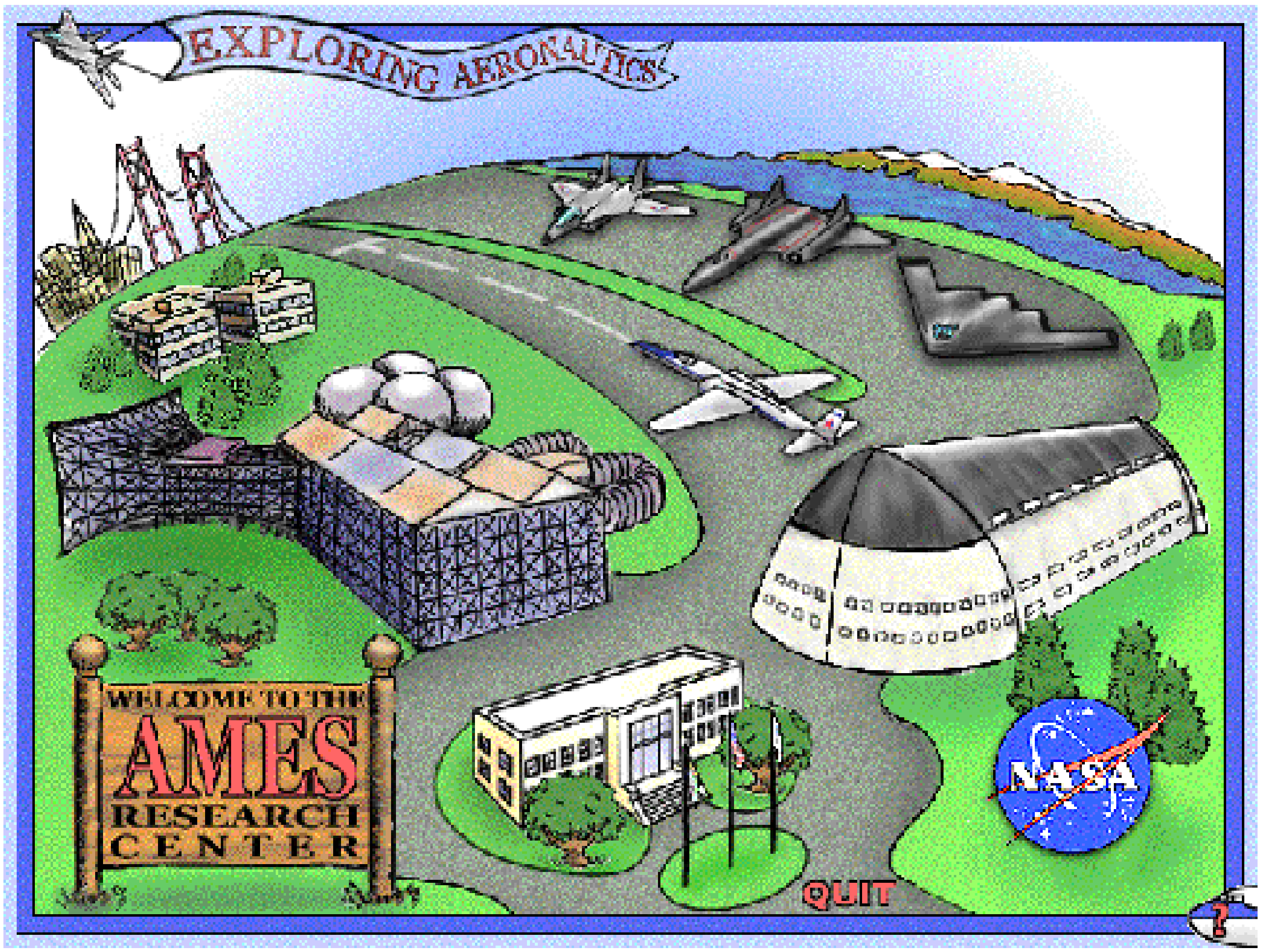
Regimes of Flight

A Supplemental Aeronautics Guide



To accompany EXPLORING AERONAUTICS CD-ROM
and Supplemental Unit *Integrating with Aeronautics*
A curriculum in Aeronautics for the 5th through 8th
grade level

aero-nau-tics \-iks\ *n pl but sing in constr* **1**: a science of dealing with the operation of aircraft **2**: the art or science of flight

Regimes of Flight

A Supplemental Aeronautics Guide

produced by the

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Program Goals

1. To stimulate and increase student awareness of, interest in and achievement in science. Specifically, to stir young people's imagination and fuel their enthusiasm for the study of science, mathematics and technology using the fundamental themes of aeronautics.

2. To engage students in learning activities which increase their understanding of aeronautics-related concepts.

Goals and Objectives

Goal 1

To use the Scientific Method to answer a question or solve a problem.

Objectives

The Learner will be able to:

- recite the steps of the scientific method;
- develop each part of the scientific method:
  - identify a question,
  - identify a hypothesis,
  - construct an experiment;
- list procedures which will complete the experiment:
  - list materials needed to perform experiment,
  - perform experiment;
- record results of experiment:
  - write a conclusion;
- observe and record the observations;
- identify a new question generated by the experiment.

Goal 2

To understand that there are different types of vehicles which have been designed to fly for specific purposes and in specific ways.

Objectives

The Learner will be able to:

- identify and describe the basic categories of vehicle types;
- identify and describe the different regimes in which vehicles fly;
- compare aircraft types based upon their flight characteristics;
- compare aircraft types based upon their structure;
- compare aircraft types based upon how each generates lift;
- define the speed of sound;
- describe the phenomenon of flight at the speed of sound;
- identify and describe how sound travels in waves;
- identify the historical significance as each regime was established.

Goals and Objectives – *continued*

Goal 3

To understand the four forces and their effects on aircraft in each regime.

Objectives

The Learner will be able to:

- name and define each of the four forces;
- describe the effect of each of the four forces upon an aircraft in each regime.

Correlation to the National Science Education Content Standards

Unifying Concepts and Processes

- Systems, order and organization
- Evidence, models and explanation
- Form and Function

Content Standard A

Students should develop abilities necessary to do scientific inquiry.

- Identify questions that can be answered through scientific investigations.

Students should design and conduct a scientific investigation.

- Use appropriate tools and techniques to gather, analyze, and interpret data.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.

Students should develop understandings about scientific inquiry.

- Current scientific knowledge and understanding guide scientific investigations.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigation.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
- Scientific investigations sometimes result in new ideas and phenomena for study....

Content Standard B: Physical Science

All students should develop an understanding of motions and forces.

- The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.
- An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Content Standard E: Science and Technology

All students should develop understandings about science and technology.

- Many different people in different cultures have made and continue to make contributions to science and technology.
- Science and technology are reciprocal.
- Perfectly designed solutions do not exist.
- Technological designs have restraints.
- Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

Content Standard F: Science in Personal and Social Perspectives

All students should develop an understanding of science and technology in society.

- Science influences society through its knowledge and world view.
- Societal challenges often inspire questions for scientific research....
- Technology influences society through its products and processes.
- Science and technology have advanced through contributions of many different people, in different cultures, at different times in history.
- Scientists and engineers work in many different settings....

Content Standard G: History and Nature of Science

All students should develop understanding of science as a human endeavor.

- Women and men of various social and ethnic backgrounds...engage in the activities of science, engineering.... Some scientists work in teams, and some work alone, but all communicate extensively with others.
- Science requires different abilities, depending on such factors as the field of study and type of inquiry.

All students should develop understanding of the Nature of Science.

- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists.

Daily Lesson Planner

Day 1

- Use the overhead guides to help illustrate the student reading on *Regimes of Flight*.
- Hand out copies of student reading and note taking guide with the details side blanked out.
- Read aloud to class and model note taking as you go.
- Read, discuss and take notes.
- Student Activity Sheet: Regimes of Flight

Day 2

- Read and discuss student reading *Speed of Sound* at this time or do this later as need for this information arises.
- Student Activity Sheet: Speed of Sound

Day 3

- Review procedure for the experiment "Air has Weight".
- Hand out procedure card and lab sheet for said experiment.
- Students do experiment (partners, small groups, etc.).
- Using the overhead guides for this experiment, review results with the class. Model what a well written hypothesis and conclusion look like.

Day 4

- Review procedure for the experiment "Air has Stuff in It".
- Hand out procedure card and lab sheets for said experiment.
- Have students do experiment (partners, small groups, etc.).
- Using the overhead guides for this experiment, review results with the class. Model what a well-written hypothesis and conclusion look like.

Day 5 - 10

- Choose one or more of the activities listed under Additional Student Activities/ Projects.

Teacher Reading
Aircraft Speedline

Aircraft can be grouped by the range of speed in which they are designed to operate. Aircraft speed has improved with time; consequently, our discussion of aircraft speed will also follow the development of aircraft over time. The "Aircraft Speedline" is divided into five speed ranges, called regimes. Each section below discusses the speed range, design issues, and types of aircraft for these speed regimes, as well as the characteristics that limit the speed in each category.

Low Speed Flight, 0-100 MPH

The early development of human flight includes air vehicles in this speed range. The first air vehicles included kites, balloons, and gliders. These unpowered aircraft were very slow. The development of relatively lightweight engines paved the way for early airships and winged aircraft, but the materials, knowledge and technology available limited these aircraft to low speeds.

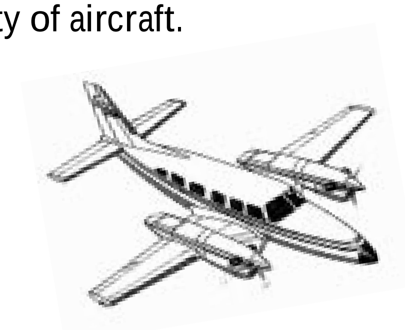
These vehicles had to be very lightweight because of the limited power of the available engines. To build lightweight structures, designers used external bracing. That, and the open fuselage designs of the day, resulted in vehicles with high drag. So the limited thrust available was overcome by the drag produced even at speeds as low as 50 mph. The most famous example is the 1903 Wright Flyer.

Modern vehicles in this category include kites, balloons, hang gliders, ultra-light hobby aircraft, and airships. As in the early days, these aircraft are limited by the power available from small, light engines and by lightweight structures.These aircraft are generally faster than their predecessors because of stronger, light-weight materials (nylon and aluminum), improved knowledge of aircraft design, and improved engines (with a higher ratio of power to weight).

Medium Speed Flight, 100-350 MPH

In order to build faster aircraft, several areas or technologies had to be improved. First, the drag had to be reduced substantially. This was accomplished largely by developing enclosed, streamlined fuselages and stronger wings that did not require external bracing. This meant the structure had to be made stronger, but hopefully not heavier. Thus, materials and structures were developed with a higher ratio of strength to weight. Next, the thrust had to be greatly increased without making engines too heavy. Thus, the engine's ratio of power to weight increased. All of these areas improved in a leapfrog manner. For example, a new engine might be developed with 50 percent more power (good!) that weighed 25 percent more (not so good!) Note that this engine has a higher power-to-weight ratio, but it also weighs more. To carry this extra weight, the fuselage would have to be stronger and heavier. The resulting aircraft might not really be faster until it could be designed to be lighter. Finally, our knowledge of aerodynamics improved through the use of new tools such as wind tunnels and a lot of basic research.

The vehicles that are found in this regime are limited by the source of the thrust and, to a lesser extent, the drag. The engines are almost all propeller types, and the wings are almost all straight and fairly thick. Vehicles in this category are propeller craft like Fokker, Junkers, Cessna and Beechcraft. The need for higher-performance aircraft during WWII accelerated the development of aircraft in this speed regime. At the same time that speed was being improved, so was the carrying capacity of aircraft.



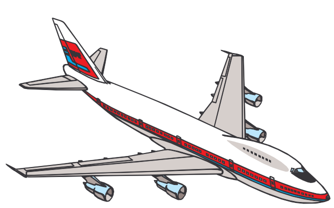
High Speed Flight, 350-760 MPH

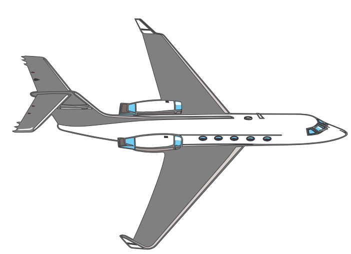
In order to go faster, aircraft needed engines with even higher performance (power/weight). The development of the jet engine was the first key to faster aircraft. As aircraft exceeded 500 mph, the drag increased rapidly, and a new aircraft design was needed to reduce the drag. The development of the thin, sweepback wing provided the second key to high speed flight. As before, improvements in aerodynamic knowledge and technologies such as materials contributed to the evolution of modern, high-speed aircraft.

The resulting vehicles were limited by the power of their engines and the amount of drag they made. Generally, the more swept the wings, the faster they could go. They were all sleek-looking shapes that minimized drag as much as possible. Aircraft were approaching the speed of sound, and drag was increasing dramatically. The speed of sound is about 760 mph at sea level and about 650 mph at 35,000 feet, and is called Mach 1 (for one times the speed of sound). At these speeds, the air has difficulty "flowing" around the airplane, with the result that shock waves form and drag increases dramatically. Also, the aircraft was difficult to control at these speeds. This largely limited aircraft to flying below the speed of sound, called subsonic flight. There are no airplanes that spend significant time flying between 700 and 800 mph because of the high drag and the control issues.

Modern airplanes that fly slower than the speed of sound (fast, but still subsonic) all peak out in speed well short of the speed of sound (below Mach <0.9). Higher speed flight would be desirable, but today the best tradeoff between speed and economy for transporting a large number of passengers or cargo is near Mach 0.8. Vehicles in this class are the commercial Boeing 700 series, the Boeing B-47 Strato Jet, Vickers Viscount, the Lear Jet, and many military aircraft.

Speed of Sound: The actual speed of sound depends on the compressibility and density of the air as well as its temperature. This means that an airplane flying at the speed of sound at ground level under normal atmospheric conditions will actually be flying at a speed of 760 mph. However, while flying the at the speed of sound at 37,000 feet at normal stratosphere temperature, the airplane would actually be flying about 660 mph. If an airplane is flying slower than the speed of sound we say it is moving at subsonic speed. If it is flying at the speed of sound it is traveling at sonic speed. If it is flying faster than the speed of sound we say it is traveling at supersonic speed. When we refer to the speed of sound we measure it in Mach numbers. If an airplane is traveling at Mach 1 it is moving at sonic speed or at the speed of sound. If it is traveling at Mach 2 it is moving at two times the speed of sound. The word "Mach" comes from the Austrian scientist Ernst Mach who studied airflow and the speed at which sound travels.



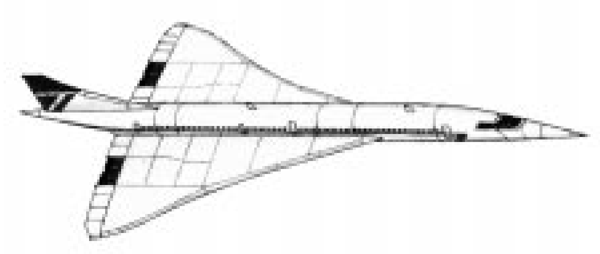


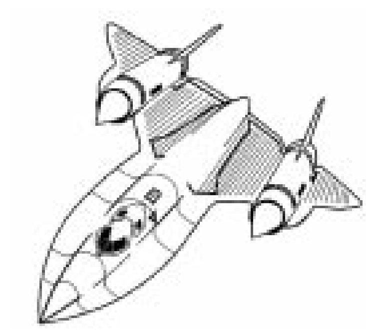
Supersonic Flight, 760-3,500 MPH (Mach 1 to Mach 5)

With the desire to fly faster, primarily for military aircraft, aeronautics technologies were developed to fly efficiently above Mach 1. Efficiency is a relative term—the aircraft are still very expensive to operate and most are for military use. To date, only one aircraft, the Concorde, provides commercial transportation above Mach 1. Efforts are underway to develop new technologies so that a more cost-effective supersonic airplane can be built in the future.

Supersonic aircraft have special high-performance jet engines that can make a lot of thrust, very thin wings that have lots of sweep, and use novel materials to provide strength. Early fuselages tended to be shaped like a wasp's body (thin at the waist). The thinning of the fuselage helps reduce the drag that the airplane makes when flying near the speed of sound. It is relatively easier to fly above Mach 1 than near Mach 1. Hefty engines are needed to provide the thrust necessary to push the airplane through the air at such high speeds. The wings are super thin and swept to slice through the air while making as little disturbance as possible. The most modern supersonic aircraft spend so little time near Mach 1 and have such powerful engines, that they are not shaped as much like a wasp's body. Still, these aircraft have sleek overall shapes that are carefully designed to minimize supersonic drag.

It is interesting that airplanes designed to fly supersonically do not fly very well at subsonic speeds. The same features that let them fly fast do not work well when flying slowly. In fact, flight at the lowest speeds—takeoff and landing—is an extra challenge when designing these aircraft. Vehicles in this category include the commercial airliner Concorde, F-15 Eagle and the SR-71.





Hypersonic Flight, 3,500-7,000 MPH (Mach 5 to Mach 10)

With the advent of rocketry, the first hypersonic vehicles were developed. Although they are not airplanes, rockets travel at these speeds as they accelerate into Earth orbit. Also, re-entry capsules such as those in the Apollo program travel at these speeds as they descend from orbit.

Once again, new technologies and new vehicle shapes had to be developed for hypersonic flight. In particular, new materials had to be developed to handle the intense heating caused by atmospheric friction.

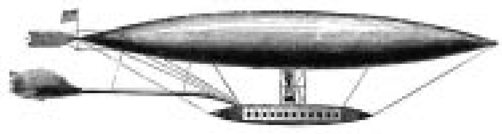
The best known examples of hypersonic flight vehicles are the rocket-powered X-15 and the space shuttle which flies through all of the speed regimes when it re-enters the Earth's atmosphere. The space shuttle is coasting from a very high speed and high altitude when it flies hypersonically. It is decelerating the entire time. There are no aircraft today that can cruise at these speeds.

Research programs are underway to develop new engines that can operate at these speeds so that we can develop aircraft to cruise in this speed regime. Two such experimental aircraft currently being tested include the X-33 and the X-34. It is a tremendous challenge to design an airplane shape and an engine that can take off subsonically, accelerate through supersonic speeds, and cruise efficiently hypersonically.

What's faster than hypersonic? Hypersonic flight occurs at very high altitudes where the air is very thin. This helps reduce the drag and the heating due to friction. This thin air and high speed is part of what makes it so difficult to design an engine for these aircraft. To fly faster than hypersonic speed requires even thinner air at higher altitude. At these speeds and altitudes a vehicle is essentially outside our atmosphere and would more correctly be called a spacecraft. The space shuttle is both a spacecraft and aircraft.

Overhead Informational Guides

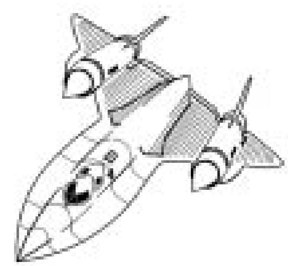
- low speed



- medium speed

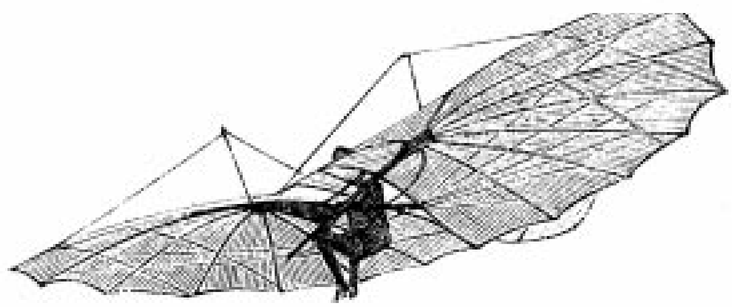
- high speed

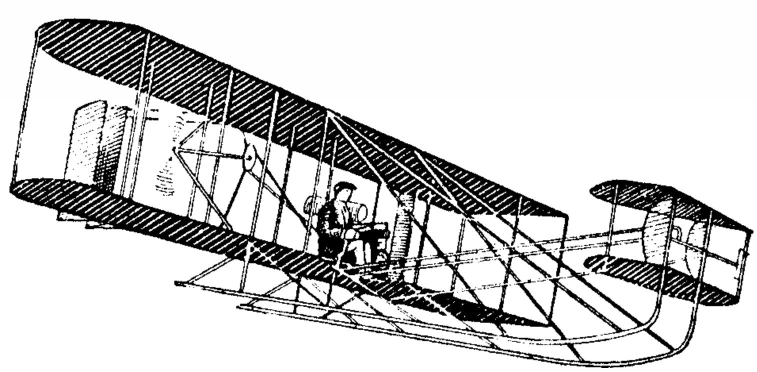
- supersonic speed



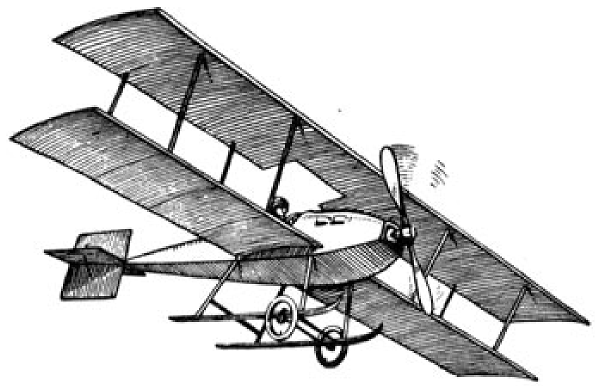
- hypersonic speed

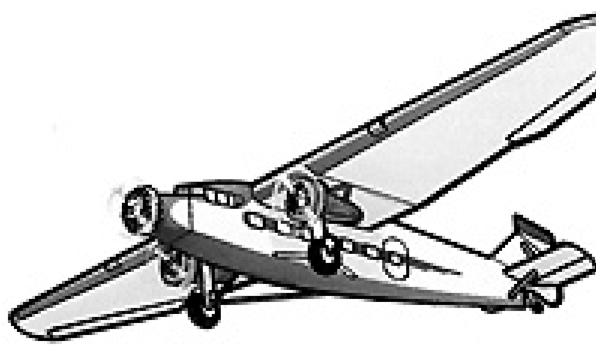
Low Speed



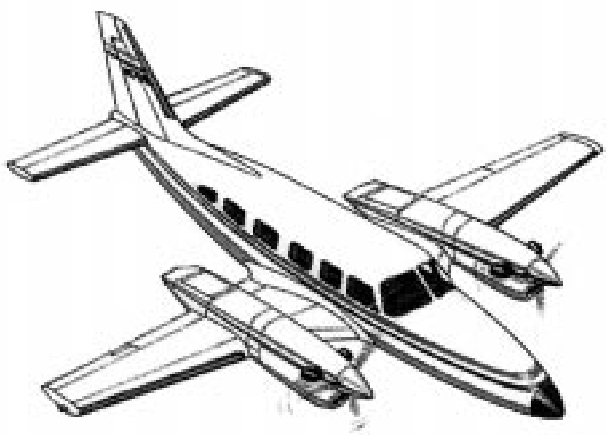


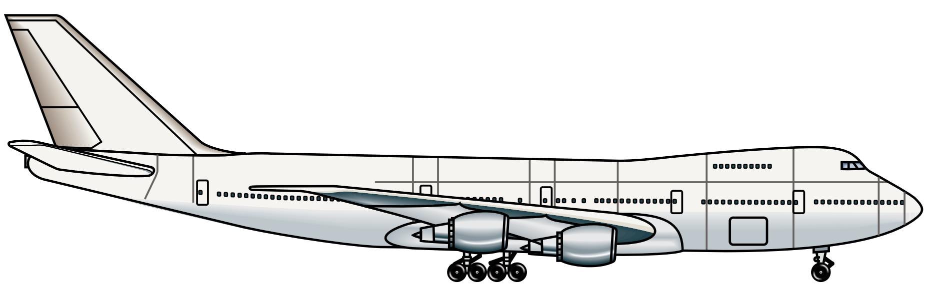
Medium Speed



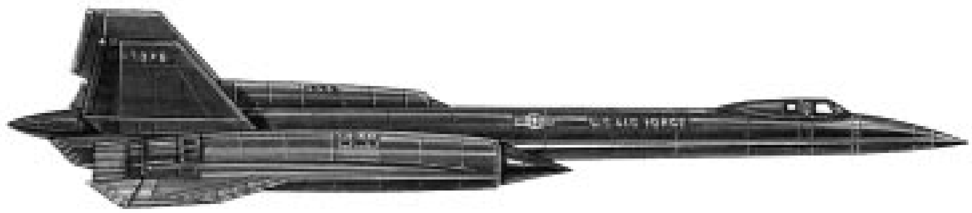


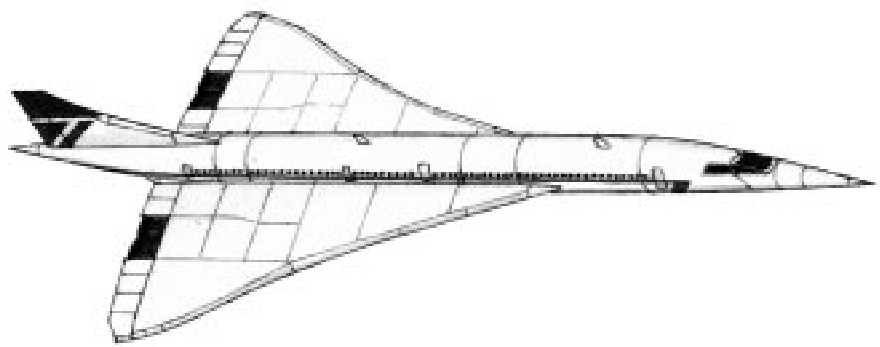
High Speed

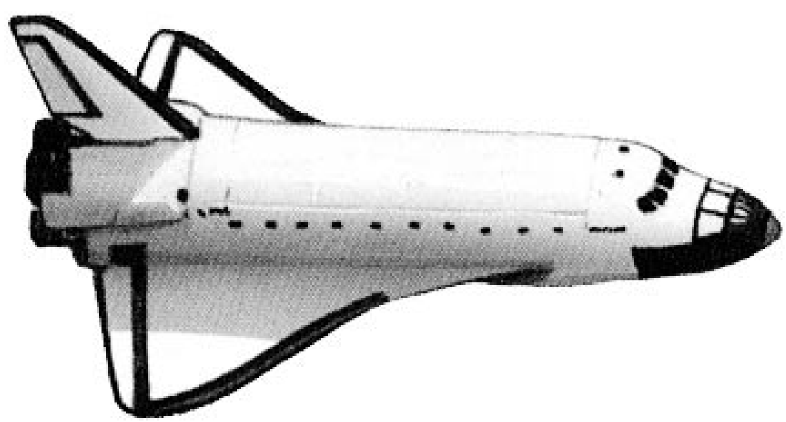




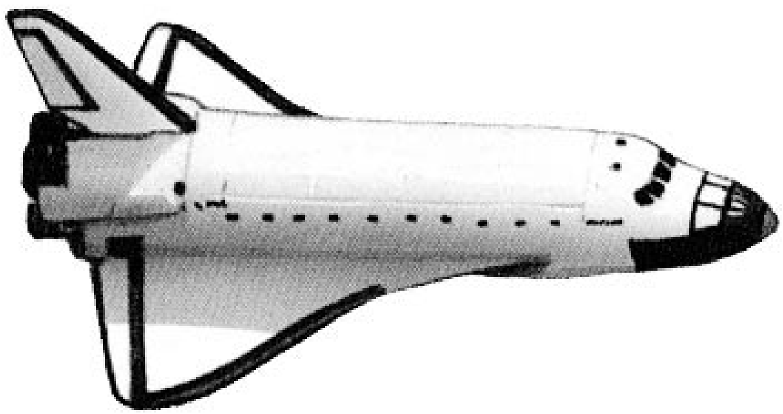
Supersonic Speed





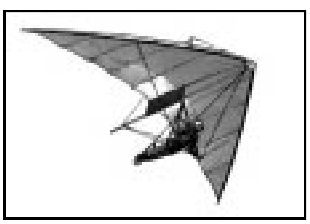


Hypersonic Speed

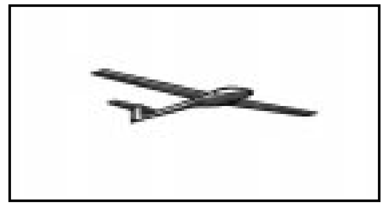


Student Reading
Regimes of Flight

After the invention of the airplane, designers and engineers created new aircraft for a variety of uses. Airplanes became a part of daily life. Aircraft were used regularly to ship cargo and to transport people. Over time, the speed of aircraft has increased. We put aircraft into groups based upon how fast they can fly. We call these groups the speed regimes (pronounced "ra-jeems") of flight. There are five basic speed regimes. These include the earliest aircraft to the most modern.

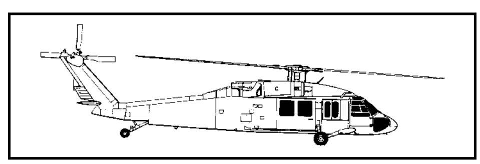


The first speed group flies in the low speed regime. Aircraft in this group travel at speeds between 0 and 100 miles per hour (mph).These tend to be lightweight vehicles with a small engine or no engine at all. The aircraft in this group include the earliest types of aircraft, such as kites, balloons and early airplanes. Modern aircraft in this speed regime are hang gliders, balloons, ultralights and airships (blimps, dirigibles).

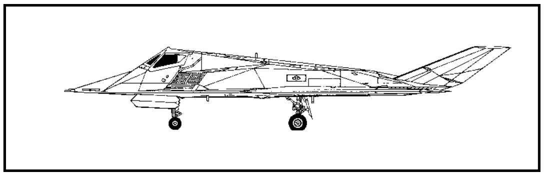


The second group flies in the medium speed regime. These aircraft fly between 100 and 350 mph. These vehicles are usually airplanes with straight, thick wings.This category includes sailplanes, biplanes, propeller planes, helicopters and autogyros. Early German-made planes like the Fokker and the Junkers are in this category. Small planes, like the modern Cessna and Beechcraft, are also grouped within this speed regime.

The third group flies in the high speed regime. The aircraft in this category are the powerful propeller airplanes and jet planes that fly between 350 and 700 mph. These vehicles usually have thin, sweepback

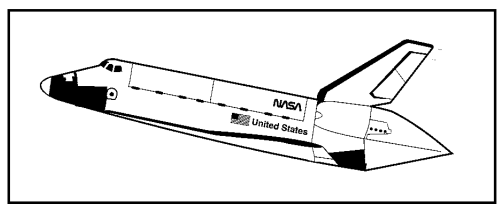


wings. The greater the sweep, the faster they can go. The fuselage is a sleek shape. The Boeing 747 Jumbo Jet, the Lear Jet, the Sikorsky Blackhawk helicopter and many fighter planes fly within this speed regime.



The fourth group flies in the supersonic speed regime. This group includes aircraft that can go faster than the speed of sound, which is approximately 760 mph. The supersonic speed regime goes up to 5 times the speed of sound. These vehicles have high-powered jet engines, a sleek fuselage and super thin, sweepback or delta wings. The Concorde, the F-15 Eagle, and the SR-71 Blackbird are some examples of airplanes that can fly at supersonic speeds. The X-1 was the first plane to fly faster than the speed of sound.

The last speed regime is hypersonic flight, which is between 5 and 10 times the speed of sound. This is 3,500-7,000 mph. These vehicles have high-powered rocket engines with short, thin wings.They have highly advanced heat protection systems to protect the aircraft from the extreme heat faced during re-entry. Rockets travel at these speeds as they accelerate into Earth orbit. Also, re-entry capsules like Apollo travel at these speeds as they descend from orbit. The best known examples of hypersonic aircraft are the X-15 and the space shuttle



which flies through all of the speed regimes when it re-enters Earth's atmosphere. The space shuttle is coasting from a very high speed and high altitude when it flies hypersonically. There is currently no aircraft that can cruise at these speeds, however NASA is currently researching flight at hypersonic speed using experimental prototypes like the X-33 and X-34.

Student Note Taking Guide
Regimes of Flight

Big Ideas	Important Little Details
Mastery of Flight	• better technology made improvements in aircraft control • aircraft became part of daily life: ship, transport, search and rescue, survey, protection • aircraft have become sophisticated and fast • regimes of flight: categories based on speed
Regimes of Flight	
Low Speed	• 0 - 100 mph • lightweight structures with small or no engine • kite, balloon, hang glider, airship
Medium Speed	• 100 - 350 mph • propeller types with straight, thick wings • Fokker, Junkers, Cessna, Beechcraft

Student Note Taking Guide
Regimes of Flight

Big Ideas	Important Little Details
High Speed	• 350 - 700 mph • powerful propeller or jet-powered engines with thin, sweepback wings and a sleek fuselage • Boeing B-47, Vickers Viscount, Lear Jet, Sikorsky Blackhawk helicopter
Supersonic Speed	• 760 mph - Mach 5 • high-powered jet engines, sleek fuselage with super thin, swept-back or delta wings • Concorde, F-15 Eagle, Stealth
Hypersonic Speed	• Mach 5 - Mach 10 (3,500 - 7,000 mph) • rocket, re-entry capsules (Apollo), X-15, Space Shuttle, X-33, X-34 • high-powered rocket engines, short, thin wings, heat protection system

Student Activity Sheet: Regimes of Flight

Directions: Match the category from the box on the right to the descriptions given on the left. Place the letter in the blank next to the proper description.

Category:
L) low speed
M) medium speed
H) high speed
SS) supersonic speed
HS) hypersonic speed

_____ 1. 100 - 350 mph

_____ 2. kites, balloons, airships

_____ 3. high-powered jet engines, sleek fuselage with super thin, swept-back or delta wings

_____ 4. 350 - 700 mph

_____ 5. high-powered rocket engines with thin, short wings

_____ 6. Cessna, Fokker, Junkers

_____ 7. Mach 5 to Mach 10

_____ 8. lightweight structures with small or no engines

_____ 9. greater than 760 mph, but less than Mach 5

_____ 10. propeller types with straight, thick wings

_____ 11. rockets, Space Shuttle, X-15

_____ 12. 0 - 100 mph

_____ 13. Boeing B-47, Lear Jet, Vickers Viscount

_____ 14. Concorde, F-15, Eagle, Stealth

_____ 15. powerful propeller or jet-powered engines with thin, sweepback wings and a sleek fuselage

Student Activity Sheet: Regimes of Flight
Key

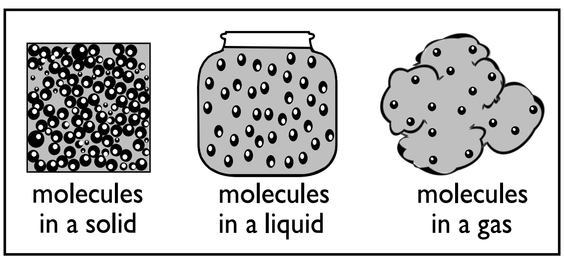
Directions: Match the category from the box on the right to the descriptions given on the left. Place the letter in the blank next to the proper description.

M	1.	100 - 350 mph
L	2.	kites, balloons, airships
SS	3.	high-powered jet engines, sleek fuselage with super thin, swept-back or delta wings
H	4.	350 - 700 mph
HS	5.	high-powered rocket engines with thin, short wings
M	6.	Cessna, Fokker, Junkers
HS	7.	Mach 5 to Mach 10
L	8.	lightweight structures with small or no engines
SS	9.	greater than 760 mph, but less than Mach 5
M	10.	propeller types with straight, thick wings
HS	11.	rockets, Space Shuttle, X-15
L	12.	0 - 100 mph
H	13.	Boeing B-47, Lear Jet, Vickers Viscount
SS	14.	Concorde, F-15, Eagle, Stealth
H	15.	powerful propeller or jet-powered engines with thin, sweepback wings and a sleek fuselage

Category:
L) low speed
M) medium speed
H) high speed
SS) supersonic speed
HS) hypersonic speed

Student Reading
Speed of Sound

Sound waves can travel through air, water or even metal. In fact, sound can travel through anything made up of molecules. These molecules carry the sound waves by bumping into each other, like Dominoes knocking each other over. Gases, liquids, and solids are all made up of molecules. So how fast does sound travel? It depends on what is carrying the sound. Sound waves do not travel at the same speed through gases, liquids, and solids. The speed of sound depends on how close together the molecules are. If they are close together, as in a liquid, they can bump into each other more easily and carry the sound wave. In a gas, the molecules are farther apart, so sound waves are slower. Each molecule of a gas has to travel farther to bump into its neighbor. As you can see, to know the speed of sound, you have to pick a material. Let's pick air.



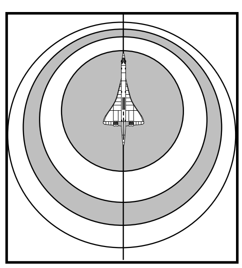
How fast is the speed of sound in air? Well, as one rises higher in the Earth's atmosphere the air becomes thinner. The atmosphere is thinner because the molecules of air are actually farther apart. With molecules farther apart, the sound wave goes slower. Therefore, the speed of sound in air depends on how high up in the sky you are. Let's pick sea level as our height.

So, how fast is the speed of sound, in air, at sea level? It is about 760 mph. That means it travels about one mile in five seconds! Have you ever heard a band performing its music live on stage, but you are seated a great distance away? Have you noticed that you can see the drummer hit the drum before the sound of the drum reaches your ears? Or have you noticed that thunder can take a long time to reach you after a lightning bolt hits? This is because, although 760 mph seems fast, it still takes a while for sound to travel to you.

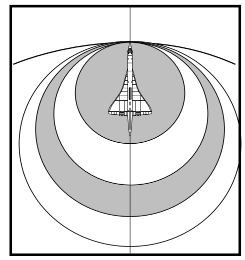
If an airplane is flying slower than the speed of sound, we say it is moving at **subsonic** speed. If it is flying at the speed of sound, it is traveling at **sonic** speed. If it is flying faster than the speed of sound, it is traveling at **supersonic** speed. When we refer to the speed of sound, we measure it in **Mach** numbers. So, if an airplane is traveling at the speed of sound, we say it is flying at Mach 1. If it is traveling at two times the speed of sound, we say it is flying at Mach 2. The word "Mach" comes from the Austrian scientist Ernst Mach who studied airflow and the speed at which sound travels.

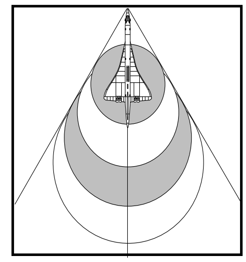
Mach

When an airplane moves through the air at speeds lower than the speed of sound, the air molecules ahead of the plane can get out of the way and pass around the plane. The air behaves like water does when you swim through it.



However, when an airplane moves faster than the speed of sound, the air doesn't have enough time to get out of the way. Instead, it piles up in front of the airplane and forms a shock wave. So, if an airplane were traveling toward you at the speed of sound, you would not hear it coming. That's because the sound it makes is traveling at the same speed as the plane itself. If that same plane flew toward you at a speed faster than the speed of sound, you would not hear it until after it had passed.





Student Activity Sheet: Speed of Sound

Directions: Use the student reading "Speed of Sound" to help you answer the questions below.

1. In order for sound to move it must have a medium through which to travel. List three media through which sound travels.

2. What is the speed of sound in miles per hour? Under what conditions is this speed measured?

3. Draw a picture of how sound waves coming from a subsonic aircraft move through the air at subsonic speed.

4. Draw a picture of how sound waves coming from a supersonic aircraft move through the air at supersonic speed.

Student Activity Sheet: Speed of Sound
Key

Directions: Use the student reading "Speed of Sound" to help you answer the questions below.

1. In order for sound to move it must have a medium through which to travel. List three media through which sound travels.

   Solid, liquid, gas

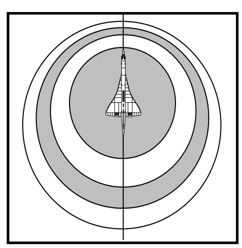
2. What is the speed of sound in miles per hour at sea level?

   760 miles per hour

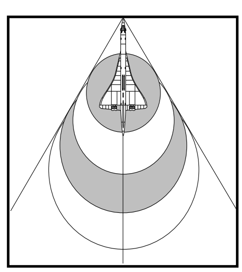
   Under what conditions is this speed measured?

   Under normal atmospheric conditions

3. Draw a picture of how sound waves coming from a subsonic aircraft move through the air at subsonic speed.

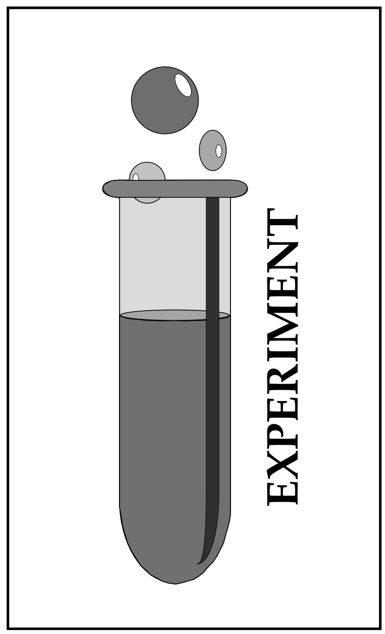


4. Draw a picture of how sound waves coming from a supersonic aircraft move through the air at supersonic speed.



Experiments: Student/Teacher

All Experiments can be located by finding the Experiment Test Tube logo.



Experiment: Air Has Weight
Procedure Card

Materials

2 balloons of equal size

string or thread

yard (meter) stick

tape

straight pin

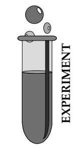
Experiment Set Up

- Inflate both balloons as equally as possible.
- Find the center of gravity for the stick and tie the string around that point leaving a length of 10 inches.
- Cut two equal lengths of string.
- Tape one end of a piece of string to one end of the stick and tape the other end to a balloon.
- Repeat with the other balloon and string.
- Double-check the center of gravity on the stick.

Experiment Procedure

1. Hold stick horizontally by string tied at its center of gravity.
2. Observe and record.
3. Take the pin and carefully pop the balloon so that it does not disintegrate into small pieces. It is important to keep the balloon intact when releasing the air from it.
4. Hold stick horizontally by the string.
5. Observe and record.

The Scientific Method
Air Has Weight Experiment



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

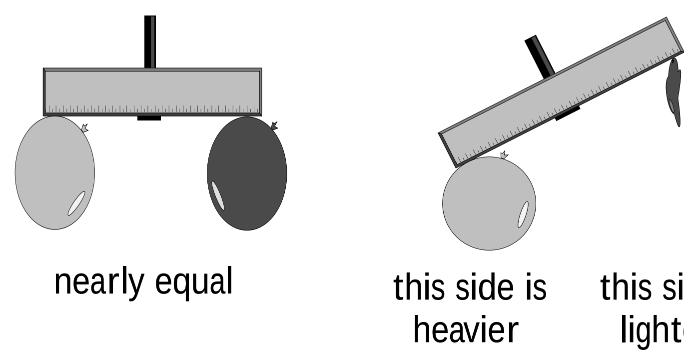
The Scientific Method
Air Has Weight Experiment

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?)*	

The Scientific Method - Key
Air Has Weight Experiment

Steps	Data
1. State the problem. **QUESTION** *(What do I want to know?)*	*Does air have weight?* *Does air weigh anything?*
2. Form a hypothesis. **PREDICTION** *(What do I think is going to happen?)*	*I think that the broken balloon will weigh less than the unbroken balloon.* *I think that they will weigh the same because air doesn't have anything in it.* *I think that the full balloon will weigh more because I know from the other experiment that air takes up space so it must weigh something too!*
3. Design an experiment. **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *2 equal-sized balloons (inflated with as close to an equal amount of air as possible) • string • yard/meter stick • tape • stick pin* *Procedure:* *1. Gather materials.* *2. Tie string to center of stick (in a horizontal position) so that the stick hangs evenly in a horizontal position.* *3. Tape a balloon to each end of the stick.* *4. Hold stick by the centered stick and observe and record.* *5. Take the straight pin and carefully puncture (pop) one balloon so as not to disintegrate it into smaller pieces.* *6. Hold stick by centered string and observe and record.*

The Scientific Method - Key
Air Has Weight Experiment

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*Before the balloon was popped:* *- Stick remained nearly level in horizontal position.* *- After balloon was popped, that side of the stick rose.*
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?)*	*Because the balloon full of air caused the stick to lower at that end, it means that it was heavier there than at the popped end.* *Because both balloons are identical and weigh the same, the unpopped balloon weighs more because it has air in it. Air, then, must have weight.*

Experiment: Air Has Stuff in It
Procedure Card

Materials

dry handkerchief or small cloth

tape

wide mouth jar (empty and dry)

basin with water

Experiment Set Up

- Fill basin with approximately 6 inches of water.
- Bunch up cloth and secure it inside the bottom of the empty, dry jar (with tape if necessary). Secure it in such a way that it will not drop down when the jar is turned upside down.

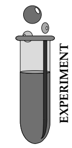
Experiment Procedure

1. Hold the bottle upside down so that the mouth is perpendicular to the water.
2. Quickly place the upside-down bottle straight down into the basin of water.
3. Hold it firmly down on the bottom of the basin.
4. Observe and record.
5. Withdraw the bottle by quickly bringing it straight up from the bottom of the basin.
6. Pull out the piece of cloth.
7. Observe and record the state of the cloth and the inside of the bottle.

The Scientific Method
Air Has Stuff in It Experiment

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

The Scientific Method
Air Has Stuff in It Experiment

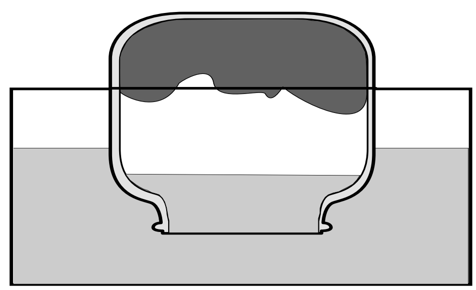


Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	
5. Organize and analyze data. *(Make a graph, chart, picture or diagram.)*	
6. Draw conclusions. *(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)*	

The Scientific Method - Key
Air Has Stuff in It Experiment

Steps	Data
1. <u>State the problem.</u> **QUESTION** *(What do I want to know?)*	*Does air take up space?*
2. <u>Form a hypothesis.</u> **PREDICTION** *(What do I think is going to happen?)*	*I think air will take up space in the bottle and the water will not fill up the bottle completely. Because air will keep the water out, the cloth will remain dry.* *OR* *I think that water will fill the bottle because it is empty. The cloth will get wet.*
3. <u>Design an experiment.</u> **MATERIALS & PROCEDURES** *(What steps will I take to do this experiment? What things will I need?)*	*Materials:* *empty glass • small, dry handkerchief/cloth • basin of water* *Procedure:* *1. Collect the materials.* *2. Shake the bottle out to make sure it is completely empty.* *3. Stuff (tape) handkerchief to bottom of glass jar (so it doesn't fall or hang down).* *4. Hold the jar with its mouth perpendicular to water and quickly immerse it in water.* *5. Hold it firmly against the bottom of the basin. Observe and record.* *6.Withdraw bottle by reversing method and pull out handkerchief. Observe and record.*

The Scientific Method - Key
Air Has Stuff in It Experiment

Steps	Data
4. Perform the experiment. **OBSERVE and RECORD DATA** *(What information did I gather during this experiment?)*	*A few bubbles came up to the surface immediately after the jar was immersed.* *Water rose only part way (1/2, 1/3, 1/4) up into the jar and stopped.* *Handkerchief remained dry.*
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 water only came up part way because the air took up space and kept it out. Because air has weight, air can push or has pressure.* *This pressure keeps the water out.*

Additional Student Activities / Projects

Group Mural

Divide class into four groups and give each group a category from the Speedline (low, medium, high, supersonic). Assign each group the task of creating a mural that depicts not only the definition and description of the category, but also depicts aircraft from that category.

New Aircraft

Assign each student one of the four speed categories (regimes). Using the New Aircraft guidesheet, have them design a new aircraft that would fly in the assigned regime. Have them draw and label the diagram and give the uses of the new aircraft. You will find a list of names of some aircraft for research on pages 40-41.

Individual In-depth Aircraft Research

Assign each student a category and allow each to choose a specific aircraft for research. Have each complete the information card and illustrate the aircraft.

In-depth Aircraft Research
(Suggestion List)

Hindenburg (airship)
USS Macon (airship)
Stealth/Spirit
Fokker Monoplane
Mustang
ER-2
U-2
SR-71 Blackbird
AD-1
Boeing 707
Boeing 747
Pathfinder
Concorde
Boeing 314 Clipper
Lockheed Constellation
Spirit of St. Louis (Ryan Monoplane)
Graf Zeppelin
The Hawk (Percy Pilcher's Glider)
The (Wright) Flyer
Bleriot XI
Royal Vauxhall Balloon (or Great Balloon of Nassau)

Vickers Viscount
Spitfire
Hawker Hurricane
Gossamer Condor
Passarola (Great Bird)
Montgolfiere (balloon)
Le France (balloon, 1884)
Avion III (Ader)
Sopwith Camel
Sikorsky Russian Knight
Messerschmitt
de Havilland Comet I
Autogiro
Bell 206 Jetranger
Hawker Siddeley Harrier
Bell Boeing V-22 Osprey
Deperdussin racer (1913)
Sikorsky R-4 Hoverfly (1943)
Golden Flier (Curtiss)
Apache (helicopter)
Tiger Moth (aerobatic airplane)
Optoca

In-depth Aircraft Research
(Suggestion List) - *continued*

Rockwell Sabreliner
No. 19 Demoiselle (1907)
Eipper Quicksilver
Lockheed Electra (1934)
Curtiss Model-D Pusher (1911)
USS Akron Airship (1933)
Avro Triplane IV (1910)
Pegasus XL SE Ultralight
Schleicher K23 Glider
Bell Boeing Tiltrotor
Voyager
Douglas DC-3
Farman F.60 Goliath
Supermarine S.6B Seaplane
McDonnell Douglas F-18 Hornet
Lockheed C-130 Hercules
Bell X-1
Lockheed F-117 Nighthawk
Junkers Ju.52
Boeing Chinook
Discovery (Space Shuttle)
Hughes H-1
Hughes H-4 Hercules
Lockheed L-1011 Tristar
Northrop T-38 Talon
DHC-2 Beaver
Piper Chieftain
Voisin-Farman Biplane
Gloster Meteor
Airbus A340
Lynx (helicopter)
Canadair CL-415

Student Activity Sheet: In-depth Aircraft Research
Fact Sheet

Aircraft Name:

Regime:

Brief Description:

Brief History:

How do the four forces work on this vehicle?

How is this vehicle controlled?

Student Activity Sheet: New Aircraft
Guidesheet

Directions: You have been assigned the ________________ regime. Design a totally new and different vehicle which flies in this speed catagory. First, complete the information chart below and then draw a diagram of your new vehicle and label the parts.

REGIME	AIRCRAFT NAME	TYPE OF WORK IT WILL PERFORM	SPECIAL FEATURES

Diagram of new aircraft (with labels)

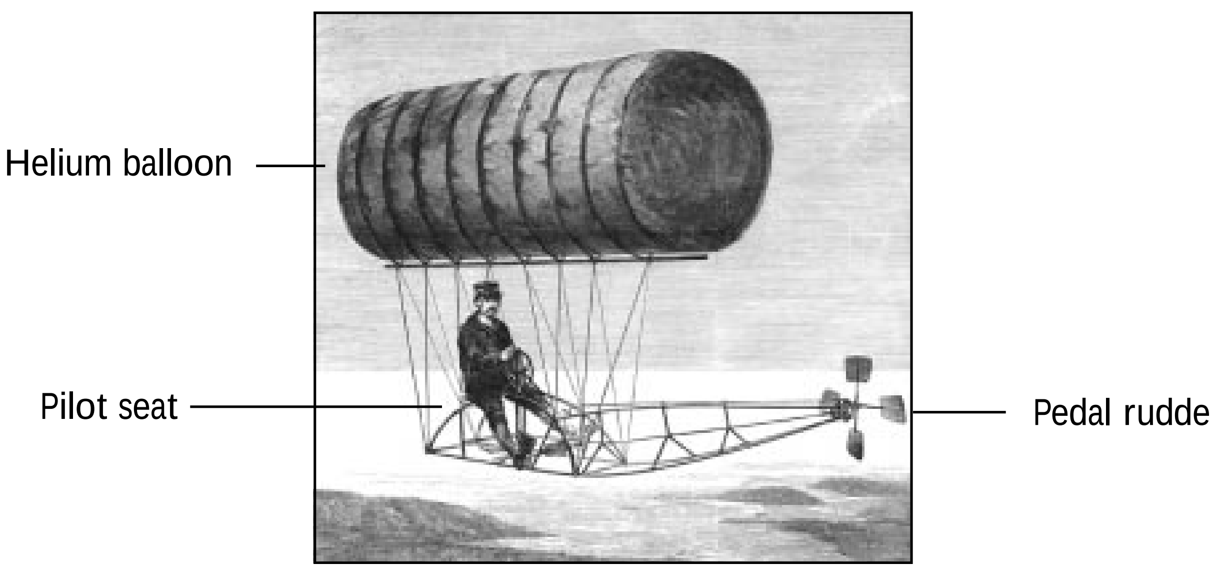
Student Activity Sheet: New Aircraft

Key

Directions: You have been assigned the ____*Low*______ regime.
Design a totally new and different vehicle which flies in this speed catagory. First, complete the information chart below and then draw a diagram of your new vehicle and label the parts.

REGIME	AIRCRAFT NAME	TYPE OF WORK IT WILL PERFORM	SPECIAL FEATURES
Low	Air Scooter	Low altitude aerial surveying of agriculture	Observational Equipment Pedal Power Rudder

Diagram of new vehicle (with labels)



Writing Experiences

Sound Wave Travel

Pretend you are a sound wave or a group of molecules through which a sound wave moves. Describe what happens to you when a supersonic aircraft flies through your airspace.

OR

Create a cartoon that humorously describes what happens to a group of molecules when a supersonic plane flies through their airspace.

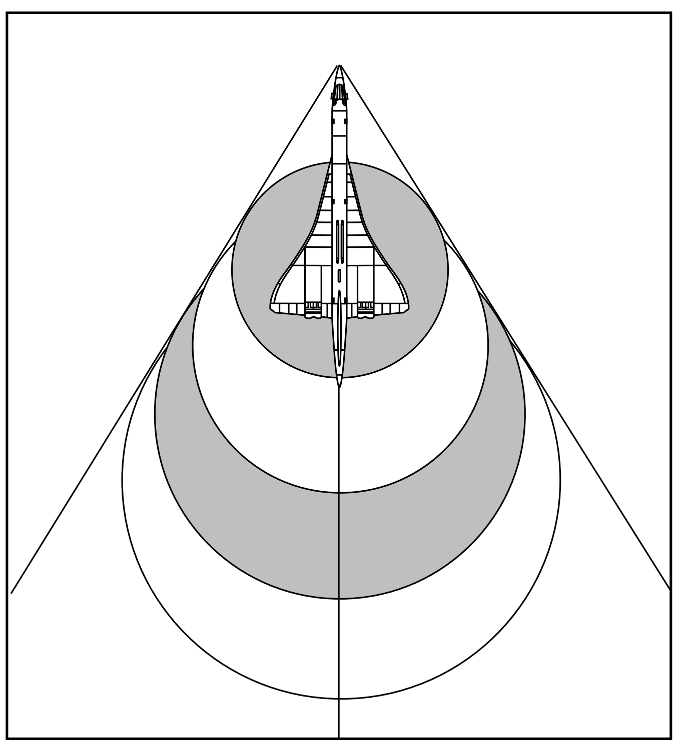
Airplane Discussion

With a partner write and perform a dialogue in which each of you is an aircraft from a different regime and you are sharing your flight experience with each other.

Writing Experience: Sound Wave Travel

When sound travels through air it has a very definite effect upon the air molecules. As an airplane moves through airspace at the speed of sound, it causes a big disturbance that results in the "sound barrier being broken". This causes a sonic boom.

Pretend that you and your group of friends are actually molecules floating in the atmosphere. You are located up where the supersonic aircraft fly. In the **first paragraph** describe what the atmosphere is like at that altitude and how you and your group of friends would be acting. In the **second paragraph** describe what happens when a supersonic aircraft flies through your airspace. Describe not only the sounds, but what it would feel like when the wave moves through your group. Would it be disruptive? Would it feel like you were roughly jostled or would it feel more like floating on an ocean wave? Finish your description with a **third paragraph** that describes how all of you would get back to your normal routine as molecules in the atmosphere. Be imaginative and use show-not-tell language. Try to describe things using more than one of your senses. Try adding dialogue as you and your friends talk your way through the experience.



Writing Experience: Airplane Discussion

Using the information gathered from your in-depth aircraft research assignment, work with your group members to write a discussion that takes place among a small group of airplanes. Have each member take on the identity of his/her aircraft and talk about their flight experiences.

Pretending you are the aircraft you researched, and include in the discussion some of your design facts, what kind of work you do, and an experience you might have had during a particular flight.

Use the writing guide below to help you get started on writing your discussion in script form.

Another Day at the Airport Comes to a Close

Vehicle #1: Boy, practicing touch and go landings with that new pilot trainee sure is tough on my undercarriage.

Vehicle #2: Oh, you Cessnas always think your work is so hard. Puttin' around out there is nothing compared to the long hauls I have to make.

Vehicle #3:

Mach and Mile Mathematics with the X-15

Background: The National Aeronautics and Space Administration (NASA) conducts space flight research to collect data on high speed aerodynamics. The X-15 aircraft was used extensively from 1959 - 1968 to fly faster and higher than any aircraft had before. The X-15 was the first aircraft to fly to the edge of space and return to Earth. The results of many X-15 test flights would later be used to design the Space Shuttle.

People who fly and work with high speed aircraft often use the term “Mach number” to describe the speed of an aircraft. “Mach number” was named after an Austrian physicist named Ernst Mach (1838-1916) who studied sound. A Mach number is special because it takes into account both the speed of the aircraft and the environmental condition of the air through which the aircraft is flying.

The Mach number is calculated by dividing the speed of the aircraft by the speed of sound at the altitude the aircraft is flying. Remember to keep the units for speed of the aircraft and the speed of sound the same!

$$\frac{\text{speed of the aircraft in miles per hour}}{\text{speed of sound in miles per hour}} = \text{Mach number}$$

If an aircraft is flying at Mach 1, we say that it is flying at the speed of sound. If an aircraft is flying at Mach 2, we say that it is flying twice the speed of sound. If an aircraft is flying at Mach 6, we say that it is flying six times the speed of sound.

Also, for these exercises you will need to remember that:

one mile = 5,280 feet

Mach and Mile Mathematics with the X-15

Exercise 1

Directions: The X-15 had a very unique way of starting its flights. It was mounted on the belly of a B-52 and flown to an altitude of 45,000 feet, where it was launched at a speed of 500 miles per hour. A rocket in the X-15 would then provide thrust for roughly 120 more seconds, and then the X-15 would glide over 200 miles back to a runway. Navy Test Pilot, A. Scott Crossfield, was the first to fly the X-15.

Many test pilots flew the X-15 during the years it was tested, but two pilots broke world records during their flights. On August 22, 1963, NASA test pilot, Joseph A. Walker, flew the X-15 to an unofficial world altitude record of 354,200 feet. On October 3, 1967, Major William Knight, an Air Force Test Pilot, set the world speed record for winged aircraft. He flew 4,520 miles per hour. One year later, after 199 test flights, the X-15 was retired on October 24, 1968.

Question 1: The world altitude record, set by Test Pilot Walker, was 354,200 feet. What was his altitude in miles?

Question 2: The flight plan for Test Pilot Walker's record-breaking flight called for him to point the nose almost straight up and provide maximum rocket thrust after he was launched from the B-52. If the B-52 launched the X-15 at an altitude of 45,000 feet, how many feet up did he fly to break the altitude record?

Question 3: How many <u>miles</u> upward did he fly to break the altitude record?

He gained almost 90% (that is, almost all!) of his total altitude after he was launched, almost straight up, from the B-52 - in only 120 seconds! How would you like to have gone along for that ride?

Question 4: Can you think of a town that is between 58 and 67 miles away from your hometown? You can check the distance on a map. Does that town seem far away? Imagine going that distance, but going straight up! It might be fun to draw a picture of Test Pilot Walker's record-breaking flight!

Question 5: Test Pilot Major Knight had an equally exciting flight when he broke the world speed record! The old speed record was 4,486 miles per hour. By how many miles per hour did Major Knight beat the old record?

Question 6: The speed limit on most United States highways is 65 miles per hour. How many times faster did Major Knight fly than your car can legally go on the highway?

Question 7: The "speed of sound" is a measure of how fast sounds travel through the air. The "speed of sound" on earth, when the air temperature is 59 degrees, is 762 miles per hour. So, when a friend calls to you from across the schoolyard, the sound comes out of his/her mouth and enters your ears at 762 miles per hour!

The speed of sound changes as altitude and air temperature change. The speed of sound at the altitude at which Major Knight made his record-breaking flight was 87 miles per hour slower than on the ground. What was the speed of sound at Major Knight's altitude?

Question 8: Now that you know the speed of sound at Major Knight's altitude can you calculate the Mach number of the record-breaking flight?

Question 9: If Major Knight was flying Mach 6.7, how many times faster than the speed of sound was he flying?

Mach and Mile Mathematics with the X-15

Exercise 2

Directions: Based on what you learned in Exercise 1, Mach 1 would be one times the speed of sound. At sea level this is roughly 762 miles per hour.

Have you ever traveled at Mach 1?

Probably not! The fastest commercial jet airplanes in the United States generally fly below 500 miles per hour. However, there is a European airliner built by the French, the *Concorde*, that does fly just above Mach 1. If you have flown the *Concorde*, say from Paris to New York, then you are one of a fairly small group of people that has flown faster than the speed of sound!

Most of us have had to be content with driving, riding or flying at less than Mach 1. To see just how far below Mach 1 we generally travel, answer the following questions.

Remember that the speed of sound changes for two reasons. It changes according to altitude and the environmental condition of the air. You will need the following table for your calculations:

Altitude Range	Air Environmental Conditions	Speed of Sound
sea level	59 degrees F	762 miles per hour
20,000 - 30,000 feet	-30 degrees F	693 miles per hour
top of the atmosphere	-67 degrees F	662 miles per hour
350,000 - 360,000 feet		675 miles per hour
outer space	there is no air!	0

Question 1: In the United States the maximum speed limit on a freeway is 65 miles per hour. Assume that this freeway runs right along the ocean and it is a cool day. At what Mach number are you driving if you are driving at the speed limit?

Question 2: Say that you are a very accomplished mountain climber and you have decided to climb Mount Everest, the highest mountain on earth. It takes you many days, but finally you are standing at "the top of the world"! While you are standing there, trying to keep warm in -30 degree F weather, you see an F-14 flying at the same altitude you are standing! As she whizzes past you, the pilot gives you a "thumbs up" to congratulate you for making it to the top. If the pilot was flying at Mach 1, use the table above to determine how many miles per hour she was flying. Hint: Mt. Everest is 29,028 feet tall.

Question 3: How many miles per hour slower did the pilot of the F-14 have to go to achieve Mach 1 at the altitude of Mt. Everest, than you would have to go at sea level?

Question 4: In Exercise 1, Test Pilot Joseph Walker, broke a speed record in the X-15 at an altitude of 354,200 feet. If you were still standing on Mr. Everest, how many feet higher would Test Pilot Crossfield have been than you?

How many miles would that be?

If you were to travel the same number of miles by land from your hometown, where would you be? (Use a map to help you determine your answer.)

Question 5: The Space Shuttle flies at approximately 3,111 miles per hour right before it escapes from our atmosphere and enters outer space. What Mach number is this?

A tricky question: If the Space Shuttle flies 17,000 miles per hour in space, what is its Mach number? (Hint: Remember that the Mach number is a representation of the speed of sound. Think carefully about what affects the speed of sound!)

Question 6: A world class marathon runner can easily run at 15 miles per hour. What mach number is this? Assume he/she is running on the beach.

If he/she were running on the top of Mt. Everest, how much slower could they run to stay at Mach .02?

Mach and Mile Mathematics with the X-15

Exercise 1 Key

1: *354,200 feet / 5,280 feet/mile = 67.08 miles*

2: *354,200 feet - 45,000 feet = 309,200 feet*

3: *309,000 feet / 5,280 feet/mile = 58.6 miles*

4: *answers will vary*

5: *4,520 miles/hour - 4,486 miles/hour = 34 miles/hour*

6: *4,520 miles per hour / 65 miles per hour = 69.5 times faster!*

7: *762 miles/ hour - 87 miles/ hour = 675 miles/hour*

8: *4,520 miles hour / 675 miles/hour = Mach 6.7*

9: *6.7 times the speed of sound*

Exercise 2 Key

1: *65 miles/hour / 762 miles/hour* = Mach .085 *from table*

2: *from table: for altitude range of 20,000 - 30,000 feet, the speed of sound in the stated air conditions is 693 miles/hour. When the pilot is flying at Mach 1, he/she is flying at the speed of sound, or 693 miles/hour.*

3: *762 miles/hour at sea level - 693 miles/ hour at 29,028 feet = 69 miles/hour*

4: *354,200 feet - 29,028 feet = 325,172 feet*
325,172 feet / 5,280 feet = 61.6 miles
answers will vary

5: *3,111 miles/hour / 662 miles/hour = Mach 4.7*

6: *15 miles per hour / 762 miles per hour = Mach .02*
That's two one-hundredths of the speed of sound!
Mach .02 X 693 miles/hour = 13.86 miles/ hour

Critical Thinking Questions

1. Why you think people thought man would never be able to fly faster than the speed of sound?

2. Identify what types of changes needed to be made in airplane design in order for an airplane to fly at supersonic speed.

3. Create another method of categorizing aircraft or flight speeds.

4. Predict a new category or regime of flight that you foresee in the future.

5. Evaluate the importance of being able to fly at hypersonic speed.

6. Predict a new design for airports that might be needed in the future as air flight becomes faster and more sophisticated.

7. Explain why it was important to understand how air molecules act before people were able to design airplanes that flew faster than medium speed planes.

8. What types of work would low- or medium-speed aircraft do?

9. What types of work would high-speed aircraft do?

10. What types of work would supersonic-speed aircraft do?

11. Examine how a change in air temperature changes the way an airplane flies through the air.

12. Explore how sound travels through a solid, a liquid and a gas.

13. In your own words, explain why you would not hear an airplane flying towards you at supersonic speed until it flew by you, but you would see it.

14. Define the “sound barrier”.

15. Describe how aircraft are a part of our daily lives.