By Barnaby Wainfan

Cooling a pusher-engine installation requires special attention.

As we have seen in previous months, there are many aspects of pusher configurations that are different from tractors. While many of these are not problems per se, they do need the designer's attention and may require a different design approach than a tractor configuration would.

Cooling

Engine cooling has been the single biggest Achilles' heel of pusher piston-engine configurations. Many otherwise promising airplanes have given their designers fits when trying to get the engine to cool properly.

A tractor installation of an air-cooled engine is intrinsically easy to cool. The engine is ahead of the fuselage and behind the propeller where the oncoming airflow can get to it easily. At low airspeeds or during ground runs, the propeller helps force air into the cooling inlets and keeps air flowing through the cylinder fins.

On a pusher, the engine is behind the fuselage or nacelle and in front of the propeller. The engine is shielded from the oncoming flow by the fuselage, and the propeller slipstream goes back away from the engine.

This is not much of a problem on ultralights with exposed engines. Most two-stroke ultralight engines are either liquid cooled or fan cooled. As long as some cool air gets to a fan-cooled engine, the cooling fan forces enough air through the fins to keep temperatures within limits. On a liquid-cooled engine, the radiators must be mounted where they get cool air. On ultralights, where the drag of an exposed engine and radiator is not a major concern, this is relatively easy to accomplish.

Scooping Air

If a pusher engine is cowled, getting adequate cooling flow is a major concern. Air must be scooped up and directed over the cylinders. In most configurations, the fuselage is at least as wide as the engine, so the air must be turned around the firewall to get to the cylinders. The most common approach is to use a single, relatively large scoop either above or below the fuselage.

On the Cessna Skymaster, the rear engine is cooled by air from a scoop on top of the fuselage. The advantage of a top-mounted scoop is that it is likely to have the least negative effect on the shape of the afterbody. As we saw in a previous article, the afterbody of most pushers is already swept up to move the thrust line up so the propeller clears the ground on landing. The upswept afterbody is steep, and steepening it further to accommodate a scoop can cause the flow to separate and generate buffeting and drag. The air pressure at the lower corner of the afterbody is also low as the air accelerates around the corner, and a low-pressure zone is a poor place to put an inlet.

Unfortunately, low local pressure can also be a problem for an over-the-top scoop because the air accelerates around the windshield brow on top of the cabin. The big disadvantage of a topside scoop is that at higher angles of attack, the airflow over the top of the fuselage is at low pressure. High-angle-of-attack conditions are typical of climb. This is the most critical flight condition for cooling because the power setting is high, generating a lot of heat, and the airspeed is low, reducing the amount of cooling airflow available.

In addition to the local low pressure, the airflow on top of the fuselage may be slightly separated and have a thick, low-energy boundary layer. All of these factors decrease the amount of air going into the cooling scoop. Designers counter this by raising the scoop above the cabin-top skin line, leaving a boundary layer diverter channel below the lower lip of the inlet. Of course, nothing in aerodynamics is free. The boundary layer diverter improves the flow into the cooling inlet but increases drag.

Bottom-side cooling air scoops solve some of these problems. The pressure at the bottom-side scoop increases as angle of attack increases. This helps force air into the inlet. As we have seen, the two problems with a belly scoop are afterbody shape and the path the air must take once it enters the cowl.

Almost all engines are set up for downdraft cooling, where the cool air flows from the top of the engine down through the cooling fins on the cylinders. This is easy to implement with a topside scoop, as the cooling air can come out of the inlet directly into the upper plenum above the cylinders. If the air comes in the bottom, there must be baffling or ducting to divert it up over the engine into the upper plenum. This long flow path with sharp turns causes turbulence in the cooling air that absorbs energy and increases drag.

One alternative is to use a belly scoop and updraft cooling. Updraft systems have been used successfully on several airplanes, both tractor and pusher. They work, but they are different to set up than conventional downdraft systems. This is not a disadvantage in itself, but it means that there is less experience and a smaller body of data to draw on when designing and troubleshooting the system.

In general, the most important factor in getting the engine to cool is having a strong supply of cool air. On this basis, a belly-mounted scoop is preferable to a topside scoop provided the afterbody behind the scoop can be designed so that the flow does not separate. On an airplane with a slender fuselage (single seat or tandem), a boat-tailed shape behind the cooling-air inlet can keep the airflow happy and the drag down. The combination of a belly-mounted NACA inlet and a boat-tailed afterbody is used on several modified VariEze and Long-EZ airplanes that have done well in races and on economy runs. On a side-by-side configuration, integrating a bottom-side inlet is harder because the afterbody is too short and wide to boat-tail effectively. This is probably why Cessna chose a topside inlet for the Skymaster.

On some pusher airplanes, the engine is set above the fuselage or nacelle. This is common on the low-boom, pod-and-boom configuration that is a favorite of ultralight, amphibian and sport aircraft designers. If the engine on such a configuration is cowled, the easy way to get cooling air to it is to use an inlet that forms the front face of the engine cowl sitting on top of the pod. This type of inlet is also appropriate for a pylon-mounted pusher engine like that on the Lake Amphibian.

Ground Cooling

On a tractor airplane, the propeller forces air into the cooling inlets even when the airplane is idling on the ground. On a pusher, the cooling-air outlets are in front of the propeller. There is no prop-driven air flowing into the cooling-air inlets. This presents a problem if the engine must be run on the ground for any significant period of time.

If the propeller is mounted close behind the cooling-air outlets, it may pull enough air through the cowl for low-power engine operation such as taxiing. Large cowl flaps may also help this effect. However, on some airplanes this effect does not force enough air through the cowling to keep the engine cool. Constant-speed propellers do not do well at drawing air out of cooling outlets because the root area of the blades is not airfoiled. It is rounded into a blade shank that goes into the hub and allows the blade to change pitch. Unfortunately, this rounded shank area does not move any air and is no help to cooling. Ground cooling is particularly difficult for extension-shaft configurations where the engine is deeply buried in the fuselage and the cooling-air exits are far from the propeller.

Cooling the engine over the whole range of operating conditions is one of the biggest design challenges of a low-drag pusher airplane. As some of the more popular canard pusher homebuilts show, pusher engines can cool reliably if the installation is done properly.

Updraft systems are somewhat better at ground cooling than conventional downdraft systems, particularly if the cooling-air outlets are on top of the cowl. The natural tendency of hot air to rise produces a chimney effect that pulls some air up from the belly inlet, through the hot cylinders and out the top outlets. This natural convection also helps keep the engine compartment from getting too hot after engine shutdown when other sources of cooling air disappear.

If there is not enough natural air flow to keep the engine cool on the ground, the designer must provide some sort of cooling fan to help force air through the engine. Most air-cooled, two-stroke engines used on ultralights come with cooling fans and are designed to be fan-cooled at all times. This makes the engine installation much easier, but the cooling fan does eat up some power. Because of the problems we have just discussed, a free-air-cooled pusher two-stroke is difficult to get to work without melting. If the engine does not have a built-in cooling fan, one must be added. Several amphibians with conventional four-stroke airplane engines have used multi-blade fans that mount directly to the crankshaft just before the propeller. These fans are relatively small diameter and have many blades. They pull air through the cowling and replace the missing propeller-driven air to keep the engine cool.

A few designs have gone even further than this. At least one airplane with a buried engine installation had thermostatically controlled pop-open doors on the top of the engine compartment and electric fans to force air through the engine compartment during ground operations. While this system was rather complicated, it did work, and it has the added advantage of preventing the engine compartment from heat-soaking when a hot engine is shut down and left standing.

Cooling the engine over the whole range of operating conditions is one of the biggest design challenges of a low-drag pusher airplane. As some of the more popular canard pusher homebuilts show, pusher engines can cool reliably if the installation is done properly. There are many approaches to the pusher-cooling problem, but on average, it requires far more of the designer's attention than it would on a tractor configuration. **KP**

Aerodynamic questions of a general nature should be addressed to "Wind Tunnel" c/o KITPLANES, 8745 Aero Dr., Ste. 105, San Diego, CA 92123.