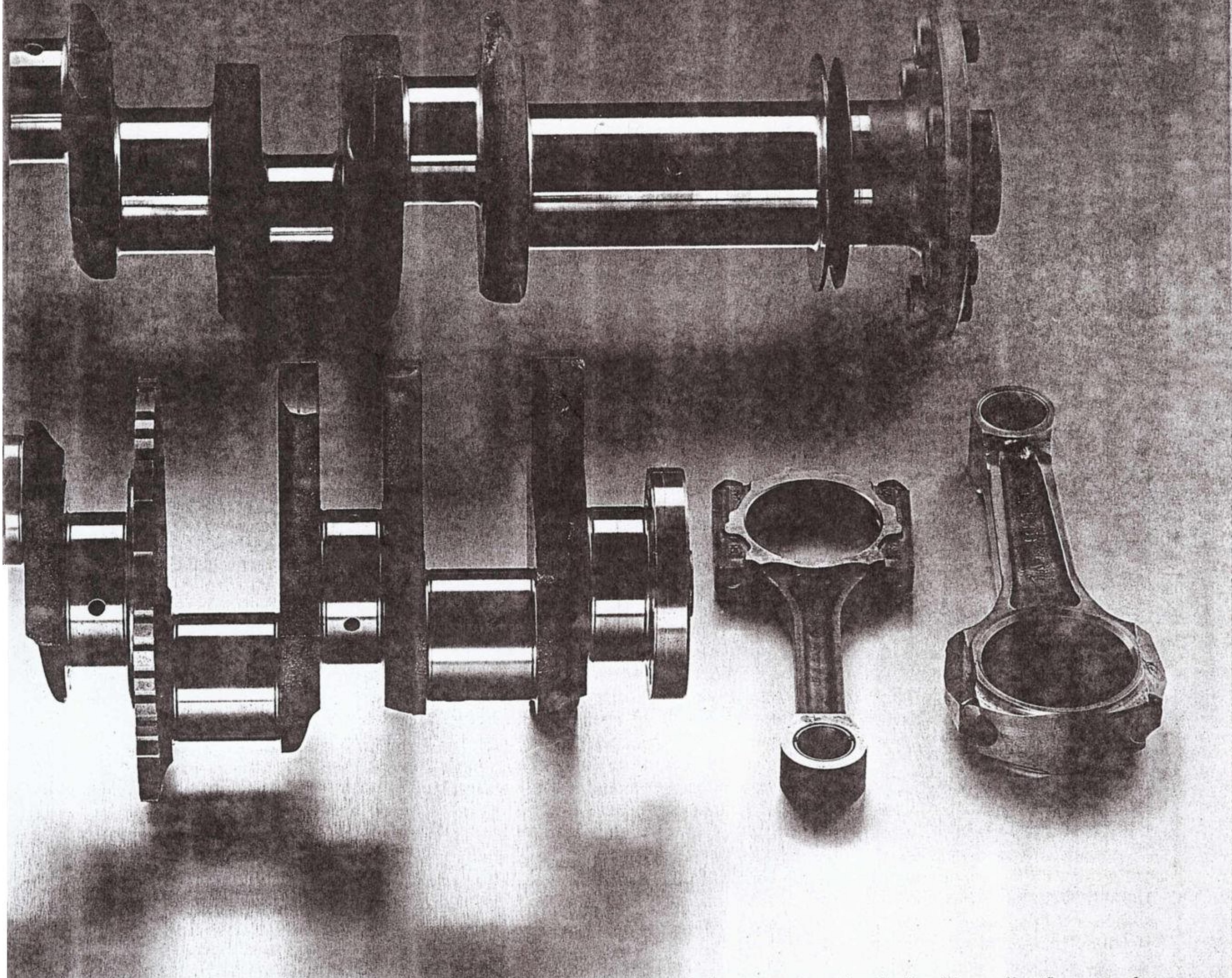
Power Struggle

Why car engines won't fly.

by Don Sherman



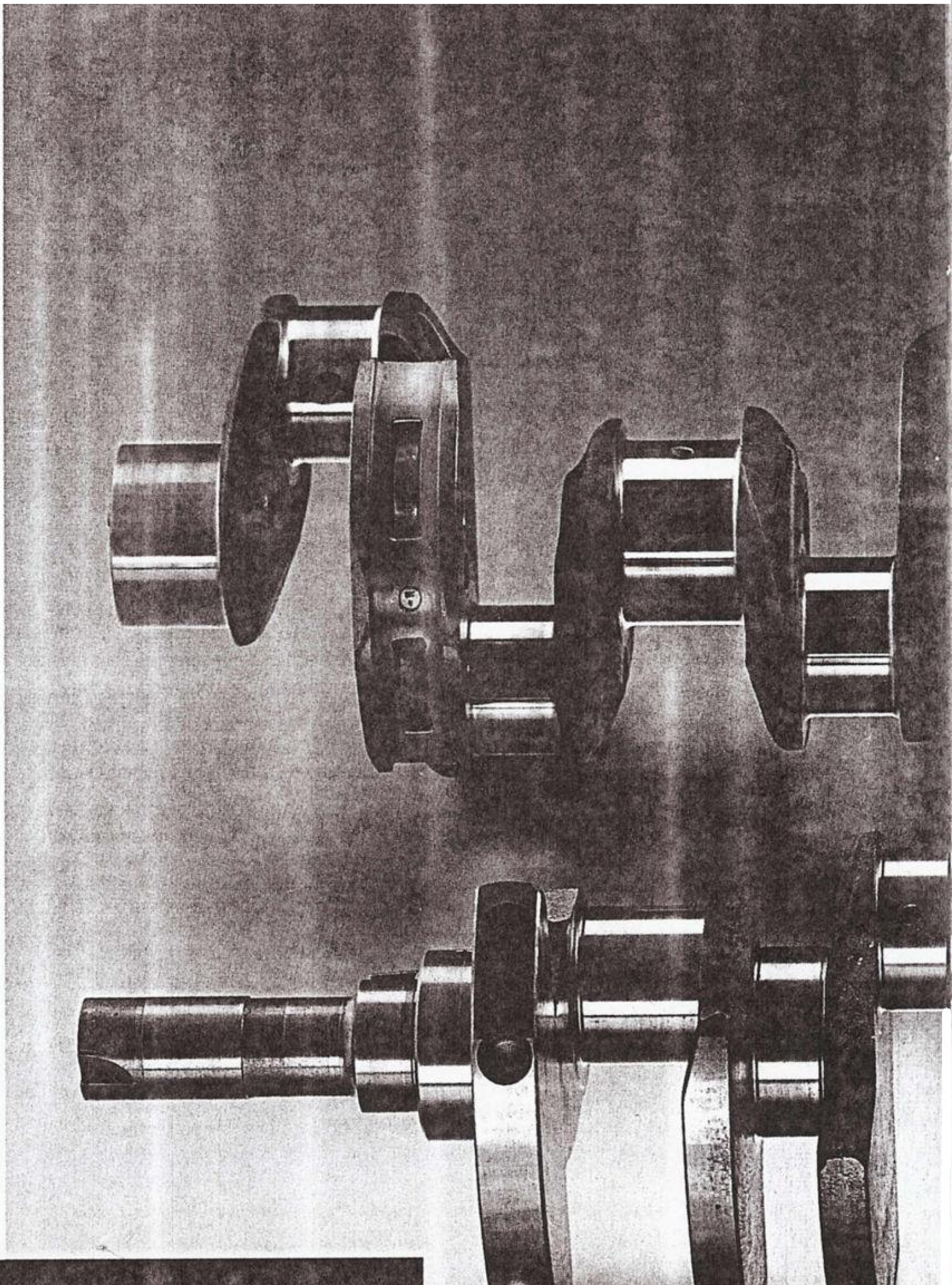
The crankshafts and connecting rods of two 300-horsepower engines illustrate the stark differences between automobiles and aircraft. The Cadillac Northstar V-8 crankshaft (foreground) has five main bearing journals, all narrower and of larger diameter than the four connecting rod journals, each of which is linked to a pair of pistons. The large toothed ring near the middle of the crankshaft governs spark timing. The Lycoming IO-540 crankshaft (background) has four main bearing journals, including the extra large one for the propeller at the front end (right) and six connecting rod journals, one for each cylinder. The cooling fins on each cylinder increase the engine's intercylinder distances, making the crankshaft considerably longer than the Cadillac's (inset). Because of their length, combined with a more severe operating environment, aircraft cranks must be made heavier than a car's.

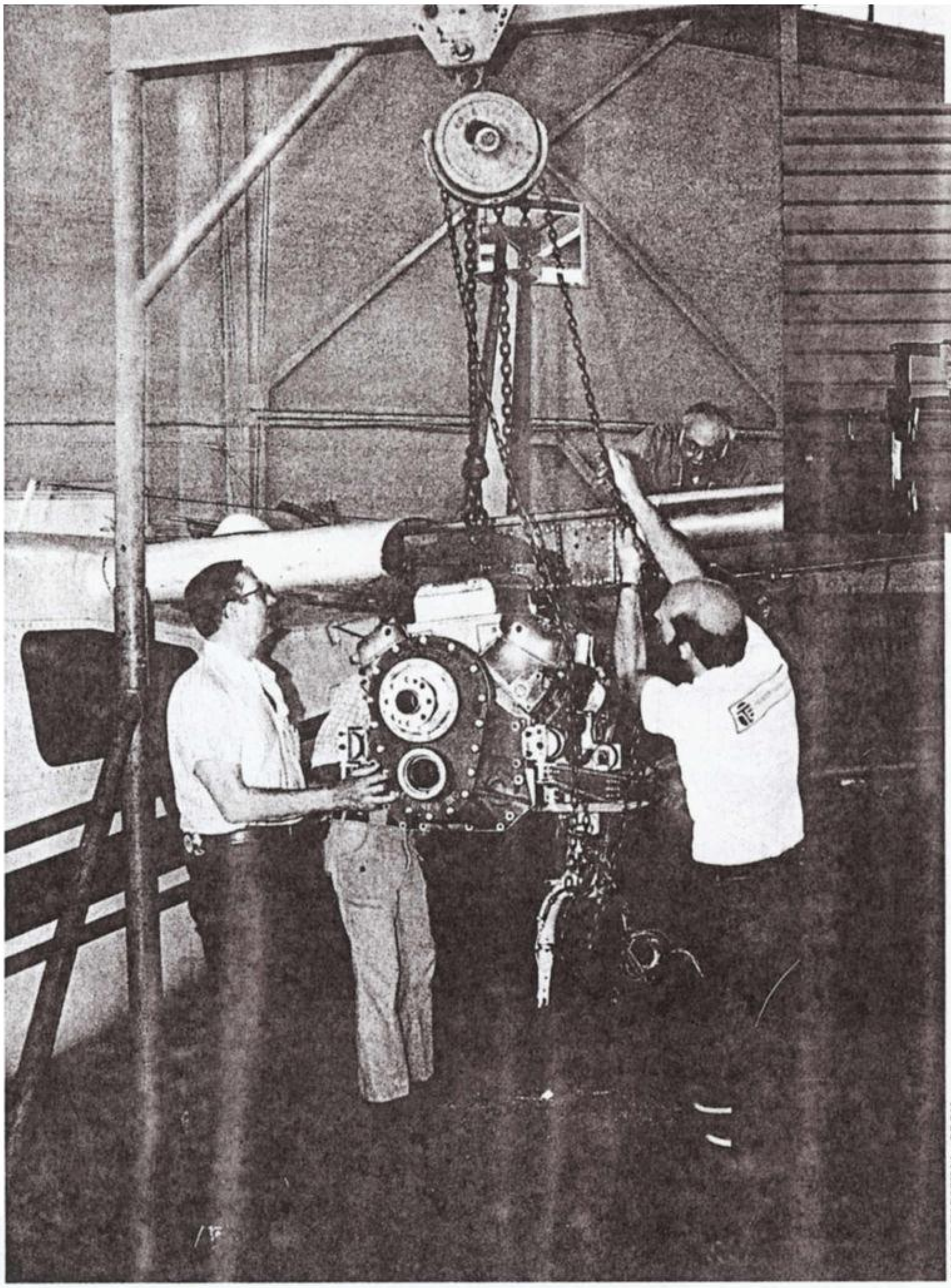
During World War II, liquid-cooled piston engines did more than their share to help secure victory. The U.S. Allison V-1710 in the P-40 Warhawk and P-38 Lightning and the British Merlin in the Hurricane, Spitfire, and P-51 Mustang were "fighter" engines: two banks of six cylinders arranged in a "V" not much wider than the pilot's shoulders, the whole thing shoehorned into a slim cowling that parted the air like a stiletto. The Allison notwithstanding, the Americans had a preference for air-cooled radial engines, and liquid-cooled engines were a primarily European technology. It was the license-built Merlin that made the Mustang a legend (see "Who Made the Mustang?" Aug./Sept. 1996), and after the Allisons, no American liquid-cooled V was produced in volume.

In the United States today the only aircraft piston engines of any kind in volume production—leaving aside for a moment the issues of liquid cooling and the V configuration—are produced by Teledyne Continental Motors (TCM) and Textron Lycoming. The two companies offer primarily air-cooled engines that have cylinders opposed in a horizontal, or "flat" layout, and produce 100 to 425 horsepower. They have been used primarily in light, general aviation single- and multi-engine airplanes. (TCM wraps the cylinders in water jackets to cool its "Voyager" series engines, but the layout is unchanged.)

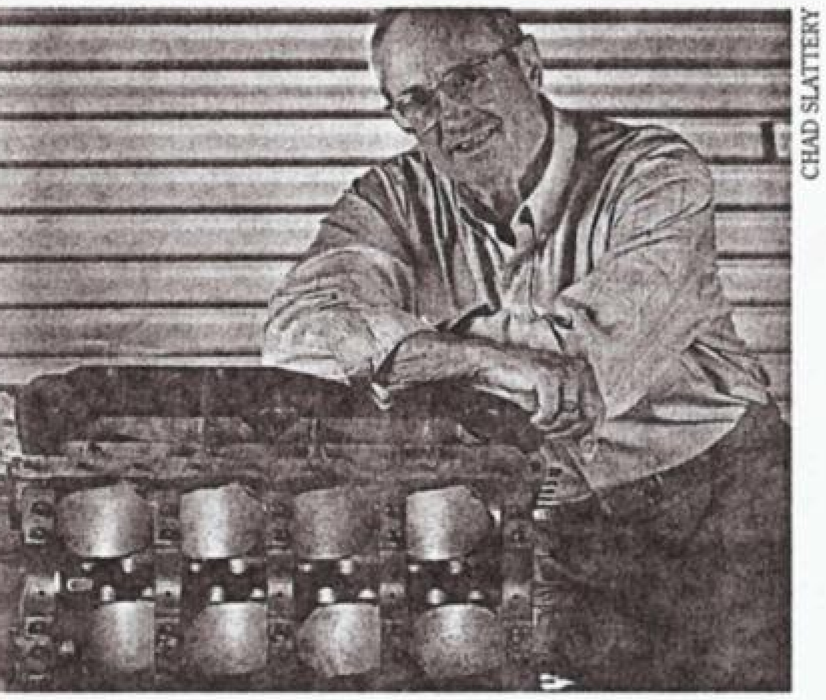
With the exception of these small engines, the piston engine has been replaced in aircraft by the powerful, lightweight turbine. Even in Europe the liquid-cooled V has long been extinct, and today, not a single modern descendant of the thundering Merlin has made its way into a current aircraft. The largest U.S. piston engine for aircraft made today is the 46-inch-long eight-cylinder Lycoming IO-720 rated at 400 horsepower. An Allison 250-B17, the closest comparable turbine engine, produces 420 shaft horsepower but weighs only 35 percent as much as the big Lycoming. It makes up for the lower weight with a higher price,

ROBERT T. VanMARTER (2)





COURTESY DICK MacCOON



CHAD SLATTERY

Dick MacCoon (above) tapped the motor racing community to develop the Thunder engine from a racing version of a Chevrolet V-8. In tests on an Aero Commander twin (left), the engine developed horsepower without adverse vibration or overheating.

however. So between roughly 400 and 500 horsepower, where you might expect some overlap and active competition between pistons and turbines, there is instead a gap, and in terms of price alone, the gap is more like a canyon.

The inherently compact arrangement of two banks of cylinders in a V-shaped block lives on in the automobile, where it thrives today in V-6s, V-8s, and a few V-12s. Now two enterprises, working completely independently, want to take the liquid-cooled V back from the automotive industry so they can return it to the airplane and fill the piston-turbine gap. The problem is that the liquid-cooled V is an automobile engine now. There is no airplane left in it.

The idea of powering light airplanes with automobile engines is hardly new (see "Classical Gas," p. 76). For years experimenters and homebuilders have been drawn to converted automobile engines because they're relatively cheap and plentiful compared to aircraft engines, which are manufactured in much lower volume. Many also complain that while the "Lyconental" technology has grown stale, automobile engines have enjoyed rapid advances, with such innovations as overhead camshafts, multi-valve combustion chambers, and microprocessor-controlled fuel-injection and ignition systems, to name a few.

For aircraft, there are inherent advantages in both liquid cooling and the V layout. Liquid cooling allows cylinders to be packed closer together, which results in a shorter, stiffer crankshaft, and the V configuration is narrow. Although the only source for such engines is the automotive industry, neither team working on the two current projects will simply pull a Buick block out of a boneyard and stick it in a biplane. First they have to strip the car out of the engine and put some of the airplane back in.

One enterprise pairs United Technologies' Hamilton Standard division with the Toyota Motor Corporation. Hamilton Standard's effort employs advanced technology and enjoys the deep pockets of one of the world's wealthiest industrial groups. But the partners are so secretive that not much is known about their plans.

The second player is the Orenda Division of Fleet Aerospace in Ontario, Canada. There are no secrets about the Orenda team's plan. They have taken aim at nothing less than the world's most popular turbine: the Pratt & Whitney Canada PT6 family of turboprops.

To understand why something so seemingly easy as adapting an automobile engine to power an airplane isn't really easy at all, it's essential to acknowledge that all piston engines are not created equal, and that moving a car down the road has little in common with propelling an airplane through the air. The key difference between automobile and aircraft engines is the intensity and duration of loads placed on them, or their "duty cycles."

One of the most sophisticated automobile engines currently in production is Cadillac's Northstar V-8. Light and compact, this 279-cubic-inch prime mover generates 300 horsepower from a 400-

Kevin Kruger

Paul

612 454 0144

Why an Airplane Is Not Like a Car

Both cars and airplanes exact their share of torture on an engine, it's just that the nature of the torture is different. Because the output shaft of any engine is an extension of the crankshaft that turns the pistons' reciprocating motion into rotary motion, the crank is the place where stress and strain have the most direct effect.

When your teenager pops the clutch to make the tires chirp, there's a massive flywheel and built-in driveline flexibilities (tire slippage, for one) to protect the crankshaft from excessive stress. Automatic transmissions provide fluid-filled torque converters that keep the shock from the occasional pothole from being passed on to the crank (Figure 1).

Under normal circumstances aircraft engines have no shock loads to contend with. Instead, their cross to bear is torsional vibration. The simplest illustration of torsional vibration is a rubber-band-powered flying model. Like the rubber band, an airplane's propeller shaft has an inherent flexibility that extends all the way through the crankshaft and any drive system or reduction gearbox to the point where the propeller is attached. Every time a cylinder fires, portions of the driveline are twisted or wound up with respect to the rest of the system. And like the rubber band, these wound-up portions spring back. This repeated twist and untwist is torsional vibration in its simplest form.

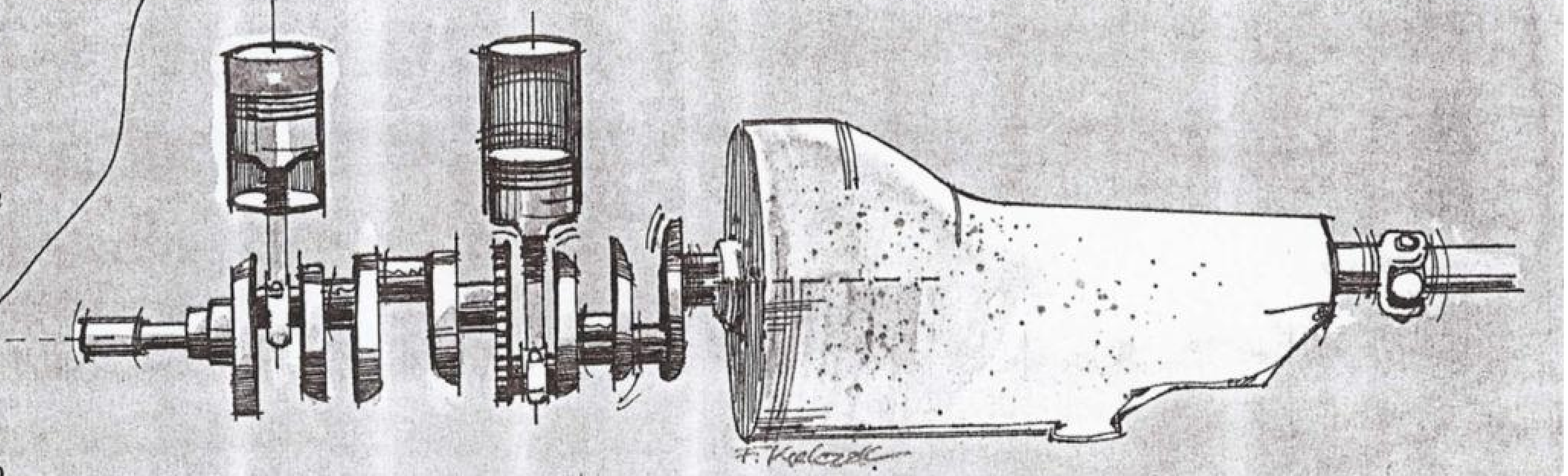
On a car, flexible driveline elements such as the tires and the torque converter absorb torsional vibration. But the airplane's propeller is a large mass that can contribute torsional vibration of its own to the crankshaft. In fact, the flexibility of the propeller drive and the propeller's rotating inertia constitute a torsional system (Figure 2).

Every torsional system has a natural or resonant frequency analogous to the pitch of a plucked violin string. Rubber-band models have a very low natural frequency of only a few cycles (wind, rewind) per minute. Airplane engines and propellers have much higher resonant frequencies and usually several of them. The plot of torsional vibration versus ~~speed~~ rpm for a Merlin V-12 is a roller coaster of a dozen or more peaks and valleys. In addition to firing impulses, other disturbances such as a change in prop pitch can influence torsional vibration characteristics. Problems arise when some vibrational disturbance coincides with the system's natural frequency. After the accumulation of so many twist cycles at its natural frequency, the crankshaft is susceptible to local cracking followed by total failure. Severe torsional vibrations must be analyzed by engineering tests and either eliminated or labeled "critical speed" in operational manuals so they can be avoided during sustained cruising.

Another means of avoiding torsional-vibration problems is to use a very short, very stiff crankshaft, one of the prime advantages of a radial engine. But in opposed cylinder arrangements or in V engines, air cooling mandates greater inter-cylinder distances to provide room for cooling fins. A liquid-cooled V has an inherently compact layout that leads, in turn, to shorter, stiffer crankshafts.

ILLUSTRATIONS BY FRANK KULCZAK

Figure 1 *Automotive engines are subjected to sudden acceleration, long periods at idle, and shocks from irregularity in the road surface that can be transmitted to the engine. When an individual cylinder fires, the force from the combustion of the fuel-air mixture causes a momentary twisting~~, or torque-wise, force to be imparted to~~* (torque) impulse at *the crankshaft. But just as the car's driveline tends to absorb road shocks, it also dampens ~~the forces that create torque-wise vibration.~~* torsional vibrations to minimize their ill effects.



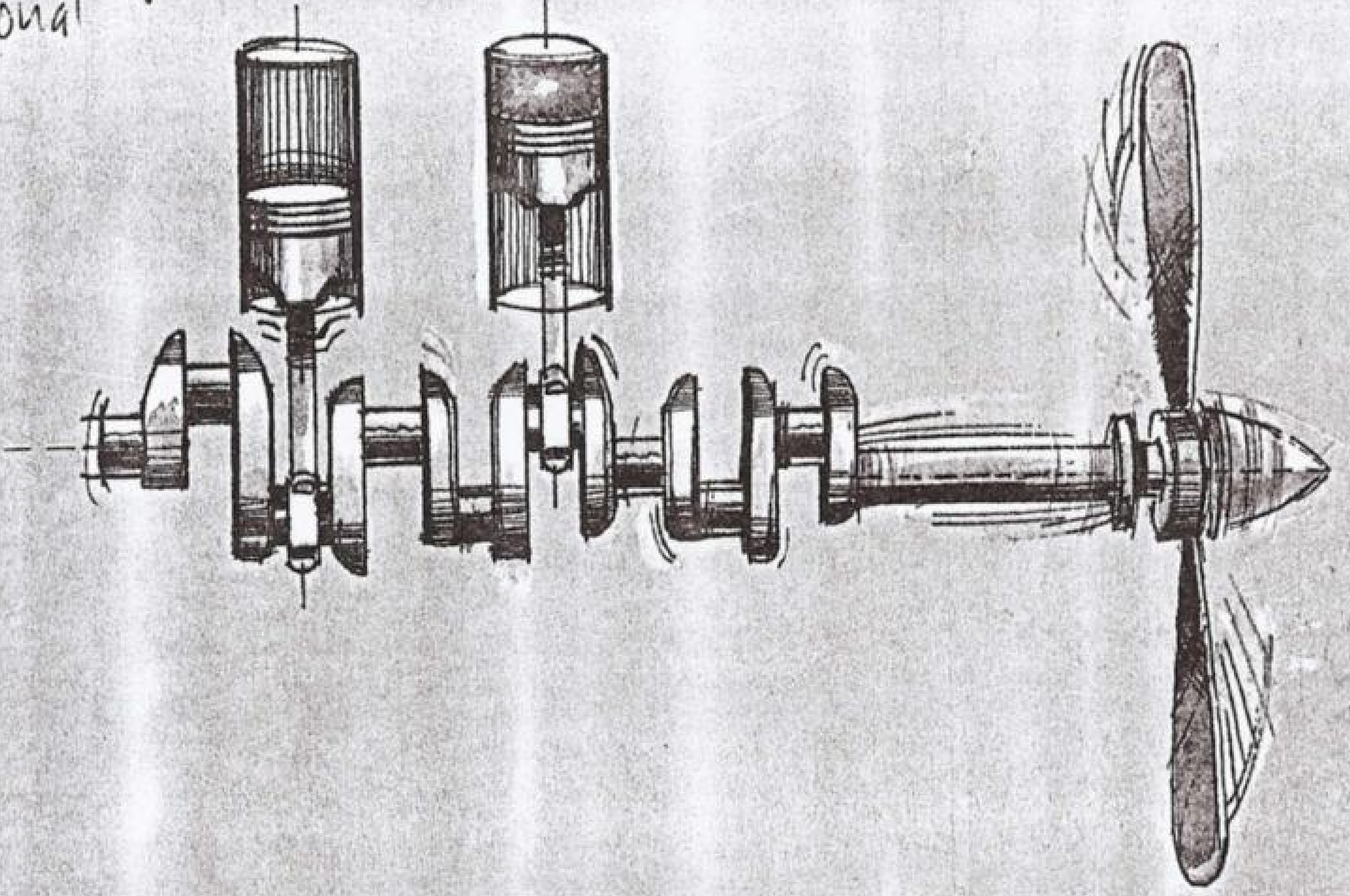


Figure 2 *The force created when combustion occurs in the cylinder also twists the crankshaft of an airplane engine. But in this case, the propeller blade may actually amplify the pulse by "ringing" at the same frequency and imparting a twist in reaction that travels back down the crankshaft. The propeller blade can flex along its length, and its center of mass is at a considerable distance from the propeller hub, ~~an ideal combination to create a vibrating system.~~* a combination that creates ~~difficult~~ vexing torsional vibration problems