EXPLORING AERONAUTICS

Part I

Section 2

Content

Section Overview

Introduction to Aeronautics

What can be said about the "Introduction to Aeronautics" except that it introduces the learner to the topic while briefly discussing how aeronautics evolved, what an airplane is, and how engineers study the science of aeronautics. It is, in itself, a brief look at aeronautics!

CD-ROM Usage

At this point, to pique the students' interests in aeronautics, the teacher could show the opening segment of the CD-ROM and demonstrate how to navigate the interface. If the teacher wishes, allow the students to browse in the Resource Center. Use the Word Hunt (page 46 of the Student Logbook) as a way to familiarize students with the glossary.

Materials List

If the teacher has not done so already, the Opening Set found on page 32 can be used here prior to the reading. For this Set, the following materials will be needed:
• pre-fabricated balsa wood or Styrofoam™ glider
• homemade wooden glider

Student Handouts

Student Reading: Introduction to Aeronautics
Student Note Taking Guide
Student Worksheet: Aeronautics
Quick Quiz: Introduction to Aeronautics

Teacher Reading
Introduction to Aeronautics

First of all - what is aero?

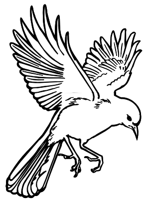
"Aero" is a Greek prefix signifying air. Everyone knows what air is - we breathe it all the time! However, some of the concepts important to aeronautics use a technical definition of air which, at first, may seem counter-intuitive. Air is made up of a mixture of gasses, and thus is itself a gas. However, in all the reading about aeronautics you have done (and will do!) air is referred to as a fluid. For instance, air obeys the laws of fluid dynamics. Thinking of air as a fluid is definitely counter-intuitive, particularly for students. After all, we breathe air - but if we breathe fluid we drown! The solution lies in the technical definition of a fluid. That definition states that a fluid is any substance that flows. Obviously water flows, but so does air and so do powders! So, technically speaking, air and powders are fluids. Of most importance to our study of aeronautics is the fact that air obeys the physical laws of fluids. A very interesting open-ended question for students is how our everyday definitions for words are oftentimes not technically correct. When someone says "fluid" why do we always assume they are talking about a watery substance?

What is aeronautics?

Aeronautics is typically defined as the art or science of flight, or the science of operating aircraft. This includes a branch of aeronautics, called aerodynamics, that deals with the motion of air and the way it interacts with objects in motion, such as an aircraft. Both of these branches are a part of the tree of Physical Science. Aviation refers to the operation of heavier-than-air craft.

How did aeronautics begin?

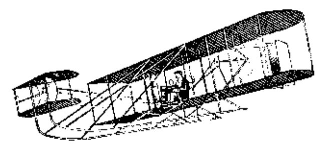
The theoretical basis for these branches stems from the work of Sir Isaac Newton in the 1600s. Newton developed laws that defined the effects of forces acting on objects in motion or at rest. He also developed the concept of viscosity, or fluid friction, which is the resistance of air or any other fluid to flow. Daniel Bernoulli, in the 1700s, developed the principle that the speed of a fluid is directly related to pressure. That is, the faster the flow of a fluid, the lower the pressure that is exerted on the surface it is flowing over. For example, if air is flowing faster over the top of a surface than under a surface, the pressure on the top of the surface will be less than that on the bottom. These concepts were



necessary to the development of flight. Without understanding the aerodynamic principles of flight, humans would simply be mimicking the actions of birds. It was demonstrated through many spectacular yet often disastrous attempts, that pure imitation would not enable humans to fly.

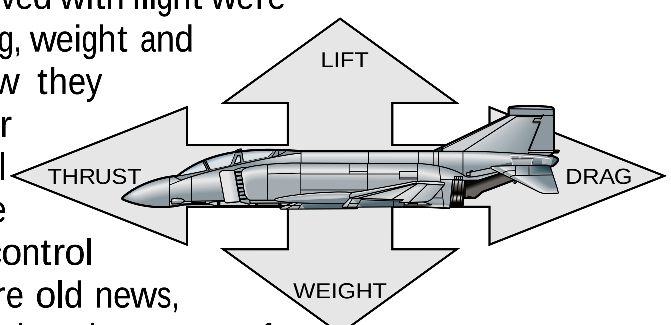
How did aeronautics evolve past the imitation of birds?

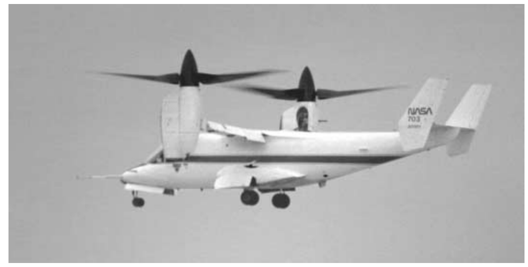
The science of aeronautics really began to evolve in the late 18th century and the early 19th. Philosophers and early scientists began to look closely at physical phenomena such as gravity and motion. As paths of communication were established between distant cultures, the understanding of flight began to coalesce. With their wealth of understanding of kites, rockets and fireworks, the Oriental cultures defined and harnessed propulsion. The Europeans with their penchant for analysis, definition and precision, began to piece together the concept of force. This growth in knowledge and communication continued throughout the 19th century. By the very late 19th and early 20th centuries, this knowledge had evolved to the point where people sought to put it to practical use. As space is the frontier of today, flight was a frontier of that time.



Along with factual knowledge, the methods of discovery, trial and error evolved into the scientific method. The scientific method became a widely accepted process to question, analyze, test and verify results. Concepts and ideas that were subjected to the scientific method received general acceptance and were used as bases for generating new ideas.

The classification and definition of forces involved with flight were developed. We know them today as lift, drag, weight and thrust. Scientists began to understand how they worked together to enable an object heavier than air to fly. Once these concepts were well understood, it was only a matter of time before humans figured out how to not only fly, but to control their flight. Balloons, which by this time were old news, enabled people to fly, but aeronauts remained at the mercy of the wind to determine where they went. With the premier of airplanes, people could fly when, how and where they wanted. Another frontier had been conquered. Within a few short years, airplane designers refined the shape of wings and overall construction to improve airplane performance and safety. Further improvements in airplane design allowed flight to become accessible to everyone.





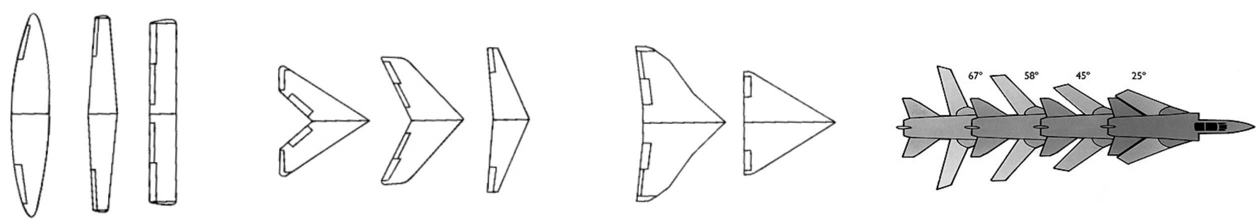
What is an airplane?

What is the difference between air<u>craft</u> and air<u>plane</u>? Aircraft is the more general term, and refers to any heavier-than-air craft that is supported by its own buoyancy or by the action of air on its structures. An airplane is a heavier-than-air craft that is propelled by an engine and uses fixed aerodynamic surfaces (i.e. wings) to generate lift. So, every airplane is an aircraft, but not every aircraft is an airplane! Gliders are aircraft that are not airplanes. The Space Shuttle is definitely an aircraft, but it is not an airplane. It does not carry engines for propulsion. Helicopters are also aircraft that are not airplanes because their aerodynamic surfaces are not fixed - they rotate.

In **Exploring Aeronautics** we will use the term "airplane" when we are talking specifically about definitions and concepts that relate strictly to a craft that uses wings for lift and has engines for propulsion. When we use "aircraft" we will be referring to a set of craft that includes balloons, gliders, and airplanes.

Why are there so many different types of airplanes?

The characteristic that most readily identifies the type, performance and purpose of an airplane is the shape of its wings. There are four basic wing types: straight wings, sweep wings (forward-sweep/sweepback), delta wings and the swing-wing (or variable sweep wing). Each shape allows for premium performance at different altitudes and at different speeds. Lots more information about wings will be covered in the " Wings" section.



Another important discriminator between airplanes is speed. Airplanes fly at subsonic, transonic, supersonic, and hypersonic speeds. These speed classifications are called the "regimes" of flight. The suffix -sonic refers to the speed of sound, which is dependent on altitude and atmospheric conditions (nominally 340 meters per second). "Mach" is a term used to specify how many times the speed of sound an aircraft is traveling. Mach 1 is one times the speed of sound. Mach 2 is twice the speed of sound, and so on. Mach numbers less than 1 are speeds less than the speed of sound.

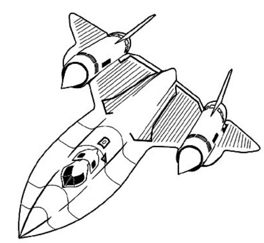
Supersonic refers to all speeds greater than the speed of sound, which is the same as saying all speeds above Mach 1.

Subsonic refers to all speeds less than Mach 1.

Transonic refers to all speeds from approximately Mach .9 to Mach 1.5 - that is, the speeds at which an aircraft is going through the speed of sound or “breaking the sound barrier”.

Hypersonic refers to all speeds greater than Mach 5. Note that an aircraft flying at hypersonic speeds can also be said to be flying at supersonic speeds.

Every modern aircraft that is built today is built for a specific purpose. Airplanes are designed for different altitudes, different speeds, different weight carrying capacities, and different performance. Jet fighters are relatively lightweight, highly maneuverable and very fast. They are designed to carry a relatively small amount of weight, including fuel, which necessitates refueling on long flights.



Passenger airplanes are larger, carry more weight, and can fly longer distances. However, they are less maneuverable and slower than jet fighters.

Other aircraft, like the SR-71, are designed to fly at very high altitudes and high speeds for very long periods of time.

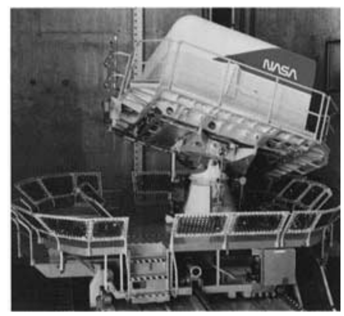
Every aircraft fills a particular niche in the gigantic matrix that is modern aviation. As you learn more about aeronautics you will be able to look at an aircraft and identify what niche that particular airplane fills - what are its purposes, what are its strengths and what are its weaknesses.

How do aeronautical engineers study aircraft and design new ones?

As the use of the scientific method became increasingly important, it also became clear to aircraft designers that testing their hypotheses with human subjects was too risky. Wind tunnels were the first tool of aeronautics to be developed. In the very early 1900s designers built models of their aircraft and placed them in tunnels through which air could be blown to simulate flight. While wind tunnels did provide valuable information and were certainly safer than human flight, there were many questions that were left unsolved, simply because the interactions of all the forces on an aircraft were too complex for the analysis methods of the day.

The advent of the computer changed everything. Now massive quantities of data could be gathered from wind tunnel tests and analyzed quickly and efficiently using the computer. In addition, new tools were developed.

Next came flight simulators which enabled a pilot to fly without ever leaving the ground. Flight simulator cockpits were designed to be exact duplicates of real aircraft cockpits. Motion systems were added and have evolved to the point where it is very hard to tell the difference between an airplane ride and a simulator ride.



As computers got faster than we ever could have imagined and became able to handle humongous amounts of data, we began to consider simulating airflow in a computer. Computational Fluid Dynamics was born. As advances in computer graphics have been made, it is now possible to sit at a desk and watch a computer-generated airplane fly - complete with the ability to visualize airflow and pressures and fly the airplane from takeoff to landing.

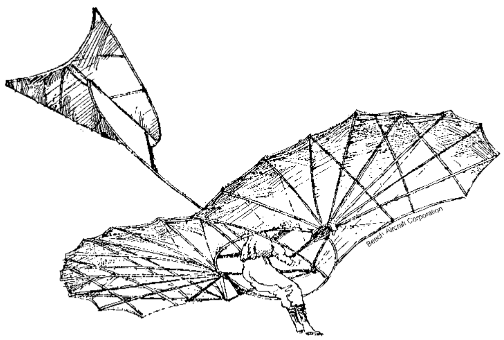
However, even with our increased ability to use computers, simulators and wind tunnels, the final and most definitive test of an aircraft is whether or not a pilot can fly it. Flight test, in which a human climbs into the cockpit and flies the aircraft, was the first tool of aeronautics and remains the final and most important test that an aircraft must undergo. Vast improvements have been made in the safety of flight test and the ability of ground engineers and pilots to predict and avoid hazardous situations. All the tests using the other tools of aeronautics result in an aircraft being far more flight-worthy by the time it reaches flight test than it has in the past. However, the bottom line still remains - can a pilot fly an aircraft, control it, and make it do what he or she needs it to do.

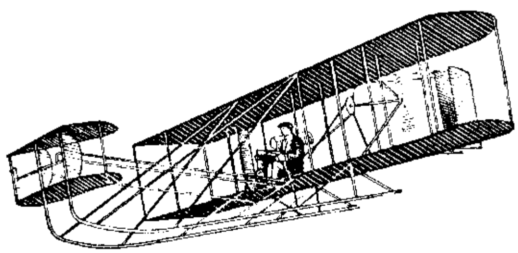
What does aeronautics research mean to you?

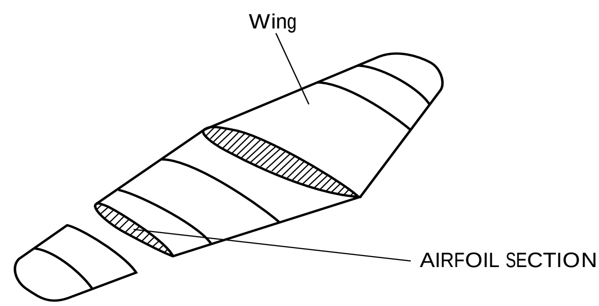
The development of powered flight has been one of the major human achievements during the 20th century. Flight has touched every facet of our day-to-day lives, and not a single corner of the world, including the most remote, has remained untouched by its development.

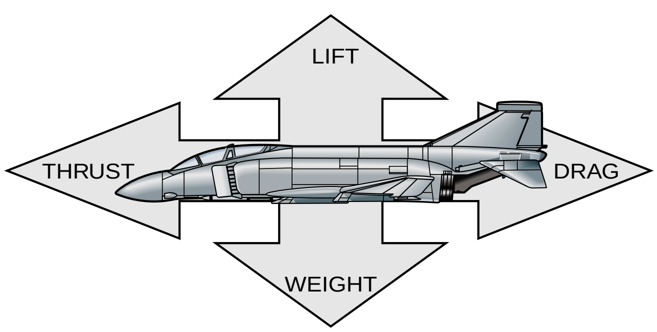
NASA scientists and engineers work together with other researchers from universities and aerospace companies to learn how to design better airplanes. What does this mean to the general public? Improved or more modern airplanes are easier to maintain, cost less to operate (which means a cheaper ticket for the passengers aboard), are safer to fly, and are better for the environment. NASA focuses on several areas including weather-related safety, aging airplanes, advanced structures and engines for airplane design, air traffic control, helicopters, airport and supersonic engine noise reduction, turbulence prediction, and the human factor.

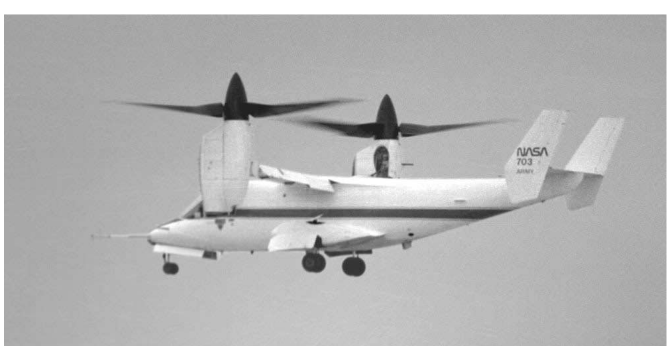
Overhead Guides

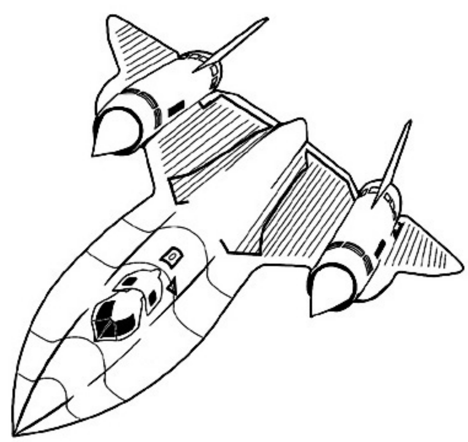










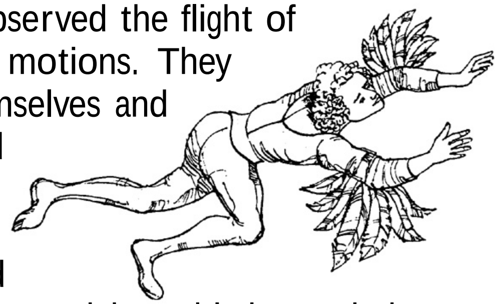


Student Reading

Aeronautics

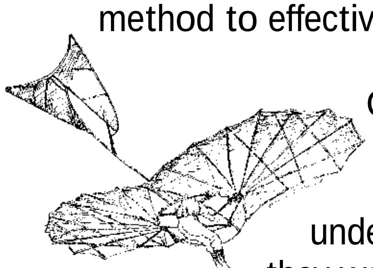
Look up in the sky at nearly anytime of the day or night and you can see some kind of aircraft traveling overhead. Flying is common in our modern world. Through the centuries people slowly learned what it took to fly. They have studied flight and air. These studies have become a science or system of knowledge.

Aeronautics is a science that studies flight and the operation of aircraft. A lot of the information scientists and engineers know about aeronautics comes from the research that has been done in aerodynamics. Aerodynamics is a part of aeronautics that studies the way air moves and the way it moves around objects (like airplanes).



During the very early days of aeronautics, people observed the flight of birds, created imitations of them and imitated their motions. They thought that by attaching feathers or wings to themselves and flapping their arms, they could fly. They soon realized that there was more to flight than imitating birds.

They began to make closer observations of birds and their wings. They discovered the unique shape of wings and how birds used them to control flight. Then, they tested their ideas using trial and error. Unfortunately, trial and error cost many early inventors their lives. As a result, they began to use the scientific method to effectively and safely test their ideas.



Gradually, by doing experiments, they gathered much useful information about the way air moves and acts. They discovered the basic principles of gravity and motion. They began to understand the four forces of drag, lift, weight and thrust and how they work together to make flight possible. They saw how the shape of wings could be changed to improve flight. They developed wind tunnels to test their early flight designs. This information led inventors to create safer aircraft that could be controlled and flown higher and faster than ever before.

This led them to develop aircraft with special features that could be used for a great variety of purposes, such as to fight fires and do scientific and atmospheric surveys.

Later on, scientists and engineers created better ways to test new aircraft designs. Besides using a flight test, they also used modern technology like computers and simulators. They developed other useful tools to help them make safer aircraft that could fly in very different ways.

Today aeronautics and aerodynamics continue to be carefully studied. The knowledge we gain from these studies has helped to improve our daily lives in ways we never imagined. The world of medicine, communications technology and manufacturing have all benefited from research on aeronautics and aerodynamics. Aeronautics will continue to improve aircraft design as it expands our horizons and pushes the envelope of flight.

Student Note Taking Guide

Big Ideas	Important Little Details
science	a system of knowledge
aeronautics	a science that studies flight and the operation of aircraft
aerodynamics	a part of aeronautics that studies the way air moves around objects
early studies	imitated birds using feathers and a flapping motion
closer observations	observed birds more closely noticed unique shape of wing used trial and error to test ideas scientific method started to evolve
got more information	performed experiments discovered basic principles of gravity & motion understood how 4 forces (drag, lift, gravity, thrust) work together improved shape of wings created safer planes
test aircraft	built safer airplanes flight test developed better ways of using computers, wind tunnels, simulators
knowledge	improves daily lives helped medicine, communications, technology, manufacturing improve aircraft design and safety

Student Worksheet: Aeronautics

Directions: Use the student reading "Aeronautics" to help you answer the questions below using complete sentences.

1. Give the definition of the three terms below as they are defined in your reading:

science -

aeronautics -

aerodynamics -

2. List two ways early inventors and scientists made discoveries and gathered information.

3. List three areas of our lives that have been improved by our study of aeronautics and aerodynamics.

4. List two new topics that were mentioned in this reading that you might be interested in learning more about.

Student Worksheet: Aeronautics - Key

Directions: Use the student reading "Aeronautics" to help you answer the questions below using complete sentences.

1. Give the definition of the three terms below as they are defined in your reading:

science - *a system of knowledge*

aeronautics - *a science that studies flight and the operation of aircraft*

aerodynamics - *a part of aeronautics that studies the way air moves around objects*

2. List two ways early inventors and scientists made discoveries and gathered information.

- observed the motions of birds
- observed the way air moves
- tested ideas: used trial and error
scientific method
flight test
wind tunnels
computers
simulators

3. List three areas of our lives that have been improved by our study of aeronautics and aerodynamics.

- safer airplanes
- medicine
- communications technology
- manufacturing
- make better airplanes (improve the design of aircraft)

4. List two new topics that were mentioned in this reading that you might be interested in learning more about.

answers will vary

Quick Quiz

Introduction to Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. What is the definition of aeronautics?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

2. Which areas of our lives have been improved by the study of aeronautics?

   A. better and safer airplanes
   B. communications technology
   C. manufacturing
   D. all of the above

3. What is the definition of science?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

4. How did early scientists and inventors make discoveries and gather information?

   A. scientific method
   B. observed the motion of birds and how air flows
   C. tested in wind tunnels
   D. all of the above

5. What is the definition of aerodynamics?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

Quick Quiz - Key

Introduction to Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. What is the definition of aeronautics?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

2. Which areas of our lives have been improved by the study of aeronautics?

   A. better and safer airplanes
   B. communications technology
   C. manufacturing
   D. all of the above

3. What is the definition of science?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

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   A. scientific method
   B. observed the motion of birds and how air flows
   C. tested in wind tunnels
   D. all of the above

5. What is the definition of aerodynamics?

   A. the study of the way air moves around an object
   B. a system of knowledge
   C. a science that studies flight and the operation of aircraft

Section Overview

The Scientific Method

This section serves as a guide not only for the students, but also for the teacher in providing a step-by-step process for how to teach the Scientific Method.

CD-ROM Usage

The only segment of the CD-ROM which employs the Scientific Method is found in the "Activity Center". Do **not** use that segment until nearly the end of the science unit, as it is important that the students are comfortable with the process before conducting the major experiment found in this segment.

Materials List

- one medium to large sized balloon
- one Styrofoam cup
- string (two - three pieces of equal length approximately 2 feet long)
- a sink or large pan or large bucket
- another container for pouring water
- water
- ring stand (preferably)
- drinking straw

Student Handouts

Student Reading: The Scientific Method
Abbreviated Student Guide Sheet: The Scientific Method
Experiment Log page 1
Experiment Log page 2
Student Reading: Newton's Third Law
Student Worksheet: The Scientific Method
Quick Quiz: The Scientific Method

Teacher Reading
The Scientific Method

Scientists use any one of a number of techniques to gather facts and solve mysteries. These techniques vary widely and the choice of technique is based on the question being asked, the test facilities and other resources available, and the preference of the researcher. However, the process that scientists and engineers use to organize and effectively utilize these many techniques is standard. The name of the process is the Scientific Method. Though relatively simple and straightforward, adherence to this method generally assures a researcher that his/her conclusions will be considered worthy of consideration by his/her peers. Note that this does not mean that his/her peers will agree with the researchers conclusions - or even the question! - but they will generally agree that the research is worth reviewing. Further, the method serves as a basis for discussion because the terms associated with the method are well- and widely understood.

The basic steps of the Scientific Method are as follows:

State the problem (question)
Form a hypothesis (answer)
Design an experiment (materials and procedure)
Perform the experiment (observe and record data)
Organize and analyze data
Draw conclusions

Initial attempts to guide students through the Scientific Method are often painstakingly slow. Students invariably want to jump to conclusions without taking the time to fully complete each step. Particularly with simple experiments, students find it difficult to justify the extra care and attention that the Scientific Method requires. As the experiments become more difficult, those who follow the Method will generally be successful, while those who take shortcuts will invariably not be able to produce good data or draw valid conclusions.

Following this section is a Student Guidesheet which can be used to introduce the Method. The Abbreviated Student Guidesheet can be used as reference throughout the Science of Flight Unit.

In each of the experiments in the Science of Flight Unit, students will be required to keep a log. The log provides a format that will enable students to adhere to the Method. The Experiment Log: Blank Template can be copied and used throughout the unit.

Two experiments follow. The first is led by the teacher and requires no advance preparation. The second is preceded by a Student Reading on Newton's Third Law, and is also teacher-led. Leading the students through their first two experiments should give them adequate preparation for the experiments to follow in the rest of the Unit.

The more students use the Scientific Method in their experiments, the more comfortable they will become with its use. A suggested sequence for experiments throughout the rest of the Unit, is to display the Procedure Card (that accompanies the experiment) on an overhead projector, then quickly go over how to do the experiment without giving away the results. Next, release the class according to student groupings to perform the experiment. After the students have completed their experiments and written conclusions, lead them through a discussion of the results. Place a transparency of the Experiment Log Key on the overhead projector and guide students in a reflection reviewing the entire experiment.

The Experiment Log Keys consist of the Experiment Log with the "Details" side filled in. Bear in mind that the details for each step are written only as a guide. Student answers will vary. Be open to those variations, while making sure that students can justify their assertions.

This section concludes with a Student Worksheet on the Scientific Method.

Student Reading

The Scientific Method

Scientists use many processes to uncover new facts and to solve mysteries. The process they use the most is called the Scientific Method. Throughout this process scientists keep a log of all their ideas and all that they see and do. The basic parts of the Scientific Method that we will use throughout this unit include the following steps:

1. State the problem (question)
2. Form a hypothesis (prediction)
3. Design an experiment (materials and procedure)
4. Perform the experiment (observe and record Data)
5. Organize and analyze data
6. Draw conclusions

Each step will be explained below. You will then practice using the Scientific Method by performing a simple experiment. Use your Experiment Log to help you follow all of the steps.

State the problem (question)

Sometimes you notice events around you and wonder why they happen the way they do. You then ask yourself a question or maybe you ask someone else that question. You can find a good answer to your question using the Scientific Method.

Form a hypothesis (prediction)

You have noticed an event and formed a question about it, so now you can predict what the answer will be. This prediction is called the hypothesis (hi-pa-the-sis). You can make your prediction by using some information you already know or you may simply guess. Your prediction might not be correct, but that is all right! You will have learned important information about your question.

Design an experiment (materials and procedure)

Now you must create an experiment of your own to help prove that your hypothesis is right or wrong. As you design this experiment you must write down the steps. These steps are called the "procedure". The procedure must tell exactly what you will do to perform the experiment. Your directions must be very clear, so that someone else could repeat your experiment to check the results. Remember to include a list of materials you will need to perform the experiment. Be sure to list the size and shape of containers you will need and to specify what items need to be made of. For example, would you need a plastic spoon or a metal spoon?

Perform the experiment (observe and record data)

While you are following your procedure, you need to remember to observe carefully what happens. The information you get from your observations is called "data". You might need to measure results or note a change in size, shape, color or movement. Always record your data as you observe it - don't wait until after the experiment! You might not remember precisely what happened.

Organize and analyze data

Take all your observations and data and get them organized! You can write down your observations in paragraph form as well as put your data in a list, table or graph. When you organize your data remember to make it neat and easy to read.

Draw conclusions

Now you really have to think about all that you have done. Read back over your written observations and your well-organized data. Go back and look over your question and your hypothesis. At this point you might want to look up some more information about the topic or have a discussion with a fellow scientist to review your findings.

Do your results prove your hypothesis? If they do, explain why you think they did. Are there any further questions or hypotheses that you can think of?

If your results do not prove your hypothesis, try to explain why you think they did not. Remember that if your results do not prove your hypothesis, it does not necessarily mean you did something wrong! Oftentimes it is just as important to prove a hypothesis is not true as it is to prove that a hypothesis is true!

You might not know the exact reason why your results proved or disproved your hypothesis, but you can do research to find more information or repeat your experiment using different procedures or materials.

Abbreviated Student Guidesheet
The Scientific Method

State the problem (question)

- *What is it that puzzles you?*
- *What is the question you would like answered?*

Form a hypothesis (prediction)

- *Using what you know, write down an answer to your question.*
- *Using what you know, write down a prediction of what you think might happen.*

Design an experiment (materials and procedure)

- *Design an experiment that will help you prove or disprove your hypothesis.*
- *Write down a step-by-step procedure that tells how you will do the experiment.*
- *List what materials you will need to do the experiment.*
- *Tell what size and shape containers you need and what the materials need to be made of.*
- *Make sure your procedure is very specific.*

Perform the experiment (observe and record data)

- *Follow each step of your procedure very precisely.*
- *Record what you observe and any measurements you take.*
- *Give details with lots of description.*

Organize and analyze data

- *Organize the data you collected:*
  - *make a graph*
  - *make a chart*
  - *draw a picture (before and after)*
  - *draw and label a diagram*

Draw conclusions

- *Using the data you have gathered and what you know, explain why you think the experiment turned out like it did.*
- *Explain why you think your hypothesis was proved or disproved.*
- *Can you relate the results to anything else you have observed before?*
- *Do your conclusions generate any further questions or ideas?*

Experiment Log

Page 1

Experiment:

Steps	Data
<u>1. State the problem.</u> **QUESTION** *(What do I want to know?)*	
<u>2. Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	
<u>3. Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	

Experiment Log
Page 2

Experiment:

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	

Teacher - Led Experiment

Balloon Thrust – Procedure Card

After introducing the Scientific Method, the teacher can walk the students through this simple experiment to help them become accustomed to using the Method.

Lead the students through a discussion of everyday things they have observed and then wondered why they happened. Use the template on the following pages as a guide.

1. For example a question might be:

   "How is it that an airplane can move forward?"

2. Next, field predictions from the students of what the answer might be:

   "Air coming out the back end pushes it forward."

   "The engines make it go."

3. Ask students to propose steps for an experiment to prove or disprove their hypothesis. Lead them towards the Balloon Thrust Experiment. Explain to the students what steps you will perform and then have them assist you in creating the procedure and the materials list.
4. Follow the procedure and ask students to observe carefully with all of their senses.
5. Get ideas from the students on how to organize the data: graph, chart, drawing, etc.
6. Ask each student to write their own conclusion.
7. Share and discuss their conclusions.
8. Distribute the Student Reading: Newton's Third Law and read it to them, discussing it as you go.
9. Ask them to rewrite their conclusion based upon this new information.
10. Show them the conclusion given in the Experiment Log Key and ask the students to carefully compare what they wrote to what is given in the Key. Ask them to identify ideas that are missing in their conclusions. Save this work for future comparison.

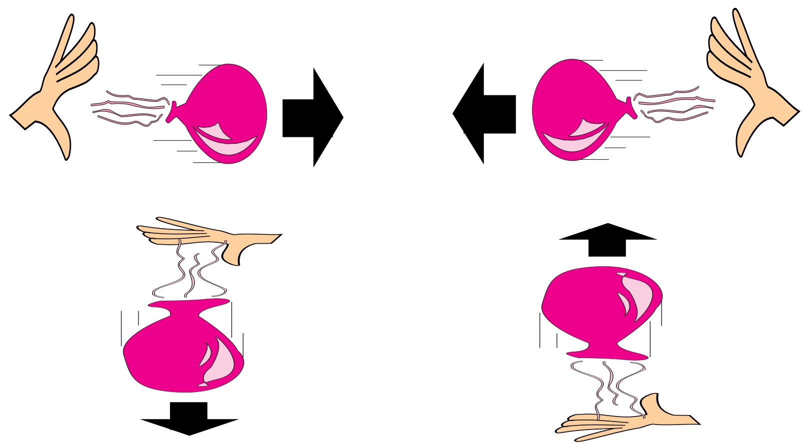
Experiment Log – Key
Page 1

Experiment: Balloon Thrust

Steps	Data
<u>1. State the problem.</u> **QUESTION** *(What do I want to know?)*	*How is it that an airplane can move forward?*
<u>2. Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	*Examples:* *- Air comes out the back end and pushes it forward.* *- Air blows out one way and the aircraft moves the opposite way.*
<u>3. Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials: Balloon* *Procedure* *1. Gather materials.* *2. Blow up balloon and hold tightly (do not tie a knot).* *3. Hold in midair with the mouth of the balloon facing left, so it's parallel with the ground.* *4. Let go of balloon and observe.* *5. Repeat steps 2-4, but have mouth of balloon facing to the right.* *6. Repeat steps 2-4, but have mouth of balloon facing up.* *7. Repeat steps 2-4, but have mouth of balloon on the ground.*

Experiment Log – Key
Page 2

Experiment: Balloon Thrust

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The first time the balloon traveled quickly to the right and then it went up and did some loops before it ran out of air. The second time the balloon traveled quickly left for a bit before shooting downward in a loop and hitting the ground. The third time the balloon went nearly straight down quickly into the ground where it ran out of air. The fourth time the balloon shot up nearly straight up into the air and did some loops before it ran out of air and fell to the ground.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	 *Each time the balloon was released, it immediately traveled in the direction opposite the way the mouth was pointed. For example, when the mouth was pointing to the left, the balloon went to the right. After that, the balloon kind of traveled in the direction opposite where the mouth of the balloon was pointing.*
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*The air rushing quickly out of the mouth of the balloon must push the balloon forward. That means the air rushing out is the thrust that gives the balloon its forward motion. Newton's Third Law says that for every action there is an equal and opposite reaction. The action is the air coming out of the mouth of the balloon. The reaction is when the balloon travels in the direction opposite to where the mouth is pointing. The second hypothesis is correct. An airplane works like a balloon. When the engines blow the air out one way, the airplane goes the opposite way.*

Student Reading

Newton's Third Law

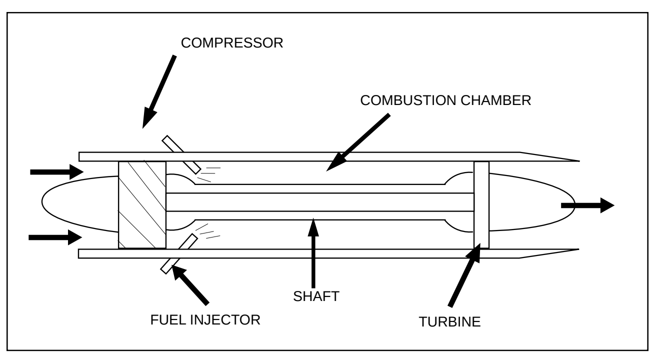
At the time Newton published his laws of motion in the work *Principia,* his Third Law was a very new idea. It states that for every action there is an equal and opposite reaction.

Remember that there are two parts, or components, for every force: magnitude and direction. Magnitude is the amount or strength of the force. Direction is the way the object moves when the force is applied.

Newton's Third Law says that when a force moves an object in one direction (called the "action"), another force is generated in exactly the opposite direction (called the "reaction"). The magnitude of the two forces will be exactly the same.

For example, imagine a person on a skateboard facing a wall. The person then pushes against the wall. The push is the "action" and is in the direction of the wall. This action causes a "reaction" in the opposite direction - the skateboard (with the person on board) rolls away from the wall. If the person pushes lightly against the wall (action), the skateboard will move slowly away from the wall (reaction). If the person pushes on the wall with more power (stronger action), the skateboard will move farther away from the wall and more quickly, too (stronger reaction).

A jet engine demonstrates Newton's Third Law. A jet creates a stream of high speed air flowing ("jetting") out the back of the engine (action). This action causes a reaction in the opposite direction - it thrusts the airplane forward.



Air is sucked into the front of the engine. Spinning blades compress the air - the blades push the air molecules closer together. The compressed air is then heated by flames from fuel burning in the combustion chamber. The hot air is then released with great force from the back of the engine. This is the force that causes the airplane to move forward. A jet engine works the same way as the balloon. Air is blown into the balloon. When the balloon is released the air "jets" out through the mouth of the balloon, thrusting the balloon forward.

Teacher-Led Experiment

Cup with Water – Procedure Card

Review the previous experiment ("Balloon Thrust") which discussed jet engine thrust and Newton's Third Law. Ask the question: "Will Newton's Third Law apply to a force created by water, instead of air?"

1. Have students copy the question onto their Experiment Log.

2. Ask them to write down one hypothesis based upon what they learned from the Balloon Thrust experiment and/or from what they know from their own experience.

3. Discuss their answers.

4. Ask students to propose steps for an experiment to prove or disprove the hypothesis. Lead them to the following:

   Punch three equidistant holes around the top of the cup and tie string through them so that the cup can be suspended and held in a somewhat level manner. See diagram on page 2 of the Experiment Log Key.

   Punch a hole the diameter of a straw near the bottom of one side of the cup. It is recommended that the hole punching be done in advance. It is also recommended that the straw fit snugly into the opening.

   Hang the cup over a bucket or sink and have handy a container of water to pour into the cup.

   Pour the water into the cup while holding your thumb over the opening. Release your thumb and observe. As the water rushes out of the opening at the bottom of the cup, the cup will move slightly in the opposite direction of the water's flow.

5. Have the students write down the procedure as well as any materials that will be needed.

6. Do the experiment a couple of times and have students individually record their observations.

7. Discuss ways for them to organize and present the data.

8. Allow time for students to write their own conclusion based upon what they observed.

9. Have students share their conclusions in partners or small groups.

10. Model the type of conclusion you wish students to create using the Key or creating a conclusion of your own.

By this time students should be comfortable with the Scientific Method. All experiments performed in this Unit should be presented in the same manner. Each experiment will include the following:

- Procedure card with materials list, preparation directions and experiment procedure
- Experiment Log Key
- Student readings or handouts.

Use the blank Experiment Log found on page 131 to copy and provide to students.

Experiment Log – Key

Page 1

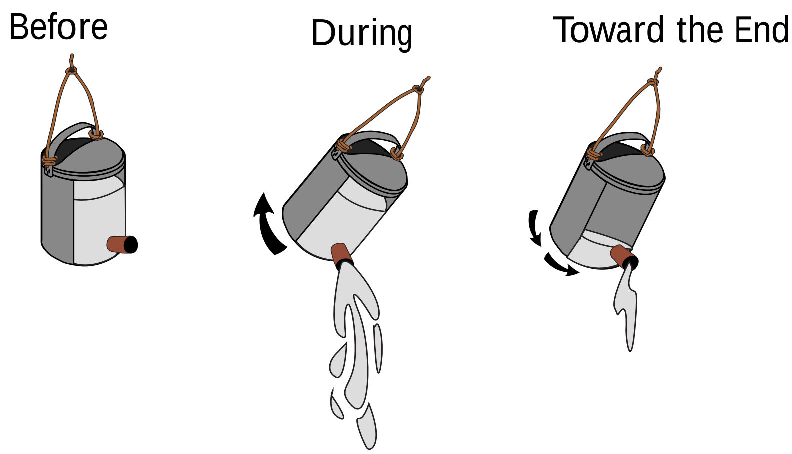
Experiment: Cup with Water

Steps	Data
1. <u>State the problem.</u> **QUESTION** *(What do I want to know?)*	Does water act the same way as air according to Newton's Third Law? (Will the water draining out of the can cause the can to react?) Will Newton's Third Law apply to a force created by water instead of air?
2. <u>Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	I think the water will not act in the same way as the air. I think the water will just drain out of the cup. As the water pours out of the hole, I think the cup will tip in the opposite direction from the force of the flow.
3. <u>Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	Materials: string • cup with holes • water in container • sink/bucket • piece of straw 1/2" in length Procedure: 1. Gather and set up materials. 2. Make sure cup is firmly hung and still. 3. Hold cup and block hole at bottom of cup while filling cup with water. 4. Gently remove block from hole. 5. Observe and record. 6. Repeat steps 3-5.

Experiment Log – Key

Page 2

Experiment: Cup with Water

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*After gently releasing the water from the cup, there was a slight sway. The water poured out the hole in a steady stream with some force. The cup then moved slightly in the opposite direction of the water. It stayed in that position for a while and then as the water started coming out more slowly it also slowly moved back to its original position.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*As soon as the water was allowed to pour out, the cup moved from its perpendicular position to a slight leaning position. It leaned in the opposite direction from the way the water was pouring out. This means that water has the same effect on objects as air does. Just like Newton's Third Law, the water's action of draining out of the hole caused the cup to react by moving in the opposite direction. My hypothesis was incorrect. I thought that Newton's Third Law only worked with air, but it also works with water. This means that water acts and causes reactions the same way as air.*

Student Worksheet
The Scientific Method

Directions: Using the Student Guidesheet, answer the questions below. Write in the correct step number in the blank for each step described.

_____ 1. organize and analyze data
_____ 2. form a hypothesis
_____ 3. draw conclusions
_____ 4. perform the experiment
_____ 5. state the problem
_____ 6. design an experiment

Directions: Answer the following questions.

7. Name four (4) ways that data can be organized.

8. Describe what you will be doing when you perform an experiment.

9. What two items must be included when you design an experiment?

10. When you "State the problem", what kind of statement are you making?

11. When you "Form a Hypothesis", what kind of statement are you making?

Student Worksheet Key

The Scientific Method

Directions: Using the Student Guidesheet, answer the questions below. Write in the correct step number in the blank for each step described.

__*5*__ 1. organize and analyze data
__*2*__ 2. form a hypothesis
__*6*__ 3. draw conclusions
__*4*__ 4. perform the experiment
__*1*__ 5. state the problem
__*3*__ 6. design an experiment

Directions: Answer the following questions.

7. Name four (4) ways that data can be organized.

graph
chart
draw a diagram with labels
draw a picture

8. Describe what you will be doing when you perform an experiment.

observing and recording data

9. What two items must be included when you design an experiment?

procedure: how the experiment will be done
materials: what will be needed for the experiment

10. When you "State the problem", what kind of statement are you making?

question

11. When you "Form a Hypothesis", what kind of statement are you making?

prediction

Quick Quiz

The Scientific Method

Directions: Circle the letter of the answer that best answers the question.

1. How can data be organized?

   A. make a graph
   B. make a chart
   C. draw a diagram with labels
   D. all of the above

2. What is included when designing an experiment?

   A. procedure
   B. materials
   C. hypothesis
   D. both A and B

3. When you "State the Problem", what kind of statement are you making?

   A. a question
   B. a prediction
   C. a materials list
   D. none of the above

4. What two (2) things are done when performing an experiment?

   A. forming a hypothesis and stating the problem
   B. observing what happens and recording data
   C. drawing a graph and drawing a conclusion

5. When you "Form a Hypothesis", what kind of statement are you making?

   A. a question
   B. a prediction
   C. a materials list
   D. none of the above

Quick Quiz - Key

The Scientific Method

Directions: Circle the letter of the answer that best answers the question.

1. How can data be organized?

   A. make a graph
   B. make a chart
   C. draw a diagram with labels
   D. all of the above

2. What is included when designing an experiment?

   A. procedure
   B. materials
   C. hypothesis
   D. both A and B

3. When you "State the Problem", what kind of statement are you making?

   A. a question
   B. a prediction
   C. a materials list
   D. none of the above

4. What two (2) things are done when performing an experiment?

   A. forming a hypothesis and stating the problem
   B. observing what happens and recording data
   C. drawing a graph and drawing a conclusion

5. When you "Form a Hypothesis", what kind of statement are you making?

   A. a question
   B. a prediction
   C. a materials list
   D. none of the above

Section Overview

Four Forces of Aeronautics

This section defines a force and the four forces of lift, weight, thrust and drag which act upon an airplane.

CD-ROM Usage

Go to the segment "How an Airplane Flies" (or the runway) and use the subsections "Lift" and "Four Forces". The animated movies can be used to illustrate important points during the reading. Use the corresponding Student Logbook Sections "Lift" and "Four Forces" to reinforce the concepts.

Materials List

- two ping pong balls
- two pieces of thread equal lengths
- ring stand or table edge to tape them to
- tape
- 2 large bolts or nuts or washers of equal size and weight
- 4 pieces of thread of equal lengths
- plastic grocery bag
- balloon
- sheet of paper
- sturdy book

Student Handouts

Student Reading: Four Forces of Aeronautics
Student Worksheet: Four Forces
Experiment: What a Drag! Procedure Card
Experiment: The Force of Thrust Procedure Card
Experiment: A Little Lift Procedure Card
Quick Quiz: Four Forces of Aeronautics

Teacher Reading
Four Forces of Aeronautics

This section will explore the basics of how airplanes fly. This reading covers the principles which define aeronautics and discusses how they interact to enable flight.

The Four Forces

A force is defined most simply as a push or a pull. There are two components to a force: magnitude (or the amount of force applied) and direction. Thus we say that "a force of a certain magnitude is applied in a particular direction".

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. After explaining what the four forces are, a simple model of flight will be presented that will be used throughout **Exploring Aeronautics**.

All objects in the universe exert an attractive force on each other that is called **gravity**. The magnitude of this force is dependent on the mass of the object. In our day-to-day lives this attractive force is recognizable only for objects with enormous mass, such as the Earth. **Weight** is the word we use to define the attractive force specifically between the Earth and all the billions of objects that are within its influence. Included in a list of these objects would be people, airplanes, helicopters - even the moon!

The Earth's gravity weakens as objects move farther away from it. Thus we say that objects that are far from the Earth "weigh less" than when they are on the Earth. For objects "on" and "close" to the Earth (we will assume that airplanes fly at altitudes "close" to the Earth) the weight of an object can be considered constant.

In order for an airplane to fly, a force in the upward direction must be generated that is stronger than the weight force. That force is called **lift**.The lift force is generated by air flowing over an object. The direction of the lift force will always be perpendicular to the direction that the air is flowing. As an airplane is flying, air is flowing over its wing, from the front (or leading edge) to the back (or trailing edge). This generates a lift force perpendicular to the direction of the airflow, that is, in most cases, "up".

It is easy to understand that the shape of the wing will have a direct influence on "how" the air flows from front to back. "How" the air flows will have a direct influence on how much lift the wing can generate. An object that is shaped to generate maximum lift is called an "airfoil".

When an airplane is sitting on the ground, there is not enough air flowing around it to create lift. Another force is needed to get the airplane moving through the air, so that the airflow can do its job of creating lift. This force is called **thrust**. Thrust propels an object in a particular direction. The arm of a baseball pitcher generates thrust and applies it to a baseball (that is, throws it) towards a batter. Likewise, a jet engine generates thrust and, because it is attached to the wing of an airplane, its thrust will be applied to the airplane. So, as the engines thrust the airplane in the direction that they are pointed, air flows over and under the wings which creates the lift force. If enough lift is generated, the airplane will fly.

The fourth primary force is **drag** - and the drag force does a great job of living up to its name. Drag is the force that resists any object trying to move through a fluid.The drag on an airplane is the result of, among other things, the energy needed to move the air out of the way of the airplane. Obviously drag is hard at work when a massive object, like an airplane, tries to fly through a fluid like air. Any motion or movement by the airplane will always be resisted by a drag force. The direction of the drag force is opposite to the direction of flight. The thrust force is aligned to counter the drag force.

Reducing drag is one of the main concerns of aeronautical engineers when designing aircraft. Drag can stress different parts of an aircraft which can lead to structural failure during certain maneuvers. Further, reduction of drag has a "domino" effect on other important aspects of flight.The less drag an aircraft has, the faster an aircraft can go, or the less power is needed from the engine. Less powerful engines are generally lighter (that is, have less weight) and need less fuel (that is, cost less to fly). A lighter aircraft means that less lift is needed to fly and the airplane can be more maneuverable. If less lift is needed, a smaller wing is required which decreases weight and drag. All of this, taken together, reduces the cost of building and flying the airplane.

A Simple Model of Flight

Obviously, a discussion of just these four forces can get complicated very fast! For the 5th through 8th grade level, we will use a simplified model of the four forces. The difference between this simplified model and more complicated ones, is that this model does not take into account all the myriad of directions that an airplane can fly. For example, airplanes can climb, descend, turn and roll. Our model will make the assumption that the airplane is flying "straight and level". That is, the thrust of the engines is propelling the airplane "forward". Drag is resisting the thrust motion and trying to pull the airplane "back". Lift is "lifting" the airplane "up" into the sky. Weight is trying to pull the airplane "down" toward the ground.

In this simplified model we say that thrust and drag are "opposing" forces (they work against each other) and lift and weight are "opposing" forces. Further, in this simplified model, we say that if lift is greater than weight and thrust is greater than drag, an airplane will fly. Obviously "greater than" covers a wide range from "just a little bit" to "a whole lot". Simple qualitative relationships can be derived from "how much greater than". For instance, an airplane whose lift is much greater than its weight can probably fly higher more easily than an airplane whose lift is only a little greater than its weight. Likewise, an airplane whose thrust is much greater than its drag can probably fly faster more easily than one whose thrust is only a little greater.

The Four Forces in Balance

Let us look more closely at the interplay between the four forces. Recall that in our model, the four forces work in pairs: lift versus weight and thrust versus drag.

When forces are in balance, that is their magnitudes are the same and their directions are opposite, the speed and direction of the object will not change. Imagine an airplane, flying along at it's cruising speed and its cruising altitude. The wings are creating enough lift to counteract the weight of the aircraft and keep it at its cruising altitude. The engines are creating enough thrust to counteract the drag of the aircraft and keep it at it's cruising speed.

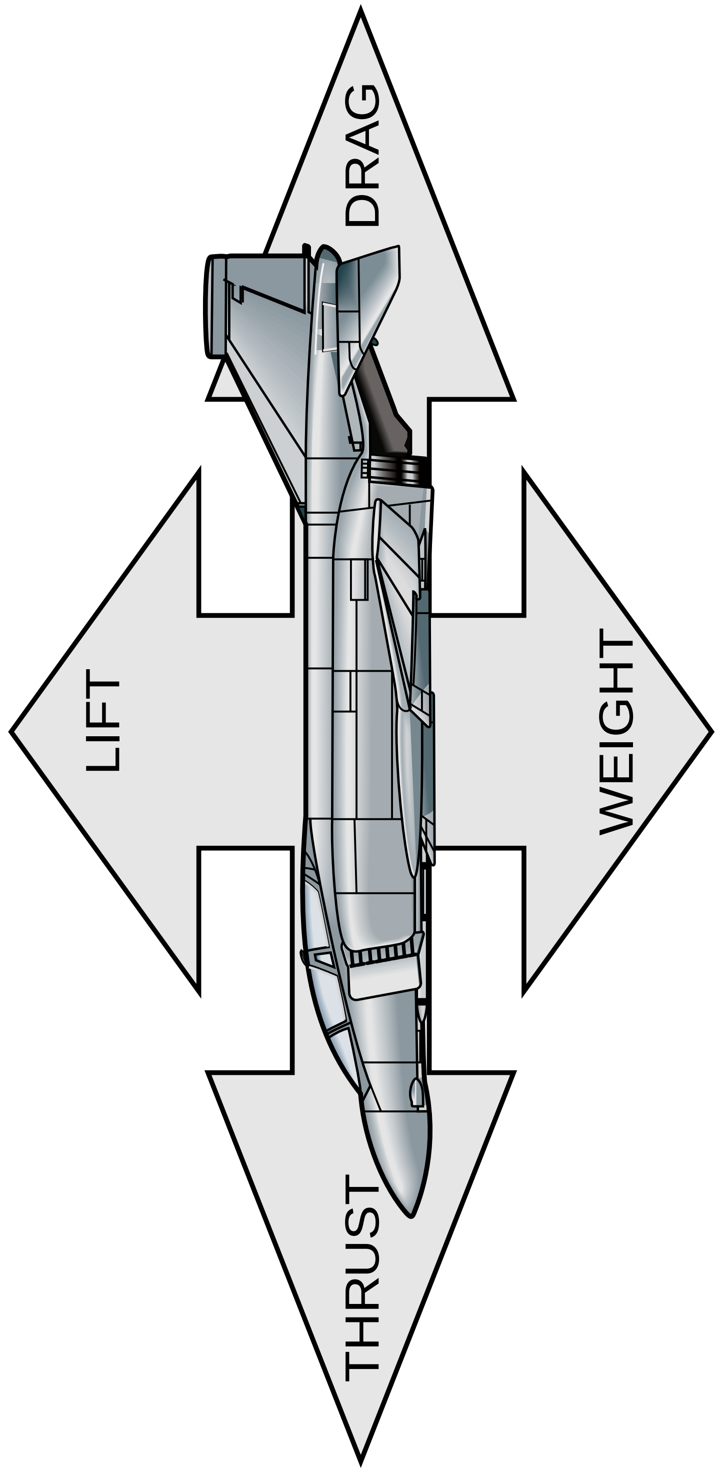
Now, say that the lift force is increased (exactly how that force is increased will be discussed later). Now there is an imbalance between the lift force and the weight force and the airplane will rise. Conversely if the lift force is decreased, or the weight of the aircraft is decreased (it's using up fuel, for instance) the lift force and the weight force will not be balanced and the airplane will descend.

In the same way, if the thrust force is increased, an imbalance is created, and the airplane will increase its speed in the direction the thrust is directed. Similarly, if the thrust is decreased, or the drag increased (say the flaps on the wings are extended), the airplane's speed will decrease.

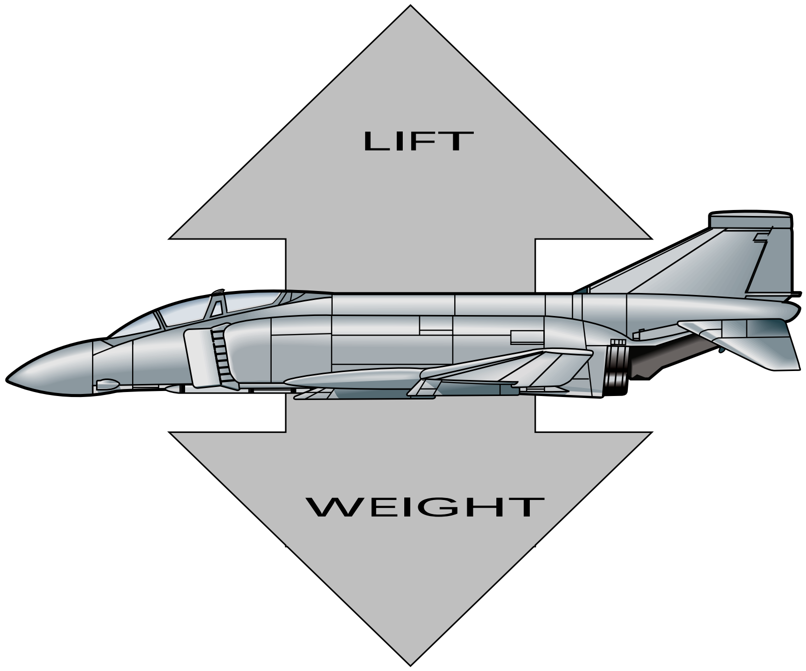
Thus, the task of a pilot is to manage the balance between these four forces - we call this flying!

Overhead Guides

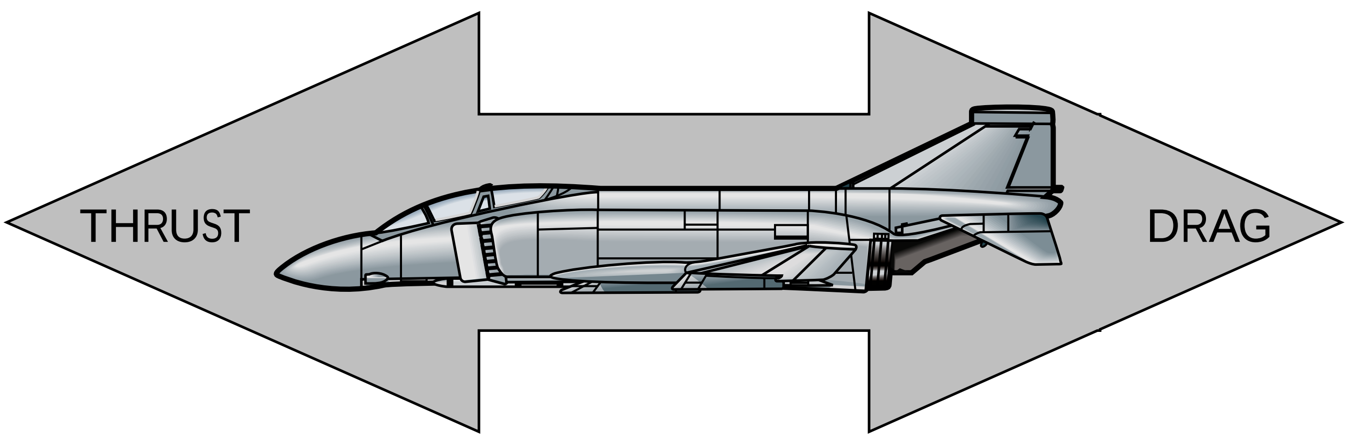
Four Aeronautical Forces



The Four Forces in Balance

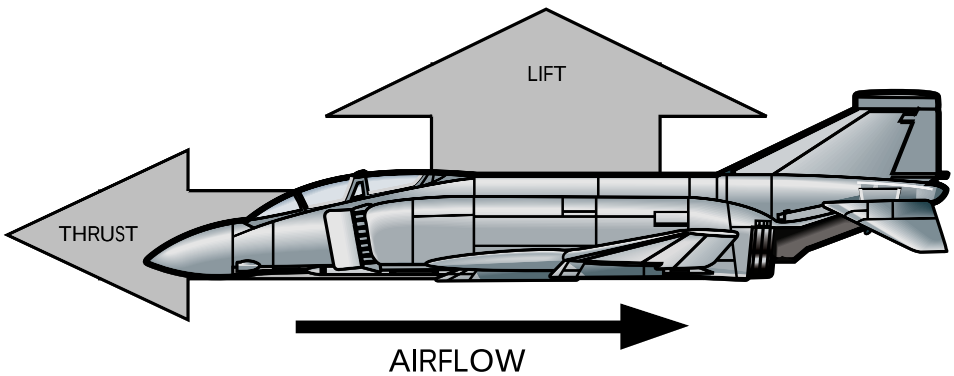


Lift and Weight must be balanced to maintain the same altitude

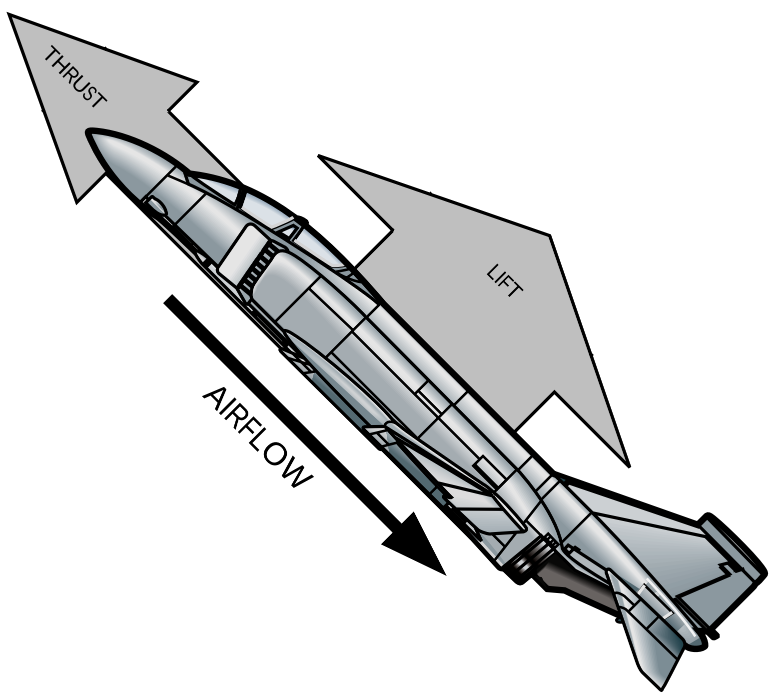


Thrust and Drag must be balanced to maintain the same speed.

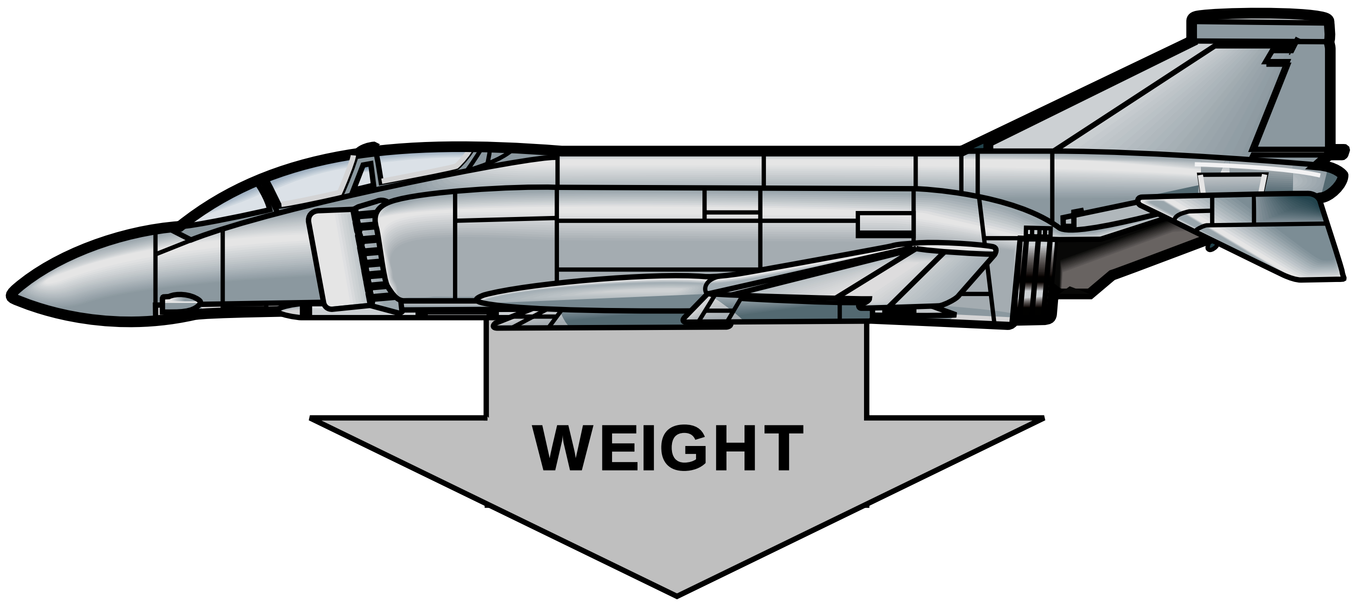
The Angle of Lift



In our simple model, lift occurs at a 90° angle from the direction of thrust

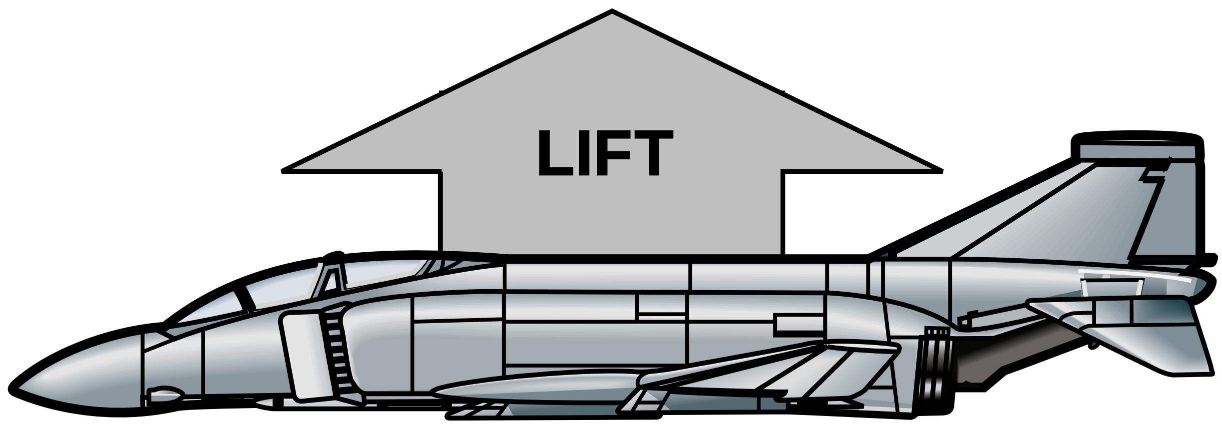


Weight



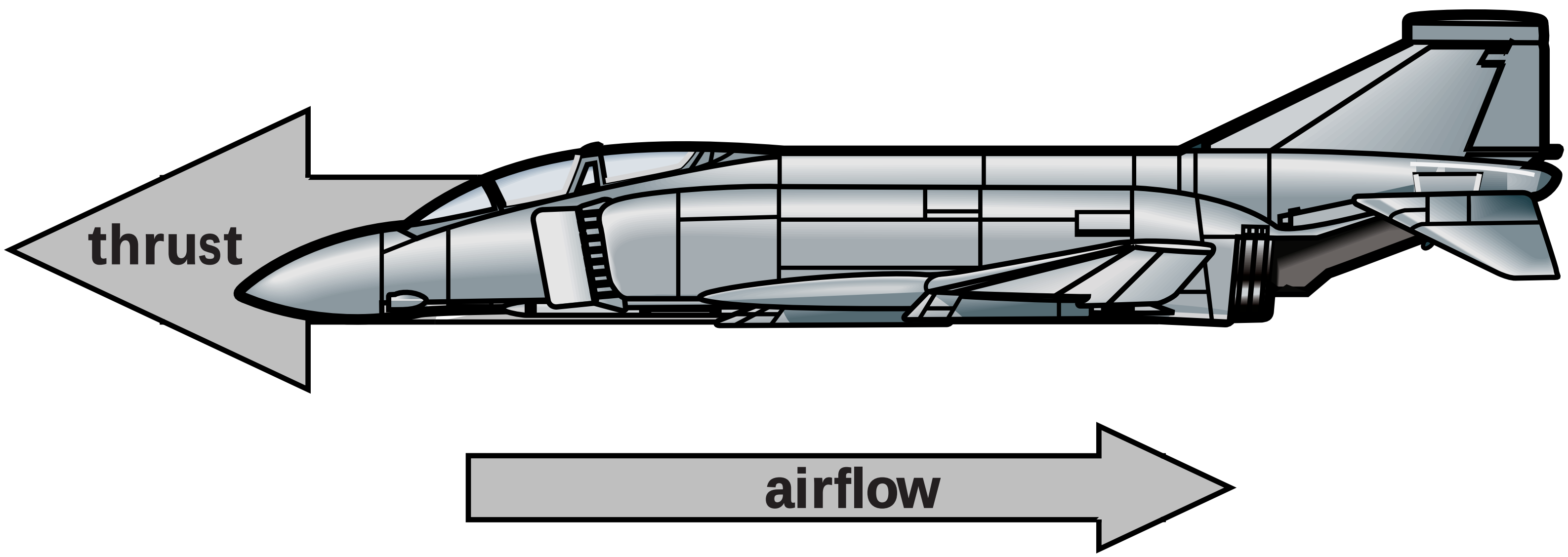
- All objects in the universe exert an attractive force on each other.
- The greater the mass, the greater the attraction.
- Gravity is the attraction between Earth and an object.
- Weight is how we measure gravity.

Lift



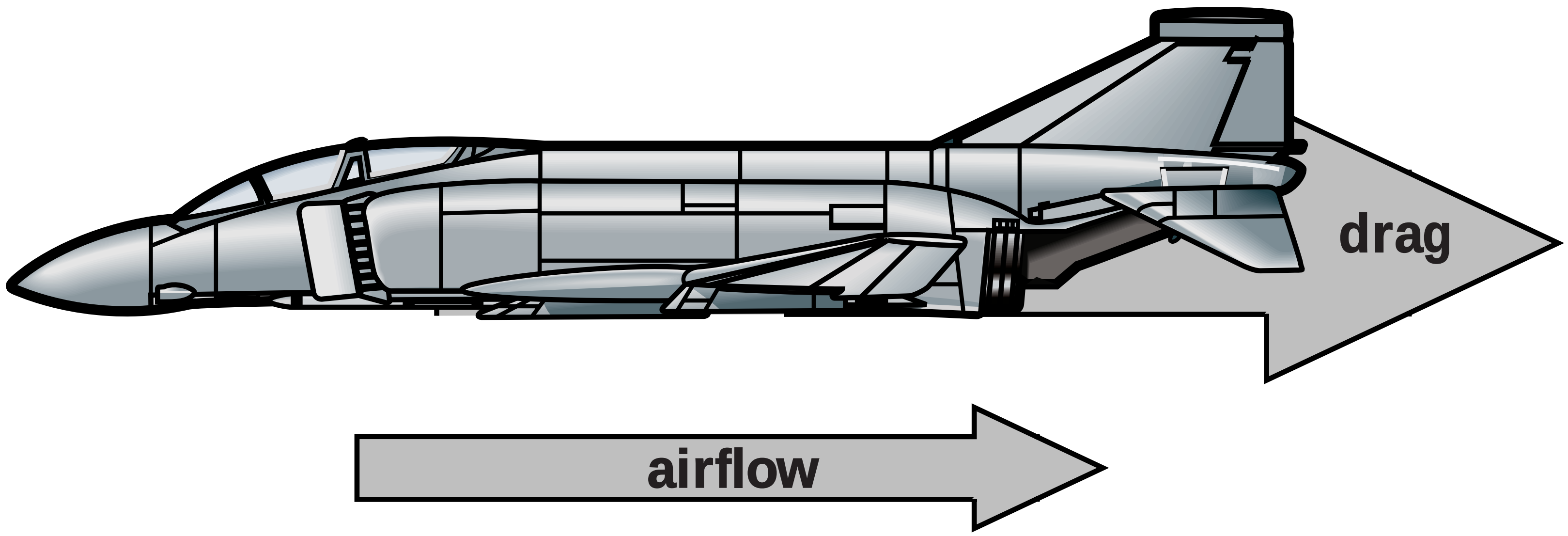
- A force that opposes weight.
- A force that pulls an airplane into the air.
- Created by air flowing over the wings.

Thrust



- A force that is generated by an airplane's engines.
- The direction of the thrust force is based on where the engines are pointed.
- Thrust is aligned with the direction of flight.
- Thrust is opposite to the direction of the airflow.

Drag



- A force that opposes thrust.
- A force that resists the movement of objects.
- Generated by air not flowing smoothly across the surface of the aircraft.
- Drag is aligned with the direction of the airflow.

Student Reading
Four Forces of Aeronautics

What is a force?

Can you think of examples of force? If you push a door closed, your push is a force. If you pull a drawer open, your pull is a force. A force actually has two parts. One part is the strength of the force. When you pushed the door closed, did you push it gently or did you slam it? How hard you pushed is the strength (or magnitude) of the force.

The other part is the direction of the force. Say that you pulled on a rope. Did you pull it to the right, or to the left? Did you pull it up or down? Where you pulled is the direction of the force.

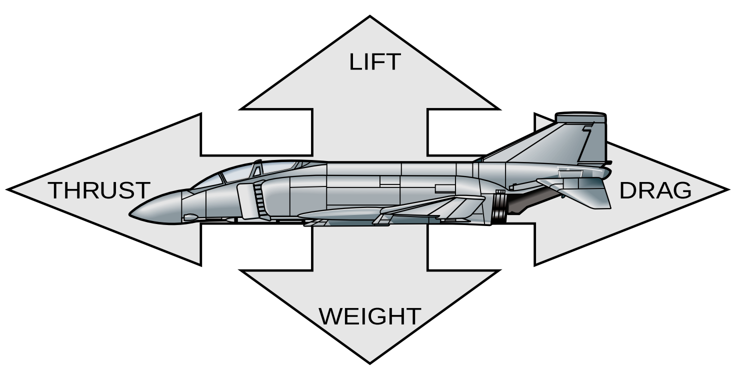
So, when we talk about forces we must talk about both their magnitude and their direction.

Forces in Aeronautics

In aeronautics, four important forces have been defined. These forces are called **lift**, **weight**, **drag** and **thrust**. All of the four forces work in a specific direction. Their magnitude can range from very weak to very strong.

All of these four forces are hard at work when an airplane is flying. Sometimes they work in opposite directions from each other, but they all work together when the airplane flies.

Four Aeronautical Forces



Weight

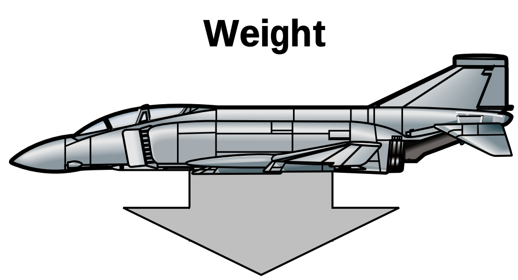
Weight is a force that you probably already know about. When you step on a scale, you are checking to see what your weight is. Well, an airplane has weight too - just like every other object that exists around the Earth.

All objects, whether big or small, exert a gravity force on every other object. As you are sitting in your chair, you are exerting a gravity force on the person next to you - even if you aren't touching them!

If an object is very, very large it can exert a lot of force on objects around it. One example of a very, very large object is the Earth. We know that the Earth exerts a gravity force on us - we call it weight! The Earth's gravity force pulls on all objects that are within it's reach. And, the gravity force has a very long reach! The moon can feel the gravity force of the Earth.

When you weigh yourself, you are actually measuring the force of Earth's gravity on your body. Remember that there are two parts to a force: magnitude and direction. The direction of your weight force is toward the Earth. The magnitude of your weight force is how heavy you are.

Airplanes have a weight force too. Even as they fly many feet above the Earth, their weight force is pulling them toward the Earth. Since they are so heavy (certainly a lot heavier than you are), the magnitude of their weight force is very large.



Lift

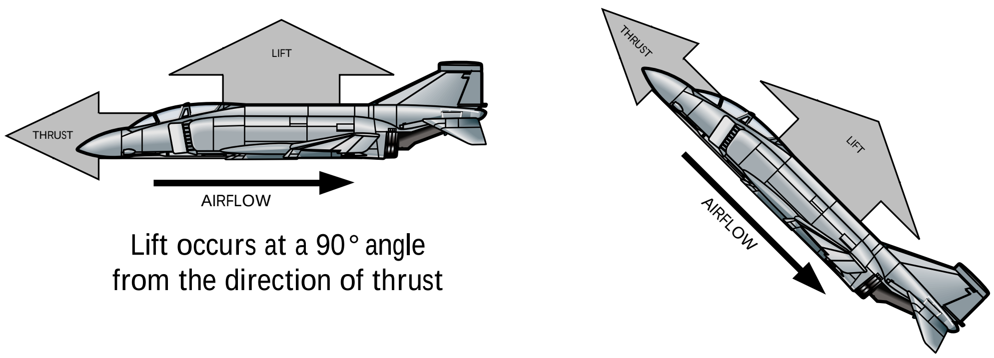
You are probably also familiar with the lift force. You lift books off of a desk. When a strong wind blows, pieces of paper and other light objects are lifted off the ground. When that piece of paper lifts off the ground that means that the lift force is so strong that it is stronger than the weight force of the paper. If the weight force were stronger the piece of paper wouldn't lift off the ground.

The lift force works the same way on an airplane. If an airplane can create enough lift, so that the lift force is stronger than the airplane's weight, then the airplane can fly. Since the weight force of an airplane is so large that means that a lot of lift has to be created.

The lift force is generated by the air flowing over the wings of the airplane. You can imagine that the air flow must be really strong to make the lift force strong enough to get an airplane off the ground.

As the air flows over the wing, the lift force is created in an interesting direction. Can you guess what that direction is? Most of the time the direction is "up". But it really is at a 90 degree angle to the airflow. Most of the time the airflow is going over the wing from front to back. So, the direction of lift is up into the sky.

The Angle of Lift



Lift occurs at a 90° angle
from the direction of thrust

Thrust

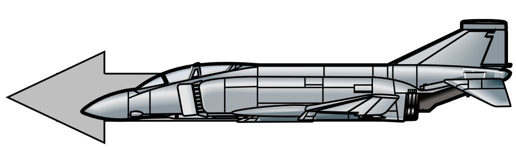
In order for the lift force to be created, air has to be flowing over the wings. Now, how do we make air flow over the wings? The answer is that we don't make the air itself flow over the wings, but we make the wings go through the air. As the wing goes through the air, the air flows over and under the wing - this creates lift.

Somehow, we have to get the airplane moving. This is done with the engines. Engines are mounted on the wings or on the fuselage. They propel the airplane down the runway and forward through the air.

The force that is created by the engines is called the thrust force. The direction of the thrust force is based on where the engines are pointing. Since the engines are mounted facing forward, the direction of thrust is towards the front of the airplane.

A very strong engine can create lots of thrust while smaller engines will create less thrust. So, the magnitude of the thrust force is determined by the size and power of the engines.

Thrust



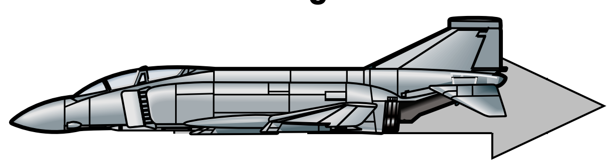
Drag

As the airplane is thrust through the air, it must push aside all those air molecules that are in its way. As a wing goes through the air, the air separates and some of the molecules go above the wing and some go below. The same thing happens with the rest of the airplane. The air molecules must separate so the airplane can get through.

Air molecules resist this separation and this resistance is called drag. So, drag tries to hold the airplane back. The thrust force must be stronger than this resistance.

Also, it is best for the air flowing around the airplane to stay smooth, like a stream gently flowing around a rock. More drag force can be created if the airflow does not stay smooth.

Drag

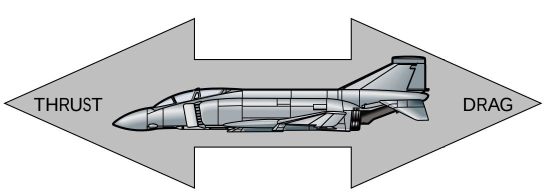


Four Forces in Balance

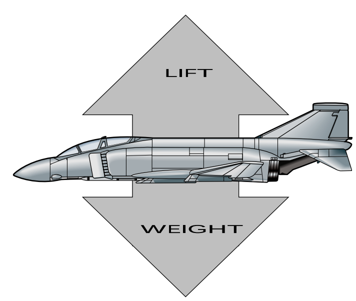
As you've read above, the four forces work in pairs. The lift force pulls the airplane up while the weight force tries to pull it down. The thrust force tries to propel the airplane forward while the drag force tries to hold the airplane back. We say that these forces work in opposition to each other. This means that they are working in opposite directions. Like in a tug of war, the airplane goes in the direction of whichever force is strongest.

In order to fly, the lift force on an airplane must be stronger than the weight force and the thrust force must be stronger than the drag force. All the four forces and all the parts of the airplane work together to enable the airplane to fly!

The Four Forces in Balance



Thrust and Drag must be balanced to maintain the same speed.



Lift and Weight must be balanced to maintain the same altitude.

Student Note Taking Guide

Four Forces of Aeronautics

Big Ideas	**Important Little Details**
force	a push or a pull has two parts: magnitude (strength) and direction
forces in aeronautics	lift, weight, drag, thrust all forces work together to make the airplane fly sometimes they work in opposite directions
weight	everything has weight all objects exert a gravity force on each other large objects exert a large force the Earth exerts a force on everything around it, called gravity weight is measuring the force of gravity direction of the weight force is toward the Earth magnitude of the weight force depends on how big the object is
lift	force generated by air flowing over the wings has to be strong to overcome weight direction of the lift force is 90 degrees to the direction of the air flow
thrust	created by the engines engines propel the airplane so air flows over the wings to create lift direction of thrust is in the direction the engines are pointing magnitude of the thrust force depends on the size and power of the engines
drag	drag is the resistance caused by air molecules air molecules separate as they go around the airplane if the air flow isn't smooth it will cause more drag drag holds an airplane back
four forces in balance	forces work in pairs pairs work in opposite directions lift and weight are a pair thrust and drag are a pair to fly, the lift force must be stronger than the weight force and the thrust force must be stronger than the drag force all forces work together when airplanes fly

Student Worksheet
Four Forces of Aeronautics

Directions: Use the Student Reading on the four forces to help you answer the questions below.

1. Give the definition of a force.

2. A force has two parts, what are they?

3. Match the name of the force to its description below and write the number in the blank next to the name.

   1. drag   2. lift   3. thrust   4. weight

_____ A) the measure of the pull of the Earth on an object

_____ B) propels an airplane in the direction the engines are pointed

_____ C) force that acts at a 90 degree angle to the airflow

_____ D) a force that gives resistance

4. Name the force that's opposite to the force given.

   weight - _________________

   thrust - _________________

5. In order to fly, which two forces must be the strongest? Circle your answers.

   drag   lift   thrust   weight

Student Worksheet – Key
Four Forces of Aeronautics

Directions: Use the Student Reading on the four forces to help you answer the questions below.

1. Give the definition of a force.

   a push or a pull

2. A force has two parts, what are they?

   magnitude (or strength) and direction

3. Match the name of the force to its description below and write the number in the blank next to the name.

   1. drag 2. lift 3. thrust 4. weight

__4__ A) the measure of the pull of the Earth on an object

__3__ B) propels an airplane in the direction the engines are pointed

__2__ C) force that acts at a 90 degree angle to the airflow

__1__ D) a force that gives resistance

4. Name the force that's opposite to the force given.

   weight - __*lift*__________

   thrust - __*drag*__________

5. In order to fly, which two forces must be the strongest? Circle your answers.

   drag *lift* *thrust* weight

Experiment: What a Drag!

Procedure Card

Materials

15 centimeters x 15 centimeters square piece of plastic grocery bag
four pieces of thread, 12 centimeters in length
one metal ring or weight

Experiment Set Up

Tie a piece of thread to each corner of the plastic grocery bag square.

Tie the remaining ends of each thread together onto the metal ring/weight.

Experiment Procedure

1. Hold the metal ring/weight at a height of about three meters and let it go.
2. Observe and record.
3. Hold the plastic piece at its center with the weight hanging down.
4. Hold it at a height of about three meters and let it go.
5. Observe and record.

Experiment Log – Key

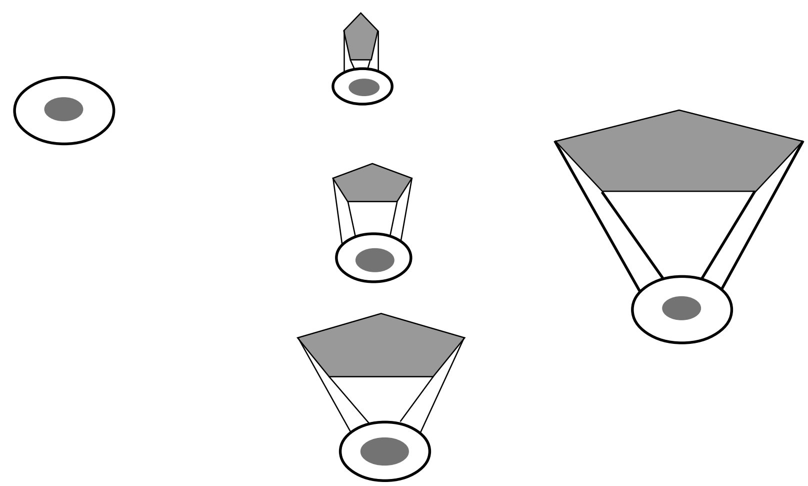
Page 1

Experiment: What a Drag!

Steps	Data
1. <u>State the problem.</u> **QUESTION** *(What do I want to know?)*	*What does drag do to a moving object?* *OR* *How does drag act on moving object?* *OR* *How does drag slow things down?*
2. <u>Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	*I think the weight will not fall to the ground as fast with the cloth attached to it because the cloth will be like a parachute and catch the air underneath it, slowing it down.* *OR* *I think the weight will slow down a little because the cloth will catch the air.*
3. <u>Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *Square piece of plastic grocery bag • thread • metal ring/weight* *Procedure:* *1. Drop metal weight from 3 meters above ground.* *2. Observe and record.* *3. Assemble cloth and thread and attach to weight.* *4. Drop weight from 3 meters above ground.* *5. Observe and record.*

Experiment Log – Key
Page 2

Experiment: What a Drag!

Steps	Data
4. <u>Perform the experiment.</u> **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The first time the weight went straight down fast.* *The second time, the plastic piece spread out and caught air under it. This slowed down the fall of the weight. It floated a lot slower to the ground.*
5. <u>Organize and analyze data.</u> *(Make a graph, chart, picture or diagram.)*	
6. <u>Draw conclusions.</u> *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*I was right. The plastic piece acted just like a parachute. As the weight fell, it opened up and caught more air molecules underneath it. This made a force that slowed the plastic piece and the weight down.*

Experiment: The Force of Thrust

Procedure Card

Materials

elongated balloon
tape
soda straw
three meters of fishing line, secured at one end

Experiment Set Up

Secure one end of the fishing line to a wall or sturdy table leg, etc.

Tape the straw length-wise to the elongated balloon.

Inflate the balloon, but do not tie it off. Pinch the mouth closed.

Thread the unsecured end of the fishing line through the straw so that the mouth of the balloon is not pointed toward the secured end.

Experiment Procedure

1. Pull the fishing line tight and release the mouth of the balloon.

2. Observe and record.

Experiment Log – Key

Page 1

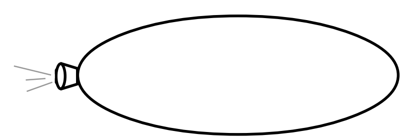
Experiment: The Force of Thrust

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	*How does thrust move an object?* *OR* *In what direction does thrust move an object?* *OR* *How does thrust work?*
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	*I think thrust will push the object forward along the line as the air comes out the back end.* *OR* *As the air inside comes out the opening of the balloon, it will push against the air outside and move the balloon forward. I think the balloon will move faster at first and then slow down as the air runs out.*
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials: Soda straw • balloon (elongated)* *Procedure:* *1. Gather and prepare materials.* *2. Inflate balloon, hold mouth closed and place on a string.* *3. Pull string tightly and let balloon go.* *4. Observe and record.*

Experiment Log – Key

Page 2

Experiment: The Force of Thrust

Steps	Data
4. <u>Perform the experiment.</u> **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The balloon moved fast at first and then slowed down as the balloon ran out of air.* *The air came out the back end of the balloon which pushed the balloon in the opposite direction.*
5. <u>Organize and analyze data.</u> *(Make a graph, chart, picture or diagram.)*	
6. <u>Draw conclusions.</u> *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*These results mean that Newton's Third Law of Motion (which we talked about earlier) explains how thrust works. The air comes out in one direction and pushes the balloon in the opposite direction. This must be how rockets work. My hypothesis was right because I had seen this done before. I do wonder why the air comes out of the balloon — I'm not squeezing the balloon. I wonder if it has something to do with air pressure.*

Experiment: A Little Lift

Procedure Card

Materials

book
piece of standard size notebook paper

Experiment Set Up

Gather the materials.

Experiment Procedure

1. Stand the book upright.

2. Place one end of the piece of paper about 7 to 8 centimeters into the middle of the book so that it bends over and away from you.

3. Gently and steadily blow across the surface of the curved paper.

4. Observe and record.

Experiment Log – Key

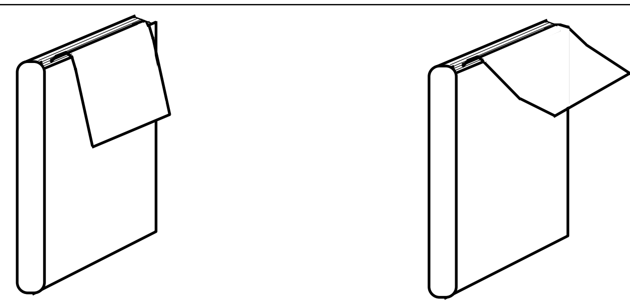
Page 1

Experiment: A Little Lift

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	*How does a wing get lift?* *OR* *Can flowing air create lift?*
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	*Air flowing over the paper will cause the paper to bend lower (or raise higher) because the air will push down (lift up).*
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *sheet of standard size textbook paper • book* *Procedure:* *1. Stand book upright.* *2. Stick paper vertically into the book about 7 - 8 centimeters in and let it bend over.* *3. Gently and steadily blow across the top of the curved surface of the paper.* *4. Observe and record.*

Experiment Log – Key
Page 2

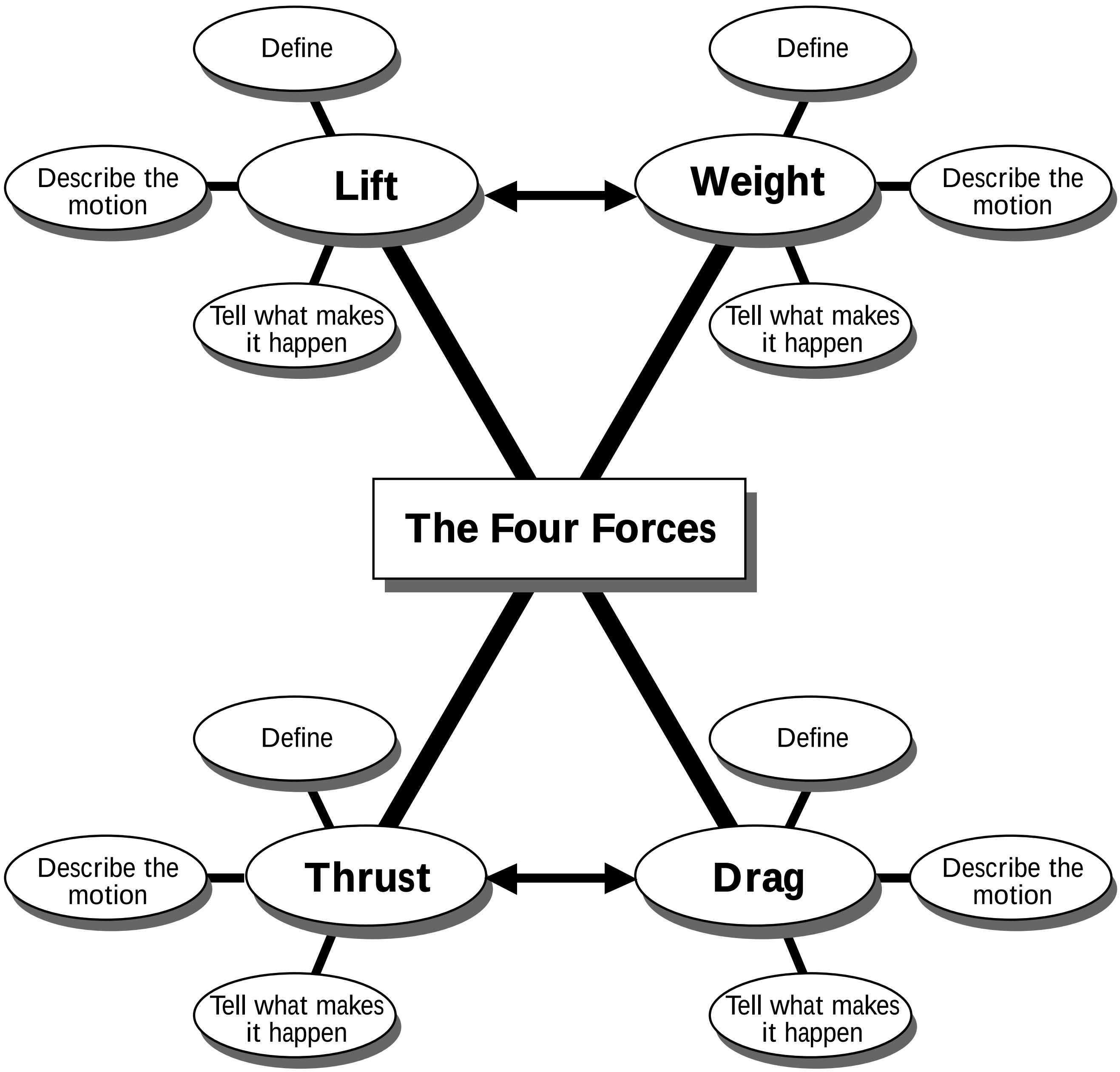
Experiment: A Little Lift

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The lowered end of the paper rose a little.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*As the flowing air went over the top of the curved paper, it created a low pressure area above the paper. So the paper rose up into that low pressure area. It was pushed there because the high pressure area underneath pushed the paper into the low pressure area above the paper.*

Additional Student Activities

- Create a concept map that names, describes and depicts the four forces in action. See the next page for an example.
- Create a series of comic panel drawings that show how the four forces interact differently during the three stages of flight: take-off, cruise and landing.
- With a small group, safely demonstrate how the four forces interact on an airplane using physical movements.
- Investigate how the four forces interact with a helicopter, hang glider or sailplane.
- Create a learning center that teaches about helicopters and the four forces.

Concept Map
The Four Forces



Writing Experiences

- Using interactive software, create a display about the four forces. It can be a text-based piece or, you can use graphics and music to convey the information.
- Write a song (perhaps a ballad) or a poem (perhaps a rap) that describes, depicts and teaches about the four forces that affect flight.

Critical Thinking Questions

- Explain the importance of Newton *writing down* his law of gravity and his law of motion.
- Explain what would happen to an airplane if gravity was not overcome by lift during takeoff (e.g. the airplane weighed too much).
- While an airplane was landing, explain what would happen if the thrust were greater than the drag.
- Explain how the four forces are cooperating when an airplane is flying straight and level, at a constant speed.

Quick Quiz

Four Forces of Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. What is thrust?

   A. the measure of the pull of the Earth on an object
   B. a force that propels an airplane
   C. a force that acts at a 90 degree angle to the airflow
   D. a force that gives resistance

2. What is a force?

   A. a push only
   B. a pull only
   C. a push and a pull
   D. none of the above

3. What is lift?

   A. a force that acts at a 90 degree angle to the airflow
   B. a force that propels an airplane
   C. the measure of the pull of the Earth on an object
   D. a force that gives resistance

4. In order to fly, which two forces must be strongest?

   A. drag and weight
   B. lift and thrust
   C. drag and thrust
   D. lift and weight

5. What is drag?

   A. the measure of the pull of the Earth on an object
   B. a force that propels an airplane
   C. a force that acts at a 90 degree angle to the airflow
   D. a force that gives resistance

Quick Quiz - Key

Four Forces of Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. What is thrust?

   A. the measure of the pull of the Earth on an object
   B. a force that propels an airplane
   C. a force that acts at a 90 degree angle to the airflow
   D. a force that gives resistance

2. What is a force?

   A. a push only
   B. a pull only
   C. a push and a pull
   D. none of the above

3. What is lift?

   A. a force that acts at a 90 degree angle to the airflow
   B. a force that propels an airplane
   C. the measure of the pull of the Earth on an object
   D. a force that gives resistance

4. In order to fly, which two forces must be strongest?

   A. drag and weight
   B. lift and thrust
   C. drag and thrust
   D. lift and weight

5. What is drag?

   A. the measure of the pull of the Earth on an object
   B. a force that propels an airplane
   C. a force that acts at a 90 degree angle to the airflow
   D. a force that gives resistance

Section Overview

Wings

The important discoveries of Newton's Laws and Bernoulli's Principle are covered along with the concept that air has stuff in it. The various shapes found in wing design are discussed as well as how wings generate lift. The basic parts of the airplane are shown.

CD-ROM Usage

Using the "How an Airplane Flies" section again (go to the plane on the runway), use the subsections Wing Shape and Parts. These can be used simply to demonstrate and display the various wing designs as well as the parts of the airplane. Students use the Student Logbook Sections "Wing Shape" and "Parts" to review the concepts presented in the reading.

Materials List

- 1 straw cut in half
- lightweight index card or heavy weight sheet of paper (5" x 7")
- 2 ping-pong balls
- tape
- two pieces of thread of equal length (approximately 25 cm)
- ring stand or table edge to which to tape the thread
- 2 strips of paper 25 cm x 5 cm
- full size pencil

Student Handouts

Student Readings: Part I and Part 2
Student Note Taking Guide: Part I and Part 2
Student Worksheets: Part I and Part 2
Experiment: Faster Moving Air = Lower Air Pressure I Procedure Card
Experiment: Faster Moving Air = Lower Air Pressure 2 Procedure Card
Experiment: Lift and an Airfoil Procedure Card
Quick Quiz: Wings

Teacher Reading

The Work of Wings

The Ancient Chinese discovered that kites with curved surfaces flew better than kites with flat surfaces. Lilienthal and Cayley, in the 1800s, demonstrated that a curved surface produces more lift than a flat surface. This led to the conclusion that a wing needs to have **camber**. That is, the top needs to be slightly curved, like a hump. The bottom is left flat or straight. An object with this shape is called an **airfoil**. Often, the words “wing” and “airfoil” are used interchangeably, but they shouldn’t be. Airfoil shapes are designed to generate as much lift as possible while incurring as little drag as possible.

Camber causes the air that flows over the top of the airfoil to move faster than the air that flows beneath it. In the 1700s, Daniel Bernoulli (see below for more information on Bernoulli) showed that a fluid that flows faster over a surface will create less pressure on the surface than fluid that flows more slowly. This concept later became known as Bernoulli’s Principle. Further, since air is a fluid, air follows Bernoulli’s Principle. Thus, we have a situation where there is less air pressure on the top of an airfoil than on the bottom. This difference in pressure will cause the wing to move. That is, the difference in pressure will generate a force. As you can probably guess from our discussion above, the force that is generated is called “lift”.

By virtue of its shape alone, an airfoil will generate lift as air flows over it. However, even more lift can be generated by the airfoil if it is tilted with respect to the airflow. This tilt is called an airfoil’s **angle of attack**. As the wing is tilted, the air flowing over the top of the wing flows even faster than the air flowing underneath. As the difference in the speed of the two airflows increases, the difference in pressure increases also. Remember that it is this difference in pressure that generates the lift force. So, as its angle of attack increases, the wing generates more lift.

Think of an airplane taking off - remember, airplanes always take off heading into the wind. As the airplane speeds down the runway, it is already starting to get “lighter”. That is, the airplane is feeling the effect of the lift generated by the shape of the airfoil. Further down the runway, the pilot pulls the nose up. This increases the angle of attack of the wings which causes more lift to be generated. The airplane then flies merrily off to it’s destination.

However, there can be too much of a good thing! The airfoil's ability to create lift is dependent on the airflow remaining smooth. Think of a stream flowing gently around a rock. The stream changes direction to go around/over the rock, but it remains smooth - it doesn't get jumbled or choppy - and it hugs the rock as it flows around it. Now, if that rock were a larger rock, the water would hit it, get all jumbled up and then eventually move on. The flow around that rock would not be smooth. Well, the same thing happens with a wing. Up to a certain angle of attack the air will flow smoothly. The wing acts like a small rock. If the angle of attack becomes too great, an effect similar to throwing a big rock in a stream is created. The air will get all jumbled up and not flow smoothly around the airfoil. If this happens, lift will not be generated. We say the wing "loses its lift" or "**stalls**".

Stalls can be caused by real-life flying situations. If the engines quit, or a sudden gust of wind hits, the airplane's forward speed drops, the airflow over the wing decreases and the amount of lift drops.The weight force then takes over and a potentially hazardous situation results. Fortunately, pilots spend many hours learning how to recover from a stall. Flight simulators are used extensively to train pilots how to recognize an oncoming stall and prevent it, and if one should occur, how to maneuver the airplane so the generation of lift is restored.

Another cause of an airplane stalling is wing icing. When ice builds up on a wing, it changes the shape of the airfoil to a shape that stalls more easily. What's worse, the ice also adds weight, so this can be a dangerous situation. Obviously the solution to this problem is getting rid of the ice - which airlines spend many hours doing during the winter months.

In the *Tools of Aeronautics* section of the CD-ROM **Exploring Aeronautics**, students can learn about research that is being done in wind tunnels to allow airplanes to increase their angle of attack without losing lift.

Wing Design

The amount of lift produced by an airfoil depends upon many factors:

- angle of attack
- the lift devices used (like flaps)
- the density of the air
- the area of the wing
- the shape of the wing

- the speed at which the wing is traveling

The shape of a wing greatly influences the performance of an airplane. The speed of an airplane, its maneuverability, its handling qualities, all are very dependent on the shape of the wings. There are four basic wing shapes that are used on modern airplanes: **straight, sweep (forward and back), delta and swing-wing**.

The straight wing is found mostly on small, low-speed airplanes. General Aviation airplanes often have straight wings. These wings provide good lift at low speeds, but are not suited to high speeds. Since the wing is perpendicular to the airflow it has a tendency to create appreciable drag. However, the straight wing provides good, stable flight. It is cheaper and can be made lighter, too.

The sweepback wing is the wing of choice for most highspeed airplanes made today. Swept wings create less drag, but are somewhat more unstable at low speeds. The highly swept wing delays the formation of shock waves on the airplane as it nears the speed of sound. How “swept” the wing is depends on the purpose of the airplane. A commercial airliner has a moderate sweep. This results in less drag but a maintenance of stability at lower speeds. High speed airplanes (like fighters) have high sweep. These airplanes are not very stable at low speeds. They take off quickly and descend to land quickly.

The forward-sweep wing is a wing design that has yet to make it into mass production. An airplane (like the X-29) is highly maneuverable, but it is also highly unstable. A computer-based control system must be used in the X-29 to help the pilot fly.

A delta wing looks like a large triangle from above. It is very highly swept with a straight trailing edge. Because of this high sweep, airplanes with this wing can reach high speeds - many supersonic airplanes have delta wings. Because of the high sweep, the landing speeds of airplanes with delta wings are fairly fast. This wing shape is found on the supersonic transport *Concorde.*

The swing-wing design attempts to exploit the high lift characteristics of a primarily straight wing with the ability of the sweepback wing to enable high speeds. During landing and takeoff, the wing swings into an almost straight position. During cruise, the wing swings into a sweepback position. There is a price to pay with this design, however, and that is weight. The hinges that enable the wings to swing are very heavy.

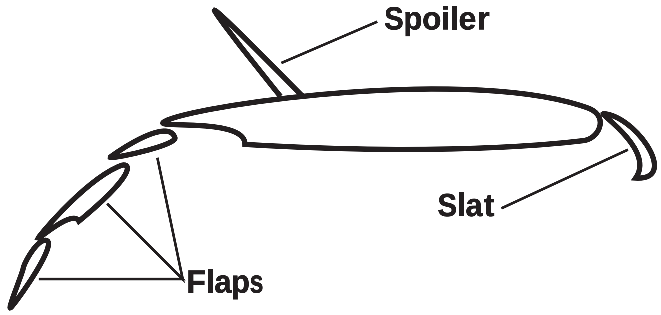
High Lift Devices

When an airplane lands and takes off, it is desirable to fly as slowly as possible. Ideally, for landing, an airplane would have a large wing with a very cambered airfoil. However, airfoils designed to perform well at slow speeds are not good at flying at greater speeds, and vice versa. Airplane designers have developed a set of features that allow the pilot to increase the wing area and change the airfoil shape to compensate for this.

The trailing edge of the wing is equipped with **flaps** which move backward and downward. These are not to be confused with ailerons, which are also located on the trailing edge of the wing, but have an entirely different purpose. The flaps increase the area of the wing, and the camber of the airfoil. With this increase in area, the airflow has further to travel which spreads the pressure difference between the top and bottom of the wing over a larger area. An equation for the lift force is

lift = pressure x area

Given this equation, if the area increases, the lift increases also.



Slats are located on the leading edge of the wings. They slide forward and also have the effect of increasing the area of the wing, and camber of the airfoil.

Flaps and slats are used during takeoff and landing. They enable the airplane to get off the ground more quickly and to land more slowly. Some airplanes have such large flaps and slats that the wing looks like it's coming apart when they are fully extended!

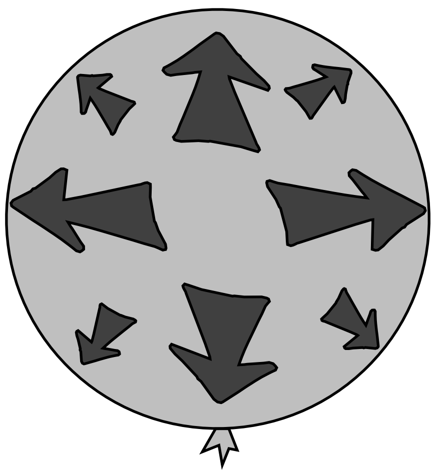
Spoilers are devices that are located on top of the wings. Spoilers have the opposite effect from flaps and slats. They destroy lift by disrupting the airflow over the top of the wing. Spoilers are deployed after the airplane has landed and lift is no longer needed. They also substantially increase the drag which helps the airplane to slow down sooner.

Some more information about Bernoulli ...

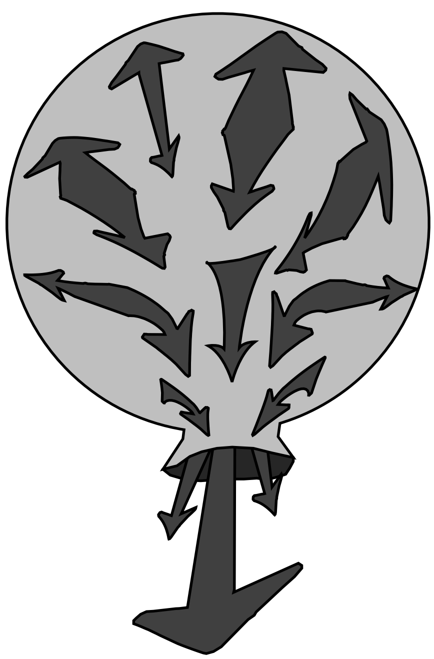
Daniel Bernoulli was a Swiss mathematician. He was born on February 8, 1700, in Gröningen, Netherlands. As a university student he studied philosophy and logic, excelling at mathematics and mechanics. After graduation, he worked with his brother Nikolaus at the St. Petersburg Academy of Sciences in Russia, doing research in mathematics. Next, he became a professor at the University of Basel in Switzerland, from 1733 until his death. He is best known for his work in the field of fluid dynamics. In 1738, he published the book *Hydrodynamica,* long considered the definitive work in fluid dynamics. In this book he presented theories about how gases move and how the speed at which they move influences their pressure on the surfaces they move over.This work helped to lay the foundation for aeronautics many years later - specifically, helping to define and describe lift. He died on March 17, 1782, in Switzerland.

Overhead Guides
Newton's Third Law

"For every action there is an equal and opposite reaction."



The inflated balloon has compressed air pressing equally against all the sides.

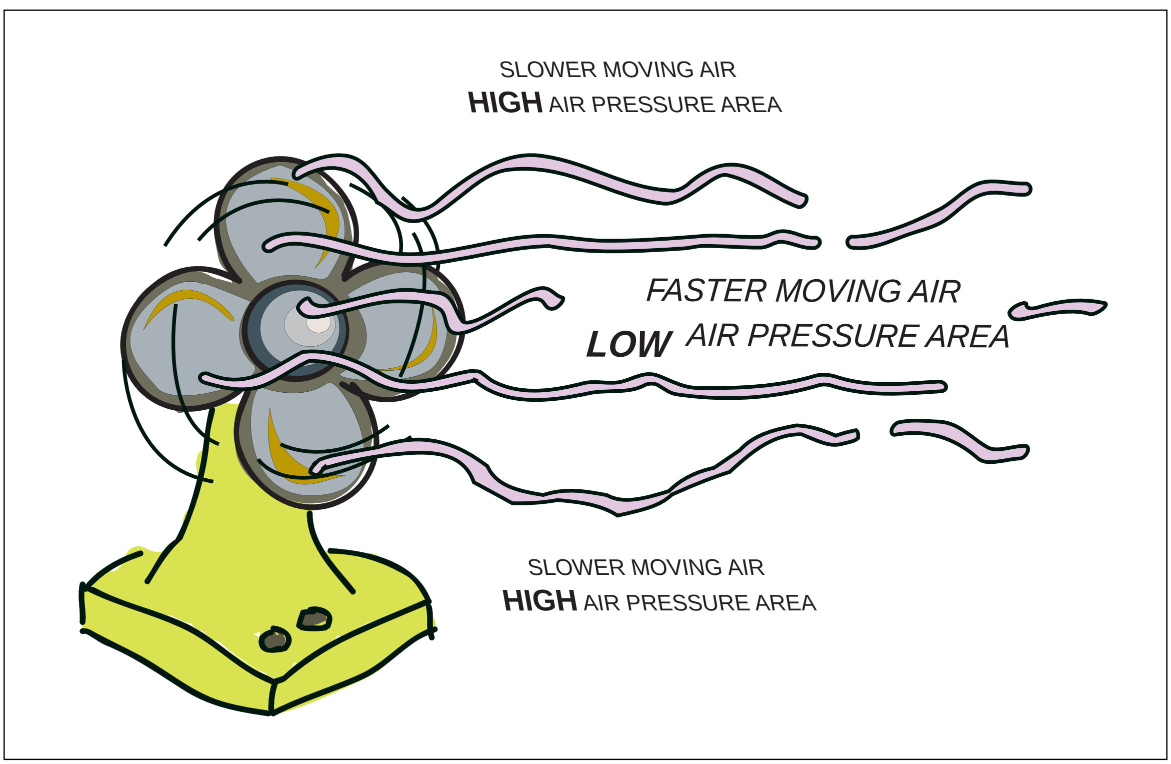


The air rushes out the open hole at the bottom. The action is that the air is pushed out in one direction. The reaction is that the balloon flies in the other direction.

Bernoulli's Principle

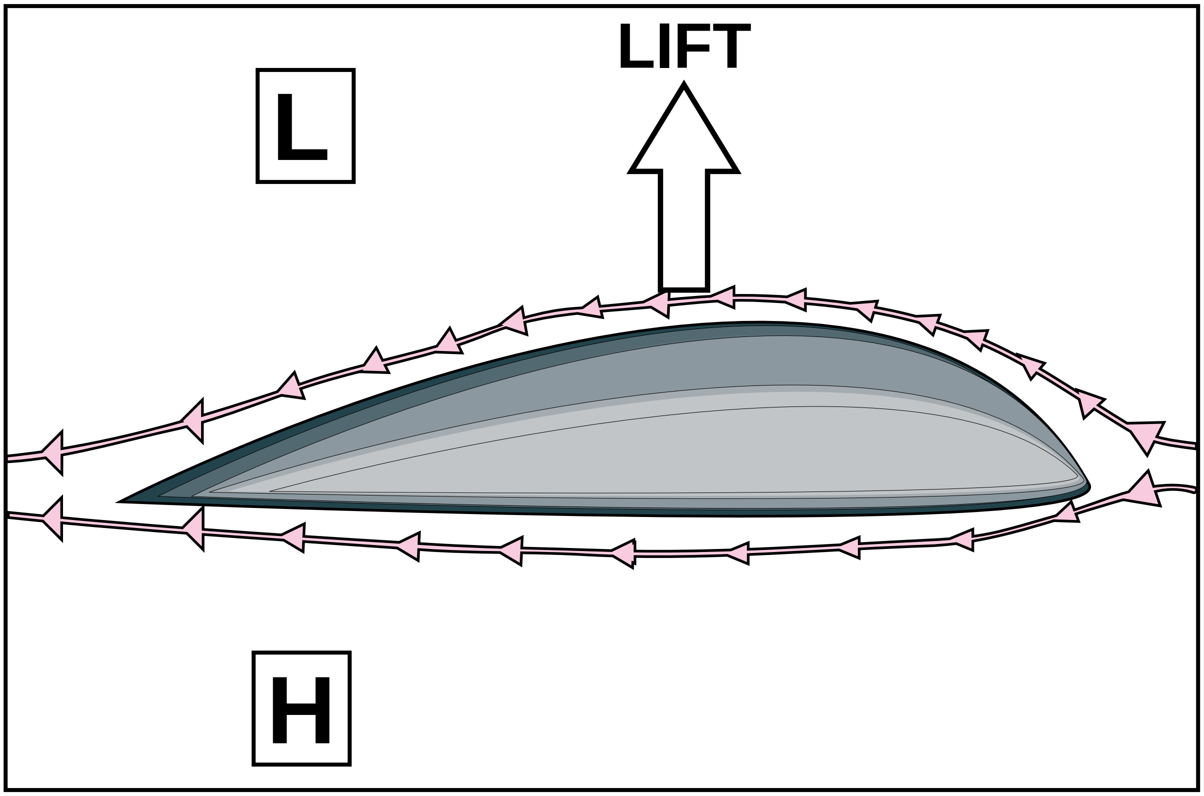
Bernoulli developed the principle that the speed of a fluid (like air) is directly related to the pressure the fluid is exerting on the surface it is flowing by. The faster the flow of a fluid, the lower the pressure that is exerted on the surface it is flowing by.

Daniel Bernoulli



How an Airfoil Works

AIRFLOW IS FASTER OVER THE TOP OF THE WING
THUS THE **LOWER** AIR PRESSURE

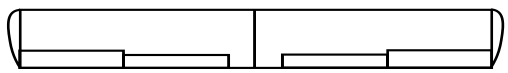


AIRFLOW IS SLOWER UNDERNEATH THE WING THEREFORE
THE AIR PRESSURE IS GREATER/**HIGHER**

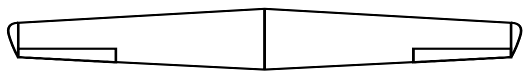
Airflow is faster over the top of the wing, thus lowering the air pressure exerted on the top surface of the wing. Airflow is slower underneath the wing, therefore the air pressure exerted on the bottom surface of the wing is greater.

Four Basic Wing Designs

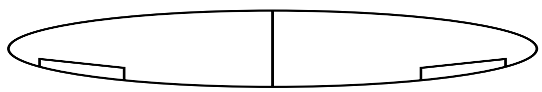
1. Straight



Rectangular straight wing

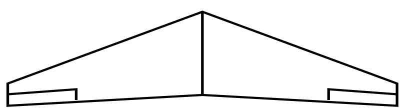


Tapered straight wing

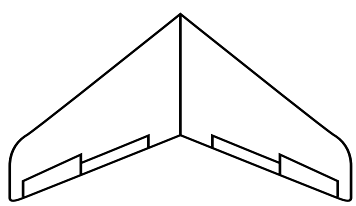


Rounded or elliptical straight wing

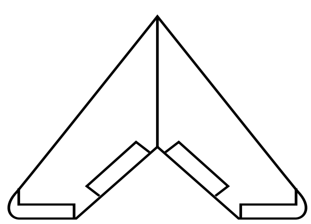
2. Sweep



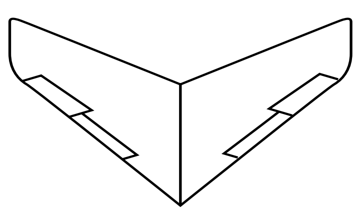
Slight sweepback wing



Moderate sweepback wing



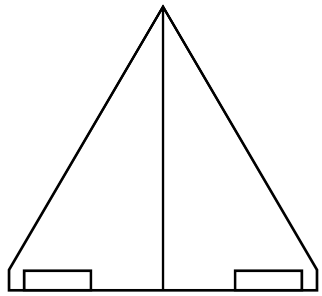
Great sweepback wing



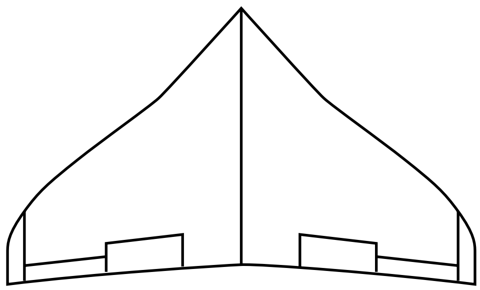
Forward sweep wing

Four Basic Wing Designs

3. Delta

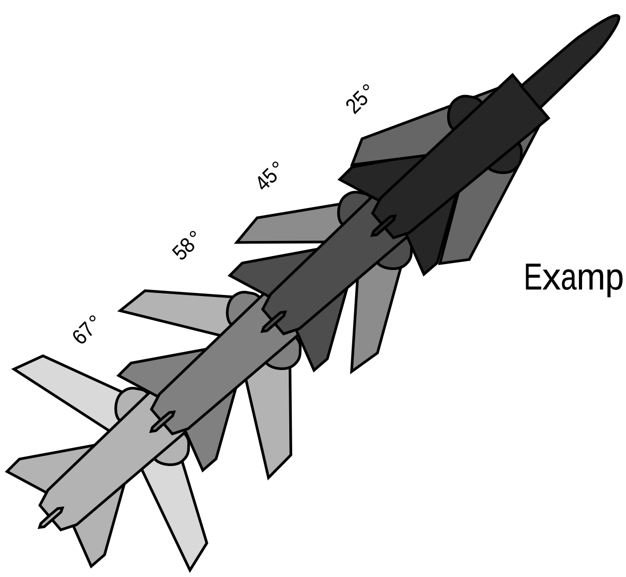


Simple delta wing



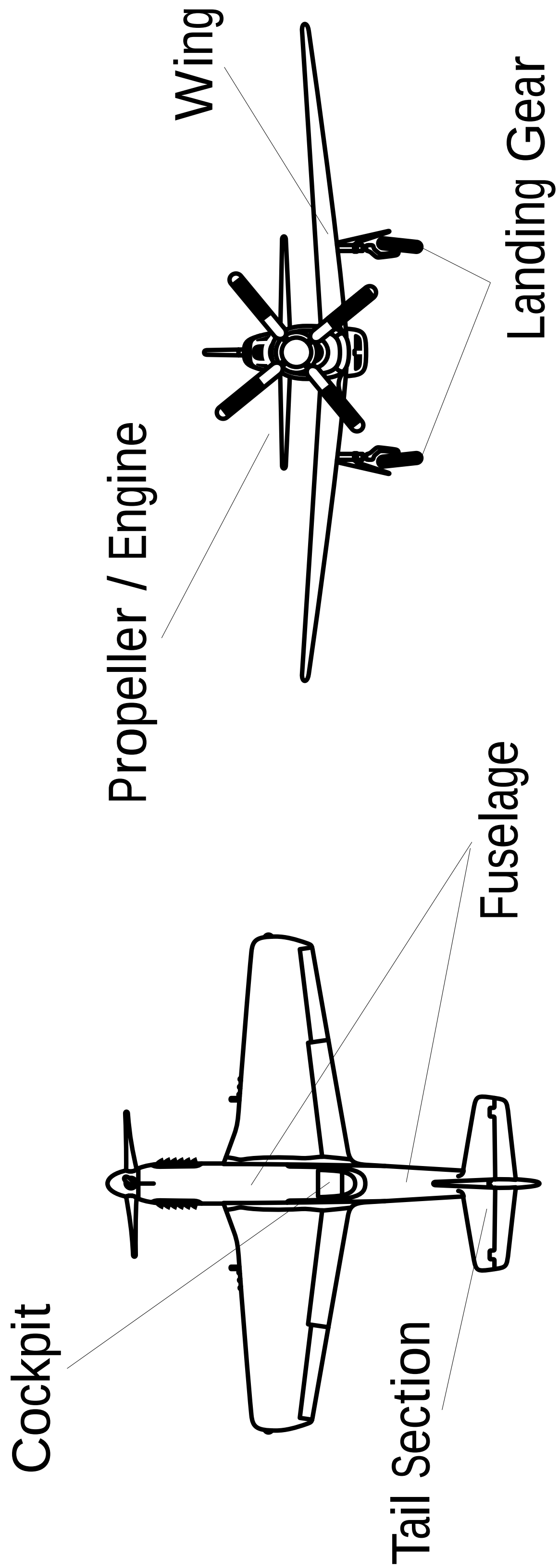
Complex delta wing

4. Swing



Example of swing or variable wing

Diagram of an Airplane's Structure

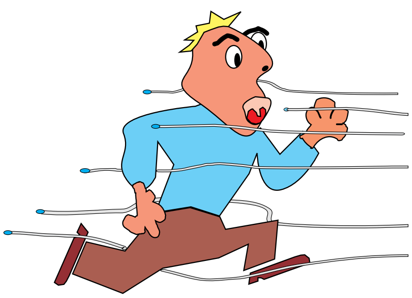


Student Readings

Wings - Part 1

Air is made of "Stuff"

To fly, you must pass through the air and although we cannot see the air, it is made up of millions of little molecules that push against our bodies. These particles of air take up space or "have volume". They are made up of matter so they have "mass", too. They also have "weight". Air can exert a tremendous amount of pressure and force. As you rise higher in elevation, say as you take drive up into the mountains, you can feel that your ears need to "pop." The air pressure on the outside of your eardrum becomes lower as you gain altitude. You are feeling the higher air pressure inside your inner ear pressing against your eardrum.



You can feel the air pushing against you when the wind blows, too. When you move through a room, you push against the air. You change where the air is located and what the air is doing. Knowing that air is not empty space, but actually made of "stuff", led to some important discoveries.

Important Discoveries

In the late 1700s, Sir Isaac Newton wondered about the forces that move people and objects around on Earth. He experimented and recorded what he found. His writings are now known as "Newton's Laws". His "Third Law" states that "for every action there is an equal and opposite reaction." For example, when you are swimming and you want to move forward in the water, you move your arms so that you push the water backwards. By pushing the water backwards (the action), you thrust your body forward (the reaction).

Newton also described the principles of gravity. He correctly hypothesized that all objects in the universe exert an attractive force on each other that is related to their mass - the greater the mass, the greater the attraction. We measure the attraction between the Earth and other objects, called gravity, by weight. Weight is measured in pounds or newtons (That's right, named after Sir Isaac Newton!).

You probably know how many pounds you weigh. To get off of the ground, objects need to pull upward with more force than the Earth is using to pull them down. That requires a lot of lift.

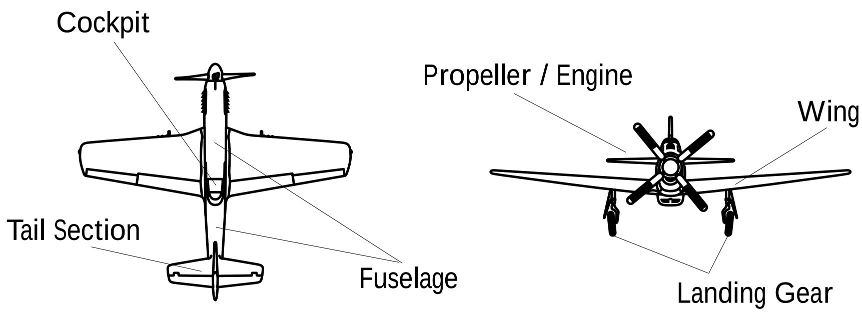
Around 1783 Daniel Bernoulli, a Swiss mathematician, discovered that if you increase how fast the air is flowing over a surface, the air pressure on that surface decreases. This is the same principle that allows the liquid to rise through a straw when you blow across the top opening of the straw while it is standing in a glass of liquid. The faster air blowing across the straw opening decreases the air pressure in the straw. The water then flows up the straw. Scientists used this principle to design the shape of a wing.

Borrowing from Nature

Many early adventurers tried to copy the motion of birds rather than study exactly how the birds flew. Many created "flying machines" that used a flapping motion. These machines failed to fly. Their inventors did not understand that it was the shape of a bird's wing and the slight changes in how the wing is held during flight that create lift. The flapping motion only created the thrust needed to move the bird forward. Merely copying the actions of birds did not keep these early flyers up in the air for very long.

Even after they understood the concept of lift, they still needed to understand how flight could be controlled. Later on, as research continued, scientists and engineers borrowed shapes from the birds when designing a plane. They copied a bird's basic body shape (fuselage), its flat tail (tail assembly or empennage), its wings and its feet (undercarriage). Using Bernoulli's Principle they figured out how to create lift. Using Newton's Third Law, they developed ways to make thrust. When they put all of this together they were able to fly!

Diagram of an Airplane

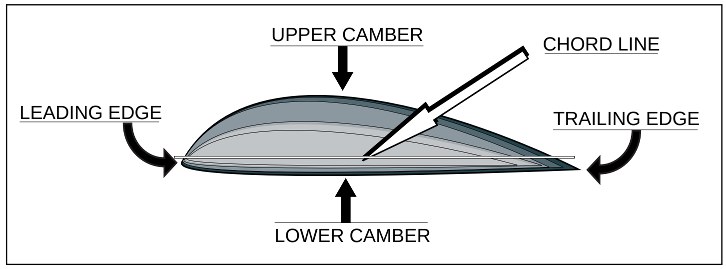


Student Readings

Wings - Part 2

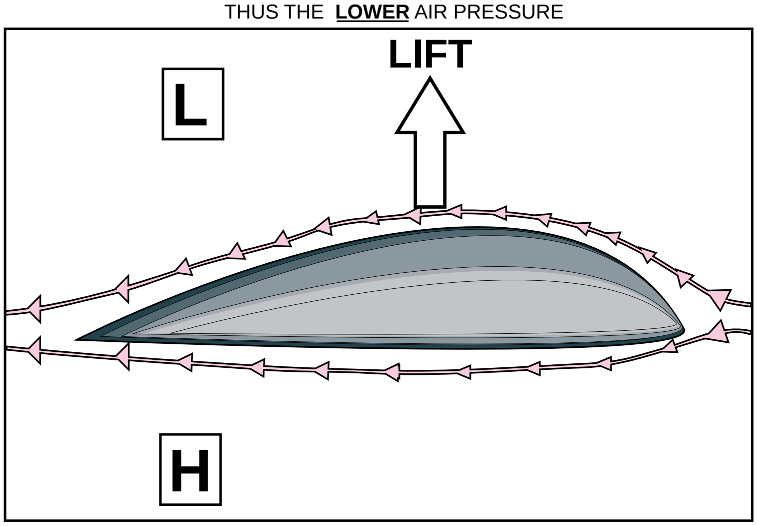
The Work of Wings

Have you noticed the curved shape of a bird's wing? An airplane's wing is curved also. A wing is designed for flight. It has a special shape called an airfoil shape. Airfoil shapes can be found on wings, fans and propellers. The airfoil shape provides a lifting (aerodynamic) force when air flows around it. An airfoil has a thicker leading edge (or front end) and a very thin trailing edge (or back end). In between the leading and trailing edges, an airfoil is curved both on the top and the bottom surfaces. However, in general, the top surface is much more curved than the bottom. When a surface is curved we say that it "has camber" or "is cambered".



An airfoil takes advantage of Bernoulli's Principle. Since the top surface of the wing has more camber than the bottom surface, the air flows faster over the top of the wing and thus the air exerts less pressure on the top surface than on the bottom. So, when air is flowing over the wing, the air pressure on the top surface is less than the air pressure on the bottom surface - and the wing "lifts".

AIRFLOW IS FASTER OVER THE TOP OF THE WING
THUS THE **LOWER** AIR PRESSURE



AIRFLOW IS SLOWER UNDERNEATH THE WING THEREFORE
THE AIR PRESSURE IS GREATER/**HIGHER**

Student Note Taking Guides
Part 1

Big Ideas	Important Little Details
air	made up of molecules has volume (takes up space) has mass (made up of matter) has weight exerts pressure and force when you move through air you push the molecules around
discoveries	Sir Isaac Newton, 1700s for every action there is an equal and opposite reaction Third Law of Motion gravity = a pull that the Earth has on an object every object has weight weight measures gravity's pull to rise off the ground you have to exert more force than the force of gravity thrust = the force that moves an object forward
discoveries	Daniel Bernoulli, 1783 increase the speed of air flowing over a surface the air pressure on the surface decreases air pressure = the amount of force the air uses to push on a surface airfoils = the shape wings, fans or propeller blades specially designed to give lift
borrowing from Nature	ideas for plane design came from birds from bird - body = fuselage flat tail = tail assembly or empennage wings = wings (shape) feet = undercarriage

Part 2

Big Ideas	Important Little Details
wing shape	designed for flight special shape called airfoil
airfoil	shape of wings and propellers thicker leading edge with thinner trailing edge curved surface is called camber normally greater curve on top than on bottom air moves faster over top so air pressure is less air moves slower underneath so air pressure is greater Bernoulli's principle when air flow gets fast enough plane rises (lift)

Student Worksheets

Wings - Part 1

Directions: Use Student Readings Part 1 to match a term from below to its proper description. Place the letter in the blank.

A)	pounds	F)	Third Law
B)	Newton	G)	lift
C)	weight	H)	bird
D)	thrust	I)	molecules
E)	Bernoulli	J)	gravity

______ 1. air is made up of these

______ 2. every action has an equal and opposite reaction

______ 3. this mathematician observed that air flowing quickly over a surface will exert less pressure on the surface than air moving more slowly over it

______ 4. how the force of gravity is measured

______ 5. the pull of the Earth on an object

______ 6. force used to overcome gravity

______ 7. wrote down his observations and developed the laws of motion

______ 8. the idea for the body, tail and wings of an airplane came from this animal

______ 9. weight is measured in these units

______ 10. force that is generated by a jet engine

Student Worksheets

Wings - Part 2

Directions: Use Student Readings Part 2 to match a term from below to its proper description. Place the letter in the blank.

A) leading edge
B) camber
C) trailing edge
D) wings
E) airfoil

______ 1. these are designed for flight

______ 2. the special shape of a wing

______ 3. front end of an airfoil

______ 4. thinner back end of an airfoil

______ 5. the curvature of an airfoil

Directions: Complete each sentence by filling in the blank.

6. Air traveling over the top of the wing moves ____________ than the air traveling ________________ the wing.

7. The air pressure under the wing is _________________ than the air pressure above the wing.

8. _____________________ Principle explains changes in air pressure on a surface by changes in the speed of the air flow over the surface.

9. _____________________ are designed to create lift.

Student Worksheets: Wings - Keys

Part 1

1. *I*
2. *F*
3. *E*
4. *C*
5. *J*
6. *G*
7. *B*
8. *H*
9. *A*
10. *D*

Part 2

1. *D*
2. *E*
3. *A*
4. *C*
5. *B*
6. *faster, under*
7. *greater*
8. *Bernoulli's*
9. *Wings*

Experiment: Faster Air = Lower Air Pressure 1

Procedure Card

Materials

12 centimeter x 18 centimeter notebook paper
soda straw
flat surface (tabletop)
ruler
tape

Experiment Set Up

Holding the paper long side horizontally, measure and mark off one centimeter at each end.

Fold each end of the paper along those lines.

Using the folds as legs, stand the paper up on the flat surface and tape it in place. Make sure the paper has only a slight slack to it.

Experiment Procedure

1. Use the straw to blow a steady stream of air underneath the standing paper.

2. Observe and record.

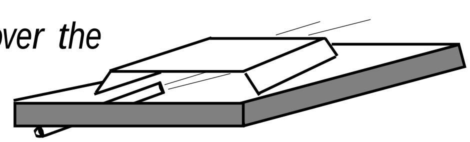
3. Use the straw to blow a steady stream of air above the standing paper.

4. Observe and record.

Experiment Log – Key

Page 1

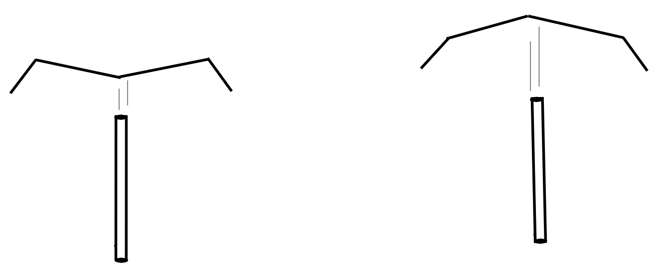
Experiment: Faster Air = Lower Air Pressure 1

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	*Does air pressure change or stay the same when it goes from being still to flowing?* *OR* *When air changes from being still to flowing, does the air pressure change?*
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	*I think that when the air starts to move it will have no effect on the air pressure as nature will try to keep the pressure even.* *OR* *I think the air pressure will be greater (or lesser) where the air is flowing and less (greater) when still.*
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *12 centimeter x 18 centimeter paper • soda straw • flat surface (tabletop) • tape* *Procedure:* *1. Fold two opposite end of the paper in 1 centimeter each. Have both folds going the same way (perpendicular) to the tabletop.* *2. Set the paper with the folds as "legs" perpendicular to the tabletop and tape to tabletop.* *3. Using the soda straw, blow a strong and steady stream of air underneath the paper. (See diagram)* *4. Observe and record.* *5. Repeat step 3, but blow over the top of the card.* *6. Observe and record.* 

Experiment Log – Key

Page 2

Experiment: Faster Air = Lower Air Pressure 1

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*1. When I blew under the paper, the paper bowed downward.* *2. When I blew across the top of the paper, it bowed upward, but it was slight.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*The air pressure really does change. There is a big difference in pressure between flowing air and still air. Where the air is moving the pressure is not as great. The greater pressure on the other (opposite) side of the paper pushes on the paper.*

Experiment: Faster Air = Lower Air Pressure 2

Procedure Card

Materials

two ping-pong balls
tape
thread
soda straw
hanging apparatus (table, overhang on a counter)
ruler

Experiment Set Up

Cut two pieces of thread about 25 centimeters long each.

Tape one end of the thread to a ping-pong ball and attach the other end of the thread to the hanging apparatus.

Repeat this with the other ping-pong ball, one to two centimeters away from the first ping-pong ball.

Experiment Procedure

1. Hold the end of the straw about five centimeters away and perpendicular to the space between the ping-pong balls.

2. Without making contact with the ping-pong balls, blow steadily through the straw.

3. Observe and record.

Experiment Log – Key

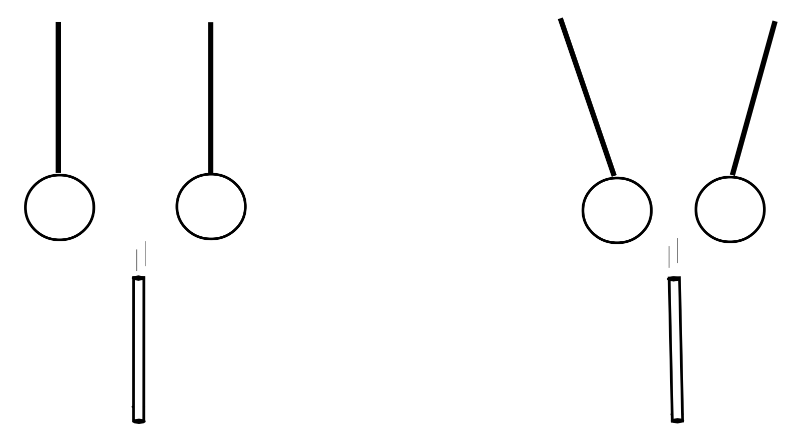
Page 1

Experiment: Faster Air = Lower Air Pressure 2

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	*When air changes from being still and becoming a flowing current, does the air pressure change?* *OR* *Does flowing air cause a change in air pressure?*
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	*I think the ping-pong balls will move farther apart because the moving air will exert more pressure between them and push them away from each other.* *OR* *I think the ping-pong balls will move closer together because flowing air has less pressure than still air, so the balls will move into that low pressure area.*
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *2 ping-pong balls • a ring stand or tabletop • thread • straw • tape • ruler* *Procedure:* *1. Gather materials.* *2. Cut 2 pieces of thread at identical lengths.* *3. Tape one end of the thread to a ball and the other to the stand so that it hangs freely.* *4. Repeat step 3, but hang the ball so that it hangs freely not more than 2 centimeters apart from the other ball at the same distance.* *5. Take the straw and without touching the balls, blow a steady stream of air in between them.* *6. Observe and record.*

Experiment Log – Key
Page 2

Experiment: Faster Air = Lower Air Pressure 2

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*As I blew air through the straw and in between the ping pong balls, they moved (leaned) closer together. At one point, they nearly touched.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*My results mean that moving air exerts less pressure than still air. So, still air has greater pressure and pushes more or exerts more pressure against the ping pong balls. The lower air pressure between the balls might have pulled the balls closer together too.*

Experiment: Lift and an Airfoil

Procedure Card

Materials

2 strips of notebook paper 25 x 5 centimeters

pencil

tape

Experiment Set Up

Tape the two ends of one piece of paper together so that it forms a circle loop.

Tape the two ends of the second piece of paper together so it forms a teardrop loop.

Make sure the tape connects the ends together smoothly.

Experiment Procedure

1. Place a pencil through the circle-looped piece of paper.
2. Hold the pencil in front of your mouth horizontally with one hand and use the other hand to extend the circle-looped piece of paper, taped end away from your mouth.
3. Blow gently across the top of the looped paper, releasing it as you begin to exhale.
4. Observe and record.
5. Repeat steps 1 through 4, but this time use the teardrop looped piece of paper.

Experiment Log – Key

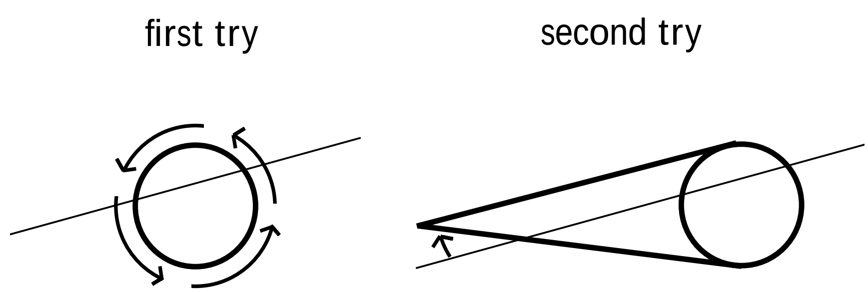
Page 1

Experiment: Lift and an Airfoil

Steps	Data
1. <u>State the problem.</u> **QUESTION** *(What do I want to know?)*	*Which shape will generate (create) the greater amount of lift- a circle shape or a teardrop shape?*
2. <u>Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	*I think the circle shape will have more lift because the camber is greater.* *OR* *I think the teardrop shape will have more lift because it allows for better airflow.*
3. <u>Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *pencil • 2 strips of paper 25 x 5 centimeters • tape* *Procedure:* *1. Gather and assemble materials.* *2. Place a pencil through the circle-looped piece of paper.* *3. Hold the pencil in one hand and use the other hand to extend the circle-looped piece of paper taped end away from you.* *4. Blow gently across the top of the circle-looped paper, releasing it as you begin to exhale.* *5. Observe and record.* *6. Repeat steps 2 through 5, but this time use the teardrop loop.*

Experiment Log – Key
Page 2

Experiment: Lift and an Airfoil

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The circle loop spun in a circle, but did not rise much.* *The teardrop loop's back end rose a little and did not spin around after I let it go.*
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*The teardrop shape was very stable when it was blown upon. The rear edge (trailing edge) rose a little when I blew across the top. The airflow seemed to be smoother around this shape than the circle loop (which spun around). I wonder if I made this teardrop shape out of molded plastic with a flatter bottom if it would rise higher?*

Additional Student Activities

1. Research the four basic wing types (sweep, straight, delta and swing). Then create a mobile, bulletin board, set of trading cards or three dimensional presentation.

2. Create a concept map that names, describes, depicts and explains the design and effectiveness of the four basic wing types: sweep (forward- and back-), straight, delta and swing.

3. Give students background information on Picasso and show some reproductions of his work as examples. Display a photograph of an airplane and have students create a Picasso-style drawing that uses only geometric shapes to depict the look and feel of the airplane.

4. Create a multimedia presentation that demonstrates how wings generate lift.

5. Create a flip-book that demonstrates how a wing generates lift.

Writing Experiences

1. Develop a song (perhaps a ballad) or a rhyme (perhaps a rap) that tells about the different types of wings or how wings create lift.

2. Create a set of note cards that describes how a wing generates lift.

3. Pretend you are a wing. Describe the sensation of generating lift as the airplane rolls down the runway and picks up speed to take off.

Critical Thinking Questions

1. In your own words, explain how Bernoulli's Principle applies to airflow and air pressure.

2. Explain the importance of Bernoulli's Principle to wings.

3. Why do you think that the wings found on the Wright Flyer from 1903 look different from the wings found on a modern 747?

4. Use a comparison chart to compare the wings on two different airplanes from two different time periods.

5. Research the role of wind tunnels in the development of wings.

Quick Quiz

Wings

Directions: Circle the letter of the answer that best answers the question.

1. Air is made up of what?

    A. pounds
    B. molecules
    C. newtons
    D. gravity

2. Which scientist below said that every action has an equal and opposite reaction?

    A. Bernoulli
    B. Wright
    C. Ashby
    D. Newton

3. What is the special shape of a wing called?

    A. leading edge
    B. camber
    C. airfoil
    D. trailing edge

4. Which scientist below made observations about water that also helped explain airflow?

    A. Bernoulli
    B. Wright
    C. Ashby
    D. Newton

5. Which force below is used to overcome gravity?

    A. weight
    B. lift
    C. thrust
    D. drag

Quick Quiz - Key

Wings

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    A. leading edge
    B. camber
    C. airfoil
    D. trailing edge

4. Which scientist below made observations about water that also helped explain airflow?

    A. Bernoulli
    B. Wright
    C. Ashby
    D. Newton

5. Which force below is used to overcome gravity?

    A. weight
    B. lift
    C. thrust
    D. drag

Section Overview

Airplane Control

This content section reviews the parts of an airplane and discusses the control surfaces (aileron, elevator and rudder) and motions of an airplane (roll, pitch and yaw).

CD-ROM Usage

Using the runway section of the CD-ROM once again ("How an Airplane Flies") the teacher can demonstrate how the control surfaces operate and move the airplane as well as demonstrating how the airplane moves. Students can then review the concepts after the reading, using the Student Logbook pages 12 - 20.

Materials List

- 3 sheets of paper per student (allow for mistakes)

Student Handouts

Student Reading: Airplane Control
Student Note Taking Guide: Airplane Control
Student Worksheets: Airplane Parts and Motions
Student Project: Make Your Own Glider
Experiment Data Sheet #1
  Control Experiment #1: Procedure Card
Experiment Data Sheet #2
  Control Experiment #2: Procedure Card
Experiment Data Sheet #3
  Control Experiment #3: Procedure Card
Quick Quiz: Airplane Control

Airplane Control
Teacher Readings
Parts of an Airplane and Their Functions

The modern aircraft has five basic structural components: **fuselage, wings, empennage** (tail structures), **power plant** (propulsion system) and the **undercarriage.**

The main body structure is the **fuselage** to which all other components are attached. The fuselage contains the cockpit or flight deck, passenger compartment and cargo compartment. While wings produce most of the lift, the fuselage also produces a little lift . A bulky fuselage can also produce a lot of drag. For this reason, a fuselage is **streamlined** to decrease the drag. We usually think of a streamlined car as being sleek and compact - it does not present a bulky obstacle to the oncoming wind. A streamlined fuselage has the same attributes. It has a sharp or rounded nose and sleek, tapered body so that the air can flow smoothly around it.

The **wings** are the most important lift-producing part of the aircraft. Wings vary in design depending upon the aircraft type and its purpose. Most airplanes are designed so that the outer tips of the wings are higher than where the wings are attached to the fuselage. This upward angle is called the **dihedral** and helps keep the plane from rolling. Wings also carry the fuel for the airplane. Wings are covered in much more detail in the Wings Section.

The **empennage** or tail assembly provides stability and control for the aircraft. The empennage is composed of two main parts: the vertical stabilizer (**fin**) to which the rudder is attached; and the **horizontal stabilizer** to which the elevators are attached. These stabilizers of the airplane help to keep the airplane pointed into the wind. When the tail end of the airplane tries to swing to either side, the wind pushes against the tail surfaces, returning it to its proper place. The rudder and elevators allow the pilot to control the yaw and pitch motion of the airplane, respectively.

The **undercarriage** or landing gear consists of struts, wheels and brakes. The landing gear can be fixed in place or retractable. Many small airplanes have fixed landing gear which increases drag, but keeps the airplane lightweight. Larger, faster and more complex aircraft have retractable landing gear that can accommodate the increased weight. The advantage to retractable landing gear is that the drag is greatly reduced when the gear is retracted. When flying on a commercial airliner you will notice that the pilot retracts the landing gear very soon after the airplane leaves the ground. This helps to decrease drag as the airplane ascends.

The **power plant** is simply the propulsion system and consists of the **engines**. The sole purpose of the engines is to provide thrust for the airplane. There are many different types of aircraft engines including: piston, turboprop, turbojet and turbofan. Turbojet and turbofan are jet engines. Some aircraft, notably gliders, do not have an engine. To take off they must have another source of thrust - that is, the tow-plane which pulls them into the air.

Piston Engines and Propellers

Within a piston engine, the pistons can be arranged in four ways: radial, in-line, oppositional and "V". The radial engine has the pistons arranged in a circle with the spinning shaft in the middle. These engines were once the most widely used aircraft engine. They never found much favor outside of aviation and are not used in modern aviation.

The pistons on an in-line engine are lined up one behind the other along the length of the shaft that turns the propeller. These have been used in many applications including cars. They are not used a great deal in aircraft, as they tend to be long and heavy. Aircraft engines must be as lightweight and compact as possible.

The oppositional piston engine is much like the in-line, except that the pistons are mounted in pairs on opposite sides of the shaft. This makes for a much shorter and lighter engine and in-line engines have become very popular in the small airplane market.

The "V" engine is much like the oppositional engine, except that the pistons are not parallel to each other. Instead they are slanted in a "V" arrangement. The V8 engine is perhaps the most well know engine as it has been used to power millions of automobiles. The V8 is rarely used in airplanes as they tend to be heavier than the oppositional engines.

Piston engines drive a spinning shaft. The propeller is attached to that shaft. At least two (but usually three or four) blades make up the propeller. The more blades, the more air that can be moved by the propeller. A blade has an airfoil shape which generates lift as the blade slices through the air. Because the propeller is pointed forward the force generated is in a forward direction - that is, it thrusts the airplane forward.

Jet Propulsion and Jet Engines

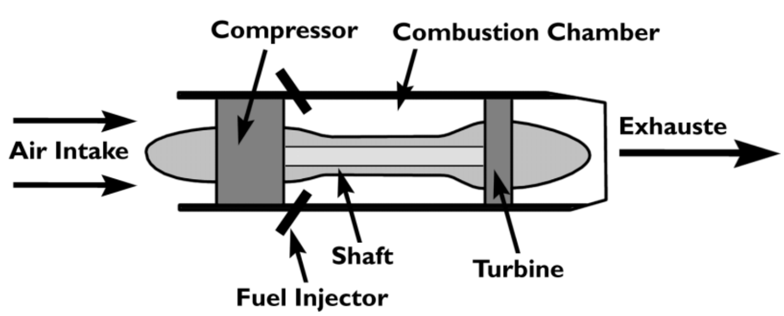
Jet propulsion is similar to the release of an inflated balloon. The pressure inside the balloon is pushing in all directions. It is also “jetting” out from the mouth of the balloon. The end of the balloon opposite to the mouth is not open.This creates an imbalance and causes the balloon to move in the direction away from the open mouth. Jet engines work in a similar fashion.

There are several types of jet engine: ramjet, pulsejet, turbojet, turbofan.The last two are the most widely used.

The **ramjet** is as simple a jet engine as can be found. Air enters the inlet and is compressed. This raises the pressure of the air. As the air arrives at the combustion chamber, fuel is added and an electric spark is generated. This causes a controlled explosion that raises the temperature and the pressure of the air tremendously. The hot, high-pressure air “jets” out the nozzle of the engine providing the forward thrust. This seems so simple, why would anyone want a more complex engine? The weakness of this engine is that the air coming in the inlet must be traveling at a very high speed (supersonic) for good efficiency. A ramjet does not work well at low speeds. This is simply not practical for most flying situations.

The **pulse jet** solves the problem of requiring supersonic speeds. It works well at a lower speed, and with a little help, can get started when it is standing still. It is much like the ramjet, except that it has doors that close the inlet. When the doors are open, the air flows in and is compressed. The doors then close, forming a chamber in which the fuel is ignited. The hot, high-pressure gas then “jets” out the exhaust nozzle. The cycle of air in, doors closed, air out, then repeat, is where this engine gets its name. Pulse jets are not widely used for two reasons. They are very noisy, and they are very inefficient. They are the gas guzzlers of the aviation world.

The **turbojet** was the first really useful jet engine to be built. The air flows into the engine through the inlet. The design of the inlet makes the air slow down and also raises the pressure. The air then goes through the compressor where sets of blades compress the air even more, greatly raising the pressure. The air then enters the combustion chamber where the fuel is added and ignited. The very hot, high-pressure air rushes past the turbine blades making them spin very fast. The turbine blades are connected back to the compressor blades by a shaft. The turbine blades take some of the energy from the air and returns it to the compressor. The hot, high pressure air that gets past the turbine, “jets” out the exhaust nozzle thrusting



the engine forward.

To increase the thrust available, a device called an afterburner is sometimes built into the engine. Fuel is dumped into the hot exhaust gas exiting the nozzle causing another controlled explosion. This makes the air even hotter which adds more energy to it, thereby increasing the thrust. This is not an efficient thing to do however, and is only done for brief periods when extra thrust is needed. For instance, on takeoff or when a burst of speed is needed during a dog fight, or when an extra push is needed to reach supersonic speed. You may have seen movies with high performance jets, like the F-14. If you watch one of these jets from the back, and the pilot turns on the afterburners you will hear a burst of noise and see an orange glow around the outlet of the engines. The airplane will then shoot up into the sky.

The **turbofan** is a refinement to the turbojet that results in a more efficient engine. A large set of fan blades is set right in the front of the inlet. The fan works much like a propeller, thrusting the engine forward, pushing a large amount of air backwards. As the air is pushed back by the fan some of it goes into the engine and some bypasses the engine.The engine that sits behind the fan is basically a turbojet. The air that goes into this engine receives the same treatment as air that goes through the turbojet. The turbine in a turbofan drives the fan as well as the compressor. The air that “jets” out the back of this engine has less thrust than air that exits a turbojet, but that decrease in thrust is made up for by the thrust generated by the fan. A turbofan engine actually is more efficient than a turbojet and is quieter as well. Afterburners can be fitted to a turbofan if required.

The **turboprop** engine is essentially a turbofan engine where the fan is replaced by a propeller. The propeller is placed outside of the inlet. A gearbox is introduced which controls the spinning of the shaft, enabling speed control for the propeller.This is the most efficient means of propulsion, however it is limited in forward speed. Because the propeller is out in the free stream air, not mounted in the inlet (where the air speed is reduced) the propeller has to rotate at faster speeds. The speed of the propeller approaches the speed of sound a lot more quickly than the airplane itself. As the speed approaches the speed of sound, drag greatly increases. So the speed of the airplane must be maintained well below the speed of sound to prevent the tips of the propeller from going too fast.

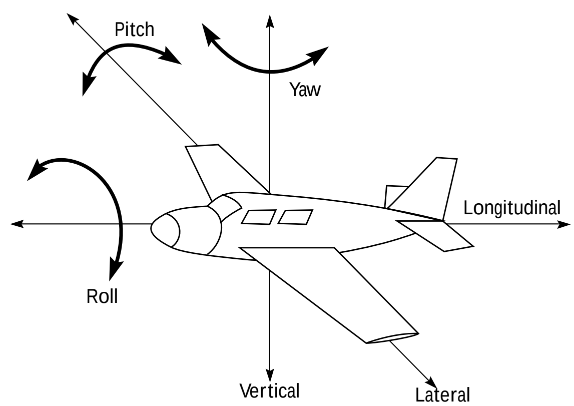
If you want to fly at moderate speeds efficiently, then turboprops are a good choice. If you want to fly fast, but subsonically, then turbofans are a good choice. If you want to fly supersonically then a turbofan with afterburner is a good idea. If you want to fly slowly and only have a small budget, or a small airplane, then a piston engine is a good choice.

Teacher Readings

The Use of Coordinate Axes in Aeronautics

For purposes of basic understanding and student discussion, all references to motion and direction will be made using an imaginary three-dimensional coordinate system. This coordinate system will help to describe the motions of an aircraft in three-dimensional space. The center of the coordinate system is found at the centroid of the aircraft - roughly between the wings in the middle of the fuselage. A centroid is an imaginary point around which all rotation takes place. The three axes intersect at the centroid at right (90 degree) angles to each other. The longitudinal axis runs the length of the aircraft from the nose through the tail. The lateral axis runs across the wings from tip to tip. The vertical axis runs from the top (ceiling) of the airplane to the bottom (floor). These axes extend indefinitely from the center of the aircraft (see figure). Movement along or around one axis does not necessarily involve any movement on or around the other two.

Moving on Three Axes



Once in flight, an airplane can have six motions along and around the three axes. Mathematically speaking, all possible movements that an airplane can make can be defined in terms of these six directions. This is the basis of the mathematical modeling of airplanes and flight (see Section 2.5 Tools of Aeronautics). Three of the movements are **linear**: front and back along the longitudinal axis; side to side along the lateral axis; up and down along the vertical axis. The other three movements are **rotational**: movement around the longitudinal axis, called **roll**; movement around the lateral axis, called **pitch**; movement around the vertical axis, called **yaw**. The best way to understand these motions is by making a three-dimensional coordinate axis system out of straws, skewers or some other sticks. Label the axes of your system and then use your hands to describe motions along and around the axes.

An interesting exercise is to make a comparison between the movements an airplane can make with the movements a car can make. Of the linear motions, a car can obviously move along the longitudinal axis. It can not move laterally, (except on ice) but it can rotate (yaw). Cars cannot move up and down vertically on their own. Of the rotational motions, a car is limited to only one, yaw. A car will pitch slightly when the brakes are applied or the gas is stepped on. A car will not roll - or at least it's not supposed to! So, under normal driving conditions a car has only two motions: forward/back and yaw.

An airplane, in contrast, can roll, pitch and yaw through the use of its control surfaces. It can move forward and backward by using its engines. However, unlike a car, it can move side to side or up and down by using the three rotational motions. We use stabilizers to keep the airplane flying primarily longitudinally. This is why mathematical modeling, much less a simple description of airplane movement, can get very complex.

Stability

Stability is the ability of a plane to return, of its own accord, to its original attitude in flight after it has been disturbed by some outside force, like wind gusts. It also refers to an airplane's respnse to the pilot's use of the controls.

The empennage plays an important role in the stability of an airplane - much like the tail feathers of an arrow are critical to the stability of the arrow. If an arrow is shot without its tail feathers, it will wobble.The tail feathers keep the arrow stable and help it to stay on course. The empennage works the same way. The vertical fin helps to maintain stability in the direction of yaw. The horizontal stabilizer helps to maintain stability in the directions of pitch and roll. The empennage structures do produce drag, however. Researchers have developed ways to fly tail-less airplanes, but the airplanes must use computer-based control systems to maintain their stability. While the empennage structures of different airplanes can be very dissimilar, most modern airplanes still do have some form of fin and horizontal stabilizer.

An important component of stability for an airplane is the center of gravity (cg). The cg is an imaginary point about which the weight of an airplane balances. If you put a ruler across your finger and place it so it balances, your finger is at the cg of the ruler. The cg in an airplane does not stay in the same place at all times. The loading of heavy cargo onto an airplane will shift the cg as will the drainage of fuel from the tanks during flight. Pilots have to recognize shifts in the cg and respond accordingly. Sudden shifts in the cg can be catastrophic. Say, if an airplane experiences turbulence during flight and a large cargo load shifts, the pilot may have trouble reacting quickly enough to the shift to maintain stability of the airplane.

Imagine putting a small weight on the back of an arrow. Because the cg of the arrow has shifted, it will wobble and become unstable. An easy way to demonstrate this is to build and fly a paper airplane or a balsa-wood glider. After this nominal flight, put a small weight (such as a paper clip) on the back of the airplane and fly it again. It is not the weight of the paperclip that effects the stability of the airplane, it is the shift in the cg caused by adding more weight to the back end.

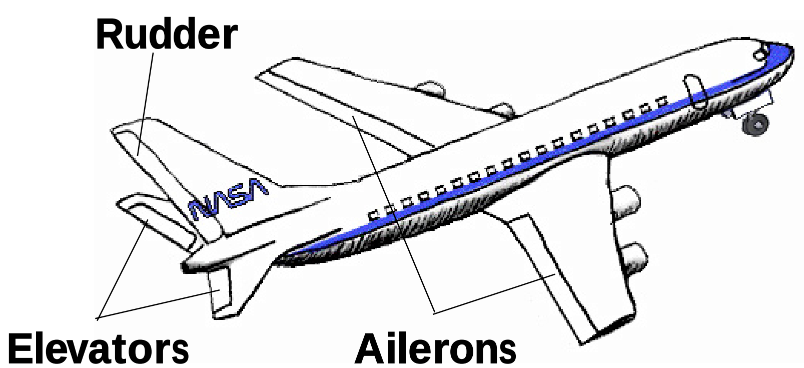
Controlling Motion

An airplane has three control surfaces: **ailerons**, **elevators** and a **rudder**. Within the cockpit, two **controls** "control" the control surfaces. The **control stick** controls the ailerons and elevators. The **rudder pedals** control the rudders.

The table below explains the control flow from pilot to control to control surface to the motion.

control in cockpit	control surface	motion
control stick (right and left)	ailerons	roll
control stick (front and back)	elevators	pitch
rudder pedals	rudder	yaw

The ailerons are flap-like structures on the trailing edge of the wings -one on each side. When the pilot moves the control stick to the right, the right airleron will tilt up and the left aileron will tilt down. This will cause the airplane to roll to the right. When the pilot moves the control stick to the left, the left aileron tilts up, the right aileron tilts down and the airplane rolls to the left. This happens because as the aileron tilts downward (effectively increasing camber) more lift is created and the wing rises. As it tilts upward, less lift will be created and the wing will fall. If the wing on one side of the airplane rises and the other falls, the airplane will roll towards the side of the decrease in lift.



The elevators are also flap-like structures that are mounted on each side of the horizontal stabilizer. When the pilot pushes the control stick forward, the elevators tilt downward. This causes the tail of the airplane to rise and the fuselage to tilt down - this is called pitching down. When the pilot pulls the control stick back, the elevators tilt upward, the tail goes down and the fuselage pitches nose-up. When the elevator tilts downward more lift is created (like the ailerons) and the tail rises. When the elevator tilts upward, less lift is created and the tail falls.

pushes the control stick forward, the elevators tilt downward. This causes the tail of the airplane to rise and the fuselage to tilt down - this is called pitching down. When the pilot pulls the control stick back, the elevators tilt upward, the tail goes down and the fuselage pitches nose-up. When the elevator tilts downward more lift is created (like the ailerons) and the tail rises. When the elevator tilts upward, less lift is created and the tail falls.

The rudder is located on the fin. The two rudder pedals are located at the pilot's feet. When the pilot pushes on the right rudder pedal, the rudder tilts to the right and the airplane yaws nose-right. When the pilot pushes on the left rudder pedal, the rudder tilts to the left and the airplane yaws nose-left. Again this is due to lift. However, the direction of this lift force is different than the lift force that causes the airplane to rise. When the rudder tilts to the right, more lift is created on the right, which "lifts" or pushes the vertical stabilizer to the left. This, in turn, causes the airplane to yaw nose-right. The opposite motion occurs when the rudder tilts to the left.

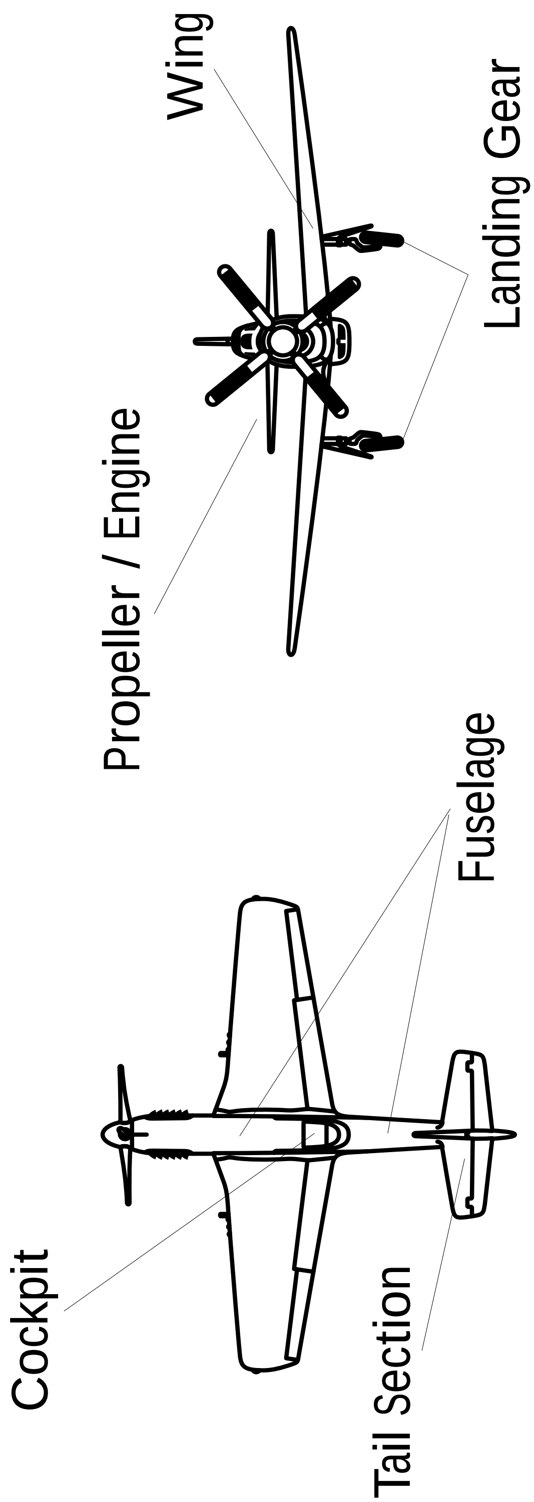
In trying to figure out all of this tilting right and left, remember that if a flap tilts so that it obstructs the airflow, then the airflow is going to push hard on that flap. An imbalance will be created between the side where the flap is obstructing the airflow and the side where it isn't. This will cause the airplane to swing away from the side where the flap is extended. That is why when a pilot pushes the right rudder pedal, the rudder tilts to the right - the air will push harder on the right side of the tail causing it to swing right, which will cause the nose to swing right. The best way to understand these complicated interaction is to make or acquire a model of an airplane with control surfaces. Move the control surfaces up and down and right and left and see what happens when you fly the airplane!

Maneuverability

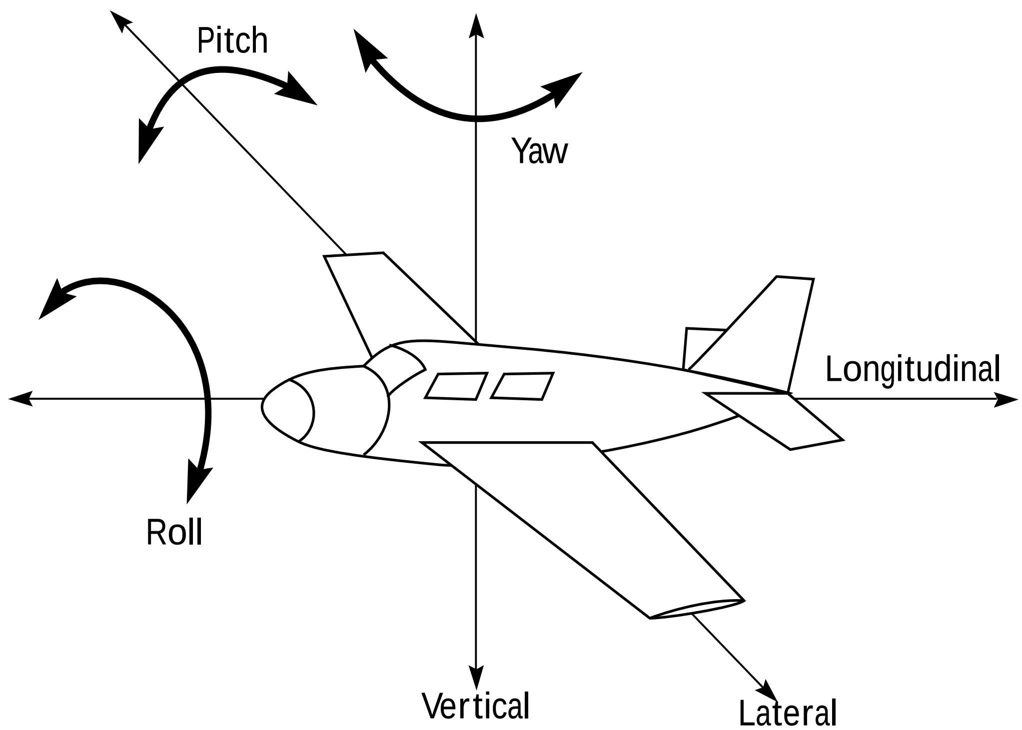
There is often a trade-off between stability and maneuverability. An airplane that is highly maneuverable and can do amazing things in the air is probably not very stable. Sometimes we refer to an automobile as having "tight" steering. That means that the car responds readily to movements of the steering wheel. There is no slack or lag. On the other hand, it also means that the automobile responds quickly and decisively, but does not over-respond. It does precisely what the driver tells it to do through the steering wheel - no more no less. An airplane works the same way. "Tight" stability means the airplane responds precisely to the pilots' controls. The X-29 is a good example of this. The X-29, with its forward-swept wing, is amazingly maneuverable. It can move like no other aircraft. However, the X-29 is also very unstable. A computer based control system is required to help the pilot keep the airplane under control. The control system operates all the control surfaces based on a combination of what the pilot tells it to do and whats its sensors say the airplane is doing. It makes minute and extremely rapid changes in the control surface positions to maintain the stability of the airplane. A human cannot perceive, absorb and react to this much information in the infinitesimally short time required - computer help is needed.

Overhead Guides

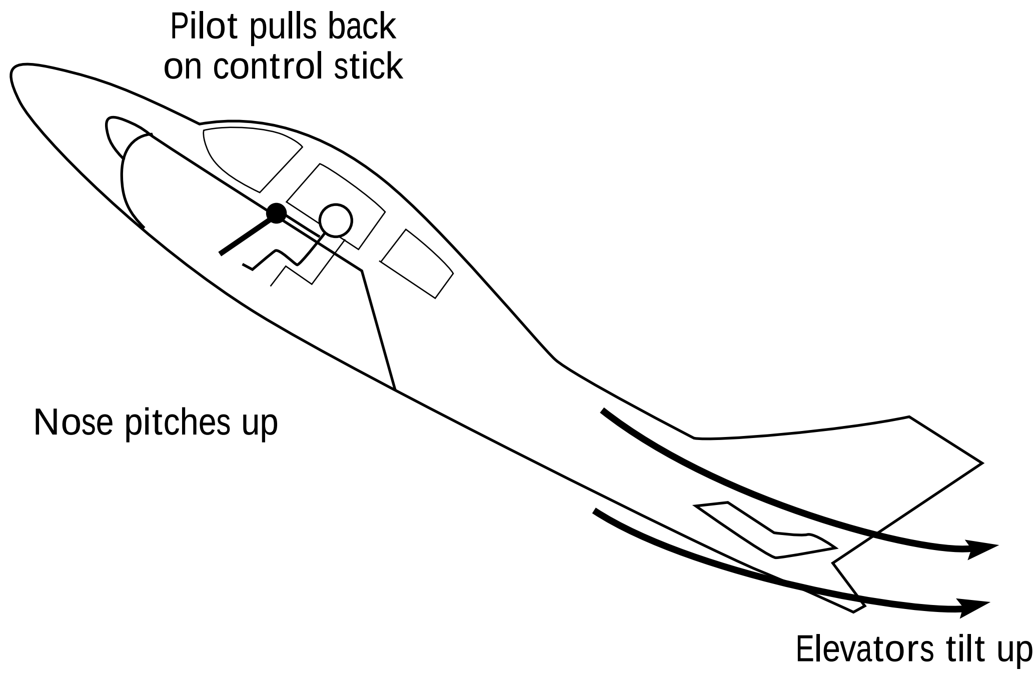
Parts of an Airplane



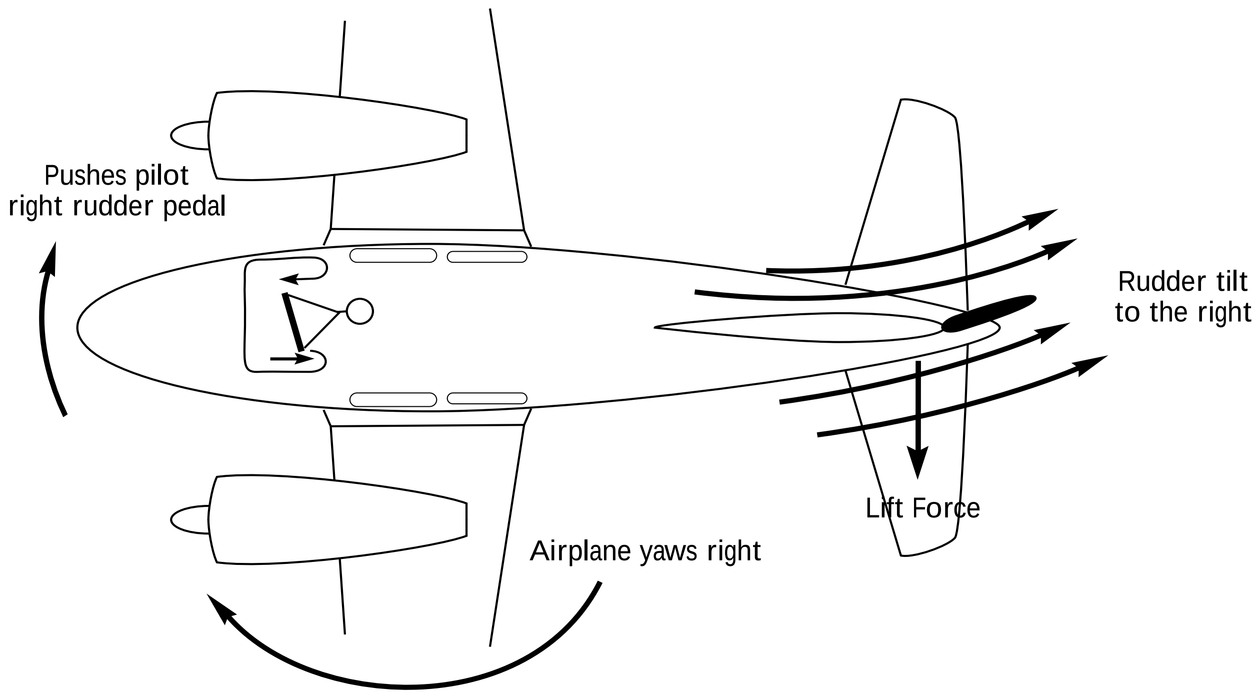
Axes Around Which an Airplane Moves



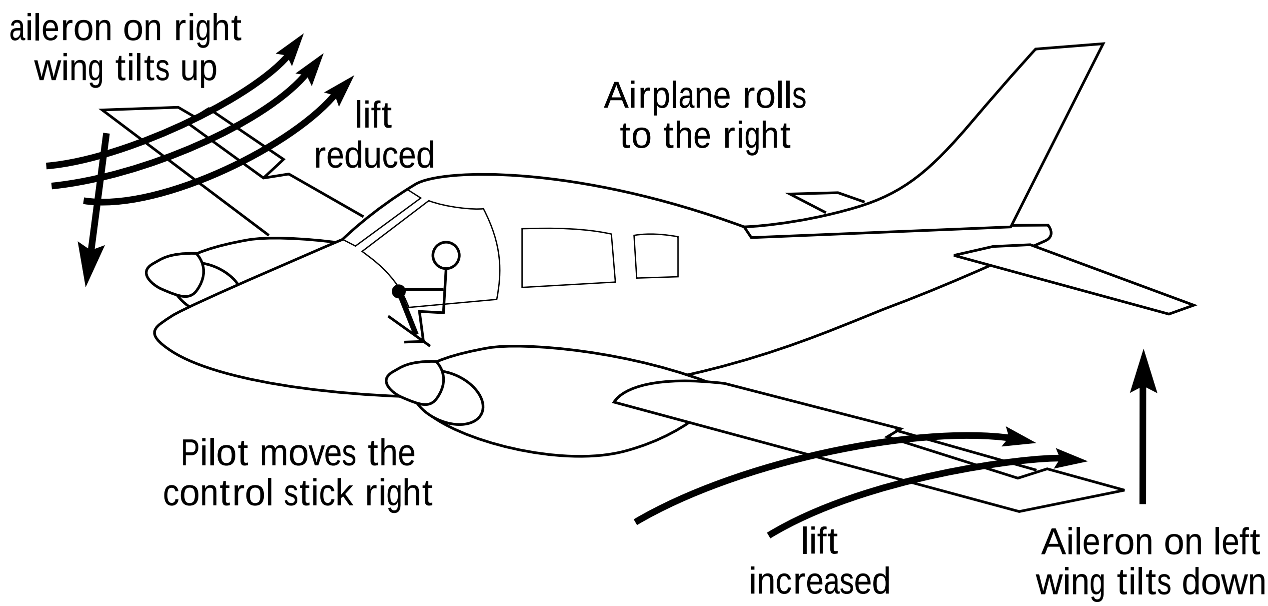
Pitch – Motion and Control Surface



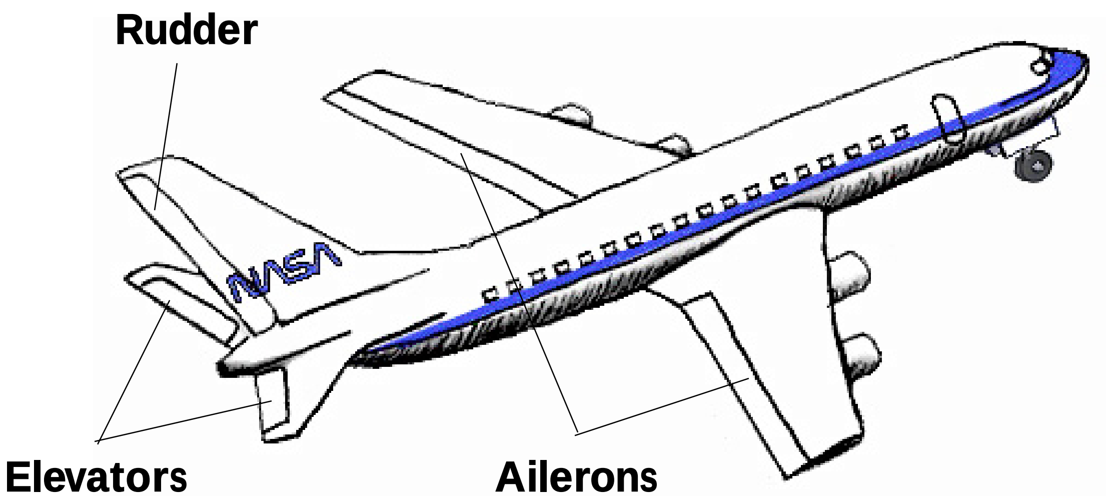
Yaw – Motion and Control Surface



Roll – Motion and Control Surface



Control Surfaces



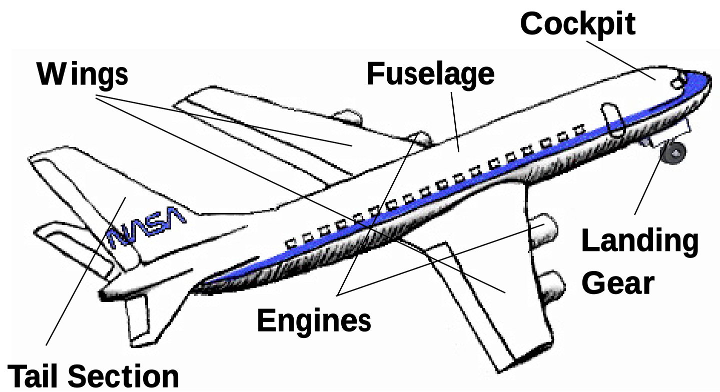
Student Reading
Airplane Control

Parts of an Airplane

The modern airplane has five basic parts. They are the **fuselage, wings, empennage** (tail structure), **engine** and the **undercarriage.**

The main body of an airplane is the **fuselage**. All the other parts of the airplane are connected to the fuselage. The fuselage contains the cockpit or flight deck, passenger compartment and cargo area.

The **wings** are a very important part of the airplane because they create lift. Wings come in different shapes depending on the type of airplane. Airfoil is the name of the shape of the wings' cross-section. This shape is designed to give the greatest amount of lift and the least amount of drag.



The **empennage** or tail structure gives stability to the airplane. The empennage has two main parts: the vertical stabilizer (fin); and the horizontal stabilizer.

The **engine** is system that propels the airplane. There are many different types of engines. Common types of engines are piston engines, turboprops, turbojets and turbofans. On airplanes with propellers, the engine causes the propeller to turn.

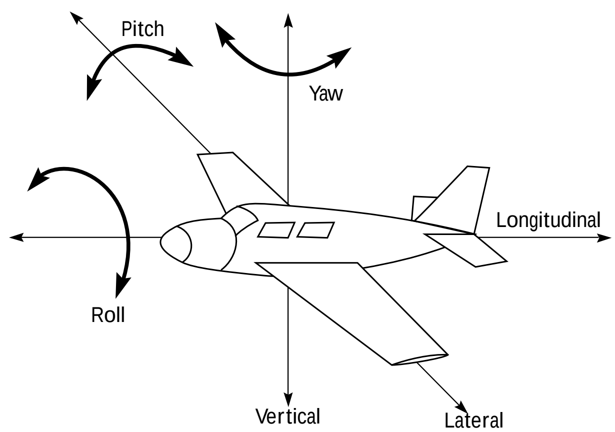
The **undercarriage** or landing gear includes struts, wheels and brakes. The primary function of the undercarriage is to help land the plane on the ground or on water. The landing gear can be fixed or retractable. Many small, single-engine propeller planes have fixed landing gear, which means they stay extended during the entire flight. This increases drag.

Larger airplanes have retractable landing gear. The landing gear is tucked up into the fuselage after takeoff. It is extended again before landing.

How an Airplane Moves

Even though it looks like an airplane moves in many different directions, it really only moves in six ways. It is a combination of all of these six motions that enable an airplane to be flown wherever the pilot wants it to go.

Draw a picture in your mind of an airplane. Imagine that there are three long lines that all cross in the exact middle of the airplane - right between the wings. One line extends from the nose of the airplane through the tail of the airplane - right down the middle! This imaginary line is called the **longitudinal axis**. Another line extends from wing-tip to wing-tip - also right through the middle of the airplane. This imaginary line is called the **lateral axis**. The third line extends from the roof of the fuselage to the floor. And, just like the other lines it goes right through the center of the airplane. This imaginary line is called the **vertical axis**.



Three of the six motions of an airplane are straight along these three **axes**. These are called **linear** motions - note that the word "linear" includes the word "line"! One linear motion is back and forth along the longitudinal axis. Can you draw a picture in your mind of an airplane moving back and forth along its longitudinal axis?

Another linear motion is side to side along the lateral axis. Again, picture in your mind an airplane moving side to side along it's lateral axis.

The third linear motion is up and down along the vertical axis. Now, try to move the airplane in your mind along all three axes. You can make the airplane move in a lot of directions, just along those three axes!

Two of the linear motions are controlled, in part by the balance between the four forces. The up and down motion is controlled by a balance between lift and weight. The back and forth motion is controlled by a balance between thrust and drag.

The other three of the six motions of an airplane are <u>around</u> the three axes. These are called **rotational** motions - because the plane "rotates" around the axes. The rotational motion around the longitudinal axis is called **roll**. In your mind, roll your airplane over so its wing is pointing up. Can you roll the airplane over onto its back?

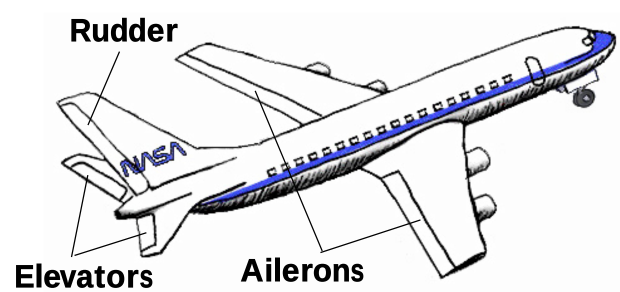
Another rotational motion is around the lateral axis. This motion is called **pitch**. Think of the nose of the airplane moving up and down as the airplane pitches. Can you pitch the nose of your imaginary airplane until it is pointing straight up? How about straight down?

The third rotational motion is around the vertical axis. This motion is called **yaw**. Think of the nose of the airplane moving right and left as the airplane yaws. Think about yawing your imaginary plane all the way to the right. Then yaw your airplane all the way to the left. Can you yaw your airplane so it is pointing backwards?

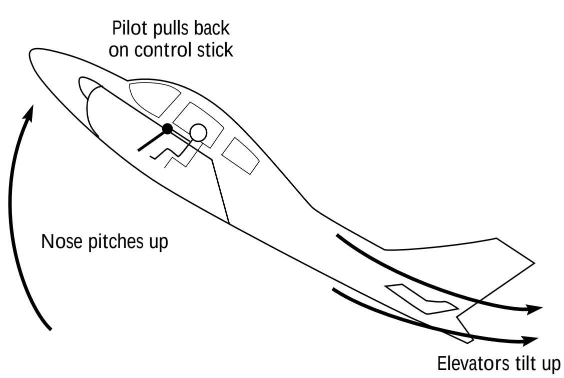
Imagine your airplane moving forward and backward, right and left, up and down, and rolling, pitching and yawing. It is easy to see that any motion an airplane can make is a combination of these six motions!

Controlling the Motions

The three rotational motions (pitch, roll and yaw) are directly controlled by **control surfaces** located on different parts of the airplane. There are three basic types of control surfaces: elevators, ailerons, and rudder. The elevators are located on the horizontal stabilizer. The ailerons are located on the wings, one on each wing. The rudder is located on the fin. Each control a different motion and when used together maneuver an airplane according to the pilot's commands.



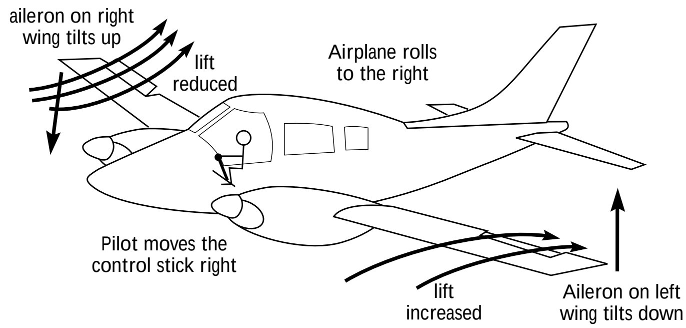
To pitch the airplane's nose up or down, we need to take a look at the tail end of the plane. The horizontal stabilizer has a set of movable surfaces on it called **elevators** - one on each side of the fin.



Can you see this in your mind? When the elevators tilt downward imagine the airflow pushing against them. The pressure of the airflow would push the tail up. And, if the tail goes up, then the nose must pitch down!

When the back edges of the elevators are tilted upward, the airflow pushes the tail end of the plane down. When the tail goes down then the nose must pitch up.

The roll motion of the airplane is controlled by the **ailerons**. The ailerons are located near the tips of the wings - one on each side. The two ailerons work in opposite directions. When one aileron tilts up, the other tilts down. This happens automatically when the pilot moves the control stick from left to right.



When the aileron on the right wing tilts up which way does the aileron on the left wing tilt? It tilts down! Imagine the airflow pushing on both ailerons. Because the right aileron is tilted up, the airflow pushes down on the right wing. Since the left aileron is tilted down, the airflow pushes up on the left wing. If the right wing goes down and the left wing goes up, we say that the airplane is rolling to the right.

What causes an airplane to roll to the left? If the left aileron is tilted up, then the airflow will push the left wing down. If the right aileron is tilted down, the airflow will push the right wing up. If the left wing goes down and the right wing goes up, we say that the airplane is rolling to the left.

The yaw motion of the airplane is controlled by the **rudder**. The rudder is located along the back edge of the fin. It works the same way that the elevators and ailerons do. When the rudder is tilted to the right, the airflow pushes the tail of the airplane to the left. If the tail of the airplane moves to the left, then the nose of the airplane must yaw to the right. We say that the airplane is yawing to the right.

When the rudder is tilted to the left, the airflow pushes the tail of the airplane to the right. If the tail of the airplane moves to the right, then the nose of the airplane must yaw to the left. We say that the airplane is yawing to the left.

Controlling the Control Surfaces

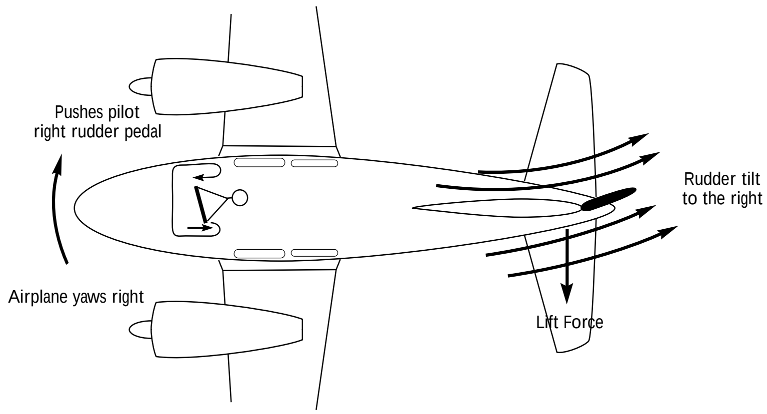
How does a pilot control the control surfaces?

The **control stick** is located in front of the pilot. It controls two of the rotational motions.

If the pilot moves the control stick to the right or to the left, this will activate the ailerons and the airplane will roll to the right or to the left.

If the pilot moves the control stick forward or back, this will activate the elevators and the airplane will pitch up or down.

Rudder pedals at the pilot's feet control the rudder. Pushing on the right rudder pedal will cause the airplane's nose to yaw to the right. Pushing on the left rudder pedal will cause the airplane's nose to yaw to the left.



Student Note Taking Guide

Airplane Control

Big Ideas	Important Little Details
Parts of the Airplane	
fuselage	main body all of the other parts are connected to it has flight deck, passenger compartment and cargo area
wings	give lift are sometimes called airfoils because of their special shape the airfoil shape is designed to create the greatest lift and the least drag each wing has an aileron near the tip
empennage	tail section with two parts the rudder is mounted on the fin (vertical stabilizer) the elevators are mounted on the horizontal stabilizer
engines	provide propulsion many types of engines engine drives propeller
undercarriage	landing gear fixed or retractable enables plane to land on ground or water

Big Ideas	**Important Little Details**
How an Airplane Moves	
three axes	imaginary lines that cross at the center of the airplane longitudinal - from nose to tail lateral - from wing-tip to wing-tip vertical - from floor to ceiling of fuselage
six motions	three linear - straight along axes up and down along vertical right and left along lateral forward and back along longitudinal three rotational - around axes pitch - tilting nose up and down roll - one wing-tip goes up, the other goes down yaw - nose moves left and right
balance of forces	controls two linear motions up and down - balance between lift and weight forward and back - balance between thrust and drag

Student Worksheets
Airplane Parts and Motions

Directions: Match the part of the plane to its proper description. Write the letter in the blank.

A)	empennage	D)	undercarriage
B)	fuselage	E)	engines
C)	wings		

_____ 1. located underneath the fuselage and sometimes can be retracted during flight

_____ 2. contains the flight deck, passenger and cargo areas

_____ 3. the propulsion system

_____ 4. the tail section

_____ 5. attached to the fuselage and give lift to the airplane

Directions: Match the motion to its proper description. Write the letter in the blank.

A)	lateral	D)	vertical
B)	roll	E)	pitch
C)	yaw	F)	longitudinal

_____ 6. motion of the airplane as nose is raised and lowered

_____ 7. forward

_____ 8. motion of airplane as nose moves left and right

_____ 9. airplane moves straight up or straight down

_____ 10. airplane turns to the right or turns to the left

_____ 11. one wing-tip moves up and the other moves down

Student Worksheets

Airplane Parts and Motions – Key

Directions: Match the part of the plane to its proper description. Write the letter in the blank.

A) empennage
B) fuselage
C) wings
D) undercarriage
E) engines

_*D*_ 1. located underneath the fuselage and sometimes can be retracted during flight

_*B*_ 2. contains the flight deck, passenger and cargo areas

_*E*_ 3. the propulsion system

_*A*_ 4. the tail section

_*C*_ 5. attached to the fuselage and give lift to the airplane

Directions: Match the motion to its proper description. Write the letter in the blank.

A) lateral
B) roll
C) yaw
D) vertical
E) pitch
F) longitudinal

_*E*_ 6. motion of the airplane as nose is raised and lowered

_*F*_ 7. forward

_*C*_ 8. motion of airplane as nose moves left and right

_*D*_ 9. airplane moves straight up or straight down

_*A*_ 10. airplane turns to the right or turns to the left

_*B*_ 11. one wing-tip moves up and the other moves down

Student Worksheets

Airplane Control

Directions: Draw a picture that shows the motion named. Write a short description of the motion.

1. yaw

description of the motion:

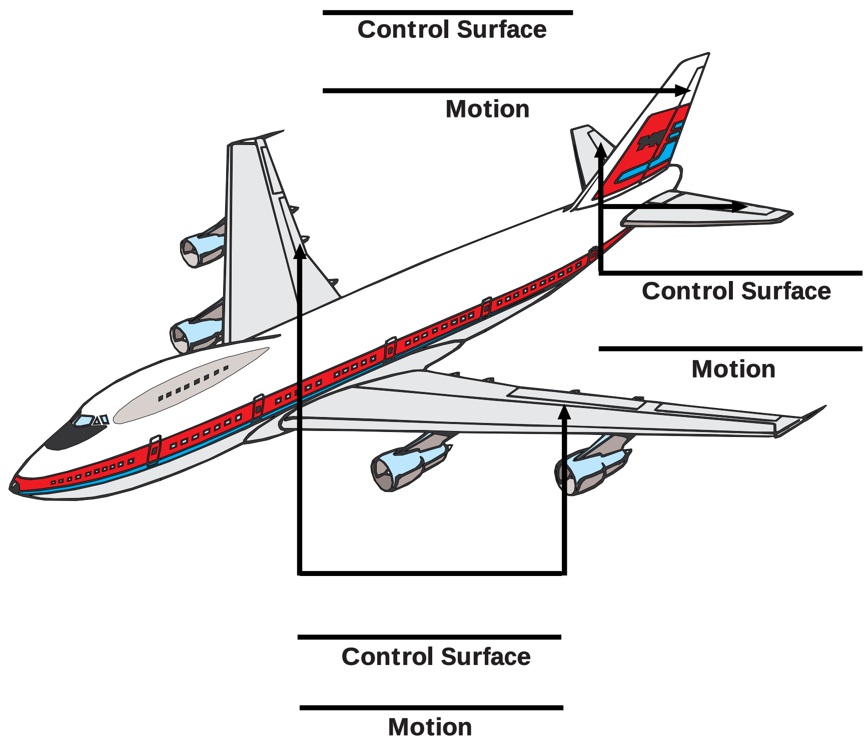
2. pitch

description of the motion:

3. roll

description of the motion:

4. On the diagram below, label each control surface and tell which rotational motion it affects.



5. Name the pilot controls that control each control surface.

A) The ailerons are controlled by ____________________.

B) The rudder is controlled by ____________________.

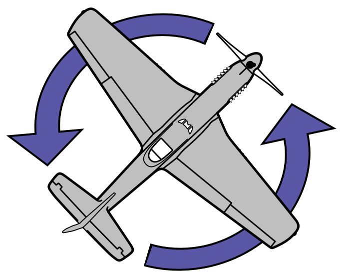
C) The elevators are controlled by __________________.

Student Worksheets

Airplane Control – Key

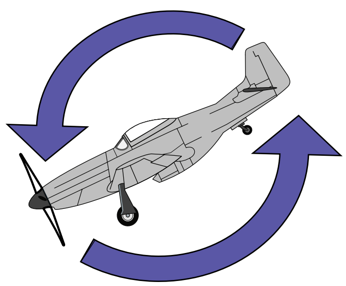
Directions: Draw a picture that shows the motion named. Write a short description of the motion.

1. yaw



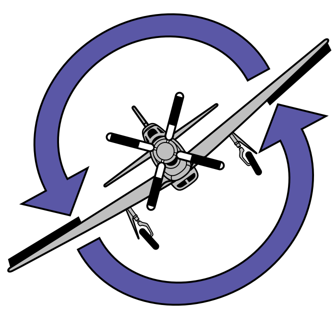
description of the motion: *the nose moves to the left and right*

2. pitch



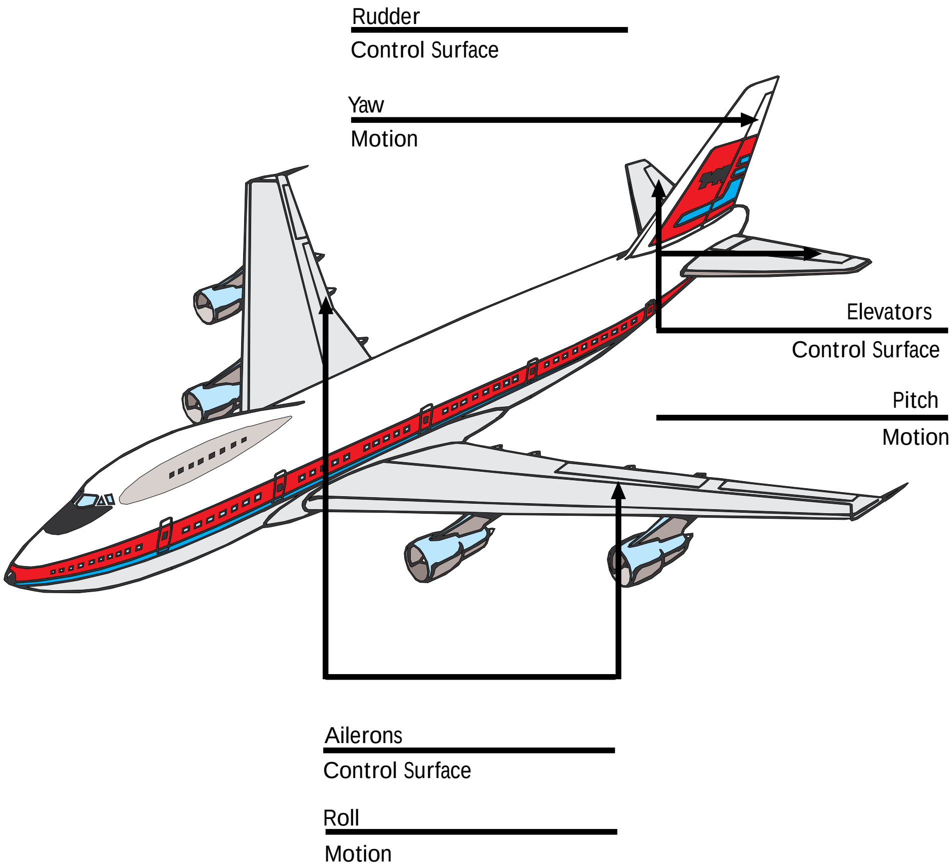
description of the motion: *the nose moves up and down*

3. roll



description of the motion: *one wing-tip goes up and the other goes down*

4. On the diagram below, label each control surface and tell which rotational motion it affects.



5. Name the pilot controls that control each control surface.

A) The ailerons are controlled by __*the control stick*________.

B) The rudder is controlled by __*the rudder pedals*_________.

C) The elevators are controlled by _*the control stick*________.

Student Project

Make Your Own Glider

Directions: Using the paper and glider pattern given to you by your teacher, follow the procedure below to make your own glider.

Procedure

1. Use the Glider Template page (next page) and cut out the Glider.

2. Fold a piece of sturdy card stock paper in half lengthwise.

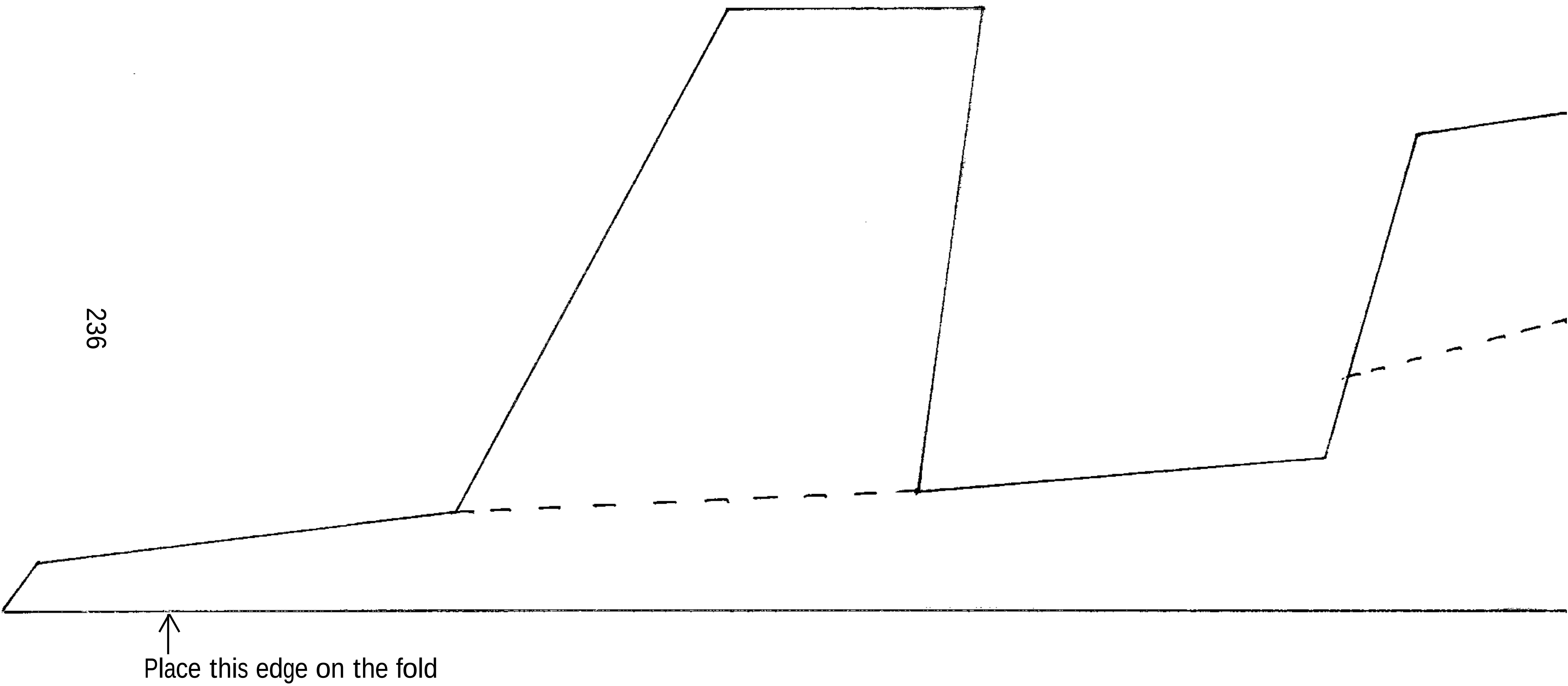
3. Take the pattern of the glider and place it on the folded card stock so that the long straight line is on the folded edge.

4. Trace the pattern onto the folded piece of paper. Mark the dotted lines as shown on the pattern.

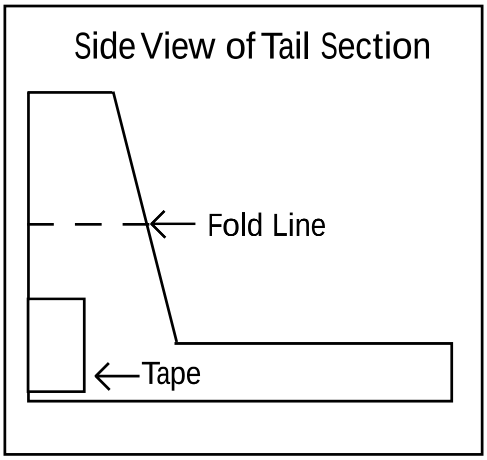
5. Use scissors to carefully cut along the traced outline. Be careful to hold the two folded sides of the paper together while cutting. Do not cut along the dotted lines!

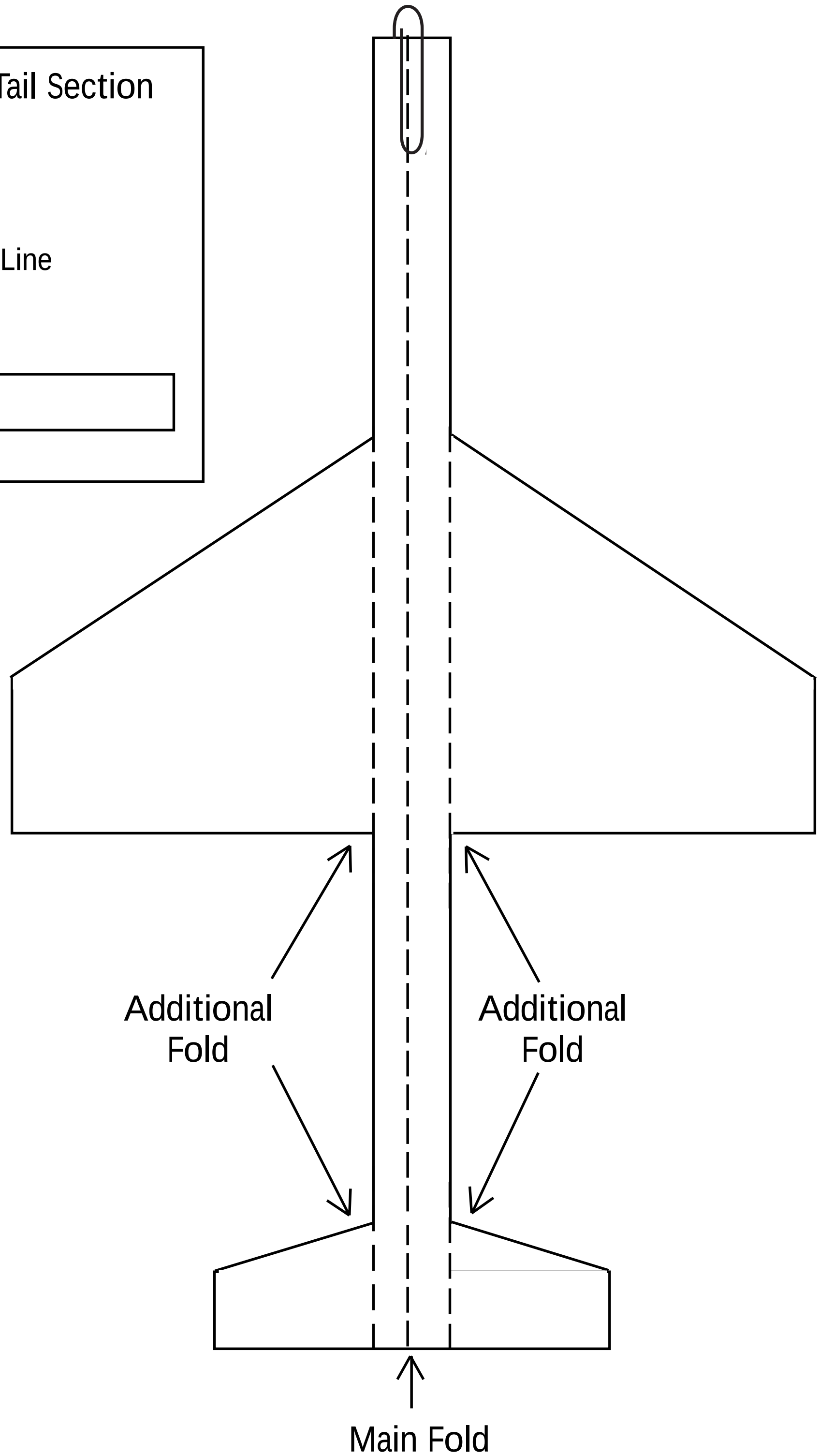
You will use your glider to perform the experiments in this section.

Glider Template

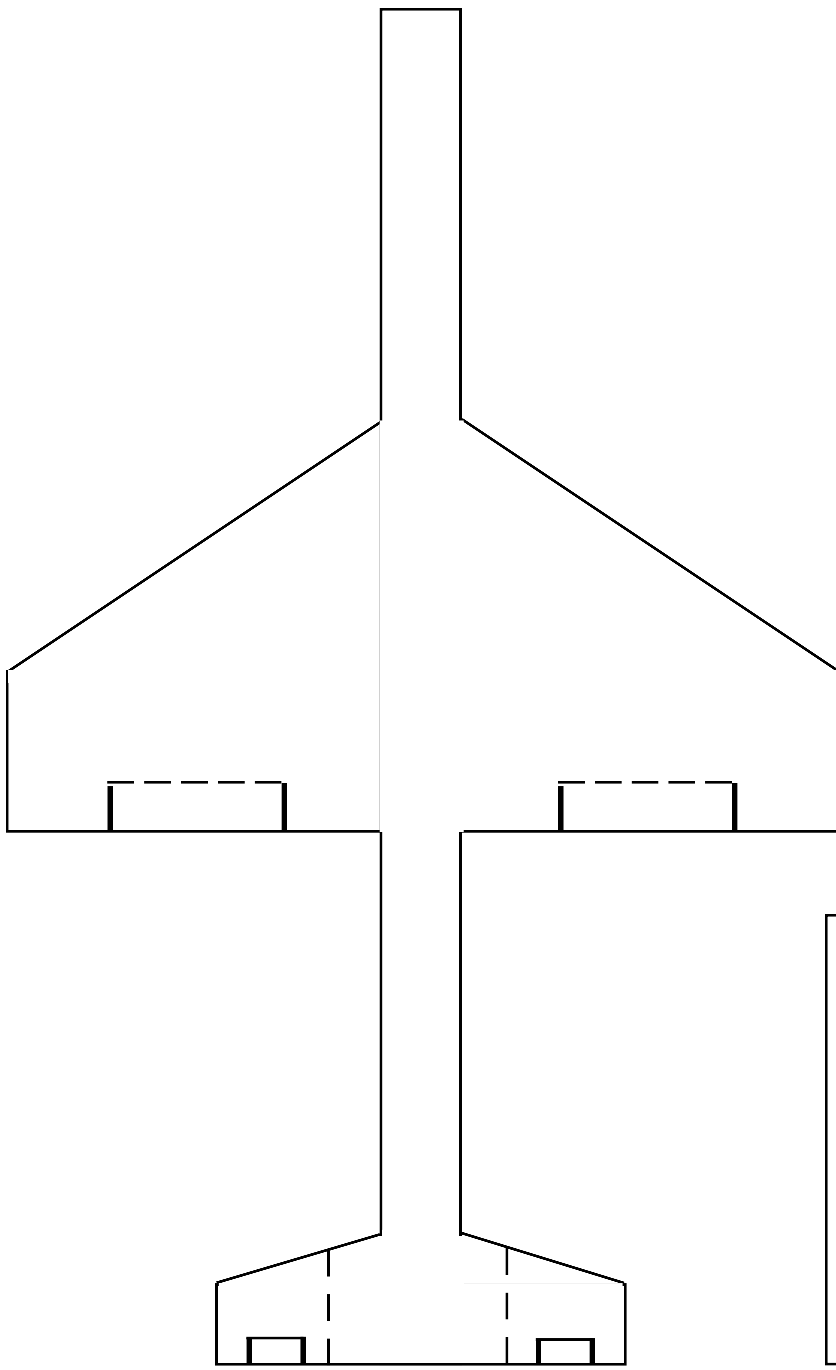


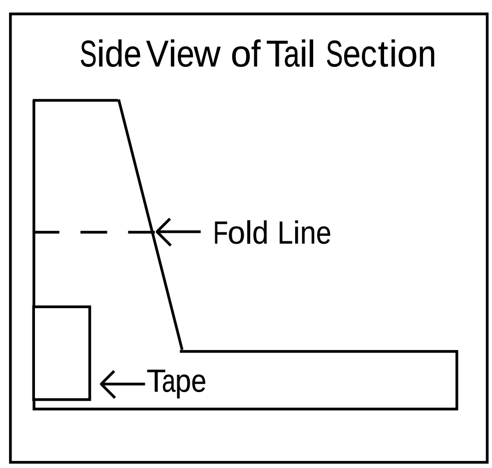
6. Bend the wings and the tail section where shown. Attach a lightweight paper clip to the nose section.
8. Tape together the two edges at the tail of the glider.





9. Mark the wings and the tail section with dotted lines as shown in the diagram below.

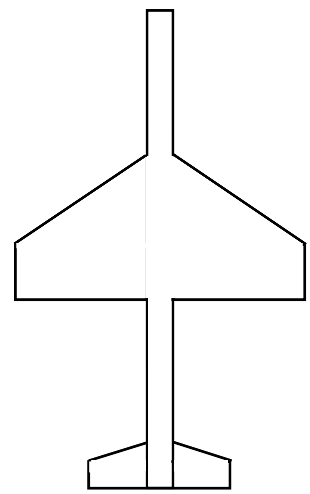




Experiment Data Sheet #1

Control Experiment #1

Directions: Follow the steps from the procedure card for Control Experiment #1. As you test each control surface with your glider, complete this data sheet.



1. On the diagram shade the part of the plane you are testing.

2. Name the control surface you just shaded.

3. Tell what position you moved that control surface to (up, down, left, right, etc.).

4. Briefly describe the glider's flight.

5. Draw the glider's flight path.

6. Circle the type of motion that this control surface controls.

   pitch yaw roll

7. Circle the axis around which this motion takes place.

   longitudinal lateral vertical

8. Use this space for any other observations you might have.

Control Experiment #1

Procedure Card

Materials

standard size sheet of plain white paper
scissors
paper airplane construction directions
tape
paper clip

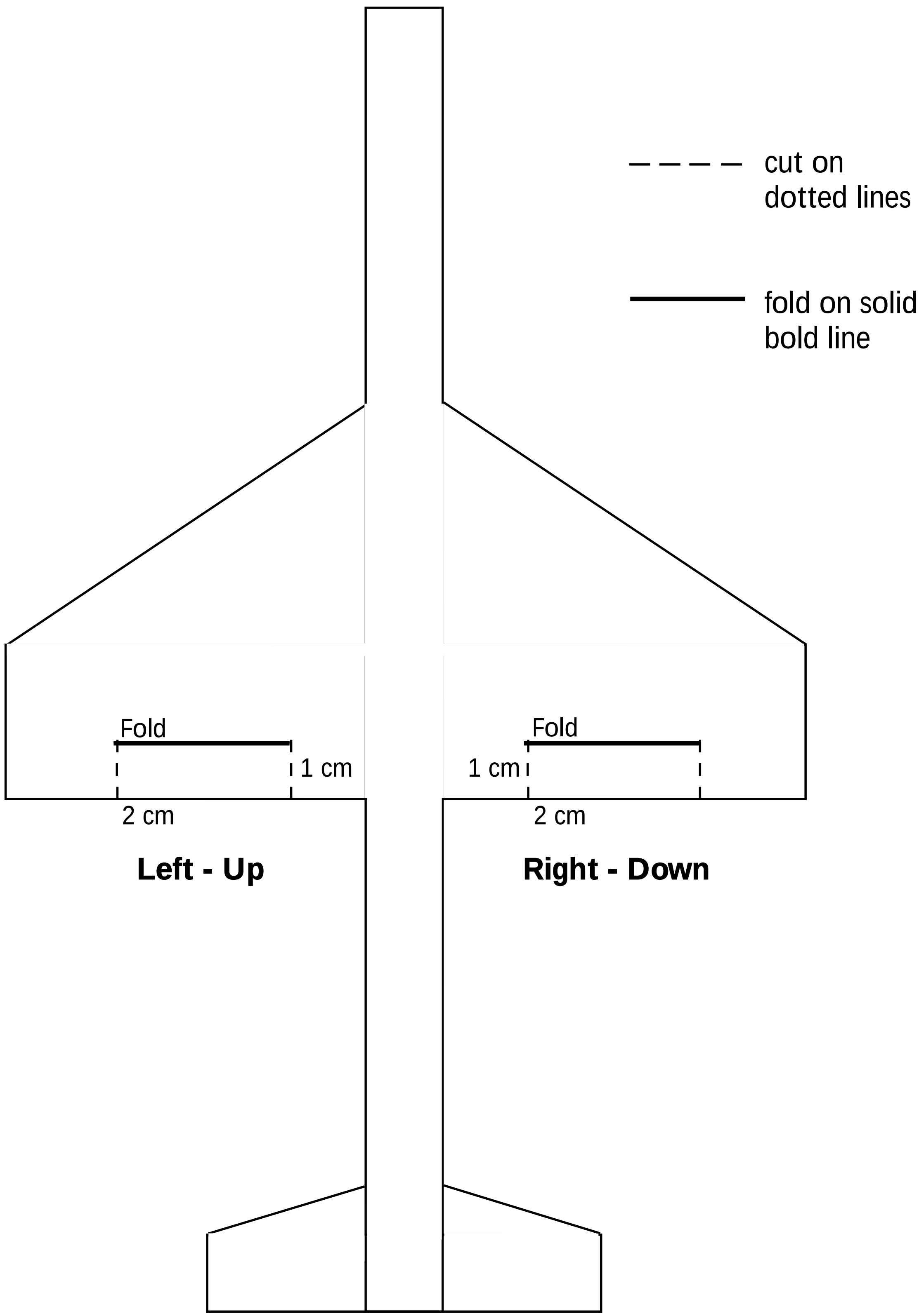
Experiment Set Up

Follow the directions for constructing a paper airplane that your teacher gives you.

Experiment Procedure

1. Make two cuts in the trailing edge of each wing (see diagram on next page).
2. This part of the plane is the aileron and controls movement around the longitudinal axis.
3. Bend the left aileron up and bend the right aileron down.
4. Predict how the plane will fly.
5. Launch the plane by throwing it gently forward.
6. Observe and record.

Top View

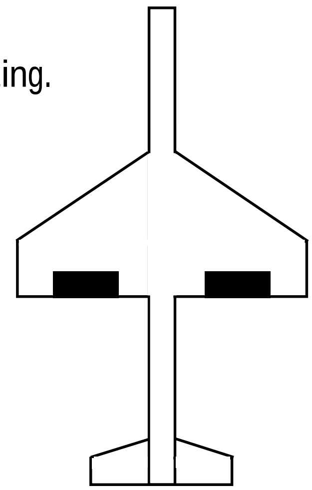

cut on dotted lines
fold on solid bold line
Fold
Fold
1 cm
1 cm
2 cm
2 cm
Left - Up
Right - Down

Experiment Data Sheet – Key

Control Experiment #1

Directions: Follow the steps from the procedure cards for Control Experiments #1, #2, and #3. As you test each control surface with your glider, complete this data sheet.

1. On the diagram shade the part of the plane you are testing.



2. Name the control surface you just shaded.

   aileron

3. Tell what position you moved that control surface to (up, down, left, right, etc.)

   left aileron up, right aileron down
   or
   left aileron down, right aileron up

4. Briefly describe the glider's flight.

   the glider rolled left
   or
   the glider rolled right

5. Draw the glider's flight path.

6. Circle the type of motion that this control surface controls.

   pitch yaw *roll*

7. Circle the axis around which this motion takes place.

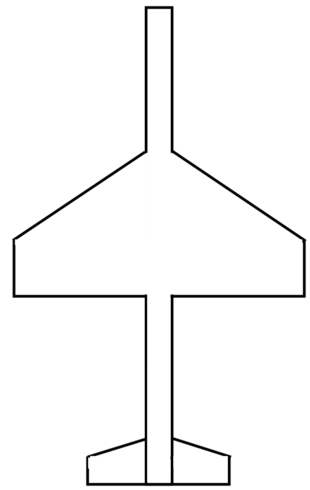
   longitudinal lateral vertical

8. Use this space for any other observations you might have.

Experiment Data Sheet #2

Control Experiment #2

Directions: Follow the steps from the procedure card for Control Experiment #2. As you test each control surface with your glider, complete this data sheet.



1. On the diagram shade the part of the plane you are testing.

2. Name the control surface you just shaded.

3. Tell what position you moved that control surface to (up, down, left, right, etc.).

4. Briefly describe the glider's flight.

5. Draw the glider's flight path.

6. Circle the type of motion that this control surface controls.

   pitch yaw roll

7. Circle the axis around which this motion takes place.

   longitudinal lateral vertical

8. Use this space for any other observations you might have.

Control Experiment #2

Procedure Card

Materials

standard size sheet of plain white paper
scissors
paper airplane construction directions
tape
paper clip

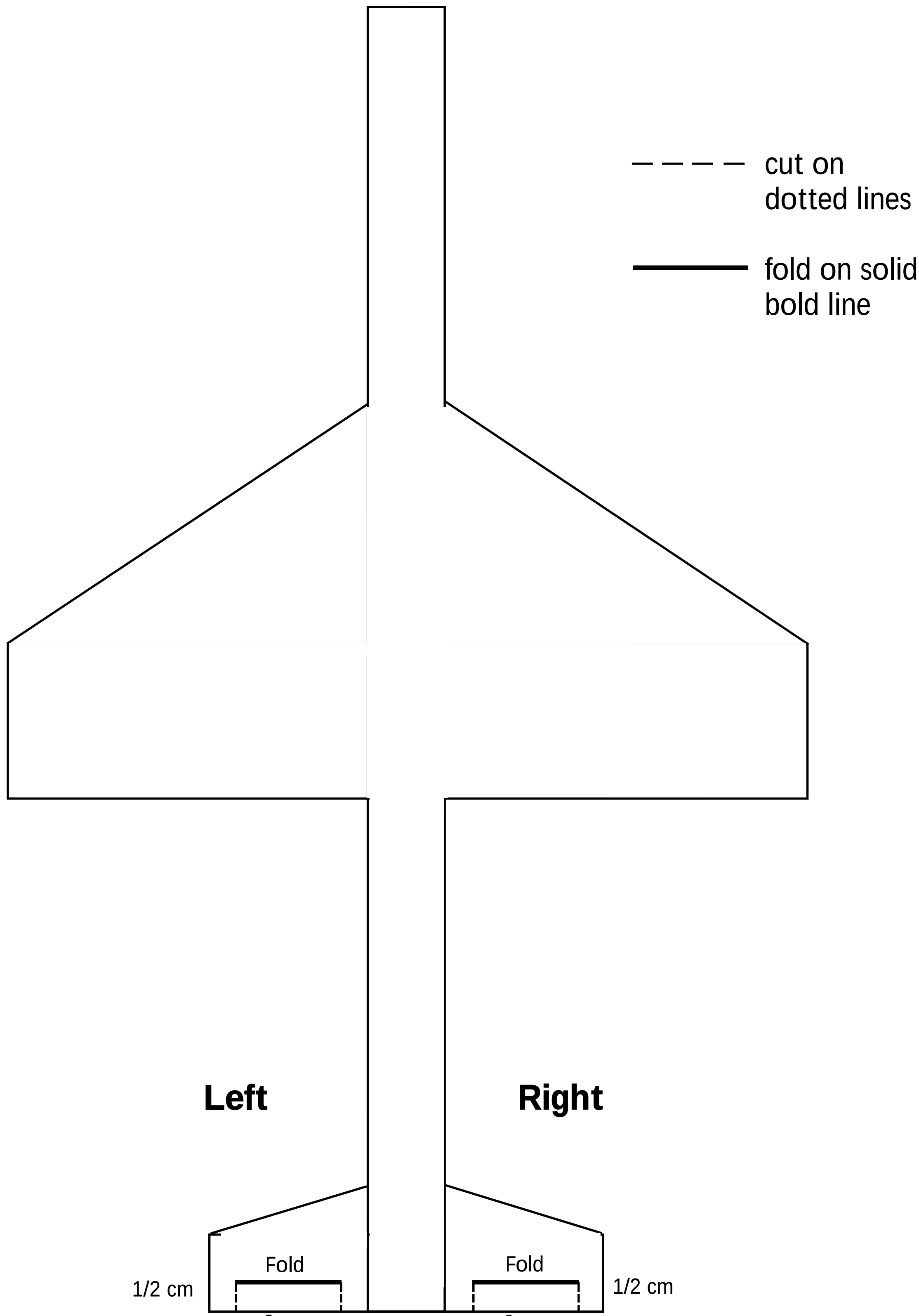
Experiment Set Up

Follow the directions for constructing a paper airplane that your teacher gives you.

Experiment Procedure

1. Make two cuts in the back of the horizontal stabilizer (see diagram on next page).
2. These are the elevators and they control movement around the lateral axis.
3. Bend both elevators up.
4. Predict how the glider will fly.
5. Launch the plane by throwing it gently forward.
6. Observe and record.
7. Bend both elevators down.
8. Repeat steps 5 and 6, launching the airplane at the same speed every time.

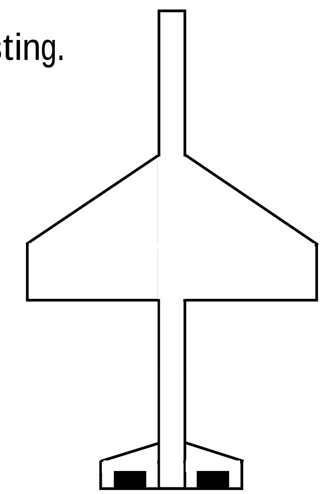
Top View


cut on
dotted lines
fold on solid
bold line
Left
Right
Fold
Fold
1/2 cm
1/2 cm
2 cm
2 cm

Experiment Data Sheet – Key

Control Experiment #2

Directions: Follow the steps from the procedure cards for Control Experiments #1, #2, and #3. As you test each control surface with your glider, complete this data sheet.



1. On the diagram shade the part of the plane you are testing.

2. Name the control surface you just shaded.

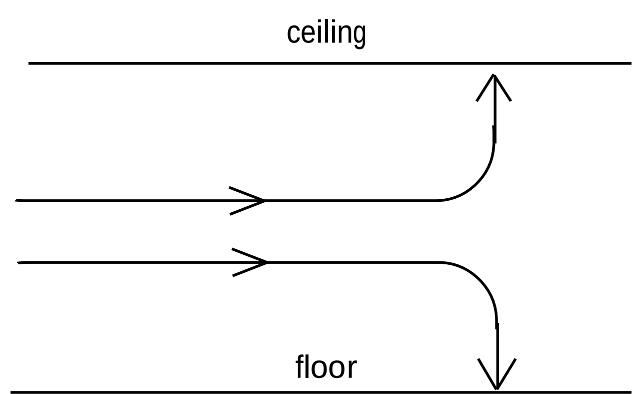
   elevators

3. Tell what position you moved that control surface to (up, down, left, right, etc.)

   both elevators bent up
   or
   both elevators bent down

4. Briefly describe the glider's flight.

   the glider's nose pitched up
   or
   the glider's nose pitched dowr



5. Draw the glider's flight path.

6. Circle the type of motion that thi

   pitch yaw roll

7. Circle the axis around which this motion takes place.

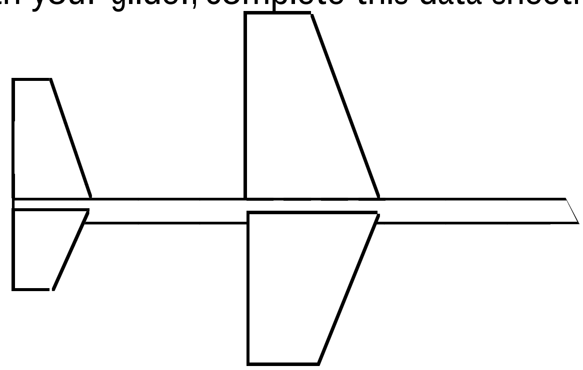
   longitudinal *lateral* vertical

8. Use this space for any other observations you might have.

Experiment Data Sheet #3

Control Experiment #3

Directions: Follow the steps from the procedure card for Control Experiment #3. As you test each control surface with your glider, complete this data sheet.



1. On the diagram shade the part of the plane you are testing.

2. Name the control surface you just shaded.

3. Tell what position you moved that control surface to (up, down, left, right, etc.).

4. Briefly describe the glider's flight.

5. Draw the glider's flight path.

6. Circle the type of motion that this control surface controls.

   pitch yaw roll

7. Circle the axis around which this motion takes place.

   longitudinal lateral vertical

8. Use this space for any other observations you might have.

Control Experiment #3

Procedure Card

Materials

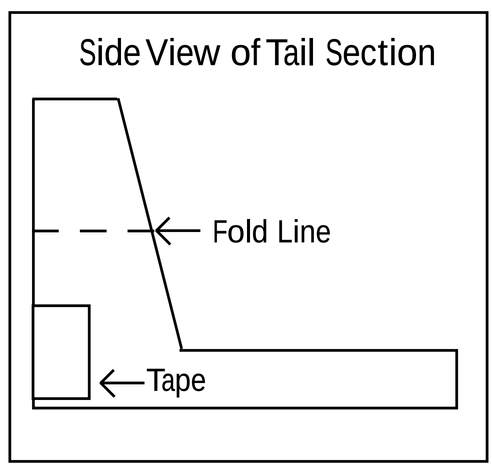
standard size sheet of plain white paper
scissors
paper airplane construction directions
tape
paper clip

Experiment Set Up

Follow the directions for constructing a paper airplane that your teacher gives you.

Experiment Procedure

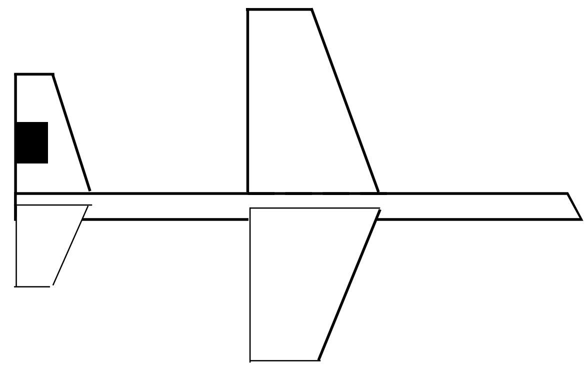
1. Make two cuts on the back of the fin (see diagram on next page).
2. This is the rudder and it controls movement around the vertical axis.
3. Bend the rudder to the left.
4. Predict how the plane will fly.
5. Launch the plane by throwing it gently forward.
6. Observe and record.
7. Bend the rudder to the right.
8. Repeat steps 5 and 6.



Experiment Data Sheet – Key

Control Experiment #3

Directions: Follow the steps from the procedure cards for Control Experiments #1, #2, and #3. As you test each control surface with your glider, complete this data sheet.



1. On the diagram shade the part of the plane you are testing.

2. Name the control surface you just shaded.

   rudder

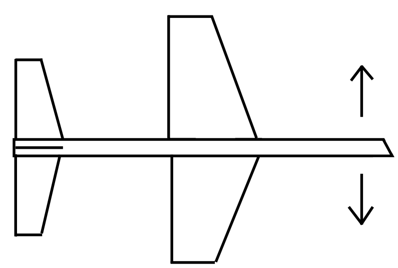
3. Tell what position you moved that control surface to (up, down, left, right, etc.)

   to the left
   or
   to the right

4. Briefly describe the glider's flight.

   the glider's nose yawed left
   or
   the glider's nose yawed right

5. Draw the glider's flight path.



6. Circle the type of motion that this control surface controls.

   pitch *yaw* roll

7. Circle the axis around which this motion takes place.

   longitudinal lateral *vertical*

8. Use this space for any other observations you might have.

Additional Student Activities

1. Create a dance or a series of movements that depict(s) the six motions of an airplane.

2. Using large cardboard boxes and pieces of cardboard, string, paint and tape to create a "box model" of an airplane with control surfaces that are color-coated and labeled and can be manipulated. Include a key that not only identifies the control surfaces, but also tells what motion each one controls.

3. Create a concept map that names, describes and depicts the motions and control surfaces of an airplane.

4. Create a flip book that demonstrates each of the following motions: yaw, pitch and roll.

S. Create a three dimensional airplane out of any material you choose and label the parts and the control surfaces.

6. Create a paper glider with movable control surfaces. Demonstrate the following maneuvers: a downward left bank and an upward right bank.

Writing Experiences

1. Pretend that you are a passenger in an airplane of your choice. In five paragraphs describe a short trip you took during which the plane did the following maneuvers: steep roll with a downward pitch and an unexpected yaw right. Describe the airplane's motion, control surface positions and what the movement did to you inside the passenger cabin.

2. Write a song, poem or rap that names and describes yaw, pitch and roll as well as tells about the control surfaces which control these motions.

3. Draw the flight path of an airplane. Have the airplane change directions at five points along the path, and label each point. Describe what movement occurred at each point and what control surfaces controlled that movement.

Critical Thinking Questions

1. Using a toy airplane, demonstrate the motions of an airplane.

2. Predict how an airplane would fly without a rudder.

3. Predict how an airplane would fly without the ailerons.

4. Predict how an airplane would fly without the elevators.

5. Why do you think it took so long to develop the capability of controlled flight?

6. How did the early inventors solve the problem of maneuverability in their airplanes? (See the Wright brothers' wing warping technique.)

Quick Quiz

Airplane Control

Directions: Circle the letter of the answer that best answers the question.

1. What part of the airplane is the main body that holds the passengers and cargo?

   A. tail section
   B. fuselage
   C. undercarriage
   D. wings

2. What is yaw?

   A. motion of the airplane as the nose is raised or lowered
   B. one wing-tip moves up as the other wing-tip moves down
   C. motion of the airplane as the nose moves left or right
   D. forward motion

3. What part of the airplane creates thrust?

   A. propulsion system or engines
   B. fuselage
   C. tail section
   D. wings

4. Which control surface controls roll?

   A. rudder
   B. ailerons
   C. elevators

5. What part of the airplane is designed to be used only during landing and takeoff?

   A. fuselage
   B. tail section
   C. wings
   D. empennage or landing gear

Quick Quiz - Key

Airplane Control

Directions: Circle the letter of the answer that best answers the question.

1. What part of the airplane is the main body that holds the passengers and cargo?

   A. tail section
   B. fuselage
   C. undercarriage
   D. wings

2. What is yaw?

   A. motion of the airplane as the nose is raised or lowered
   B. one wing-tip moves up as the other wing-tip moves down
   C. motion of the airplane as the nose moves left or right
   D. forward motion

3. What part of the airplane creates thrust?

   A. propulsion system or engines
   B. fuselage
   C. tail section
   D. wings

4. Which control surface controls roll?

   A. rudder
   B. ailerons
   C. elevators

5. What part of the airplane is designed to be used only during landing and takeoff?

   A. fuselage
   B. tail section
   C. wings
   D. empennage or landing gear

Section Overview

Tools of Aeronautics

The four tools of aeronautics are discussed and demonstrated: computational fluid dynamics (CFD), wind tunnels, flight simulation and flight test.

CD-ROM Usage

Click on the wind tunnel and you are directed to the "Tools of Aeronautics" section. Introduce the student reading with the subsection "Aero Research." Introduce each tool of aeronautics with the first question found in each subsection (What is CFD? What is a wind tunnel? What is flight simulation? What is flight test?). After completing the student reading and worksheets, students can review the concepts by using the Student Logbook pages 27, 28, 29, 30.

Materials List

- 1 ping-pong ball
- piece of string 30 cm long
- tape
- straw
- ring stand or table end

Student Handouts

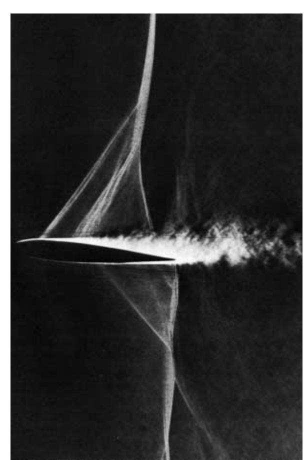
Student Reading: Tools of Aeronautics
Student Note Taking Guide: Tools of Aeronautics
Student Worksheet: Tools of Aeronautics
Experiment: Air Pressure and Current of Air Procedure Card
Experiment: Object Shape and Drag Procedure Card
Quick Quiz: Tools of Aeronautics

Teacher Reading
Tools of Aeronautics

The Four Tools

Researchers in the field of Aeronautics primarily use four “Tools” to test their hypotheses: Computational Fluid Dynamics, Wind Tunnel Testing, Flight Simulation and Flight Test. Each of these four “Tools” consists of unique and specialized equipment and experts trained in the development, management and operation of the Tools. These Tools were developed only within the last 100 years and have evolved in parallel with technology in other areas. On one hand their evolution was dependent on the development of technology and on the other hand, their evolution pushed the technology faster and to greater heights. Each Tool has its own niche in the design cycle of a new airplane or in the modification of an existing one. Data from one Tool can feed into the tests performed using another Tool. Oftentimes, research will be completed using one Tool and proceed on to another, only to return to the previous Tool because of a new question generated during tests using the second Tool. Selecting which Tool to use is based on the question being asked. A Tool that can provide excellent data on, say, the aerodynamics of a wing may not be able to give any information about how that wing affects the controlability of the entire airplane.

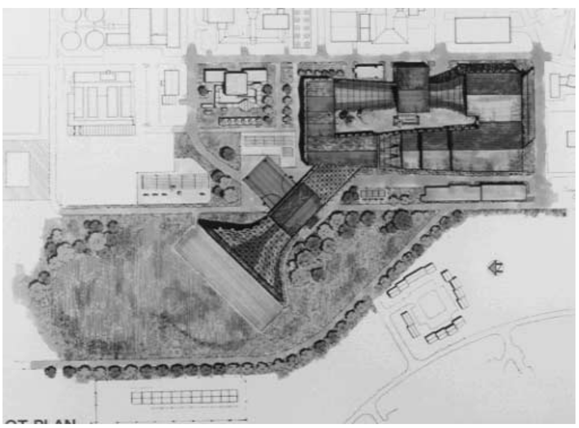
Wind Tunnels



Wind Tunnels were the first Tool to be developed and have been used since the time of the Wright brothers. The name “Wind Tunnel” is very appropriate. A wind tunnel is basically a long tube or tunnel through which air is blown at controlled speeds. A scale model of an airplane, or part of an airplane is mounted in the tunnel and measurements are taken of the forces and pressures that the model experiences when the air is blown. The basic idea of a wind tunnel is to move wind past a stationary airplane, instead of flying the airplane through the air. This is safer, cheaper, and provides a more controlled environment in which to test. It has been proven that data gathered in this way is able to accurately predict forces and pressures generated during real flight.

The models mounted in the tunnel can either be a scaled version of the real airplane, or a scaled version of part of the airplane. Note that the scaling must be extremely accurate or the prediction of forces and pressures will be in error.

Measurements are made by sensors which are embedded in the model and mounted throughout the tunnel. Examples of sensors are strain gauges, balances and pressure sensors. Examples of sensors mounted within the tunnel are floor balances (much like bathroom scales), barometers, thermometers, anemometers, pressure sensors and microphones. Data from all of these sensors are fed into computers. Researchers and engineers then display the data in numerical form (lists of numbers) or graphical form (graphs and plots). Some tunnels have the capability to inject oil, smoke or water into the airflow so that photographs may be taken. Other visualization techniques using lasers, paint that changes color in response to changes in pressure, and other high technology tools are currently being tested.



The largest wind tunnel in the world.

Wind tunnels come in all shapes and sizes, from small hypersonic tunnels (3000+ miles per hour) to very large low-speed (115 miles per hour) tunnels which can test full-sized models. Many wind tunnels exist throughout the world. The largest wind tunnel can be found at NASA Ames Research Center in California. The test section - where the model is mounted - is 80 feet high by 120 feet wide. A full-size model of a Boeing 737 airplane can be mounted in the test section.

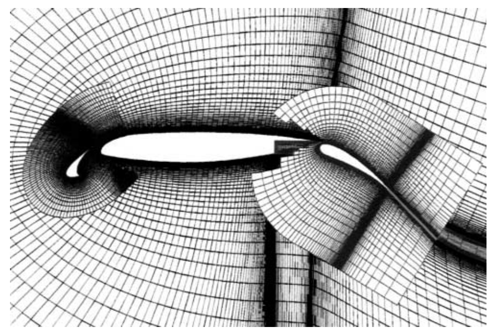
A model of an F-18 in the 80x120-foot test section.

Wind tunnel testing is critical during the design of a new airplane or changes to an existing airplane. A common usage of wind tunnel testing is to gather data to help build a mathematical representation of an airplane that can reside in a computer - called a mathematical model. This type of information is invaluable to researchers and enables them to more fully utilize the other Tools. Cars, trucks, parachutes and helicopters are also tested in wind tunnels.

Computational Fluid Dynamics

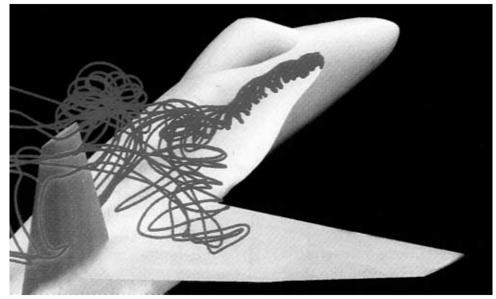
Wind tunnel tests can be very expensive. Wind tunnels themselves use massive amounts of electricity to generate the airflow. The maintenance of machinery, equipment and tunnels the size of multiple football fields is also very expensive. Airplane models with their rigorous requirements for precision and durability take much time and money to build.

In the early 1960s the idea was conceived to run wind tunnel tests in a computer. In those days, computers were large, slow and cumbersome compared to the computers of today. However, given a mathematical model of an airplane, they were able to fairly accurately predict forces and pressures in support of research in fluid dynamics. The real beauty of this technique, however, was the ability of the computer to display graphical pictures and representations of the data which allowed researchers to almost instantaneously perceive and analyze what was happening to a particular model. This visualization was only available in crude forms in the wind tunnel. The field of fluid dynamics was thus able to perform research computationally, inspiring the moniker Computational Fluid Dynamics or CFD.



In the early days, however, computers had not evolved far enough to handle the huge amounts of data and computations needed to accurately model modern airplanes. In an excellent example of aeronautics research needs pushing the evolution of another technology, aeronautical researchers cried out for faster computers that could handle huge amounts of data. With the advent of the supercomputers, their dreams were realized. Supercomputers can easily perform over one billion calculations per second. It would take a person solving one equation every second, 24 hours a day, over 32 years (or a whole career) to solve what a supercomputer can in one second. As fast as today's computers are, however, many aeronautical models are so complex that hours are needed to compute them.

However, the results are well worth the wait! Modern computer graphics that can present data in three-dimensions give a researcher information about the aerodynamics of an entire airplane on one computer screen. While the graphics are visually striking and artistically beautiful, their most valuable contribution to aeronautical engineering is their ability to present an incredibly large amount of very complex information in a manner that enables researchers to quickly and accurately draw conclusions from their data. The capabilities of CFD will continue to expand and grow as computer and visualization technology continue to evolve.



Flight Simulation

The previous two Tools have not included one very important aspect of flight - the pilot. Flight Simulation incorporates the ability of a human to subjectively observe and analyze his or her experiences.

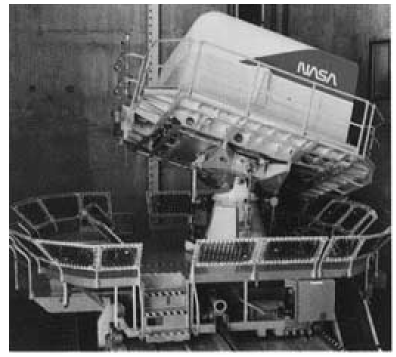
As in CFD, a mathematical model of the research airplane is programmed into a computer. Instead of providing graphical images of the model, a flight simulation computer controls a cockpit mock-up designed to look like the interior of an airplane, a motion system to simulate the movements of an airplane, visual computers to create out-the-window scenes for the pilot, sound systems, and instruments all working together to provide the pilot an extremely realistic flying environment.

Again, the evolution of computers has greatly influenced the ability of flight simulators to accurately simulate real flight. There are two primary uses of flight simulators: training and research. Training simulators now enable pilots to learn to fly new airplanes on the ground. They are able to perfect their skills prior to taking off in the real airplane. Flight simulators are particularly adept at training pilots to handle emergency situations. Engine-out, loss of hydraulics, blown tires, and a host of other life-threatening situations can be accurately simulated, and effective pilot responses learned, all without the possibility of loss of life or airplane.

Research flight simulators are used extensively to examine the handling qualities of an airplane. As drivers of cars we are intimately familiar with, and often critical of, how our vehicles handle. The same holds true with pilots and airplanes. Modern high performance airplanes (such as the X-29) are very difficult to "handle". Complex computer-based control systems are used to help the pilot fly. In some cases the airplane could not be flown without the aid of a control system. These control systems must be extensively tested and fine-tuned before they are incorporated into a real airplane. Much of this testing takes place in flight simulators.

Research simulators are flown by test pilots. Test pilots are trained how to provide accurate and technically sound subjective evaluations of an aircraft's handling qualities. On some occasions, test pilots will fly a set of maneuvers in a simulator in the morning and fly the same set of maneuvers in the real airplane in the afternoon.

The Vertical Motion Simulator (VMS) at NASA Ames Research Center in California is the largest motion-base simulator in the world. It is known as a six-degree-of-freedom simulator. This means that the cockpit can move in the three translational directions (forward/back, up/down, side to side) and generate the three rotational movements (roll, pitch and yaw). The simulator cockpit can travel vertically over 60 feet and can experience accelerations close to 32 feet per second per second (or “1 g”). The VMS is one of the most technically advanced flight simulators in the world. Because simulators are so cost effective and can so accurately mimic the motion and environment of flight they have become critical in the development of new airplanes and modifications to existing ones.



Vertical Motion Simulator (VMS)

Flight Test

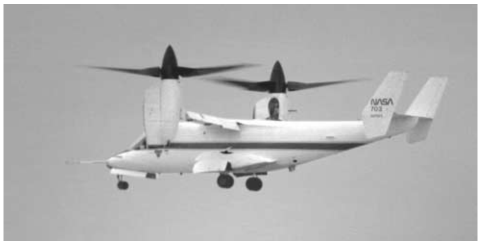
After all the above three Tools have been used and used again, the true test of any airplane is real flight. This is where the Tool of Flight Test becomes critically important.

A new airplane, or a newly modified airplane, is not built and immediately pressed into service. It must undergo rigorous flight testing. All the predictions made using the other three Tools are only that - predictions. Flight Test is when those predictions are finally proved or disproved.

Flight Tests require much advance planning and preparation. Instruments are placed in the airplane to record forces, pressures, control surface movements, pilot movement of controls, and radio communications. Every possible bit of information about the flight is recorded.

On the ground, tracking stations are set up. Microphones and cameras are readied. Barometers, thermometers and anemometers are installed to record the environment during the flight.

A precise and exhaustive list of all maneuvers that researchers want the pilot to fly are compiled in a test plan. Every action of the pilot is prescribed in this test plan - from takeoff to landing.



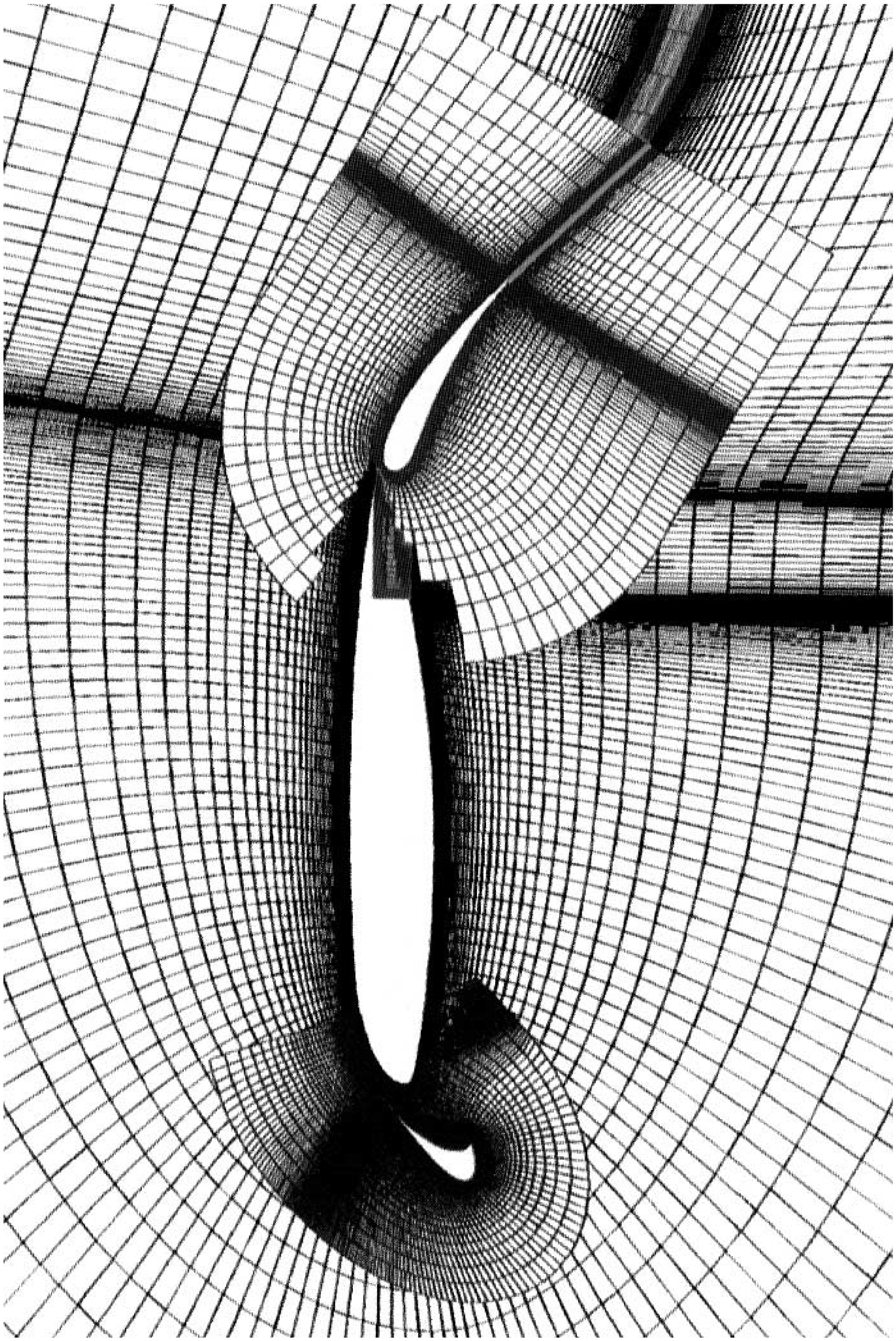
NASA Tiltrotor undergoing a flight test.

A test pilot receives hours of training, not only on how to fly and how to handle emergency situations, but how to accurately report what he or she is seeing, feeling, and hearing throughout the flight. Test pilots wear a flight suit that has snaps and straps that allow them to strap the test plan to one leg and a notepad on the other. Everything the pilots says is recorded and analyzed. A test pilot must be able to follow the flight plan precisely. And, if something goes wrong the test pilot must be able to quickly determine the cause of the problem and its severity. It is a point of honor for all test pilots to land their airplane. One of the most difficult but also the most challenging decision a test pilot must make is whether or not, when a problem arises, the airplane is still flyable. Unfortunately, history has seen test pilots who have "stuck it out" thinking they could successfully land the airplane, when in fact they couldn't. Being a test pilot is an incredibly demanding and dangerous occupation! The advent of flight simulators and CFD has helped reduce the risks of flight test by making sure the design is more mature before testing.

Based on the results of a flight test, an airplane may be tested further using one of the other three Tools, more flight tests may be recommended or it could be determined that the research questions have been adequately answered.

Overhead Guides

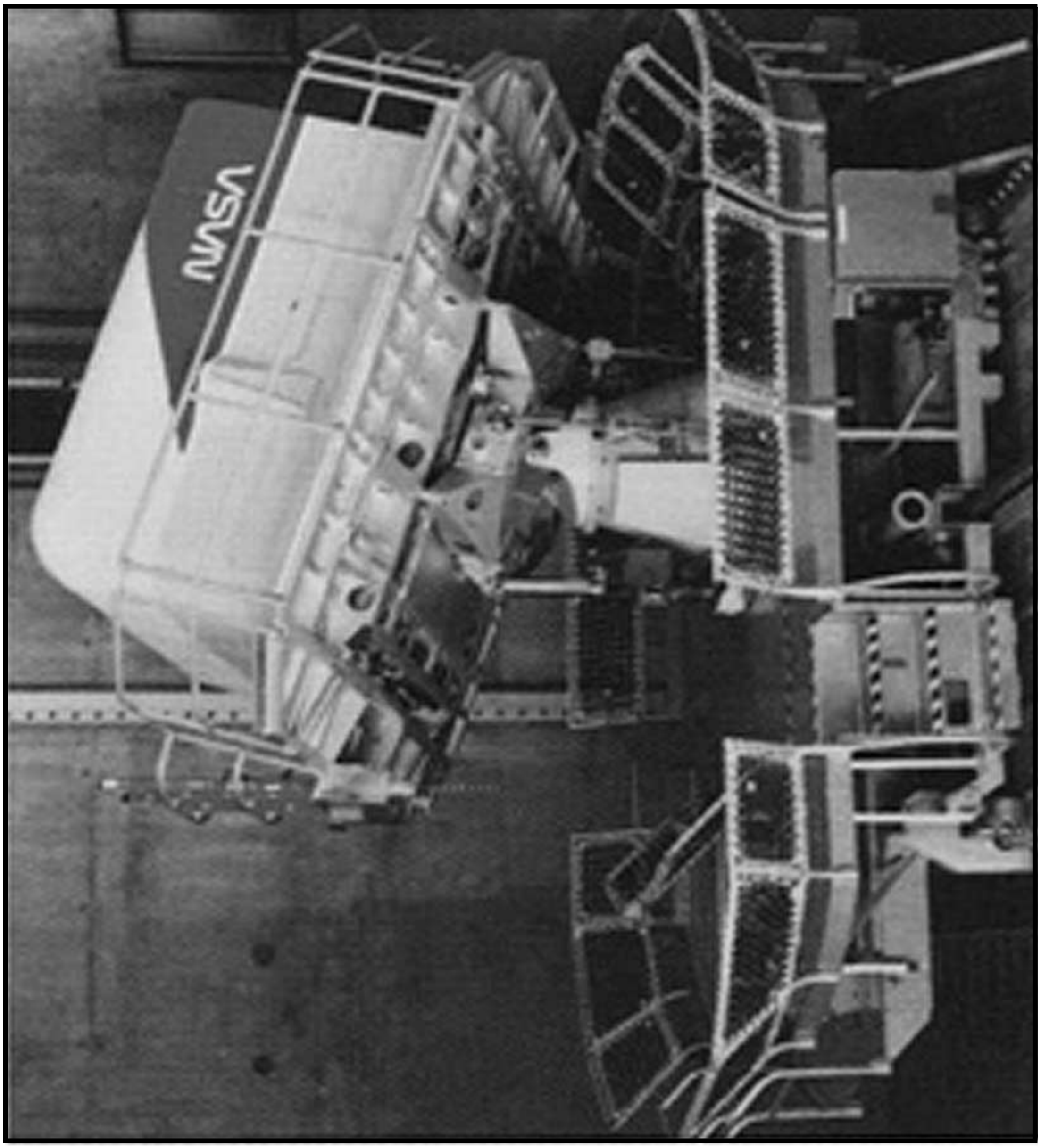
Computational Fluid Dynamics



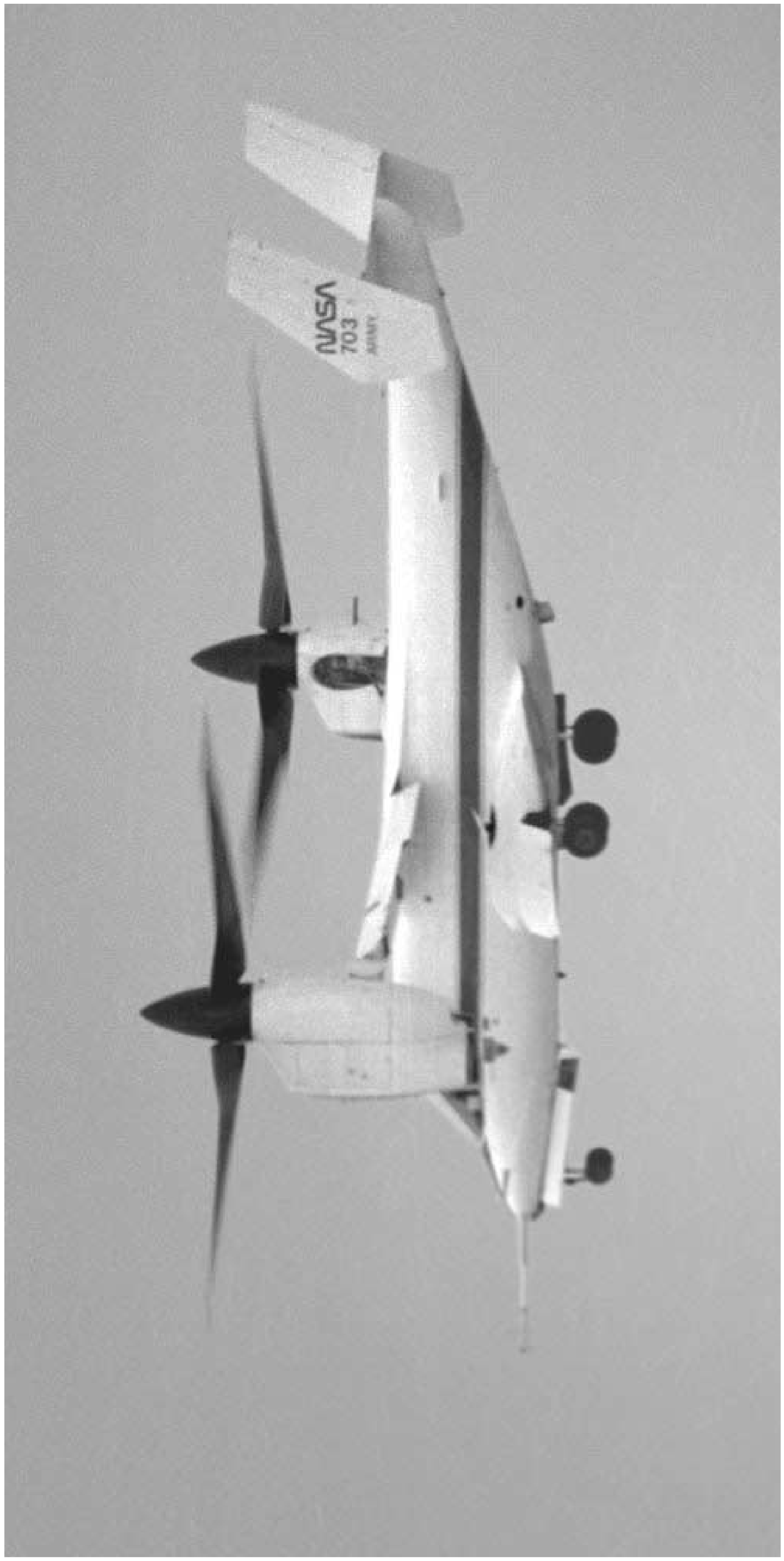
Computational Fluid Dynamics

Wind Tunnel

Flight Simulation



Flight Test



Student Reading

Tools of Aeronautics

Sometimes scientists create a **model** to help them explain how or why something works the way it does.

You may have seen model airplanes. These model airplanes are smaller than the real thing, and while the outside might look like the real thing, the inside does not. Many models are **scale models**. This means that every part of the airplane is made smaller by the same amount. Thus a scale model is an exact copy of the real thing - only smaller!

There are other types of models, too. A mathematical model is made up of mathematical equations that describe a real object - like an airplane. A mathematical model is stored in a computer. When special programs are run, researchers can fly the mathematical model in the computer, just like a pilot would in the real world. A video game of a race car is an example of a model stored on a computer.

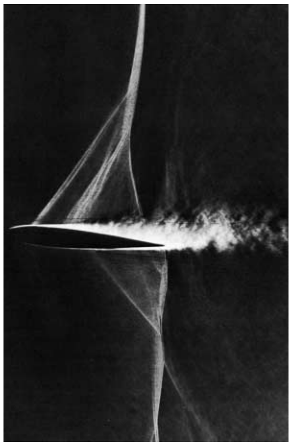
Either a scale model or a mathematical model can be used to test a researcher's hypothesis in a safe and controlled way. In aeronautics, researchers and engineers use models with four different tools to design and modify airplanes.

Aeronautical researchers can make a scale model and mount it in a **wind tunnel**. A wind tunnel is a tube or tunnel through which air is blown. So, instead of an airplane flying through the air, a scale model of the airplane is mounted in a wind tunnel and air is blown around it.

Some wind tunnels are very large and can hold models that are almost the size of the real airplane. Some wind tunnels are very small and can only hold very tiny scale models of the airplane, or maybe a scale model of a part of the airplane. Some very small wind tunnels can only blow air at over 3000 miles per hour, while some very large tunnels can blow air at less than 150 miles per hour. This may sound slow, but this is near takeoff and landing speeds for many airplanes. So, these big wind tunnels are very useful.

A model of an F-18 in the 80x120-foot test section.

Engineers place instruments on the scale model and in the wind tunnel to take measurements while the wind is blowing. They measure the forces on the model and the pressures. All the measurements are collected and analyzed so that the researcher's hypothesis may be proved or disproved.

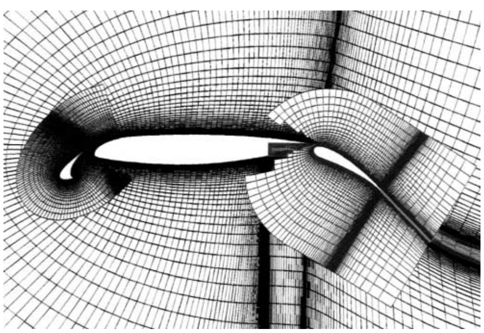


A model of an airfoil in a small wind tunnel

Another tool used by aeronautical researchers is **Computational Fluid Dynamics, or CFD** for short. With CFD, researchers use a mathematical model. This mathematical model is programmed into a computer. The researcher then "flies" the model and the computer measures the forces and pressures on the mathematical model. It is hard to imagine, but a mathematical model is just as "real" to a computer as a scale model is to you!

Very large and very fast computers are needed to do CFD. It wasn't until the supercomputer was invented that researchers were really able to use CFD. A supercomputer takes just one second to do what it would take a researcher over 30 years to do! Sometimes the mathematical model for an airplane is so complex that even though a supercomputer is very fast, it takes hours for the program to run.

A supercomputer

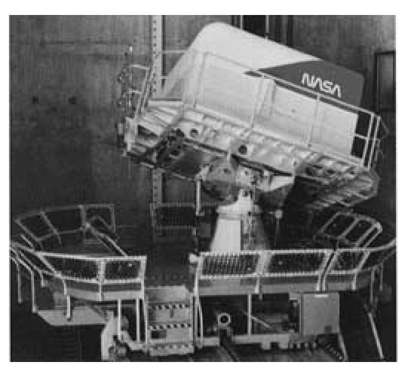


CDF (Computational Fluid Dynamics)

The computer can display graphical pictures of the forces and pressures on the model. Oftentimes the lines for the forces and pressures are drawn in many different colors. Each color represents the magnitude of the force or the amount of pressure. The pictures are really fun to look at! The computer can display information in ways that a wind tunnel cannot. The researcher can use this information to quickly and accurately prove or disprove his or her hypothesis.

Mathematical models are also used to drive a third tool of aeronautics - **flight simulators**. Maybe you are familiar with flight simulators on your home computers or at arcades. The flight simulators used by NASA are much larger and much more complex than those used in other places.

Instead of displaying pictures of the mathematical model, a flight simulation computer uses the mathematical model to control a cockpit that is built to look just like a real airplane.

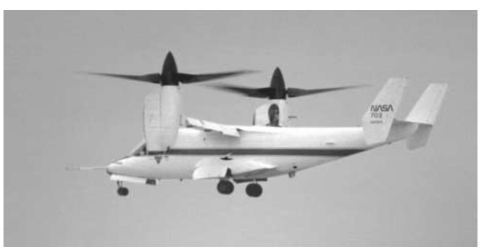


Vertical Motion Simulator (VMS)

This cockpit is placed on a motion system that enables it to move and turn in all different directions. The computer also generates out-the-window scenes that make the pilot think that he or she is flying in the real world. The computer also generates sounds and makes the controls in the cockpit act just the controls in the airplane.

A test pilot climbs into the flight simulator and feels like he or she is climbing into a real airplane. During a flight simulation, the test pilot will report on how the simulated airplane handles. This is important for developing a new aircraft design. Different airplanes handle differently - just like different cars handle differently! Sometimes pilots will learn to fly an airplane unfamiliar to them in a simulator. Sometimes pilots will practice new maneuvers or learn what to do in case of an emergency. It is a lot safer to practice new skills in a simulator than it is in a real airplane!

The fourth tool of aeronautics is **flight test**. While all the tools we've talked about so far use only models of airplanes, in flight test real pilots fly real airplanes. Test pilots fly a new or modified airplane according to a test plan. This test plan tells the pilot exactly what to do - from takeoff to landing. During the flight test, the pilot reports on his or her experiences. Instruments are also mounted in the airplane and on the ground to measure information about the test.


NASA Tiltrotor undergoing a flight test.

Being a test pilot is a very important career. It also can be dangerous! Sometimes a new or modified airplane will not respond in a way that was predicted by other tests. This can cause an emergency situation. The test pilot must quickly determine what the cause of the problem is and whether the airplane is still flyable. A test pilot would always prefer to land their airplane. However, sometimes the airplane has been damaged or a critical part has failed in which case the pilot must decide whether to try to land or bail out. All of these decisions must be made in a matter of seconds!

All of the four tools of aeronautics are used to help researchers prove or disprove their hypotheses. Aeronautical engineers and researchers use the Scientific Method, just like you are learning to do. Sometimes a hypothesis made by an engineer or researcher is correct and sometimes it is not. But, in all cases, they learn how and why things work the way they do by using the Scientific Method.

Student Note Taking Guide

Big Ideas	Important Little Details
model	helps to explain how or why something works the way it does scale model is exact replica - just smaller mathematical model is a model in a computer
wind tunnel	tube or tunnel through which air is blown scale model mounted in tunnel tunnels can be either large or small wind can blow very fast or slow instruments placed in the model to measure forces and pressures measurements collected and analyzed to prove or disprove a hypothesis
CFD	mathematical model used fly model in computer and measure forces and pressures need supercomputers display graphical pictures of forces and pressures can quickly analyze picture and prove or disprove hypothesis
flight simulation	mathematical model used like flight simulators at home or in arcades - but more complex computer uses mathematical model to control simulator: cockpit, motion system, sound, controls, out-the-window scenes pilot feels just like he or she is in a real airplane pilot testing how airplane handles simulators used to train or practice
flight test	real pilots fly real airplanes fly according to a test plan pilot reports on his or her experiences instruments in the airplane or on the ground measure information test pilot very important career - must make decisions quickly
summary	all four tools used to prove or disprove hypothesis researchers and engineers use Scientific Method sometimes a hypothesis is correct, sometimes it is not in all cases researchers and engineers learn from using the four tools

2.5.4 Student Worksheet

Student Worksheet

Tools of Aeronautics

1. Explain why scientists make a model.

2. Name two different types of models.

3. List the four tools of aeronautics.

4. In your own words, explain what CFD is.

5. In your own words, explain how a wind tunnel works.

6. Why do you think researchers don't just build a plane and fly it, but use the tools of aeronautics to test it.

Student Worksheet – Key
Tools of Aeronautics

1. Explain why scientists make a model.

   to explain how or why something acts the way it does

2. Name two different types of models.

   scale model and mathematical model

3. List the four tools of aeronautics.

   wind tunnels
   CFD
   flight simulation
   flight test

4. In your own words, explain what CFD is.

   A mathematical model is programmed into a computer. The researcher then flies the model in the computer. The computer measures the forces and pressures on the model.

5. In your own words, explain how a wind tunnel works.

   Engineers/researchers mount a scale model in a wind tunnel. Instruments are mounted on the model. When the wind blows, the instruments measure the forces and pressures.

6. Why do you think researchers don't just build a plane and fly it, but use the tools of aeronautics to test it.

   it's safer
   it's cheaper - instead of building, testing, re-designing, re-building all of this can be done with models
   airplane is more thoroughly tested using all four tools

Experiment: Air Pressure and Current of Air

Procedure Card

Materials

ping-pong ball
piece of string 30 centimeters long
tape
soda straw
hanging apparatus (ring stand)

Experiment Set Up

Tape one end of the string to the ping-pong ball.

Attach the other end of the string to the hanging apparatus so that the ball hangs freely.

Experiment Procedure

1. Gather materials.

2. With the ball in a still position, blow through the drinking straw so that the current of air passes alongside the left side of the ball. Do not blow directly on the ball or touch the ball with the straw.

3. Observe and record.

4. Repeat step 2, but blow through the straw so that the current of air passes alongside the right side of the ball.

5. Observe and record.

Experiment Log - Key

Page 1

Experiment: Air Pressure and a Current of Air

Steps	Data
1. <u>State the problem.</u> **QUESTION** *(What do I want to know?)*	What is the effect of a current of air (airstream) on an object? OR Does an airstream (current of air) have an effect on objects it blows by?
2. <u>Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	I think the airstream will push the ball away. OR I think the airstream will create a low pressure area close to the ball and the ball will move toward that.
3. <u>Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	Materials: ping-pong ball • tape • thread • straw • ring stand Procedure: 1. Gather materials. 2. Hang ball in a still position. 3. Blow through straw so air travels alongside the left of the ball. 4. Observe and record. 5. Repeat steps 3-4, but blow to the right of the ball.

Experiment Log – Key

Page 2

Experiment: Air Pressure and a Current of Air

Steps	Data
<u>4. Perform the experiment.</u> **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*1. Ball moved to the left, closer to the airstream.* *2. Ball moved to the right, closer to the airstream.*
<u>5. Organize and analyze data.</u> *(Make a graph, chart, picture or diagram.)*	
<u>6. Draw conclusions.</u> *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*Because a moving current (stream) of air lowers the air pressure, the ball will move toward the area of low pressure. It does not move directly into the path of the air, but stays on its edge.*

Experiment: Object Shape and Drag
Procedure Card

Materials

3 identical sheets of notebook paper:
- 1 crumpled into a tight ball
- 1 smooth and flat
- 1 rolled into a tight cone and secured with two short pieces of tape

Tape
Measuring stick

Experiment Set Up

Crumple one sheet of notebook paper into a tight ball.

Tightly roll another sheet of notebook paper into a cone shape. Secure the flap with one small piece of tape at the smaller end of the cone and another small piece of tape at the larger end.

Measure two meters from the floor and mark that point. This will serve as the starting point for the drop.

Experiment Procedure

1. Using more than one person to hold the pieces of paper, hold all three pieces at the two meter mark. Hold the flat sheet of paper horizontally (or parallel to the floor).

2. Release all three at the same time.

3. Observe and record the order in which each piece of paper contacts the ground.

4. Repeat the drop four more times and observe and record

Experiment Log - Key

Page 1

Experiment: Object Shape and Drag

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	How does an object's shape affect drag? Will objects of different shapes, but same mass and weight have different amounts of drag? Will 2 objects of the same mass, weight and material have different amounts of drag depending upon their shape?
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	The more rounded an object is, the less drag it will have compared to a squarer or wider or flatter shaped object of the same weight (or mass) because there will be less/ smoother surface area to create drag.
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	Materials: 3 identical sheets of notebook paper:1 crumpled into a tight ball • 1 smooth and flat • 1 rolled into a tight cone and secured with two short pieces of tape • Tape • Measuring stick Procedure: 1. Using more than one person to hold the pieces of paper, hold all three pieces at the two meter mark. Hold the flat sheet of paper horizontally (or parallel to the floor). 2. Release all three at the same time. 3. Observe and record the order in which each piece of paper contacts the ground. 4. Repeat the drop four more times and observe and record.

Experiment Log - Key

Page 2

Experiment: Air Pressure and a Current of Air

Steps	Data
4. <u>Perform the experiment.</u> **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*The flat sheet was always last.* *Most of the time the cone hit the ground first with the ball right after.* *A few times the cone and ball hit at the same time.*
5. <u>Organize and analyze data.</u> *(Make a graph, chart, picture or diagram.)*	see table below
6. <u>Draw conclusions.</u> *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	*Because the flat piece always hit the ground last, it has the most drag. It has the most drag because its wide shape catches a lot of air (molecules) under it -- this makes it float. Both the cone and the ball are rounded shapes that allow the air to move smoothly around it, and not much air gets trapped underneath.*

	Flat	Cone	Ball
Drop # 1	3	1	2
Drop # 2	3	1	2
Drop # 3	3	1	1
Drop # 4	3	2	1
Drop # 5	3	1	2

Additional Student Activities

- Students and other more skilled volunteers can build their own classroom or grade level wind tunnel and perform their own experiments. A fan can be used to blow the air.
- Perform additional research on the physical structure of wind tunnels (their size, for example), then draw and label a diagram of a wind tunnel.
- Create a flowchart that depicts the testing of an airplane going through the development process.
- Debate the issue of the importance of aeronautical research to our modern society.

Writing Experiences

- Pretend you are a model of an experimental aircraft and have been placed in a wind tunnel. Write a descriptive paragraph that tells about your experience in the wind tunnel. Try to describe the way it feels as the air flows around you.
- Write a test plan for a flight simulation or a flight test. Remember to tell the test pilot exactly what to do.
- Pretend you are a test pilot and write a letter to your cousin telling him or her about your recent flight test experience.

Project
Creating an Airflow Relief Sculpture

Most sculptures you probably have seen are free standing. That means the artistic piece can stand by itself. Another type of sculpture is meant to hang on the wall like a painting, but it does not have a flat surface. It's surface is in "relief." "Relief" means that it is raised above a flat surface - it sticks out a little.

You have learned about wind tunnels and have observed pictures, photographs and results of wind tunnel experiments. For this project you will artistically show in a relief sculpture, an airplane or airfoil and the airflow around it during a wind tunnel test. Follow the steps below to create your Airflow Relief Sculpture.

1. Gather the following materials:

   aluminum foil
   clay
   glue
   scissors
   cardboard piece (25 cm x 25 cm)

   "relief" items of your choice:

   popsicle sticks
   yarn
   string
   parts of Styrofoam containers
   parts of plastic containers
   toothpicks
   plastic eating utensils
   bits of wood

2. Arrange the objects as you desire on the cardboard piece. Keep in mind you are trying to depict the airflow around an airfoil or wing during a wind tunnel test.

3. Once the pieces are arranged the way you like them, glue or fasten them securely to the cardboard.

4. Cover the relief (not tightly) with aluminum foil. Carefully rub it down with a soft, damp cloth so that all the shapes underneath it show up clearly.

Critical Thinking Questions

1. Explain why you think we would need different sized wind tunnels for research?
2. How important do you think computers are to research?
3. Explain in your own words how a wind tunnel actually works.
4. Why are aeronautical tools so important to aeronautics?
5. How has research on airflow changed the way we make airplanes?
6. How has research on airflow changed the way we fly airplanes?
7. Explain the benefits of wind tunnel research.
8. List the differences between flight test and flight simulation.
9. How important do you believe aeronautical research is to our modern society?
10. Explain how the Scientific Method is a part of aeronautical research.

Quick Quiz

Tools of Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. Which tool of aeronautics is a tube or tunnel through which air is blown?

    A. computational fluid dynamics
    B. wind tunnel
    C. flight simulation
    D. flight test

2. What are the two types of models that aeronautical researchers use?

    A. scale model and mathematical model
    B. scale model and aerodynamic model
    C. mathematical model and aerodynamic model

3. Which tool of aeronautics uses mathematical models and supercomputers?

    A. computational fluid dynamics
    B. wind tunnel
    C. flight simulation
    D. flight test

4. Why do scientists make a model?

    A. it is easier to work with larger objects
    B. to explain how or why something acts the way it does

5. Which tool of aeronautics uses a prototype with special instruments attached to it, and a real pilot who flies according to a test plan?

    A. computational fluid dynamics
    B. wind tunnel
    C. flight simulation
    D. flight test

Quick Quiz - Key

Tools of Aeronautics

Directions: Circle the letter of the answer that best answers the question.

1. Which tool of aeronautics is a tube or tunnel through which air is blown?

   A. computational fluid dynamics
   B. wind tunnel
   C. flight simulation
   D. flight test

2. What are the two types of models that aeronautical researchers use?

   A. scale model and mathematical model
   B. scale model and aerodynamic model
   C. mathematical model and aerodynamic model

3. Which tool of aeronautics uses mathematical models and supercomputers?

   A. flight test
   B. wind tunnel
   C. flight simulation
   D. computational fluid dynamics

4. Why do scientists make a model?

   A. it is easier to work with larger objects
   B. to explain how or why something acts the way it does

5. Which tool of aeronautics uses a prototype with special instruments attached to it, and a real pilot who flies according to a test plan?

   A. computational fluid dynamics
   B. wind tunnel
   C. flight simulation
   D. flight test