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1990 Volume VII: What Makes Airplanes Fly? History, Science and Applications ofAerodynamics

Up, Up, And Away

Curriculum Unit 90.07.07
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I. Introduction

The title implies taking off, reaching for the limitless skies. The students will be challenged to observe, predict, test and generalize through a series of demonstrations and investigations. These exercises will introduce and clarify some aspects of the science of aerodynamics. Gravity, pressure and the properties of gases are areas of initial interest. The investigations in these areas include hands on activities that will hopefully motivate the students to readily gather their data, record their findings and support their ideas. This unit is primarily designed for presentation to the elementary student in grades three, four and five. It is intended to introduce the key elements of scientific investigation; observation, data collection and prediction. A majority of the activities ask the students to predict an outcome for an individual event. Some of these experiments are straightforward but others have been chosen because they to not result in what might be expected. They are intended to intrigue students and cause them to question and formulate conclusions.

The activities emphasize a sequential development toward an appreciation of some of the aspects of what makes an airplane fly. Considerations are first given to gravity, pressure and gases. The student should gain a clearer understanding that these are the elements in his environment that have a great effect upon him, even though in daily life they are usually taken for granted. It should become evident that the forces of pressure and gravity must be considered in order for flight to take place in our atmosphere. The activities that follow these elaborate upon Bernoulli's Law, a principle directly related to flight. Finally there are constructions for the student to build. This involves the making of three different types of flying paper objects and the collection of data on their accuracy, duration and length of flight. Many of the activities can be done by the students individually or in small groups. This unit allows the teacher to have a rich resource of activities for the class to do. Most of the lessons are designed to be presented in a fifty minute period, however the constructions and the presentations of the Bernoulli activities may demand an extended period.

After some sections there are student activity sheets that are accompanied by teacher planning outlines. The student sheets in the unit have been reduced, they may be returned to original size by setting the enlarger on a copier to 120%. There is also material on file at the Yale-New Haven Teachers Institute office on this topic if further activities are desired.

II. Gravity and Pressure

Student activity sheet 1 *Guess What?* is to accompany this discussion. Gravity is a component of the environment that is often overlooked. The fact that objects fall and that this fall is due to gravity is usually the extent of the elementary experience. It is with this information that the activities begin to build. The first activity directs that two spheres, in this case balls of different sizes, be dropped simultaneously. The question to be answered is, "Which will land first?" The answer is that they will both hit at the same time. The students can be told that it seemed a radical discovery four hundred years ago when a scientist named Galileo taught that all objects fall with the same speed regardless of size. This was true unless there was air resistance—a topic that is on the next section's activity sheet for students. Students may have heard Isaac Newton's name and recall the fall of the apple, but are they aware that the observation of the apple lead him to theorize that the force that pulled the apple toward the earth was the same force responsible for holding the earth together? This force also holds us on our planet and gives us our weight. Our weight is determined by the earth's gravitational pull on our mass. The gravitational force of this pull in turn is due to the earth's mass. On other planets that have different masses, different amounts of gravitational force are exerted. Our weight would vary with these changes from planet to planet. Mass is the amount of matter something is made up of, and matter is anything that takes up space. As an extension the class could be asked, "Does an object have weight at the center of the earth?" No, because the earth's matter pulls on it with the same force in all directions. Now that we have established some understanding of gravity we can proceed to a consideration of pressure. The second activity is designed to illustrate that in a column of liquid the highest pressure is near the bottom. If three holes are put into a tall can and the can is filled with water the stream of water from the lowest hole will stream out the farthest, the hole half way up less and the top hole the least. Now it's gravity that is exerting its force on the column of water and it's the combined weight of the column that creates the pressure that forces the bottom stream out with the most force. Now an analogy must be drawn, this column of water could represent the ocean or our atmosphere! We are at the bottom of an ocean of air! We have columns of air exerting a force on us all the time. Our muscles allow us movement in our world. Astronauts were studied to see if their muscles weakened while in weightless space. Scientists discovered that indeed they did and exercise is necessary in a weightless environment.

This activity on the student's sheet asks for first a guess of what will happen, what will the shape and distance of the streams of water from each hole be? Tape may be placed over all the holes and one at a time uncovered. Measurements might also be taken to show at what point each of the lower holes stream's length is equal to the initial length of the stream from the top hole. The seconds hole's stream will be the same as the top hole's original stream when there is an amount of water above it equal to the original amount of water above the top hole. When the amount of water above the hole is the same the pressure producing the streams of water are the same.

Activity C checks the understanding of activity B. "If we are at the bottom of an ocean of air, what is above us? . . . above the sheet of newspaper?" When these questions are asked the students should respond that there is a column of air above us and above the paper. If this is a fourth or fifth grade they might multiply the length and width of the newspaper sheet by 14.7 pounds per square inch, the atmospheric pressure at sea level, and arrive at roughly 9,000 pounds rests uppon each average page. Even with these calculations completed the students most likely will not be able to predict that the paper does not move and that the meter stick may very well be broken at the table's edge after being struck. This exercise provides a vivid examole of the pressure that is exerted at the bottom of our ocean of air.

If practiced in advance the card will stay on when the glass of water is inverted and the water will remain in the glass. This is activity D. This is another deceptive demonstration. We should ask, "Why does the water remain in the glass?" It may remain with the card holding it for only half a minute until the water's seal is broken, but it is being held for that short time. Again the key to understanding the problem is understanding something else about pressure. In a fluid or gas at rest pressure is transmitted within a gas or fluid equally in all directions at any one point. In this case the direction happens to be up! If we pause a moment and consider the last statement we can understand why water drops are spherical. If an eye dropper is used to drop drops the shape of the drop at first resembles a tear. Once it begins to fall it becomes spherical. The pressure is being exerted equally in all directions creating the spherical shape. The same is true of bubbles rising in the water—they too become spheres as they head towards the surface. The original study of the distribution of pressure in fluids was done by Blaise Pascal in the seventeen hundreds. His work has had far reaching consequences. The principle of pressure distribution that is now called Pascal's Law is the key in the study of hydraulics.

Guess What?

(figure available in print form)

I. Topic Area

Gravity

II. Start Off Statement

Using a series of demonstrations we will explore invisible forces that surround us.

III. Science Processes

a. observation

b. prediction

IV. Materials

3x5 card, empty jar, water, meter stick, news paper, spherical shapes, hammer

V. Question To Ask

What do you think will happen?

VI. Behind The Events

The demonstrations should leave the class wondering what is was that they have seen. The visible outcomes seem contrary to common sense. Use these outcomes to lead to discussion.

a. The upside down glass

Air exerts pressure in all directions, holding the cardboard on the bottom of the jar. Yes it even pushes up!

b. Newspaper punch

The pressure of air at sea level is roughly 14.7 pounds per square inch. This dramatically shows the 9,055.5 pounds that are on a piece of paper 22”x24”.

c. The Ball Drop

Here we must stress that gravity acts with the same force on on all objects, no matter what the size or mass. A very important thing to do is to drop the spheres at exactly the same time.

VII. Procedure

a. Gather all the materials

b. Be sure each student has a Guess What sheet. Be sure the student fills in the column for their prediction.

c. Do these activities as a teacher demonstration with student helpers. Do the experiments as many times as needed so that the students have time to formulate some idea of what took place.

VIII. Discussion

a. If gravity is responsible for our weight on this planet, what would we weigh on other planets?

III. Gases

The intent of student activity sheet 2, *Now What?* is to get the elementary children thinking about their environment. The wondrous qualities of the gases that surround them are not usually realized. A discussion to begin this investigation could pose the questions, “When is a room empty? . . . Is it empty when all the children have left? . . . Is it empty if all the furniture is removed?” The inference to be drawn is that unless somehow the air is removed the room is never empty. This clear stuff that sound travels through, that surrounds us, and that is necessary for our very existence is everywhere in our environment. Activity A shows the students that air offers resistance to the sheet of paper. The sheets of paper were identical, but once crumpled, one falls at a much greater speed. The students may recall that on activity sheet 1 the objects fell at the same speed regardless of their size and weight, but their spherical shapes offered little resistance to the air. In fact it was stipulated that objects fall at the same rate if there is little or no air resistance. Elementary students may be aware of the term vacuum, a space from which the air has been removed. If the sheets of paper were dropped in a vacuum they would fall at the same rate. Extensions of this section of the lesson that could be considered might include the following. The observation that air not only offers resistance but also exerts force. Fans move air for us on hot days, gentle breezes set leaves in motion and sailboats are pushed gracefully along, these scenarios and others could be brainstormed in discussion. A discussion could study the composition of the air in our atmosphere. Specific gases, their symbols and their characteristics could be mini research projects.

Activities B, C and D show that Gases can be compressed, can be expanded by heating and can even be present in liquids. These properties are amazing! Balloons, tires, floats and balls of many shapes and sizes are blown up, that is air is compressed into them. Compressed oxygen helps the ill as well as the welder and the diver uses compressed air to dive beneath the sea. Sport balloonists depend upon compressed gases to heat and expand the air for their vehicles. Rising columns of air heated by the earth’s surface allow birds and glider pilots to soar. If enough air is heated it may become a low pressure area on our weather map. Finally if rushing streams and slapping waves didn’t absorb oxygen what would happen to the fish and other creatures of the sea? In addition don’t forget our favorite beverages. The bubbles in the carbonated drinks do come out of the liquid. In the final activity if a balloon is put over the top of the seltzer bottle it inflates, making the presence of the gas more concrete to the young learner.

Now What?

(figure available in print form)

NOW WHAT?

I. Topic Area
    Some Of The Properties Of Gases
II. Starting Off Statement
    What is this stuff we call air and what are some of its properties?
III. Science Processes
    a. observation
    b. prediction

IV. Materials

sheets of paper, propane torch, plastic laundry clothes bag, hair dryer or hot air paint stripper, tape, seltzer

V. Questions To Be Asked

a. Which object will fall faster? They are both sheets of paper what is different about them?

b. What has been done to the gas in the metal container?

c. Why does the balloon rise? What is the difference between the air in the balloon and outside the balloon? What effect does the heat have?

d. Where do the bubbles in the seltzer come from?

VI. Behind The Events

Sometimes it is as if we do not pay attention to the ocean of air we live at the bottom of. These activities are meant to illustrate some of the properties of gases.

a. The Paper Drop

The paper in the crumpled ball offers less resistance to the air than the flat sheet of paper. It should be noted that the weight of the sheets is the same, but the surface area has changed.

b. The Propane Torch

The gas in the metal container has been compressed or squeezed. Could you do this to a stone or a desk top. You do this when you inflate a tire, basketball or balloon, your outdoor gas grill uses compressed gas and some homes are heated this way.

c. The Hot Air Balloon.

The heated gas expands, weighs less and therefore is lighter, the balloon rises.

d. The Seltzer Bottle

The carbon dioxide has been pressurized into the liquid. Some liquids make their own bubbles, champagne and beer for example. Again the bubbles come out of the liquid.

VII. Procedure

a. Completely a teacher demonstration

b. Be sure each student has a Now What sheet. Be sure the student fills in the column for their predictions.

IV. Fluids

The two initial activity sheets have included investigations of gravity, pressure and gases. The analogy was drawn between the ocean and the atmosphere. The effects of gravity and pressure on both were discussed. Scientists unite the matter that occurs in gaseous and liquid states in a field called fluid mechanics. In this context a fluid is a material that flows. Fluids can be studied at rest or in motion. Fluid mechanics is the basis for aerodynamics. Even though water is nearly eight hundred times as dense as air, the compressibility of gases does not have to be considered until supersonic speeds are approached. It is now time to consider in what ways liquids and gases are alike. One important aspect of these fluids is that they change shape easily. A parallel could be drawn between objects that are placed in an aquarium full of water, the water immediately surrounds every facet of what is submerged, and our being 'submerged' in a room full of air. Is there any place air isn't?—the inside of light bulbs! Perhaps the most important similarity between fluids of different states for those who study aerodynamics is that the streamlines, lines that indicate local velocity about an object, are the same. Usually streamlines in a wind tunnel may be shown by lines of smoke injected at equal intervals in the flow field. Another experiment would have children raise their hands as the scent of a cologne reaches them. This should be followed with the more concrete demonstration using a clear gallon container full of water to which is added a drop of dye. Both fluids permit diffusion. Children may come up with many other ways in which gases and liquids are similar.

V. Flight

Flight takes place when a machine carrying one or more people under a pilot's control raises itself into the air, goes forward without a loss in speed and eventually lands at an equal or higher elevation. This is as true today as it was in 1903. These were the conditions that the Wright Brothers were able to achieve and document, in order to proclaim that they were the first to fly. They had studied the works of two other scientists, Otto Lilienthal and Octave Chanute, and united ideas and designs to create their Wright Flyer I. Their craft was almost totally wings and they had calculated that it was the wing and its shape that is primarily responsible for lift. An airplane in order to achieve and maintain flight must both exert and overcome certain forces. These are the aerodynamic forces of weight, lift, drag and thrust. (see figure 1) Weight is again the force of gravitational pull on the mass of the plane. Thrust and lift are forces that put a plane in motion and drag and weight are the forces that attempt to bring the plane to a stop. A unioue situation arises when a plane is at a particular altitude at a fixed speed. In this case the thrust and drag are equal and the lift and weight are equal, there are no aerodynamic forces working on the plane.

The four aerodynamic forces Figure 1

(figure available in print form)

The key to flight is lift. It was Daniel Bernoulli's investigations in the eighteen hundreds that led to an important part of the explanation of lift. He found that observation of one dimensional motion of a steady, inccmpressible flow where density is constant provided a model from which to derive a mathematical and physical description of fluid motion. His calculations linked the laws of conservation of mass and energy. Pressure, velocity and cross sectional area were the variables when considerating calculations of mass, while pressure, kinetic and potential energies were the variables in the energy calculations. While the total of the variables remained constant, Bernoulli demonstrated that proportional shifts in variables were allowable. If the velocity of a fluid is increased, the pressure is decreased and if the area is decreased, velocity will be increased and pressure lowered. Now the wing and how its shape effects the flow of air must be considered.

The wing and streamlines showing the air flow over and under it Figure 2

(figure available in print form)

The major parts of a wing are; A the leading edge, B the trailing edge and C the upper surface with its curve given the special name camber. Figure 2 has indicated two positions with numerals 1 and 2. In a wind tunnel the velocity would be the same at those two points. Lift occurs because of what happens over and under the wing. The camber forces the air passing up over the leading edge to l) travel further and 2) be forced into a smaller area. Bernoulli calculated the fluid must move faster to maintain its velocity at point 2 and as a result the pressure above the wing becomes less, we have lift! Meantime the air under the wing remains for the most the same and then there is higher pressure under the wing. The activities on the student sheet that follows this section *What Now?* are all examples of applications of Bernoulli's law. The task of the students is to explain what happens using velocity and pressure relationships.

Not all lift is explained by Bernoulli. Isaac Newton's third law of motion states that for every action there must be another action in the opposite direction of equal force. A wing deflects air especially at take off. The amount of deflected air depends upon its angle of attack, or tilt into the wind. When this air is deflected downward there is an opposite reaction that forces the wing upward.

A final, seldom mentioned, amazing factor that creates lift is the Magnus effect. Magnus studied the ideal flow around a cylinder. Then he theorized a second flow of concentric streamlines around a rotating cylinder. Employing Bernoulli's law he had a low pressure on the top and a high pressure below that created lift on a cylinder. see Figure 3

Flows that are imposed for the Magnus effect Figure 3

(figure available in print form)

The lift was evident in illustration C of figure 3. Illustrations A and B are superimposed to create C. This interesting phenomenon has more immediacy in our lives than you might at first realize. Any spinning sphere in a wind tunnel would exhibit the same cross sectional streamlines. Therefore we can actually account for the curve of a pitched baseball by understanding the Magnus effect. Hooks and slices of both tennis and golf balls also be explained this way. An explanation of how to demonstrate the Magnus effect is at the Institute office. In summation, "The whole theory of lift is an excellent example of the mixture of ideal and real flows, steady and unsteady motion, all combining to explain the remarkably complex circumstances in which heavier-than-air machines can fly." Wegener, 8.9

What Now?

(figure available in print form)

WHAT NOW?

Bernoulli Who?

I. Topic Area

Bernoulli's law—the higher the speed of a flowing fluid, liquid or gas, the lower the pressure and conversely as the speed decreases the pressure increases

II. Start Off Statement

All of the activities relate to a single law, in what way are all these activities similar?

III. Science Processes

a. analysis

b. evaluation

c. prediction

IV. Materials

paper strips, spools, pins, 3x5 cards, vacuum, books, styrofoam balls, string

V. Questions To Be Asked

a. Why does the paper come up when you blow over the strip?

b. Why do the balls come together when you blow between them?

c. Why does the card stay on the book when you blow under it?

d. Why doesn't the card blow off the spool when we blow into the hole in the opposite end?

e. Why is the ball suspended in mid air?

f. Why does the paper rise up the tube and end up all over?

VI. Behind The Events

All of the activities relate to Bernoulli's law.

a. The fast stream of air causes a low pressure area above the piece of paper so the paper rises.

b. Again the stream of air causes a low pressure and the balls come together.

c. Blowing under the card causes a low pressure area and the card is actually held on the books.

d. As you force your breath threw the hole, the higher speed at the other end next to the card causes a low pressure area and the card is held in place.

e. The outsides of the column of air from the vacuum surround the ball with air moving at high speed the lower pressure in the middle keeps the ball in place.

f. The path of the air over the hollow tube creates a low pressure in the tube and the light bits of paper are drawn up the column and then blown about.

VII. Procedure

The materials could be placed in areas about the classroom and the students could go from station to station.

I. Topic Area

Twisters, Circle Fliers and Paper Airplanes

II. Start Off Statement

The students are to build three types of fliers. They will fly their constructions and record distance, accuracy and length of flight data.

III. Math Science Processes

a. metric measurement	a. Collecting data
b. recording data	b. Observation
	c. Computing the rate of fall in cm. per sec. with d=rt or r=d/t

IV. Materials

paper, straws, scotch tape, glue, scissors, markers, targetsto be constructed, tape measures, stopwatches, patterns of the constructions

V. Questions To Ask

a. Will the circle flier fly without wings?

b. What does the twister remind you of? Why does the rotor turn when it is dropped? How can the way it fallsbe changed?

c. Will the paper airplane be the best at staying in the air for the longest time?

VI. Behind The Events

The circle flier's unique construction in conjunction with lift and drag allow it to fly like a paper airplane. It is simply a special design! The twister resembles a helicopter, but the rotor spin does not pick it up, instead it reduces the rate of fall because once spinning it increases the lift.

VII. Procedure

a. Gather all the materials and pattern that will be necessary for the construction of the vehicles.

b. For the different types of craft different types of targets may be found useful. The twisters are dropped therefore this target is one on the ground. Hula hoops might serve as targets to test accuracy of the gliders. The most important thing is to insure that there is some consistency in the testing methods developed by the students.

c. Now there are still the construction of the vehicles and the testing of the craft that must be done. These tasks may be done separately if time does not allow for a period of an hour or more. One day you might build and the next test and record data.

d. Pairs of students are the best way to attack this project. Three or four pairs could share the stopwatch and help each other record data.

Fly These
The Twister
(figure available in print form)
The Circle Flier
(figure available in print form)
Hit the Target
(figure available in print form)
Time Up!
(figure available in print form)
How Far Can It Go?
(figure available in print form)

STUDENT'S BIBLIOGRAPHY

Airplanes And Balloons . Macdonald First Library. New York: Macdonald Educational, 1975.

Truly a first text, simple but clear pictures of early balloons and airplanes. There is even Lilienthal's gilder. Some abbreviated discussion of lift and of the moving parts on the wing and tail of the plane.

Ardley, Neil. *Air And Flight.* New York: Franklin Watts, 1984.

Contains easy activities for students that illustrate how air can make things fly.

Arvetis, Chris. *Why Does It Fly* ? New York: Children's Press, 1984.

This text is very easy to read. Animal characters discuss flight in a very clear and simple way however,all the key vocabulary is presented.

Blandford, Edmund. *The True Book Of Flight* . Chicago: Childrens Press, 1968.

Mr. blandford writes a simple but fascinating text. He mentions Chinese kites, the Arabian Flying carpet and gods with wings, as well as Leonardo da Vinci, Sir George Cayley and Lindbergh!

Feravolo, Rocco. *Junior Science Book Of Flying* . Illinois: Garrard Publishing Company, 1960.

An easily read text that touches many aspects of flight and includes a number of student activities.

Lindop, Edmund. *George Washington and the First Balloon Flight* . Chicago: Albert Whitman and Company, 1964.

An amusing story about the first balloon flight in the United States. This could serve as the starting point for a time line.

Toney, Sara. *Smithsonian Surprises* . Washington D. C.: Smithsonian Institution Press, 1985.

This is an educational activity text. It has many activities in many subjects; this inculdes making a model of the Bléroit XI-

TEACHER'S BIBLIOGRAPHY

Barnaby, Ralph. *How To Make And Fly Paper Airplanes* . New York: Four Winds Press, 1968.

This text does a good job explaining aeronautics and the paper airplane.

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This booklet contains twenty experiment, many that relate to flight. Topics include; "Just Plane Wings," "Rockets Away," and "Skydiver".

Herbert, Don and Ruchlis, Hy. *Beginning Science With Mr. Wizard, Flying* . New York: Doubleday and Company, Inc. 1960.

This text was perhaps the most useful, with a wealth of experiments presented in such a way as to aid in the explanation of flight.

McFarland, Kenton. *Airplanes How They Work.* New York: G.P. Putnam's Sons, 1966.

This is a more complex explanation of flight appropriate for upper elementary and middle school students.

Morris, Campell. *The Best Paper Aircraft* . New York; Perigee Books, 1986.

They are very good and fly well.

Ninomiya, Dr. Yasuaski. *Whitewings* . Osaka: AGCO Ltd. 1980.

This stand by text makes great gliders!

Paper Airplane Power. Yugoslavia: Publications International Ltd., 1989.

This text includes seventy-two airplanes to be built by students. There are six different designs. This makes a wonderful class pack!

Wegener, Peter P. *What Makes Airplanes Fly?* New York: Springer Verlag Inc. 1990.

A masterful text that includes the history, science and applications of aerodynamics. To truly understand flight this text is essential.

Weiss, Stephen. *Wings And Things* . New York: St. Martin's Press, 1984.

There are almost three dozen foldable flying things.