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Close-Coupled Pilot Injections

Enabling Quieter Diesel Engines

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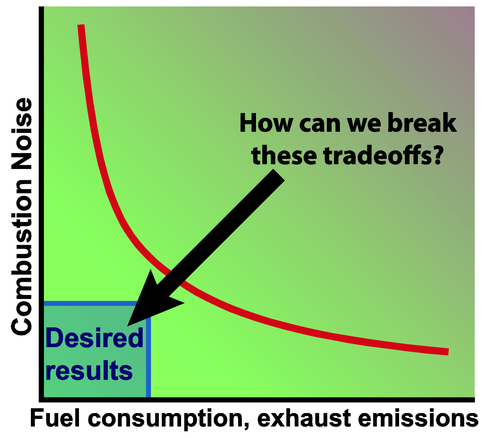
Motivation

Controlling combustion noise is a key factor in getting advanced, high efficiency engine technology into the marketplace

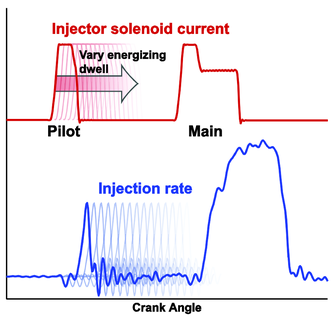
- "High noise levels can be an impediment to customer acceptance and market penetration in automotive applications where customers demand refinement in terms of both cabin noise and vehicle radiated noise." – ACEC Light-Duty Noise Guidelines for Advanced Combustion Research, USDRIVE Advanced Combustion and Emission Control Technical Team, Jan. 2015
- Engine calibration engineers must manage tradeoffs between emissions (NOx, soot, UHC), noise, efficiency, and exhaust temperature

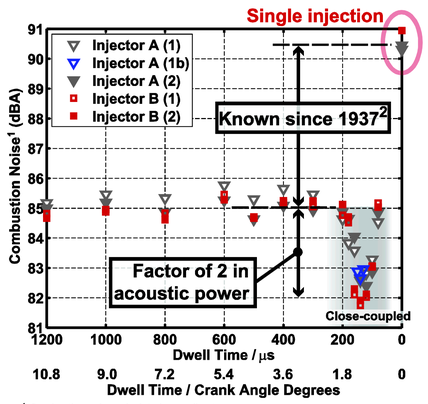


Reducing combustion noise with pilot injections

Pilot injections have long been understood to reduce noise, but further noise reductions are observed with close-coupled pilots

- **A collaborative project between GM and SNL** was devoted to the study of close-coupled pilots
- For fixed load, combustion phasing, and pilot mass, pilot-main delay (dwell) is varied
- Engine combustion noise is measured for each dwell





[1] *Combustion noise calculated according to*: Shahlari, A., Hocking, C., Kurtz, E., and Ghandi, J., "Comparison of Compression Ignition Engine Noise Metrics in Low-Temperature Combustion Regimes", SAE Int. J. Engines 6(1):541-552, 2013, doi: 10.4271/2013-01-1659.

[2] *Reduction of noise by pilot injections reported in*: Jáfar, D., "Pilot Injection", in *Engineering Magazine*. 1937: London.

Industrial Collaborations

Collaborative projects with industrial partners provide valuable feedback so Sandia's work remains relevant and competitive

- This close-coupled pilot study was part of a multi-year contract between General Motors R&D and Sandia's light duty diesel research lab
- The latest research results are provided to GM through periodic meetings and teleconferences, but the agreement with GM allows publication of results
- DOE funding provides further support to analyze data, develop ideas, and publish results that support the EERE's mission

Combustion noise modeling

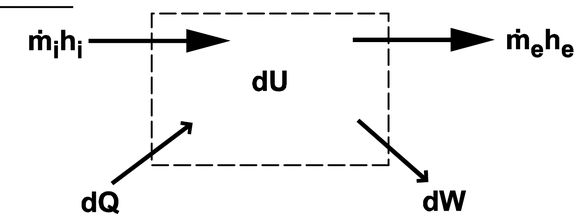
A simple thermodynamic model is developed to model the relationship between heat release and cylinder pressure

$$dP = \frac{(\gamma-1)dQ - \gamma P dV + (\gamma-1)(\dot{m}_i h_i - \dot{m}_e h_e)}{V}$$

$$dT = \frac{PdV + VdP}{mR} - T\frac{dm}{m}$$

$$dQ = dQ_{heat\ release} - dQ_{woschni}$$

$$\gamma = 1.35 - 6\cdot 10^{-5}T + 1\cdot 10^{-8}T^2 \quad *$$

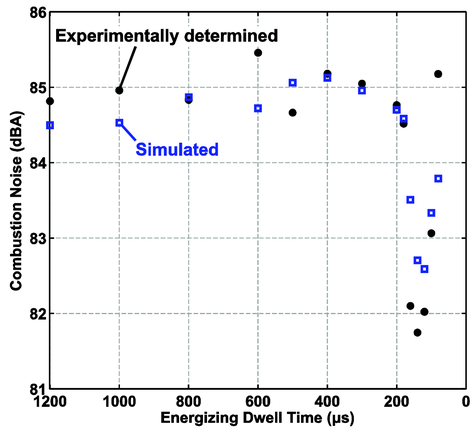


* Source: Brunt, M. and Platts, K., "Calculation of Heat Release in Direct Injection Diesel Engines," SAE Technical Paper 1999-01-0187, 1999, doi:10.4271/1999-01-0187

Understanding the combustion noise reduction mechanism

The close-coupled pilot combustion noise reduction mechanism is captured with a very simple thermodynamic model

- Combustion noise trends are well approximated by the simple model
- Noise reduction is independent of main injection rate shape changes
- Main injection vaporization cooling can further reduce combustion noise
- Further analysis shows the phasing of heat release events destructively alters the pressure trace's frequency content



Potential impact of this new noise control method

This combustion noise reduction enables improvements in the noise-soot tradeoff and may be applicable to other combustion modes

- For a given combustion noise level, soot emissions are significantly lower
  - Future optical studies will focus on combustion and soot formation / oxidation with close-coupled pilot injections
- The physics of the noise reduction mechanism can easily be integrated into model-based engine controls and reduce engine calibration effort
- Understanding this noise reduction may be helpful for noisy premixed combustion modes

Summary

Close-coupled pilot injections may be a valuable tool to reduce combustion noise, but more importantly to **break the traditional tradeoffs between combustion noise, NOx, soot, and efficiency**

New understanding of the close-coupled pilot-injection combustion-noise reduction mechanism should **help advanced combustion technologies reach the market**

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