Technical - Jaguar's Supercharged, Turbocharged Six

Editor: The other day a club member pulled the 3.4 litre engine out of his Mk2 and thought about sending away to get it rebuilt. He was quickly talked out of that idea by a group of other members who offered to help him rebuild it.

It was discussed that a carburetted six-cylinder XK twin overhead camshaft engine, is actually a very a simple motor.

We then discussed what is currently used on the latest Jaguar cars. For example, with the F-Pace, one has the choice of:

- Turbocharged 2.0 litre 4 cyl (300hp)
- Turbocharged 3.0 litre 6 cyl diesel
- Supercharged 5.0 litre V8 (575hp)
- Twin scroll turbocharged and electric supercharged 3.0 litre 6 cyl. (395hp).

I thought that the last option was worth writing about. Can you imagine trying to sort out a problem on turbocharged-electric supercharged engine with all the associated electronics.

Well, I guess the new mechanics of this world will.

A couple of decades or so ago, any petrol-engine car with a supercharger or turbocharger was considered a performance car. Which it almost certainly was, because that was the way to squeeze more power out of a given engine. (As much as 50% additional horsepower).

These days, of course, it's a bit different and you'll actually struggle to find a brand-new petrol car without a turbocharger or a supercharger.

So, given that turbocharging and supercharging technology is now the rule rather than the exception, it's likely that some Club members already have one under their bonnet, or will have in the future.

Forced Induction

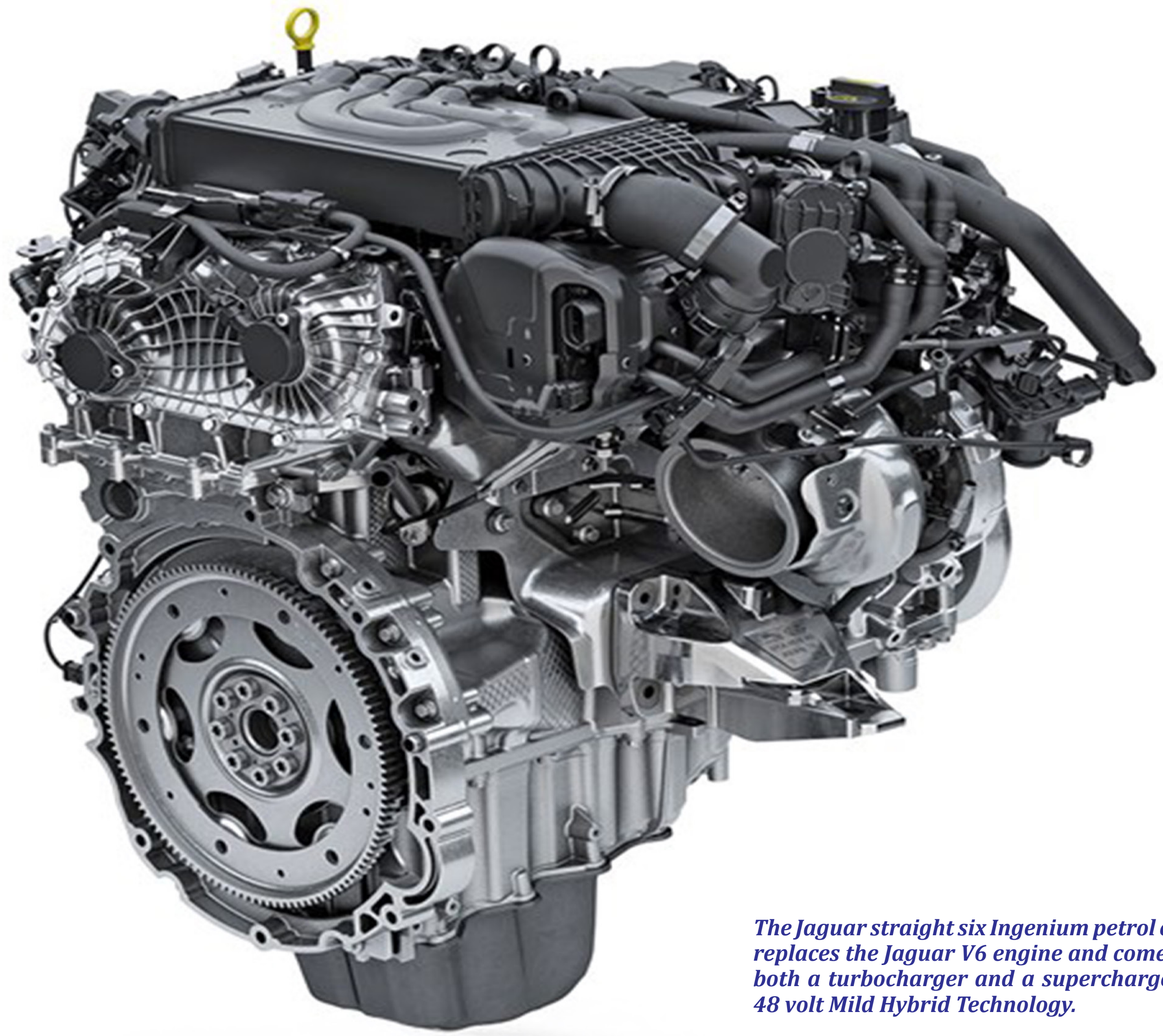
A supercharger or turbocharger simply blows more air (oxygen) into the engine, and it can suddenly burn more fuel and, therefore, make more power. Turbocharged vs supercharged doesn't matter: The science is the same.

This process is called forced induction. And even though they achieve the same thing, a supercharger and turbocharger work in different ways.

A supercharger as we have traditionally known, is an engine-driven pump that forces air into the engine under pressure.

A turbocharger, unlike a supercharger, does not require a belt to drive it and instead the pump is driven by exhaust gas. The turbo's fan blades are spun by the force of the exhaust leaving the engine. In effect, it's free power because there's no drag on the engine from a belt. In reality, the turbo is powered by a waste product (the exhaust gasses) so it's guilt-free boost.

The biggest gripe with turbos is that they contribute to turbo lag. *(cont page 38)*



The Jaguar straight six Ingenium petrol engine replaces the Jaguar V6 engine and comes with both a turbocharger and a supercharger and 48 volt Mild Hybrid Technology.

Turbo engine lag is the delay between putting your foot down and the turbo building the boost.

Since it's being driven by exhaust gasses, those gasses have to start flowing before anything happens. That's unlike the belt-driven supercharger which starts to make boost the moment you start spinning it by revving up the engine.

While turbochargers can take a couple of seconds to spool up, mechanical superchargers still having some inherent lag. Also compressing air takes a whole load of energy. A supercharger can consume as much as 20% of an engine's total power output. Hence the development of electric superchargers.

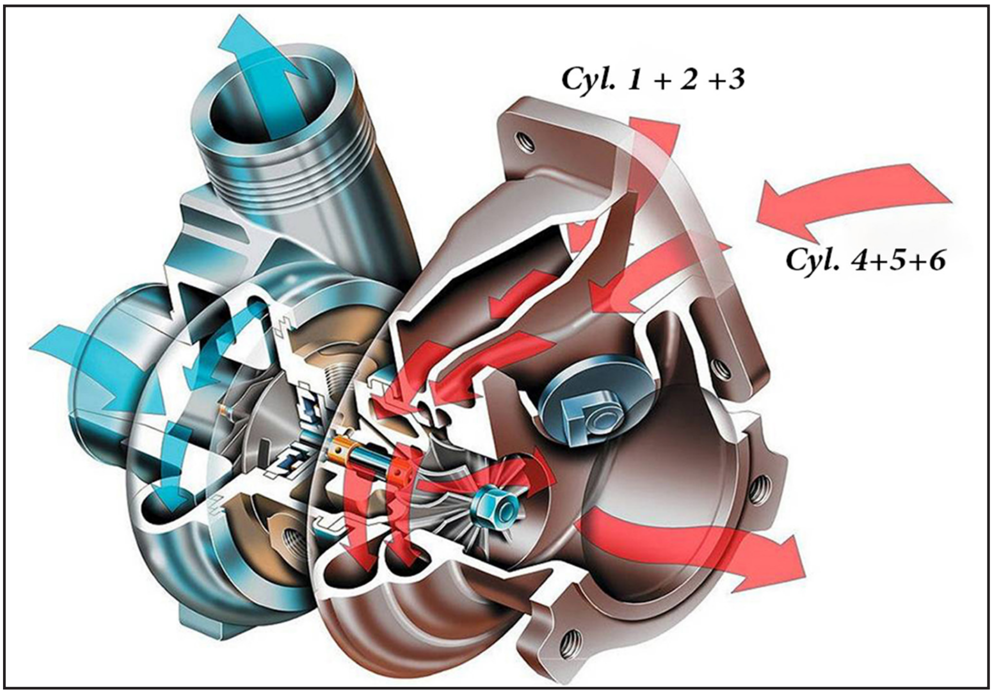
E-Supercharger

An electric supercharger uses a donor turbocharger with an electric motor attached, otherwise known as an E-supercharger.

The electronics come in the shape of the electric motor connected to the accelerator, which in turn allows for the electric motor to spin the fan at a rate in proportion to the amount of throttle being applied, simulating the belt-driven action of a conventional mechanical supercharger. This motor is powered by an attachment to the car's battery which brings up an inherent problem with electric supercharging.

Although an E-supercharger can create the required boost, it still needs a large electrical supply to function to its full potential. Therefore, to power all of a car's electrical equipment as well as an additional E-supercharger, a 48-volt battery is needed. Although, considering the sheer amount of electrical tech on cars these days, it probably won't be long until a 48-volt unit becomes standard.

The benefits of an electric supercharger come in the form of a minimal lag time and a high rotational speed. An electric supercharger can spool fully in as little as 0.5 second through the direct connection with the throttle, giving virtually instant maximum boost. Mechanical superchargers max out at around 60,000rpm whereas the electrical equivalent can reach a speed of up to 120,000rpm, even higher than most turbochargers.



Twin scroll turbo's offer several benefits including taking up less space than a comparable twin turbo system, they provide a faster boost response and better fuel consumption (up to 5%). The above diagram is for a six cylinder engine - firing order 1,5,3,6,2,4.

Speaking of turbochargers, with the new inline six-cylinder Ingenium petrol engine, it doesn't stop at the supercharger. The engine also uses a twin-scroll turbocharger.

Turbocharger - Power Delivery

As previously noted, in a typical turbocharged engine, as exhaust gas flows out of the cylinders, the exhaust manifold channels it into a single passage on the turbocharger.

This passage surrounds a bladed wheel known as the "turbine." This wheel spins as the exhaust gas flows over it. This turbine is connected by a shaft to a finned wheel known as the "impeller" on the intake side of the turbocharger. As the impeller spins, it compresses incoming fresh air and sends it at high pressure through the intake manifold to the cylinders via an intercooler.

As noted, this denser air contains more oxygen; more oxygen means more ignition, and therefore, more power from the same size engine.

Turbochargers inherently have issues that impede consistent power delivery, thanks to the fickle nature of exhaust gas and manifold pressure. One of the largest problems engineers have to grapple with is that exhaust gas is not a continuously even flow of air with constant pressure. Instead, exhaust pulses in rhythm with the firing order of the cylinders, and it ebbs and flows with engine RPMs.

In a traditional single-scroll, single-turbo setup, every cylinder's exhaust gas must flow through the same manifold.

This means that while one cylinder's exhaust valves are finishing letting out air, another cylinder's exhaust valves are already open, changing pressure drastically inside the manifold.

This inconsistency in pulses and pressure causes interference between cylinders' exhaust gas and slows down the air moving over the turbine.

The slower spinning of the turbine, in turn, adds more pressure to the manifold and further interferes with exhaust flow.

In severe cases, if the backpressure gets too high, exhaust gas can be forced back through the manifold into the cylinders (a process known as reversion); this can cause engine damage, and the only way to prevent it is with less aggressive valves and engine timing - both of which cut back on power.

Turbo Lag

As noted, the second common issue with turbo power is much more familiar to anyone that's ever driven an eighties turbocharged car: turbo lag.

The easiest way to combat this is with a smaller turbo that needs less exhaust flow to make peak pressure. Smaller turbos make less power at higher RPMs, however, so in a single-turbo system, there will always be a trade off between turbo lag and loss of top-end power.

The other option is multiple turbo's. Of course, the downside of both sequential and parallel twin-turbocharging is obvious. It's vastly more expensive than a traditional single-turbo setup, because you need two of everything - exhaust manifolds, turbochargers, wastegates, intercoolers, sometimes even intake manifolds - and it's hard to fit in the engine bay, because you need two of everything. It's also heavy, because… well, you need two of everything.

Twin-scroll Turbo

There is one other option to solve the problems of lag and exhaust flow, however, and it is the twin-scroll turbocharger. Twin-scroll turbo's are a single turbo housing with a single turbine blade, but with two channels (also known as "scrolls") for exhaust gas to travel through. The manifold is divided into two scrolls, and each one gets half the cylinders' exhaust.

This doubles the time between valve openings in each scroll, even though they both feed the same turbine. With this setup, the exhaust pulses can be separated and timed like a parallel twin-turbo car, reducing flow interference, while still only using one turbo.

Running a turbo engine with less fear of reversion means more ignition delay can be used, resulting in lower cylinder temperatures and leaner air/fuel mixtures, which increases efficiency.

Additionally, making one scroll large and routed to the outer edges of the turbine blades, and one scroll small and routed to the inner section of the turbine blades, allows for airflow that is optimised for the entire rev range. The small scroll allows for faster airflow - and less lag - at low RPMs, and the large scroll keeps the powerband strong even at high RPM. This reaps the benefits of a sequential twin-turbo system with vastly less complexity.

In short, twin-scroll turbos deliver more power from less fuel than a single turbo, and provide similar power to a twin-turbo setup with vastly lower weight and fewer parts.

To all of the above, the six-cylinder Ingenium petrol engine has continuous variable valve lift (CVVL), Variable Cam Timing (VCT), 48-volt Mild Hybrid Technology (MHEV), roller bearing camshafts, and variable coolant and oil pumps.

The MHEV 48V system uses an integrated electric motor to harvest energy lost during deceleration, and then redeploys it to assist the engine to maximise efficiency.

It all makes for one very efficient but complicated engine.

By comparison, an SU carburetted XK engine, is a walk in the park. ■

Editor: Information for this article sourced from various publications.