Hip Pocket Aeronautics

There's nothing more satisfying than flying a model you built yourself

Growing Embryo Endurance Models

or Hatching Embryo Endurance Airplanes

By Bruce Feaver

Two thousand winds of an elastic band in a 16-inch wingspan model airplane is amazing, the propeller just keeps on spinning. It's exciting to watch these airplanes climb out at a 30-degree climb toward an 80-foot ceiling in a full size airliner hangar and see them cruising around for minutes on end. I have spent many hours enjoying the nature of flight with these small model airplanes and have learned more about flight than with any other type of airplane model.

The Embryo Endurance model is small and efficient and makes flight to the ceiling look effortless. The Embryo class of model is a straightforward design that subscribes to a predetermined set of rules for competitiveness and fun. I started building these airplanes a number of years ago in an effort to learn to fly Indoor Model Airplanes. One fine example of this is the very popular Prairie Bird model, designed by Peck-Polymers, found at many of the local hobby shops. It did not take long to get the Prairie Bird to fly a minute and a half with consistent results. Searching for new challenges, I began working on my own designs of Embryo's and in the process developed a design procedure that focuses on the detailed points of Embryo Endurance Models.

In the pages that follow, you will find guidelines that describe the aerodynamic and stability requirements for the Embryo Endurance Model and other models in the free flight discipline. After you have completed reading this information you should be more comfortable in designing your own great flying Embryo Endurance airplane. Perhaps you will win some competitions with your own design. In this article we look at the purpose for the design and the arrangement of aerodynamic factors that make up the Embryo class of airplanes. You will develop a design procedure for the development of the airplane and I will help you go through the layout of your first working drawing in order to build the design from that.

Embryo Endurance models fly great and are fun to design and build, so lets look at the class of the model in detail.

Embryo Endurance Rules

1. For rubber powered models with not over 50 square inches of wing area for monoplanes. For biplanes, not over 70 square inches, with 45 square inches maximum for the largest wing area. Stabilizer area is not to exceed 50% of the wing area.

2. Fuselage volume is meant to enclose a space 1.25 x 1.50 x 3.00 inches or larger.

3. Wing and tail to be built up frame, covered on both sides with Japanese tissue or equivalent.

4. Model must ROG (Rise Off Ground) from a card tabletop UNASSISTED from a three point rest.

5. Landing gear legs must be in a conventional configuration and have 3/4 inch wheels or larger. (Example: two wheels on one landing gear is prohibited.) Wheels must turn on their axles.

6. Unlimited attempts for three official rise off table top level flights.

7. A bonus for the following details will be given: 5 points for a raised cabin or windscreen with an open cockpit and headrest. Raised cabin must have at least 30 degrees windshield slant. 3 points for 3-dimensional wheel pants. 1 point for 3-dimensional exhaust pipes.

8. Highest flight total plus bonus points wins. Fly-off to break ties. Bonus points once again added to flight points.

Design Procedure

The design procedure is a series of steps to work with that allows one to design to the specifications of the airplane rules in this class. The airplane design follows on the idea of a strong purpose arrived at from the rules. These basic steps are followed:

1. Purpose for which it is intended
2. Arrangement of aerodynamic factors that best satisfy the purpose
3. The type most suitable for the purpose
4. Size and proportions
5. Shapes and features

Purpose

The purpose of the Embryo Endurance models is based around the premise of maximum time aloft, taking into consideration certain limits of size and shape. The point of this is to test ones ability to get a model airplane to perform with distinct characteristics.

Additional non-aerodynamic features are included to introduce some style and additional competition points. Performance is assessed on the highest flight time total of 3 from four flight attempts plus bonus points to win. These considerations set the stage for a design that is optimized for fine flight times and a high degree of style. Lets take a look at the list of requirements for the Embryo Endurance airplane as laid out by the Flying Aces Club rule book.

a) Wing area not to exceed 50 square inches for a monoplane, or 70 square inches in a biplane where the larger wing can't be more than 45 square inches.

b) Stabilizer not to exceed 50 % of the wing area.

c) Fuselage volume to enclose a space of defined dimensions bounded by the measurements of 1 1/4" by 1 1/2" by 3" or larger, arranged in any direction.

d) Landing gear with 3/4" wheels or larger.

e) Plastic or any Non-Folding propeller.

f) Rubber powered only.

g) Model must R.O.G. from a card tabletop, unassisted from a 3-point rest.

h) Additional Bonus Features

i) 5 bonus seconds for a raised cabin or windscreen with a open hole and headrest

j) 3 bonus seconds for wheel pants.

k) 1 bonus second for 3 dimensional exhaust pipes.

So in a nutshell, good flying endurance, realism in design with good looks and style. When it comes down to the final situations, these rules are not so hard to live with.

Arrangement of Aerodynamic Factors

Now that we have looked at the overall design procedure and the embryo rules and understood the overall purpose of our design we can go about arranging the aerodynamic factors of an airplane that will begin to fit into the overall design purpose. The factors to be considered are:

- Center of Lift
- Center of Gravity
- Thrust Line
- Stabilizer Tail Moment Arm and Size
- Fin Moment Arm and Size
- Lateral Area
- Wing Dihedral
- Weights and structural considerations
- Shapes and non-aerodynamic features

Each one of these factors develops relationships with other aerodynamic factors to produce a design that relates to our design purpose. To create a duration design in the Embryo class that performs properly requires a large component of stability built into the design. Now we must arrange the aerodynamic factors in a manner that promotes good stability.

Of Planes and Pendulums

The first condition of stability that we begin with, that promotes good flight qualities, is the condition similar to a pendulum. Since the pendulum develops a tendency for equilibrium through its relationship with gravity, we shall use this property of equilibrium in our design for stability. The pendulum defined as an object suspended from a fixed support that swings freely back and forth through the action of gravity. This pendulous motion is found in the lateral and longitudinal stability of an aircraft in flight. The aerodynamic factors that use the pendulous relationships in flight are the Center of Lift and the Center of Gravity.

In a duration design, the center of gravity shall be supported below the center of lift. This will set up the relationships between lateral and longitudinal stability. As the distance between the center of gravity and the center of lift increase, so does the ability of our airplane to remain upright and have small tendencies to swing from side to side. As the distance between the center of lift and center of gravity decrease so does the tendency of the airplane to swing from side or side. Since the airplane design is supported by the wing in flight, through the center of lift, a fairly low center of gravity is required. The Center of Lift is a position on the wing that the action of lift and drag work through, most commonly called the Center of Pressure of the wing.

The Embryo class of model is required to have a fuselage volume of 1.25 x 1.5 x 3 as a minimum and this can be arranged to our benefit in allowing us to mount the wing on top of the enclosed volume. This lets the overall gravity of the airplane hang down below the wing. This also sets a relationship up between the Center of Lift in the wing and the Center of Gravity in the fuselage. In order to design a good flying Embryo airplane, a rule of thumb can be employed that sets up a level of static stability between the center of lift and the center of gravity. The optimum distance the Center of Lift and the Center of Gravity should measure is "One Sixth" the Tail Moment Arm. I tested this rule out on the great flying Embryo airplane called the "Prairie Bird" by Peck-Polymers. The tail moment arm of this airplane is 8 inches, which is the distance between the balance point positions on the wing to the center of the chord position on the stabilizer.

A calculation of 1/6 of a tail moment of 8 inches measures 1.3 or 1 - 11/32 inches. If we measure this out on the Prairie Bird from the Center of Lift at the 50% chord point on the wing downwards into the fuselage volume, we get a spot, which is right in the middle of the longest length of the fuselage. This happens to be where the centerline of the airplane is and its thrust line. This should be the maximum depth the

Center of Gravity should reside. I checked the balance point on my Embryo and found that the vertical C of G was slightly above this point or only 1 inch below the center of lift. Perhaps this is due to the fact that I had made no wheel pants and I had used slightly larger and lighter wheels than the rules call for. As it stands the rule holds up quite nicely. The 1/6th of the tail moment arm rule is only a guideline to serve as a starting point for basic design layout.

Locating the Application of Thrust

In many typical designs the thrust line is set below the wing. Since the wing in flight supports the airplane, thrust contributes to flight by making the airplane pitch up under power and pitch down while power is off; this is a favorable effect during takeoff and full power climb.

The question is, what is the best distance the thrust line should be below the wing and to what degree do we want this pitching under power applications? The answer is some but not much. Pitching is controlled partially by the center of gravity being below the wing but also by the action of the distance the stabilizer is from the wing and the stabilizer's size.

If we locate the thrust line below the wing and also below the center of gravity, we have a situation in our favor for the thrust line and the wing but not in our favor for our center of gravity. In this case, as the power pitches the plane upward with the wing, the center of gravity will continue to assist the plane to pitch up. This is not such a good thing, as we would need a big stabilizer to control this over-pitching.

What if we could use the center of gravity to help the plane from over-pitching instead of a bigger stabilizer? We can, we just need to locate the center of gravity below the thrust line and now our pendulum situation, we initially designed for, works to stabilize any over-pitching from the thrust. We now have a system that begins to manage itself through the placement of aerodynamic factors without making the tail longer or the stabilizer bigger, all of which could add extra weight.

A good rule to follow for endurance designs is to locate the thrust line 1/16 the tail moment arm below the wing center of lift. The other alternate rule is to locate the thrust line as close to the vertical center of gravity as possible. This was one issue that I found contradictory to the information I described previously. When I checked the Prairie Bird Embryo design, I found that the thrust line was located below the center of lift but also below the center of gravity, it should have been above the C of G or pretty close to it. Fortunately the vertical C of G was not far above the thrust line. So for interests' sake, try to locate the C of G as close to the thrust line as possible and below the wing center of lift if at all possible. Room for deviations from this rule seems to be governed by the style of the aircraft and the visual presentation of the overall design. The tail moment arm and the stabilizer size will tend to control the airplane's stability when these deviations from the rule are made.

Lets look at our Tail Moment Arm we calculated earlier. Since we measured a distance 50% of the chord line on the wing to the center of the stabilizer a particular distance, we need to understand how we arrived at this value. For starters, we measured right off a set of plans for an existing design and came up with a measurement that someone else had arrived at. What if we want to develop a design of our own and have no set of plans to work from, where do we start?

The Tail Moment Arm is characterized by the distance the tail is aft of the center of gravity location. Since the Center of Lift is located above the center of gravity the tail moment arm is also the measurement of the tail behind the center of lift. The purpose of this situation sets up a degree of longitudinal and lateral stability required for stable flight. Rules of thumb state that for endurance designs a moment arm of 40% to 60% of the Wingspan should be calculated. This is a 20% of variation, which is quite large. If we test this on our Prairie Bird design, we find that the measurement is 8 inches and this is 50% of the wingspan.

Another method is to measure 2 1/2 times the wing chord. Since the chord of the wing on the Prairie Bird is 3" the result for a tail moment arm is 7.5 inches. This is 46% of the wingspan, which falls into our first rule between 40 to 60% of the span. This is plenty of tail length, which allows for a reasonably long motor. We now have some general guidelines to follow to begin to set up a basic Embryo design. It's important to remember that the stability of our airplane will be reflected in the distance the tail is behind the wing.

Stabilizer Requirements

Since the Center of Lift is located between 25% to 50% of the wing chord, during the different stages of flight, its relationship to the Center of Gravity is important. Usually the C of G is fixed throughout flight and the C of L will move for and aft. This sets up a relationship of changing stability that needs to be controlled at all phases of flight. We do this through the action of the Stabilizer. Since our stabilizer is located at the end of the tail moment arm it has to be the proper size to do the best job possible without creating extra weight or drag. The size is related to how far behind the wing it is and the pitching forces of the wing, gravity and thrust line. The job of the stabilizer is to ensure that the wing flies at the proper angle of attack for the different phases of flight. The further back the Center of Gravity gets behind the Center of Lift, the larger the stab must become to control the pitching stability requirements of the wing. Conversely, the farther the stabilizer is placed behind the wing the smaller it requires being, to do the same job of stabilizing the wing.

So how big do we make the stabilizer to balance between the length of the tail moment arm, center of gravity and the changing pitching requirements of the wing in flight? In the Embryo Endurance class of airplanes the stab is allowed to be up to 50% the area of the wing. This is quite large for the models flight conditions. Typical designs are around 38% of the wing area and work well at a tail moment of 40%

to 60% of the wingspan. I calculated the Prairie Bird Stab area at 33% of the wing area and this seems to work quite well for a center of gravity position of 50% of the wing chord.

Other things that may force a designer toward larger amounts of stab area are the length of the nose and the size of the propeller. Both of these have tendencies to destabilize airplanes in flight. Another popular value that takes these factors into account is 38%. Going larger is permitted only if the center of gravity is to be located more aft or the tail moment arm is shortened.

Fins are for Fish

The fin of the airplane is of smaller concern for major flight stability and performance but does play a part in how the airplane flies. Fish require a large fin for stability in the water and well as a mode of propulsion; our airplanes have propellers up front for that. These props require stabilizing due to large amounts of gyroscopic precession that will tend to make an airplane behave erratically in flight. A good-sized fin will provide good control for the reactions of propellers. The fin shall ensure the airplane travels in a forward direction in flight and keep it from turning around backwards. There are no guidelines in Embryo Endurance Rules that dictate the size of the fin, but too large, we tend to carry around extra weight that we don't require. The basic rule for fin size is 10% of the wing area and is based on the fact that they are mounted close to the same distance behind the wing as the stabilizer. The fin tail moment arm for endurance airplanes of this embryo type is between 40% to 50% of the wing area, so we can use the stab moment arm for a value and go from there. Remember that the farther the fin is out on the design the smaller it can be, but be careful that it's not too small. 10% is a minimum size. If the airplane is to have a short tail and low or no dihedral then the fin must be up to 20% of the wing area to ensure directional stability.

The Flying Fish

How should our airplane look as viewed from the side? Fat like a fish or lean like a shark? The answer is, it depends... It always depends. Mostly on a balance of the internal space required by the design to meet its proposed requirements, and streamlining for good flight characteristics.

In Embryo design, our rules specify that the airplane shall have a defined fuselage volume, perhaps to simulate the cabin or cockpit area of the airplane. I like this rule as it forces model designers to make airplanes look like real airplanes and not just flying sticks. It also forces the design to take on some fuselage volume and develop lateral area for stability in flight. Lateral area is the term used for the amount of side area an airplane has as it incorporates things like places for people and freight. Too much side area ahead of the center of gravity and the airplanes directional control is compromised, often making it turn around backward.

If we design our plane to have more lateral area behind the center of gravity it will have a tendency to fly straight and in line with the direction of flight similar to the motion of a fish or shark.

What is the Center of Lateral Area anyway? It's the center of pressure of the air striking the side of the plane. This air striking the side of the plane has an influence on the directional stability and the spiral stability of an airplane. If the center of lateral area is too far forward, the airplane looses its tendency to travel forward through the air. In general the lateral area should be located behind the center of gravity to make the airplane directionally stable. Just the fact that we have a fin attached to the tail section of the airplane ensures that the center of lateral area gets located behind the center of gravity. Long noses tend to add lateral area ahead of the center of gravity and reduce the directional stability so we have to be careful about the length of the nose of the plane.

A rule of thumb to follow for the location of the lateral area is 10% to 20% of the tail moment arm. For the Embryo airplane lets pick 15% for starters. To measure this out, add up the area of the side view of your model and include the rudder area in the calculation. If you can calculate the area of this side view and multiply it by 15%, you will get a measurement in inches that you can measure from the center of gravity rearward to locate your center of lateral area. This is not such an easy task as fuselage profile shapes are irregular and hard to measure out in area. You will find that the fin area on most designs will locate the center of lateral area back behind the center of gravity enough to do the job of stability just fine. Fuselages should be close to 6" inches long and 1 inch in height. However, up to 9 inches long and 1 inch in height is not out of the question for good streamlining. This rule will help in drawing up a suitable shape for fuselages without the fin attached.

The rules call for a fuselage volume that is contained by the dimensions of 1 1/2 inches by 1 1/4 inches by 3 inches. This volume can be arranged any way one likes but the conventional arrangement is for the 3-inch length aligned longitudinally. This allows for a wing position to be mounted high and the thrust line underneath for good stability. Your fuselage profile can be shaped to enclose this fuselage volume in a fashion that allows for good streamlining.

Wings for Lift and Stability

Designing a wing for the Embryo is partially completed already, as the wing area is set by the rules of no larger than 50 square inches. Most Embryo designs use a pretty common 3-inch chord and a 16-inch wingspan but we are not bound to simple rectangular shapes. Elliptical or parabolic plan forms can be used as can taper or double tapered wings. The most common is a rectangular with tapered tips like the wing found on the Prairie Bird design.

One important aspect of the flying performance of the Embryo design is wing dihedral. In high wing designs, the amount of dihedral required is equal to .125 to .155 of the wingspan. This will tend to raise the center of lift to a position slightly above the wing mount position. More built-in stability is developed through an increased distance between the center of lift and the center of gravity, improving the pendulum margins of stability. Since the wingspan is, say 16 inches, then each panel is about 8 inches. By multiplying this number by .155, you will get about 1 1/4-inch dihedral each tip on each panel or 2 1/2 inches of overall span. This will ensure adequate lateral stability and move the center of lift up a little higher above the wing.

Weights and Structure

The Embryo class of model operates in a wing loading of .0098 oz per square inch. This equates to models in the 14-gram class. The great thing about this class, is the fact that the wing loading is still pretty light. This makes for flight speeds in around the 15 to 16 mph range. There seems to be a good margin for changes in weight with respect to the size of the wing. It is also a fine size of airplane to fly indoors and out. Most target weights are between 10 grams to 16 grams for best performance. A good performing Embryo that operates indoors is capable of up to 2 minutes flight on a 15 inch strand of 3/32 rubber band.

Shapes and Non-aerodynamic Features

Up to now we have concentrated on the aerodynamic considerations of the Embryo Endurance model.

Other features of this model are equally important, like shapes, exhausts, landing gear, finish and color. Each one of these is designed to fit the overall look and style of your airplane. Fortunately you have probably given quite a bit of thought to what you want your airplane to look like and have a concept in your mind of how your plane will appear.

Landing gear should be long enough to allow the propeller to clear the ground on the takeoff. Windshields are likely built into the design of the fuselage. Many designs use the Fuselage volume rule to become a cabin to wrap a windshield around. Exhausts are quite simple and anything you desire to represent an exhaust pipe is allowed, just keep it light. Wheel pants are another feature that adds some style to the plane, in fact quite a bit. Remember to build them light and allow the wheels to rotate freely within. Many of these features have little bearing to the aerodynamic considerations but can add weight to the airplane, which detracts from the overall flight performance.

Up to this point we have reviewed much of the concepts behind the nature of Embryo Endurance models and have done quite a bit in the preliminary designing. In this next section we will progress through the complete design of an Embryo Endurance model so that you can see how all the aerodynamic considerations go together.

Embryo Endurance Model #1

Proportioning the model — The Wing

In this design, rules dictate a maximum wing area of 50 square inches is allowed. We will try to get as close as we can to this quantity for maximum wing area. Lets label this quantity; A = Area. A = 50 in sq. Since the wing area is set we can begin to design the next parameter called Aspect Ratio. This will help us establish the Chord of the wing. Before we can estimate the wing Chord we have to look at another feature of our airplane called the Fuselage Volume. Fuse Volume of no smaller than 1 1/4" by 1 1/2" by 3" or larger is set by the Embryo rules. Many people use the longest dimension in this Volume as the wing Chord amount so that the wing has a good support to get mounted to. So a minimum dimension of 3" can be considered, but not limited to these three inches. Lets designate wing Chord C. C = 3 inches or greater. This sets one dimension of our wing so we can begin to find the Span S, from our wing area and wing chord. Span is A/C so 50 / 3 = 16.6 inches, so Span = 16.6 inches. Now that we have the Span we can complete the design of Aspect Ratio and refine the wing a little further. Aspect Ratio is a measure of performance so we need to find a respectable balance between Span and Chord. High aspect ratio wings offer better efficiency for these types of airplanes, however, too high and the wings get too long and skinny. A good aspect ratio for this airplane is between 4.8 and 6. If we do the math for Aspect Ratio we will calculate Span / Chord. S / C = 16.6 / 3 = 5.53 which is a good measure of wing efficiency and structural robustness. To review our information in the design for the wing so far we have:

A = 50 sq. in.
C = 3 in.
S = 16.6 in.
AR = 5.53

The next feature of our wing should be the wing section or airfoil. In the Embryo Endurance design the flying surfaces have to be covered with a covering, most commonly a Japanese Tissue. This promotes a flat-bottomed type airfoil for ease of construction and strength. Airfoil shape is not so critical so a general rule of thumb for cambered airfoils for this design is 1/12 the Chord dimension. So a chord of 3" the thickest portion of the wing section will be about 1/4 of an inch. Thickness = 1/4" = 1/12 C = 1/12 * 3 we can use a typical Clark Y airfoil type which is plenty efficient for Embryo and easy to build.

Now we have most of the important factors of our Embryo Endurance model wing. Now we can go about designing where the wing will go on the fuselage and be supported by the airframe. We can also design the dihedral into the wing at this time but first we will locate it on the fuselage. It's up to you and your sense of style to locate the wing on the fuselage but there are a couple of considerations. In our previous chapters we discussed stability and how this related to wing position. It was determined that if we positioned the wing above the line of flight it was most stable and that this situation promoted a high wing position. However, if care is taken, shoulder wing or low wing designs can be made to work just fine. So, for this design, we will settle on a high wing position and accept a good degree of stability. Since the wing is mounted high, a large amount of dihedral is not a big requirement, between .125 inches to .155 inches of dihedral per inch of wing panel is suitable. Since each wing panel on our design is 8.3 inches long, we shall multiply this panel length by say .155 inches and get about 1 1/4 inches of dihedral at each wingtip or 2 1/2 inches in total dihedral for a 16.6-inch wingspan. This concludes the main elements of the Embryo wing design.

Proportioning the model — The Fuselage

To continue proportioning the model, it is best to make a force diagram that shows how the aerodynamic factors are arranged. This satisfies our need to visually represent the relationships found in the design that makes up the basic stability of an Embryo Endurance Model. The basic reference line for our airplane will be our direction of flight, which is parallel to the thrust line.

Draw a line horizontally on a fresh piece of paper, right in the middle. This will become the thrust line. This line is now divided into two sections which become the nose moment N, and the tail moment M.

Tail moments for Embryo models are about 1/2 of the wingspan and since we calculated the wingspan at 16.6 inches, the tail moment M = 1/2S = 16.6/2 = 8.3, so M = 8.3 inches. Previously in the paragraph on Tail Moment Arms, we also stated that moments of 40% to 60% of the wingspan were also common. Further to that, a tail moment arm of 2 1/2 times the wing chord was also common.

On this same line we calculate the nose moment which is generally 1/2M = 8.3/2 = 4.15, so N = 4.15 inches. To continue the layout on the page, measure from left to right, first 4.15 inches, then 8.3 inches, which adds up to a total length of 12.45 inches. The location where N intersects M is where we locate our center of lift; this is also the location that the center of gravity acts through.

Wing mounting or wing support, shall follow the rule of 1/6.6 M above the thrust line where the center of lift of a wing without dihedral is located. Center of Lift location =1/6.6M = 8.3/6.6 = 1.23 inches. So locate C of L 1.23 inches up from the thrust line where N and M intersect.

The Center of Gravity is next; it will reside hopefully below the thrust line or just on it where Nose and Tail Moment intersect. A general rule is 1/16M but this is going to vary from design to design.

Now things begin to get a little confusing here so I will try to keep it as clear as I can. The wing mounting saddle is located 1/2 the dihedral angle below the Center of Lift position. Our C of L was calculated at 1.23 inches above the thrust line but the wing saddle will be 5/8 inches below this Center of Lift position. Or 1/13.23M = 0.625 inches above the thrust line. This saddle is 3 inches long to support the chord of the wing and satisfy the fuselage volume rule.

All this preliminary setup with the C of L, Thrust line and C of G, must be carefully worked out step by step as outlined above. The time taken to set the design up properly like this will ensure a fine flying design almost every time. But one must try to stay within the confines of the rules for Embryo Endurance. However there are plenty of fine adjustments that move these calculations one way or another from our math that will still allow fine flying operation.

By now we should have a good organization of information to allow the Embryo design to emerge. Other things not yet determined are stabilizer, fin and propeller requirements. Other elements that add to the nature of the design are windshields, landing gear and exhausts, all that add to your personal elements of style.

Proportioning the model — Tail Feathers

Now that we have solved our wing and fuselage we have yet to design for our stabilizer tail moment arm and stabilizer size as well as the fin tail moment arm and fin area. These features are based on simple rules of thumb that are defined from many models in the past. The stab is located aft of the center of gravity and aft of the center of lift a measured amount. Common designs use a tail moment rule of 2 1/2 times the wing chord C, or 1/2 a wingspan, or 40% to 60% of the wingspan. In our previous calculations we settled on a wing chord of 3 inches. Stabilizer tail moment arm is M=1/2S where S = wingspan. The tail moment became M = 16.6/2 = 8.3 inches. In this case that's 50% of the span, or 2 3/4 of the wing chord. A decision to adjust up towards 60% or down towards 40% is something that you will have to decide upon. Perhaps just understanding that the longer the tail moment the more dynamically stable the plane becomes and the shorter the tail moment gets the less dynamically stable the airplane becomes. Dynamic stability is based on the time it takes for an airplane to recover from an upset like a stall. Static stability is based on the tendency that the airplane will recover in a positive manner. Just having a tail makes the airplane statically stable, the length of the tail and the size of the stabilizer sets up the nature of the recovery time dynamically. So we need a plane that is long enough, but not too long, to fly efficiently. A choice of 2 3/4 of the wing chord is acceptable. So the distance from the center of the wing to the center of the stab is 8.25 inches.

Now that we have located the stab position we can calculate the stab area. In our previous discussion we reviewed the stab rules for the Embryo class to be up to 50% of the wing area. Understanding that this is a large amount of area we could reduce it to 33% and still operate the model with a normal center of gravity position between 33% to 50% of the wing chord. A 33% stab area will provide a good level of stability. So 33%of the wing area = stab area. Aw * .33 = Area Stab, where 50 square inches x .33 = 16.5 sq inches of Stabilizer.

The Rudder or Fin tail moment arm was previously discussed as well and it was decided that a length of between 40% to 50% of the wingspan was adequate for good yaw stability.

In this example we will calculate both extremes and pick one. Span x .40 = Tail Moment Arm Fin, or Span x .50 = Tail Moment Arm Fin. 16.6" x .40 = 6.64 inches up to 16.6 x .50 = 8.3 inches. So now we need to decide which to pick. As an example, on the Peck Polymers Prairie Bird a measurement of the location of the center of the fin was at 8.25 inches aft of the center of gravity. So we could pick the 50% position and do the math at Span x .50 = 8.3 and place the fin 8 5/16" after of the center of gravity, center of lift. Fin/rudder areas are typically 10% of the wing area so Wing Area x .10 = Fin Area, 50 x .10 = 5 square inches. The calculation of a Peck Prairie Bird reveals a fin area of 4.52 sq. inches so our math of 5 sq. inches holds up nicely.

In my Sharkies Machine design, the stabilizer was designed as a parabolic shape primarily to satisfy my need for some style. You can use any shape you like that gives you the area required. However, an appropriate aspect ratio of Stab Span / Stab Chord = Stab Aspect Ratio. The Prairie Bird measures an aspect ratio of 3 but my calculations in Stab Aspect Ratio worked out to close to the same. To calculate the area of a parabolic shaped Stab you must modify the calculation with a constant of 0.8. Stab area = span x average chord x 0.8, so 7" x 3" x 0.8 = 16.8 square inches. This fits very nicely with the Stab area requirements previously arrived at. The Fin/Rudder is styled any way you like but be aware of the area required and that it's measured properly. My Sharkies Machine design is actually 9.5% of the wing area and this works great.

Proportioning the model — Propellers and Details

Embryo Endurance designs are allowed propellers that are non-folding and are allowed to freewheel. Sizes range from 5.5 inches to 7 inches primarily due to airplane weight and where the model is flown. Very light 10-gram embryo models can use a 5.5" prop but are not common. The bigger outdoor flying embryo's in the 14 to 18 gram class operate with a 7" propeller and use a little more rubber for power. The Indoor Embryo in the 12-14 gram class is usually flown with a 6" Peck Polymers plastic prop. Fine performance is achieved with this size propeller. One measurement for propellers that is common is the Pitch to Diameter Ratio. The 6" plastic gray Peck Prop has a pitch to diameter ratio of 1.5. This is a good starting point for other calculations in design for many other model airplane rubber power propellers.

Typical Rubber Motors for this airplane is Tan II rubber from Peck Polymers or Sig. Sizes range in length from 14 to 20 inches and thickness between 3/32" to 1/8". Good performance is reported with these sizes, but it will be up to you to test for the right size of motor on your own as every airplane is different.

By now your model will have taken on some major features and your elements of style will play a big part in the character of your design. Bonus points can be received for windows or windscreens, wheel pants and simulated exhausts. Feel free to add these items to your hearts content, just remember that weight is important so keep these items light and as simple as you can. I like to use these features to add some personality to the airplane so wheel pants were fashioned around the required 3/4-inch wheels.

Windscreens or raised cabins are part of the bonus points and must have at least a 30 degree windshield slant, but on my designs I forego a little style and make my windshield a little smaller in angle as seen on the Sharkies Machine. It's ok to do with a little less when it comes to bonus points. Some people go without exhausts or wheel pants.

On To the Building of Embryo Endurance Models

Embryo Endurance models are easy to design and look good and fly great. Use this information to your advantage when you design new embryo endurance airplanes. Please remember that these calculations are for fairly standard configurations and that you now have permission from me to deviate from these basic rules to form your own designs from here. The presentation here will help you understand the nature of Embryo Endurance Airplanes and get you well on your way to great flying models. Please feel free to contact me , Bruce Feaver, to discuss any of the points you've read here and together we can enjoy great model designs in the Embryo Endurance Class of Airplane.