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THE DREADED COMPRESSION TEST

by Mike Busch

It takes place at least once a year and is guaranteed to provoke anxiety in even the most sanguine aircraft owner. I'm talking about that awful moment when your IA hooks up his compression test gauges to your powerplant, pumps 80 psi of air into the top spark plug holes, and writes down those six momentous two-digit numbers that determine whether or not your power-plant will be permitted to soldier on intact, or whether it will have to be relieved of one or more of its cylinders.

Your mechanic doesn't have any choice about putting you through this stress-provoking ordeal. The requirement to perform a compression test at each annual and 100-hour inspection is written right into the FARs [Part 43 Appendix D paragraph (d)(3)]. Those regulations further require that "if there is weak cylinder compression," it must be inspected "for improper internal condition and improper internal tolerances." In plain English, that means that if a cylinder flunks the compression test, it has to come off. Or does it?

The traditional definition for "weak compression" is a differential compression gauge reading worse than 60/80. This threshold, which dates back to before World War II, is not actually written into the FARs, but it is memorialized in the FAA's "bible" for A&P mechanics: Advisory Circular AC43.13-1B: "Acceptable Methods, Techniques and Practices - Aircraft Inspection and Repair". That document goes on to instruct mechanics that cylinders failing to meet this threshold need to come off for internal inspection.

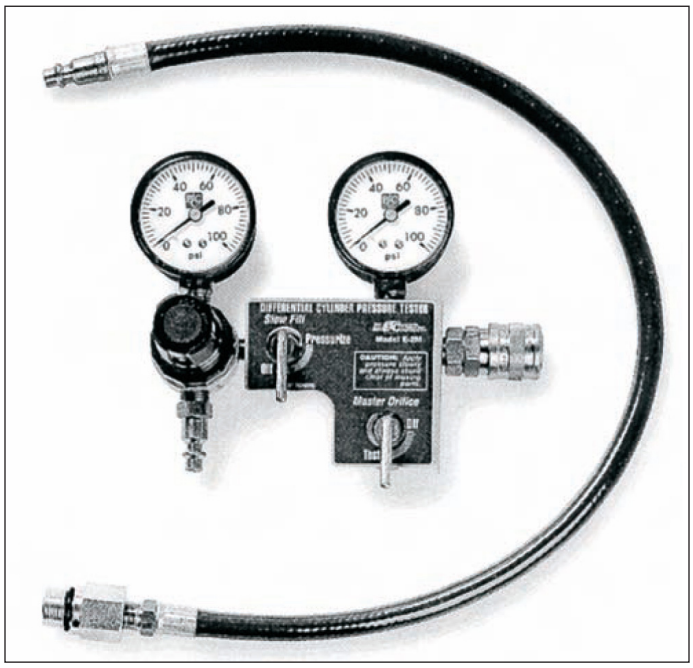

FIGURE 1: *This Eastern Model E2M compression tester has a built-in master orifice that establishes the tester's go/no-go limit. The old 60/80 rule for rejecting a cylinder is no longer applicable, at least for Continental engines.*

However, the very first page of AC43.13-1B states that its guidance is to be used "only when there are no manufacturer repair or maintenance instructions." Since TCM does provide instructions for performing compression tests and evaluating the results, the guidance in AC43.13-1B (including the 60/80 threshold and the requirement for cylinder removal) does not apply to any TCM engine.

TCM Changed the Rules ...

In 1984, TCM issued Service Bulletin M84-15 to provide official guidance to mechanics about performing compression tests on TCM engines. M84-15 radically changed the criteria for determining "weak compression" in a couple of important ways.

Instead of the using the traditional 60/80 threshold, M84-15 instructed mechanics to hook up their compression gauges to a special "master orifice tool" - essentially a calibrated leak that represents the maximum permissible leakage for a TCM cylinder. Whatever gauge reading is obtained by measuring the master orifice tool is today's definition of "weak compression."

I conducted an informal survey of a dozen IAs and asked them to report what values they were seeing on their compression testers when hooked up to the master orifice tool. The responses - almost all were in the 41 - 43 psi range. That means that a cylinder with a compression test reading of 45/80 is quite airworthy as far as TCM is concerned.

Wait a minute! Would *you* feel comfortable flying behind an engine with compression readings in the mid-40s? If you were an A&P/IA, would *you* feel comfortable signing off an annual inspection on an engine with such compressions? Does TCM's guidance make any sense?

Actually, it makes excellent sense. TCM did considerable research before issuing that guidance. They ran numerous tests of an IO-550 engine on a dynamometer while honing the compression ring gaps oversize, intentionally reducing cylinder compression readings to progressively lower and lower values. TCM engineers found that an IO-550 with 40/80 compressions puts out *exactly the same horsepower* as an IO-550 with 75/80 compressions! The 40/80 engine blows a lot more oil out the breather, and the oil gets dirty a lot faster (so it needs to be changed more often), but there is no measurable loss of power.

So yes, you should feel quite comfortable flying behind an engine with 45/80 cylinders, as long as you check the oil before every flight, perform regular oil and filter changes, and don't get too upset by oil on the belly of the airplane.

In addition, Service Bulletin M84-15 made another change that was arguably even more significant: It stated that while substantial leakage past the rings was perfectly okay, *no leakage past the valves* was acceptable. Even if the compression reading was 75/80, any indication of air leaking past the valves (i.e., audibly coming from the induction or the exhaust) meant the cylinder was unair-worthy and had to come off.

This "zero-tolerance" policy about valve leakage during compression tests was considered unreasonably harsh by many experienced A&Ps, and some even fudged a little when doing compression tests. This requirement caused a lot of cylinders to be needlessly removed from TCM engines. It was not unusual for a cylinder to be removed because of leakage past the valves, and then inspected internally without finding any discrepancies at all.

I distinctly recall pulling a cylinder off my airplane at the annual inspection in 2002 because of air leaking quite audibly past the exhaust valve. After spending hours wrestling the suspect jug off the engine and performing a detailed inspection, I was frustrated to discover that I couldn't find a thing wrong with it.

... Then Changed Them Again!

All this changed profoundly in March 2003, when TCM issued a new Service Bulletin SB03-3 on the subject of compression checks, superseding M84-15; the definitive guidance on the matter for nearly 19 years. In some respects, SB03-3 offered similar guidance to M84-15, but in other respects TCM's guidance to mechanics changed radically.

In particular, SB03-3 continued the use of the master orifice tool to establish the maximum acceptable leakage. This means that cylinders measuring 45/80 are still considered airworthy and don't need to come off. That's a good thing.

Fortunately, SB03-3 did completely away with the "zero-tolerance" policy concerning leakage past the valves. Under SB03-3, a cylinder that measures 51/80 is considered airworthy regardless of whether the air is leaking past the rings or past the valves. This means that far fewer cylinders will be removed needlessly, and that's a very good thing.

In lieu of the previous policy on valve leakage, SB03-3 introduced a new requirement that astonished many A&Ps: It requires mechanics to perform a *borescope inspection* of the cylinders in conjunction with every compression test.

A borescope is a fiber-optic device that can be inserted into a piece of machinery to facilitate internal visual inspections that would otherwise be impossible. Borescope inspections have been standard procedure in turbine engine maintenance for years, but until recently has seen very little use for piston engines. The reason for this is simple: The flexible fiber-optic borescopes used by turbine shops are expensive critters, frequently costing $10,000 or more. Relatively few piston shops could afford that kind of investment.

FIGURE 2: *This rigid nine-inch borescope is the one recommended by TCM, and costs about $1,000. TCM requires a borescope inspection at each compression test.*

In recent years, however, a new breed of low-cost borescopes became available, primarily to meet the needs of automotive mechanics. It is now possible to purchase a high-quality rigid borescope (like the Lennox "Autoscope" recommended by SB03-3) for less than $1,000. There are even some el-cheapo automotive borescopes available for under $300, but their image quality leaves a lot to be desired. The availability of high-quality, low-cost borescopes was a big factor in TCM's decision to require a borescope inspection in conjunction with every compression test. SB03-3 makes it explicitly clear that a mechanic should never decide to remove a cylinder without first performing a borescope inspection. That's a marvelously good thing.

The Joys of Borescopy

What makes the borescope so awesome for piston engine maintenance is that it allows a mechanic to perform the FAA-mandated "internal inspection" of a cylinder that exhibits weak compression without having to remove the cylinder. This means that mechanics who have a bore-scope and know how to use it properly, should no longer find themselves removing cylinders, only to find out that there's nothing wrong with them.

For example, if a cylinder exhibits air leakage past the exhaust valve during the standard differential compression test, the mechanic has to be concerned that the valve might well be leaking hot exhaust gases during actual engine operation. In fact, the valve might not be leaking exhaust gas at all; it's actually quite common for cylinders to exhibit air leakage past the valves during a compression test without leaking at all during actual operation. That's because a test using 80 psi air at cool temperatures is a very poor predictor of what the cylinder will do when pressurized to 800-1,000 psi at hot operating temperatures.

By inserting a borescope into the cylinder and inspecting the exhaust valve directly, the mechanic can tell unambiguously

whether or not the valve has been leaking during actual engine operation. If it has been leaking, then the cylinder clearly needs to come off for repair; if not, there's no reason for the cylinder to come off.

Remember the jug I pulled off my engine at the annual in 2002? Had the exact same symptoms occurred one year later (after SB03-3 had been issued), that cylinder would not have come off, and would undoubtedly still be flying happily alongside its neighbors.

How To Do a Compression Test

SB03-3 provides a step-by-step explanation of precisely how to perform the compression test. It makes interesting reading, and differs in several important details from the method I've generally seen practiced by A&Ps in the field.

I've watched a good number of mechanics perform a lot of compression checks over the years, and done quite a few myself. The usual procedure I've observed - and indeed the one I was taught during my A&P training - 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. The prop may be rocked back and forth a few degrees to obtain the highest possible reading.

For what it's worth, I've experimented doing compression tests both "the old way" and "TCM's new way" and concluded that the new way gives better, more consistent results.

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

How To Do a Borescope Inspection

SB03-3 also contains specific guidance on the procedure to be used for borescope inspections. Since most piston maintenance shops didn't even own a borescope prior to the issuance of SB03-3, the service bulletin even includes a recommendation about what kind of borescope to buy (Autoscope 6600K from Lennox Instrument Company, which sells for under $1,000).

Normal Combustion Chamber. Exhaust valve has reddish combustion deposit in center with dark outer edge. Intake valve has light brown combustion deposits. Combustion chumber has light brown deposits.

Burned exhaust valve. Note edge of valve face that has lost all combustion residue and striations moving toward center of valve.

FIGURE 3: *These photos in TCM Service Bulletin SB03-3 help mechanics identify what burned valves look like during borescope inspection.*

SB03-3 advises that each cylinder should be inspected twice: Once with the piston at top-dead-center at the end of the power stroke (so that the exhaust valve is open), and again with the piston at top-dead-center at the end of the intake stroke (so that the intake valve is open). Items that should be looked for during borescope inspection include:

- Erosion and burning of valve seat inserts.
- Protrusion of spark plug heli-coils into the combustion chamber.
- Heavy carbon deposits or the presence of excessive oil in the combustion chamber.
- Localized discoloration of the intake and exhaust valve faces.
- Cracks or erosion on the edges of the valves.
- Scoring, piston rub, or piston pin rub on the cylinder walls.
- Corrosion on the cylinder walls.
- Erosion of the piston crown.
- Visible damage to the piston crown or cylinder head by foreign debris.

FIGURE 4: *Borescope inspection of this TCM exhaust valve revealed the characteristic signature of a burned valve - an asymmetrical pattern of deposits with an area nearly devoid of deposits where the valve is overheating (left). Side views of the removed valve (right) show just how warped and eroded it had become. A few more hours in service would almost certainly have resulted in complete loss of power in the cylinder.*

SB03-3 includes a number of photographs to help mechanics identify what normal and abnormal cylinders look like through the borescope.

Interpreting the Test Results

In addition to explaining exactly how to perform the compression test and borescope inspection, SB03-3 provides precise guidance on how mechanics should interpret the test results. Here are some highlights:

If the compression test reveals that a cylinder is below the no-go leakage limit, the aircraft should be flown at 65 to 75 percent cruise power for at least 45 minutes and then the compression test should be repeated. Only if the cylinder still measures below the no-go limit during the re-test should it be removed for repair.

If the engine has abnormally high oil consumption (in excess of one-half quart per hour) with excessive oil discharge out the breather (i.e., oily belly syndrome), the borescope inspection reveals heavy carbon deposits in the combustion chamber and on the piston crown as well as excessive oil puddling in the cylinder barrel, then the cylinder should be removed for repair, regardless of the compression reading.

If there is any detectable leakage of air at the spark plug boss or at the head-to-barrel junction (between the fins), then the cylinder should be removed for repair, regardless of the compression reading.

The Bad News

SB03-3 is arguably the best guidance ever written on the subject of compression tests. If mechanics follow its guidance, unnecessary cylinder removal would be almost completely eliminated. The bad news is that there are still a lot of A&Ps and shops that haven't yet adopted the program. Some shops still don't own a borescope, and lots of mechanics still have little or no experience in using one. There are even some greybeard mechanics still recommending yanking a jug if it measures less than 60/80.

If your mechanic isn't borescoping your cylinders at every annual, beat him over the head with a rolled-up copy of SB03-3. If that's not sufficient to persuade him to buy a borescope, then it may be time to find a different mechanic. COPA

About the Author

Mike Busch has been a pilot for more than 40 years and 7,000 hours, and an aircraft owner and CFI for more than 35 years. He became increasingly interested in the maintenance aspects of aircraft ownership about 20 years ago, and ultimately earned his A&P/IA. Mike is also a prolific aviation writer of hundreds of technical articles published in *American Bonanza Society Magazine, Aviation Safety, AVweb, Cessna Pilots Association Magazine, IFR, Light Plane Maintenance,* and *The Aviation Consumer*. He co-founded AVweb in 1995 and served as its editor-in-chief for more than seven years. Mike conducts weekend "Savvy Owner Seminars" at which aircraft owners learn how to obtain better aircraft maintenance while spending a lot less money. Questions for Mike Busch may be emailed to mike.busch@savvyaviator.com