# INVESTIGATING F1'S NEW DAWN

With a revolutionary change coming to Formula One engines in 2013, Cranfield MSc student **Ralph Koyess** undertook an assessment of the performance benefits of turbocompounding a 2013 F1 engine for his thesis. Here he explains his findings

**IN 2008**, the FIA enforced the controversial 10-year engine freeze in an aim to reduce the running costs of Formula One teams. This regulation prevented manufacturers from developing their engines with the exception of reliability improvements which had to be approved by the FIA. The freeze can only be contested after a five-year period and with the unanimous consent of the teams.

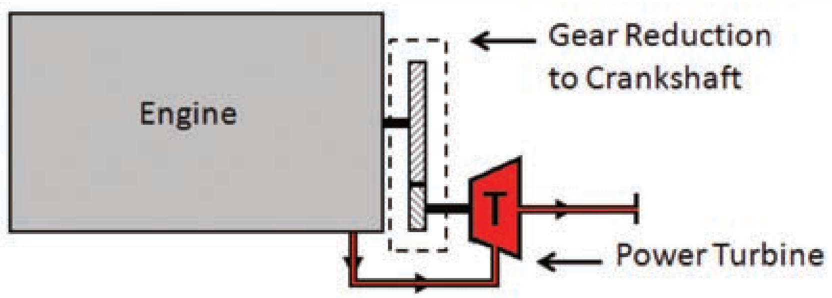
With this five-year period coming to an end after the 2012 season, engine manufacturers are in discussion to change the engines for 2013. The configuration agreed upon is a 1,600 cc in-line four-cylinder engine with an expected rev limit of 10,000 rpm in order to be of more relevance to the production car industry – and as a recent research has revealed, over 64% of cars built in 2010 were powered by a four-cylinder engine. Furthermore, the fuel flow is expected to be capped at around 25 g/s in order to promote a more environmental image for the sport. With the desire to keep power levels similar to today's engines, turbocharging and energy recovery systems are expected to be permitted. These regulations present the perfect platform for a long-awaited technology to make its way into Formula One: turbocompounding.

### WHAT IS TURBOCOMPOUNDING?

Compounding is the use of two or more sources to produce a single output. Turbocompounding is the use of a turbine as one of the sources and the engine as the other to produce one output: torque at the crankshaft. Its simplest form is presented in Figure 1.

The exhaust gases represented in red are

***FIGURE 1*** **Basic form of turbocompounding**




**RIGHT** Ready to move out of the dark ages? F1's engine technology has stagnated under the FIA's engine freeze. The 2013 season offers the opportunity to embrace solutions like turbocompounding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channelled to the turbine commonly referred to as a power turbine. The pressure and kinetic energy of the gas spin the turbine and produce mechanical power which is transmitted to the crankshaft through a mechanical linkage, generally a gear reduction.

The more likely scenarios for a Formula One application are presented in Figure 2 and Figure 3.

In these configurations, the exhaust gases are used to power the turbocharger and then routed to the power turbine which recovers further energy from the exhaust. Two setups are possible, the first, presented in Figure 2, consists of mechanically linking the power turbine to the crankshaft and the second, presented in Figure 3, consists of connecting the turbine to a generator that converts the mechanical energy to electricity that can be stored in a battery and then used to increase the engine's output through a motor or to power ancillaries. This second setup is called electric turbocompounding.

**AEROSPACE INNOVATION**

Turbocompounding was first used in the 1950s on aircraft engines. The most successful application was on the Wright R-3350, an 18-cylinder radial engine with a displacement of 54.9 litres powering military aircraft, most notably the Canadair CL-28, the Lockheed P2V-7 and the Fairchild C-119. The fuel mass flow into the engine translated into a 5,650 hp input of which only 1,680 hp resulted in engine power and a significant 2,915 hp or 51.6% was released into the exhaust. Exhaust energy recovery was therefore paramount and the implementation of turbocompounding increased the engine output by 160 hp.

Other noteworthy applications in the aerospace industry include the Allison V-1710 and the Napier Nomad, both of which were developed as test engines but never made it to production.

Nowadays, the technology is being used on large displacement diesel engines for heavy vehicles. The best examples are the Cummins and Scania engines that power many of the freight transport trucks. In these applications, the aim is to reach a certain power output at a lower rpm and hence reduce fuel consumption. The first successful application was on the Cummins NTC-400, a turbocharged six-cylinder diesel engine with a displacement of 14 litres that produced 400 hp at 2,100 rpm. Turbocompounding the engine resulted in a decrease in fuel consumption of about 27 g/kW.h over the operating range.

Other manufacturers such as Caterpillar and John Deere are known to have worked on electric turbo compounds for their engines.

So why hasn't it been used in F1 yet? In the late 1980s, during the turbo era, Cosworth worked on a turbocompounded Formula One engine. However, it was advised by the FIA that it would be banned and the project was dropped. Ever since, the regulations haven't allowed the use of this technology.

**HOW CAN AN F1 ENGINE BENEFIT?**

Engines in general are inherently inefficient and Formula One engines are no exception. Only about one third of the energy input to the engine in the form of fuel ends up as useful power. One third is dissipated as heat in the cooling system and a third is released in the exhaust. Assuming that a current Formula One engine produces 560 kW, another 560 kW is released in the exhaust. This constitutes a very important source of energy to tap into in order to increase the efficiency and hence the power output of the engine.

In order to assess the performance benefits of turbo-compounding a 2013 Formula One engine a full study was completed by the author for his MSc in Motorsport Engineering and Management at Cranfield University. The study involved building a 2013 spec Formula One engine in AVL Boost, a commercial engine simulation software used by various engine ▶

***FIGURE 2*** **Mechanical turbocompound on a turbocharged engine**

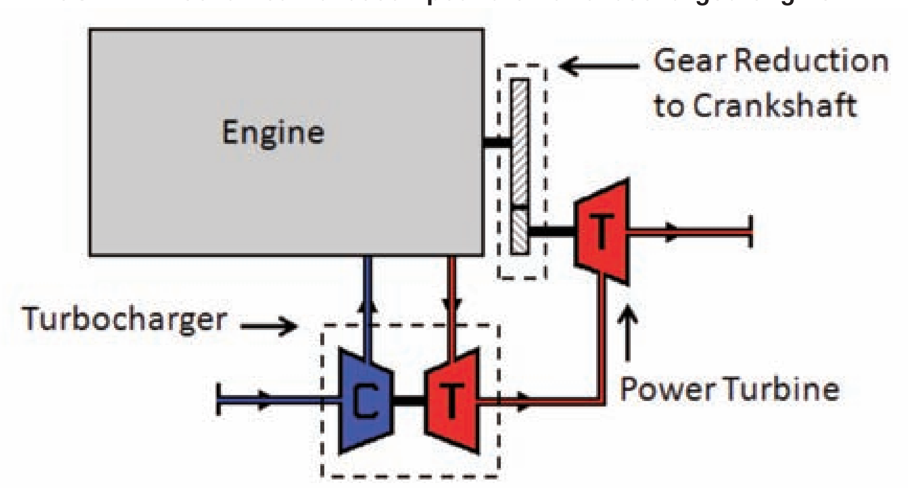
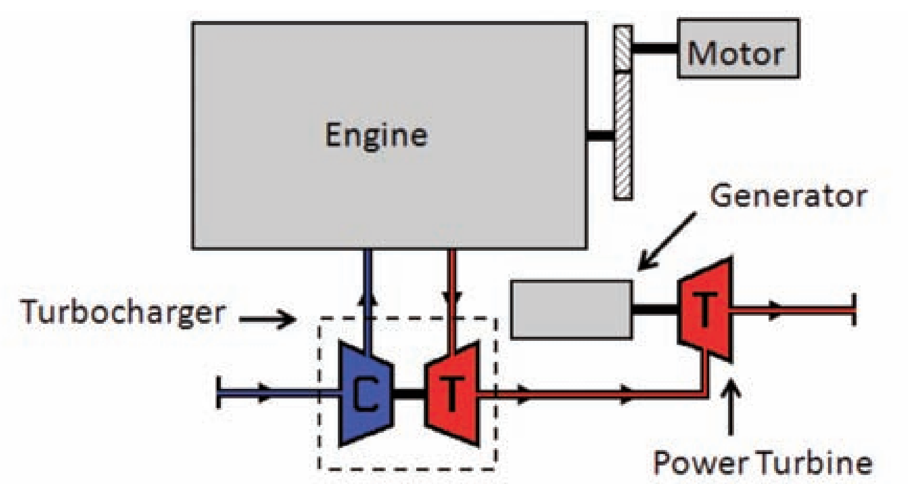



***FIGURE 3*** **Electric turbocompound on a turbocharged engine**



manufacturers. The main engine parameters are presented in Table 1.

The simulation procedure consisted of modelling the engine naturally aspirated first in order to obtain a running engine model before adding components and complexity. In order to keep the focus of the study on turbocompounding, most of the parameters of the engine were fixed and only the necessary ones were left as variables to allow the output to be optimised at each stage in the process. The parameters that were left as variables are the inlet and exhaust primary lengths and the intake and exhaust valve lift and flow coefficient profiles. Others such as the ignition timing, camshaft profile, maximum valve lifts and the air/fuel ratio were set to constant values.

The next step consisted of modelling the turbocharger which required the matching of a compressor and turbine that can generate the required pressure ratio across the compressor. The model was optimised to obtain the desired output by varying parameters such as the turbine and compressor map scaling factor and the pressure ratio in addition to the parameters modified for the naturally aspirated model.

The final step consisted of adding the power turbine to the model. A major part in this step was the study of axial and radial turbines to identify the most appropriate one for the application. The axial turbine resulted in less backpressure and was therefore used for the simulations. The final simulation model is shown in Figure 4.

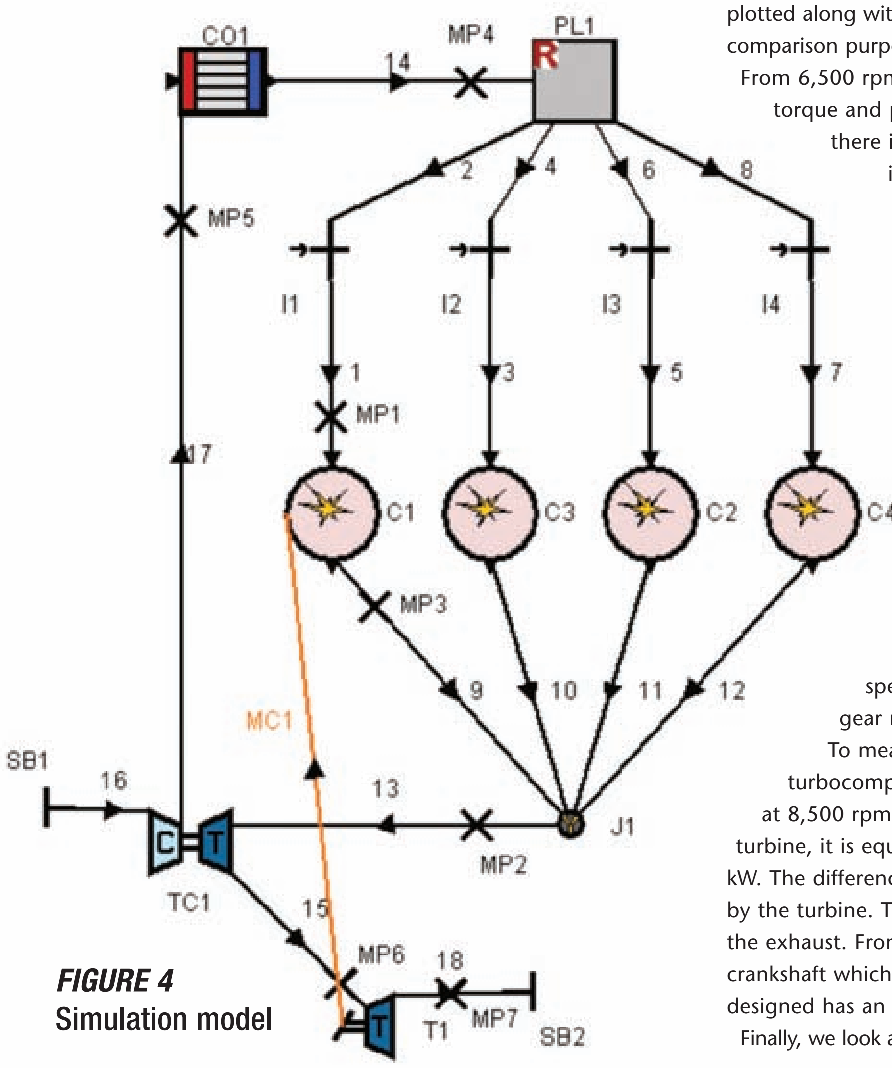



***FIGURE 4***
**Simulation model**

## TABLE 1: ENGINE SPECIFICATIONS

| | |
|---|---|
| **Configuration** | In-line 4 |
| **Displacement** | 1.6 litres |
| **Compression Ratio** | 12:1 |
| **Rev Limit** | 10,000 rpm |
| **Bore** | 82 mm |
| **Stroke** | 75.74 mm |
| **Conrod Length** | 143.5 mm |
| **Mean Crankcase Pressure** | 100 kPa |
| **A/F Ratio** | 13.965 |
| **Fuel Consumption** | 25 g/s |
| **Firing Order** | 1, 3, 4, 2 |
| **FMEP at 10,000 rpm** | 2.8 bar |

The turbocharger and power turbine are labelled TC1 and T1 respectively. Mechanical turbocompounding was used as opposed to an electrical system. The orange line labelled MC1 represents the mechanical link with a fixed gear ratio between the power turbine and the crankshaft. The results of the simulations are presented in Figure 5. The turbocompound engine performance is plotted along with the turbocharged engine performance for comparison purposes.

From 6,500 rpm the turbocompound engine produces more torque and power. However, it is only from 8,000 rpm that there is a significant increase in output. The output increases by 26.7 kW and 27.7 Nm on average which represents a 7% power increase and 6% torque increase in the range where the engine spends over 85% of its life. There is a peak increase of 31.5 kW and 31.7 Nm at 9,500 rpm. At the most useful speed, 8,500 rpm, there is an increase of 26.5 kW and 29.8 Nm which translates into a 6.5% increase to both power and torque. Since there is an increase in power for the same fuel consumption, the BSFC is lower for the turbocompound engine. It is important to note that the gear ratio of the mechanical linkage was optimised to get the highest value possible for the power at 8,500 rpm. Furthermore, the ratio was the same for all speeds. A higher output can be obtained if the gear ratio is variable and is optimised at each speed.

To measure the efficiency of the mechanical turbocompound system, the exhaust energy is calculated at 8,500 rpm before and after the power turbine. Before the turbine, it is equal to 382.3 kW and after the turbine is 344.2 kW. The difference is 38.1 kW which is the total power absorbed by the turbine. This represents 10% of the energy released into the exhaust. From the 38.1 kW, 26.5 kW end up at the crankshaft which means that the turbocompound system designed has an efficiency of 70%.

Finally, we look at the efficiency of the engine. The turbocharged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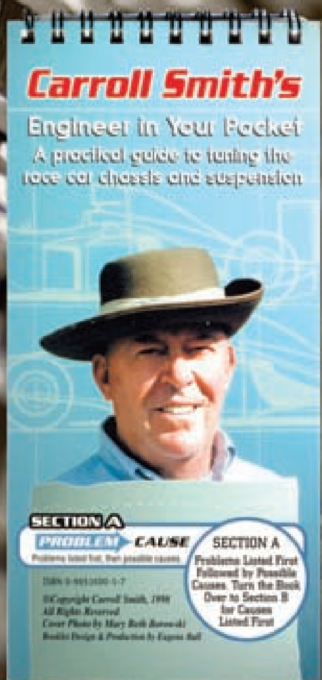


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engine without the power turbine has an efficiency of 36.9%. The turbocompound engine has an efficiency of 39% which represents a 2 percentage point increase in efficiency over the turbocharged model. This is quite a significant increase that highlights the benefits of turbocompounding.

While turbocompounding adds power at no extra fuel cost, it adds weight to the vehicle. The mass of the added components to the turbocharged engine is estimated at 16.5 kg. It is commonly known that there is a time penalty of around 0.3 seconds per lap for every 10 kg added to the car. Adding 16.5 kg to the car would theoretically slow it down by about half a second a lap. However, Formula One cars carry 30-50 kg of ballast in order to reach the minimum weight. The weight of the turbocompound system is subtracted from the ballast and the result is a higher centre of gravity. Increasing the centre of gravity by 10 mm will result in a time penalty of 0.1 second. However, the 2010 F1 technical regulations state that the centre of gravity of the engine must not lie below 165 mm and the weight of the engine must be a minimum of 95 kg. If similar regulations are instated in 2013, the engines will be designed around the minimum weight allowable with the turbocompounding system considered part of the engine. The result is that the turbocompound system will not alter the total weight or the centre of gravity of the engine which will always be close to the minimum stated by the regulations.

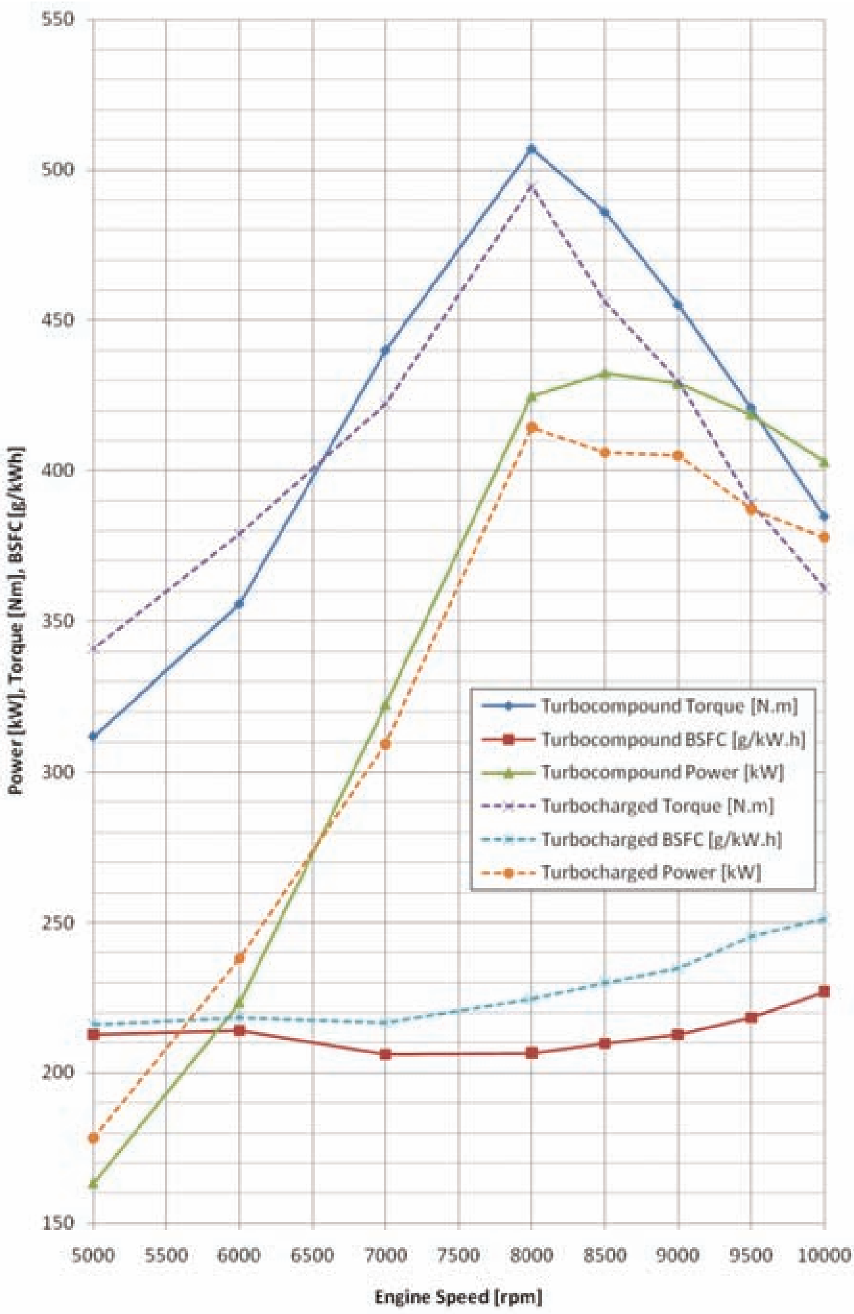
## CONCLUSION

Turbocompounding was theoretically proven to be beneficial for the 1.6-litre Formula One engine modelled. Turbocompounding was found to increase the power by about 27 kW or 7% over the useful range of the engine, from 8,000 to 10,000 rpm. The peak power increase occurs at 9,500 rpm with 31.5 kW or approximately 8% added to the turbocharged engine which results in a 2% increase in engine efficiency. The power increase comes at no additional fuel consumption when compared to the turbocharged engine. This is ideal if the fuel flow rate is capped by the FIA. The study also revealed that an axial turbine induces less backpressure than a radial turbine and is therefore better suited for this application.

KERS and turbocharging offer a great platform for the development of the electric turbocompound system described in Figure 3. Adopting such technology in Formula One will surely go a long way to enhance the green credentials of motorsport and in addition develop a technology that will prove beneficial in road car applications.

• This research was sponsored by Cosworth and was completed by Ralph Koyess with the technical support and supervision of Stuart Grove (Cranfield University), Matthew Harrison (Cranfield University), David Gudd (Cosworth) and John Bell (Cosworth). RT

**FIGURE 5** Turbocompound and turbocharged engine performance





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