Designing & Building Indoor Propellers

by

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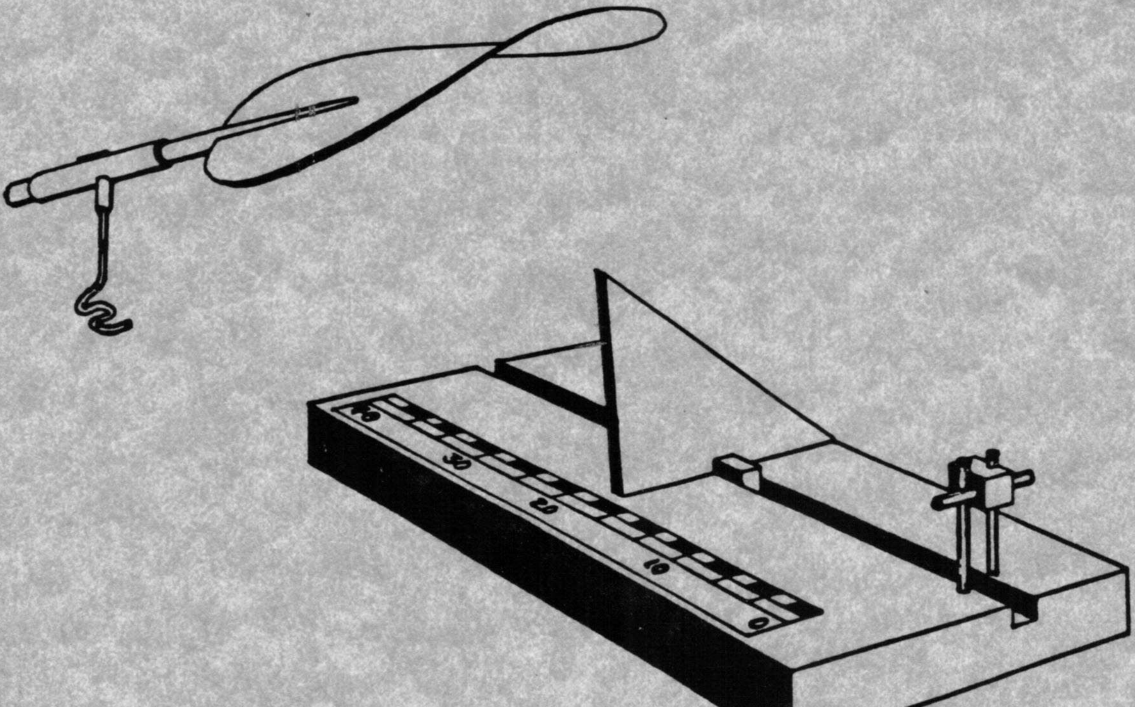
April 1991



Designing & Building Indoor Propellers

1) Introduction and Overview

Building a good indoor prop requires knowledge, skill, experience, and precision. The path to success is through rules-of-thumb, experience, and rational experimentation. A thorough study of aerodynamic principles would not likely yield major performance improvements over current practice.

This article describes the design and construction of indoor props for peanuts, no-cals, penny planes, and EZB's. The designs and construction techniques are based on the experiences and mistakes of ourselves and others.

Section 2 **Some General Rules of Thumb**, discusses some general conclusions about the design of indoor props. Section 3 **Propeller Pitch**, mathematically defines pitch and mathematically explains why helical pitch propellers are more efficient. Section 4 **Calculating Optimum Pitch Setting**, is a hypothetical exercise in computing the optimum pitch setting for a pennyplane prop. The computed optimum pitch is quite close to that commonly used in current high performance pennyplanes. Section 5, **Carved Pitch Blocks**, gives dimensions for sixteen different blocks with pitch settings from 6 to 36 inches. Section 6, **Bottle Propellers**, contains an exact mathematical analysis of pitch settings formed by warping blades on a cylinder. A computer program is given to solve the derived equations. Sections 7, 8, and 9 provide specific designs and construction techniques for building **peanut, nocal, limited pennyplane, pennyplane,** and **EZB** propellers.

We do not claim that these are THE best techniques and designs, but they do work well and have proven themselves in national competition.

A fool learns from his own mistakes while a wise man learns from the mistakes of others.

We hope that you may profit from our many foolish mistakes!

2) Some General Rules of Thumb

To maximize flight times, experience has in general proven that indoor propeller diameters should be **as large as possible.** This is probably a consequence of the following energy considerations.

A simple **energy analysis** shows that flight time will be maximized if the rubber motor is **twice** the weight of the model. In reality rubber weight is considerably **less** than this theoretical optimum. The following data are from my flights at Johnson City (108 ft. ceiling):

Model Design	Model Wt(gm)	Rubber Ln(in)	Rubber Wt(gm)	Turn	Time
Peanut-Hergt	4.9	20	2.2	1700	2:22
NoCal	6.2	24	3.1	2020	5:18
Limited Penny	3.1	22.5	2.3	2200	13:23
Penny	3.1	22	2.84	1800	15:35
EZB	0.74	14	0.75	2000	21:51

Note that in all five examples the rubber weight is considerably **less than the theoretical optimum** of twice the weight of the model (F1D models weigh about 1 gm. and may have motor weights of as much as 1.4 gms). It is, for example, impossible (for structural and other reasons) to put a 10 gm. motor in a 5 gm peanut. Therefore it is a practical fact that we will always have less than the theoretical optimum motor weight.

Given this constraint, it follows that:

To maximize flight time, the model should have the greatest possible rubber motor weight.

There are two possible ways to put a lot of rubber on a model:

1. Use a **very long** motor with a moderate cross-sectional area.

2. Use a **large cross sectional** area and moderate length.

The first approach would allow many turns and a small diameter prop. However a very long motor is problematic given the typical lengths between the prop and the rear hook.

The second approach necessitates the use of large diameter props and has, in general, been found to yield longer flight times. Also, a larger diameter prop is theoretically more efficient. Therefore:

Always use the largest possible diameter prop and the largest possible cross section area rubber motor.

The diameter of the prop is limited by the ability of the model to balance the torque reaction. Typical prop diameters and average flight RPM's are:

Model	**Wingspan (in.)**	**Max Prop Dia.(in)**	**RPM**
Peanut	**13**	**7**	**700**
NoCal	**16**	**10**	**380**
Limited Penny	**18**	**12**	**150**
Penny	**18**	**18**	**104**
EZB	**18**	**15**	**83**

A typical common fault for the begineer is that the prop vibrates and does not track properly. Two possible causes of this vibration are:

1. **The prop is not balanced.**
2. **The blades do not have the same pitch.**

We are rather particular when making a prop and to be sure it balances we sand both blades to the same weight. However indoor props are quite light and therefore the blades have limited inertia. Prop vibration is not usually caused by a prop being a bit out of balance.

The most likely cause of prop **vibration** is that the two blades have **different pitch settings**. Pitch must be set precisely using a **pitch gage**; it cannot be 'eyeballed'!

3) Propeller Pitch

Propeller pitch is **defined** as the theoretical distance that the blade will 'screw' itself forward in one revolution. Mathematically, pitch is:

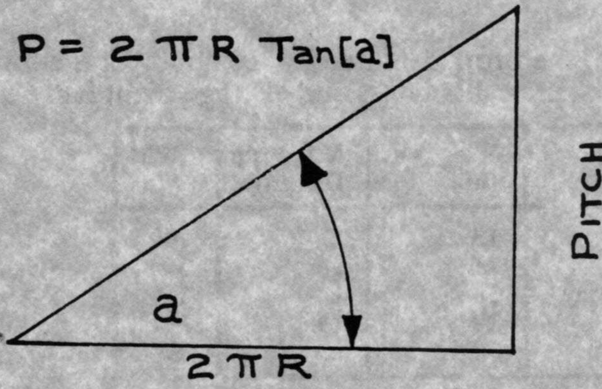
$$\text{Pitch} = 2*\text{Pi}*R*\text{Tan}(a)$$

Pitch = Forward travel per revolution (in.)

Pi = 3.14159

R = Distance from hub (in.)

a = Angle of blade section relative to rotating propeller disk (deg.)



Propeller Pitch Defined

The pitch can vary from the hub to the blade tip. For example, it is possible that a EZB prop blade might have a 30 in. pitch at the root and 26 in. pitch at the tip: The pitch at any distance from the hub depends solely on the blade angle at that point.

Indoor prop blades typically have **the same pitch from hub to tip**. A prop blade that has the same pitch from hub to tip is called a **'helical'** or constant pitch propeller.

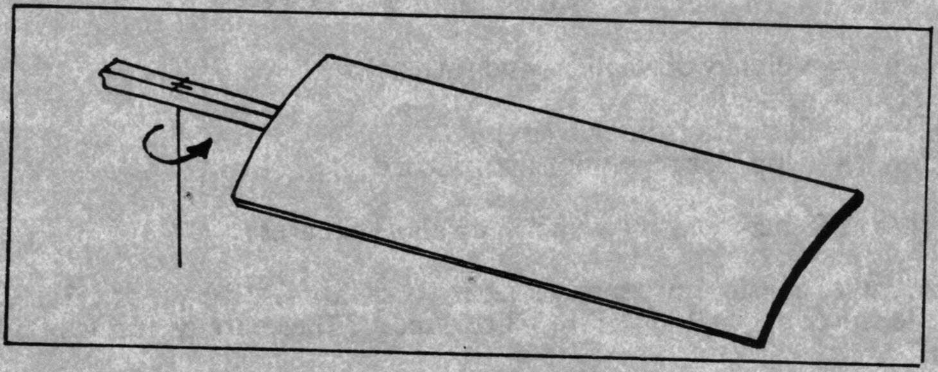
Consider, for example, a limited penny plane prop with 25 in. helical pitched blades. At any distance from the hub, the blade angle is such that in one revolution that section would theoretically screw itself forward 25 inches.

For a particular model, **what propeller pitch setting will maximize flight time?** Theoretically the optimum pitch changes throughout the flight; from climb, to cruise, to descent. Again optimum pitch cannot be determined theoretically, it is a matter of experience and experimentation. Our experience indicates the following pitch settings:

Model	Pitch (in.)	Typ Prop Dia.(in)	RPM
Peanut	10 to 15	7	700
NoCal	12 to 16	10	380
Limited Penny	20 to 28	12	150
Penny	22 to 30	17	104
EZB	22 to 32	15	83

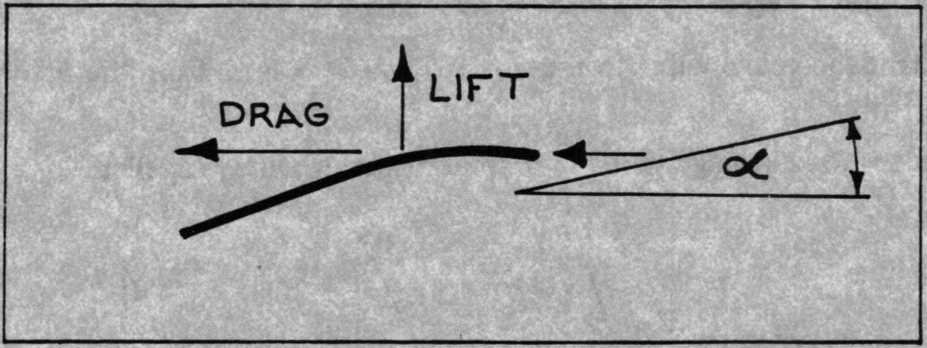
Why Not Use a Flat Pitched Prop?

A flat pitch prop has the same blade angle at every section from hub to tip and is the easiest prop to make. It is, however, quite inefficient as is described in the following paragraphs.



Flat Pitch Propeller

A propeller can be viewed as a series of joined airfoil sections that produce lift and pull the model forward. Airfoils work 'best' when orientated at a particular angle of attack to the relative wind. This angle is typically less than ten degrees:



Airfoil at Angle (a) to the Relative Wind

The direction and magnitude of relative wind changes from hub to tip on a rotating propeller. The relative wind that a rotating propeller sees is made up of two components:

1. The relative wind due to the **forward motion** of the model.
2. The relative wind due to the **rotation** of the propeller.

The first component, that due to the **forward motion** of the model, is **constant** from hub to tip.

The second component, that due to **rotation, varies** from zero at the hub to a maximum at the tip according to the following relationship:

$$V_p = 2*\mathrm{Pi}*R*W$$

Vp = Velocity of relative wind (in./sec)
Pi = 3.14159
R = Distance from hub (in.)
W = Propeller revolutions per second

Note that as R increases, the velocity Vp also increases.

For example, consider a penny plane moving through the air at 36 in./sec with the propeller revolving at 100 RPM (5/3 rev./sec.). (These are typical values for a penny plane).

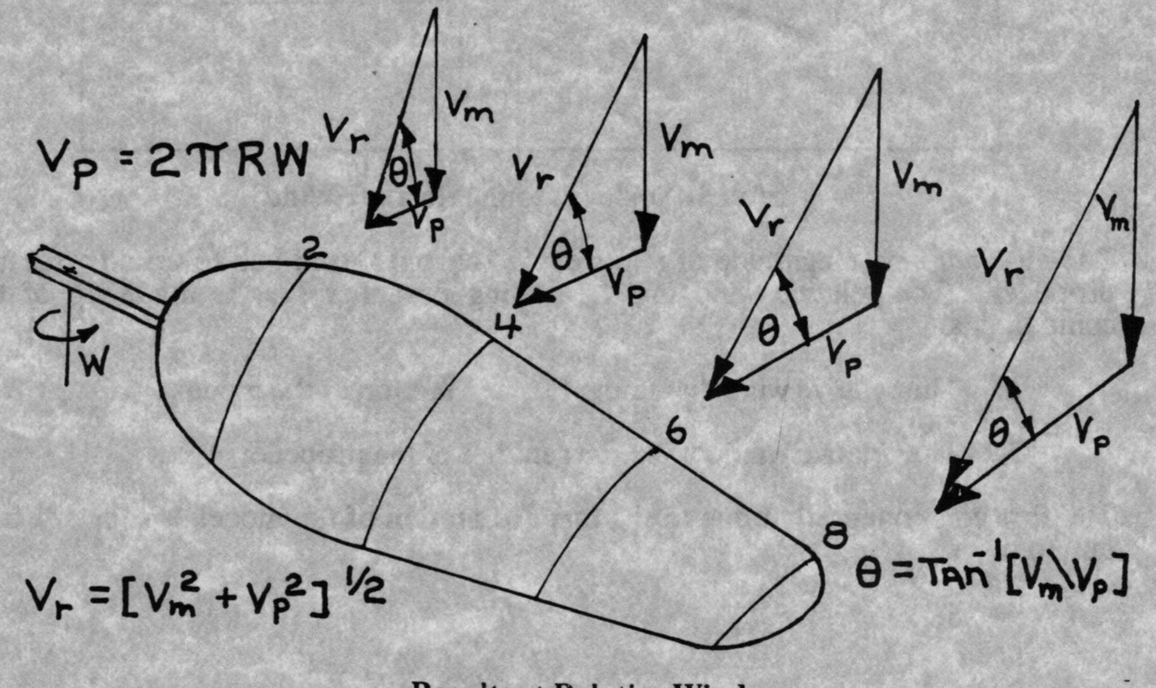
First consider the relative wind due to propeller rotation (Vp) at R equals 2, 4, 6, and 8 in. from the hub:

$$V_p = 2*\mathrm{Pi}*R*W$$

@ R = 2: Vp = 2*Pi*2*5/3 = 20.94 in./sec.
@ R = 4: Vp = 4*Pi*2*5/3 = 41.89 in./sec.
@ R = 6: Vp = 6*Pi*2*5/3 = 62.83 in./sec.
@ R = 8: Vp = 8*Pi*2*5/3 = 83.78 in./sec.

Note that the velocity due to rotation (V_p) at R = 8 in. from the hub is four times that at 2 inches.

Consider the following figure of the rotating pennyplane propeller:



Resultant Relative Wind

Vm = Relative wind due to forward motion.
Vp = Relative wind due to propeller rotation.
Vr = Resultant relative wind.

Note the direction and magnitude of the resultant relative wind (Vr) varies between the hub and the tip of the rotating propeller: The magnitude increases and the angle between the rotating propeller disk and the resultant relative wind (Vr) decreases.

The velocity of the resultant relative wind (Vr) can be calculated at each location as:

$$Vr = [Vm^2 + Vp^2]^{1/2}$$

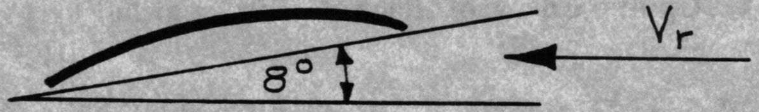
$$@\ R = 2: Vr = [36^2 + 20.94^2]^{1/2} = 41.65 \text{ in./sec.}$$
$$@\ R = 4: Vr = [36^2 + 41.89^2]^{1/2} = 55.23 \text{ in./sec.}$$
$$@\ R = 6: Vr = [36^2 + 62.83^2]^{1/2} = 72.41 \text{ in./sec.}$$
$$@\ R = 8: Vr = [36^2 + 83.78^2]^{1/2} = 91.19 \text{ in./sec.}$$

The angle Θ between the rotating propeller disk and the resultant relative wind (Vr) can be calculated as:

$$\Theta = \mathrm{Tan}^{-1}(Vm/Vp)$$

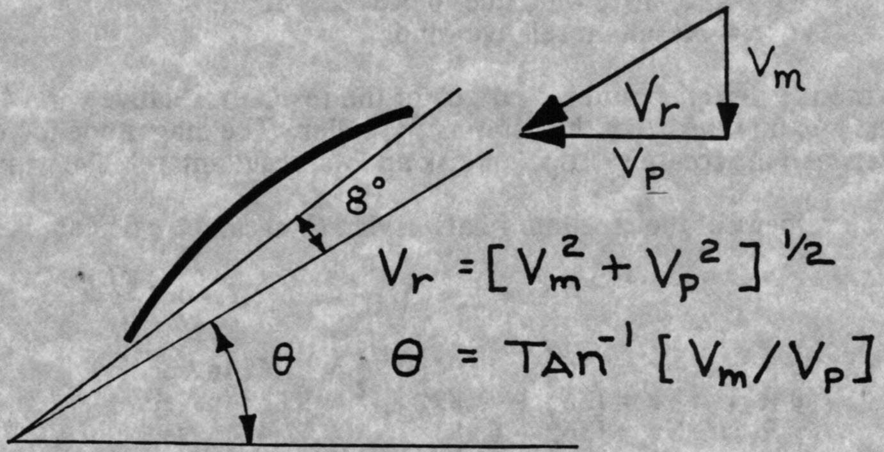
$$@\ R = 2: \Theta = \mathrm{Tan}^{-1}(36/20.94) = 59.81^{o}$$
$$@\ R = 4: \Theta = \mathrm{Tan}^{-1}(36/41.89) = 40.68^{o}$$
$$@\ R = 6: \Theta = \mathrm{Tan}^{-1}(36/62.83) = 29.81^{o}$$
$$@\ R = 8: \Theta = \mathrm{Tan}^{-1}(36/83.78) = 23.25^{o}$$

Each cross section of the blade can be viewed as a separate airfoil. Recall that an airfoil 'works best' at a particular angle of attack to the relative wind. For this penny plane example, assume that this angle of attack is 8 degrees:



Propeller Blade Section at Optimum Angle of Attack

For our penny plane propeller, the angle (Θ) of the resultant relative wind (Vr) varies from hub to tip. Therefore for optimum airfoil performance, the blade angle at any section should be set at (**8 +** Θ) degrees relative to the rotating propeller disk:



Optimum Angle for Propeller Blade Sections

Since θ varies from hub to tip, it follows that the blade angle relative to the rotating propeller disk must vary from 90 degrees at the hub to some lesser angle at the tip in order to get the 'best' propeller performance.

For a flat pitch propeller (constant blade angle from hub to tip), angles of attack at tip sections will be at too steep and the airfoil sections will be stalled. Angles of attack near the hub will be at too shallow and the airfoil sections may actually be producing negative lift (thrust). And this explains why a flat blade propeller is inferior to one having a helical pitch.

4) Calculating Optimum Pitch Setting

To calculate the 'optimum' propeller pitch settings, we need to know the following:

1. **Velocity of the model (Vm).**
2. **Propeller revolutions per second.**
3. **Optimum angle of attack of propeller airfoil section.**

In fact, we don't know what these values are and furthermore, they vary throughout the flight!

However, we can use our penny plane example to calculate some 'ball park' optimum pitch settings. From this example we have the following values:

Vm = 36 in./sec. (Velocity of the model).

RPS = 5/3 rev/sec (Propeller revolution per second).

a = 8 degrees (Optimum angle of attack).

R	Vr	Θ	$\Theta + a$
2	41.65	59.81	67.81
4	55.23	40.68	48.68
6	72.41	29.81	37.81
8	91.19	23.25	31.25

R = Distance from hub (in.).

Vr = Velocity of resultant relative wind (in./sec).

Θ = Angle of resultant relative wind (deg.).

$\Theta+a$ = Angle of blade airfoil relative to rotating propeller disk.

Recall that propeller pitch is the theoretical distance that the blade will 'screw' itself forward in one revolution:

$$\text{Pitch} = 2*\text{Pi}*R*\text{Tan}(\Theta+a)$$

Pitch = Forward travel per revolution (in.)

Pi = 3.14159

R = Distance from hub (in.)

$\Theta+a$ = Angle of blade section relative to rotating propeller disk (deg.)

For the penny plane propeller, the optimum pitch settings are:

R	Vr	Θ	$\Theta + a$	Pitch
2	41.65	59.81	67.81	30.81
3	47.78	48.89	56.89	28.90
4	55.23	40.68	48.68	28.59
5	63.54	34.51	42.51	28.80
6	72.41	29.81	37.81	29.25
7	81.67	26.16	34.16	29.84
8	91.19	23.25	31.25	30.50

Note that the theoretical optimum pitch varies from hub to tip. This is a mathematical consequence of adding the 8 degrees (a) to value of Θ.

These optimum pitch settings are based on the assumed values for the model forward velocity (36 in./sec), propeller revolutions per second (5/3 rev/sec), and optimum angle of attack of the propeller airfoil section. Changing any of these values will change the optimum pitch settings.

In fact, my best penny plane propeller has a 29 in. helical pitch. At the 1990 USIC in Johnson City this model placed first in penny plane and holds the current site record at 15:35. This would seem to verify the above computations.

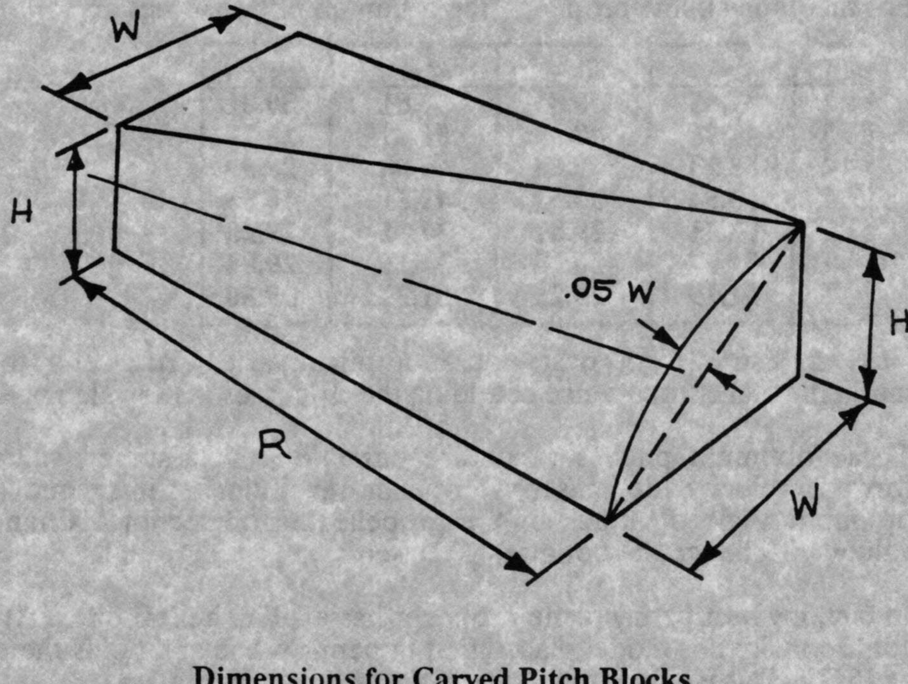
The experiences of indoor modelers have determined the approximate optimum pitch settings for the various categories of indoor models and it is usually not necessary to go through such theoretical computations. In general, we warp propeller blades to a particular pitch (as described in following sections) and position the blades onto the hub using our pitch gage. Flight testing is then used to experimentally 'tweak' these settings to maximize flight times.

For indoor models the ratios of pitch to diameter (P/D) are typically between 1 and 2. Peanut scale models have P/D ratios between 1 and 1.5. For example, a 6 in. diameter peanut scale propeller with P/D of 1.5 would have a pitch setting of 9 inches. EZB's have P/D ratios between 1.75 and 2. An EZB with a 14 in. diameter propeller with P/D of 2.0 would have a pitch setting of 28 inches. A general rule is:

The lighter the wing loading the higher the pitch to diameter ratio.

5) Carved Pitch Blocks

Carved pitch blocks are what we 'purists' use to warp propeller blades to a particular pitch setting. A separate block must be carved for each different pitch. Over the years, I have carved about a dozen different blocks.



Dimensions for Carved Pitch Blocks

The following table gives dimensions for a good range of pitch settings carved out of wood blocks of varying sizes:

Pitch	6	8	10	12	14	16	18	20
Radius	2.55	3.40	4.24	4.37	5.09	5.82	6.45	7.16
Width	2.00	2.00	2.00	2.00	2.00	2.00	2.25	2.25
Height	0.75	0.75	0.75	0.88	0.88	0.88	1.00	1.00

Pitch	22	24	26	28	30	32	34	36
Radius	7.88	7.05	7.64	8.23	8.19	8.73	9.28	10.03
Width	2.25	3.00	3.00	3.00	3.00	3.00	3.00	3.50
Height	1.00	1.62	1.62	1.62	1.75	1.75	1.75	2.00

On a correctly carved pitch block, a straight line can be projected on the helical surface from the midpoint at the hub to the midpoint at the tip. During carving, check for straightness by laying a straight edge on the helical surface between these two midpoints. A **circular airfoil** is carved onto the helical surface to give the propeller blades about 5 percent underchamber.

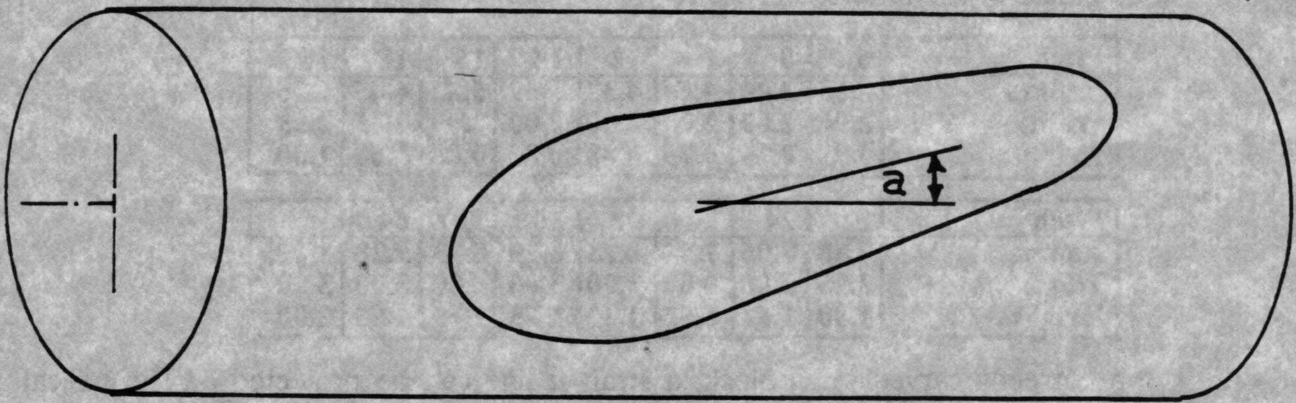
Finished propeller blades are soaked in hot water for 20 minutes and then wrapped onto the helical surface of the pitch block using a 2 in. wide 'Ace' elastic bandage. The blade must be carefully positioned along the centerline of the helical surface. Cook this assembly in a 220 deg. F oven for 30 minutes. Water soaking the blades makes them amenable to being warped to the helical surface. Cooking the blades permanently warps them to the pitch setting.

Note: Some people soak both blades and stack them together on the pitch block. This saves times and is more likely to produce two blades with exactly the same pitch. However, sometimes the two blades will adhere to each other during the cooking process. We do not recommend this procedure.

Note: If I want to make a propeller with a 26 in. pitch and my closest pitch block is 24 in., I warp the blades on the 24 in. pitch block and then glue the blades to the propeller spar at 26 in. pitch using the pitch gage.

6) Bottle Propellers

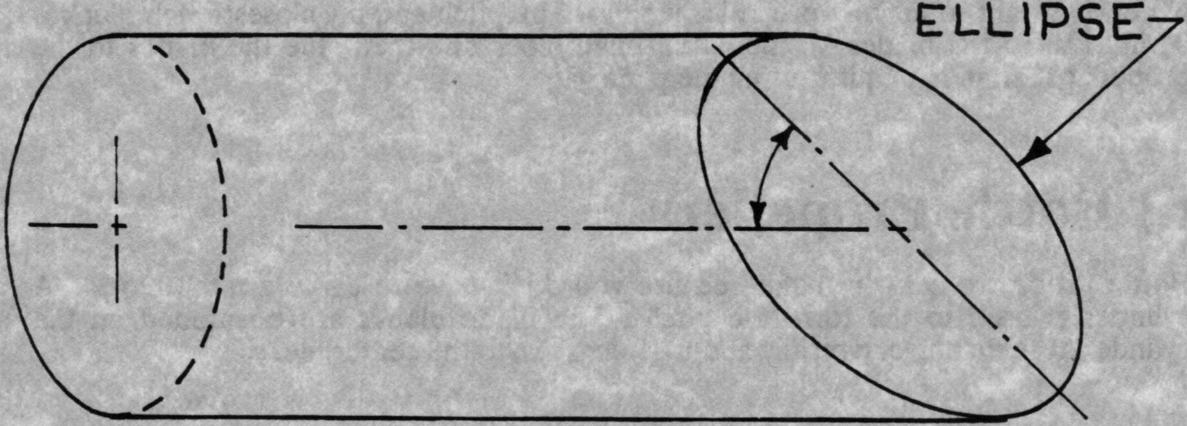
Bottle props are easy to make because you don't have to carve a pitch block. A cylinder is used to the form the pitch. The blade blanks are positioned on the cylinder at some angle, typically about 15 degrees, to the centerline.



Forming Bottle Props on a Cylinder

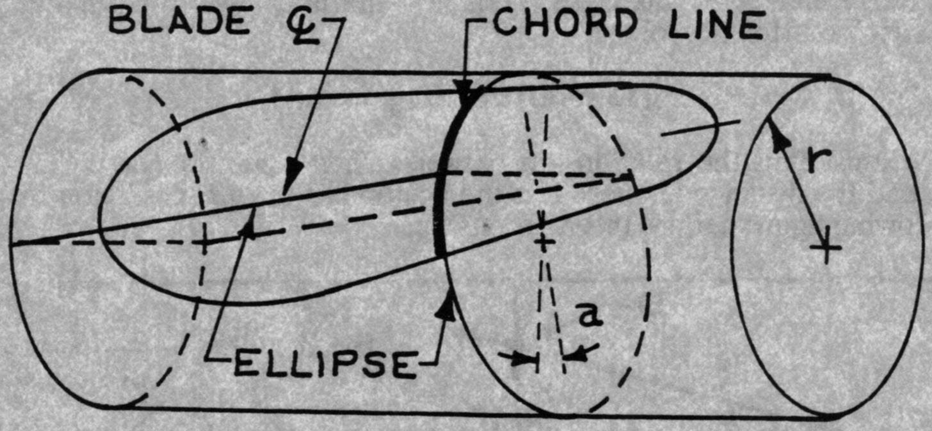
Max Chernoff ("1964-65 Model Aeronautic Year Book", F. Zaic) and Ron Williams ("Building and Flying Indoor Models") have presented tables for cylinder diameters and blade angles based on the angle at the blade tip. These are actually approximate solutions. The following is, I believe, and exact solution for the geometry of bottle props.

The mathematics of bottle props are a bit complex. Consider a plane intersecting a cylinder at some angle to the centerline of the cylinder. If this angle is 90 degrees to the centerline then the intersection will circumscribe a circle. If the angle is greater or less than 90 degrees, the intersection will circumscribe an ellipse:



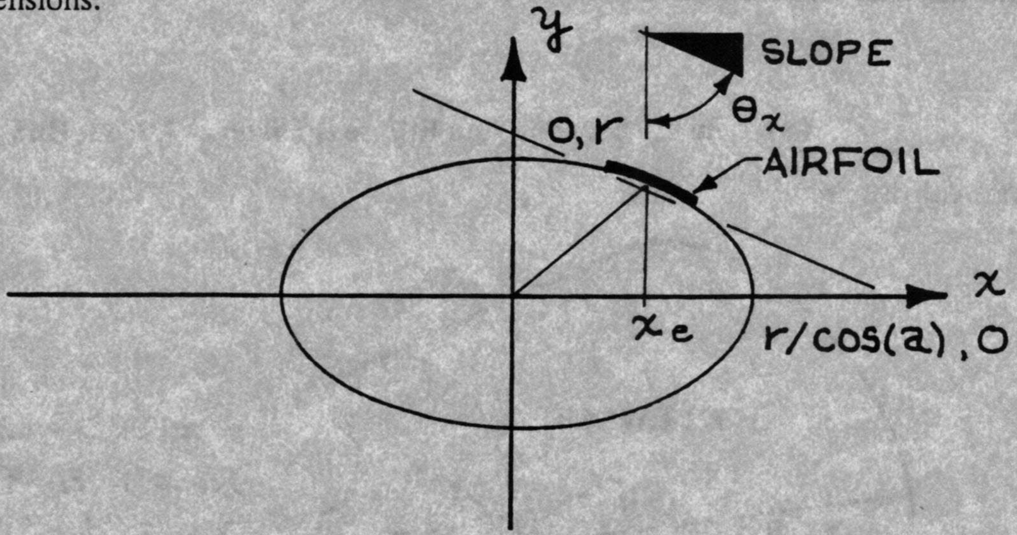
Plane Intersection of a Cylinder

For a bottle prop we must consider two such intersection: First that circumscribed by the centerline of the prop blade and secondly that circumscribed by the blade airfoil section. The two elliptical surfaces are perpendicular to each other:



Blade Centerline and Airfoil Section

The airfoil section lies on the perimeter of an ellipse formed from the plane intersection of the cylinder at some angle 90 + (a) deg. and will have the following dimensions:



Ellipse and Airfoil Section

For the given X-Y coordinate system, the equation for this ellipse is:

$$X_e^2 * \mathrm{Cos}^2(a) + Y^2 = r^2 \tag{1}$$

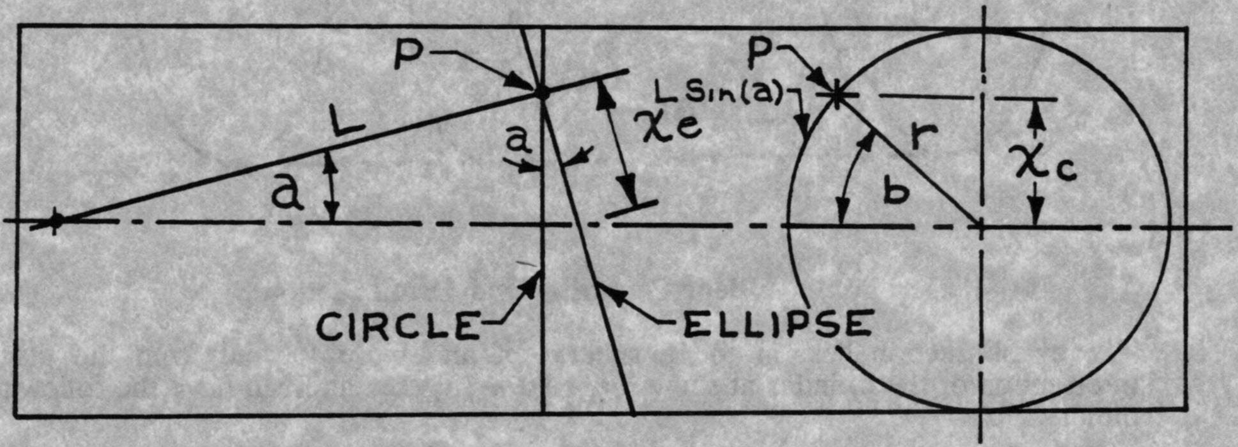
After solving equation (1) for Y, the **slope** at any point X_e on the perimeter of the ellipse is equal to:

$$dy/dx = -[X_e*Cos^2(a)] / [r^2 - X_e^2*Cos^2(a)]^{1/2} \qquad (2)$$

The negative inverse of this slope is equal to the **tangent of the pitch angle** (Θ_x) at that particular airfoil section:

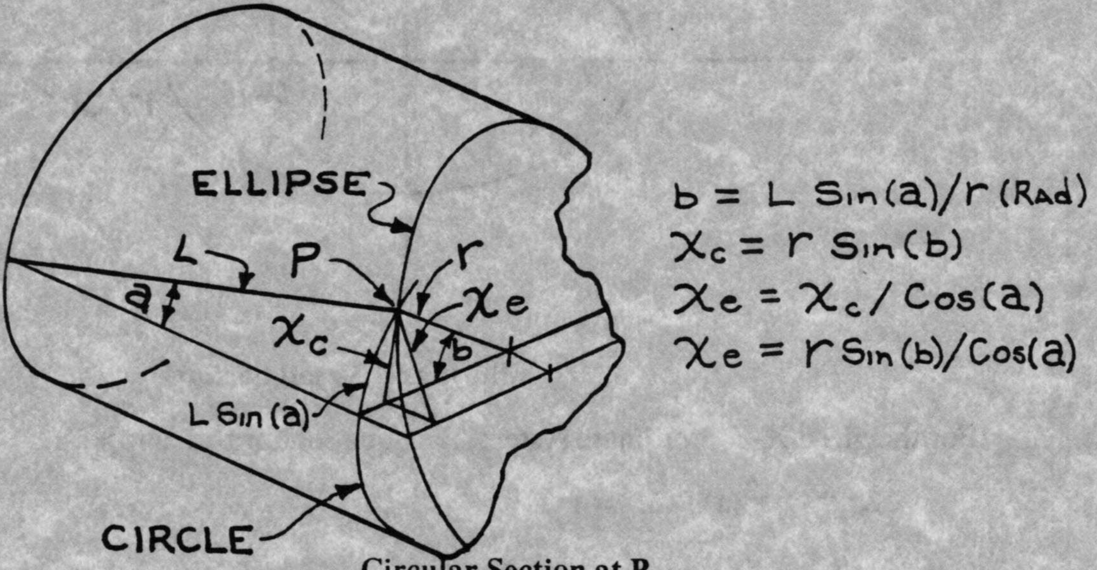
$$Tan(\Theta_x) = \{r^2 - X_e^2*Cos^2(a)\}^{1/2} / \{X_e*Cos^2(a)\} \qquad (3)$$

Next we must find the relationship between X, the position of the airfoil on the ellipse, and the distance L where L is the position of the airfoil section from the hub. The following figure defines this relationship:



Relationship between X_e on Ellipse & Distance L from Hub

Consider the circular section at point P:



Circular Section at P

The angle (b) expressed in radians and the distance (X_c) are equal to:

$$b = L*\mathrm{Sin}(a) / r \ (\mathrm{rad}) \tag{4}$$

$$Xc = r * \mathrm{Sin}(b) \tag{5}$$

The distance X_e on the ellipse can now be expressed in terms of the two angles (a) and (b) as follows:

$$X_e = X_c / \mathrm{Cos}(a) \tag{6}$$

Therefore:

$$X_e = r*\mathrm{Sin}(b) / \mathrm{Cos}(a) \tag{7}$$

Putting equation (7) into (3) yields the relationship between the two angles (a) and (b) and the pitch angle (Θ_L) at distance (L) from the hub:

$$\mathrm{Tan}(\Theta_L) = 1 / [\mathrm{Cos}(a)*\mathrm{Tan}(b)] \tag{8}$$

Θ_L = Pitch angle at distance L from hub.
a = Angle of blade centerline relative to centerline of cylinder.
Pi = 3.14159
r = Cylinder radius.

These equations can be used as follows:

1. Specify the cylinder radius (r), propeller radius (L), and angle between the centerline of the cylinder and the centerline of the prop blade (a).
2. Calculate the angle (b) using equation (4).
3. Calculate the tangent of the pitch angle at (L) using equation (8).

The following BASIC program can be used to solve the above equations:

```
'******************************************************************************'
' MicroSoft QuickBasic program for computing bottle prop pitch settings.
'                        by Lester W. Garber PhD

' Inputs:  1.  Angle (deg.) between centerline of cylinder and centerline
'              of prop blade.
'          2.  Cylinder radius (in.).
'          3.  Prop radius (in.).'
'
' Outputs: 1.  Pitch angles at 1/2 in. increments along prop centerline.
'          2.  Pitch in inches at 1/2 in. increments along prop centerline.
' *****************************************************************************'

Pi# = 3.141592654#

INPUT "Angle between cyl. centerline & blade centerline (deg.): "; AlphaDeg#

Alpha# = Pi# * AlphaDeg# / 180       '  Angle of Prop CL to Cylinder CL (Rad)

INPUT "Cylinder Radius (in,): "; r#                          ' Cylinder Radius
INPUT "Prop Radius (in.): "; PropR#                         ' Propellor Radius

FOR L# = .5 TO PropR# STEP .5
   Beta# = L# * SIN(Alpha#) / r#                    ' Cylinder Angle (Radians)
   Pitch# = ATN(1 / (COS(Alpha#) * TAN(Beta#)))       ' Pitch Angle (Radians)
   PRINT USING " Radius: ###.##"; L#;
   PRINT USING " Pitch deg: ###.##"; Pitch# * 180 / Pi#;     ' Pitch (Degrees)
   PRINT USING " Pitch in.: ###.##"; 2 * Pi# * L# * TAN(Pitch#) ' Pitch (in.)
NEXT
END
```

BASIC Program for Bottle Prop Pitch Settings

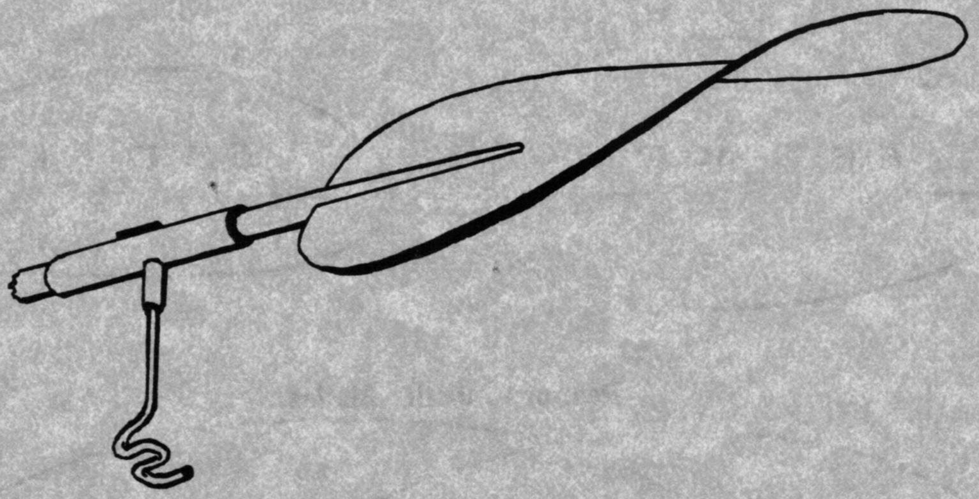
Prop blades formed on cylinders have two basic faults: First the centerline of the blade is not a straight line, rather it is a helical curve similar to a screw thread. Secondly the pitch (in inches) varies from hub to tip. Using the above equations, for example, a 6 in. radius blade formed on a 6 in. diameter cylinder at 16 deg. will have a pitch of 59.22 in. at the hub to 50.37 in. at the tip.

The following table gives data on existing practice for the construction of bottle props:

Prop Radius	**3.5**	**6**	**6**	**6**	**6.5**	**7**
Cyl. Dia.	**2.88**	**5**	**5**	**6**	**6**	**5**
Angle (deg)	**26**	**16**	**12**	**15**	**15**	**16**

Although bottle props do not form true helical pitch and the blade centerline is curved, they have in fact proven themselves in competition. In practice the blades are warped using parameters from the above table and then gluing the blades to the prop spar using a pitch gage to set both blades at the desired pitch setting.

7) Peanut and No-Cal Propellers



Typical Peanut/No-Cal Propeller

Our peanut and no-cal propellers are similar in design details and are built with plug in blades so that the pitch settings on each blade can be adjusted.

Prop shafts are bent from 0.020 music wire with a reverse 'S' hook to hold the rubber. The length of the shaft should just be long enough to accommodate the front bend, hub, washers, and thrust bearing\noseblock. The rubber hook, when viewed from the rear looks like a reversed 'S'. This causes the rubber motor to center itself in the middle of the reverse 'S' and thus minimize the likelihood that the motor will work itself off the hook.

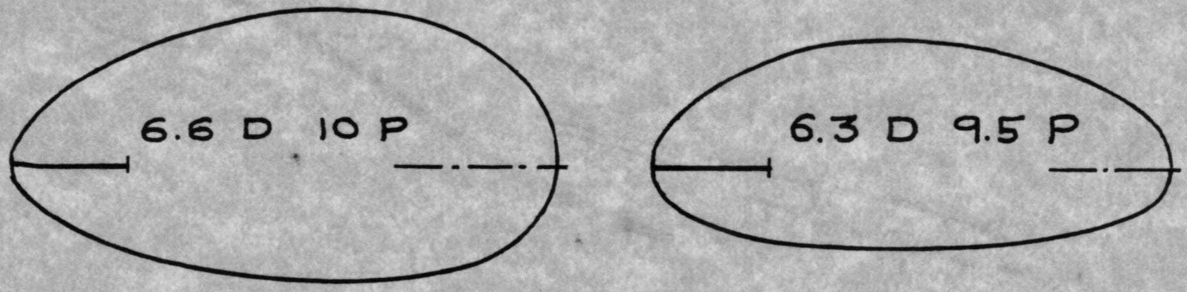
For **washers,** we use a short piece of Teflon tubing (0.10" L, .020" ID, 0.040" OD) and sometimes back this tube up with small Teflon washers (.090 OD) purchased from Indoor Model Supply.

The **prop hub** is a plastic tube (0.60" L, 0.070" ID, 0.120" OD) cut from the ink tube of a 'Pilot BPS' fine ball point pen. These ink tubes are cleaned by pulling pipe cleaners through them that are dipped in acetone. A short piece of bamboo (0.10" L, 0.070" D) is centered in the hub and a drill press is used to drill a perpendicular 0.020" hole for the prop shaft.

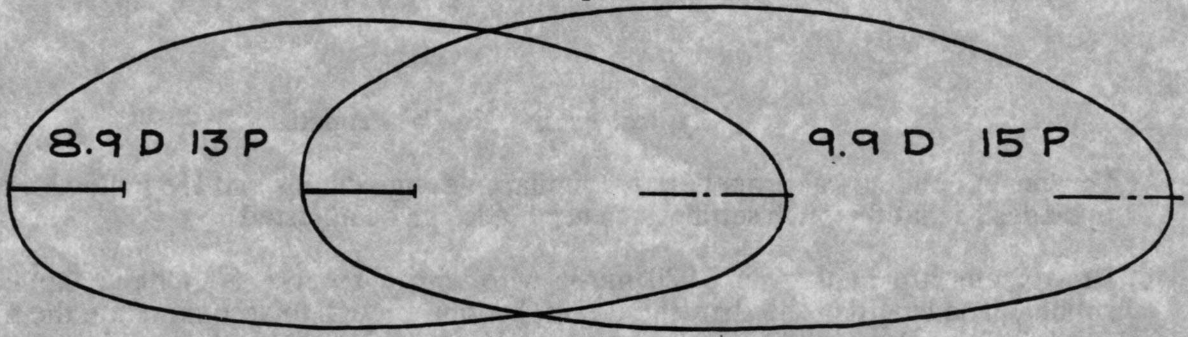
To **assemble** the hub and shaft, the shaft (with washers in place) is pushed into the 0.020 hole in the hub and a 90 degree bend is made 0.125 in. from the front end. Check that the hub and shaft are perpendicular and glue with a tiny bit of CA. On the front of the prop, build up a bit of baking soda around the shaft and hub and hit it with some more CA. This will eliminate any possibility of the shaft breaking free from the hub.

The **prop spars** are from bamboo skewers and are typically 1.0 in. long and are press fit (not glued) into the hub. The fit between the hub and spars is critical: The spars should be snug in the hub so that blade pitch will not be changed if the model bumps into the ceiling, but not so tight as to prevent intentional pitch changes. To accurately size the prop spars, we use a jewelers draw plate purchased from Micro Mart Tool Co.

Some typical blade shapes for peanut and nocal props are:



Peanut Propeller Blades



NoCal Propeller Blades

The **prop blades** are cut from 5 to 6 lb/ft^3 quarter grain balsa sheet 0.050" thick and sanded to weight and dimensions. The blade blanks are tapered to about 0.018" at the tips. Sand a thin airfoil section with the trailing edge about 0.018" thick. The finished weights of the sanded blades should be identical.

Assemble the blades and prop spars by carefully cutting a slot (0.60" L, 0.070" W) for the prop spar and gluing the spars to the blades with CA (alignment is critical).

Next, soak the blades in hot water for 30 minutes and heat form them to the desired pitch setting as described in the previous two sections.

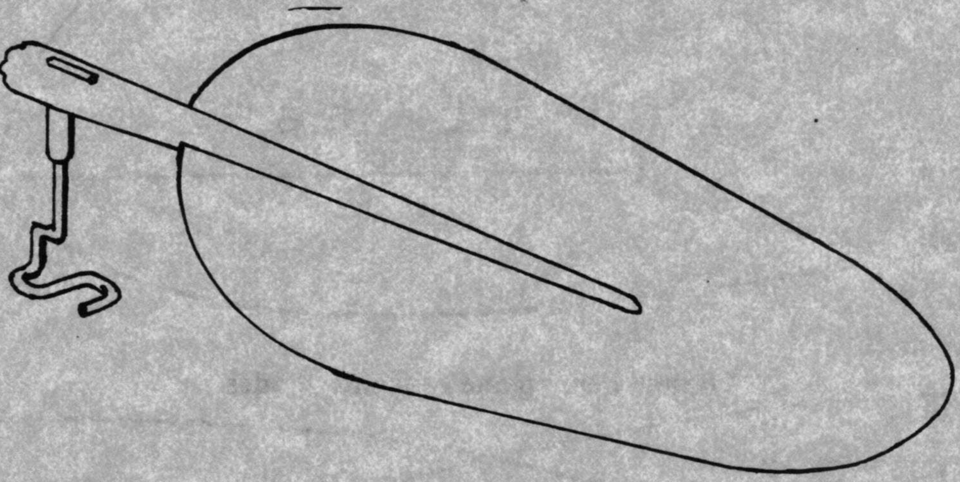
Felt tip pens (elMarko permanent) are used to color the blades. Allow the ink to dry and then sand lightly. If you can afford the weight, Tamiya acrylic water based paints give a very nice finish. Again, check that the finished blade weights are identical. If necessary, add a bit more finish to the light blade.

Finally, assemble the blades to the hub using a pitch gage to set both blades to the same pitch setting. A rule of thumb is to initially set the pitch at 1.5 times the diameter. For example, an 8 in. diameter prop would have a pitch setting of 12 inches.

The following table provides typical values for peanut and nocal props:

	Peanut	NoCal
Diameter (in.)	6.0 to 7.5	9.0 to 12.0
Pitch (in.)	9 to 15	15 to 20
Weight (gm)	0.5 to 1.0	0.6 to 1.2

8) Pennyplane Propellers



Typical Pennyplane Propeller

Our limited pennyplane and pennyplane propellers are similar in design details and are built with sheet balsa blades and a balsa prop spar. Pennyplane propellers require a greater degree of craftsmanship than do limited pennyplane propellers. Both should have about the same final weight but pennyplane propellers are significantly larger.

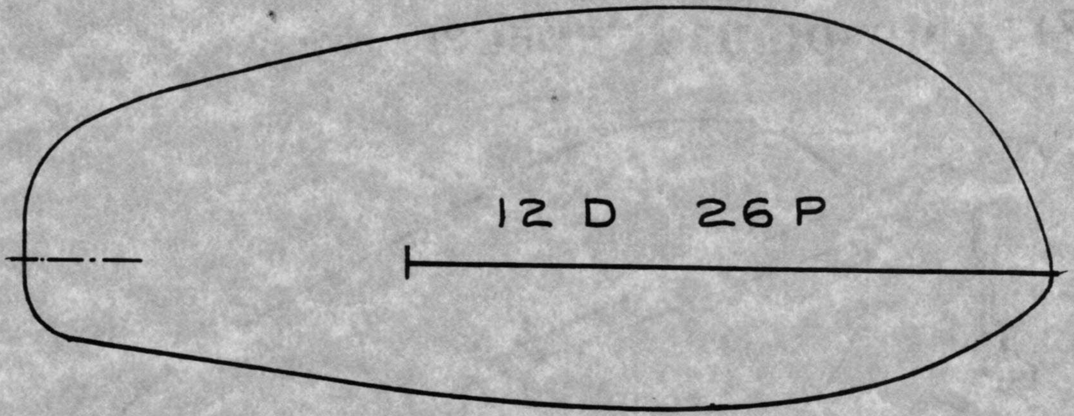
Prop shafts are bent from 0.015 music wire with a reverse ‘S’ hook to hold the rubber. The length of the shaft should just be long enough to accommodate the front bend, prop shaft, washers, and thrust bearing. The rubber hook, when viewed from the rear looks like a reversed ‘S’. This causes the rubber motor to center itself in the middle of the reverse ‘S’ and thus minimize the likelihood that the motor will work itself off the hook.

For **washers**, we use a short piece of Teflon tubing (0.05" L, .020" ID, 0.040" OD) and sometimes back this tube up with small Teflon washers (.090 OD) purchased from Indoor Model Supply.

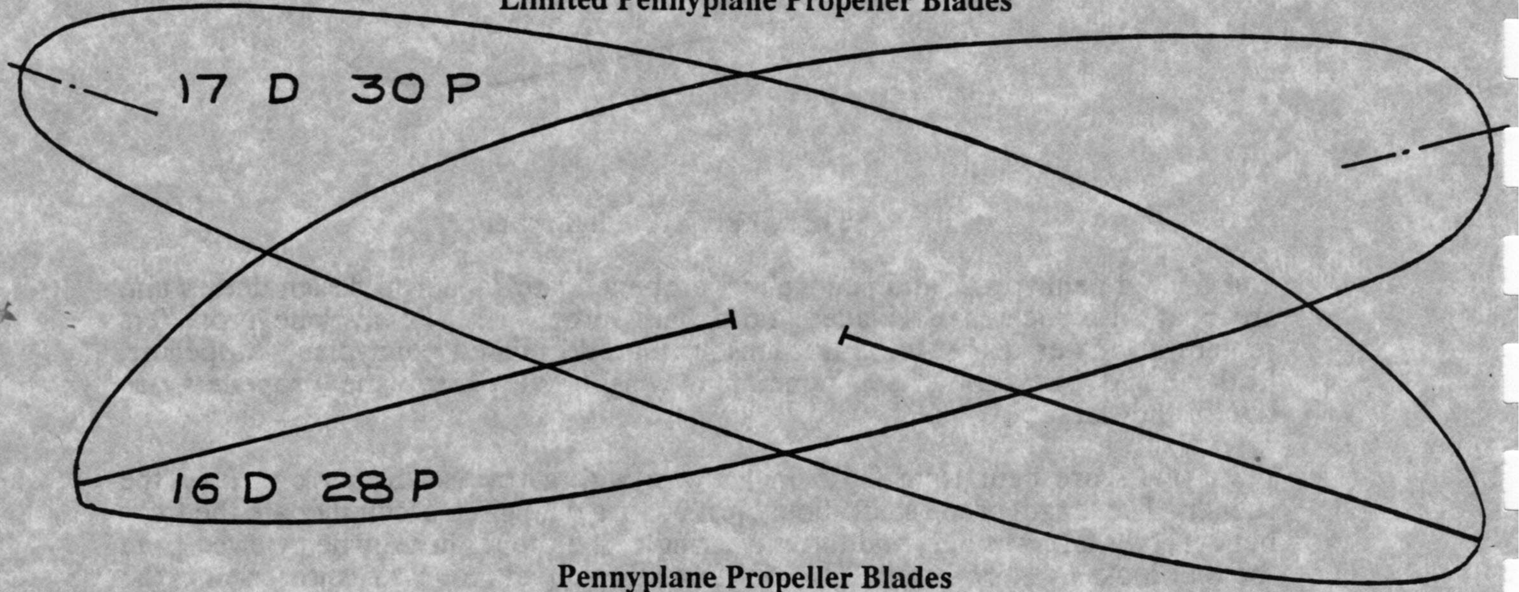
Prop spars are cut from 1/8" balsa with a density of 8 lb/ft^3 balsa. The spars are 8 in. long, 0.125" D. at the center, and tapered to 0.075 D. at the tips. a drill press is used to drill a perpendicular 0.015" hole for the prop shaft.

To **assemble** the prop spar and shaft, the shaft (with washers in place) is pushed into the 0.015 hole in the spar and a 90 degree bend is made 0.125 in. from the front end. Check that the spar and shaft are perpendicular and glue with a tiny bit of CA. On the front of the prop, build up a bit of baking soda around the shaft and spar and hit it with some more CA. This will eliminate any possibility of the shaft breaking free from the spar. The assembled prop spar, shaft and washers should weigh about 0.28 grams.

Some typical blade shapes for limited pennyplane and pennyplane props are:



Limited Pennyplane Propeller Blades



Pennyplane Propeller Blades

The **prop blades** are cut from 5 lb/ft^3 quarter grain balsa sheet 0.035" thick and sanded to weight and dimensions. The blade blanks are tapered to about 0.012" at the tips. Sand a thin airfoil section with the trailing edge about 0.012" thick. The finished weights of the sanded blades should be identical. Typical blade weights should be about 0.28 grams. Using a waterproof pen, draw a line on top of each blade to locate the prop spar on each blade.

Next, soak the blades in hot water for 30 minutes and heat form them to the desired pitch setting as described in the previous sections.

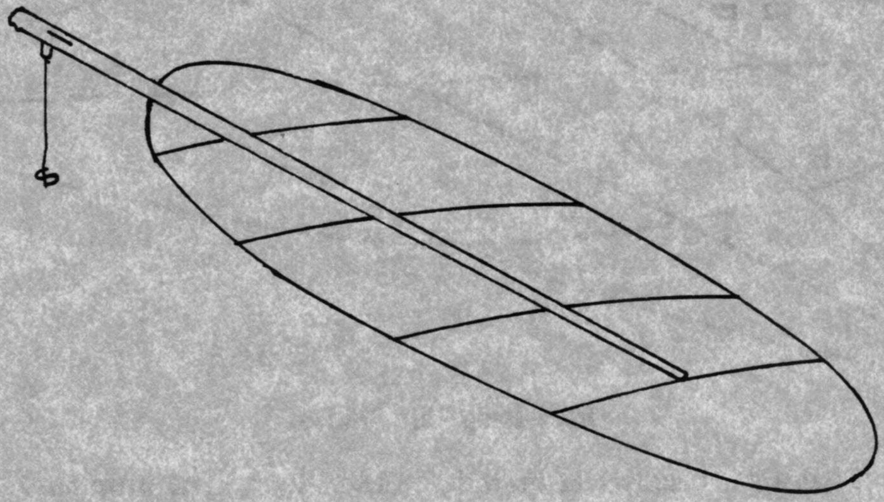
Finally, assemble the blades to the spar. Some people cut a slot in each blade for the shaft while others glue the spar to the bottom surface of the blades. Out of shear laziness, we prefer to glue the spar to the top surface of the blades. Using a syringe (0.010 D needle) and Duco cement thinned with three parts acetone, apply a thin coat of cement to the contact areas on the blades and spar.

Use a pitch gage to position the blade on the spar at the correct pitch setting. Glue the spar to the blade using a small brush dipped in acetone to soften the preglued contact areas. A rule of thumb is to initially set the pitch at 1.75 times the diameter. For example, an 12 in. diameter prop would have a pitch setting of 21 inches.

The following table provides typical values for limited pennyplane and pennyplane propellers:

	Limited Penny	**Pennyplane**
Diameter (in.)	**12.0**	**16 to 18**
Pitch (in.)	**20 to 28**	**22 to 32**
Weight (gm)	**0.7 to 1.1**	**0.7 to 0.9**

9) EZB Propellers



Typical EZB Propeller

To build really good EZB propellers requires the greatest level of craftsmanship, the best possible materials, and a lot of luck. Current practice dictates the use of large diameter propellers with wide blades. A typical EZB prop is 14 in. diameter, 28 in.

pitch, weighs 0.150 gms, and will rotate at about 85 RPM when averaged over a 21 minute flight.

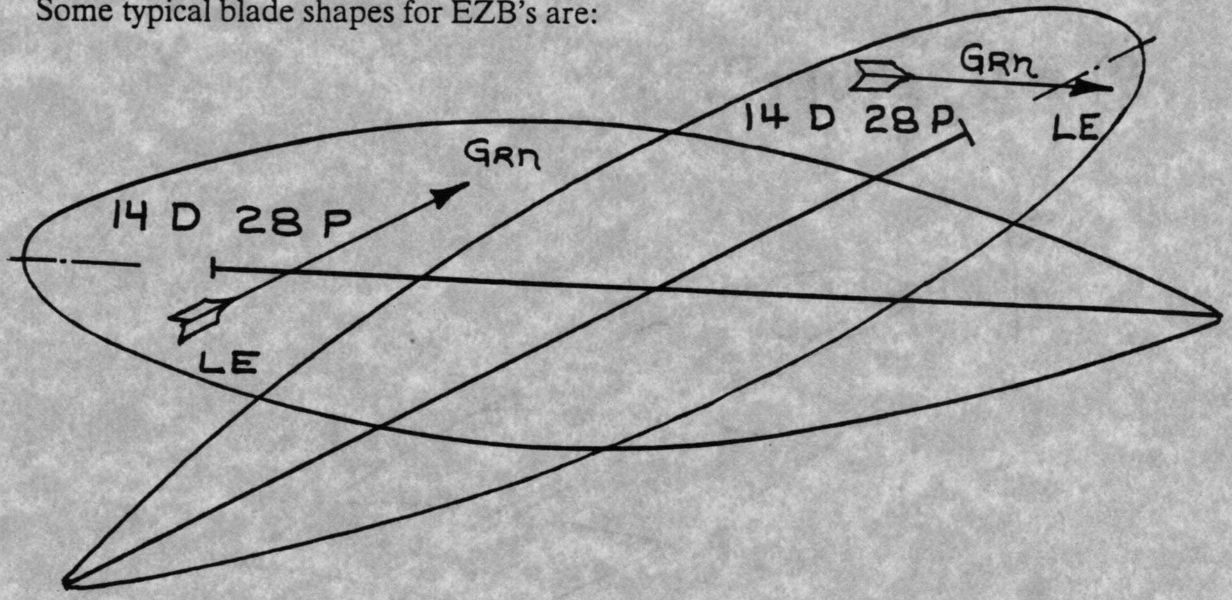
Prop shafts are bent from 0.011 music wire with a reverse 'S' hook to hold the rubber. The length of the shaft should just be long enough to accommodate the front bend, prop shaft, washers, and thrust bearing. The rubber hook, when viewed from the rear looks like a reversed 'S'. This causes the rubber motor to center itself in the middle of the reverse 'S' and thus minimize the likelihood that the motor will work itself off the hook.

For **washers**, we use a short piece of Teflon tubing (0.03" L, .012" ID, 0.030" OD).

Our **Prop spars** are typically 12 in. long for a 14 in. diameter propeller. The spar is spliced together from three pieces of 0.055 square balsa. The center section is 3 in. long and 5 lb/ft^3 balsa. The tips are 4.5 in. long and 3 to 3.5 lb/ft^3 balsa. The spar is tapered from 0.052 in.^{2} at the center to 0.028 in.^{2} at the tips. A drill press is used to drill a perpendicular 0.010" hole for the prop shaft.

To **assemble** the prop spar and shaft, the shaft (with washers in place) is pushed into the 0.010 hole in the spar and a 90 degree bend is made 0.100 in. from the front end. Check that the spar and shaft are perpendicular and glue with a tiny bit of CA. The assembled prop spar, shaft and washers should weigh less than 0.045 grams.

Some typical blade shapes for EZB's are:



EZB Propeller Blades

Indoor sheet balsa is typically 1.12 in. wide by 18 in. long. The **prop blades** are built up from the very best 3 to 3.5 lb/ft^3 quarter grain balsa sheet 0.010" thick. Using a micrometer, 400 grit sandpaper, and a sheet of glass, carefully sand the 0.010 sheets to a thickness of 0.005 to 0.006 inch. Hold the sheet at one end, apply very light sanding pressure, and always keep the wood in tension while sanding. If you sand back and forth the sheet will buckle on the return stroke. Use a micrometer to check for uniform thickness after every five or six strokes. Typically you will have to sand two sheets to get enough wood for two prop blades.

Design & Building Indoor Propellers

Note that the grain on the prop blades is at a 30 degree angle to the spar. This increases the chordwise stiffness of the blade. Sections of the sanded sheets are cut to length and the top edges are preglued (Use a small brush and Duco cement thinned with 4 parts acetone). Assemble the adjoining sheets on a sheet of glass overlapping the segments with 0.060 in. lap joints. With a small brush and acetone, soften the cement to adhere adjoining segments. The lap joints double thickness and greatly increases the chordwise stiffness. Another advantage of lap joints is they are easy to make and don't warp the blank as butt joints do. Using a cardboard template, cut the blades to their finished shape. The weight of each blade should be less than 0.045 grams.

Next, soak the blades in hot water for 10 minutes and heat form them to the desired pitch setting as described in previous sections.

Finally, assemble the blades to the spar. We glue the spar to the top surface of the blades. Using a syringe (0.010 D needle) and Duco cement thinned with three parts acetone, apply small drops of cement every 0.50 in. along the line of contact between the blades and spar.

Use a pitch gage to position the blade on the spar at the correct pitch setting. Glue the spar to the blade using a small brush dipped in acetone to soften the preglued contact areas. A rule of thumb is to initially set the pitch at 2 times the diameter. For example, an 14 in. diameter prop would have a pitch setting of 28 inches.