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

Flight

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I. Introduction

When the offer to participate in the Yale-New Haven Teachers Institute arose, I thought that this would be the time to learn something about an interesting topic, flight. I had a lot of childhood "facts" which I had never seriously investigated and I was sure that these would stand me in good stead. I was never so wrong. Just being able to say "Bernoulli", is not enough. My work would be presented to two distinct audiences, teachers and students. It would be wonderful if the students were students in the real sense, but many are not. How do we get them interested in a topic such as flight? I have always thought that a "hands on" approach was best for me and therefore best for my students. The idea of looking at flight through the paper airplane seemed to be a natural thing to do. Many trips to bookstores, libraries and hobby shops enabled me to get a good collection of materials for this paper. My next problem seemed to be, how best could I use these materials? Since Flight did not begin and end with the Wright brothers it would be wise to research flight and to try and put the events of Kitty Hawk into proper perspective.

A long time ago I had become interested in a TV series called *Connections,* hosted and written by James

Burke. The premise of the show was that the events which have shaped and continue to shape our world are often the product of seemingly unrelated events, which eventually fall into place and lead to a great global change. Flight was one of these global changes. How would Burke have handled this topic? It's my guess that it all started in the universal wishes of man to free himself from the chains of gravity, as evidenced in the myths of many cultures. From this starting point we would look at kites, the lateen sail, flight toys (old and new), hot air balloons, propulsion units, hang gliders, and the men who made them. Eventually we would end with the Kitty Hawk experience, the controlled flight of man in an aeroplane.

I think that all of my students could handle this part of the study of flight. The readings are fascinating and delightful. Within these readings are opportunities for experimentation, which can be done in the classroom.

As much as possible the classroom should be an experimental arena, a place where both the student and the teacher are involved, learning from each other. To read that the lateen sail enables a sailboat to move into the wind is not enough. Let us experience it. Get a shop vacuum (with its hose in the exhaust port), take some different diameter dowels, drill them, create a mast and a boom, make a triangular paper sail, glue it into place, and anchor all of this into clay or wood on top of a roller skate or toy truck and experiment, experiment, experiment!

There are a lot of good ideas out there, you just have to look for them. I know that planes fly because of the magnus effect, Bernoulli's laws and the laws of Newton. I have been a passenger in several airplane flights, but it was not until I made an airfoil out of balsa wood and exposed it to a blast from my shop vacuum, and saw this "wing" rise, did I really believe it. Students are told this and that, all day long, they resent it. When they get a chance to "hands on" class work the class period does not drag and "we" learn more. Yes, our class will be louder than the one which is across the hall, but so what, we are learning out loud.

Some of the activities are complex, too complex for the slow student, so put him or her on some other task. Models which depict yaw, pitch and roll can be made to dress up the classroom. A working model of flight controls can be made by a student who is good with his hands. David Macaulay's *The Way Things Work* is a wonderful reference book for this. Remember that the Wright brothers got their mechanical aptitude from mother (dad was an intense record keeper), so do not leave the girls out of the model making tasks.

When these and other activities have been done, I will introduce the class to four different paper airplane "texts". Hopefully we will be able to understand some of the ideas we have learned in a "make and take home" series of lessons. I will start with the very pleasurable *The Great International Paper Airplane Book* and move on through to the complex and demanding *Whitewings* . The first book will be a "turn on", I usually get questions like, "Will that thing really fly? You must be joking!". The last book *Whitewings* will be a real work out, not just a cut, crease, tape and fly routine. The students will be required to read (with pencil in hand), work with formulas, and record data, cut, layer, glue, spray and then fly.

II. A General History of The Events Which Led To Kitty Hawk

The event (the flight of an airplane) which took place on December 17, 1903, did not just happen as a random event, it began in the "day dreams" of primitive man and has not stopped. Greek mythology tells us of the tragic end of Icarus. Daedalus and Icarus had been imprisoned on an island from which there was no escape, except through the air. Daedalus fashioned wings, using feathers held together by wax. He warned his son

(Icarus) not to fly too close to the Sun for its heat would melt the wax and disaster would follow. Icarus did not obey his father and fell to his death. We have stories of kites (made by the Chinese) which were large enough to carry a man. In early days navigators of the sea had a serious problem. Their ships were of the square rigger variety, to sail you would place your stern to the wind and then you pretty much had to go where it took you. Great for fuel economy but how do you get home to sell your wares? Along about 900 AD this changed with the introduction of the lateen (a triangular sail, fitted to the mast and a movable boom), an airfoil applied to a boat. This type of sail allowed a ship to sail directly into the wind, by executing a series of zig-zag moves. Now you did not have to wait for the trade winds to shift in your favor (every 6 months), and you could sail "both ways" thus doubling your trips and profits.

(figure available in print form)

The next major problem for navigators was that of steering their boats. The stern oar was the device of the day. As commerce grew, boats became ships too big to be controlled by an oar. About 1240 (as shown by a ship which appeared on a coin of the day) the stern rudder made its way to Europe. This device was copied from the Arabs who had copied it from the Chinese. Slowly at first the parts (connections) are beginning to fall into place. Dreams, kites and sail foils, and rudders all contributing to the events at Kitty Hawk.

For a good many years man tried to fly like a bird, flapping his arms and feet and falling like a rock. It took some time for him to realize that this was a "dead end" pursuit. About 1700 hot air balloons became the toys of flight, and after a series of fires (burning straw was the balloon's heat source and propellant), these ideas went into a temporary "limbo". In 1776 Henry Cavendish, an English Chemist, isolated inflammable air, hydrogen, which had one-eleventh the weight of an equal volume of air. It is said that a professor at Glasgow University, Scotland, prepared a lesson to show that a vessel of hydrogen could rise from a table, but by the time he located a suitable container he was on a different lecture. So that demonstration was never made (to that class).

Before we can continue with our next "connections" we must mention the work and writings of Archimedes, 300 B.C. The following laws are the ones which interest us the most at this time. Any object suspended in a liquid or gas experiences an upward thrust (loss of weight) equal to the weight of the medium it displaces. A balloon, which contains one thousand cubic feet of air, would be subjected to an upward thrust of eighty pounds. If you can fill the balloon with some gas which is lighter than air then you could (if the quantities are enough to off set the weight of the balloon) achieve "lift off". This sets the stage for the entrance of the brothers Montgolfier.

Legend has it that one day while drying his wife's lingerie in front of a fire, Joseph Montgolfier took notice of how the fabric billowed. If this force could be contained in a bag, would it not lift things? He set about to experiment with this idea and he soon realized that this hot air could carry man aloft. Joseph wrote to his brother Etienne, (who had been educated as an architect and a mathematician) and told him to come home for they were going to do some wonderful experiments. These events came to brothers who were prepared to receive them, for their family was in the paper manufacturing business. Another link in a long line of "connections".

The brothers worked together on researching buoyancy and making light weight frames and paper-lined cloth covering for their hot air balloons. This construction was not done in a random manner; Etienne made these very interesting observations, which were recorded in Gillispie's *The Montgolfier Brothers And The Invention Of Aviation* , "The weight of an approximately spherical balloon is proportional to its surface and thus increases with the square of its diameter . . . The lifting force is proportional to the difference between the weights of the enclosed gas and of the displaced air. It is a function of the volume and hence the cube of the radius. Thus levity increases exponentially with size". In June of 1783 the brothers, in full view of the public, launched a paper-lined hot air balloon, its heat source was a container of burning wool. The balloons diameter was 30 feet and it floated up to a height of six thousand feet and landed a mile away. The next launch carried some farm animals: a sheep, a duck and a rooster. Finally on November 21, 1783, two men, Francois Pilatre de Rozier and the Marquis d'Arlandes, floated into space. All of France rejoiced.

In the wings was one J.A.C. Charles, who was also interested in flight but in a different kind of a balloon. Charles had taken the experiments of Cavendish (chemist who had "discovered" hydrogen, a gas lighter than air) and was busy fashioning a balloon which could contain this new gas. His balloon was to be fabricated of a rubberized silk, through which the new gas could not pass. Ten days after the Montgolfier's balloon flight, Charles publicly launched his two-man balloon. This balloon floated for two hours and landed twenty-seven miles away. On the second part of the flight, minus one man, this balloon rose to a height of nine thousand feet. Man was in the air to stay. His remaining problem was how to control the direction of the flight.

As a point of interest it should be noted that to generate the necessary amount of hydrogen, to fill a small balloon (12 feet in diameter) Charles had to mix 1000 pounds of iron filings with 498 pounds of sulfuric acid. Later balloons were to need more than ten times this amount.

Combinations of the two types of balloons met with disastrous results. Pilatre attempted to fly one such combination from France across the English Channel. With a crowd watching, the balloon (under hydrogen power) rose to a height of 6,000 feet. Pilatre needed more height so he fired off some straw, to generate hot air lift, there was an explosion and Pilatre's name was entered into the record books for a second time.

1783—Montgolfier's Hot-Air Balloon

(figure available in print form)

1785—Hydrogen and Hot-Air Balloon

(figure available in print form)

By 1785 two men had crossed the English channel, in a charliere (hydrogen balloon) aided by the wind. One hundred years later the search for a suitable source for powering balloons led us to Karl Benz who made the first practical gasoline engine. Alberto-Dumont took this engine and successfully adapted it to a "reshaped" balloon (a dirigible). On November 13, 1902 this dirigible made its first powered flight. The following year this dirigible made sustained flights of 22 and 38 miles. Man was now in control of one form of flight.

1883—Tissander Airship

(figure available in print form)

Our skies are not filled with balloons but they are filled with airplanes, so we must go back to the days of Sir George Cayley (1796-1855) who earned the title of "The Father of Aerial Navigation". Cayley was an English gentleman experimenter who was fascinated with ideas of flight and flying. When he was a boy he received a toy helicopter, an old Chinese toy which had been updated by the French, so began a love affair with flight, which was to last his entire life. Mr. Cayley improved on the toy's design by installing an elastic band to power its propeller. His later contributions to the field of aviation were many. He was first to come up with the concept of a fixed wing craft with a cruciform tail, and an auxiliary propulsion system, tensioned wheels for aircraft. It is said that Sir George constructed a glider which could carry a man (his own coachman, who promptly resigned). His other inventions were, pilot-operated elevators and rudders, and probably the most important thing of all his ideas and experiments were all logged into notebooks and published so that those who came after him could learn from his experiments and knowledge.

If we look into Charles H. Gibbs-Smith's text on Cayley we can read his long list of achievements or "firsts". I will list a few more. First to realize that a cambered airfoil provides greater lift than a flat one, first to suggest an internal combustion engine for aircraft, and to publish these ideas. For a complete list I suggest that you read pages 201-204.

Among the many men who followed Cayley was a William Samuel Henson who in 1842 designed an airplane, not unlike Cayley's design, which featured a vertical rudder, three wheels landing gear, a power-driven propeller, which could be placed in front or the back of the plane. The proposed craft never flew, because the steam engines of the day were just too heavy. By 1857 Felix Du Temple designed a craft whose wings were set in a V shape, this gave greater stability to the glider. This idea was proposed, demonstrated and published in 1808-1810 by Cayley.

In 1872 a brilliant but tragic figure came onto the scene, Alphonse Pénaud. Alphonse Pénaud designed the toy helicopter which one Milton Wright purchased and presented to his sons in the fall of 1878. Pénaud was also famous for designing another experimental model (I would rather not call it a toy) which had a rubber band propulsion system and two fixed wings, a main wing and a tail wing (which was angled slightly down to give greater stability). In 1876 he designed a "joy stick" for glider which would control both elevation and direction. His next ideas were those of retractable landing gear, glass covering for the cockpit and propellers which were 66% efficient. Today's propellers have an efficiency rating of about 85%. Pénaud had plans for a sea plane but lacked a suitable source of power. His design and plans were radical, his peers ridiculed him, unable to handle the pressure, at age 30 he put a bullet into his brain.

Pénaud's Toy Plane

(figure available in print form)

In 1894 Sir Hiram Maxim (inventor of the machine gun) tried his hand at finding a suitable propulsion system for an airplane. He constructed a machine which weighed 3.5 tons, had a wing span of 110 feet, and was powered by steam engines, which generated 360 horse power. This monster ran down a track and became air borne for a moment. In his own mind Sir Hiram Maxim had shown that an engine could cause "lift off", and there he let the matter lie. He went on to other things.

Our next important contributor was Otto Lillienthal (1848-1896), author of *Bird Flight As A Basis Of Aviation* who was deeply interested in flight. Lillienthal concentrated on how birds control their flight. Not wanting to stay in the abstract, Lillienthal used what he had learned and gave it concrete expression, the hang glider. These hang gliders were mostly monoplanes, with arched wings and a fixed tail. He learned to control flight by shifting his body, as the birds do, while in flight. His flights (over 2000 in number) were documented by photographs which were seen all over the world. Unfortunately Lillienthal's hang glider stalled and he fell to his death from a height of 50 feet. News of his death sparked two men, who ran a bicycle shop, in America into action. Their name was Wright.

Lilienthal's Biplane Glider (1895)

(figure available in print form)

Octave Chanute (1832-1910) an engineer from France who spent most of his life in America became interested in aviation and set about to collect all the information he could on the subject, encouraged fellow engineers to study the problems and to submit their studies to him. He became a point of focus for flight information in this country. Chanute published his findings in his book, *Progress In Flight* . At the age of sixty Chanute undertook to work on air frames for gliders. He hired workers and managed to make and test, stable and superior gliders. The Wright brothers became his friends and they exchanged thoughts and ideas and correspondence on flight and its control on air frames (gliders).

Our next distinguished guest was Samuel Pierpont Langley (1834-1906) noted engineer, scientist, and astronomer, head of the Smithsonian Institution in Washington, D.C. Working on a grant from the United States Governmenthe managed to produce two working, powered model airplanes. The first model had a steam engine, was launched from a catapult and flew for three quarters of a mile. The year was 1896. His next experiment was to use a gasoline engine in a model plane (then hopefully in a full-sized plane). He commissioned a Stephen Lytton to produce an engine. When completed it was radical (pistons radiated from center) in design, delivered 53 hp. and weighed 125 pounds. A quarter-size model flew beautifully, so work was begun on a full-size model which would be launched from the top of a house boat. Its pilot had never flown a glider or anything else. Two attempts at flight were made, both failed. Within ten days the Wright brothers would fly at kitty Hawk.

Wilbur (1867-1912) and Orville (1871-1948) Wright, were two men who ran a bicycle shop in Dayton, Ohio, and who were "turned on to flight" by their father, Milton, who had purchased a toy helicopter, designed by Alphonse Penaud (France). Their mother had great mechanical ability and their father was an avid record keeper. The brothers worked as one unit in all that they did. The news of Lillienthal's tragic death triggered a renewed interest in flight in them. They searched everywhere for information which could help them learn about flight and flying. Once involved they experimented checked data, constructed instruments to measure flight (wind tunnel, gauges), made kites, gliders, finally gliders which could carry man and engine. These brothers were determined to draw information from any source, check it out, and then test it. If it was applicable it went into their work. They even worked on the gasoline engine which was to power their "glider". It was no accident that they were the first. They armed themselves with all of the information of the day and then went to work to make that first flight possible. The brothers Wright did come up with some unique invention. They were superb flyers (of gliders) and were able to stabilize the flight of their craft by a process which had come to be known as wing warping. At this point I would like to add this information, Tom Crouch has written a wonderful book, *The Bishop's Boys* , in which he covers the lives of his most unusual family, it's a pleasure to read and reflect upon.

As a general wrap-up I would like to list some of the dates and names of the men who developed the power sources which were adapted to the space ships of the past. In 1852 Henri Giffard of France designed a 3.5 hp. engine which powered a 140 foot air ship. In 1872 Paul Haenlin of Germany piloted an airship using a 5.5 hp. hydrogen powered engine, which took its energy from its own balloon. A man named Ritchel invented a foot powered airship in 1878, it was not very good but it was an attempt. In 1883 Albert Gaston Tissandiers invented an electric motor capable of delivering 1.5 hp. to power his balloon. Europe was hard at work looking for a suitable power source for both balloons and gliders.

Warped wing.

(figure available in print form)
Wright Brother's Flyer (1903)
(figure available in print form)

III. The Great International Paper Airplane Book

This book came about a result of a contest begun by *Scientific American's* advertisement which appeared in *The New York Times* on December 11, 1966, which called for entries to the "1st International Paper Airplane Competition". This goes into the history of the competition, and presents the entire affair in a witty manner. Included in this book are the plans and photographs of the "winner models". There are winners in various categories, longest time in the air, origami, aerobatics, and distance winners, to name just a few. Of what use will it be in the classroom? Aside from the inherent beauty of the photographs and designs, the students will get practice in following directions, and seeing some "impossible" models really fly. This will have a lot of social interaction, and "hands on activity", in a "make it take it home" setting. Too many of today's toys are all done in a plastic and are labeled with the words "no assembly required". I will push for manual dexterity and reading skills to be sharpened. I will also try to foster some good old fashion competition among the students. Too many sit back for fear that they will be "stuck out" and "disrespected" by their peers and elders.

This first try at the paper airplane is designed to get the students involved. Its to be a "hook" to pull them in to doing things on their own. All lessons will be checked in the "book", we are not here to waste time, all must participate. I will also do my best to expose the students to the rich humor of this book. I will read some of the contest letters to them including the one which is totally written in Japanese. I do have two favorite models which we as a class will do, they are #18, picked for its "far out" design and #8, which cries out "come fly me".

(figure available in print form)

The Paper Air Force

In *The Great International Paper Airplane Book* there was no space given to the technical side of planes or flight. It was just a nice experience, a "hook". With Michael Vogt's *The Paper Air Force* we are introduced to some parts of basic aerodynamics. Wings, cross sections are examined. We discover things like AOA (angles of attack), factors which lead to stall, different types of wing design, camber and other ideas. We are now going to learn some of the technical vocabulary of aeroplanes. When we read about vortex I will want the students to know correct spelling and what it part it plays in flight. Aspect ratio and how it differs from a glide ratio is important to know if your going to carry on an intelligent discussion on planes and what makes them fly. Michael Vogt's work is a mild introduction to flight. On pages 54 to 57 we find a good trouble shooting guide. I intend to demonstrate with a bad plane and have the students trouble shoot its problems. If you want to have one of the worlds great fighter planes, fully "decked out" in war paint and wing tanks, and rockets then you will have to follow some elaborate instructions on cutting and pasting.

I have included a copy of one of Vogt's peace planes for you to see. Michael Vogt encourages the owner of this text to photocopy his plans. In this day and age that is an offer you rarely ever get. My students had a chance to show off their manual dexterity with Vogt's planes.

The Ultimate Paper Airplane

This text was chosen for the students because it had a different "angle". Two men Richard Kline and Floyd Foglemana as young men were connected by the last flight of the Hindenburg dirigible. Richard saw it pass over his house the day before it exploded in a ball of flame at Lakehurst, New Jersey, and Floyd's uncle brought the ship's mascot (a German bulldog) to his house after the disaster, prior to shipping it back to Germany. Richard loved to make paper airplanes of his own design and had entered his model in "the great international paper airplane contest". His entry did not win, but he had fun anyway. One day while showing off to a fellow worker (Floyd Fogleman), Richard tossed one of his paper planes down the hall and it performed beautifully. Fogleman an artist, model (powered) plane enthusiast and former pilot thought the basic design of this paper airplane was unique and worth investigating. The text takes a good amount of time telling us about their efforts to patent the idea and then to market it. This is an interesting book for it shows that its possible to go from a paper model to a gas engine model plane, the pair wanted to extent this to real aircraft but to date have found no takers.

Whitewings

Whitewings is a very sophisticated paper airplane book designed for the serious student or adult. This is really a package deal which contains a sixty page booklet and special paper on which you will find the patterns of 15 different paper airplanes. The designs are fairly light and do not zerox well. The zerox paper is not suitable for constructing these planes, something on the order of "bristol board" or "bristol paper" is. The kit is about $15.00 not a bad deal for an airplane club, which is just where I will use this it. Dr. Yasuaki Ninomiya designer of this package holds a doctorate in microwave measurement theory, was the grand prize winner in the categories of Duration flight and Distance flight in the 1st International Paper Plane Contest (Pacific Basin Division) 1967, has a pilot's license, and has sold 13 million copies of his 7 volume publication *Collection Of High Performance Paper Planes* . This is a serious kit. This kit requires the students to use exacto knives, duco cement, lacquer sprays and good sense. Such an experience should be as a reward for the students who have worked hard and who will be up to the challenge which this book presents. Gluing times for some phases of this work is over 6 hours, but the reward is, when done, your planes will stay aloft for as many as 60 seconds. Every phase is connected to mathematical formulas, graphs, sketches, and reading (without distraction). Formulas are employed to compute the best surface area for the horizontal stabilizer and a different one to find the best surface area for the vertical stabilizer. This book is a real challenge. I will try this first with a "club" arrangement, tools and plans will be in the class after or before school and those who want to may make these planes (under my supervision).

IV. Flight. What Causes It?

In this work its assumed that a suitable power source plant is in place and functioning. A properly designed airfoil when angled into the airstream creates a maximum amount of downwash (and therefore a maximum amount of lift) while at the same time creating the least amount of turbulence (drag) on its surface. The airfoil's top surface should be cambered (slight curvature) to encourage the air flow flowing over its surface to travel a greater distance. This would cause a flow differential (top, fast-bottom, slow) which would result in a pressure differential, (low on the top, high on the bottom), or an enactment of the laws stated by Daniel Bernoulli (1700-1782) which in effect said that when the velocity of a fluid is increased the pressure it exerts is decreased. In layman's terms the wing will experience "lift".

Before we tackle any more questions it would be useful to look at our own encounters with air flow. We can wait for a hurricane or get into the family car to gather first hand encounters with the wind. Accelerate the car to 55 m.p.h. and put your hand out the open window, it may be presented to the air in one of three basic positions. First hold your hand parallel to the ground. The air should stream past in an even flow. Next tilt your hand up at about a 20 degree angle and your hand will rise quickly. You're experiencing Newton's law—action equals reaction. Your palm is hit by the air, which in turn "downwashes" and your hand rises for you have exposed more of its area to wind. You experience lift and an increased drag at the same time. The last position, hold your hand at right angles to the wind. Your hand is hard to control for it wants to move with the air stream to the rear, your getting a lot of drag, for you have exposed a maximum amount of area (palm) to the moving air.

We want an airfoil which will rise into the air and then level off into smooth flight. If we wanted to increase our rate of fall or had to stop quickly then we would present a lot of drag surface (palm) to the air stream. What we are discussing here are angles of attack (AOA). Angles at which an airfoil is presented to the airstream. An airfoil which is angled to the airstream would flip back causing a rotation along its longitudinal axis This prevented by the fuselage (which acts a a lever) and the tail wing. The tail wing falls in response to the rotation and becomes an air foil with a positive angle of attack so it rises, gets lift, and levels out the nose of the plane and settles back into a zero angle with respect to the oncoming stream of air. The plane then stabilizes itself into a level flight.

The next part of the discussion has to do the “boundary layer” which is best seen as part of visual example. Place a large telephone book on a table. Place one finger on the cut edge which is parallel to its spine and apply a gentle but firm pressure. The upper pages will slide quickly, the pages in the middle will move less rapidly and the bottom will stick to the desk top. According to Ludwig Prandtl (1875-1953) air on airfoil does much the same thing. The first layer which is in contact with the wing sticks there and does not move, except with the plane. About this first layer are a series of layers which make up a boundary layer. In this boundary layer air moves across the wing first in a laminar flow (steady) and finally as it proceeds across the wing changes into a turbulent flow. As each layer, which is within the boundary layer, gets further from the wing’s surface its speed accelerates until it matches the velocity of the airstream above. This laminar region thickness ranges from one tenth of an inch, at the leading edge, up to a few inches at the trailing edge. As air streams over this boundary layer it first encounters the region over the laminar part of the boundary layer where there is no friction. This changes when this air must stream over the turbulent part of the boundary layer where it encounters friction or drag. When a wing’s angle of attack is too great this boundary layer can no longer adhere to the wing, the wing loses its lift capability and the craft falls.

The trick is to design an airfoil which encourages laminar flow. In John Anderson’s *Introduction To Flight* airfoils standard and laminar are compared on pages 139-140 figures 4.34. The lift capability of the laminar design is clearly shown.

(figure available in print form)

We next look at the Magnus effect. If a cylinder is placed in an ideal air flow (one in which there is no viscosity) air will pass around the cylinder as in an uninterrupted flow. If we take a rotating cylinder and observe in a real fluid, we will see that a portion of the surrounding liquid will swirl in the same direction as the cylinder is rotating. This we refer to as a bound vortex. Now if we take this experiment and place it in an airstream, the bound vortex of the spinning cylinder will cause a few things to happen. First take the air stream as coming from the left through to the right. Secondly the cylinder is rotating in a clockwise manner. The bound vortex downwashes onto the streamline below, slowing them and causing pressure, as it passes up over the front of the cylinder it enhances the stream lines accelerating them, causing a drop in pressure (Bernoulli’s law) and the cylinder rises. This demonstration can be done in any class room as shown in the demonstration sheet which is included at the end of this paper.

The Magnus effect was included to help us visualize the next theory on lift which is referred to as the circulation theory. The theory takes the Magnus effect and connects it to an airfoil, and mathematically it works. If the air flow is from the left, the circulation theory says that there is a closed curve which has a clockwise flow and moves with and around the airfoil. The clockwise flow moves down from the trailing edge compressing the air below causing pressure, continues on its way up over the leading edge, accelerating the on coming air, causing an enhanced lift. This, circulation, combined with an angle of attack and Bernoulli law is what causes lift and leads to flight.

This is an attempt to introduce the reader to some of the underlying ideas of flight, and the men who made it possible.

(figure available in print form)

V.

(figure available in print form)

VI. Paper Helicopter Experiments For The Classroom

This is a "make and take" exercise for the class room. The students will make a helicopter and experiment with it, and make some observations. To begin with we will have to have some good quality paper (ditto), rulers scissors and #2 pencils for good dark lines. Here is where we will do some work. Have the students copy the pattern from the blackboard onto their papers. I know that it would be better to have me make the copy and put it into the ditto but here I am going for some eye-hand coordination skills. Make two sets of "plans", we will need them. This helicopter is a paper plane and to function it relies on a different set of laws (from the normal paper airplane).
(figure available in print form)

Test Flights

> 1. Drop the helicopter. Which way did it spin? What do you think caused it to spin? How would you reserve it spin? Have you seen anything in nature which spins like this? (Seeds from trees)
> 2. Cut off one half of a rotor (blade). Drop the helicopter. How does it behave. Cut the entire rotor off. What happens? If dropped up side down, what will happen? Try it.
> 3. Add weights to the helicopter and observe what happens (after dropping it). Try changing the lengths of the rotor, color the rotors for a patterned effect.

Some Sample Lesson Plans

One of the nice parts to a basic geometry course is that you have time to do a lot of constructions. The students have to follow directions, written and oral, and have a change to use their eye hand coordination skills. Here is a lesson which I have taken from *Whitewings* by Yasuaki Ninomiya, in which he shows how to determine the center of gravity on a non-rectangular wing plane (paper). The diagrams are Fig 15 and 16 on page 29 from the same book. Here are his instructions and they will make a wonderful lesson in my classes. “Make a sketch of the wing in which Tt is the chord length at the wing tip and Tr is the chord length at the wing root. Extend line Tt the distance of the line Tr and extend line Tr the distance of the line Tt. Connect the two points (T&R) at the end with a dotted line. Find 1/2Tr and 1/2Tt and divide the wing with another dotted line. These two lines form point M. Draw a line parallel to the planes body through M. This line will be the Mean Aerodynamic Chord Length of the wing. The center of gravity should be placed at a point 25% or 50% of the MAC as seen in Fig 16.”

You will supply a suitable non-rectangular wing pattern, rulers, compass (for bisecting Tr and Tt). The students should understand that serious mathematics enters into any serious endeavor.

(figure available in print form)

(figure available in print form)

Another suggestion is this. Teach a quick lesson on buoyancy. Take some plasticine and a dish pan filled with water. Make a good sized ball of plasticine and place it into the water. It will sink. Now fashion this same ball of plasticine into the shape of a box and place back into the water and it will float. Finally take and put some weights in your plasticine “boat” and see how much the water will support. Students should be made to see that while a ball of plasticine is heavier than an equal amount of water we can get the water to support it if we reshape the ball there by increasing its total volume. It’s this that makes it (plasticine) and iron and cement float on water. We can work into this lesson idea of the volume of rectangular solids and hopefully on to the calculation of the volumes of spheres and a good study of hot air and hydrogen balloons. The students can really get involved in this part.

(figure available in print form)

There are all sorts of activities you can do, paper airplane contests in which longest flights, most acrobatic awards are given. If you have a few dollars you can take care of 2 to 3 classes. For $6.29 plus tax I picked up a discounted package of paper airplanes in a kit called *Paper Airplane Power* which contains 72 paper airplanes (6 different designs) on a pad. All are brightly colored and look like they would be fun to make and fly (outside). Along with this kit is an instruction booklet (32 pages). All of this is done by Louis Weber, C.E.O. Publications International, Ltd. Lincolnwood, Illinois (1989). I found it at the Price Club in North Haven. Its a nice gift for the students.

VII. Orthographic Views

(figure available in print form)

VIII. Readings For Students

Aviation Education Source Book . The School of Education, Stanford University. Hastings House Publishers, Inc. New York 1946.

This book presents materials suitable for the classroom from the primary level up through junior high. Its filled with lots of ideas, experiments and things to do for all level of students.

Burke, James. *Connections* . Little Brown and Company. Boston, Mass. 1978. Here is a book for the more mature reader. The books theme is that great events are not random but depend on interconnected events. This is a great book which can be read in sections.

Crouch, Tom. *The Bishops Boys* . W.W. Norton & Co. New York, 1989 If you want many hours of pleasurable and fascinating reading about the Wright Brothers their family, work, dreams, it is all here in readable form.

Dalton, Stephen. *The Miracle Of Flight* . McGraw-Hill Book Company, New York. 1977. A wonderful book which studies, through photos, the flight of insects and birds and then ties them into aircraft. An informative book.

Dwiggins, Don. *Riders Of The Winds* . Hawthorn Books Inc.. New York, 1973. An easy to read book on ballooning.

Gillispie, Charles. *The Montgolfier Brothers And The Invention Of Aviation* . Princeton University Press, New Jersey. 1983. A well documented and interesting book on the earliest days of ballooning.

Kline, Richard. *The Ultimate Paper Airplane* . Fireside Book. Simon & Schuster, Inc.. New York. 1985.

Macualay, David. *The Way Things Work* . Houghton Mifflin Co., Boston, Massachusetts. 1988.

No school library should be without this text. The outside cover reads “A visual guide to the world of machines”, and that it is. You have to see this book to understand what a pleasure it is to read it. It would be impossible not to learn from this book.

Mander, Jerry.,Dipple, George, Gossage, Howard. *The Great International Paper Airplane Book* . Fireside Book. Simon & Schuster, Ind., New York 1967.

Niomiya, Yasuaki. *Whitewings* . A.G. Industries Inc., Yodogawa-Ku, Osaka, Japan. 1986.

Smith, A.G. *History Of Flight Coloring Book* . Dover Publications, Inc. New York, 1986.

Looking for good clear sketches of space machines? Look no further. A coloring book, suitable for the classroom bulletin boards and reports.

Vogt, Michael. *The Paper Air Force* . Contemporary Books. Chicago, Illinois. 1989.

Ward, Alan. *Flight and Floating* . .Osborne Publishing Ltd., London, England. 1981.

A wonderful little pocket book of information which tells us that it contains “save experiments to do at home”. I would add that this would be great for the non-motivated student, who has a short attention span. Very nice activities for all.

Weiss, Harvy. *Sailing Small Ships* Young Scott Books, New York, 1967.

Here is another nice book from the children’s section of the library. It contains a very nice section on buoyancy, and how weight and volume have to be considered. This is an informative and interesting book.

Wegener, Peter. *What Makes Airplanes Fly?* Springer Verlag, New York, Inc., (in press) 1990.

If you are looking for one text which contains the a great deal of information on flight, here it is (for the serious student and teacher).

IX The Teacher’s Bibliography

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Crouch, Tom. *The Bishop’s Boys* . W.W. Norton & Co., New York, 1989.

Gibbs-Smith, Charles. *Sir George Caylay’s Aeronautics* . Her Majesty’s Stationary Office. London, England. 1962.

Gillispie, Charles. *The Montgolfier Brothers and The Invention Of Aviation* . Princeton University Press, New Jersey. 1983.

Dalton, Stephen. *The Miracle Of Flight* . McGraw-Hill. New York. 1977.

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Macaulay, David. *The Way Things Work* . Houghton Mifflin Company, Boston, Massachusetts. 1988.

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