Ed Note: The following article appeared in the March 1938 issue of Air Trails - There is much we can learn from it

How the propeller works -

concluding the model design series. By Frank Zaic Author of The Model Aeronautics yearbook

ONE of the cleverest devices invented by man is the propeller. It converts stored energy into motion which has no dimensional limitations. It is comparatively easy to understand its circular-inclined-plane principle when we apply it to a solid object such as earth or wood, and even to such fluids as water. However, when it comes to air, the propeller assumes mysterious properties and we are at a loss to know just how it carries on its business of pulling the plane. We know that it somehow screws itself forward, but very few of us can correctly proportion the propeller to a particular model.

The propeller is nothing else but a set of rotating wings, and every principle applied to the wing is applicable to the propeller blades. The wing has to have sufficient lift to neutralize the force of gravity, and the propeller has to have sufficient pull to overcome the drag of the model. Because of rotating motion, the blades must be so set that every portion will have a similar angle of attack when the propeller is working at its best angle. This can be easily explained by referring to the thin and thick column stairways. *(Shown in the illustration on the next page)* If we want to rise the same distance on each stairway with every complete turn we must naturally increase the slope of the thinner helix.

If we were to assume a propeller in a fixed position, but let it rotate like an ordinary fan, the aerodynamical reactions are as shown. Note that the path of the propeller is at right angles to its center line. Since the path of the airfoil determines the air flow, it is only natural that the air strikes the blades also at right angles to the center line. It is rather hard to turn a propeller at this position, since the high angle produces a large drag which must be overcome by the motor. This naturally slows the propeller down and it explains why we cannot base the propeller duration by winding the model and letting it unwind while in our hands. Of course, we also have a large lift which comes very handy when we launch the ship. The excessive initial rubber power is then nicely taken care of by this combination. Referring to the blade angles (See illustrations) we note that there is a large difference in angle of attack between the tip and the hub. The tip has a fair angle, but the hub is definitely stalling.

The moment the model is launched radical changes take place — the most important being that the air flow has changed from direct right angle flow to a different angle. We can best demonstrate this by the following experiment. Take a sheet of paper and a pencil and have some one draw the pencil across the paper while you pull the paper back. The result will be a diagonal line. The backward moving paper can be assumed to be the air and the sidewise motion of the pencil can be the rotating prop.

If the paper or air is speeded up the angle will be steeper. If the propeller is speeded up the angle will be lower. This means that a high model speed and slow propeller will give a steep angle, and a slow model and fast rotating propeller a low angle.

Taking for granted that the air flow has changed as soon as the model moved, we now have aerodynamical forces as shown. Note how the direction of the lift force is determined by the air flow. If in this position the thrust is still greater than the load, the model will speed up and consequently bring the line of air flow still closer to the blade angle.

We definitely know that it is the drag of the model which determines the angle at which the propeller will work. We must, therefore, design our propellers so that they will operate at their best angle. This means that before we carve the prop we must know what characteristics the model has. If the lines are blunt, we know that the propeller must be of low pitch and have plenty of blade area. The low pitch will assure a low angle of attack and the blade area will provide sufficient thrust with minimum of blade drag. However, a streamlined job can use a higher pitch propeller with a fair amount of blade area. Just remember that thrust depends on the blade area of the section and the angle of attack.

Through a process of elimination the following propeller blank was found most satisfactory. The drawing shows the way in which the block is tapered before carving. The reason for all this is as follows: We know that the hub contributes very little thrust because of its high blade angle, which produces a lift component which results in torque. So, what we do is to decrease this angle so that it will be a streamlined section following the air flow. This is done by cutting the blank in toward the hub, which automatically decreases the blade angle. Therefore, if we have a five degree angle of attack at the center, the angle at the hub will be zero. The reason that we start our "X" taper from a midpoint is that we want as much area as possible at the center. As we know, the tips have regular tip losses just like the wing.

You will also note that the tip dimension is slightly changed to give a lower pitch than the center. This is also done to lower the tip losses. The reason that we have such a venturi shape is that since the propellers work at several degrees angle of attack we have the downward sweep of air, as we have pointed out in the case of the wing airfoil. In case of the propeller this air is sped backward, which reduces the pressure right behind the blades. Consequently, the air outside of the propeller's influence tries to come into the reduced area.

This peculiar pressure radiation leads us to believe that we have nothing to worry about the tips, but experiments have shown that if a silk thread is placed behind the tip it will be sucked forward. You can try it for yourself if you have a gas job. Therefore, be sure to give the tips a very clean elliptical outline.

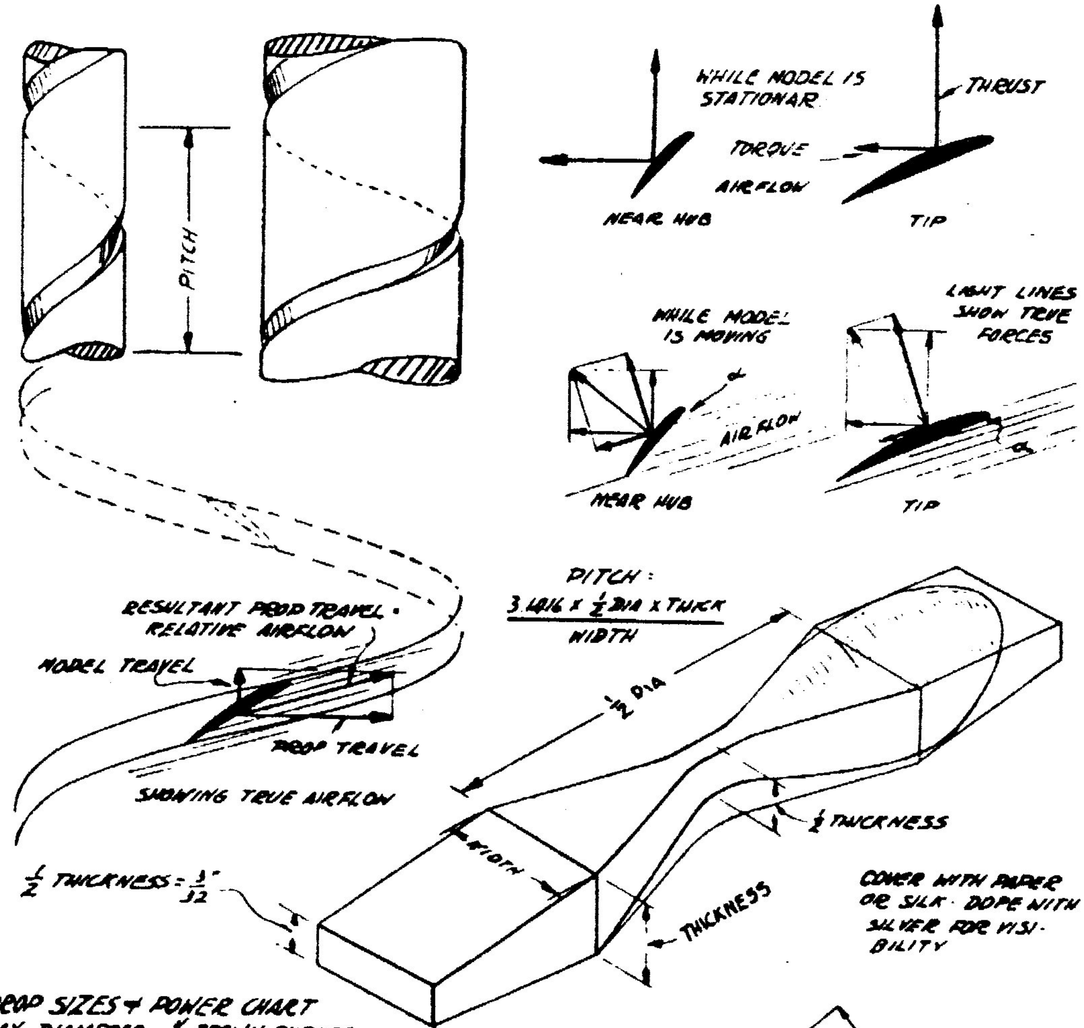
So far, we have just given the advantages this particular blank design has in the way of thrust. As you will note from the force diagrams, the lower the blade angle, the closer is the lift resultant to the center line. In case of high angles you will note that this lift is actually a working part of its force against the rotation — so that besides the usual drag we also have this force to overcome by the power. This is another reason why we lowered the blade angle at the hub, and why a spinner will increase the efficiency. If we simply have these forces to overcome by power it would not be so bad, but the pity is that the total of these forces is transmitted to the rear of the motors and it presents itself as our arch enemy, the torque.

In finishing a propeller we must still carry on the idea that we must fit the propeller to the model. As we have learned before, a cambered airfoil gives much more lift at a given angle than the streamlined section. If a model is heavy and bulky, carve in plenty of camber; this is especially applicable to flying-scale models, On a streamlined job you can use just a shade of under-camber. Since every bit of blade drag is made evident in torque it behooves us to give the propeller a very smooth finish, with fine sandpaper and doping. It always pays to coat them with wood filler with a final sanding, wet or dry.

The final word will be on "to freewheel or not to freewheel" Freewheeling is unquestionably the desired method. (However, folding propellers are best.) By analyzing the still and rotating propellers, we can definitely determine the value of freewheeling. The diagram shows the action of airflow in both cases. On the still propeller the airflow is head-on and it makes the forces as shown. We have a drag and a lift which is translated into a rotating tendency, a poor feature for which we must make counter adjustments.

Now a freewheeling propeller has an air flow which is negative in respect to its flying conditions. This negative angle of attack is determined by the drag the propeller has; the greater the drag, the greater must be the angle to provide sufficient force to keep the propeller rotating. We know that an undercambered propeller poorly finished will need a large negative angle. Large blade area will also require greater lift force. Therefore, in the case of free wheeling propellers it is essential that we use ball bearing washers and freewheelings which work on a ratchet or other means which do not use a spring force. Also be sure that the blades are well polished and well outlined.

There is no question but that the propeller is the most important part of the model. It is our only means of changing the energy stored in the twisted rubber into a forward motion. The sooner you decide that you give more time to the propeller, that much sooner you will reach the "expert" class.



PROP SIZES + POWER CHART
MAX DIAMETER 1/8 BROWN RUBBER

WING AREA	ORDINARY MODEL				STREAMLINED			
	DIA.	TH.	WD.	POWER	DIA.	TH.	WD.	POWER
50	8	7/8	1 1/8	6	9	1	1 1/2	6-8
75	9	1	1 1/2	8	10	1	1 5/8	8-10
100	10	1	5/8	10	11	1 3/16	1 1/16	10
125	13	1 1/8	1 5/8	16-14	14	1 1/16	1 1/16	14
150	15	1 1/8	1 7/8	20	15	1 1/8	1 7/8	18
175	16	1 1/2	2	24	16	1 1/2	2	22
200	17	1 1/8	2 1/2	28	17	1 1/8	2 1/2	26