An Analytical Study On Turbocharging A V6 SUV High Speed Direct Injection (HSDI) Diesel Engine
An Analytical Study on Turbocharging A V6 SUV
HSDI Diesel Engine

• Introduction
• Simulation Boundary Conditions
• Simulation Results
• Summary
Sport Utility Vehicles (SUV)
Passenger Car and Light Duty Truck Sales in the US

Source: EPA
Combined Fuel Economy (City+Highway) for SUV

Source: EPA
### Boundary Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Engine configuration</td>
<td>90°-V6, turbocharged and intercooled</td>
</tr>
<tr>
<td>Rated power @ rated speed</td>
<td>186 kW (250 hp) @ 4,000 rpm</td>
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<tr>
<td>Rated torque</td>
<td>583 Nm (430 ft-pds) @ 2,000 rpm</td>
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<tr>
<td>Low end torque</td>
<td>257 Nm (190 ftpds) @ 1,000 rpm or: $\lambda \geq 1.3$ (A/F$\approx$18.8)</td>
</tr>
<tr>
<td>Displacement</td>
<td>4.0 L</td>
</tr>
<tr>
<td>Bore</td>
<td>92 mm (3.62&quot;)</td>
</tr>
<tr>
<td>Stroke</td>
<td>101 mm (3.98&quot;)</td>
</tr>
<tr>
<td>Firing order</td>
<td>even: 1-6-3-5-2-4-1 (split-pin crankshaft)</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5</td>
</tr>
<tr>
<td>Maximum peak pressure</td>
<td>155 bar</td>
</tr>
<tr>
<td>Intake valves</td>
<td>2 x $\varnothing$34 mm</td>
</tr>
<tr>
<td>Exhaust valves</td>
<td>2 x $\varnothing$28 mm</td>
</tr>
<tr>
<td>Turbocharger</td>
<td>Derived from existing hardware</td>
</tr>
<tr>
<td>Computer code</td>
<td>GT-Power</td>
</tr>
</tbody>
</table>
GT Power Model - Baseline, One Turbocharger with Waste Gated Twin Flow Turbine
a. One turbocharger with twin flow turbine, waste gated
b. One turbocharger with single turbine entry, waste gated
c. One turbocharger with single flow variable turbine geometry (VGT)
d. Bi-Turbocharger system with single flow turbine, waste gated
e. Bi-VGT turbocharger system with single flow turbines
f. Two stage turbocharging system with single entry turbines
Comparison of Waste Gated Twin Flow and Single Flow Turbine with Same Compressor, and Same Turbine Size

- Twin flow turbine with waste gate
- Single flow turbine with waste gate

Graphs showing:
- Relative AFR vs. Engine speed (rpm)
- Max. cylinder pressure vs. Engine speed (rpm)
- Engine BMEP vs. Engine speed (rpm)
- BSFC vs. Engine speed (rpm)
Comparison of Waste Gated Twin Flow and Single Flow Turbine - Same AFR @ 2000 rpm

- Twin flow turbine with waste gate
- Single flow turbine with reduced turbine size (60%) to match the low speed

- Required

Relative AFR vs. Engine speed (rpm)
Max. cylinder pressure (bar) vs. Engine speed (rpm)
Engine BMEP (bar) vs. Engine speed (rpm)
BSFC (g/kWh) vs. Engine speed (rpm)
Comparison of Engine Performance @ 2,000 rpm, Twin Flow vs. Single Flow Turbine, Waste Gate Closed

- Twin flow turbine
- Single flow turbine

- Twin flow turbine, overall power = 14.4 Kw
- Single flow turbine, overall power = 12.3 Kw

- Twin turbine flow - left
- Twin turbine flow - right
- Single flow turbine

- Twin flow turbine, overall eff. = 0.64
- Single flow turbine, overall eff. = 0.66
Comparison of Gas Pressure Across Engine Cylinder No. 1 - Twin flow and Single Flow Turbine @ 2000 rpm

Waste gate closed

Diagram showing pressure across the engine cylinder with two graphs comparing twin and single flow turbines at 2000 rpm.
a. One turbocharger with twin flow turbine, waste gated

b. One turbocharger with single turbine entry, waste gated

c. One turbocharger with single flow variable turbine geometry (VGT)

d. Bi-Turbocharger system with single flow turbine, waste gated

e. Bi-VGT turbocharger system with single flow turbines

f. Two stage turbocharging system with single entry turbines
Comparison of Waste Gated Twin Flow Turbine Turbocharger with Single Flow VGT Turbocharger

- Twin flow turbine with waste gate
- Single flow VGT

Relative AFR vs. Engine speed (rpm)

Max. cylinder pressure (bar) vs. Engine speed (rpm)

Nominal turbine size vs. Engine speed (rpm)

BSFC (g/kWh) vs. Engine speed (rpm)
 Turbocharger Arrangements

a. One turbocharger with twin flow turbine, waste gated
b. One turbocharger with single turbine entry, waste gated
c. One turbocharger with single flow variable turbine geometry (VGT)
d. Bi-Turbocharger system with single flow turbine, waste gated
e. Bi-VGT turbocharger system with single flow turbines
f. Two stage turbocharging system with single entry turbines
Comparison of Biturbo Waste Gated Single Flow with One Single Flow VGT Turbocharger

- 2 Single flow waste gated turbochargers
- 1 Single flow VGT turbocharger
- 1 Twin flow waste gated turbocharger

Relative AFR vs. Engine speed (rpm)

Max. cylinder pressure (bar) vs. Engine speed (rpm)

Engine BMEP (bar) vs. Engine speed (rpm)

BSFC (g/kWh) vs. Engine speed (rpm)

Comparison of Biturbo Waste Gated Single Flow with One Single Flow VGT Turbocharger
a. One turbocharger with twin flow turbine, waste gated

b. One turbocharger with single turbine entry, waste gated

c. One turbocharger with single flow variable turbine geometry (VGT)

d. Bi-Turbocharger system with single flow turbine, waste gated

e. Bi-VGT turbocharger system with single flow turbines

Two stage turbocharging system with single entry turbines
Comparison of One Single Flow VGT Turbocharger With Bi-Turbo Single Flow VGT Turbochargers

- Relative AFR [-]
- Max. cylinder pressure (bar)
- Engine BMEP (bar)
- BSFC (g/kWh)

Graphs showing performance metrics for different turbocharger configurations.

- 1 Single flow VGT turbochargers
- 2 Single flow VGT turbocharger
- Twin flow waste gated turbocharger
Comparison of Two Single Flow VGT With One Waste-Gated Twin Flow Turbine Turbocharger - Influence of VGT Vane Position Dependent Turbine Efficiency
Turbocharger Arrangements

a. One turbocharger with twin flow turbine, waste gated
b. One turbocharger with single turbine entry, waste gated
c. One turbocharger with single flow variable turbine geometry (VGT)
d. Bi-Turbocharger system with single flow turbine, waste gated
e. Bi-VGT turbocharger system with single flow turbines
f. Two stage turbocharging system with single entry turbines
Comparison of Two-Stage Turbocharging System vs. Other Arrangements

- 2 Stage single flow turbine
- 2 Single flow VGT turbines
- 1 twin flow waste gated turbine

Relative AFR

λ Required

Max. cylinder pressure (bar)

Pmax allowed

Engine speed (rpm)

BSFC (g/kwh)

Engine BMEP (bar)

FEV
Summary

- The V6 engine with even firing order is beneficially turbocharged using a system with two separated exhaust volutes.
- The engine equipped with one twin-flow waste-gated turbocharger offers high low end torque at low cost compared to other turbocharging systems.
- The engine equipped with one VGT turbocharger improves high speed fuel economy compared to the waste-gate turbocharger, and will become the standard turbocharger system.
- The engine equipped with a bi-turbo VGT turbocharger system shows the best low end torque capability and high speed fuel economy but it adds cost and complexity.
- The two-stage turbocharging system offers the highest potential for low end torque and best-in-class fuel economy but adds complexity. It is superior for extended downsizing with dramatic improvement in transient response.