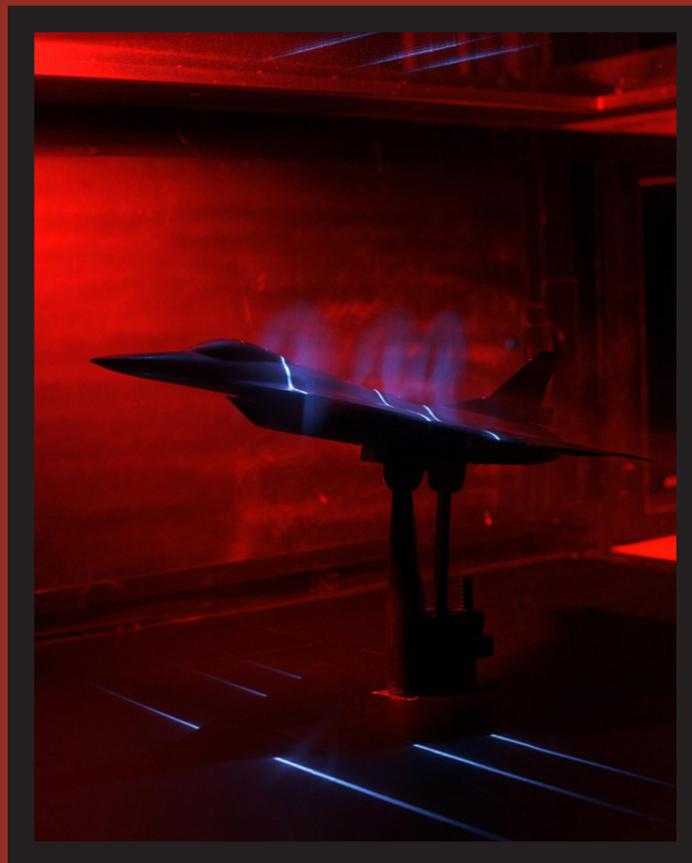


National Aeronautics and Space Administration



It's A Drag

A museum experiment for students



FOUR TO SOAR AERODYNAMICS UNIT



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It's a Drag!



Grades: 5–8

Time: 45 minutes to 1 hour

In this lesson, students manipulate simulated landing gear to see how it impacts the distance traveled by an air trolley.

Objectives

Students will understand how the angle of landing gear affects drag.

Main Concepts

- Scientific progress is made by asking meaningful questions and conducting careful investigations.
- A force has both direction and magnitude.

Education Standards

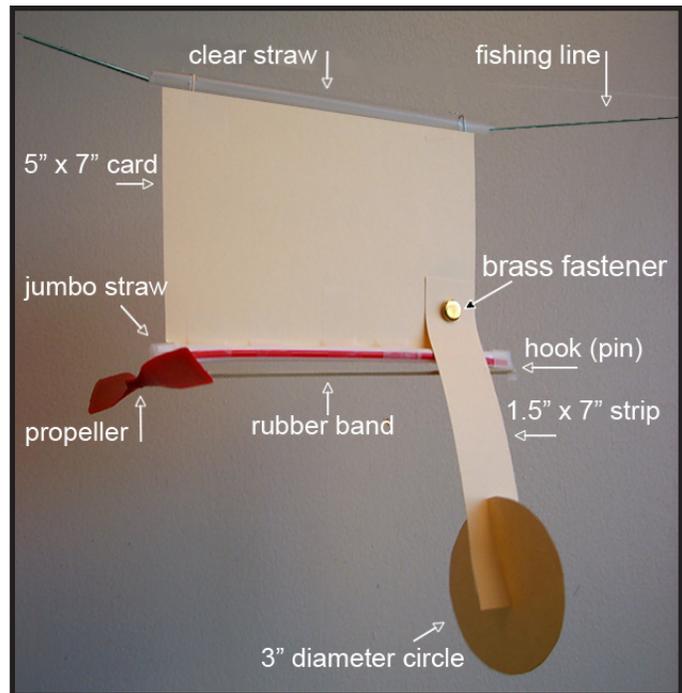
<i>California Science Content Standards</i>	<i>National Science Education Standards</i>
<p>Grade 5</p> <ul style="list-style-type: none"> • Investigation and Experimentation: 6e, 6f, 6g, 6h <p>Grade 6</p> <ul style="list-style-type: none"> • Investigation and Experimentation: 6b <p>Grade 7</p> <ul style="list-style-type: none"> • Investigation and Experimentation: 7a <p>Grade 8</p> <ul style="list-style-type: none"> • Forces: 2a, 2c, 2d, 2e • Investigation and Experimentation: 9a, 9b, 9c, 9e, 9f 	<p>Grades 5–8</p> <p>Science and Technology, Content Standard E</p> <ul style="list-style-type: none"> • Abilities of Technological Design: a, b, c, d, e • Understanding About Science and Technology: d, e <p>Physical Science, Content Standard B</p> <ul style="list-style-type: none"> • Motions and Forces: b, c



Materials List

Each team of 2–4 students will need:

- ***It's A Drag Data Sheet*** (p.15)
- Pencil or pen for recording data
- Protractor
- 1 testing station using the following materials:
 - 10-lb. test fishing line (5 m length)
 - 2 straws (any diameter)
 - Masking tape
 - Tape measure or meter stick
- 1 pre-assembled air trolley using either FOSS kit materials or the following balsa airplane kit materials:
 - 1 clear straw
 - 1 brass fastener (size 1")
 - 1 balsa wood stick or jumbo straw (9" length)
 - 1 rubber-powered propeller assembly (5" to 6" in diameter)
 - 1 rubber band (size #117B) or long piece of rubber string (16" length)
 - 1 index card (5" x 7") or cardstock* cut to size
 - 1 cardstock* strip cut to size (1.5" x 7")
 - 1 cardstock* circle cut to size (3" diameter)
 - 1 hook or pin to secure far end of rubber band/rubber motor
 - Transparent tape or masking tape (1" to 2" wide)



* can use file folder material

National Aeronautics and Space Administration					
 <i>It's a Drag Data Sheet</i>					
Team Members: _____					
Directions: 1. Rotate and measure the landing gear at 0° (down position), at 45°, and at 90° (up position). 2. Wind the propeller 60 times and let the air trolley go. 3. Measure and record the distance traveled in centimeters by the air trolley. 4. Repeat for the same angle two more times.					
Landing Gear	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Total of 3 Trials	Average of 3 Trials
Fully Extended 0°					
Partly Retracted 45°					
Fully Retracted 90°					
<small>Four To Soar: It's A Drag 15 November 2008 v.2</small>					

The above list is adapted from the Full Option Science Systems (FOSS) kit Air Trolley activity in the *Force and Motion* unit. Many of these items can be obtained by ordering them online from Delta Education Refill Center. (<http://www.delta-education.com> Select "Delta Refill Center," then search with keywords "Force and Motion.") Comparable materials from other suppliers may be freely substituted. Most small rubber-powered balsa airplane kits, such as those from Paul K. Guillow, also contain sufficient parts to build the air trolley.



Background

There are four primary forces that act on an airplane in flight: **thrust, weight, drag, and lift**. It is the interplay between these four forces that result in an airplane's motion.

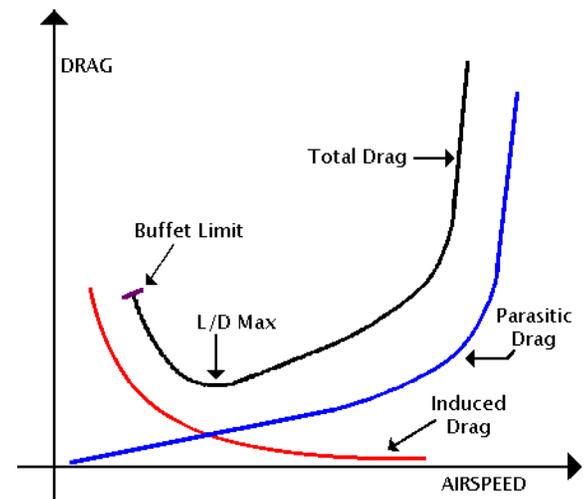
Drag is the force of air resistance that opposes an aircraft's motion through the air. Drag results from the interaction of every part of the airplane, including the engines and the landing gear, with the surrounding air. Drag is also produced as a consequence of the lift created by a wing.

Drag results from the motion of a solid body, like an airplane, through a **fluid** (liquid or gas). Hold your hand out the window of a car. The air pushing your hand backwards is called drag. For drag to occur, the solid body (such as your hand or the airplane) must be in contact with the fluid, (in this case, the air). If there is no fluid (as in outer space), then there is no drag.

Newton's First Law of Motion states that an object in motion remains in motion unless acted upon by an outside force. This law is seldom apparent in nature, due largely to the invisible force of drag. A glider launched into flight does not remain in flight forever; instead, it gradually slows, loses altitude, and returns to Earth due to the force of drag. Drag is the outside force working to slow any object flying through the air, and a source of thrust—another of the four forces—is usually needed to maintain flight for an extended period.

Drag is a force with both a magnitude (strength) and a direction. Drag acts in a direction that is opposite to the motion of the aircraft. We can think of drag as aerodynamic resistance to the motion of the aircraft through the air. Drag from an aircraft's shape and the way it interacts with the flowing air around it is called **parasitic drag**. *Parasitic drag is low when an aircraft's airspeed is low, but increases significantly as airspeed increases.* Early airplane designs had multiple wings and struts, open cockpits, and huge fixed landing gear. The parasitic drag of such airplanes was significant and limited airspeed even as more powerful engines became available. During the 1930s, engineers began to design sleek, more aerodynamic airplanes with single wings, enclosed cockpits, and landing gear able to be pulled up and tucked away in the wings or fuselage. Such design improvements reduced parasitic drag and allowed dramatic increases in airspeed.

A second form of drag is called **induced drag**. Induced drag is created by the wing during flight and is greatest when the angle of attack (the angle between the wing and the oncoming air stream) is greatest. *Induced drag is greatest at low airspeeds and decreases as the airplane's airspeed increases.* The total drag force on an airplane is a combination of parasitic drag (which increases with airspeed) and induced drag (which decreases with airspeed). Airplanes experience the least total drag at an intermediate cruising speed. At this intermediate speed, the airplane will have the longest range and consume the least possible fuel over a given distance.



The above information is adapted from Beginner's Guide to Aeronautics, What is Drag?, <http://www.grc.nasa.gov/WWW/K-12/airplane/drag1.html>



Engage

1. Create excitement in the students.

Launch a rubber band powered airplane or fly a battery operated or radio controlled propeller plane, if available.

Draw on prior knowledge through these discussion questions

- What happened here?
- How does an airplane fly?
- What are the four forces necessary for flight?

2. Introduce and discuss the forces of flight.

Aerodynamics is the science of flight. In aerodynamics, we are interested in the motion and energy of an aircraft. We want to know about the forces at work on an aircraft and how that aircraft is controlled.

What is a force, anyway? In science we often work with forces, which are pushes or pulls on an object. Forces can be invisible, like gravity, or they can be completely visible, like someone pushing open a door with their hand. In the case of an airplane, there are always four forces at work any time the airplane is in flight. These forces are called lift, weight, thrust, and drag.

Lift is the upward force created by the wing of an airplane. It is a very important force because without it airplanes would simply be very expensive cars—they would be able to roll around on the ground but would never rise into the air. A wing creates lift in part by deflecting air downwards and in part due to the way air flows over its special shape.

Weight is the force of gravity acting on the mass of the airplane. It is what pulls an airplane down towards the ground. Weight is helpful in making sure that our airplanes do not float around once they are parked, but when an airplane flies it must overcome its weight to take to the air. Today, designers work with lightweight alloys and special plastics called polymers to build airplanes that are lightweight yet strong.

Drag is a force created by the friction of air against the skin of an airplane as it moves forward. Drag affects more than just airplanes—you can feel it pushing back on your hand if you hold your hand out the window of a moving car. In an airplane, drag increases as speed through the air increases. Faster airplanes will have ways of pulling up their landing gear, among other things, to reduce drag and to increase speed. We will investigate drag further in our group.



Thrust is a forward push or pull that accelerates an airplane and keeps it in flight at a constant speed despite the slowing force of drag. Thrust comes from an airplane's engine, be it a small airplane with a propeller or a large airplane with a giant jet engine. Thrust is a very important force, since an airplane cannot fly without forward motion through the air.

Major concepts

- A force is simply a push or a pull.
- There are four forces of flight.
- Weight is the measure of the force of gravity on the mass of an object.
- Thrust is the force that moves an object forward and, in the case of an airplane, is usually generated by the airplane's engines and propellers.
- Drag is a force that resists the forward motion of an object, such as the resistance of air molecules that are pushed aside as an airplane travels through the air.
- Lift is the upward force that causes an object to rise or, in the case of an airplane, to fly. Lift is generated primarily by airflow over the wings of an airplane.
- In order for an aircraft to remain in flight, lift must be equal to or greater than weight and thrust must be equal to or greater than drag.

NOTE: For the following discussion, you may want to use the image of the airplane with the four force arrows on page 9 or one of the following NASA articles, videos, or animations:

- The Four Forces of Flight, NASA Explores
http://www.nasaexplores.com/search_nav_5_8.php?id=01-083&gl=58
- Future Flight Design, NASA Quest
<http://futureflight.arc.nasa.gov/aero.html>
- Virtual Skies, NASA Quest
<http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html>
- Beginner's Guide to Aeronautics, NASA Glenn Research Center
<http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html>



Guidelines for a discussion to help illustrate these concepts

An object has opposite forces acting on it at any given time. We especially see this with airplanes. When an airplane flies, it has a force pushing down on it, pushing up on it, pushing it backward, and pushing it forward.

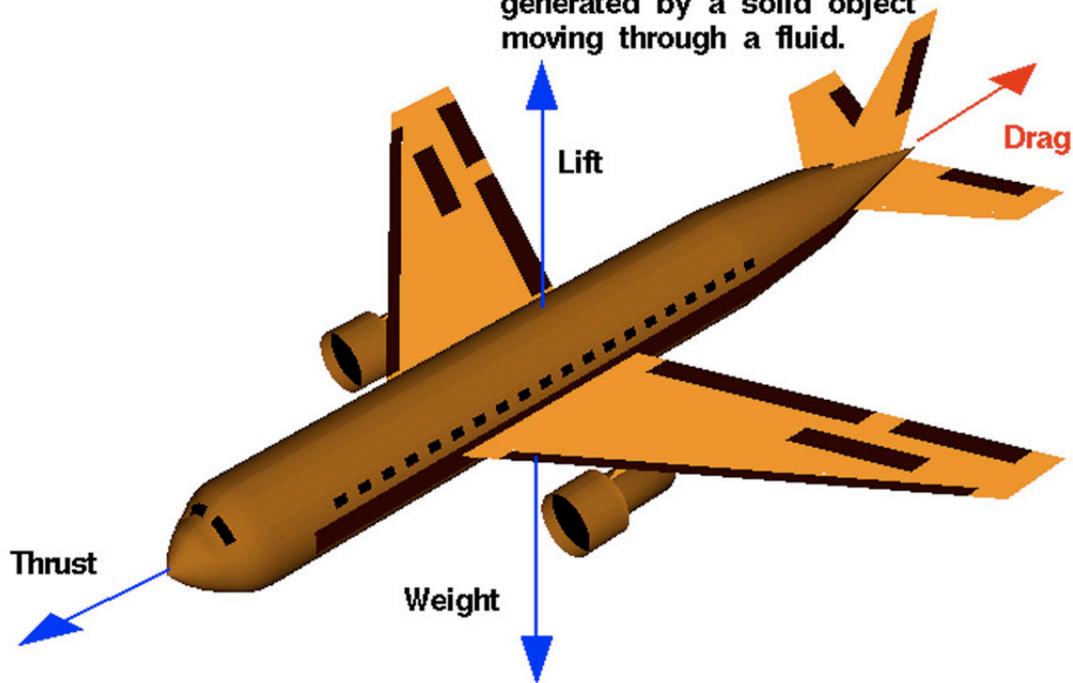
- What is pulling the airplane downward to the ground?
(Weight) **Weight** is the measure of the force of gravity on the mass of an airplane.
 - What direction is the opposite of weight? (up)
 - What must an airplane do to fly? (It must overcome weight.) This upward force is called **lift**.
 - How might lift be generated?
(In an airplane or glider, lift is generated by air flowing over the wings.)
 - In what direction does your hand get pushed when you hold it out the window of a moving car and feel the air pushing against it? (Backward) We call this backward force **drag**.
 - What do airplanes need to overcome this backward force of drag? (A forward push.)
 - What pushes an airplane forward? (The airplane's engines or propellers.) We call this forward force **thrust**.
 - When an airplane takes off, how would you describe its thrust compared to its drag?
(Thrust must be greater than drag.)
 - How would you describe the airplane's lift compared to its weight?
(Lift must be greater than weight.)
 - Once in the air, if an airplane is maintaining the same height (or altitude) and speed (or velocity), how would you describe the four forces?
(They would be balanced. Thrust would equal drag and lift would equal weight.)
3. Discuss the main focus of this lesson – the drag force.
- What parts of an airplane might increase drag?
 - How can we design an airplane in order to minimize drag?
 - What do landing gear do on an airplane?
 - Holding up the airplane you have flown from step 1, point to the landing gear and say, *“On large airplanes, the landing gear go up and down during takeoff and landing. Why don't airplanes fly with the gear in the down position the whole time?”* Use the answers to begin a discussion of drag.



What is Drag?

Glenn
Research
Center

Drag is a mechanical force generated by a solid object moving through a fluid.

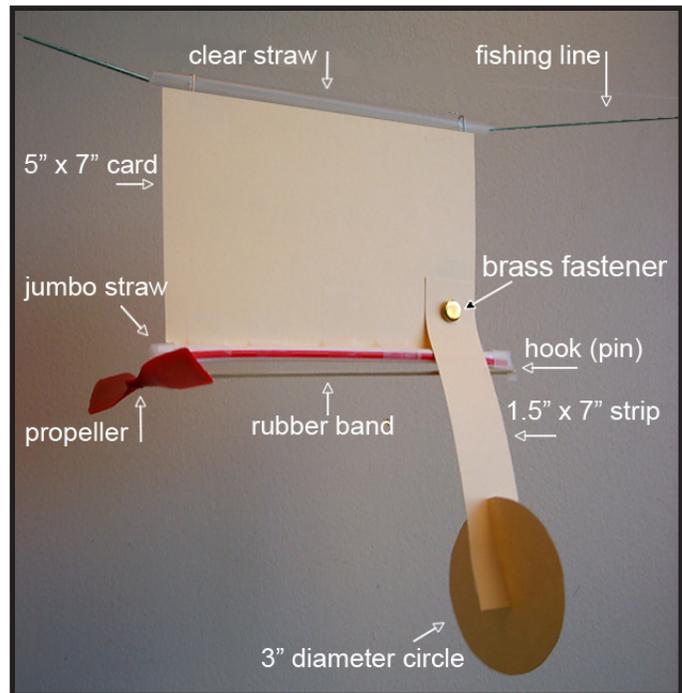




Explore

1. Prepare one propeller trolley per group of 2–4 students.

- Begin by taping a straw along one long edge of the 5" x 7" card.
- Continue trolley construction. Tape or otherwise secure the balsa stick (or a jumbo straw if using FOSS materials) onto the opposite long edge of the 5" x 7" card.
- Attach the propeller to the front of the balsa stick (or jumbo straw) and ensure that it can turn freely. Attach the rubber band to the rear of the balsa stick using either a pre-installed metal hook, a plastic end cap, or a push pin depending on materials.
- Punch a hole in the 5" x 7" card about 1" above and 1" in from the rear of the back, bottom corner of the trolley. Punch a matching hole in one end of the 1.5" x 7" strip approximately 0.5" from the end.

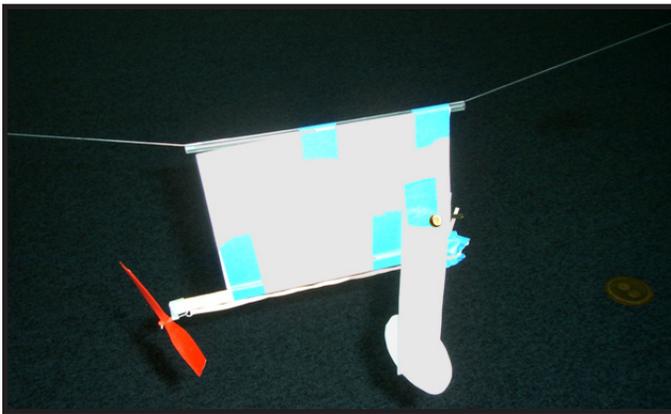


- Attach the 1.5" x 7" strip to the trolley by pushing a 1" brass fastener through the two holes.
- Cut matching 1" slits in both the free end of the 1.5" x 7" strip and the 3" diameter circular card. Push both pieces together and tape in place to complete the landing gear assembly. Make sure that the circular card is perpendicular to the strip after the two pieces are attached.
- Test the landing gear assembly's motion to ensure that it can be moved into the three test positions: 0°, 45°, and 90°. If the landing gear slips between positions, a small piece of masking tape can be applied at the top to hold it in place.

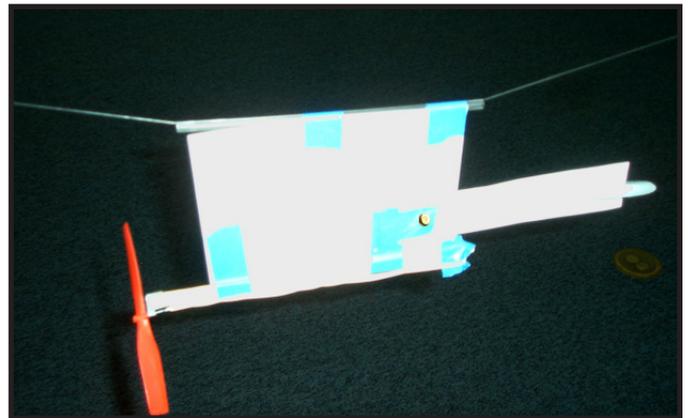


2. Explain the experimental procedure.

- Cut a piece of fishing line 5 meters long for each station. Slide the fishing line through the straw at the top edge of the propeller trolley, and then tie additional straws to both ends of the fishing line to form handles.
- Tape or otherwise secure one end of the fishing line to a wall or other attach point, approximately child's eye level above the ground. The other end may be secured on an opposite wall or hand held so long as the line is taut during each trial with no detectable slope.
- Mark a starting point on the fishing line with permanent marker. The trolley will be launched from this point for each trial.
- Measure and mark points on the fishing line that are one, two, and three meters from the starting point on the fishing line.
- Using a protractor, set the landing gear tab at the angle called for in the experiment. A 0° angle is fully extended (down), and a 90° angle is fully retracted (up).



Fully extended landing gear: 0°



Fully retracted landing gear: 90°

- Wind the propeller exactly 60 times to store energy in the rubber band. Hold the propeller after winding without releasing it.
- Move the trolley to the starting point and release both the trolley and its propeller.
- When the trolley comes to a complete halt, measure the distance traveled from the starting point to the point where it came to rest.
- Record data on data sheet and continue to the next trial.



3. Introduce the drag experiment.

Following are samples of the types of things you may want to say to explain this experiment as you demonstrate with an actual model.

- “You may have noticed that when a large airplane takes off, the landing gear is lifted up into the airplane during the flight and is brought down again only when the plane lands. Why do you think that is? Does the position of the landing gear during the flight have any affect on the airplane’s flight?”
- “Look at your experimental setup. You have what is called an air trolley with a circular piece attached to the back of the trolley. This piece simulates landing gear and can be adjusted. The gear is currently down and fully extended at an angle of 0° .”
- “Try changing the angle of the landing gear and see how far down the line your air trolley can travel. You should wind the rubber band 60 times for each trial you make. Test the gear in the down position (0°), at a 45° angle, and in the up position (90°). Use a protractor to help you measure and record the angle you select.”

NOTE: If the class has not done the *Angles Everywhere* lesson prior to their visit or if they are not familiar with using a protractor, you may want to have the **Sample Angles** worksheet (pp.8-9) from the *Angles Everywhere* lesson handy for chaperones to use to help students quickly learn how to use a protractor.

For younger students, you may want to have pre-marked lines on the trolley labeled with the angle measurements so they can quickly and easily move and test the landing gear without learning how to use a protractor.





Explain / Evaluate

Students share their results with the class and discuss the questions below.

- Why do we do each experimental trial more than once?

If a trial is done only once, it is difficult to know if the results are an outcome of the experiment or instead a fluke, accident, or mistake due to equipment failure, unusual conditions, or operator error. If a trial is repeated a number of times, then the chance that the results are due to some unexpected condition or mistake will be smaller. If the whole experiment can be repeated by many groups of people, in different places, and with different equipment, then the results are more believable. We call this **reliability** and **reproducibility**.

- As the angle changed, what happened to the distance the trolley traveled?

As the angle changes, there may not be much difference between 0° (down) and 45° since much of the landing gear is still in the air stream, therefore creating substantial drag. However, there should be a measurable difference in distance traveled between having the gear fully extended (0°) and the gear fully retracted (90°) since having the gear up decreases drag.

- What does the angle of the landing gear have to do with how far the trolley can travel?

With the gear retracted (90°), the trolley can travel further down the string. This happens because the surface area of the landing gear that faces in the direction of the trolley's motion is greatly reduced when the gear is retracted. Even though the landing gear has the same weight, size, and shape, it strikes the air nearly edge-on when it is fully retracted. This reduces parasitic drag and permits the trolley to travel farther and faster than it can with the landing gear extended downward, where it meets the air face-on with substantially higher drag.

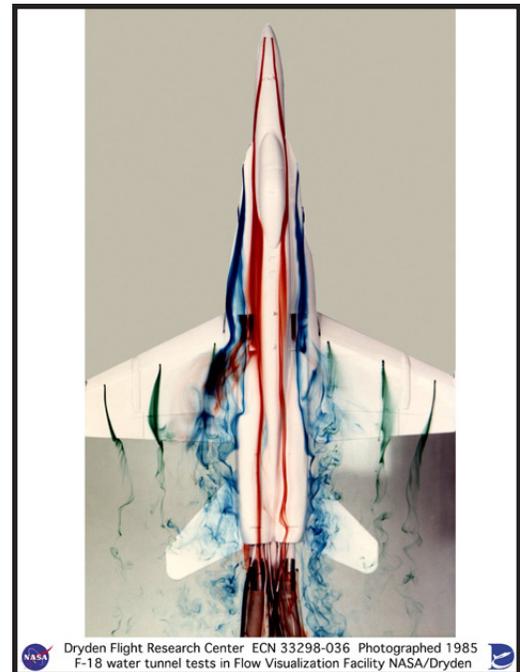
The same is true on an airplane. Airplanes with retractable landing gear will only lower the landing gear just before landing when the airplane is already flying at a low speed and the added drag does not significantly affect the airplane's flight. The landing gear is retracted again immediately after takeoff, before the airplane accelerates to cruising speed.



Extend / Apply (in the classroom)

The following activities are for students once they return to the classroom.

- Experiment to see if there is a difference with the landing gear mounted near the front versus the back of the trolley.
- Research the difference in landing gear between small and large aircraft.
- Calculate the mean (average) cm traveled for each trial and graph the results. How much different is the mean from each of the results? Calculate this difference in percentage.
- Research careers in aeronautics and aviation.



Resources

- Future Flight Design, NASA Quest: [http:// futureflight.arc.nasa.gov](http://futureflight.arc.nasa.gov)
- Exploring Aeronautics, EP-2005-09-601-ARC, <http://quest.arc.nasa.gov/projects/aero/ExploringAero>
- Four Forces on an Airplane, NASA Glenn Research Center: <http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html>
- Future Flight Design career fact sheets, NASA Quest: <http://futureflight.arc.nasa.gov/cfs.html>
- Astro Venture career fact sheets and trading cards, NASA Quest: <http://astroventure.arc.nasa.gov/>
- Virtual Skies, each section has career information, NASA Quest: <http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html>
- NASA Quest, a great resource for careers and further technical information related to the lessons: <http://quest.nasa.gov/>



It's a Drag Data Sheet

Team Members: _____

Directions:

1. Rotate and measure the landing gear at 0° (down position), at 45° , and at 90° (up position).
2. Wind the propeller 60 times and let the air trolley go.
3. Measure and record the distance traveled in centimeters by the air trolley.
4. Repeat for the same angle two more times.

Landing Gear	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Total of 3 Trials	Average of 3 Trials
Fully Extended 0°					
Partly Retracted 45°					
Fully Retracted 90°					