Exhaust noise control case study for 2800 class locomotive

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ABSTRACT

In NSW, Environment Protection Authority Licences for railway systems activities define noise limits for locomotives applying for permission to operate on the network. This paper describes a case study involving one particular locomotive class (the 2800 class) that had been refused permission to operate in NSW on the basis of low-frequency noise emissions. This paper describes investigations into the locomotive noise and muffler performance, and the steps taken to re-design the muffler to optimise its performance. The objective was to reduce low frequency noise emissions to comply with the EPA licence requirements. The project achieved a reduction in overall L_{max} noise levels of up to 5 dB in the highest engine notch settings. The low frequency benefit (in the 25 Hz and 50 Hz one-third octave frequency bands) was of the order of 8 dB. The locomotive class has subsequently been granted approval to operate in NSW.

Keywords: Muffler, Locomotive, Noise I-INCE Classification of Subjects Number(s): 13.4.1, 34

1. INTRODUCTION

In recent years, Australia has seen considerable investment in rail infrastructure, and more growth is needed to meet demand for sustainable transport of freight within urban areas and across the country. Noise impacts on communities near rail lines are often a constraint on freight infrastructure development. With increasing numbers of freight movements, increasing attention is focussed on the noise emissions of rolling stock. The noise emissions of locomotives currently operating in New South Wales (NSW) vary widely across locomotive classes.

In NSW, Environment Protection Licences (EPLs) for railway systems activities require Environment Protection Authority (EPA) approval prior to the operation of new classes or types of locomotive (or locomotives that have been substantially modified) on the NSW rail network. The general noise limits for stationary and in-service operating conditions as defined in the EPL Conditions are shown in Table 1, from reference (1).

These noise limits are not applicable to locomotives already operating on the NSW rail network. However, it is possible that noise emissions from existing locomotives may be targeted in future. In requiring an audit of the noise performance of locomotives on the network, ARTC's EPL 3142 (1) states:

"Almost a third of all rail noise complaints received by the Environment Protection Authority (EPA) between 2007 and 2011 were generated by pass by noise from locomotives. For this reason the EPA considers the ongoing monitoring and management of locomotive noise to be a critical component of environmental regulation on the NSW rail network."

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Table 1 – General noise limits for locomotives

Operating condition	Speed and Location of Measurement	Noise Limit*
Idle with compressor radiator fans and air conditioning operating at maximum load occurring at idle.	Stationary 15 m contour	70 dB(A) $_{Max}$
All other throttle settings under self-load with compressor radiator fans and air conditioning operating.	Stationary 15 m contour	87 dB(A) $_{Max}$ 95 dB Linear $_{Max}$
All service conditions	As per Australian Standard AS2377-2002 (2) except as otherwise approved by the EPA	87 dB(A) $_{Max}$ 95 dB Linear $_{Max}$

* Noise limit at a microphone height of 1.5 m above ground level

2. PROJECT BACKGROUND

Aurizon (formerly QR National) initially applied to operate the 2800 class locomotives in NSW in 2006. This initial application was made for the locomotive using the original (as-supplied) transition muffler and coffin muffler (see section 2.1). At this time, permission to operate in NSW was refused on the basis of noise emissions. Subsequently, modifications were made to the transition muffler, improving its performance, and Aurizon again applied to the EPA for permission to operate this class in early 2012.

The locomotive was again refused permission to operate by the NSW EPA on the basis of low-frequency noise emissions. Noise type testing of Locomotive 2815 indicated that while the A-weighted maximum noise levels met the EPA requirements, the linear maximum noise levels exceeded the L_{max} noise level criterion of 95 dB from Notch 5 through to Notch 8, being 96 dB, 98 dB, 98 dB and 99 dB respectively. The 50 Hz frequency band was observed to be almost entirely responsible for the overall linear noise levels. Overall, the locomotive noise emissions were 4 dB above the EPA target level. SLR Consulting was engaged by Aurizon to investigate the cause of the exceedances and to re-design the muffler, with the objective of complying with the NSW EPA requirements.

Specific terminology relating to mufflers is used throughout this paper. Detailed explanations of the terms can be found in Bowden and Glad (3) as well as Davis et al (4). The following sections provide a brief summary of each term in order to assist those unfamiliar with the terminology.

2.1 Muffler nomenclature

The 2800 class locomotive employs a two-stage muffler incorporating a transition muffler and a coffin muffler. The transition muffler is named because in this muffler, the exhaust flow is in transition from the turbocharger of the locomotive into the coffin muffler.

The coffin muffler is named as such due to its resemblance to a coffin in both size and shape. The coffin muffler forms the final stage of the exhaust system.

2.2 Expansion chamber

An expansion chamber is a pipe or duct with a larger cross-sectional area than the pipe or duct directly upstream. At the juncture of the expansion chamber where the cross-sectional area changes, part of the sound incident on the juncture will be transmitted downstream, and the remaining parts will be reflected back upstream.

An expansion chamber effectively acts as a low-pass filter, having a cut-off frequency that is governed by multiple parameters, particularly the length of the chamber and the difference in cross-sectional area at the juncture (the ‘expansion ratio’).

2.3 Quarter wave chamber

A quarter wave chamber is a muffler component designed to attenuate a narrow-band frequency component of the overall noise. The quarter wave chamber, as the name suggests, is a chamber of a length that is one quarter of the wavelength that is desired to be attenuated. The basic principle is that when the wave is reflected back into the main duct, it will be one half of one wavelength out of phase with the sound in the duct, and will effectively eliminate the resultant noise at that narrow-band frequency. A detailed explanation of quarter wave chambers can also be found in Craig and Howard (5).

2.4 Definitions of muffler performance

There are three measures that are commonly used to quantify the noise reduction of a muffler: transmission loss, insertion loss and sound reduction.

Transmission loss can be summarised as the logarithmic ratio between the sound power transmitted into the muffler from upstream (W_u) and the sound power transmitted out of the muffler downstream (W_d), where there is a reflection-free termination on the downstream side, as shown in Equation 1. The absence of an ideal reflection-free termination generally makes the transmission loss a difficult property to measure.

$$Transmission\ Loss = 10\log(W_u / W_d) \quad (1)$$

When comparing a muffler prototype design to a reference design, the ratio of the sound pressure level measured downstream of both mufflers is known as the insertion loss. In Equation 2, P_m is the measured sound pressure level downstream from the prototype muffler and P_r is the measured sound pressure level downstream from the reference muffler. Insertion loss is easy to measure, provided the upstream source can be controlled.

$$Insertion\ Loss = 20\log(P_m / P_r) \quad (2)$$

The Sound Reduction is simply the ratio between the measured sound pressure levels upstream (P_u) and downstream of the muffler (P_d) as shown in Equation 3. The Sound Reduction depends heavily on the measurement positions and also requires control of the upstream source.

$$Sound\ Reduction = 20\log(P_u / P_d) \quad (3)$$

3. SOURCE INVESTIGATIONS

3.1 Sound intensity testing

Sound intensity testing of Locomotive 2815 was undertaken to establish the sources of noise across the frequency range. This testing confirmed that the exhaust outlet was the source of the noise in the 50 Hz one-third octave band, as shown in Figure 1.

3.2 Investigation of muffler system performance

To understand the performance of the various muffler elements, testing was undertaken of noise emissions at 3 m from the exhaust outlet (at outlet height, see Figure 2) for three scenarios:

1. The original transition muffler with the original coffin muffler
2. The modified transition muffler with the original coffin muffler
3. The transition muffler removed (ie, no transition or coffin muffler)

On the basis of this testing, it was concluded that the original combination of transition and coffin muffler resulted in particularly poor performance at frequencies below 100 Hz, with noise emissions in several frequency bands (including 50 Hz) amplified rather than attenuated. The modified transition in combination with the original coffin muffler was an improvement over the original system; however performance remained poor at low frequencies. The overall linear transmission loss of the system was observed to be 7 dB. In the critical 50 Hz band, the muffler system provided no attenuation.

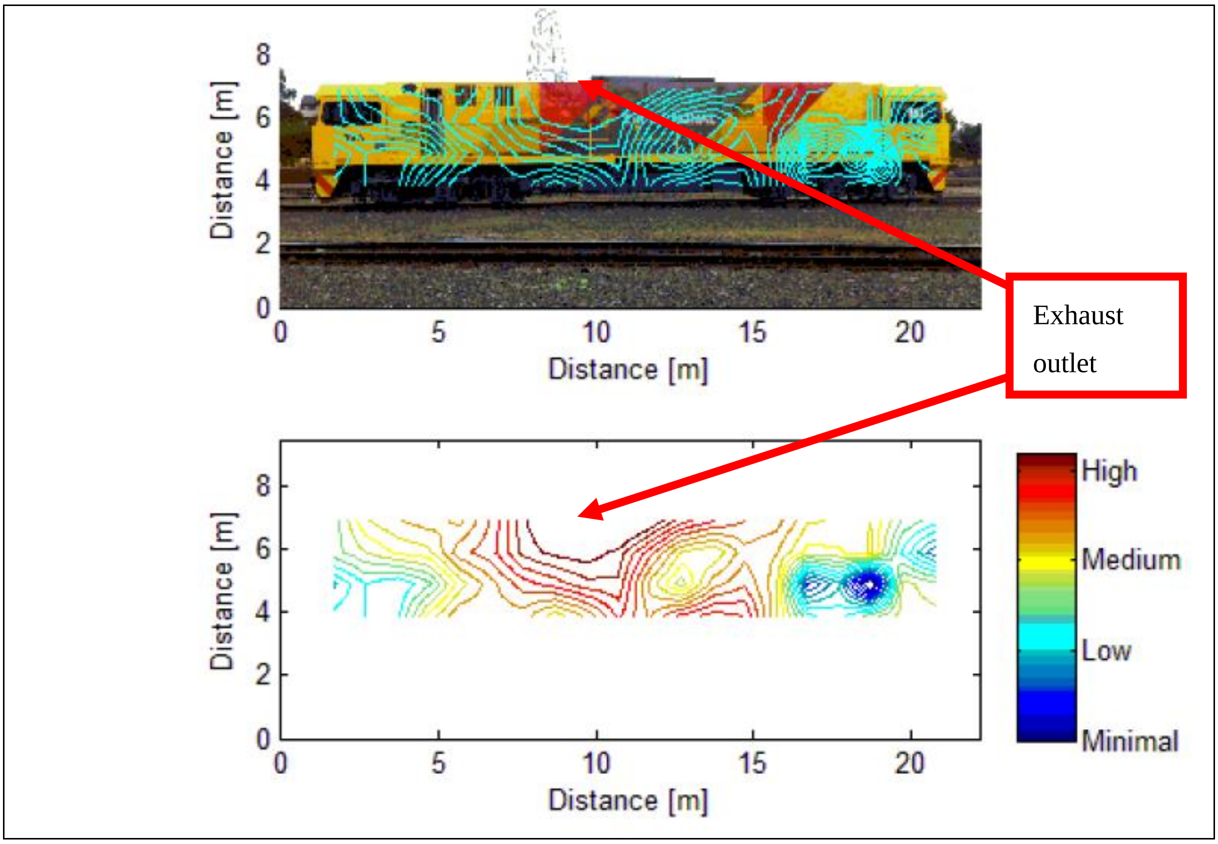

Figure 1 – Sound intensity contours at 50 Hz

Figure 2 – Muffler noise testing at 3m from exhaust outlet

4. DEVELOPMENT OF A MODIFIED COFFIN MUFFLER

A modified coffin muffler was developed following several design iterations to optimise the performance of the system. New muffler internal modules were proposed and tested using Dimensional Analysis methods. The principles of Dimensional Analysis methods are discussed in detail in Munson et al. (6), but can be summarised as testing using a scale model prototype and correspondingly scaled environmental parameters (air temperature, density etc.). For this project, both half scale and full scale models (at cold temperatures) were tested using a pink noise source upstream, as shown in Figure 3 and Figure 4.

Figure 3 – Full scale cold testing of original muffler using a pink noise source

Figure 4 – Full scale prototype cold testing

The resulting new design is a double expansion chamber with tuned quarter wave chambers added to further improve the low frequency performance. The volume of the new muffler was increased by nominally 60% by increasing the height of the muffler body while maintaining the width and length. Absorptive material was added under the quarter-wave chambers, to provide some additional attenuation. The placement of the absorptive material was critical to minimise potential corrosion from contact with diesel engine particulate emissions.

The resulting modified coffin muffler design was manufactured as a prototype and fitted to Locomotive 2815.

5. PROTOTYPE TEST RESULTS

Hot testing of the optimised prototype fitted to Locomotive 2815 took place on 11 March 2013 using an identical 3m microphone positioning to that employed for the transmission loss tests of the original muffler.

The spectrum of the noise emissions for the new design in Notch 8 under self-load are shown in Figure 5 along with the noise emissions from the original muffler. Results are presented for both designs tested with the previously modified transition muffler.

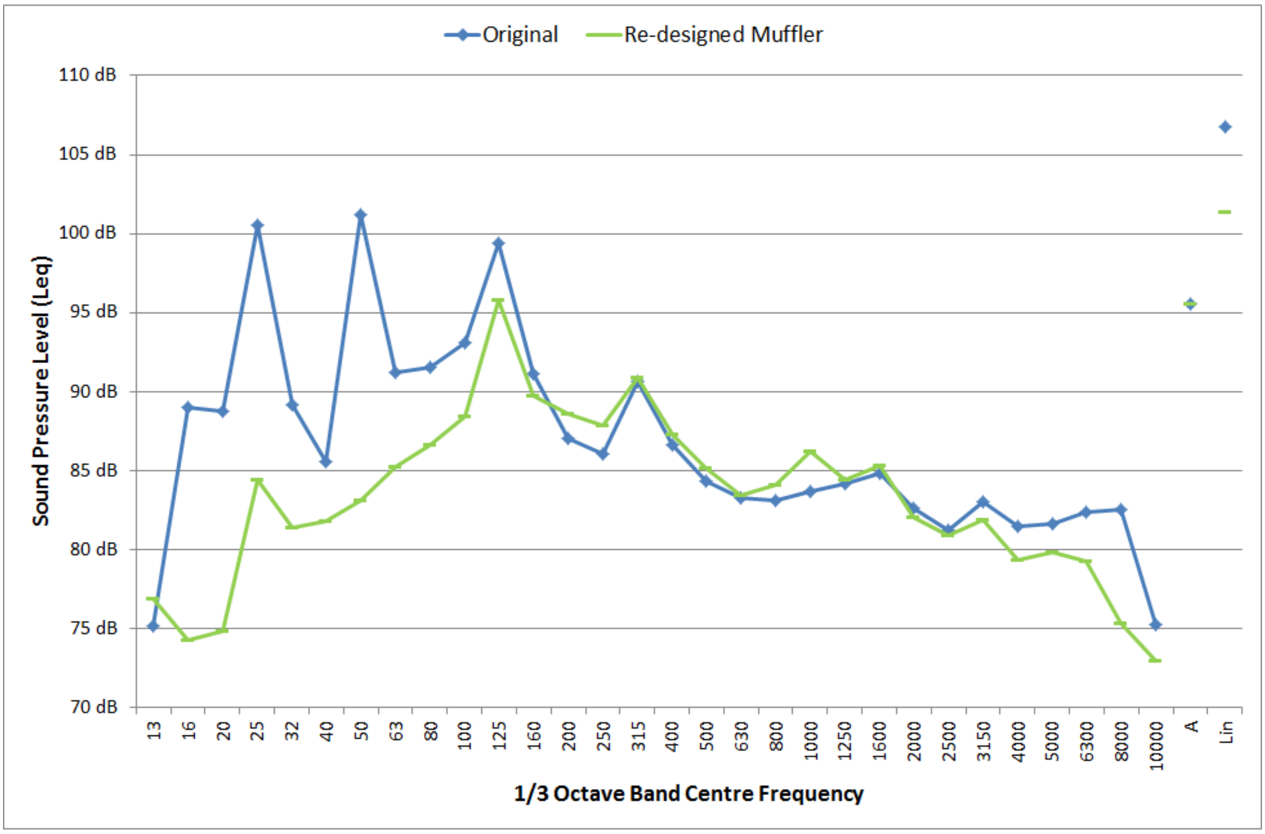

Figure 5 – Redesigned muffler performance vs original muffler

The re-designed muffler performance in Notch 8 against the original muffler is summarised in Table 2. Notch 8 is the engine setting with the highest noise emissions, and is also the operational setting of most concern due to the relative time spent in Notch 8 when maximum power is required, such as when travelling uphill.

Table 2 – Muffler performance in Notch 8

Parameter	Sound Pressure Level at 3m from exhaust outlet		Increase in muffler attenuation
	Original muffler	Re-designed muffler	
A-Weighted Overall L_{AEq}	96 dBA	96 dBA	0.0 dB
Linear Overall L_{Eq}	107 dB	101 dB	5.4 dB
25 Hz 1/3 Octave Band L_{Eq}	101 dB	84 dB	16.1 dB
50 Hz 1/3 Octave Band L_{Eq}	101 dB	83 dB	18.1 dB

The new design was found to reduce the overall linear noise levels by 5 dB, whilst maintaining the A-weighted levels. Major reductions in tonal noise were achieved in the target spectral range. In Notch 8, emissions in the 50 Hz band have been reduced by 18 dB. The reduction in the 25 Hz band was observed to be 16 dB.

The apparent insertion losses achieved by the original and re-designed coffin mufflers across the frequency range are shown in Figure 6.

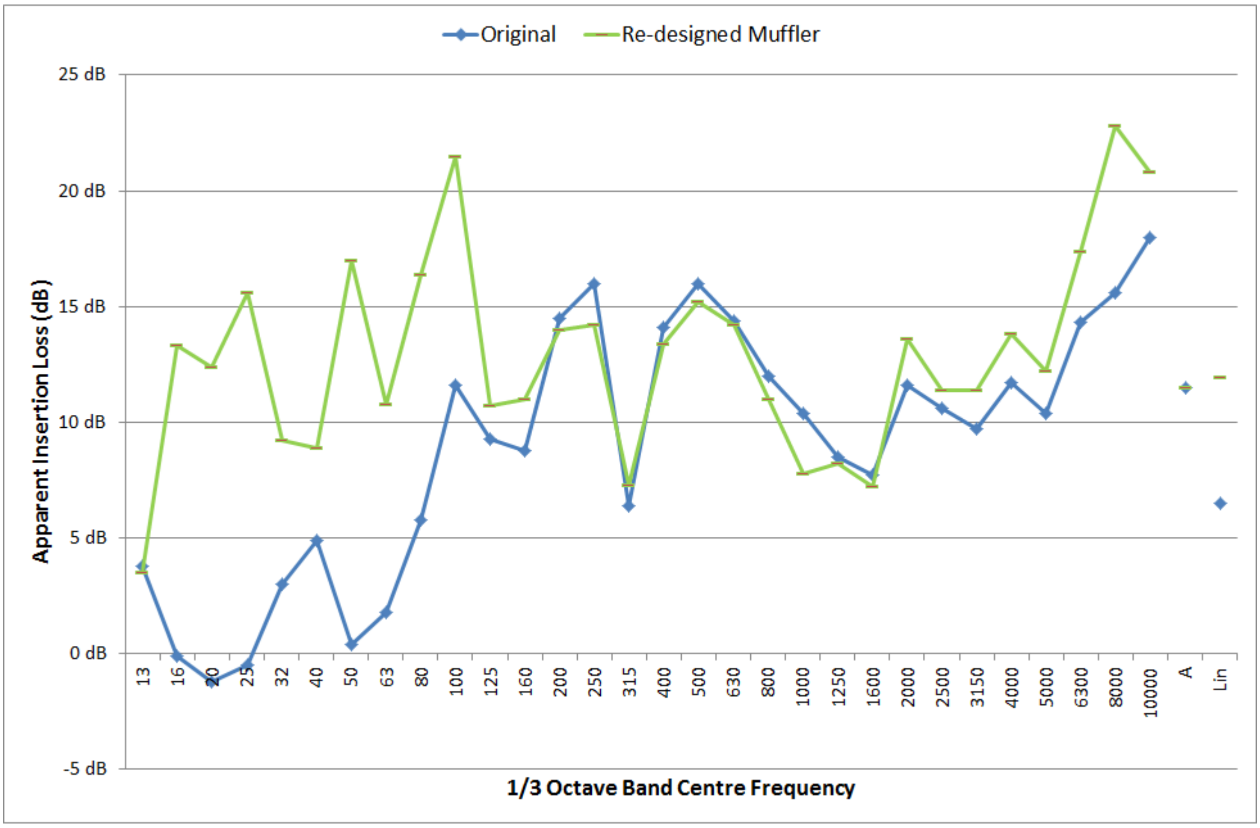

Figure 6 – Insertion loss re-designed muffler performance vs original muffler. Results for both cases shown include the previously modified transition muffler.

6. PROJECT OUTCOMES

Noise type tests in accordance with AS 2377:2002 were repeated with the re-designed muffler on Locomotive 2815. The measured overall noise levels at the 15 m type test measurement distance were found to comply with the relevant EPL conditions.

The modifications made to the locomotive muffler have resulted in a reduction in overall L_{max} noise levels of up to 5 dB in the highest engine notch settings. The overall noise emissions at 15 m (which include noise from all sources, not just the exhaust system) in the 50 Hz band of concern to the EPA have been reduced by 8 dB. Similar reductions have been achieved in the 25 Hz band.

The EPA has subsequently approved this locomotive class (rebadged as the 3200 class) for use in NSW, stating that *“Based on the information provided, the EPA considers that the noise performance of the 3200 class locomotive is consistent with current best practice in NSW.”*

ACKNOWLEDGEMENTS

This project was undertaken for Aurizon Pty Ltd. The authors are grateful for the assistance proved by Aurizon throughout the project, in particular Matt Pearce and Ray McCabe. Aspects of this work have been previously presented at the Heavy Haul Rail Conference in Newcastle (31 July – 1 August 2013).

REFERENCES

1. Environment Protection Licence Number 3142, version date 18 December 2012 issued to Australian Rail Track Corporation Limited by the NSW Environmental Protection Authority.
2. Australian Standard AS2377-2002 Acoustics - Methods for the measurement of railbound vehicle noise.
3. Bowden H, Glad R. Exhaust and Intake Noise and Acoustical Design of Mufflers and Silencers, Handbook of Noise and Vibration Control, John Wiley & Sons, 2007, p1034-p1053.
4. Davis D, Stokes G, Moore D, Stevens G. Theoretical and Experimental Investigation of Mufflers with Comments on Engine-Exhaust Muffler Design, National Advisory Committee for Aeronautics 1954.
5. Craig R, Howard C. Development of an Adaptive Quarter-Wave Tube Attached to a Large Diesel Engine, Proc ACOUSTICS 2012, 21-23 November 2012, Fremantle 2012.
6. Munson B, Young D, Okiishi T. Fundamentals of Fluid Mechanics, John Wiley & Sons, 1998, 3rd Ed. p165-199.