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Engine Performance Simulation of Ricardo WAVE for GTDI Optimization

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Abstract: The aim of this paper is to simulation software platform, RICARDO WAVE as used to simulate GTDI engine with the intention of maximizing the engines efficiency and minimizing the emission. In this paper using actual parameter and specification of the 3 cylinder SI engine with the prospect of allowing optimum engine to be built and tested in real world conditions without the need for multiple expensive prototypes and long delays.

Keywords: GTDI, Ricardo wave simulation, Ricardo wave software, Ricardo wave engine simulation.

I. INTRODUCTION

In a GTDI engine, fuel is delivered to the engine compartment by a low-pressure fuel pump, using a return less fuel system. Fuel then passes through a mechanically actuated high-pressure fuel pump mounted on top of the cylinder head and driven by a four-sided camshaft lobe. The fuel travels through a stainless-steel fuel rail at pressures between 65 and 2150 psi, depending on demand, and then to the fuel injectors, which inject fuel directly into the combustion chambers.

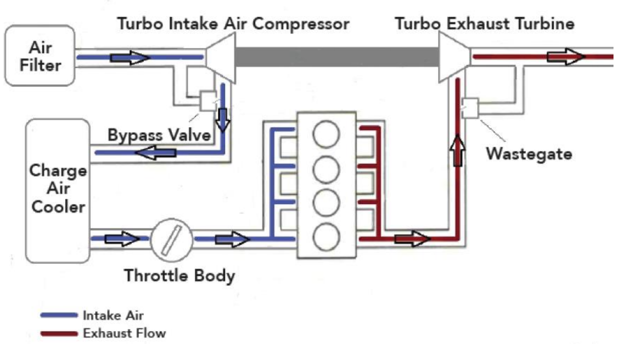

Fig. 1. GTDI Engine Layout

Intake air enters through the air filter and is compressed by the compressor side of the turbocharger. The very hot compressed air is forced through the charge air cooler (CAC)—because as we all know, cool air is denser, which means it combusts more efficiently than hot air—then passes through the throttle body to the intake manifold, past the intake valves and into the combustion chamber.

After combustion, the exhaust is pushed into a dual-chamber exhaust manifold, which incorporates an air gap between the exhaust and the engine compartment. This keeps the exhaust hotter, which makes for more efficient turbocharger operation, and helps keep the engine compartment cooler. The hot expanding exhaust gases travel to the turbine side of the turbocharger, spinning the rotor at speeds of up to 200,000 rpm, which in turn spins the compressor side of the turbocharger. That's the basic start-up and go of the GTDI engine. There haven't been many changes made to the base engine to accommodate GTDI. They have dual-overhead camshafts (DOHCs) over four valves per cylinder, which are governed by variable cam timing (VCT). The cylinder heads are aluminum, and all Eco-Boost engines but the 1.0L and the 2.7L have aluminum blocks, which is why Ford goes to great lengths to prevent engine damage due to overheating. The compression ratio is a modest 10:1 for all GTDI engines except the 2.0L, which is 9.3:1, and the 2.3L, which is 9.5:1. The lower compression is necessary in forced-air engines to prevent detonation. At 15 psi of turbo boost at sea level, an engine with a 10:1 compression ratio has an effective compression ratio of about 20:1. This ratio flirts with the detonation knock limit. Compression any higher can lead to pre-ignition of the air-fuel mixture, causing some nasty detonation.

One concern that's becoming a problem with all GTDI engines is excessive carbon buildup on the back side of the intake valves. This causes hard-to-diagnose misfires, especially when the engine is cold, and can also create a rough, rolling idle. One reason for this is valve timing.

When the exhaust valve opens on the exhaust stroke under boost conditions, the intake valve opens slightly to allow forced air into the combustion chamber. This push of forced fresh air aids in the evacuation of exhaust from the cylinder. During this overlap, a small amount of combustion gases can sneak past the intake valves, causing carbon buildup on the back side of the valves. The direct fuel injection worsens this condition because fuel isn't sprayed directly onto the intake valve to clean it off; direct injection sprays fuel directly into the combustion chamber. GTDI turbochargers are mounted directly to, or in some applications integrated with, the exhaust manifolds. The turbo being so close to the combustion chambers allow them to reach maximum speed more quickly. This, along with the low-inertia rotors that drive the turbine, allows for quick turbo reaction and virtually no turbo lag. But the location of the turbo does create some issues. They get hot. They're also vulnerable to damage from loose carbon pieces that might fly out of the cylinder, which is why you should never perform an induction service on a GTDI engine.

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The excess heat created by the cleaner and the breaking away of rough carbon chunks are killing turbo. Ford is working on an approved induction cleaning system.

II. WHY GTDI NECESSARY?

In GTDI Engine Turbocharger output must be regulated to prevent excessive intake pressure, or over boost. The power train control module (PCM) controls exhaust flow to the turbo using a turbocharger-mounted waste gate, which directs exhaust flow around the turbocharger when needed. The waste gate is opened by a diaphragm operated by engine vacuum or boost pressure, depending on the application. The PCM uses an intake manifold-mounted MAP sensor to monitor boost pressure. Then, using a waste gate regulating valve solenoid, it commands the diaphragm to move a poppet style valve that redirects exhaust flow around the turbo. The valve is held in the closed position by spring pressure. A threaded rod connects the diaphragm to the valve, and although the rod has an adjusting nut, it’s not adjustable. The rod comes from the factory with a painted cage over the adjusting nut. If the cage is missing, or if the paint is disturbed, someone has tried to adjust it, and the entire turbo must be replaced, since the waste gate and rod are not serviced separately.

During quick throttle releases, intake air from the high-pressure turbocharger outlet is redirected to the low-pressure turbocharger inlet by the turbocharger bypass valve (TCBV). This recirculation of airflow prevents loud air sounds that are caused by the backup of intake air through the turbocharger. When the TCBV is stuck closed, the air sound during a quick deceleration can be pretty loud, and will often generate a customer complaint. Depending on the application, the TCBV will be operated by an electric motor or by engine vacuum.

Most issues with turbocharger control will set a DTC, but not all. I recently serviced an Explorer with the 3.5L GTDI that would lose power on acceleration at about 40 mph. There were no DTCs stored in the PCM, so I proceeded with a visual inspection, which is your most valuable tool in all diagnoses. The vacuum hose from the air intake to the TCBV was cracked and leaking, causing intake air to bypass the turbochargers during a time when boost air was needed the most. Since then I’ve seen a few of these hoses that were soft and cracked. Be sure to check this when diagnosing a loss of power on a GTDI engine.

Before performing any diagnosis on a GTDI engine, visually inspect all air intake and vacuum hose connections. The smallest air leak can cause drivability issues and set DTCs. During your visual inspection, you might notice oil residue around the turbo. This is normal due to the PCV system. Oil leaking, draining or paddling is not normal. A few more things about the turbo. The only change in the evaporative emissions system to accommodate GTDI is a check valve positioned between the intake manifold and the canister purge valve to prevent boost pressure from entering the vapor canister.

There’s a screen located in the turbocharger oil supply line. Always replace it when replacing a turbo that has failed, and if you remove the air inlet or outlet hose from the turbo, cover the opening with a shop rag. The smallest piece of debris can launch that turbo. The 1.5L GTDI uses a water-cooled CAC. Coolant is circulated through the cooler by an electric coolant pump. This auxiliary cooling system is filled through the same degas bottle as the engine cooling system, and a bleeder valve is provided above the cooler.

The low-pressure pump is primed by the activation of the interior lamp circuit. So when you open the door, the low pressure pump turns on for a couple of seconds to establish fuel pressure. When the PCM receives an engine start signal, it sends a 65V boost to the fuel injectors to give them a kick start, and then modulates voltage as needed. Since the high-pressure pump is mechanical, it starts working as soon as the engine starts turning.

III. RICARDO WAVE ENGINE SETUP

Ricardo wave is industry standard 1- dimensional engine performance simulation software. Ricardo wave is used worldwide in engine industries and enables automotive manufacturers to perform engine performance simulation on intake, combustion and exhaust system configuration.

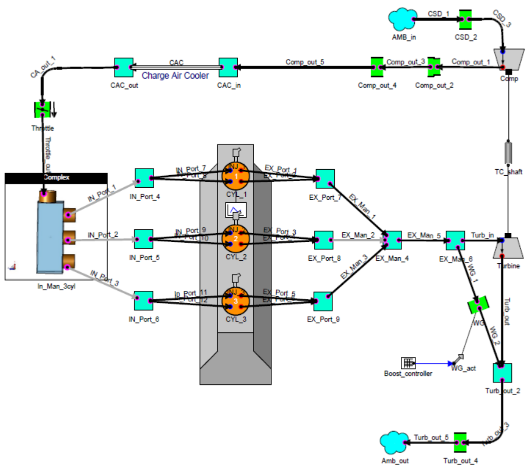

Fig. 2. Ricardo WAVE set up of GTDI Engine

A. *Engine Data:*

Engine data refers to all dimensions and characteristics associated with the actual engine itself. This includes the cylinder head and inlet and exhaust ports. For the basic engine only minimal information is required:

- Bore Stroke
- Connecting Rod length
- Wrist Pin offset
- Compression ratio
- Firing order and timing

The ports require more detailed information which can only be collected from testing the ports on a steady state flow rig.

Typical information needed is:

- Port flow coefficients taken from measured data
- Valve diameters
- Valve event timings
- Valve lift or Cam profiles

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It is often very useful to make moulds of the ports. This allows you to measure the lengths and diameters more accurately. This is particularly true of a 3/4/5 valve per cylinder engine when the multiple ports branch off from one entry volume in the cylinder head. This type of cylinder can require more geometric information relating to:

- Shape of the cylinder head, ports, and combustion chamber
- Position of valves in the combustion chamber and position of spark plug
- Orientation and size of piston top shapes
- Wall temperature characteristics and transfer coefficients
- Piston ring and cylinder liner friction

B. *Operating Parameters*

Operating Parameters refer to conditions at which the simulation will be run. Typical data required for an engine are:

- Inlet and exhaust wall temperatures
- Engine operating speed
- Fuel flow rate or fuel/air ratio
- Piston, Head, and Liner average surface temperatures
- Ambient conditions
- Combustion data

These are the minimum conditions required to get the basic model running. It is necessary to have temperatures in several locations in the exhaust system as this varies greatly and has a significant effect on predicted performance. If you do not have measured data available, a range of typical operating temperatures for various parts of the engine is given in the example models. In-cylinder temperatures are rarely measured but typical values can be found. Combustion data should be measured from and correlated to a test engine.

Further test data is later required to perform the correlation of the model, including:

- Dynamic intake and exhaust pressures
- Cylinder pressure trace
- Engine performance - IMEP, BMEP, volumetric efficiency, etc.

C. *Gtdi Engine Parameters And Consideration:*

PARAMETER	DATA
Fuel	Gasoline
Strokes	4
Bore diameter (mm)	72
Stroke length (mm)	82
Compression ratio	10.0
Injection System	DI
Displaced volume (cc)	1.0032
Clearance height (mm)	1.2
No. of intake valves	2
No. of exhaust valves	2
Intake max valve lift (mm)	8
Exhaust max valve lift (mm)	8
Intake valve opening and closing time (CAD)	103
Exhaust valve opening and closing time (CAD)	126
Connecting rod length (mm)	136.5
Engine head surface area (mm2)	1.19
Piston wrist pin offset (mm)	7.45
Intake & Exhaust valve diameter (mm)	27 & 23
Piston bowl depth (mm)	0
Piston bowl diameter (mm)	50
Piston bowl rim diameter (mm)	50
Piston bowl volume (mm3)	Auto
RPM Range	1000 to 6500
Peak Power	132 kW @ 6000 rpm
Peak Torque	250 N*m @1500- 4500 rpm
BSFC at Peak Eff.	245 g/kW/h

IV. RESULT AND ANALYSIS OF ENGINE PERFORMANCE PARAMETERS

- Brake power and Engine speed relation

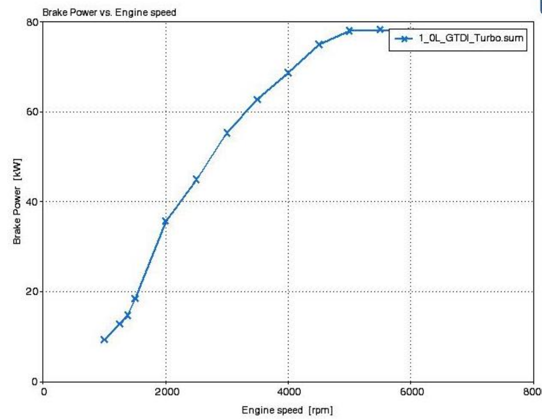

Fig. 3. Brake power vs Engine speed

- Indicated power and Engine speed relation

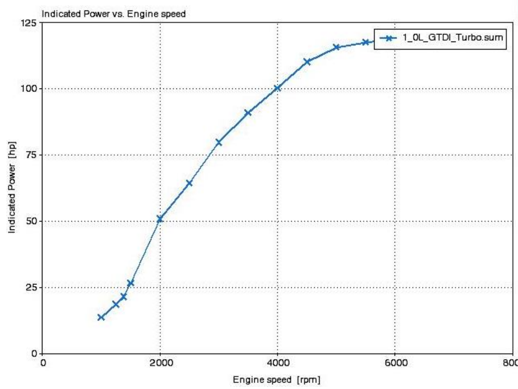

Fig. 4. Indicated power vs Engine speed

- BSFC and Engine speed relation

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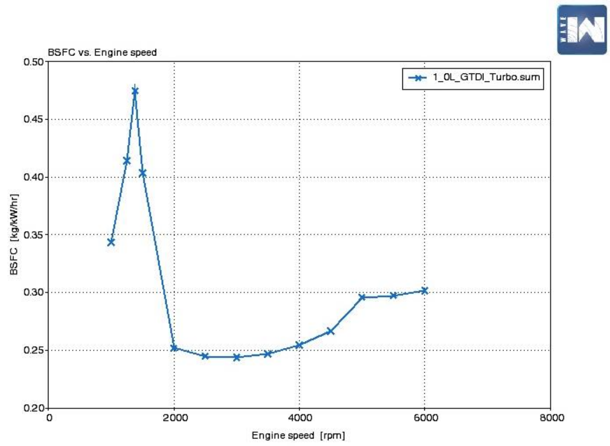

Fig. 5. BSFC vs Engine speed

- ISFC and Engine speed relation

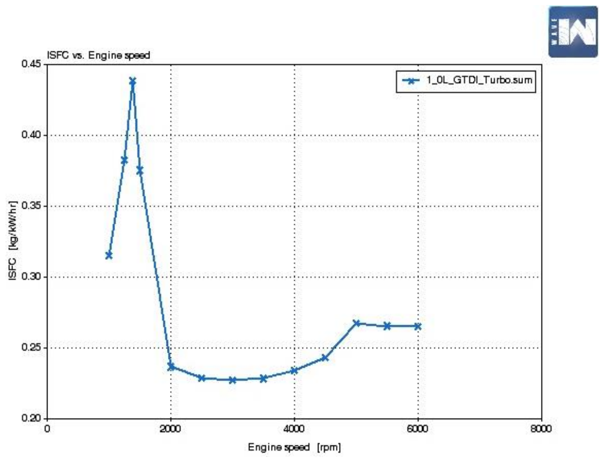

Fig. 6. ISFC vs Engine speed

- Total volume Efficiency and Engine speed relation

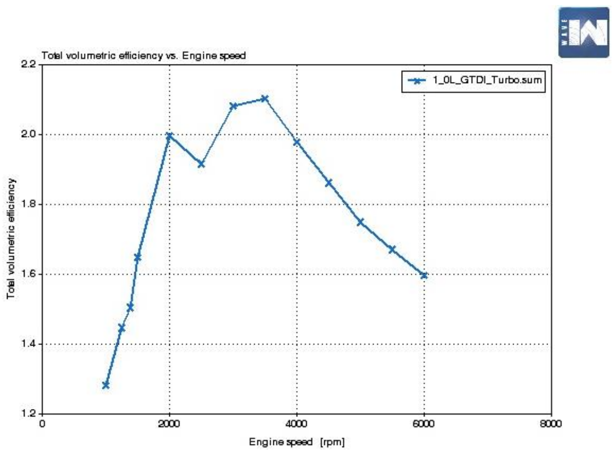

Fig. 7. Total volume Efficiency vs Engine speed

- Brake Thermal Engine Efficiency and Engine speed relation

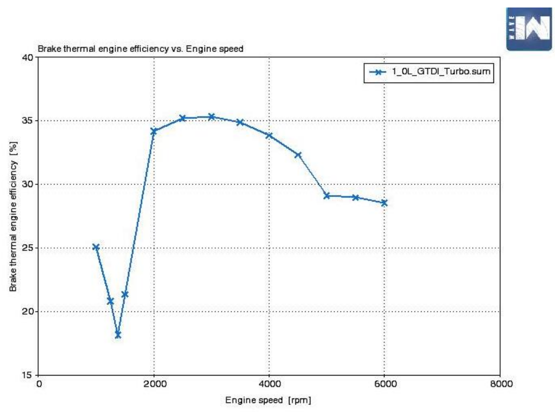

Fig**. 8. Brake Thermal Engine Efficiency vs Engine speed**

- HC and Engine speed relation

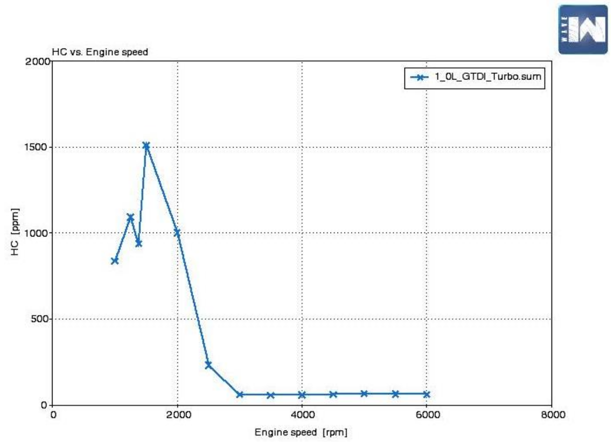

Fig. 9. HC vs Engine speed

- CO and Engine speed relation

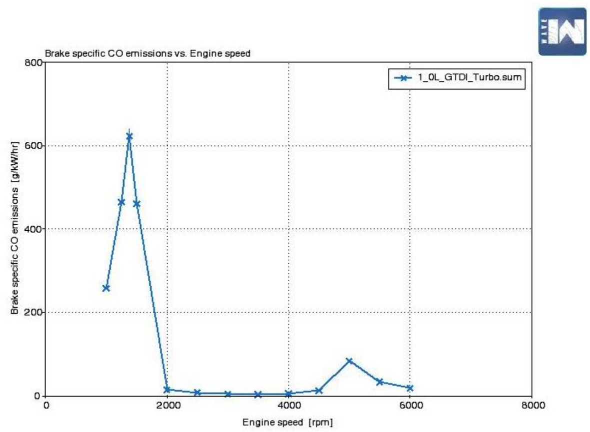

Fig. 10. CO vs Engine speed

V. CONCLUSION

To conclude, the engine modeled successfully in Ricardo WAVE have been validated the initial model and tuning the following cases to match the given data from experiments with good levels of accuracy. All models could be used to easily predict improved emissions. In this paper any engine development we consider some parameter for test and simulate.

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In GTDI engine we can see all efficiency, power and Emission parameters to achieve accurate results. In Ricardo WAVE software it's easy to change any variables as they are all in one constant.

The main benefit of using 1D software is that the calculations are fast.

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