It was one of the most unusual challenges of recent engineering in the UK. How to turn a humble 140 bhp diesel engine from its usual use, powering a JCB digger, into a 750 bhp racing unit capable of winning a land speed record? David Tremayne, who has reported on many speed record attempts, describes the engineering achievements involved in creating the JCB Dieselmox streamliner.
A turbo system with inter-stage and after-cooling was developed in order to deliver the required air flow across the engine speed range. A water injection system provided a further level of charge cooling to protect the pistons and valves. “Getting the fuel and air in was the single most difficult thing as far as I was concerned,” said Matt Beasley, Chief Engineer for the engine on the Dieselmax project. “The fuel system was a big challenge, getting the engine to run the speed we needed to achieve the power we needed.”

ENGINE OVERHAUL
The first step was easily achievable – the engine was bored and stroked to five litres. The greatest challenge lay in getting sufficient air and fuel into it to increase power, and then managing that air and fuel flow and the associated heat generated by two-stage turbocharging operating at over 6 bar. A turbo system with inter-stage and after-cooling was developed in order to deliver the required air flow across the engine speed range. A water injection system provided a further level of charge cooling to protect the pistons and valves. "Getting the fuel and air in was the single most difficult thing as far as I was concerned," said Matt Beasley, Chief Engineer for the engine on the Dieselmax project. "The fuel system was a big challenge, getting the engine to run the speed we needed to achieve the power we needed."

The combustion and fuel systems were very much the heart of the engine. Ricardo used its High Speed Diesel Race (HSDR) direct injection combustion technology wherein fuel was delivered via two parallel, high pressure pumps to a common rail system delivering an injection pressure of 1600 bar. The cylinder head had to be modified slightly to encompass the larger injectors required, and the actuation time for each injector was subtly modified. "You need to put an awful lot of fuel in, in a very, very short space of time, and you've got to put it through a minute office to get the fuel to mix. Diesel fuel is not as prone to mixing as gasoline because it's a heavy fuel so it doesn't evaporate, so you don't have the time to do that and you have to inject it through a tiny pinprick hole at massive pressure in a tiny space of time. That's why the fuel system on any diesel engine is a major challenge! JCB invested huge effort to create reliable components, as the bore 'pick up' problems continued. With the original 108 mm piston design the upright engine achieved almost 700 bhp (680) in December 2005. However as the inclined engine switched to a 109 mm Federal Mogul piston in February 2006, the problems really began and the focus of troubleshooting became the brand new dry-sump lubrication system and its oil scavenging shortfall. There was so much oil flow because, in order to control the piston, there had to be an increase in its oil cooling. "You have got oil spraying the underside of the piston which then just creates a big foaming mess, so there is an awful lot of oil flow and 6 bar boost" continued Penny. "That means there is a huge amount of gas flow through the engine and latterly you have got oil spraying the underside of the crankcase, so in terms of managing the dry-sump system you have got an awful lot of oil and air flow to control!"

Once Sir Anthony Bamford, Chairman of JCB, had set his heart on breaking the land speed record for diesel-powered vehicles, he was adamant about one thing, he wanted to prove the versatility of JCB's standard diesel engine. The JCB444 LSR engine was the single most difficult thing as far as I was concerned," said Matt Beasley, Chief Engineer for the engine on the Dieselmax project. "The fuel system was a big challenge, getting the engine to run the speed we needed to achieve the power we needed."

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Andy Green and the rest of the JCB Dieselmax team celebrate breaking the world record on the first pass (see above), this effort was enough to give Andy Green and the team an average speed of 350.092 mph, thereby setting a new FAI diesel land-speed record.

**CUSTOMISING THE PISTONS**

While the valve train was essentially carried over in its original form with the exception of high temperature exhaust valve material and uprated springs, the pistons were totally new with a large, quartzic combustion chamber with reduced compression ratio, and specific features to reduce the risk of thermal damage to the combustion chamber components. Adequate piston cooling was assured by doubling the size of the oil cooling jets and adding more, to increase oil flow for each piston by around 600 per cent.

A completely new, fully machined connecting rod was also incorporated, including a significantly enlarged small-end bearing to increase strength and robustness. While giving a longer stroke, the billet-machined crankshaft was lightened but retained its main and big end bearing sizes and shells.

**POWER ATTAINED**

Eighteen months of development yielded impressive results. By July 2006, the engine weight had come down to 375 kg. Peak power had risen to 750bhp at 3800rpm (almost twice the original 444’s rotational speed) and peak torque to 1500 Nm.

“We have talked this through, and so long as the engines are close enough to each other in specific output and run at the same speed, they will regulate themselves mechanically,” Leverton explained. But once the car began running in tests at RAF Wittering in the UK in July, and then on the Bonneville Salt Flats in Utah in August, a significant problem became apparent. Driver Andy Green, who had driven Thrust SSC to its supersonic record of 763.035 mph back in October 1997, discovered that while the front engine established boost easily, the rear lagged behind. Each engine needed an exhaust temperature in excess of 400°C before boost could be sustained.

**THE LAYOUT**

The JCB Dieselmax streamliner located one engine and transmission ahead of the driver’s cockpit, the other behind it. Apart from the ground, there was no mechanical link between the two, and the gearshifts were synchronised electronically.

**LAST MINUTE HITCHES**

It transpired that the rear unit was merely going along for the ride, acting like a brake! This was a vexing problem, but would prove to be the only unreliability the highly tuned engines displayed. Beasley conceived a balance pipe to act as a mechanical link between the two engines to ensure that the available boost was distributed evenly.

By 17 August things had reached crisis point following another failure of boost despite the balance pipe and Green adopting a technique of dragging the brakes with his left foot in order to give the engines more time to warm up.
and JCB Dieselmax

46 INGENIA ISSUE 32 SEPTEMBER 2007

something to work against and increase their working temperature. It then transpired that a software problem had intervened, fouling the rear engine into thinking it was in neutral and therefore only fuelling it to run at 2100 rpm.

With the software problem cured, Green achieved a one-way run at 308.622mph, well over the existing US national record of 300.8mph. The next day, under the rules of Bonneville’s Speed Week, he made his mandatory return run and hit 325.791mph, to set a new SCTA-BNI national average of 317.021mph. That was only the beginning of establishing the JCB Dieselm by’s full potential. Thus far they had only used 600bhp ‘mule’ (test) engines, not the 750bhp ‘race’ units.

GOING FLAT OUT

Twice the following week, now with the software problem recurred as the yellow and black car stammered down the course, eating up precious run-up area at pitiful speed. Then Green coaxed it back on song, and it shot on to the horizon. It remained to be seen just how much damage had been done to the crucial average for the two runs.

The speed for the second run was 335.695mph. The FIA calculates the elapsed times for the measured mile, then divides them and calculates the speed from the result. Green had just done enough. The average speed was 335.092mph. JCB’s PR team set about expressing frustration now revealed the team’s jubilant and proud spirit at their achievements.

GREEN SPIN-OFFS

Ricardo’s Global Director of Diesel Engineering, Ian Penny, was proud of the engine’s ecological credentials. “It runs a very low compression ratio, which brings the pressure and temperature down. It’s 10.5 to 1, whereas a diesel is normally between 16 and 20 to 1. It’s also got very high charge cooling so that the intake manifold temperature is 25 to 30 degrees centigrade, and that’s after we have compressed it to six bar. So it’s got very low pressure, very low temperature, it has water injection, which is a fantastic emissions control feature, and it runs a high pre-mix combustion system. This means the kind of combustion we are operating is very much towards the future, low-temperature combustion. In these respects it is a very green engine.”

GOING FLAT OUT

Twice the following week, now running under Federation Internationale de l’Automobile (FIA) international sanction and with the ‘race’ engines installed, Green and JCB Dieselm by thus marked the first time in many years that a JCB Dieselmax has been involved in land speed records. In these respects it is a very green engine.”

A RECORD BREAKER

“I’m so pleased that we got the car to what was only ever the maximum aspirational run speed”, said Andy Green, “and that with a problematic start and so much more to come. It was still pulling like a train once I got it going, and I still haven’t used sixth gear! It’s got so much to give, this car. It’s fantastic! Now all we need are new tyres, to make it go a lot faster!”

JCB may yet go back to the Salt in 2008, but regardless of that, the 2006 record success wrote another great chapter in the remarkable story of British engineering in record breaking. It was not motivated merely by corporate vanity; indeed, Bamford’s practical desire all along was to prove the quality of his engine and to explore potential developmental avenues for future introduction to his company’s product range. JCB Dieselm by thus marked the first time in many years that a speed project was undertaken for business reasons, and it remains the only time anyone has reeled for glory on anything so humble as a digger engine.

Further reference
www.jcbdieselmax.com
www.ricardo.com

BIOGRAHY: David Tremayne

David Tremayne is a freelance motorsport writer who covers the FIA Formula One World Championship for a number of clients, including The Independent and The Independent on Sunday. A prolific author, he wrote the definitive biography of speedking Donald Campbell, and the inside stories of the Thrust2, ThrustSSC and JCB Dieselm by land speed records.

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Harnessing energy from the ground

JCB Dieselmax is part of the Mott MacDonald Group of companies providing sustainable solutions for a better future. Mott MacDonald provides professional engineering services through its 150 offices worldwide. It has 6,000 people working from offices in the UK, Europe, North America and Asia.

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