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REGULATION OF HEAVY VEHICLE ENGINE BRAKE NOISE IN AUSTRALIA

Jeffrey Parnell[1] and Bruce Dowdell[2]

[1]Manager Noise Strategies, NSW Dept. of Environment and Climate Change,
PO Box A290 Sydney South, NSW 1232, Australia.
[2]Manager Vehicle Emissions Management Program, NSW Roads and Traffic Authority
260 Elizabeth St, Surry Hills, NSW 2010, Australia.
jeff.parnell@environment.nsw.gov.au

Abstract

Engine brake noise is a long standing issue both in Australia and overseas with it being generally accepted that it is the character of this noise rather than its loudness that leads to most complaints. To date, the majority of the investigation and research into engine brake noise, and possible solutions, has been commissioned by Australian road agencies.There is now sufficient research in Australia, and agreement from all stakeholders, that action must be taken to provide a foundation for in-service regulations to control excessive engine brake noise. This paper describes the process being followed to achieve scientific acceptance of a method to identify excessively noisy engine brakes and its passage towards regulation in Australia. Steps in progressing this method have included developing a Modulated RMS algorithm that was capable of:

- discriminating between annoying and less annoying engine brake noise;
- discriminating between muffler effectiveness;
- correlating well with the subjective response of panel members to engine brake noise;
- being coded in software so that large amounts of roadside noise data can rapidly analysed.

1. INTRODUCTION

Excessive noise from heavy vehicles applying engine compression brakes has long been a major source of community complaint, yet has remained largely unregulated in either Australia or overseas. Engine brakes are auxiliary retarders that help to slow heavy vehicles by causing the engine to act as a compressor. The compressed air is released in short bursts which cause the characteristic engine brake 'bark'. It is mostly the nature of this noise, rather than its loudness, that causes complaints. On long downhill grades the use of engine brakes can improve safety by reducing the load on the brakes and reduce the risk of them overheating [1]. Use of engine brakes elsewhere provides no safety benefit but does provide an economic benefit to operators through reduced brake wear.

To date there has been no definition of what constitutes excessive engine brake noise, nor has there been assessment criteria, test methods or enforcement guidelines. This paper describes the process being followed to achieve scientific acceptance of a method to identify excessively noisy engine brakes and its passage towards regulation in Australia.

1.1 Control of Vehicle Noise in Australia

The Commonwealth Government sets standards for new vehicles in Australia through Australian Design Rules (ADRs) which are based on Economic Commission for Europe (ECE) Regulations. These Regulations limit the drive by noise of vehicles but do not explicitly control engine brake noise. The National Transport Commission (NTC) is responsible for the development of in-service regulations in Australia. These regulations currently include a stationary exhaust noise test as an in-service test for muffler effectiveness although this does not specifically address engine brake noise.

Over the last decade most transport regulators in Australia have attempted to address the engine brake problem by both non regulatory and regulatory approaches [2] (including use of Offensive Noise provisions) however these efforts have been largely ineffective.

2. DEVELOPMENT OF AN ENGINE BRAKE STANDARD

The NTC commissioned a number of studies to examine the feasibility of regulating engine brake noise [1], [3] and [4] which concluded that an in-service engine brake noise standard was feasible both in terms of meeting both safety concerns and legislative requirements. Additionally Sonus [5] identified the modulation of exhaust noise caused by the engine brake as the factor that caused annoyance and nominated a 'Rise and Fall' algorithm defined as a minimum of 5 modulations of 7 dB(A) over a 0.5 s period of the pass-by as being a possible measure. Acoustic Technologies (AT) undertook further analysis with a view to establishing an algorithm that could be readily used in instrumental identification of unacceptable engine brake noise [6]. Their conclusion concurred with Vipac [7] that RMS is a good predictor of engine brake annoyance and proposed a modulated RMS algorithm purported to be superior to the 'Rise and Fall' method in identifying and quantifying engine brake noise.

The NTC released an Engine Brake Noise Draft Regulatory Impact Statement in 2006 [2] which recommended a preferred option based on a practical and enforceable in-service engine brake noise test. It was the intention of the NTC to use the RMS test in the regulations but before doing so it was necessary to confirm that the RMS algorithm was able to:

- Discriminate between "acceptable" and "unacceptable" engine brake noise.
- Discriminate between systems that effectively muffled engine brake noise and those that don't.
- Be set at a level that would provide some relief to the community near heavy vehicle routes.

2.1 Ability of RMS to Discriminate

The capacity of the RMS method to discriminate between acceptable and unacceptable engine brake noise was established by:

- a review of the literature;
- a comparison of RMS against psychoacoustic measures;
- subjective panel testing.

2.1.1 Literature review

The majority of the investigation and research into the nature of engine brake noise, and possible solutions, has been commissioned by Australian road agencies. The use of the modulation characteristic as a way to identify engine brake noise annoyance is supported by previous studies commissioned by Austroads [7] and [8] which concluded that:

- A-weighted peak engine brake noise level was not an adequate predictor for assessing the changes in noise emission due to brake operation; and
- the annoyance due to engine compression brakes was the result of a change in the spectral characteristic of the noise emission rather than due to an increase in the overall A-weighted peak noise level.

Additionally, Fidell and Horonjeff [9] had conducted psychoacoustic experiments in which people judged the relative annoyance of engine brake noise recordings made during field measurements. They concluded that:

- effective mufflers can reduce the impulsive effect of engine brake noise;
- a correction (to the maximum A-weighted sound pressure level) based on crest factor (peak RMS ratios) greatly reduced the variability of annoyance judgements of highly impulsive engine brake signals.

2.1.2 Comparison with psychoacoustic measures

A range of acoustic measures and psychoacoustic measures were identified. Each measure was used to assess a range of engine brake noise recordings and the correlation between the different measures was assessed. It was found that there was good correlation between a number of these measures but that established psychoacoustic descriptors such as Zwicker's Unbiased Annoyance [10] were unable to provide the required differentiation between the range of samples analysed. It was also found that the good correlations were largely as a result of reference to loudness, which is a common and critical element in the calculation of most measures.

As it is known that the annoyance caused by engine brakes is not necessarily related to loudness, it was concluded that a methodology for subjectively ranking the engine brake recordings and correlating against a new type of descriptor would be required. The use of psychoacoustic and other measures as a surrogate for community perception was not sufficient.

2.1.3 Subjective panel testing

The UNSW Injury Risk Management Research Centre was commissioned to provide advice, including a methodology for using a panel of community members to subjectively analyse a range of recorded engine brakes applications. In summary, a selection of engine brake recordings of 5 s duration were used as noise stimuli and replayed to a panel under controlled conditions. To reduce the influence of loudness on the panellists judgement of noise character, the methodology was modified by normalising the L_{10} of the replayed recordings to a standard 65 dB(A).

Following a modified set of instructions employed by Berry [11] the subjective panel assessed a set of seven different engine brake recordings against the criterion of "How much would the noise bother, disturb, or annoy you if you heard it regularly inside your home?" To facilitate analysis, the answers were given a numerical score and the mean determined for each engine brake noise.

Thirty three panellists were surveyed in eight sessions. It was found that there was a good relationship between the RMS value and the mean subjective rating with a $R^2 = 0.896$ as shown on Figure 1. It was therefore concluded that the RMS algorithm could effectively establish the "acceptability" of different engine brake recordings to the community.

The authors expect to release a more detailed report on the methodology used and the findings of the panel testing in the near future.

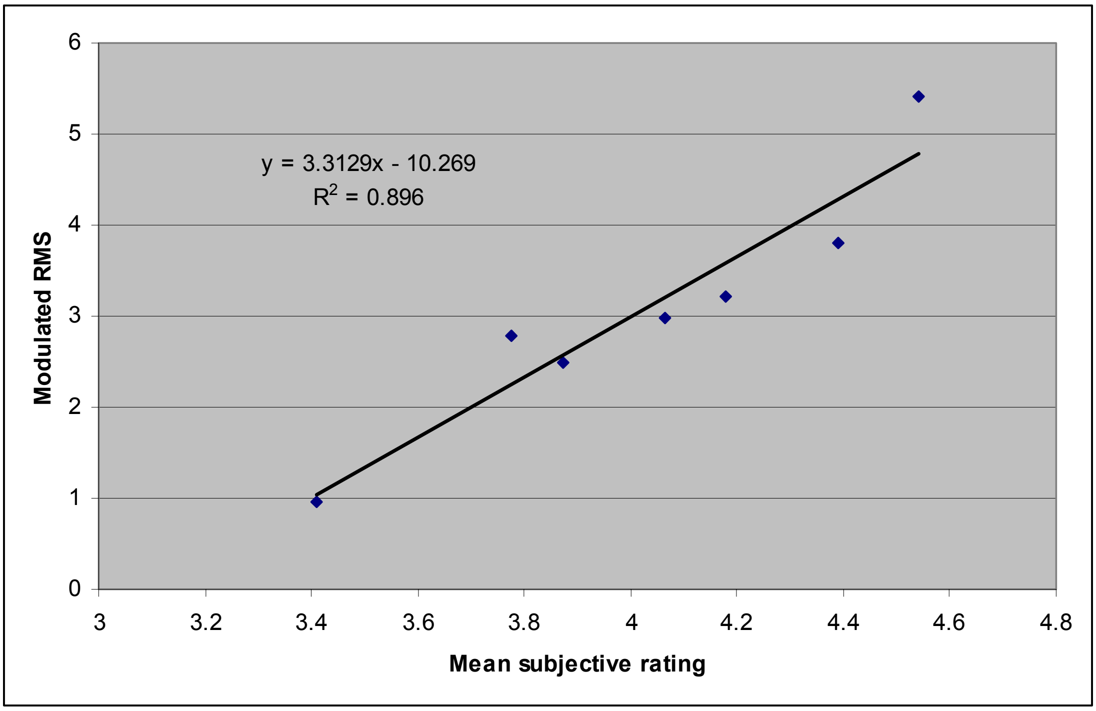

Figure 1: Relationship between subjective test results and RMS values

3. MODULATED RMS ALGORITHM

Before any roadside nosie data was analysed, adaptations of the RMS algorithm were trialled to assess the sensitivity of results to variations in the Modulated RMS specification. These adaptations included variations to the bandpass filter and time averaging constant as well as examination of the influence of signal duration and sampling rate. It was found that very little modification to the original RMS algorithm was necessary to optimise it. The final version of the RMS algorithm was coded to allow rapid analysis of large amounts of data. All of the analysis reported in this paper was conducted with the coded algorithm.

A further advantage of the RMS measure is that it is largely independent of absolute sound pressure levels, thereby allowing some latitude in locating measurement equipment, and the need to measure and account for the distance between source and receptor.

4. MUFFLER EFFECTIVENESS

A test program was conducted on two occasions at Schofields Airstrip in north western Sydney to establish the ability of existing heavy vehicles to use engine brakes and to meet the any future standard based on the RMS algorithm. A prime mover, typical of the type used in articulated vehicles, was driven past a test point with the engine brake operating. This test was repeated a number of times with a range of muffler designs including a straight pipe (no muffler) whilst the noise events were recorded as wave files. The noise under acceleration was also measured for each exhaust system. These recordings were then analysed to establish their RMS level.

Figure 2 shows that the RMS values varied from about 1 to 7. The acceleration test results were all at the bottom of the scale with a maximum value of 1.6 being recorded. The "straight pipe" results were at the top of the scale, along with the results of a muffler that was perceived by observers during testing as being the least effective system. The systems that were perceived as being most effective (a specialist muffler designed to minimize engine brake noise and a muffler fitted with an oxidation catalyst) were at the lower end of the range next to the acceleration readings.

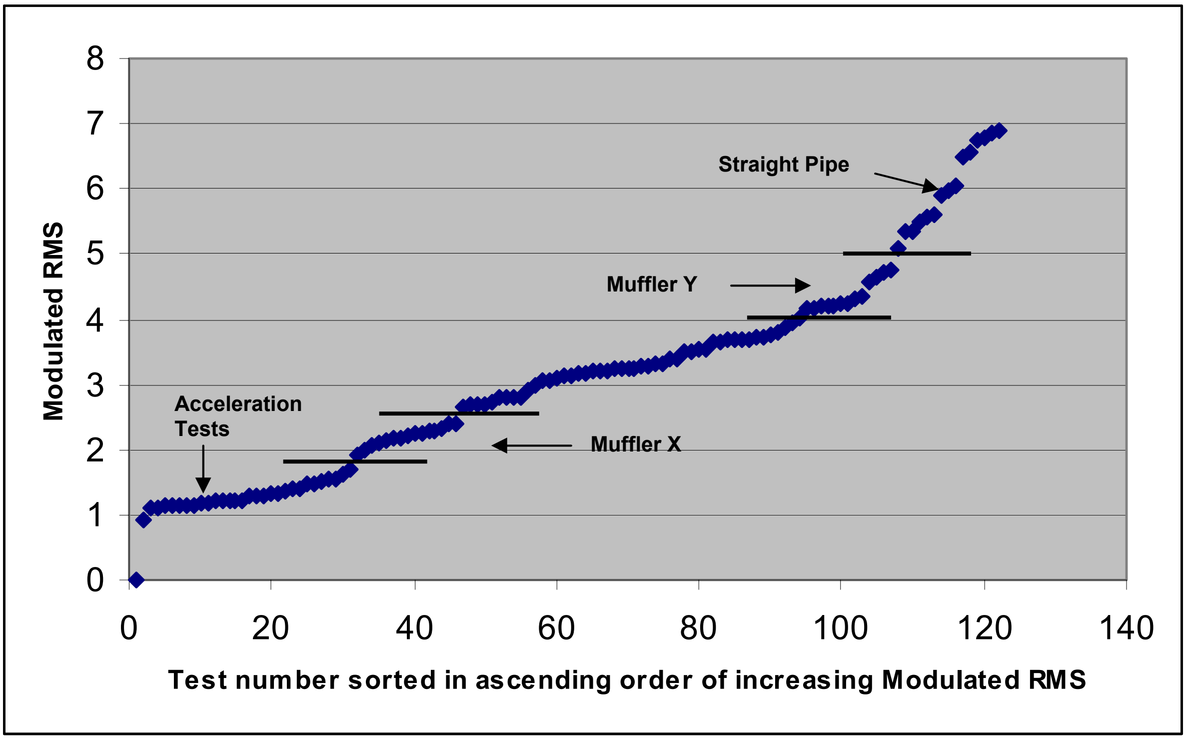

Figure 2: Relationship between RMS values and muffler design

From this testing it was concluded that the Modulated RMS algorithm could adequately discriminate between systems with varying levels of performance at muffling engine brake noise. Furthermore the difference in noise signals identified by the Modulated RMS algorithm can also be easily visualised. Figures 3 and 4 show the results of a qualitative analysis of two engine brake recordings using audio analysis software. The low RMS noise is shown in Figure 3 followed by a high RMS example displaying the distinctive fishbone appearance of a high RMS signal in Figure 4.

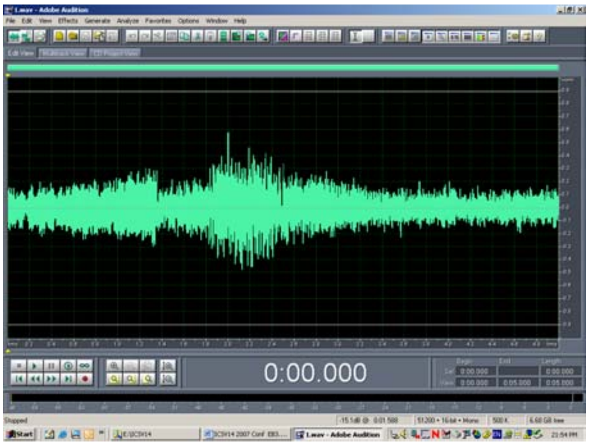

Figure 3. Nominally acceptable Engine Brake
RMS = 1.74

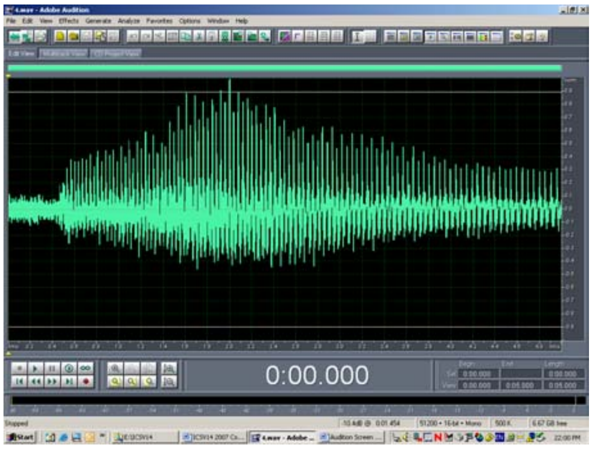

Figure 4. Unacceptable Engine Brake
RMS = 4.73

In particular Figure 4 graphically depicts the greater spread of acoustic energy over the amplitude and the distinct modulation characteristics of the signal. Further detailed analysis of this data is expected to be reported by the authors in the near future.

5. ASSESSMENT OF ROADSIDE NOISE LEVELS

Recent technological advances in acoustic equipment have allowed complex analysis of recorded wave files to millisecond intervals and detailed frequency spectra analysis to be undertaken relatively easily. Combining the use of readily available commercial software with specifically designed equipment such as the Noise Camera developed by Acoustic Research Laboratories (ARL) for the South Australian Department of Transport, Energy and Infrastructure (SA DTEI) and described in detail by Klos [12], has created for the first time the potential to identify and quantify the noise signature of the operation of an engine brake.

The availability of this Noise Camera system has allowed the unattended gathering of significant amounts of data. To date, large amounts of roadside noise data have been collected from sites in Victoria, South Australia and NSW both by the noise camera and through unattended monitoring. It is anticipated that such a data collection program will continue. The availability of this large data set and an efficient means of analysing it means that an informed judgement is possible when establishing a limit for engine brake noise. It will also allow for the efficient monitoring of the implementation of regulations and any associated education campaigns. This monitoring will make it easier to justify any changes that may be made to the standard or to regulations in future years.

Figure 5 is an example of the data that can be analysed by such a process. It shows the results of around 3,000 recordings of engine brake noise recorded by a noise camera system located at Mt Ousley on the F6 Southern Freeway near Wollongong, NSW. The system was set to trigger at a minimum of “2” RMS.

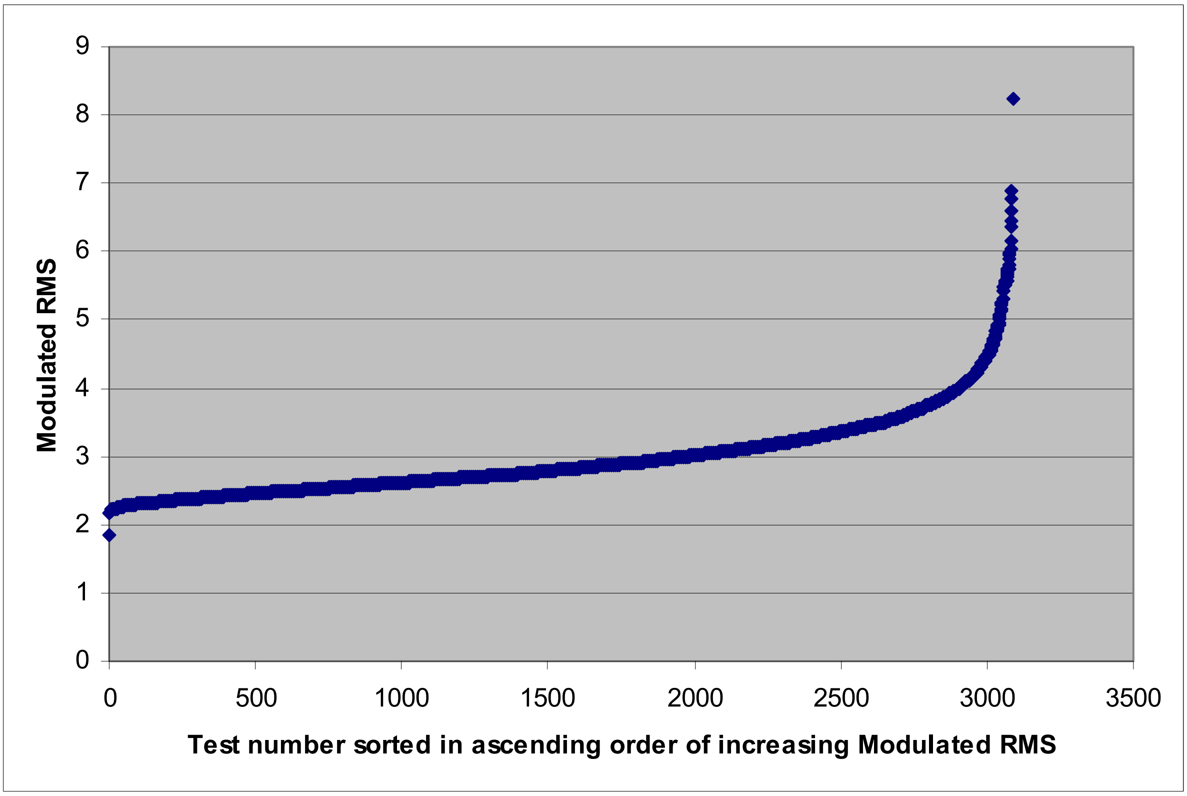

Figure 5: RMS roadside data from Mt Ousley Wollongong NSW.

6. FUTURE WORK

6.1 Improve Muffler Performance

During the investigation it became apparent that in general muffler design for heavy vehicles is based on a trial and error approach and that there has been very little technological advancement. Improved muffler design was identified as an area with significant potential for reducing the annoying characteristics of engine brake noise.

Further investigation is being undertaken by UNSW to model the performance of a range of heavy vehicle mufflers with an objective of optimising their performance in reducing the annoying characteristics of engine brake noise.

6.2 Develop Engine Brake Noise Regulations

The NTC released the Engine Brake Noise Draft Regulatory Impact Statement in June 2006 for public comment. The draft National In-Service Engine Brake Noise Test Procedures for Heavy Vehicles incorporating the Modulated RMS algorithm is now in the process of being finalised for release based on work by the authors.

It is expected that the limit on engine brake noise will be made under the Road Transport Reform (Vehicles and Traffic) Act 1993 and will amend the Australian Vehicle Standards Rules 1999, which were made as regulations under that Act.

7. CONCLUSIONS

The Modulated RMS algorithm, developed for the NTC by Acoustic Technologies and refined by the authors, has been shown to be capable of:

a. effectively discriminating between engine brake noise that is annoying and noise that is less annoying;
b. discriminating between mufflers that are effective at muffling engine brake noise and those that are less effective;
c. correlating well with the subjective response of panel members to engine brake noise;
d. being coded in software so that large amounts of roadside noise data can rapidly analysed to assist in developing suitable standards for engine brake noise.

The SA DTEI noise camera (and other systems in development) can be used with the Modulated RMS algorithm to identify trucks with unacceptable levels of engine brake noise.

ACKNOWLEDGEMENTS

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