Cooling Drag

Making the air work for you

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Engine cooling is a popular topic in homebuilt circles. Closely related, but perhaps less well understood, is cooling drag. The fundamental idea is simple: take some air through the inlets into an expansion chamber, route it through the cooling fins, and finally, exhaust it back into the slipstream. There are many effective ways to accomplish this task. With some knowledge and a little extra effort, cooling can become both effective and efficient.

Flexible Baffles and the Hard Plenum

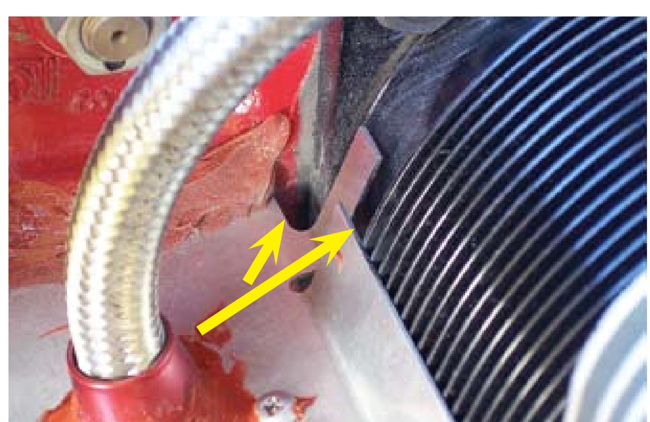
Ideally, airflow passing through the cooling system should be limited to just that needed to maintain desired engine temperatures. Of course, one would need to guarantee that 100 percent of that air passed through the cooling fins. Conventional cooling system configurations with flexible baffle seals have an inherent drawback that makes this goal elusive: the difficulty in creating a perfect seal between the moving engine and the stationary cowling.

The importance of maintaining a good seal cannot be overstated. NASA Report CR3405 covers a number of topics pertaining to the cooling of horizontally opposed aircraft engines, and presents one rather illuminating finding: an enormous amount of leakage occurs in a typical general aviation cooling system. Amazingly, tests found that one-third of the air entering the engine compartment leaked and never made it to the cooling fins of the engine. The primary source of leakage was the flexible baffle seal. Installing a hard plenum and sealing the aluminum sheet metal with silicone stopped all leakage. The concept of a hard plenum chamber is not new. However, its use is not widespread and is virtually absent in the realm of certificated aircraft. Fortunately, in the homebuilt arena we are free to explore this appealing option.

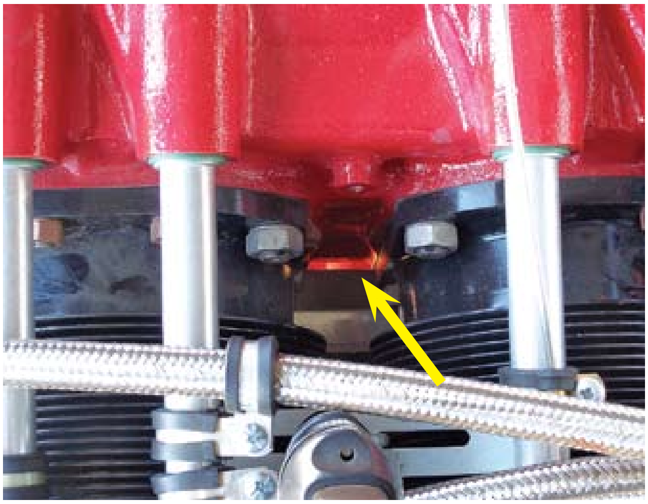
Leaks and Efficiency

Leaks hurt aircraft performance in multiple ways. Most obvious, of course, is that any air finding its way through a leak does not assist in cooling the engine. Leaks also reduce the pressure differential across the engine face, the driving force that pushes air through the cooling fins. Reduce the differential and your cylinder head temperatures (CHT) will rise. Leaks will also cause more air to flow through the engine compartment by lowering overall system resistance. More total flow translates into more drag on the airframe. In other words, leaks hit you twice, reducing cooling and increasing drag.

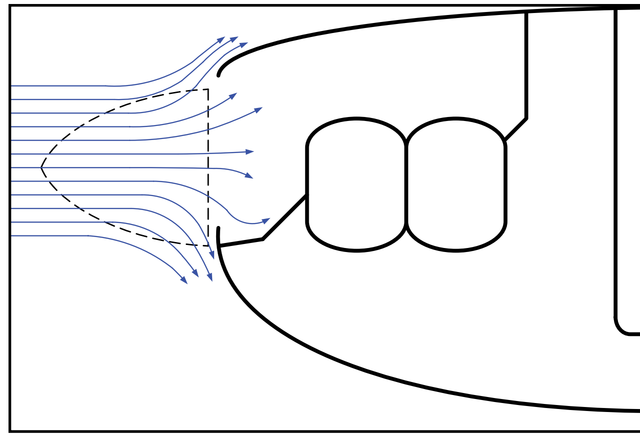
Leaks can be well hidden. The interface between sheet metal and engine offers many opportunities for air to sneak through, especially in areas underneath the engine that are



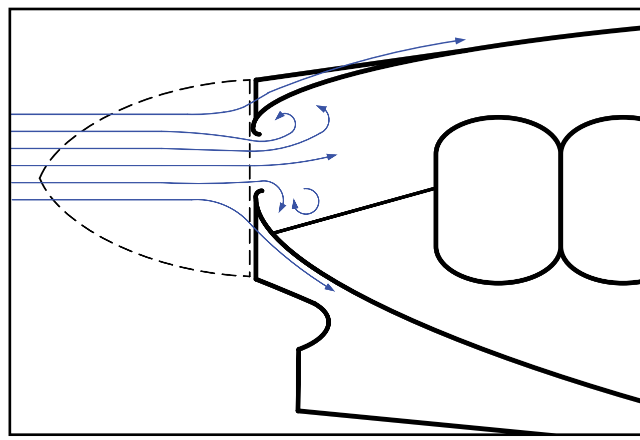
Some extra sheet metal plus RTV was needed here. From the air's point of view, a hole like this is much more appealing than the long and narrow path between two cooling fins.



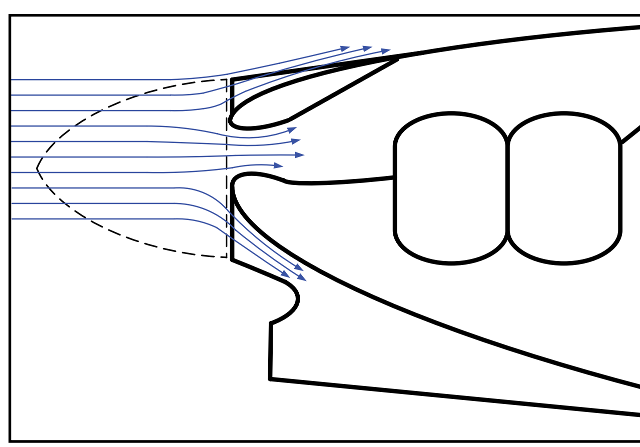
Even factory-made inter-cylinder baffling needs to be sealed with RTV—a flashlight underneath reveals the gap.



LOW INLET VELOCITY RATIO ($V_{inlet}/V_{aircraft}$) < 1.0
The inlet cross section slices through a projected volume of air that is greater than that which can flow through the engine compartment. Air slows down ahead of the inlet, causing pressure recovery to occur in front of the inlet (external pressure recovery).



HIGH INLET VELOCITY RATIO WITHOUT DIFFUSER
A high inlet velocity ratio inlet without smooth transition to the plenum chamber causes severe turbulence and poor pressure recovery. This combination is to be avoided.



HIGH INLET VELOCITY RATIO ($V_{inlet}/V_{aircraft}$) > 1.0
The inlet cross section slices through a projected volume of air that is smaller than the actual volume being pulled through the engine compartment. Air accelerates through the inlet. All pressure recovery occurs during expansion behind the inlet in the diffuser (internal pressure recovery).

hard to see and hard to reach. Every piece of sheet metal should be sealed to the engine with RTV sealant—the effort is well worth it. Fellow builders have been shocked by the drop observed in CHTs after a thorough job of methodically filling every hole and sealing every gap with RTV sealant.

Inlet Size and Efficiency

Contrary to what intuition may indicate, inlet size is not the main driver in determining how much air enters the cooling system. Instead, the inlet size determines where your pressure recovery takes place. When a large inlet slices through a volume of air that is greater than can be fed through the engine compartment, the air approaching the inlet will slow down, causing pressure to rise (external pressure recovery). When an inlet becomes small enough, air no longer slows down ahead of the inlet and all pressure recovery takes place during expansion, downstream of the inlet (internal pressure recovery). Small inlets offer the potential of lower overall drag. They can also spell disaster if the subsequent flow expansion is done improperly. Small inlets need good diffusers, but many stock inlets have just a short lip that is immediately followed by a sudden expansion into the engine compartment. The air velocity through a small inlet is very high, and without a good diffuser it will generate turbulence with high losses and poor pressure recovery.

Space constraints always make it difficult to obtain theoretically ideal expansion as the air transitions from the inlet to the plenum chamber. The maximum available distance between the propeller and the cylinders should be used for the diffuser to derive the greatest benefit. Critical to success is avoiding steps or sharp corners, where the air velocity is high. Once air is slowed down, it can be led on a mighty circuitous path without much harm—a good thing considering how cluttered engine compartments can become. Flow expansion inside the engine compartment will always have losses associated with it; the idea is to not add losses unnecessarily.

Plenum Top: plug, mold and finished part.

Diffusers: plugs, molds and finished parts.

Piccolo tube used to measure static pressure above the engine. Additional probes are located below the cylinders and at the cowling exit.

The Exit Is the Throttle

The exit serves as the throttle to the cooling system. Even though configurations will vary from one aircraft type to the next, the principle remains the same. A good exit is configured to provide a low-pressure source that helps pull air through the cooling system. By adjusting the exit area, much like a cowl flap does, the amount of air passing through the system is regulated. The effectiveness of the exit will vary with orientation, location on the airframe, and internal ducting leading to the exit. Here again sharp corners need to be avoided as the air velocity increases near the exit.

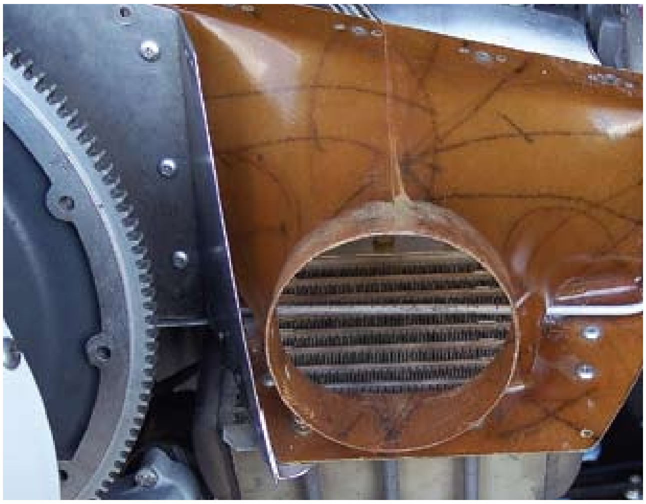
The Plenum Conversion

I flew my Lancair 360 for several years with the stock cooling system. While temperatures were not dangerously high, they certainly needed to be monitored. Over time, several less invasive alterations were employed to aid in cooling, such as adjusting exit area and attempting to smooth the transition at the inlet. Incremental improvements were obtained, but that quantum leap in performance I desired needed a more comprehensive approach.

In planning the cooling system makeover, one of my concerns was aircraft downtime; I simply hate downtime. This pointed me down the path of making a new cowling from the ground up rather than trying to modify the existing one. I could work on new parts while keeping the aircraft in flying condition. I set out making molds for a number of pieces: a new cowling, two diffusers, and the plenum top. All finished parts were made of fiberglass. Composites are ideal for this sort of work since the material can easily conform to the required complex geometry. A key aspect of the new cowling is that the inlets are fully contained in the lower cowling half, providing access for sealing the inlets to the diffusers. The plenum top was designed and built to be a drop-in replacement for the silicone baffle seal material. Aside from trimming a few pieces, the conversion required no changes to the existing sheet metal attached to the engine. Even the screw holes used to attach the silicone baffle material were reused to hold the plenum in place. Everything below the engine also remained unchanged. While fabrication of new molds and parts spanned a number of months, the actual installation on the aircraft required only three weekends.

Testing

Initial flight testing of the new cooling system was performed during a heat wave, with daily temperatures reaching 105°F and an inversion layer keeping the temperatures aloft hot as well. How fortunate! This provided a great opportunity to test the new system in highly stressed conditions.



Initial testing was devoted to gathering temperature data. The aircraft was flown at altitudes from 7,500 to 17,500 feet at full throttle and with a variety of different mixture settings. The results were stunning. Given the same conditions of manifold pressure, exhaust gas temperature, altitude, and outside air temperature, cylinder head temperatures had dropped by 30 to 50°F. While busy collecting temperature data, the reduction in cooling drag was also quite apparent. Once officially measured, a 5 knot

LEFT: Piccolo tube across the face of the oil cooler. A second probe spans across the exit. ABOVE: Completed plenum chamber and diffusers installed on the Lancair 360.

increase in airspeed was recorded, the equivalent of increasing engine power by 8 percent! The enormous amount of energy once lost to excess airflow, leaks, and turbulence was recaptured and put to much better use—speed.

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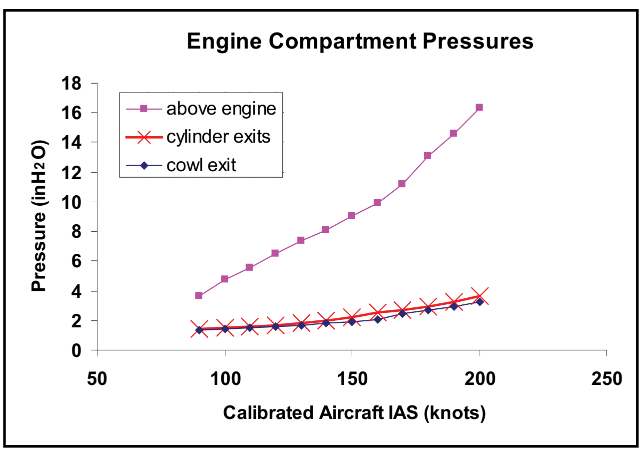
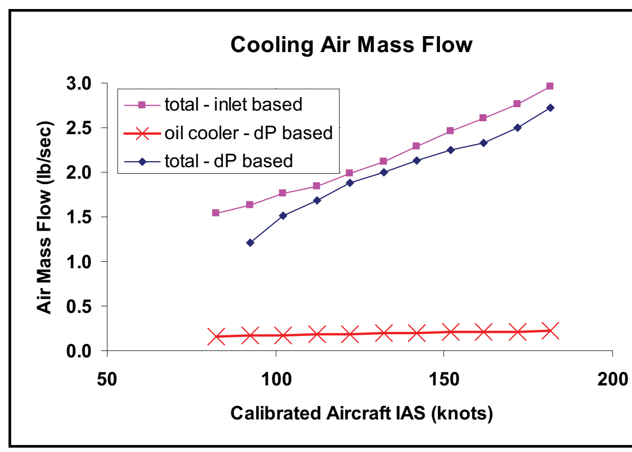
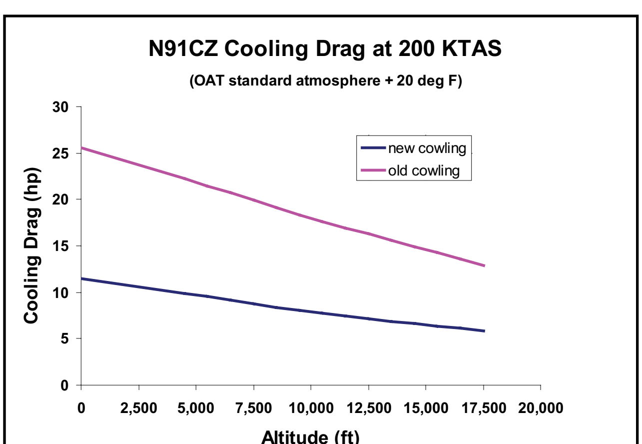
After instrumenting the engine compartment with pressure probes and a pitot tube, a second series of test flights was conducted to record pressures and airflow. The purpose of these tests was to determine the actual mass flow through the engine compartment and the pressure differential across the engine and oil cooler. After recording the various pressures and flows on a number of flights at speeds from 80 to 200 knots indicated airspeed, the results confirmed what was observed in the temperature data. The system was providing excellent pressure recovery despite having a high inlet velocity, an indication that the diffusers were doing



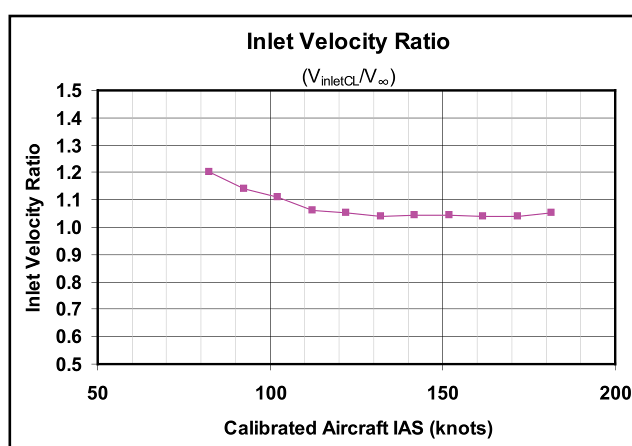
Static Pressure measurements taken in the engine compartment.



Engine compartment mass flow derived from pressure measurements and from air velocity through the inlets.



Cooling Drag is computed from pressure drop, mass flow and air density through the engine compartment.



Inlet Velocity Ratio relates the air velocity in the throat of the inlet to that of the aircraft. Note that the inlet velocity is higher than the aircraft velocity.

From flight testing and primer (far left) to the finished paint, the cooling mods to the Lancair 360 have given it a quantum leap in performance.

their job. Armed with all this pressure data, the actual cooling drag could be calculated. Remarkably, the new cooling system had cut cooling drag in half!

Excellent cooling and low cooling drag can indeed go hand-in-hand. With a little extra effort and the fabrication of some additional hardware, substantial performance gains can be achieved. While the conventional approach is certainly the easiest to fabricate and implement, it leaves significant performance on the table. Fortunately, the experimental category gives us the freedom to break free and improve the breed.

Chris Zavatson is a mechanical and aeronautical engineer working on military powertrain and cooling systems for BAE Systems. The Lancair 360 he finished building in 1997 was awarded a Bronze Lindy at AirVenture 1999. Since then, he has been designing and building improvements for the Lancair.

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