Boosting Performance

Aircraft design, construction and pilot techniques determine the result.

By Bill Welch

Performance: That's what it's all about for some builders and pilots. How to get the best out of your aircraft is the big question. There are plenty of generalities about improving performance that most people in sport aviation know about, but that's only part of the story. And there is no single answer to optimizing performance. The right one depends on the particular kind of performance you want, the aircraft design, and even the prevailing weather conditions. More than anything, maximum performance depends on attention to detail.

Pilots tell some wild tales of performance and how to get it, but most of these fall before a critical look. The old term *getting on the step* is one will-o'-the-wisp. Seaplane takeoff, where the aviation term originated, is different. In that case, getting up from buoyancy to planing on the bottom surface forward of the step definitely reduces water drag and facilitates takeoff. Although there are specific circumstances in which a distinct step in airborne performance can be achieved, they depend on design faults such as bad flow that is cleaned up at lower angles of attack.

High Speed

If speed is your object, surface finish, smoothness (fairness) of contours and elimination of leaks are important factors. A sharp break in a contour almost anywhere can trigger turbulent flow or separation and increase drag. Gaps around doors and canopies or between other components can also cause a major increase in drag. This is why taped joints are a common sight at competitions.

Figure 1 shows the drastic effect of NACA's *standard roughness* on the leading edge of a wing. Automotive body fillers are often applied to improve surface quality despite the associated weight.

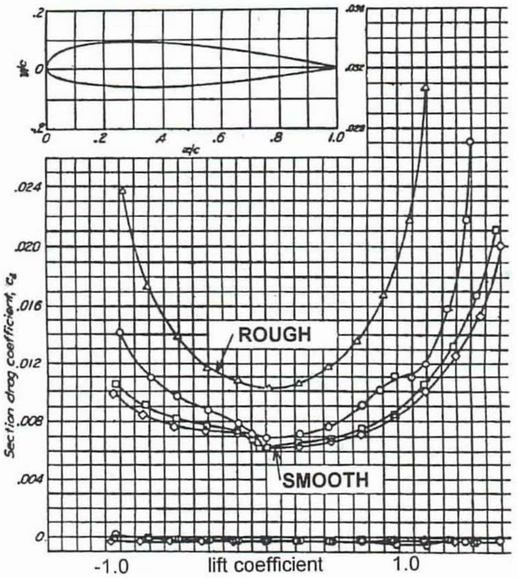

Figure 1. The upper curve shows lift and drag coefficients with leading-edge roughness.

Engine Power

But what about power? Speed demands all you can get of that, which in turn requires its own brand of TLC.

Vital questions about power include whether the engine gets all the air it needs at a good ram pressure. That alone demands careful design attention and workmanship in the execution.

Few aircraft have really good induction systems. First, the intake must be in the right place to obtain maximum total pressure recovery, and it must be the right size. Next, the pressure must be contained and conducted right to the carburetor or manifold. If there is an air filter in the system, it must be large enough and the velocity through it low enough to avoid serious loss of ram pressure.

Hot air leaking in when not needed can take a large bite out of available engine power. So can unintended heating of the basic induction system. The SeaBee, for example, suffered from a built-in temperature rise that reduced its available power.

Internal cleanup of the engine and accurately fitted components such as pistons and rings can be important. Power output tolerance for a type-certificated engine is 5%. There are shops that specialize in cleaning and tuning engines to maximum performance, sometimes called *blueprinting*. That's just to get the rated power. In some cases the rated power is exceeded by a variety of means including operation at higher speed.

Outside Influence

Most airplanes have a number of bumps and lumps or external features such as antennas, airscoops and exits. They all produce drag. Maybe not much individually, but in total they are significant. An external feature that is not properly faired can cause additional drag on the main body of the aircraft, beyond the drag of the extra feature itself.

Even those manufactured with supposedly favorable shapes generally fall short of optimum streamlining. The best thing to do with an antenna is to hide it. In an airplane with nonmetallic components, it is often possible to place antennas internally. On metal airplanes, wingtip caps may be nonmetallic and good enclosures for the antenna. Directional performance might require two connected elements at the two wingtips. Fin tips and leading edges also have been used to advantage.

An intersecting strut or unavoidable external antenna needs a fillet long enough to minimize the interference drag. According to Hoerner in his book *Aerodynamic Drag*, its length should be in the order of 10 times the strut or antenna chord. The best fineness ratio for a strut or mast is about 3:1. For a blister, as much as 15:1 is needed.

For a wing/fuselage or tail intersection, the purpose of a fillet is to open any re-entrant (closed angle) corners and reduce the effective thickness ratio of the wing at the juncture. In most cases where two different shapes join, the transition should be as gradual and as smooth as possible. Look at how a bird's wing and body are blended.

When external features are unavoidable, it may be possible to pick a location where the damage is limited. Numerous studies have shown that areas aft of the maximum thickness of a fuselage or aerodynamic surface is where protuberances add the least drag. In the vicinity of maximum thickness, the velocity near the surface is at a maximum, appreciably greater than free-stream velocity. To minimize drag, you would want to avoid anything sticking into these high-velocity areas.

Cooling It

The manner in which cooling air and engine exhaust are discharged can be very good or very bad for performance. If engine baffling is sloppy and leaky, more pressure differential is needed to move enough cooling air through the cylinder fins and oil cooler. When the inlet or outlet is in a poor location, obtaining that pressure difference will cause more drag than if the locations are well chosen.

Giving a little thought, you soon realize the pressures on aircraft surfaces vary wildly. Taking advantage of them is not difficult; you just have to pay attention and look at typical pressure distributions. Better yet, measure some pressures on the particular aircraft involved. A water manometer is simple to rig and safe to use.

Discharging the flow as nearly as possible parallel to the external flow is best, and if you can match the velocities with proper outlet sizing you have the best possible conditions.

For an oil cooler or a radiator, don't aim a concentrated stream of air at the core. Use a plenum chamber ahead of the unit so the velocity is as uniform as possible through the core. This arrangement takes the least total flow and causes the least drag. Merely expanding a duct does not work unless the expansion is so gradual that the flow remains attached to the diffuser walls.

Because there is twice as much energy in the cooling air and exhaust as is delivered to the propeller, it is even possible to recover some useful propulsive thrust with clever design. The P-51 demonstrated this principle in the early 1940s with an outlet area properly matched to the heat to be dissipated and the external flow.

Once you are satisfied the engine is delivering as much power as it should, and that cooling drag has been held to a minimum, it's time to optimize the propeller design for the desired result. Again, if speed is the object, the propeller can be fine-tuned for maximum airspeed at the maximum propeller rpm. This is not a simple task, and you need either a good propeller designer to advise you, or one of the available propeller specification computer programs to find the right combination of diameter, pitch, solidity and number of blades.

Low-Speed Performance

If takeoff and climb performance is your game, the propeller selection must be biased to favor these segments of a flight. However, this would penalize cruise speed and limit maximum speed because of the need to avoid overspeeding the engine. The solution to these problems is controllable propeller pitch.

Prop diameter is constrained by tip speed, which can impose a large penalty if excessive. The general principles apply: You need large diameter to have large thrust at low speeds. At high speeds, large diameter can hurt, and it is not needed for efficiency because ample mass flow through the system is inherently available at high airspeeds.

Although I do not generally recommend wingtip modifications, when dealing with an existing airplane and the need to maximize takeoff and climb performance, you may find them useful. The winglet or end plate can be used to improve induced drag in specific conditions. But it can be a tight tradeoff between cutting induced drag and increasing parasite drag. The main caution here is that these fixes may work only at high lift coefficients and will not improve high-speed cruising at moderate altitudes.

Another low-speed problem is that high-speed airfoils often don't behave well at low speeds where high lift coefficients and large angles of attack are needed. Consequently, the low-speed performance of some airplanes has been improved along with handling characteristics by the installation of a drooped leading edge. This is usually done on an existing airplane with a glove or cuff fitted over the leading edge to increase the camber of the airfoil. The leading-edge radius can also be increased for some further increase in maximum (stalling) angle of attack. STOL (short takeoff or landing) kits have been certificated for some lightplanes using these leading-edge gloves.

Flaps installed on some airplanes can reduce low-speed drag at moderate extension angles. This is a chancy situation, as the improvement would occur in a narrow speed range and would depend on precise technique. Either the manufacturer's recommendation or a careful examination of power-required and power-available curves with flaps extended is necessary to be sure of the potential benefit.

At Any Speed

External components such as fixed landing gear can be major drag producers or they can be easy on the power required. The key words are *well-faired* in real aerodynamic terms.

Long flowing shapes are usually not the best. Optimum length/diameter ratios for three-dimensional bodies are on the order of 3:1. This is because skin friction drag adds rapidly with increasing total wetted area. Much of the drag often originates in the junctures such as where the strut joins a wheel fairing. These can be treated with proper fillets similar to those at other intersections.

Common spring landing gear struts are flat, usually with rounded edges. Much better shapes can be used for composite struts or those made of metal tubes. The ellipse is appropriate, as it is difficult to predict the exact direction of air flow across the entire length of a strut. Elliptical cross sections are less sensitive to angle of attack than flat ones or those with sharp trailing edges, but they still have modest drag coefficients.

Retractable landing gear presents a different problem. Most are not well sealed when retracted. Some leave the wheel partly outside the airframe contours, making matters even worse. This is a case needing attention to minute detail.

Flying technique has a great deal to do with the performance actually realized in any aircraft. A pilot who continually applies unnecessary control inputs will reduce performance. On the other hand, an airplane without adequate stability will demand continuous control, and performance can be improved by the correct pilot technique. Even more improvement can be achieved by increasing the inherent stability. Sometimes a dorsal fin or similar extension on the horizontal tail is enough. Keeping the center of gravity as far forward as possible can also help an airplane that is marginally stable.

Operating the engine on optimum fuel/air mixture can make a little extra power available. With a controllable propeller, the engine can be operated at full throttle in many situations, which favors fuel efficiency and enables the pilot to attain the airplane's maximum range. Selecting the most favorable altitude for performance also helps to squeeze out every bit the airplane can give.

Selection of cruise speed is another opportunity to maximize performance. While you need to see the power-required and power-available curves for the airplane to find the best-range speed, you can always increase range by reducing cruise speed below normal levels.

Finally, you can often take advantage of weather data and forecasts to maximize cross-country performance. Most favorable wind (or least harmful) can usually be identified in the winds aloft forecast.

Here is an easy, little-known trick that you can exploit using the pressure-pattern navigation technique. With a first estimate of time en route, calculate the total drift, both cross track and along track, for all the winds along the route. Then offset your destination in the opposite direction the same distance, and navigate to this corrected location using only a single heading. This works because you are not flying a fixed track on the ground; you are flying in moving air. Therefore, you are aiming for the air that will be at your destination when you arrive.

General

There are many things the builder and pilot can do to obtain the very best possible performance from any existing airplane or building project. Most important of all is the careful attention to details and thoroughly analyzing any proposed deviations from a design. ***KP***

Author Bill Welch died in February of complications from pneumonia. Bill's widow, Virginia, has allowed us to publish his articles still on file, agreeing that they are a tribute to his life's work.—Ed.