EXPERIMENTAL ANALYSIS OF THE INDOOR PROPELLOR

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The indoor model airplane occupies a unique position in the freeflight model aircraft spectrum. It is the only type of model whose sole competitive goal is to fly for the longest possible time under (presumably) still air conditions. Such goal requires that the model be under power for the entire flight, never normally reaching true power off conditions, and so the design, construction, and adjustment of the model are all geared to the attainment of this end. The model flies freely under fixed adjustments with a wound up elastic motor providing the source of energy. High available power at the start of the flight provides climb; dimunution of power results in level flight, Further diminution of power results in descent.

It follows that level flight will occur only under a precisely defined set of conditions. If we change the adjustments, the overall weight, the center of gravity, we have changed the conditions for level flight. There is thus, for any specific set of conditions. a fixed power requirement for the model in level flight, excluding the power consumed by the propellor. As a corollary, for any specific set of conditions there is a single, fixed, level flight velocity. (While not pertinent to this paper, it might be of some interest that unpublished analyses by the author of laboratory movies of indoor models in flight show lowest flight velocity in climb and highest velocity during descent!) Since level flight provides easily measured data, it would be nice if, in some way, we were able to use these data for propellor analysis.

It proves to be relatively simple to do this graphically by a method which the author first demonstrated some years ago. (Ref. 1). Additionally, the data enable easy calculation of propellor efficiency. To understand the procedure we will look firstly at the lift and drag forces (which at the outset are unknown) on an airfoil and then how they are oriented on a propellor blade — which is but an airfoil with a substantial amount of twist. Secondly, we will look at the measurable forces on a propellor blade, those due to thrust and torque. Lastly, we will see how these two sets of forces can be linked to ascertain the lift and drag on a blade cross section through a graphical process and calculate the propeller efficiency from the data which have been obtained.

Figure 1 shows the lift and drag exerted on an airfoil by the air flow over it. By definition the lift is perpendicular to the relative wind; the drag parallel. These two forces are at right angles and so we can obtain a "resultant" single force, combining the lift and drag as shown.

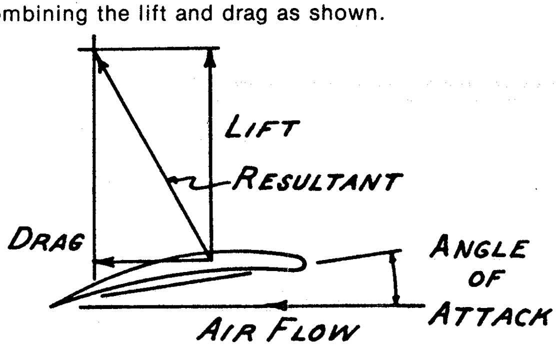


Figure 1

We can visualize these forces on a section of a propellor blade as this blade is turning, moving forward through the air. The air is flowing past the blade shown in Figure 2 with the lift, as before, normal to the air flow, the drag parallel to it. For the present we need not be concerned with the location of this cross section along the blade. Later we will use the cross section at the middle of the blade length as representing the average of conditions upon the balde (Ref. 2).

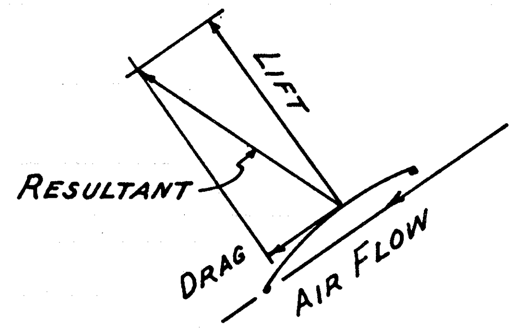


Figure 2

Now let us look at another set of forces produced by the air and acting upon the turning propellor, Figure 3. The air is pushing forwards against the propellor to urge the model ahead: this is the thrust. The air is also acting upon the propellor to keep it from spinning; this force, for want of a better term, we will call the "torque force." Since torque is force times arm, we can obtain this force by dividing the motor torque by a suitable arm. In this case the arm will be the distance from the propellor shaft to the midpoint of the blade length.

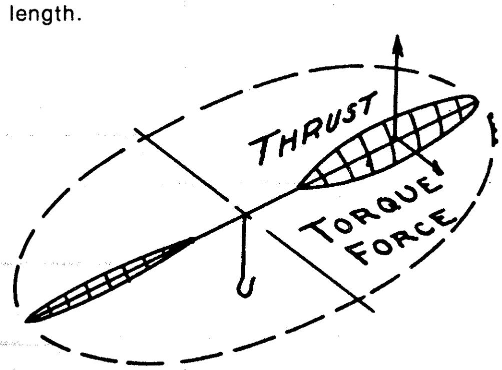


Figure 3

These two perpendicular forces can be combined as we did the lift and drag. We then obtain their resultant force as shown in Figure 4.

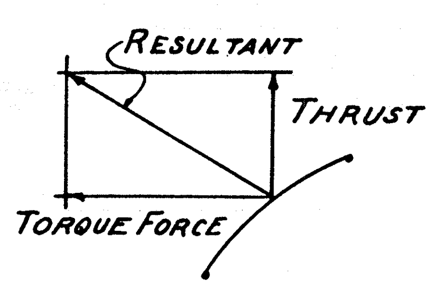


Figure 4

What has been accomplished by this? The apparently different resultant forces shown in Figures 2 and 4 are actually one and the same. By superimposing these two diagrams we tie together all of the important forces upon the propellor (Figure 5). This diagram deserves careful inspection. The thrust is the only element in it which is constant. Losses are compounded. Suppose, for example, the blade drag is increased. Additional lift is needed to maintain the same thrust. This additional lift can come only from higher blade RPM which, in turn, requires higher torque.

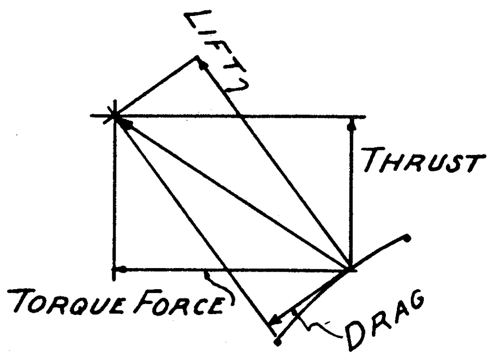


Figure 5

A little test work and an accurate scaling of Figure 5 will provide a satisfactory amount of information on an indoor propellor. As an illustration, consider a model having the following measured values:

Propellor:	16" dia., 1½" x 6¾" blades, 39° pitch angle at blade middle 1.2 RPS in level flight
Torque	0.10 inch oz.
Thrust	0.016 oz. (Model drag)
Velocity	23"/sec. in level flight

The only item of any question is the thrust. How was it measured? The bending of a straight length of small diameter music wire, one end being mounted in a handle was calibrated. This was then used as a wand to tow the model. The scheme proved reasonably successful. Since the thrust is equal to the model drag, glide techniques to evaluate the L/D ratio of the model could also be employed. In any event, if a given model is used for a series of propeller tests, and a little care is employed to ensure unaltered overall weight, C.G. location, and adjustments, the drag will remain constant. We cannot hope for absolute accuracy, while the relationships we obtain through a series of tests will not be affected by a possibly slightly erroneous constant value of drag. In Figure 6 the following steps, based on the above data, have been carefully laid out to scale. (In the original the force scale was 0.1" = 0.001 oz. and the distance scale 0.1" = 1.0").

1. Circular distance swept out by blade midpoint each second, midpoint diameter x pi x RPS = 9.25 x 3.14 x 1.2 = 34.8 inches.
2. Forward motion per second = 23 inches
3. Relative wind direction
4. Thrust, 0.016 oz., parallel to flight path
5. Torque force, torque/radius of blade midpoint = 0.10/4.62 = 0.0216 oz.
6. Resultant force on blade
7. Lift line drawn perpendicular to relative wind
8. Drag line drawn parallel to relative wind

At this stage the lift and drag can be scaled directly from the drawing and the lift/drag ratio immediately obtained. By drawing a last line at 39°, the pitch angle, the angle between this line and the relative wind — the angle of attack — can be obtained.

The results for the case at hand would appear slightly unusual. The blade lift is 0.025 ounces; the blade drag, 0.009 ounces. The lift/drag ratio for the propellor with the model in level flight is only 2.8! This may seem rather low and suspect, but it should not be. Indoor models are not noted for high lift/drag ratios. Hundreds of glide tests by the author on another project (Ref. 3) found lift/drag ratios ranging downwards from five. Hacklinger (Ref. 4) obtained, at best, a ratio of about 6.5 for his championship model. When indoor models, carefully trimmed, and with areas in the vicinity of a square foot are only capable of such puny lift/drag ratios it is not to be wondered that a propellor with but a tenth the area, severely twisted, would have an L/D of only 2.8.

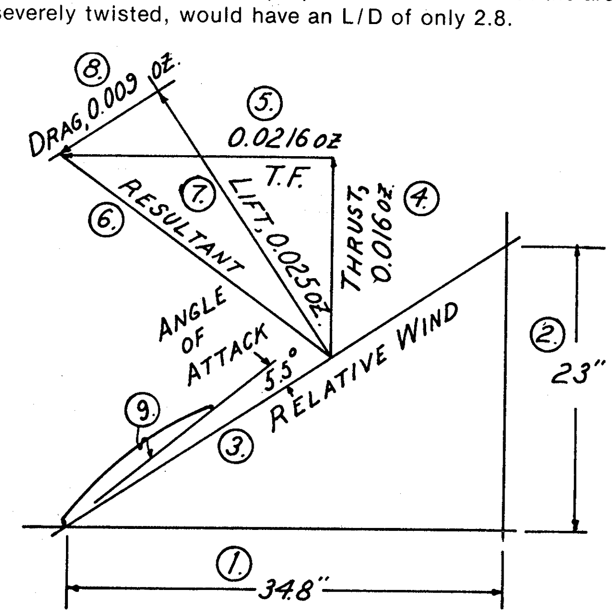


Figure 6

Sufficient information also exists to determine the propellor efficiency. In the sense in which we use it, the efficiency is the output divided by the input. The output is the model velocity times the drag; the input is two pi times RPS times the torque. The calculated efficiency for the propellor we are analyzing is 49%.

A number of years ago the author constructed an adjustable pitch 14" diameter propellor. A series of tests had been made on this propellor at varying pitch/diameter ratios, flying a rather standard B tractor. The results are shown in the graphs of Figures 7 and 8. The results would seem to agree with indoor practice. Both the lift/drag ratio and the efficiency are increased as the pitch setting is increased. The 20% increase in efficiency from a P/D ratio of 1.6 to a P/D ratio of 2.0 is sufficient explanation for the use of high P/D ratios, the upper limit normally being governed by the stalling of the propellor.

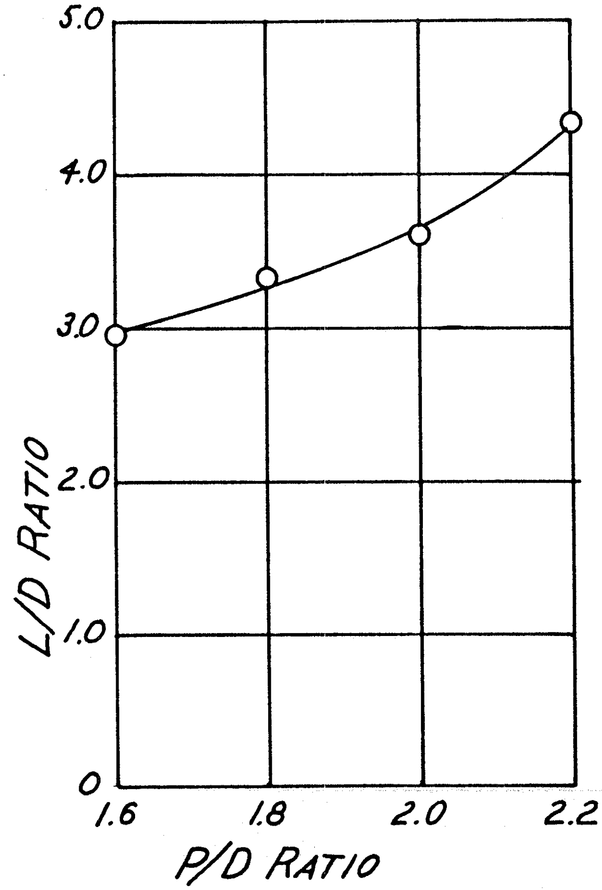
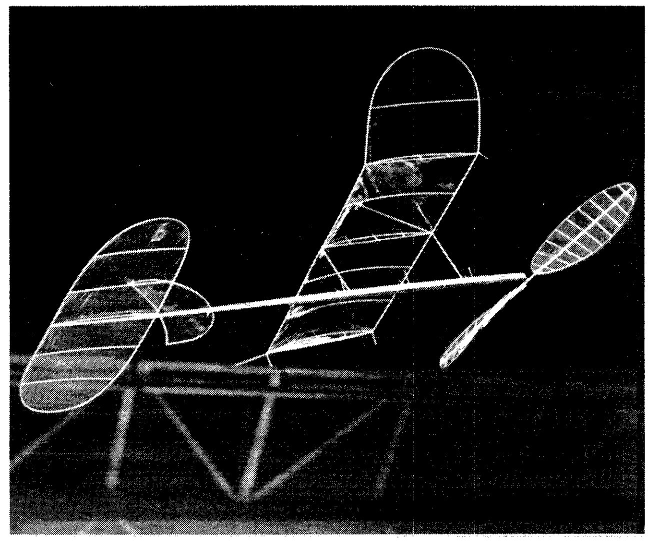


Figure 7



. . . Ron Williams' FAI

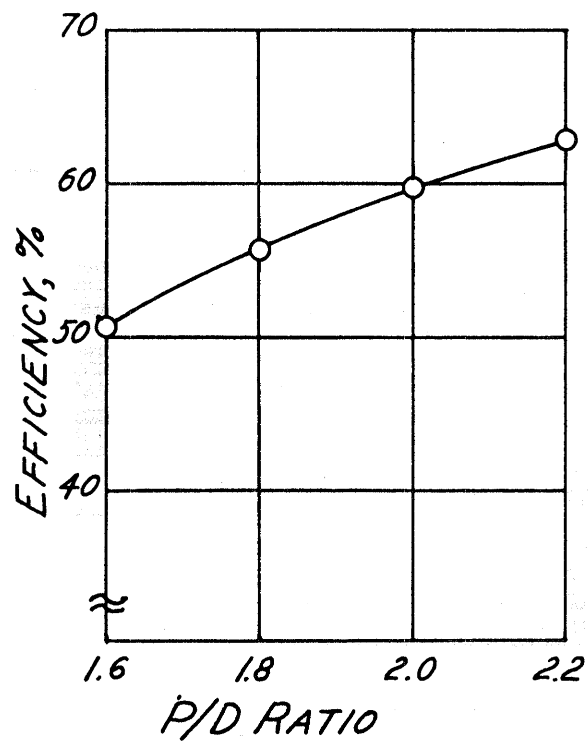
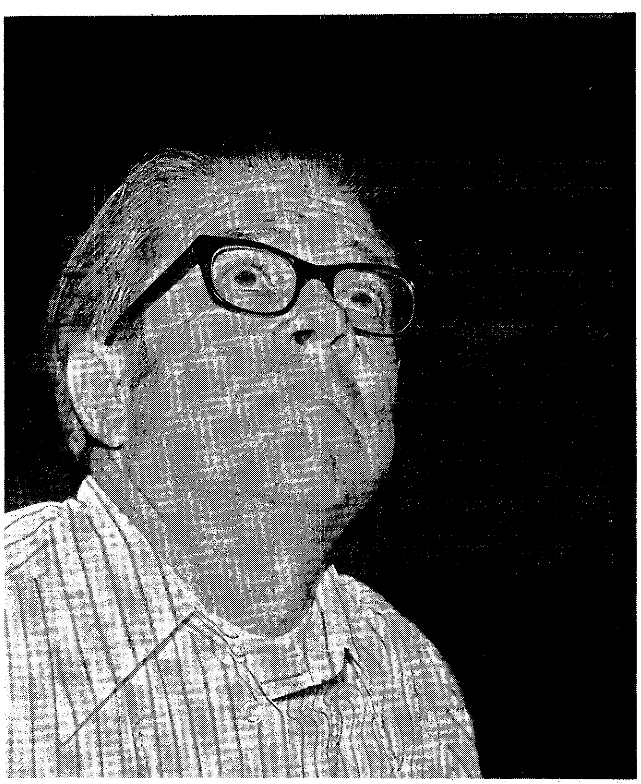


Figure 8



Al Rohrbaugh observes. . .

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