Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1990 Volume VII: What Makes Airplanes Fly? History, Science and Applications ofAerodynamics

Problem Solving Through Aviation

Curriculum Unit 90.07.02
by Joyce Bryant

Outline

Introduction

This unit is designed for middle and high school students.

The unit will focus on problem solving through real life situations that will involve aviation.

For more than eighty years men and women have been designing and building airplanes in an amazing variety of shapes and sizes. In spite of the shapes and sizes, all airplanes fly in the same way and the problems of the aviation industry are basically the same.

Some of the problems in this unit will deal with the tests that have already been made in the United States by the National Aeronautics and Space Administration, Federal Aviation Agency, and by the Department of Defense. These tests were done in order to ensure safety, convenience, and efficiency in this swift, and powerful aviation world of ours.

The current control facilities are barely able to cope with the movement of supersonic traffic. Scheduled supersonic flights will very soon saturate the present airways facilities. Transports will move at speeds more than three times those of the present jet-liners. Traffic-control sectors will have their control time proportionately reduced.

In the past decades aviation has progressed tremendously in many ways making use of modern technology.

Aircraft instruments have largely relinquished their individual roles to become part of integrated systems tied to navigation and automatic flight control. Instruments and systems will be covered, included will be Air-operated Indicators, Gyroscopic instruments, Flight Directors, Autopilots, Radio and Inertial Navigation Systems and Weather Radar.

Today’s modern aircraft can fly under most conditions. In general aviation is safe. It is one of the safest ways to travel. Statistical safety analysis have been generated for every facet of flight. Every accident, every cause factor, every related factor are matters of record. The National Transportation Safety Board and the Federal Aviation Administration are the two agencies that operate in a cooperative fashion with regards to aviation safety. The National Transportation Safety Board is an independent federal agency that serves as the overseer of U.S. transportation safety and its responsibilities are internodal. The Federal Aviation Administration is on a level equivalent to that of the N.T.S.B.

Under the Independent Safety Board Act both boards have the authority to investigate, determine the facts, condition, and circumstances and determine the cause or probable cause of aircrafts accidents, and to issue recommendations, recommending corrective actions.

Since 1903, the boundaries of wing-borne flight have been pushed back. The top speed has risen from around 50 to 1,330 miles per hour and height from a 30,000 feet to 45,000 feet in altitude, and most other planes can fly 6,000 miles nonstop. The time it takes to cross the Atlantic has been cut from days to hours and in the process a worldwide, multibillion dollar multimillion passenger air transport industry has been developed. (see figure 1).

Unit Objective

The main objective of this unit will be to discuss examine, and appreciate the science of flight. Also to give students hands on experience through speakers, field trips and a trip on an aircraft. The unit will attempt to teach about airplanes through an electric approach.

Airplanes

The airplane is one of the newest and fastest means of transportation. Only spacecraft travel faster than airplanes. A modern jet transport plane can carry a heavy load of passengers and cargo across the United States in less than 5 hours. It can fly nonstop halfway around the world—from Chicago to Calcutta, India in about 15 hours. Passengers can ride in comfort 30,000 to 45,000 feet (9,100 to 13,700 meters) above the ground. On many long flights, they can watch a movie or listen to music. The largest jets can hold nearly 500 passengers.

Rocket planes, the world's fastest airplanes, have been flown at speeds faster than 4,500 miles per hour (mph). However, rocket planes are used for research only.

Most airplanes are not so large or powerful as jets. About 80 percent of all the planes in the United States have only one engine and can carry only a few passengers at a time. Many people use these light airplanes for short business or pleasure trips.

An airplane is a heavier-than-air machine. The largest transport planes weigh more than 350 short tons (320 metric tons) when fully loaded. A plane's engines, wings and control surfaces enable it to fly. The engine or engines move the plane forward through the air. As the plane moves, the air that flows over the wings moves faster and therefore has less pressure—than the air under the wings. This difference in air pressure, called lift, keeps the plane in the air. The pilot keeps the plane balanced in flight by adjusting the control surfaces, which are movable sections of the wings tail.

Today's airplanes can be divided into five main groups: (1) commercial transport planes, (2) light planes, (3) military planes, (4) seaplanes, and (5) special-purpose planes. This section discusses some of the different kinds of planes in each group and describes how they are used.

Commercial transport planes are large planes owned by airline companies. Most of these planes are designed specially to carry passengers and some cargo. Such transports are called airliners. Other commercial transports are designed to carry cargo only.

Supersonic transport planes are the fastest airliners. They can soar through the air at 1,330 mph with more than 100 passengers. Currently Supersonic transport planes can fly from Paris to New York City in less than four hours. However, their number is very limited and they play a minor role.

Most large airliners carry from 100 to 250 passengers. However, some carry many more. The Boeing 747 has room for nearly 300 passengers. It has 12 washrooms and 6 galleys and carries more than 47,000 gallons of fuel.

Four-engine jets, such as the Boeing 747 and the McDonnell Douglas DC-8, are designed for long-distance flights. Most of these planes can fly nonstop 6,000 miles or more—farther than the distance from New York City to Toyko. Four-engine transports cruise at an altitude of 30,000 to 45,000 feet (5.7 to 8.5) miles.

Some three-engine jetliners, such as the Boeing 727 and the McDonnell Douglas DC-10 can carry as many passengers as most four-engine jets can. But most three-engine jets are designed for shorter flights. They can also use shorter runways. The Soviet Yak-40 and some other three-engine jet airliners carry only about 40 passengers. These planes can land and take off at small air fields.

Most twin-engine commercial airliners carry fewer than 100 passengers. These planes serve many small and medium-size cities. Twin-engine, propeller-driven planes travel at less than 400 mph (640 kph) and make most short flights. But twin-engine jets can travel faster and farther. The McDonnell Douglas DC-9 and the Boeing 767 can fly at speeds faster than 575 mph and can make nonstop flights of 2,000 miles or more. They can carry as many passengers as most four-engine jets.

Many large airliners are designed so that their seats can be removed to make room for a full load of cargo. These planes have extra-large doors, and they may also have built-in machinery for loading and unloading.

Transport planes that carry only cargo look much like airliners except that they have no passenger windows. The largest of them, such as the Lockheed C-5A Galaxy and the all-cargo model of the Boeing 747, can carry 100 short tons of cargo more than 4,000 miles nonstop.

Most transport planes carry expensive, lightweight goods, such as electronic equipment and machine parts. These planes also transport goods that must be delivered quickly, including fresh flowers, fruits, and vegetables. The largest transport planes carry heavier loads such as building materials and military equipment. Some cargo planes carry goods in large metal boxes called containers. Special equipment easily and quickly lifts the containers on or off these planes.

Light planes are much smaller than commercial transport and can land and take off at small airfields. Most of these are single-engine, propeller-driven planes and are privately owned. There are more than 100,000 single light planes in the United States. Some of these planes weigh more than a few hundred pounds and have room for only the pilot. Other single-engine light planes can carry up to 12 passengers.

The largest light planes have two reciprocating engines and can carry up to 19 people. These planes are really small airliners. Air taxi services and commuter lines use such planes to transfer passengers between small airports and the large airports that serve commercial transports. Many business firms also own single twin-engine light planes. Such businesses use the planes to fly their executives, managers, salespeople and other employees to out-of-town assignments or meetings. A few of these business, or executive planes are three or four-engine transports powered by reciprocating engines.

Light planes have hundreds of other uses.

An airplane is a mechanical device that obeys mechanical laws. To fly a plane, a person must know these laws and the laws of aerodynamics. Flying an airplane differs from driving an automobile. The driver of an automobile simply turns the steering wheel when making a turn, but to make a turn in an airplane, the pilot must operate several controls at once. The plane has three basic movements: pitch, roll and yaw. (see figure 2).

Pitch is the motion of a plane axes as its nose moves up or down, a roll is when one wing tips down lower than the other. Yaw is a planes motion as the nose turns right or left. A plane has many controls, but four of them are basic. They are: the elevator and rudder parts of the tail assembly, the ailerons, located on the wings and throttle. A system of cables, rods, and pulleys leads from the outside controls to the pilots controls in the cockpit. The pilots yoke or stick controls the ailerons and elevator. The rudder pedals control the rudder. The pilot uses the throttle to control the engine's speed and power. (see figure 3).

The two major principles that relate to aerodynamics forces are lift and drag.

Lift is the aerodynamic force produced by the motion of an airfoil (wing) through the air. The lift force acts at a right angle to the direction of motion. Lift gives an airplane the ability to climb into the air and holds it up during flight.

A typical airfoil has a rounded leading edge and a sharp trailing edge. As the flow of air approaches the leading edge, it splits to go around the airfoil. To produce lift, the flows along the upper surface and the lower surface must be unsymmetrical. An unsymmetrical flow can be created by the curved shape of the airfoil, called the camber. Such a flow also occurs when the airfoil meets the air at an angle. Furthermore, the two flows must merge smoothly as they leave the trailing edge. The Kutta condition, in combination with the unsymmetrical flow of air, produces a faster flow along the upper surface, thus reducing the air pressure on that surface. As a result, the airfoil is lifted into the air.

Lift can also be explained by an airfoil's ability to deflect air downward. An airfoil deflects air by its camber and by meeting the air at an angle.

The amount of lift produced by a wing depends mainly on its angle of attack and high-lift devices. The density of the air and the area and speed of the wing also affect the amount of lift.

Angle of attack is the angle that a wing makes with the air flowing past it. A pilot can change this angle by changing the plane's pitch. Up to a certain point, increasing the angle of attack increases the lift force produced by the wing. An increase in lift means the plane can climb faster or fly slower. (see figure 4)

The angle of attack plays an important part in safe flying. Air cannot flow smoothly over the wing if the angle becomes too steep. Instead, the air stream suddenly breaks up into small whirlpools called eddies on top of the wing. The eddies sharply decrease the lift and let the plane drop toward the ground. This condition is called a stall. The aircraft may crash unless the angle of attack is quickly reduced. Planes fly at an angle ranging from 3 to 4 degrees. Most planes will stall if the angle becomes larger than 15 or 20 degrees.

The lift produced by an airfoil depends on the wing's speed through the air. If the wing does not move fast enough, the difference in pressure above and below the wing will not produce enough lift to keep the plane in the air. During landings and take-offs, however, pilots want to fly as slowly as possible.

Planes have special parts which provide enough added lift for the plane to fly at minimum speeds. These devices include (1) the flap, (2) the slat, and (3) the slot.

The flap is a hinged section at the back of each wing. The pilot lowers the flaps for a landing and sometimes for take-off. When lowered the flaps increase the camber of the wing, furnishing extra lift. They also help slow the plane when landing.

The slat is hinged section near the front tip of each wing. When a plane slows down, the slats automatically move forward to increase the wings' camber and lift.

The slot is an opening along the front edge of the wing. It helps air flow smoothly over the top of the wing so the plane can fly at a large angle of attack without stalling. Such an angle increase the lift.

Drag is an aerodynamic force that resists the forward motion of an object. The shape of the object influences the amount of drag. Objects shaped to produce as little drag as possible are called streamlined or aerodynamically clean. Aircraft designers build planes to reduce drag to a minimum. Planes with low drag need less engine power to fly, and reduced drag also improves airplane's performance. Automobiles, trains, trucks, and other vehicles also encounter drag.

Two types of drag—friction drag and form drag—act on all moving objects. A third type, induced drag, affect only objects with lift. Still another kind of drag results when a plane flies faster than the speed of sound.

Friction drag occurs next to the surface of an object. It is produced in a thin layer of air called the boundary layer. Friction results whenever one layer of a fluid slides over another layer. The air in the boundary layer move in either (1) orderly paths parallel to the surface or (2) irregular paths. Engineers call an orderly motion of the molecules laminar flow and an irregular motion turbulent flow which increases friction drag.

The boundary layer is laminar at the front of an object. The flow of air can become turbulent at some point as the air moves along the object. Aircraft designers try to delay this change from laminar to turbulent as long as possible to keep friction drag to a minimum. One way they do so is to make the surface of the object as smooth as they can.

Form drag results when the air flow past an object breaks away from the object. This type of drag produces swirling eddies of air that take energy from the object and slow it down. Form drag occurs with non-streamlined objects. For example, a motorist following a large truck at high speed may feel the car shaken by the eddies behind the nonstreamlined truck.

Engineers reduce form drag by streamlining the object. They also put vortex generators on airplane wings. These devices are small airfoils that stick up in long rows on top of a main wing. Vortex generators produce small disturbances in the boundary layer that keep it from breaking away from the wing.

Here are only a few of the more important instruments which a pilot uses to help operate the plane.

Oil Pressure Gauge indicates the pressure of the oil in the engine. The dial is colored so that it is easier for the pilot to instantly spot any danger.

Oil Temperature Gauge tells the temperature of the oil in the engine.

Rate-of-Climb Indicator tells the pilot the speed at which his plane is climbing or dropping. The indicator is at zero when the plane is flying level.

Air Speed Indicator notes how fast the plane is moving through the air. Four colors are used for greater safety. Red is used to show maximum speed at which the plane can fly. Yellow shows a caution range—speeds approaching maximum speed. Heavy blue is used for normal cruising speeds. Light blue is used to show landing speed.

Turn-and-Bank Indicator is actually two separate instruments. The curved glass tube with a metal ball in liquid, the bank indicator, located near the bottom of the instruments shows whether the plane is tilted to the right or left. The turn indicator show the direction in which the nose of the plane is headed to the left, straight ahead or to the right.

Instruments Landing System Indicator helps the pilot land his plane when the airfield is covered by fog or very low clouds. When the two pointers line up with the white circles on the dial, the plane is directly on path approaching the runway for a perfect landing.

Fuel Gauge indicates how much gasoline the plane has in its tank.

Tachometer tells the pilot how his motor is doing. It indicates the number of revolutions of the engine or the speed at which the propellers are turning.

Altimeter shows the height of the plane above the ground. There are three pointers—the smallest shows height in tens of thousands of feet above the ground; the medium-sized pointer shows height in thousands of feet; and the longest pointer shows height in hundreds and parts of hundreds of feet. The altimeter pictured here shows an altitude of height of 14,750 feet. (see figure 5).

Directional Gyro and Magnetic compass are used to guide the plane. The magnetic Compass acts like any regular compass you have seen; it points to the north. The directional gyro is used by the pilot to set his course. If the plane changes direction, the gyro shows this to the pilot.

Artificial Horizon helps a pilot when he is flying at night, in a cloud or in fog. During a clear day, a pilot keeps his plane straight and level by watching the horizon. At other times, he must use this instrument.

Drift Indicator is usually installed level with the floor. It shows the pilot how the wind might be blowing him off course.

In multi-engine, conventional aircraft, there is a separate oil pressure and oil temperature indicator and a tachometer for each engine. In addition, there is generally a separate fuel gauge for each tank in the plane. Thus, if you were to look at the panel of a large four-engine airliner which has six fuel tanks, you would see seventeen more instruments than you see here. Furthermore, there is an identical set of dials for the co-pilot in addition to the pilot, and on some planes a third set of dials is used for the navigator-engineer. (see figure 5).

All airplanes, except a few experimental planes, have the same basic parts and they have progressed tremendously (see figures 6 and 7).

Lesson Plans

Invite a speaker in to speak to the classes from one of the major airlines to talk about aviation in general. Plan a trip to an airport ex: Tweed New Haven and an Air Museum. Have students write reports on different aspects of their experience.

Divide the students into groups and provide the groups with different parts of the text and have them do further research and report to the class as a whole.

Provide students with data and have them write problems based upon the math that is involved. Have students critique each others work.

Experiments

How one can demonstrate the working of an elevator: Take a 3 by 5 card and fold a 1-inch section along edge upward at a 45-degree angle. Paste the card, along its short center line, to a piece of balsa wood about 10 inches long. Balance the wood with the attached card on a round pencil, like a seesaw. Mark this “balance” point and push it straight in through the balsa so that it is parallel to the card.

Hold the pin lightly between the thumb and forefinger of both hands. Hold the balsa wood in front of your mouth with the card farthest away. Now when you blow with all your might, the raised portion of the index card acts like a plane’s elevator. The front end of the balsa wood nearest your mouth will move upward, like the nose of plane.

The seesaw effect in the above experiment is the result of gravity. The force of gravity acts upon the total weight. Weight pulls the object downward because of the gravity. The force of gravity is always pulling all objects on or near the earth toward the center. Lift acts upward against the downward force of weight. Lift is derived mainly from the flow of air over the object. Air is mainly a mixture of two gases, oxygen and nitrogen. We live in a sea of air weighing billions of tons which hugs the earth because gravity is constantly pulling down upon it. Without the atmosphere and the pressure it exerts on everything it touches, we could not fly.

Take a balloon and inflate it, then let it go, the air inside the balloon will escape, as it rushes out, the balloon flies through the air. This illustrates the principle which makes the jets fly. It is also an example of Newton’s third law of motion, “for every action, there is an equal and opposite action reaction.” As the air rushes out the back, the balloon goes forward. There are several types of jet engines and they all work on the same principle. The jet plane uses air to give it forward motion or thrust.

A kite is a heavier-than-air device that is flown on the end of a string, line or rope and is kept aloft by forces created by wind pressure.

For our purpose, lets consider kites to be heavier-than-air devices, they weigh more than the air they displace. In order to stay aloft on the end of the string a kite must overcome the force of gravity. The force of the wind is used to accomplish this task.

Divide students into groups and have them build a kite and fly it.

Materials needed for a simple kite:
Sticks

Measuring device

String

Glue or friction tape

Scissors

Paper, plastic or cloth

Word Problems

1. You are flying a plane from New York returning to Portland Oregon. You are at 10,000 feet altitude. Your speed is 220 miles per hour. You can descend at 465 feet per minute.

How far from Portland should you begin to descend? Write down how you reached your answer . . .

2. Eastern Airlines is having a sale on its airline tickets to Paris. When the ticket counter opens there are eighteen customers waiting in line. A new customer arrives every ten minutes and it takes six minutes to service a customer. Which new customer will be the first to arrive and not have to wait in line?

3. Use the formula $h=vt16t^2$ to solve the following problem. An airliner sitting on the ground launched a flare with an initial velocity of 192 feet per second. How many seconds will it take for the flare to return to earth?

4. At Cape Canaveral a missile is launched with an initial velocity of 2,230 ft per second. When will it be 40,000 feet high?

5. The weight of an object on the moon varies directly as its weight on the earth. Tomarrka Brown weighs 168 pounds on earth and 28 pounds on the moon. Oneil Chambers weighs 108 pounds on earth. What would he weigh on the moon?

Let X = weight on the moon

Let Y = weight on the earth

Then Y = KX. Find the value of K.

6. An aircraft travels 3,600 miles in three hours flying with the wind. On the return trip, flying against the wind it took four hours to travel 4,000 miles. Find the rate of the wind and the rate of the plane in still air.

Let A = rate of plane in still air and W = rate of the wind.

9. Mrs. Bryant and Miss Fletcher’s Algebra I classes will be traveling to Orlando Florida via Delta Airlines. There are 40 students and 4 chaperons.

The airlines has awarded the class and chaperons the following:

Plane tickets $178.00 each

Local transportation + to and from airports $20.00 each

Gayway Motel Quad Occupancy $44.00 per room

Four breakfasts $3.50 per breakfast per person

Four dinners $8.00 per person

Wet N Wild Water Park $9.00 per person

Mark Two Dinner Theater $22.00 per person

Disney World and Epcot Center 3 day pass $80.00 per person

Insurance $10.00 per person

Compute the total cost for per person and the total cost for the trip.

10. Plan an overnight trip to Washington D.C. and have the students visit the Air and Space Museum at the Smithsonian Institute. There are also other museums that the students will be able to visit.

Give the students the information and data and have them plan the trip.

An Up-to-Date Fleet

Delta's fleet, one of the industry's newest, is the most modern of the major U.S. carriers, with an average aircraft age of 8.61 years. The newest aircraft in operation is the medium-range Douglas MD-88, to be followed in Summer '90 by the Boeing 767-300ER, which will be used mainly for international service. Delta's current long-range aircraft, the L-1011-250/500, cruises at 548 miles per hour and can reach an altitude of 43,000 feet. For medium-range service, Delta operates the fuel-efficient Boeing 767-232/332 and 757-232 aircraft. Delta is constantly servicing, updating, and streamlining the entire fleet to provide the most efficient, economical, and comfortable service to the traveling public. Presently, there are 519 aircraft on order and options representing a value of $23 billion.

Figure 1—Courtesy of Delta Airlines

(figure available in print form)

Airplane's basic movements

An airplane has three basic movements (1) *pitch* , (2) *roll* , and (3) *yaw* . A plane makes each movement on an imaginary axis. Pitch is a plane's movement on its *lateral axis* as the nose moves up or down. Roll is a plane's movement on its *longitudinal axis* as one wing tip dips lower than the other. Yaw is a plane's movement on its *vertical axis* as the nose turns left or right.—WORLD BOOK diagram

Figure 2—Diagrams are after World Book

(figure available in print form)

Figure 3—Diagrams are after airplanes and How they Work.

(figure available in print form)

Figure 4—Diagram is after American Scientist

(figure available in print form)

Figure 5—Diagrams are after airplanes and How they Work

(figure available in print form)

Figure 6—Diagrams after airplanes and How they Work

(figure available in print form)

Figure 7—Diagram is after American Scientist

(figure available in print form)

Resource List

Dr. Wayne Burwell

United Technologies Research Center

(203) 727-7654

Professor K.R. Sreenivasan

Dept. of Mechanical Engineering

Yale University

2159 Yale Station

New Haven, CT 06520

(203) 432-4345

Tweed New Haven Airport

East Haven, CT

(203) 787-8283

Smithsonian Institute

Independence Ave.

Washington, D.C. 20560

(202) 357-2700

Hours 10 a.m. to 5:30 p.m.

Bibliography

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1. Bernarde, James V., *Aviation and Space in the Modern World:* E.P. Dutton & Co., New York, 1968.
2. Davis, J.M., *The Aerodynamics of Golf Balls* :
3. Kuchemann, D., *The Aerodynamics Design of Aircraft* : Pergamon 1978.
4. Kuethe, A.M., & Chow C.Y., *Foundation of Aerodynamics* : Wiley, 1986.
5. McFarland & Kenton D., *Airplanes and How They Work* G.P. Putnam's and Sons, New York, 1966.
6. Oliver, Stewart, Aviation: *The Creative Ideas* ; Frederick A. Prager, New York, 1966.
7. Sweetman, Bill, *High Speed Flight* : Jane's Publishing Company, London, 1983.
8. "Peter P. Wegner, *What Makes Airplanes Fly* ?" Springer Verlag New York, Inc., (in Press) 1990.
9. Britannica Encyclopedia, Britannica, Inc. 1989.
10. Technology of Change, Southside Publishers, Volume 1 and 3, Chicago
11. American Scientist, May-June 1986.