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Drag Reduction 101:

Cleaning Up Your Flying Cactus.

Drag reduction is the single best way to improve airplane performance. Increasing power can make an airplane faster, but the extra speed comes at the cost of increased fuel consumption and reduced range, or lower payload if we do not increase gross weight. Reducing drag, on the other hand, saves fuel, makes the airplane faster and increases either range or payload at a constant gross weight.

Some ways of reducing drag involve major changes to the airplane, but many do not. Drag reduction can be relatively simple and cheap. Most airplanes have a lot of unnecessary drag that can be eliminated by some careful modifications.

Assessing Your Aircraft

The first step in a drag cleanup program is to identify as many sources of unnecessary drag as possible. These need not all be big drag producers. Reducing drag is like scraping barnacles off a boat. Even though you may not see the effect of removing one barnacle, if you get rid of enough of them, the effect can be large. A walk around the airplane with an eye toward what features are likely to disturb the airflow will usually reveal some things that can easily be improved.

Most airplanes have components that stick out from the skin of the airplane into the airstream. Each of these produces drag. Some airplanes look like flying cacti, with a forest of antennas, exhaust pipes, boarding steps, vent pipes and other projections. Often these are on the bottom of the airplane and we don't see them when standing on the ramp. Exposed hinges and door handles are also common. All of these generate drag, and the cumulative penalty can be quite large. Fortunately, most of this drag can be greatly reduced with a little work.

Count Your Cylinders

Many airplane components have cylindrical cross-sections. Among these are landing-gear legs, exhaust pipes, antennas, boarding steps, some bracing struts and wires, vents and drains, and most of the structure of many ultralights. These cylinders are high drag for their size. A cylinder normal to the flow has a drag coefficient based on frontal area of 1.1 at low Reynolds Numbers and 0.3 at high Reynolds Numbers. This is approximately five times the drag coefficient of a turbulent airfoil at high Reynolds Numbers and can be as much as 50 times the drag coefficient of a laminar airfoil at lower Reynolds Numbers.

There are three approaches to reducing the drag of cylindrical projections. The first is to eliminate the cylindrical projections or keep them as small as possible. The second is to fair the cylinders into a more streamlined shape, and the third approach is to sweep the cylinder forward or back relative to the airflow.

Fairing a cylinder into an airfoil shape can reduce its drag by up to 90%. For fixed components such as struts, wires and landing-gear legs, we can get this 90% drag reduction by adding relatively simple fairings. Even a simple, straight-sided wedge fairing mounted on the back side of the cylinder can decrease its drag by 60%.

Wires are harder to fair because they are flexible. Streamlined bracing wire can be used in place of cylindrical wire to reduce drag, although it is relatively expensive and has to be made specially for each length because there are threaded cylindrical ends to accept fittings. In the early days of aviation, when the drag of cylinders was not properly appreciated, designers did not believe that the drag of the bracing wires was significant. However, the development of streamlined wire did much to improve the performance of the airplanes of the 1920s and '30s.

Where fairing is impractical, sweeping is the preferred approach to reducing the drag of cylinders. Sweeping a cylinder causes its drag to decrease quickly with increasing sweep angle. This can be useful because some projecting components are difficult to fair with add-on parts. Exhaust pipes are a good example. They are relatively large and hot enough to melt or char a composite or plastic fairing. Sweeping an exhaust pipe back 45° can reduce its drag by 65%. Sweeping it back 60° can reduce its drag by as much as 85%. Antennas that cannot be covered without losing effectiveness should be swept as much as possible to reduce drag.

Many production airplanes have boarding steps that remain fixed when the airplane is in flight. Usually, these consist of a step mounted below the airplane on a piece of cylindrical tubing. Often, the step itself is also a piece of cylindrical tubing. A typical step can cause as much parasite drag as several feet of wing. A boarding step should either be retractable, removable or, at the very least, made of streamlined tubing to reduce the drag.

Another common drag culprit

on light airplanes is the outside air temperature (OAT) probe, which often sticks out perpendicular to the surface of the airplane near the top of the windshield. This is a particularly bad place for a protrusion, as the air is locally accelerated when it flows over the crest of the windshield. Putting the OAT probe in this position guarantees that the high-drag cylindrical probe is sitting in an area of high-speed airflow, where its drag will be as high as possible. It's easy to think that something this small doesn't produce enough drag to be important, but on a clean, fast airplane, it can actually cost several knots.

Locks seem to be another area where people get lazy about drag. Many airplanes have multiple door locks, on cabin doors and baggage doors. Often, the barrel of the lock sticks up at least a quarter-inch above the surface of the skin.

Bumps and Blobs

Many of the items that project from the airplane surface have relatively smooth shapes. These bumps may include hinges, lights, fuel-filler caps and similar items. The drag penalty of a smoothly faired bump is relatively small unless it is placed where the flow over the bump interferes with the flow over another part of the airplane. The drag penalty can become larger if such bumps are placed in a critical area such as the upper surface of a wing. A bump will cause the boundary layer to become turbulent, and an expanding wedge of turbulent flow will form behind it. If the bump is placed in an area where it might cause the flow to separate, the drag penalty might be high.

Some bumps are not truly streamlined and have shapes that are bluff and more closely resemble hemispheres or flattened cylinders. The drag penalty of these shapes is higher than that of smoothly faired bumps because the flow will separate from the bluff after-portion of the bump. This can be particularly bad if the bump is on the upper surface of the wing, where it acts as a small spoiler.

Another culprit in this area is fuel-filler caps. It is common for these to project above the wing surface and induce separation over part of the wing surface aft of the cap. The drag penalty of such a design can be large. If it is necessary to put filler caps in the upper surfaces of wings, they should be as far aft as possible, and they should be flush with the wing surface. Such a cap will still trip laminar flow, but at least it will not cause a large area of flow separation on the vital upper surface of the wing. GPS antennas mounted on top of the airplane near the crest of the windshield are another high-drag culprit.

If the airplane must have bumps on its surface, they should be as smooth and as streamlined as possible. Bluff shapes should be avoided, and no bumps should appear on the upper surface of the wing. Items that can be mounted flush should be. Lights for night flying are a good example. Tip lights, strobes and rotating beacons are often mounted on the airplane surface. Many of these can be flush-mounted, particularly those on the wingtips.

Items such as locks and gas caps should also be flush with the skin. If this is not possible, then the area around the cap or lock barrel should be built up to form a gradual ramp in front of and behind it. The same approach can be used to fair door hinges.

How Much Do You Gain?

Drag cleanup efforts seem to provoke a lot of discussion and disagreement in the homebuilt community. One builder will make a modification and report a speed increase, and someone else will try the same thing and report a significantly different result. Often, this prompts an argument about who "did it right" or who is reporting results accurately. In fact, it is likely that both modifiers are right because the speed increase they got from their modification is affected not only by the amount of drag the modification itself produced, but by the drag of the airplane as a whole.

The effect of a given amount of drag reduction on the performance of an airplane depends on two things: the total drag of the rest of the airplane and the speed the airplane is flying. Suppose, for example, we retract the landing gear. If the rest of the airplane is high drag, the drag of the landing gear is a small percentage of the whole, so eliminating the drag of the gear by retracting it may not produce a useful increase in speed. Early airplanes had many drag producers other than fixed landing gear and until these were eliminated, retracting the gear didn't do much good. Tumbleweed with retractable gear isn't a whole lot less draggy than plain old tumbleweed.

As the airplane gets aerodynamically cleaner, the penalty due to a given drag wart gets larger, both because it is a larger percentage of the total drag of the airplane and because the airplane is going faster in the first place. The faster the airplane is flying, the more drag a given component of the airplane produces.

For example, suppose we had an airplane that had 180 hp and a top speed of 100 knots (very draggy indeed, maybe an open-cockpit biplane). If I clean up a typical rotary beacon light by fairing it, the airplane gains only about 0.1 knots in top speed, hardly worth the effort. If the airplane goes 150 knots, the same fairing increases speed by 0.6 knots. If the airplane goes 200 knots, the fairing increases speed by 2.0 knots (this starts to be worth doing). If the airplane is very clean, and can do 250 knots in its original condition, then the fairing of the same beacon light increases speed by almost 5.5 knots.

The important thing to understand is that something that might not be worth the effort on a slow, high-drag airplane can produce worthwhile gains on a cleaner, faster airplane. As performance increases, the gains we can get from cleaning up relatively small drag-producing features of the airplane can be quite significant.

Aerodynamic questions of a general nature should be sent to editorial@kitplanes.com. Use "Wind Tunnel" as the subject line.