## Propeller geometry

Two things sparked my wish to know more about propellers.

For my indoor lightweights I make prop blades that plug into a tissue-tube hub. This means that they are easily replaced but it is tricky to get both props equally set. This means the model sometimes vibrates and I am sure that I could get longer flight times with a bigger pitch. So I wanted to know how to make a jig.

The second was chatting to a club member who flies 3D behemoths with enormous props. He was talking about fitting an even larger prop than the twenty-something inch one on the model. I think he told me that the pitch would be 18 inches (sorry about mediaevalism). I wondered why the pitch was so large.

### How props work

First the principles. Thrust is generated because the prop pushes on the air to accelerate it and the air pushes back (Newton's Third Law). Props are rotating wings. They have two main dimensions – diameter and pitch. Pitch is the theoretical distance the prop moves forward in one revolution.

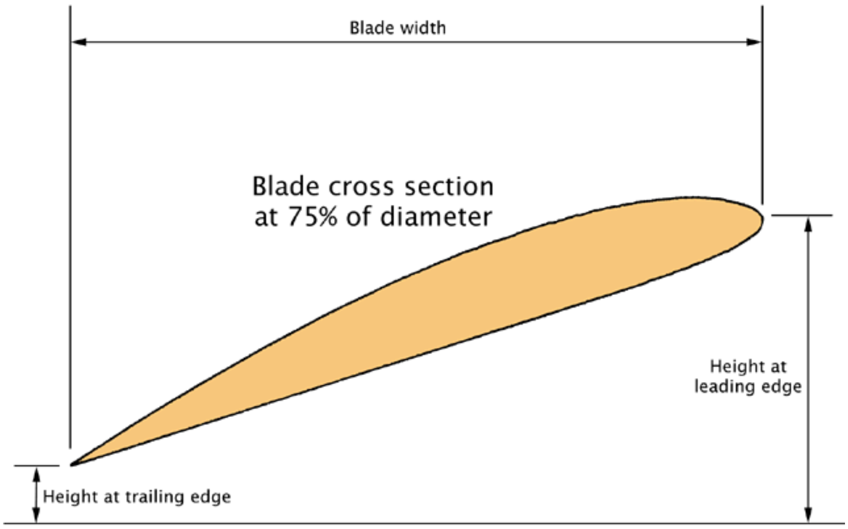
A prop blade has an aerofoil. You can see it if you look at a broken blade. Not got one? Borrow one of mine. As it turns it cuts the air. When static the angle of incidence is effectively the angle of the prop blade, which is about 12°, so it is stalled and very inefficient. When moving through the air the prop's angle to the air will drop almost to zero. In theory then, if you measure the angle of the blade, simple geometry should tell you the pitch. For each revolution the tip of the propeller travels in a spiral through the air a distance equal to the circumference of its circle. Apparently a good propeller has about 85% efficiency.

### Maths

At radius r on the prop the following measurements are made:
Width of the blade W
Difference in height of leading edge h1 and trailing edge h2, measured from a flat surface.
The tangent T of the angle of attack is (h1 – h2) / W
The circumference of the path of the measurement point is found:
Circumference = 2 x Ω  x r
Pitch = Circumference x T
Pitch = 2 Ω r (h1 – h2) / W

“The reason we measure pitch at 75% of the diameter is two-fold. Generally, the pitch of a propeller is not completely constant, varying somewhat from hub to tip to optimize it for the different linear speeds at each point along the blade. The pitch at 75% corresponds roughly to the average effective pitch of the propeller. Secondly, the propeller is sufficiently wide at 75% to allow one to get reasonably accurate measurements of blade width and height.“

The angle of a blade changes as you move outwards because the outer parts of the prop are travelling further (circumference) so must have a lower angle to give the same pitch. “To put it another way, propeller blades are twisted to change the blade angle in proportion to the differences in speed of rotation along the length of the propeller and thereby keep thrust more nearly equalized along this length. If the blades had the same geometric pitch throughout their lengths, at cruise speed the portions near the hub could have negative angles of attack while the propeller tips would be stalled.” Put yet another way, ”Propellers operate most efficiently when the aoa [angle of attack] at each blade station is consistent (and, for propeller efficiency, that giving the best lift drag ratio) over most of the blade, so a twist is built into the blades to achieve a more or less uniform aoa.”




I gave the maths a practical test. I used a fairly large prop to make measurement easier.
I covered the markings so I couldn’t know the answer.
I marked the 75% point out from the centre. Here the diameter was 380mm.
I held the prop firmly down on a flat surface.
I measured the heights of the centres of the leading and trailing edges.
Rear 4.5 mm Front 12.5 mm Difference 8 mm
The blade width viewed from above = 36 mm
So the tangent of the blade angle is 8/36 = 0.22
So the pitch should be circumference x 0.22
Circumference = Ω x d = 3.142 x 380 = 1194 mm
Pitch = 1194 x 0.22 = 265 mm
In mediaeval units this is 10.5”
And what was the marked pitch? 10”.
Considering the systematic errors in measurements (+/- 0.5mm) this is pretty good.
QED.

So what are the answers to what started all this?

To build a jig I must decide on a prop diameter. Then I must decide on a pitch. Then I settle on a prop width at 75%. Then I calculate the angle needed. Then I make a card jig. Done!

Why was the pitch so big on the big prop? Because as the diameter goes up a prop with the same angles will automatically give a larger pitch because the circumference is bigger. A given geometry will give a 200mm pitch on a 300mm prop and a 400mm pitch on a 600mm one. The performance will be the same. So if you have a small and a large prop with exactly the same angles of attack the larger one will have a larger pitch.

This article included quotations, which I enclosed in quote marks, from the following sites.
http://avstop.com/ac/flighttrainghandbook/basicpropellerprinciples.html
http://www.pilotfriend.com/training/flight_training/fxd_wing/props.htm
http://www.stefanv.com/rcstuff/qf200203.html

On one site I had asymmetric blade factor explained. This occurs during takeoff. The propeller disk is tilted so the top is further back. This means that, as it starts to move forwards, until the tail lifts the downward moving blade has a larger angle of incidence and produces greater force. With conventional rotation this means the aircraft will turn to the left. For an explanation of the various upsetting forces due to the engine and prop (torque reaction from engine and propeller, corkscrewing effect of the slipstream, gyroscopic action of the propeller, asymmetric loading of the propeller (P factor)) go to
http://www.free-online-private-pilot-ground-school.com/propeller-aerodynamics.htm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