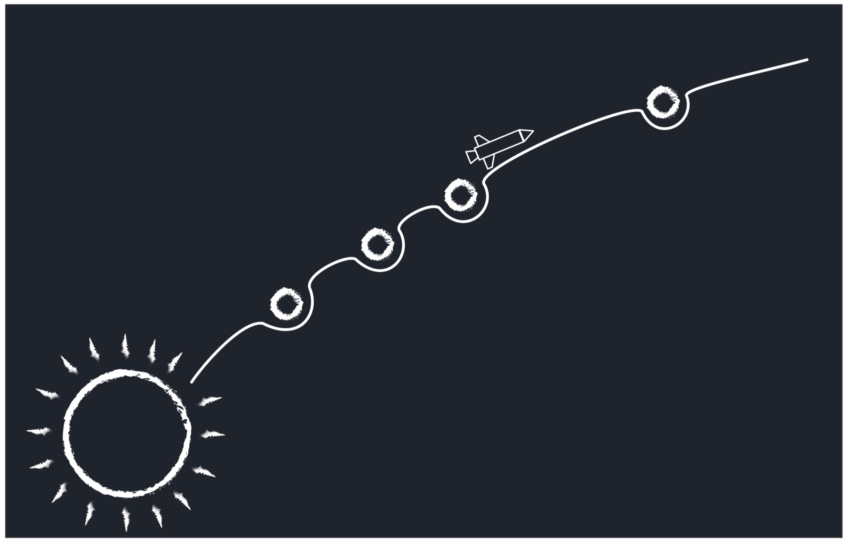
Spaceflight is All “Uphill”

All objects in the universe are attracted to each other by a force that depends on their mass and the distance between them: the bigger – and closer – an object is, the more pull it exerts on you. This is Newton’s Law of Gravitation.

In flying from the Earth to the Moon, the gravity of the Earth is like a hill the spaceship must climb. Just as you lose speed going uphill on a bike or in a car, a spaceship loses speed as it climbs away because the Earth is pulling back on it.

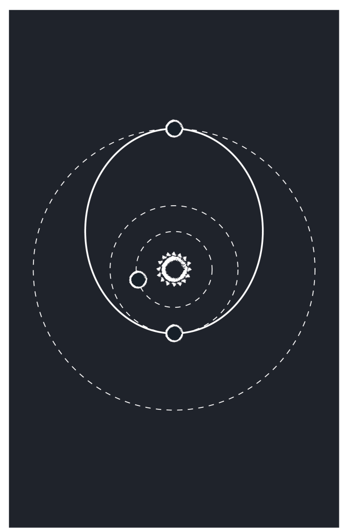
The top of the ‘hill’ between the Earth and Moon represents the point at which the two bodies are equal. If the spaceship has enough speed to coast ‘over the hill’ it will head on to the Moon.

Approaching the Moon, its gravity becomes stronger and begins to control the flight of the ship. Your flight path goes ‘uphill’ away from Earth, and then goes ‘downhill’ toward the Moon. The Moon’s gravity is like a smaller hill, but one you’re already at the top of so you speed up as you draw close.
Out in the solar system, the “hill” is created by the gravitational force of the Sun.
All of the objects in the solar system want to “roll down the hill” and into the sun. The speed of the planets in their orbits is what keeps them from rolling down the hill. It is *speed* that conquers gravity. The Earth travels at around 66,000 mph around the Sun because his is the speed that *any* object needs to attain in order to orbit at the same distance as the Earth.



Earth and the other planets are following orbits around the sun. A spacecraft flying to Mars from Earth can achieve this only by going into orbit around the sun as well – and elliptical orbit: a stretched circle that crosses both the orbits of Earth and Mars.

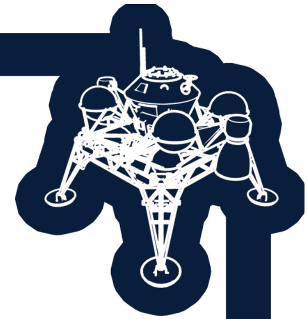
You would need to add speed in order to go "uphill" against the sun's gravity to travel from the Earth to any planets further from the sun – like Mars, Jupiter, etc., and reduce speed to go "downhill" towards the sun to reach Venus or Mercury.



The planets and other objects in the solar system, like the Earth and the Moon, each have their own "gravity hills". The more massive the object, the bigger its gravity hill and if you come close enough you can fall in towards them, but with just enough speed you can go into orbit around them.

Remember that there are no real "hills" in space. There is only the invisible force of gravity that acts like a hill – pulling everything towards the sun.

“Hills” are something we have all experienced and therefore discussing the force of gravity and relating it something we can all recognize helps us to make sense of something as exotic as spaceflight.



The Moon

What is the Moon?

The Moon is the only natural satellite of Earth, this means it orbits around the Earth just like the Earth orbits the Sun. The moon was likely formed after a Mars-sized body collided with Earth and the debris formed into the most prominent feature in our night sky. The moon makes Earth more livable by helping to stabilize our climate and shields the Earth, absorbing numerous meteoroid impacts that would otherwise strike the planet.

What is it like there?

The gravity is only 1/6th of Earth and the moon has no real atmosphere and as a result the temperature varies wildly: broiling in sunlight (256F, 130C) and immediately dropping to impossibly frigid temperatures in the shadow (-170F, -110C) – deadly for humans and machines. With no atmosphere and no wind or rain to wear down the surface, the Moon is covered in craters, dust and rocks. When we look at the Moon we see dark areas called Maria (seas) that were formed long ago when the moon was volcanically active and lava flowed across its surface. The brighter areas are mountains, or highlands. The moon orbits at around 239,000 miles (384,633 kilometers) and is tidally locked with Earth. This means that it takes 28 days to go around the Earth and 28 days to rotate once around it's axis– so its same face always shines down on us. There is no 'dark side' of the Moon – only a side we never see.

How do we get there?

The course to the Moon is a high ellipse (a stretched circle) that stretches from Earth orbit to the Moon. To voyage to the Moon you fire your engines and increase speed to more than is needed to fly in low earth orbit. The extra speed causes your ship to fly out away toward the Moon. If your flight path is just right, the ship will cross the orbit of the Moon just as the Moon sweeps by.

Where would we go?

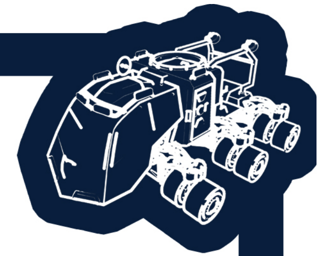
On July 20, 1969 human beings first landed on the Moon. Over the next few years 12 American astronauts walked on the Moon but we haven't been back since 1972.

One day soon we will return to the Moon – to stay.

Water ice has been detected on the Moon. We know that from water we can get oxygen to breathe and hydrogen for energy production and rocket fuel. Large quantities of ice are thought to exist in permanently shadowed (and therefore frigid) craters on the Moon.

The best spot for a Moon Base may be on the northern rim of Peary crater, close to the North Pole. Because of the minimal tilt of the Moon's axis, we suspect there are high points, nicknamed Peaks of Eternal Light, where the Sun always shines. This means that temperatures there might still be cold (-58F, -50C) but manageable and constant sunlight would mean the base could use solar power.

You will be landing at the rim of Peary crater and descending into a 1:1 simulation of Whipple Crater built using laser altimeter data from NASA's Lunar Reconnaissance Orbiter – another crater on Peary's rim, to visit an ice-mining facility.



Mars

What is Mars?

Mars is the 4th planet from the Sun and is often called the “Red Planet” because the iron oxide on its surface gives it a reddish appearance.   It is the second smallest planet in the Solar System, after Mercury.

What is it like there?

Mars is a terrestrial (rocky) planet with a very thin atmosphere resulting in surface features reminiscent both of the craters of the Moon and the volcanoes, valleys, deserts, and polar ice caps of Earth. The thin atmosphere and low pressure make Mars a challenging environment for human exploration.

The gravity on Mars is roughly 1/3 that of the Earth’s. An astronaut that weighs 150lbs on Earth would only weigh 57lbs on Mars.

The Martian day and seasonal cycles are similar to those of Earth, as is the tilt that produces its seasons. Mars’ Northern hemisphere is almost entirely sunken while the southern is all highlands. Mars is the site of Olympus Mons, the largest volcano and second-highest mountain yet discovered in the solar system. Mars is also home to the Valles Marineris (the Mariner Valley) a canyon nearly the width of N. America.

Mars has two moons, Phobos and Deimos, which are small and irregularly shaped. These may be captured asteroids.

How do we get there?

Mars is incredibly far away. To travel to Mars we have to escape Earth’s gravity entirely and put the ship into it’s own orbit around the sun: a highly elliptical one that stretches from the Earth’s orbit all the way to that of Mars.

Mars is moving the entire time, traveling in its orbit around the sun. You need to aim not at Mars– but at where Mars will be when your spacecraft arrives. If your flight path is just right, you will reach Mars right as it sweeps by and you will be pulled into its orbit.

Why would we go?

Mars is an entire planet worth of space – land, resources, and discoveries yet to be made. Colonizing Mars would make humanity a multi-planet species, helping to ensure our survival against catastrophes like those that befell the dinosaurs – creatures that ruled the Earth for many, many times longer than humans.

Where would we go?

There is an entire planet to explore – but with Mars' thin atmosphere colonization may be difficult. The atmosphere is too thin to protect astronauts from radiation from space and far too thin to breathe. The closer to the surface, the greater the pressure and it may be that deep in valleys like the Valles Marineris the pressure and atmosphere may be greater and the steep valley walls may provided astronauts with added protections.

In this exhibit you will land on the western edge of the Valles Marineris in an interesting formation known as the Noctis Labyrinthus, the Labyrinth of Night, notable for its maze-like system of deep, steep walled valleys. The area of the landing is a 1:1 simulation built using data from NASA's Mars Reconnaissance Orbiter's laser altimeter.

Jupiter

Jupiter: the 5th planet from the sun and the largest in the solar system. It is a gas giant – this means it is made of mostly gas and liquid and has no solid surface.

What's it like?
Jupiter looks beautiful but you wouldn't want to live there. Its stripes are made up of layers of swirling frozen clouds. The color differences are the result of different types of gas and ice. It is a planet of winds and storms – and some of the storms, like the Great Red Spot, are far larger than the Earth itself. Jupiter is so massive that if it were the size of a basketball, Earth would be the size of a marble.

The pressure of Jupiter's atmosphere is so great that it would soon crush any spaceship. Even if you could survive, there is very little oxygen so human life would be impossible. Jupiter is made of mostly hydrogen. High in Jupiter's atmosphere the hydrogen exists as a gas but the deeper into the planet that you go, the greater the heat and pressure. The hydrogen gets squeezed by this pressure and becomes a liquid. At Jupiter's core the temperature is thought to rise to around 55,000 degrees!

Can we get there?
Jupiter has an incredibly strong magnetic field that traps and accelerates particles creating intense belts of radiation. As a result, Jupiter is surrounded by a blazing field of deadly radiation that poses the greatest challenge to human exploration of the planet. Robot explorers have made the trip but for a crewed mission, a spacecraft would need a shield capable of protecting the astronauts and systems from the radiation. Without this yet to be invented technology a journey to Jupiter would be impossible. Jupiter is still a worthy destination – from hellish Io to frozen Europa, Jupiter's moons may hold more mysteries than the rest of the solar system.

Jupiter's rings and moons.

Jupiter is part of the solar system but in a way it is like its own solar system.

Jupiter has a thin ring system made up of three parts – the outer part called the Gossamer rings, the middle (and brightest) part called the main ring and the inner ring called the halo. Jupiter's rings are made mostly of dust and bits of rock.

Jupiter has over 60 moons but the most famous are its four largest moons, called the Galilean Moons because the astronomer Galileo discovered them. They are:

Ganymede – the largest moon in the solar system and nearly the size of the planet Mercury.

Io - closest to Jupiter and covered in erupting volcanoes.

Callisto - is rocky and covered in craters.

Europa - is the smallest of the Galilean Moons and has a surface of mostly ice. Scientists think there may be an ocean under this ice that could possibly support life.

Ceres

What is Ceres?

Ceres is the largest object in the Main Belt of asteroids between Mars and Jupiter. It is approximately 587 miles (945 kilometers) across. Composed of rock and ice, Ceres is estimated to make up about one third of the mass of the entire asteroid belt – and yet it is still only around 4% of the mass of Earth's Moon.

Ceres is the only object in the asteroid belt known to possess enough mass to be shaped into a sphere by its own gravity – the rest of the objects in the asteroid belt are irregularly shaped.

From Earth, Ceres is too dim to be seen with the naked eye, except under extremely dark skies.

What's it like there?

Ceres appears to be differentiated into a rocky core and icy mantle, it may even contain remnants of an internal ocean of liquid water under the ice. Its surface is probably a mixture of water ice and various water-rich minerals such as clay and carbonates. In January 2014, emissions of water vapor were detected from several areas on Ceres. This was a surprise because large objects in the asteroid belt do not usually emit vapor, a hallmark of comets.

The famous bright spots seen by NASA's DAWN spacecraft as it approached make Ceres unique in the solar system and are thought to be caused by surface ice – or mineral salts left behind as the ice sublimates away into space.

Ceres' gravity is very low, only 2.8% of Earth's. Lower even than the Moon's gravity. You couldn't jump into orbit – but it would take you a long time to come down. There are indications that Ceres may have a fragile water vapor atmosphere – outgassing from ice on or below the surface.

It takes 4.6 years for Ceres to make 1 orbit around the Sun. Ceres' day lasts only 9 hours and 4 minutes.

How do we get there?

Most of the difficulty of getting into space is getting out of Earth orbit. Once that is accomplished it takes little more energy to get to Ceres than it does to Mars. The flight path to Ceres is a great ellipse around the Sun whose path stretches from the orbit of the Earth to the orbit of Ceres.

Why would we go there?

Access to water is the key to sustained human presence in space. From water we can get hydrogen for rocket fuel and oxygen to breathe and use in combustion but water is heavy. Rockets powerful enough to lift the water we'd need into space would be too large and expensive and so we must find it out there.

Some astronomers believe that Ceres may have more water ice beneath its surface than all of the seas of Earth combined! If we can utilize the natural resources of Ceres, the entire solar system could potentially be open for human exploration and colonization.

Sidebar

Ceres Facts

Ceres was the very first asteroid discovered, by Giuseppe Piazzi in 1801. And was originally considered a planet. It was reclassified as an asteroid when many other objects in similar orbits began to be discovered.

It is now called a dwarf planet and yet still sometimes referred to as an asteroid.

The Asteroids

What are asteroids?

Asteroids are rocky, airless worlds that orbit our sun, but are too small to be called planets. Asteroids are rocky remnants from the early formation of our solar system about 4.6 billion years ago.

What are they like?

Most asteroids are irregularly shaped – like potatoes, but a few are almost spherical. They are often pitted or cratered. They have no atmospheres and rotate as they spin around the sun on elliptical orbits (stretched circles), tumbling erratically through space.

More than 150 asteroids are known to have a small companion moon – and some have two moons. There are also binary (double) asteroids, where two rocks that are roughly the same size orbit around each other. There are triple asteroid systems as well. The asteroid Chariklo was found to have two rings!

Where are they?

Most of this ancient space rubble is found orbiting the sun within the main asteroid belt – a vast donut-shaped ring between Mars and Jupiter.

The belt is estimated to contain somewhere between 1 and 1.9 million asteroids larger than .6 miles (1 km) in diameter, and millions of smaller ones. Early in the history of the solar system, the gravity of newly formed Jupiter brought an end to the formation of planets between it and the orbit of Mars and caused the small bodies that remained to collide with one another, smashing them into the asteroids we see today.

Asteroids range in size from Ceres - the largest at about 590 miles (950 km) in diameter, also called a dwarf planet) - to bodies that are less than

0.6 mile (1 km) across. The total mass of all the asteroids combined is less than that of Earth's Moon.

Asteroids that pass close to Earth are called near-earth objects. There are more than a 6,000 near-earth objects larger than 165 feet (50m). Asteroids of this size can survive a trip through our atmosphere and hit the surface. Of these there are approx. 1,106 that may pose a danger of striking the Earth.

How do we get there?

We could travel to an asteroid in the same way that we can travel to any other world. An elliptical orbit (a stretched circle) around the Sun that stretches from the orbit of the Earth to the orbit of the asteroid will take us there if the spacecraft is launched at the right moment and its journey is timed so that it arrives at the asteroid's orbit at precisely the moment that the asteroid itself arrives.

Why would we go?

Asteroids are potential sources of natural resources – from ice to rare and precious minerals. Some private companies estimate that even a smaller asteroid may contain as much as $1 billion US dollars worth of rare minerals!

Asteroids, Comets, Meteors? What's the difference?

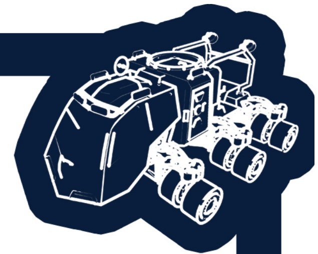
Asteroid: Relatively small, inactive, rocky bodies that orbit the Sun.

Comet: Also relatively small, but active at times. They made up of rock, ice and dust. The ices can vaporize when coming close to the sun to form an atmosphere (coma) and, often, a tail of dust and gas.

Meteoroid: A small fragment of an asteroid or comet orbiting the Sun.

Meteor: The bright light that results when a meteoroid enters the Earth's atmosphere and burns up. Otherwise known as a shooting star.

Meteorite: A meteoroid that survives its passage through the Earth's atmosphere and crashes into its surface.



What is a Spaceship?

A spaceship is a vehicle designed to travel in space and may be launched from Earth by a launch vehicle. It may carry a payload to accomplish a mission with or without people and return to Earth.

What are the components all spaceships must have?

All crewed spacecraft require certain basic systems to function properly. Among these systems are: propulsion (engines), guidance (steering), life support (air to breathe, food and water), crew quarters (crewed operations and living area), communications (radio transmission and reception), thermal protection (isolation from the extreme temperatures of space as well as the heat of reentry), and displays and controls (a means of controlling and monitoring the ship).

What makes a spaceship capable of interplanetary flight?

Life support systems must be capable of supporting human life for weeks, months or even years. Once a vehicle leaves Earth orbit and the protection of Earth's magnetosphere, a spaceship must protect astronauts from a constant background of high-energy cosmic rays, which pose a health threat during long duration space flight. Approaching any planet (including Earth), spaceships will pass through belts of high radiation trapped by the planet's magnetosphere.
Any major failure to a spacecraft in-flight is likely to be fatal, and even a minor one could have dangerous results if not repaired quickly. The crew of Apollo 13 survived despite an explosion caused by a faulty oxygen tank.

How do you fly a spaceship?

It's all about orbits! An interplanetary spacecraft spends most of its flight time moving under the gravitational influence of a single body – the Sun.

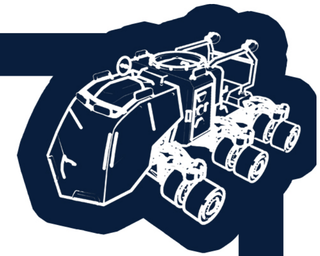
Only for a brief time, compared with the total length of the flight, is its path shaped by the gravity of the departure or arrival planet.
The first step in flying a spacecraft between worlds is to select an elliptical orbit (a stretched circle) around the sun that takes the spacecraft from the gravitational influence of the planet you are leaving to that of the world you are trying to reach. This is called a heliocentric (sun-centered) transfer orbit.
Because each planet's orbit around the sun is not a perfect circle, the distance between worlds is constantly changing. Spacecraft need to be launched within a special period of time where the planets are at their closest. This is called a Launch Window. Outside these launch windows the planets are much, much harder to reach from Earth because the flights would be so long that the dangers would mount and the amount of supplies needed would increase. This limits where and when astronauts can go and prevents rescue in case of an emergency.

Artificial Gravity?

The creation of artificial gravity is desirable for long-term space travel or habitation, for ease of mobility and to avoid the adverse long-term health effects of weightlessness. A number of methods for generating artificial gravity have been proposed, but for our ship we chose rotation.

Rotating part of the ship will produce a feeling of gravity on its inside hull referred to as centrifugal force, the "pull" is actually a caused by objects inside the ship attempting to travel in a straight line due to inertia. With centrifugal force, unlike real gravity that pulls towards a center, the gravity created pushes away from the center of rotation – so if the center of rotation were the middle of a room, the astronauts would be standing on the walls.

Artificial gravity levels also vary with the distance from the center of rotation. If the arms of our ship were too small, the amount of gravity felt at an astronaut's head would be greatly different from the amount felt at their feet. These forces can act on the inner ear and cause dizziness and nausea. We can feel artificial gravity produced in this same way when we visit amusement parks and go on pendulum rides and centrifuges that provide rotational force. Roller coasters also produce an artificial gravity effect when they go over crests or loops.



What is a Rover?

A rover is a space exploration vehicle that can move across the surface of a planet or other object. Some rovers are designed to transport astronauts while others are partially or fully robotic. Rovers usually arrive on a lander spacecraft and have advantages over stationary landers. They can examine more territory and they can be directed to interesting features.

What are the components that all rovers must have?
In order to explore, rovers must be able to move over the surface. This means they need some form of power (solar, nuclear, etc.) and a means to apply that power against the surface in order to propel itself forward (See Newton's Laws!).

What are the challenges in building one?

Rovers travel on spacecraft and are used in environments very different from those on Earth. This means they must be designed with certain factors in mind:
Reliability. Rovers have to withstand high levels of acceleration, extreme temperatures, pressure variation, dust, corrosion, cosmic rays and remain functional without repair for as long as they are needed.
Compactness. Rovers have to travel inside spacecraft. The bigger and heavier the rover, the bigger and heavier and more expensive the craft that must carry it – so rovers need to be as small and light as they can be.

Autonomy or human capacity? Rovers that land on bodies far from Earth, such like NASA's Mars Exploration Rovers, cannot be remotely controlled in real-time since the speed that radio signals travel is far too slow, and the distances between worlds far too great, for real time or near-real time communication. Sending a signal from Mars to Earth takes between 3 and 21 minutes, depending on where the planets are in their orbits. These rovers need to be capable of operating on their own with little assistance from ground control, although they still require humans to help them identify targets to explore, and to solve problems that may come up.

How do you drive one?

Carefully, the nearest repair center might be millions of miles away! Differences in gravitation will cause the rovers to behave differently compared to a vehicle on the earth. The lack of plant life to bind soil together and wind and weather to erode surfaces can cause precarious landforms to exist as a hazard to threaten crews and equipment.

Take it slow and plan ahead!

DID YOU KNOW: There are robotic rovers operating right now on Mars but so far the only rover to take humans over the surface of another world was the Apollo LRV.

What is a Lander?

A lander is a type of spacecraft that descends to the surface of another astronomical body – be it a planet, planetoid, comet or asteroid.

On worlds like Mars, with an atmosphere, landing occurs after entry into the atmosphere, during which the lander may need to be housed inside another vehicle specially built to protect it against the forces of entry. A lander could use parachutes – or even the shape of its protective vehicle, to slow down… but only if the atmosphere was thick enough. Landing is most often accomplished by powered descent via rocket(s) and touchdown on landing gear. Some missions (such as Mars Pathfinder) used inflatable airbags to cushion the lander's impact rather than landing gear but this would not work for a crewed vehicle. On celestial bodies with low gravity, tethers or other anchoring methods may be used.

Of all the inner planets of the solar system, Mercury is the only one that has yet to be visited by a robotic lander and only one, our Moon, has been visited by a human crewed lander.

What are the components that all landing vehicles must have? Manned/unmanned.

All landers must have some type of method for slowing their descent, usually rockets, fuel and reactant tanks. They need an electronics package with sensors to control its flight and communications equipment for contact with Earth. Landers also need storage for payload such as scientific experiments. A crewed lander would need to possess a pressure vessel and life support to protect the crew.

Could a Moon Lander land on Mars?

No. The Landers may look similar but Mars has a stronger gravitational field compared to the Moon, therefore a lander's engines would need to be more powerful to act against it. More power means carrying more fuel so the lander's tanks would need to be larger. The landing legs would also need to be larger and able to bear more weight.

Because Mars also has an atmosphere, the Mars lander will need an atmospheric entry vehicle or protective shroud. The lander would need to fit within the shroud and therefore its landing legs may need to fold in order to do so.

How do you fly one?

A spaceship needs to be able to move in all three dimensions. These movements are discussed in terms of pitch, roll and yaw. When flying the lander you will use mostly the pitch control to point your craft in the proper direction to fire your main engines.

To speed up, you pitch your ship around to face your main engines into the direction of travel. To slow down, you pitch around to fire them forward. To rotate your spacecraft, you fire a pair of side-pointed thrusters located on opposite sides of the spacecraft. To stop rotating, you need to fire thrusters in the opposite direction.

Keeping People Alive and Healthy in Space

The human body is adapted to living on the surface of the Earth, within the protection of its atmosphere and magnetic field. When we leave the Earth, we leave its protections behind as well. There are dangers to contend with in space beyond those piloting spaceships.

The Dangers of a Vacuum

A vacuum of is a lack of air and a lack of pressure. On Earth, we don't feel the pressure of our atmosphere but it is there pushing down on us. In a vacuum there is no pressure outside and this causes the gas and fluids within us try to escape– with potentially deadly results.

Without the oxygen in Earth's air an astronaut will pass out within 10 or 12 seconds and could perish after a couple minutes.

These dangers can be reduced or even eliminated by wearing a space suit. Space suits provide oxygen to breathe and pressure enough to keep our insides in.

The Dangers of Extreme Variation in Temperature

In a vacuum, there is no atmosphere to regulate temperature swings. In the sunlight the heat can soar to broiling and in shadow temperatures can instantly drop beyond freezing. Humans need the life support system of a spacesuit or spacecraft to keep them comfortable and safe.

The Dangers of Radiation

Without the protection of Earth's atmosphere and magnetic field, astronauts can be exposed to high levels of radiation. A year in orbit results in radiation dose 10 times greater than living on the ground.

Beyond Earth magnetic field, cosmic rays pose further challenges to human spaceflight significantly increasing the chances of cancer as the length of exposure increases.

Rare Solar Flare events can give a fatal radiation dose in minutes. It is thought that protective shielding and protective drugs could lower the risks to an acceptable level in the future.
High levels of radiation damages the immune system, meaning that astronauts can get sick more easily upon returning to Earth. Radiation has also recently been linked to vision problems in astronauts. Solar radiation, other than direct sunlight —particularly ultraviolet rays– may cause severe sunburn in a few seconds.

Spacecraft and spacesuits must be able to protect humans from these short and long-term radiation dangers.

The Effects of Microgravity on the Human Body

Exposure to weightlessness or microgravity can also be an issue for human health.

Short-term exposure to microgravity causes space adaptation sickness, sort of like space motion sickness.

Long-term exposure to microgravity can cause multiple health problems, including changes in the shape of the eyes and other organs and loss of bone and muscle mass. Over time these effects can reduce astronauts' mental ability, increase their risk of injury, reduce their level of fitness and slow down their cardiovascular system. On Earth, gravity pulls on the fluids within our bodies but in space this doesn't happen – changing the makeup of our bodies. This redistributing of fluids around the body can cause balance disorders, distorted vision, and a loss of taste and smell.

To help mitigate the effects of microgravity, artificial gravity systems like the centrifuge system of the Interplanetary Spacecraft you will pilot, have been proposed. Spinning properly designed habitats can produce gravity via centripetal force.

Food and Nutrition

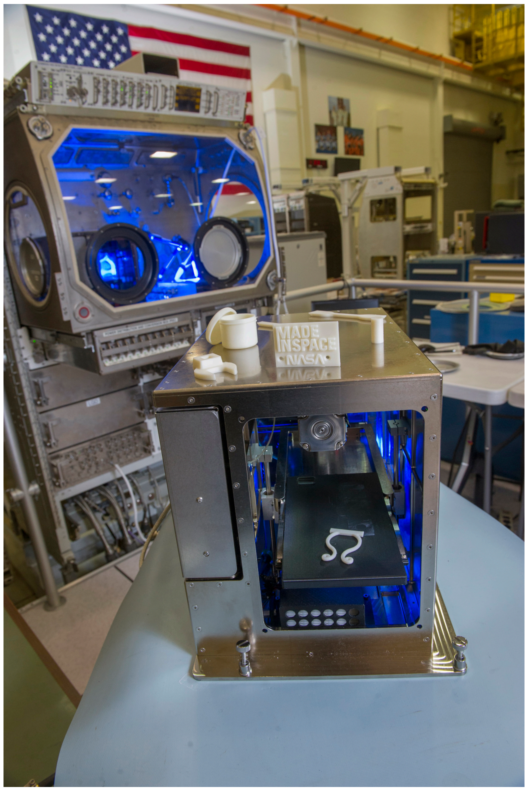
Explorers have always had to face the problem of how to carry enough food for their journeys. Food needs to remain edible throughout a voyage, and it also needs to provide all the nutrients required to avoid vitamin-deficiency diseases such as scurvy.

Dehydration, canning, thermostabilizing, pasteurization, refrigeration and freezing allow food to be stored and carried on long journeys. Food that is packaged and stored for use on Earth is not always suitable for use in space. Size and weight are a big concern in space flight so food must be specially packaged and prepared.

Mental Health

On long duration spaceflights the mental health of astronauts must be considered as well as their physical health and safety. Human beings need to relax and (mentally) decompress in order to perform at their best. Entertainment and distractions must be provided and human emotions taken into account. Crew selection must be made to minimize any friction between crewmembers and loneliness and isolation must be addressed. Imagine not being able to be with friends or loves ones for months or even years! Now imagine that not only can you not be with them, but also you can't really carry on a conversation with them either! The incredible distances involved in space flight means that even simple communication becomes difficult. On space flights far from Earth, just sending a message one-way could take many minutes or even hours.

3D Printing in Space



3D printing:

A 3D printer is actually a type of industrial robot that works by melting plastic and then squeezing it out through a specialized tip that builds, layer upon layer, all sorts of three-dimensional objects. These objects can be of almost any shape and are produced from a 3D model or other electronic data source. Some companies are already using 3D printed parts in commercial rocket launches.

Future 3D printers may produce huge components or even completed vehicle hulls.

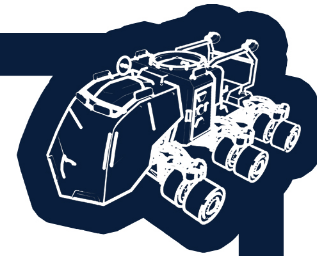
A spaceship far from Earth could conceivably carry just the raw materials for parts and tools and print only what was needed. Once the tools were finished, they could be recycled into raw materials to be used again – saving the mass of carrying everything you might need on a space mission.

But where would we get these raw materials? Launching them from Earth would be expensive? The answer lies with In-Situ Resource Utilization.

In-Situ Resource Utilization (ISRU) is the practice of living off the land – in space! The biggest cost in any space mission is getting anything off of the Earth. There is a tremendous price to be paid to overcome the force of gravity, and the more you have to send up – the more expensive and difficult everything becomes. In order for space exploration make economic sense we must use the resources that are already out there.

The first form of ISRU is the use of solar energy to power spacecraft. The vehicle didn't bring its fuel along with it – it used the solar radiation that was present in its environment. In the future we will use the soil of the moon and planets as feedstock for 3D printers and use ice found on planets and asteroids to support our exploration and colonization of the solar system.

As you move through your missions in this exhibit you will see examples of ISRU on the Moon where crews are mining ice from the permanently shadowed side to produce water, hydrogen for rocket fuel and oxygen for life support as well as on Ceres where human explorers are hunting for the ice locked in the dwarf planet's crust.



Lesson Plans and Activities:

Each Lesson and Activity is described below. For ease of use and printing the full individual lesson plans are included in PDF form within subfolders in within the BtA Educator's Guide link provided. These can be printed and distributed at will

Launching to the Moon and Beyond – Fun Pages
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education
Grade Levels: K-4
Subjects: General Science
These coloring pages include labeled drawings of the Ares rockets that will take astronauts to orbit and return them to the moon. The pages also include a word search puzzle, a maze, a connect-the-dot puzzle and a cut-out Ares I rocket.

Launching to the Moon and Beyond Fun Pages [564KB PDF file]

3...2...1...PUFF!
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: K-8
Subjects: Technology

Students will construct small "indoor" paper rockets, determine their flight stability and launch them by blowing air through a drinking straw.

3...2...1...PUFF! [1MB PDF file]

Food for Spaceflight
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education, Students
Grade Levels: 3-5
Subjects: General Science, Life Science
This lesson will help your students answer the question:
What foods are best suited for spaceflight and what makes foods suitable for spaceflight?

In this lesson, students will
- Select foods to test for spaceflight suitability.
- Subject foods to spaceflight suitability testing based upon criteria.

- Gather data by sorting foods based upon the results of the suitability for spaceflight testing.
- Develop packaging for the suitable foods for spaceflight.
- Develop a conclusion based upon the results of this activity.

Food for Spaceflight Activity
> For educators [468KB PDF file]
> For students [198KB PDF file]

Touchdown!
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education
Grade Levels: 3-8
Subjects: Technology

Design and build a shock-absorbing system that will protect two "astronauts" when they land. In this challenge, students follow the engineering design process to do the following:

1. Design and build a shock-absorbing system out of paper, straws and mini-marshmallows.
2. Attach their shock absorber to a cardboard platform.
3. Use test results to improve their design.

Touchdown [1MB PDF file]

Newton's Car
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: 3-12
Subjects: Technology

Student teams use a wooden car and rubber bands to toss a small mass off the car. The car, resting on rollers, will be propelled in the opposite direction. During a set of experiments, students will change the variables. They will then measure how far the car rolls in response to the action force generated.

Newton Car Activity [1MB PDF file]

Let's Investigate Mars!
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education, Students

Grade Levels: 3-5
Subjects: General Science, Life Science, Space Science, and Technology
This lesson will help your students answer the question:
What do I need to know about Mars in order to live there in the future?

In this lesson, students will
- Formulate an original question based on recent Mars robotic investigations.
- Formulate an original, collaborative inquiry investigation.
- Present their inquiry question and investigation to the class.
- Revise the investigation based on feedback from the class.

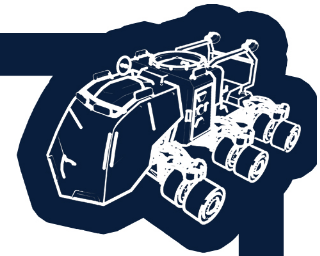
Let's Investigate Mars Activity
> For educators [141KB PDF file]
> For students [488KB PDF file]

Cool Suits!
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education, Students
Grade Levels: 3-5
Subjects: General Science, Life Science, Technology
This lesson will help your students answer the questions:
Which color, black or white, reflects energy better? Which color absorbs energy better?

In this lesson, students will
- Gather data by measuring temperature in two different colored envelopes (black and white).
- Use data to infer which color reflects energy better and which color absorbs energy better.

Cool Suits Activity
> For educators [525KB PDF file]
> For students [281KB PDF file]

Designing a Crew Exploration Vehicle
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education, Students
Grade Levels: 3-5
Subjects: General Science, Life Science, Technology
This lesson will help your students answer the question:
Can I design and build a Crew Exploration Vehicle that will be a model for future space exploration?



In this lesson, students will
- Design a model CEV for future space exploration.
- Develop a conclusion based upon the results of this design.
- Compare individual results to class results by looking for patterns.

Designing a Crew Exploration Vehicle Activity
> For educators [666KB PDF file]
> For students [136KB PDF file]

Moon Mining
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education, Students
Grade Levels: 3-5
Subjects: Earth Science, General Science, Space Science
This lesson will help your students answer the question:
How can I find and mine valuable resources from a simulated moon surface?

In this lesson, students will
- Gather data by spectroscopically locating the simulated ilmenite.
- Collect simulated ilmenite by mining the simulated lunar surface.
- Gather data by using observations while extracting oxygen from the simulated ilmenite over time.
- Develop a conclusion based upon the results of this simulation.
- Compare individual results to class results to look for patterns.

Moon Mining Activity
> For educators [808KB PDF file]
> For students [296KB PDF file]

Foam Rocket
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: 4-12
Subjects: Mathematics

Students will construct rockets made from pipe insulating foam and use them to investigate the trajectory relationship between launch angle and range in a controlled investigation.

Foam Rocket [997KB PDF file]

Impact Craters
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: 4-12
Subjects: Earth Science, General Science, Space Science

Impact craters are formed when impactors such as meteorites smash into the moon's surface. The factors affecting the appearance of impact craters include the size and velocity of the impactor and the geology of the surface. Students will use flour, baking soda and cornmeal to recreate a lunar surface. They will then drop impactors such as marbles onto their lunar surface from various heights. Finally, they will measure various characteristics of the impact craters formed.

Impact Craters Activity [189KB PDF file]

Field Trip to the Moon – six activities
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: 4-12
Subjects: General Science, Space Science

Students explore the moon's habitability and sustainable resources with activities that culminate with plans for the design and creation of a lunar station.
Students will:
• Utilize an inquiry-based learning approach that fosters team building and introduces students to careers in science and engineering.
• Develop their cooperative learning skills to design a self-sufficient lunar station.

Lesson Activities and Sequence
The Field Trip to the Moon curriculum guide is divided into six investigations that are described below.
Ecosystem Investigation:
This team will investigate ecosystems and food webs. Using the information they gather, they will design a sustainable ecosystem for the lunar station.
Geology Investigation:
This investigation locates and analyzes resources at the chosen landing site. The student teams will then determine the natural resources available and select a mining area.
Habitat Investigation:
This investigation identifies the living, working and recreational space

needed for humans on the moon. The student teams will then design a model of a sustainable habitat for humans.
Engineering Investigation:
This investigation determines the energy resources available on the moon and design a power station for the lunar station.
Navigation Investigation:
This investigation chooses one of two possible landing sites on the moon. The students will then pack the rocket so that all the needed materials from each team will fit in the cargo bay.
Medical Investigation:
This investigation explores various types of emergencies that may occur on the moon and select the medical equipment that would be best suited for responding to those emergencies.
Lesson Guide
Field Trip to the Moon Lesson
[103KB PDF file]

Designing Spacesuits
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education
Grade Levels: 5-12
Subjects: Physical Science

The steps that spacesuit engineers and technicians follow to create their product are the same as those used in nearly every technological endeavor. Students will follow these steps to create a product. The challenge is to design and build a full-scale, wearable model spacesuit to be used to explore the surface of Mars. The pages in this section of the Suited for Spacewalking Educator Guide outline a multifaceted technology education activity on spacesuits. This section includes an overview of the challenge in the Design Brief and includes Interface Control Documents so teams can communicate critical details about systems to other teams. The activity, designed for an entire class to work on as a team, combines skills and content from science, mathematics and technology.

PDF File: 188960main_Designing_Spacesuits_Mars 5-12.pdf

Close Encounters of the Asteroid Kind
Product Type: Lesson Plan/Activity
Audience: Educators, Informal Education
Grade Levels: 6-8
Subjects: Math

Students will use their math skills to discover how bright two asteroids discovered in 2010 will be on their closest approach to the Earth – and they will calculate how likely it is that these asteroids could impact our planet.

Close Encounters – Asteroids grades 6-8.pdf

Egg Drop Lander
Product Type: Lesson Plan/Activity
Audience: Educators
Grade Levels: 7-9
Subjects: General Science

Velocity and acceleration of falling objects affect the force of their landing. In this activity, students design a package to protect a raw egg from breaking as it falls to the ground.

Egg Drop Lander [146KB PDF file]

Flight Testing Newton's Laws
Product Type: Lesson Plan/Activity
Audience: Educators, Students
Grade Levels: 9-12
Subjects: Mathematics, Physical Science
"Flight Testing Newton's Laws" uses aircraft to stimulate students' interest in the physical sciences and mathematics during the course of ten lessons with corresponding videos. The main emphasis lies in showing how Newton's three Laws of Motion and the four forces of flight apply to flight-testing an aircraft. Students solve problems involving kinematics and dynamics. Complementary areas of trigonometry, vector addition, weight and balance, and resolution of forces are employed. The collection includes an educator's guide that is presented in the format of a flight instructor's manual to help guide teachers and students through each lesson.

Flight Testing Newton's Laws Instructor's Flight Manual [3MB PDF file]
Flight Testing Newton's Laws Student's Flight Manual [3MB PDF file]

Additional Activities:

Newton's Laws:

Soda Pop Can Engine

TOPIC: Newton's Laws of Motion
OBJECTIVE: Rocketry
DESCRIPTION: Water streaming through holes in the bottom of a suspended soda pop can causes the can to rotate.
CONTRIBUTED BY: Tom Clausen, KSC Explorations Station
EDITED BY: Roger Storm, NASA Glenn Research Center

MATERIALS AND TOOLS:

- Empty soda pop can with the opener lever intact
- Nail or ice pick
- Fishing line
- Bucket or tub of water

PROCEDURE:

1 Lay the soda can on its side and using the nail or ice pick carefully punch four equally spaced small holes just above and around the bottom rim. Then before removing the punching tool for each hole, push the tool to the right (parallel to the rim) so that the hole is slanted in that direction.

2 Bend the can's opener lever straight up and tie a short length

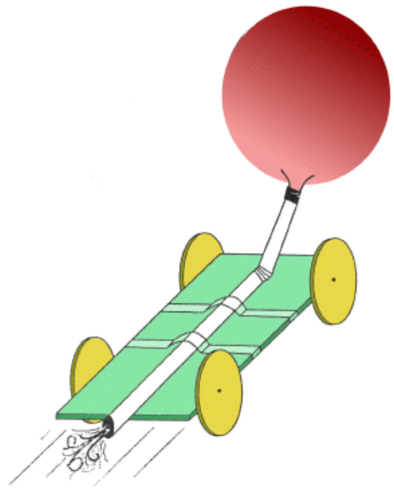
of fishing line to it.

3 Immerse the can in water until it is filled. Pull the can out by the fishing line. Water streams will start the can spinning.

4 If the can does not spin try making the holes larger or adding a fishing swivel to the string above the can.

DISCUSSION: The Soda Pop Can Engine is an excellent demonstration of Newton's Laws of Motion. The can rotates because a force is exerted by the flowing water (1st. Law). The rate of rotation will vary with different numbers of holes and different diameters of holes in the can (2nd. Law). Try two holes and try a can with large holes verses a can with small holes. The can rotates in the opposite direction from the direction of the water streams (3rd. Law).

Rocket Car



TOPIC: Newton's Third Law of Motion
OBJECTIVE: To construct a car to demonstrate how rockets move by means of action and reaction.
DESCRIPTION: A small car is propelled by the action/reaction force generated by a balloon.
CONTRIBUTED BY: Gregory Vogt, OSU
EDITED BY: Roger Storm, NASA Glenn Research Center

MATERIALS and TOOLS:

- 4 pins
- Styrofoam meat tray
- Cellophane tape
- Flexi-straw
- Scissors
- Drawing Compass
- Marker pen
- Small party balloon
- Ruler
- Emery Board

PROCEDURE:

1. Using the ruler, marker, and drawing compass, draw a rectangle 3 by 7 inches and four circles 3 inches in diameter on the flat surface of the meat tray. Cut out each piece. Use an

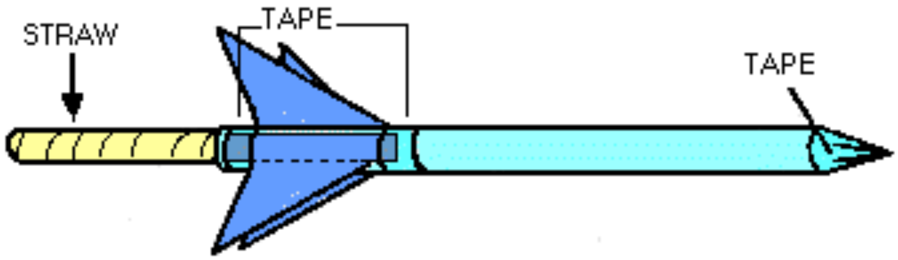
emery board to make the wheels as round as possible.

2. Push one pin into the center of each circle and then into the edge of the rectangle as shown in the picture. The pins become axles for the wheels. Do not push the pins in snugly because the wheels have to rotate freely. Test them to be sure they rotate freely. It is okay if the wheels wobble.
3. Inflate the balloon a few times to stretch it out a bit. Slip the nozzle over the end of the flexi-straw nearest the bend. Secure the nozzle to the straw with tape and seal it tight so that the balloon can be inflated by blowing through the straw.
4. Tape the straw to the car as shown in the picture.
5. Inflate the balloon and pinch the straw to hold in the air. Set the car on a smooth surface and release the straw.

DISCUSSION: The rocket car is propelled along the floor according to the principle stated in Isaac Newton's third law of motion. "For every action there is an opposite and equal reaction." The balloon pushes on the air and the air pushes back on the balloon. Because the balloon is attached to the car, the car is pulled along by the balloon.

Paper Rockets

SUBJECT: Rocketry
TOPIC: Stability
DESCRIPTION: Small flying rockets to make out of paper and propel with air blown through a straw.
CONTRIBUTED BY: Gregory Vogt,OSU
EDITED BY: Roger Storm, NASA Glenn Research Center



MATERIALS:

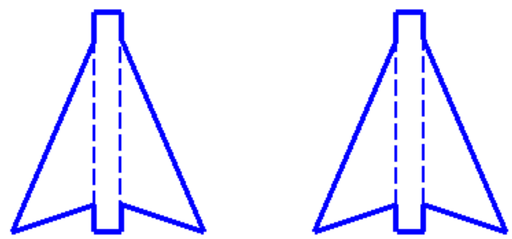
- Scrap bond paper
- Cellophane tape
- Scissors
- Sharpened fat pencil
- Milkshake straw (slightly thinner than pencil)

PROCEDURE:

1. Cut a narrow rectangular strip of paper about 5 inches long and roll it tightly around the fat pencil. Tape the cylinder and remove it from the pencil.
2. Cut crown points into one end of the cylinder and slip it back onto the pencil.
3. Slide the crown points to the pencil tip and squeeze the points together and tape them together to seal the end to form a nose cone (the pencil point provides support for taping). An alternative to the crown points is to just fold over one end of the tube and seal it with tape.
4. Remove the cylinder from the pencil and gently blow into the open end to check for leaks. If air easily escapes, use more tape to seal the leaks.

5 Cut out two sets of fins using the pattern below and fold according to instructions. Tape the fins near the open end of the cylinder. The tabs make taping easy.

Cut along Solid Lines

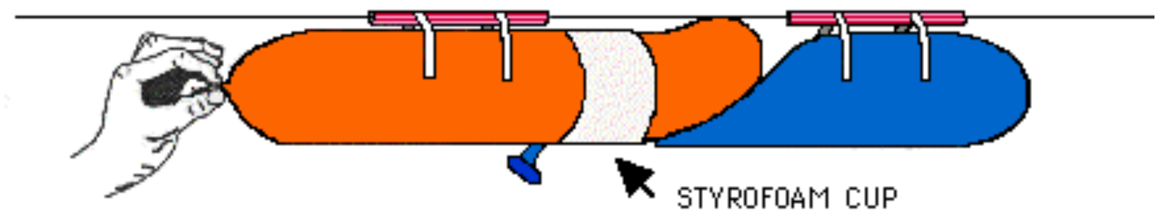


Fold towards you on Dashed Lines

FLYING THE PAPER ROCKET:
Slip the straw into the rocket's opening. Point the rocket towards a safe direction, sharply blow through the straw. The rocket will shoot away. Be careful not to aim the rocket towards anyone because the rocket could poke an eye.
DISCUSSION: Paper rockets demonstrate how rockets fly through the atmosphere and the importance of having fins for control. For experimental purposes, try building a rocket with no fins and one with the fins in the front to see how they will fly. Practice flying the rockets on a ballistic trajectory towards a target. Also try making a rocket with wings so that it will glide.

Balloon Staging

TOPIC: Rocket staging
OBJECTIVE: To demonstrate how several stages of a rocket can operate in steps to propel a rocket.
DESCRIPTION: Two inflated balloons are joined in a way simulate a multistage rocket launch as they slide along a fishing line on the thrust produced by escaping air.
CONTRIBUTED BY: Gregory Vogt, OSU
EDITED BY: Roger Storm, NASA Glenn Research Center



MATERIALS and TOOLS:

- 2 long party balloons (round balloon will not work)
- Nylon monofilament fishing line (any weight)
- 2 Plastic straws (milkshake size, non-bendable)
- Styrofoam cup
- Masking tape
- Scissors

PROCEDURE:

1 Thread the fishing line through the two straws. Stretch the fishing line snugly across a room and secure its ends. Make sure the line is just high enough for people to pass safely underneath.

2 Cut the cup in half so that the lip of the cup forms a continuous ring.

3 Loosen the balloons by pre-inflating them. Inflate the first balloon about 3/4 full of air and squeeze its nozzle tight. Pull the nozzle through the ring. While someone assists you, inflate the second balloon. The front end of the second balloon should

extend through the ring a short distance. As the second balloon inflates it will press against the nozzle of the first balloon and take over the job of holding it shut. It may take a bit of practice to achieve this.

4 Take the balloons to one end of the fishing line and tape each balloon to a straw. The balloons should be pointed along the length of the fishing line.

5 If you wish, do a rocket countdown and release the second balloon you inflated. The escaping gas will propel both balloons along the fishing line. When the first balloon released runs out of air, it will release the other balloon to continue the trip.

Conclusion

Travel into outer space takes enormous amounts of energy. Much of that energy is used to lift rocket propellants that will be used for later phases of the rocket's flight. To eliminate the technological problems and cost of building giant one-piece rockets to reach outer space, NASA, as well as all other space fairing nations of the world have chosen to use a rocket technique that was invented by 16th-century fireworks maker Johann Schmidlap. To reach higher altitudes with his aerial displays, Schmidlap attached smaller rockets to the top of larger ones. When the larger rockets were exhausted, the smaller rocket climbed to even higher altitudes. Schmidlap called his invention a "step rocket."

NASA utilizes Schmidlap's invention through "multi staging." A large first stage rocket carries the smaller upper stages for the first minute or two of flight. When the first stage is exhausted, it is released to return to the Earth. In doing so, the upper stages are much more efficient and are able to reach much higher attitudes than they would have been able to do simply because they do not have to carry the expired engines and empty propellant tanks that make up the first stage. Space rockets are often designed with three or four stages that each fire in turn to send a payload into orbit.