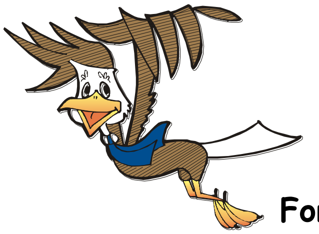


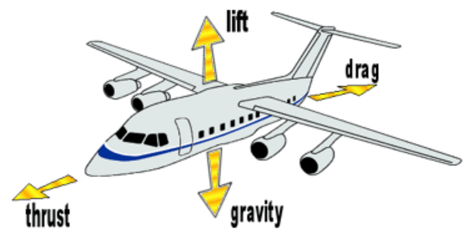
Civil Air Patrol's

"Forces of Flight"
For Use with CAP Balsa Planes & Intermediate Students
by AAS/SW Joint National Project: STEM Outreach

Where Imagination Takes Flight

Partners in Aerospace and STEM Education:

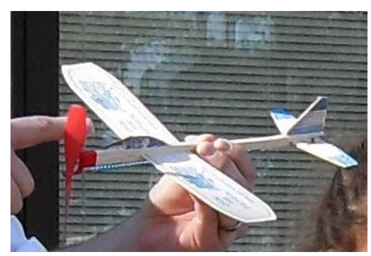
Arnold Air Society | **Civil Air Patrol** | **United States Air Force** | **Air Force Association** | **Silver Wings**



Topics: forces, motion (science)

Length of Lesson: 45 minutes- or, as long as you want to make it, using as much or as little of this detailed lesson as you desire

Objectives:
- Students will identify and define the four forces of flight: gravity (or weight), lift, thrust, and drag.
- Students will demonstrate the four forces of flight.
- Students will experiment with flight.



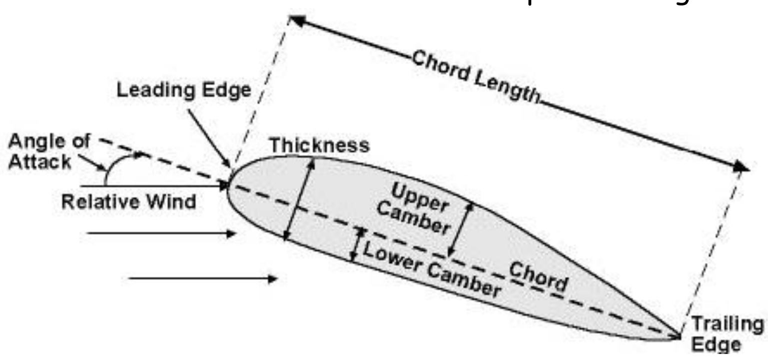
National Science Standards:
- Content Standard A: Science As Inquiry
- Content Standard B: Physical Science
  - Position and motion of objects
- Content Standard E: Science and Technology
  - Abilities of technological design

Background Information:
Explaining how and why an airplane flies is very complex; however, this simple explanation will help students acquire an elementary understanding of the forces of flight.

- Thrust is a force that moves an object in the direction of the motion. It can be created with a propeller, jet engine, or rocket. With a propeller or jet engine, air is pulled in and then pushed out in an opposite direction. A household fan can demonstrate this. Throwing an object, such as a Frisbee or a paper airplane, also creates thrust. Throwing your balsa airplane will create the thrust you need to conduct this lesson.

- Drag is the force that acts opposite to the direction of motion. It tends to slow an object. Drag is caused by friction and differences in air pressure. An example is putting your hand out of a moving car window and feeling it pull back.
- Weight is the force caused by gravity.
- Lift is the force that holds an airplane in the air. The wings create most of the lift used by airplanes. Lift is created due to angle of attack (the angle that the wings make against the air flowing towards them). Angle of attack relates to Newton's laws of motion. Depending on how the air is "hitting" and moving away from the wing affects the altitude of the plane.

The angle of attack is the angle at which relative wind meets an airfoil (shape of a wing). It is the angle that is formed by the chord of the airfoil and the direction of the relative wind or between the chord line and the flight path. The angle of attack changes during a flight as the pilot changes the direction of the aircraft. It is one of the factors that determine the aircraft's rate of speed through the air.



The angle of attack is the angle between the chord of the airfoil and the relative wind.

Notice the clouds in the picture to the right. The positive angle of attack of the wing pushed air down into the clouds behind the airplane thus pushing the airplane up. The airplane did not create the trail by flying through the clouds. The trail was created by the deflected relative wind bouncing off the bottom of the wing.

The increase in angle of attack increases lift up to a point. The angle of attack forces the relative wind hitting the airfoil down. (The relative wind is the flow of air past an airfoil relative to the path of flight. It is parallel and opposite in direction to the aircraft's path of flight.) By Newton's third law of motion (equal and opposite reaction), the wing is pushed up (lift). Lift is not created without a trade off. The relative wind also pushes the wing backward (induced drag). At some point, the force of drag is greater than lift as the angle of attack increases. The aircraft will stall (stop flying and start falling) without enough lift.

Depending on the angle of attack, there will be a force backward (induced drag) and a force upward (lift). The amount of force depends on the angle of attack. If the angle of attack is small, the drag and lift are comparatively small.

Bernoulli's principle helps explain the efficiency of a wing design. Bernoulli's principle explains that there is a difference in air pressure above and below the wing. Faster air moving over the top of the wing creates low pressure, which creates a "pulling" type of effect. Slower air moving underneath the wing creates a higher pressure which provides a "push" upward on the wing.

Materials:

- "Airfoil" pictures or transparency showing the cross section of an airplane wing with air traveling over and under it (picture included)
- "Four Forces of Flight: Illustrations" pictures or transparency (picture included)
- computer with Internet and projector (optional)
- overhead projector (or alternate method of displaying transparency information)
- balsa plane kits (provided by CAP)

Lesson Presentation:

1. Display a pre-assembled balsa plane. Ask students if they can explain how an airplane flies. Tell them that they will be able to explain the forces that act upon things that fly and they will experiment with flight today.

2. Show the "Forces of Flight: Illustrations" transparency/information and briefly describe each force's effect on an airplane. (See background information for explanation of the forces of flight.) Explain lift and gravity last. (An alternate way to explain the forces of flight and why airplanes fly is to go to http://www.nasa.gov/audience/forstudents/k-4/stories/ames-how-planes-fly-slideshow.html and read the story.)

   To help explain the forces of flight, make comparisons to traveling in a car. For example, a car's engine provides the "thrust" needed to move it forward. An airplane's engine and propellers create its thrust.

   Lift, drag, and angle of attack are easily observed by sticking your arm out of the car window while riding with hand extended with fingers together. Imagine your arm is now a wing. Rotate your hand to change the angle of attack. At each angle, notice the relative wind hitting your hand. When your hand is parallel to the relative wind (angle of attack = zero degrees) the relative wind puts pressure on the leading edge of your wing only. Keeping your hand in one place is fairly easy. This is the point where lift and drag are both lowest. Rotate your hand so your thumb is higher than your pinky finger (angle of attack is greater than zero) and your wing finds lift. Notice the relative wind also pushes your hand back (induced drag). Continue rotating your hand and you will find an angle of attack where the drag pulling your arm backwards is greater than the lift. Your wing has stalled.

Now rotate your hand the other direction so that your thumb is lower than your pinky finger. Notice the same rules apply. The angle of attack is negative and the relative wind now hits the top of your hand. The lift is pushing your hand into the ground! A pilot can change the aircraft's angle of attack to fly both up and down through the air. To remain in the air, the aircraft will need lift to continually overcome gravity; therefore, the angle of attack for normal flight is greater than zero. Aircraft wings are designed and built with a positive angle of attack for this very purpose.

3. Show the airfoil transparency with the air flow over the airfoil diagram. Explain that the curved edge of a Frisbee serves the same purpose as the curved front of the wing. This particular shape is called an airfoil, and it helps create lift. Further explanation should be given:

   Airplanes are able to fly because of the movement of airflow above and below its wings. As the engine and propellers work together to provide thrust and move the plane through the air, air flows above and below the wing. The angle of attack affects the altitude of the plane, or the plane's lift. Another factor that aids in lift is Bernoulli's principle, which relates to the pressure difference that occurs between the area over and under the wing. Air molecules traveling over the top of the airplane move faster than those moving below the wing. This fast movement of air causes a low pressure above the wing, which creates a "pulling" effect. The slower moving air under the wing creates a higher pressure that creates a "pushing up" effect. Both the pull and push forces work together to keep the plane lifted into the air.

   (optional) Show the two short video animations at the URLs below to further explain lift.
   http://quest.nasa.gov/aero/planetary/atmospheric/Aero_movies/airfoil01.mov
   http://quest.nasa.gov/aero/planetary/atmospheric/Aero_movies/angle01.mov

4. Ask students what keeps a car on the ground. (gravity) Ask students to explain why gravity keeps a car on the ground but not an airplane. If students say a car cannot go fast enough to take flight, dispel that thought by telling them that a small, lightweight aircraft can take off at speeds around 60 miles per hour, and a car can certainly go faster than 60 mph! A German plane was developed in WWII that could take off at about 25 miles per hour! Speed is not the reason a car doesn't lift off of the ground. It has to do with design; specifically, there are no wings that generate lift! Airplane wings generate most of the lift for airplanes.

Cars were not designed to fly. Yes, the forces of drag and lift act on a car, but due to the design of cars and the "angle of attack" of their parts against air, they do not take off. In fact, to try to keep race cars, like Formula One cars, from coming off the ground, an inverted airplane wing is located in the front and back of the car. This improves "downforce," which adds more weight on the tires. (Even some regular automobiles utilize a type of inverted wing to correctly and efficiently direct air flow.) This doesn't mean though that race cars will never come off of the ground. The right speed and angle of attack (remember, racetracks are not always flat) could cause it to lift off of the ground, but it won't stay in the air for long (no continued thrust and wrong angle of attack)!

5. Using the bottom picture on the "Forces of Flight" transparency, point to the different arrows and ask the class to name the force indicated by the arrow.

6. Provide a plane kit to each student. Guide students through the building process. **Important to stress being gentle with the balsa planes as they are made of thin wood and will easily break.** *Two planes per student have been included, just in case of breakage.*

7. Once the planes are made, have students gently write their name on their plane with a marker or pen.

8. Have students hold their assembled airplane with the nose pointed toward the front of the classroom. Call out each of the four forces of flight and ask students to orient their plane correctly to show the effect of the force. For example, when you say "thrust," students should move their plane forward. When you say "drag," students should move their plane back. Remind students that each force is necessary in order for airplanes to fly.

9. Tell students that they will go outside to demonstrate the forces of flight and experiment with flight. Go over safety issues with students before flying. (e.g., Do not fly airplanes in close proximities. Be vigilant at all times, etc.)

10. Take the class to an open area and allow them to experiment with their planes. (You may wish to take some tape outside to help with any necessary flight repairs.)

11. After students have had time to practice, gather them to discuss what they learned.

Summarization:

Ask students to share their flight experiences. Ask them to identify problems they encountered with their flights and any solutions at which they arrived.

Ask students the following review questions.

- What provided thrust for their airplane? (throwing the airplane)
- What eventually brought the airplane back to the ground? (gravity)
- What force worked against the forward motion of the airplane? (drag)
- What force helped hold the airplane in the air while thrust was being generated? (lift)
- Ask students if they have any ideas as to why lift occurred with the airplanes even though the wing is not curved like an airfoil? (orientation of the wings to the air - angle of attack)

Character Connection: Tell students that just like there are forces that affect flight, there are forces all around us that affect our lives. Some of the forces are good and some bad. For example, the force of peer pressure might cause us to do something we will regret if peers are pressuring us to do something wrong. Our parents, teachers, coaches, and other adults in our lives can be a strong force in our lives to encourage us to do good things. Media (television, movies, magazines, etc.) can be a force that influences our decisions. Encourage students to be aware of the forces around them and make good decisions that will positively impact their lives. Encourage them to be a positive force to motivate others to make good decisions as well.

Drug Demand Reduction (DDR) Connection: Ask students to review the forces of flight by naming them and explaining how each affects a Frisbee or an airplane. Ask students to take a piece of notebook paper, drawing paper, or poster board and divide it in half, lengthwise like a hot dog. Have students draw a line down the middle of the paper to separate the paper into two sections. Have students write "drag" along the left edge of the paper and "thrust" along the right edge of the paper. In the "drag" section of the paper, have students illustrate that drugs and alcohol can drag them down. On the right side of the paper, have students illustrate things that thrust (or propel) them forward. Conversely, students could do this same activity by dividing another piece of paper or poster board in half the other way, drawing a line across the middle of the paper, labeling the top as "lift" and the bottom as "weight."

Assessment:

- leader observation
- construction of airplane
- "Four Forces of Flight" Worksheet (optional)

Additional activity ideas to enrich and extend the primary lesson (optional):

- Have students complete the "Four Forces of Flight" worksheet.

- Present the following information about Frisbees:

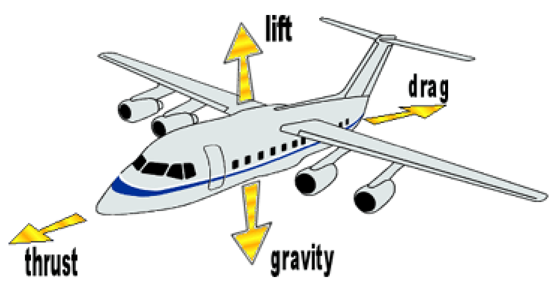
  Many people claim to have invented the Frisbee. They got their start in New England colleges during the 1800's when students would fling empty pie tins from the Frisbee Baking Company for fun. In 1948, a Los Angeles man named Walter Frederick Morrison invented the first plastic version that flew further and with better accuracy than the pie tin.

  Just like the shape of an airplane, the shape of a Frisbee has a great deal to do with its ability to soar through the air. A Frisbee is an airfoil, just like the wing of an airplane is an airfoil. An airfoil-shaped body moving through the air produces a force called lift. A Frisbee's spinning action creates stability for the Frisbee, the same way that airplanes and birds have tails, and rockets have fins to help keep them stable during flight.

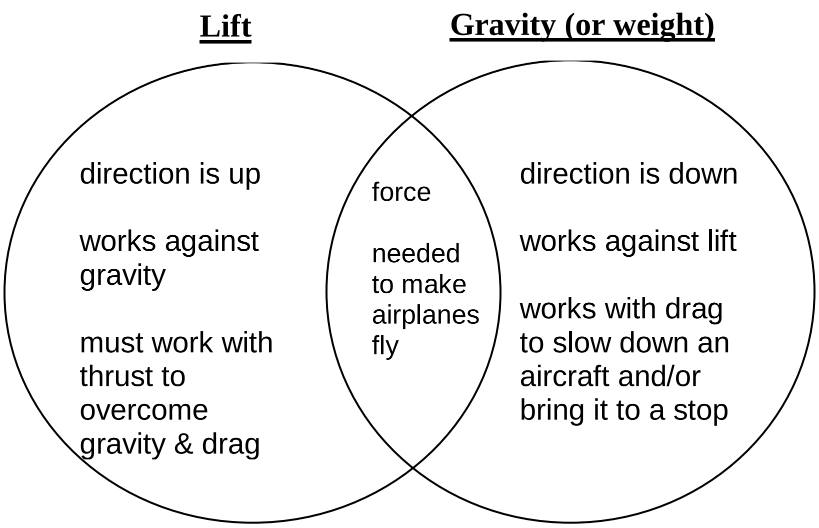
  Potential Additional Activity: Have students demonstrate the four forces of flight with a Frisbee. Have them experiment with Frisbees of different shapes and sizes and draw reasonable conclusions.

- Print copies or make a transparency of Education World's "The Fabulous Frisbee" paragraph for students to edit. This can be found at http://www.education-world.com/a_lesson/edit/pdfs/edit0110.pdf. Have students edit the paragraph. Answers are at http://www.educationworld.com/a_lesson/edit/edit0110.shtml.

- Divide students into small groups to determine other ways they can demonstrate the four forces of flight. Then, let the groups share their ideas with the class.

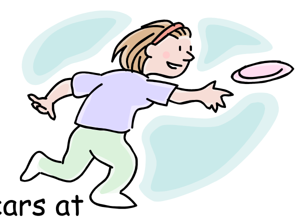


- Have students compare and contrast the four forces of flight on an airplane. Remind students that each force has an opposite force that works against it. Example:

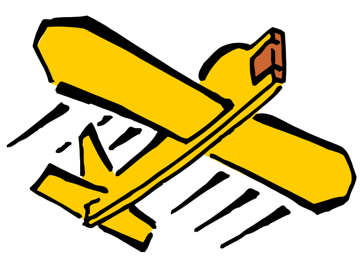


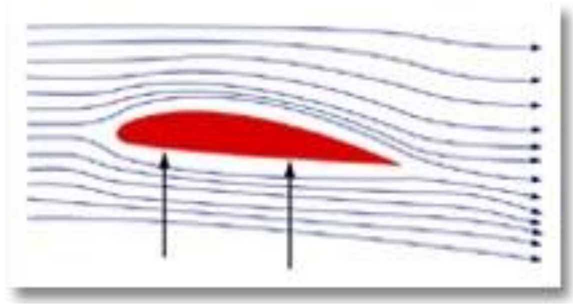
- If there is additional time or another session with the students, the complete lesson entitled "Graphing the Forces" can be used.

Associated Literature and Websites:



- *Frisbee* by Dr. Stancil E. D. Johnson
- *Fabulous Frisbee* by Dorothy Childers Schmitz
- Read more about the aerodynamics of Formula One cars at http://www.formula1.com/inside_f1/understanding_the_sport/5281.html.
- Read more about the forces of flight at http://www.nasa.gov/audience/foreducators/k-4/features/F_Four_Forces_of_Flight.html.





Cross Section of an Airfoil (such as an airplane wing)

Source: http://spaceplace.jpl.nasa.gov/en/kids/phonedrmarc/2003_april.shtml

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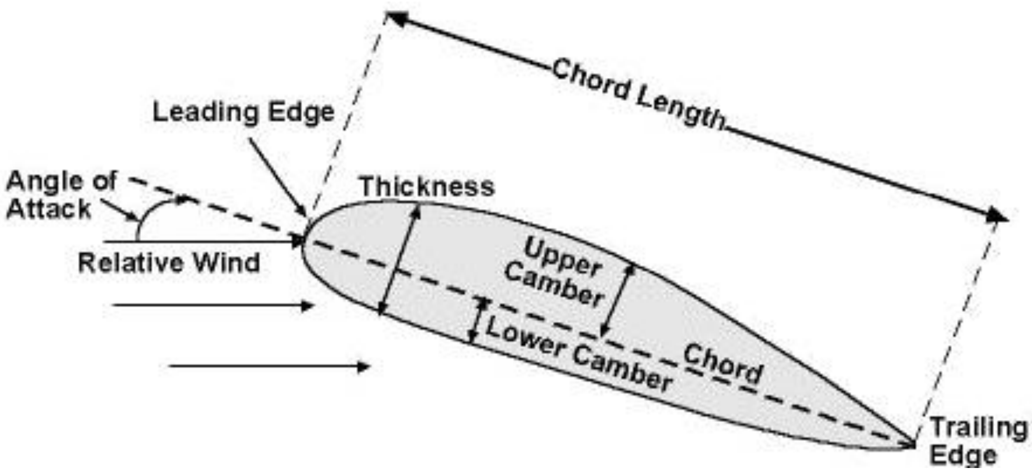
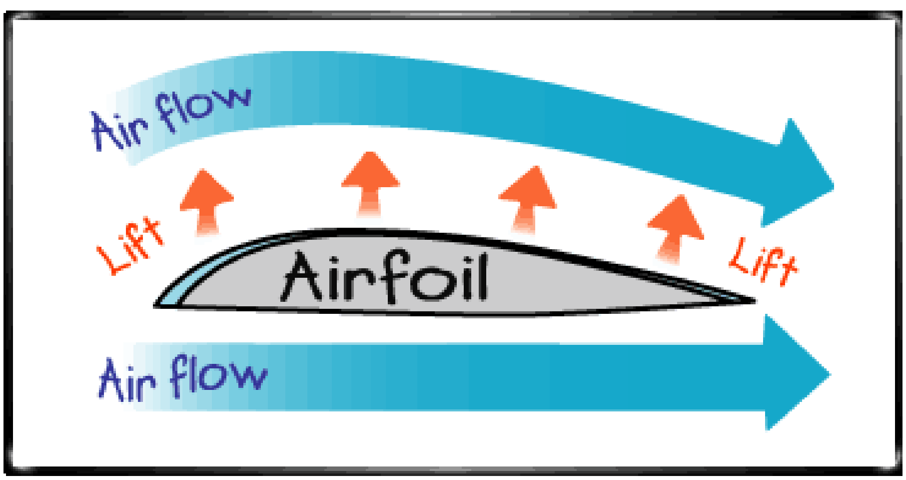


The **angle of attack** is the angle between the chord of the airfoil and the relative wind.

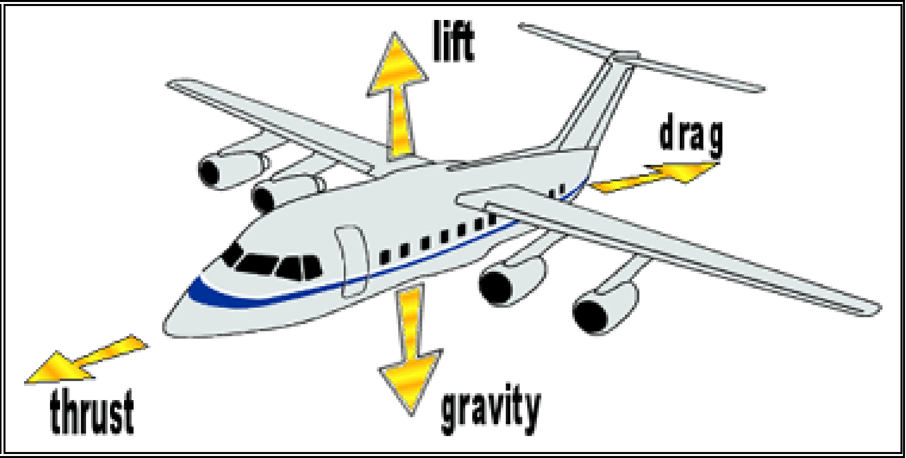
Source: Civil Air Patrol



Airflow Above and Below an Airfoil (such as an airplane wing)

Source: http://www.ueet.nasa.gov/StudentSite/dynamicsofflight.html

FORCES OF FLIGHT: ILLUSTRATIONS (transparency)

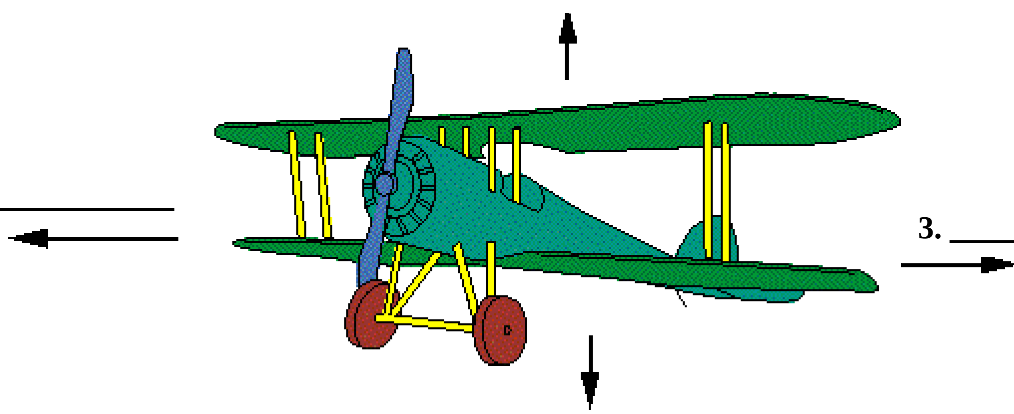
Four forces of flight	
Lift - upward **Drag** - down and backward **Weight/Gravity** - downward **Thrust** -forward	

Above Picture Source: http://www.ueet.nasa.gov/StudentSite/dynamicsofflight.html

Name of the force of flight represented by each arrow.

2. ______________

1. ______________



3. ______________

4. ______________

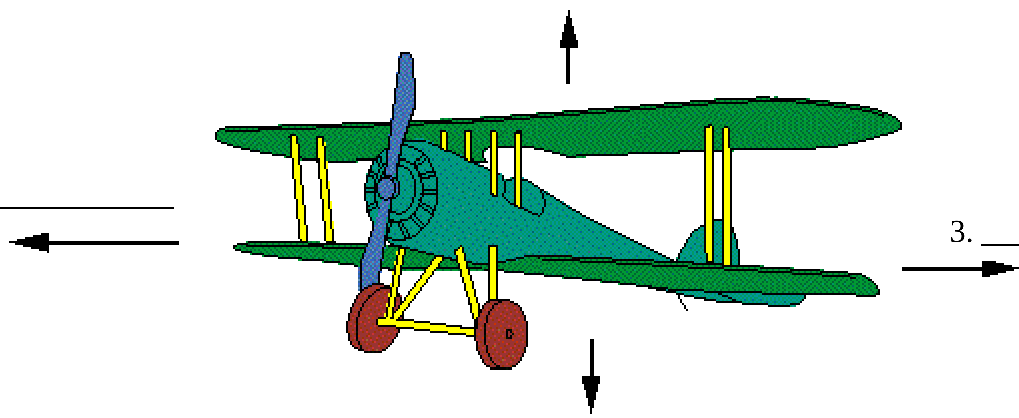
Source: NASA Explores

FORCES OF FLIGHT (student worksheet) **Name ____________________**

Write the name of the force of flight represented by each arrow.

2. _______________

1. _______________



3. _______________

4. _______________

Write the letter of the correct term beside each description. You may use a letter more than once!

A. Lift B. Drag C. Thrust D. Weight (or Gravity)

______ 1. The special shape of the wings and how air moves over the wings creates this force.

______ 2. This is a force that moves the object in the direction of motion. An engine or a propeller can create this force.

______ 3. This force is the air resistance affecting a moving object. It seeks to slow down the object.

______ 4. This force always pulls downward.

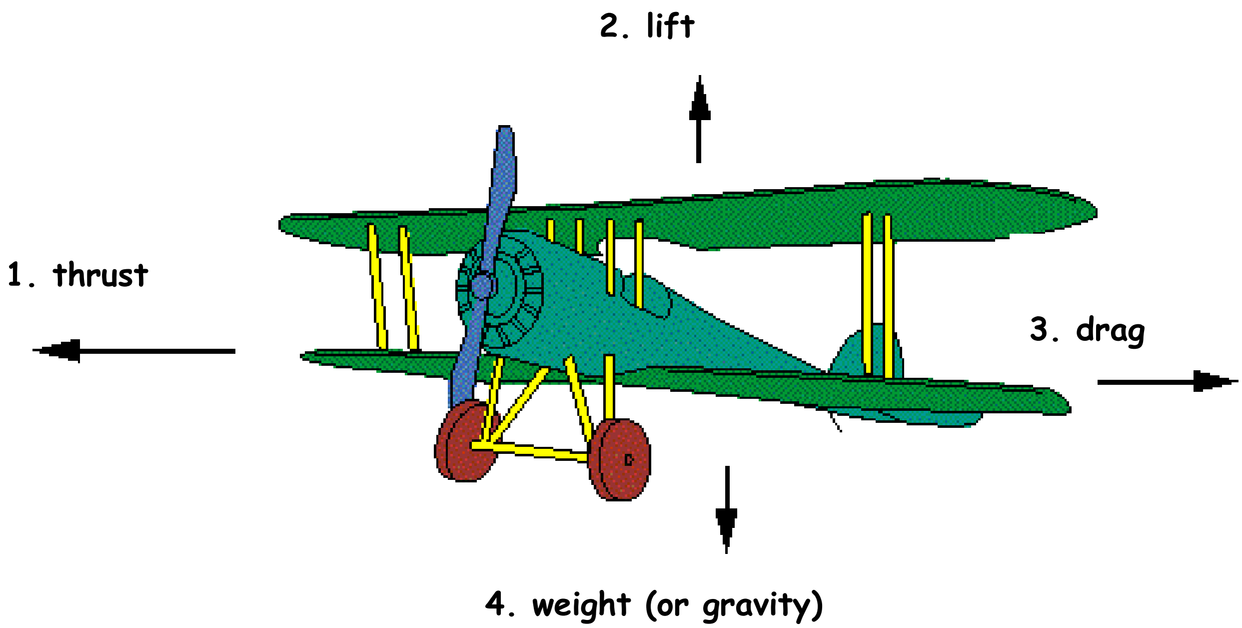
______ 5. This force is opposite of drag.

______ 6. A demonstration of this force is putting your hand out of the window of a moving car and feeling the air <u>pushing your hand back</u>.

______ 7. This force is the opposite of gravity or weight.

Forces of Flight Answer Sheet

Write the name of the force of flight represented by each arrow.



Write the letter of the correct term beside each description. You may use a letter more than once!

A. Lift B. Drag C. Thrust D. Weight (or Gravity)

__*A*__ 1. This force is created by the special shape of the wings and how air moves over the wings.

__*C*__ 2. This is a force that moves the object in the direction of motion. An engine or a propeller can create force.

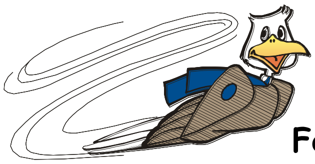
__B__ 3. This force is the air resistance affecting a moving object. It seeks to slow the object.

__D__ 4. This force always pulls downward.

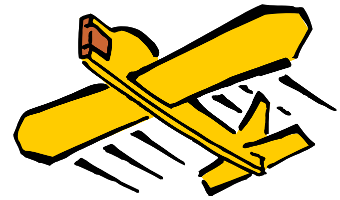
__*C*__ 5. This force is opposite of drag.

__B__ 6. A demonstration of this force is putting your hand out of the window of a moving car and feeling the air <u>pushing your hand back</u>.

__*A*__ 7. This force is the opposite of gravity (or weight)



"Graphing the Four Forces"
For Extension of the Basic Balsa Plane Activity
with Intermediate Students



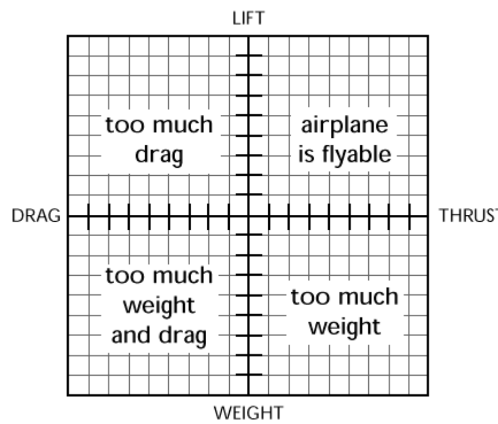
Topics: forces, graphing (math, science)

Lesson Reference: http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/graph.html
NASA Quest http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/force.html

Length of Lesson: 45 minutes, or as long as is desired or there is time, using as much or as little of the activity as is needed

Objectives:

- Students will describe the four forces of flight (lift, weight/gravity, thrust, drag).
- Students will graph information to determine whether or not a plane is flyable.
- Students will make inferences using the graph results.



National Standards:

Science Standards

- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science
  - Motions and forces
  - Transfer of energy
- Content Standard E: Science and Technology
  - Abilities of technological design

Math Standards

- Algebra
  - Construct graphs that accurately represent the relationship between variables
  - Investigate how a change in one variable relates to a change in a second variable
- Data Analysis and Probability
  - Use a graph that is appropriate for the type of data to be displayed
  - Read and interpret quantitative and qualitative data
  - Make predictions based on experimental and theoretical probabilities
- Representation
  - Model problem situations with objects and use representations such as graphs to draw conclusions
  - Create and use representations to organize, record, and communicate mathematical ideas
  - Select, apply, and translate among mathematical representations to solve problems

Background Information: (from NASA Quest)

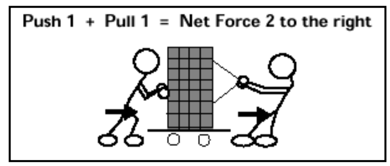
A force is defined in its simplest sense as a "push" or a "pull". These definitions do not imply a direction. Students can "pull" in any direction as they can "push" in any direction! The terms are frequently used because students can readily identify with the actions of pushing and pulling, and the fact that these actions usually have an effect on what they are pushing or pulling.

Review with students that there are two parts to the definition of a force. In fact, when a force is defined it must have both parts - one is not enough! The two parts are: magnitude (a quantity that can be measured) and direction. The direction of a force is self-explanatory, and again, has nothing to do with the terms "push" or "pull".

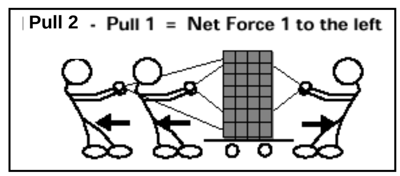
The magnitude of a force can be described as "how hard the force is" or "how much power the force has." For example, a force of magnitude 10 can be described as a "stronger" force than one of magnitude 2, which can be described as a "weaker" force.

When two forces act in parallel, in either the same or opposite direction, measuring them is simply a matter of adding or subtracting their magnitudes. When two forces are acting in parallel and in the same direction, measure them by adding the magnitudes together.

In the example to the right, a "push" of magnitude 1 added to a "pull" of magnitude 1 equals a net force of magnitude 2. The cart will then move in the direction of the greatest magnitude - in this case to the right.

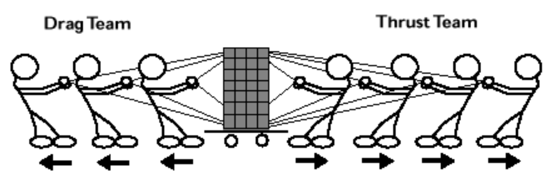


When two forces act in parallel in the opposite direction, measure them by subtracting the magnitudes. In the example below, a pull of magnitude 1 is acting opposite to a pull of magnitude 2. The cart will move in whichever direction has the greatest magnitude. In this case the cart will move to the left.



Forces that act in opposite directions are called "oppositional" forces. Four of the forces in aeronautics (lift, drag, weight, and thrust) can be thought of as "oppositional" pairs.

thrust acts in a direction opposite to drag
lift acts in a direction opposite to weight



The oppositional forces can be introduced as a game of tug-of-war. Teams can be named as the four forces. For example, a tug-of-war can be set up between a thrust team and a drag team.

In the above graphic, the "Thrust Team" has a magnitude of 4 and the "Drag Team" has a magnitude of 3. The net force will be

Thrust 4 - Drag 3 = Net Force 1 to the right

Since the "Thrust Team" has the greater magnitude, the cart will move in the direction that the "Thrust Team" is pulling, in this case to the right.

Since the "Thrust Team" has the greater magnitude, the cart will move in the direction that the "Thrust Team" is pulling, in this case to the right.

The concept of force can be effectively represented on a graph using the Cartesian coordinate system. By representing four of the aeronautical forces (lift, drag, thrust, weight) on a graph, students can visualize both parts of the definition of force: magnitude and direction.

In this lesson, students will use information about four forces to make a decision about whether or not an airplane is (theoretically!) able to fly.

This lesson concentrates on the actual representation of the forces on a graph. If, after combining the four forces, the net force is plotted in the upper right quadrant (quadrant I) of the graph, then we will draw the conclusion that the airplane is able to fly.

Materials:

- overhead projector and transparencies of the introduction pictures or alternate means of showing the images
- student copies of “Graphing the Four Forces” worksheets

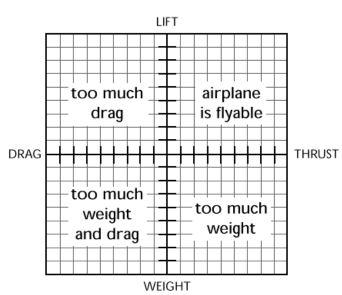
NOTE: This lesson is more effective if students have received a forces of flight lesson, such as the first lesson, “Forces of Flight.”

Lesson Presentation:

1. Review information about the four forces of flight by asking students to share information about the forces of flight. Allow them to illustrate the information on the board if they prefer.

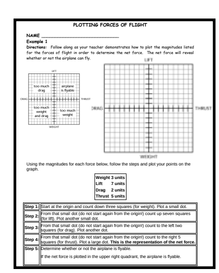
2. Explain to students that they will use information about the four forces of flight today to make a decision about whether or not a plane is able to fly. Explain that this is in theory as there are other factors regarding the plane that would be taken into consideration.

3. Show students introductory picture #1. Tell students that in the case of this graph, direction is determined by the force of flight. Point out that lift is "up toward the top of the paper", weight (or gravity) is "down toward the bottom of the paper", thrust is "forward toward the right of the paper" and drag is "back toward the left of the paper". Lift and weight are parallel forces. Thrust and drag are parallel forces.



Tell students that they will use magnitudes (to be defined later) for each force of flight to plot points on the graph. Once all points are plotted correctly, it should be easy to determine if the overall forces of flight affecting the plane will allow it to fly.

4. Distribute student copies of “Graphing the Four Forces. Tell students to follow along on their student sheet for the example, as you demonstrate the process to the class. Follow the



directions on the page. You may choose to use introductory picture #2 to demonstrate how to correctly graph the magnitudes of each force in order to reveal the net force.

5. Once the example problem is completed, ask students if they have an idea of what "magnitude" means as it is used with each force of flight. Confirm that magnitude, as it is used in the examples, is a number that describes the amount of force. To fully describe a force acting upon an object, not only does one need to know the direction, but also magnitude. For example, if Bob weighs 100 pounds and he stands on a chair, he is applying a downward force of 100 pounds on the chair. The reverse is also true; the chair is applying an upward force of 100 pounds. With our forces of flight, we know how the force affects direction. Lift is up, weight/gravity is down, thrust is in the front of the plane, and drag is at the rear. As NASA Quest explains, "The magnitude of a force can be described as 'how hard the force is' or 'how much power the force has.' For example, a force of magnitude 10 can be described as a 'stronger' force than one of magnitude 2, which can be described as a 'weaker' force." In the forces of flight graphing activity, the given magnitudes of the forces of flight help one to better understand the "power" of each force and to plot the forces on the graph.

6. Ask students if they can define "net force." If help is needed, display "introductory picture #3," and explain the pictures to the students. The examples in "introductory picture #3" simplify the concept of net force by adding or subtracting only two parallel forces. Explain that in the graphing exercise they just completed, they did not only take into account just two parallel forces, they "added" all four forces of flight which resulted in the net (overall total) force acting on the object, which in this case, is an airplane.

7. Ask students if they have any questions about how to plot the forces of flight using direction and magnitude. If there are no other questions, allow students to complete the other problems provided.

8. Go over the answers with the students.

Summarization:
Ask students to share what they learned. Ask students to share their definition of the following: lift, thrust, weight drag. Ask students what two components are necessary to fully describe a force acting upon an object. (direction and magnitude) Ask students to explain what magnitude means, as it relates to forces. (number relating to amount of force is acting on an object) Ask students to explain net force. (overall total force acting on an object)

Ask students why it is important to know how to use a graph. (Plotting information on a graph creates a visual representation of information which can make information easier to understand. Information on a graph can reveal important information.)

Tell students that in life, forces push and pull us. Sometimes, forces want to pull us in the wrong direction. Just like the forces of flight graphs reveal whether or not a plane will fly, we should consider making a visual representation of how positive forces can "lift" us up and negative forces can bring us "down" or cause us to go backward instead of moving forward. When faced with making a choice, decide if your answer will place you on the side of "lift" and "thrust" or will it place you in a position of "drag" and "weight."

Assessment:

- leader observation
- student answers to class discussion questions
- "Graphing Forces of Flight" worksheet

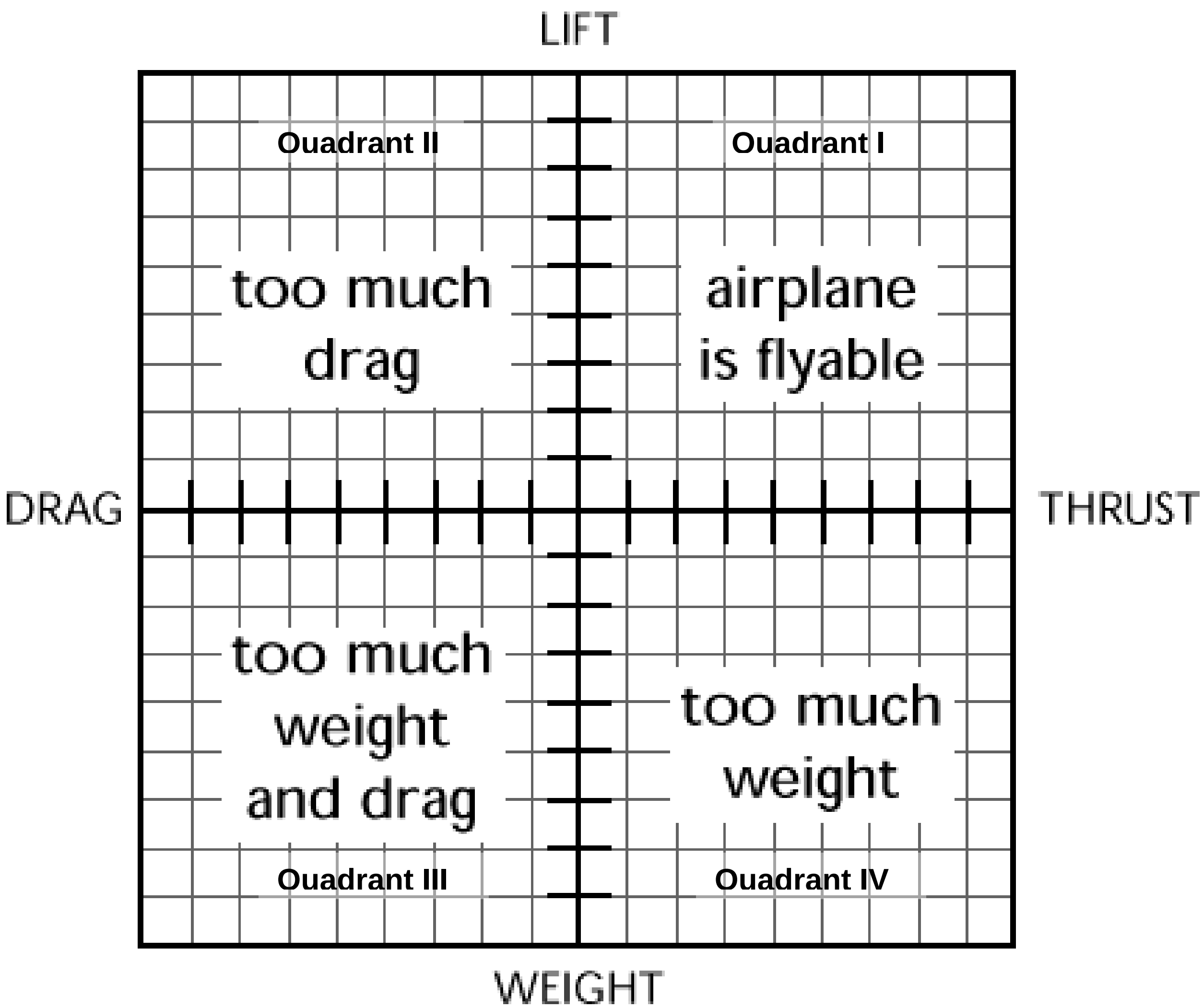
Additional activity ideas to enrich and extend the lesson (optional):

- Make copies of "introductory picture 2," and allow students to create their own magnitudes for each force of flight and plot it on a graph. Allow students to exchange sample problems to see if a classmate confirms the same results.
- Discuss with students the answers to the "expert questions" on the "Graphing the Four Forces" problems for numbers 1-4. Explain to the students that the graph information tells us so much more than just whether or not the plane will fly. If we fully understand the forces of flight and the graph information, we can easily discern how to make the airplane flyable if it was identified as "not flyable" after calculating the net force.
- Teach or have students write the plotted points of lift, weight, drag, thrust, and net force for each problem with actual x and y coordinates, such as (-2, 7).
- Discuss further how to calculate the net force of two opposing forces, as discussed in the background information. Then, allow students to complete the "Use the Force" worksheet.

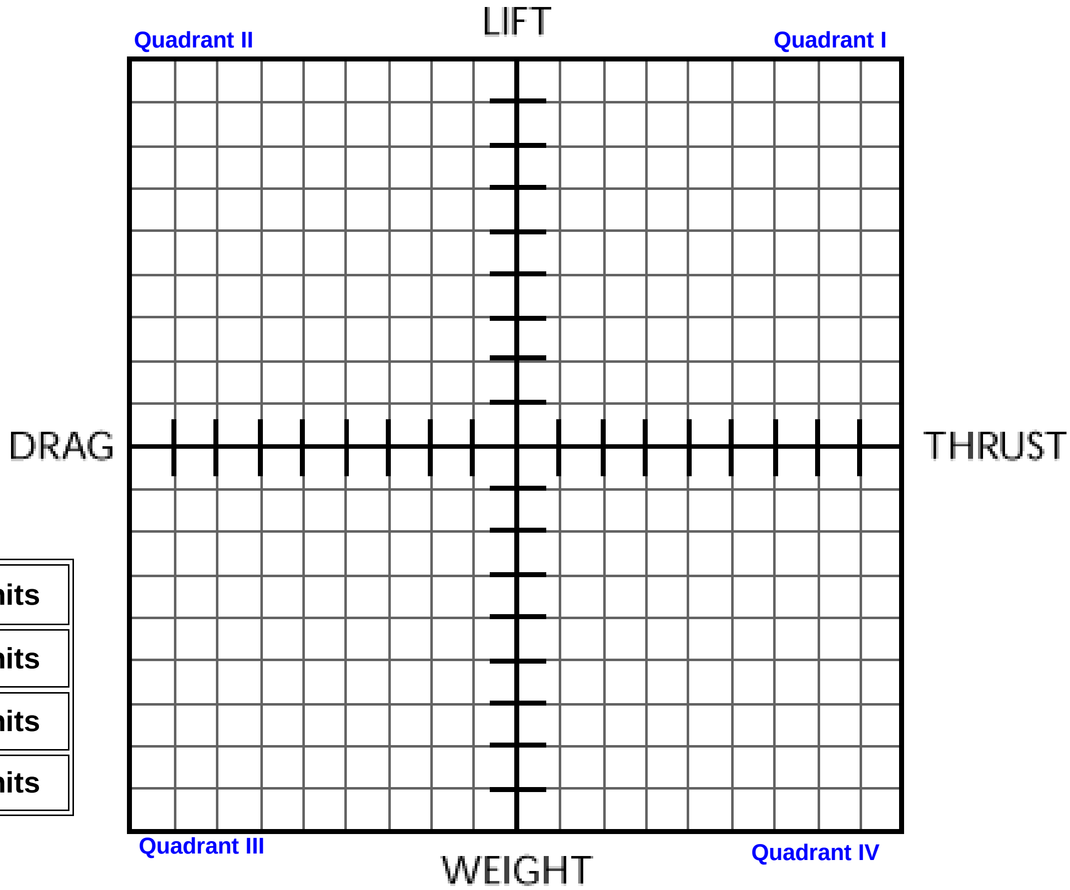
Associated Websites:

- Learn more about force at http://www.physicsclassroom.com/Class/newtlaws/.
- Read about forces on an airplane at http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html.
- Read about forces on a rocket at http://exploration.grc.nasa.gov/education/rocket/rktfor.html.
- Learn about forces on a baseball at http://www.grc.nasa.gov/WWW/K-12/airplane/ballforce.html.

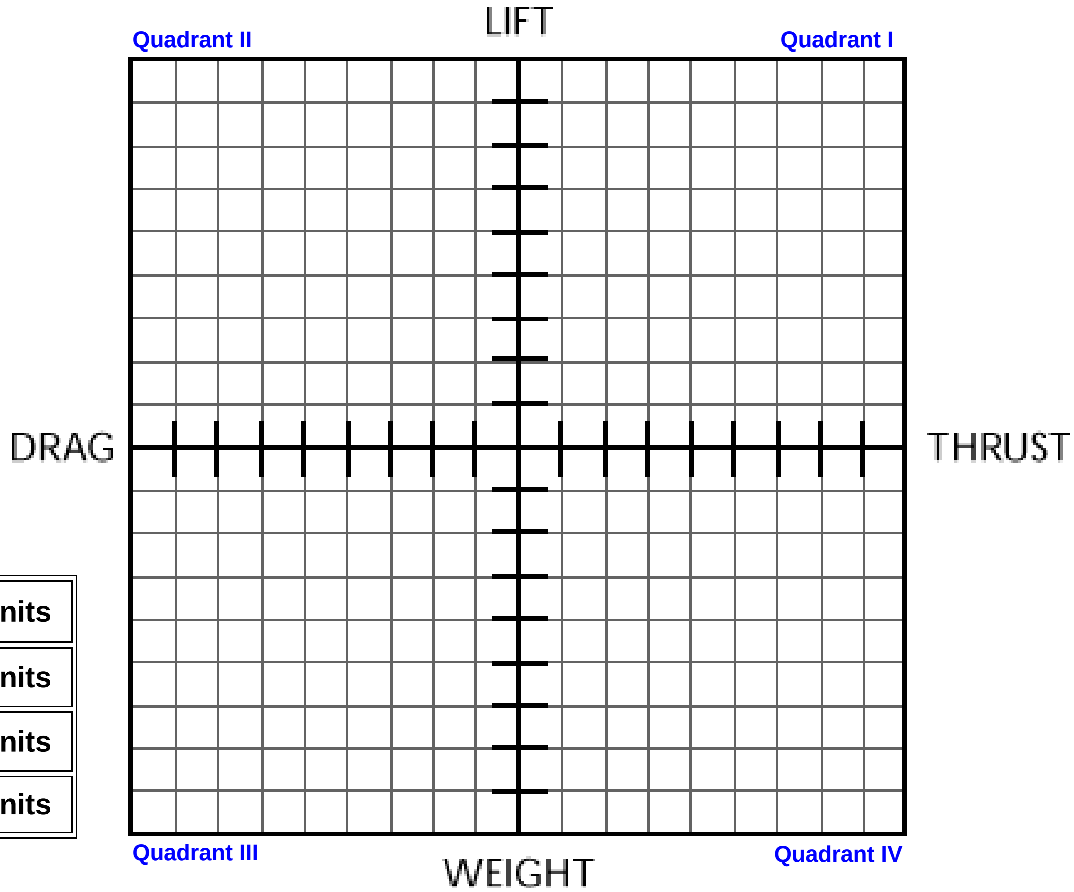
Introductory picture #1 (Graph)



Introductory picture #2



Weight	units
Lift	units
Drag	units
Thrust	units

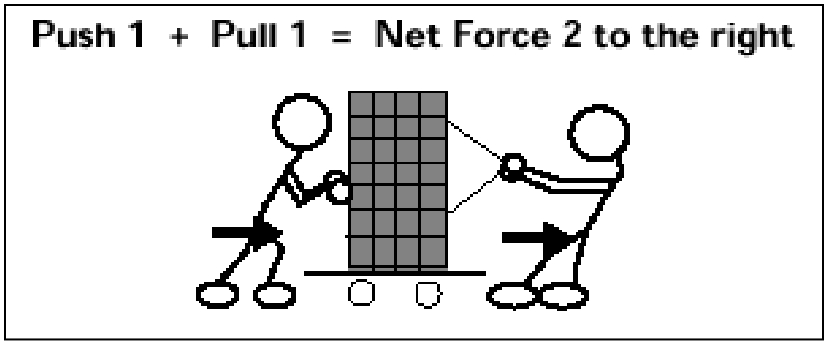


Weight	units
Lift	units
Drag	units
Thrust	units

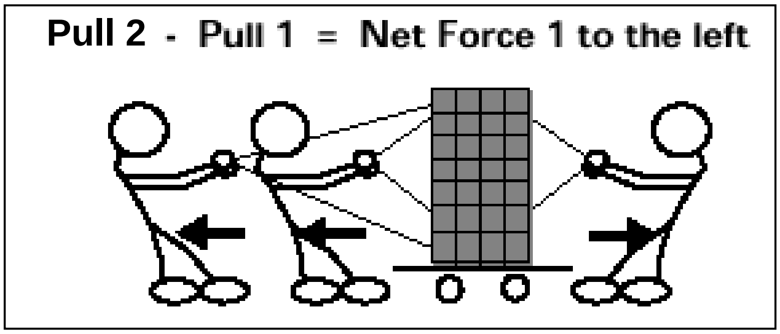
Introductory picture #3 (Net Force)

When two forces act in parallel, in either the same or opposite direction, measuring them is simply a matter of adding or subtracting their magnitudes.

When two forces are acting in parallel and in the same direction, measure them by adding the magnitudes together. In the example below, a "push" of magnitude 1 added to a "pull" of magnitude 1 equals a net force of magnitude 2. The cart will then move in the direction of the greatest magnitude - in this case to the right.

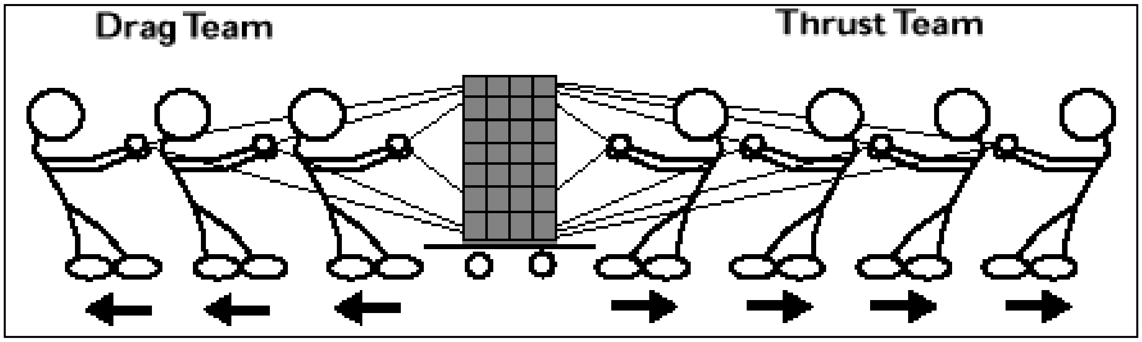


When two forces act in parallel in the opposite direction, measure them by subtracting the magnitudes. In the example below, a pull of magnitude 1 is acting opposite to a pull of magnitude 2. The cart will move in whichever direction has the greatest magnitude. In this case the cart will move to the left.



Forces that act in opposite directions are called "oppositional" forces. Four of the forces in aeronautics (lift, drag, weight, and thrust) can be thought of as "oppositional" pairs.

thrust acts in a direction opposite to drag
lift acts in a direction opposite to weight



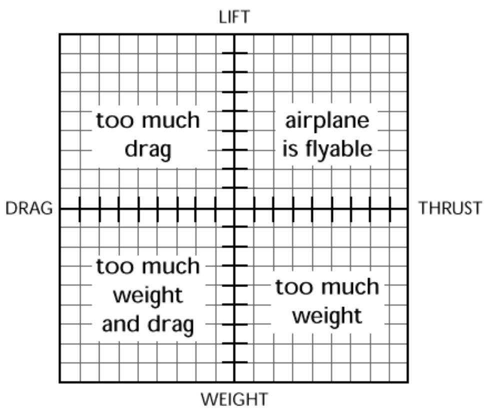
In the above graphic, the "Thrust Team" has a magnitude of 4 and the "Drag Team" has a magnitude of 3. **The net force will be: Thrust 4 - Drag 3 = Net Force 1 to the right.** Since the "Thrust Team" has the greater magnitude, the cart will move in the direction that the "Thrust Team" is pulling, in this case to the right.

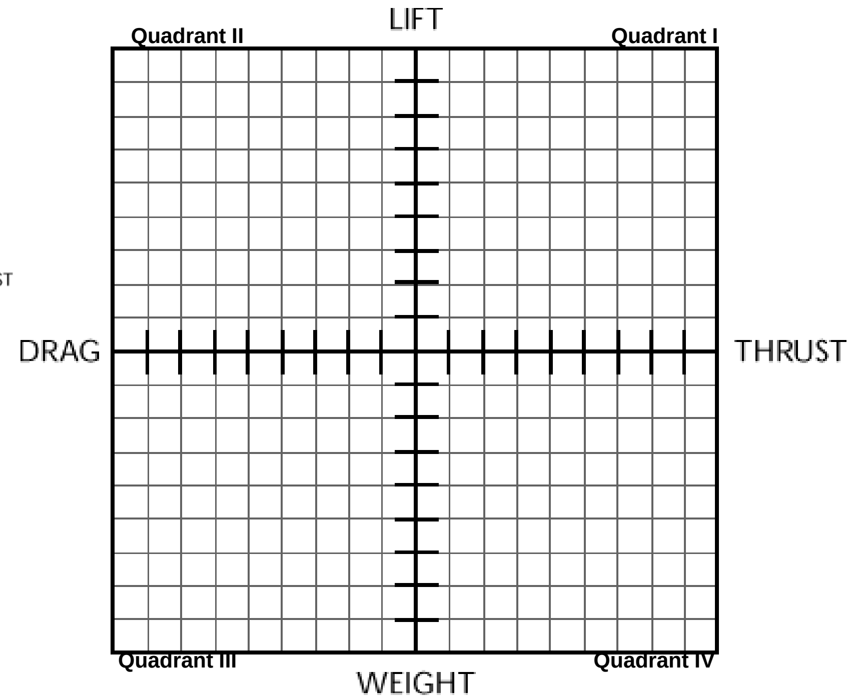
from NASA Quest at http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/force.html

GRAPHING THE FOUR FORCES

NAME _______________________________ **Example**

Directions: Follow along as your teacher demonstrates how to plot the magnitudes listed for the forces of flight in order to determine the net force. The net force will reveal whether or not the airplane can fly.





Using the magnitudes for each force below, follow the steps and plot your points on the graph.

Weight	**3 units**
Lift	**7 units**
Drag	**2 units**
Thrust	**5 units**

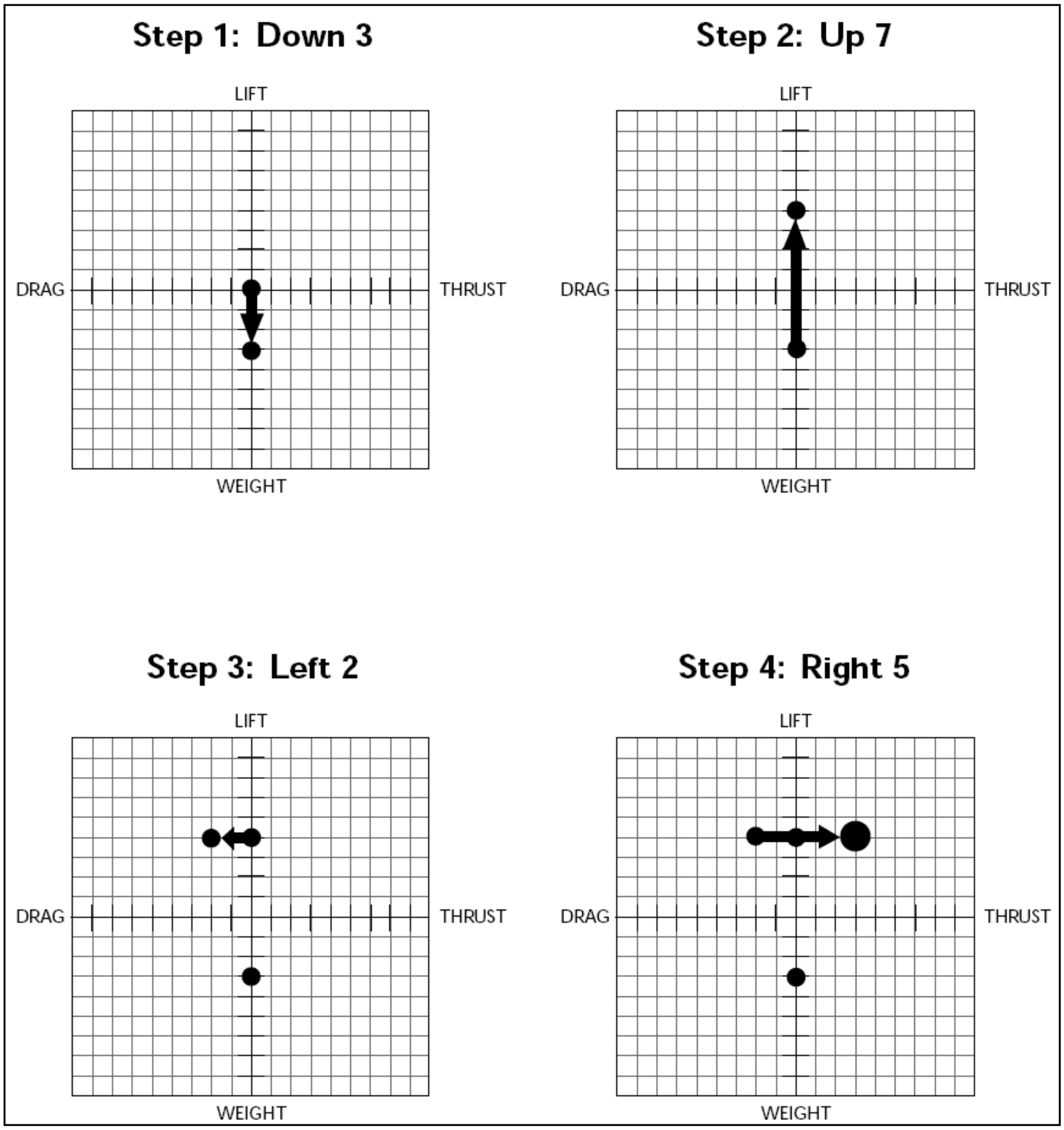
Step 1:	Start at the origin and count down three squares (for weight). Plot a small dot.
Step 2:	From that small dot (do not start again from the origin!) count up seven squares (for lift). Plot another small dot.
Step 3:	From that small dot (do not start again from the origin!) count to the left two squares (for drag). Plot another dot.
Step 4:	From that small dot (do not start again from the origin!) count to the right 5 squares (for thrust). **Plot a large dot. This is the representation of the net force.**
Step 5:	Determine whether or not the airplane is flyable. If the net force is plotted in the upper right quadrant, the airplane is flyable. If the net force is plotted in the upper left quadrant, the airplane is not flyable; it has too much drag. If the net force is plotted in the lower left quadrant, the airplane is not flyable; it has too much drag and weight. If the net force is plotted in the lower right quadrant, the airplane is not flyable; it has too much weight.

Source: http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/graph.html

GRAPHING THE FOUR FORCES

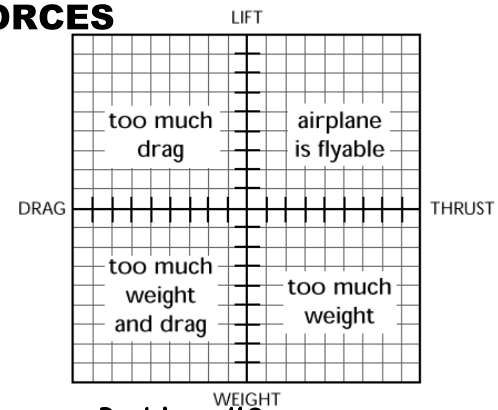
NAME ________________________________

Check your answer to the example problem.



http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/graph.html

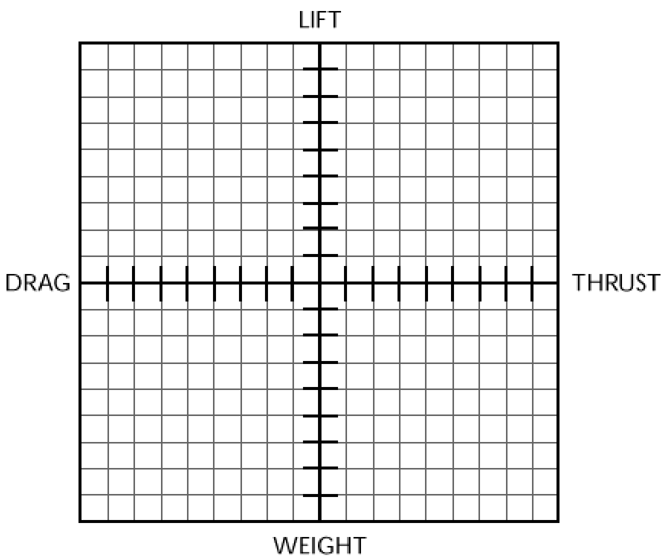
GRAPHING THE FOUR FORCES



NAME ________________________________

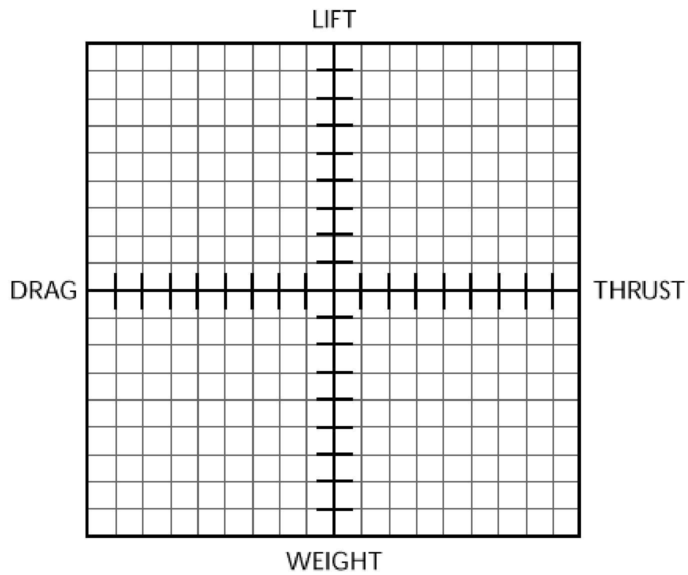
Directions: Use the magnitudes provided for each force to determine whether or not the plane can fly. If the plane cannot fly, explain why.

Problem #1.



Weight	**4 units**
Lift	**10 units**
Drag	**2 units**
Thrust	**10 units**

Problem #2.



Weight	**8 units**
Lift	**4 units**
Drag	**6 units**
Thrust	**4 units**

#1

Will the plane in problem #1 fly? _______

If the plane does not fly, why doesn't it fly?

Expert level: If the plane does not fly, what could be done to make it fly?

#2

Will the plane in problem #2 fly? _______

If the plane does not fly, why doesn't it fly?

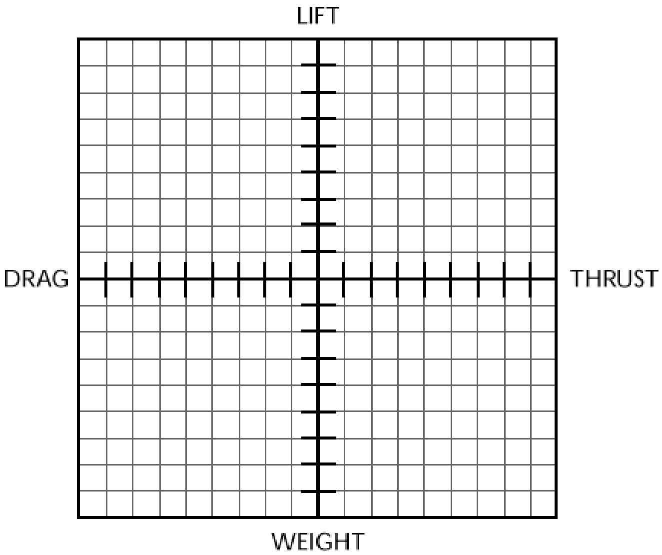
Expert level: If the plane does not fly, what could be done to make it fly?

Graphs: http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/graph.html

GRAPHING THE FOUR FORCES

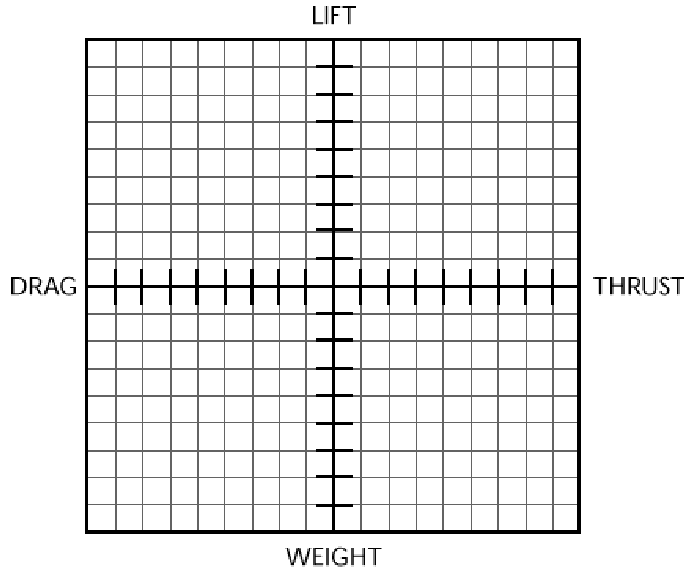
NAME ______________________________

Problem #3.



Weight	**3 units**
Lift	**6 units**
Drag	**8 units**
Thrust	**5 units**

Problem #4.



Weight	**4 units**
Lift	**9 units**
Drag	**2 units**
Thrust	**7 units**

#3

Will the plane in problem #1 fly? _________

If the plane does not fly, why doesn't it fly?

Expert level: If the plane does not fly, what could be done to make it fly?

#4

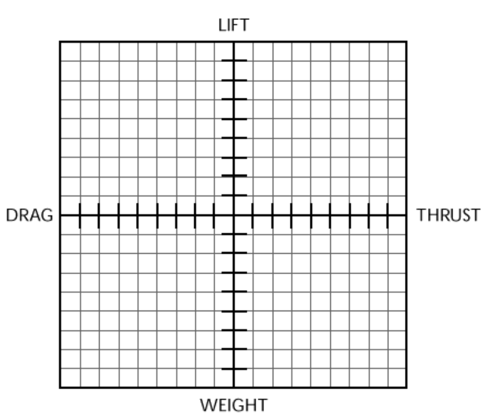
Will the plane in problem #2 fly? _________

If the plane does not fly, why doesn't it fly?

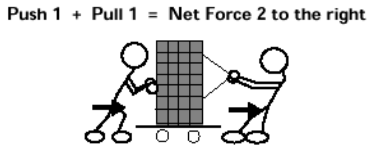
Expert level: If the plane does not fly, what could be done to make it fly?

BONUS:

Weight	**2 units**
Lift	**10 units**
Drag	**2 units**
Thrust	**2 units**



Explain what is happening with the "bonus" plane. What could it be?



USE THE FORCE

Name ____________________

1:	Define the word "force".
2:	Complete the sentences below by filling in the blanks. A force can move in different ________________. A force has strength or ______________________ that can be ______________________. Parallel forces can be added or __________________.
3:	An F-14 is flying west. Its engines are creating a thrust force of magnitude 4,000. A strong headwind is blowing to the east creating a drag force on the F-14 of magnitude 1,000. What is the net force on the F-14? _______________ In what direction will the F-14 fly? _______________ Draw a picture of this event. Make sure you include the F-14, the wind, arrows to represent the magnitudes, and the equation that gives the net force. Draw one arrow for each 1,000 units of magnitude.
4:	After the Space Shuttle is launched, its huge rocket engines lift it upward with incredible force. As it blasts through the top of the atmosphere into outer space, the engines are creating a force pushing up into space with a magnitude of six times the force of gravity. We write this as "6g". The gravity force is pulling the Shuttle back down in the direction of the earth with a magnitude of one times the force of gravity. We write this as "1g". What is the net force on the Space Shuttle? _____________ Draw a picture of this event to help you answer the question. Be sure to include the Shuttle, the Earth, arrows to represent which direction the engines and the earth are pulling, and the equation that gives the net force. Draw one arrow for each g.
5:	Four people are pulling on ropes attached to a cart. Each person is pulling with a magnitude of 1. Two people are pulling to the right and two are pulling to the left. What is the magnitude of the net force? ____________ In which direction will the cart move? _____________ Draw a picture of this event to help you answer the questions. Be sure to include the cart, the people, arrows to represent the directions that the people are pulling, and the equation that gives the net force. Draw one arrow for each unit of magnitude.

Source: NASA Quest http://quest.arc.nasa.gov/aero/wright/teachers/wfomanual/math/force.html

"GRAPHING THE FOUR FORCES" ANSWER KEY

Note: the arrows may be drawn in any order; you will always end up at the same place!

Problem 1 - Key

Starting at the origin:
The end of the weight arrow will be at (0,-4). The end of the lift arrow will be at (0,6).
The end of the drag arrow will be at (-2,6.) The end of the thrust arrow will be at (8,6).
Since (8,6) is in the upper right quadrant (quadrant I), the airplane ***IS flyable****.*

Problem 2 - Key

Starting at the origin:
The end of the weight arrow will be at (0,-8). The end of the lift arrow will be at (0,-4).
The end of the drag arrow will be at (-6,-4). The end of the thrust arrow will be at (-2,-4)
Since (-2,-4) is in the lower left quadrant (quadrant III), the airplane is ***NOT flyable.***
Both weight and drag are too great. Possible answers to make the plane flyable: To make the plane fly, the plane needs weight to decrease or lift to increase. This could occur if the plane were lighter or if the plane's wing design was improved. Drag needs to be decreased or thrust needs to increase. This could occur if the design of the plane changed to reduce drag or if the engines provided more thrust.

Problem 3 - Key

Starting at the origin:
The end of the weight arrow will be at (0,-3). The end of the lift arrow will be at (0,3).
The end of the drag arrow will be at (-8,3). The end of the thrust arrow will be at (-3,3)
Since (-3,3) is in the upper left quadrant (quadrant II), the airplane is ***NOT flyable.***
Drag is too great. Possible answers to make the plane flyable: To make the plane fly, the plane needs drag decreased or thrust increased. This could occur if the design of the plane changed to reduce drag or if the engines provided more thrust.

Problem 4 - Key

Starting at the origin:
The end of the weight arrow will be at (0,-4). The end of the lift arrow will be at (0,5).
The end of the drag arrow will be at (-2,5.) The end of the thrust arrow will be at (5,5).
Since (5,5) is in the upper right quadrant (quadrant I), the airplane ***IS flyable****.*

Bonus

The end result is (0,8). The plane ***could be flyable, provided the plane is designed to be able to adjust its thrust.*** *Since the thrust equals the drag in this problem, the plane is not moving forward or backward. This could be a helicopter or a flying saucer hovering over a specific place!*

"USE THE FORCE" ANSWER KEY

1: A force is a "push" or a "pull". It has two parts: magnitude and direction.

2: Directions
magnitude, measured
subtracted

3: 3,000
West
thrust 4,000 - drag 1,000 = net force 3,000 in the direction of thrust

4: 5g
up 6g - down 1g = net force 5g in up direction **or**

lift 6g - weight 1g = net force 5g in direction of lift

5: 0
neither
pull 1 - pull 1 = net force 0