<u>Education in Flight: Science: A Mini Course for Students in Grades 6-12</u>

Adopted from the U.S. Air Force for use by the EAA

The ***<u>Education in Flight: Science</u>*** short course provides a good example of how aviation science may be integrated into a physical science class. The topics covered involve traditional physical science topics such as density, buoyancy, pressure, Newton's Laws, waves, light, and sound. However, these topics are taught through applications to aviation.

<u>Topics Covered in the Mini Course</u>

1. Density and Buoyancy
2. Fluid Pressure and Flight
3. Helicopters and jets
4. Rockets
5. Waves

Lesson 1: Density and Buoyancy

Density

Density is operationally defined as the slope of a mass vs. volume graph. As such, the density of a material is a ratio of the change in mass for every change in one unit of specified volume. This ratio allows for a convenient comparison of how different materials fill a set space with matter. Because mass is usually measured in grams or kilograms, while volume is usually measured in cm3 or m3, density is usually expressed in g/cm3 or kg/m3.

The mathematical model for density, obtained from a mass vs. volume graph is :

$$\mathbf{m = Dv}$$

which may be rearranged to the form

$$\mathbf{D = m/v}$$

where D is density, m is mass, and v is volume.

Calculations-Density

1. Calculate the density of an object with a mass of 542 g and a volume of 17.0 cm3.
2. Calculate the volume of a substance with a mass of 9.30 g and a density of 15.0 g/cm3.
3. 2.80 L of a material has a mass of 3.50 kg. Determine the density of the material. (Hint: 1 L = 1000 cm3, and 1 kg = 1000 g)

Many ships that float on a top of water are made of steel, yet steel is heavier than water. The walls of balloons and zeppelins are made of materials heavier than air, yet they float upward into the atmosphere. How is this possible? The answer lies in the comparison between the density of the surrounding fluid and the overall average density of the craft or other object. By filling the craft with a much less dense substance, like air in water craft or helium in blimps, the overall average density of the craft (including its contents) falls below the average density of the surrounding fluid, and the craft floats in the fluid.

Mini-Lab – Aluminum Boats

Materials Needed:

1. wide, deep bowl
2. water
3. 10 small metal paper clips
4. Two 5 cm x 5 cm pieces of aluminum foil
5. Sewing needle

Procedure

1. Fill the bowl almost completely with water
2. Using one of the foil squares, place five paper clips in the center and tightly fold or ball the foil around the paper clips. Carefully place the foil ball onto the water in the bowl. Observe.
3. Make a boat using the other foil square by folding each of the edges upward 1.0 cm, making sure to leave no holes or open seams. Place the other five paper clips onto the boat. Carefully place the boat onto the water in the bowl. Observe.

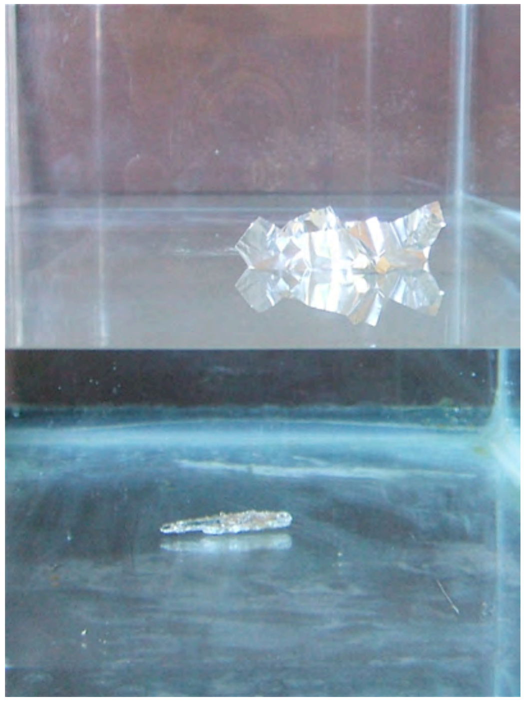


Photo shows crumpled aluminum foil and paper clips on the bottom and floating aluminum boat with paper clips on the top.

4. Without submerging the boat, carefully use the sewing needle to poke a small hole in the floor of the boat.

Buoyancy and Archimedes' Principle

The upward force exerted on an object which is either partially or fully immersed in a fluid is called the buoyant force. The origin of this force stems from the fact that the deeper one is in a fluid, the greater the pressure that is exerted by the fluid.

From an insight made by the ancient Greek mathematician/scientist Archimedes', Archimedes' Principle states that the weight of the fluid displaced by an object is equal to the buoyant force pushing upward on the object. For example, if an ice cube is dropped into a glass of liquid water, the less dense ice cube will float, but some of the ice cube will lie beneath the original surface level of the water. To determine the buoyant force that is pushing upward on the ice cube, just weigh the water that is moved out of the way by the floating ice cube; the weight of that displaced water is equal to the buoyant force on the ice cube.

An object floats, or is said to have buoyancy, if the force of gravity (weight) pulling downward on the object is less than the buoyant force that would result if the entire object were submerged. The ice cube described above floated because its weight was less than the maximum buoyant force that could be exerted on the ice cube by the water. During the actual floating, the ice cube will only sink into the water until the weight of the water displaced by the ice cube is equal to the entire weight of the ice cube. Needing no further buoyant force to offset the weight, the remaining portion of the ice cube will lie above the surface of the water.

On the other hand, the ice cube sinks (falls to the ground) when released in air because the weight of the ice cube is greater than the maximum buoyant force exerted by the air. Ultimately, buoyancy is an issue of relative weights of the object and the surrounding fluid. Since weight is tied directly to mass and density, the denser an object is, the more it will weigh, and therefore it will be less buoyant.

Mini-Lab Freshwater vs. Saltwater

Materials Needed

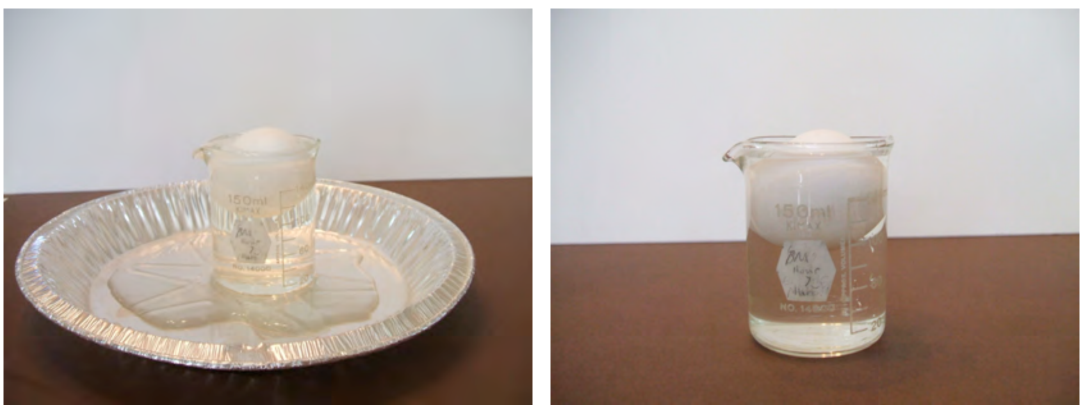
1. Uncooked egg in shell
2. 4 drinking cups
3. Large (1 L or larger pitcher)
4. water
5. Salt
6. Stirring rod or spoon
7. 2 aluminum pie pans

Procedure

1. Weigh egg. Weigh 2 empty cups and label them A and B. Record the weights.
2. Completely fill one unweighed drinking cup with water. Place the cup onto the pie pan to catch the overflowing water. Gently lower the egg into the water. Observe. Pour the water that spilled onto the pie pan into cup A. Weigh cup A containing the displaced water. Determine the weight of the displaced water only placed in cup A by subtraction and compare to the weight of the egg.

Egg sinks in tap water. The weight of the displaced water is less than the weight of the egg.

3. Fill pitcher more than half-full with water. Stir in salt until saturated.
4. Repeat step 2 using the other unweighed cup, saltwater mixture, and cup B.



Egg floats in salt water solution. The weight of the displaced salt water is the same as the weight of the egg.

Mini-Lab Density and Buoyancy

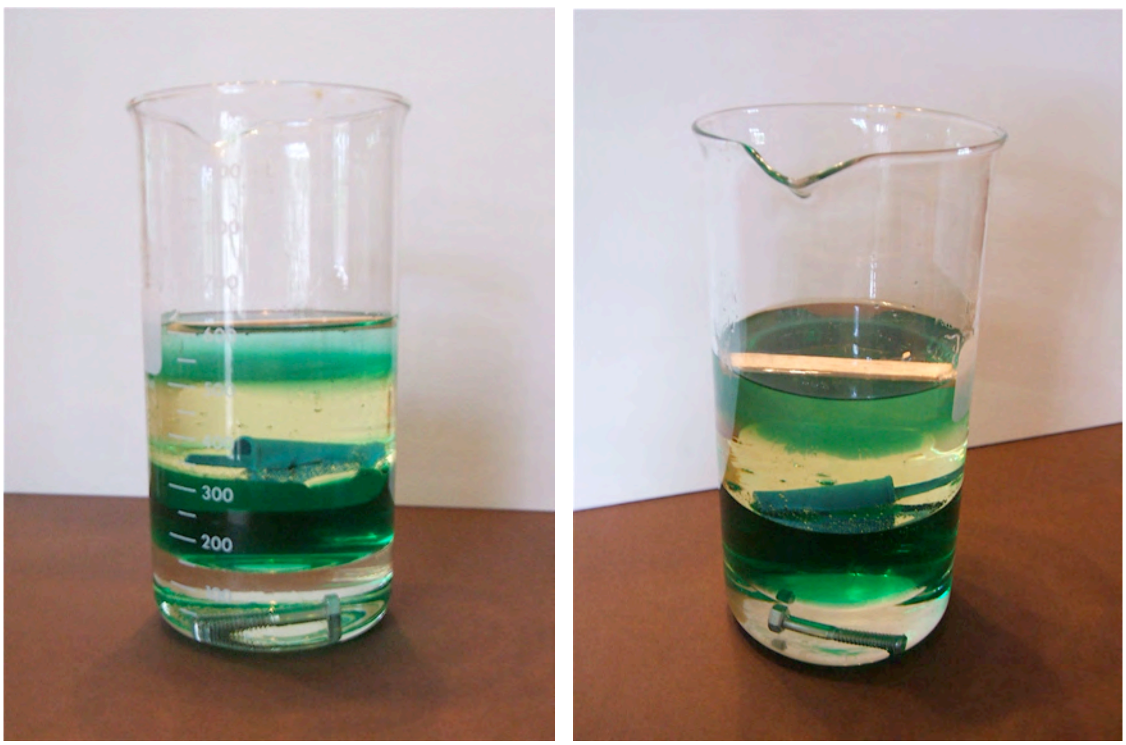
Materials Needed:

1. large 1000 mL glass beaker
2. small 400 mL glass beaker
3. stirring rod or spoon
4. 2 cm3 piece of balsa wood
5. polyethylene pen cap
6. small steel bolt
7. 200 mL of distilled water
8. food coloring (dark red or blue)

9. 200 mL of ethyl alcohol
10. 200 mL of vegetable oil (yellow)
11. 200 mL of corn syrup

Procedure:

1. Carefully place the steel bolt, the polyethylene cap, and the piece of balsa wood into the large beaker.
2. Pour the water into the small beaker. Stir in five drops of food coloring.
3. Slowly pour the colored water into the large beaker and observe.
4. One at a time, slowly pour the corn syrup, then the vegetable oil, and then the ethyl alcohol into the large beaker. Allow the mixture to settle before adding the next solution. Observe after each pour.



The bolt is on the very bottom, the plastic pen cap is resting on the water, and the balsa board is floating on the very top of the ethyl alcohol.

5. Gently stir to mix the contents of the large beaker. Observe.

Data: Complete the data table shown below.

Object/Substance	*Density (g/cm3)*	*Location (1 = top, 7 = bottom)*
Corn Syrup	1.38	
Ethyl Alcohol	0.79	
Vegetable Oil	0.82	
Water	1.00	
Steel	7.81	
Balsa Wood	0.12	
Polyethylene Plastic	0.92	

Analyses:

1. List the objects and substances in the order that they came to rest, starting at the top of the large beaker and ending at the bottom of the large beaker.
2. How is your list in question 1 related to the densities in the table above?
3. What do you know about the density of air based on this experiment?

Conclusion:

Explain how density of fluids (and solid objects placed into fluids) affects buoyancy.

Extensions:

1. Frozen water floats on top of liquid water. Explain how the density of water changes when water undergoes the physical change of freezing or melting.
2. Research the densities of helium and atmospheric air. Explain why both float on water. Also, determine how much helium is needed to float a foil balloon in air if the uninflated balloon has 24.3 g of mass and 2.8 cm3 volume.

Lesson 2: Fluid Pressure, Bernoulli's Principle, and Lift

Pressure is operationally defined as the slope of a graph of force vs. area. As such, the pressure exerted is expressed as a ratio of the change in force applied on a surface for every change in one unit of specified surface area. This ratio allows for a convenient comparison of different force exertions for a set amount of surface area. Because force is usually measured in pounds or newtons, while area is usually measured in in3 or m3, pressure is usually expressed in lbs/in2 or N/m3. In addition, 14.7 lbs/in2 is also considered 1 atmosphere of pressure, and 1 N/m2 is called a 1 Pascal of pressure

Based on the observations of Swiss scientist David Bernoulli in the 1700's, Bernoulli's principle states that as the speed of any fluid-liquid or gas-increases, the pressure in that fluid, decreases. This occurs because the fluid becomes relatively less dense than its surroundings, causing it to float ahead of or above more dense substances. This phenomena creates slipstreams for bicyclists and birds (drafting for racecars) to closely follow behind their leaders with less air resistance.

<u>Mini-Lab Bernoulli Under a Funnel</u>

Materials Needed:

1. ping pong ball
2. flat table or floor
3. funnel large enough to lie face down over the top of the ping pong ball with little extra room

Procedure:

1. Place ping pong ball on flat table top
2. Place funnel with its large mouth face down, centered over the top of the ball, flat on the table top.
3. Plow as hard as possible through the small drain hole in the funnel. Observe the ping pong ball as you blow.

Add to Bernoulli's Principle the notion that nature abhors (hates) a vacuum and you'll understand why dust and leaves seem to "chase" a quickly passing truck down the street. You will also see the beginning of controlled flight.

When the force of lift is greater than the weight of a place (caused by gravity pulling the plane's mass downward), the plane rises. When the force of lift is less than the weight of the plane, the plane falls. Lift is accomplished using Bernoulli's principle. A plane's wing, called an airfoil, is curved more severely on the top than on the bottom. Therefore, air passing around the wing must travel faster to cover the greater distance over the top of the airfoil than across the bottom. This results in lower air (fluid) pressure aobe the wing, and the wing is pulled upward (lifted) to fill the pressure gap.

Airplane Flight

Four forces work together to determine whether an airplane rises or falls, speeds up or slows down: thrust, drag, lift, and weight. Thrust is the force which pushes a plane forward through the air. Propellers, jet engines, tailwinds, and other outside sources, even catapults, can provide needed thrust. Without enough thrust, air won't move past the plane quickly enough to produce lift. Drag is the force that resists forward motion and acts against thrust. Drag is created primarily by friction between the plane an the atmosphere. If the force of drag is too great, then the plane will move slower and will lose lift. The gravitational attraction between the plane and the earth, results in pull downward on the plane , giving it weight. As described earlier, when the force of lift exceeds the plane's weight, the plane rises.

Modern airplanes are sophisticated machines with thousands of moving parts. The propellers, the jet engines, or the rocket engines provide thrust for the plane. The wings are shaped like airfoils to create lift using Bernoulli's Principle. The elevators are hinged, horizontal surfaces attached to the back tail of the plane. Elevators control the plane's movement upward or downward. When the elevators are raised, the tail is forced downward, the wings are force upward, and the plane climbs. The ailerons are hinged, horizontal surfaces attached to the back, outer edges of the wings of the plane. The ailerons are used to turn the plane. As one aileron rises, the opposite aileron lowers, raising one wing and lowering the other, tilting (or banking) the plane toward the lower aileron. The rudder is a hinged, vertical surface attached to the tail of the plane that helps the plane enter and recover from turns by swinging the tail to the left or right.

Mini-Lab Paper Airplane Designs

Materials Needed:

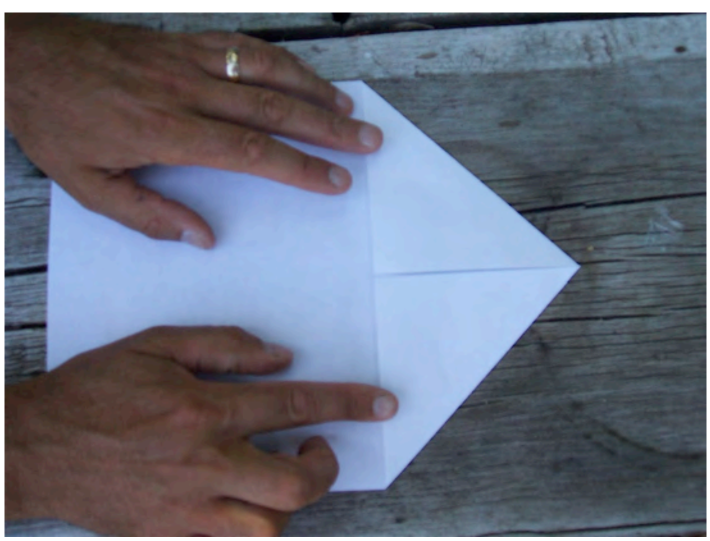
1. Crisp paper without holes
2. scissors

Procedure:

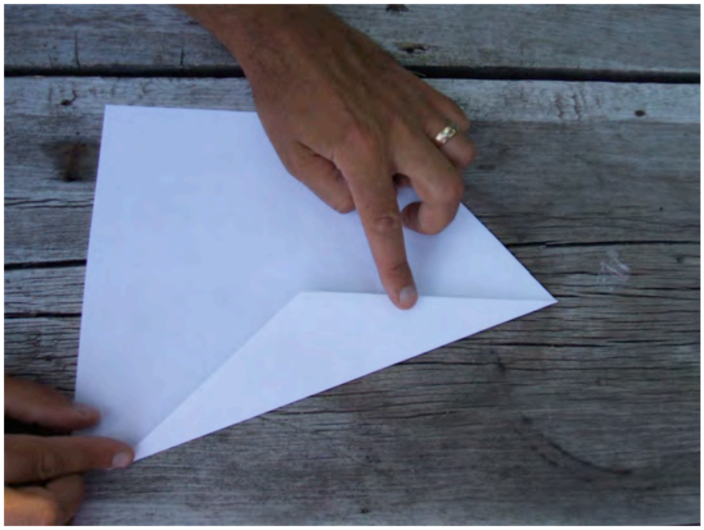
1. Create both paper airplanes from the designs shown below.

Paper Plane Model #1

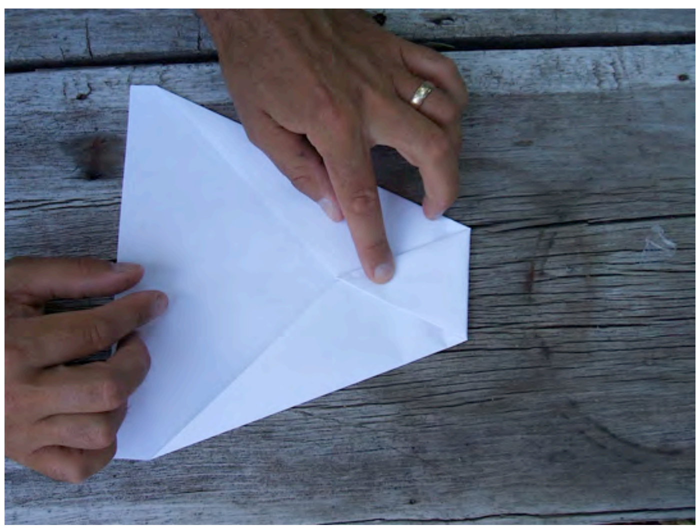
- Fold the top left and top right corners, such that, they meet at the mid-line of the 8-1/2" x 11" sheet of paper.



- Fold the left and right folds over again, such that, they again meet at the mid-line.

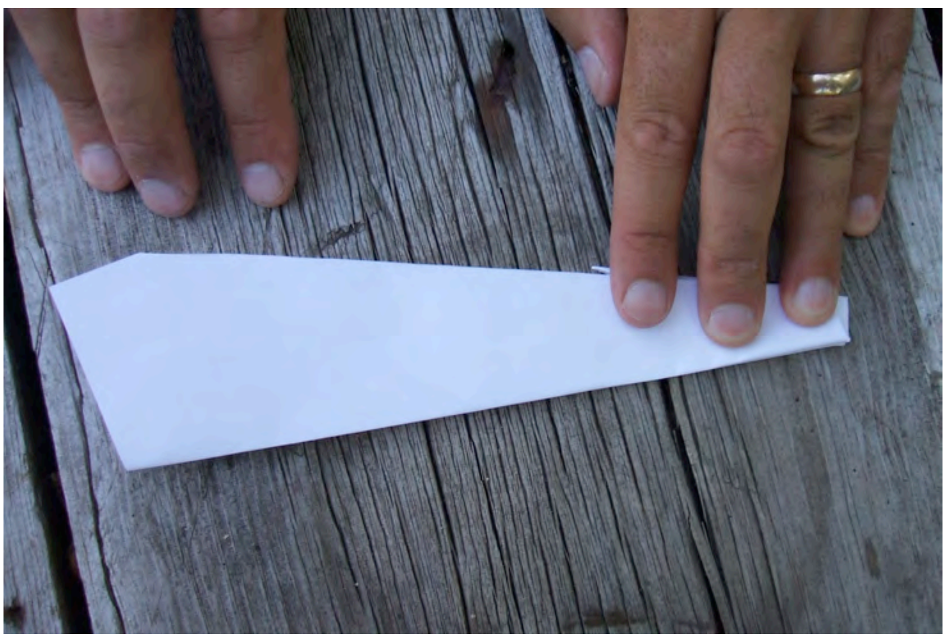


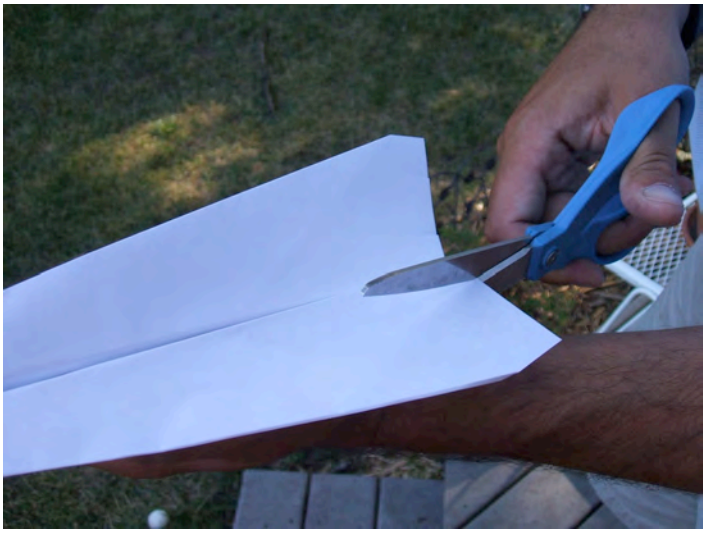
- Fold the tip down, such that, the tip ends up at the vertex of the other two sides.



- Flip the paper over and fold the left side to the right side, such that, the outside edges of the wings line up.

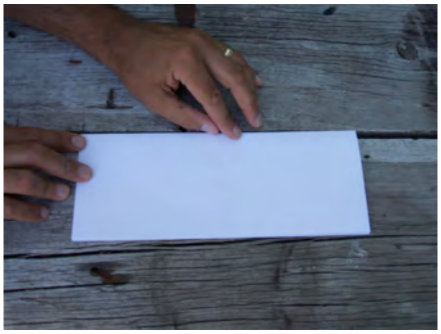
- Fold the wings down, such that, the outer edge of the wing lines up with the base of the center section. Cut two slits, one inch apart, along the back edge of each wing for elevator adjustments. You can add wing dihedral by tilting the wings slightly upward. Now, you are ready to fly.



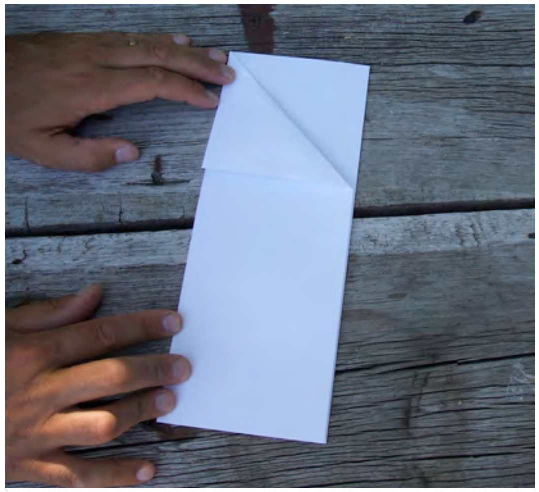


Paper Plane Model #2 (Courtesy Science in Flight…Classic Design)

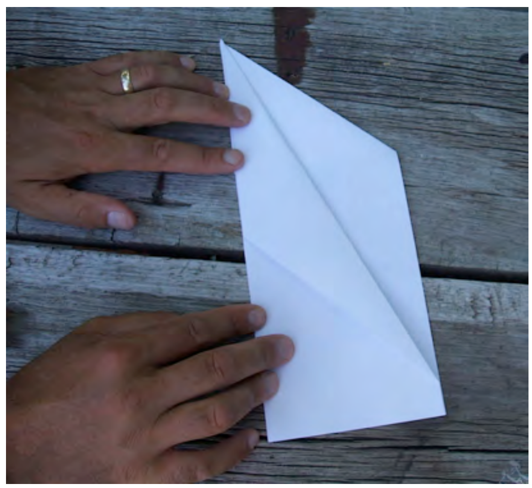
- Take an 8- ½" x 11" sheet of paper, fold it in half lengthwise. Make sure the folds are sharp, crisp, and precise.



- Fold the short edge of one side down to the first fold (producing a 45^{o} angle). Repeat for the other side.

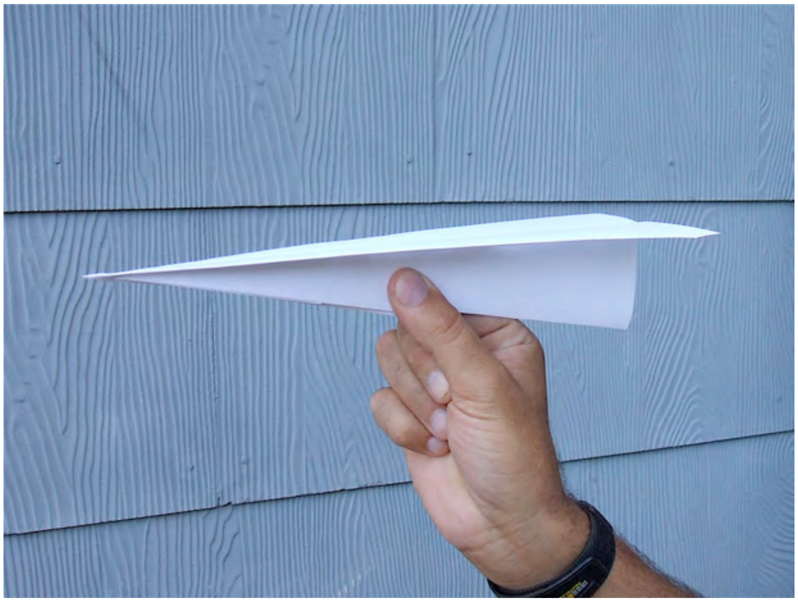


- Fold down the new fold you have created to the original fold down the center. Repeat for the other side.



- Fold down the new fold you have created to the original fold down the center. Repeat for the other side.

- Hold center and open wings out. Now throw!



2. Launch each plane. Observe the flight of each plane.
3. Use the scissors to cut flaps at the tail end of the plane. Fold one flap upward and the one flap downward. Launch the airplane. Observe its flight.
4. Fold both flaps upward or downward. Launch the airplane. Observe its flight.

Lesson 3: Helicopters and Jets

Helicopters

The roots of the helicopter date back at least as far as the 15^{th} century drawings of the Italian artist and inventor Leonardo da Vinci. Today, helicopters can carry thousands of pounds of cargo, weaponry, and passengers over very long distances with superb control, but the key mechanics of the helicopter haven't changed much.

A helicopter's rotor blades create lift essentially by screwing into the air much the same way that a metal screw slices and pulls forward into solid matter. Taking advantage of Bernoulli's Principle, a lower-pressure region is generated on one side of the blades, and the blades are pulled into that region. Basically, a helicopter rotor is very much like an airplane propeller, pulling its aircraft along by utilizing pressure differentials on the two sides of the airscrew. Because a helicopter's rotor pulls its vehicle upward while the force of gravity on the helicopter, by the earth, pulls the craft downward, a helicopter has a distinct advantage over most winged airplanes: the capability to hover in place by creating a net vertical force of zero.

Mini-Lab Air Movement Through A Fan

Materials Needed:
1. paper
2. goggles
3. table
4. large box fan

Procedure
1. With the fan turned off and unplugged, inspect the pitch of the fan blades.
2. With the fan plugged in, turn the fan on and then off. Inspect the direction of rotation of the fan blades as the blades come to a stop.
3. Turn on the fan. Release a piece of paper vertically a few inches behind the fan. Observe.

4. Repeat step 3, this time releasing the paper in front of the fan.

5. If the fan has variable speeds, repeat this process on different fan speeds.

A pilot can control the tilt (or pitch) of the rotor blades to move a helicopter in almost any direction. Just as a toy kite gains lift by tilting through moving air, so does tilting a helicopter's rotor blades create lift for an aircraft. However, unlike a kite, a helicopter must move itself through moving air rather than taking advantage of air naturally flowing past it. Thus, lesser pitch in the blades decreases lift, and gravity may pull the helicopter downward. However, a helicopter can also rise straight upward with great stability. By tilting the entire saucer created by the spinning of the rotor blades, a helicopter pilot can make the vehicle move forward, backwards, or even sideways, even while ascending or descending through the air. Additionally, control over the pitch of the smaller set of revolving vertical blades near the tail helps to turn or keep the helicopter straight. Such maneuverability is the other major advantage that helicopters have over most other winged aircraft.

Basic Jet Engines

A jet engine is any mechanical device that discharges a jet of fast-moving fluid (liquid, gas, or plasma) to generate a reactionary force of thrust. Technically, this category includes water jets, ramjets, and rockets, though the term is jet engine. Modern definitions, limit the term jet engine to gas turbine engines like turbojets and turbofans, which involve a continuous series of compression and exhaust activities.

If one releases an open-nozzle balloon filled with compressed air, a jet of air rapidly escapes through the nozzle, and the balloon travels in the opposite direction. The escape of air is an action, and the balloon's movement is a reaction. Isaac Newton described this in his Third Law of Motion.

Mini-Lab Balloon Jet

Materials Needed:

1. rubber balloon (cylindrical balloons work best)
2. plastic drinking straw
3. tape
4. fishing line

Procedure

1. Thread a long piece of fishing line through the straw. Ties the ends of the line to two places far apart, such that, the string is taut.
2. Inflate the balloon and pinch the nozzle shut. Tape the balloon to the straw aligning the nozzle with the string. Release the balloon. Observe.

In all types of jets, air is drawn into a combustion chamber, compressed, mixed with injected fuel, and ignited. Rapidly expanding gases created by the burning of the mixture rush out of the rear nozzle. This action generates the reaction of forward movement.

A ramjet has few moving parts. Air is compressed in a ramjet by the plane's forward movement, which means that a ramjet can only work when the plane is moving. Thus, a "mothership" has to launch a ramjet. A pulsejet is only slightly more sophisticated, having an inlet valve that controls the amount of air intermittently entering the engine.

Turbojets, Turboprops, and Turbofans

The primary parts of gas-driven turbojet engines are enormous sets of fans call turbines. Facing the front of the airplane, the first set of turbines is the turbocompressor, which draws a large volume of air into the front of the engine by spinning to take example of Bernoulli's Principle. The air molecules are then forced into narrow tubes, where the air molecules are extremely compressed and heated.

The hot, compressed air next enters the combustion chamber in the middle of the engine, where the air is mixed with jet fuel that is sprayed into the chamber by a fuel injection system. The heat of air (often assisted byan electrically generated spark) ignites the fuel, which produces even greater levels of heat and pressure in the chamber. As the hot gases expand within the combustion chamber, their only path of escape is to blast out the exhaust nozzles at the back of the turbojet engine.

Before escaping through the nozzles, however, the superheated and pressurized gases pass through a bladed turbine wheel. The turbine wheel then turns the main shaft, which operates the front compressor, increasing the efficiency of the engine by capitalizing on the gases' high velocity, which the engine created in the first place.

Additionally, some aircraft, especially supersonic planes, employ afterburners before the jet of high velocity gases fully leave the engine. These devices burn any remaining traces of unused jet fuel at extreme temperatures (exceeding 3000^{o}F), thus expanding, pressurizing, and accelerating the gases to generate even greater forces as they are pushed outward through the nozzles at the rear of the engine. The resulting force of the exhaust provides the action against which the plane is thrust forward in reaction, following Newton's 2nd and 3rd Laws of Motion.

While turbojet engines accelerate a small mass of air by a large amount, propellers accelerated a large mass of air by a small amount. Turbojets, accordingly, are used primarily to provide thrust for faster aircraft that travel relatively long distances. On slower (especially subsonic) or shorter flight aircraft, turboprop engines that use a gas turbine powered propeller are more common.

Jet engines on most modern aircraft today belong to the even more sophisticated category of turbofan engines. In these engines, the turbocompressor not only acts as an intake fan, but also provides airflow to a bypass duct that sends its less heated air outside the compression chamber to cool the turbine blades and vanes to prevent melting.

Lesson 4: Rockets

Rockets and Newton's 3rd Law of Motion

At least 800 years ago, the people of China had mastered the basics of solid fuel rockets in the form of gun powder propelled fireworks that carried color burning chemicals in casings of bamboo and paper. Today, rocket engines also drive supersonic planes, carry satellites into orbit around the earth, propel weaponry missiles, and launch human and their creations into outer space, although the basic mechanics of rockets haven't changed much.

If you throw a baseball forward while standing on a skateboard, the ball will exert a force backward on you equal to the force you exert forward on the baseball. The forward push you exert on the ball is the action and the push exerted by the ball on you is the reaction. Similarly, when you fire a gun, the explosion in the chamber pushes the bullet forward out of the barrel, results in backward push on the gun itself. English mathematician and scientist Sir Isaac Newton described this event in his Third Law of Motion. For every action there is an equal and opposite reaction. Rocket flight is based on this principle.

Some rockets use solid fuels, often including black gunpowder and a mainly rubber binder. Starting with the 1926 experiments of Robert Goddard, many other rockets, including rockets that launch missiles, orbital craft, and planes employed by the U.S. Air Force, use various liquid fuels. The most common of these chemicals are hydrogen peroxide, various forms of alcohol and gasoline, and liquefied forms of hydrogen, fluorine, or liquid oxygen maintained under extreme pressure and temperature conditions. The advantage of liquid fuel over solid fuel is control over thrust; solid fuel burns completely once ignited.

Gases created by the burning of such propellants try to rush outward in all directions within the thrust chamber of the rocket, but the gases are released only through the exhaust nozzle. This exhaust is the action which, by Newton's 3rd Law of Motion, generates the reaction of thrusting the craft forward or upward. The difference , though, between a rocket engine and a shotgun is that the shotgun must throw only a single ounce of mass approximately 700 miles per hour. Indeed, 700 miles per hour is much faster than your arm can throw a baseball, but the amount of force exerted by a firing shotgun can't drive a multi-ton supersonic aircraft through the atmosphere, especially for a sustained run.

The necessary difference between a shotgun's mechanism and the engine of a rocket ship lies primarily in the fuel mixture. The typical mixture for a single explosion gun powder is 75% nitrate, 15% carbon, and 10% sulfur. A slight tweaking to a 72%/24%/4% mix can produce a decent rocket fuel that can generate a rapid, yet sustained, burn. Of course, far more sophisticated chemical combinations are used in today's high-powered rocketry.

Rockets and Newton's 2nd law of Motion

Rockets designed to launch their payloads into outer space beyond the earth's atmosphere require huge amounts of force from their engines, but even smaller craft on lower trajectories still need enormous amounts of force. Sir Isaac Newton's Second Law of Motion states that the acceleration experienced by an about is directly proportional to the unbalanced force exerted on the object and is inversely proportional to the mass of the object. In equation form, Newton's 2nd Law is **$a = F_{net}/m$**.

Calculations: Newton's 2nd Law

1. Calculate the unbalanced force, in Newtons, needed to accelerate a 3.2 kg ball at 25 m/s2.
2. Determine the resulting acceleration if a 100 N unbalanced force is applied to
   - A 5 kg mass.
   - A 10 kg mass.
   - A 20 kg mass.

Newton's 3rd Law explains how exhausting gases backwards, through a nozzle, results in a forward thrust or force on the rocket. Newton's 2nd Law allows one to calculate the change in motion that will occur as a result of this thrust, given the mass of the rocket. Rocket ships, rocket planes, and rocket driven missiles have masses from dozens of kilograms to millions of kilograms. For an object to travel to outer space, its rocket must produce enough thrust (resulting in an acceleration) to reach and maintain an escape velocity of 25,000 miles per hour. Such efforts require enormous amounts of fuel.

When fuel burns, the fuel's mass in solid or liquid form is the same as the mass of the gases made after combustion according to the Law of Conservation of mass. Therefore, rockets must carry very large amounts of fuel mass and must tremendously accelerate the mass of that fuel through chemical combustion reactions in order to generate the desired thrust. Just imagine how much mass must be used simply to produce enough force to drive a 150 pound pilot for 10 minutes, and you'll understand why many rocket-driven vehicles carry dozens of times more mass in fuel than the mass of their payloads.

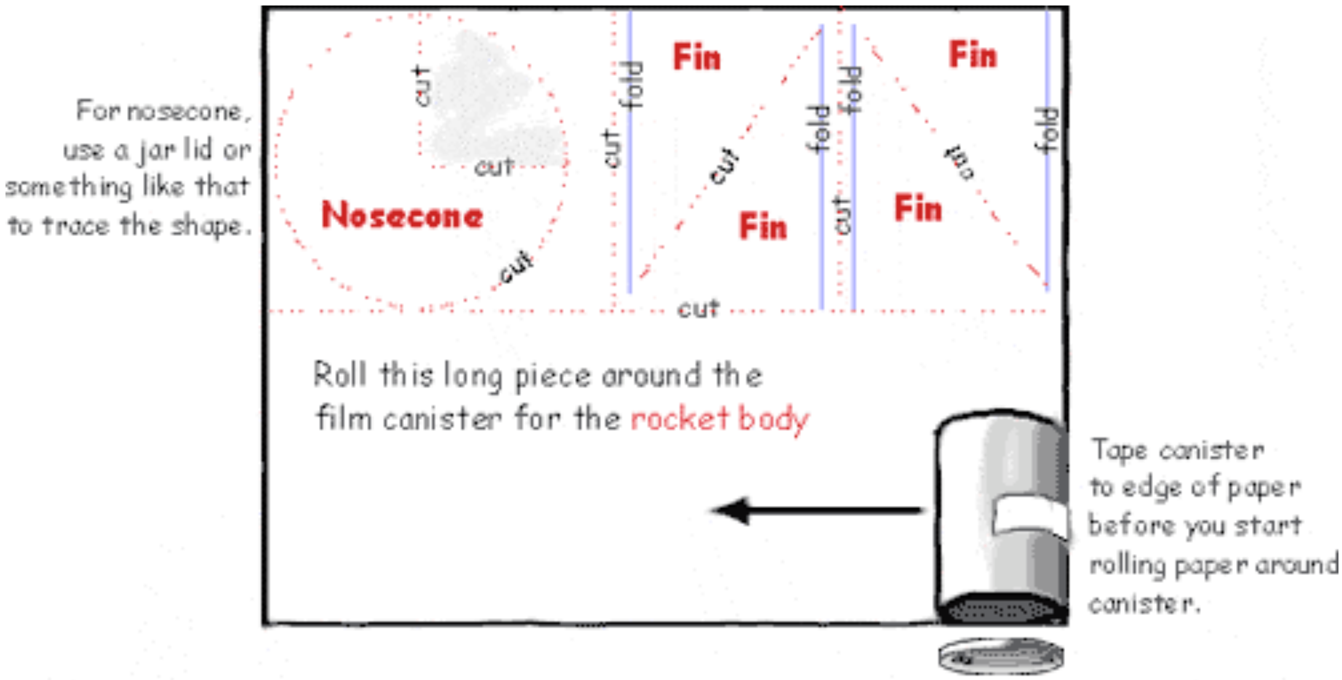
Lab Pop Rockets

Materials Needed For Each Lab Group:

1. 35 mm film canister with internal cap
2. 2-3 effervescent antacid tablets, each cut into halves
3. several pieces of paper
4. scissors
5. cellophane tape
6. water
7. stopwatch
8. small coins or other attachable weights
9. goggles
10. wide, open space with hard, flat floor

Procedure

1. Using paper, scissors, and tape, assemble a nosecone and an open cylinder body around the outside of the film canister, leaving the open end of the canister facing downward (away from the nosecone) so that fuel may be added later. Choose your own design and record the design details.



2. Turn the rocket upside down. Carefully pour water into the film canister, filling approximately ½ of the canister's volume without wetting the paper.
3. Quickly perform the following: Drop into the canister a half tablet of the effervescent antacid. Close the canister by inserting the lid. Place the rocket right-side-up onto the hard floor, and back away from the rocket.
4. Have a lab partner time the flight of the rocket using a stopwatch. Observe the flight, and record observations.
5. Collect the rocket, disassemble the paper body, and repeat the above steps after changing a design detail. Perhaps attach extra weights (small coins), change the amount of water in the rocket, or change the body structure. However, only change one variable at a time.
6. Repeat several more times, continuing to vary the selected variable.

Data: Complete the Table Below After Each Launch

Design Details	*Time of Flight*	*Other Flight Observations*

Analysis:

1. Describe any patterns in your observations based on the changes in your design.
2. Determine the height your rocket flew during each flight based on the air time.
3. What chemical reaction took place with the rocket fuel you used?

Extension: How would your results differ if vinegar had been used?

Lesson 5: Waves

Sound Waves: The Doppler Effect

Sound is created when matter vibrates at a frequency that can be interpreted by a receiving device (like the human ear). As the frequency of vibration increases, the pitch of the sound grows higher. For example, a middle C note on a piano is created when the key's hammer strikes a string that is tuned to vibrate at 261.64 Hz (vibrations/second), while the string of a slightly higher D note vibrates at 293.68 Hz.

You may have notice that as fast-moving objects like cars and airplanes rush past your ear,
Their pitch changes from a high note (as the object approaches) to a lower note (as the object moves past and away). This phenomena, the Doppler Effect, occurs because the sound waves created by a moving object appear to the observer to be emitted closer together in front of the object and farther apart behind the object. This observed phenomena is due to the relative motion between sound source and sound receiver.

As an airplane moves forward while making a continuous sound, the airplane chases its own waves, and each new sound wave is bunched closely behind the previous wave. When the compressed or bunched waves hit your ear, your ear receives them rapidly after one another, or at a higher frequency than they were emitted. Behind the airplane, the waves are spread farther apart as the airplane "runs away" from those sound waves traveling backwards. The result is that the waves behind the plane reach your ears more spread apart, or at a lower frequency than they were emitted. Note the airplane pilot moves with the sound source and does not hear the Doppler Effect due to his or her own plane.

Mini-Lab Doppler Effect in Water

Materials Needed:

1. large rectangular baking pan
2. Water

<u>Procedure</u>

1. Pour water into the baking pan about 1 inch deep

2. Beginning at one end of the pan, tap your finger vertically into the bottom of the water and vertically back out of the water again. Repeat the taps in a straight line toward the other end of the pan without tapping beyond the expanding waves.
3. Observe the waves hitting the pan walls in front of and behind your finger.

The finger is moving from right to left across this pan. Notice the closer spacing of the waves in front of the finger and the larger spacing of waves behind the finger.

Sound Waves: Mach Number and Sonic Booms

The speed of sound in dry air is described as $v = 331.4$ m/s + T(m/s^{o}C), where T represents the temperature in ^{o}C. Molecules in warmer air vibrate faster and, therefore, are more often nearer to one another, increasing the rate at which sound energy can be transferred from one molecule to another. Thus, at 0^{o}C sound travels through dry air at about 331.4 m/s (or 769.664 miles per hour), while at 20^{o}C the speed of sound in dry air is slightly faster at 343.6 m/s (or 769.664 miles per hour). Humidity and pressure both affect air density, so they also affect the speed of sound through air.

Velocity of a very fast aircraft is described using Mach number, which tells how many times the speed of sound (at 0oC) an object is moving. For example, a plane traveling at mach 5.1 has a relative velocity of 331.4 x 5.1 = 1690.14 m/s.

For many years, airplane pilot and engineers believed that the so-called “sound barrier” could not be broken. This doubt arose from failed attempts to fly aircraft at supersonic speeds, as planes vibrated violently and sometimes fell out of control. Today we know that most of the problems at speeds near the sound barrier were created by a phenomena called the compressibility effect. This effect occurs at flow speeds above 250 miles per hour (and is particularly noticeable near Mach I) as some of the energy of the aircraft compresses the air and changes its density, thereby altering the amount of drag on the aircraft.

When humans finally broke the sound barrier, a new phenomena burst onto the scene: the sonic boom. As an airplane continually races forward and passes through sound waves emitted by its engine, the waves begin to overlap in an expanding cone moving away from and behind the plane, particularly in the downward direction where air is denser. The amplitudes of the overlapping waves add together, and for sound waves, amplitude translates into volume. Thus, the cone of overlapping sound waves sounds like an enormous boom as the shock wave strikes the ears of people beneath the flying plane.

Mini-Lab Shock Wave in Water

Materials Needed:

1. large rectangular baking pan
2. Water

Procedure

3. Pour water into the baking pan about 1 inch deep
4. Beginning at one end of the pan, tap your finger vertically into the bottom of the water and vertically back out of the water again. Repeat the taps in a straight line toward the other end of the pan , but make each tap at or slightly beyond the expanding waves.
5. Observe the waves overlapping and hitting the pan walls to the sides of your path.

Electromagnetic Waves: Radar

Radar is an acronym that stands for **ra**dio **d**etection **a**nd **r**anging. The mechanism takes advantage of two properties of waves, reflection and the Doppler Effect. Regardless of whether they are mechanical (like sound waves or water waves) or electromagnetic waves (like radio, light or microwaves), all waves reflect off surfaces with an angle of reflection that is equal to the angle of incidence with respect to and across a normal (line perpendicular to the surface of reflection).

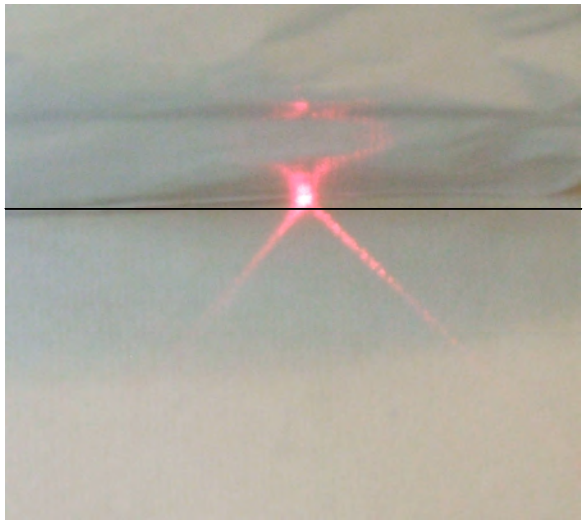
Mini-Lab Law of Reflection

Materials Needed:

1. aluminum foil or small mirror
2. tape
3. flat table
4. two books
5. laser pointer
6. protractor

<u>Procedure</u>

1. tape aluminum foil or small plastic mirror to the face of one book
2. Secure the book in a vertical position, with the center of the reflective surface directly over the middle of the protractor.
3. Point the laser pointer at some angle of incidence over the top of the protractor toward the center of the flat side of the protractor (and reflective surface).



This is a top view of the reflection. The laser pointer is located in the lower right and the aluminum foil reflector is about 2/3 of the way up the picture, as indicated by the dark line.

4. Note the angle at which the light reflects off of the protractor.
5. Vary the angle of incidence and note the angle of reflection.

Radar works by sending a short pulse, often 0.0000016 s or less) of electromagnetic waves in a particular direction and then listening for waves that are reflected back off of a surface. Radio waves and microwaves instead of sound waves are used because of their high frequency, high speed, greater longevity, and wider variety of frequencies (to undermine detection). Usually, the pulses are frequency modulated to increase reflection potential against a variety of sizes and textures of surfaces.

Depending on size, shape, texture, and other factors about the reflecting surface and the wave carrying medium, reflected wave energy is usually less than 10% of the transmitted energy of the original pulse. Thus, radar emitting devices must have supporting computers that accurately record direction, frequency, and speed of the sent radio waves. Receiving devices must be equally detailed and very sensitive; radar reception antennas typically are shaped like parabolic dishes to increase the number of captured return waves.

Additionally, a radar mechanism can calculate the speed of a moving object by accounting for a Doppler shift created by waves reflecting off of moving objects. When radar waves encounter a reflecting surface that is moving toward them, the waves are accelerated and compressed on the return by the speed of the moving object. When a reflecting surface is moving away, the radar waves are decelerated and rarefied (spread apart) on the return. The radar mechanism's computer record the time that the waves take to return and then calculates the position and velocity of the detected moving object.

Some modern airplanes use a variety of stealth modifications to minimize detection by radar and other devices. Interestingly, many stealth modifications are creative lower tech ideas, including paint color schemes that undermine visual detection, subsonic travel to preclude audio detection by sonic booms, and flawlessly smooth, flat hulls with sharp edges that simply reflect radar away from its emission source. Some stealth planes don't even have tails. Far more sophisticated technological advances that enhance stealth capabilities include internalized engines whose heat generation and other input and output signatures are disguised by baffling devices, graphite-ferrite microspheres in surface paints that absorb electromagnetic energy, and layers of gold and indium foil on windows to prevent detection of distinguishable shapes inside the cockpit. Even the inner layers of stealth aircraft have geometries of varying angles and shapes to avert detection when frequency modulated radar waves penetrate the outer hull. Ultimately, engineers know that no aircraft can be made totally invisible, but stealth aircraft sacrifice some structural stability and speed in favor of significant decreases in detectability.

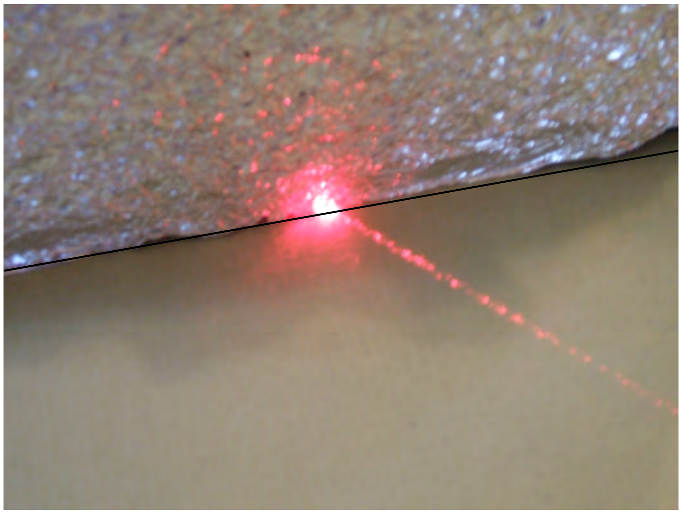
Mini-Lab Wave Deflection

Materials Needed:

1. aluminum foil
2. tape
3. flat table
4. two books
5. laser pointer
6. protractor

Procedure

1. Crumple the aluminum foil and tape the foil to the face of one book
2. Secure the book in a vertical position, with the center of the reflective surface directly over the middle of the protractor.
3. Point the laser pointer at some angle of incidence over the top of the protractor toward the center of the flat side of the protractor (and reflective surface).



This view is above and to the left. The laser pointer is located in the lower right. A black line has been added to indicate the edge of the foil. Notice the lack of precision of the reflection due to the many directions of the "stealth surface".

4. Note the angle at which the light reflects off of the protractor.
5. Vary the angle of incidence and note the angle of reflection.