FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

HEAVY VEHICLE NOISE REDUCTION STUDY

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ABSTRACT

Misuse of engine compression brakes in urban areas is of concern, particularly when heavy vehicles have defective, missing or non-approved mufflers. While operators of heavy vehicles fitted with such auxiliary brakes state that they are used for safety reasons, previous studies suggest the reason for use of supplementary brakes is to lower costs by reducing brake lining wear.

As a large number of prime movers in NSW, and throughout Australia, are fitted with engine compression brakes, there is a need to pursue answers to anecdotal information concerning the operations of such vehicles.

The overall primary objectives of this research (funded by the Roads & Traffic Authority, NSW) were to:

- monitor and compare brake lining temperatures with manufacturer safety limits,
- evaluate the relationship between service brake wear and engine compression brake usage,
- address anecdotal evidence concerning adverse fuel consumption associated with 'standard' versus 'after-market' mufflers,
- investigate engine compression brake noise associated with standard versus after-market mufflers.

Other objectives include establishing relationships apparent in the measured data to help determine:

- the relative frequency and duration of engine compression braking on trips involving downhill runs, and
- whether a restriction on engine compression brakes is likely to adversely effect the wear life or reliability of a vehicle's service brakes.

1.0 INTRODUCTION

The scope of the research study was to instrument a commonly used heavy vehicle and gather dynamic data whilst the vehicle travelled on the road. This data was then to be analysed to establish apparent relationships between noise and various engine and brake parameters, such as engine speed, fuel consumption, deceleration, brake usage, brake lining temperatures and brake wear. The overall objective of the research was to evaluate the relationship between service brake temperatures, service brake wear and engine compression brake usage, together with addressing the anecdotal evidence concerning adverse fuel consumption associated with 'standard' versus 'after-market' mufflers. Other objectives include investigating engine compression brake noise associated with a 'standard' muffler and a common 'after-market' muffler; determining the relative frequency and duration of engine compression braking on both long distance and local trips having downhill runs; determining whether restrictions on engine compression brake usage is likely to adversely affect the wear life or reliability of the vehicle's service brakes; and determining the effect on fuel consumption of fitting an 'after-market' muffler.

2.0 ENGINE COMPRESSION BRAKES

Engine compression brakes (ECBs) are a secondary braking system fitted on heavy vehicles to provide assistance to the service brake, and can be especially useful during periods of steep descent. Engine compression brakes emit a distinctive sound when used and have been singled out as a major source of noise annoyance to residents living in close proximity to major roads.

The Jacobs brake, or Jake Brake®, is a device which, when energised, effectively converts a power producing diesel engine into a power absorbing air pump. The reverse thrust is provided by the compression of air in the combustion chamber as the engine's piston is forced upwards. As the piston approaches the top of the compression stroke the exhaust valves are opened allowing the air to be released. The exhausted air then finds its way through the exhaust manifold, pipe and muffler to the atmosphere.

Having exhausted the air, the piston returns down with the valve open, the effect being a net energy loss since the work done in compressing the charge is not returned during the expansion process.

The undesirable noise or "crackle" heard when the Jacobs brake is applied is associated with the release of multiple air "packets" as each cylinder in turn exhausts compressed air to the exhaust manifold in the manner described above.

3.0 PROJECT CONCEPT

3.1 THE TEST VEHICLE

A 1995 model Freightliner® semi-trailer (prime mover with trailer) heavy vehicle was used throughout the tests, incorporating a Detroit Diesel Series 60, 12.7 litre direct injection, 405 HP (302 kW) engine. The gross vehicle mass (GVM) is 23,500 kg. The vehicle is fitted standard with an engine compression brake (ECB) system by Jacobs® Vehicle Equipment Company.

To simulate a loaded heavy vehicle, the vehicle was fully laden with blue metal aggregate during all tests.

3.2 OVERVIEW

For this study the test vehicle was driven along two types of pre-defined and controlled routes: a set of local trips and a set of long haul trips. The test vehicle was then further tested during a normal work cycle (ie non-controlled haul trips).

Two straight-through type mufflers were tested. These were; a 'standard' original equipment manufacturer or OEM muffler (manufactured by Donaldson) and a commonly available 'after-market' muffler (supplied by Tubengineers Pty Ltd). A dynamometer test was used to determine the exhaust system back-pressure of each muffler, and the results were:

- OEM muffler — 6.4 kPa (or 1.9" Hg) @1900 rpm
- After-market muffler — 2.5 kPa (or 0.75" Hg) @1900 rpm

The mufflers incorporate a 127 mm inlet and outlet diameter with a 254 mm main body diameter, 1118 mm long. The maximum allowable exhaust system back-pressure is 10.1kPa (or 3" Hg) at 1900 rpm, as set by the test vehicle's engine manufacturer.

With respect to brake details, the following information was supplied by the vehicle's brake lining manufacturer:

- Optimum Durability Temperature Range: 121 - 177 ^{0}C
- Maximum Transient Temperature: 427 - 482 ^{0}C
- Acceptable Soak Temperature: 288 - 316 ^{0}C
- Safe Operating Temperature: 343 - 399 ^{0}C.

4.0 DYNAMIC DATA ACQUISITION

During all controlled local and long haul trips, and during the non-controlled haul trips, the test vehicle was fitted with the following instrumentation:

1. A commercially available after-market on-board computer management system.

2. A mobile satellite telephone system.

3. A specially developed data acquisition system comprising the following components:
   a) A serial interface for the satellite telephone system (see Photograph 1).
   b) A microphone (with wind sock) located 1 metre from the exhaust outlet connected to a noise logger and positioned behind the vehicle cabin to minimise aerodynamic influences (see Photograph 2).
   c) Six Type K thermocouple probes (one in each brake shoe on 6 different axles) and signal conditioner modules.

The following block diagram illustrates the general concept behind data acquisition pertinent to this study.

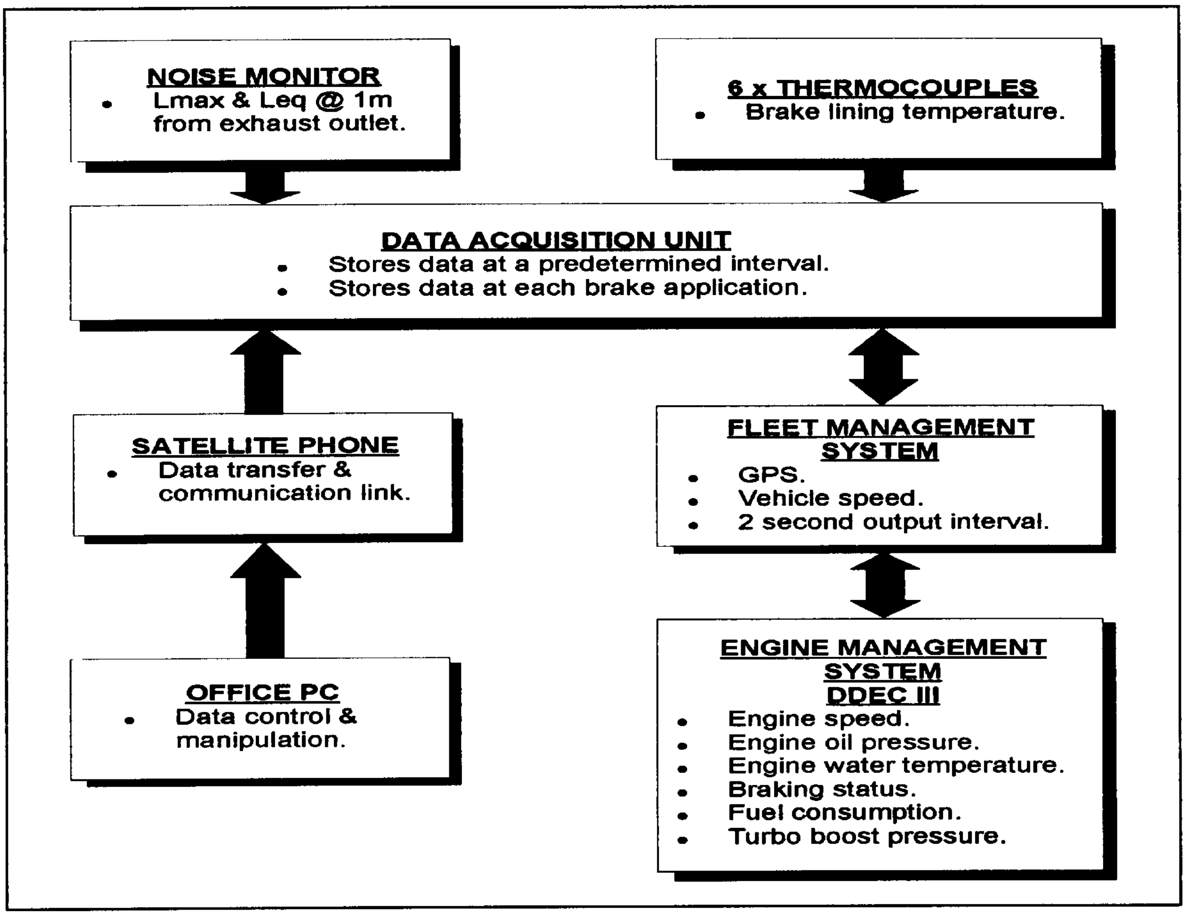
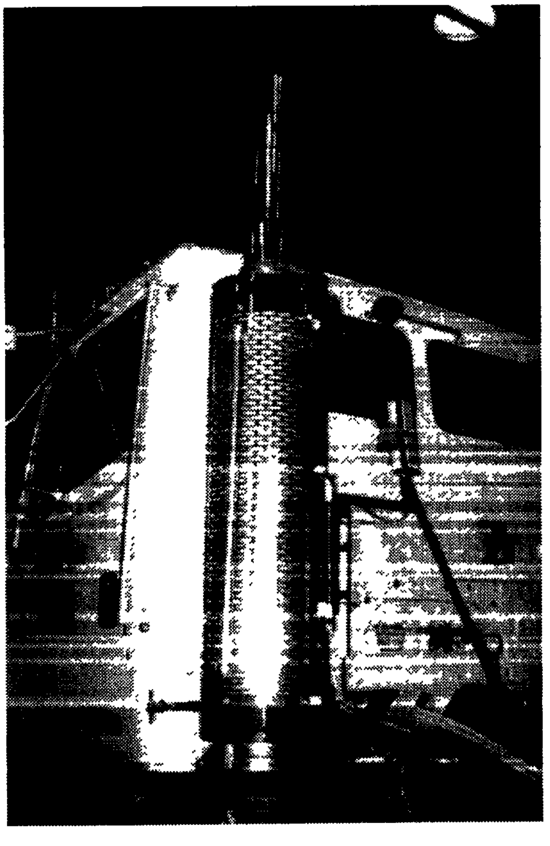


Figure 1: Dynamic Data Acquisition System



Photograph 1 (above): Mobile Satellite Phone with Data Acquisition unit inside vehicle cabin.

Photograph 2 (left): Heavy vehicle with noise monitor behind cabin.

5.0 CONTROLLED LOCAL HAUL TESTS

The local haul route for this part of the study is approximately 32 km long and extends from Boral Transport's maintenance service facility, at Greystanes Road, Greystanes, to Canterbury Velodrome near Tempe Station in Sydney, NSW.

5.1 PROCEDURE

For the controlled local haul tests, the test vehicle was driven on local metropolitan Sydney roads to and from the suburbs of Greystanes and Tempe, for a number of test configurations: with and without the use of the ECB and each of the two (OEM and After-market) mufflers fitted. Each configuration was tested twice. The test vehicle made 4 trips per day (two in the morning and two in the afternoon) over two days. Trip times and average speeds recorded varied depending on traffic conditions and were in the ranges of 1 hr+5mins to 1hr+30mins and 19 to 32km/h, respectively.

5.2 DISCUSSION OF RESULTS

5.2.1 Total Travel Times & Braking

The measured effects on total travel times between trips were not attributable to the use of the ECB and/or the use of different mufflers. No reliable correlation was evident between the type of muffler tested and each of the following variables: number of brake applications; total braking duration; total trip times and average speed of each trip. That is, travel time differences recorded for trips with and without the use of the ECB and with each of the two mufflers, appear unrelated to the vehicle configurations tested.

Similarly, measurable differences noted in the total number of brake applications and the total brake duration, appear inconsistent and unrelated to the use of service brakes, ECBs and the two mufflers tested.

Further to this, the results indicate that a change in the back-pressure of the test vehicle's exhaust system and the use of ECBs does not control the number and duration of brake applications, and also does not control total trip times on metropolitan roads. In general, road traffic conditions appear to be the controlling factor on travel times and braking.

5.2.2 Brake Lining Temperatures

The maximum recorded brake lining temperature during these tests was 237 ^{0}C. The short duration over which this temperature was recorded, renders it a transient temperature event. The highest average temperature recorded was 230 ^{0}C.

From the results discussed above, it is shown that brake lining temperatures measured during the local haul tests were always below safe operation limits, as specified by the brake lining manufacturer.

5.2.3 Mufflers & Noise

Overall, the OEM muffler outperformed the after-market muffler during tests where the ECB was used. This was generally by a noise factor of 5-7dB(A) in terms of L_{eq} and 5-10dB(A) in terms of L_{max} for all recorded engine speeds.

However, as expected noise emissions from the two mufflers, during tests where only the service brake was used, were similar [ie within 1-2dB(A)] for all recorded engine speeds.

These results are consistent with expectations formed following the results obtained from the dynamometer back-pressure tests.

6.0 CONTROLLED LONG HAUL TESTS

Long haul tests were conducted to obtain an insight into activities relating to the way in which heavy vehicles are operated whilst travelling on long and hilly roads in NSW.

6.1 THE ROUTE

The route selected for the long haul test extends from Boral Transport's maintenance service facility, located at Greystanes Road, Greystanes, then to Wootton in NSW (located approximately 250 km north of Sydney), and then back to Boral's facility in Greystanes via Glenbrook (located in the outer western suburbs of NSW). Major roads traversed include the F3, Pacific Hwy and M4 motorway.

6.2 PROCEDURE

For the controlled long haul tests, various vehicle configurations were tested: ie with and without the use of the vehicle's ECB; and with each of the two (OEM and After-market) mufflers. The tests were conducted over eight days, with each configuration tested twice. Each test day involved a return trip between Greystanes and Wootton. On test days when the ECB was used, the driver was instructed to use all 6 engine cylinders for engine braking.

To monitor brake lining wear, six brake shoes on the test vehicle were selected and their weight was measured at the start and finish of the testing and at milestone points between testing.

6.3 DISCUSSION OF RESULTS

6.3.1 Brake Use

The total number of brake applications and the total duration of service brake use did <u>not</u> necessarily increase when the ECB was not used over the study journey. Also no consistent trend was evident in the results when brake usage was analysed in terms of muffler type.

6.3.2 Road Travel Time

Similarly, there is no apparent correlation in the test results to indicate either a reduction or an increase in road travel time for the journey when ECB was used or not.

6.3.3 Mufflers & Fuel

Based on average data, the OEM muffler consistently provided a better fuel consumption rate than the after-market muffler. However, the OEM muffler does not consistently outperform the after-market muffler on an individual daily basis.

In general, the test results show, that fuel consumption does not necessarily increase with the use of a muffler which has higher back-pressure. It is noted however, that the back-pressures for the mufflers tested were both below the engine manufacturer's maximum limit. Nevertheless, this result is contrary to anecdotal evidence which suggests that mufflers with higher back-pressure tend to significantly increase fuel consumption.

6.3.4 Mufflers & Noise

Overall, the OEM muffler outperformed the after-market muffler during tests where the ECB was used. This was generally by a noise factor of 5-6dB(A) in terms of L_{eq} and approximately 6dB(A) in terms of L_{max} for all recorded engine speeds.

However, noise emission from the two mufflers were similar, during tests where only the service brake was used. This outcome is consistent with the results of the dynamometer back-pressure tests and those of the local haul tests (see Section 5).

During tests where only service braking was permitted, the typical difference between the average L_{eq} and average L_{max} noise levels was 6 and 7dB(A) for the after-market and OEM mufflers respectively. However, during ECB tests with the after-market muffler this difference increases to 10dB(A).

6.3.5 Brake Lining Wear

In an attempt to quantify the effect the ECB has on brake lining wear, brake lining mass reductions were measured. Brake lining mass reduction data was analysed in detail and used to indicate the amount of lining wear. Brake shoes on both drive axles of the prime mover showed most loss in lining material of all six shoes tested over the entire duration of the controlled long haul tests.

Results of this study suggest that the use of the ECB does <u>not</u> reduce service brake usage. However, it is clear that the use of ECBs <u>do</u> reduce brake lining wear during long journeys. This indicates less service brake pressure is applied when braking is assisted by the ECB, hence the reduction of brake lining wear. Overall, it was shown that brake lining material can wear between <u>2 and 3.6 times more</u> if the ECB was not used to assist braking.

6.3.6 Brake Lining Temperatures

The maximum recorded brake lining temperature during these tests was 286 ^{0}C, and was exhibited by the rear drive axle on the prime mover. The duration of this temperature reading renders it as a transient temperature. The highest average temperature recorded was 151 ^{0}C.

From the results discussed above, it is clear that brake lining temperatures for all tests were always well within the safe operating temperature limits specified by the manufacturer.

7.0 NON-CONTROLLED HAUL TESTS

To gain further insight into the every day activities carried out by the test vehicle, data was gathered whilst the test vehicle performed its daily duties under non-controlled conditions.

The test vehicle was placed into its normal routine and stationed at its normal depot. The vehicle had its OEM muffler fitted for the entire non-controlled monitoring and the driver operated the ECB as normal. It should be noted that during all tests performed throughout this study, the same driver was utilised.

7.1 JOURNEYS TRAVELLED

The vehicle was monitored for five days while traversing various routes within metropolitan Sydney during this part of the study. During this test period, it also travelled to Wollongong and back via Mt Ousley (a known hilly route).

7.2 DISCUSSION OF RESULTS

The maximum recorded brake lining temperature during these tests was 180 ^{0}C. The very short duration in which this temperature was recorded, renders it a transient temperature.

From the results discussed above, it is clear that brake lining temperatures for all tests were always within the safety limits specified by the manufacturer.

8.0 CONCLUSION

Over the entire study, a negligible difference in the fuel consumption rate was recorded between the two mufflers tested despite differences in muffler back-pressure and noise reduction performance.

The restriction on the use of engine compression brake usage produced higher brake lining temperatures, but such temperatures were significantly below the safe operating temperature limits specified by the brake manufacturer. In fact, the highest recorded transient temperature for any given brake lining, for all tests performed, was more than 55^{0}C below the manufacturer's safe operating temperature range.

Use of the ECB can reduce brake lining wear by up to 3.6 times, but no correlation was evident between travel times and ECB usage.

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