TECH TOPICS

Tech Topics is a column written by Mike Busch, CPA's staff twin expert and the lead instructor in CPA's twin courses. Mike is a regular contributor to CPA Magazine as well as editor-in-chief of AVweb, the Internet's aviation magazine and news service (http://www.avweb.com). He also is the owner of a pristine 1979 Cessna T310R which he maintains almost entirely himself under an A&P's supervision.

Putting Compressions in Context

The differential compression check is one of the quickest, easiest, and most useful tools we have for measuring the top-end health of a piston aircraft engine. Yet many owners, mechanics, and even the FAA seem confused about how to perform the test properly and how to interpret the results. It's not rocket science.

By Mike Busch <mbusch@cessna.org>

The toughest part of writing my column for *CPA Magazine* is coming up with an interesting and worthwhile topic to write about each month. Sometimes my columns are inspired by something that happened to me during the prior month, but often they're prompted by the questions I receive from CPA members.

This month, it seemed like a disproportionate number of the questions I fielded from CPA members revolved around cylinder compression checks. They seemed to reveal an alarming lack of understanding of how to perform a compression check properly, and what the results mean. It's not just the members who seem confused about this, but also their mechanics.

Q1: Leakage past the valves

One member from Oregon emailed me about the problems he was having with the factory new TCM TSIO-520-R engine that he'd installed in his T210 just over a year ago. After 11 months and 240 hours, compressions had dropped to 58/80 to 62/80, and the member contacted TCM for help. Two months and 50 hours later, two of the cylinders were showing 44/80 and 48/80 with air clearly leaking past the exhaust valves. According to the member's email, the TCM tech rep said that such leakage was considered normal, that the airplane was safe to fly, and that the owner should continue to fly the airplane and see if the situation "stabilizes."

I responded to this member by pointing out that TCM is very clear that no leakage past the valves is permissible, and has documented this explicitly and repeatedly in TCM Service Bulletin M84-15, the "bible" on how to do compression checks on Continental engines. (We'll examine the details of M84-15 in a moment.) I told the member that I thought flying the engine with known serious exhaust valve problems was just asking for an in-flight engine failure.

It seems inconceivable that a TCM field rep would not be aware of TCM's official guidance on the subject of compression tests, or that the rep would make recommendations to a customer that directly contradicts that official guidance. Yet the member says the tech rep put his "safe to fly" recommendation in writing. We're continuing to follow up on this one.

Q2: Turbocharging problems

Another member from Portugal emailed me for assistance with problems he was having with his Cessna 402B. The engines were approaching published TBO, and exhibiting problems with the turbocharging system. The owner reported that both engines were suffering serious losses of manifold pressure at altitudes as low as 10,000 to 12,000 feet (worse on the right engine than on the left).

The member's mechanic had been unable to find any induction or exhaust leaks, and said that the wastegates and controllers checked out fine. The mechanic told the member that the engines had low compressions, with the two lowest cylinders on the left engine measuring 52/80 and the two lowest on the right engine measuring 65/80. The mechanic attributed the turbocharging problems to low compression, saying that the reduced exhaust output volume could easily cause the observed loss of turbo boost.

I replied to the member that his mechanic was on the wrong track, and that the compression readings had nothing to do with the lack of turbo boost. I pointed out that the left engine had the worst compression readings, while the right engine had the more serious boost deficiency. Even if the compression readings had been much worse—say 40/80 on all cylinders—the loss of turbo boost would have been unnoticeable. (Recently, TCM engineers honed the compression ring gaps of an IO-520 engine until all cylinders measured 40/80, then ran the engine up on a test stand and were unable to detect any horsepower loss.) I suggested several troubleshooting ideas that could help isolate the cause of the problem.

The member emailed back to say that he had an upcoming flight to the Azores—about four hours over water each way—and wanted my advice whether it would be safe to make the flight with those low compression readings. I responded that if those compressions were due to leakage past the rings (not the valves), I'd have no hesitation about making the flight. At the same time, I said I thought it was important to get to the bottom of the turbocharging problems before tackling 900 nm over water.

Q3: Pre-purchase inspection

Yet another member wrote about a Cessna 320E he was thinking about buying. One of the plane's engines had about 900 hours SMOH, and according to the aircraft logbooks, compression readings had deteriorated over the past two years from 64-70 to 62-67. The member said his mechanic was pretty negative about this downward trend in compression readings, and was urging the member not to buy the airplane.

I responded that those compression readings were just fine for a TSIO-520-B with 900 SMOH. I also pointed out that even if a couple of cylinders had unacceptably low compression (which wasn't the case), that didn't seem like a good reason not to buy the airplane. I suggested that the member focus his prepurchase research on big and expensive problems—airframe corrosion, structure cracks, deteriorated deice boots, leaky fuel bladders, exhaust system flaws, engine mount beam problem, etc.—that could cost $5,000 or $10,000 or $15,000 to repair, and not get hung up on minor faults like a soft cylinder or two.

Old wives' tales

The differential compression check has been a mainstay of piston aircraft engine maintenance for the last 70 years, give or take. Like anything else in aviation that's been around for a long time, various Old Wives' Tales (OWTs) have evolved about the procedure, passed on from journeyman mechanic to apprentice, and later taught in A&P schools and documented in various textbooks and advisory circulars. Ask your mechanic why he performs a compression check a certain way or interprets the test results as he does, and if he's honest he'll probably answer, "that's the way I was taught to do it and that's the way I've always done it."

One of the most pervasive OWTs about compression checks goes something like this:

- High 70s are excellent
- Low 70s are good
- High 60s are marginal
- Low 60s are bad
- Below 60/80 is unairworthy

Now perhaps this had some validity back in the days when radial engines were king. But for modern horizontally-opposed engines, it's simply wrong—certainly wrong for Continental engines, where the manufacturer has set forth very specific procedures for doing compression tests and evaluating the results (in M84-15). According to TCM, a cylinder with a compression reading of 70/80 might be unairworthy (if the leakage is past one of the valves), while another with a compression reading of 55/80 might be absolutely airworthy (if the leakage is strictly past the rings).

Another widely accepted OWT is that an engine with compressions in the low 60s is a "tired engine" that will not put out its full rated horsepower. This is just plain wrong. As I mentioned earlier, TCM ran some tests with an engine that was intentionally "tricked out" to reduce compressions to 40/80 and detected no measurable horsepower loss. An engine would very likely produce full rated horsepower (or darn close to it) with compressions of 20/80—just not for very long, because the extreme blow-by would wind up pressurizing the crankcase and blowing most of the engine oil overboard.

When an owner asks us whether to be concerned about low compression readings, one of our very first question is, "how's the oil consumption?" If a cylinder isn't burning oil or pressurizing the crankcase or leaking past the valves, it's probably just fine regardless of what the compression numbers are.

What the FAA says...

After repeatedly hearing mechanics say "if the compression is less than 60/80, the cylinder is unairworthy and has to come off," I got curious where this magic number came from. So I did a little research to see what the FAA has to say on the subject.

The first place I looked was FAR Part 43 Appendix D, which is where the FAA defines what must be done during an annual or 100-hour inspection. Appendix D does indeed require that each annual and 100-hour include a compression check, but it doesn't offer much guidance about how the results should be interpreted. It states "if there is weak cylinder compression," the engine must be inspected "for improper internal condition and improper internal tolerances." In other words, if the compression is weak, the cylinder needs to come off. But it doesn't define what constitutes "weak" compression.

Next, I turned to the A&P's bible, FAA Advisory Circular AC43.13-1B, "Acceptable Methods, Techniques, and Practices—Aircraft Inspection and Repair." While non-regulatory in nature, this AC provides a wealth of maintenance information "acceptable to the Administrator" that A&Ps can use as guidance (to cover their derrières) in the absence of specific maintenance instructions from the particular aircraft or engine manufacturer. Paragraph 8-14 is devoted to "compression testing of aircraft engine cylinders." Sure enough, the second sentence of paragraph 8-14 says:

> *If a cylinder has less than a 60/80 reading on the differential test gauges on a hot engine, and procedures in paragraphs 8-14b(5)(i) and (j) fail to raise the compression reading, the cylinder must be removed and inspected.*

That's pretty direct and unequivocal, isn't it? It says that if a jug measures less than 60/80 in a hot compression test, and the reading can't be raised by running the engine and "staking" the valves with a mallet and fiber drift, then the cylinder must be removed. So if your mechanic tells you that a jug on your big-bore Continental measured 58/80 during the annual inspection and has to come off, he's right... Right?

Wrong! Your mechanic needs to go back and read the very first sentence of AC43.13-1B, which states:

> *This advisory circular (AC) contains methods, techniques, and practices acceptable to the Administrator for the inspection and repair of nonpressurized areas of civil aircraft, only when there are no manufacturer repair or maintenance instructions.*

In other words, if the engine manufacturer provides specific instructions for performing or interpreting a compression check, then those instructions take precedence over any general-purpose guidance provided by the FAA. Indeed, Teledyne Continental Motors provides detailed instructions on the subject in Service Bulletin M85-14. So at least for Continental engines, the old 60/80 rule should be tossed right out the window. It simply does not apply.

Incidentally, my exhaustive computer search of FAA publications turned up one other place where the magic number 60/80 is mentioned: Advisory Circular AC20-105B, "Reciprocating Engine Power-Loss Accident Prevention and Trend Monitoring." This little-known publication is actually quite well-done and worth reading. It's largely devoted to subjects like fuel exhaustion, starvation and contamination (since that's usually what makes engines quit), but it does get into various maintenance subjects as well, including fouled plugs, stuck valves...and yes, compression checks. Interestingly enough, AC20-105B says that if a cylinder measures less than 60/80, a visual borescope inspection is recommended (as opposed to pulling the jug). Nobody ever accused the FAA of consistency...

But once again, the FAA makes it clear that if the manufacturer provides instructions on this subject, then those instructions must be followed and contradictory information (from the FAA or whomever) should be disregarded.

What TCM says...

In December 1984, TCM issued Service Bulletin M84-15 titled "Cylinder Leakage Check (Compression)" to explain how to perform the test procedure properly and how to interpret the results correctly. They issued this document specifically to discredit the various OWTs about compression checks, and to deal with an epidemic of perfectly airworthy cylinders that were being arbitrarily removed simply because they failed to make the "passing grade" of 60/80 on a single differential compression test. (If you've signed up for access to the members-only section of the CPA website, you can view the full text at http://www.cessna.org/members/m8415.pdf.)

M84-15 starts out by explaining a crucial concept—that the differential compression check is actually two distinct cylinder leakage tests: a static seal test and a dynamic seal test. If there's one thing that you need to understand about compression testing, this is it.

The "static seal" is the part of the cylinder assembly that isn't supposed to leak at all. It comprises the valve-to-seat seals, the sparkplug-to-head seals, and the head-to-barrel joint. (See Figure 1.) No leakage at all is permitted at the static seal. None whatsoever. Zero.

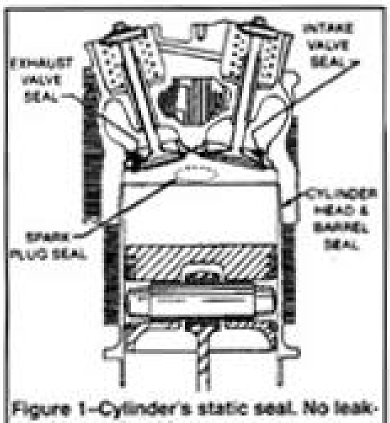

Figure 1–Cylinder's static seal. No leakage is permitted here.

If there's any leakage at all through the static seal—by far the most common leakage site being the exhaust valve—and it can't be eliminated by "staking" the valve, then the cylinder is considered unairworthy and must be removed from the engine and the static seal leakage corrected.

Incidentally, "staking" a leaky valve means tapping it with a mallet and drift to dislodge any carbon or other debris that might be preventing the valve face from sealing perfectly with the valve seat. Don't get your hopes up, though, because staking very rarely succeeds in rescuing a cylinder that's leaking at the exhaust valve.

The "dynamic seal" is the part of the cylinder assembly that is expected to leak. The dynamic seal is made up of the cylinder barrel, the compression (top) rings, the piston, and the oil film on the cylinder walls and in the piston ring grooves. (See Figure 2.) This seal is never perfect—it always leaks—partly because the compression rings leak at

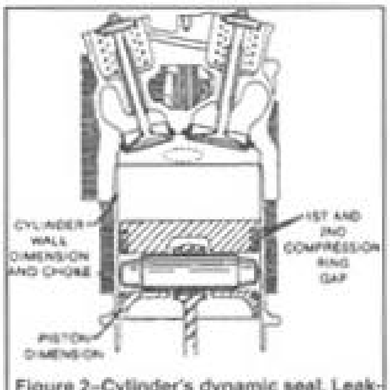

Figure 2–Cylinder's dynamic seal. Leakage here is expected and inevitable.

their end gaps, and because the interface between the piston, rings and barrel is never perfectly airtight, even in the presence of engine oil to fill in the tiny gaps. Leakage at the dynamic seal is perfectly normal and expected. The only question is how much is too much?

AC43.13-1B says that anything worse than 60/80 is too much, but TCM disagrees—and for Continental engines, what TCM says is what matters.

Part of the problem, says TCM, is that compression test gauges are notoriously inaccurate, and it's quite common for different gauges to give markedly different readings. For that reason, TCM does not publish any specific value (60/80 or whatever) as the go/no-go threshold for the dynamic seal leakage test. Instead, TCM requires that your A&P establish a go/no-go threshold for his particular compression test gauge by using a special tool—TCM part number 646953 (see Figure 3)—which is actually a calibrated orifice that represents what TCM defines as the maximum allowable dynamic seal leakage for a cylinder. M84-15 instructs your mechanic to hook up his compression tester to this calibrated orifice, measure its leakage just as he would a cylinder, and write down the value he gets. That value then becomes the maximum allowable dynamic seal leakage for your cylinders when using his particular compression tester. (For most compression testers we've checked, this value turns out to be in the low 50s or high 40s—it never comes even remotely close to 60/80.)

What? Your mechanic doesn't have a TCM p/n 646953 calibrated orifice handy? Tell him he better buy one, be-

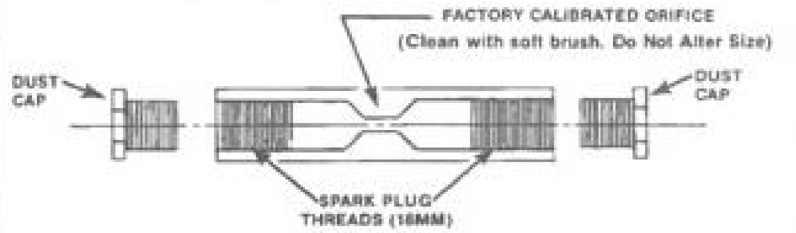

Figure 3–Master orifice tool (TCM p/n 646953) establishes the go-no-go threshold for leakage at the cylinder's dynamic seal (rings).

cause he cannot legally perform an annual or 100-hour inspection on any TCM engine without one. I kid you not.

Testing technique...

The remainder of M84-15 provides a step-by-step explanation of precisely how to perform the compression, ahhh, cylinder leakage test. It makes interesting reading, and differs in several important details from the method I've generally sees practiced by A&Ps in the field, or indeed the method taught by most AMT schools.

I've watched a goodly number of mechanics perform a lot of compression checks over the years, and indeed done quite a few compression checks myself. The usual procedure I've observed—and indeed the one I was taught—is to rotate the prop to bring the piston in the cylinder being tested to top-dead-center (TDC), hold the prop firmly while turning on the air valve to apply 80 psi through the test gauge, and then rock the prop back and forth a few degrees either side of TDC until the highest stable reading is obtained.

Wrong, says TCM! The piston should be positioned so that it's just starting to come up on the compression stroke in the normal direction of crankshaft rotation. Then while firmly holding the prop stationary (preferably with the help of an assistant), the cylinder should be pressurized to 20 psi and the prop slowly rotated (against the air pressure) until the piston reaches TDC—you can tell when you get there by a sudden decrease in force required to turn the crankshaft. At this point, the prop is held stationary, the air pressure is increased to 80 psi, and the leakage reading is noted.

If the crankshaft is inadvertently rotated past TDC, TCM warns that it is necessary to back up at least a half-turn and start all over again, because the slightest movement in the reverse direction breaks the seal between the compression rings and the piston lower lands and can result in a lower-than-accurate gauge reading. No wiggling allowed, says TCM!

With the piston at TDC and the cylinder pressurized at 80 psi, the cylinder must be checked for leakage at the static seal. This is done by listening carefully for any sound of air leaking through the exhaust port (exhaust pipe) or the intake port (induction inlet); if the leakage is at the dynamic seal (rings), it can be heard by listening at the oil filler.

TCM also points out that the dynamic seal leakage can be profoundly affected by the orientation of the compression ring end gaps. (See Figure 4.) The rings rotate during normal engine operation, so how they're oriented at the time of the compression test is purely a matter of chance. If a cylinder flunks the dynamic seal leakage test, TCM recommends repeating the test from the beginning using the opposite direction of crankshaft rotation, thereby reversing the direction of side-load on the piston and possibly resulting in a significantly better (or worse) test result.

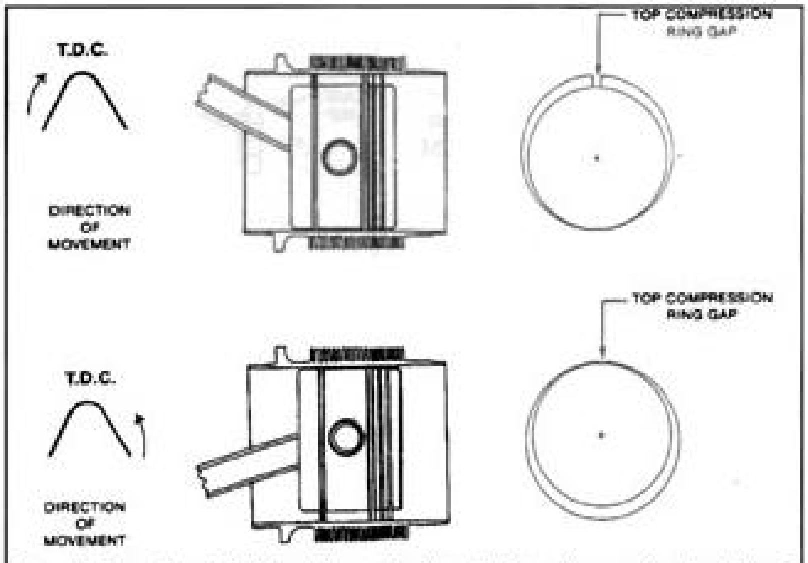

Figure 4–Dynamic seal leaking will vary significantly depending on the orientation of the compression ring end-gaps and which direction the crankshaft is rotated to reach top-dead-center.

Putting it in perspective

TCM's M84-15 applies only to Continental engines, but its fundamental concepts make a lot of sense for any piston aircraft engine. The most important of these concepts is the clear distinction between the static and dynamic seals of a cylinder. The most important result of a cylinder compression check is not the amount of leakage (gauge reading), but rather where the leakage is occurring (exhaust, intake, crankcase). It's more important to use your ears (to detect where the leakage is) than your eyes (to read the gauge). So if your mechanic informs you of the results of a compression test by simply giving you a series of numbers, he's leaving out the most important part.

Any detectable leakage past the valves is unacceptable and represents a serious problem that is bound to get worse, usually rapidly. Continuing to fly with known leakage at the exhaust valve is risking a serious in-flight failure.

On the other hand, an astonishing amount of leakage past the rings can be tolerated with perfect safety, and with no measurable loss of power. Unless such leakage is accompanied by some other confirming symptom—excessive oil consumption, oily sparkplugs, metal in the oil filter, or a big spike in the oil analysis report—you probably shouldn't lose any sleep over it.

I've long been puzzled why the same FAA-approved 60/80 standard would be applied equally to all sizes of aircraft piston engines from O-200s to GTSIO-520s. Common sense would suggest that more dynamic seal leakage should be expected in a big-bore engine than in a small-bore engine, simply because the fit of the piston in the cylinder when the engine is well below full operating temperature is necessarily looser in a big-bore engine. Indeed, despite what the FAA would have you believe, a compression reading of 65/80 is of considerably greater concern in a TCM IO-360 than in an IO-520.

Never allow a cylinder to be pulled on the basis of a single compression test—unless the gauge reads zero or something close enough to zero that you're pretty sure you have a hole in the piston or a chunk missing from the exhaust valve. If the compression is simply weak (as opposed to non-existent) and clearly leaking past the rings, fly the airplane for another three to five hours and then recheck the compression again. There's at least a fair chance that the compression rings will have rotated enough to change the gauge reading substantially—hopefully for the better.