<u>Indoor Duration propellers. (Feb 2017) – Tony Hebb.</u>

This article sets out to update the one that Bob Bailey did so well for the Free Flight Symposium back in 2002, many aspects remain unchanged but there have been a few movements especially in relation to F1D propellers.

I've sought to add value either from my own experience or add/reference articles from other leading flyers. Likewise I am not seeking to cover every possible way of doing things, rather provide one useable way which, as you gain experience, you will modify to suit your own building style

The areas covered are:-

1. Basic Propeller theory - as it applies to Indoor Duration models
2. Propeller design considerations.
3. Forming propeller blades.
4. Making blades from balsa sheet eg. F1L, LPP, LRS.
5. Making built up blades - Including Boron/balsa ones.
6. Covering built up blades.
7. Pitch Gauges.
8. Setting up a Fixed Pitch (FP) prop.
9. Setting up a Variable Pitch (VP) prop.

Appendix 1.   World Leading propeller Shapes.

Appendix 2.   Reg Boor's Larrabee prop. shaper.

Appendix 3.   Leo Pilochowski article on prop pitch angles.

Appendix 4.   Article by Kang Lee on trimming high climbing F1Ds.

Appendix 5.   Notes from Bob Bailey on making prop spars.

Appendix 6.   Chart of Pitch Angles at given radius to Pitch Inches.

I hope this can be a living document so that we can incorporate both improved knowledge and practises as they evolve……. let's see how we go.

1) **Basic Propeller Theory** – by Bob Bailey.

The propeller in conjunction with the rubber motor is the heart of an indoor duration model and is the main contributor to achieving long flights, after all in many classes the rules are such that the basic layout of all models tends to be quite similar. It is the area where most efficiency is gained – or more often lost!

Main Characteristics.

- Indoor duration propellers are large with a diameter of at least 75% of the wingspan.
- The Pitch to Diameter (P/D) Ratio is much higher than for other disciplines, 1.5 to 1.8 being typical.
- The blades may be from balsa sheet (obligatory in some classes such as F1L, Gyminnie Cricket, Living Room Stick(LRS)) or built up. The latter are usually from balsa but recent innovations in lightweight

composite structures have allowed blades and spars to be made from such materials (eg. Boron fibres, Carbon Fibre, Kevlar).

- The Prop spar normally runs from tip to tip but again the extra stiffness gained from composite materials permits use of a partial spar that stops at an inboard rib station.

Propeller Diameter.

Generally “the bigger the diameter the more efficient the prop.” has been an indoor maxim for some time and generally held true for Variable Pitch (VP) props; however recently (2015) in Slanic Zoltan Sukosd has used a smaller diameter prop (16.6”) on his F1D model coupled with thin rubber (1.13 gm/m) to gain amazing performance from a Fixed Pitch (FP) Prop.

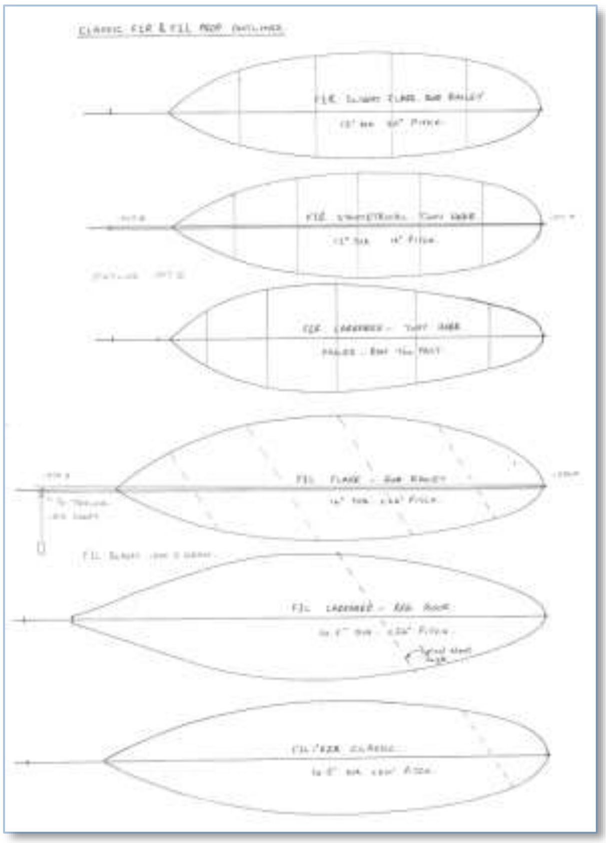
I think the best advice is to start with a prop. of conservative diameter from a known well performing model, then once confident of the performance make other prop. variants against which this known performance can be compared. The challenge of indoor duration is that we don’t know all of the answers and we mainly can’t predict which is the best direction to go in; so trial and error and closely following others is the only route open for us.

Because F1D is flown as the only International competition, development continues at some pace whereas with other less flown events such as F1L, F1R etc. you will find that you are relying on design criteria that are long established – so there is probably more room for improvement!

2. Propeller Design considerations.

Having established your new prop’s diameter and therefore how long the blades are going to be you now have to determine the exact shape and the pitch you will set them at. To some extent this will certainly vary depending on the type of flying you intend eg. Low or high ceiling, VP or FP.

Here are some proven World Class Prop shapes – you can see more full sized outlines in ***App 1***.



Flaring props ie. those with more area in front of the prop spar seek to increase pitch early in the flight when torque is high then gradually settle to design pitch as this subsides. The objective being to enable higher torque launches with more turns yet limit the climb height especially in lower ceiling venues. American EZB and LPP designs tend to use quite extreme variants.

One thing for sure many different blade shapes *work,* how well is actually a very difficult thing to assess. However we can take the world’s best models, which have proved themselves many times, and simply say "find fault with that prop!". Treger and Schramm VP props are very typical F1D Indoor Duration shapes, even Zoltan Zucosd' (FP) has only a very small non symmetrical tip – make of that what you will……see outlines in ***App. 1*** which show the shapes of recent props from the above world class flyers, also Bob Bailey's and my own for F1R and an F1L props.

However there are other approaches which honestly work well, is it the prop or the model? We may never know definitively.

Let's take a look at some typical propeller dimensions.

- Chord to diameter ratio at maximum chord is typically 0.11 to 0.14, maximum chord is usually at 55 – 60% radius.
- At 75% of radius, where most of the lift is produced, the chord to diameter ratio is typically 0.1 to 0.12. (Ref John Barker's article Prop Picker in 2000 FF Forum Report).
- Blade shapes are rarely extreme (perhaps LPP and US EZB excepted?), running from the Larrabee shape through Symmetrical to Flared – see above for typical variants. You can generate your own Larrabee shape using this Spreadsheet **from Reg Boor** reproduced in ***App 2***.
- There are many plans published and most will have full sized prop. blade outlines which you can initially either copy or modify to suit your own ideas. Very soon you'll have a library of possible shapes and a box full of props….
- Bob points out that for indoor use Larrabee propellers tend to run a little fast, I made one for an F1R model and found exactly that. However Mark Benns is flying this shape on his current F1D (Jan 2016) and again the prop. runs fast but this in turn helps a very rapid climb on thinner rubber than normal but couples this with a lovely slow let down rpm – we're not sure why. You can modify this behaviour by cropping the tips and moving the blade outboard on the spar – but then you've got a pretty normal looking prop…….

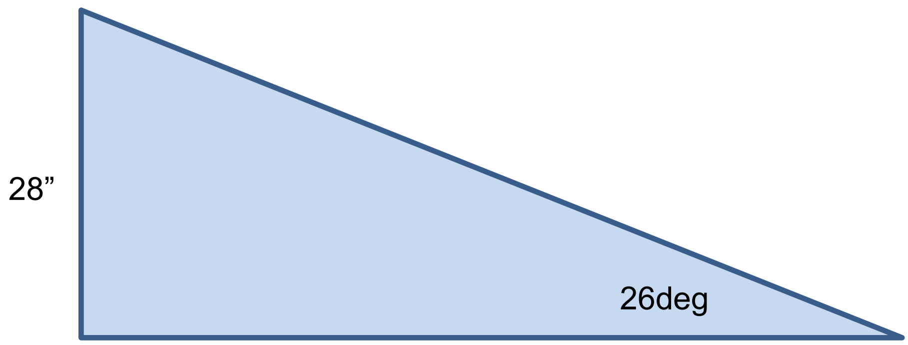
A quick look at propeller Pitch.

OK so we've decided the diameter and the blade shape, what about the angle we need to set the blades at? Let's start with a simple helical pitch distribution; I've used this for some time now on my F1D props.

The pitch of the prop is the distance each blade would travel forward if moving in something solid - like a nut on a bolt. So for our initial purpose we can imagine it actually is working like that.

Looking at the tip of the propeller from the front, as it turns it describes a circle. My maths is not great but the circumference of that circle even I know can be calculated by 2*PI*R.

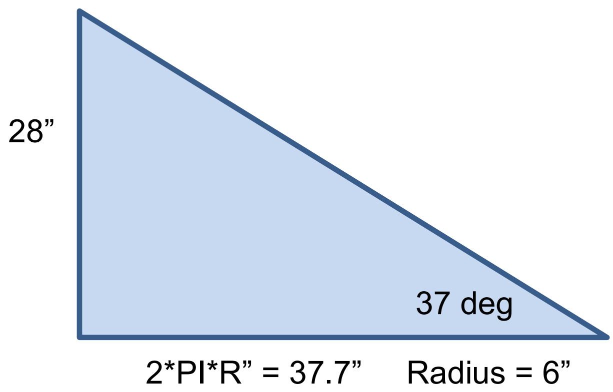
By visualising this as a straight path we can draw this quite simply in a triangle. Say we want a prop to have a pitch of 28" and a diameter of 18" (radius 9" then!) the base of the triangle needs to be 2*3.142*9 (= 56.5") and the opposite face 28" – OK you may need to scale these a little. Join up the line ends and measure the angle (It's 26 degrees) – that's what your tip angle needs to be for the 28" pitch prop.



2*PI*R" = 56.6"   Radius = 9"

Not to scale.

But since we want to set the pitch at about 70% of the blade radius we need to calculate the angle at that point. You can do this by measuring the radius from the centre (prop shaft) and that is the new number you use to find the blade angle at that point.



If you look at the table below you can see that as you move towards the hub of the blade the angle increases, this is because that point on the blade is not travelling as far as the tip and therefore has to move more quickly forwards.

28" Pitch Prop	Radius inches	Blade angle
	2	66
	4.45	45
	6	37
	7	32
	8	29
	9	26

You can calculate it too….

Of course you don't have to draw diagrams to get the angles, oh no, the wonders of a little mathematics will do the trick too. It's really not that difficult - if you can do it fine - otherwise go back to the website and click on the click on the spreadsheet link that'll do it for you – saves me trying to write the formula in Word! Of course you can also calculate the pitch from a known Radius and Blade Angle – useful when comparing notes with other flyers. You'll also need this when working with your Pitch Gauge.

Pitch to Diameter (P/D)Ratio.

Let's just have a quick look at the P/D ratios of a few indoor props that I know well for comparison purposes. Pitch is usually measured at about 75% of the blade radius – where the prop does its best work.

F1R – this model is equipped with a VP hub so the base pitch can be adjusted. Currently mine sits at 18" on a 12" diameter prop – so nice and easy P/D is 1.5, just bear in mind that the model spends most of its time flying at higher pitch therefore pulling up the average P/D ratio.
F1D – for the current 17" diameter FP prop the base pitch is about 26" giving a P/D of 1.53. Earlier props using VP hubs were typically 19" diameter and c29" pitch or a P/D of 1.53.

F1L – diameter 14" and pitch about 26", P/D 1.86

So all fairly consistent there then!

But not all props use purely helical pitch distribution, sometimes unintentionally – I was shocked when I measured mine accurately with a digital angle finder! Several had wash in at the tip – definitely not recommended anywhere!

In fact Bob Bailey advocates that the root and tips of propellers are washed out or carry less than the calculated helical pitch angle.

His recommended pitch distribution looks like this:-

Fraction of Radius	0.2	0.4	0.6	0.75	0.85	1.0	1.1
Fraction of Pitch	0.69	0.94	1.0	1.0	0.98	0.97	0.96

Also, and this gets into areas I don't pretend to understand well, the pitch you set the blades at is likely to be different to the design pitch. Most will rotate the blades to give them an "angle of attack", normally by a couple of degrees or so (+ve). So do you form the blades at a lower pitch to take account of this?
Leo Pilochowski wrote an interesting piece on this topic, you can find it in **App 3.**

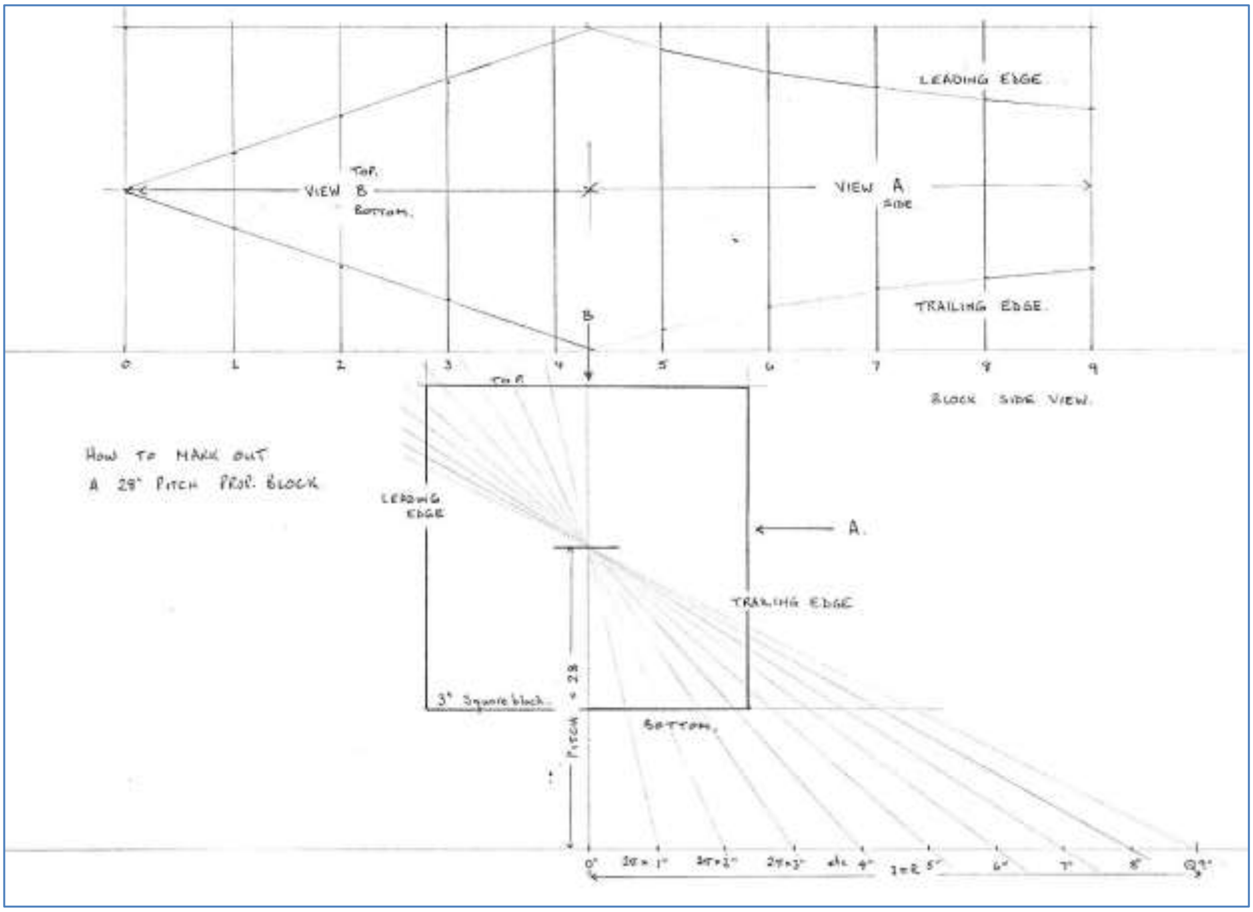
3. Forming the propeller blades.

Next up we have to form our propeller to conform to our design parameters of diameter, blade outline and pitch.

A very simple propeller can have the blades formed around a suitable cylinder or a cone, this seems to work as well as anything else for small props eg. Living Room Stick, Gyminnie Cricket, No Cal etc. Indeed if weight is not such an issue you can even make the blades directly from the plastic bottle or cup!

However this is not to be recommended for anything bigger – here we need to form the blades on a purpose made prop block, sometimes available from suppliers.But certainly the cheapest way to go is to make your own….not really that difficult but a bit fiddly and can create a lot of balsa shavings……

First thing to do is plot the angles you'll need along the blade using the technique we used above. The one shown below was drawn to ¼ scale and lets you see the blade angles at points where you can mark them on your intended prop block. A 3" inch one is shown but this could be reduced to 2.5 inches for F1D and maybe 2" for F1R. Also note that you could use less material if you rotate the block and only laminate the thickness you really need. I've not shown this as it just complicates things.



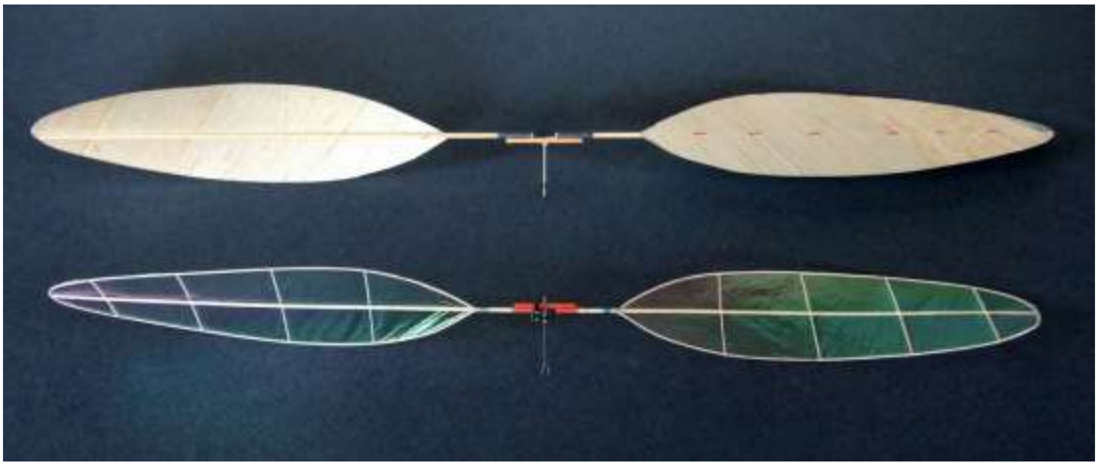
Next decide if you're going for a one piece carved block or a planked one.

Either way it is important that the line of the spar is central down the block and is straight as can be, insert a piece of harder wood eg. 1/8 or 3/16 square spruce down the centre line to help when carving to shape. The block face needs to be wide enough to accommodate the largest prop blade you are likely to make on it. You can also flatten off the base of the block to make the top face easier to work on.

If carving from a block mark out squarely at 1" intervals from the root then plot the line intersections from your drawing and join up - yes the Leading and Trailing edges do follow a curved line where they meet the edge of the block. Note when carving that the line from leading to trailing edge is straight at all points at right angles to the length of the block. A sanding block with a curved front face helps here.

If making a planked form then cut formers using your drawn angles above and plank with soft 1/16" or 3/32" sheet, glue on front and back pieces from medium 3/16" then sand down to meet the planking.

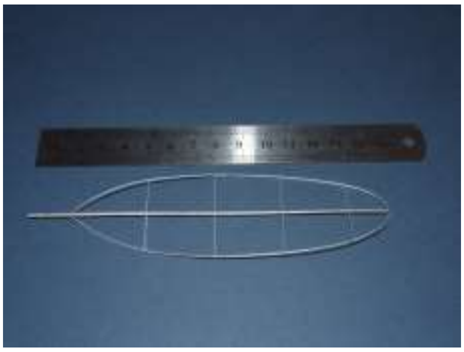
4. Solid blade propeller eg. F1L, 35cm Challenge, Gyminnie Cricket, Limited Penny Plane, Living Room Stick or F1M there is no better description of how to proceed than Jeff Hood's excellent INAV article which can be found in issue 120 (2006/12) Page 17. Larry Coslick also covers the ground pretty well in his Hobby Shopper article (INAV issue 107).



The upper image is a prop for an F1L prop the lower one an 12" F1R prop with Treger VP hub.

5. Built up propeller. Eg. F1R, F1D, F1M.

If you are aiming for a traditional built up prop blade then Steve Brown's older articles still cover most of the ground - find it here in INAV issue103 (2001/08) Part I Page 18 and Part 2 in issue 104 (2001/10). **App. 5** has some useful notes from Bob Bailey on making spars.

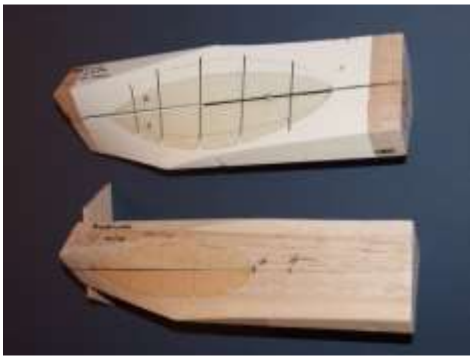


This is an F1R prop blade.

Personally, since making many boron/balsa blades, I now prefer building around a former mounted on the prop block you've made. First cover your prop block with strips of sellotape or solarfilm which prevent the blade from sticking to it and getting the block wet during forming. For all balsa props. the template is made from (typically) .015 medium sheet to the inside blade dimension. This is contact glued to the centreline of the block; take the spar slot out after gluing to the block.

The upper block is for a flaring F1D prop and has a fibreglass blade form that can be turned over to facilitate boron application. (See below).

The lower one shown is for an F1R prop of traditional construction - the blade shown is symmetrical but the same technique applies for a flared prop. blade since there is no need to turn the blade over during construction.

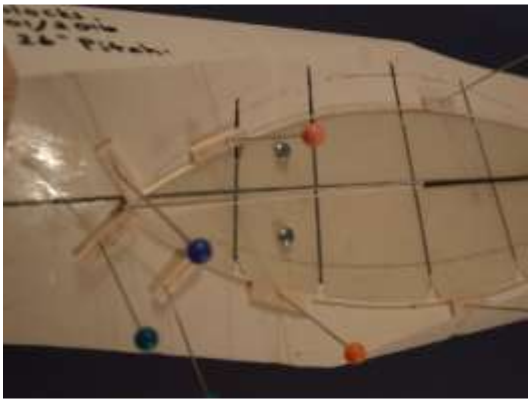


I still form the outline wet around a flat template and dry first before transferring to the Prop. block and wetting (NOT the tip it will kink)/ drying twice more to make sure that twist stays in place.

Boron/Balsa/Boron outline prop blade. Eg. F1D.

This type of prop construction has become popular over the last couple of years, typically the prop will also have a partial spar for weight considerations. The reason for the popularity is that it seems to remove much of the variability of all balsa propellers – every prop that I have made with this method is pretty much the same as earlier ones. This in turn means that you can more effectively try out different types of prop to see what, if any, improvements in performance there are!

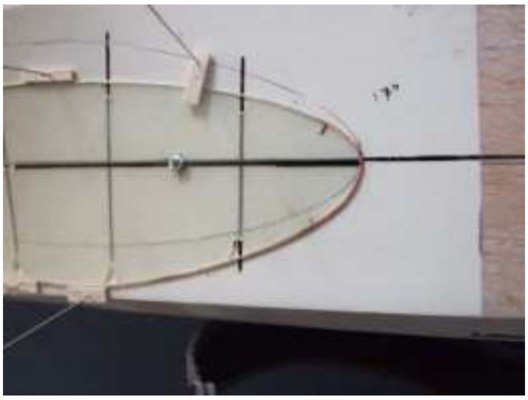
1) First of all cover the helical prop block with solarfilm or similar so that the fibreglass prop. former will release without sticking. Shrink the covering and seal tightly around the edges.
2) Draw the blade shape onto the solarfilm and then laminate the blade former from fibreglass cloth (I used a top and bottom layer of 0.5 oz cloth and 3 inner layers of 1.5 oz cloth) about .020 final thickness is just right. You can see this in the photo above.
3) Whilst this is curing make up the blade outlines, these taper from about .045 deep at the root to .022 at the tip, .024 thick. I make up from 2 pieces of tapered strip scarf jointed just off centre to the rear of the tip. Soak in warm water then form around the flat blade template and set aside in a warm place eg. Airing cupboard overnight.
4) The Partial spars taper from .070 to .050 and have 4 x .003 boron applied.
5) Release the fibreglass template from the mould and trim to shape then carefully sand down to the final blade shape. Admire it!



6) Since you need to boron the underside of the outline first, mount the template onto the prop block upside down so that the flare is towards the rear of the prop block.

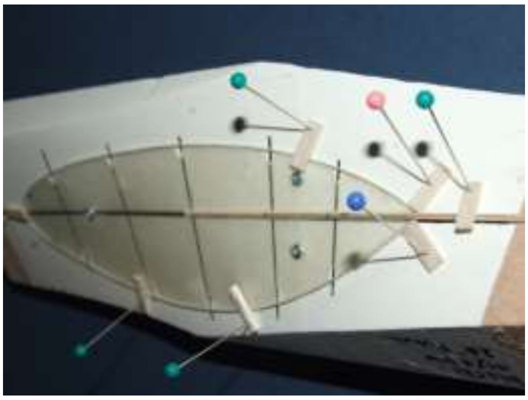
7) Take one of the blade outlines and clamp it in place around the fibreglass template on the prop block. Cut through the outline at the root and glue the ends together.

8) Apply .003 boron centrally along the blade outline from the root (leave the spar width uncovered) to the outside of the outboard rib position down both sides. Then glue Kevlar thread (the red bit) around the tip. I use 70% Duco for this.



9) Remove when dry, turn the fibreglass template over and repeat the boron application, no Kevlar needed on the tip this side though.

10) Remove the root section of the blade to allow the spar to be inserted, glue in the spar.



11) Add the ribs, I add 2 x .003 boron to the second rib, depending on your chosen rib camber (I use 4%) it may be necessary to shim the two root ribs with small balsa pieces between the rib and the spar, glue firmly in place.

12) Carefully remove the blade from the form, tease out with a razor blade, any difficulty and you've been a bit heavy handed with the glue!

13) Bind the spar to the outer rib with a few Kevlar fibres and add the gussets.

14) Repeat for the other blade, remembering to first turn the former over again!

Carbon fibre outline eg. as used by Brett Sanborn and Lutz Schramm.

The final method currently used is to form the outline and/or spar from ultra-lightweight carbon fibre and resin. You can find an article by Brett Sanborn (USA) via a link on the main website – reproduced with permission from INAV.

6. Covering a built up blade.

There are several ways of going about this, all of which I think I have tried! I think it's one of those things that you will try and get on well with one variant or other. Steve Brown's prop. article Part II describes a classic method which is simple and works well enough – INAV Issue 104.

The method described below is one of mine that Hans Staartjes modified and I have to say improved!

It started life as laminated balsa blade shaped hoop to which I attached OS Film with Vaseline. I like this because you can tauten or slacken the film as required until you are satisfied. Problem is it's got a fixed pitch depending on the block you laminated it on. So Hans made a similar hoop out of soft 3/32 Ali welding wire, it's easy to bend to pretty well any shape - it doesn't have to be perfect either – just match it roughly to the pitch block you've made the prop on. Attach film with Vaseline, then you can not only vary the film tension but also lay the blade onto the film and tease in more or less twist as you want. Once you find the best "sit" of the blade on the film, mark the blade position on the film, then lightly spray the blade with Photomount and drop onto the film. Trim slightly oversize with a soldering iron and glue to balsa outline with very thin dope. Another great point is that you'll find as you apply the thinned dope it creeps under the Photomount glue and softens it enabling you to further tighten the film up to the outline before all sets.

7. Pitch Setting and Pitch Gauges.

People ask "what pitch is your prop"?, easy question - but you probably don't know exactly. Whereabouts on the prop blade you measure the pitch is quite critical. Most people will actually respond by saying something like " Not sure but I set the blade at 34 degrees at the 75% point" "Oh, thank's" you say and walk of muttering darkly…..Others might say "Don't know but its doing 50 rpm on let down" – so now you need a stroke watch too! To be honest that's about the size of it, you initially do all the design then you decide what revs. the prop needs to do to get to your target time and work from that.

Back to some advice from Bob Bailey now.

When the prop is complete it is essential that the blades are set to identical pitches otherwise the prop will run with a noticeable wobble in flight. Many fliers use paper or fibreglass tubes at the root wherein the blades may be rotated to the correct pitch, a drop of ambroid either side of the tube/spar will lock it in place sufficiently but allow blade removal/angle change later. For minor pitch changes Bob will also gently twist the spar root and when satisfied apply a tiny drop of cyano to the spar to lock the balsa fibres in place – somewhat brutal for some I know! …and not really practical if you have 4 boron fibres on the spar!

NB. It really is a good idea to have a means of adjusting the blade pitch as each model/site is different and need varying pitch depending on height of venue, air conditions and rubber size.

Various types of Pitch Gauge.

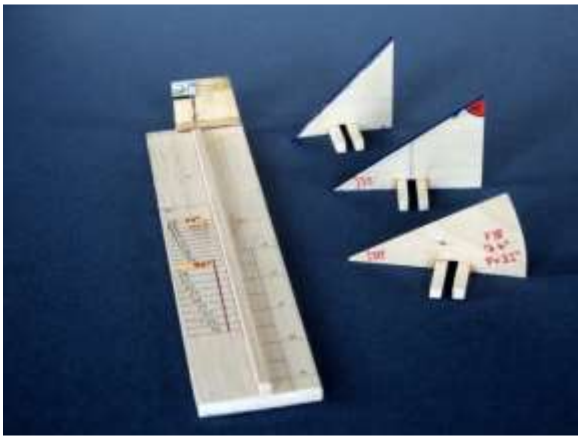
Measuring and setting the blades to the desired pitch is carried out using a pitch gauge, which can be quite simple or relatively sophisticated.

All require a means of holding the prop shaft vertical and either a fixed or variable angle setter.

A shaft holder is the first component. This could be:- a filed down Harlan type of dual bearing, a bent aluminium or similar metal holder with 2 Vs cut in it, ditto but a machined item, a spring is then required to hold the shaft in place. I have been lucky to inherit a wonderful little custom made clamp made by Peter Ing – photo on the right. Whichever way you go the shaft holder must hold the shaft vertical.

The one in the photo on the left was made for me by Rodney O'Neill, on the right one from Peter Ing.

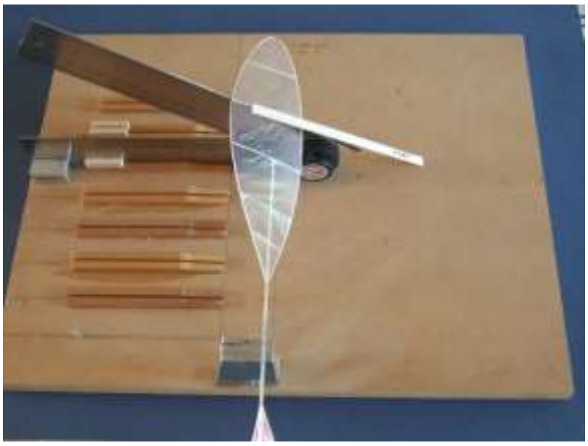
7. Types of Pitch Gauge.



1) Fixed shaft support with sliding fixed angle blade support – this has worked well for me - I use a fixed angle blade support, either set at 35 or 45 degrees depending on the prop diameter so that I can set (or check) the pitch at about the 75% radius point on the blade. (Ref. John Barkers article in FF Forum report 2000).

   Here's also a close up of the type of shaft spring retainer used.

2) Fixed shaft support with a variable angle blade support. I use a cheap Digital Angle Finder at fixed radius intervals and a chart (**App 6**) to convert angles at these radii into Pitch inches. Works brilliantly but rather cumbersome for travel. Use 6" radius for c17" props and 7" for larger ones. Make sure the angle finder is held vertically.

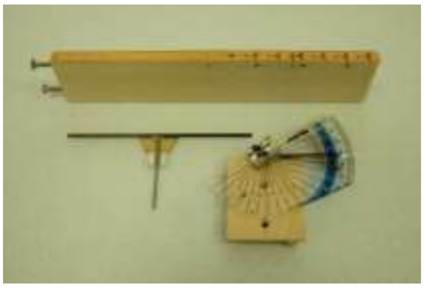


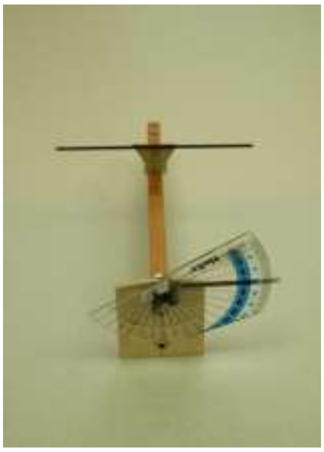
3) All purpose gauge with rotating shaft support and sliding blade guide.

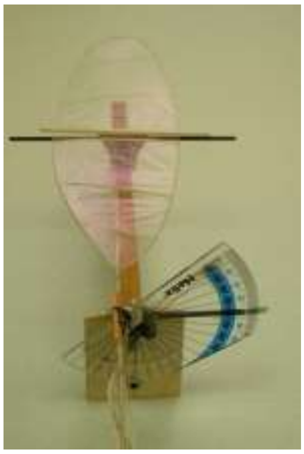
The nice thing about this type of pitch gauge is that it is quickly assembled / dismantled and travels well in a small box. To be honest I don't find it that easy to use but great to have in the toolbox when travelling.

As per normal you'll see that mine is made from quite readily available bits and pieces from usual modelling sources. You'll also see the same sort of thing beautifully manufactured from turned Aluminium!

Photo left – the components, right – assembled and in action.







The protractor and prop shaft holder are rotated until either the desired angle is obtained or the blade sits on the T bar support. The T Bar sits in holes and locates in slots at 1" intervals down the wooden spine, the radius together with the angle can then be used to determine the Prop blade pitch in inches if required.

Attaching the blades.

For a fixed spar, solid blade prop (eg. F1L) then you need to mount the blades onto the spar using thinned aliphatic glue at your desired pitch angle as described in either Jeff Hood or Larry Coslick's excellent articles.

For an adjustable hub with separate blades then first mount the hub into your prop shaft holder on the pitch gauge, insert both prop blades into the holder tubes. Set the pitch gauge to your desired pitch and adjust the blade angle very carefully so that the blade leading and trailing edges just touch the pitch gauge's blade guide. Rest a light piece of balsa across the blade as shown above and apply 2 small spots of Ambroid either side of the spar/tube joint.

NB. For a VP prop hub it's a good idea to set the low pitch adjuster screw to the middle of its adjustment range before gluing the blades in place.

You should now have a prop. that runs smoothly with no wobble, if that's not the case then first recheck that the pitch has not changed on each blade – not unknown as the glue sets – then check the shaft is perfectly square, correct as necessary and once again recheck the blade pitches.

8. Setting up a model to fly on a Fixed Pitch (FP) prop.

Basically if a model can comfortably out climb the intended site then a VP prop is likely to offer some improvement in duration, of course not all classes allow VP props….F1L, LRS, LPP, Gyminnie Cricket etc.

I think Bob Bailey has covered this well in his articles on FP trimming, especially where a variable amount of rubber is allowed, you can find these on the **indoorduration-gbr website under How Do I….? >Trim and Fly.**

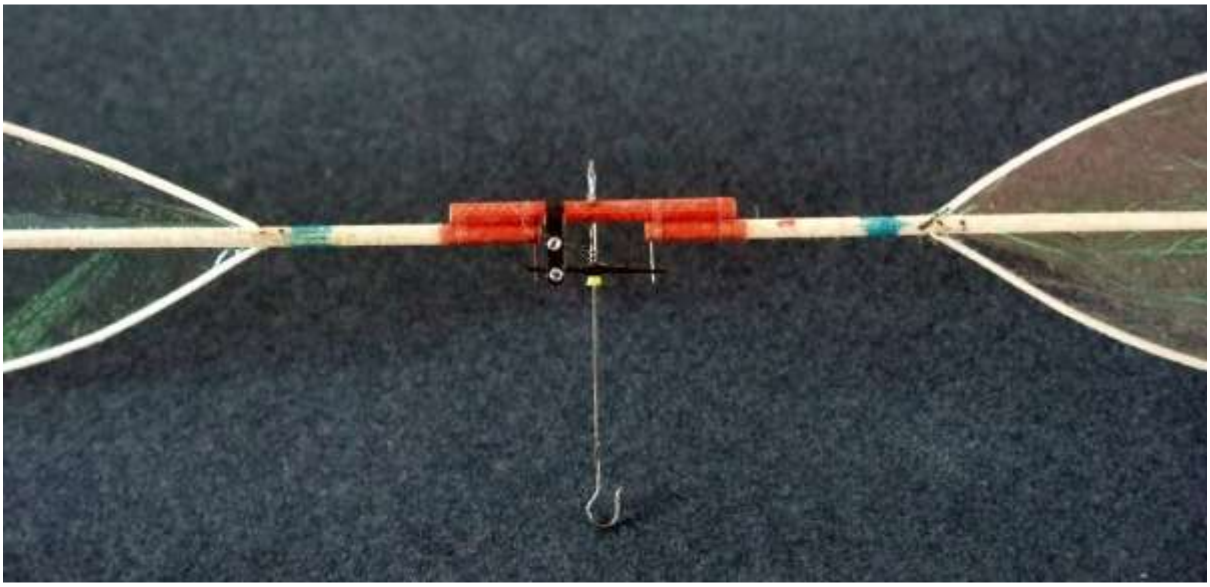
Also the current world Champion, Kang, wrote an interesting article on high ceiling F1D flying which you can find in **App. 4**.

There have been some more interesting results recently in F1D where conventional wisdom has been overturned somewhat. In 2015 the New Rules for F1D had just come into effect (1.4gm model and .4gm rubber) as we were going to Slanic for the European Championships. We knew that we had to climb as high as possible and felt the ceiling height was achievable so went with a mix of VP and FP props, but in the then current style of big'ish blade area and diameters. We were shocked to find that the Romanian flyers were using much smaller props, thinner rubber and achieving astonishing climb rates/times. We could not match their performance by about 5 minutes and nothing could be done on site to reduce our prop areas. Back in the UK we were able to replicate the performance and start to push the boundaries a little. We found that smaller props with lower pitch could be run on even thinner rubber with yet more turns – which are valuable to keep the prop turning on descent from height after a long flight. Just what the lower pitch boundary is we do not yet know but there is clearly a wide margin where there is little difference in performance, but all require smaller props and thinner rubber than we had ever used before.

9 Setting up a model to fly on a Variable Pitch prop.

A good description of basic VP set up for F1D models can be found on the **indoorduration-gbr website under How Do I…?>Trim and Fly -** this works pretty well for F1R, F1M too.

This is an F1R VP hub made by Ivan Treger - just 40 mg, magnificent! Prop all up weight is 80mg.



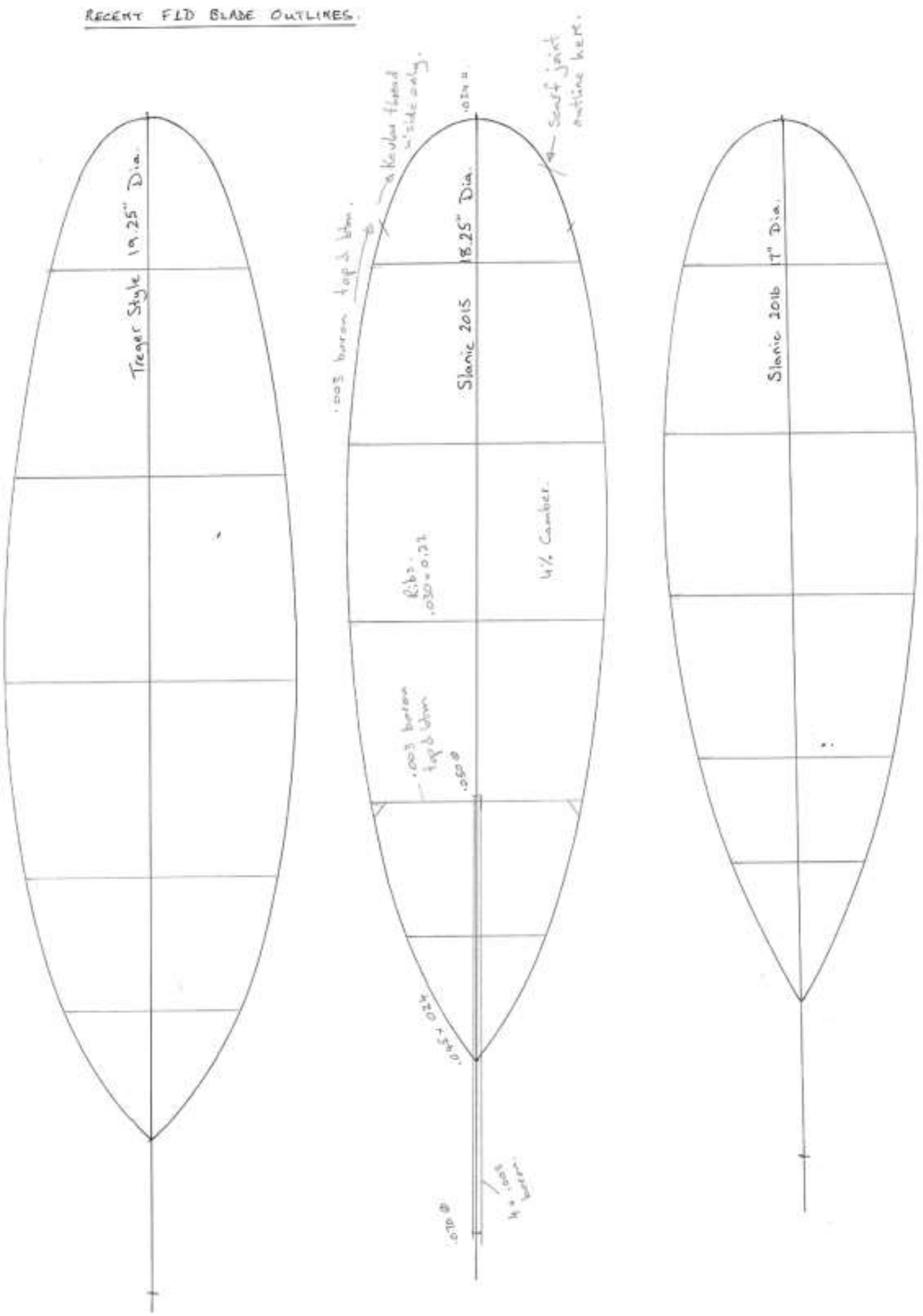
Well that's all for now, hope you found some parts interesting – do let me know if you find bits that are inaccurate, incomplete or could do with clarification or expansion. If you have prop related items that would be worth including then please let me have them at tony_hebb@hotmail.com.

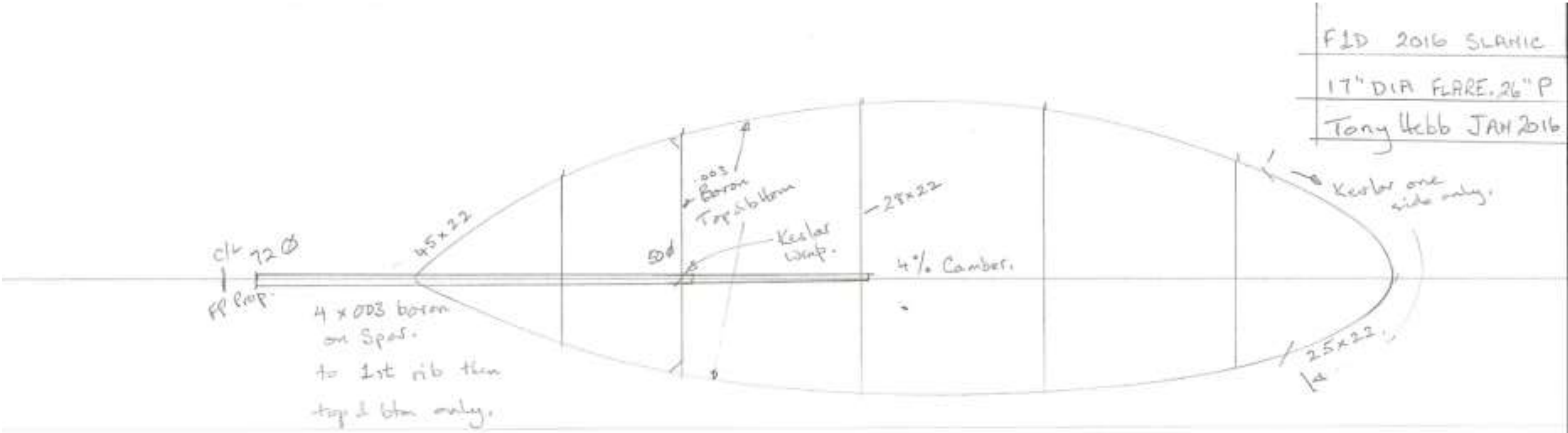
Many thanks for reading.

Tony Hebb

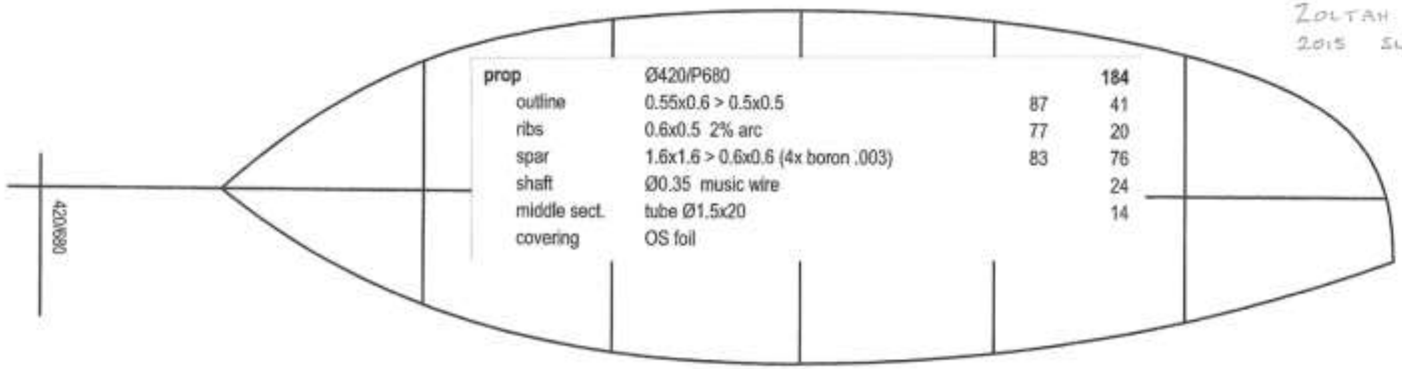
Appendices.

App 1. Proven World Class Propeller shapes.



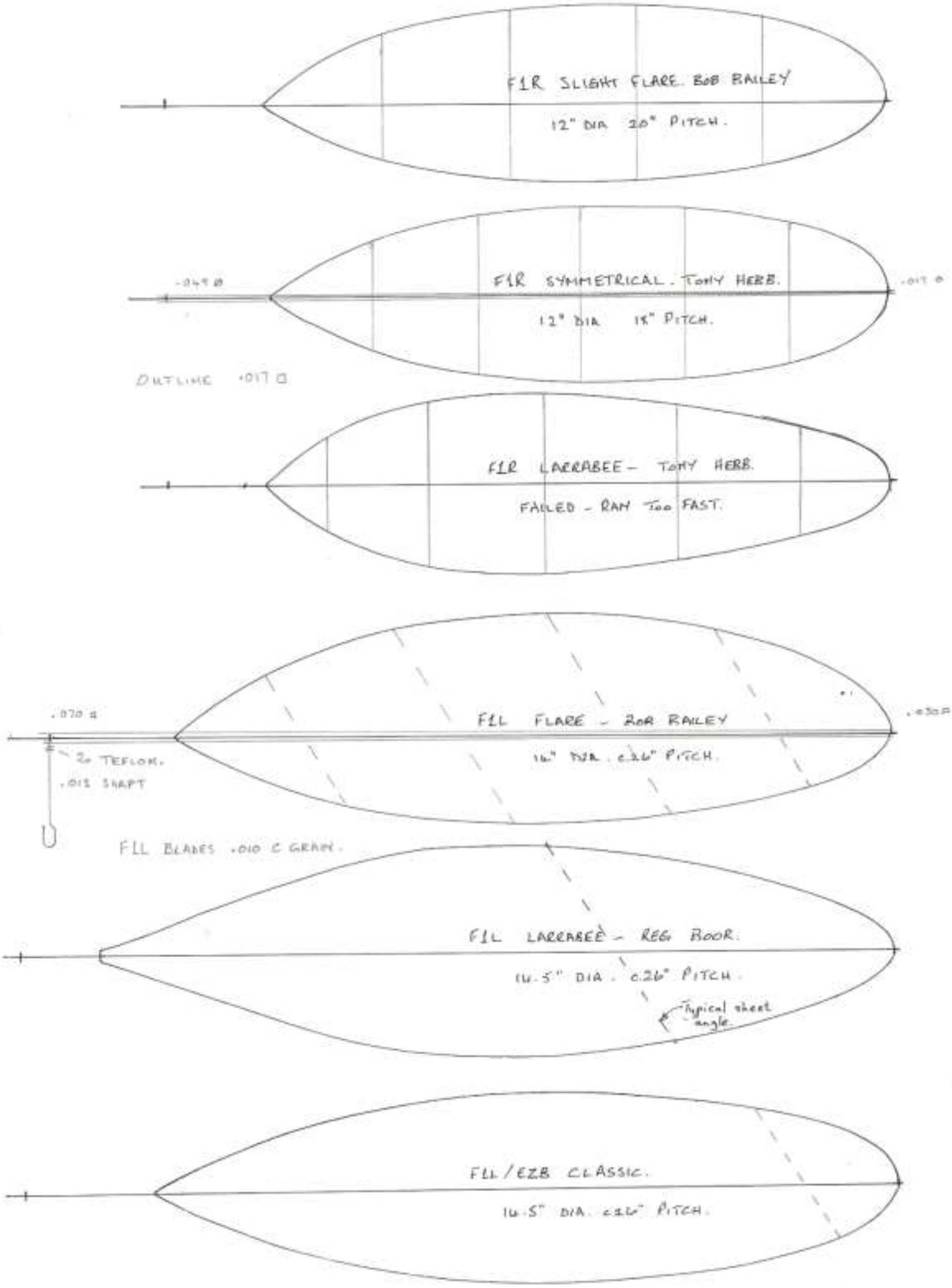


ZOLTAN SUKOSD
2015 SLANIC PROP.



prop	Ø420/P680		**184**
outline	0.55x0.6 > 0.5x0.5	87	41
ribs	0.6x0.5 2% arc	77	20
spar	1.6x1.6 > 0.6x0.6 (4x boron .003)	83	76
shaft	Ø0.35 music wire		24
middle sect.	tube Ø1.5x20		14
covering	OS foil		

CLASSIC F1R & F1L PROP OUTLINES.



App 2. Reg Boor’s Larrabee prop shaper.

These are Reg Boor's original notes dating from 1990 Aeromodeller article.

	Propeller blade planforms based on Prof. Eugene Larrabee theory							
	Propeller Geometric Pitch to Diameter (P/D) Ratio							
Fraction of Radius	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2**
0.1	0.193	0.173	0.157	0.143	0.130	0.121	0.112	0.105
0.2	0.575	0.532	0.493	0.460	0.431	0.403	0.380	0.360
0.3	0.864	0.828	0.793	0.759	0.727	0.695	0.667	0.642
0.4	0.986	0.975	0.959	0.940	0.922	0.899	0.879	0.860
0.5	0.986	0.997	1.000	1.000	0.999	0.992	0.985	0.978
0.6	0.914	0.936	0.953	0.967	0.980	0.986	0.993	0.998
0.7	0.795	0.823	0.848	0.869	0.890	0.904	0.921	0.935
0.8	0.645	0.673	0.696	0.720	0.742	0.751	0.780	0.799
0.9	0.449	0.471	0.490	0.508	0.528	0.544	0.561	0.578
0.95	0.315	0.330	0.344	0.359	0.373	0.385	0.398	0.411
0.96	0.282	0.295	0.308	0.320	0.333	0.345	0.357	0.368
0.97	0.244	0.256	0.266	0.277	0.289	0.298	0.309	0.319
0.98	0.197	0.207	0.217	0.226	0.235	0.243	0.252	0.261
0.99	0.139	0.147	0.152	0.160	0.166	0.171	0.177	0.184

Let us be quite clear. This method does not design your propeller, you have to do that by choosing the P/D ratio that best suits the required performance and by deciding the diameter that will absorb the power.

The method given here produces a blade planform that goes some way towards satisfying minimum induced loss conditions for that propeller, making the transfer of power from rubber to thrust a more efficient process.

The figures given in the table above are ordinates for Larrabee like propellers. The P/D ratios are typical for indoor duration models.

First of all decide on the propeller diameter, its pitch and the maximum chord of the blade to be used.
Divide the Pitch by the Diameter to get the P/D ratio.

Then multiply the radius of your propeller by the figures in the extreme left hand column, write down these values
Draw a line and mark off the radii along it.

Next multiply your chosen maximum chord by the column of ordinates under your designed P/D ratio and write these chord figures alongside the radii you've just calculated.

For each of your marked radii positions measure and mark half the chord each side of the line.

Join up your dots and you should have a Larrabee style blade shape.

App 3. Explanation of prop. blade Angle of Attack by Leo Pilochowski (USA)

A plane that advances or goes forward 22.5" for each revolution of the prop is said to have a prop with a 22.5" advance ratio (AR). If an EZB prop is built on a 22.5" helical pitch block, has an advance ratio of 22.5" (the as built helical pitch and the
AR often do not come out to be the same), and is set at a pitch of 26" at a 5" radius, the prop blade will have an angle of attack (AoA) of 4 degrees along its whole length. How does one get the 4 degrees? The angle of a blade set at 22.5" pitch is 35.6 degrees at a 5" radius. The angle if the blade is set at 26" pitch at a 5" radius is 39.6 degrees. The difference of 4 degrees is the AoA of the blade.

An EZB is often a much lighter and slower plane compared to an F1L. The as flown AR's may not be the same so a good EZB prop design may not work well for an F1L. As a point of comparison, my current F1L flies with an advance ratio of about 23" (this is by design and I built the prop on a 23" helical block). I set my blades with an AoA of 7.5 to 8.5 degrees (or a 30" to 31" pitch at a 5" radius). The prop has a 15" diameter. This AoA (or pitch) is similar to many other F1L's, w hile the AR of my F1L is more than usual. Stan Chliton's Spirit F1L has an AR of just over 20" and a pitch of 26.5" (I do not know the exact radius but somewhere between 4.5" and 5") for his 15" prop. This gives an AoA of about 7-7.5 degrees. The same AR, AoA, and pitch are found on Laurie Barr's CargoLifter F1L (14.7" prop diameter. Both of these planes are among the best F1L's and one cannot go very wrong copying their design parameters.

Leo P.

App 4.

Article by World Champion (2014) Kang Lee.

It is a great pleasure to fly a F1D in a high ceiling site. The F1D is unleashed to show its greatest potential. In the Salt Mine of Romania, the F1D climbs steeply in what the Romanian fliers call “our cathedral” and looks like an angel ascending to heaven. In the glow of the early evening sun at Lakehurst, the F1D floats motionlessly high up against the girders and takes your breath away with its beauty. I hope you are fortunate enough to someday experience one of these scenes or one that is similar.

“Altitude is king” in indoor flying, and you must get to the ceiling to be competitive. All things being equal, if your competitor flies his F1D 10′ higher than you, he will beat you by more than 45 seconds, no matter the site.

The power stall likes to show its ugly head and ruin your high ceiling experience. When your F1D’s attitude gets too steep, its speed may decrease enough for the prop to stall. More speed is lost, and the model loses its aerodynamic forces to fight the torque in the motor. The left wing drops, the tail drops, and the model gets to an almost irrecoverable position. The power stall could be more moderate but is still detrimental when the model flies off pattern and finds the wall.

We want the model to climb steeply in a controlled left circle. Ideally, the model holds a high attitude but flies fast enough to avoid stalling the prop. It should be banked slightly left but rolls right so that the left wing doesn’t drop. This is the classic spiral climb.

Alternatively, we cannot sacrifice the cruise and let down portions of the flight. If your model climbs to the ceiling but has an under-elevated trim for cruise and descent, your time will suffer.

There are two main ingredients to a successful climb: down thrust and left thrust.

I believe 1.5 to 2 degrees of down thrust are necessary during the first minute or so of flight. This is to prevent the model from going excessively nose up and to keep the model’s speed up. On most indoor models, the zero-degree thrust line runs below the vertical center of gravity. Thus, at zero degrees, the thrust creates an upward rotating torque. This upward rotating moment is especially high at launch and causes the model’s attitude to go excessively steep. One part of the solution is to decrease this upward moment by increasing the down thrust. Different fliers do it differently, and many use a motor stick that bends under high tension. In our design, we use 1 to 1.5 degrees of down set statically and will use additional down by letting the MS bend under tension if necessary. When the motor stick bends, there is also “down” elevator to govern the model’s attitude. In actuality, on Salt Jr., it takes 4.7 degrees of “down” for the thrust line to run through the vertical CG. Although our setting is called “down” thrust, what we are doing is actually reducing the amount of “up” thrust.

The extra down thrust that comes from the bending of the motor stick will remain until the rubber’s motor tension relaxes. The unbending of the motor stick depends on the stiffness of the stick and the amount that it was bent. In my experience, the motor stick does not fully bend back until the very end of flight. When we loosen the bracing line to allow the stick to bend and adding down elevator, the model will be under elevated during cruise. Hence, the model has to be re-trimmed for cruise whenever the bracing post’s height is changed.

The second main ingredient is left thrust. Left thrust and left wing wash-in help to keep the left wing up and the model rolling right. However, when the model’s speed is reduced, the aerodynamic forces from wing wash decreases. Without enough left thrust, the model will drop its left wing and then its tail. I believe 3 to 3.5 degrees are necessary.

In addition to down thrust and left thrust, the secondary ingredients are to have enough left wing wash-in and left rudder. For Salt Jr., if you set the wing flat at rest, this should result in enough left wing wash-in during the climb. Set left rudder to 2 degrees; left rudder helps the model to turn while maintaining its left bank during its climb and turn.

The following are additional solutions to common problems that you may encounter.

- The wing posts must be strong. Check for loose boron and make sure that all joints — wing to wing tubes, wing posts to wing tubes, wing posts to motor stick — have no looseness. The wing posts take a tremendous amount of beating during launch. I have experienced wing post issues a number of times and have also witness them many times in other fliers. Problems are not easy to diagnose, so examine all connections to your posts carefully.
- The CG must not be too far aft. I recommend that Salt Jr. be flown at 84% CG. At this CG, it would have the same static stability margin as my world championship model, which is to say that it should be safe. Flying at 90% CG is also possible. Further back than 90% is not recommended. If your CG is too far back, your model will be nearly un-trimmable for the climb. On one flight, the model will stall. Decreasing the incidence slightly, say by .25 degrees will result in a dive on the next launch. It's extremely difficult to identify this issue during a trim session, so make sure to have the right CG before you fly.
- The tail boom to extension fit must be tight. When the model's attitude goes nose up, the tail boom could loses its setting if it's not tight. The model then experiences elevator "up", and the model may stall. Check carefully that the tail boom is snuggly plugged in place. There must be no movement. If necessary, put a drop of glue at the top and bottom of the tail boom to hold it in place during the contest.
- The pigtail in the bearing must not be loose. You measured the left thrust to be 3.5 degrees. However, when the motor pulls on the prop hook, the real left thrust could be more than 1 degree less. Tighten the pigtail.

In a high ceiling site, an aggressive climb is wasted unless the model is trimmed well for an efficient descent. As our model may have a couple of degrees of down thrust, we want to make sure that the prop does not point down during descent. Watch the prop's attitude, not that of the motor stick. Until we run out of turns in the descent, we want the prop to be level or pointing slightly up. If the prop points down, it may mean:

- The prop pitch is too low. Increase the prop pitch by 1 degree.
- The decalage is not enough. Increase the wing's incidence or decrease the stab's incidence.

- The trim needs more nose up. Decrease the stab’s incidence and the wing’s incidence by the same amount.

For Salt Jr., I recommend 1.5 degrees of down thrust and 3.5 degrees of left thrust. Salt Jr is a short model at 30″ and has a short nose at 1.5″. For a model with a longer nose, say at 2.0″, use slightly less down and left thrust.

Set the stab’s incidence to negative 1.5 degrees to match the thrust line. Optimum decalage will be between 2.5 and 3 degrees. Start cruise trimming with 1 degree of positive incidence in the wing, and adjust the model’s trim by changing the wing incidence. Trim for cruise using the procedure described in a previous article. When cruise trim is good, start trimming for the climb.

In the climb, if your model goes steeply nose up, loses its speed and stalls, then more down thrust is required. Reduce the tension post by .020″ at a time. You will have to re-trim the cruise by adding a small amount of wing incidence.

If your model has enough forward speed but side slips (or “crabs”) and either turns with a large circle or does not turn at all, you need more left thrust and/or more left-wing wash in. Check that you have no looseness in the pigtail. Check that the wing does not have left-wing wash out at rest. Adjust both left thrust and left-wing wash in as needed.

Climb trim requires making fine adjustments. After each adjustment, make sure that cruise trim remains optimum.

Appendix 5. Notes on making prop spars by Bob Bailey.

It is essential to make the prop spar in two halves so that they can be made to be identical in stiffness. Weight imbalance is not a problem. These notes are written primarily for F1D props but are applicable to all classes.

Wood density
I recommend the following:
F1D 4.5 - 6 lb
F1R 4 – 5lb
F1L 5.5 – 6 lb
F1M 6 – 8 lb

Selection
Use wood which has been tested for stiffness via a deflection test The usual problem is to use untested wood which almost invariably will be either too heavy or too flexible. The best means of testing is to use the article on wood testing in the Forum reports. However, a quick and easy way is as follows:
Select several pieces of up to 100 thou (2.5 mm) thickness, up to ½" wide and about 10" long. This size is enough for cater for a FP or VP prop.
Hold each piece in turn hanging over the edge of the bench or similar.
Deflect by hanging a weight on the free end and measure the deflection.
The one which gives the least deflection is the best!
Taper the wood from 2.0 mm at one end to about 1mm at the other. Make the taper as uniform as you can. **Use a micrometer for this purpose.** At the thick end, mark one wide face with a line running diagonally from one side to the other using a marker pen or similar.
With a wood stripper, strip off two pieces 2.0 mm wide (each will have part of the diagonal line) on one face.
Each of these two pieces is now tapered down to 1mm thick at the other end in the same manner as for the first stage to give a double tapered spar half.
Use the micrometer to make sure the spar thickness is the same in both directions and for both spars at each distance from the root. 5 points are usually enough. You have made them as nearly identical as you can and this will speed up the next stage which is matching the two halves for stiffness in both directions.
I use a length of 1/8" sq wood with ballast on one end to weigh about 0.3 g for all except F1M. The wood has a small hook on it to allow it to be hung on the spar. To use the weight to measure deflection, mark the weight with a scale above the hook with zero at the hook.
To measure deflection, hold the spar half under a steel rule at about 6" from the end or the rule using the root ½" of the spar to clamp it against the rule.
Now hang the weight on the spar as close to the end of the rule as possible and measure the deflection ie how much the weight drops. This should not be more than about 6 mm.
Measure each half by holding the spar with the mark against the face of the steel rule. One half may well bend more than the other. Sand the stiffer one over the 6" distance from the root with a few smooth strokes and recheck the stiffness. You are trying to make the two as near the same as you can.
Now repeat this process, holding the spars against the rule with the marks on the side. You are now testing the stiffness in the other direction.
Now you are going to check for the stiffness distribution along the two halves.
Hold the two halves side by side with the marks uppermost between thumb

and forefinger so that they are alongside each other all the way to the tips. Now press down on the two spar halves about halfway along to bend them through an easily seen angle. The two halves should follow the same curve but usually they don't. One section will be straighter than the other over part of the curve. Sand the straighter piece on a deflected face to make it bend a bit more. One or two gentle strokes are usually enough. Now retest and repeat as necessary.
Repeat this process by holding the spar halves in the middle and repeat for the tip sections.
Now turn the two spar halves so that the marks are now on the sides and repeat the entire deflection tests.
So, why bother with all this?
There is a very good reason; you are trying to make sure that the two prop blades bend equally under load, particularly at launch. If they don't, the prop will wobble badly.
All this effort will reward you with props that run nice and smoothly, look good and will give you better flight times!

Good luck!

Bob Bailey. Feb 2015.

App 6. Chart of Pitch Angles at given radius and Pitch inches.

4" Angle	Pitch	5" Angle	Pitch	6"angle	Pitch	7" angle	Pitch
25	11.7	30	18.1	26	18.4	21	16.9
26	12.3	31	18.9	27	19.2	22	17.8
27	12.8	32	19.6	28	20.0	23	18.7
28	13.4	33	20.4	29	20.9	24	19.6
29	13.9	34	21.2	30	21.8	25	20.5
30	14.5	35	22.0	31	22.7	26	21.5
31	15.1	36	22.8	32	23.6	27	22.4
32	15.7	37	23.7	33	24.5	28	23.4
33	16.3	38	24.5	34	25.4	29	24.4
34	17.0	39	25.4	35	26.4	30	25.4
35	17.6	40	26.4	36	27.4	31	26.4
36	18.3	41	27.3	37	28.4	32	27.5
37	18.9	42	28.3	38	29.5	33	28.6
38	19.6	43	29.3	39	30.5	34	29.7
39	20.4	44	30.3	40	31.6	35	30.8
40	21.1	45	31.4			36	32.0
41	21.8	46	32.5			37	33.1
42	22.6	47	33.7			38	34.4
						39	35.6
						40	36.9