Science Olympiad Wright Stuff Event Construction Tips

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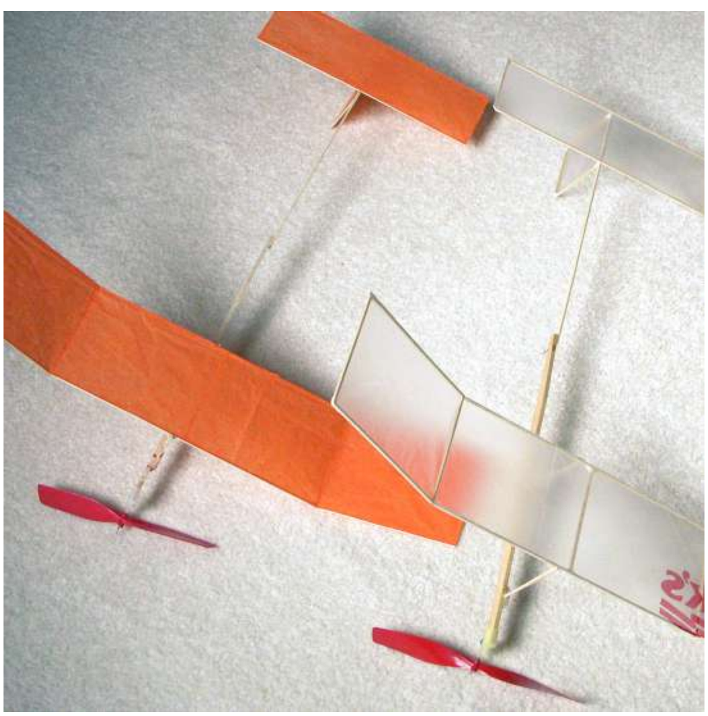
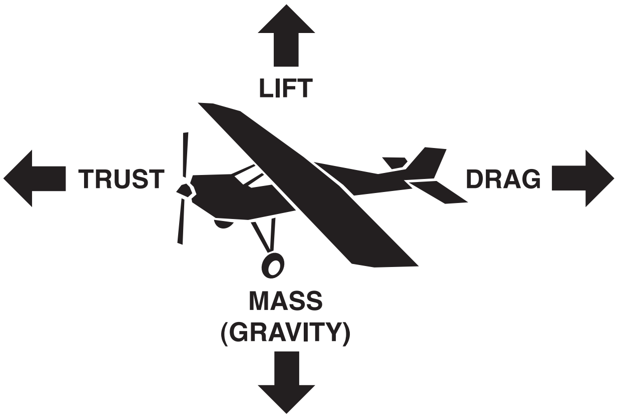
It has been my observation that some teams that come to the competitions are well-prepared with excellent models and the knowledge to fly them to their utmost capability. On the other hand, some teams come to the competitions with airplanes built from kits that may have cost quite a bit of money and their models resemble those previously mentioned excellent ones, but they just do not fly. Their expectation is that it looks like an airplane so it will fly like an airplane. Nothing could be further from the truth. It is rare that a newly-constructed airplane (model or full-size) will fly at its best on the first flight. So, building the airplane the night before the competition and expecting a modicum of performance is quite unrealistic. Since the competition rules require a flight data log from a minimum of ten test flights for a full score, it is hoped that such behavior is discouraged.



The purpose of this article is to provide information that will lead the student to a successful airplane. That is an airplane that flies, an airplane that will allow the student to make observations and collect data necessary for scientific exploration that is the essence of the Science Olympiad program. The purpose is not to show the student how to build a winning airplane at his or her first effort. However, it is almost a certainty that those who do build this simple airplane will not do poorly in competitions. Along the way the student will learn what is necessary to compete with a model airplane at the highest levels of competition. It would be a mistake for the student to aim for the highest performance possible from the first effort. Attaining such performance requires expert knowledge in a variety of areas that are beyond the scope of this article.

There will be much written about construction of an airplane later on. However, because the success of an airplane project depends on more than just attaching part A to part B, the first part of this paper will deal with the problems that are bound to arise, some of them due to faulty construction and some due to a lack of basic aerodynamic knowledge. Construction of a flying model airplane is a world apart from construction using K'NEX- or LEGO brand toys.

The Wright Stuff category of airplanes fits into a class of competition models known as Indoor Freeflight aircraft. There are probably less than 200 people in the USA who consider Indoor Freeflight as their primary hobby. The total membership in the Academy of Model Aeronautics is close to 150,000. The great majority of that group has only a vague idea of what is involved and are awestruck upon seeing Indoor aircraft in flight.



Many of you have probably seen the standard diagram of the aerodynamic effects of the four parameters: **Lift, Thrust, Drag and Mass.** Good airplanes have Lift and Thrust emphasized with Drag and Mass minimized. We shall try to show how these effects can be better understood to make your airplane fly or make your airplane fly better.

The list of major aerodynamic faults leading to failure is:

1. The center of gravity (balance point along the fuselage) is not located properly.
2. Parts of the airplane that should stay in place are allowed to move.
3. The wing has no dihedral to provide lateral stability.
4. The airplane is much too heavy.
5. Standard asymmetric construction for circular flight is ignored.
6. The combination of rubber motor and propeller is incorrect.

As you will see, many of the above faults are inter-related. For example, a heavy airplane (fault number 4 above) may be the result of too much mass in a part of the airframe that does not need substantial strength (assuming that strength increases with the mass of materials) and that, in turn, leads to improper balance (fault number 1 above). Certain parts of the airframe are high-stress components that need the extra mass so they do not move (fault number 2 above) and if the mass is misplaced from a low-stress component, the result may be a structurally-weak, out-of-balance airplane.

Specific details about how to address the issues identified above will be addressed individually, but it is important to point out that ignoring any one of them is likely to result in poor performance at best and a major disappointment at worst.

Balance Point (center of gravity):

The center of gravity (CG) and its relationship to another point on the airplane, called the neutral point (NP), or aerodynamic center, determines the static pitch stability of the aircraft. Pitch stability is a characteristic that will correct a flight that is too much nose up (stall) or too much nose down (dive). The CG is the same as the balance point of the airplane along a line that runs from the front to the back. It can be simply determined by finding the point on the fuselage where the airplane balances. If the airplane's center of gravity is behind the neutral point then it is unstable. That is, the airplane will tend not to recover from being upset from its flight path. If the CG is in front of the NP, the airplane will be stable. Different types of aircraft require different margins of stability; that margin is the distance the balance point should be placed in front of the neutral point.

The neutral point and a corresponding margin of stability can be calculated from three measurements: 1) the area of the wing, 2) the area of the stabilizer, 3) the distance between the wing and stabilizer. Making the calculation is quite simple as there is a website calculator that requires only the basic information. Instead of the areas, the spans and chords of the wing and stabilizer are put into the formula. Simply plug in the measurements and click for the answer. Connect to http://adamone.rchomepage.com/cg_calc.htm. or simply type "aircraft center of gravity" into your favorite search engine.

Let's try a few examples using a hypothetical airplane that conforms to the specifications for the Wright Stuff Division C models from 2006-2008.

Wingspan 50 cm, wing chord 7 cm, stabilizer span varied from 30 cm to 15cm, stabilizer chord 4.5 cm and distance from leading edge (LE) of wing to leading edge of stabilizer varied from 20 cm to 60 cm.

The conclusion from the chart below should be obvious. The center of gravity can be moved to the rear as the distance between the wing and stabilizer is increased and also as the size of the stabilizer is increased. You may ask, “How can I use that information?” The first is that you can find where your airplane balances and determine if it is stable or unstable. To find the balance point, you must attach a dummy rubber motor weighing 2 grams (1.5 grams for 2008-2009) between the propeller hook and the rear hook because the motor is part of the total mass of the model while in flight. You may need to double the motor to four strands and stretch it to keep it in place. The second use has a more sophisticated answer. As the center of gravity progresses to the rear the airplane becomes more efficient.

The reason for the increase in efficiency may be due to both a reduction in overall drag as well as a contribution to lift from the stabilizer as the flight load is shifted.

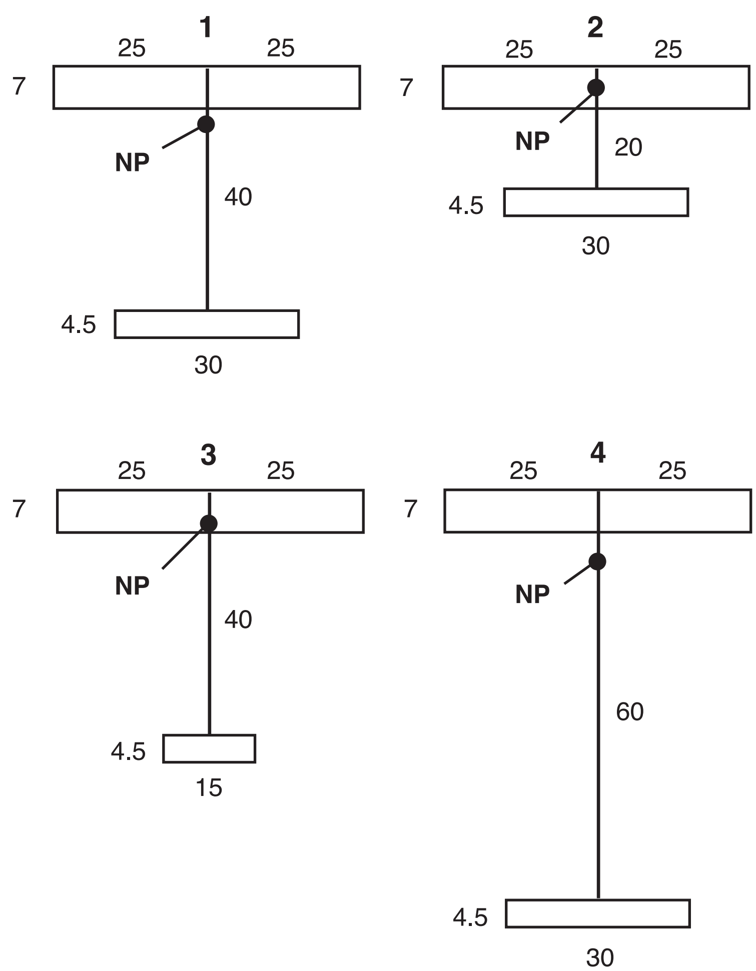
AIRPLANE EXAMPLE	**1**	**2**	**3**	**4**
WING ROOT CHORD	7	7	7	7
WING TIP CHORD	7	7	7	7
WING SWEEP	0	0	0	0
WING HALF SPAN	25	25	25	25
STAB ROOT CHORD	4.5	4.5	4.5	4.5
STAB TIP CHORD	4.5	4.5	4.5	4.5
STAB SWEEP	0	0	0	0
STAB HALF SPAN	15	15	15	15
DIST. BETWEEN LEs	40	20	40	60
STATIC MARGIN %	10	10	10	10
DISTANCE WING LE to NP	7.55	4.8	4.85	11.11
DISTANCE WING LE to CG	6.80	4.1	4.15	10.41

All length measurements are in centimeters.
The static margin is a pre-determined percentage.

An observation of how many turns of the rubber motor were actually used in flight is a good measurement of that efficiency. The ideal flight for an Indoor model will use the very last turn of the rubber motor just as the model lands. However, that ideal rarely is seen, but can be approached.

The extremes of 20 cm and 60 cm between the wing and stabilizer leading edges were placed in the table for illustration only. It will be very difficult to build an airplane with the 60-cm distance and it may not be practical as the gain in efficiency will be minimal once the center of gravity is moved to extreme aft positions. A second practical consideration is that the model may not fit into a box for carrying it to practice and competitions.

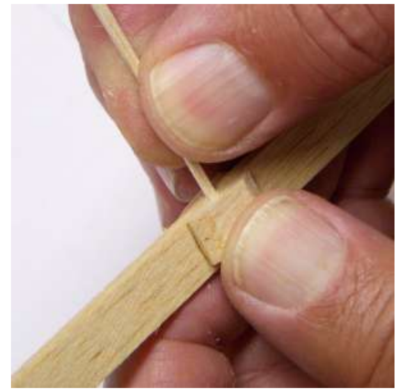
Finally, you may want to ask “what is bad about a forward center of gravity?” It was implied above that efficiency improves when the CG is located as far back as possible without making the airplane unstable. The converse holds true.



Efficiency decreases as the CG is moved forward because greater angular difference between wing and stabilizer will be required, increasing induced drag. In addition, a rubber-powered airplane may become difficult to adjust because the available torque from the motor is much greater at the beginning of a flight than in the middle of the flight. That is, at high torque early in the flight, the propeller rotates much faster than at lower torque during the remaider of the flight. Because of this RPM differential, the airplane flies faster at the beginning than at the end. The faster airspeed combined with greater angular difference between the wing and stabilizer (required for a forward CG) makes the airplane tend to loop (at worst) or stall (at best) while at lower speeds it is well behaved. Remember that these airplanes have all their adjustments fixed at launch. There is no pilot or control to change the adjustments while in flight.

Parts that move when they are not supposed to:

A typical Indoor Freeflight competition model has two to four removable parts. The main purpose of having removable parts is that it makes transportation of the airplane possible. For example, every two years there is a World Championship competition and models must be packed up and flown to distant locations as several countries send competition teams. A few of our younger USA Indoor Team representatives got started in the Science Olympiad Wright Stuff event. For Wright Stuff competition, the simplest arrangement is to have a removable wing and keep everything else fixed. There is only one good way to remove a wing for transport and replace it for flying. That way is to have sockets or tubes in the fuselage and balsa dowels on the wings that fit snugly into those sockets. These dowels are called “wing posts.” A loose fit between the dowel and socket will not hold adjustments to the precision required. Using rubber bands or wire clips or other methods in place of a snug dowel and socket connection will result in a wing that is prone to change every flight. You will not be able to perform meaningful test flights as you try to optimize performance. An added advantage of the socket and dowel connection is that you may move the dowels up or down in the sockets to adjust flying attitude. This ability is critical to finding the proper relationship between the wing and stabilizer angular difference. Once that relationship has been established, it is vital to mark the wing posts so that each time the airplane is re-assembled, the same relationship results. A second, equally important, outcome of using the socket and dowel connection is that the proper warps can be established for flying the airplane in a circular pattern. The word “warp” may sound like a bad thing for a wing and excessive warps are bad. The warps are actually given names like “Washin” and “Washout” because they help the airplane stay level in circular flight. See the section to about asymmetric construction and circular flight later.



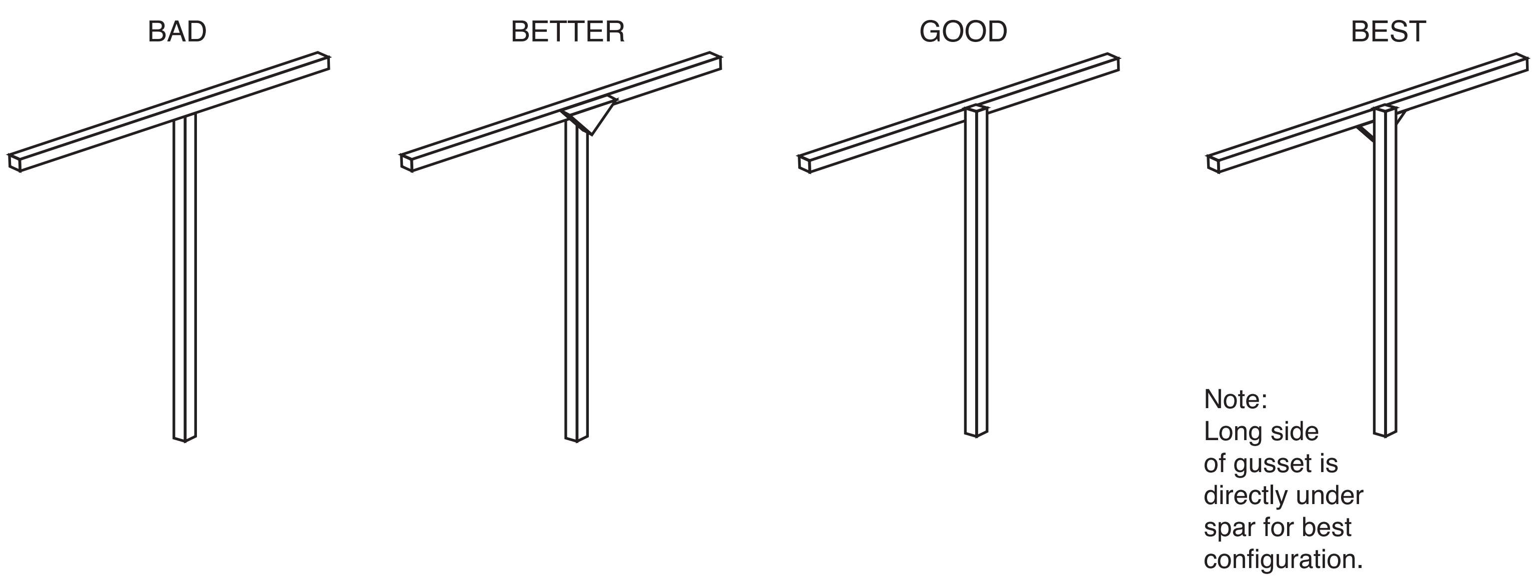
The next moving parts to avoid are things that flex under the stress of flying. One cause of flex is having a weak piece of balsa wood where a strong one is necessary. There are five places where strong (heavier) balsa wood should be used: The motor stick, the wing spars (leading edge and trailing edge) and the wing posts to the wing. If the wing is constructed with a three-panel configuration, the center spars should be strong, but those for the tips can be much weaker and lighter.

If the motor stick flexes under tension from the rubber motor, changes in propeller thrust angles will occur as the motor unwinds giving rise to inconsistent flights. A second cause of propeller thrust angle changes due to movement is in the propeller hanger. If the hanger flexes under load, bad things can happen. Some hangers are one-piece plastic units that push onto the front of the motor stick. It is important that this unit does not wiggle. Use shims of scrap balsa wood to keep it steady. Some hangers are made of aluminum or plastic that can bend under load. This bending can result in thrustline changes as the motor unwinds. That is, if you push on the front of the propeller hanger at the location where the thrust hook wire goes through, you may see some movement. In such cases, it is best to add a brace between the fuselage motorstick and the propeller hanger.

Some models have a soft wire connector between the motorstick and the tailboom. The idea behind the connector may be that the angle of the tailboom can be adjusted by bending the wire. The adjustment can change the incidence angle of the stabilizer as well as the offset of the rudder depending on which axis is chosen. There may have been good intentions in that design, but overall it is an undesirable complication for two reasons: The first is that the desired adjustments are usually so fine that bending the wire can easily cause over-adjustment. The second is that the wire may be bent accidentally to lose the flying trim that the student has been working to establish. Other models have the tailboom connected to the motorstick by means of a small rubber band. All the arguments above about the soft wire connector also apply to the rubber band connection. If you happen to have either kind of airplane, once you find acceptable flying trim glue the tailboom and motorstick together using a balsa wood splint if need be.

I have seen some models where parts are glued together in such a way that the slightest bump while flying or handling cause the parts to separate. It is not known if the person constructing the airplane did not follow directions either due to inattention or to accomplish some other mission. A glaring example is the attachment of the wing posts to the wing leading and trailing edges to make a “T” joint. Gluing the top of the wing post to the bottom of the wing edge is asking for trouble if no reinforcing members are added. It is much better to glue the side of the wing post to the front of the wing edge as glue is more effective with the grain of the wood than with the end of the wood. The joint is not considered part of the wing chord and will not make the airplane out of specification. The attachment of the wing post to the wing edges is critical to setting the wing washin and washout. If that attachment is broken and re-glued, you are back to square one for adjusting the flight of the airplane.

Some models have paper tabs glued on the fin or stabilizer to provide flight adjustments. A bad practice. It is too easy to bend the paper accidentally and change the flight adjustments unintentionally. Better to glue lightweight balsa wood tabs that will hold their adjustment setting during handling and shipping of the airplane.



Wing Dihedral:

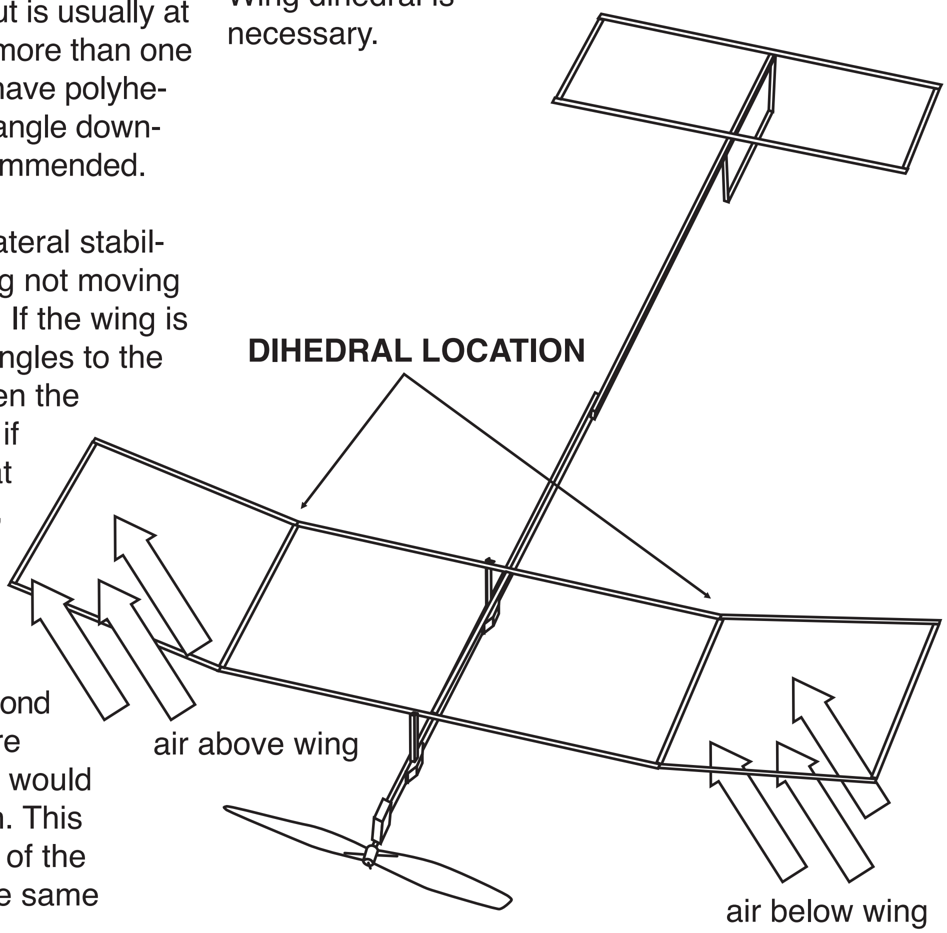
With one exception, the wing of a Freeflight model airplane requires dihedral. The word dihedral comes from the geometric description of the angle formed when two flat surfaces intersect. Wing dihedral provides lateral stability to the airplane. Without it the airplane, upon being upset ever so slightly, will continue in that upset mode and usually have it intensify to result in a spiral dive. An airplane flying in a circular path is, by definition, flying in a slight upset mode! That is, if the airplane could be made to fly perfectly straight, no dihedral would be necessary. However, besides being very difficult to attain, perfectly straight flight is not even desirable for Indoor duration as the model would fly into the wall... another upsetting occurrence.

Going back to the geometric description, wing dihedral is a change of angle in the wing at one or more points along the wing span. That is, the leading edge and the trailing edge are cut and re-glued upwards at an angle. The cut is usually at the position of a wing rib. If there is more than one dihedral change, the wing is said to have polyhedral. If the wing is re-glued with the angle downwards, it is called anhedral...not recommended.

To describe how dihedral provides lateral stability, try to visualize the airplane's wing not moving but having a flow of air pass over it. If the wing is held so that the air passes at right angles to the LE, it is the same as it would be when the airplane is flying straight. However, if the wing is rotated to the side so that the air passes at an angle to the LE, it is the same as the airplane flying in a circle. When the wing has dihedral and is angled to the wind, there will be more wind under the side of the wing that would correspond to the inside of a circle and also more wind above the side of the wing that would correspond to the outside of the turn. This difference counteracts the tendency of the airplane to go into a spiral dive in the same direction as it was circling.

The one apparent exception to the need for dihedral is a wing with full-chord tip plates. Tip plates look like rudders at the very tip of the wing. Their intended purpose is to improve the efficiency of the wing. This increase of efficiency has been documented for full scale aircraft, note commercial jets for example. However, that effect has not been proven for model airplanes. But they are an apparent exception to the need for dihedral because, in a dihedral sense, they are just exaggerated dihedral angles and the stability forces are the same as for lesser dihedral angles.

It seems that many beginners choose to build their airplanes without dihedral because they do not pay attention to that detail on the plans, do not understand that it's needed, or do not know how to form it in construction. I think this is both a symptom of the builder's inexperience as well as that of the designer's lack of communication. Some things found on airplane construction plans can be modified or disregarded. Others are absolutely necessary.
Wing dihedral is necessary.



Keep it Light:

Engineering of airplane construction is an exercise in the proper choice of materials to provide an adequate safety margin of strength and stiffness while keeping the airframe to an acceptable overall mass. I have heard the oxymoron, “add lightness” as the goal for Indoor Freeflight model airplanes. Just for comparison purposes, the usual minimum mass for the Science Olympiad Wright Stuff airplanes has been 7-8 grams over the years. Experienced Indoor modelers are able to build rubber-powered models of a similar size as the Wright Stuff models that have a mass of 0.5 grams. Some of the techniques they use are very helpful in keeping the airframe mass of your Wright Stuff model at the very minimum.

The first thing to consider is the fixed mass of the parts. This is not a trivial undertaking because there is a wide variance in the mass of the materials used to construct an airplane. Again, using the 2006-2008 Wright Stuff Div C specifications, the following mass of materials can be calculated:

Coverings range from 0.08 grams to 0.64 grams for the lightest available plastic to standard model airplane covering tissue. Propellers range from 2.4 grams to 6.5 grams. Balsa wood components to construct the model can range from 1.3 grams to 5.0 grams. The weight of adhesives, wire and connectors can add from 0.3 grams to 1.5 grams. Adding up all the components gives a range of 4.08 grams to 13.64 grams. Not counted is ballast mass to set the center of gravity. Some models at the heavy end easily require up to 5 grams of ballast for that purpose.

You can go to the appropriate locations and find the lightest covering material and the lightest propeller. These locations are on the Internet and will require some planning ahead to make sure that everything is on hand when you start to build the airplane. You can even find acceptable kits that provide all the necessary materials to make the Wright Stuff airplanes. However, it is possible to build Wright Stuff airplanes for a small fraction of the cost involved with those kits. There will be instructions for that purpose once you read through all the important stuff about why the airplanes do not fly.

Let's suppose you have purchased the lightest propeller, 2.4 grams. Instead of the very lightest covering (0.08 grams on the airplane), much expense can be saved by using plastic bags from the grocery store that will add from 0.4 to 0.6 grams. That still leaves 4 grams for the rest of the model. If the balsa wood is mid-range of the possible densities, about 3 grams will be added. However, if the balsa wood is selected so that extra light wood is used for low-stress components, the total weight of the wood can easily be reduced. Adding up the propeller, lightweight grocery bags and balsa wood comes to a total of 5.8 grams. That leaves 1.2 grams for wire, propeller hanger, adhesives and ballast to arrive at a 7.0 gram airplane.

One aspect of the airplane's mass is the ballast required to place its center of gravity so that the airplane has stability. Usually, extra ballast at the nose of the airplane is required. If you inspect the distances between the wing and the tail and also the distance from the wing to airplane's nose, you will see that the ratio is usually about three to one (3:1). That ratio means that for every tenth of a gram you can remove from the tail the total weight of the balanced airplane can be reduced by 0.4 grams....a very good reason to make the tail end of the airplane of much lighter-weight wood than the rest of the airplane. Other low stress components of the airplane can also use lightweight wood without sacrificing strength. They are the wingtip spars (three panel wing), all the ribs (wing and stabilizer), the tailboom, and of course the fin. Another obvious way to reduce the overall mass is to reduce the total amount of wood. Can you make do with 5 ribs rather than seven or eight? Most certainly.

You must be judicious about wood selection. If you have access to a sensitive balance, weigh each piece or combination of pieces, for example, group and weigh all the wing ribs together before starting the actual construction. Balsa wood is graded for lightness in units of pounds per cubic foot. The very lightest is about four pounds per cubic foot, the heaviest 20 pounds per cubic foot. From here on, the “per cubic foot” will be removed from the grade and only the first part will be mentioned, for example “seven-pound balsa.” In metric units,

$$\frac{\text{Mass (grams)}}{\text{Volume (cubic inches)} \times 0.262} = \text{Density (in pounds per cubic foot)}$$

the conversion of “four pound” comes out to be 0.064 grams per cubic centimeter. Wood of this lowest density is very difficult to come by and you should not even consider using it for Wright Stuff airplanes. Medium weight balsa is about eight-pound density, heavy balsa about 16-pound density. Most balsa wood sticks belong to the 16-lb club and should be considered only for high stress components. (We are assuming that strength is proportional to density, of course). There is no need to make assumptions about density. The dimensions of the wood can be measured to find volume and its mass determined on a balance. Just do it.

Balsa wood is sold in the USA with inch-unit measurements. The gauge I use for measuring the thickness of the wood is calibrated in units of one-thousandth of an inch. A formula for density was developed based on the way my instruments are used. The mass of the wood is measured in grams because that's the kind of balance I have. To determine the density in units of pounds per cubic ft use the formula at the top of this page. A gauge is used to measure the thickness of the wood because the size given on the label is usually not accurate. For example, balsa wood labeled as 1/16” (0.0625”) usually measures to be 0.070” or greater.

In order to provide balsa wood of the appropriate sizes and densities at a reasonable cost it is preferred to strip wide sheets of 1/16”- thick balsa into sticks. This is a skill worth developing. Use a metal straight edge from a tri-square tool and a sharp single-edged razor blade. Once you develop the skill, you will notice that some strips have more mass than others but seem to be the same size. That is because the density of wood in a sheet will vary across the sheet. To observe the variance, hold the sheet up to a light bulb. The denser parts will appear darker than the less dense wood. Use this variance to help select wood for the application desired.

The choice of pre-cut balsa strip is limited to standard sizes with 1/16” square the smallest. For construction of the stabilizer and fin of an airplane, it is advantageous to use 1/32” sheet and strip it to provide 1/32” square lengths of up to 30 cm in length. If that is done, the mass of the wood has been reduced to one-fourth of what it would be for 1/16” square balsa of the same length.

One last thought on balsa wood and saving mass has to do with tapering long pieces of wood so that the thicker part is at the most stressed portion of the beam and the thinner part at the least stress portion. Note how a light pole is tapered: wider at the bottom than at the top. It is advantageous to taper the tailboom so the thinner part is at the stabilizer position.

There is much more to know about balsa wood, especially selecting the correct grain and how to pre-test the strength of each piece. However, that knowledge is beyond what is necessary for construction of Wright Stuff airplanes.

Adhesives should be used sparingly. If you can see the glue on the airplane you probably have used too much. When cyanoacrylate (CA) glues are used for construction, if the glue doesn't hold the first time, the tendency is to add more glue resulting in a heavier and weaker joint than if the glue had cured correctly the first time. The reason it is weaker is that CA glue does not adhere well to itself once cured. If parts do not fit together snugly before gluing, do not expect the glue to fill the gaps and still provide a strong joint.

The use of an aliphatic resin glue (Titebond brand) or a solvent-based model airplane glue (Duco brand) offers speed of construction when used sparingly plus the time to make sure things fit together before the glue sets up as it might with a CA glue. Large globs of aliphatic resin or solvent glues take a long time to dry because they depend on loss of water (aliphatic resin) or organic solvent (Duco) to gain full strength. If large quantities are used, drying at the surface inhibits the evaporation of the liquid beneath the surface and very slow drying is the result. While either the water or solvent is evaporating, they carry the glue molecules into the fiber of the wood to provide a bonding focus that exceeds the surface area of the two parts of the joint. CA glues, on the other hand, cure by a process known as polymerization. There is no solvent to be lost, however in their best bonds, some CA glues penetrate the fibers of the wood before polymerization takes place. Think about what happens when two pieces of wood are glued together. A combination of wood micro-fibers and glue molecules becomes established that becomes a localized unit of adhesion once the glue either dries or cures. To take maximum advantage of this combination, the two pieces of wood must in very close contact. If there is a visible gap between the two pieces of wood, filling it with glue will result in a weaker and heavier construction than making sure the parts fit before gluing. That is in direct opposition to your goal: **stronger and lighter**.

Besides flying better, there is a second advantage to building certain parts of the airplane light. When the airplane gets upset from its normal flight pattern, some period of time will be required to return to that normal pattern. During the period from the upset to return, the airplane generally loses altitude. Loss of altitude contributes to lowering the overall duration of the flight. The time required to return to normal can be reduced by lowering the moments of inertia in the structure. That is, make the extremities of the airplane as light as possible and try to concentrate mass close to the center of gravity.

To illustrate a common moment of inertia effect, think of a swinging pendulum with a weight at the end. If the weight is great, it will take more energy to stop the pendulum from swinging than if the weight is small. That energy comes at the expense of the potential energy stored in the rubber motor as well as in the altitude of the airplane. The result is a reduction of flight duration.

Circular Flight:

One of the common questions I hear about flying Freeflight model airplanes is, “What makes it fly in a circle?” The answer is complex. The first thing to consider is that flying in a circle is normal, we can only try to control the diameter of that circle so the airplane does not fly into the wall of the Indoor site. Besides the diameter of the circle, the direction of the circle, left or right, must be considered. The conventional way of thinking left or right is from the perspective of the pilot of the airplane. Of course, our Wright Stuff airplanes do not have an on-board pilot, but we can place an imaginary pilot on board and use that perspective to establish the difference between the two directions.

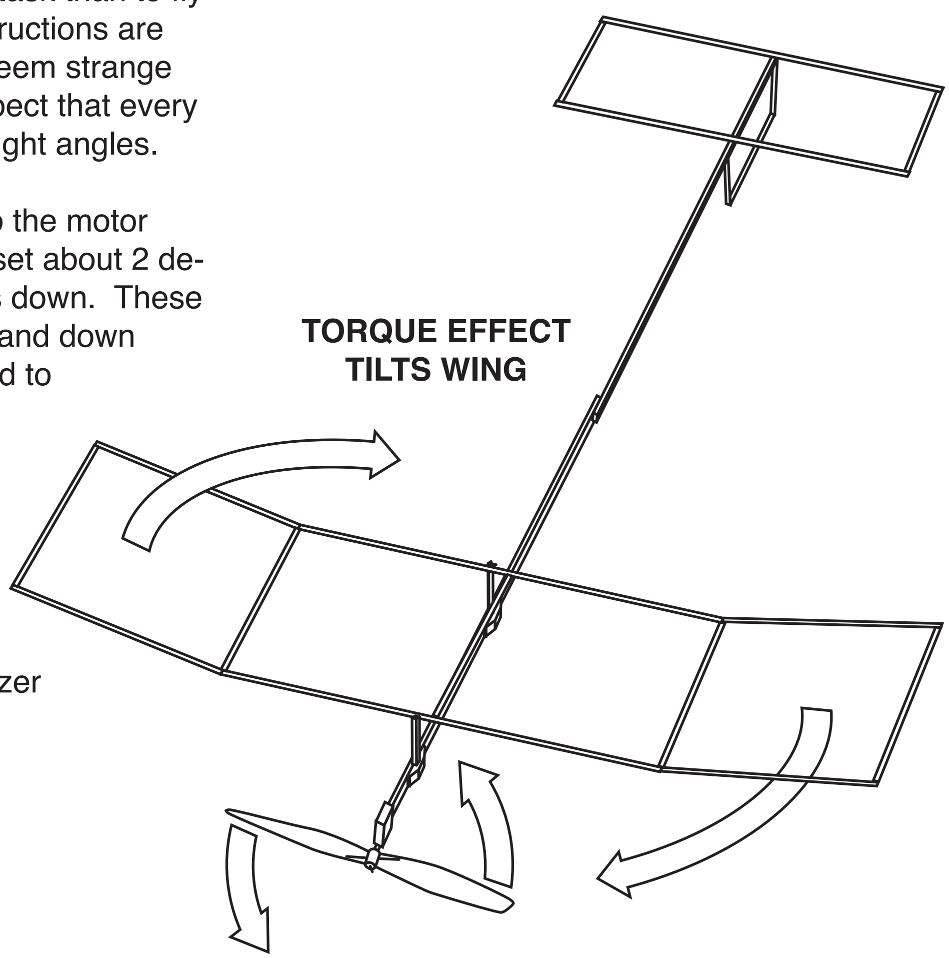
An important force acting on the airplane is that of the spinning propeller. As the propeller, viewed from in front of the airplane, spins in a counter-clockwise direction, the rest of the airplane wants to spin in a clockwise direction. This is a direct consequence of Newton's third law of motion, “For every action, there is an equal and opposite reaction.” However, the airplane does not spin on its axis like the propeller because the relatively large areas of the horizontal surfaces compared to the propeller area resist that reaction. But the airplane tends to fly with the left wing lower than the right. In other words, the wing is said to be banked to the left. An airplane with a left-banked wing will fly in a left circle because a portion of the wing's lift is directed towards the left. It is said to be flying “with the torque” using aeronautic jargon. For Indoor Freeflight models, unlike their Outdoor counterparts, the torque range of the rubber motor is relatively small. Outdoor rubber powered models are universally adjusted to fly to the right under power to provide a safe counter to the extreme range of motor torque encountered. Indoor models, however, are adjusted to fly with the torque as a means to direct the energy stored in the motor to longer flights. A rubber-powered model flying in right-hand circles is fighting the torque resulting in an undesirable use of the total stored energy in the motor. Adjustments are built into the model because the best flight path will always be counter-clockwise circles. A second important consideration is that if the airplane is flying in right-hand circles at the beginning of the flight, the direction can change to left-hand circles later on. If so, the diameter of the right-hand circles will increase as the flight proceeds leading to collisions with the structure of the flying site.

Because the airplane has no other task than to fly in circles, certain asymmetric constructions are employed. This asymmetry may seem strange to those who are conditioned to expect that every piece must either be straight or at right angles.

Propeller thrust angles in relation to the motor stick are not straight ahead, but offset about 2 degrees to the left and also 2 degrees down. These thrust settings are called left thrust and down thrust. Left thrust is usually required to keep the airplane in a constant diameter flight path when the torque of the motor is reduced as turns are used up. Down thrust is required to keep the airplane from stalling due to the differential angles of attack between the wing and stabilizer necessary for pitch stability.

The wing is not centered on the fuselage. It is mounted so that the portion of the wing on the left side of the fuselage is about 10% longer than the portion on the right side. This is one construction to provide more lift on the left than on the right to keep the wing level in flight.

The wing is also twisted a small amount to provide a greater angle of attack on the left than on the right to help keep the wing level in flight. The left wing thus twisted is said to be washed-in; trailing edge lower than the leading edge. A washed-out wing panel has the trailing edge higher than the leading edge. If you sight down the fuselage axis of the airplane, the wash-in and wash-out of the wing should be seen by a crossing of the LE and TE but at a very small angle.



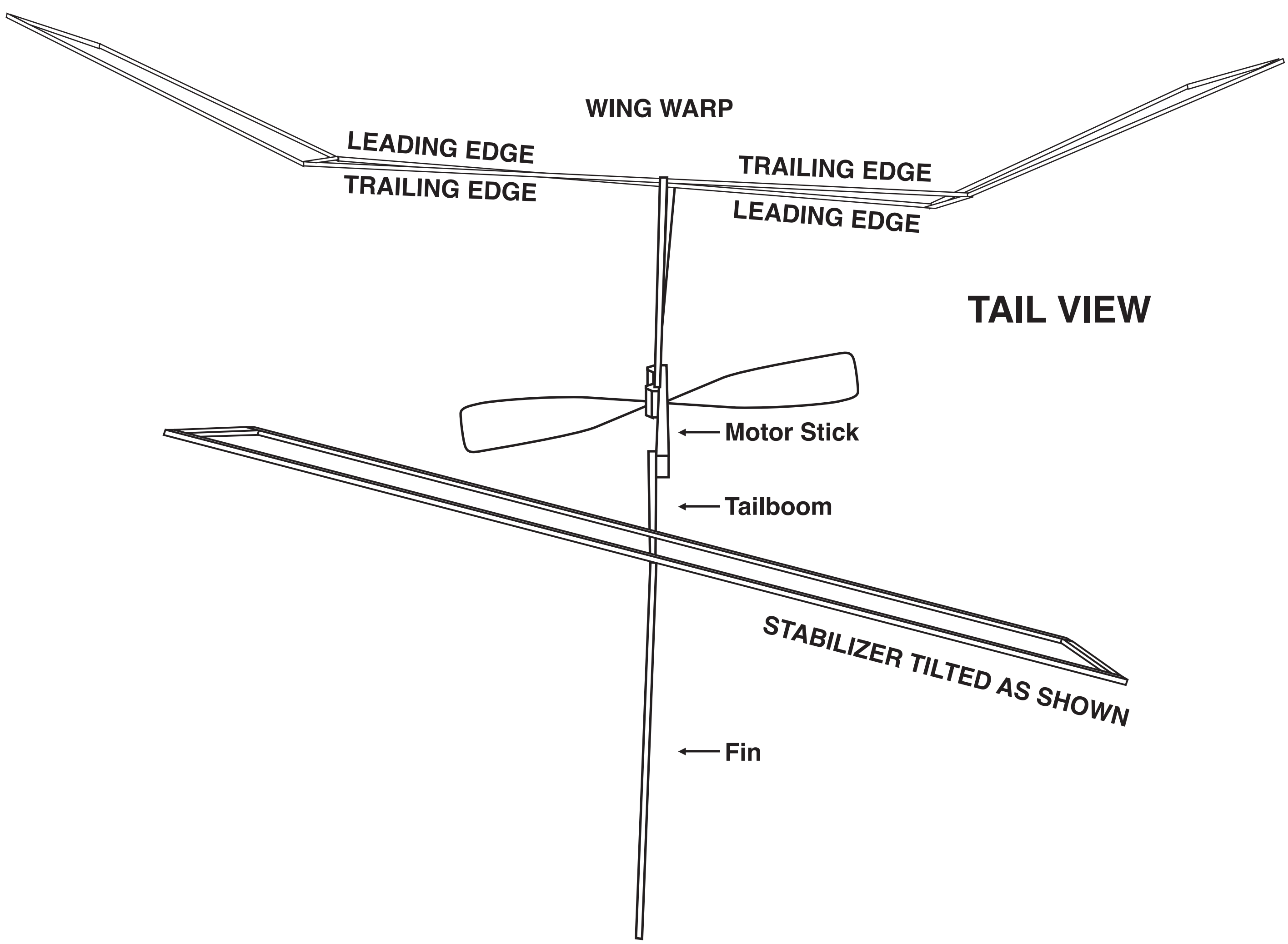
The reason for wanting the wing to fly level is that a wing will generate lift in a direction perpendicular to its path of flight. If the wing is banked, the lift will be directed at some angle less than the desired vertical and increased energy will be required from the motor for the airplane to gain altitude.

The stabilizer is tilted. The tilt has the left tip of the stabilizer higher than the right tip. With this tilt, the airplane will fly to the left. The lift direction of the stabilizer tilted as above is to the right. Since that force is behind the center of gravity it causes the airplane to yaw to the left. The other effect is to counter the tendency of the fuselage to twist under the force of a wound rubber motor. That twist will place the right tip of the stab higher than the left, opposite of the desired setting. Take care that no warps occur in the stabilizer as they will have a profound effect on the direction the airplane turns.

The tailboom is attached to the motor stick so that there is a slight “up” angle, about 2 degrees, the same as the downthrust angle in the propeller. This is to provide horizontal trim to the airplane. The stab is said to be at a negative incidence angle; trailing edge higher than the leading edge.

A rudder tab may be attached to the trailing edge of the fin to provide left turn. Glue thin lightweight balsa wood for the tab. Never use paper or tape.

All the above asymmetries are not to be overdone. Each one contributes a small amount to the overall drag of the airplane and that in turn reduces the overall performance of the airplane. Without these asymmetries, the airplane will not fly, that is it will not be in aerodynamic trim. It is not possible to provide strict guidelines to how much of each should be used. However, it is intended that the builder and flyer of the airplane will be able to examine the structure to make sure that all the asymmetries are in the proper direction.



Propeller and Motor:

An airplane propeller has two basic dimensions, diameter and pitch. Diameter is the length of the propeller measured on a line from tip to tip that includes the thrust axis. Pitch can be thought of as how big a bite of air the propeller blade takes per revolution. It is advantageous to use the largest diameter propeller allowed by the rules. Large propellers are more efficient than smaller ones. The pitch of a plastic propeller can be adjusted with two long-nosed pliers. One pliers holds the propeller near the hub and the second pliers next to the first is used to twist the blade or spar to either increase or decrease the angle of the blade.

Propeller blades are usually curved so the rear of the blade is concave and the front is convex. Wright Stuff airplanes have been seen where the propellers were mistakenly placed on backwards (concave to the front and convex to the rear). If so, the propeller suffers a considerable loss of efficiency.

Rubber motors are made from rubber strip by tying a knot. Some knots work very well and others may come undone while winding or even while the airplane is flying. Two recommended knots are the "figure eight" knot and a combination of a square knot with two overhand knots behind it to keep the rubber from pulling the ends through the square knot. The knots must be pulled very tightly, so tightly that you must pull as hard as you can. It is very unlikely that you will be able to break the rubber by pulling on it. To keep the rubber from cutting into itself while the knot is tightened, use some liquid soap or soap and water on the end being tied to lubricate the knot tightening.

Rubber motors work best if they are lubricated. Commercial rubber lube can be purchased or you can substitute "Armour All" brand automotive vinyl fabric cleaner. Put a little lubricant in a plastic bag with the rubber motor and rub the lubricant into the motor. Motors that are used without lubricant suffer several ways: The number of potential turns in the motor is reduced, the life of the-motor is shortened, and the friction of unwinding reduces the overall energy available for flying the airplane. Motors without lubrication will demonstrate adhesion of the strands when unwound.

Some teams come the competition with motors that are obviously much lighter than the maximum allowed. Others weigh out 1.5 grams of rubber strip and then tie the knot. The rubber behind the knot is wasted. If it is cut off, typical mass of a motor from 1.5 grams of rubber strip is 1.2 to 1.3 grams. In effect, they are giving their airplane a 10- to 20 percent disadvantage from a full 1.5-gram motor.

There is more than one source of rubber motors. However, the best currently available is called FAI Super Sport rubber and is sold by FAI Model Supply along with many other items. Do not even bother with less than the best if you want to do well.

A 1.5-gram rubber motor made from rubber strip of 3/32" thickness has a capability to be wound to over 1300 turns. To obtain such a result, the lubricated motor must be stretched to at least 5 times its relaxed length as winding starts. As the number of turns increases past approximately 700 the amount of stretch is reduced until the final turn is put in the motor when its length is the same as the distance between the propeller hook and the rear hook. It should be obvious that a geared winder will be necessary to obtain 1300 turns. Winders with gear ratios of 15:1 and 16:1 are readily available. That is, each time the winder crank is turned, 15 or 16 turns are put into the motor. It takes practice and patience and many broken motors to learn the skill of winding a rubber motor to the max.

If you have a well-trimmed airplane and fly it in a low-ceiling site, such as a school gym, with maximum turns in the motor, it will rapidly climb into the beams and wires and baskets and all sorts of other trouble. To avoid that happening, the flyer takes advantage of a characteristic of rubber by unwinding some of those hard-won turns before launching. The available torque from a rubber motor decreases rapidly as the first few turns are taken off. With reduced torque, the propeller rpm is also reduced, the airplane flies a little slower and doesn't climb as fast. It is much better to wind the motor to its maximum (1300 turns) and then unwind to 1200 turns than it is to wind to 1200 turns and launch. The initial torque of the motor wound to 1200 is much greater than that of the motor reduced to 1200 turns after being at 1300.

Rubber motors do get tired quite rapidly when wound to maximum turns. You may notice that the motor is longer after winding the first time than it was before winding. The energy curve from a tired motor is much different than from a fresh motor, especially after the first 20% of the turns have been used. You will notice that the airplane may climb almost as quickly as it did when the motor was fresh, but it comes back to the floor much more rapidly than before. This observation may lead you make an item in your flight log regarding the number of times the motor was used.

Once your airplane is adjusted for stable and efficient flight, the most important consideration to obtain the longest flights from it is finding the best combination of rubber motor and propeller.

Dedicated Indoor Freeflighters have an arsenal of equipment that is normally not within the reach of the great majority of Science Olympiad teams for fine-tuning the propeller and rubber combination to optimize flights. They use a torque meter to determine the appropriate torque for launch of the airplane, a rubber stripper to provide motors of various widths, sometimes only one-thousandth of an inch different, a micrometer to measure the thickness of the rubber strip and a variety of propellers depending on the conditions and ceiling height. For Wright Stuff teams limited to one or two motor widths and a propeller at maximum diameter, the only change available is to adjust the pitch of the propeller. If the airplane lands with too many turns left in the motor, the adjustment is to decrease the pitch of the propeller. If rubber motor runs out of turns while still at altitude, the adjustment is to increase pitch. For the best flights, the rubber motor and propeller should be matched so that very few turns are left in the motor when the airplane lands. That is, the airplane is under power for the whole flight.

Construction:

If you have not read the preceding part of this article, please do before starting to build your airplane. You will find reasons for why the airplane is built the way it is. For now, avoid deviations from the instructions as the presentation is specifically designed to allow the building of a successful airplane. To my knowledge, there will be nothing left out and nothing that has to be added. In other words...no changes! The airplane will fly and will fly well enough to get you a medal in most competitions at the regional level. To fly well enough to medal at the State or National competitions you will have to build something a bit better, but that will require materials and equipment that may cost more than you want to pay just to get started. Remember, you are just learning how to do this. One does not give an expensive and exotic race car to someone who has never driven before. The typical Science Olympiad Wright Stuff project for the great majority of students will require three or four airplanes, each one a little better than the previous one. With each airplane built, the student will gain both building skills and knowledge of how to make each airplane fly to its optimum level. Because this project is aimed at learning, the cost of materials will be kept low so that that goal will not be inhibited.

To keep the cost of your first airplane at a minimum we are going to use plastic bags from the produce section of your local supermarket as the covering material. They will cost you nothing, but be sure to look for the HDPE logo on the bag. Do not use bags that are LDPE. The problem with HDPE covering is that very few adhesives are suitable for holding it on the airplane framework. Three products that do work are Weldwood brand non-flammable contact cement, Dave Brown products Southern's Sorghum, and Michaels Arts and Crafts Aleene's FoamCraft Foam Glue. The Weldwood product can be purchased at most hardware stores. The sorghum product is sometimes available at hobby stores, but can also be purchased from Tower Hobbies (towerhobbies.com). They all cost about the same for a container, but you get much more product with the Weldwood non-flammable contact cement. Contact cement can also be used to construct cardboard boxes for carrying your airplane. All three cements are actually contact cements. That is, the way they normally work is to put some cement on both pieces to be joined. After the glue has dried the two pieces are pressed together and they never can be taken apart. For model airplane construction, the cement is diluted with water, coated on only the wood surface and then pressed onto the plastic covering while still wet. After a few minutes, the water evaporates and the wood and plastic covering are joined. The amount of water for dilution is about equal to the amount of cement as it comes from the container. The reason that the cement is diluted is reduce the overall weight of the airplane. You may want to experiment with exactly how much water can be used for the dilution. More water means less mass on the airplane.

A few words of caution: Contact cements are messy to use. Take care to keep the cement off your clothing as it is almost impossible to remove once applied. Weldwood contact cement comes in a rim-sealed paint can. It is difficult to remove a small amount without getting the cement in the rim. If that happens, after re-sealing, the rim will be almost impossible to remove again. A solution to this problem will be presented in the construction part of this article. Most contact cements on the market are solvent-based. Besides the hazard of flammable solvents and their associated odor, they cannot be diluted with water. But, most importantly, solvent-based contact cements simply do not adhere to the grocery bag plastic.

Note: In place of plastic bags and contact cement for covering, tissue paper and a glue stick may be used. The resulting airplane will be a bit heavier, but construction will be much easier and not as messy. All paper has a "grain," that is, a direction to which the fibers are aligned. You can determine the grain by tearing a scrap of the tissue to see which way provides the straightest tearing. The paper grain should be aligned with the longest direction of the structure that will be covered. As paper tears more easily in one direction, it also is easier to slice away the excess in the direction of the grain.

The balsa wood for the airplane needs to be carefully selected. Earlier, the portions of the airplane that require extra strength due to flight stresses were mentioned: The main spars (leading edge and trailing edge) for the inner panel of the wing and the wing posts that come down from the spars should be the hardest you can find. The size of those spars are 1/16-inch square sticks. The sticks are sold in 36-inch lengths. The weight of each 36-inch stick should be about 0.7 grams. The second strong piece of wood is the fuselage motor stick. Its cross-section is 1/8 inch by 3/8 inch. A 36-inch length should weigh between 4.5 and 5.0 grams.

All the rest of the wood for construction should be quite light in weight. You will be very lucky to find such wood in the hobby shop as strips. For example, the 1/16-inch square strips should weigh no more than 0.3 grams for each 36-inch length. It is much better to find a sheet of 1/16 x 3 x 36 inch balsa wood that weighs about 14 grams or less. Strips of wood are cut from that sheet using a razor blade and a metal straight edge. Cutting such strips from a sheet is a vital skill that must be mastered through practice. Before stripping the wood, cut it into lengths no longer than the longest piece that will be required for your airplane. It is much easier to strip a short length than a long one. Place the shortened sheet on a piece of cardboard with the cardboard flutes at right angles to the length so you don't cut into your work bench or table. The flutes are at right angle so there is nothing to influence your cut to wander. Place a metal straight edge on top of the sheet of balsa wood so that the amount of wood visible from the top of the sheet to the straight edge looks like about the same as the thickness of the wood to strip a square stick. Use the corner of a single-edged razor blade to slice the wood by running the blade next to the metal straightedge.

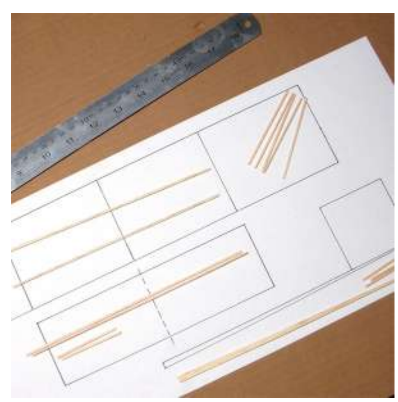
Be sure to hold the razor blade as vertical as possible. It helps to stand up so your eyes are directly over the part being cut. In fact it is almost impossible to make a vertical cut while sitting down. It may take two or three slices to go all the way through the wood depending on how hard it is. Use fairly gentle pressure. If you try to cut all the way through in the first cut, it is much more difficult to keep the blade next to the straightedge. Even if you are successful, the strip of wood may become warped due to the stress placed upon it during cutting. If you have to discard several pieces of wood while learning this skill, you will still be money ahead of buying individual strips. It is not so important that each strip of wood is exactly 1/16-inch by 1/16-inch. However, it is important that each strip is fairly uniform in the width that you cut.

It is quite unusual to find a sheet of balsa wood that is the same density throughout. If you hold the sheet up to a light, you will see parts that appear lighter than others. Those lighter parts are less dense than the darker parts and will provide the lightest weight balsa from the sheet. To help remember where they are, the wood can be marked with a felt-tipped pen to outline the desired place to cut a strip.

The next item is the propeller. For a beginner's airplane, there is no better and cheaper propeller than the one that comes with the so-called "Delta Dart" kit. It is usually red in color and comes already fitted to a propeller hanger that can be slipped onto a 1/8-inch by 3/8-inch piece of balsa wood that you bought for your airplane's motor stick.

If you buy the Delta Dart (it is also called the AMA Cub) kit for the propeller, consider building the whole airplane from that kit. You will use many of the techniques for the DD that can be applied to the Science Olympiad airplane. In addition, you can learn some things from flying the DD that will be valuable for your Wright Stuff model. Because the DD is covered with paper, it is recommended that a glue stick be used for attaching the wood to the paper. Fast-curing epoxy (so-called "5-minute" epoxy) should be used for setting the wing dihedral when the fuselage is glued to the wing.

Let's review: We have the covering from grocery store produce bags...the very lightest bags weigh about 2 grams. We have contact cement that will hold the plastic covering to the framework. There are glues available for the other part of the airplane too. We have hard balsa for the high-stress components of the airplane and lighter balsa for the low-stress parts. And finally, we have a propeller and a propeller hanger to attach it to the airplane.



Plans can be easily drawn by the student. All that is required is the ability to measure, a pencil, some paper and tape, and straight edge. The airplane will have rectangular flying surfaces (wing, stabilizer and fin) for simplicity. Start with two sheets of standard printer paper, 8-1/2” by 11”. Tape the two pieces together joining the short ends with no overlap. The joined sheets should be a bit over 55 cm long. For the wing, draw a rectangle on the joined sheets that measures 40 cm by 8.0 cm, center the rectangle at the place where the two sheets are joined. Draw three lines from the top to the bottom of the rectangle, one at the center and two more 10 cm from the center. The two lines 10 cm from the center separate the wing into three panels, the main (center panel) and two tip panels. After the wing is constructed flat on the plans, dihedral will be put into the tip panels. Draw another rectangle for the stabilizer that measures 20 cm by 6 cm. Again, this rectangle should be centered at the place where the paper was taped together. Now double-check your measurements, especially the 6-cm stabilizer chord to make sure it is not greater by even a fraction of a millimeter. The wing and stabilizer must fit inside the rectangles. An oversized chord on the stabilizer will cause your airplane to be disqualified. If the measurements are not precise, start all over again, do not try to erase and draw over the erasures. For the fin, draw a square that is 6 cm on each side. Tape the plans to a flat surface.

Note: The instructions that follow are for use of the plastic bag and contact cement covering. If you decide to use tissue paper and a glue stick, just substitute where you see the plastic and contact cement mentioned. There is no need to dilute the glue stick...apply directly to the wood. Use of tissue paper will result in an airplane that is about 0.6 grams heavier than would result from using the plastic covering.

A grocery store produce bag is cut to open the bottom and one side. That will produce a single sheet that is approximately 60 cm long and 40 cm wide. Be careful not to stretch the plastic while cutting. Lay the plastic over the plans and tape it down so there are not too many wrinkles. Remember, this plastic will become the covering for the airplane.

Now that the plans are drawn it’s time to prefabricate the balsa wood for the structure. In other words, make a kit.

Wing center panel LE and TE are cut from the very hard 1/16 sq balsa stick. They are both 20 cm in length. Put the remainder in a safe place as it will be used to make the wing posts that are also very hard balsa.

Wing tip panels LE and TE are from lighter weight balsa and should be cut longer than 10 cm. The excess will be trimmed away after the wing is near completion. Four pieces will be needed.

Wing “ribs” are cut from the light balsa and should be no longer than 7.6 cm. Five pieces will be needed. Take care to make sure all five are exactly the same length.

Stabilizer LE and TE are cut from the light balsa just over the 20-cm length, two pieces.

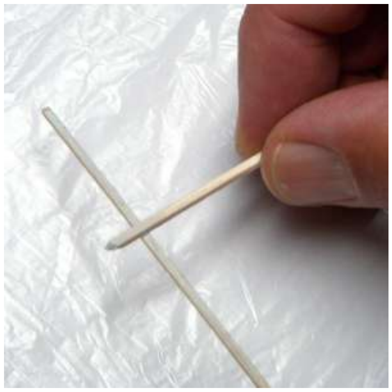
Stabilizer ribs are from light balsa, no more than 5.6 cm in length: two pieces. These must be exactly the same length. The maximum allowed stabilizer chord is 6.0 cm. If the chord is greater than 6.0 cm, the model will be judged out of spec.

Fin LE and TE are light balsa, 6 cm in length. The Fin tip balsa wood starts out longer than needed and then trimmed to length.

Tailboom is from light 1/16 sheet balsa. It is 24 cm in length and tapers from 0.6 cm to 0.2 cm over its length.

Motorstick is from 1/8 x 3/8 medium hard balsa and is 25 cm long.

Prepare the covering adhesive by diluting it with water. If you have the Weldwood non-flammable contact cement, use a Styrofoam egg carton for mixing. Into one of the egg wells place some undiluted cement. Use a scrap of the Styrofoam to transfer the cement from the can to the egg well so that the rim of the can stays clean. Mix in some water, about equal to the amount of cement and stir until completely mixed. Throw away the mixing scrap and re-seal the can.

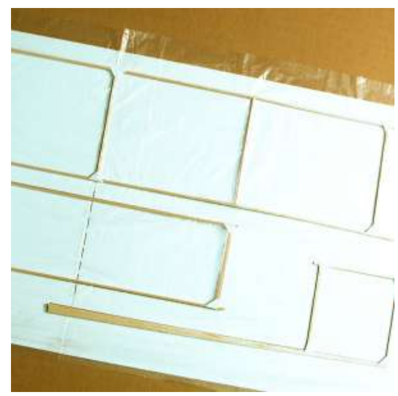


With a sharp razor blade cut a new strip of Styrofoam to be used as a glue applicator. It should be about 0.5 cm wide with a beveled tip. It also will be discarded when done using. Remember that contact cements are very messy and cannot be cleaned up from brushes, containers or your clothing.

Start with the stabilizer. Apply the thinned contact cement to completely cover one surface of the LE or TE. Make sure there are no coverage gaps. Because the contact cement may be difficult to see on the wood, it is suggested that small ink dots from a felt-tipped pen can be placed on the surface to be coated before starting the application. While the cement on the wood is still wet, place the cemented side on the plastic covering at the position of the LE of the stab making sure that it overlaps both tips in length and that the line on the plan is just barely visible adjacent to the outside of the wood. In the same way place the two ribs at the tips on the plastic making sure that there is no gap between the rib and the LE. Finish by adding the TE, making sure that the line on the plan is visible outside the wood and that there is no gap between the TE and the ribs at the tips.

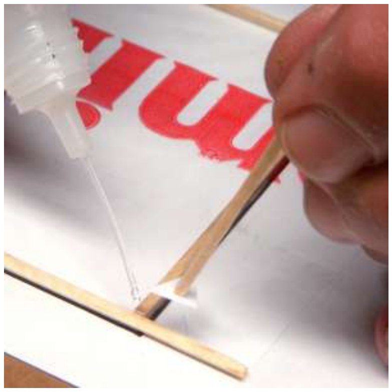
Note that there is no rib at the center of the stabilizer; the tailboom will become a structural member at the center of the stabilizer. Placing a rib at that position is redundant and only adds weight to a location where it is desirable to reduce weight. You will note two things: One is that the wood warps when the adhesive is applied. The other is that the wood does not stick immediately to the plastic. Because the wood will warp, it is very necessary to make sure that the outline of the structure fits inside the rectangle you have drawn. If any part is outside the rectangle, your airplane may be disqualified for having its chord too wide. (This doesn't apply to the span because the excess wood will be cut away from the LE and TE before you complete the stabilizer.) To make the wood stick to the plastic, you will have to gently push it down after a few minutes. It takes some time for enough of the water to evaporate and make the cement sticky enough to do its job. The wood will warp in a direction that is away from the side to which the glue was applied. That is because the wood fibers expand when wet.

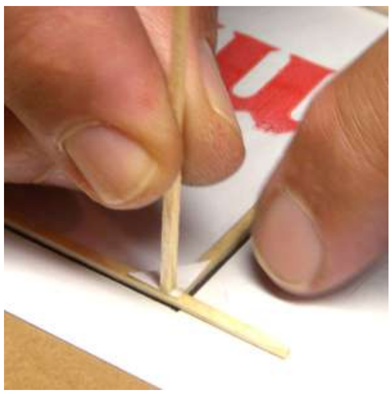
The wing is constructed similarly to the stabilizer. That is, the LE is first glued to the plastic followed by five ribs and then the TE. However, it is a bit more complicated because the LE and TE are each three pieces.

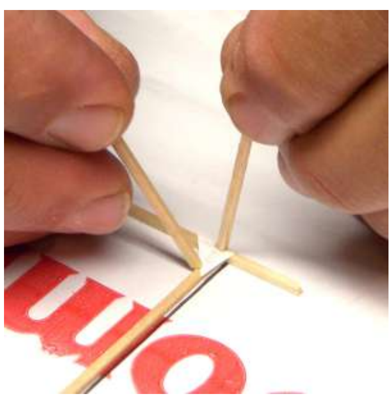


Start with the center section 20-cm hard balsa LE. Make sure it is placed exactly between the two marks that are 20 cm apart. Next come the two tip spars. They must be perfectly in line with the center spar and fitted so there is no gap between the center spar and the tip spars. Now add the five ribs. One at each tip, one at the center position and one at each junction of the center and tip spars. Continue with the TE spars. First place the center spar and then the two tip spars making sure that there is no gap between the spars and the ribs. A mistake to avoid is placing the rib between the center spar and the tip spar for either the LE or TE. That is, the spars must be a continuous length of three pieces.

To reinforce the wing and stabilizer, small paper triangles are glued at the corners. These triangles are called gussets. The strongest gussets are those where the grain of the paper is parallel to the longest side of the triangle. To find the grain of a piece of paper, try tearing it and observe which way the cleanest tear can be made. That is usually the same as the 11-inch dimension of standard computer paper. Cut a strip of paper about 0.5 cm wide along its grain. From this strip cut triangular gussets that have a 90-degree angle. You will need at least 10 of them, but it doesn't hurt to have extras. To pick up such small pieces, use a scrap of balsa wood with one end wetted with saliva from your tongue. Use brush-on Super Glue to coat the wood on both sides of a corner of the wing or stabilizer. Immediately, place the triangle on the glued corner and hold it for a few seconds until the glue sets hard. Continue until you have all four corners of the wing and all four corners of the stabilizer with paper gussets. Next place gussets at the wing center rib where it meets the LE and TE. There are no gussets at the other two ribs.







Trim the excess covering from the wing and stabilizer structures using a sharp new single edged razor blade. First cut around the structures leaving a border of 2-4 cm so the covered structures can be removed from the building board. Next, use the corner of the razor blade to strip the covering away from the wood structure right at the juncture of the covering and the wood. This is best accomplished by holding the structure up with one hand while the blade slices through the plastic covering. If you feel resistance to the cut you are probably cutting away wood and should stop immediately before you cut away too much of the balsa wood. Once stopped, the cut can began again only with the direction changed towards the mistake. To help precision in cutting, move your wood-holding hand as the cut proceeds so that it is not more than 5 cm from the razor blade.

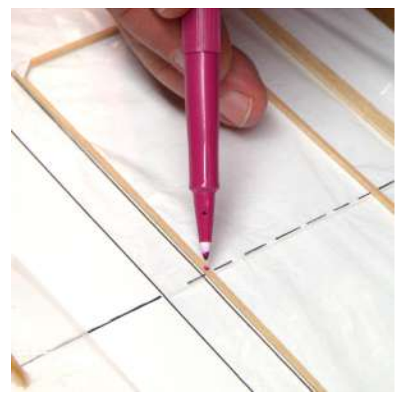
Be sure to save the plastic and plans for the tailboom and rudder construction. We will get to that in a few minutes, after the wing dihedral is started.

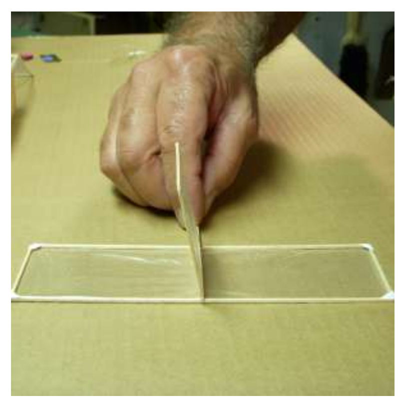
To set the dihedral in the wing place the center section, covered side down, on a support that is about 4 cm high so that both tip sections hang down. The support can be two pieces of plywood or some books, as long as they are flat. Underneath the supports must be a surface into which pins may be pushed. Hold the tips down with pins and scraps of balsa wood.

The dihedral joint will be set with fast-setting epoxy glue, sometimes called “5-minue” epoxy. Epoxy glues come in two parts, called the resin and hardener. They must be mixed very thoroughly or else the glue will not harden. Use a non-porous surface (egg carton Polystyrene will do) and place equal amounts of each part of the epoxy next to each other. With a toothpick mix the two parts together with a circular motion for about one minute. Wipe off the toothpick onto the side of the mix about half way through the mixing and continue mixing it all together. Place a small gob of the mixed epoxy into each of the four dihedral joints and rib junctures so that all three pieces of wood will be held together. Wait at least 15 minutes before picking up the wing. If you pick it up too soon, the partially hardened epoxy will not hold the dihedral angle setting and your wing will be ruined.

The tailboom-fin-stabilizer is a single unit. On the finished model, the fin will be below the stabilizer.

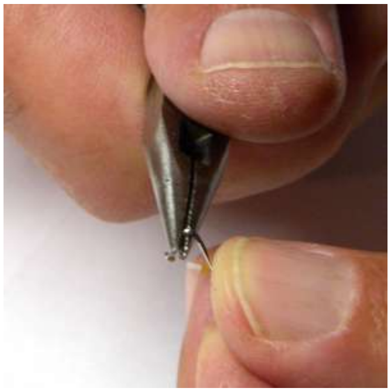
Build the fin onto the tailboom. Using the tailboom as part of the fin saves one piece of wood and a little bit of weight from the tail of the airplane. Remember, each savings at the tail saves four times that weight overall for the airplane. Cover the rectangle that was drawn earlier with plastic from the grocery-store bag. Use the thinned contact cement to attach the rear 6.0 cm of the tailboom to the covering on the rectangle. Attach the two 6- cm sticks to the covering so that there is no gap between them and the tailboom. Finially, attach the forth stick to the other two to complete the rectangle. Use the paper gussets and Super Glue to reinforce the corners as you did with the wing and stabilizer. When dry, trim away the excess covering with a sharp razor blade.



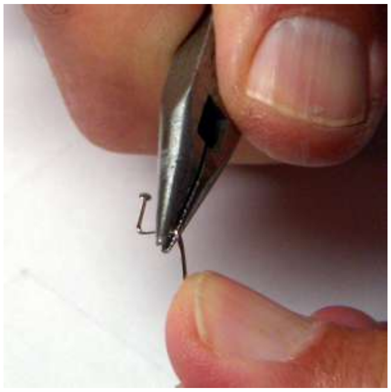


Mark the center of the stabilizer's LE and TE with a small dot from a fine felt-tipped pen. Put a little CA glue on each dot and hold the tailboom and fin construction from above onto the glued stabilizer for a few seconds until the glue sets. The tailboom is held at an angle to provide stabilizer tilt for left-turning flight. That is, looking at the TE of the stabilizer, the tailboom and fin should be tilted a bit to the left as it is held while the glue cures.

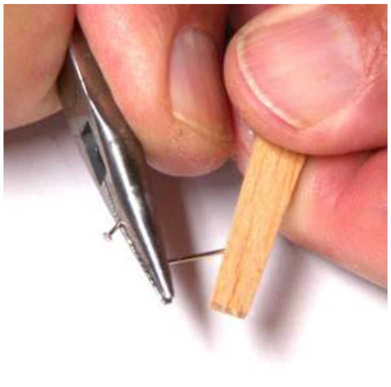
Bend a straight pin into a letter “J” shape. The sharp point of the pin is on the long leg of the J.



Make a second bend in the long leg at right angles away from the dip in the J.

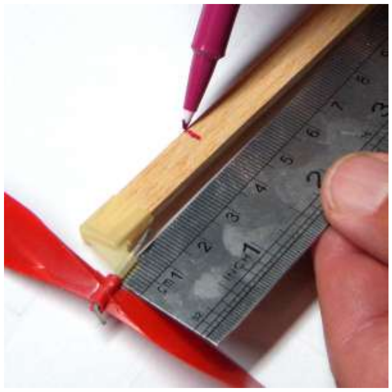


Push the sharp point into the rear of the motor stick with the open end of the dip facing towards the rear of the motor stick.



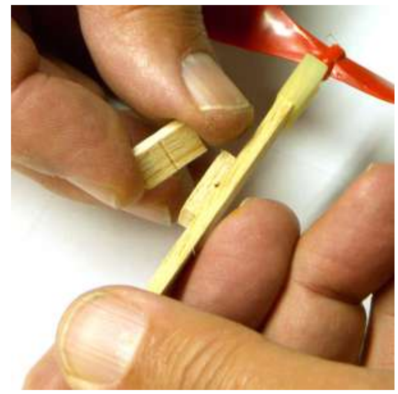
Coat it with glue at the motor stick to keep it from twisting. The propeller assembly is pushed onto the front of the motor stick so its thrust hook and the rear hook are on the same edge.

Make marks on the top of the motorstick 4 cm from the thrust bearing and 12 cm from the thrust bearing. These marks will be the location of the wing sockets.

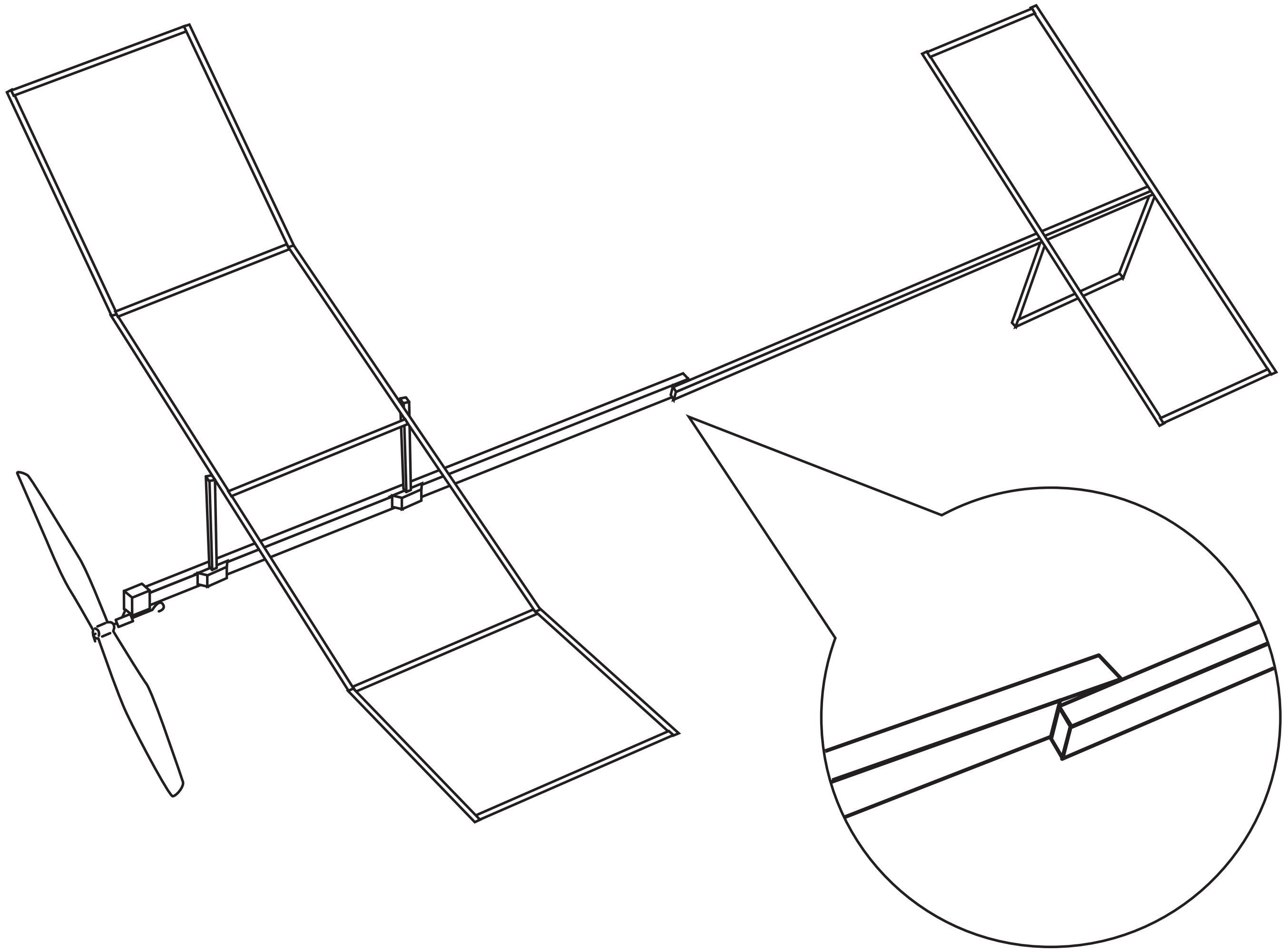


With a sharp razor blade cut a V-shaped grooves in the motor stick at the two marks from the top of the motor stick to its bottom. The groove should be less than 1 mm deep.

Cut two pieces of the motor stick stock balsa wood (1/8 x 3/8) about 2 cm long. In the center of each piece, cut grooves similar to those you have already cut in the motor stick. Be sure that the grooves are cut across the balsa grain, same as for the motor stick grooves.



Glue the short pieces to the motor stick so the groove on the motor stick and the groove on the short piece make a tunnel. This tunnel will be a pilot hole for a round hole that will be made with a 1/16” drill bit. Make the round hole either by twirling the drill bit between your fingers or use an electric drill to hold the bit while the hole is drilled to size. These two holes are the sockets into which the wing posts fit.

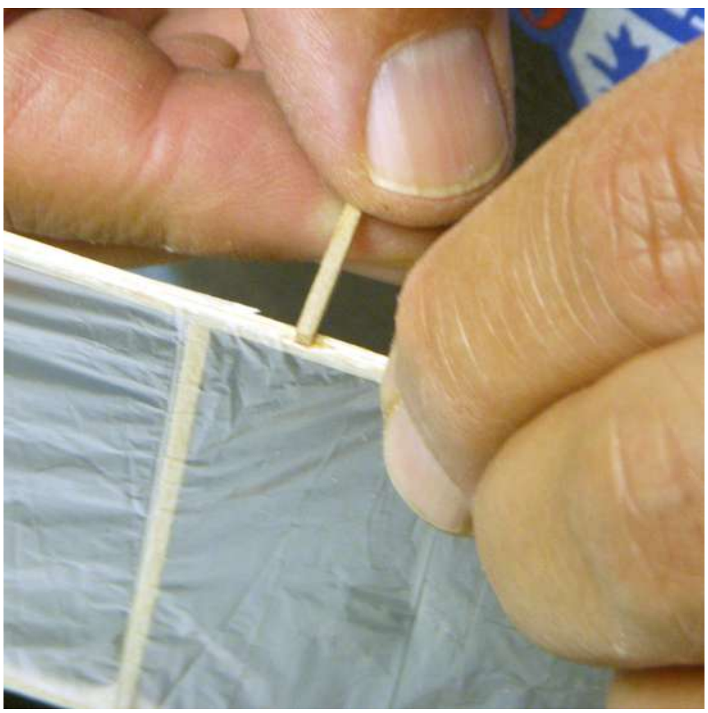


Glue the tailboom assembly of the stabilizer and fin to rear of the motor stick, overlapping about one centimeter. The tailboom should be attached so that it slopes up a few degrees, no more. This will provide the necessary angular difference between the wing and stabilizer.

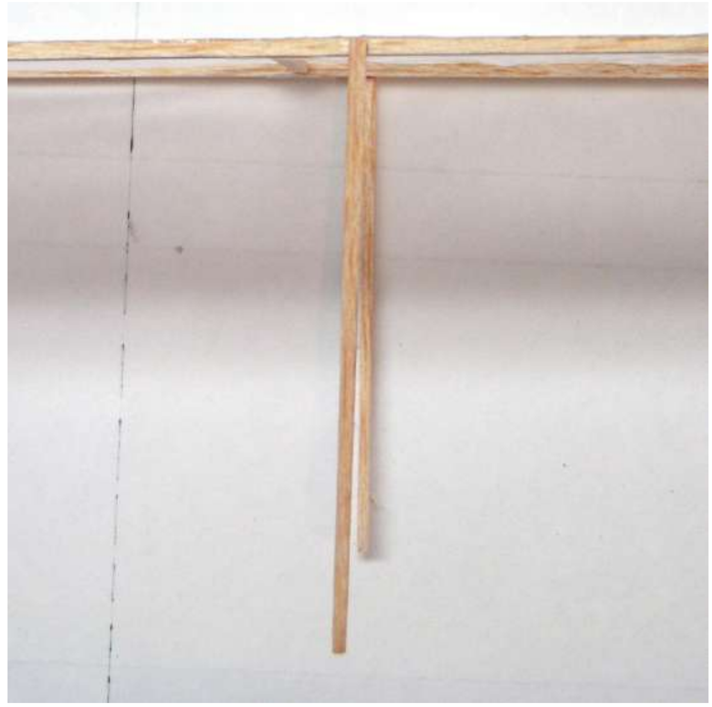
Use the hard 1/16" square balsa wood for wing posts. With sandpaper and a sanding block, carefully remove some of the wood from the four corners of each wing post so that the bottom end of each wing post is slightly rounded. Place a mark on the un-rounded end so that you can easily tell the two ends apart. Test the fit of the rounded end of the wing post in the sockets to make sure it is not too loose or too tight. Do not twist the wing posts while trying to insert them into the sockets. Hold the wing post close to the insertion end to avoid breaking it while putting it in and also while taking it out of the socket. When the model is completed, the wing will be removed for transportation and attached for flying by these wing posts. A slight bit of carelessness in removing or inserting the wing posts into the sockets can cause the wing post to break. Remember that although the models are easy to repair, all the adjustments will have to be re-established after the repair.

Cut each wing post to length, one at 6.5 cm and the other at 7.0 cm. The longer will go on the leading edge and the shorter on the trailing edge.

Make a mark on the LE and TE one cm from the center rib. The short side will be on the right and the long side on the left of the airplane, thus defining which spar is the LE and which is the TE. With Super Glue attach the 7.0 cm wing post to the front of the LE at the mark. Make sure that the angle of the wing post on the LE is at 90 degrees to the LE.



Glue the 6.5 cm wing post to the back of the TE at the 1-cm mark you have made. The angle of the wing post should be slightly skewed to the left when viewed from behind the TE. Skewing the wing posts will translate into the desired twist in the wing when they are inserted into the sockets. (Review the part about Circular Flight earlier in this



document in case you didn't pay attention when you read it the first time.)

Cut small triangles of 1/16" balsa wood and glue them to the underside of the LE and TE at the wing posts to reinforce the junctures.

When the Super Glue is fully cured, attach the wing to the fuselage by putting the wing posts into their respective sockets. The wing posts should be pushed all the way to the bottom of their sockets.

Make a rubber motor equal to the maximum weight allowed (1.5 grams). Place the motor between the thrust hook and rear hook. If it is too long to stay in place, double the motor to help keep it on the hooks.

Adjust the balance point of the fully assembled model (including the rubber motor) so that it is located 2.0 cm in front of the rear wing post. You may use modeling clay for initial CG adjustment, but the final CG location should be fixed by gluing a length of wire to the appropriate location.

Time to Fly!

To fly the airplane you will need a fairly large place. A school gymnasium will do nicely, but arrangements will have to be made to have the heating and air-conditioning (HVAC) fans turned off. If you fly the airplane in the drafts caused by the HVAC system, very little useful information will be obtained. It will be like flying a full-sized airplane in a hurricane.

To store the airplane when not in use and to transport it to the flying site, a container that keeps out all air drafts is an absolute necessity. Just walking with the airplane outdoors in the slightest wind is likely to break it. A cardboard box will do fine. Some people like to buy expensive plastic storage boxes however. To construct a custom cardboard box, start with a large box and use the cardboard and contact cement (no water added at this time) to make one just right for your airplane. A good source of large cardboard boxes is automotive body shops. The box for your airplane should have a removable top such as found on boxes for copier paper. Beware of boxes with folding flap tops. On windy days, the wind will get into the box and could destroy your airplane.

To make a motor from rubber strip a knot must be tied to make a loop. The best and simplest knot is known as a figure-8 knot. The knot must be pulled very tightly to keep it from unraveling while winding the motor. You must pull on the rubber strands as hard as possible to finish the knot. However, this pulling can cause the rubber strip to cut into itself and create a flaw for later breakage. To avoid the rubber cutting into itself, the rubber strip is first placed in some soapy water to make it slippery.

Place the rubber motor into a plastic bag with a few drops of rubber lubricant. Massage the bag in you hands to coat the entire motor. Using the bag keeps most of the lube off your hands. Motors will have to be re-lubricated after about 3 uses. Place the lubricated motor on the propeller hook with the knot at the rear.

Place the knotted end of the motor on your winder hook.

Have a helper hold the fuselage at the propeller end so that the propeller is kept from turning as you wind the motor.

Stretch the motor while winding. Reduce the stretch to be equal to the approximate distance between the propeller hook and the rear hook at the end of the winding.

The holder pinches the motor at the knot end about one cm from the knot while you unwind to make a small open loop than the holder can place on the rear hook after removing it from the winder hook.

Hold the airplane by the fuselage under the wing with one hand and the propeller with the other hand for launching.

Launch the airplane very gently...please no hard throws. All the motive force comes from the propeller. A hard throw will probably break the airplane. A properly built and adjusted airplane will climb under power to about 20 meters under full power. If it doesn't climb, that problem cannot be solved by brute force.

The first flights are just to adjust the trim of the airplane and should not use anything close to a fully wound motor. A total of about 300 motor turns (20 turns from a 15:1 winder) will do nicely.

The model is in trim when it flies in a counter-clockwise turn with no banking of the wing and there is no diving or stalling.

Turn direction can be adjusted by gluing a balsa wood tab to the back of the fin.

Turn direction can also be adjusted by changing the thrust line of the propeller to the left.
Remove the propeller assembly and shave a small wedge of balsa wood from the right side of the motor stick. Glue the wedge to the left side and replace the propeller assembly. Care must be taken to let the Super Glue cure completely lest the propeller assembly also becomes glued to the motor stick (OK once you have the correct side thrust).

Diving and stalling is adjusted by moving the wing post up or down in the sockets to change the wing incidence.

Once the airplane has been adjusted at low power, the number of winder turns in the motor can be increased to provide longer flights.

How to not break your airplane:

No one sets out to break an airplane that has required hours of work to assemble and test. However, careless and unthinking behaviors often result in broken airplanes, especially the lightweight Indoor models. The need to place the airplane in a well-sealed box for transportation and storage has already been mentioned. One student reported that his airplane in a flap-top cardboard box was destroyed when the family cat tried to get into the box!

Make sure that those observing the flying keep their distance and beware of waiting in line at competitions to have your airplane measured by the contest officials. It is your job in such cases to concentrate on holding the airplane so people cannot brush against it. Your friends may be interested in observing how you get the airplane ready for flight, but make sure they keep their distance.

Indoor airplanes are designed to bump into an obstacle and keep flying. It is rare that such bumps cause the airplane to break. However, sometimes the airplane will get caught on structural features in the room where you are flying: beams, baskets and light fixtures. Retrieval of the airplane often results in a breakage or destruction. Plan your flights to avoid such hazards by not over winding the motor and by observing your launch location and the airplane's expected flight path. Practice the winding technique described earlier: Better to wind fully and then remove winds before launching so that the airplane does not climb above the hazards in the gym. It takes a lot of practice to master the technique of winding the motor.

If the airplane is on a path to collide with a person, provide instruction to that person to just hold still and let the airplane hit as long as his or her eyes are not the target. Trying to walk out of the way will create an air current that the airplane will follow right to the person who is trying to get out of the way and is a common cause of damage to the airplane. It would be best to explain this ahead of time.

The most common location for flying Indoor airplanes is a school gym. Make sure that no other activities are going on at the same time you are flying. Your airplane is no match for a bouncing ball of any sort. No running allowed in the flying site; stirring up the air by running is detrimental to good flights at best and destructive at worst. If there is more than one group flying airplanes at the site, good manners and good sense require that you (and they) do not walk across the floor except to retrieve their airplanes and do not stand in the middle of the floor while airplanes are flying.