Shock Cooling Revisited

BY KAS THOMAS

Not long ago, a writer for a major aviation publication called to ask my opinion(s) on the subject of shock cooling. It turns out the caller had already written his article, but he wanted to run some ideas by me to make sure he wasn't missing something. Since I get a lot of calls on this subject, I had some ready answers for him. Not necessarily *correct* answers—just *ready* answers.

I don't think that anybody has *provably* correct answers to questions involving shock cooling of aircraft engines. To my way of thinking, there is no scientific proof that shock cooling plays a significant role in cylinder damage in aviation. "Scientific proof" is perhaps a poor choice of words. What I'm simply trying to say is, the hard evidence is scanty. I know of no fleet studies on this subject. I know of no pilot who can say "I went up and did this and this and this to the engine, and then when I landed I found these cracks that weren't there before."

Still, it's hard to argue with common sense, and common sense says that if you thermal-cycle a piece of cast aluminum (especially while beating on it!) you just might induce it to crack. Pilots can perhaps be forgiven for harboring a strong gut feeling that yanking the throttle back is a good way to bring on cylinder cracking. Certainly, many millions of dollars' worth of spoiler kits and CHT systems have been sold to pilots on this basis over the years.

My own gut tells me that shock cooling—while bound to induce dimensional changes in the engine—is *not* a great contributor to cylinder cracking. We know it induces dimensional changes, because (for example) valve sticking has been induced in some engines by sudden power reductions. (A *Lycoming Flyer* article once stated: "Engineering tests have demonstrated that valves will stick when a large amount of very cold air is directed over an engine which has been quickly throttled back after operating at normal running temperatures." See *101 Ways to Extend the Life of Your Engine*, page 96.) But it's a big jump to go from that to saying you can make a cylinder head crack just by pulling the throttle back too quickly.

To my knowledge, Bob Hoover has not experienced any problem with cylinder-head cracking on his Shrike, despite his rather odd predisposition to feather both engines while in a redline dive. (Maybe this is what FAA meant by "cognitive defect"? Just kidding.)

Besides which, I think any careful examination of the concept of "cooling" (as it applies to current aircraft engines) will leave one virtually empty-handed, because I think it could be argued that cooling fins on aircraft cylinders are of mainly ornamental value. I suspect that you could hacksaw much of the finnage off, say, a TSIO-520's cylinders and not affect inflight CHT readings by very much. As it happens, this is exactly what Continental did when it created the "lightweight" Crusader engine—the TSIO-520-AE used in the Cessna T303. The cooling fins on this engine are fewer in number, and about half the size of, those on a standard TSIO-520. And yet, CHTs in the T303 are remarkably cool. (One of our readers, in fact, reports a problem in getting CHTs to stay in the green; see this month's "Questions and Answers," page 26.)

Although he is better known for creating the Ercoupe, Fred Weick played a key role in many of NACA's early studies of engine cooling.

Various investigators have done "energy balance sheets" on aircraft engines, and the result is always the same: Only about 12% of the heat energy generated in combustion goes out an "air-cooled" engine's cooling fins. The biggest fraction (around 44%) goes right out the exhaust pipe, of course. Another 8% or so finds its way into the oil—which is quite interesting, because it means the oil plays almost as big a role in cooling your engine as air does. The remaining energy shows up as work at the crankshaft.

Throttle placement doesn't have nearly as direct an effect on CHT as you might think. Back in 1983, there was an SAE paper (No. 830718) by three Texas A&M researchers who tried to correlate OAT (outside air temp), CHT (cylinder head temp), EGT (exhaust gas temp), power settings, air density, and cowl pressure drop in Lycoming TIO-540 engines. Their work was partly based on the NACA Cooling Correlation (NACA Report No. 683, published in 1940), which in turn was based on pioneering work done by Fred Weick in the late 1920s. The Texas A&M group merely extended NACA's approach, verifying their results with inflight measurements taken on a Piper Turbo Aztec and a Rockwell 700. One of their key findings was that the difference between CHT and OAT is proportional to the difference between EGT and CHT, which is (if you dwell on it long enough) intuitive, since the difference between the average exhaust temperature and CHT is what "drives" CHT changes to begin with. (If this isn't intuitive to you, you may want to go back and re-read Fourier's classic *Analytic Theory of Heat*.) This portion of the group's findings might be summarized by saying that the *stored* heat of the cylinder head is proportional to the *input* heat, represented by EGT minus CHT.

But there are two aspects to cylinder cooling. One is the "supply side" aspect (which we have just been talking

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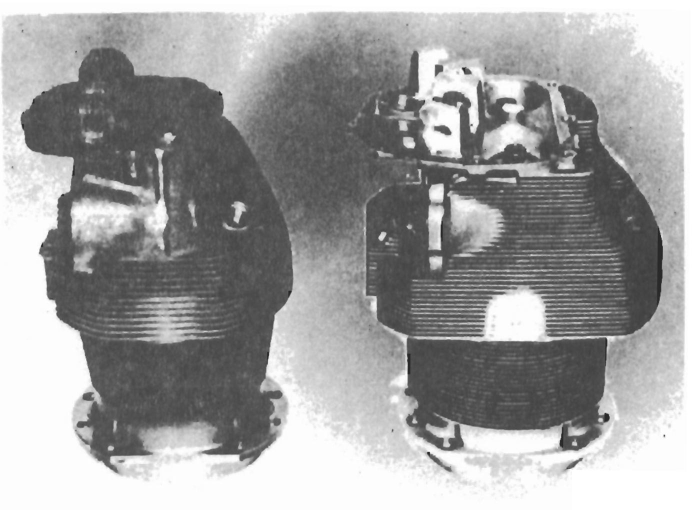

The Continental TSIO-520-AE (used on the Cessna T303 Crusader) features a special "light-weight" cylinder assembly (left) with vastly reduced fin area compared with a stock IO-520 head (right). Oddly enough, CHTs are no higher on TSIO-520-AE than on other TSIO-520 engines (in fact, they may be cooler).

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about—all this business about EGT minus CHT), while the other is the taking-away of heat, or "cooling" aspect. The Texas A&M group accounted for this too. They found that the stored heat is proportional to the input heat—proportional, that is, by a factor ψ. The factor ψ, in turn, is made up of engine power raised to a certain exponent, divided by cooling airflow delta-p raised to a certain exponent. The engine-power exponent is fractional; for the Rockwell 700 it turns out to be 0.33. (It varies from plane to plane depending, apparently, on peculiarities of engine installation and operating envelope.) The air-cooling delta-p exponent is also fractional (0.29). In plain English: CHT depends on the cube root of engine power, divided by the cube root (roughly) of the cooling-airflow pressure drop.

After a few rough scratchpad calculations, you find that cutting an engine's power by half (but leaving airspeed constant, such as in a descent) results in a CHT drop of only 10% or so, or about 80° F. (Recall that in calculations of this sort, you want to use a Rankine temperature scale, which begins at absolute zero, or minus-460° F.) Most of the time, a 50% power cut is accompanied by some loss of indicated airspeed, which would tend to offset the CHT drop, making it less than 80° F. The numbers are within reason, evidently. But is this kind of CHT drop capable of trashing a set of cylinders? I doubt it.

Of course, the *rate* of the drop is plainly an important factor here (not just the magnitude of the drop). In this connection, I am reminded of an experiment once done by John Schwaner (of Sacramento Sky Ranch). It seems Schwaner, curious as to whether he could "crack" a cylinder at will, in a shop environment, one time took a cylinder that was heated to several hundred degrees in an oven (I believe it was an O-320 jug, although here I'm going from memory) and dunked it in a bucket of cold acetone. The abruptly cooled cylinder was later examined, and no abnormalities could be found in it.

And then there's ordinary rain. Every pilot flies through rain at one time or another, and rain should be a very effective coolant (more so than mere air, certainly)—yet no one, as far as I can determine, ascribes cylinder damage to flying through too much rain. In fact, most pilots (I think) consider just the opposite to be true; namely, that flying through rain is *good* for an engine, *because* of the extra cooling.

Let us assume that a moderate downpour contains one cubic centimeter (one gram) of water per cubic meter, and let us further assume a cooling airflow of 100 cubic meters per minute for a high-performance engine. (David Thurston's *Design for Flying* suggests 77 cubic meters per minute as typical for many engines.) We might reasonably expect, therefore, that 100 grams of water might enter the cowling per minute while flying in rain. Considering that water has a heat of vaporization of about 540 cal/g, it's not impossible for 100 g/min of rain influx to give about 54,000 cal/min of cooling, which is about 200 British Thermal Units per minute.

The question is, how does this compare with the heat of combustion? We can do a rough calculation this way: We know that (by ASTM spec) avgas contains a minimum 18,720 BTU per pound or about 112,320 BTU per gallon. If an O-470 burns 13 gal/hr in cruise (or 78 lb/hr, roughly), the engine is capable of producing 24,336 BTU per minute of combustion heat—if combustion is 100% efficient. In the real world of mixture maldistribution, rich mixtures, and incomplete combustion, we can safely say that probably no more than 21,000 BTU per minute of heat is actually liberated, of which 12%, or some 2,520 BTU/min, goes to the outside world via the cylinder cooling fins. If rainwater cooling were 100% efficient (no droplets escaping between cooling fins; all of the water 100% evaporated in contact with fins), we might expect rain to reduce the cylinder fins' burden by about 8% (200 divided by 2,520). If you could somehow translate this into a direct CHT reduction, it might mean a reduction of 64° F (assuming your CHT started out at 800° Rankine). That's a pretty sizable reduction of CHT. In fact, it should qualify as shock cooling.

I think the fact that Navajos and 421s aren't raining engine parts down on unsuspecting civilians while flying through precip (I was going to say *while penetrating virga*—but decided against it) is pretty good evidence that "sudden cooling" of an air-cooled engine does not contribute in any *dramatic* way to cylinder-head cracking.

If shock cooling were a definite hazard, your engine should fall apart when you bring the mixture into idle cutoff at the end of a flight. CHTs fall at a rate of 100° F/min or more in the first seconds of shutdown—triple the rate that starts the typical "shock cooling" annunciator blinking. Does anyone complain that repeated shutdowns are causing head cracking? Of course not.

Then why are we worried about pulling the throttle back? ☐