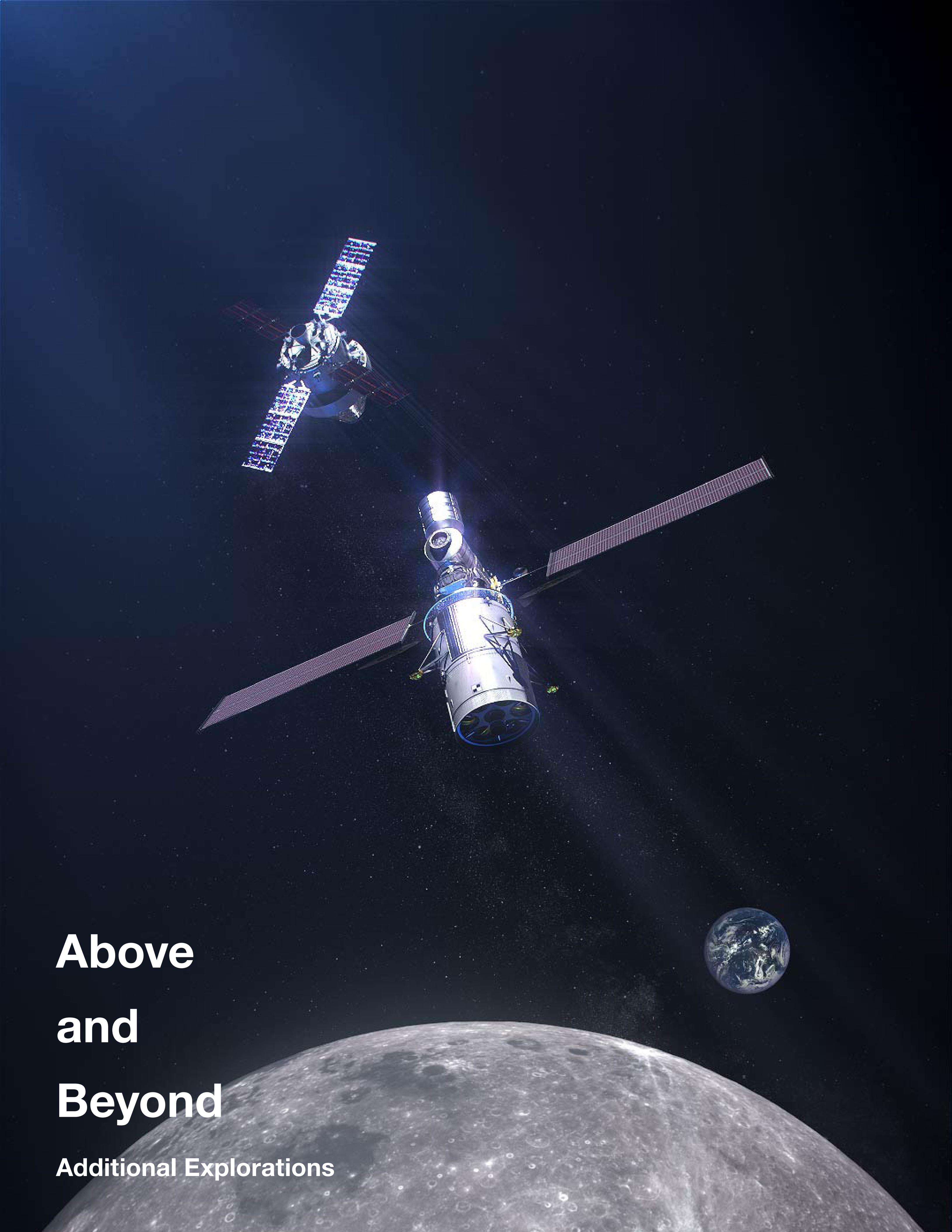


Above and Beyond

Additional Explorations

How High?

Using Mathematics to Estimate Rocket Altitude

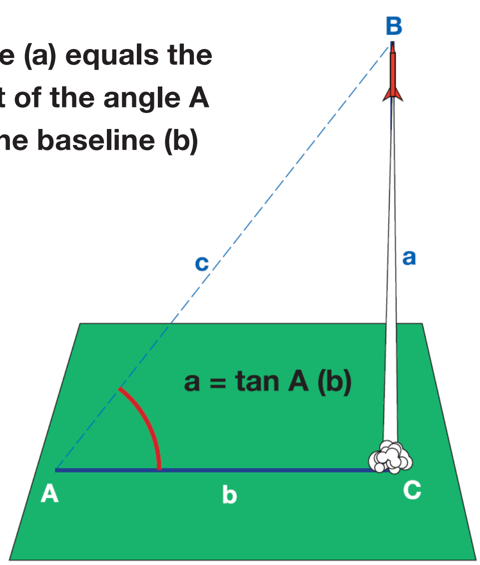
Students are excited to learn what altitude their rockets achieve. Altitude tracking is both simple and tricky. If the rocket goes straight up, it is pretty easy to get a good estimate of the altitude. The altitude tracker activity (page 81) provides a simple instrument and instructions for estimating rocket altitudes. A baseline is stretched out from the rocket launch site. The angle to the rocket, just before it starts its fall back to Earth, is measured.

The tangent of the angle is determined from the tangent table in the tracker activity. The tangent, multiplied by the length of the baseline, gives the altitude.

Single station tracking is easy to do. If you have two or more students measure the angle, averaging their estimates can increase accuracy.

Single Station - No Wind

alttitude (a) equals the tangent of the angle A times the baseline (b)



Sample Measurement:
Angle A = 40 degrees
Tangent A = .8391
Baseline b = 25 m

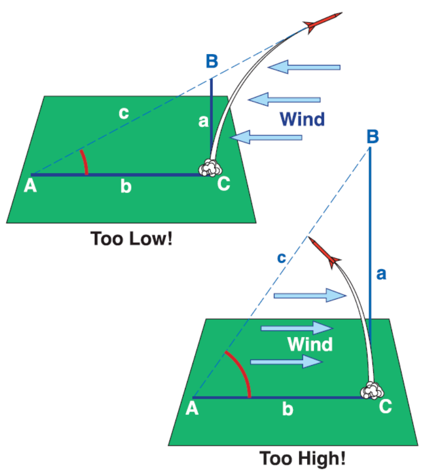
a (altitude) = tan A x 25 m
a = 20.97 m

Tracking becomes more challenging when rockets stray from straight up. Wind will cause the rocket to drift. Wind pushes the fins away while the nose cone points towards the wind. This causes the rocket to nose into the wind, resulting in larger altitude error estimates.

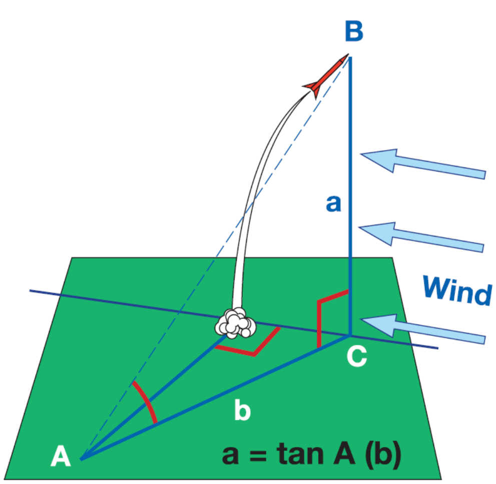
Angle	Tangent	Angle	Tangent
0	.0000	46	1.036
1	.0175	47	1.072
2	.0349	48	1.111
3	.0524	49	1.150
4	.0699	50	1.192
5	.0875	51	1.235
6	.1051	52	1.280
7	.1228	53	1.327
8	.1405	54	1.376
9	.1584	55	1.428
10	.1763	56	1.483
11	.1944	57	1.540
12	.2126	58	1.600
13	.2309	59	1.664
14	.2493	60	1.732
15	.2679	61	1.804
16	.2867	62	1.881
17	.3057	63	1.963
18	.3249	64	2.050
19	.3443	65	2.145
20	.3640	66	2.246
21	.3839	67	2.356
22	.4040	68	2.475
23	.4245	69	2.605
24	.4452	70	2.747
25	.4663	71	2.904
26	.4877	72	3.078
27	.5095	73	3.271
28	.5317	74	3.487
29	.5543	75	3.732
30	.5774	76	4.011
31	.6009	77	4.331
32	.6249	78	4.705
33	.6494	79	5.145
34	.6745	80	5.671
35	.7002	81	6.314
36	.7265	82	7.115
37	.7536	83	8.144
38	.7813	84	9.514
39	.8098	85	11.43
40	.8391	86	14.30
41	.8693	87	19.08
42	.9004	88	28.64
43	.9325	89	57.29
44	.9657	90	---
45	1.000	---	---

One method for reducing windy day error is to set up the baseline perpendicular to the wind direction. In the diagram, wind causes the rocket to drift to the right. This stretches the baseline a bit, but the overall error for the altitude is reduced. Challenge advanced students to come up with a way of determining how much the baseline changes when the rocket drifts to the right.

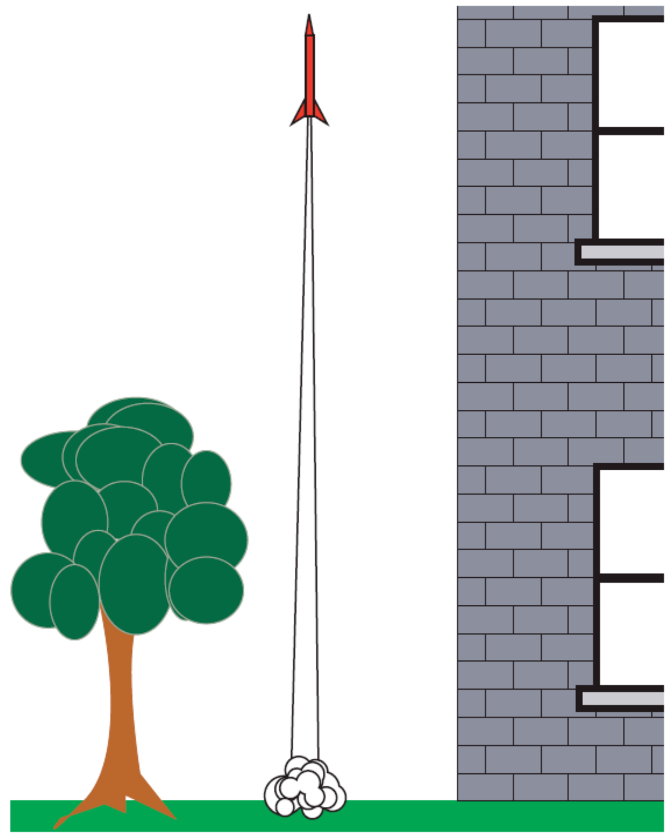
Wind effects can also be addressed by employing two tracking stations at opposite ends of the baseline. The baseline is stretched up and downwind. Each station measures the altitude the rocket achieves. Both stations calculate the altitude (one result will be higher than the actual altitude and the other lower) and divide by two.



Single Station - Tracking with Wind



Angle A is reduced, but line b is increased by the drift of the rocket.



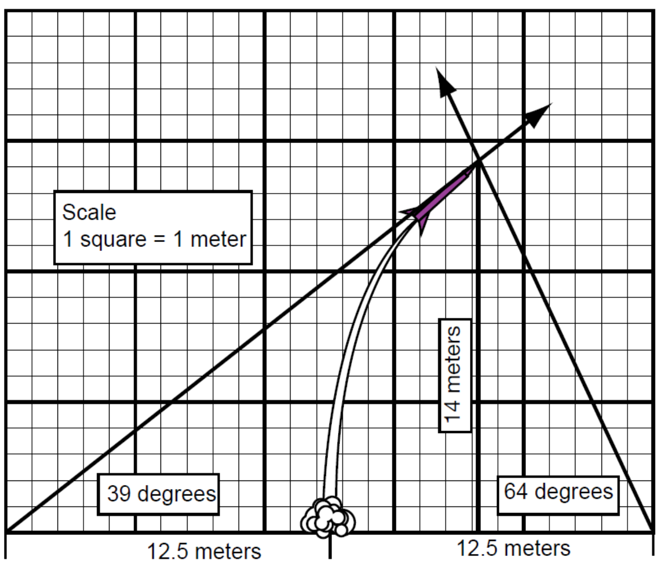
The above picture shows a different method for estimating altitude that is appropriate for lower grade students launching rockets that don't travel very high (e.g., straw rockets). Tracking students simply stand back and compare the rocket altitude to a building, tree, flagpole, etc.

A rough estimate of rocket altitude can also be made with a stopwatch. Time the total flight of the rocket and divide the time by 2. This yields the approximate time it took for the rocket to fall from its highest point back to the ground. The equation for falling bodies yields the altitude estimate. This method won't work if the rocket has a recovery system such as streamers or parachutes to slow its fall.

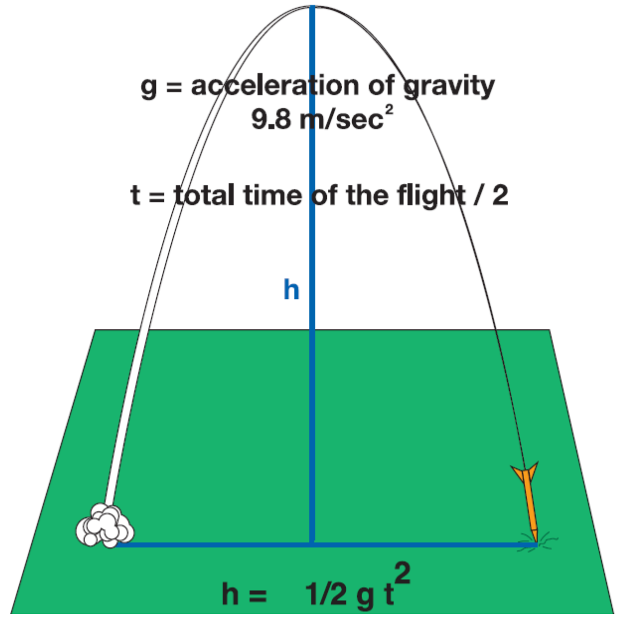
Sample Measurement:

Total flight time: 6.2 seconds
Falling time/2 = 3.1 seconds

$$h = 1/2\ g\ t^2$$
h = 1/2 x 9.8 m x 9.6 (the seconds cancel out)
$$h = 47.04\ m$$



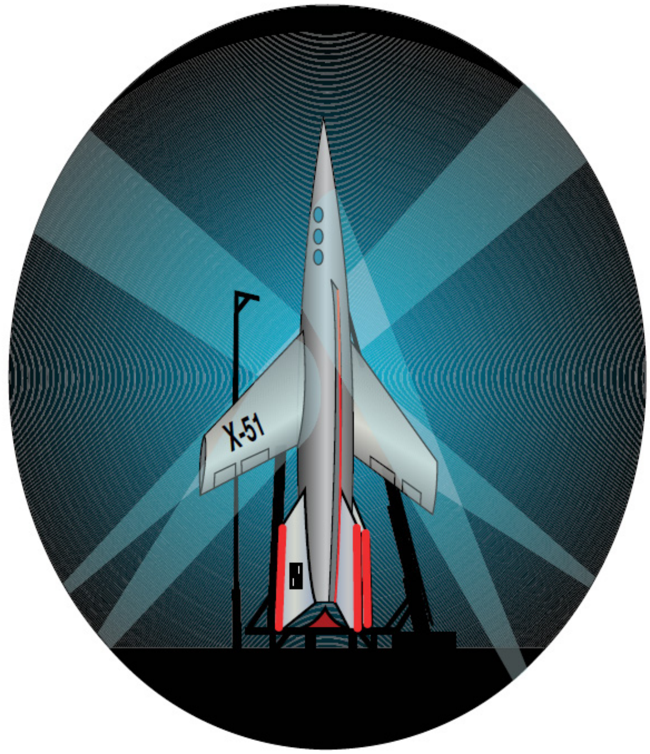
Here is a method for calculating altitude graphically. Two tracking stations are placed equidistant from the launcher. In this example, the stations are each 12.5 m from the launcher. Both stations measure the angle. On a piece of graph paper, a scale drawing of the stations and the launch site is made. Using the principle of similar triangles, the scale altitude of the rocket is measured - 14 m.



Provides a rough estimate of the altitude reached. Air drag on the rocket is a significant source of error.

There is a considerably more advanced method for altitude tracking that also involves two tracking stations. The method not only requires measuring the altitude angle of the rocket but also its azimuth, or compass direction, from the tracking site. These two measurements from each station provide very accurate estimates of altitude regardless of how much the rocket drifts from the vertical. The problem with the method is that it requires a tracking device similar to a surveyor transit plus experienced trackers to take the measurements. Rocket hobbyists, especially those that participate in high performance rocketry, use small recording altimeters inside their rocket payload sections. These rockets are easily capable of flights of several thousand meters, and ground tracking stations have a hard time providing consistent and accurate data. Upon recovery, the altimeters are read. For more information on two-station tracking and altimeters, search the Internet for "rocket altitude tracking."

Science Fiction and the Exploration of Space



Long before the first astronauts entered space, humans dreamed of space travel. Little about the space environment was known, and it seemed reasonable that the worlds above would be like the world below. In imagination, existing forms of transportation were sufficient to travel through the heavens. Storytellers, the first science fition writers, concocted adventures that carried people to the Moon on sailing ships and platforms suspended beneath eagles flying to catch legs of mutton dangled just out of reach by sticks. Giant spring-propelled sleighs and whirlwinds transported others. In one story, people traveled to the Moon on the temporary bridge created by Earth's shadow during a lunar eclipse.

During the nineteenth and twentieth centuries, fictional space explorers began to travel through space using rockets, cannons, and antigravity substances. In 1865, Jules Verne's story, De la terre á la lune, space explorers traveled to the Moon inside a cannon shell. In 1901, an H.G. Wells story propelled a spacecraft to the Moon with an antigravity substance called "cavorite" in The First Men in the Moon.

Near the end of the nineteenth century, motion pictures were invented. Space exploration science fiction (sci-fi) stories quickly moved to the silver screen. Sci-fi became one of the first movie genres. In 1902, the 8-minute Le Voyage dans la lune was released. Loosely based on Jules Verne's story, the movie startled audiences with its special effects.

Special effects scene from *Le Voyage dans la lune.*

Another early effort was Fritz Lang's 1929 movie *Fra im Mond.* It featured a Moon rocket launched from underwater.

Since the earliest film efforts, hundreds of space exploration sci-fi movies and weekly "cliff-hanger" serials have been created. They tell fantastic stories and stretch the viewer's imagination from Earth orbit to the deepest reaches of outer space. In the late 1940s, movies were joined by television and began broadcasting multi-episode space "westerns."

Today, space exploration sci-fi is among the most popular of film and television genres. Audiences love the stories, in part because they make almost anything seem possible. The stories they tell are often visionary. Long before the Apollo program, movies took humans to the Moon and Mars. Long before they were needed, movie and television makers created spacesuits and space maneuvering units. Large space stations were erected in imaginary orbits. The first space stations didn't reach Earth orbit until the early 1970s, but they orbited Earth in 1950s films. Every few days a new extrasolar world is discovered by scientists. Science fiction space explorers have been exploring those worlds for decades.

However improbable and however dopey some of the early special effects may now seem, space exploration movies and television have much to offer.

Comparing the science and technology they present to real space exploration is a fascinating endeavor. What has turned out to be real and actually happened? What hasn't happened yet? What is scientifically correct? What is scientifically incorrect or just plain silly?

Regardless of their scientific and technological authenticity, space exploration movies and television energize the imagination. They have excited the masses and have helped generate popular support that makes real space exploration possible.

Opportunities for Student Research

Space exploration sci-fi offers students interesting and entertaining research lines. Telling the difference between good and bad science and technology requires knowing good science and technology. Have students select a movie and review it for the science and technology presented. The following are a few questions students might try to answer in their reviews:

- What is the movie's title?
- When was the movie made?
- What is the plot (story) of the movie?
- How was space travel accomplished?
- Describe the vehicle used. What was its power source?
- Did the movie employ real science and technology? Give some examples.
- Did the movie make science and technology mistakes? Give some examples.
- Has NASA used similar science and technology to explore space? Explain.
- Did the movie accurately predict the future?Give some examples of how.

Here are a few suggested movies for students to review. All are available on DVDs from rental stores and online rental stores.

Scene from *Fra im Mond.*

Rocketship XM (1950)
Engine and fuel problems during flight cause Rocketship XM to zoom its crew past its original target, the Moon, and arrive at Mars instead. G forces and a destroyed Martian civilization are some of the challenges faced by the crew.

Conquest of Space (1956)
A space crew onboard a spinning wheel space station uses a space taxi during space walks to prepare their ship for launch. On its way to Mars, the crew dodges a flaming asteroid and deals with emotional problems.

Forbidden Planet (1956)
Humans travel by flying saucer to a distant world and meet their inner selves.

First Men in the Moon (1964)
An H. G. Wells story adaptation carries two accidental space travelers and an eccentric scientist to the Moon in an antigravity-propelled space sphere.

2001 A Space Odyssey (1968), 2010 (1984)
In a series of slow-moving visual experiences, humans travel to the Moon and Jupiter to follow mysterious alien signs. The film predicts space hotels and multi-year space missions.

Star Wars, Episodes I - VII (1977 - 2005)
Rebel forces battle an evil empire across a galaxy far, far away. A wide range of space vehicles, robots, and alien life sustain the action.

Star Trek (1979 - 2002)
In a series of movies Captains Kirk and Picard save Earth and strive for peace in the galaxy. Using warp drive and transporters, they boldly go where no humans have gone before.

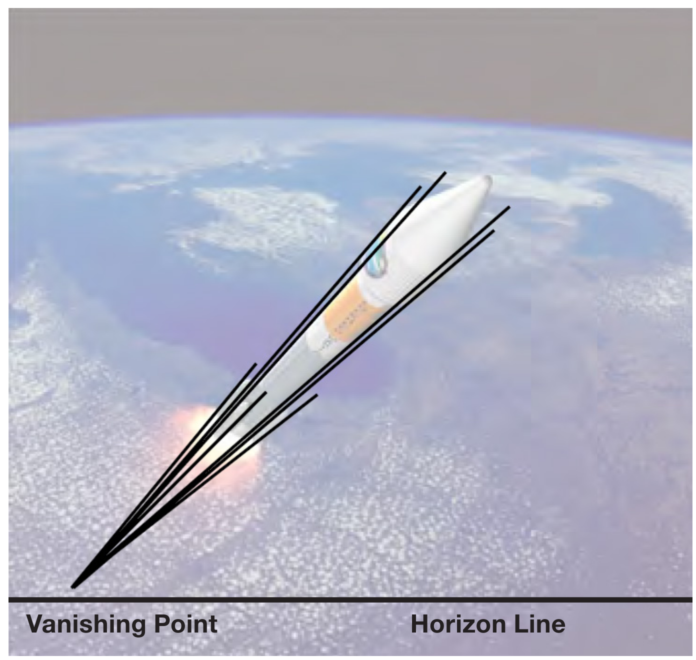
The Art of Spaceflight

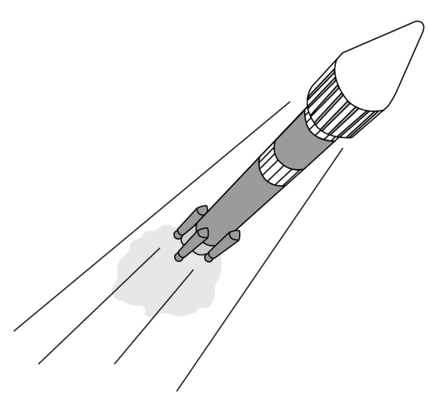
Space art has long been a key part of the exploration of space. In the 1950s, space artists such as Chesley Bonestell illustrated space exploration concepts for books and magazine articles. At the same time, animation artists at Disney Studios, working with space experts such as Dr. Wernher von Braun, showed what the first missions to space, the Moon, and beyond might look like. The American public was enchanted by dreams of spaceflight, and the American effort to explore outer space was born.

Space art continues to support the exploration of space. Besides promoting mission concepts with decision makers and the public, space art also provides scientists, engineers, and technicians a concept picture of what they are trying to do. They see what the systems they are working on look like when assembled together. Furthermore, space art excites and motivates students to pursue careers in science, technology, engineering, and mathematics.

Early space art was created using traditional materials and techniques. Many space artists still portray their dreams this way, but computer graphics has also found a place in space art. Spacecraft can be created using 3D technology that permits them to be rotated, enlarged or reduced, and brought forward or backward and layered on one of many backgrounds.

The three pictures on the right show how forced perspective is accomplished. The top picture is a space art conception of the 1999 Terra Spacecraft launched on an Atlas II rocket. The middle picture shows the relationship between horizon line and the vanishing point. The bottom picture shows a sketch based on the original but with a few lines added to emphasize motion.

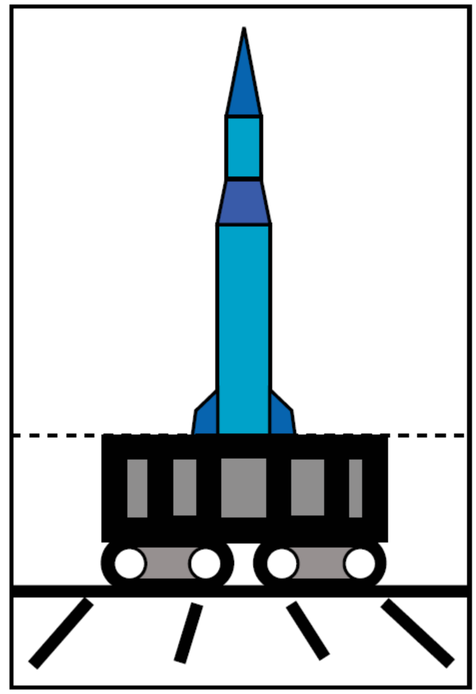




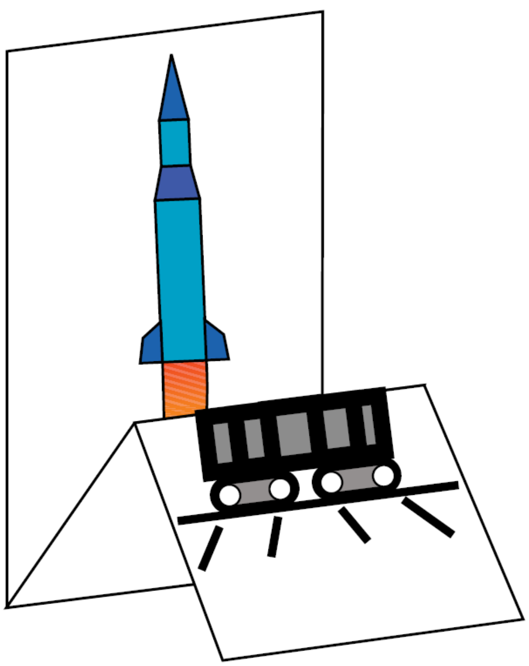
To create excitement, space artists often take advantage of forced perspective. For example, seeing a rocket launched from above provides a unique and exciting experience for the viewer. To create such a view, a horizon line and a vanishing point are laid out on the canvas or screen. Lines merging into the vanishing point provide guides for the 3D effect. Rockets, drawn within the lines, appear to go into or out of the picture.

Invite students to create their own space art. Space art begins with a mission. Students should first decide where they want their spacecraft to go. If the destination is Mars, what will the Mars spacecraft require for the mission? The length of time required to reach Mars will necessitate a larger vehicle than a vehicle for going to the Moon. More supplies and more crew will be needed, etc.

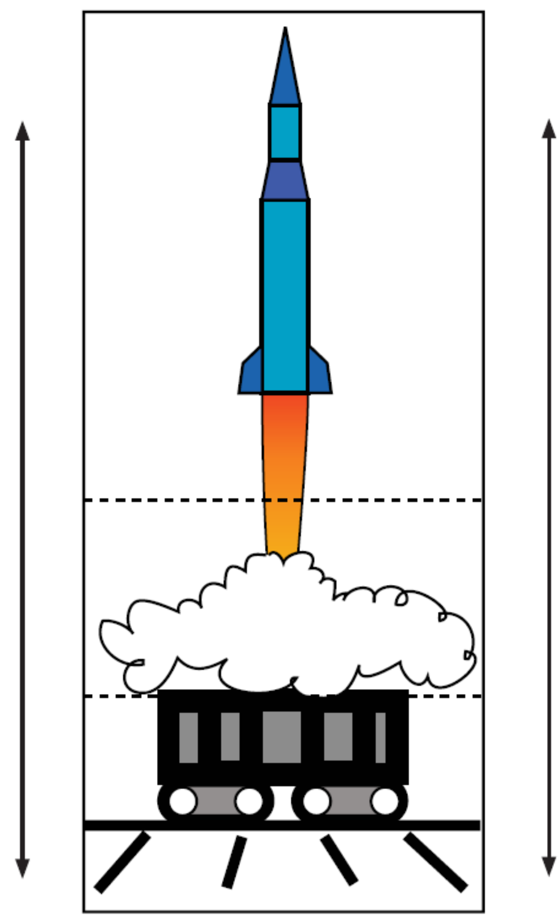
Space art is something that students of all ages can do. Young students can create an animated space launch with a simple paper fold trick.



Fold the paper to prepare the rocket for launch.



Make two folds in a strip of paper. Draw a launch platform on the lower segment. Draw a rocket launching on the upper two segments.



Pull on the top and bottom of the paper to open the folds and launch the rocket.

Rocket Glossary

Action - A force (push or pull) acting on an object. See Reaction.

Altitude - The height above Earth achieved by a rocket or other vehicle.

Artemis Program - NASA's new lunar exploration program, which includes sending the first woman and the next man to the Moon.

Attitude Control Rockets - Small rockets that are used as active controls to change the direction (attitude) a rocket is facing in space.

Balanced Force - A force that is counterbalanced by an opposing force, resulting in no change in motion.

Canards - Small movable fins located towards the nose cone of a rocket.

Case - The body of a solid propellant rocket that holds the propellant.

Center of Mass - The point in an object about which the object's mass is centered.

Center of Pressure - The point on the surface of an object about which the object's surface area is centered.

Combustion Chamber - A cavity inside a rocket where propellants burn.

Compressed - Material that is forced into a smaller space than normal.

Drag - Friction forces in the atmosphere that "drag" on a rocket to slow its flight.

Exploration Ground Systems (EGS) - NASA's program to develop and operate the systems and facilities necessary to process and launch rockets and spacecraft.

Fins - Arrow-like wings at the lower end of a rocket that stabilize the rocket in flight.

Gimbaled Nozzles - Tiltable rocket nozzles used for active flight control.

Igniter - A device that ignites a rocket's engines.

Liquid Propellant - Rocket propellants in liquid form.

Mass - The amount of matter contained in an object.

Mass Fraction - The mass of propellants in a rocket divided by the rocket's total mass.

Microgravity - An environment that imparts to an object a net acceleration that is small compared to what is produced by Earth at its surface.

Motion - Movement of an object in relation to its surroundings.

Movable Fins - Rocket fins that can move to stabilize a rocket's flight.

Newton's Laws of Motion - Laws governing all motion and in particular rocket flight.

Nose Cone - The cone-shaped front end of a rocket.

Nozzle - A bell-shaped opening at the lower end of a rocket engine through which a stream of hot gases is directed.

Orion - NASA's new spacecraft to carry humans on deep space missions.

Oxidizer - A chemical containing oxygen compounds that permit rocket fuel to burn in the atmosphere and space.

Passive Controls - Stationary devices, such as fixed fins, that stabilize a rocket in flight.

Payload - The cargo carried by a rocket.

Propellant - A mixture of fuel and oxidizer that burns to produce rocket thrust.

Reaction - A movement in the opposite direction from the imposition of an action. See Action.

Rest - The absence of movement of an object in relation to its surroundings.

Solid Propellant - Rocket fuel and oxidizer in solid form.

Space Launch System (SLS) - NASA's new super heavy-lift launch vehicle.

Space Station - An Earth orbiting space laboratory and testing ground for technologies needed for missions into the solar system.

Stability - A measure of the smoothness of the flight of the rocket.

Stages - Two or more rockets stacked on top of each other in order to reach a higher altitude or have a greater payload capacity.

Throat - The narrow opening of a rocket nozzle.

Thrust - The force from a rocket engine that propels it.

Unbalanced Force - A force that is not countered by another force in the opposite direction.

NASA Resources

The National Aeronautics and Space Administration (NASA) has an amazing collection of resources for the classroom. Educator guides, fact sheets, activity booklets, and lithographs, just to name a few, have been developed and are free to download. Photo galleries, a video database, and a YouTube channel are also available. Information about programs, projects, and current & future missions can be found on NASA's portal. To speed you and your students on your way to your space exploration adventure, a few useful links are highlighted below.

NASA Portal – www.nasa.gov

Artemis Program – www.nasa.gov/specials/artemis/

Space Launch System – www.nasa.gov/sls

Orion – www.nasa.gov/orion

Exploration Ground Systems – www.nasa.gov/egs

STEM Engagement – www.nasa.gov/stem

Social Media – www.nasa.gov/socialmedia

Image Galleries – www.nasa.gov/multimedia/imagegallery/index.html

Videos – www.nasa.gov/multimedia/videogallery/index.html

YouTube Channel – www.youtube.com/user/NASAtelevision

NASA Centers – www.nasa.gov/about/sites/index.html

History – www.nasa.gov/topics/history/index.html