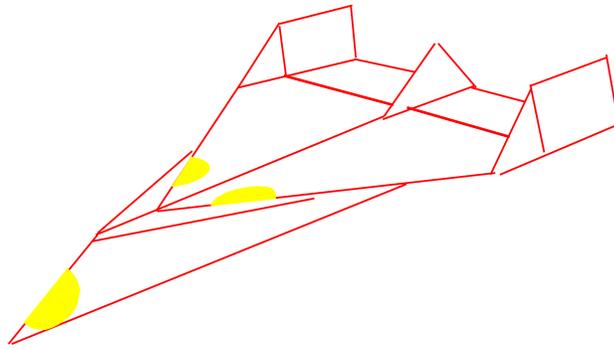


Pat's Planes

Pat Morgan



Forward

With all of the modern technology producing so much to entertain our young people there is little room for interest in paper planes like there was 40 years ago. However, there will always be a small group of students of science that make time for the study of flight. What I would like to do is produce a study that will be of interest to those students and raises their awareness that simple paper airplanes have all the science of flight the big ones (at least sub sonic ones) have without having to worry with the complexity of all the power, hydraulic, electrical, etc systems. There is may be a few parents or paper folding fans that are looking for plane designs to fold or cut and glue who aren't interested in the science at all.

Taking both groups into consideration has led to choosing the following format for this eBook. The eBook has been split into four separate sections: Basic information and instruction, folded plane designs, card stock/poster board planes, and the advanced science section. Anyone can download the sections they want to customize their own book.

This project was started in November, 2008 with the start of patsplanes.com website and was finally finalized with this major update released in February 2017.

I would like to give thanks to the folks who have created and made available free software that I have used to create these designs and documentation. Without them this eBook would not have been possible. First the documents were completed using LibreOffice. A complete office suite that has all the power needed to produce good documents including the math symbols required in the Science of Flight section. Next, most of the design graphics were done using Inkscape a vector graphic package. At first, LibreCAD software was used to develop the folded graphics since a cad package allows more construction methods eliminating the need to trig or measure the plane to get accurate graphics. The decision to switch to the vector graphic package was because the *.png output seemed to look more sharp then the *.gif output from the cad package. Any photo editing was done with the Gimp, a full photo editing package. Last, it is nice to be able to use preferred software even if it is on a public computer. The solution is using these programs as portable (from a USB drive) using PortableApps software.

Pat Morgan

February, 2017

Introduction

In today's high tech world, the simple things seem to get lost. However, there are still a few fans of the paper airplane. Since at least, 1909 paper planes have been flown and become addictive to the true fan. It doesn't matter whether you are looking for just a few planes to fold or the basics for a science fair project this document should have something to offer everyone who is interested in paper planes.

My personal interest in paper airplanes started in the school year of '69-'70. I also became a big fan of the balsa wood glider that year. I maintained that interest over the next several school years, always watching for someone to show me how to fold something a little different since there were maybe a half dozen unique design concepts available, with the classic dart the most folded by far.

This was about as far as I got until I found a book on The Great International Paper Airplane Contest. The contest was held in the winter of '66-'67 but I did not know about it until about 1975. This was the first time I found instructions for folding some different types of planes and was introduced to the concept of cutting the paper to make more varieties of gliders.

I had a very high interest in space flight as a profession and went to college as an aerospace engineer. This is a degree in engineering that specializes in both space vehicles and airplanes. While there I met many others who shared my passion for paper airplanes. Many of them were also more interested in the airplane side of classes than space.

By my third year I became a co-op student at Martin Marietta in New Orleans working on the external fuel tank for the space shuttle. There I had a lot of engineers who were more than willing to share their boyhood plane designs. I was also responsible for getting contests going at lunch (that did not make all the bosses happy).

After college I begin to collect more books on the subject and started to push my paper airplane fascination onto my boys with just a little success. However, we did get a call from school one day because one of the boys made a plane at school. To our surprise he wasn't in trouble so much as the teacher wanted us to show the other kids how to make planes! The art of paper planes was already being lost by then (about '86, I think).

As the boys grew up my plane folding days decreased until our youngest son came along. By this time I was getting instructions off of the internet. One day in January of '04, a few days after my youngest son's seventh birthday, I was trying to fold a plane from instructions on the internet but was distracted and had my paper turned the wrong way. Instead of throwing it away, I decided to try to design my own plane. It worked great. I have not stopped since.

Some Airplane History

The Greek philosopher Aristotle had the concept that air was a substance and had weight. Archimedes developed the law of buoyancy. This gave the foundation for the true study of flight as a science. Leonardo da Vinci studied the flight of birds and developed the concepts for the first gliders (along with a helicopter and a parachute) around the year 1500.

Sir George Cayley, an Englishman, is considered the father of modern aerodynamics. He built several successful gliders using the concepts of angle of attack and curved airfoils. In 1853, he built the first passenger glider. However, it is believed that the first passenger was actually one of his coachmen and not Sir George. The next major step was made by the German, Otto Lilienthal, who flew over 2000 flights before being killed in a crash in 1896.

This started the race to achieve powered flight. Dr. Samuel Pierpont Langley designed small steam-powered airplanes including one with a 5-meter wing span. Known as the "the Aerodrome," it flew over half a mile in 1896. He built a full-scale version of the same airplane designed to carry a pilot which crashed twice during October and December of 1903. This gave the opportunity for the Wright brothers to be the first to have a successful combined powered and manned flight. On December 17, 1903, the Wright brothers achieved success at Kitty Hawk, North Carolina. At last, manned flight was here to stay.

The next several years saw a bit of improvement in engine power vs weight (engines designed specifically for aircraft) and more efficient load carrying fuselages and wing structures. But it was very slow in development because only a few wanted to invest in what was believed to be a non-useful technology. Even the military was slow getting aboard at first. Then the prelude to WWI were beginning to unfold. Now money for development was available. Most aircraft of the war were still wood frame and fabric covered. The biggest exception being the German Fokker D.VII which was considered to be the best fighter of the war. It was a canvas-covered metal frame. It was its strength and durability that made it the best as some of the wood frame planes were lighter, faster, and more maneuverable. The Germans also developed the first all-metal monoplane with a cantilevered wing. Developed in 1915 before the war it saw some action mainly to drop supplies at the front line. The metal body worked so well only one was lost to anti-aircraft fire from the ground and none were shot down by fighter craft. But the plane was not efficient as a combat plane and its use was limited.

The years after the war saw some increased commercial and military interest. But, the depression years put a damper on available funds so progress was slowed down but not stopped. But wood and fabric wings and fuselages were now replaced with metal frames and skins by every major country. Engine power saw more improvement in power and speeds. It was the period of the aviator more than the plane in some respects. Charles Lindbergh being a great example with his 1927 crossing of the Atlantic in "The Spirit of Saint Louis", a fabric over metal monoplane using plywood ribs in the wing. Built by Ryan Airlines a manufacturer of mail carrier planes. It was powered by a Wright Whirlwind J-5C radial engine. This single engine as well as much of the design improvements over Ryan's existing design, the Ryan M-2, was insisted on by Lindbergh himself. Just 10 years later Amelia Earhart was making her famous attempt to circle the world in a Lockheed Model 10 Electra (an American twin-engine, all-metal monoplane) when she went down in the Pacific. By now Lockheed, Boeing, Douglas, and others were making all-metal, multiple engine aircraft.

At least the advances made in the industry helped to meet the needs that were brought on by WWII. The prewar and early stages of the war began the most rapid development of airplane technology both for speed and maneuverability of fighters to size and load-carrying capacity of bombers and transporters. Even manufacturing improvements helped reduce the cost per plane. The war also saw efforts to make jet engines practical (test and short flight began in 1939 just days before the start of the war).

To back up a little, helicopter flight started only a few years after the first powered flight in 1907 actually. Development was much slower than airplanes. But finally by WWII the German military was building and using helicopters in combat for transportation of supplies and the wounded. By the end of

the war the value of the helicopter for military use was proven and helicopter production begin to spread to every major military.

Although some prewar passenger aircraft existed the development of bombers and transporters set the stage for bigger more practical and profitable commercial passenger flight. Jet engines improvements also increased commercial and military value and design improvement has not stopped since. We are a society that now so heavily depends on flight it is somewhat amazing how many skeptics there were just a little over a hundred years ago. As we watch modern military jets and the vapor trails of commercial airlines it can seem strange that it has only been a little over 160 years since Sir George's unnamed coachman started man's launch into flight.

I realize this very short history section barely touched the surface even for the early years and not really anything of the modern age. Its purpose is to simply spark an interest that can lead to encouraging the student to research for themselves the interesting world of aviation.

Some Folded Paper Airplane History

Paper airplane history is not an easy thing to track due to the fact that in its early history there was not much recorded. It does not appear that there was anyone out there trying to find as many designs as possible in order to sell books. However, I do want to share what I know or believe to be accurate.

By 1920 there were recorded documents that placed the making of the classic dart to at least as early as 1909. Also, there are recorded interviews and statements that indicate that both gliders and darts were being made from single sheets of paper at that same time. In fact, the terms glider and dart appear to be in use by this time for distinguishing between planes with little lift and planes that "floated". There also seems to be more documented design of gliders in England than in the US.

In talking with my dad (born 1928), I found that in the 1930's paper airplanes were popular among kids because purchased toys were too expensive and almost everything had to be handmade. According to his observation here in the US only a few boys knew how to make gliders and were very protective of how they were built. Sharing information was not as important on the playground as showing how much you knew compared to others. One point of interest is that for many years popularity was split between darts and very slow acrobatic gliders. Straight level flight over a distance was not as important since darts could go further and slow gliders stayed up longer. There were no contests for such things as hitting a target at 20 feet for the medium speed glider to win.

About the time of WWII more of the slow gliders popular in England begin to become more popular on the playgrounds of America. Perhaps this was due in large part to soldiers stationed in England returning and showing American kids how to make planes such as The Swallow and improved versions of other slow gliders. Also, during WWII, there was a cereal company that put cutout designs of allied military craft used in the war on the back of their boxes. Prior to this I do not know how popular or common cutout and glue-up planes were although some designs did exist in boy's magazines but these were not affordable for most kids during the depression. By direct communication with Japanese acquaintances I do know The Swallow was being folded in Japan by the late 1940's. This is from the oldest Japanese I have had contact with so I don't know how far back it was being folded there. With its origami style where did The Swallow originate?

These activities may have had an impact on how many designers and experimenters were available to develop new planes such as the Trapezoid (my version is the Classic Aero) and various flying wings. The 1950's and 1960's was a time that airplane designs began to show up everywhere. However, the trend was toward flying wings and odd cutout shapes rather than trying to make nice gliders without scissors. Some of the classics around by this time were: The Helicopter, the Flying Wing, the Bishop's Hat, the Trapezoid, and several cut out planes similar to my Vintage Fighter.

By the 1970's, there was finally more effort put into designing good, faster gliders. Many designs for new slow gliders also began to appear. Cutout style, as well as, weighted nose types (mainly from paper clips) became popular by this time. Also, by this time, books on the subject became much more common and there were so many planes to choose from. The day for fast folded gliders finally arrived with the appearance of the full sheet version of the Vintage Fighter. I have seen multiple sites claiming to be the origin of this plane and have no idea where it came from other than I can't find any pre 1970 documentation. I think the big change in paper airplane design of the 70's was sparked by changes in the modern shapes for real airplanes and also the popularity of science fiction, as well as real, space flight. Ever shape possible from real to total fantasy became acceptable.

By the early 1980's paper airplanes began to become a lost art due to so many other "high tech" attractions to the middle school age kids. Paper airplanes by this time were mainly an activity between preschool to early elementary age kids and their parents. The kids do not seem to continue the hobby with the drive to test and improve designs like they did in years past. I hope that the paper plane does not get lost as a thing of the past.

Some Card Stock Paper Airplane History

The title of this section is a little deceptive; because, to discuss the history of airplanes made by gluing card or index stock, poster board, or cereal box cardboard pieces together must start with a study of the history of balsa wood aircraft. In 1926 Paul K. Guillow, a WWI naval pilot, started selling balsa wood aircraft models of famous WWI aircraft. With the flight of Charles Lindbergh in 1927 business took off with high demand for any thing having to do with aviation. Soon, the company expanded and had added designs of small simple flat wing gliders that were very affordable. The business continued to grow and supply more variety of these simple models until the start of WWII. During the war effort the major bulk of the balsa wood supply was going to manufactures for life jackets and life rafts and similar military products.

This is when heavy paper and light card board started being used as a substitute for balsa. Cereal manufactures started printing models of famous combat craft of the time. Card stock planes were here to stay, at least to some degree. However, once the war was over, the balsa wood gliders and rubber band fliers ruled again. Through the next three decades millions of these kits were sold and probably not only slowed down development of card stock designs; but, even the development of folded paper aircraft.

This left the card board aircraft out of business; but, still in the hands of a few enthusiastic fans. There has always been, and hopefully, always will be the need for creativity. Those few who find the need to design, build, and test their own models tend to keep trends going that later are a benefit for many. This has lead to a few attempts with some success back in the business world.

From the looping aircraft sold by a salesman in the mall during the 70's to a thin Styrofoam model sold in the Atlanta airport several years later (around 1990) there has been an interest in these small models that fly (I include this one here because even though not of card stock it's design was more similar to card stock then balsa). The use of card stock or index stock became more popular with the introduction of "White Wings" to the US by Dr. Yasuaki Ninomiya. In addition to "White Wings" at least one other good source is "Great Paper Fighter Planes" by Norman Schmidt.

Learning about Paper

Paper has been around for a long time. A few thousand years ago, the Egyptians took a marsh grass known as papyrus and cut the stems into thin strips. These were softened and layered to form a material suitable for writing. Today our word paper comes from the name papyrus. However, this material was not yet real paper. The first true paper came from China. In the year 105, T'sai Lun began experimenting with various plant fibers (including mulberry wood), separating the fibers in water, and screening them into a thin layer. Once dried, this became the first true paper. Today, paper is still made in a very similar way.

Making paper remained a very slow and expensive process for hundreds of years. This expense made books and writing paper too expensive for the average person to obtain in quantity. Finally, around the year 1900, modern paper mills were able to make a lot of affordable paper. At about this same time, real airplanes began to fly and there was need of paper for kids to make paper fliers for play. By 1930 when the Great Depression was keeping money scarce, paper was still cheap enough for most kids to make planes. Toys were too expensive to buy and fun had to be made with what was available.

Leaving history, we can move on to the important stuff, modern paper. From experiment we can find out that some types of paper make better airplanes than other types. Also, certain planes may work well on one kind of paper and be a total dud on another. Some characteristics of paper just make it difficult to fold and make the plane, but other characteristics actually affect the ability of the plane to fly even when well made. This can have much more effect on gliders than darts. Some of the most important of these characteristics are: weight, texture, strength, stiffness, and stretch. To better understand this we need to know a little more about how paper is made today.

First we are going to look at what kinds of materials are used to make paper. The main ingredient of paper is cellulose, the primary material that plants use for cell walls. In the plant stems fibers made from cellulose are held together with a glue-like substance known as lignin. To start the paper making process the plant material is chipped or cut and soaked in water to dissolve most of the lignin away. Many different types of plants can be used including soft woods, hard woods, cotton, and flax. The type of plant material, or combination of materials, is the first thing that will affect the properties of our paper. The best type of material for most paper airplanes is wood because it produces paper with better folding characteristics as well as a better texture. The type of paper which is used to make money would not be good for planes because it is made of 75% cotton and 25% linen (flax). Also, parchment or resume' paper contain a large percentage of cotton and do not make very good plane material.

The next part of the process that can have an affect on our plane is the amount of lignin that is removed. Somewhere between 90% and 95% is removed. To make a soft bendable paper requires more lignin to be removed. Also, during this part of the process the cellulose fibers are broken down into smaller fibers. To get a good quality paper requires small fibers. This additional processing to remove more lignin and make the fibers smaller takes more time and effort, causing the cost of the paper to go up. The type of wood will also affect how small the fibers can be broken up. Softwood trees will make the best paper. We can see the difference fiber size makes by looking at construction paper and comparing it to bond paper (the best plane paper). If you tried to make airplanes out of construction paper, very few gliders would work well because of the rough texture caused by large fibers.

Once the fibers are broken down they are screened to remove them from the water. From this point, the fibers are run through heavy rollers that will thin them down to a constant size. This rolling process has two main affects on the paper characteristics. First, the weight of the paper is controlled by how thick the paper is left after the rolling process. Second, the rollers may have a rough texture instead of a smooth surface. This is to make the paper look and feel like old fashion parchment. Some of our gliders will do fine with texture and some won't. Experiment and try slight different adjustment to get better results. Going back to the thickness, most of our designs will work better on heavier bond

paper. The three most common thicknesses are: copy paper and light weight ink jet (20 lb), heavy weight ink jet (24 lb), and extra heavy weight ink jet (28 lb). My favorite for fast, straight planes is 24 lb and 28 lb if I am going to glue their folds up for shooting with a rubber band launcher. However, for slow gliding, acrobatic, or even fast gliders with a lot of stacked folds 20 lb is still the way to go.

Three of the important characteristics (strength, stiffness, and stretch) are important because they control our ability to fold the plane and the ability of the plane to resist damage. Strength is the property of being able to resist tearing under load. It is very closely related to stiffness, the ability to resist bending. Both of these properties help to keep our planes from being damaged during landing or crashing into walls. However, if they get too strong and stiff the paper cannot be easily folded. Also stiff paper can cause planes to fly very poorly for reasons to be discussed in the advanced text (Science of Flight). Stretch is the ability of the paper to bend without tearing. This is a good property that is better in paper made from wood than in paper made of cotton or flax. It can really be noticed when trying to reverse the direction of a bend.

Weight is an important property for more than one reason. It directly has effect on the strength and stiffness of the paper. In addition, it becomes very important for how well an airplane can fly. Since paper airplanes do not have any power except the initial toss it is important to get all the energy possible during the toss. The weight, or actually the mass, of the paper becomes important here since the speed of the throw will be the same for both light weight paper and heavier paper. Heavier paper will have more momentum that will resist slowing down from the drag, allowing the plane to stay in the air longer and go further. However, the airplane will drop if there is not enough lift to hold up the weight. It seems that we end up with good points and bad points that must be balanced out for every design. Each design will have a best weight paper.

Texture is also a very important property of paper. It has a lot to do with how the air flows around the plane. This can change how much of the wing is actually effective at producing lift (unlike real planes a large part of the wing area of a paper air plane does not help with lift). This will cause the plane to be trimmed differently as the texture changes. For a given design, this texture change may help or hurt. We can begin to see that paper airplane design can be a real challenge and is not as simple as it seems.

An even heavier but stiffer paper is cover stock or index stock, both of which can be labeled as card stock. Cover stock will normally be found in 60 lb or 65 lb weight. Index will be found in 90 lb or 110 lb weights. Because of how paper is weighed, 65 lb cover stock is very close to 110 lb index stock. Both of these types can be used for planes that are cut out and layers glued together to make rigid models (a whole new "paper" airplane method). Card stock in general is too stiff to fold into regular paper planes.

So enough of the facts of paper production and getting to what does this all mean as to choosing the right paper to use: That's our next topic.

Thickness Comparison for Different Paper Weights:

Bond Ledger	Cover (Card Stock)	Index (Card Stock)	Thickness (inches)	Thickness (millimeters)	Type of Plane
20	28	42	.0038	0.097	Folded Slow/Acro
24	33	50	.0048	0.12	Folded Fast Glider
28	39	58	.0058	0.147	Folded (rubber band)
47	65	97	.0078	0.198	Glued Card Stock
53	74	110	.0085	0.216	Glued Card Stock
67	93	140	.01	0.25	Glued Card Stock

Choosing the Correct Paper

Paper is the most critical part of the paper aircraft. Yup, it's all about the paper. This may sound so obvious that it becomes ridiculous. However, there are several properties that can vary between different types and brands of paper. Understanding these properties and how they change the airplanes aerodynamics is essential to designing and building good paper airplanes.

Important paper properties include: strength, stiffness, stretch, weight, and texture. All of these properties have an effect on the actual folding of the paper, but, when it comes to flying paper planes the three most important are: stiffness, weight, and texture. What we are going to concentrate on here is what our best choices are for success in both building and flying paper airplanes.

Over the years I have noticed that if I find a paper that make good airplanes it does not seem to stay on the market for very long. Part of this is that paper sales have been based on supplying a product that is used for so many different things. I personally think that the aerodynamic quality of the stock should take precedence. However, not everyone agrees. With the demand for heavy, bright colored printer paper over the last several years, I thought that the problem was no longer going to be an issue. The only problem is that cost of making good paper airplane stock is more expensive than just making bright colored paper. The main characteristic that suffers in today's market is stiffness (not from too little but from too much).

It requires more processing time to reduce stiffness and produce a softer paper. This increases cost and in order to provide the most competitive price most stores are selling lower quality paper. My favorite airplane paper was "eXtreme colors" from Ampad and sold at Wal-Mart. Unfortunately, this paper has been replaced by "Embassy Colored Paper" from Ampad. This paper is much more stiff and can cause issues for paper airplane folding. For those of you who didn't read the advanced text PDF file, the problem that occurs with stiff paper is that the wings won't curve due to the difference in air pressure on the top and bottom of the wing. This causes a decrease in lift and an increase in drag, thereby, shortening airplane flight time. Worse, one wing can bend while the other does not and the lift and drag become unbalanced leading to instability. I have not checked Kmart or Target yet to see if they have changed their paper types. As a note, the paper they have sold before ("Hots" from Georgia-Pacific, and "Brights" from Riverside) were better than "Embassy Colored Paper". "Hots" is fairly good and "Brights" is OK but a lighter paper.

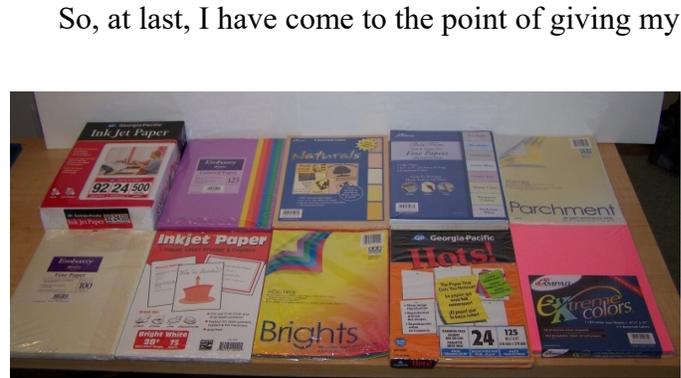


Weight is the next important property for airplane flight. Weight when it comes to paper really correlates to thickness of the sheet. Unlike full size aircraft, we are trying to get as much weight as possible built into our paper airplane if we want long, fast flight or less weight as long as we maintain structural integrity if we want slow, floating, acrobatic style flight. The reason for this is to give us the most momentum to overcome drag for fast and to reduce the need for lift for slow planes.

Most fast style paper gliders have wings that produce more than enough lift to compensate for the heavier weight as long as we maintain a good speed. All this and at the same time, the paper must remain foldable. This usually leaves us to compromise at a paper that is 24 lb weight for fast gliders.

You can search out the details of why paper is labeled under the weight values you see on the package but I am going to just present a table at the bottom of this page that show the weight values and equivalent thicknesses. For folded design we are going to be using bond paper. For those gliders that do not have too thick amount of folds 28 lb paper can be used for an even better weight. A reminder here here: 20 lb paper still has its place as it is the best weight for slow gliders (better lift to weight ratio) and for planes with many folded layers (better stretch).

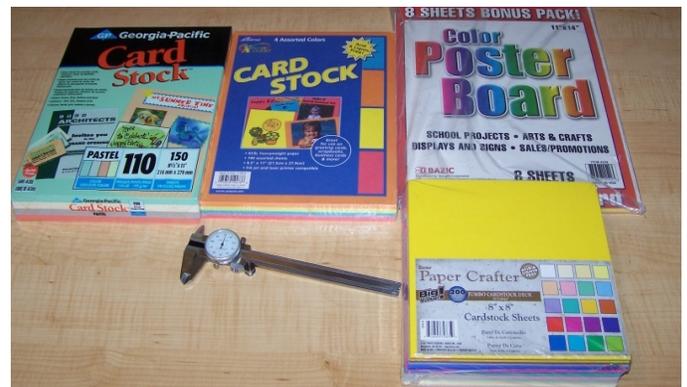
The last major characteristic to affect aerodynamics is texture. Many of the nice looking (for us with older taste, imitation parchment is nice!) papers available have a texture that can cause a bit of extra drag. This also seems to be the case with paper that I like the feel during folding. For best flight conditions on paper airplanes the paper surface should be smooth but not have a "sticky" coating. The Embassy "Fine Paper" series including the parchment look do make pretty good airplanes. The Riverside "Parchment" paper is also OK. You can see what the packages look like in the photo below.



So, at last, I have come to the point of giving my final opinion on the best paper. With the disappearance of "eXtreme colors" the best choice I have found is drum roll please..... 24 lb Ink Jet Paper (or 20 lb for slow gliders) like the type shown above from Georgia-Pacific. Yes, it is plain paper, but is also plane paper!!! I have also noted that since this type is used by the business world the quality is much more important and is maintained. Even the squareness of the cutting is more accurate making better folds.

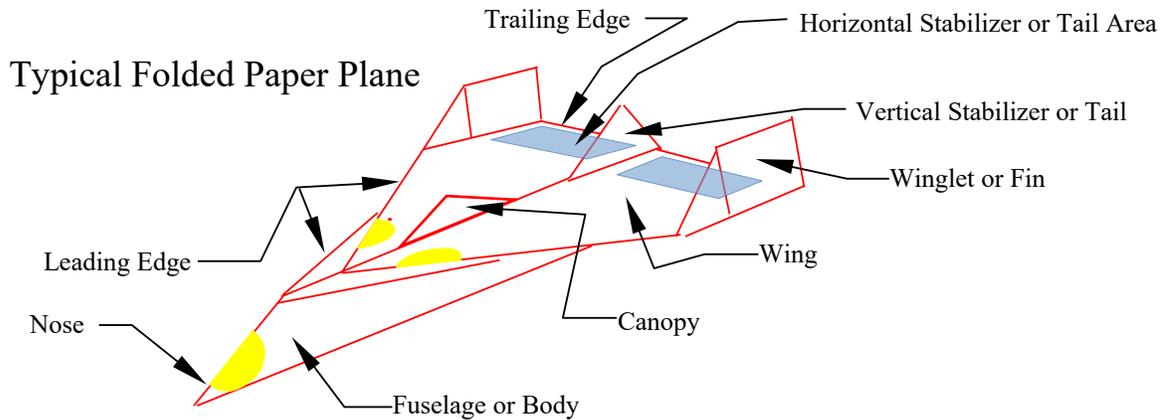
For those who need color you have two choices: Use computer graphics to add some art to your favorite designs or keep looking for that perfect paper.

Things get a little more confusing when it comes to paper or poster board to make glue up style gliders. These airplanes are a lot of fun but the weight can throw in some variables. First, most poster board or heavy craft paper for scrap booking does not even give a weight (most poster board is about 140lb index stock). When weights are given you might see 65lb or 110lb card stock. These two papers are very similar in thickness and weight. The difference is that the 65lb stock is cover stock and the 110lb is index stock, both of which are sold as card stock. Both varieties along with poster board will work for glued airplanes. The lighter stock may show a little instability if not well trimmed. On many of the craft type paper it may be too thin unless you first glue two pieces together. This would make for a nice paper airplane if two colors are used together. The biggest thing to remember is that the difference between the papers is the thickness and you may have to measure it. My personal preference is 110lb card stock. I prefer the plain white sold for printing invitations and thank you cards on your home printer. It is not pictured here but is sold in packaging similar to regular bond ink jet paper but clearly labeled as 110lb card stock. My planes seem to fly a little better on this paper. I plan on doing a series of larger, heavier planes that will need poster board thickness but that is a future project.



Parts of a Paper Airplane

Before getting started on learning about paper airplanes we need to look at the terminology for the different parts that may make up a paper plane:



Why do we use special terminology for airplane parts? The general answer is that engineers like to name things based on function. To demonstrate this we need to consider specific parts:

Body vs fuselage – The term *body* is an indication of a container to hold cargo (goods or passengers) in a vehicle. An airplane body certainly does this. But in other vehicles everything is tied to a base structure normally referred to as the frame. All loads from the engine, the wheels, and the weight of the cargo all are supported by the frame. In an airplane the frame work of the body including the skin panels ARE the load carrying structure for the engines, lift (wing and tail), control surface loads, cargo weight, and drag. This combined frame and body (cargo space) is where all the individual load carrying members are sort of “fused” together. The term for this special combination is *fuselage*.

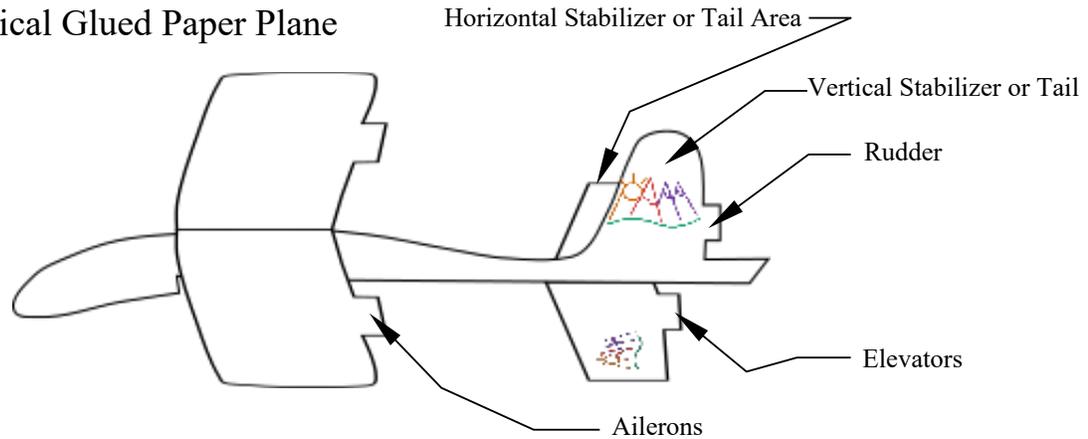
Fin vs winglet – The term *fin* is used by engineers to refer to a structure on a projectile (moving body) to help maintain intended course, often straight flight. The way they work is that if the body starts to move out of a straight line then fluid pressure (gas or liquid) on the fin “pushes” the body back in line much the same way as a weather vane is “pushed” to point to the direction of the wind. If the fins came off of a model rocket during flight and a very unstable and extremely dangerous condition would occur. The winglets on an airplane serve a totally different function. A wing has high pressure flowing air on the bottom and lower pressure air on the top. The tendency of a fluid is to flow from high to low pressure areas. Air does not flow from the below the wing’s trailing edge to above it due to what’s known as the Kutta Condition (see The Science of Flight Section for more information). However, it can come around the side edges of the wing, under certain conditions, and reduce lift. This can even happen on only one side causing the plane to start rolling and go into a dive. Once knowing that the “fins” on the wings of the paper airplane have a lot to do with stable and consistent lift production it is easier to see why the term *winglet* is appropriate. On a paper airplane the winglets often do better if folded one way vs the other (down often works best on most paper).

Fin vs horizontal or vertical stabilizer (tail) – The question arises doesn’t a tail – both the horizontal part and the vertical part act like a fin? The answer is yes BUT these surfaces do more. They normally have adjustable control surfaces that help with both horizontal and vertical stability (elevators and rudder). They are referred to as *horizontal and vertical stabilizers* and they as well as the framework that ties them together are jointly referred to as the tail. The horizontal tail section is

normally design to produce lift as well, often in the downward direction in order to create a stable aircraft. For the same reason we often have to curl our trailing edge up to create the same effect. For folded paper airplanes the tail serves a different purpose than a vertical stabilizer would on a regular plane or even a card stock plane. It acts as fin to produce the same moment as a negative lift horizontal stabilizer would produce. More about that in the next section and in much more detail in The Science of Flight section.

A few more parts are more noticeable on card stock planes:

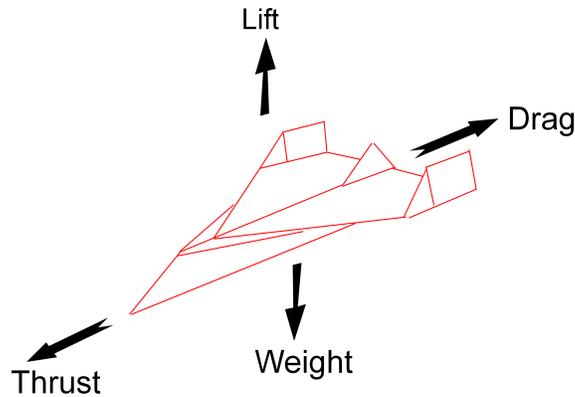
Typical Glued Paper Plane



These are just three examples and a good site to check out is NASA's airplane part section for more information.

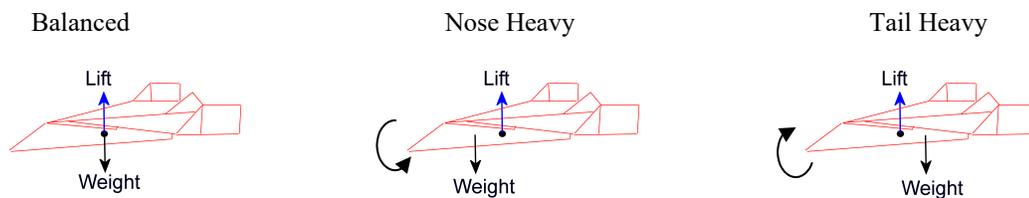
Learning about Basic Paper Airplane Dynamics

The study of how forces (loads) change the motion of a body, such as a paper plane, is called dynamics. Paper airplanes motion is determined by the action of four different forces: lift, weight, thrust, and drag. The sketch below shows the direction each of these four forces act.



We are going to study a little about each of these forces. First, lift is the force that is produced on the plane as air travels over and under the wing. The air travels a little faster on the top of the wing than on the bottom of the wing. The study of behavior of air in motion, known as aerodynamics, tells us that this causes the air on the bottom of the wing to push up a little harder than the air on top of the wing pushes down. This difference in push is the lift. Aerodynamics also tells us that the faster the plane is flying the more lift we get acting on it. The lift also depends on the geometry, or shape, of the plane. These two facts together teach us that the best throwing speed for every plane design is different.

Opposing lift is weight. Weight is simply a measure of how heavy our paper is. In order to have a straight and level flight for our plane, the weight should be equal to the lift. Too much lift and our plane will climb and too little lift and our plane will drop. Another very important feature of an airplane is that the point that the weight balances, called center of gravity, must be at the same point as the center of lift. If the center of lift is in front of the center of gravity then the nose will rise and if the center of lift is behind the center of gravity then the nose will drop. In order to balance these loads, we must often "trim" our plane. However, trimming the plane increases drag. The best solution is to slightly redesign the folds to adjust the center of gravity to balance the loads without trimming.



The next load is thrust. In real airplanes this is provided by the engines throughout the flight. But, in a paper airplane the main source of thrust comes from the initial throw. The only other source is if our plane makes it high enough that once it slows down and loses lift, then it picks up more speed as it starts to fall back toward the ground. Full size gliders can pick up height by catching warm air rising and then pick up speed (more thrust) as they drop from this higher altitude. Even model planes shot with a rubber band launcher can get some extra fly time this way. However for paper planes thrown indoors we must rely totally on the initial throw.

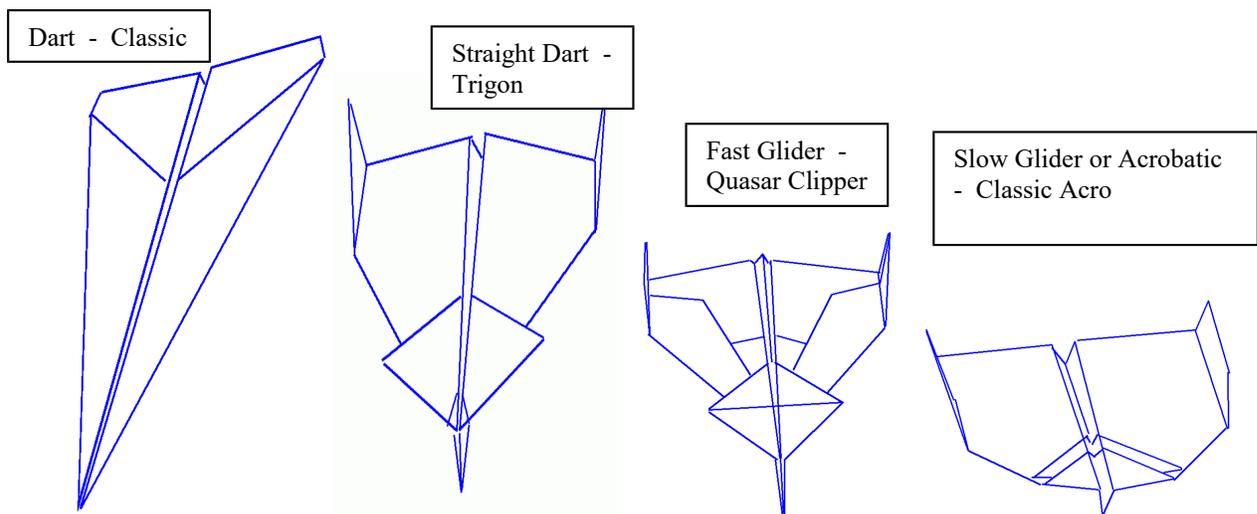
The last force is drag. This comes from the fact that there is friction resistance from the air that flows around the plane. This force opposes thrust and slows our plane down. The best we can do to

minimize drag is to make the flattest and most crisp folds (however, certain folds may require rounding a bit if not using tape – see trimming a paper airplane) we can as we make our plane and to use paper that has a texture that is low drag. The best texture is usually the smoothest paper, but some planes fly well with a texture of parchment paper. You can really see what bad texture can do if you try a glider on rough construction paper.

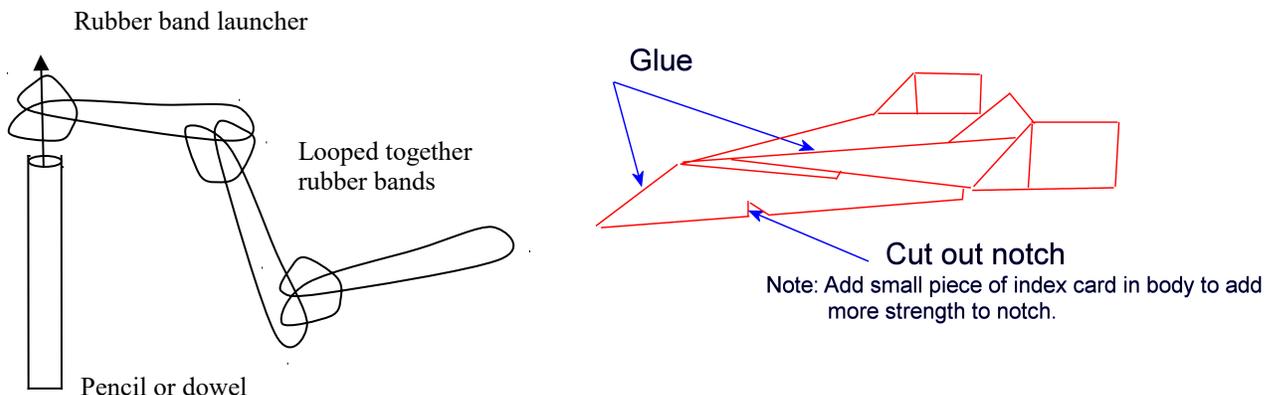
To overcome drag for indoor paper planes, often the best thing we can do is to use the heaviest paper that the plane can produce enough lift for. The reason for this is that, regardless of weight, we are going to throw the plane at the speed that produces the correct lift. Also, there will be only a little difference in drag between different weight papers. Heavier paper will give the plane more energy and momentum to resist the effect of drag. However, the plane must be able to produce enough lift for the heavier weight to maintain a level flight.

Learning about Types of Paper Airplanes

There is more than one type of paper airplane based on how the plane flies. Darts are planes that have very little lift and very little drag. Because of this, many of them basically fly in an arched path like a regular dart thrown at a dart board. They can be thrown hard to go a long distance but most of them just don't have any real straight and level flight time. The exception to this is that a few designs can fly very straight with enough lift to keep from falling at a high speed (at least high for a hand tossed plane) but will start to drop once they have slowed down to a medium speed. This really amounts to a transition between a dart and a glider and, for lack of a better term, I call them straight darts. Normal gliders have enough lift to actually fly straight and level at a medium speed. Slow gliders have enough lift to stay flying at slow speeds. They will actually stay in the air longer than normal gliders and are often the best type to do acrobatics.



Some airplanes can even be stiffened up with a little glue and shot with a rubber band shooter. When choosing a plane to be launched with a rubber band shooter, it is often best to choose either a fast glider or a straight dart. In order to make a plane strong enough to be launched by a rubber band we make the plane out of heavy paper such as 28 lb. or card stock. Once folded the fuselage (body) is glued together to stiffen it and a notch cut into it for launching. The plane can be sprayed with hairspray to stiffen it even more. Using card stock, we can even cut out parts and glue layers to make real model airplanes that can be flown with rubber band launchers.



Folding Tips and Tricks

This section is primarily for beginning folders, or those who always dreaded having to fold their school papers in half due to no knowledge of paper folding technique – BUT, there may even be an idea or two an intermediate folder could learn. And as for pro folders, please read in case suggestions for additions can be made. For those that think folding technique is not so important, watch videos of the current record holders folding their planes on YouTube. They are very precise in their folding technique.

Before we can even start we need to learn a little more about working with our primary material, paper. Learning to work with paper can be more challenging than one would originally think. Some paper just will not work for paper airplanes due to either its texture (effects air flow on wings) or its strength/stiffness (bend-ability). For more information and paper comparison you can check out my section devoted to paper. But, even if the paper makes great airplanes doesn't mean it is problem free! Some is just hard to work with and some just won't stretch enough to make a plane like the Lunar Hawk. As we talk about the problems with paper folding, we need to keep in mind that paper has been around a long time and the art of paper folding dates back to almost the same time as its invention. In other words, good folding is possible.

If we start with an airplane, even a classic dart, we first fold in half and then fold corners down to meet the center fold. And our corners don't match! We know this is not good because "For a Good Flying Airplane Symmetry is Important". Yes this is the cornerstone rule for paper airplane success. So, we look to see where we misfolded and yet everything seems good, it just doesn't line up. Although it would not occur to most people that the problem is the paper was not cut square at the factory (we are way too trusting of factory quality). If you have this problem note the brand because some are worse than others and consider changing next time you buy paper. But the planes will work fine, just try to fudge them a little to make as symmetric as possible. I mainly point this out as a warning that we can have issues to face before we even start.

The main five paper issues we will need to overcome are: difficulty in making a clean crease, fold unforgiveness, excessive puffiness under folds, crinkling, and paper tear. These problems arise from working with a thin, fibrous, and stretch resisting material. This along with the fact that once stretched, paper doesn't return back to its original shape, make a challenging material to work with.

Difficulty in Making a Clean Crease – This can be demonstrated by looking at the bend in a piece of construction paper or some card stock. The crease doesn't make a nice straight line; but, looks like a row in a plowed field with little zigzags and fiber damage on both side of the crease line. Paper that exaggerates this property will normally resist reversing a fold (folding to crease in one direction, then opening and folding in the opposite direction).

Fold Unforgiveness – Another issue is that, no matter how carefully we fold we are going to miss the mark a little sometimes. Many types of paper allow us to use our thumb and index finger to "roll" the error back in line, and some just won't let us do so. Even when we try to unfold and refold it just wants to fall back on the same old, wrong crease. I refer to this conditions as "fold unforgiveness". It can cause issues when trying to flatten out the plane as well.

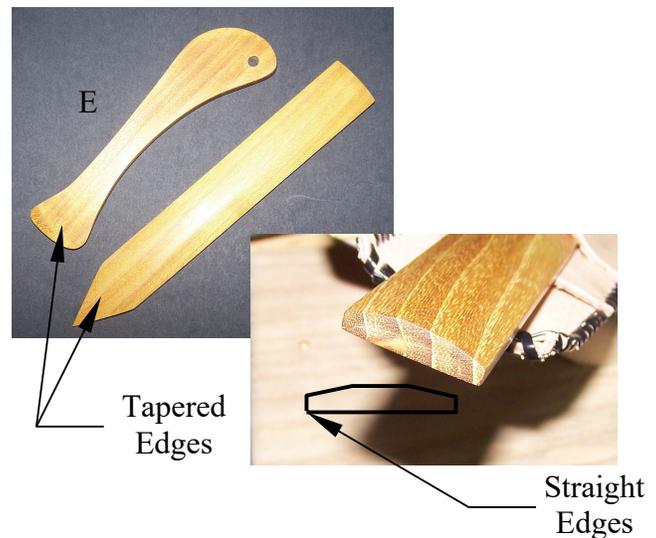
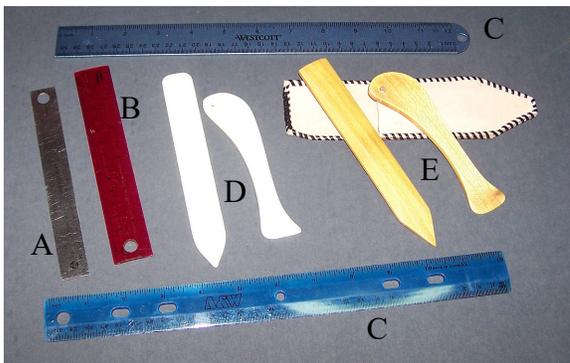
Excessive Puffiness Under Folds – We finally get towards the end of our folding and notice that our plane won't sit flat on the table top. There is a whole lot of puffiness under the folds. This is due to the fact that the paper doesn't stretch well. The folds in step 5 start pulling against the creases made in step 2. This pull results in puffiness. Where it really causes a problem is if it is different on each side. This causes different amounts of lift on each wing and thus a plane that spirals out of control. This is why you see the instruction "flatten well" over and over. It is totally fine if the crease moves a little when you flatten. This is normal and allows a flatter plane. Just note: *some* planes like the XP 22 depend on some puffiness to allow for good lift – just make sure there is symmetry.

Crinkling – When bending any material there is tendency to stretch in some areas and compress in others. Thin materials don't compress well, instead they wrinkle. Most of these wrinkles can be smoothed out and don't cause any problem. Over all this is more of a cosmetic problem than an actual

functional problem. But they do need to be taken care of after each step and not allowed to accumulate.

Paper Tear – As we continue to fold some areas get thicker and thicker. Putting one more fold on a thick section forces the paper to stretch. That’s when we find out if we have a type of paper that will stretch or if it is the type to tear. Earlier I mentioned that some paper just won’t stretch enough to make a plane like the Lunar Hawk. Instead of stretching as required the paper pulls apart at the weakest point. Back a few years ago resumes were printed on special parchment paper and actually delivered or mailed more often then now. Once a job was obtained the left over resumes were useless except as paper airplane material. For such an expensive material you were limited on what designs could be folded due to the tendency to tear. Still, even today, certain special use paper can have a tendency to tear.

Now that we have discussed the problems it is time to move on to the solutions (at least for the first four) – Folding Tools. The use of folding tools is again almost as old as paper folding. Just like the origin of paper folding, the best tools are modeled from tools used for centuries in Japan. Some articles I have read implicate that the tools originated with makers of Kimonos and then adapted to paper. With silk cloth or paper was first, use of these tools has stood the test of time. The original materials for the tools were bone and bamboo. Bone folding tools are still made and sold today. Plastic substitutes are also available. But, all of these can be expensive, and cheap or free substitutes can be found or made. Before going any further, I want to point out you don’t absolutely need any tool but a good finger nail, the rest just make things much easier.



Folding Tools:

- A. 6” Metal Ruler. Less than 1” wide. Good as straight edge for folding wings up. Help keep thicker from crinkling on the bottom. Also for marking measurements.
- B. 6” Plastic Ruler. Can be used as straight edge for bending as well as a suitable smoothing tool. Only problem is they tend to break too often and it is not as easy to find good cheap ones anymore.
- C. 12” Ruler (Plastic or Metal). Great as straight edge for long bends but inconvenient for travel.
- D. My first official folding tools. A plastic set that came with an origami kit. Curved smoothing tool is great but pointed tool did not have a flat face to allow it to be used as a straight edge. Wonderful for tucking the bottom of folds back in when they want to slip. Also, in my opinion, the best tools for smoothing out crinkles and flattening.

Cross section of pointed tool’s tapered edge



Cross section of pointed tool’s tapered edge

- E. Folding tools I made from Osage Orange wood (any hard closed grain wood can be used). Pointed tool has flat bottom to allow it to be used as straight edge for bending and a single tapered face to allow it to be used as a smoothing tool. Curved tool has a double taper going toward the edge.

Notes: If wood working tools are available folding tools can be made from a branch discarded from pruning or after a storm. Even Bradford Pear branches (always available in many parts of the U.S. after a storm) make beautiful tools. Also, a thick plastic or an old fashion wooden ruler can be fashioned into a folding tools with no more then a small hand saw and a sander.

After the essential fingernail, the next tools are rated as important. This really only consist of a 6" ruler. Regardless of what it is made from, it allows for making the airplanes that require measurements. A narrow metal one is just the right size to help folding wings because the width is just the right size for the planes fuselage. On the other hand a plastic one with a smooth bottom surface makes a good tool to smooth folds. But this does wear off the measurement marking and eventually breaks the ruler. If you can still find one an old fashion wooden 12" ruler can be modified with just a hand saw and sand paper into a wonderful all in one folding tool like the pointed one shown above.

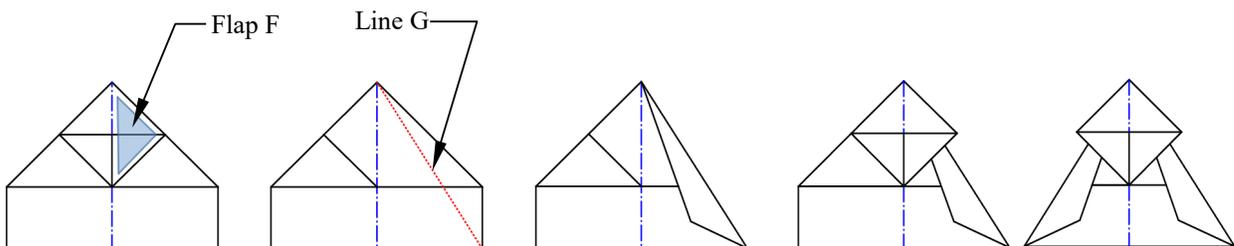
One last tool needed by those of us with less perfect eyesight – a good sharp pencil! It is very easy, especially on paper that is non white, to see where a fold needs to line up (such as the centerline). But the real value of the pencil reveals itself in helping to prevent over shooting the wing to fuselage crease when folding the tail.

Now that we have considered overcoming the short comings of paper itself our next step to to look at improvements to our technique! To name some of the bad ones: over folding the mark, folding unsymmetrical, folding nonparallel, and failing to finish cleanly.

Over Folding the Mark – One of the biggest warnings I could give to any new folder is: DON'T FOLD BEYOND THE MARK. It doesn't matter wither it is the early steps folding the top corners down to centerline or making a tail, over folding is going to lead to problems. In fact it is better if we fold a little short. For instance a lot of designs show a flap being folded from the top center of the aircraft to the bottom outer corner of the wing, usually tucked under the part that forms the nose, we will do better if fold about an 1/8" short of the shown marks. And once those edges are folded make sure they don't slip any more then they have to on the next fold. Often, the solution to this problem is to get a sharp pencil so you can clearly see.

Folding Unsymmetrical – First off you need to look at the instructions carefully. Depending on the writer and the intended audience instructions can range from true instructions to a method of showing the design with no help on how to actually make it. The difference is that beginners want to know how but experienced folders want as short as possible writing to use as reference later. I personally tend a little in the middle but lean toward the later. As an engineer we are trained to keep design and manufacturing method separate. Take a look below at each example.

Quasar Clipper (Steps 7 & 8):



Step 7

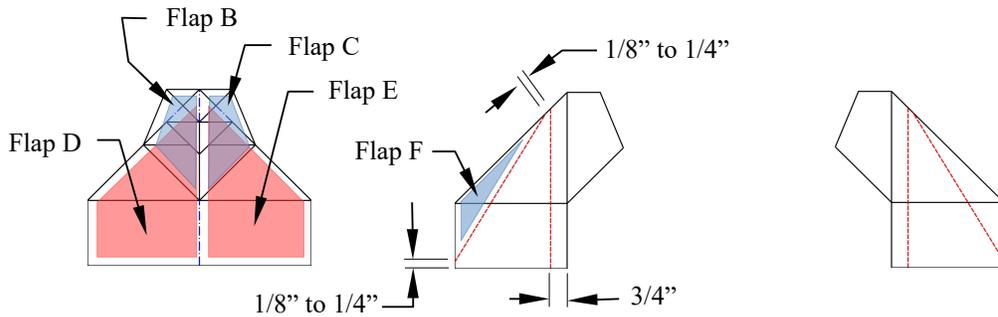
Fold Flap F along center to right side. Fold right side along Line G. Return Flap F to right side by folding back on centerline.

Step 8

Repeat step 7 for left side and fold plane in half.

These instructions work fine as long as you have experience with paper folding. You would know to stop short of the mark and have enough experience to keep both sides symmetrical. While watching a younger folder following these directions; I noticed that he kept trying to hit the mark perfectly and some times over folded. When I showed him how to stop a little short of the line he had a hard time recognizing how much to stop from the edge and messed up symmetry. This got me thinking maybe I did need to change how I documented my designs and did several like the one below.

Street Cruiser (Steps 14 –16):



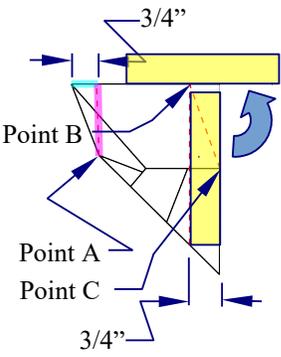
Step 14
 Fold Flaps B and C up along centerline. Fold Flaps D and E down along centerline. Flatten well and lay plane on its side as shown.

Step 15
 Fold wing over 3/4" from centerline as shown. Crease and unfold. Fold Flap F down as shown. Flip plane over.

Step 16
 Repeat for right side matching left folds. Flatten well. Unfold from centerline and lay down as shown.

Notice these instructions work much better if you have minimal experience with paper folding. To fold this way is a little slower but fewer steps are documented. I do believe that there will be mixed feelings on which method is best. The key is to realize we need to review the design document and make our own decision on how to do it.

Folding Nonparallel – Most of my designs have a squared type of body where the wings and winglets fold parallel to the centerline. I try to design this way to make it easier to keep things straight and symmetrical. The rest of the plane is summed up in a single diagram in the instructions as shown. But there is really quite a bit of folding know-how that goes into actually finishing the plane off.

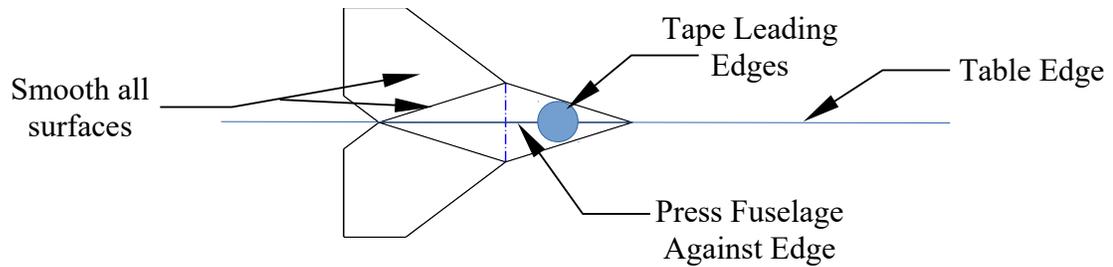


First to fold the winglets down. More important than the actual dimension shown is symmetry. I took a real plane that I fold a little fast and was not super careful to keep side symmetrical. I then took actual measurements from the outer tip to Point A. One side measured 3/4" and the other 5/8". I would fold both sides to match at the lower value of 5/8". The most important factors are: that the back edge of the winglet (highlighted cyan) line up with the back edge of the wings, and that the two winglet fold lines (highlighted magenta) are matched.

I would like to note that for many types of paper it is very helpful to fold a crease forward and backward before completing an inside reverse fold. This is used for all plane designs. Also, if you are working at a desk with a good, sharp edge; it makes a great straight edge.

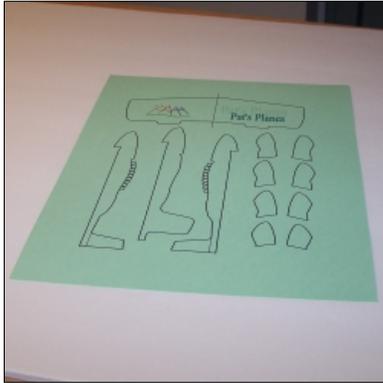
Failing to Finish Cleanly – If your work surface has straight 90° edges it can be used in several ways. It can be used to take an existing crease and fold it the opposite direction before making a

reverses inside fold. Especially, to get a good tail fold and help prevent over folding it. Some paper really resist these reverse folds and they are so commonly needed. The edge can also be used on a completed airplane by pressing the fuselage against the edge and holding one wing flat on the work surface itself to rub folds flat and level as well as holding leading edges together for taping. See the section on trimming for more info about taping a paper airplane.

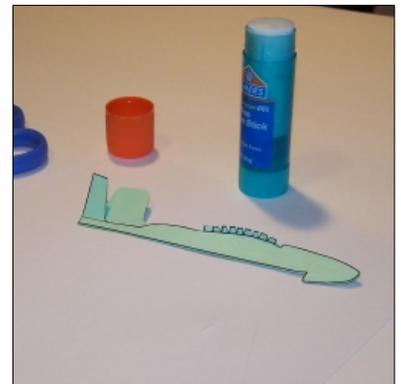
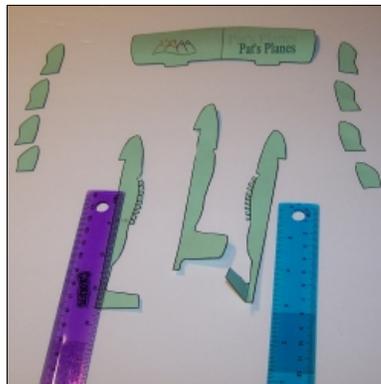
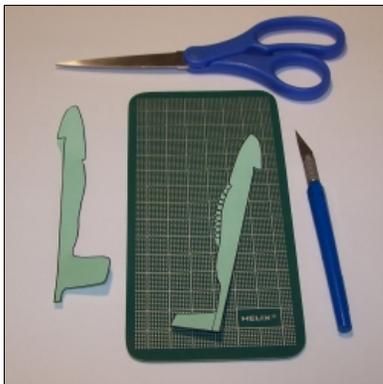


Just one last point: look up some origami web sites to learn some terminology and techniques. Good luck with your folding skills!

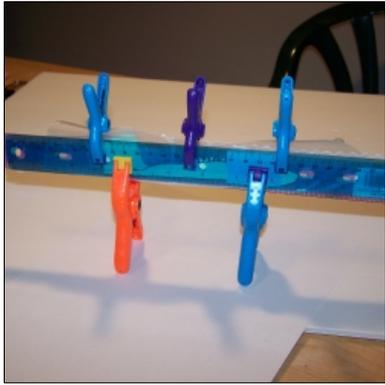
Instructions for Card Stock Planes



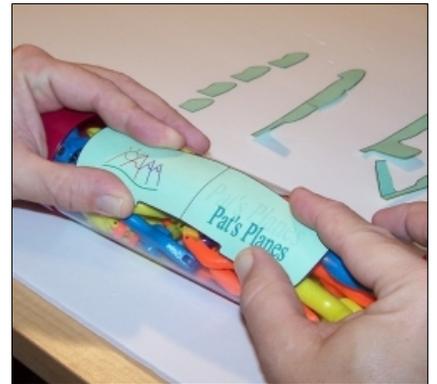
1. Download the *.pdf and print the paper airplane design onto card stock or poster board.
2. Cut out each piece of the paper plane carefully.
3. Trim the plane pieces with an X-acto knife where required. Make sure the rubber band notch (above right) and the gluing zigzag cuts (below left) are as close to the line as possible.



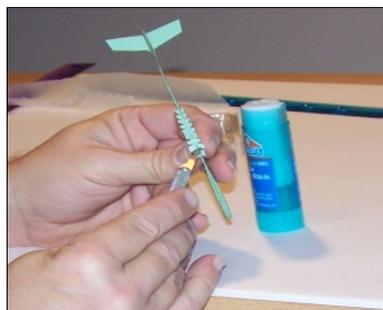
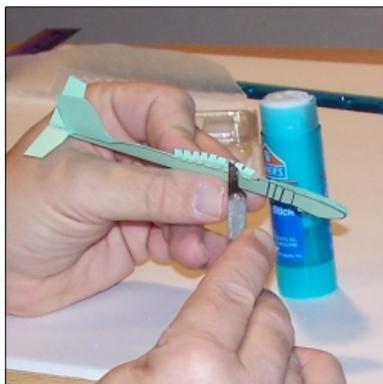
4. Use a ruler to fold out all straight folds such as the airplane's tail sections.
5. Use fingers to fold out zigzag lines for gluing on the plane's wings.
6. Glue the airplanes body pieces together. You can use a glue stick or a brush with a mixture of 50% white glue and 50% water. The stick is faster but the white glue mix will bond the paper together better. If you use glue stick to glue your paper plane together you may be able to skip steps 7 and 8 below. Note: To keep up with which piece goes where the rule is that the ink points out. Also if more than three pieces are used I will label the as 0 (center), 1L or 1R (next out), 2L or 2R (further out), etc. For even number of body sections there will be no "0" piece just glue 1L and 1R together. Left and right is based on looking from tail forward on the airplane.



7. Cover the plane with wax paper or plastic wrap including putting a small piece between the tail sections. Look carefully and you can just see this small piece in the picture above center.
8. Clamp as shown (above right) using rulers or strips of wood to flatten the paper airplane down. Medium or large binder clamps will work good as clamps (above right).

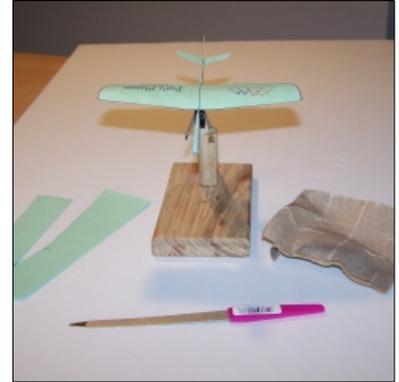
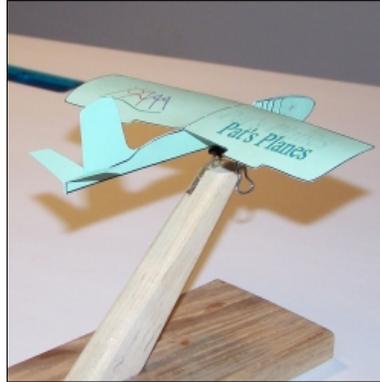
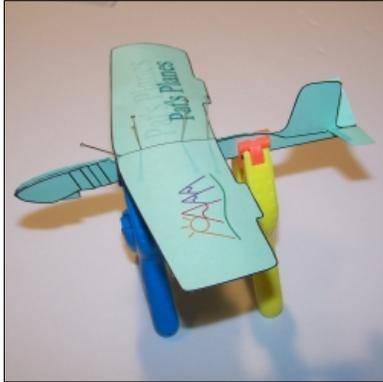


9. Allow the body to dry for a few minutes longer if using white glue mix. Remove clamps and glue the airplanes nose pieces to the body section. Reclamp on the nose of the paper airplane.
10. While the nose is drying rub the wing on the corner of a desk top to add some curvature to the bottom of the airplanes wing. You can also use a round object such as a roll of tape or a can to curve the wing.

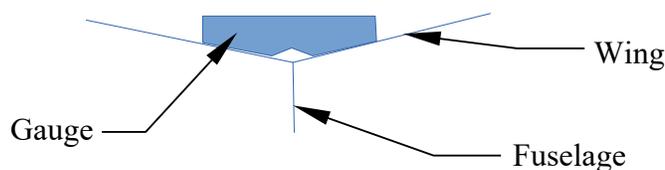


11. Apply glue to the wing making sure that the gaps are filled with glue and that the whole glue line is a smooth curve down the airplanes body. The pictures above (center and right) show how to use the side of an X-acto blade to do this. Wing direction is shown with an arrow pointing forward. Also look for a small line on one side to show lead point of wing.

12. Push a couple of straight pins through the wing on the center line.



13. Use these pins to align the wing to the paper airplanes body. while the glue dries. Add a few more pins along the wing to hold it to the plane's body until the glue dries.
14. Set the plane aside to completely dry. Since there is more glue used in the airplanes nose than the rest of the model the plane would fly nose heavy until it dries.
15. Use sand paper or a file to smooth down the edges. Test fly to see if the plane is balanced. If the nose goes up cut out and add a little more weight to the front of the paper airplanes nose. If the nose goes down either sand off some more or glue a little weight to the rear of the paper plane.
16. Newer models have more parts. They glue much as what is shown. Winglets and vertical tail pieces normally use three tabs; outer two go down, middle one goes up. Special instruction are given as needed with each model. Swept wings require right and left halves separately curved since curve must go down wing axis. Also, many have a gauge to set the dihedral angle of the wings after gluing. For wings with curvature a few drops of water at the wing body/joint may help the wings fibers to stretch to allow both curve and dihedral angle.



Extra Tips: Add a line of glue to all the joints, like caulking, after the airplane is finished. This is really a good thing to do on bends to keep the angle correct. I use white glue and apply with the tip of X-acto blade or a toothpick. Another tip is to very lightly spray the finished plane with a sealer like craft varnish or polyurethane. Even a couple of light coats of hair spray will strengthen it and add a little bit of water protection. Try flying both straight and also shooting up at about 75 to 80 degrees and allowing to slow glide down. Just be safe at all times.

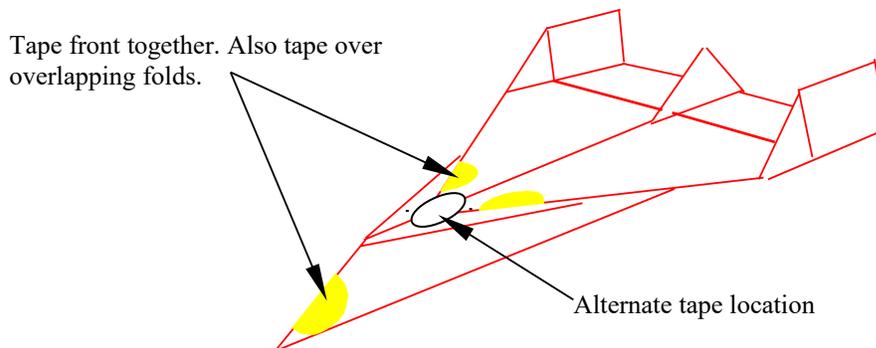
Learning How to Trim a Plane

No matter how well we fold, we will most likely have to trim our plane. We will need to decide if we are going to tape our planes or leave them open. For many years, I hated the idea of having to use tape on a paper airplane. But, I finally realized that it did make better flying gliders and allowed for more design choices (such as reverse folded leading edges).

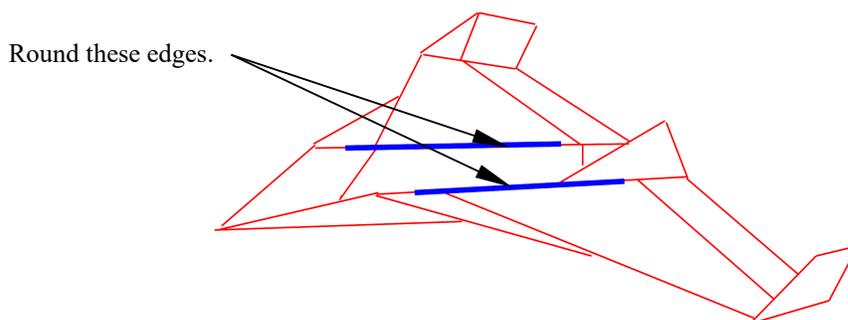
To keep it neat I prefer to use $\frac{3}{4}$ " diameter color dot labels. However, if you want to fly in an official contest you must use regular scotch tape. I have even come to realize how well a thin layer of glue from a glue stick can improve the flight of many paper airplanes instead of tape. Again, this is illegal in a formal competition where records can possibly be broken. But, if a school or other organization planes a local only competition then glue (such as glue stick might be considered). It is just a little hard to control that is being used to hold the folds together and not to change the weight and/or cg of the plane. Just make sure the rules are published so that everyone has equal opportunity of design.

Competition notes:

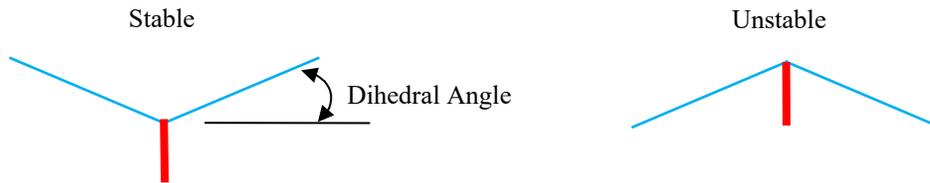
Cut the tape with a sharp knife to eliminate those little zigzags on the ends of the cuts. If you use clean glass or other slippery surface you can cut very even lengths without losing the sticky. This keeps everything symmetrical and flatter ends that stay put. This may only gain a few inches or a fraction of a second but every single bit may count!



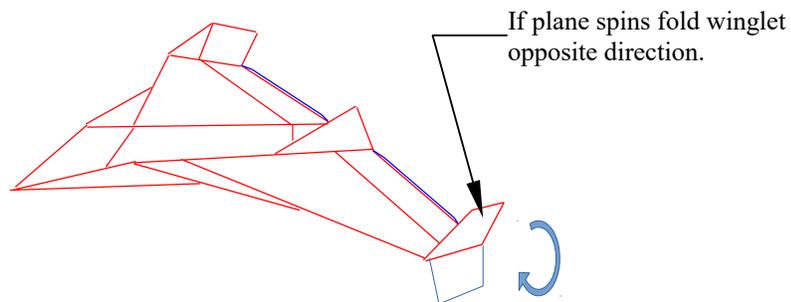
If you don't tape then you may have to smooth out some of the edges. Air does not like to flow over or across sharp corners. This can cause the plane to want to roll from one side to the other if you don't round the edges between the body and the wings as shown below. For those that want to know why see the advanced Science of Flight section.



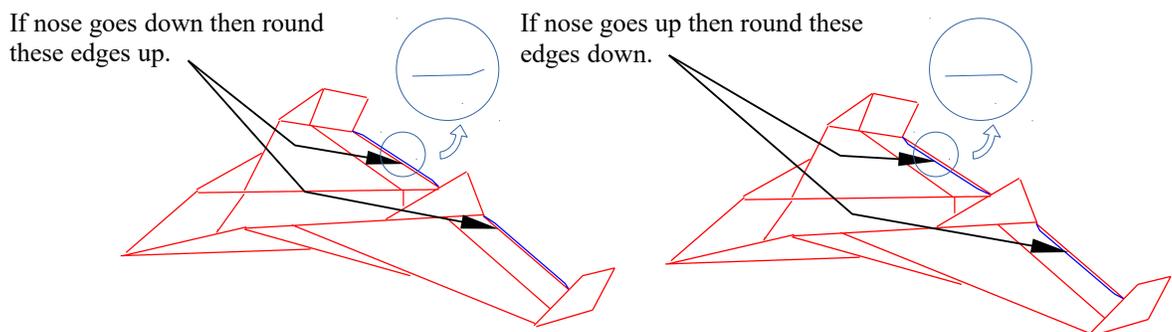
Once you have either taped, glued, or smoothed the curves; we need to check further for roll stability. If the plane still rolls out of control, then make sure that the wings are angled up, not down. This angle is called dihedral angle and is important for stability. For more discussion and details of the effects of a bad dihedral, again, refer to the advanced Science of Flight section.



If the plane continues to roll, especially if the plane has a tendency to flip over and fly upside down, one last option is to reverse which side of the wing the winglets are folded as shown:



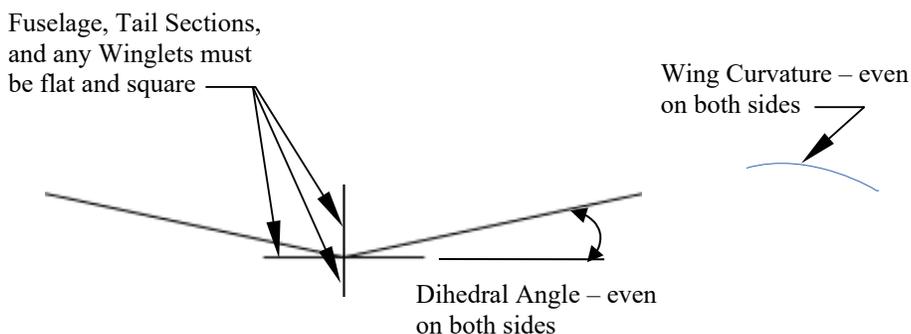
The last part of trimming is to adjust for straight and level flight. If the nose is going down or plane just doesn't have enough lift then curve back (trailing) edge of wing up as shown. If nose goes up then curve trailing edge down. For both of these adjustments, you may have to make curved edges and then straighten back as good as you can while leaving just a very slight adjustment. You can use an edge of a table to do this. Sometimes each wing will need a little different adjustment. In fact, if no other method works to keep the plane from rolling, bend the side with the wing that goes up, up and the side with the wing that goes down, down. All adjustments required should be minor. If not, there is an issue with the design, paper, or a combination of the two.



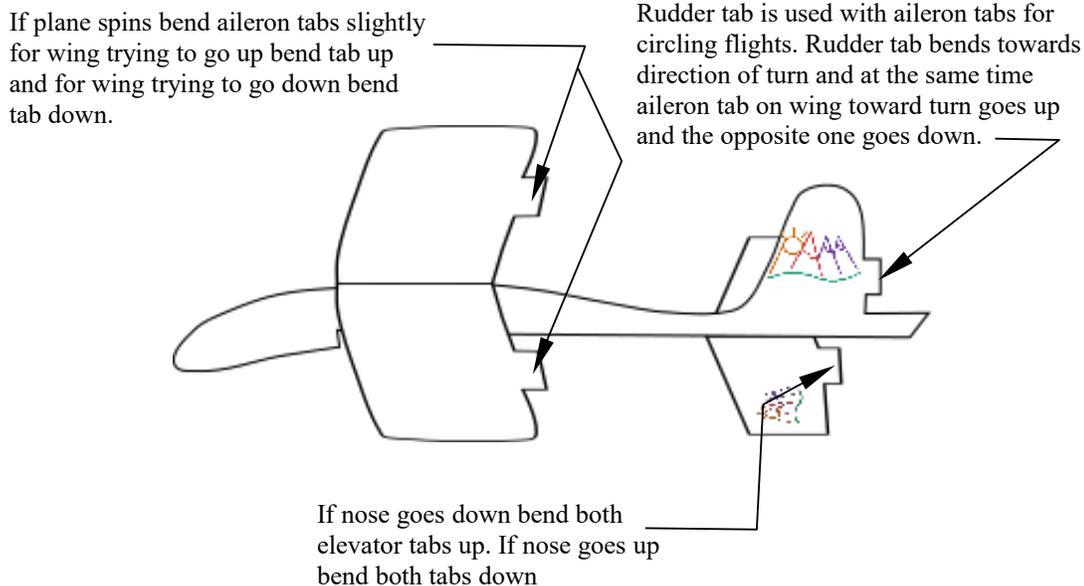
One last note: For a few designs it maybe required to add or remove the tail when going from one type of paper to another. Adding a tail will bring the nose up and removing one will bring the nose down.

When it comes to glued card stock style planes they are a little more complex. The first thing to consider is checking out if there are any craftsmanship cleanup to do. Anytime you are gluing paper together in layers there is going to be rough edges and glue squeeze-out. This needs to be cleaned with a very sharp knife and/or sandpaper or a nail file. Going down to the local Dollar Tree or similar store should provide everything needed at a very reasonable cost. I personally prefer to use a coarse and a fine nail file (diamond if available) and a box cutter (the style with a long retractable blade that dull tips just snap off). The edges of the fuselage should be smooth and each layer even where it looks like a solid body. The wing and tail pieces should be straight or smoothly curved with no fuzz or trimmings attached.

Next, check that the Dihedral Angle is correct with the gauge and is an even angle on both sides of the fuselage. Make sure fuselage, vertical & horizontal tails, and any winglets are flat and square to each other. Make sure the wing curvature looks the same on both sides.



Once the plane looks good it is time to test fly and adjust as shown below:



Sometimes, we just can't adjust the elevator tabs enough to get straight and level flight. This occurs most often if we change the paper weight (planes are designed for 110# index stock may require modification for 65# cover stock). If you can't get straight flight, then add or subtract nose weight (nose up, add - nose down subtract). Adding weight is accomplished by cutting small circles (3/8" to 1/2") and gluing to each side of the nose. Subtracting weight is done by cutting, sanding, or filing off some excess from the nose area of the fuselage.

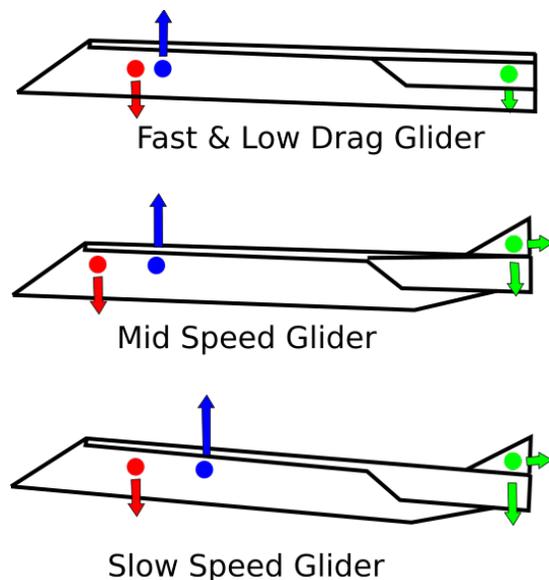
Designing Your Own Folded Planes

Anyone who enjoys folding and flying paper airplanes should try their own designs. To begin, play around with modifying existing designs to improve their flight for you. From there, you can just start folding and testing, where most of the real fun is. It is always exciting when you throw a brand new plane and it soars as well as anything you have ever made, including anybody's design. Once you are ready to begin:

Step #1 is to decide what type of paper airplane you want -- a dart, a straight glider, or an aerobatic airplane. A dart is a long, thin, sleek folded paper airplane that produces very little lift. It is made to be thrown very hard and go a long way by having very little drag. It won't stay in the air long because it doesn't have any ability to float. A true glider on the other hand has wing that produce lift and can stay airborne for longer periods of time. These come in three types - the faster straight glider, the slower glider that may even be trimmed to do long curved acrobatic flights, and a mid speed compromise between the two.

The dart is the easiest to design since all you are trying to do is fold as much of the paper toward the center as possible while leaving just enough "wing" and "fuselage" to act like rocket fins. About all you can do is start with a classic dart (or the same folds with the paper turned sideways) and start adding extra folds. These extra folds can add more weight at the "wing" edges or move more weight to the center to narrow the plane further. It does not seem much can be done but there are still a lot of published designs on people's ideas to improve the classic dart.

For a glider, wither a straight one or an acrobat, **Key Point #1** is getting the balance correct. This means that the weight and the lift must work together to keep the nose of the airplane at a certain angle relative to the ground. This angle is called the angle of attack and controls how much lift the plane receives. The larger the angle the more lift. From here we need to decide if we want a slower "floater" or a straight and fast glider. The reason is that a "floater" or "acrobatic" style paper airplane requires a lot of lift compared to a straight flier. The best ways to get this extra lift is either by more wing span or by increasing the angle of attack. We are going to look a little deeper into the idea of increasing the angle of attack. If we look at the illustration below we notice that by shifting the weight of a straight glider forward it can become more acrobatic. However we must balance the plain by heavy trimming or adding a tail. This increases the angle of attack (more lift) but increases drag slowing the plane down. Usually resulting in a mid speed glider.



However, if we leave the weight; but, increase the tail loading (bigger tail or cutting aileron tabs) we force an even larger angle of attack; thus, moving the center of lift back. Often, going to a delta wing type of aircraft will have the same result.

Note: it is very hard to design a folded paper airplane that does looping type of acrobatics. One of the reasons for this is using a rectangular sheet makes it difficult to make a long wing span and fairly short wing cord (width). The best candidates for this type of plane is one whose shape is cut out prior to folding. This was popular in the 1960's time frame. But once glued card stock planes were available they could do a better job.

A few more tips:

- ✦ Start with a smooth paper you have had good success with in the past. This can be either 20 lb or 24 lb.
- ✦ Watch first flight to see if the weight (center of gravity) must be adjusted. If nose goes up, then you need to move weight forward. Think of folds that will get it there. If nose goes down, try a tail or trimming before changing folds to move weight back.
- ✦ If plane rolls over on its back, it need winglets added/changed (folded the opposite direction) or possibly it needs the wings folded backwards from where they are currently, accomplished by turning the paper over before folding wings.
- ✦ There is usually some way to tuck in those loose flaps.
- ✦ Realize that many people have been folding paper over the last one hundred years and have probably already come up with a design like yours. If you find out later that your plane actually had been made by someone else in the past, don't despair – you still designed it too.
- ✦ Of all my designs, (70+) I expect they have been built by others in the past but I can't find directions for them. So I suggest documenting your work.

The main thing is to have fun!

Designing Your Own Card Stock Planes

Anyone who wants to design card stock planes (but is not familiar with airplane loads) have a couple of choices. First, if they don't want to study airplanes in more depth they are limited to starting with an existing design that works and make a few changes. Or, they can take the opportunity to learn more about airplane loads and stability they can really start from scratch. Here I am going to limit my discussion to tips for the first choice. I am going to add a more in depth discussion as a separate section in my advanced section (How an Airplane Flies).

In this section, I just wanted to add a few basic tips:

- Start with a smooth paper you have had good success with in the past. This can be either 65 lb or 110 lb. I prefer 110 lb.
- Start with a design very similar to one you have already built. For instance start with one of my designs and make small changes to suit your taste. Straight rectangular or elliptical wings are easiest to work with.
- Watch first flight to see if the weight (center of gravity) must be adjusted. If nose goes up, then you need to move weight forward. Adding additional layers to the nose will usually get the problem taken care of. However, sometimes it is best to redesign with a "taller" nose. If nose goes down, try adding extra layers to add support under the tail. Also use sandpaper or a nail file to remove weight from nose.
- If the plane rolls winglets may be required. Elliptical shaped wings have fewer roll problems.
- For more complex designs from scratch it will be helpful to study more the advanced section to learn more about airplane mechanics before designing.



The cool paper airplane site!