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NOISE MADE BY DIRECT INJECTION DIESEL ENGINES AS THEY ACCELERATE

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INTRODUCTION

In urban driving conditions trucks and buses are repeatedly accelerated after periods of idling or light load running. Noise radiated from the engine surfaces of direct injection (DI) diesels under these conditions is known to exceed that obtained under steady speed test bed conditions.

Part of the increase in noise is due to the increase in fuelling from light load to full load. Frequently an increase in load is accompanied by an advance of injection timing as well as an increase in fuel per stroke, both of which increase combustion noise. These two effects are well understood and typical values for the noise increase are 0.5 dB(A)/^{o}CA and 0.15 dB(A)/mm^3 per stroke per litre capacity. However, the noise from an accelerating engine exceeds that from an engine running at steady speed with full fuelling by typically 3 dB(A). This paper analyses the reasons for this further increase in combustion noise and mechanical noise, and presents results showing the influence of air temperature and engine temperature.

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COMBUSTION NOISE

The contribution from vibration set up in the engine structure by cylinder pressure to total noise radiated by the engine surfaces is defined as combustion noise. Figure 1 compares the combustion noise of a six cylinder 5.8 litre engine during acceleration with the levels obtained during steady speed, full fuelling, running. "Hot" and "Cool" steady speed conditions were obtained by respectively running at full speed or idling before the test. Five rates of acceleration were used varying between 1 and 10 secs to accelerate from 1000 to 2800 revs/min. For accuracy in the acceleration results twenty recordings were averaged at each condition. To maintain consistency, a cycle, comprising acceleration followed by a one minute period of constant speed running, was repeated and the recordings made after oil, water and air inlet temperatures near the inlet valve had been stabilised from cycle to cycle. "Hot" accelerating conditions were obtained by running at 35% load, rated speed and "cool" conditions by idling.

When the engine was hot, combustion noise increased by only 1 to 2 dB(A) during acceleration, over equivalent steady speed levels, but when it was cool the increase was 4 to 6 dB(A). At steady speeds, when the engine was cool, combustion noise levels were 0.5 to 2 dB(A) higher than when the engine was hot.

The combustion noise levels obtained during acceleration are shown in the shaded areas in Fig. 1 and have a range of approximately 1 dB(A), for hot and cool states.

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This is small relative to the large increase between the slowest acceleration and steady speed results for the cool engine. This suggests that the effect is one with a long time constant. No such effect was found in the fuel injection equipment but thermal effects have similar time constants.

On the six cylinder engine there is a close relationship between combustion noise and ignition delay, covering both acceleration and steady speed results, at any given speed (Fig. 2a). Combustion noise depends partially upon the peak rate of pressure rise which is determined by the amount of fuel available to burn at ignition. Since variations in the rate of injection are insignificant, this is likely to be monotonically related to ignition delay. There is also a good correlation between combustion noise and inlet air temperature (Fig. 2b) for all tests at a given speed, which suggests that inlet air temperature has a dominating influence on length of ignition delay and hence combustion noise.

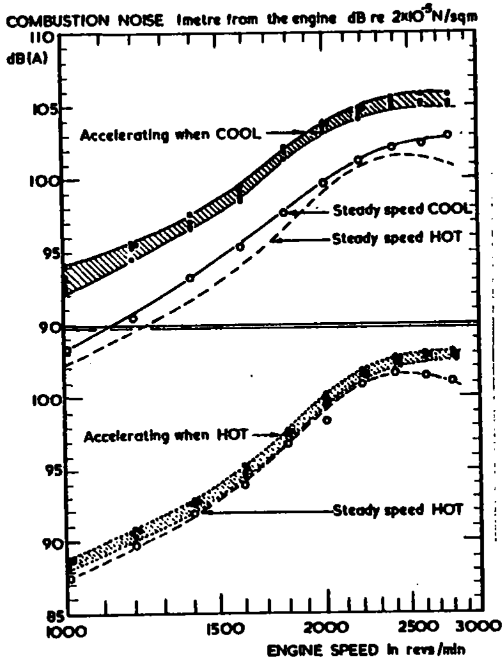

Fig. 1 - Effect of acceleration on combustion noise

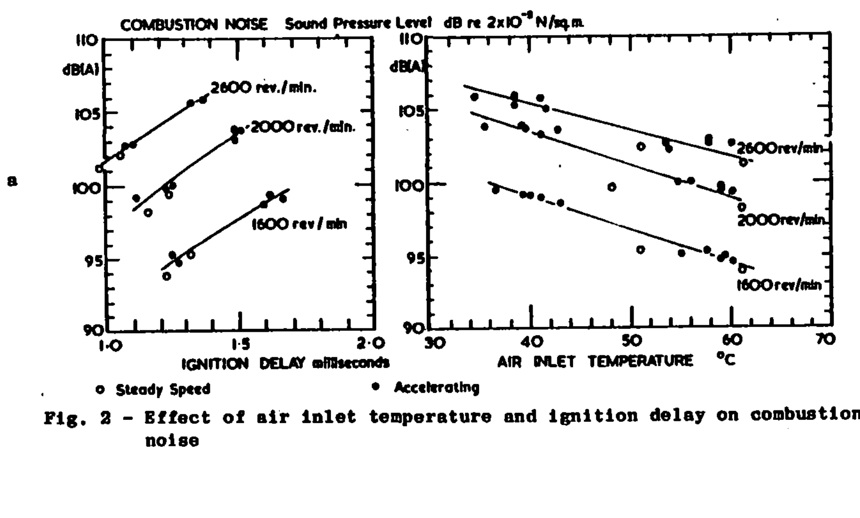

Fig. 2 - Effect of air inlet temperature and ignition delay on combustion noise

To establish the relative importance of air inlet and engine temperature, acceleration tests were performed on the three cylinder engine under three conditions:-

Air Inlet Temperature (Approx.)	27°C	23°C	15°C
Sump Oil Temperature (Approx.)	65°C	70°C	40°C

Steady state tests were run over a similar range of temperatures. A 'best fit' equation for combustion noise was derived from all these results based on engine speed, fuel per stroke, air inlet temperature and sump oil temperature.

$$Y = 2.0 + 28.2 \log_{10} \text{speed} + .137 \times \begin{matrix}\text{fuel per}\\ \text{stroke}\\ \text{in mm}^3\end{matrix} - .22 \times \begin{matrix}\text{air inlet}\\ \text{temp. in }^\circ\text{C}\end{matrix} - .029 \times \begin{matrix}\text{sump oil}\\ \text{temp. in }^\circ\text{C}\end{matrix} \quad (1)$$

where Y is the estimated combustion noise level. Fig. 3 compares Y with the measured values of combustion noise. For 80% of the tests Y lies within ±1.5 dB(A) of the measured value. The method of fuel measurement for individual cycles was not wholly satisfactory and errors of 10% were not uncommon. At full load this would give a 1 dB(A) error in Y. The steady speed and acceleration results separate at high speeds, probably because the temperatures used to calculate Y were those taken before each acceleration test and actual temperatures were likely to be higher as the engine speeds up. Within the limits of measurement error, equation (1) shows that all variations in combustion noise on the three cylinder engine can be accounted for by variations in speed, fuelling level and air and engine temperatures and that a change in oil temperature of about 7.5°C is necessary to have the same effect as a 1°C change in air inlet temperature. Combustion noise may be reduced during acceleration by intake air heating.

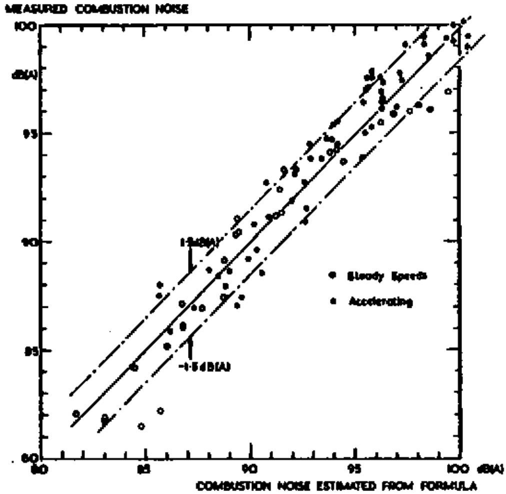

Fig. 3 - Correlation between the measured and predicted values of combustion noise

MECHANICAL NOISE

There is no suitable direct method of measuring mechanical noise so it was calculated as the difference between total and combustion noise. Fig. 4a shows the total mechanical noise of a four cylinder 3.9 litre engine at steady speed and accelerating for a range of air and engine temperatures. The mechanical noise from a cool accelerating engine is 5 to 7 dB(A) higher than that from a hot engine running at steady speed with the same air inlet temperatures. When the engine is accelerating the mechanical noise varies with both air inlet, and engine, temperatures which suggests that the increase in mechanical noise from an accelerating engine compared to steady speed running can be accounted for by temperature variations.

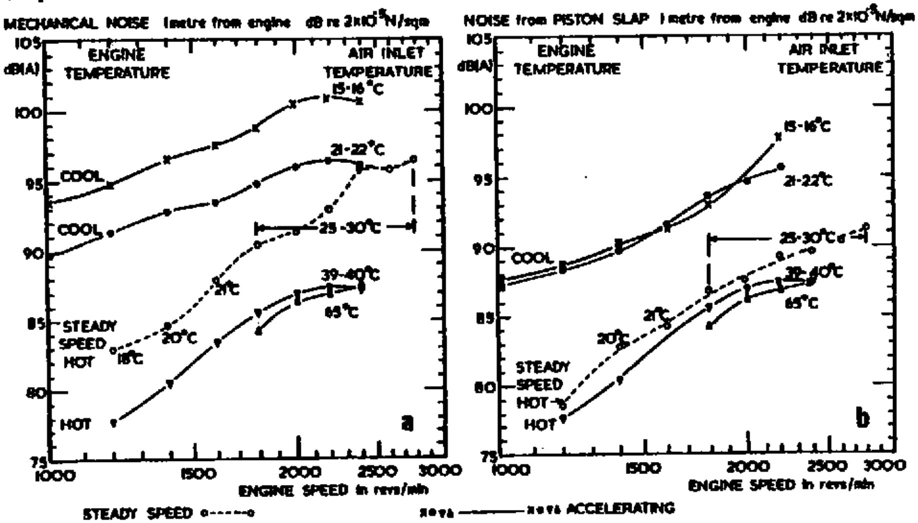

Fig. 4 - Effect of engine and air inlet temperatures on mechanical noise

Clearances between steel timing gears mounted in a mechanite casting are unlikely to change much with temperature but aluminium alloy pistons change diameter more with temperature than iron cylinder bores. The piston slap components of mechanical noise on the three cylinder engine was estimated from an accelerometer signal on the top deck of the water jacket opposite the largest slap. A transfer function between the accelerometer signal and external noise was obtained when combustion noise was suppressed by running with high cetane fuel and retarded timing. Fig. 4b shows the contribution to external noise from piston slap for the same conditions as those shown in Fig. 4a. When combustion noise is high the method of calculation is unsatisfactory as the accelerometer signal contains a significant component due to cylinder pressure. Despite this the results in Fig. 4b confirm that piston slap increases as engine temperature drops and show that it can be an important source of mechanical noise.

CONCLUSIONS

Temperatures are lower in an accelerating engine, after periods of idling of a minute or more, than in one running steadily. Combustion noise increases by up to 6 dB(A) during acceleration compared to full load steady speed conditions because: 1. Intake air is heated less by a cool manifold. 2. Air in the cylinder is heated less by combustion chamber surfaces. Mechanical noise increases during acceleration by up to 7 dB(A) because the clearance between the piston and the bore alters with engine temperature. Steel struts in the piston skirt would reduce this effect.