Low Frequency Acoustic Modeling of the Intake System of a Turbocharged Engine and the Exhaust of a Dual System

William Seldon, Jamie Hamilton, Amer Shoeb - General Motors
Jared Cromas, Daniel Schimmel - Gamma Technologies
Introduction

• Concerns about accuracy for turbocharged engines
  – Multiple encounters of specifications saying 1D simulation can't handle turbocharged engine acoustics
  – No data to support this
  – GM decided it was worth looking into in more detail

• Concerns about modern exhaust features, like X-pipe
  – Some newer features are not as straightforward in a 1D model
  – GM decided an X-pipe was worth investigating
Experimental Setup - Engine Selection

- Engine in vehicle, Mature engine (good engine model)

<table>
<thead>
<tr>
<th>Intake System Study</th>
<th>Turbocharged I4 Engine</th>
<th>Exhaust System Study</th>
<th>Naturally Aspirated V8 Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore</td>
<td>86.0 mm</td>
<td>Bore</td>
<td>103.25 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>86.0 mm</td>
<td>Stroke</td>
<td>92 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>2.0L</td>
<td>Displacement</td>
<td>6.2L</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>9.5:1</td>
<td>Compression Ratio</td>
<td>11.5:1</td>
</tr>
<tr>
<td>Rated Power</td>
<td>270 hp @ 5500 rpm</td>
<td>Rated Power</td>
<td>455 hp @ 6000 rpm</td>
</tr>
<tr>
<td>Rated Torque</td>
<td>400 Nm @ 3000–4600 rpm</td>
<td>Rated Torque</td>
<td>625 Nm @ 4600 rpm</td>
</tr>
</tbody>
</table>
Experimental Setup - Intake System

- Multiple pressure locations
- Compressor housing installations
- Microphone at snorkel (inlet)
Experimental Setup - Exhaust System

- 16 Kiel probes
- 18 K-type thermocouples
- 2 condenser microphones at tailpipe

### Conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Muffler</td>
<td>Full load sweep, 20 s</td>
</tr>
<tr>
<td></td>
<td>Full load peak torque (4400 RPM)</td>
</tr>
<tr>
<td></td>
<td>Full load peak power (6000 RPM)</td>
</tr>
<tr>
<td>Straight Pipes</td>
<td>Full load sweep, 20 s</td>
</tr>
<tr>
<td></td>
<td>Full load peak torque (4400 RPM)</td>
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<tr>
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</tr>
</tbody>
</table>
Intake Analysis - Overheating Engine

- Initial comparison not good, turns out engine was too hot
- With other data, model could be modified
- Adjust boost pressure, intercooler, air-to-fuel ratio
Intake Analysis - Predictive Modeling

• Intake system components fully predictive
Intake Analysis - Acoustic Compressor

• Novel compressor model
• Captures resonance effects of housing
• Improves acoustic response
• Small effect on engine calibration
Intake Analysis - Results

- Improved prediction of intake noise for a turbocharged engine
Exhaust Analysis - System Geometry

- GEM3D used to model manifolds, mufflers, and X-pipe
- Engine model updated with latest vehicle calibration
  - Cam timing, spark/ignition timing, etc.
- Temperatures adjusted using wall solver
Exhaust Analysis - X-Pipe

- Requires further detail than 1 flowsplit with correct angles
- Flow pattern is mostly straight, Less forced mixing

Out-of-phase oscillating flow in an X-Pipe (GT-POWER+ConvergeLite)
Exhaust Analysis - Results

- Good correlation to measured data
- Overall and Order content predicted well
Conclusions

• Good acoustic predictions can be made using a 1D model
• Complex geometries need to be modeled in detail
  • Air boxes, intercoolers, X-pipes, mufflers
  • Affects wave reflections (acoustics) not flow loss (performance)
  • Elements do not require "calibration", all geometry based
• Temperature (Speed of Sound) has significant effect on noise
  – Exhaust temperatures need be fairly accurate
• Novel compressor model used to increase accuracy
• Testing conditions need to be monitored closely
  • Simulation can be modified to match unexpected test