throw, 0, 180° crank will have even firing and the same balance condition as the inline four with a 0, 180, 180, 0° crank. Program ENGINE will calculate the parameters for opposed as well as vee and inline configurations.

14.9 BALANCING MULTICYLINDER ENGINES

With a sufficient number (m) of cylinders, properly arranged in banks of n cylinders in a multi-bank engine,* an engine can be inherently balanced. In a two-stroke engine with its crank throws arranged for even firing, all harmonics of shaking force will be balanced except those whose harmonic number is a multiple of n. In a four-stroke engine with its crank throws arranged for even firing, all harmonics of shaking force will be balanced except those whose harmonic number is a multiple of $n/2$. Primary shaking moment components will be balanced if the crankshaft is mirror symmetric about the central transverse plane. A four-stroke inline configuration then requires at least six cylinders to be inherently balanced through the fourth harmonic. We have seen that an inline four with a 0, 180, 180, 0° crankshaft has nonzero secondary forces and moments as well as nonzero inertia torque. The inline six with a mirror symmetric crank of ϕ_i = 0, 240, 120, 120, 240, 0° will have zero shaking forces and moments through the second harmonic, though the inertia torque's third harmonic will still be present. To see the results of this six-cylinder inline engine configuration, run program ENGINE and select the inline six from the *Examples* pull-down menu.

A vee twelve is then the smallest vee engine with this inherent state of near perfect balance, as it is two inline sixes on a common crankshaft. We have seen that vee engines take on the balance characteristics of the inline banks from which they are made. Equations 14.10 and 14.11 (pp. 664 to 668) introduced no new criteria for balance in the vee engine over those already defined in equations 14.3 (p. 648) and 14.5 (p. 650) for shaking force and moment balance in the inline engine. Open the file BMWV12.ENG in program ENGINE to see the results for a vee-twelve engine. The common vee-eight engine with crankshaft phase angles of ϕ_i = 0, 90, 270, 180° has an unbalanced primary moment as does the inline four from which it is made. It is an example in program ENGINE.

A vee-six engine with 0, 240, 120° crankshaft has unbalanced primary and secondary moments as does the three-cylinder inline from which it is made. This vee six needs a 120° vee angle for proper balance. To reduce engine width, vee sixes are most often made with a 60° vee angle which gives even firing with a 6-throw crank. Some use 90° vee angles to allow their assembly on the same production-line tooling as 90° vee eights, but 90° vee sixes will run rough due to uneven firing unless the crankshaft is redesigned to shift (or splay) the two conrods on each pin by 30°. This results in a more complicated 6-throw crankshaft but gives an even firing, but dynamically unbalanced engine.

Unbalanced inertia torques can be smoothed with a flywheel as was shown in Section 13.10 (p. 631) for the single-cylinder engine. Note that even an engine having zero inertial torque may require a flywheel to smooth its variations in gas torque. The total torque function should be used to determine the energy variations to be absorbed by a flywheel as it contains both gas torque and inertia torque (if any). The method of Section 11.11 (p. 548) also applies to calculation of the flywheel size needed in an engine, based on its variation in the total torque function. Program ENGINE will compute the areas under the total torque pulses needed for the calculation. See the referenced sections for the proper flywheel design procedure.

* For an inline engine, $m = n$.