Lesson Plans, Labs, and Demonstrations for the Glider and Boomerang

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Boomerang and Glider Physics 101

Note: The following are some of my notes I use to teach the physics of flight to my physics students. These are not the whole notes (it would take up too many pages), but should give you a basic understanding of the physics being used and ways to demonstrate or explain some of these concepts. Also, depending on the grade level you teach, you may have to scale up or down on some of the information. Good luck!

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There are 4 principles of physics that are used to describe the flight of a boomerang or glider. The principles are:

1. inertia
2. center of gravity, cg (center of mass)
3. gyroscopic principles (primarily used for boomerangs)
4. Bernoulli's principles
   - pressure
   - lifting force
   - air resistance due to turbulence
   - relative velocity

Inertia

Galileo said that a body at rest will remain at rest and a body in motion will remain in motion until acted upon by an external force. This was later adopted as Newton's 1st Law of Motion. There are two ways to quantify inertia.

For objects at rest compare their mass. The heavier object has more inertia than the lighter object when both are at rest.

Demonstration

Have students push an empty roller skate with their small finger as fast as they can. Next, have that same student push the roller skate, with a brick in the skate, as fast as they can. Repeat the process, each time adding a brick. Stop at 4 or 5 bricks.

Ask the question, "Which trial has the most inertia? The roller skate with 0, 1, 2, 3, 4, or 5 bricks?" Experience, not physics, tells most students the correct answer. Now ask why they answered the way that they did.

Chances are, they will say, "Because the heavy roller skate was harder to push." Basically, objects with more inertia are harder to push.

For objects in motion compare the product of mass and velocity. Inertia of a moving object is called momentum. If a heavy and a light object are to have the same momentum, or inertia, then the light object needs to travel faster than the heavy object.

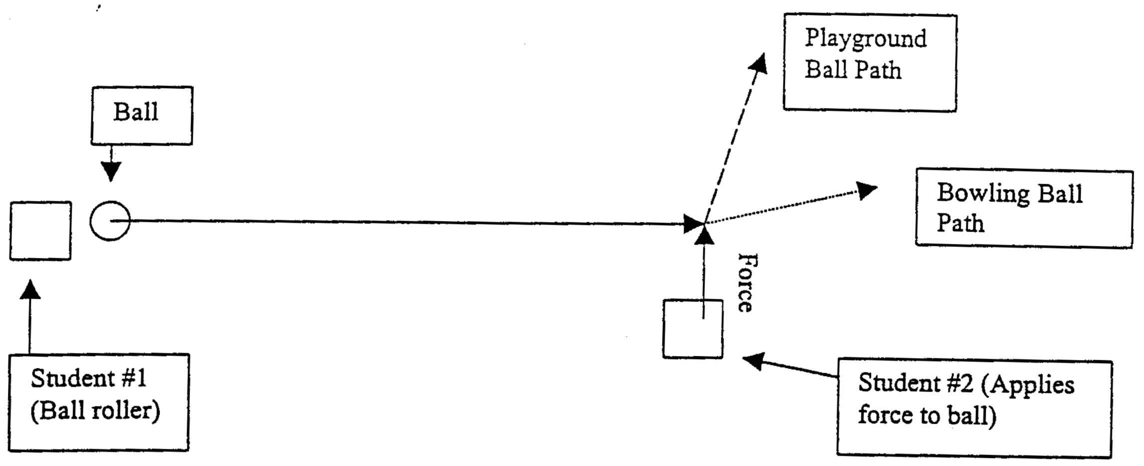
$momentum_{light} = (mass_{light})(velocity_{light})$
$momentum_{heavy} = (mass_{heavy})(velocity_{heavy})$

If the 2 momentums are the same, then:
Little mass --> Big velocity
Big mass --> Little velocity

This also means that if 2 objects of different masses travel the same speed, then the heavier object will require more force to stop or change its direction. Or, the heavier object will require more time to make the turn. Experienced drivers know this. They feel the car drift to the outside of a curve when it is heavily loaded and going too fast. The speed at which the car begins to drift to the outside of the curve is higher for the same lighter (empty) car. The lighter car will be able to make a tighter, smaller diameter turn.

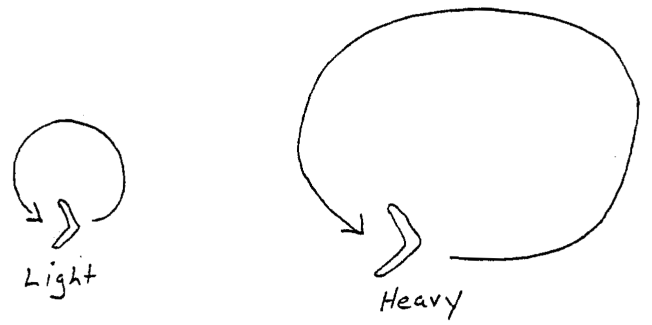
Demonstration

Get a bowling ball and a playground ball that is relatively the same size. Clear an area on the floor to roll the balls. Position the students as shown below.



Have student #1 roll the bowling ball towards student #2. Instruct student #2 to push the ball away from them at a 90° angle when it is even to him. Next roll the play ground ball with the same speed towards student #2. Instruct student #2 to push the ball with the same amount of force as they did with the bowling ball. The ball will not travel in the same arc as before. The heavier ball has more inertia and therefore requires more force to turn it in the same diameter circle.

Boomerangs and gliders work the same way. A heavier boomerang and glider will travel in a larger radius than a lighter one because of its inertia.

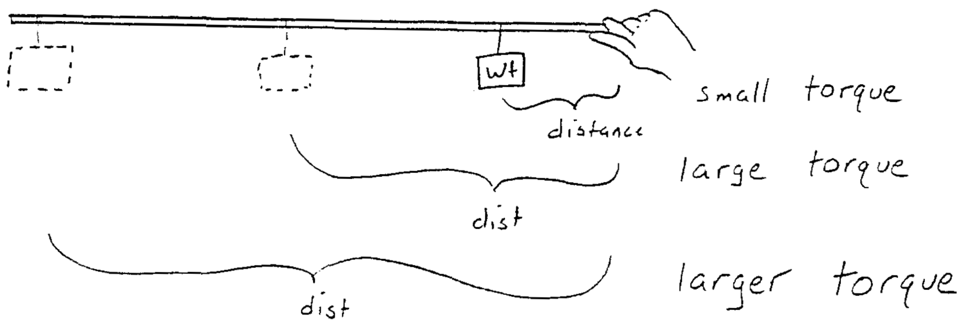


Center of Gravity (cg)

Center of gravity (also called center of mass) is the balance point for an object. All applied forces act on or about the center of gravity. Forces that act around the center of gravity creates torque.

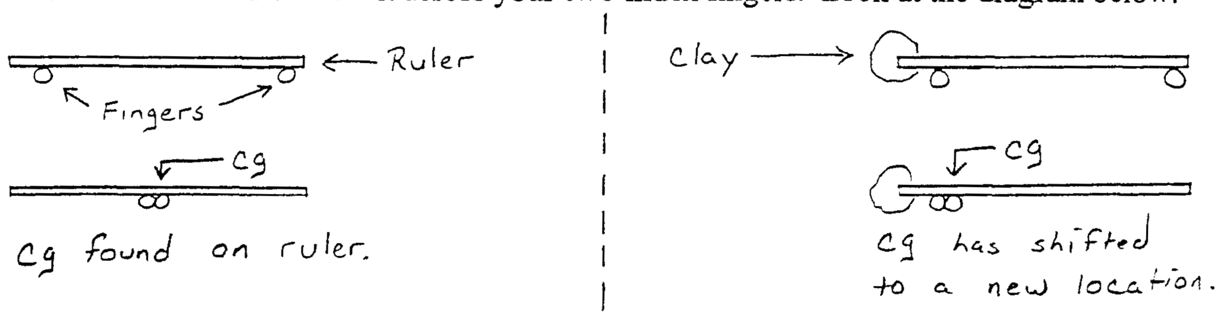
Demonstration

Torque is dependent on two things, the weight of an object and the distance it is from the pivot point (usually the center of gravity). The formula for torque is: **Torque = weight of object x distance from the pivot point**. Torque is needed to cause objects to rotate. One way to demonstrate the effects of torque is to use a large dowel rod and a weight (1 – 2 pounds will be fine). Hold firmly onto one end of the dowel rod so that the dowel rod is held horizontally. The wrist becomes the pivot point. Tie a piece of string to the weight and hang the weight so that it is close to the hand. Slowly move the weight down the rod, away from the hand. The person should experience greater difficulty holding the dowel rod horizontally. The person is experiencing an increase in torque. As the distance increases, the torque also increases.



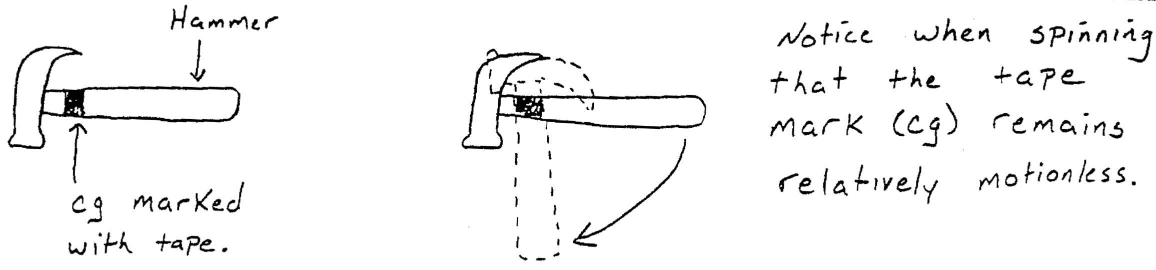
Demonstration

Take a ruler and balance it across your two index fingers. Look at the diagram below.

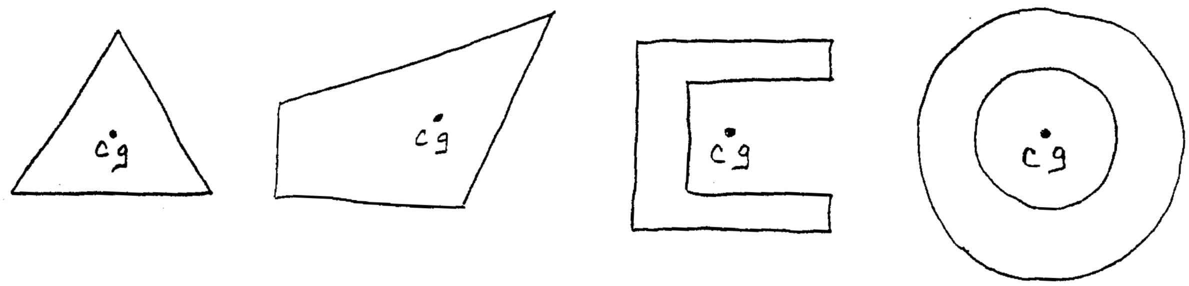


With your fingers at either end of the ruler, slowly slide them towards each other. They will meet at the ruler's center of gravity. Next, place a lump of clay (or tape pennies) to one end of the ruler. Repeat the same procedure as above. Your fingers will still meet at the center of gravity. This time, the center of gravity will not be located in the center of the ruler as before. Repeat the same procedure for a hammer. Find its cg and wrap a piece of tape around this spot.

Making sure that everyone and everything is out of harms way, toss the hammer straight up while giving it a spin along its various axis. Note that the hammer revolves around its center of gravity. The spot with the tape does not appear to move much from the rest of the hammer.

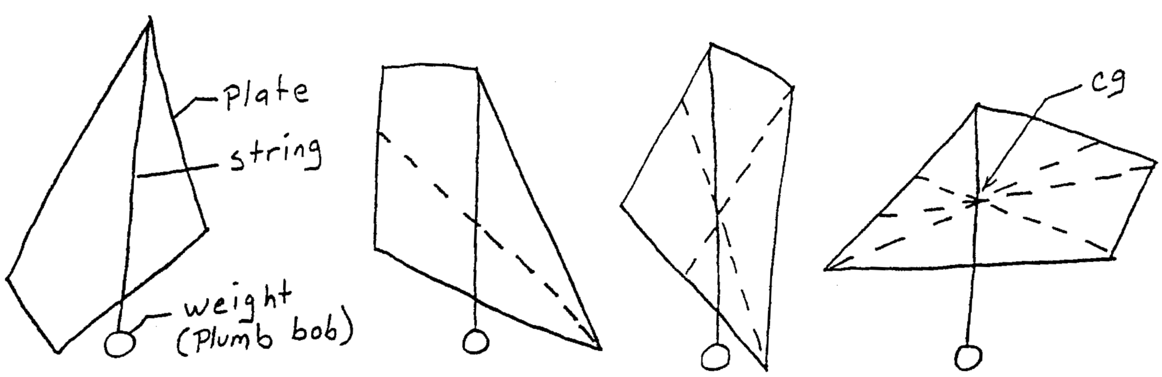


Use irregular shaped plates to show the cg on an object. Some objects may have its cg where there is no material. In other words, the cg will be located somewhere beyond the object itself. (i.e. donuts and boomerangs)



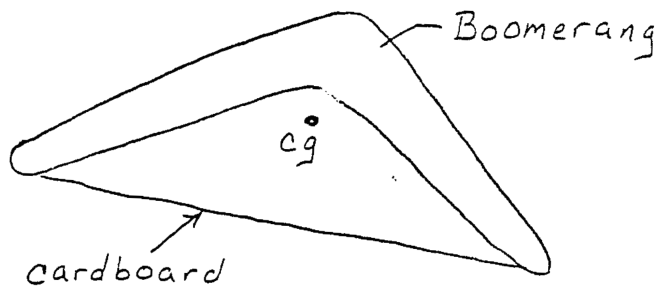
Demonstration

Get some irregular shaped plates, string, chalk, and a plumb bob (or some weight to attach to the string). Put holes in at least 4 different locations along the edge of the plate. From one of the holes, allow the plate to freely hang. Hang the plumb bob from the same location. Mark the path of the plumb bob's string. Do the same thing for all the other holes. All the marked lines intersect at the cg. Place a large dot at the cg and toss and spin the plate. The cg will remain relatively motionless from the rest of the plate.



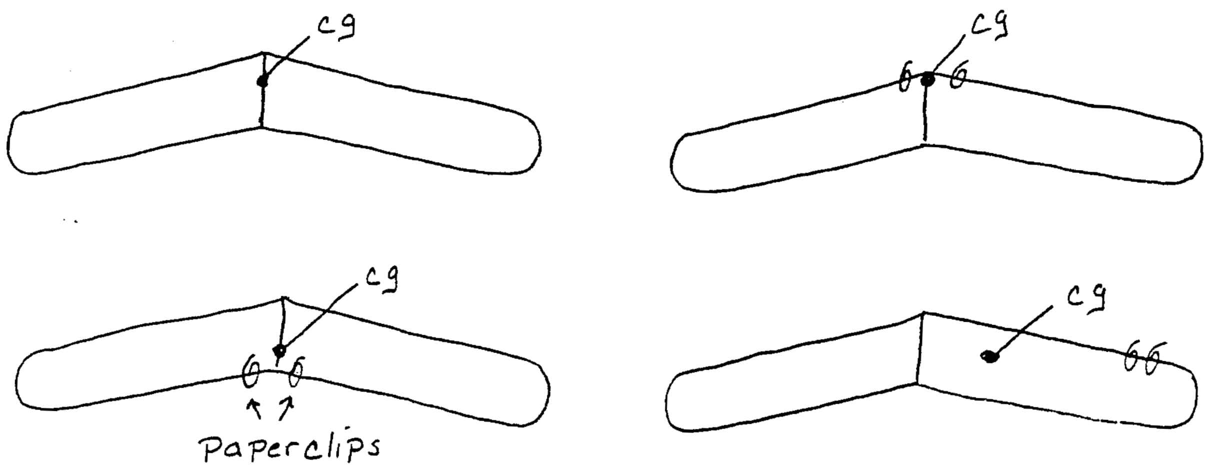
On some shapes, such as a ring, the cg is not located on the object itself. Still, when the object is tossed in the air with a spinning motion, it will rotate around its cg.

Do this same experiment using a boomerang as the irregular shaped object. The cg is not located on the boomerang itself, but below the inside of the elbow. To mark the cg of the boomerang, tape a piece of triangular shaped cardboard or manila folder to the boomerang. The cardboard should closely match the shape of the boomerang. The cardboard should cover the area inside the boomerang's bend. See the diagram below.



Toss the boomerang vertically up in the air with a spin on it. Don't use too much spin or the boomerang may curve to the side. Notice that the boomerang rotates around the cg that was marked in the experiment.

Try the same thing with the glider. Mark the location of its cg. Try different shapes of wings and notice what happens to the location of its cg. Try placing paperclips either at the nose or the wing tips of the glider and notice what happens to the location of the cg. Place extra paperclips on one of the end of the wings, find the location of the cg. Then fly the glider and notice what happens to its flight. Move the paperclips to another location of the glider, find the cg, and notice what happens to its flight characteristics.

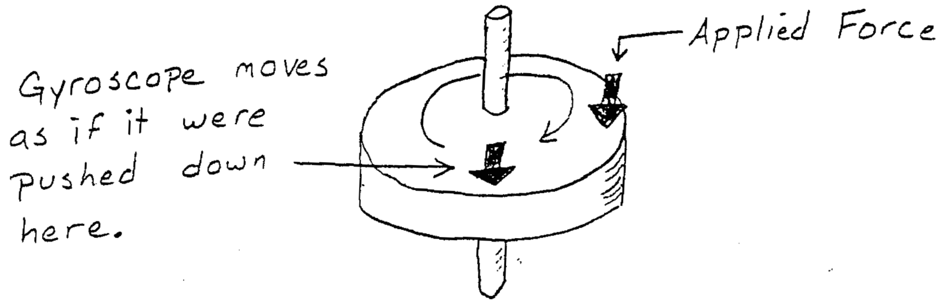


Gyroscopic Principle

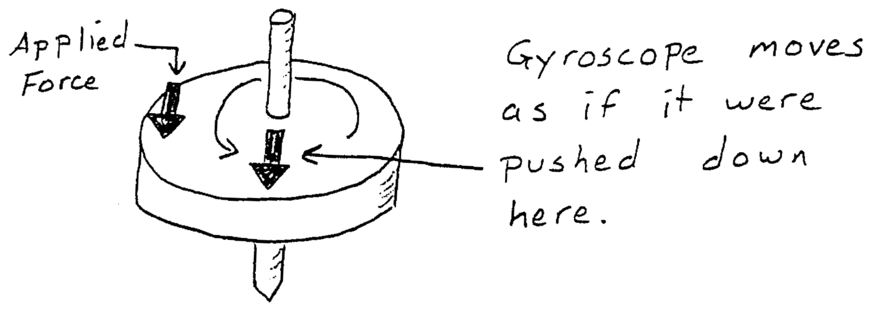
The gyroscopic principle is perhaps the most important concept if the flight of the boomerang is to be understood. The best way to understand the gyroscopic principle is by example.

Demonstration

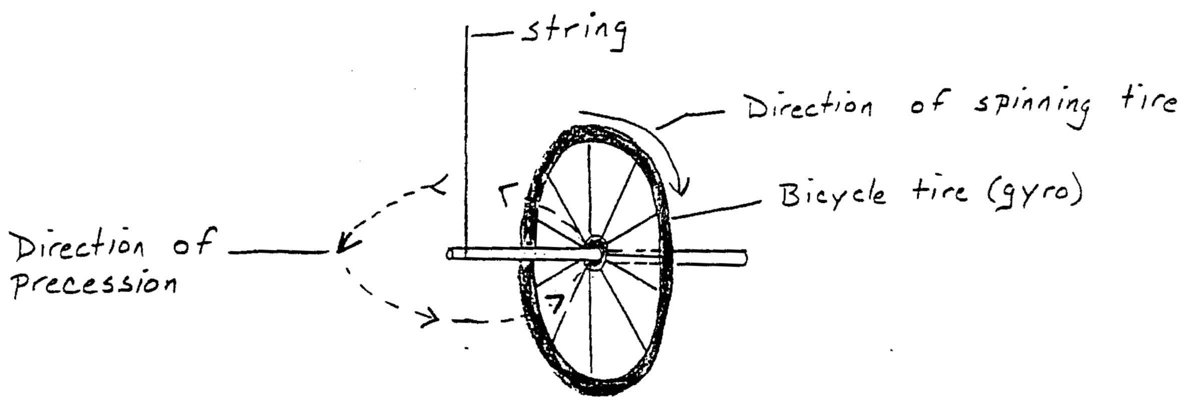
Take a toy gyroscope and spin the center disk. Now place the gyroscope on its end. Usually, gyroscopes come with a little plastic stand for just this purpose. Push down on the right side of the gyroscope's frame. Be careful not to touch the spinning disk. The gyroscope behaves as if the force were applied to the front of the frame. Below is a diagram to illustrate what happened.



The gyroscope principle says that an applied force will act a quarter rotation later. If a gyroscope is rotating counterclockwise and a force is applied to the left side of its frame, then the gyroscope will tilt as if the force were applied to the near side of its frame. See the diagram below.



Another concept relating to the gyroscopic principle is gyroscopic precession. Using the same gyro and a piece of string, lay the gyro so that its disk is now rotating along a vertical axis. Loop the piece of string and place one of the posts of the gyro through the loop. The gyro, will remain horizontal, but will also rotate around the piece of string. This is much more dramatic and easier to see if you replace the gyro with a bike wheel with two posts as handles in the center of the wheel.



Bernoulli's Principles

Bernoulli's equation and the "Law of Continuity" are essential to the concept of "lift".

Bernoulli's equation: constant = P + (0.5)pv^2

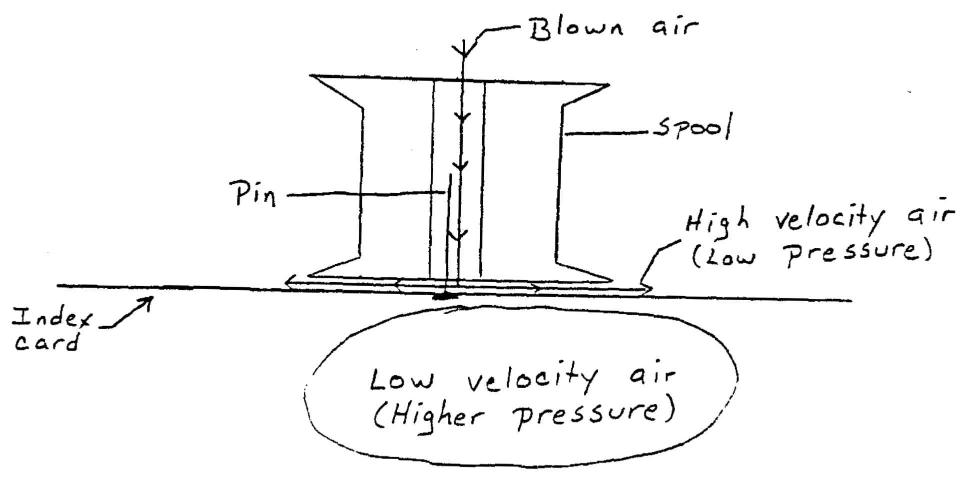
where "P" is the "static" air pressure, "p" is the fluid's density, and "v" is the velocity of the fluid relative to a surface. Air is a very non-viscous fluid. The quantity "(0.5)pv^2" is called the dynamic pressure (which is labeled as P'). The dynamic pressure only exists when a body is moving through the air. Static pressure is due to the mass of air around an object when it is at rest. Bernoulli's equation can be rewritten as: P + P' = constant (static pressure + dynamic pressure = constant). What this means is that as an object picks up speed, relative to the air around it, the object looses static pressure and gains dynamic pressure. Static pressure is what is responsible for "lift". That is to say, that as the speed of air increases and causes pressure to decrease. Look at the "Law of Continuity" to see how to change the velocity of air.

The "Law of Continuity" is really the "Law of Conservation of Matter" applied to a moving fluid. The "Law of Continuity" says: p x A x v = constant

where "p" is the fluid's density, "A" is the cross-sectional area, and "v" is the velocity of the fluid relative to a surface. For flow velocities a lot less then the speed of sound, the density will remain fairly constant. Therefore, the equation reduces down to: A x v = constant, (Cross sectional area) x (velocity) = constant. To increase the velocity of air, the path that the air is traveling in needs to be constricted.

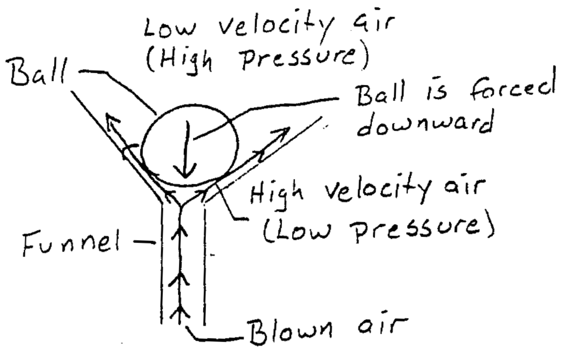
Demonstration

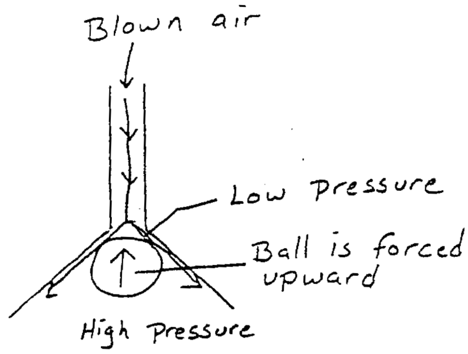
Run a pin all the way through the middle of a 3"x5" index card. Hold a 3"x5" card up against the flat side of a spool of thread, so that the pin goes up through the middle of the hole in the spool. Blow through the spool while gently holding the card against it. Then, while blowing through the spool, release the card. It will stay in place. See the diagram below.



The air coming out of the spool's bottom between the card and the spool is moving very fast. Therefore, it has a low pressure when compared to the air on the other side of the card. The air on the other side of the card is not moving at all. Therefore, the pressure underneath the card is greater than the pressure on the top of the card. This greater pressure is lifting the card up against the spool.

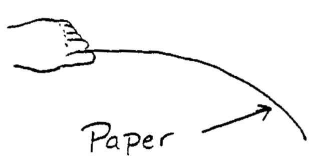
A variation of this demonstration is to use an unused, clean funnel and ping-pong ball. Place the ball inside of the funnel (small side down). Challenge a student to blow out the ball from the funnel. It cannot be done. Have the student continuously blow through the funnel and slowly rotate their head downward so that the funnel is upside down (pointed side up). The ball will remain inside of the funnel, until the student stops blowing. See the diagrams below.

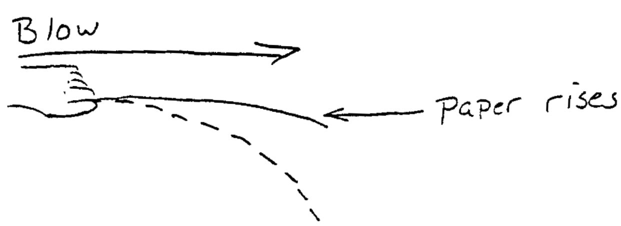




Demonstration

Cut out a strip of paper about 2 inches wide and about 8 inches long. Hold it horizontally as shown below.

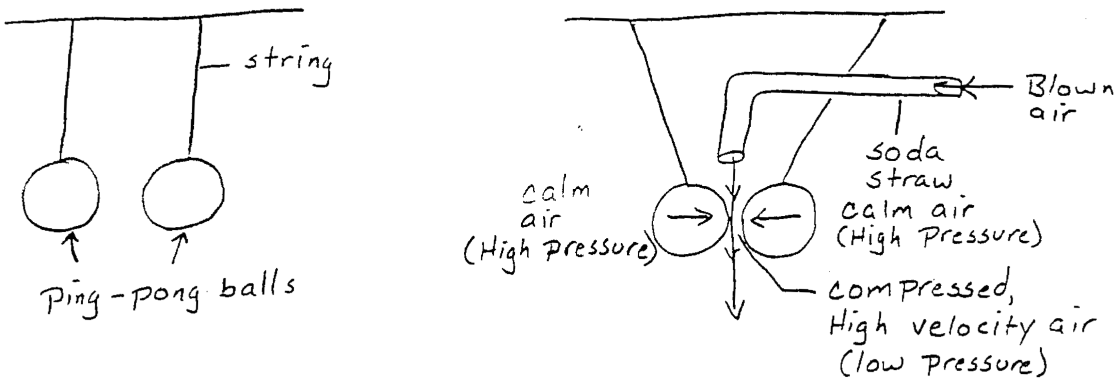




Blow across the top of the paper. The air on the upper side of the paper will move faster than the air below the paper. Therefore, as mentioned in the spool demonstration, the air above the piece of paper has a lower pressure than the air under the paper. The paper is lifted up.

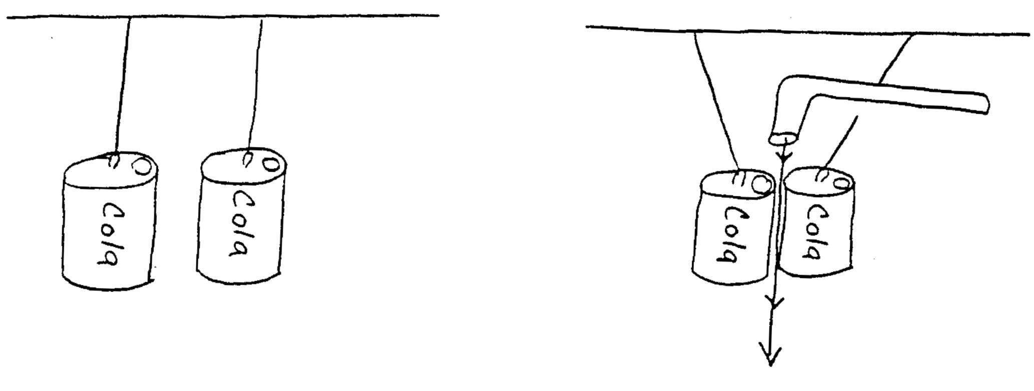
Demonstration

Use Scotch tape to tape a piece of thread to a ping-pong ball. Do the same to a second ping-pong ball. Suspend both balls so that they are beside one another, but about an inch apart. Blow through a soda straw between the two ping-pong balls. The balls will come together as long as the air blows between them. See the diagram below.



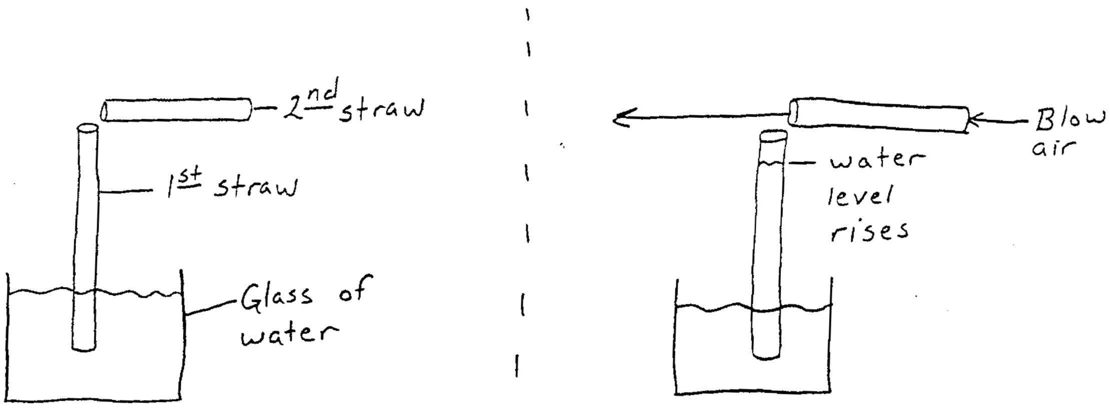
The air between the balls is moving faster than the air on the outside of the balls. Therefore, as demonstrated above, the pressure between the balls is less than the pressure on the outside of the balls. The greater pressure on the outside pushes the ping-pong balls together.

Another variation can also be done with pop cans. Replace the ping-pong balls with pop cans that are close to oneanother.

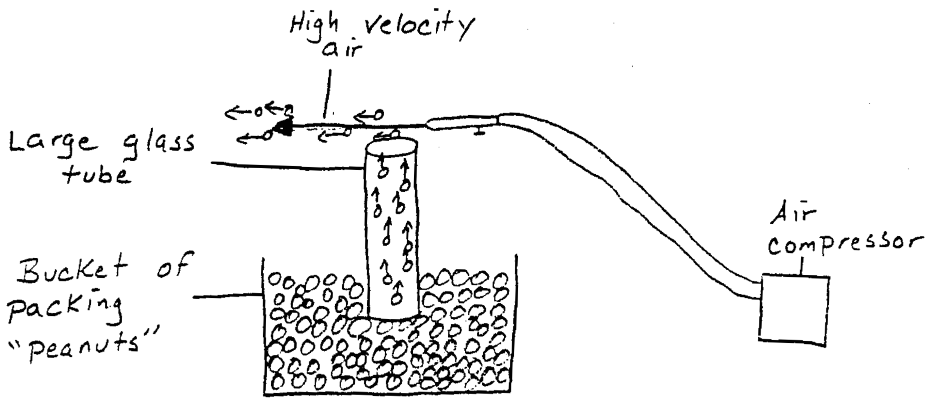


Demonstration

Use a glass of water and two straws (preferably clear). Place one straw into the glass of water, but hold it vertically and so that it doesn't touch the bottom. Use the second straw and place one end in your mouth and the other end at the top of the first straw in the water. Blow into the straw so that air rushes across the top of the straw in the water. If the straw is clear, you will see the water being drawn up into the first straw. If you blow hard enough, water will spray out the top of the first straw. See the diagram below.

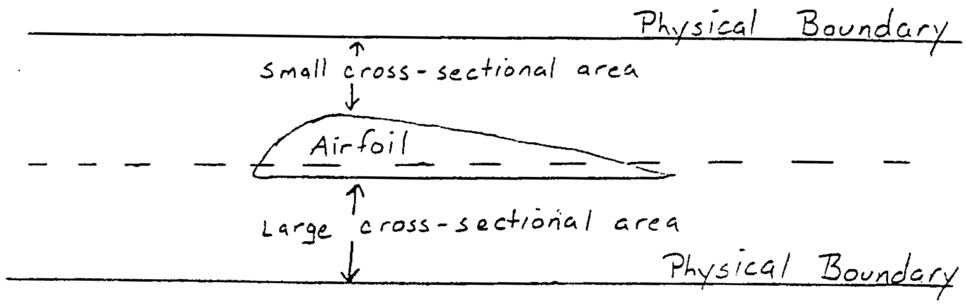


Another variation is to get a large bucket about half full of styrofoam packaging "peanuts" (or some other form of light weight particles). Place a large glass or plastic tube into the bucket. Using air from an air compressor, blow air across the top of the tube. The styrofoam material will be drawn up into the tube and out of the top.

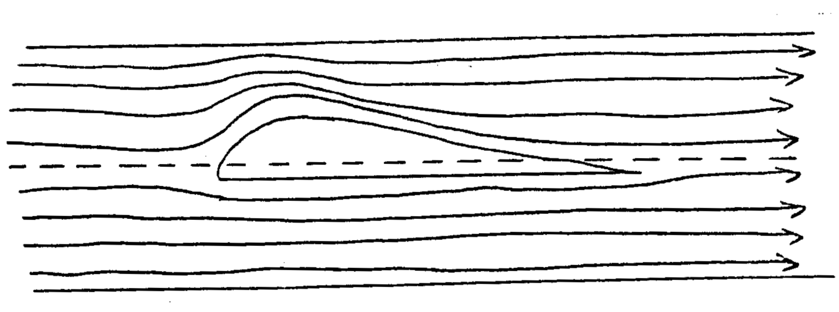


The above demonstration is how an atomizer works (type of perfume bottle) or how a draft is formed from a chimney, but it also relates to flight. The faster moving air across the top causes a lower pressure area (in comparison to the surrounding area) to occur at the top of the cylinder. Air, and any other material is drawn up, to try to equalize the pressure. Keep this in mind when going over airfoils.

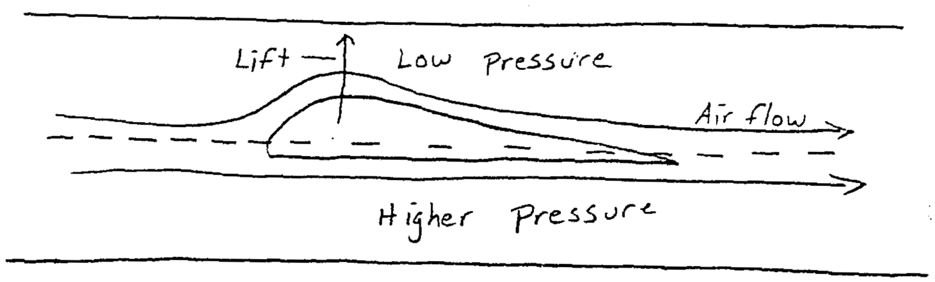
Below is a cross-section of an airfoil. The airfoil is that of an airplane wing. The airfoil is drawn with an upper and lower boundary.



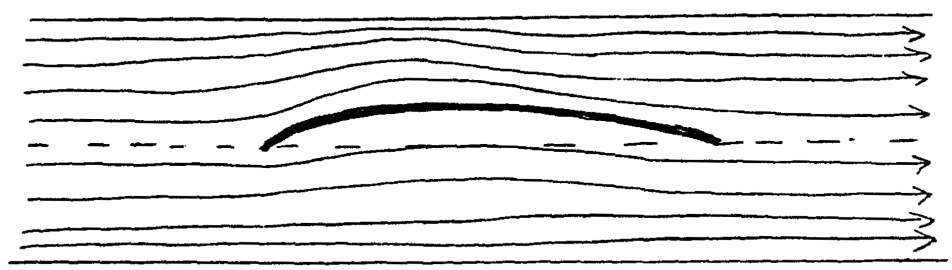
In front of the wing all the air flows with the same speed. As the air hits the front of the airfoil, its path splits. Some of the air travels over the top of the surface, the rest travels underneath the foil. Below is a diagram of the airfoil in the boundary.



The dotted line in the middle is equi-distant from both boundaries. As the air flows over the top of the airfoil, it is being squeezed through a small area. Recall that the air travels faster through a smaller, or constricted, cross-sectional area. Also recall that the faster flowing air decreases pressure. Underneath the airfoil, the air is not constricted as much as above. Therefore, the velocity is slower underneath the wing than on top. This means that the pressure under the wing is greater than the pressure on top of the wing. The greater pressure under the airfoil lifts the wing. This is what is meant by the term "lift".

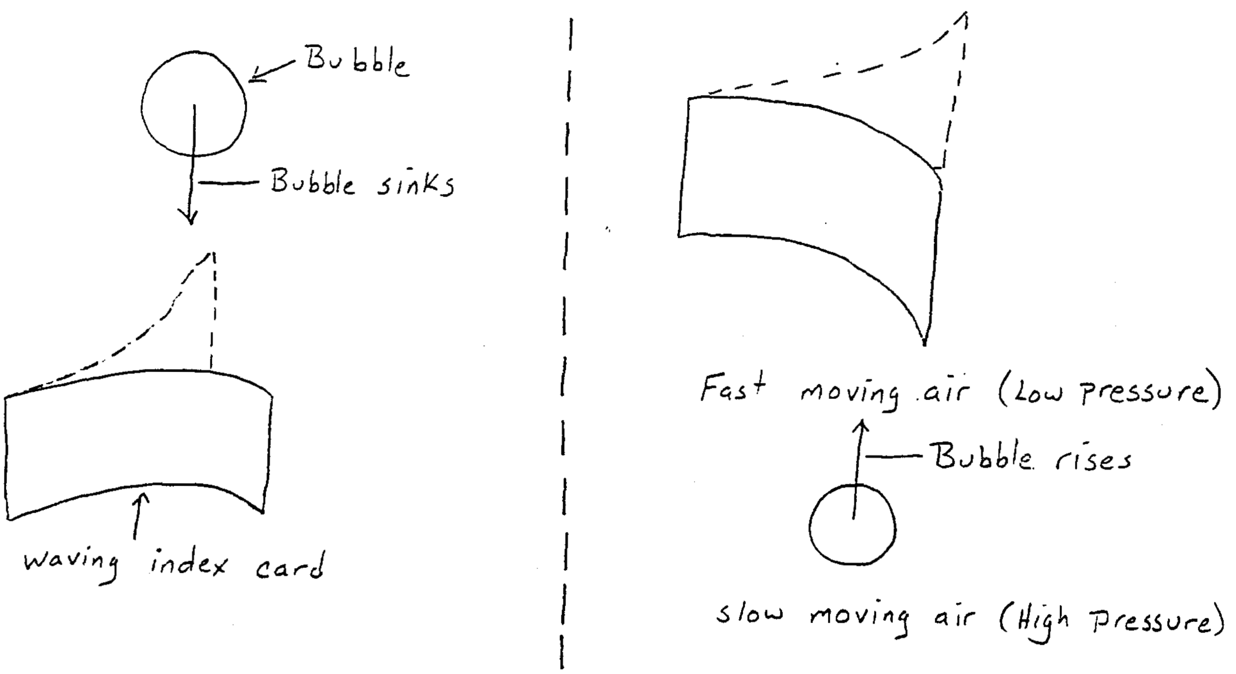


The same forces act on boomerangs and gliders that have cambered wings. Even though the airfoils are thin, the airflow on the top of the wing is greater than the bottom of the wing. The difference is still enough to generate lift.



Demonstration

Use a 3"x5" index card and bubble mix. Blow some bubbles and using the index card wave the card on different sides of the bubble. By waving the index card rapidly below the bubble will cause the bubble to sink faster. Waving the index card rapidly above the bubble will cause the bubble to rise.

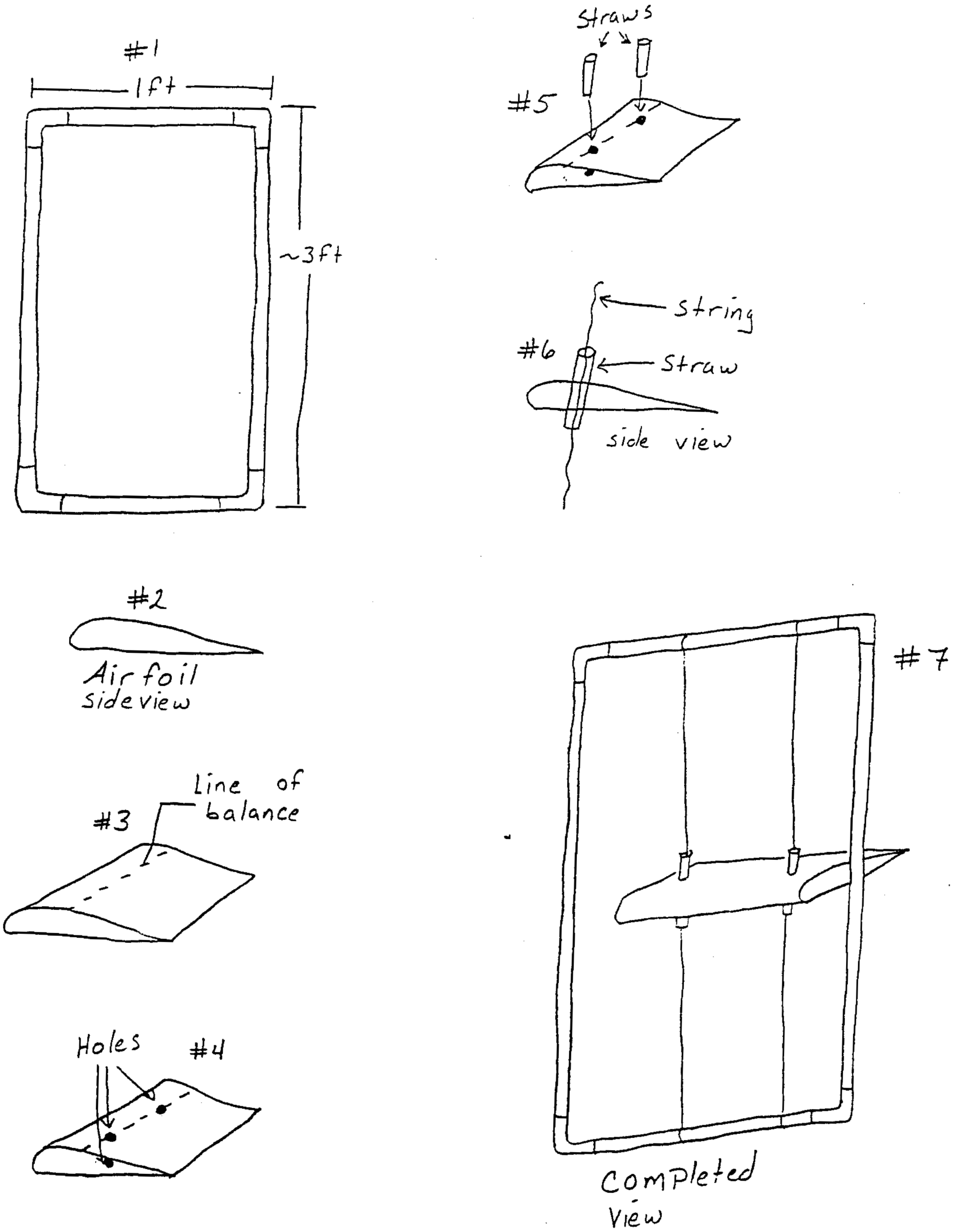


Waving the card causes the air to move faster and creates a lower pressure area. The bubble will move towards the lower pressure area. On a wing, the shape of the wing causes a lower pressure area on the top of the wing, causing the wing to rise (Lift).

Demonstration

Build a 1ft x 3ft rectangle framework using pvc pipes or wood. Using manilla folders and some tape, construct various airfoils that are about 8inches wide. Find where the airfoil will balance along its wing length and draw a line. Punch holes in both the top and bottom of the airfoil so that they are about 6inches apart. Run a piece of soda straw through the top and bottom holes of the airfoil. Run a piece of string through each soda straw (you may have to fix the straw in position with a small amount of tape). Attach each end of the string to the length of the framework and make sure the string is taut. Make sure the airfoil is able to slide up and down easily on the string within the framework.

By holding the framework, spin around, walk around quickly, or hold in front of a fan, observe how the airfoil lifts. Also observe how changing the angle of the airfoil (tilting the framework), can also cause the wing to lift and possibly stall if done too much. To better see the movement of air around the airfoil, tape bright colored thread or string on various locations around the airfoil and place the framework in front of a fan.

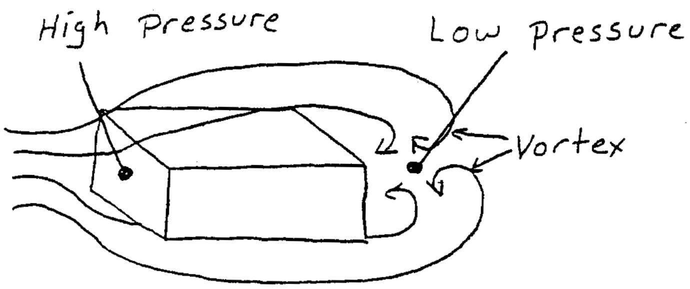


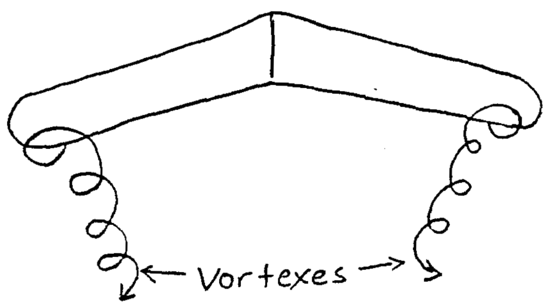
Wind Resistance

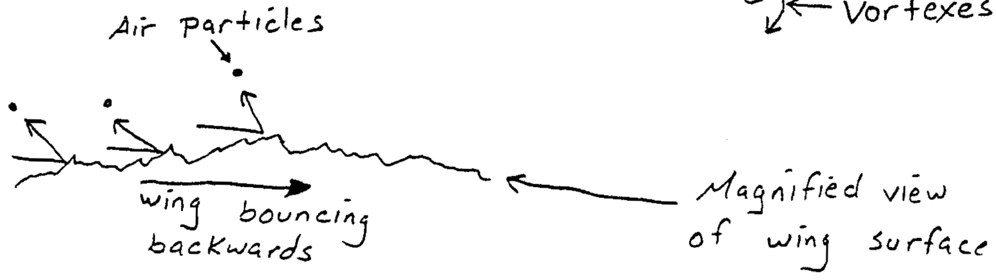
All this is a good approximation of what happens even without the presence of the physical boundaries. The air that the wing travels into is assumed as being calm air. If the air is turbulent, the "boundaries" are not as well defined. The more turbulent the air, the less the difference between the pressure above and below the wing's surfaces. In other words, turbulent air reduces lift on a wing. For example, putting something like a block in an airflow, the air pressure in the front is large, pushing it backwards. Also, a vortex forms behind the block from the low pressure, which pulls the block backwards as well.

Another form of air resistance is generated by the wings (especially the main wings). During flight, the lower pressure on the top of the wing tries to draw air up from the bottom of the wing. The higher pressure air on the bottom slips up over the wings (especially the tips), creating a vortex. This can sometimes be seen on large aircraft during landings on foggy or misty days.

Another form of air resistance comes from the rubbing of air particles against the wings. Whenever any two surfaces rub up against one another, there is always friction, which is a form of resistance. Generally, rougher surfaces will cause air particles to hit the surface and bounce backwards, thus causing the rough surface to also slightly bounce backwards. Smoother surfaces are generally better able to slide through the air with less "bouncing" back of the air and the wing. No matter, how smooth of a surface you may have, there is always some resistance of the wing against the air.



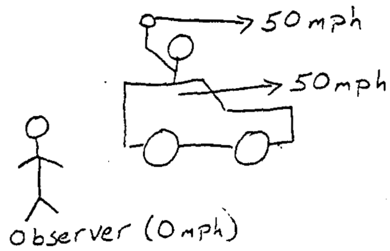




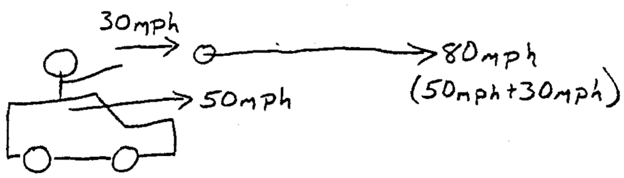
Relative Velocity

In the discussion about lift, the important term is the air velocity. This is the velocity of the air relative to the wing.

Suppose a student is riding in a car traveling 50mph. The student is standing so that his upper body is sticking out through the sunroof. When the student holds a ball up in the air, the ball feels a 50mph wind. The speed of the ball relative to the student in the car is 0mph because they are both traveling at 50mph. The speed of the ball relative to a second observer standing along the side of the road is 50mph.

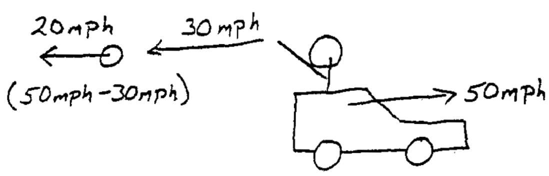


The student in the car throws the ball in front of him at 30mph. The speed of the ball relative to student in the car is 30mph. The speed of the ball relative to the observer alongside of the road is 80mph (50mph + 30mph).



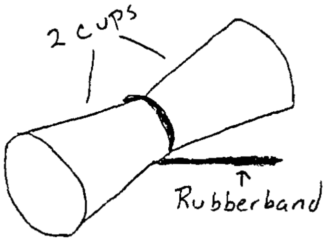
The two speeds are added together because each velocity is in the same direction.

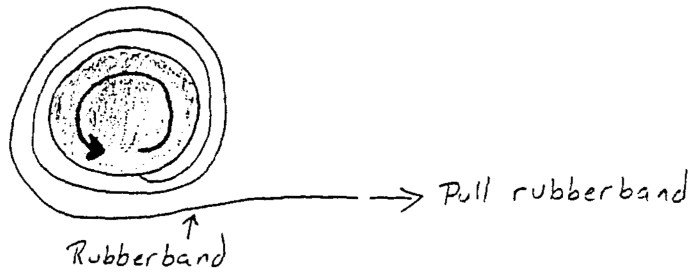
Now suppose the student were to throw the ball towards the rear of the car with a speed of 30mph. The speed of the ball relative to the observer alongside of the road is 20mph (50mph – 30mph). The two speeds are subtracted because they are heading in opposite directions.



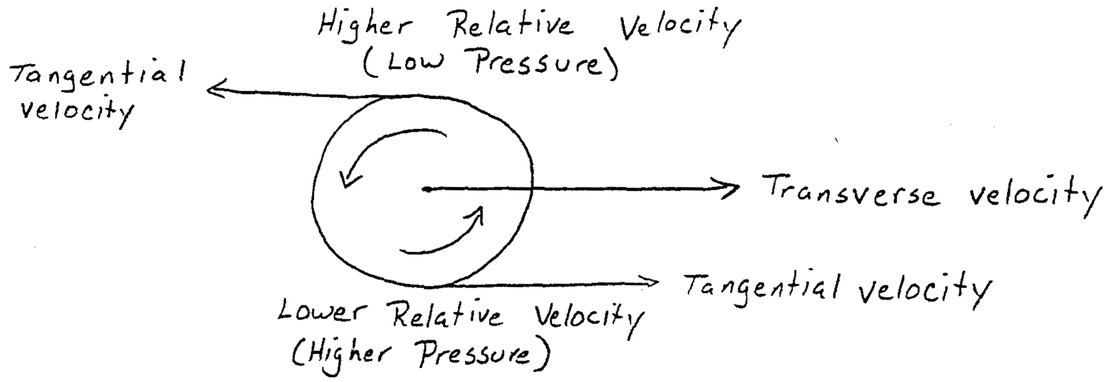
Demonstration

Glue or tape the bottom of two styrofoam or plastic cups together. Cut a large, wide rubber band so that it is one long piece. Where the cups are glued together, wrap the rubber band around the cups while stretching the rubberband. Wrap the cups until it is about 1-2 inches from the end of the rubber band. Hold the free end of the rubber band and let go of the cups while pulling the rubberband away from you. The cups will move forward off the rubber band and then curve upwards.





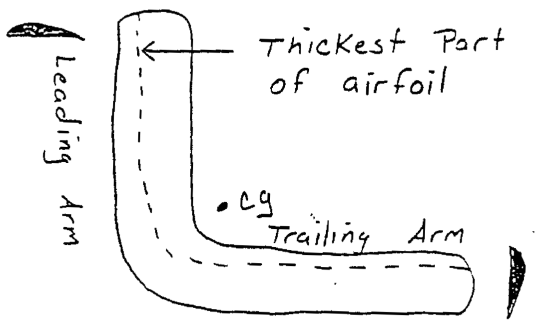
When the cups leave the rubberband it will be rotating with a back-spin. There will be a tangential component of velocity to the edge of the cups. The cups will also have a transverse velocity. Recall that the velocities associated with lift are velocities relative to the surface. Look at the diagram below.



At the top of the cups, the spin along with the forward movement of the cups, creates an even higher air velocity at the top of cups than the velocity at the bottom of the cups. The greater velocity means a lower pressure. Therefore, the pressure on the bottom of the cups is greater than the pressure on the top of the cups. This is part of the reason why the cups rise when launched.

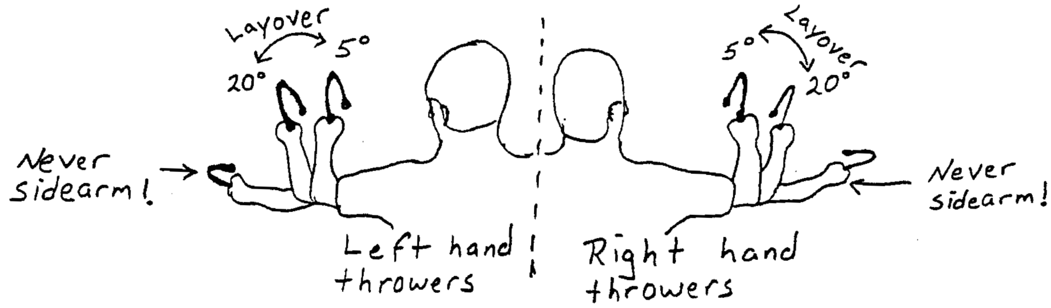
Putting it all together for boomerangs

Boomerangs come in all shapes and sizes from 3 or more blades, and boomerangs that look like people, animals, or strange designs. This section will concentrate on the "V" shaped boomerang because it is the most common and easier to explain. The arms of a boomerang are actually airfoils. Below is a diagram of a right-handed boomerang.

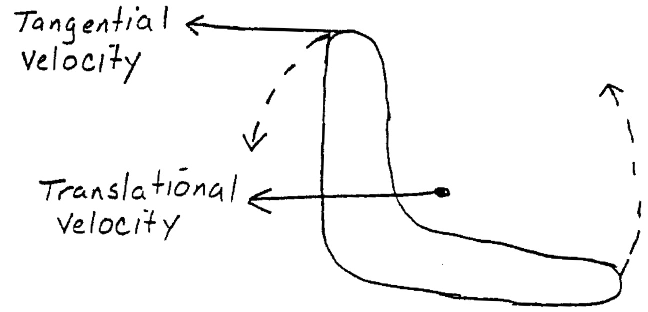


The dotted line along the boomerang shows where the thickness of the boomerang is the greatest. On each end is a cross-section of the wing tips.

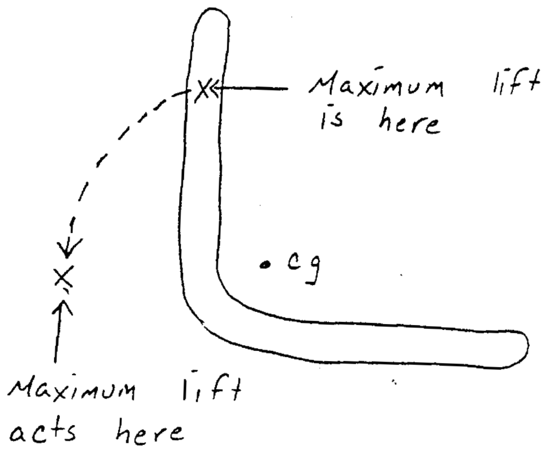
When a boomerang is thrown, it is thrown a few degrees from the vertical.



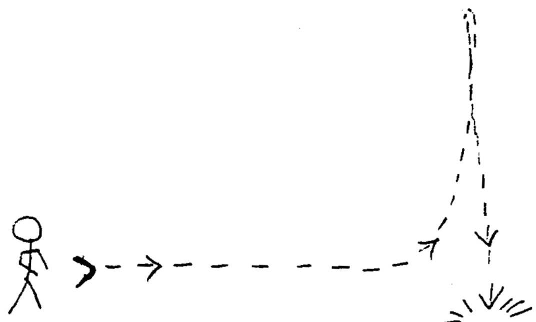
The boomerang is thrown with a translational and tangential (rotational) velocity. See diagram below.



The arm on top has a greater velocity relative to the bottom arm. Therefore, the lift on the top arm is greater than the lift on the bottom arm. The net lift is on the top arm. Due to the gyroscopic principle, the net lift acts in front of the boomerang. This is what causes the boomerang to turn. Added to it, the directional lift of the boomerang is off to the side, which also adds to the turning of the boomerang. Remember, the turning must overcome the inertia of the throw. See the below diagram.

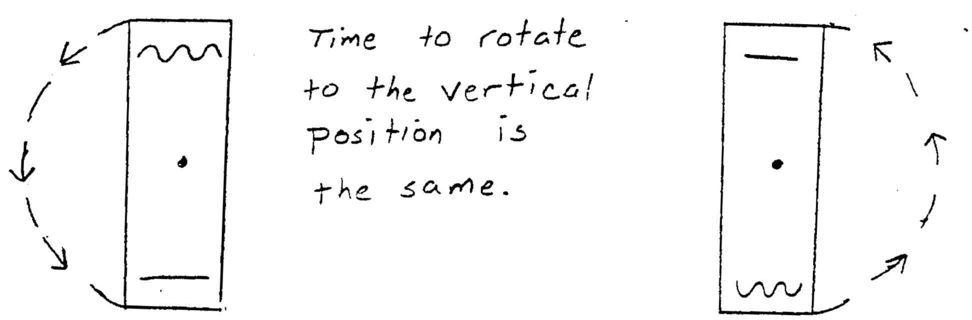


To show the effect of the rotation, throw a plastic boomerang horizontally (side-armed throw). The net lift this time is on the right side of the boomerang. The gyroscopic principle makes the force act at the front of the boomerang. Also, the directional lift is upward. Below is the path that the boomerang will travel. This is why all boomerangs are thrown vertically (or near vertical), but never horizontally (side-armed throw).

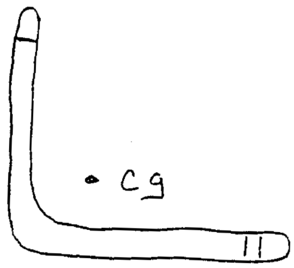


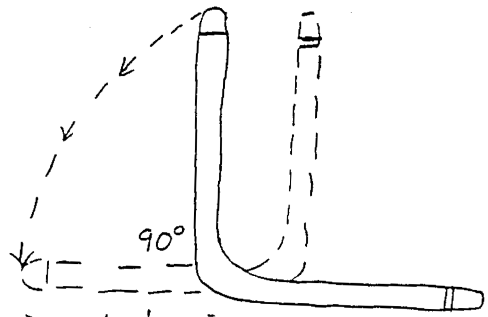
As a boomerang travels in a circle, it flattens out horizontally. There are three ways to account for this. Though all three explanations are described, the preferred description used in class follows.

If the boomerang were a straight stick, the center of lift and cg would be along the same line. The time it takes for one blade tip to reach the previous location of the other blade tip is equal.



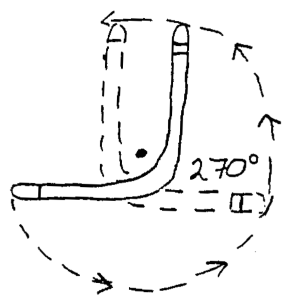
But a boomerang is curved. One arm will reach the vertical position quicker than the other. This may not seem obvious at first. Take a boomerang and lay it on a table like below on the left. Then rotate the boomerang so that the other arm is now vertical





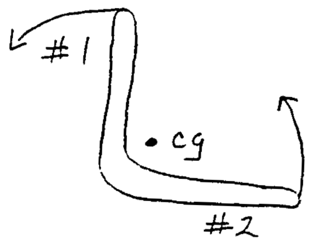
Dashed line represents the rotated position of the boomerang.

The boomerang rotated 90^0 before the other arm was vertical. Do the same thing with the other end.

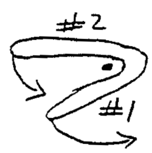


The other end rotates 270° before it is vertical.

Therefore, arm #1 takes longer to reach the vertical position of arm #2. Arm #1 is called the lifting or leading arm. Arm #2 is called the trailing or dingle arm. Maximum lift occurs when the arms are vertical to the direction of movement. Since the boomerang is spinning like a gyro on its side and the forces on the top and bottom of the boomerang are not equal, the boomerang begins to go through gyroscopic precession. Finally, the boomerang will precess until it is horizontal, much like a gyro's disk will precess as the spinning disk moves from vertical to a horizontal position.



Vertical Rotation

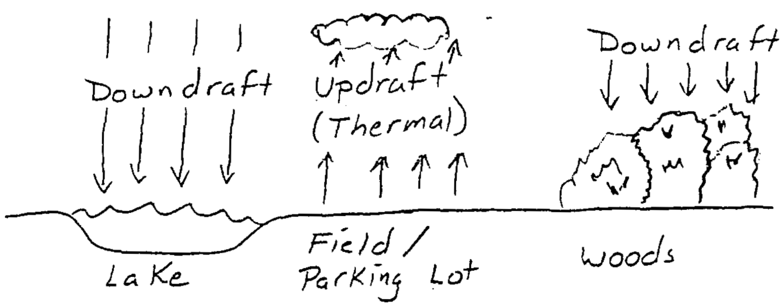


Horizontal Rotation

How to gliders and certain boomerangs stay in the air for extended periods of time

Two ways in which gliders and special boomerangs can stay in the air for a longer period of time is to either use the air coming off from an inclined surface (hills, cliffs, buildings, etc.) or thermals. Thermals are pockets of rising air created by the sun heating up the ground. Opposite to thermals are downdrafts, which are pockets of air that sink because they are cooler and denser than the surrounding air. Thermals are more likely to occur over large grassy areas like a ball field or large paved areas such as parking lots. Downdrafts are more likely to occur over bodies of water and wooded or tall grassy areas. The best time for thermals to occur are between 9:00am – 4:00pm on sunny summer days, but around 1:00pm – 2:00pm the winds begin to pick up. The exact time and locations are difficult to predict, but one strong indication of thermals in the area is when hawks or vultures are seen flying in circles near you.

Thermals have been known to make gliders and boomerangs (primarily MTA boomerangs – maximum time aloft boomerangs) stay in the air from 30 seconds – 20+ minutes! They have also been known to make them travel over a thousand feet off the ground and travel for several miles. It is strongly advised to put your name and number on your gliders and boomerangs if they are accidentally lost.

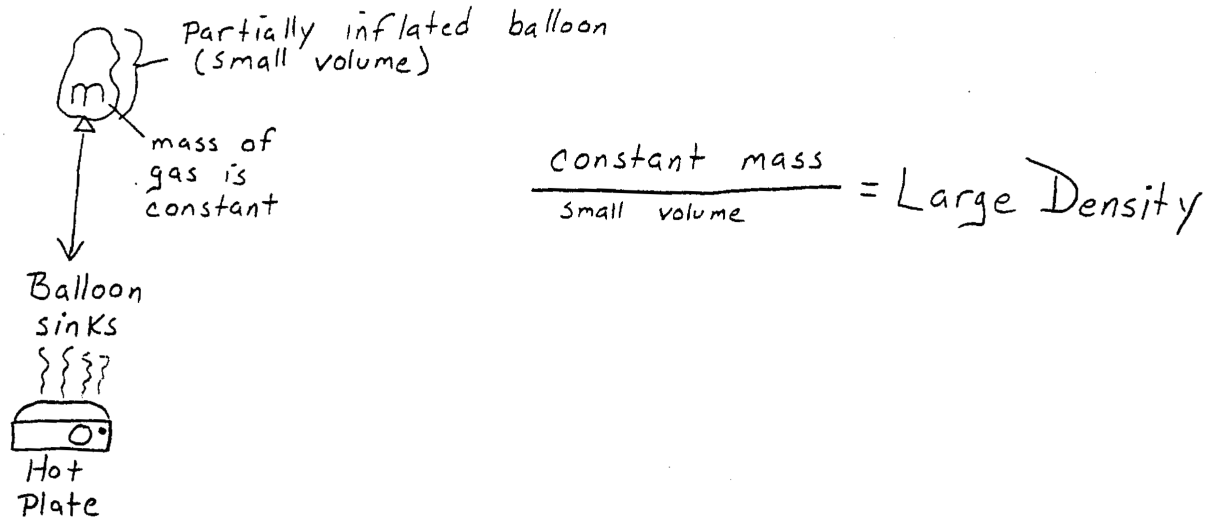


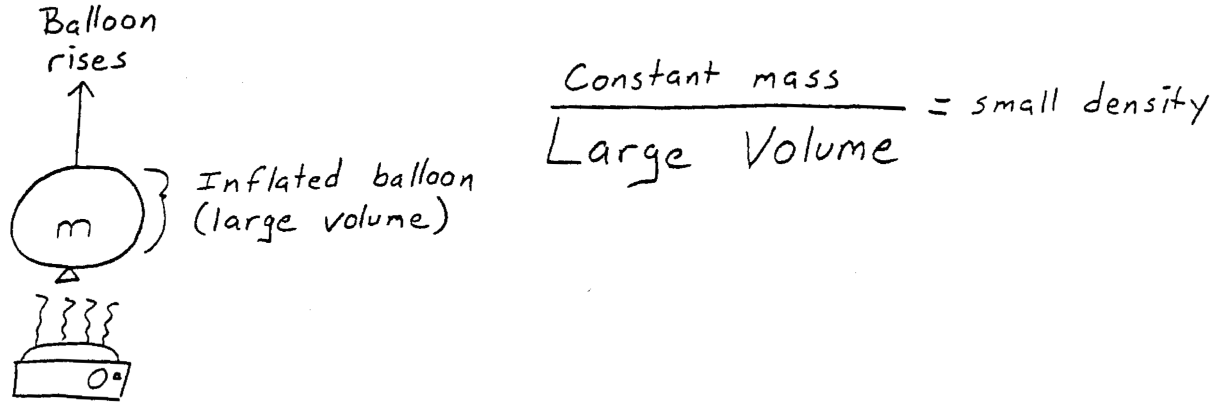
Demonstration

Many people think that warm air rises because it is lighter. The correct statement is that warm air rises because it is **less dense** than the surrounding air. The analogy I use is that a multi-ton tree is able to float in water, but a one ounce pebble will sink in water. The weight does not determine what floats or sinks, but the density. Wood is less dense than the water and the pebble has a greater density than water, so wood floats while the pebble sinks, no matter how heavy or light the objects may be.

To demonstrate this, use a mylar balloon that is partially inflated with helium so that it is no longer able to float. You may have to wait a while till it gets to that point or you can carefully remove a small amount of the helium from the nozzle of the balloon. Place the mylar balloon about 8-10 inches above a hot-plate or stove (don't do this with a rubber balloon). If you hold the too close or too long above the hot-plate, you could melt the balloon. The mylar balloon will begin to expand and eventually it will float up to the ceiling. After a short period of time, the balloon will begin to cool down, shrink in size, and fall back to the ground.

I then write the density formula on the board (**Density = mass/volume**). I then explain that less dense objects float and more dense objects will sink. So I then ask the students, which of the two, mass or volume, are changing. Since the balloon is sealed off, no extra air is able to get in or out of the balloon, so the mass of the balloon is relatively constant. The balloon can be seen to expand and contract, so the volume is changing. Looking back at the formula, if volume increases, the density decreases, and the balloon floats. If the volume decreases, the density increases, and the balloon sinks.

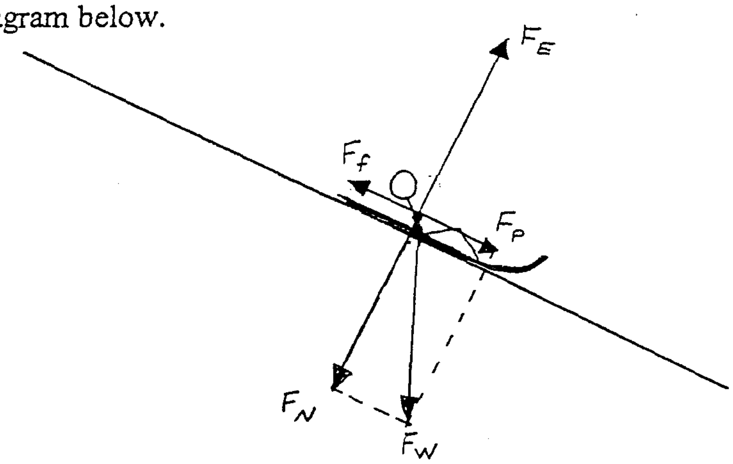




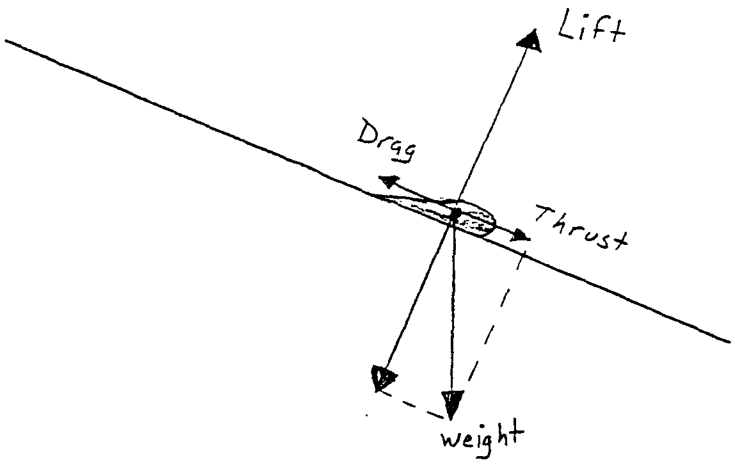
How do gliders fly?

In physics, we cover such topics and labs as to how and why balls roll down an incline and the forces present in a skier or sled rider going down a hill. In a sense, a glider rides down an invisible incline.

In a nutshell, a sled rider exerts a force straight down known as his force of weight (F_w). Being on an incline, his force of weight is broken down into several different component forces. One of the component forces is a force that is perpendicular (90^0) to the incline known as the normal force (F_N) which is the force the sledder is exerting against the hill. At the same time, the hill is reacting with the same amount of force against the normal force (F_N), which is the same amount of force, but in the opposite direction sometimes called the equilibrant force (F_E). Another component force from the weight is the force that runs parallel to the surface known as the parallel force (F_p). Another force that acts against the parallel force is friction, known as the frictional force (F_f). The normal force pushes the sledder against the hill. The equilibrant force prevents the sledder from sinking into the ground by the ground pushing up against the normal force. The parallel force pushes the sledder down the hill. The frictional force acts against the parallel force preventing the sledder from reaching the maximum acceleration and speed going down the hill. Study the diagram below.

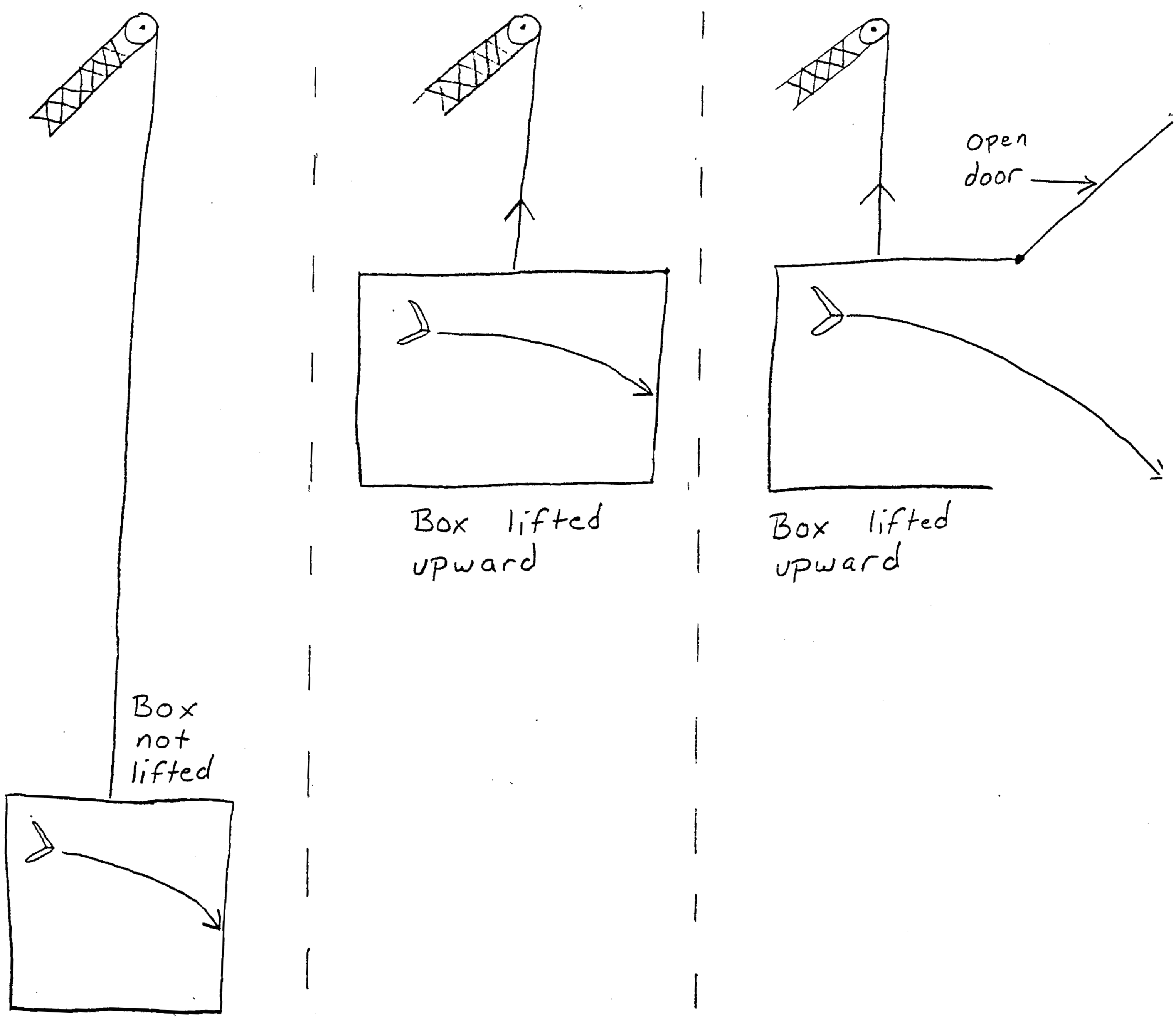


A glider gliding down at a steady rate has very similar forces. The force of weight of the glider can be broken down into several component forces. The equilibrant force on the sledder is called the lifting force (Lift, L) on the glider. The parallel force on the sledder is called the thrusting force (Thrust, T) on the glider. The frictional force on the sledder is called the resistance force (Resistance or Drag, D) on the glider. In normal air, a glider cannot remain aloft, but will eventually slide back to the ground on its invisible incline.



Gliders are able to stay aloft for extended periods of time by using updrafts of air from wind hitting an incline or thermals. The analogy I use for my students to understand this is flying a glider inside of a GIANT elevator being lifted by a crane. If you are inside of a stationary elevator, flying your glider, the glider descends as it normally would.

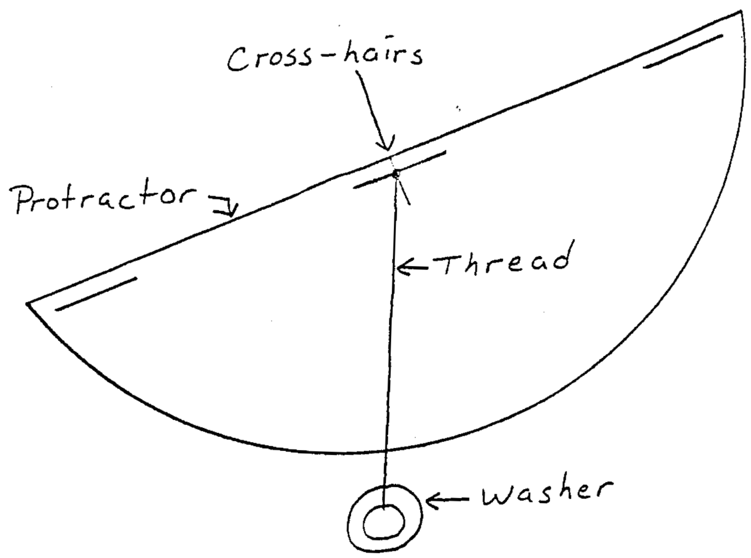
If the elevator doors are closed, and the elevator is lifted the moment the glider glides, then the air inside of the elevator is also being lifted, along with the descending glider. The glider descends as it normally would when the elevator was stationary on the ground. Right before the glider hits the bottom of the elevator, the doors to the elevator could be opened and the glider will continue to fly out of the elevator, but now at a much higher elevation. Even though the air inside of the elevator had been lifted, the glider still descends much the same way as it did on the ground, but did it in a rising bubble of air.



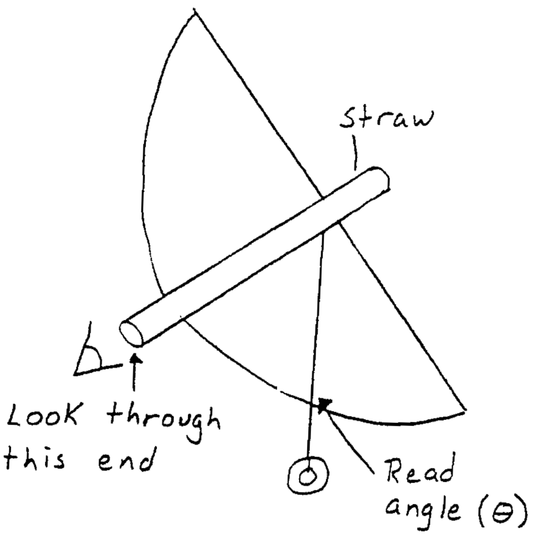
<u>How to calculate the altitude</u>

Unfortunately, there is no easy, direct way to find the height of the glider and some boomerangs. The heights can be calculated indirectly by making a simple sextant and the use of a calculator (one that has sine, cosine, and tangent).

The sextant is a tool used to measure the angle. To construct one you need: thread, washer or nut (for weight), protractor, soda straw, and some clear tape. Tie or tape one end of the thread so that it hangs from the "cross-hairs" in the center of protractor. On the other end of the thread, tie the washer or nut. See the diagram below.

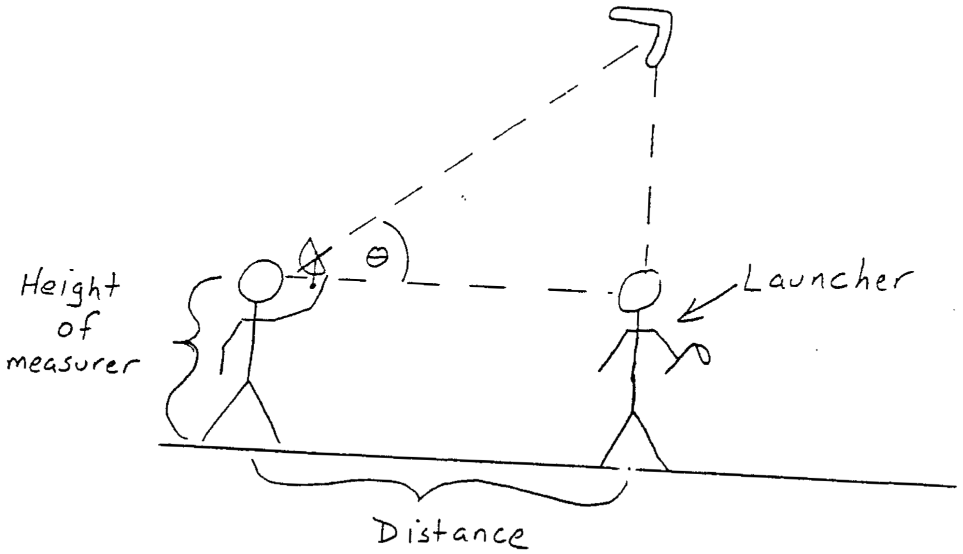


Secure the straw so that it lays across the 90^0 angle and through the cross-hairs. See the diagram below.



To use, view through the straw so that you are looking at the object that you want to measure. Read the angle from where the thread crosses the protractor.

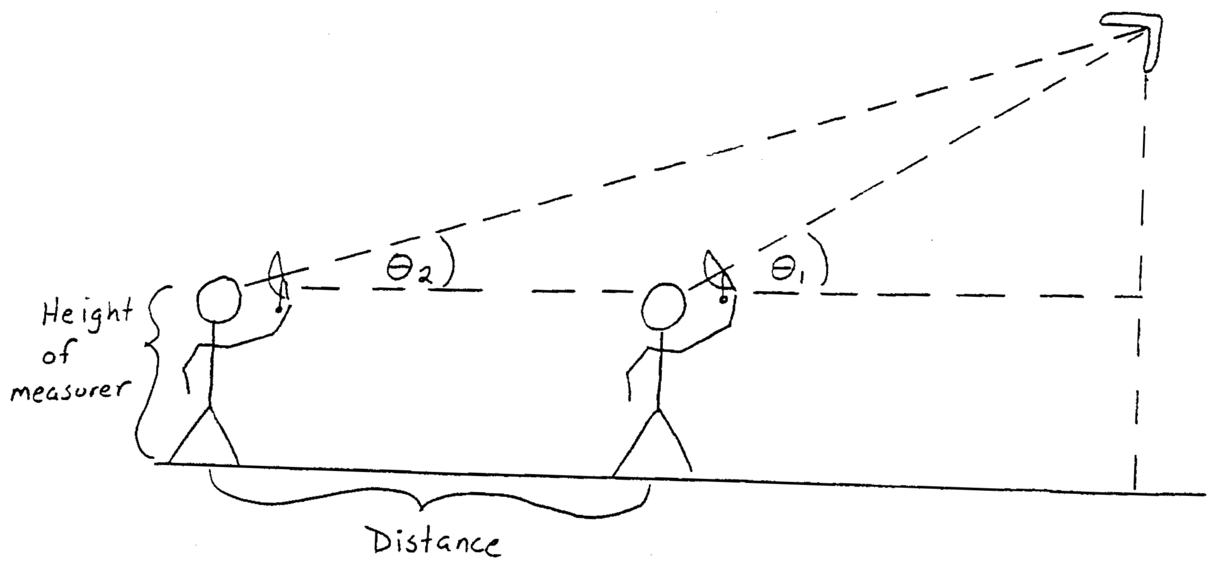
If the glider is directly overhead of the thrower, the right-angle method of finding the height can be used. The person measuring the angle needs to know how far they are from the person who launched the glider (dist). Find the angle at which the glider is located. Use the following formula to find the height of the glider: **Height = [dist (tanθ)] + height of measurer**. See the diagram below.



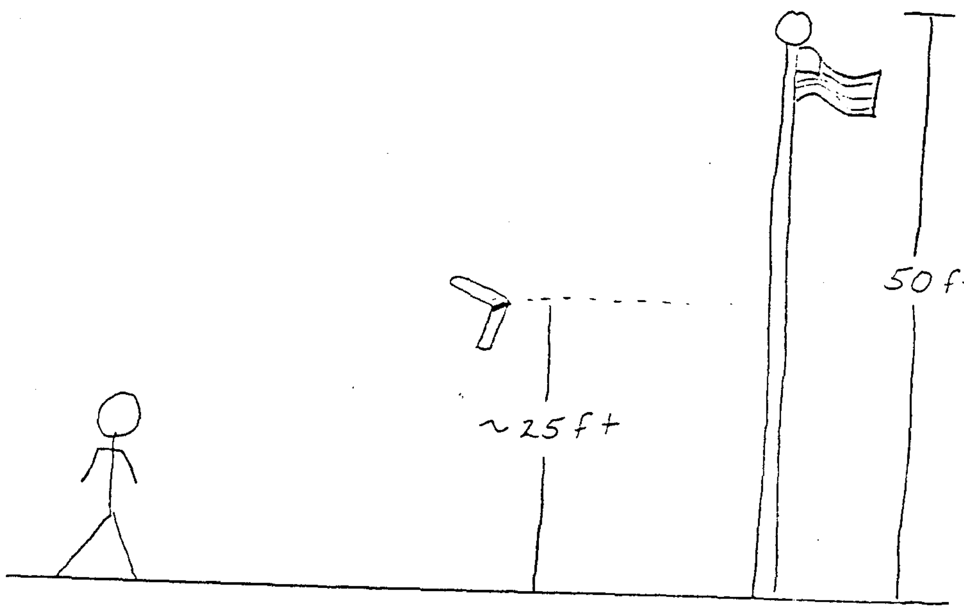
Another method to find the height, which is also helpful if the object is drifting away from the thrower is to use a non-right angle method. Two people are needed to measure the angles simultaneously and one must be behind the other. The distance between the two angle measurers must be known. Use the following formula:

$$\textbf{Height} = \frac{\text{dist} (\sin \theta_2)(\sin\theta_1)}{\sin(\theta_1 - \theta_2)} + \textbf{height of measurer}$$

See the diagram below.



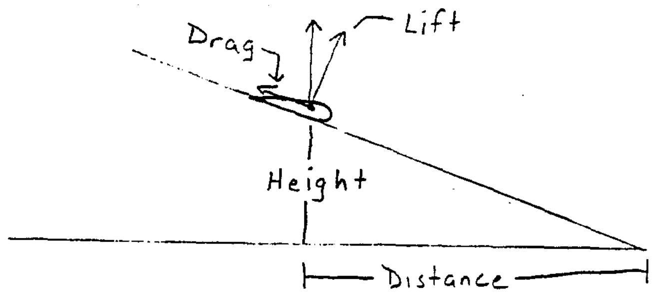
If the math is too complex for your grade level, then use the height of a known object to compare the height of the gliders or boomerangs. It isn't as accurate, but should be fine.



<u>Measuring Flight Performance</u>

It is much easier to measure flight performance when there is no wind and no rising or sinking air currents. Flight performance is measured by the range the glider and certain boomerangs fly and how long can they stay aloft (for boomerangs, this is called MTA-maximum time aloft).

Flight performance based on distance (range), gliders generally travel at a constant velocity. The formula to find the glide ratio is equal to distance/height. Glide ratio is also called the lift/drag ratio, which is equal to lift/drag. So therefore, **glide ratio = distance/height = lift/drag**. So by looking at the formula, by decreasing drag and/or increasing lift will create a larger glide ratio.



Flight performance based on the amount of time spent flying is actually measuring the rate at which it descends, usually in meters per second. So by decreasing the value of sinking rate means that it is better able to spend more time in the air. In order to have a smaller sinking rate, the glider or boomerang should be light in comparison to its surface area of the wings, this is sometimes called wing loading. The formula for wing loading is: **wing loading = weight of the glider or boomerang/area of the wings**. So by making the wing loading as small as possible, will increase the flight performance of the glider or boomerang, this is done by decreasing the weight and/or increasing the surface area of the wings.

Caution must be taken in not making the wing loading too small. Even though it will decrease the rate of descent, real planes will not go up very high, resulting in a short flight.

From the use of carbon fibers and various forms of polymer plastics, many planes, gliders, and boomerangs have been able to greatly increase their flight performance and efficiency. The use of these new materials have been able to make all of them much lighter without sacrificing strength and surface area.

Demonstration

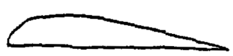
Find the cg of a glider and mark its location. Trace the glider on a graph paper and find its surface area. Then, weigh the glider. Find the wing loading of the glider. From a certain height, glide the glider and mark its location as to where it landed and measure its range. Test glide the glider at least 5 times. Find the average distance the glider flew.

Tape paperclips to various locations on the glider, but make sure that the cg does not move much from its original location. Reweigh the glider and find its wing loading. From the same height, fly the glider 5 times marking where it landed and measuring its range. Find the average and compare the results.

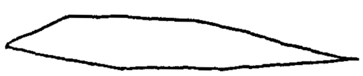
Redo the same procedures, but with more weight. Compare all of your results.

Improving Flight Performance

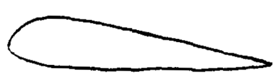
The main purpose of the wings is to support the flying object in mid-air. The cross section of the wing is called the airfoil. The shape of the airfoil is critical depending on the type of flight that is expected.



For slower speed aircrafts.
Produces high lift.

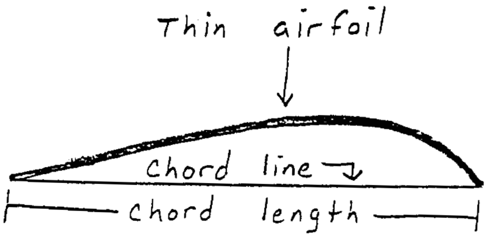


For very high speed aircrafts.
Produces little lift.

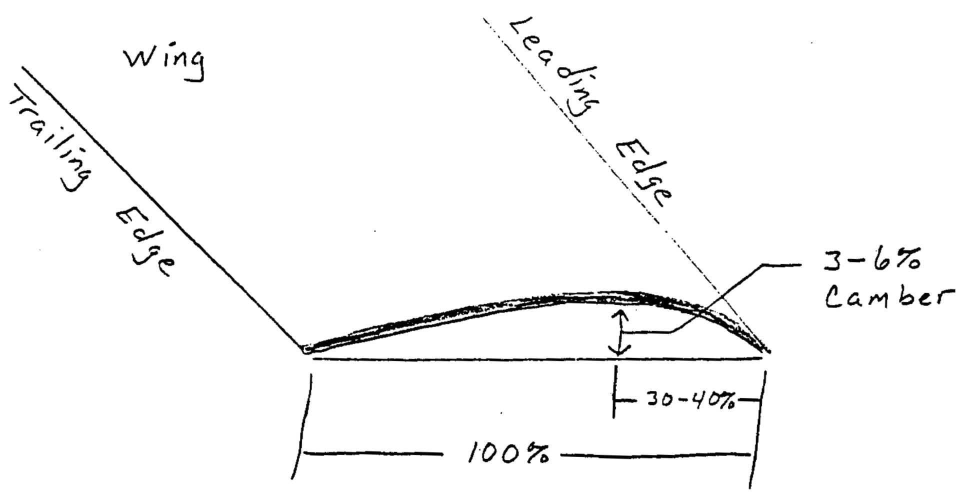


For stunt planes.
Can be flown right-side up or upside-down. Relies more on angle of attack.

For an airfoil, the width of the airfoil is called the chord length.



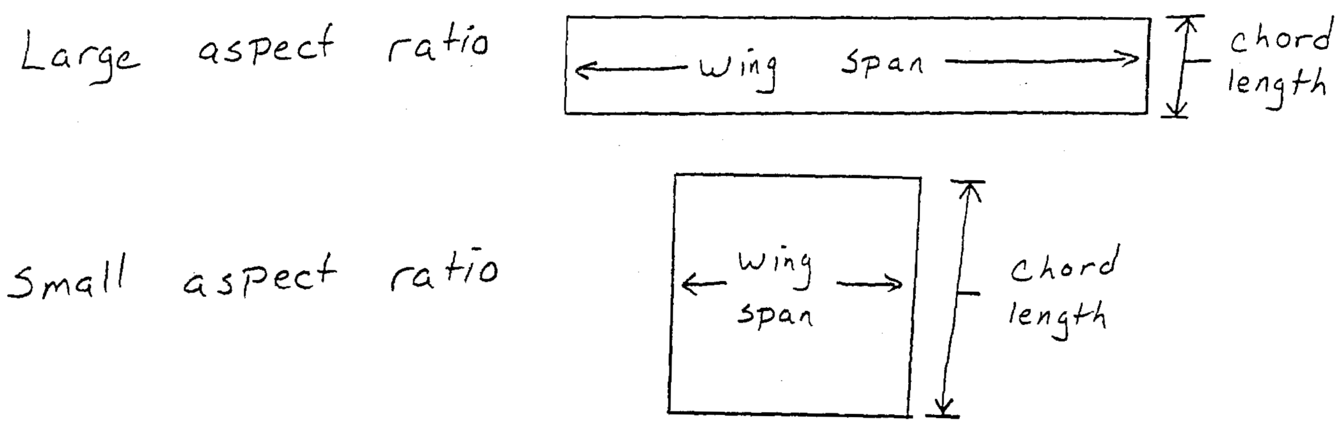
Cambering is the process of making a thin airfoil. This is easily done with your fingers. Below is a diagram of approximately how much of the whole wing must be cambered based on the wing's chord length. Depending on the type of flight performance needed, different variations of cambering are needed.



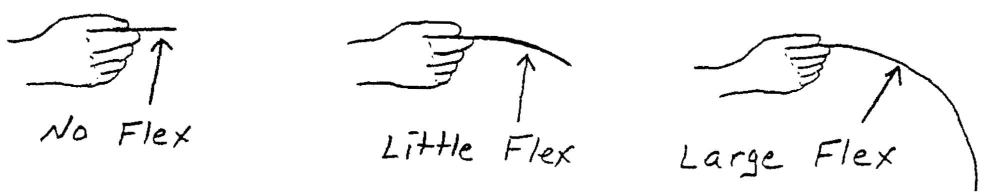
The angle of attack is the angle made by the airfoil to the wind direction. The gliders primarily use the angle of attack for their flight. The flaps in the back of the wings cause the nose of the glider to point upward. If the angle of attack is too great, the glider will stall. Stalling, in gliders, are caused when the glider flies upward and in the process slows down. As the glider slows down, lift is being lost and the glider will begin to descend. As the glider begins to speed up during its descent, lift is created over its wings and the glider is able to fly again. These gliders may go through a series of partial stalling, which is characterized by small successive rising and swooping down flight paths. If there is no angle of attack, the gliders will descend at a much faster rate. If the angle of attack and the forward thrust are fairly in balance, then the gliders will descend at a slower, steady rate.

Wing Designs

Another important factor in flight performance is the wing design. One aspect of the wing design that must be taken into consideration is the aspect ratio. The larger the aspect ratio, the less drag is created by the wing and generally better flight performance is achieved. The formula is: **aspect ratio = wing span/chord length**. The wing span is the length of the wing. To have a high aspect ratio, the wings need to be fairly long and/or slender. Real planes that are designed for long duration flight have long slender wings, such as the real gliders and the U2 spy plane.



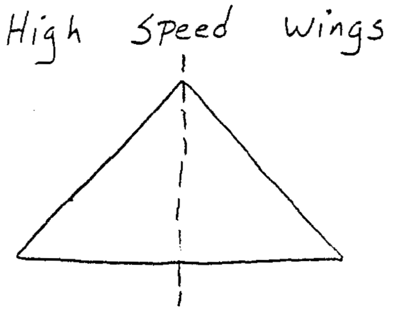
There is a limit to the aspect ratio. If the wings become too long, then the material of the wings may flex too much and possibly fail. For example, a short piece of paper held out horizontally will have nearly no flex and will be fairly rigid. The longer the piece of paper becomes, the more flexing in the paper will occur.

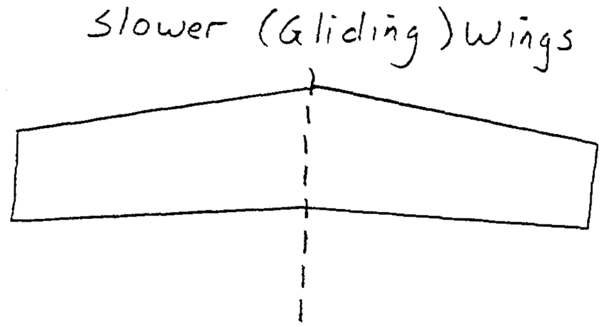


Demonstration

Using the long, medium, and short winged gliders, find the aspect ratio of each glider. Fly each glider 5 times from the same height. Record their ranges and find the average for each type of glider. Find the relationship between the range and the aspect ratio.

The shape of the wing is also important. Like mentioned before, if the wings are too long or too wide, the gliders will be unstable and not fly well. Small angles between the wings (swept back wings) are primarily used for planes that are meant for traveling at high speeds, but generally they have very little gliding ability. Some examples are the Concord and jet fighter planes. Large angles between the wings (slightly swept back wings) are primarily used for planes and gliders that are meant for traveling at slower speeds, but they have a better ability of gliding. An example are the real gliders, passenger planes, and transport planes.

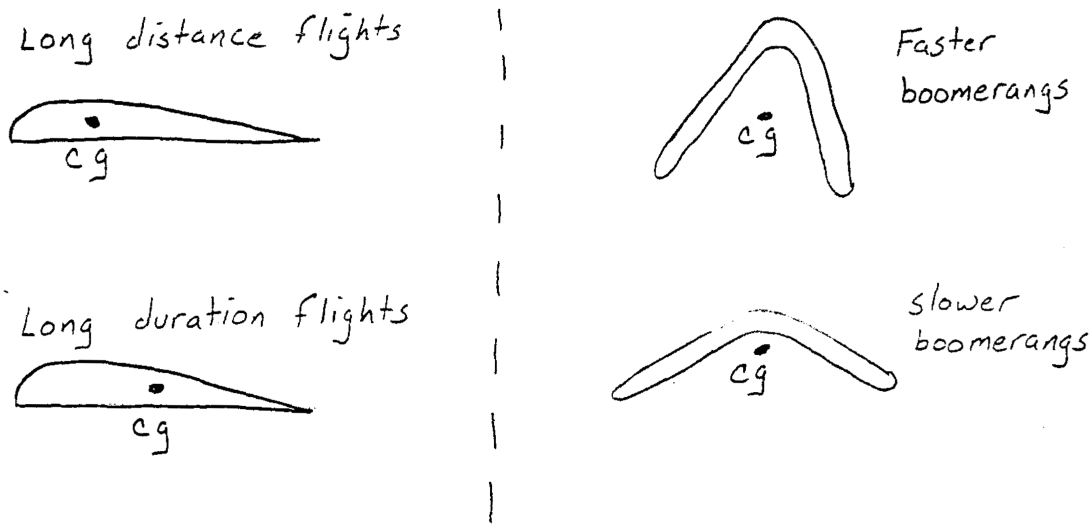




Center of Gravity (cg) and Flight Performance

The placement of the center of gravity (cg) and the angle of the wings are also very critical in how the glider and boomerangs will fly. Generally, for long distance flights on gliders, the cg is placed a little further forward. For long duration flights, the cg is placed a little further back. If the cg is placed too far forward, the glider will tend to nose dive. If the cg is placed too far back, the glider will tend to stall and may also tumble. The angle of the wings plays a factor in the placement of the cg. By changing the angle of the wings, the cg of the glider will move either move forward or backwards.

For boomerangs, the smaller the angle of the wings, generally the further back the cg. Small angled boomerangs tend to fly fairly fast and have higher spin rates. Wide angled boomerangs, the cg is further forward and tends to fly slower and have slower spin rates. If the angles become too large or small, the boomerangs become unstable and not able to fly well.



Demonstration

Using a glider, find and mark the location of its cg. Then fly the glider from a certain height and record its flight range and characteristics (i.e. approximate speed and any other unique flying characteristics).

Weight the nose of the glider with a paper clip and then find and mark the location of its cg. Fly the glider from the same height and record the same information. Add more paper clips to the nose of the glider and continue the same procedures.

Once the glider begins to essentially dive rather than glide, remove the paperclips and start adding them to the backside of the glider. Repeat the same procedures as before.

Notice the relationship of the cg to its flight characteristics and range.

Conclusion

This concludes my explanation of the science involved in the flight of gliders and boomerangs...for now. This paper by no means explains every aspect of the complex science involved, but it is my hopes that you get a better understanding and appreciation of the complexity involved in their flights. I urge everyone to further explore the wonders of the glider and boomerang and hopefully you will experience the same joy and amazement I have had in learning about these wondrous flying instruments.

Good luck, Good Flying, and many Happy Returns!

References:

Bailey, Ted. (1989-1990). The Boomerang Journal, 1-4.

Mauro, Ted. (1989). An Introduction to Boomerangs.

Hess, Felix. (1968). The Aerodynamics of Boomerangs. Scientific American, November, 124-136.

Walker, Jearl. (1979). The Amateur Scientist. Scientific American, April, 180-189.

King, Alex. (1975). Project Boomerang. The American Journal of Physics, Vol. 43, No. 9, September, 770-772.

Hanson, Michael. (1990). The Flight of the Boomerang. The Physics Teacher, March, 142-147.

Hawes, L. L., Mauro, J. B. (1987). All About Boomerangs.

Ruhe, Benjamin. (1982). Boomerang.

Trinklein, Frederick, E. (1992). Modern Physics, 93-112, 162-164.

Tippens, Paul E. (1995). Physics, 5th Edition, 192-198, 309-342.

Barnes, George B. (1984). Curve Balls, Airplane Wings, and Prairie Dog Holes. Science and Children, May, 13-15.

Goodwin, Peter. (1985). Twirly Tunes, Shower Curtains, and Prairie Dog Holes. Physics Can Be Fun, 150-156.

Alexander, R. McNeill. (1992). Exploring Biomechanics: Animals in Motion.

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