The Physics Of: The V Angle

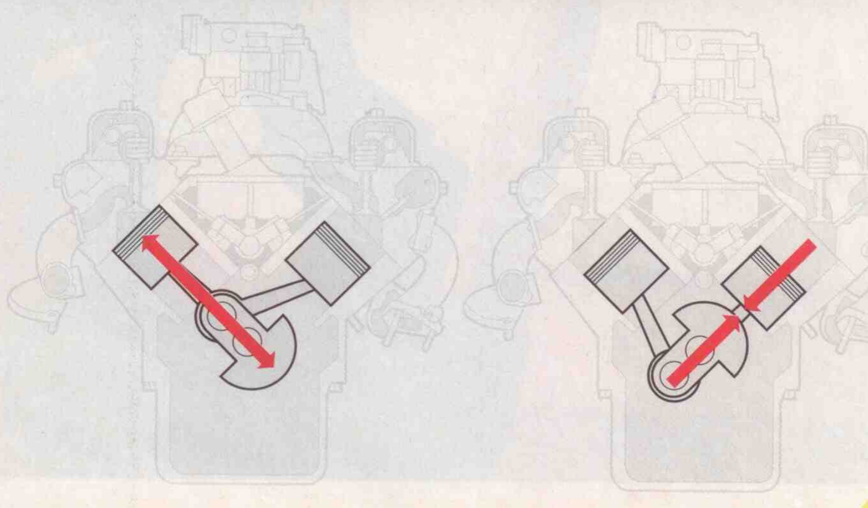
> WHY THE ANGLE BETWEEN BANKS IS CRITICAL TO A SMOOTH-RUNNING ENGINE.

by JOHN PEARLEY HUFFMAN *and* TONY QUIROGA

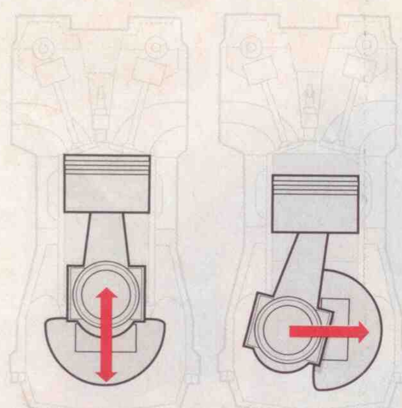
The inside of an internal-combustion engine is a just about the most violent place on Earth. Thousands of explosions happen every minute, resulting in great masses of metal being thrown up, down, and around. It's almost miraculous that engines can produce civilized, usable thrust at all. Because what an engine would really like to do is blow itself apart.

For an engine to survive all the rocking and rolling it produces, those forces need to be counterbalanced with equal—or at least nearly equal—forces. Today, most production-car engines with more than four cylinders are arranged in "V" configurations that separate the cylinders into banks. Determining the angle between the banks, i.e., the angle of the V, is crucial to the subtle yet brutal art of engine balancing.

The received wisdom on this subject is clear: Any V-8 engine is well balanced when its two cylinder banks form a 90-degree V.



TWO-TIMER Adding a piston at a 90-degree angle (creating a 90-degree V-2) allows the counterweight to balance both pistons throughout their travel. The counterweight cancels the up-and-down motion of one piston, and 90-degrees later, cancels the motion of the other piston. Unlike the single-cylinder example, the counterweight is balanced throughout its motion.



PART-TIMER In a one-cylinder engine, the up-and-down motion can be balanced by the counterweight. When the piston is at the top of its travel (shown), or the bottom, the counterweight offsets the mass of the piston. But when the piston is not at the top or bottom of its travel, the weight induces a left/right imbalance.

And V-6s tend to be best off when that V is set at 60 degrees. But the explanation of why all this is (at least conditionally) true, well, that's a bit convoluted.

"The forces that impact engine balance come from three sources," explains Kevin Hoag, the associate director of the Engine Research Center at the University of Wisconsin–Madison, "the rotation of mass that is offset from the main bearing centerline (the mass at each crank throw and counterweight); reciprocating (up and down) forces due to the continual acceleration and deceleration of each piston assembly; and the firing forces in each cylinder."

The first two of these forces—rotational and reciprocating—can often be balanced through engine configuration, as in, for example, a 90-degree V-2 [see "Two-Timer"].

A flat ("180-degree V") engine, such as a Subaru four-cylinder, also can be perfectly balanced. To counter the rotational and reciprocating forces, the cylinders in one bank move in exact opposition to those of the other, thereby completely canceling the forces created by each.

The angle of the V is critical to the third force Hoag cites, the firing force. And there's an equation to help determine which configurations will work best. In a four-stroke engine, an individual piston fires every 720 degrees (two crankshaft rotations). If you divide that by the number of cylinders, you get a figure that represents the optimal degrees of crankshaft rotation between cylinder firings.

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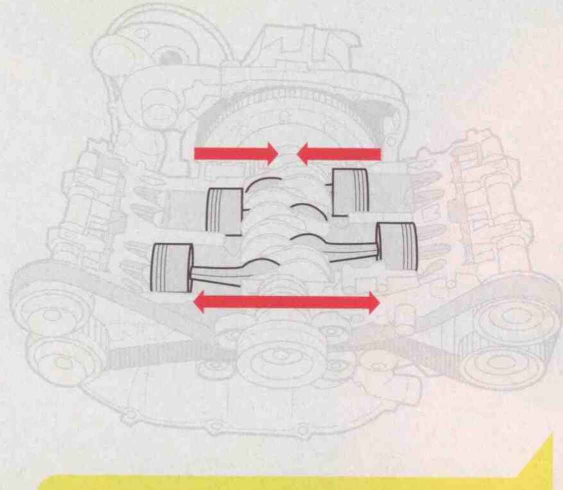
$$\frac{\text{720 DEGREES}}{\text{NUMBER OF CYLINDERS}} = \text{OPTIMAL DEGREES BETWEEN FIRINGS}$$

ILLUSTRATIONS *by* PETE SUCHESKI



BOXER BASICS In a flat (180-degree) engine, each bank of cylinders exactly mirrors the other and, consequently, the forces are canceled and the engine's up-and-down and rotational forces are balanced. The firing forces are also balanced as firing events take place every 180 degrees.

For example, a four-cylinder would like to fire at every 180 degrees of crankshaft rotation (720/4=180). Having firing events that occur in equal increments, as in this instance, is best for balance. The flat-four fires at 180-degree intervals, and its V angle is 180 degrees, which leads to a balance of firing forces. The flat-four, in fact, balances all three of the different types of forces.

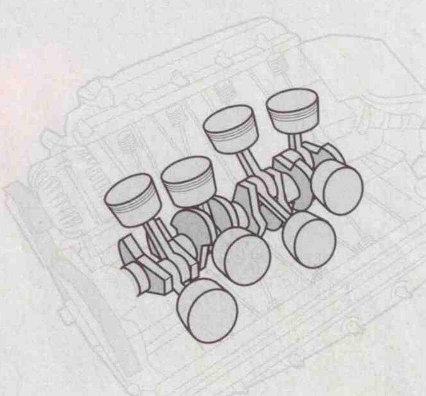
A cross-plane, 90-degree V-8 has balanced rotational and reciprocating forces because it is a lot like four of the balanced 90-degree V-2s shown in the aforementioned illustration. To balance the firing force, a cylinder has to fire every time the crankshaft rotates 90 degrees. Since the bank angle is 90 degrees and the firing forces occur in 90-degree intervals, the cross-plane V-8 also manages to balance all three of the forces.

A 60-degree V-6 engine isn't quite as successful. The rotational and reciprocating forces can't be completely balanced because this type of V-6 is essentially two three-cylinder engines stuck together. Inline-three engines, because of their odd number of cylinders, are inherently imbalanced and will tend to rock from end to end. A flat-six engine manages to cancel the rocking because the opposing banks exactly cancel out each other's motions. Putting two inline-threes together, end to end, to form an inline-six also works because each three-cylinder end of the engine exactly cancels the forces of the other. And since it's basically two straight sixes joined at a common crank, the V-12 is naturally balanced regardless of its V angle.

But the 60-degree V-6 inherently shakes; the rocking motion of the inline-three can't be canceled if the bank angle is smaller than 180 degrees. For that reason, many V-6s use balancing shafts, which are essentially additional crankshafts that use specifically weighted lobes to cancel out imbalance.

The firing forces, however, are balanced in modern V-6s. A V-6 fires a cylinder every time the crankshaft turns 120 degrees (720/6=120). That would imply a 120-degree angle between the banks, but that configuration is impractical for packaging reasons. The 60-degree bank angle is a good compromise for packaging, and because the firing events occur in degrees (120) that are evenly divisible by the angle of the V (60), the firing forces remain balanced.

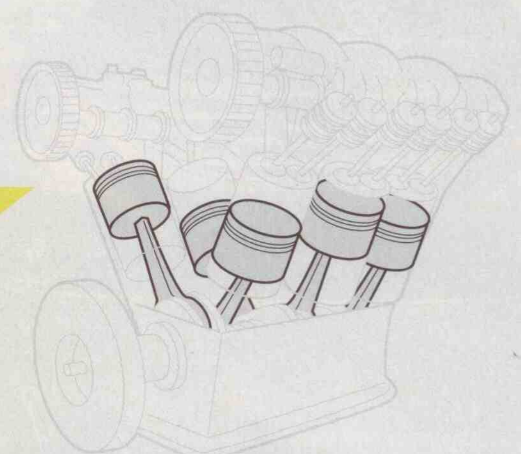
So how do GM and Mercedes-Benz get away with 90-degree V-6s? These engines would seem to have unbalanced firing pulses because 120 isn't evenly divisible by 90. When GM reintroduced its V-6 engines back in the mid-Seventies, it revived an early-Sixties design, which was essentially a Buick 90-degree V-8 with the two end cylinders sliced off. Because of the firing imbalance, the engine ran rough, sort of like a V-8 with two cylinders missing. To counteract this, the company developed a special crankshaft called a "split-pin" or "split-journal" unit that mounted the big ends of the paired connecting rods to crank journals that had been split and slightly offset so that the engine could achieve 120-degree firing despite its V angle.



EIGHT IS ENOUGH A 90-degree, cross-plane V-8 is essentially a collection of four 90-degree V-2s (see V-2 illustration on previous page). Since each V-2 is balanced, the cross-plane, 90-degree V-8 also is free of rotational and reciprocating motions. Firing forces are balanced because they occur at every 90-degree turn of the crank.

In the early Nineties when Chrysler developed the V-10 engine for the Viper (basically a 90-degree V-8 with two additional cylinders), it didn't use a split-journal crankshaft, and the V-10 subsequently fires unevenly, which produces the Viper's unusual sound. Ideally, a V-10 would use a 72-degree V angle that would produce even firing without the use of a split-journal crankshaft. The Lexus LFA V-10 uses a 72-degree bank angle for that exact reason.

The bottom line is this: At a fundamental level, every engine must be designed with balance in mind lest it risk shaking apart. Next up, we'll explain the creation of the universe.



JOY OF SIX A V-6 is basically two inline-threes bolted to one another. Inline-threes are inherently imbalanced, and pairing two together, at 60 degrees, doesn't eliminate the shake. But a 60-degree V-6 does have balanced firing forces.