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Engine & Prop Dynamic Balancing

by John Loughmiller

In 1961, my father bought me a 1954 four-door Chevrolet with power-glide transmission as a graduation gift. It took all his savings, and I, being a dumbass teenager, didn't appreciate it and wondered why he didn't buy me a Corvette instead.

The car had an annoying vibration that was present only at certain speeds, and I remember taking it down to the neighborhood gas station for a wheel-balancing episode. The local petrol-pumper (who was a bit unbalanced himself, incidentally) straightaway decided that a session with the static balancer would cure all the ills present in the fire-breathing six-banger. Out came the proverbial bubble-type tire balancer, and quick as a flash the appropriate lead weights were affixed to each wheel, the tires reinstalled, and the fee collected.

One mile down the road it became apparent that the problem was still there—maybe even worse. Back to the station, and—this time—out came the "spin the tire on the vehicle" dynamic balancer. Different weights installed at different places thereupon cured the problem as if by magic.

The Chadwick Solution

The foregoing object lesson was forgotten until recently, when I decided (after much procrastination) to do something about the foot massage I was getting from the rudder pedals on my Piper Lance at various (make that almost all) rpm ranges.

Enter the Chadwick vibration analysis machine and its keeper, Mike Jones of Aircraft Specialists, Inc., of Louisville, Kentucky (phone 502/241-0971). Now, if you haven't met Mike, let me say he's not your average wrench. Along with being an IA-rated A&P, Mike's a pilot and honest-to-goodness graduate aeronautical engineer (Purdue, 1976). He holds court along with partner Eric Taylor and the two of them can usually beat a problem into submission with generous applications of both practical and theoretical knowledge. Killing the vibrations present in my Lance presents a good case history for purposes of looking at how the Chadwick machine works and how it is used. Suffice to say, if the Chadwick were a violin and Mike were playing it at the Kennedy Center, both would get rave reviews.

We all know that anything that moves generates numerous byproducts to its movement: heat (from friction), turbulence in the medium through which it passes (wake turbulence), and so on. If a device has a rotational component, vibration is sure to be present as the mass rotates, since no mass is ever truly, perfectly balanced. The vibration occurs as the mass deflects (by Newton's third law) the object away from its rest position. The object, in the case of an airplane, may be a prop, crankshaft, etc.

Now imagine for a moment that the propeller on your airplane is a solid disk. And since we're just imagining, create in your mind a lump of extra material on the disk out near the edge. If we were to spin the disk, whatever the disk was attached to would try to follow the point of unbalance as it went along its path. The result would be vibration.

In a direct-drive aircraft engine, the prop, prop spinner, and crankshaft can be considered to be one unit as far as vibrations are concerned. Any unbalances present in the crankshaft will affect the prop, and vice-versa. If you were to instrument the engine with a device (call it a transducer) capable of measuring relative movement of the crankcase with respect to a fixed surface (the Earth), you could measure and observe the degree of vibration intensity. Further, if you knew where the prop blades should be at any given time in the rotational cycle, you could observe what effect the vibration has on the prop and predict wfere the apparent "lump of material" must be located on the rotating

Chadwick Balancing Tricks

Although the principal use for the Chadwick machine (properly called the Vibrex System) is to balance props and rotorblades, it can be a useful diagnostic tool for other engine ills as well.

The Chadwick balancer has the ability to look at inputs from two accelerometers at one time, which means the engine (or rotor system, in the case of a helicopter) can be examined in detail to determine precisely where, along the rotational axis itself, the greatest vibration is occurring. By instrumenting the fore and aft ends of the engine instead of just one end, and examining the amplitudes of the deflections, a good guess can be made as to the location of the problem.

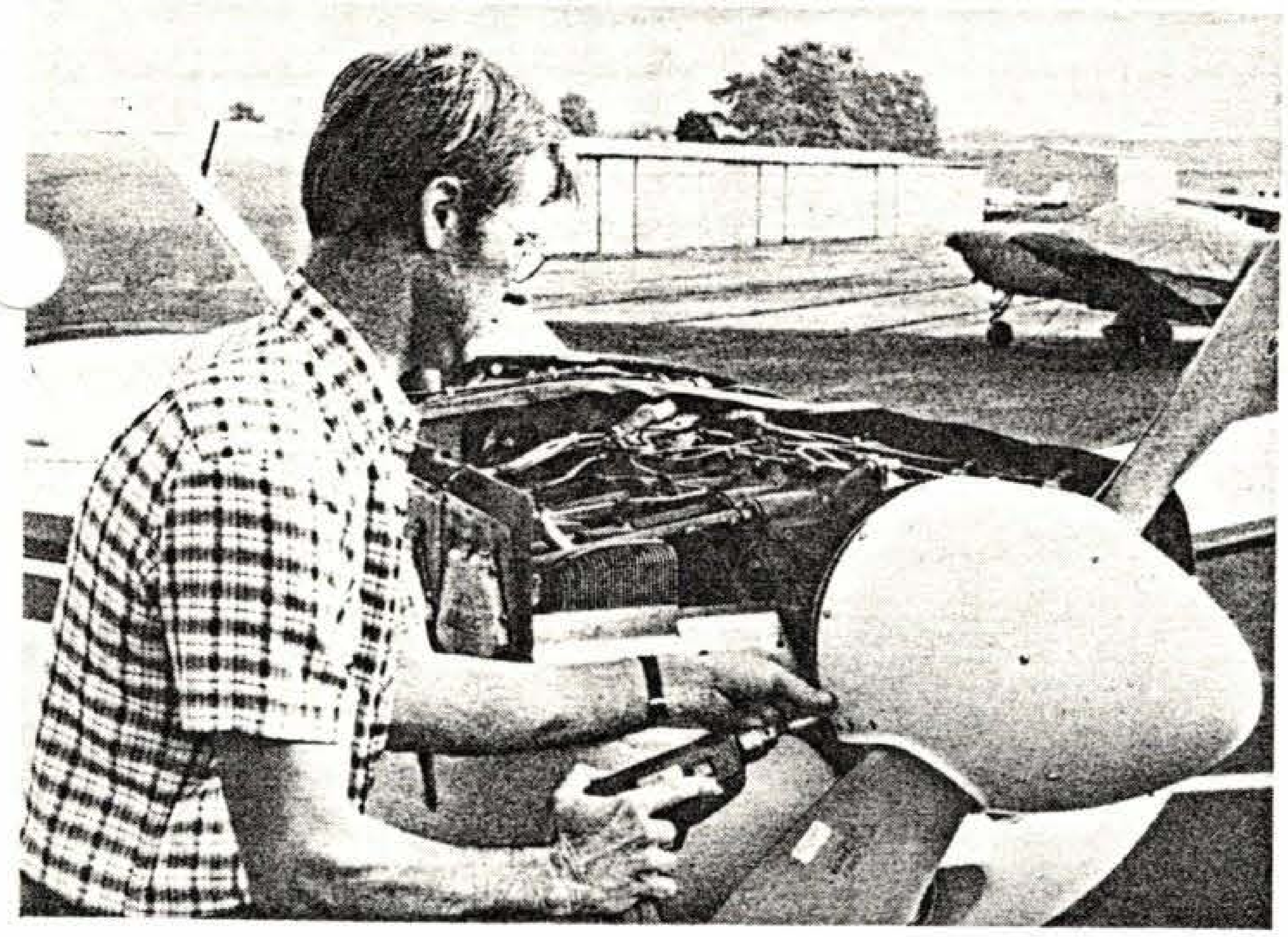
Another trick is to run the engine at one rpm and examine the half-rate product of that rpm. In the accompanying article, 2,200 rpm was the chosen prop/crankshaft speed. At that speed, the operator would look at the 1,100-rpm component, because it is there that camshaft and rod/piston problems would show up. Because four-cycle engines operate on the suck/squeeze/bang/blow principle (with half a rev for each portion of the cycle), there are components moving around during the overall process that aren't contributing to the power output at that particular time. These components can be monitored for vibration by looking at the half-rate frequency (1,100 rpm).

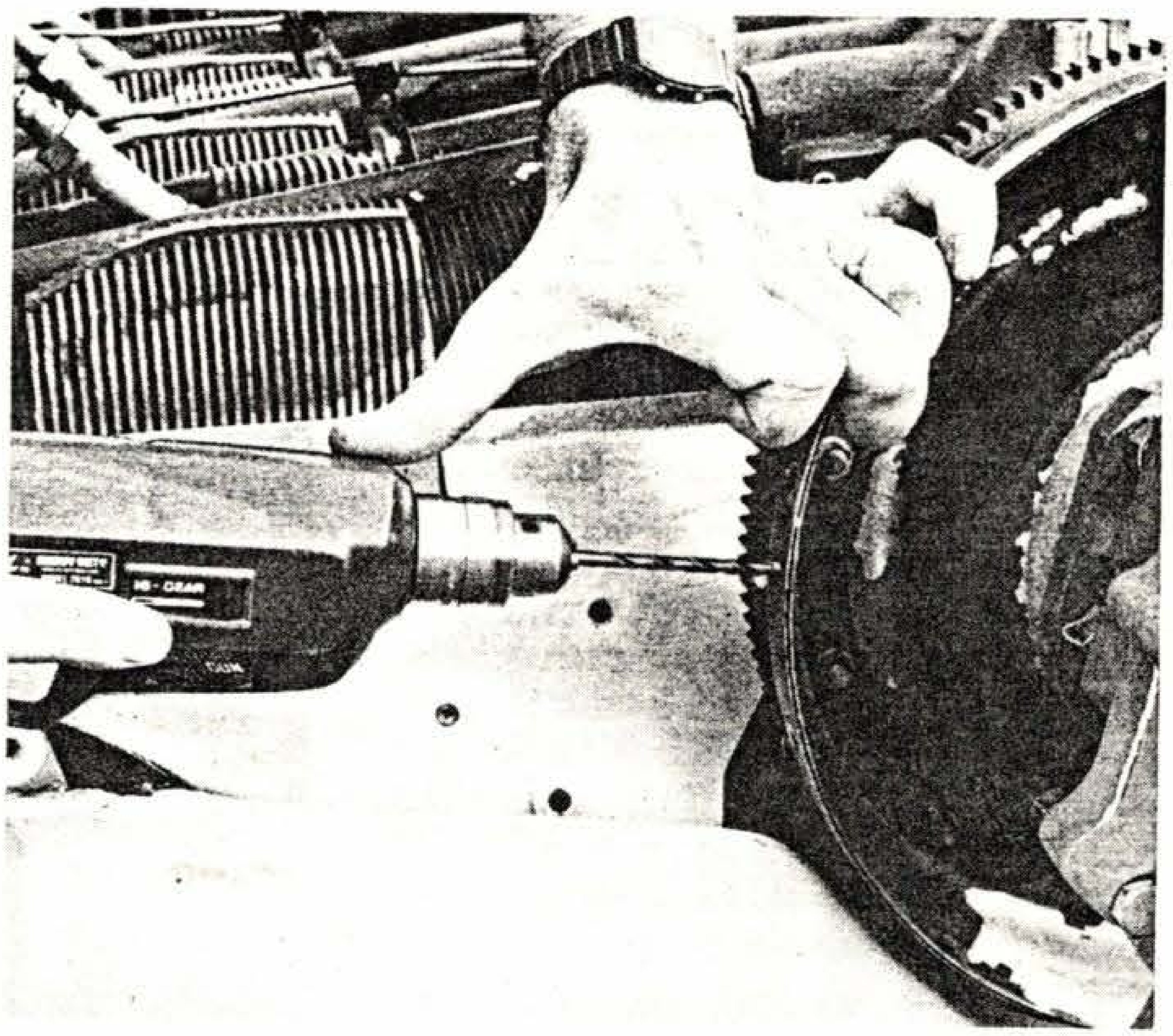
As stated in the main article, you can't balance out rod, piston, or camshaft problems with prop spinner weights, but you can certainly check further once you know about the problem. For example, if the half-rate product were high and other symptoms were present (high oil usage or low compression), you might want to pull cylinders and investigate further.

Half-rate products can be more serious than full-rate (first order) vibrations in many cases, since they can indicate hidden problems that only a top or major overhaul can cure. A spalled camshaft or a bad accessory drive gear is best discovered on the ground, if possible.

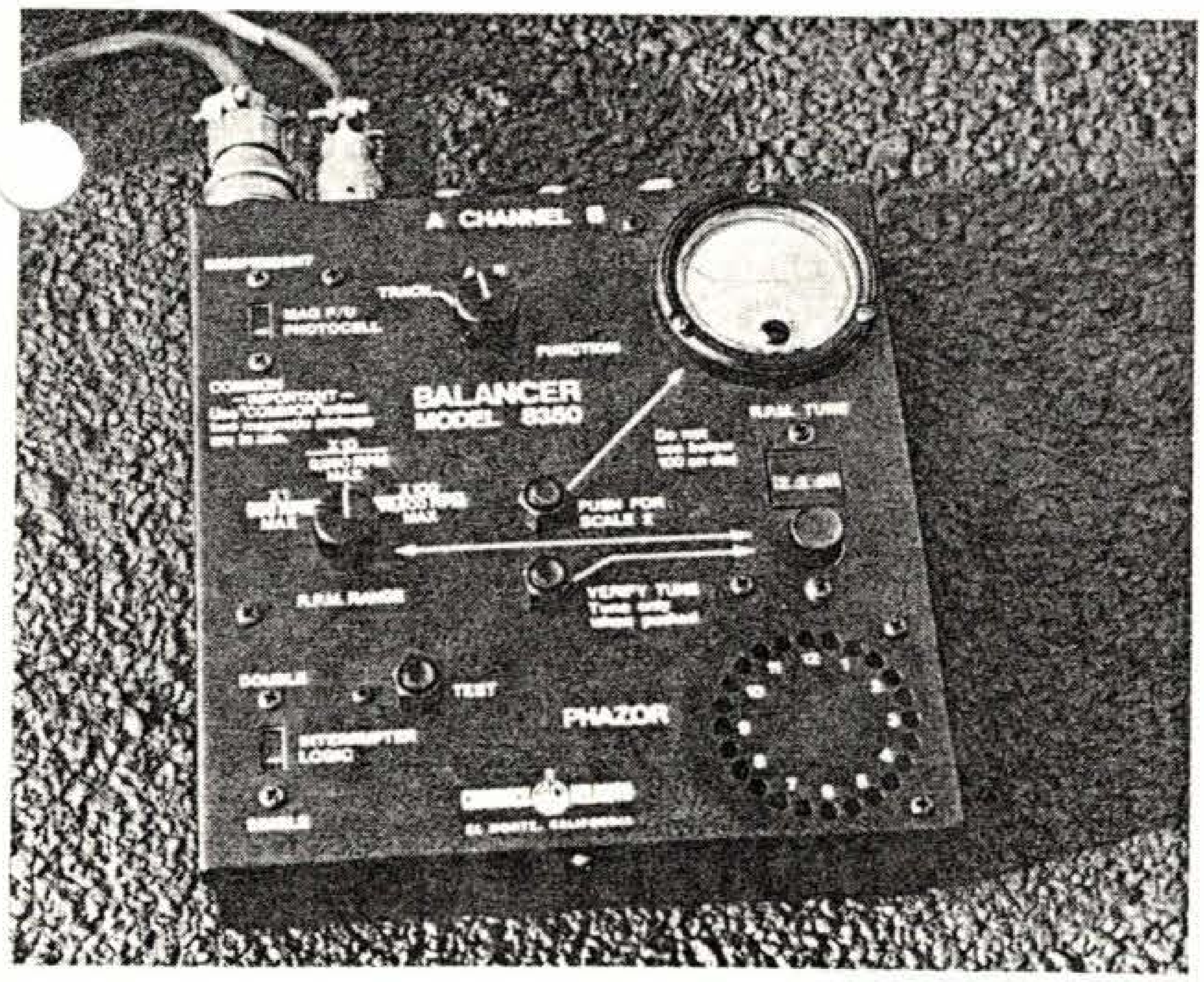
As they say, it's always better to be in the hangar wishing you were flying than the other way around.—*JL*

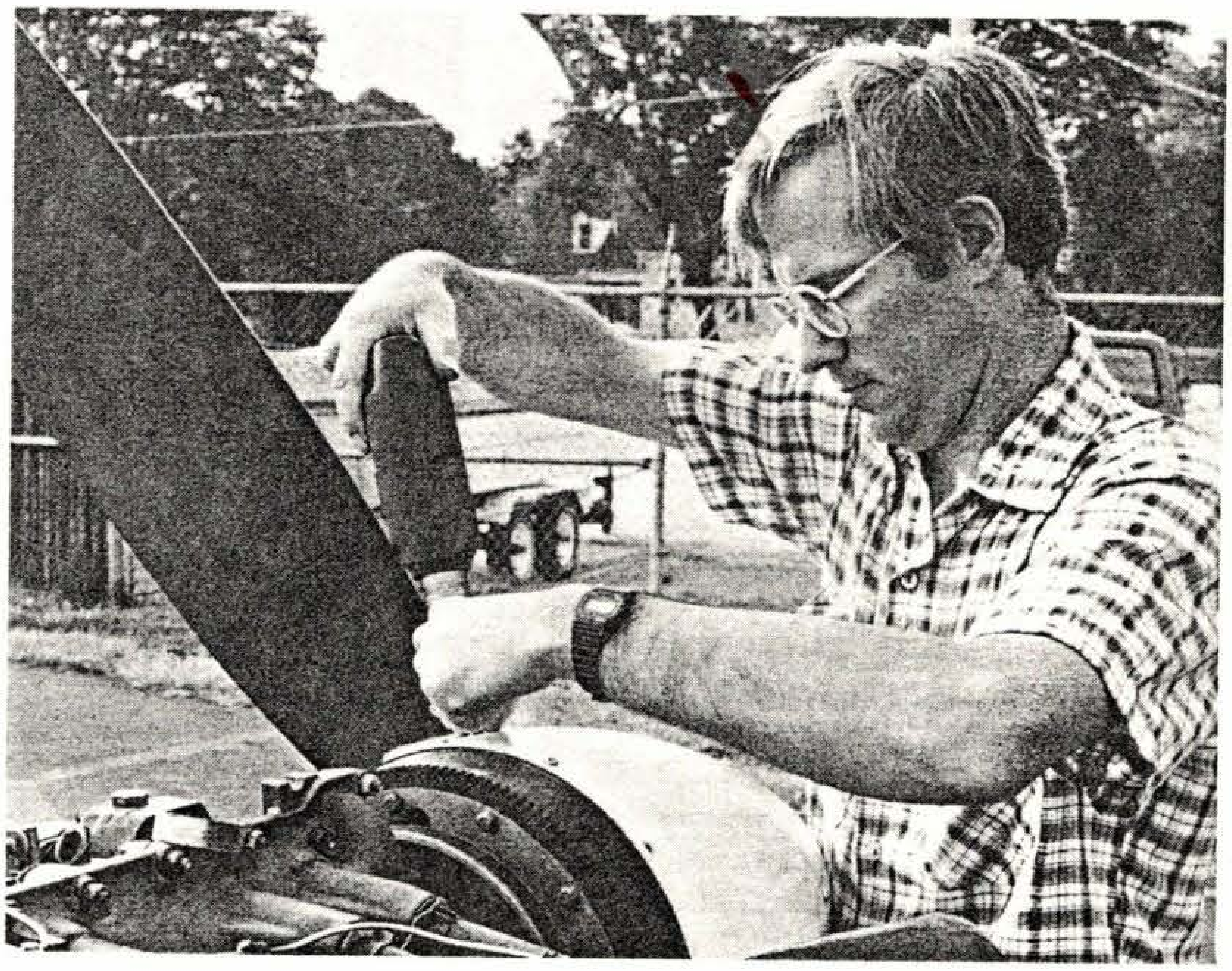
Contributing Editor John Loughmiller is a Certified Fright Instructor (Double-Eye variety) perpetrating unspeakable horrors on students in the Louisville, KY area.

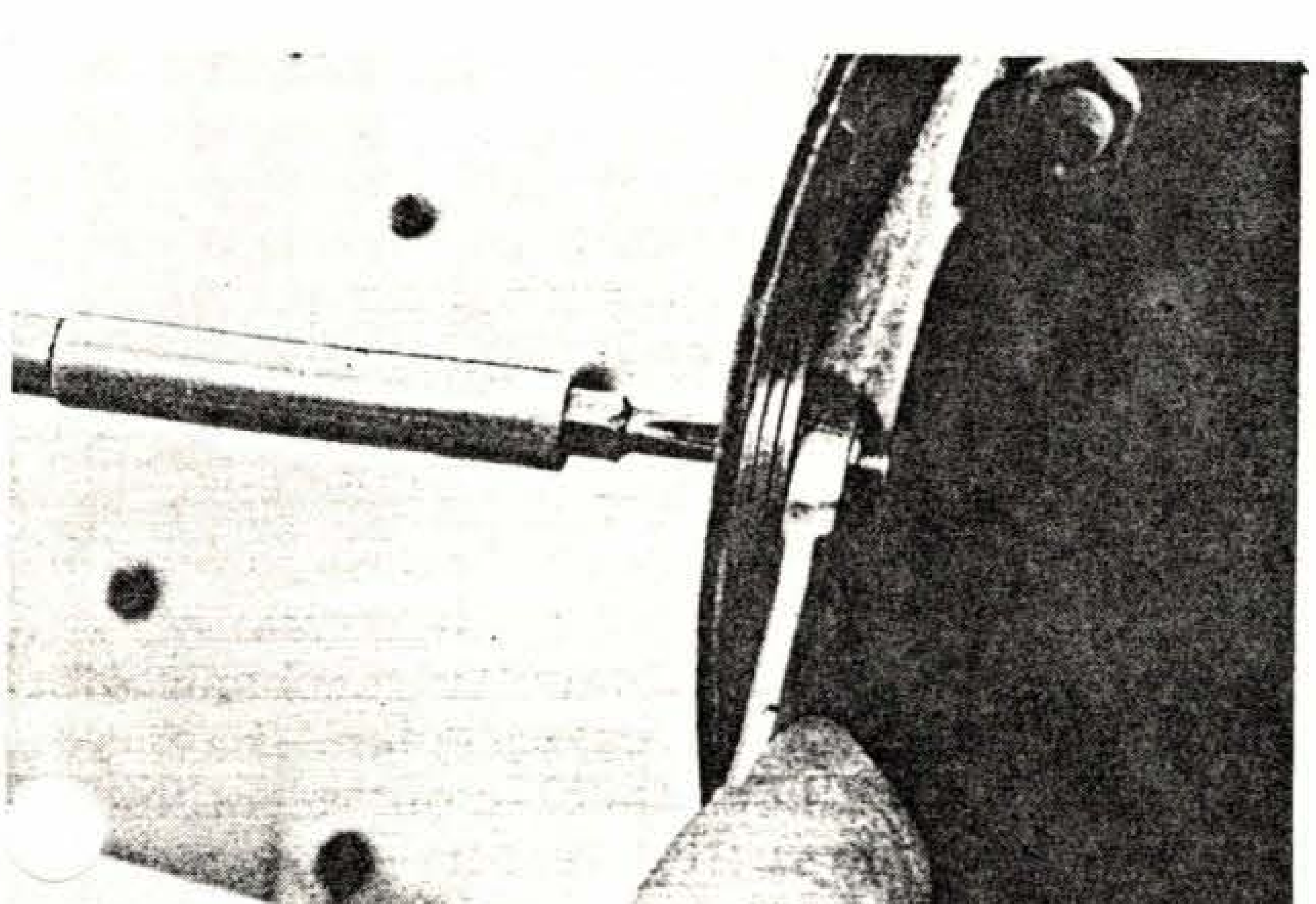


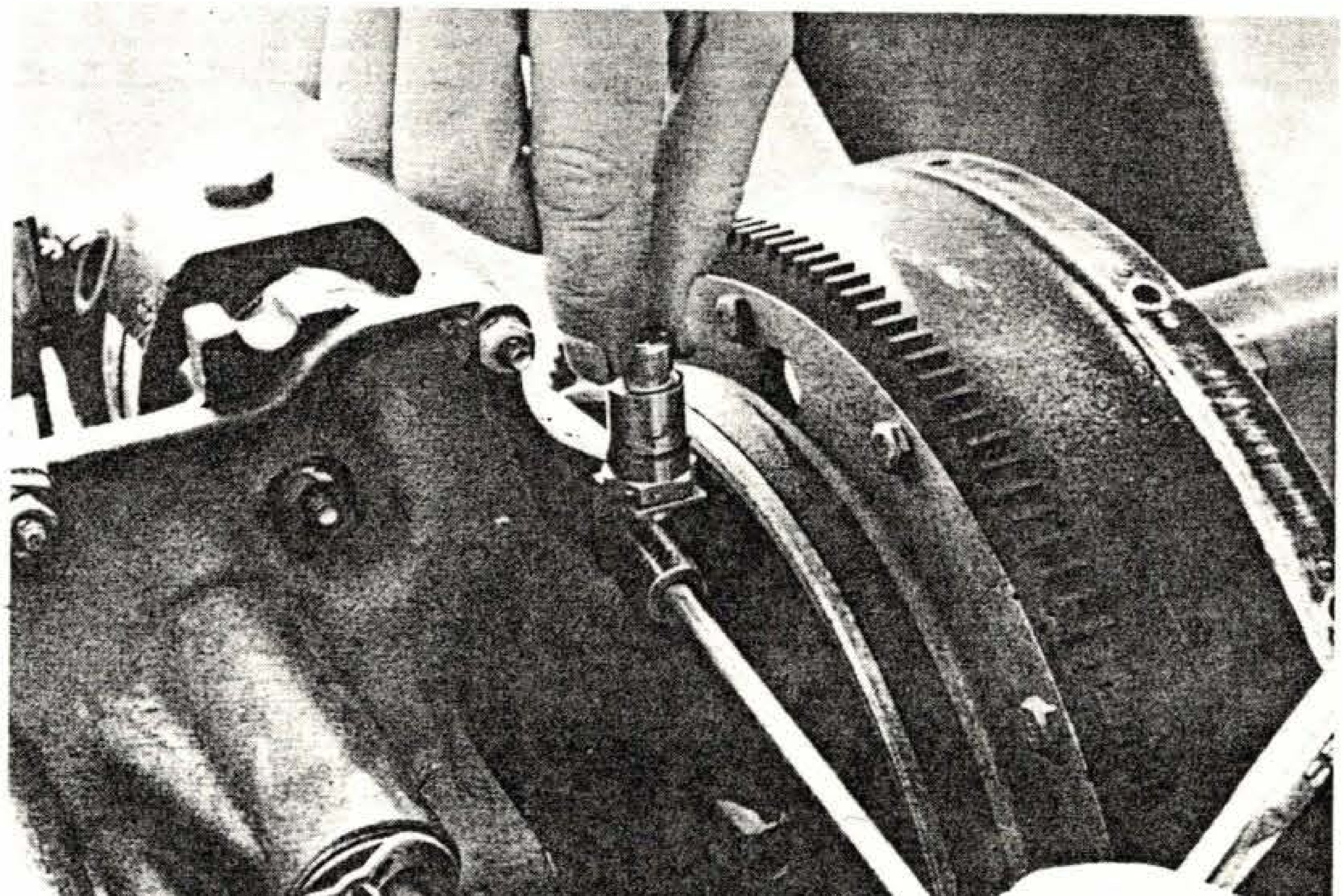


Clockwise from upper left: Mike Jones removes the spinner from the author's Piper Lance . . . . Balance weights are added to the prop spinner aft bulkhead. . . . . The strobe interrupter must be counter-balanced by its own balance weight 180 degrees opposite . . . . A tiny accelerometer mounted vertically at the front of the crankcase provides 'g' measurements . . . . Weights are attached by dedicated machine screws. Several engine runs may be needed (with successive spinner removals) to get the balance just right. . . . The Vibrex balance box gives readouts not only of vibration (in inches per second) but axial location.









PHOTOS BY JOHN LOUGHMILLER

disk that the prop has become. If you did all of these things, you'd have a Chadwick machine, and very possibly a patent infringement case to consider.

Hookup

After removing the top cowling and prop spinner from the Lance, Mike attached an acceleration-sensing transducer (or accelerometer) to the engine as far forward as he could. (He could have put it as far to the rear as possible, and the transducer would still work, but the measurements might be 180 degrees out of phase with the real world, so he stayed up front to keep it simple. Also, he could have installed the device horizontally or at an angle, but he prefers instead to mount it on top, again to keep it simple.)

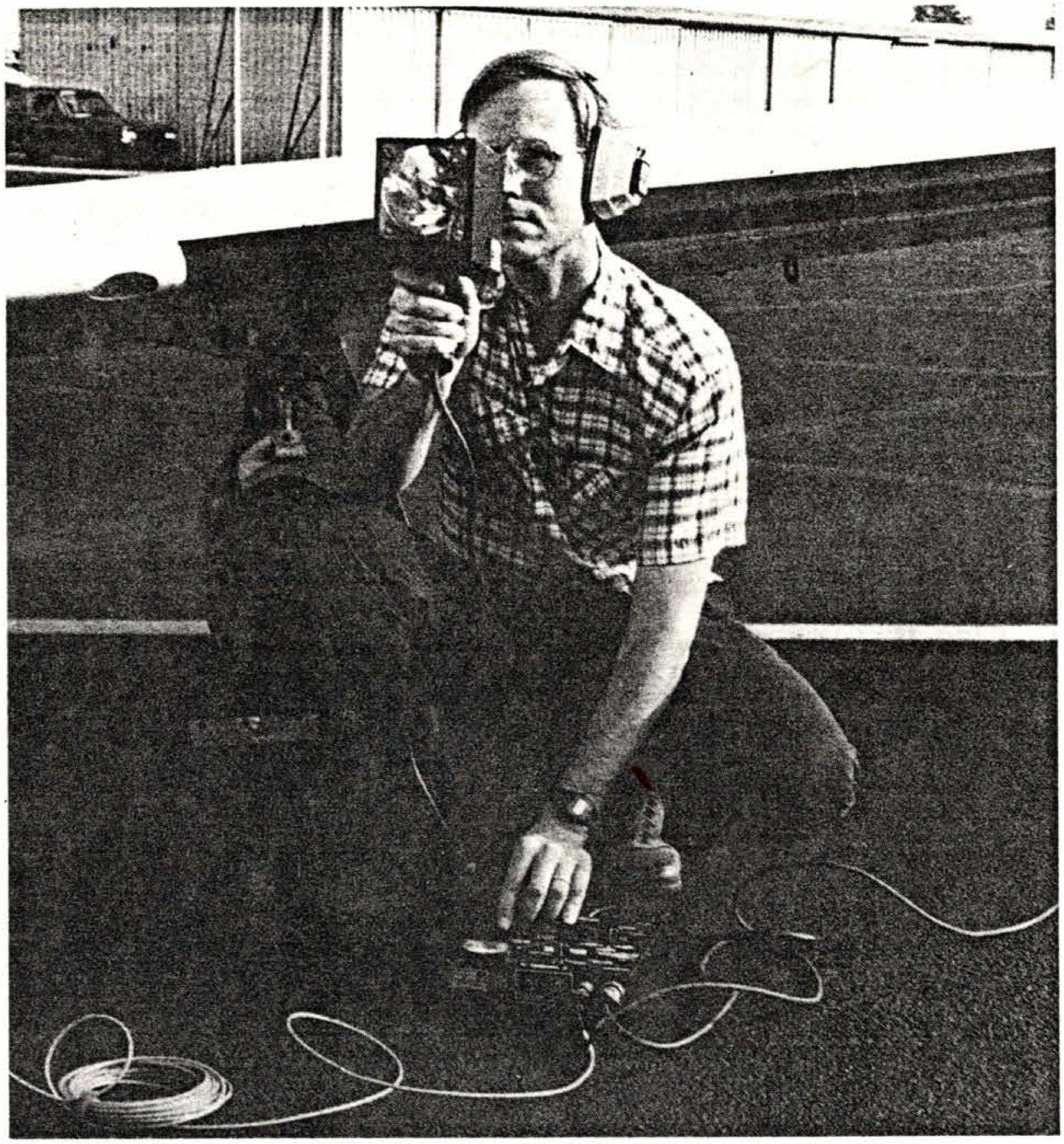
After Ty-Wrapping the leads to an engine mount, the first test run was made. The engine was started and run up to 2,200 rpm—or at least what was 2,200 according to my tach. (One of the bonuses of this procedure is that you find out the accuracy of your tachometer. Mine reads 70 rpm low, which explains why I always get better-than-book airspeeds.) In any event, the Chadwick machine said I had four times more vibration than I should have had. A deflection of zero inches is perfect; 0.1-in. is acceptable. I had 0.45-in. of deflection.

As Mike pointed the strobe light at the spinning prop, he was able to determine where he had to add weights in order to damper out the unbalanced condition. After shutdown, a countersunk hole was drilled into the aft prop spinner bulkhead. Without referring to anything, Mike fished three weights out of a container and screwed them in place inside the bulkhead lip. We fired up again.

At 2,200 rpm, the vibration had dropped to 0.08-in. deflection. We shut down, reinstalled the prop spinner—and the vibration went back up again when we again ran at 2,200.

Once more, Mike removed the spinner, and again—seemingly with no forethought—he found a couple of weights, attached them quickly to another point on the same spinner bulkhead, and reinstalled the spinner. The magic number was now 0.05-in. deflection, and Mike said it was time to quit.

The net result: the 800-rpm vibration that had always been evident was now diminished to the point of barely being noticeable. My cruise vibrations are for all practical purposes gone.



Mike Jones takes yet another reading from the Chadwick-Helmuth Vibrex box prior to making final adjustments to the author's plane. Up to half a dozen iterations may be necessary.

The engine seems much "happier" now, and my feet, after an hour in the air, no longer feel like they've been attacked by some deviate with a vibrating marital aid.

No Panacea

According to Mike Jones, the Chadwick balancer is no vibration panacea. Although it will disclose problems caused by camshaft unbalance, unbalanced pistons, and accessory case maladies, there's no simple way to balance out such problems short of splitting the case or pulling cylinders. Mike also cautions that if the crankshaft is out of balance at its rear end (where the dynamic counterweights are in many engines), it's unlikely that adding weights to the prop spinner will help. This is because a phase reversal occurs at the center of the engine. Mike warns that lots of other things besides crankshaft and prop imbalance can cause vibrations—things like chafing hoses, rattling exhaust pipes, tight control cables, missing cowl fasteners, and so forth.

For me, though, the Chadwick exercise was $130 well spent. The reduction in vibration can't help but extend the life of the engine, and prolonging engine life (postponing overhaul) is money in the pocket any way you look at it.

By the way, I asked Mike if he just got lucky when he hit the correct combination of weights for my problem on the first try, and he said no. He says he does it so often that he just knows what it takes. For the less knowledgeable, there is a table that recommends weights to be used for various unbalance conditions.

If you have vibrations you don't want to live with anymore, find yourself a competent mechanic with a Chadwick balancer and have your vibrations checked out scientifically. I believe the results will speak for themselves.

Dynamic Balancing: A Comanche Owner's Experience

I had always assumed that a heavy, rumbling vibration was natural in big-bore four-bangers. And certainly, the engine and airframe vibration I felt when flying my Piper Comanche 180 (with Lycoming O-360-A1A) *was* heavy compared to my experience in a Comanche 250 and a Bonanza. It seemed only reasonable that the six-cylinder engines would be smoother, having power strokes 120 degrees apart instead of 180, and a greater mass to dampen vibrational accelerations.

It now appears my original assumption was not correct. During a recent "owner-assisted annual" at Sky Acres Airport near Poughkeepsie, NY, I observed Jack Schneider performing dynamic propeller/engine balancing on several aircraft. This balancing is done with the engine running and uses a vibration acceleration transducer (or accelerometer) bolted to the engine, plus a synchronous strobe light, with a computer-generated readout of vibration intensity and the actual crankshaft rpm at several different engine speeds, with a recording of the imbalance's magnitude and apparent location. The imbalance is then corrected by adding weights to the light side of the prop spinner bulkhead.

Jack told me that he had heard nothing but rave reviews from aircraft owners who had had the balancing act performed. On hearing this, I made an appointment to have my Comanche balanced. How could I resist?

As a precaution, I first stripped the many years' accumulation of paint off the prop. (The layers were especially thick at the tips—exactly where weight would make the most difference.) Then I carefully and evenly repainted the prop.

Jack Schneider is a perfectionist when performing the balancing procedure, constantly and repeatedly checking and rechecking as he goes along. (The procedure is inherently labor-intensive, with many starts and stops.) Finally my engine ended up with counterbalance weights consisting of one extra-long bolt through the starter ring gear and several washers under it.

The bottom line? Performance changed in two very distinct and immediately noticeable ways. First, the airframe rumble and vibration are completely gone. (I mentioned to Jack later that I will miss the foot massage I used to get from the floorboards in flight.) Secondly, during ground acceleration and climbout, the engine power is distinctly smoother and feels stronger than ever, more reminiscent of the 250 Comanche or Bonanza, in fact, than of the O-360 Comanche—and would you believe I actually have a greater rate of climb than before at my usual climbout airspeed?

It's not unreasonable to expect longterm benefits from a good balancing job. Certainly pilot fatigue will be lessened—I've already experienced this. Reduced vibration can only mean less wear and tear on instruments, avionics, engine mounts, and a lot of sheet metal and rivets and fittings, too (not to mention the engine and propeller themselves).

Jack Schneider gets $175 for singles and $325 for twins for his balancing act, and in my book, it's the best bargain around. If you're on the East Coast, phone Sky Acres at 914/677-9353 for more information, or call the Chadwick-Helmuth Co. at 818/575-6161 for the name of an FBO near you.

—Don Jensen

Whence Cometh Chadwick-Helmuth?

El Monte, California is a quiet, stucco-fortified Mextown bastion of low tech, a beer-bottle's throw away from sunny Pasadena. Flanked by Rose Hills to the south and Mount Wilson to the north, and thus falling squat in the middle of L.A.'s noxious San Gabriel Valley, El Monte is remarkable only for the fact that it has a tower-controlled, County-operated, asphalt-covered airport with 5,000-ft. runway and instrument approaches. It's also home to Chadwick-Helmuth Co., manufacturer of the famed Vibrex Balancer.

For all the years I've operated out of EMT, I never knew Chadwick-Helmuth existed until 1984, which—not coincidentally—is when Dad bought the helicopter. You can't own a helicopter and not know about Chadwick, I don't care where you live.

All major helicopter manufacturers, without exception, recommend the Chadwick balancing system, and every slingwing operator who's not daft or incompetent knows the phone number of his local Chadwick rep by heart. Next time you see a helicopter on the ramp, take a close look at the rotor mast. Chances are at least 50-50 you'll see Strobex interrupter vanes and a magnetic pickup permanently attached to the ship.

Chadwick-Helmuth is no fly-by-night operation; the 80-employee company has been around since 1954. Originally a manufacturer of environmental test equipment, C-H got its first big break when nearby Hughes Aircraft asked them to figure out a way to balance and track the rotor system of a new helicopter. A strobe system was developed to aid tracking, and when used in conjunction with tiny accelerometers, the Strobex system, it was discovered, could be used to visualize two-dimensionally the balance requirements of a whirling rotor. Thus the Vibrex system was born.

Over the years, the Vibrex balancer has been adapted to propeller system diagnostics for everything from Gulfstream I turboprops to Beech Bonanza and smaller airplanes. The Chadwick-Helmuth exhibit has long been a familiar sight at the HAA and NBAA shows; now their prop-balancing demo is a crowd favorite at Oshkosh each year.

What claims does the company make for its equipment? "Our experience over the years shows that 80 percent of the propellers we balance result in a *substantial* improvement," one company spokesman explains. What's more, he says, "About one propeller in five is out of balance enough to induce some kind of damage—leaky oil coolers, cracked or broken exhaust manifolds, sheet metal and cowling cracks, turbo mounts broken, or wire harness damage."

Balance should be checked, says Chadwick, whenever a propeller is overhauled, after an engine is overhauled, when significant repairs are made, or whenever unusual vibrations are evident. Agreeing with this are Allison, Garrett, Hartzell, Mitsubishi, Short Brothers, Swearingen, and a list of other users that reads like Who's Who in Aviation.

At $5,000-plus for a ramp-ready kit with all the options, the Vibrex system will balance everything except your checkbook. For more information, contact Chadwick-Helmuth Co. at 4601 N. Arden Dr., El Monte, CA 91731 (phone 818/575-6161; Telex 194271), James R. Chadwick, President.

—Kas Thomas