Light Plane Maintenance®

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Top Overhaul Facts and Fiction

By Kas Thomas

The "top overhaul" is to aircraft maintenance what the coronary bypass is to medicine: a costly, controversial procedure designed to prolong life or forestall the inevitable, depending on your point of view. The cost is high, the outcome uncertain. To be sure, the top overhaul (or "ring and valve job," in automotive parlance) has its place in aircraft maintenance. But it's also one of the most oversold procedures in aviation. Got a low jug? "Let's top it," the mechanic says. On inspection, the cylinder is beyond limits. Want to grind it oversize? Okay. "But if we grind *one* jug oversize, you really should do the others, too." (Another famous sales pitch: "You know, there really isn't that much additional labor to do all four cylinders, as opposed to just one . . .")

Some operators are doing top overhauls prematurely, and there's little doubt that many of these are a waste of money. But some operators are utilizing the top overhaul as part of a carefully considered game plan for extending TBO (time between major overhauls). The market for the "TBO-extension" top overhaul, in fact, seems to be growing rapidly. Many of the questions we get in the mail—and on the phone—these days run along the lines of: "Should I major the engine at the factory-recommended TBO, or should I top it now and try for TBO-plus-400?" And: "If I top it, when should I top it?" "What should a decent top consist of?" "Who should do the work?" "How should the engine be broken in?"

These are not easy questions. They're a lot harder when you're cheek-to-jowl with Mr. Goodwrench, however. It's best to have the answers in advance.

PHOTOGRAPHY BY THE AUTHOR

Because of the higher operating temperatures, turbocharged engines—such as the Seneca's Continental TSIO-360—need more top-end attention.

Definition of Terms

The term "top overhaul" means many different things to many different people. In some quarters it means pulling the cylinders off, inspecting them, repairing them as needed, and putting them right back in service with as few new parts as possible. To some, it means a complete ring and valve job, to new limits, for every cylinder. To still others, it means reworking just the jugs that need to be reworked. (Everybody agrees on one thing, which is that the word "top" in "top overhaul" refers to the cylinders and reciprocating parts of an engine, as opposed to the "bottom end," which consists of the crankshaft, camshaft, crankcase, main bearings, oil sump, oil pump, and gear train.)

Broadly speaking, then, a "top overhaul" can be considered any operation that results in removal of one or more cylinders and the refurbishment (if not the actual replacement) of worn top-end components. As such, it has its counterpart in the turbine "hot section" inspection,

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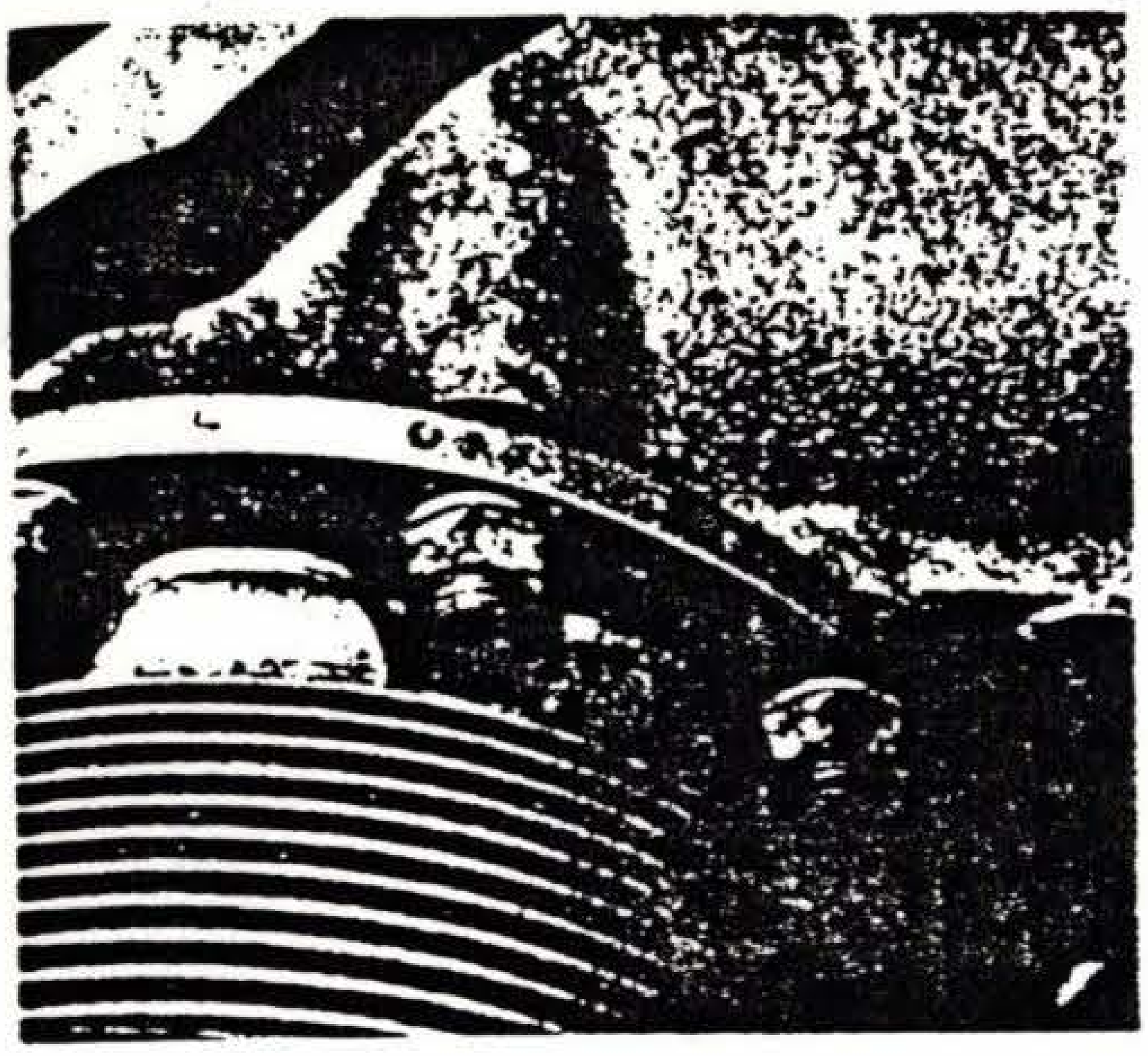

This barrel has been stamped '015' at the base to indicate oversize status.

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which for most jet engines is a required event each 1,200 hours or so. Turbine engines are enormously expensive to overhaul—$60,000 for even the smallest Garrett—and to have to tear one down every 2,000 hours would be unthinkable. Since most of the wear and tear occurs in the hot parts of the engine, it only stands to reason that the "hot section" should be inspected between major-overhauls, and the TBO extended to some fairly high value based on the results of previous hot-section inspections.

The same line of reasoning can be applied to piston engines. The highest temperatures (and the most wear) occurs in a piston engine's "top end": the cylinder barrels, pistons, rings, valves, guides, rocker bushings, etc. By inspecting and/or refurbishing the piston engine's "hot section" at regular intervals, it ought to be possible to raise the average piston engine's TBO. With the exception of the camshaft and accessory gearing, there is not much on the "bottom end" of the typical O-360 or O-470 (or IO-520, etc.) that bears looking at much oftener than 2,400 hours, especially if the engine in question is being flown daily.

Many operators have used this approach to score big TBO gains. In a previous story (September 1983 LPM) we mentioned the case of the California-based Cessna 421 operator whose Continental GTSIO-520-D engines—nominal TBO:1,200 hours—went all the way to 2,350 hours before being majored, thanks to scrupulous top-end renewal at 650 and 1,350 hours (and good operator technique, of course). We're also aware of a Part 135 operator who has obtained FAA approval for 3,000-hour TBOs on Continental IO-520s based on mandatory top overhauls at 1,500 hours. (FAA-sanctioned TBO extensions of 200 to 300 hours for air-taxi operators are extremely common, even without mandatory top overhauls.)

Overall Economics

The economics of performing a top (or partial top—i.e., a top-overhaul of two or three cylinders) as a preliminary to TBO-busting are worth pondering carefully, particularly if the engine in question is already nearing TBO. There's a rule of thumb for this, fortunately. Consider what has to happen in order for a $4,000 top overhaul to be cost-effective in the case of an engine that is nearing TBO and costs $8,000 to major. Obviously, for the top overhaul to be worthwhile, a TBO extension of 50 percent (4,000 divided by 8,000) must be achieved—e.g., your O-320 would have to go to 3,000 hours (vs. the factory TBO of 2,000), and at that point, you would simply have broken even on the top overhaul. (It will have just paid for itself in terms of forestalling the major.)

But let's look at the case of the Turbo Saratoga owner who—when the time comes—is planning not to overhaul, but to buy a factory zero-time rebuilt Lycoming TIO-540-S1AD at a cost of $23,000. In this instance, a top overhaul billing out at $4,000 will be cost-effective if a mere 17-percent TBO extension can be achieved. Since the factory TBO is 1,800 hours, this puts the break-even point at 2,106 hours—by no means an impossible goal.

One conclusion is clear. If your engine has a low TBO or is expensive to major (or you intend to spend a great deal of money on a replacement engine from the factory), a late-in-the-TBO-cycle top overhaul is more apt to be cost-effective than if your engine is a cheap one to overhaul and carries a high TBO.

Lycoming top-end parts are more expensive, generally, than Continental parts (Lycoming's sodium-filled exhaust valves, in particular, cost double or triple what most Continental valves do), and Lycoming engines tend to have generous TBOs, which might suggest that a top-overhaul (for TBO-extension purposes) would more often be cost-effective for Continental owners than for Lycoming owners. This may be true to some extent, but labor is usually a bigger factor, overall, than parts in the top-overhaul bottom line. So essentially the same rules apply to Lycoming as well as Continental owners.

With turbocharged engines, additional considerations apply. Will the turbo, wastegate, controllers, etc. (which may be in fine shape now) make it to the new target TBO? If not, how will the replacement of these items affect the payback picture?

Then too, of course, there are the normal accessories—magnetos, alternator, prop governor, starter adaptor and motor, vacuum pump, etc., all of which are normally replaced at major overhaul time. One or more of these accessories will likely need replacing somewhere down the TBO line, if not at the time of the top overhaul. Performing a top overhaul doesn't allow you to defer *all* decision-making with regard to life-limited components.

Prophylaxis vs. Repair

There may be special circumstances under which a top overhaul performed pre-

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Light Plane Maintenance®

Kas Thomas
Editor

Michael L. Stockhill
Contributing Editor

Carolyn Magruder
Art & Layout

Rosemary Royer
Production Assistant

David B. Noland
Critic At Large

Editorial Office
1111 East Putnam Avenue
Riverside, CT 06878

Subscription Office
P.O. Box 923
Farmingdale, NY 11737
Toll-free in U.S. & Canada:
1-800-227-5782

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emptively (prophylactically) is warranted—for example, if you are running a Part 135 operation and have a TBO waiver from FAA requiring you to top your engines every 1,000 hours—but generally speaking, for most operators, top overhauls should not be done on a time schedule. They should be done when top-end components are in definite need of inspection and/or repair, as evidenced by the presence of clear-cut distress symptoms.

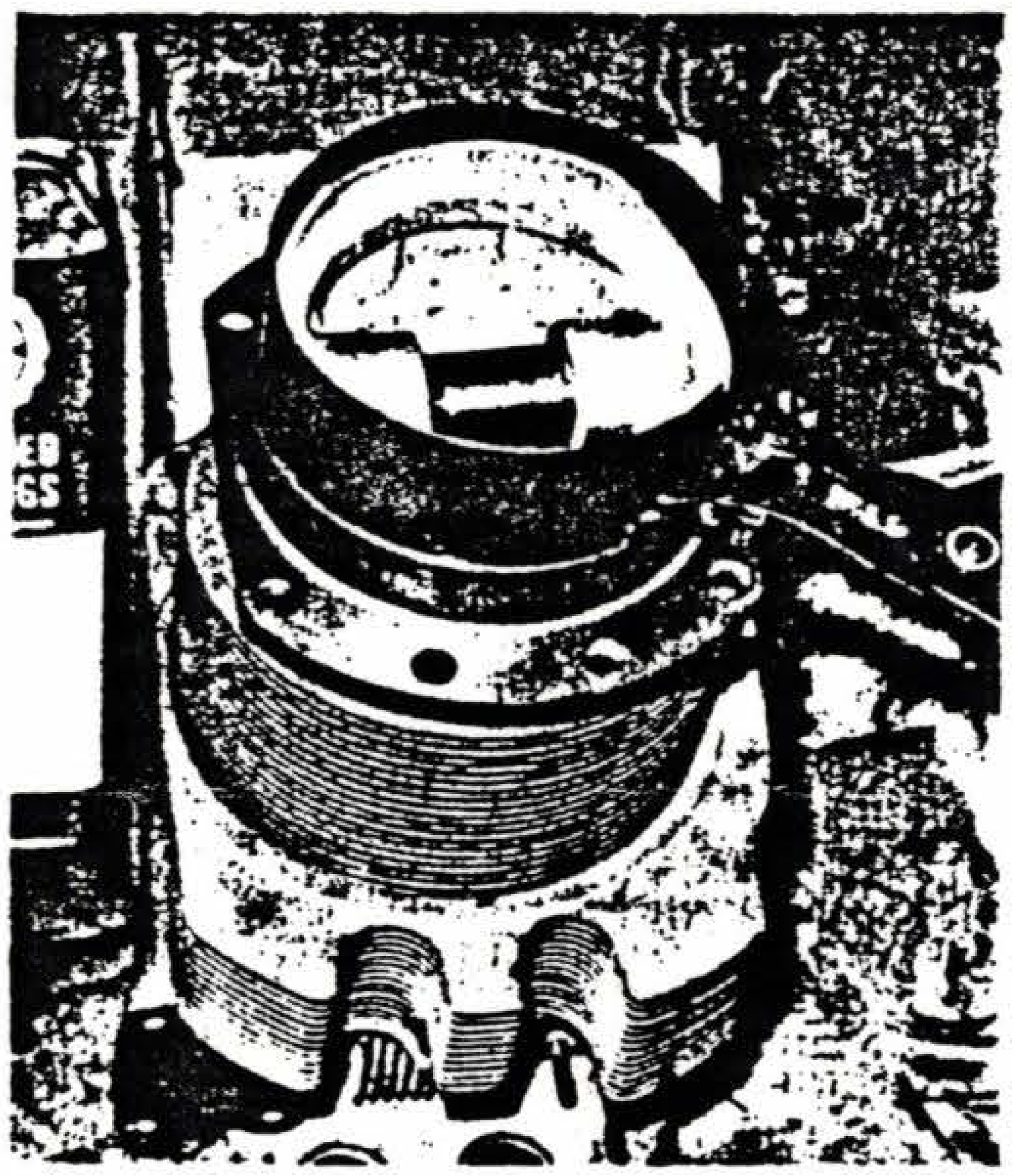
By a "clear-cut symptom," we don't mean cylinder compression in the sixties. In our opinion, far too many owners are being bamboozled into taking cylinders off simply on the basis of "poor compression," which most mechanics erroneously define as 60/80 (see "A Pilot's Guide to Compression Testing," November '82 LPM; reprints $3.00). There is no FAA rule requiring cylinders to be removed when differential compression goes below 60/80. (If your A&P disagrees with this, ask him to produce the regulation.) FAA Advisory Circular 43.13-1A does contain guidelines for compression testing, but AC 43.13.-1A is *advisory only* and does not carry the force of law. Likewise, manufacturers' bulletins are *advisory*, not mandatory, except that they may require the use of special tools per Federal Aviation Regulation 43.13, paragraph (a). On compression scores, the regulations are silent. And rightfully so.

Space won't permit us to recount the litany of compression-score myths here. We still shake our heads, though, when we read the line about "compression 75 percent of new" in the Price Digest Bluebook description of "average" plane condition. Compression in a new engine is never 80/80, and seldom 78/80. Therefore "75 percent of new" implies something below 60/80.) The important thing to remember is that most "20/80" and "30/80" cylinders fly in to the shop where they're eventually removed, so low compression is not really a safety-of-flight concern. Certainly, 60/80 doesn't qualify as dangerously low compression.

How low is low? Some years ago, Teledyne Continental issued a bulletin to Tiara engine operators (M76-18, Rev. 1) stating that compressions as low as 60/80 "are common readings for new engines," and a "limit reading of down to 55/80 is permissible."

The Pasadena, California Police Department operates a small fleet of Enstrom F-28C helicopters powered by Lycoming HIO-360-E1AD engines (with Rajay turbos); and PPD's resident IA-A&P doesn't begin to consider a low jug a problem until it goes below 55/80. If a cylinder is between 55/80 and 60/80, it will be continued in service and monitored every five to ten hours.

We agree with these guidelines. Even if a jug shows up 40/80, it should not be pulled indiscriminately (unless the engine shows other signs of distress). Before pulling a jug on compression alone, its valves should be staked (see AC 43.13-1A) and the



During buildup, parts should be coated with heavyweight mineral oil (top). A ring compressor is used (bottom) to fit the piston/ring assembly to the barrel before installing both on engine.

rings oiled, and compression measured a second and third time, using a different test rig, before condemning the cylinder as defective.

High oil consumption (one quart per hour) *might* be a good reason to top an engine—if other distress signs are evident (e.g., poor power output, wet spark plugs, low compression). But even oil wetness on top-hole spark plugs—a classical indication of advanced barrel and/or ring wear—doesn't *necessarily* mean you're looking at a top overhaul for the associated jug(s). In a fuel-injected engine, wet plugs (possibly accompanied by degraded performance and a rise in oil usage) can simply mean clogged injector nozzles. "A typical complaint from the field," one Lycoming official notes, "will be reported to us at the factory as a loss of power and the cylinders pumping oil. It is typically caused by a dirty or restricted fuel nozzle. The oil residue is a result of insufficient fuel causing low combustion pressures, which prevent the piston rings from doing their job efficiently. Without proper combustion pressures, we do not have sufficient pressure on the compression ring, which allows the oil to leak past."

The main thing to remember is that when deciding on the need for a top overhaul, trouble symptoms—not Hobbs time—should be your main concern; and no *one* indication of cylinder health should be relied on totally for making the "top" decision (unless, of course, there's a gaping hole in the side of a cylinder). Look at the total picture. Cross-compare different indicators—compression, oil analysis, spark plug deposits, engine vibration, oil consumption, etc.—and *monitor trends*; don't fixate on individual data points. If damage to piston crowns, valves, valve seats, cylinder heads, or cylinder walls is suspected, remember that these areas can be checked without removing the cylinder(s), through borescoping. (Also, valve-to-guide clearances can be monitored from the rocker box end using the techniques described in Lycoming Service Instruction S.I. 1088.) In short, don't pull a jug unless the handwriting on the wall is legible, and inescapable.

Cutting Corners

Once the decision has been made to pull a cylinder, don't scrimp or cut corners. Have the jug checked out thoroughly, especially if it's an oldie (more than 1,800 hours TT). If your A&P isn't equipped to perform detailed cleaning, inspection, and repair work on cylinders, have your errant jug(s) shipped to a properly qualified FAA Repair Station (ECI, Schneck, Van Dusen, Piedmont). That way, if special repairs are needed, they can be made on-site in minimum time. Don't expect your local mechanic to be able to weld head cracks or grind barrels oversize.

Avoid doing a "quick-and-dirty" ring job in the field to correct low compression or high oil consumption. If a preliminary dimensional check of your cylinders for bore, out-of-round, step wear, choke, etc. shows the jug(s) to be within service limits, but not within new limits, stop and ask yourself a few hard questions. What is your goal for the top overhaul? If it's merely to improve compression, you may be justified in fitting new rings to the cylinder, honing it, and putting it back in service essentially unchanged. Likewise, if all that's wrong with your jugs is glazed barrels, go ahead and hone them to break the glaze, then put them back in service (with new rings, if more than 50 hours old). If on the other hand you're trying to eliminate oil consumption in a large Continental, or continue an engine past TBO (to the point where the top overhaul will pay for itself), you should definitely bring the cylinder back to new limits. That will usually mean an oversize grind or chroming the barrel;

replacing the exhaust valve guide (and the valve, if it's deformed); fitting all-new rings; and possibly replacing the piston itself, if lands are worn or sideplay in the barrel has grown.

If the exhaust valve to guide side play is at all sloppy (consult your Table of Limits), don't expect the jug to make TBO-plus without replacing the guide. Take this opportunity to upgrade to the latest applicable guide and valve P/Ns. (Consult the latest revision of Lycoming Service Instruction No. 1037 or Continental M82-6, as applicable.) But be sure your shop *hones the guides* to proper finish before putting valves in them. Lycoming S.I. No. 1200C specifies a 30-micro-inch (RMS) surface crosshatch on the guide I.D. for best service life. Many A&Ps aren't even aware of this.

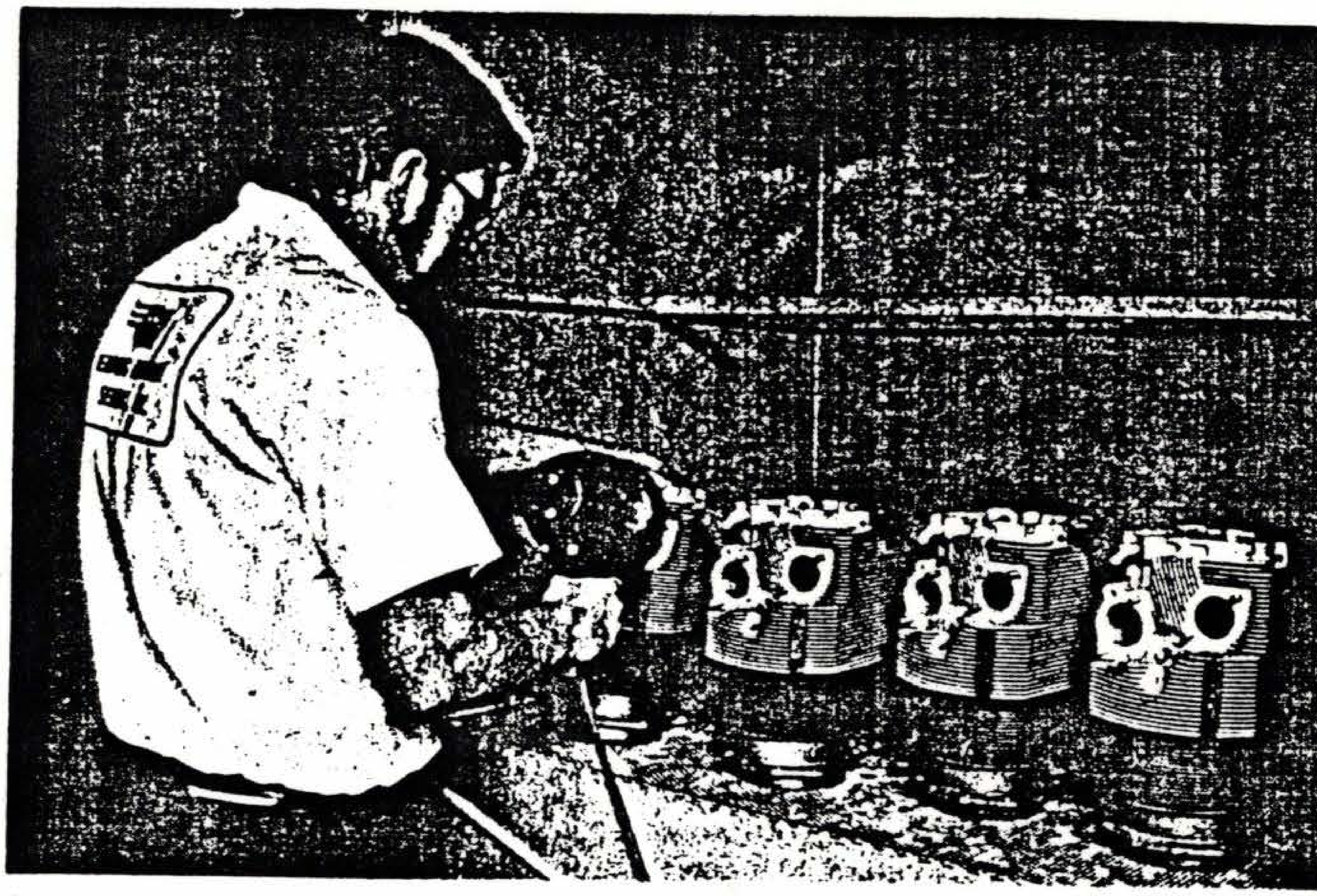
Cylinder honing is another gray area for many mechanics. "Honing is critical for break-in," a Continental engineer told us. "And not many mechanics know how to do it right. The scratches in the barrel bore should be crossed, with lines running at an angle of 22 to 32 degrees with the end of the barrel. These scratches must be wet-cut uniformly in both directions. The final pattern must be clean cut, not sharp, and totally free of torn or folded metal. All of this is spelled out in Service Bulletin M73-13, Revision 1." Also spelled out in that bulletin is a requirement for the final hone to finish out at 15 to 30 micro-inches (except at the extreme ends of the barrel, where 45 micro-inches is acceptable). According to Continental, it is okay to run figure-eights around the barrel I.D. with 200-grit sandpaper after honing to ensure removal of ridges and torn metal.

Very important: If the cylinder is to be oven-heated for valve guide replacement (or other repair operations), be sure honing is done *after*—never before—oven treatment, since otherwise residues from the kerosene-type oils used in the honing process will cook down to form varnish during the heating up of the barrel(s), thereby glazing the cylinders and preventing proper break-in.

Chrome vs. Oversize

Suppose your barrels are scored (from too many cold starts without a preheat). Or suppose your rings have stuck (or begun to stick), creating a nasty wear step on the barrel I.D. at the top of ring travel. Or suppose your jugs are okay for I.D. and out-of-round, but can't be cleaned up while also maintaining the proper choke contour. (That is, if you regrind to restore taper, you no longer meet service limits for bore diameter.) The latter is not an uncommon problem in certain large Continentals. "If you take a cylinder off a Pressurized Centurion after 800 hours," one engine man told us flatly, "you can be damn sure the choke will be gone, and the cylinder can't be returned to service."

The next step is usually to grind oversize, or chrome the barrel. Which should you do?



Cylinders are cleaned up prior to checking for choke, bore, step wear, and out-of-round. A thorough top will also include dye-penetrant inspection for cracks.

The answer is easy if you own a late-model Lycoming. All current production Lycoming engines except O-235-C, O-320-A/C/E, and IO-320-A or C employ nitrided (surface hardened) barrels. And nitrided barrels *cannot* be ground oversize, except for O-360-B and D and O-540-B barrels, which can be ground .010" over. (For more information, refer to Lycoming Service Instruction No. 1047 and the *Direct Drive Overhaul Manual.*)

Barring the above caveat, Lycoming operators with standard steel jugs actually enjoy a somewhat greater flexibility than Continental owners when it comes to oversize grinding, since standard-steel Lycoming barrels can be ground .010-inch oversize *or* .020-inch oversize (Lycoming supplies rings and pistons in both oversizes), whereas Continental jugs can be ground .015-over only. If you see green paint on a Lycoming jug, it means the jug is .010-over. Yellow paint at the base of the cylinder signifies .020-over. Orange paint in the hold-down area means the cylinder has been chromed. (Continental jugs that have been ground .015-over are not color-keyed but have ".015" impression-stamped into the cylinder hold-down flange—and written in the logbooks.)

The decision whether to chrome or go oversize is often a tough one; many factors must be considered. Are rings readily available? Chrome cylinders require special rings—namely, non-chromed, cast-iron rings—and supply problems are not uncommon. (For example, until recently there were no aftermarket suppliers of chrome-cylinder ring sets for O-235 Lycomings, and the Lycoming factory's inventory of these rings was low, leaving some customers grounded for an entire season while overhaulers waited for rings to become available.) Oversize rings are also occasionally hard to get for certain engines. Ditto for oversize pistons, which are not sold in great volume and therefore are priced higher than the corresponding normal-size pistons.

New pistons are required when an oversize grind is done, whereas when cylinders are chromed back to normal (new) dimensions, old pistons can be reused. But it is often the case that pistons must be replaced anyway, due to normal wear. (Piston replacement is not a bad idea, also, if TBO-busting is being contemplated.) The picture is further clouded by the fact that most shops will tell you that if one jug is ground oversize, its opposite mate should

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MAINTENANCE TIP OF THE MONTH: REPAIR KIT IN A TUBE

Most mechanics agree that one of the handiest "hand tools" around is a tube of RTV (silicon rubber in a tube) sealant—the kind that squeezes like toothpaste, sets in 10 minutes, and cures to a tough, resilient rubber in 24 hours. We've used (or seen A&Ps use) this stuff to make field repairs of broken insulation rubber on ignition lead elbows, "glue" chafing wires together (the joint can later be cut apart), protect ignition wires from cylinder fins—even fix leaks along airbox seams. (Apply RTV from the *outside* of the airbox.) Special high-temp (and fuel-resistant) RTV formulas are available, too. For $7.95 (roughly) per tube, it's quite a "tool."

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be ground over as well, to maintain dynamic balance. (The Avco Lycoming *Direct Drive Overhaul Manual* recom-[illegible]ds oversizing cylinders and pistons in [illegible]s for this reason.) So while the chroming operation usually costs a minimum of $175 per cylinder, versus only $50 or so to grind a jug oversize, the price disparity between the two operations is mooted by considerations involving pistons, rings, and further work on other cylinders. If only one jug is bad, the most cost-effective solution may just be to replace the cylinder assembly with a new one.

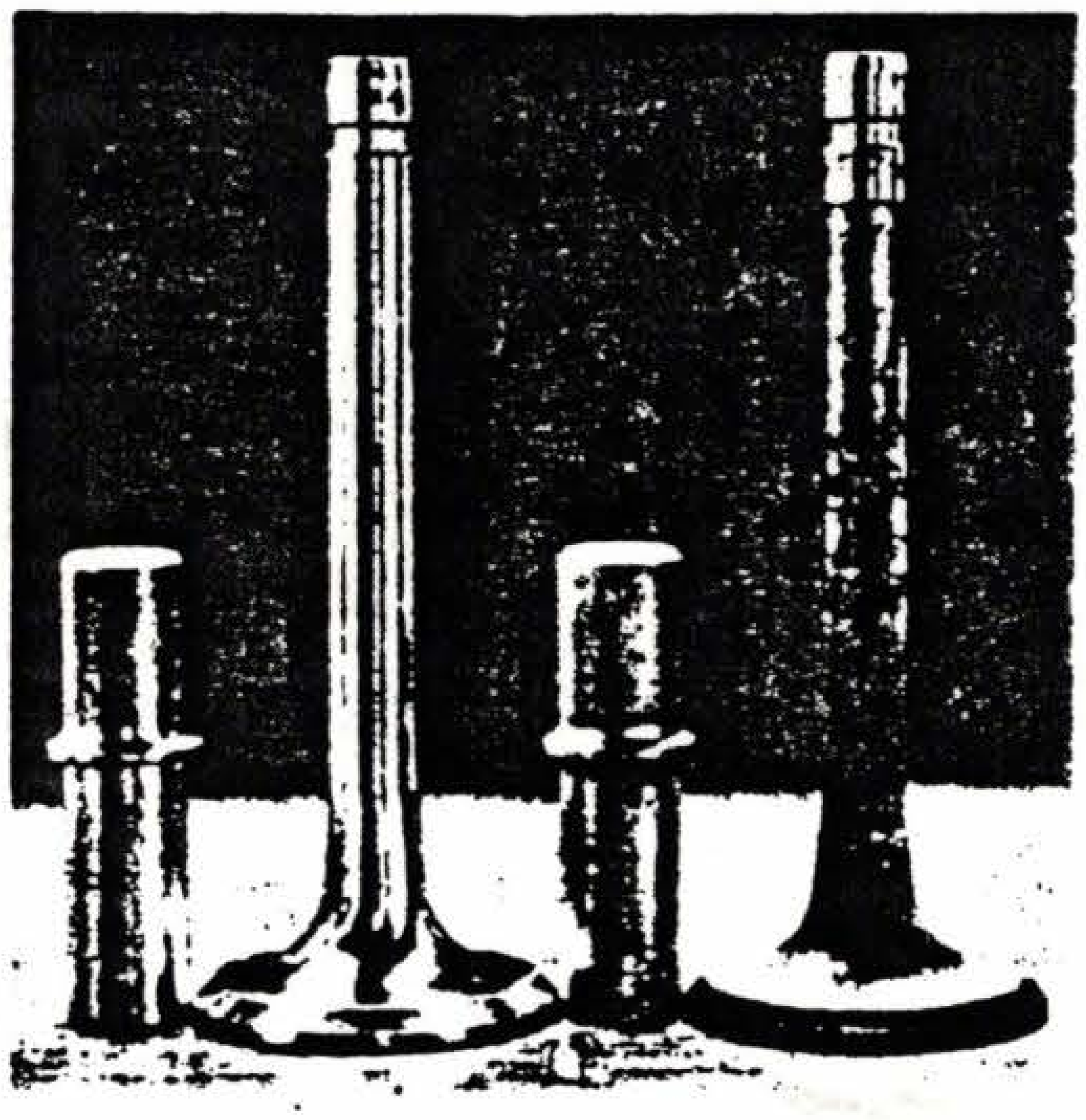
Do all cylinders have to be chromed at once? No. There is no reason why chromed cylinders can't be mixed with steel cylinders on the same engine. ("It's done all the time," a spokesman for a major east-coast overhaul shop told us.) The important thing is not to mix chrome rings with non-chrome rings.

As for oversize grinding: We disagree with those who maintain that cylinders *must* be ground oversize in pairs, to maintain balance. Dynamic balance has less to do with the mass difference between oversize and standard pistons than it has to do with the combustion forces acting on opposite sides of the crank. (Uneven compression will cause worse vibration than unbalanced pistons.) Proof of the pudding is that when oversize and standard cylinders are mixed on the same engine, no difference is discernible in the cockpit. [illegible] know, because two years ago we had [illegible]tituck install five oversize O-470-S pistons in our O-470-R Skylane in the course of a top overhaul—and if you hadn't read the logbook entry, you'd never have known that the engine contained one standard 'R' cylinder.

In general, we're in favor of doing the least work possible, even if it means mixing chrome, standard, and/or oversize jugs on the same engine. There is no benefit to be gained from pulling jugs that don't need to be pulled. Of course, if cost is no object, go ahead and put your A&P's kids through college. But if cost is no object, you're in the minority.

Break-In

If we were forced to take sides in the chrome-vs.-oversize debate, at least where top overhauls are concerned, we'd probably choose oversize grinding as our initial preference. The reason is that steel cylinders (properly honed) give more predictable break-in than chromed jugs, on the whole. Because of its inherent hardness, chrome is a more difficult surface to "seat in to" for rings, and unless ring seating is done in a test cell, break-in is a hit-or-miss affair—definitely best left to the overhauling agency, if at all possible. (Also, cylinder chroming is still something [illegible]n art, and if not done well, oil control is [illegible]. When chroming is being considered we recommend sticking with an established firm such as Engine Components Inc. or Schneck.) If you own a GTSIO-520,



Valve stem wear is rarely as advanced as shown here (on the right), but exhaust valve to guide clearance is an important parameter to watch.

chroming is no longer recommended by the factory; see Continental Service Bulletin M85-8, dated July 3, 1985.

If your overhauler will guarantee break-in of chromed cylinders, fine. Properly broken in, chromed cylinders will last a good deal longer than steel cylinders (because of chrome's hardness); and for operators who fly infrequently or are based near the coast, chrome offers vastly reduced corrosion potential. Most overhaulers, however, will not guarantee break-in on their chromed cylinders unless the engine is removed from the airplane and run in a test stand. The "in-the-airplane" break-in record of chromed jugs is not particularly good.

With steel cylinders (standard or oversize), it is important to begin the break-in as soon as possible after the cylinders are mounted on the engine, since polished (or honed) steel surfaces very quickly turn to rust unless inhibited with corrosion-preventive oil. During the break-in process, the microscopic hills and valleys in the honed barrel metal fill with varnish and combustion products to form—in effect—a protective coating which helps slow the rapid corrosion that otherwise affects new cylinders. It's essential to start this process as soon as the plane leaves the shop.

Mineral oil will not hurt your other cylinders, so if you're breaking in an engine with only one or two "topped" jugs, go ahead and put straight mineral oil in the sump for at least the first 25 hours. (Note: Phillips makes a 20W-50 mineral oil for break-in. Ask your dealer or jobber about it.) Don't ground-run the engine any more than necessary; and on the day of the first flight, don't cycle the constant-speed prop. (It lugs the engine and encourages scuffing.) After a brief warmup and mag check, slowly bring the throttle all the way in and take off. Keep the climbout shallow, and unless your engine comes with a 5-minute power restriction, don't reduce power after takeoff. Keep the rpm and manifold pressure up. "Babying" the engine at this point is a sure way to flub the break-in.

Will using an ashless dispersant oil automatically ruin your chances for a good break-in? No; it only lowers your chances. (Some engines, such as the Lycoming O-320-H and TIO-541-E, are *required* to run on ashless dispersant oil from the moment they're put in service.) You can put ashless dispersant oil in your freshly topped engine if you want to. Break-in simply won't be as predictable.

Little-Known Facts

Some little-known facts that you might want to consider when top-overhauling your engine:

1. Chromed cylinders can be rechromed.
2. New barrels can be put on old cylinder heads, and vice versa (see "The Engine Clinic," p. 13 of this issue.)
3. A common mistake in field overhauls is installing piston rings upside-down. Even if a ring looks symmetrical, it should be installed with the part-number side *up*.
4. Pistons should not be cleaned in soap or detergent solutions. (Cast aluminum is porous and will retain soap residue. Later, the soap will combine with the mineral oil in the engine to create foam, which interferes with lubrication.)
5. Many shops use STP cut with mineral oil for an all-purpose parts lube during buildup, even though STP contains an anti-wear additive that may hinder break-in.
6. Failure to mask the underside of the cylinder hold-down flange prior to painting the base area with orange, yellow, or green paint (to indicate the barrel type) is a major cause of inflight cylinder loss. A thin paint film under the base flange will cause torque to be lost on hold-down bolts, resulting in the studs shearing under high load. The same goes for RTV-type sealants, which should never be used under cylinder hold-down flanges.
7. Connecting rods and crankshaft dynamic counterweights can be serviced during a top overhaul. If you wish to rebush rods or counterweights, or replace connecting rod bolts, now's a good time to do it.
8. It *is* often necessary to remove the entire exhaust system (and/or intake system) from an engine in order to get just one cylinder off; your A&P isn't pulling your leg.
9. Cessna's labor flat-rate book says to allow six hours' removal/installation time to remove the first cylinder from a six-cylinder engine, then three hours additional for each cylinder after that.
10. Top overhaul kits containing gasket sets, ring sets, etc. for most popular engine models are available at nominal cost ($300 up) from El Reno Aviation, P.O. Box 760, El Reno, OK 73036 (phone 405/262-2387). Send for a price sheet (specify engine type)—and say you read it in LPM.