Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1988 Volume VI: An Introduction to Aerodynamics

Paper Airplanes

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1. Introduction.

a) Rationale.

Imagine your students actively involved in a learning activity. If you've been teaching for a while, you have undoubtedly developed certain lessons that you look forward to teaching. You are probably also always on the lookout for new ones. Paper airplanes seem like a good topic for such a lesson. From the beginnings of time, man has been interested in flying through the sky. Ancient religions made the heavens the realm of their gods. The gods did not suffer our limitations of being restricted to the earth. Man looked to the birds and saw freedom. Where we plodded, the birds soared. Paper airplanes offer students the opportunity to step back from daily routines and pressures and enter the fanciful world of flight.

The freedom of design inherent in paper airplanes appeals to many youngsters. They enjoy taking a piece of paper, folding it into whatever shape they desire, and flying their particular creation across the room. Another child then tries to build a plane that will fly straighter or farther or longer. Each person can participate in a critique of each other's plane. The special aerodynamic skills the students have acquired will be heard in comments such as, "Your nose is too heavy; your wings should be wider; your tail is too long."

As a teacher, you love it. Your students are interacting productively. Children, of different ability levels, are making an effort to learn. It is obvious that both you and your students are enjoying yourselves. And, as an added plus, the price to produce the lesson is right. How much does a piece of paper cost? You can even use rejected sheets from the copier.

I have spent time, money and effort developing this unit because I believe that children deserve lessons that will spark their interest while being enjoyable and educational. Working with paper airplanes allows students to solve problems by using their imagination and deductive powers. Students like to meet and overcome challenges. They like sharing their solutions with their classmates.

I also believe that children are intrinsically good; that they do want to learn. If you can create an atmosphere where the onus of learning is on the child, most of the class will respond to challenge. Because an intellectually stimulating learning environment exists in your classroom, the students will keep each other in line. You will not have to be a cop; you can be a teacher. The child will look forward to coming to school or at least to your class, and you'll look forward to being with him.

I hope that you will find this unit useful in your teaching career. At the very least, treat yourself to one of the books listed in the bibliography. In addition to increasing your knowledge, you'll have hours of fun making and flying the paper airplanes that the book describes.

This is the third unit I have written for the Yale-New Haven Teachers Institute which uses elements from the child's everyday environment. I strongly believe in using data or examples which are drawn from the student's life experiences. My contention is that even if there were nothing special in paper airplanes, the fact that everyone has at sometime made a paper airplane is reason enough to study them. When a child brings past experiences to the learning process, he is able to build on and go beyond himself.

Every child in the class can become involved in a project involving paper airplanes. Some students will attack every sheet of paper in sight. When I introduced paper airplanes this year, some of the boys in my fifth period class would skip their lunch to test their designs. These students were totally convinced that every one of their airplanes was a champion flier. One day, one of the planes wouldn't fly in the confines of the classroom. The logical solution was to launch the plane into the courtyard from my second-story classroom window. My boss observed the flight and walked up the stairs to my classroom. At first, he was reluctant to believe that the flight had been made in the name of science. But the enthusiasm of my students, convinced him that learning was taking place. On my final evaluation, he commented favorably that I made an effort to reach all the students in my class.

Other students have more reserved dispositions. They want to weigh their options before they enter into a new activity. Some of these students are overly concerned with not appearing foolish to their peer group. These students can be judges for the contests. I use more than one person for these tasks. For example, in a swim meet, there are three timers. The high and low time are discarded, leaving the middle time as the official time. When you use this system, you remove the pressure from the individual. After he has timed a few flights and compares the times he has recorded with his fellow timers, he sees that he is able to perform the task. He becomes more confident and assertive. Some students enjoy this position of authority very much and take a dominant role in the running of the contest. Other students, now that they feel more confident, cross over and become contestants.

Some of your students are good poets or artists. I have had them draw pictures and write poems about flying. I have found that the rest of the class respects artistic talent. The students know who the artists are, but many teachers don't. I was finally able to reach one girl this year when I became aware that she was a poet. With her new identity, excellent poet rather than struggling math student, she was able to raise her grade from "D's" to "B's."

Working with paper airplanes, allows a student the opportunity to explore, design, redesign and even do independent study. When your airplane doesn't fly as well as your classmates, the first thing you'll probably do is to look in a book for a better design. You'll discover that different wing shapes possess different flight characteristics. For example, if you want a long duration flight, you would make a plane with a large wing area.

A student uses the theoretically correct design and still his neighbor's plane flies better. Now you tell the student to check his work. How many times do your students just do the assignment and that's it? I'm constantly amazed how a student will arrive at a figure of $15 sales tax on a $2 item and not think that anything is amiss. But, a paper airplane presents a different story. The reason that most paper airplanes don't fly well is that they have not been properly adjusted.

There is more than one step to adjusting a plane. You should inspect it from the front. Is the fuselage curved? Are the wings warped? Inspect the plane from the side. Are the edges of the left and right wing parallel? How badly the student wants a good flier, will determine how much effort he will put into adjusting his plane. But that's okay Now the students can't look at you like you're crazy when you tell them to correct the mistakes on their spreadsheet until it's perfect. Oh, they'll still complain, but I remind them how the effort they put forth in fixing their plane improved its performance.

Paper airplanes have a universal appeal. An excellent curriculum idea would be to hold a paper airplane contest. On researching the idea, I discovered that there had been two international paper airplane contests.

b) 1st International Paper Airplane Competition.

In the winter of 1966, *Scientific American* used an unusual method to attract new subscribers. It sponsored the 1st International Paper Airplane Competition. At that point in time, France and England had just announced that they were jointly going to produce the Concorde, the world's first supersonic transport plane. The aircraft manufacturers in the United States were gearing up efforts to get their share of the supersonic transport (SST) market. The editors of *Scientific American* noticed that the models for the SST bore a striking resemblance to the paper airplanes that they had made thirty years ago when they were in their youth. *Scientific American* used this resemblance in their advertising campaign. It asked paper airplane aficionados if, at this moment, they had a design which would make the still unproduced SST thirty years obsolete.

As luck or stealth would have it, *Scientific Americanos* advertisement for its contest appeared in *The New York Times* on December 12, 1966, on page thirty-seven. Lockheed-California Corporation's advertisement for the SST appeared in the same issue of *The New York Times* on page thirty-eight. *Scientific American* said that the contest was just for fun and that no comment on the SST was intended.

You may ask, "How many people entered the contest"? There were 11,851 entries from 5,144 people living in forty-nine states and twenty-eight different countries. Five thousand of the entries were from children. Japan with 750 entries was the foreign country with the most entries. There were almost one thousand entries submitted by women. With such a turnout from such a diverse base, it would seem that paper airplanes would make an excellent educational topic.

The contestants took pride in their planes. Most of the entries were mailed inside of empty cereal boxes. The smallest plane measured .08 inches by .00003 inches. The largest entry was eleven feet.

The contest was broken into professional and nonprofessional categories, where a professional was someone who worked in the aeronautic field or who was a subscriber to *Scientific American.*

There were four events: duration aloft, distance flown, aerobatics and origami.

After preliminary flights in the hallways of *Scientific* American, the finals were held in the New York Hall of Science. The event was covered by press from the United States and from abroad. In the nonprofessional class, the winning time aloft was 9.9 seconds and the winning distance was 58'2". In the professional class the winning time aloft was 10.2 seconds and 91'6" was the winning distance. This plane would have flown farther, but it hit the back wall. The gymnasiums in our schools are large enough to house such a contest.

Was the contest educational? I would say, "Yes." Frederick Hooven's winning entry in the time aloft event was a flying wing. Flying-wing designs are controversial. Since it has no fuselage, a flying wing has an excellent lift-to-drag ratio. Unfortunately, a pilot has a hard time controlling them. Edwards Air Force Base in California is named after Glen Edwards, a test pilot who died in a plane crash while testing a flying wing. Now however, airplanes have computers to control flight. In fact the Grumman forward-swept-wing fighters were designed to be unstable. This made them more maneuverable.

There were also circular models, which were accepted as a valid shape. Flying saucers have been the shape of science fiction. They could be the shape of the future.

c) Second Great International Paper Airplane Contest.

The Second Great International Paper Airplane Contest was held on May 24,1985, in the Seattle Kingdome. *Science 86* , Seattle's Museum of Flight, and the Smithsonian Institution's National Air and Space Museum sponsored the contest. Whereas the first contest was held for fun, the alleged reason for this contest was to see if paper-airplane design had kept pace with real-aircraft design in the eighteen years since the first contest. Instead of using metal, airplanes were now being made from layers of plastic bonded together with super-strength glue. This construction is lighter and stronger than metal.

Staying consistent with the current construction methods, the Second Great International Paper Airplane Contest allowed contestants to make their paper airplanes from glued layers of paper. The organizers wanted to see if the laminated models would better the records of the first contest.

This contest retained the events and categories of the first contest. It also added a junior category for children under fourteen. This time 4,348 planes from twenty-one countries were entered. The judges were busy; a plane took off every four seconds.

As you might have predicted, the laminated models were superior. In the professional category, the winning distance was 122 feet eight inches. The plane, a laminated design of Akio Kobayashi of Tokyo, Japan, had a length of 9 inches, a wingspan of 8.5 inches and a height of 2.5 inches. The time-aloft winner was designed by Tatuo Yoshida of Yokohama, Japan. His laminated plane remained in the air for 16.06 seconds. The plane had a length of 10.5 inches, a wingspan of 9 inches and a height of one inch.

In the nonprofessional category, the winning plane in the distance event was a dart design of Robert Meuser of Oakland, California. His plane, which flew 141 feet 4 inches, had a length of 13.5 inches and dart wings of 2.5 inches on the front and 3.75 inches on the back. Meuser also won the distance category in the 1st Great International Paper Airplane Contest. First place in the time aloft went to Yoshiharu Ishii of Osaka, Japan. His laminated plane remained in the air for 9.8 seconds.

In the junior category, first place in distance went to Eltin Lucero, a twelve-year old from Pueblo, Colorado. His classical paper plane flew 114 feet 8 inches. It had a length of 9.75 inches, a width of 6.5 inches and a height of 1.25 inches. Hironori Kurisu of Osaka, Japan won the time-aloft event. The ten-year-old's laminated plane remained in the air for 11.28 seconds.

I mentioned the winners because most of them are from Japan. The Japanese are known for being hard working and paying attention to detail. Mr. Meuser said that the trick to building a good paper airplane was to spend time adjusting it. I see that as a main message. The Japanese are spending the time; maybe paper airplanes could help encourage our children to pay attention to detail.

I was talking to a pilot for the Barnes Group and he told me that tests are being made on circular wings. These wings start on the fuselage and end on the fuselage. The one continuous circular wing is structurally much stronger than the conventional pair of wings. The winning entry in the aesthetics event, nonprofessional category was a plane with a circular wing. Maybe there are ideas to be learned from paper planes.

As I continued my research on paper planes, I discovered that the object which went the farthest in the nonprofessional category was a paper aerobie. Cut out the center of a flying saucer and you have an aerobie, a flying ring with unbelievable flight characteristics. The organizers disallowed the round shape as not being a *bona fide* paper airplane. Yet as noted earlier, flying saucers were allowed in the first contest. The aerobie is so unequaled in hand-propelled flight, it will be discussed in its own section. So besides controversy, we see innovative ideas in paper planes.

I have tried to show that this unit is intended for teachers who enjoy being teachers. It is for teachers who are not afraid to have fun with their students, who enjoy a classroom with a high energy level, who feel that a pleasant atmosphere can also be academic. It is for teachers who are looking for different motivations to add to their teaching repertoire.

2. Why Airplanes Fly.

Since the first part of the word airplane is air, it is important for us to take a brief look at the makeup of air itself. The ancient Greeks believed that air was one of the four basic elements from which all things were formed; the other elements were earth, fire and water. Each element had a quality associated with it. Air was cold; fire was warm. Earth was dry and water was moist. Today's definition of air is quite different. Air is the gaseous mixture which surrounds the earth. Air is invisible, colorless, tasteless and odorless. Yet, air is as much a part of the earth as is the land and the sea. Since air is a gas, it can change its shape when it is under pressure. Because gases lack strong molecular cohesion, air will adjust its shape to completely fill any container into which it is placed.

Because we can not see air, we sometimes don't realize that it exists. Here are four simple demonstrations involving air to show your class.

When we drink all of the liquid from a glass, we say that the glass is empty. It is actually full of air. Turn the glass upside down; push it down into a pan of water. The water will not rise up all the way inside the glass because of the air inside.

Another everyday example of air is drinking through a straw. As you suck on the end of the straw, you remove the air from it. The liquid is then forced into the straw because of the air pressing down on the liquid.

To establish that air has weight, weigh a light bulb. In order for the light bulb to work, nearly all the air was pumped out. Now, make a small hole in the light bulb to let the air in. Because air has flowed in, the light bulb is heavier.

To show air resistance, drop a sheet of paper. Record the time that it takes to flutter to the ground. Now, ball up the sheet of paper. Drop the paper ball. It will fall much more rapidly to the ground since there is less air underneath this shape to resist the downward motion.

The layer of air that surrounds the earth is called the atmosphere. The atmosphere is composed of 78.09 percent nitrogen, 20.95 percent oxygen and .93 percent argon. The other .03 percent consists mainly of carbon dioxide, helium, hydrogen, krypton, methane, neon, ozone and xenon. The air in the lowest layer of the atmosphere also contains water vapor. Since some of these elements are heavier than others, the heavier elements, such as oxygen, are found closer to the surface of the earth. The lighter elements are found in the higher regions. Most of the oxygen is found below 35,000 feet altitude.

Air is in constant motion. Air moves parallel to the surface of the earth and also up and down. The differences in the weight of the air in different places causes air movement. The sun heats the earth's surface. The air that touches the surface then becomes heated. Air expands and becomes lighter when it is warmed. This warm air then rises and mixes with the air which is higher up. Some surfaces heat faster than others. Heavier air from surrounding areas fills the space vacated by the heated air forcing the light air upward.

Descartes said that the earth is at the bottom of an ocean of air. Although air is very light, it has a mass. Thus it is affected by the law of gravity and has a weight. Since air is a gas, this weight can be expressed as pressure. At sea level air exerts a pressure of 14.7 pounds per inch. The higher up in the "ocean" you go, the less air you have on top of you. Less air means less weight which means less pressure. At 18,000 feet air pressure is only one-half what it is at sea level.

The other thing to remember about air pressure is that since air is a gas, the pressure is exerted equally in all directions. A nice experiment on barometric pressure is to take a glass of water and fill it to the rim. Put a cardboard on it. Holding the cardboard, turn the glass over. With one hand on the glass, take your other hand off the cardboard. The liquid stays in the glass! Air pressure holds the cardboard up.

If your students remain skeptical, don't be upset. Since air is invisible, it has taken man a long time to recognize that it causes resistance. In fact, Leonardo da Vinci was the first to suggest that air offered resistance to motion. He predicated an expected increase in density in front of a moving body. A hundred years later Galileo stated that air resistance was proportional to velocity. He concluded this on the basis of an experiment using two pendulums that were started at different heights. Then in 1690, Christian Huygens performed experiments that showed that air resistance was proportional to the square of velocity. A little later, Newton calculated the resistance of moving bodies in a fluid. He assumed that resistance was primarily a function of density, velocity and shape. He felt that other fluid properties like viscosity would have a small effect. In 1713 one of Newton's assistants, Roger Cotes, stated that over the front half of a body the resistance is due to momentum transferred to the fluid.

It was Daniel Bernoulli, an eighteenth century Swiss mathematician, who explained in 1738 how the pressure of a moving fluid varies with its speed. Gas is a subset of fluids. Bernoulli stated that an increase in the speed of movement would cause a decrease in the fluid's pressure. This is exactly what happens when air passes over the curved top of an airplane wing.

Now that we have looked at the substance that planes fly in, we,11 move on to the forces that act on an airplane in flight. There are four forces which can be grouped into two sets of opposite forces. The first set is thrust and drag. The second set is lift and weight.

Thrust is the force which pushes the plane forward through the air. As the plane flies, it pushes air out of its way. When an airplane takes off or speeds up, thrust is greater than drag. When the plane levels off at constant speed, thrust and drag are equal. If thrust were always greater, the plane would always be accelerating.

Drag is the resistance the air exerts on the forward motion of a plane. Many diagrams show drag as an anchor. The amount of drag depends greatly upon the shape of the plane. The wings, fuselage and other protruding parts disrupts the airflow around the plane.

Weight is the combined load of the airplane and every thing in it. Weight pulls the plane down because of the force of gravity. An airplane must overcome the earth's downward pull to leave the ground and stay in the air.

Lift is the upward force that counteracts gravity and keeps a plane in the air. The wings produce lift as a result of the difference in the speed of the air over the wing versus the speed under the wing. A plane flies when the lift is greater than the planes total weight.

Lift is produced in two ways. One way is by the direct pressure of the air against a tilted wing. Air in motion exerts a pressure against any object that it strikes. Stick your hand out of a moving car window, close your fingers, and hold your palm perpendicular to the ground. Air will press against your hand and force your arm back against the door frame.

The other way that lift is created and this is the "magic" that allows planes to fly is Bernoulli's principle. We have already stated how Bernoulli showed that as the speed of a fluid increased, the pressure of the area it occupied decreased. When an airplane wing, an airfoil shape that is curved on the top and flat on the bottom, moves through the air, the speed of the air on the top of the wing is greater than the speed of the air below it. The speed of the air on top is greater because the wing is curved and the air has farther to travel. This means that the pressure above the wing is less than the pressure below it. The higher pressure below the wing generates lift.

Stick your hand back out the car window. This time angle your palm into the wind. Your arm will now move to the top corner of the door frame. You have created a low pressure above your hand which caused the lift.

3. Paper Airplane Design.

The same principles that held for actual airplanes also apply to paper airplanes. There are two conditions necessary to make a paper airplane that flies well. It must be able to glide well and it must have good stability. The most important part of a glider is the main wing. It has to support the plane during flight. The shape of the wing's cross section is called an airfoil. A chord line is a straight line drawn from the leading edge of the wing to the trailing edge of the wing. The angle that the chord line makes with the wind direction is called the angle of attack. The angle of attack changes as the nose of the plane raises or lowers. When a plane is gliding, wind pressure acts against the wing. This force can be thought of as a vector. It has a vertical component, lift, and a horizontal component, drag. The ratio of these forces is called the lift/drag ratio. A plane that flies well will have a high lift/drag ratio. The glide ratio is the distance a plane will glide divided by its altitude. The glide ratio has the same value as the lift ratio.

A good wing shape is necessary to have a high lift/drag ratio. A good way to do this is to make the wing with a slight bend or camber. The amount of camber should be no more than six percent of the chord length.

It is very important to decrease the drag on the airplane. This can be done by making the surfaces of the plane as smooth as possible. This decreases the amount of air which sticks to the surface of the plane. The plane then has less friction as it passes through the air.

For a glider, a slender wing is preferred. A term that is used when discussing drag on a wing is aspect ratio. The aspect ratio is found by dividing the wing span by the chord length. The more slender the wing the higher the aspect ratio will be. On a paper airplane, however, the body of the plane is small, the weight is light and the speed is slow. Therefore, according to Dr. Ninomiya, it is not necessary to build the wing too slender. It is more important to build a light and sturdy main wing with an aspect ratio of about five or six.

The lift/drag ratio changes with the glider's angle of attack. For paper airplanes, a 5 degree or 6 degree angle of attack is best.

The weight of the whole plane divided by the surface area of the main wing is called the wing loading. A heavy plane with small wings will have a large wing load. Planes with high wing loads glide faster so that their rate of descent is high.

Today's actual glider's have glide ratios exceeding forty. That is it can fly more than forty meters horizontally for each meter of altitude it falls. This allows skilled pilots to take advantage of updrafts and stay in the air almost indefinitely. The record for distance covered in a straight line is 1,461 kilometers and the record for altitude is 14,102 meters.

For paper airplanes if you want a flight of long duration, you want to have a low wing load. You can do this by making a large wing area with a body as light as possible. Examine the winning plane in the duration aloft category from the 1st International Paper Airplane Contest. The plane is essentially a sheet of paper which is folded in half. The fold serves as the fuselage. It would be hard to get a wing load much lower. The actual construction is: Take a sheet of paper 3 3/4” by 8 1/2”. Fold the paper in half so that the new dimensions are 1 7/8” by 8 1/2”. Open the paper. Fold one side in half. Open the paper. Fold one of the new folds in half again. Fold over again. Tape. Camber edges. Crease the folded section at the center point. Launch with a gentle horizontal motion.

A plane’s gliding speed and rate of descent depend a lot on the wing loading. You must decide what you are designing your plane for when you choose the amount of wing area you want your plane to have. If you want a long time-aloft flight, design your plane with a large wing area. If you want a long distance flight, make your plane with a small wing area.

The first airplane contest had an interesting story about thin versus thick wings. It seemed that every entrant also submitted a letter. Frederick Hooven, the winner in the professional duration aloft category, wrote one of the most interesting letters. It turns out that when he was a boy in the 1910’s, he became friendly with Orville Wright. One of the topics they discussed was thin versus thick wings. The National Advisory Committee for Aeronautics was reporting that thick wings were better. However, in their wind tunnel, the Wrights had demonstrated the superiority of thin wings. Orville Wright, Wilbur had already died, helped Hooven with his experiments. Sure enough, thin wings tested better.

Years later, Hooven learned that air viscosity plays a negligible part in low speed airflow around a small object. The flow will be more laminar than turbulent. Thus, according to the models, thin wings have a much better ratio of drag to lift. When the models and speeds are brought up to normal size, the effects of air viscosity must be accounted for. The thick wing then becomes more efficient. However, in supersonic flight, thin wings again become superior. Hooven concludes by saying how paper airplanes conform to early aerodynamic theory.

The shape of the wing or wing planform is very important in determining flight characteristics. Aspect ratio is the primary factor in determining the lift/drag ratio of a wing, where aspect ratio is the ratio of wing span to wing chord. An increase in aspect ratio will decrease the drag; a decrease in aspect ratio will increase the drag. It should be noted in actual aircraft an increase in the aspect ratio because of an increase in the wing span will also increase the weight of the wing. This increase in weight negates part of the gain.

You can choose the wing shape you want from a variety of shapes. For a good flying plane, try to avoid odd shaped wings. The elliptical wing is an ideal shape. It provides a minimum of induced drag for a given aspect ratio. However, it is difficult to construct. A rectangular wing does not provide as much lift; however, it stalls less. On a rectangular wing, air turbulence affects the central part of the wing. A sweptback wing will stall at low speeds. Air turbulence affects the wing tip which sends the plane into a tip stall which causes a sudden loss of lift.

Then there’s the Kline-Fogleman airfoil which doesn’t seem to stall. This airfoil was created and patented by Richard Kline, an advertising executive who liked flying paper airplanes, and Floyd Fogleman, a weekend pilot. Their airfoil is flat on the top and notched, partially hollowed out, on the bottom. This seems to be opposite of Bernoulli’s principle which would want air to travel farther and therefore faster on the top. Dan Santich, the chief designed for Top Flite, a company in Chicago that manufactures model-airplane kits, has done tests on the airfoil. He hypothesizes that the cutout creates a vortex within the cavity of the airfoil. This vortex produces a forward and an upward push. Thus, the vortex acts as a lifting force within the shape of the airfoil. The area seems to expand and contract according to the speed and the angle of attack. The vortex acts as a parasite boundary layer which helps prevent the separation of air molecules.

On page 47 of *The Ultimate Paper Airplane* is a picture of the flow around the airfoil in a smoke tunnel. There is a smooth flow of air over and under the airfoil. Because of this laminar flow, I believe the hypothesis.

In tests at Notre Dame, the airfoil developed better lift/drag ratios with the step on top. The wing's lift improved by 44 percent and its lift/drag ratio improved by 30 percent. Kline-Fogleman was patented with the step on the bottom for supersonic flight. As alluded above, the effects reverse themselves in supersonic flight.

There are two theories why this airfoil has not been embraced. One is that the design is too close to the Whitcomb supercritical wing which was patented by NASA in 1976. The cavity in the Whitcomb wing is not as pronounced as in the Kline-Fogleman, but it could be close enough.

The other reason could be that early tests on the Kline-Fogleman airfoil showed a poor lift/drag ratio. Kline defends this by saying that they patented a concept, not an exact shape. The drawings for the patent show a sharp leading edge. If a more aerodynamic leading edge is used, the lift/drag ratio will improve.

They also feel that the wind tunnel tests don't take into account the lift that is generated from thrust. In the previous section, I simplified the forces that act on an airplane by pairing lift as the opposite of weight. Lift is actually the sum of all forces in the upward direction. Thrust is a force which has a horizontal and vertical component. Kline-Fogleman contend that wind tunnel tests didn't calculate accurately the lift that is generated by thrust.

They also contend that the vortex the airfoil traps produces added thrust. They backup their claims by tests that have been done with radio-control models. In 1974, sixteen-year-old Richard Foch entered the Kline-Fogleman concept in the International Science and Engineering Fair. He designed a flying wing that did not need a stabilizer. In 1976, fifteen-year-old Gregory Tyler demonstrated that the airfoil was safer than the conventional Clark "Y" airfoil.

Again, the importance of this airfoil is safety; it doesn't seem to stall. Stalling is one of the principal causes of airplane accidents. The plane turns at too great an angle to the wind, loses its lift and crashes to the ground. Kline's little paper plane simply refused to stall. I'll be curious to see if anything more comes of this paper plane. The next section offers us another novel idea in flight, aerobies.

4. Aerobies.

If you think of the Beach Boys when someone mentions California, then an aerobie, which is a flying ring, is the beach toy for you. An aerobie is made of plastic and rubber. It has a diameter of thirteen inches and weighs four ounces. Alan Adler invented the shape in 1984 after studying and experimenting with frisbees for almost a decade. An aerobie is thrown like a frisbee; only it goes farther. The world record for a frisbee is 550 feet; for an aerobie, it is 1,046 feet.

Adler says that what makes the aerobie go is a special rim around the ring's outer edge. This allows the aerobie to be aerodynamically stable. In order to be stable, the front and back of a flying ring have to have an identical degree of lift. This is hard to achieve because the trailing edge of the ring is always flying in the downwash of the front. This reduces the lift on the back and that causes the flying ring to crash. Downwash is why the tail sections of conventional airplanes are always tilted down a bit. This provides the little extra lift for stability.

An aerobie is an airfoil that has to have one characteristic at the leading edge and another characteristic on the trailing edge. The aerobie's airfoil has to have a higher lift flying backwards than it does flying forward. Adler finally designed an aerobie with a spoiler lip on the upper edge of the outer ring. This reduced the lift of the leading edge and increased the lift on the trailing edge making an extremely stable flying ring.

Adler uses a piece of cardboard to explain the problems in balancing a flying disc. Throw a piece of cardboard straight out like you were flying a paper plane. It will almost immediately fly at an upward angle. The reason is that the aerodynamic force is concentrated towards the front end. This inclines the cardboard a bit more creating more lift and suddenly the cardboard has flip-flopped.

Now, take the same piece of cardboard and flip it away from you like a frisbee. Instead of flipping over, it wants to roll over. Since this cardboard is spinning when the air hits its leading edge, the forces act near its side.

Therefore, the design problem for the aerobie was that lift had to act at the center of gravity. Just cutting out the center of the cardboard isn't enough, because then you would be faced with the downwash problem.

Adler says that he nearly gave up his project several times. However, since Adler, who has lectured at Stanford University, likes to work on things that he enjoys using, he continued with his experiments. Prior to working with aerobies, Adler had experimented with sailboat design. The aerodynamics engineer has since founded his own company, Superflight. By 1986, the company had already sold over a million aerobies at $8.95 each.

This unit has been about that concept of enjoying what you're doing. I have tried to show that having fun does not necessarily have to mean playing or being involved in frivolous activities. You can work and have fun. Unfortunately, I cannot promise that you will become a millionaire like Adler. I can promise that you will become more involved in an activity. The more involved you become, the better you will learn. The better you learn, the happier you will be. So although I can't promise wealth, I do promise knowledge and happiness.

Time Aloft Model Paper size: 8-1/2x11 Time: 8 seconds

(figure available in print form)
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Distance Model Paper size: 8-1/2x11 Distance: 68 feet, 10 inches

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(figure available in print form)

6. Epilogue.

I thought that finding information about paper airplanes was going to be easy. A friend lent me a modem. I subscribed to GEnie, General Electric Company's online service. Paper airplane facts were going to be at my fingertips. Wrong. All I could retrieve was "file not found." Next, I went to Yale's Sterling Library. One of the perks of participating in the Teachers Institute is they give you a Yale library card. Not only did the card catalogue contain no entries on paper airplanes, but also the research librarian broke out laughing when I asked her under what else paper airplanes might be filed. She was then embarrassed when I convinced her that forty-year olds in business suits could be serious about paper airplanes.

I fared no better at Yale's Engineering Library. The person on duty, who was not the regular librarian, looked at me with disdain when I asked him if they had any books on paper airplanes. I then showed him one of my son's books, *Whitewings* written by Dr. Yasuaki Ninomiya. The man's tone changed, "Ah yes, distinguished Japanese doctor, very good," but still no books on paper airplanes.

My eleven-year-old son, Kasey, and I then visited my parents in Washington D.C.. While there, we visited the National Air and Space Museum of the Smithsonian Institute. And yes, we finally found books on paper airplanes. Closer to home, Walden Books stocks paper airplane books.

Kasey made and tested all the airplanes listed in this unit. We had fun working together. It was a nice and different way to spend time with my son. He came to the seminar meeting with me and demonstrated his planes. He took Dr. Wegener's challenge to build a plane that could fly across the room personally.

Kasey has seen the difficulty I have had writing this unit. He has kept after me to complete the unit. He commented to my wife, "Is it this hard getting me to do my compositions?" Seventh grade is going to be interesting.

On a topic totally unrelated to paper airplanes, but consistent with my philosophy of child development, may I please recommend books written by Lloyd Alexander. The books are loosely based on Welsh legends. They are exciting and written for boys. The tone of the books is that it is more noble to be an assistant pig-keeper than to be a war hero. Kasey and I had a good time reading and we are still enjoying discussing the series.

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