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Matching Propeller to Mission

By: Don Brooks

My all-time favorite aircraft to fly is a .40-powered semiscale P-51D Mustang. However, landing this model used to be another story entirely; it was too fast on final to make a three-point landing. Every good landing had to be a "wheels" landing with touchdown on the mains. Landed in this manner, the model often flipped over and struck the fin ignominiously on the pavement as it skidded to a stop.

My trips out on the runway to retrieve my upside-down aircraft were a source of shame. I almost decided to go back to my high-wing trainer and forget the Mustang. Then, during one particular flight, the most amazing thing happened: the engine flamed out. I had to shoot a dead-stick landing. It was the best approach and touchdown I had ever flown with the model; I even three-pointed the landing.

With the 10 x 6 propeller I was using and with the engine at idle, the model's airspeed was too high for an easy approach and landing. To reduce the airspeed on final, I switched to a 10 x 5 propeller. What a difference! The P-51 was still a pleasure to fly, and landings no longer ended with a flip and skid on the fin. Sometimes, when not limited by the pilot's skill, the landings were even graceful. Bring out the observers! I was ready to show them a thing or two.

Whether you are flying a hot warbird or a slow-flying Piper Cub, the propeller you select makes a great difference in how a model performs. With the right propeller for the model's mission, each flight is a delight.

"So, what is the model's mission?" you may ask. I judge the model's mission to be adequate performance in each of three phases of flight: takeoff and maneuvering, cruise level flight, and landing.

The takeoff-and-maneuvering phase tends to require a larger-diameter but shallower-pitch propeller for maximum thrust. Wing lift increases in step with the airspeed squared. To generate sufficient lift to maintain level flight with an aircraft having a high wing loading, we must fly at a higher cruise airspeed. So for cruise we may need a more steeply pitched propeller to get the higher speed.

If we increase the propeller pitch, we may also have to decrease the propeller diameter to maintain the engine rpm in the best operating range.

If we don't have flaps on the aircraft, we may be back to needing a lower-pitched propeller for the landing phase.

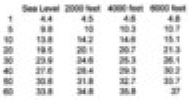
Since most of us don't have a variable-pitch propeller on our models, we must select a propeller that best matches at least the minimum requirement for each phase of flight. Therefore, selecting the propeller to match the mission requirements will be a compromise. To do this job properly, we need guidelines for making informed judgements.

I'll show you three tools you can use to make objective judgements on adjustments to match the propeller to your model aircraft's mission: graphs for calculating stall and minimum cruise speeds, graphs for calculating pitch speed, and equations and a graph for calculating the static thrust produced by a propeller.

To use these tools, you will need a tachometer. You will also need a way to calculate or measure static thrust. I'll show you how to do that. I'll make the judgements based on two rpm measurements: one at full throttle and one at idle.

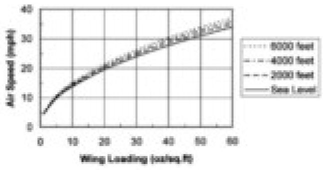
Does that sound simple? It is. I wish I had these tools when I was trying to solve the problem with the P-51. I would have been much more confident in the outcome of the propeller change and its effect on the Mustang's flying performance.

Stall and Cruise Airspeeds for Models: An estimated stall speed can be calculated using the equation in the sidebar. The calculation is even easier if one only has to look up a number on a graph, so in Figure 1 I've plotted graphs of model stall speed as a function of wing loading for four elevations: sea level, 2,000 feet, 4,000 feet, and 6,000 feet.



	Sea Level	2000 feet	4000 feet	6000 feet
1	4.4	4.5	4.6	4.8
5	9.8	10	10.3	10.7
10	13.8	14.2	14.6	15.1
20	19.5	20.1	20.7	21.3
30	23.9	24.6	25.3	26.1
40	27.6	28.4	29.3	30.2
50	30.8	31.8	32.7	33.7
60	33.8	34.8	35.8	37

Figure 1: Stall Speed as a Function of Wing Loading and Elevation



In the calculations for these graphs, I assumed a value of 1.3 for the lift coefficient, a temperature of 70 degrees Fahrenheit, and an appropriate barometric pressure for each elevation. A lift coefficient of 1.3 is the approximate value for several common airfoils when operated near the stall condition.

Please examine Figure 1. Airspeed is shown along the vertical axis. Wing loading is shown along the horizontal axis. To use the graph, calculate the wing loading; i.e., model ready-to-fly weight in ounces divided by the wing area in square feet. Locate the value of the wing loading along the horizontal axis. Slide a pencil point upward until you reach your flying-field elevation. Estimate a point for elevations not represented on a graph. Read the stall speed off the y-axis for your field elevation.

I'll use my P-51 as an example. Ready-to-fly, it weighed 88 ounces and the wing area was 490 square inches (3.4 square feet). The calculated wing loading was 26 ounces per square foot. At my flying field elevation of 4,740 feet, the stall speed for my P-51 is 24 mph.

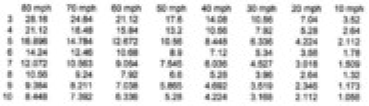
In the Model Airplane News article "Electric Power for Scale Models," Bob Benjamin recommended at least two times the stall speed as a minimum level-flight cruise speed. Applying this criteria to the P-51, the minimum cruise speed should be 48 mph. Keep these two values in mind as we look at the second tool: the pitch speed graph.

Pitch Speed at High and Low Throttle: Figure 2 shows lines of constant pitch speed for various combinations of propeller pitch and propeller rpm. The pitch speed is the maximum level-flight airspeed that would be achieved for a particular propeller rpm if the propeller did not slip in the air and the model had no drag.

However, we would never expect the model to fly at 100% of the pitch speed; real propellers do slip in air, and real models do have drag. But there is a compensating mechanism. Note that the propeller unloads when in level flight, which would make the in-flight rpm greater than what we measure during a static run-up on the ground. This propeller unloading compensates for some of the effects of slippage and drag.

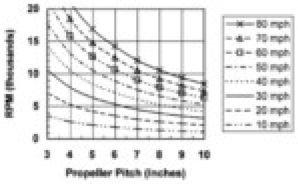
For our purposes I will assume that the high-throttle pitch speed is the same as the high-throttle airspeed in level flight. The relationship is not exact, but it gives us a useful gauging tool.

Let’s continue to use my P-51 with the 10 x 6 propeller to illustrate how this information can be used. With the 10 x 6, the high- and low-throttle rpm values were 11,000 and 3,000 respectively.



	80 mph	70 mph	60 mph	50 mph	40 mph	30 mph	20 mph	10 mph
3	28.16	24.64	21.12	17.6	14.08	10.56	7.04	3.52
4	21.12	18.48	15.84	13.2	10.56	7.92	5.28	2.64
5	16.896	14.784	12.672	10.56	8.448	6.336	4.224	2.112
6	14.24	12.46	10.68	8.9	7.12	5.34	3.56	1.78
7	12.072	10.563	9.054	7.545	6.036	4.527	3.018	1.509
8	10.56	9.24	7.92	6.6	5.28	3.96	2.64	1.32
9	9.384	8.211	7.038	5.865	4.692	3.519	2.346	1.173
10	8.448	7.392	6.336	5.28	4.224	3.168	2.112	1.056

Figure 2: Pitch Speed as a Function of RPM and Propeller Pitch



Looking at Figure 2, find the pitch of 6 and slide a pencil point upward along that line until you reach the rpm value of 11,000. Estimate the high-throttle pitch speed by the relationship of this point to the two closest pitch speed lines. Note that this point is approximately one-third of the way between the 60- and 70-mph lines. I read this pitch speed as 63 mph. This is well above the minimum cruise speed of 48 mph.

At low throttle, the pitch speed of 17 mph is not far below the stall speed of 24 mph. If the model were maintaining level flight at 24 mph, it could be just above the stall speed and fly on and on. This relatively high pitch speed with the engine at idle explains a lot about why my P-51 did not want to settle in during the final approach and landing.

When I changed the propeller pitch to 5 inches, I didn’t want to lose takeoff and maneuvering thrust. So instead of changing to a 10 x 5, I selected an 11 x 5. The 11 x 5 loaded the engine more than the 10-inch propeller, so the engine only turned it at 10,200 and 2,500 rpm at full and low throttle respectively.

Looking at the graph for a pitch of 5 inches and rpm values of 10,200 and 2,500, I read pitch speeds of 48 and 12 mph. I’m right at the recommended minimum for cruise speed. But now the combined effect of lower idle rpm and lower pitch have reduced the low-throttle pitch speed to roughly half the stall speed.

With the model on final and flying faster than the stall speed of 24 mph and with the propeller trying to move forward at 12 mph, the propeller acts as a brake to help slow the model. This combination of factors produces an easy, steady descent for landing. I have not only solved the problem, but now I have some numbers that we can tag to the aircraft performance if we want to try a different propeller.

Takeoff and Maneuvering Thrust: Now you might be thinking, “He changed the prop from a 10 x 6 to an 11 x 5. That took care of the high approach speed on final. But what did he do to the takeoff and maneuvering thrust for the model at full power?” One could calculate or measure the static thrust to ensure enough thrust for takeoff and maneuvering.

Using the thrust and air-density equations (see the equation sidebar), a modeler could simply calculate the maximum static thrust for the two propellers. For this calculation we need to know the propeller thrust coefficient and the air density.

The thrust coefficients for the Master Airscrew 11 x 5 and 10 x 6 propellers are 0.079 and 0.099 respectively. I obtained these values from Appendix C of my book Prop Talk, Understanding and Optimizing Propeller Performance for Model Electric Aircraft.

To calculate the air density, we need the local barometric pressure and air temperature. The average local barometric pressure for my flying field at 4,740 feet is 25.30 inches of mercury.

I assumed an air temperature of 70 degrees Fahrenheit. The air density under these conditions is 1.014 grams per liter. I calculated the thrust of the 10 x 6 propeller at 11,000 rpm and at this air density to be 50.6 ounces. The thrust calculated for the 11 x 5 propeller at 10,200 rpm was 50.8 ounces.

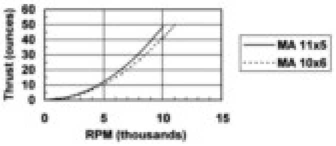
Even though the 11-inch propeller had a lower thrust coefficient and operated at a lower maximum rpm with my K&B .40 engine, it produced equivalent thrust because thrust increases with the fourth power of the propeller diameter.

If math is not your favorite thing, the thrust measurements for this third step could be made directly. A rough measurement could be made using a fishing scale attached to the tail of the aircraft during a run-up with each of the propellers to be compared. More accurate bench measurements could be obtained using an engine test device such as the American Hobby Products Thrust-Finder. This bench test could be done even before you have the aircraft built.

I plotted the thrust curves for the Master Airscrew 11 x 5 and 10 x 6 propellers, ending at the maximum rpm for each with the K&B .40 in Figure 3. These graphs show how the propeller thrust changes with rpm.

	MA 11x5	MA 10x6
0.001	0.001	0.001
2	2	1.7
4	7.8	6.7
6	17.6	15
8	31.2	26.7
10	48.8	41.8
11		50.6
10.2	50.8	

Figure 3: Thrust Graphs for Two Master Airscrew Props at 4740 Feet and Air Temperature 70 Degrees F



If the thrust coefficient, air temperature, and barometric pressure are known, plots such as those in Figure 3 can be made for any propeller for various values of operating rpm using the thrust and air-density equations. Here is some work for your calculator. These graphs may be useful on those days when the engine rpm is lower than previously measured for some reason. You could use the graphs to verify that you still have sufficient takeoff thrust.

So for the Mustang and the change to the 11 x 5 propeller, I've verified the match of the propeller to the model mission. I've reduced the model's approach speed while preserving thrust for takeoff and maneuvering and ensuring sufficient pitch speed for cruising flight. When I made the adjustment a long time ago, it was by trial and error. I've verified my expectations from the long-ago adjustment using graphical estimating tools.

Matching the J-3 Mission: My friend Ken Marler had an engine I wanted to bench-test for possible use in a 1¼4-scale Piper J-3 Cub. The engine was a Fox .74 two-stroke, and Ken's suggested propeller was a Zinger 12 x 5. We set up to test this combination on my new Thrust-Finder.

At high and low throttle, the rpm readings were 10,800 and 4,800 rpm. The Cub was projected to weigh 15 pounds (240 ounces) and would have a wing area of 1,600 square inches (11.1 square feet). The wing loading was calculated at 22 ounces per square foot.

From Figure 1, the stall speed for the J-3 would be 22 mph, and the minimum cruise speed would be 44 mph. From Figure 2, for a propeller pitch of five inches operating at the low- and high-throttle rpm we measured, the pitch speeds would be 23 and 51 mph. The measured full-power thrust was 93 ounces, which more than meets my minimum guideline of one-third the model's weight (80 ounces) for takeoff thrust.

With a stall speed of 22 mph and a low-throttle pitch speed of 23 mph, this model would be worse than the Mustang. It would never land until it was out of fuel. Obviously, we did not have the idle adjusted properly. This engine should easily idle at 3,000 rpm or less. From Figure 2, for a propeller with five-inch pitch and with it spinning 3,000 rpm, the pitch speed would be approximately 15 mph. This compared to a stall speed of 22 mph is barely low enough to land. A

12 x 4 might work better.

Let's see how the numbers work out for the 12 x 4 propeller. At 3,000 and 10,800 rpm, it would give pitch speeds of 12 and 41 mph respectively. The 12 x 4 would work better in the landing pattern but would provide a full-throttle pitch speed less than the minimum cruise speed of 44 mph. At 10,800 rpm and an air density of 1.014 grams per liter, a Zinger 12 x 4 with a thrust coefficient of 0.075 (reference Bob Benjamin's article) would produce 76 ounces of thrust, which is a bit less than we think we need.

Let's hope that the decrease in pitch results in an increase in the high-throttle rpm. If so, this could fix the thrust and cruise-speed problems. We could try this propeller knowing that the takeoff run would probably be a bit longer than with the 12 x 5.

What have we done? We defined the model mission as adequate flight performance in all three phases of model flight. We examined three tools that use rpm readings for input to help us match the propeller to the model mission.

Figure 1 can be used throughout a wide range of flying-field elevations, and Figure 2 is universally usable, regardless of location or air-density considerations. Preserve them for future reference; you could laminate Figures 1 and 2, and keep them in a handy place. Figure 3 is only good for the specified propellers, air temperature, and air pressure. If you want to use graphs such as these, you must construct your own Figure 3 for your particular propeller(s) and flying location using the thrust and air-density equations.

Have you matched the propeller of your favorite model to its mission? Try it; a successful match makes the flying much more fun. Good flying! MA

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