Two Turbos are Better than One

BMW has just released its twin-turbo, three-litre, X-5 diesel Down Under. We've been seeing twin-turbo engines for years, but this design is a 4x4 world first.

Where the BMW twin-turbo differs from other 4x4 twin-turbo diesels is in the fact that the turbos are connected in series – one feeds into the other.
The series-charging concept has been around in the truck diesel business for years: firstly in 1980s Detroit Diesel two-strokes, where a turbo was added to a supercharged engine; then Volvo's combined supercharger and turbocharger in its 1990s FL four-stroke diesel; and most recently in Caterpillar's post-2003, series-turbocharged ACERT engines and Mercedes-Benz 2006 Sprinter light commercials.
The purposes of series turbo-charging are to increase power and torque across the entire rev range, to eradicate low-speed 'lag', to improve economy and to control emissions.

Different 'Twins'

There are three different types of twin-turbo installations and each is as alike as Big Arnie and Danny. The most basic is a *twin-turbo V-engine*, such as Toyota's 200 Series 4.5-litre V8. In this engine the turbos are in parallel, with each turbo driven by and feeding air into its own four-cylinder bank.

A *sequential twin-turbo engine* has a small and a large turbo, with separate exhaust gas and inlet manifold connections. The engine is fed compressed air from the small turbo only at low to medium engine speeds, when the available exhaust energy is minimal.

As engine revs rise the larger turbo-charger is spooled up and, at higher revs, it receives its full share of exhaust pressure. At high engine revs both turbos are operating at maximum boost.

To a large extent sequential turbo systems have been replaced by variable nozzle or variable geometry turbo-chargers that change the effective size of their turbine housings to cope with varying exhaust flow rates.

Series, staged or *compound* turbo-charging achieves higher pressure ratios than other turbo systems by having one turbo-charger pressurise the air going into the inlet of another. Because of its low inertia, the smaller charger delivers full boost at low revs, without lag. As engine speed rises, the larger turbo-charger gradually takes over.

Production Series Turbo-charged Engines

Series turbo-charging is one likely way engine makers will meet the recent CO_2 and fuel economy limits set by EEC and US lawmakers. Engine downsizing is considered to be an inevitable strategy and series turbo-charging promises high outputs and good economy from small-displacement engines.

Opel’s 1.9 CDTI Vectra diesel, launched in 2004, has series turbo-charging and an impressive output of 156kW. Even more impressive is a peak torque figure of 400Nm at only 1400rpm.This engine complies with Euro 4 exhaust emission standards and uses only 6.0 litres per 100 kilometres in the European test cycle (in a sedan).

Up to 1800rpm the high-pressure turbo-charger works alone and compresses the intake air at up to 3.2 bar boost pressure. Between 1800 and 3000rpm both turbines run together and above 3000rpm only the larger turbo-charger delivers charge air to the cylinders. The complex control of both chargers is via a valve in the engine's exhaust system, controlled by engine speed and load.

The BMW X5 3.0sd series turbo-charged engine boasts 200kW and 565Nm from a three-litre straight six, with aluminium block and cylinder head construction. EEC test cycle fuel consumption is 8.8L/100km.

In the light truck market the Mercedes-Benz Sprinter 2.148-litre OM 646 DE 22 LA diesel engine employs series turbo-charging for maximum power of 110kW and peak torque of 330Nm in the 1200-2400rpm band.

Series Turbo-Charging and the Miller Cycle

Series turbo-charging has been employed by Caterpillar in its ACERT truck engines that use a Miller Cycle combustion system.
US engineer Ralph Miller patented the Miller Cycle engine in the 1940s, but it wasn’t taken seriously in the automotive world until relatively recently. Until the 1980s Miller Cycle engines were used only in ships and stationary power-generating plants.

In a Miller Cycle engine the intake valve is held open during part of the compression stroke, so that the engine is compressing against the pressure of a supercharger or turbo-charger, rather than the enclosed cylinder space.

As the piston moves upwards initially, in what is traditionally the compression stroke, some of the charge air is being pushed back out the still-open valve. In the case of a normally turbo-charged engine there would be insufficient charge air to fill the cylinder, but that’s where series turbo-charging comes in. The extra air volume, delivered by two turbo-chargers, ensures the cylinder gets the same final compression ratio as it would in a standard engine, but with less compression work done by the pistons. The result is increased efficiency, up to 15 percent.

It will be interesting to see if 4x4 engine makers adopt Miller Cycle valve timing in new series turbo-charged engines.

