

Compression Brake Noise with DPF and SCR

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ABSTRACT

Compression brake noise (also known as “Jake Brake” noise) has been a significant issue for heavy duty trucks for several decades. As a result of compression brake noise, there are many local ordinances in North America banning the use of engine brakes, and some countries such as Australia and South Africa have in the past considered total bans on compression brakes. Previous research showed that the primary problem is caused by operators who remove the OEM muffler system and replace it with a “straight stack” exhaust pipe with no sound reducing properties. On the other hand, even with the OEM exhaust system in place, compression brake noise is sometimes significant.

The introduction of exhaust aftertreatment to meet stringent 2010 EPA emissions requirements (diesel particulate filters and selective catalytic reduction systems, DPF + SCR) provides two potential benefits for compression brake noise. The first benefit is that these aftertreatment devices are very good at attenuating noise in the exhaust stream. The second benefit is that aftertreatment systems make tampering with the exhaust system a very complex engineering undertaking which few truck operators are likely to undertake. With older trucks, removing the muffler was both technically simple and only a violation of noise control regulations.

Data presented in this paper shows that at least for the truck and engine models evaluated, compression brake noise is no longer an issue. In fact, most people would be unable to detect compression brake operation, even if they are close to the truck when it is operating the brakes. As the population of older trucks without exhaust aftertreatment declines, the issue of compression brake noise should fade away, at least in markets where aftertreatment is used.

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INTRODUCTION

The compression brake was invented by Clessie Cummins in 1957 and patented in 1965 [1] to address the lack of engine braking in diesel engines. In gasoline engines with a closed throttle, work must be done to create a vacuum to pull air through the restriction of the throttle plate. Since diesel engines until recently did not have throttles, less engine braking was available at no load. This placed an additional burden on the friction brakes. Given the heavy loads carried by large trucks, it is also desirable to have more engine braking power than a closed throttle can provide.

The compression brake is an elegant device that makes use of the existing fuel injector cam lobe, an exhaust valve lobe from another cylinder, or a specific brake lobe to open the exhaust valve when engine braking is desired. The compression brake system opens the exhaust valve near top dead center of the compression stroke, at around the time that fuel would normally be injected to produce power. When the exhaust valve is opened near TDC, the compressed air will be expelled into the exhaust system, and the diesel engine

essentially becomes an air pump. In many cases, an engine with a compression brake can absorb roughly the same power that it can produce at maximum load. This reduces the load on the friction brakes that can fade in loaded trucks on long downhill grades, and it decreases associated service brake maintenance costs. This device made a significant improvement to highway safety and was recognized as a Historical Engineering Landmark by ASME in 1985 [2].

One consequence of compression brake operation is the staccato sound created due to the bursts of compressed air that are exhausted. The EPA has required low speed truck noise emissions to be below 80 dB(A) since January 1, 1988 as stated in Title 40, section 205.52 of the Code of Federal Regulations [3]. But Reinhart found that despite these regulations, mufflers were often removed in service, creating objectionable noise levels, particularly when using compression brakes [4]. Reinhart's 1991 survey in [4] showed that about 6% of trucks sampled in Indiana had their mufflers removed or disabled. A larger unpublished survey by the same author was conducted in 2000, with similar results. This later survey broke the population down by truck brands, and

showed that truck brands popular with owner-operators and small fleets, such as Peterbilt, were far more likely to have mufflers removed than were brands popular with large fleets, such as International and Volvo.

Reinhart and Wahl [5] performed noise testing of heavy-duty vehicles both with the original equipment manufacturer (OEM) muffler and with the muffler replaced by a straight stack. In that study compression braking showed approximately the same noise level as full-throttle acceleration on most vehicles when the OEM muffler was present, but was dramatically louder with a straight pipe replacing the muffler. Figure 1 shows typical results from a truck equipped with an 11 liter Cummins engine. The test procedure from [3] was used for the acceleration tests, while the procedure from [8] was used for the braking tests. The braking test procedure is basically the normal acceleration test run in reverse, where the truck comes in to the measurement section at high idle speed, and the accelerator pedal is released at a point which causes the brake to come on near the center of the test section.

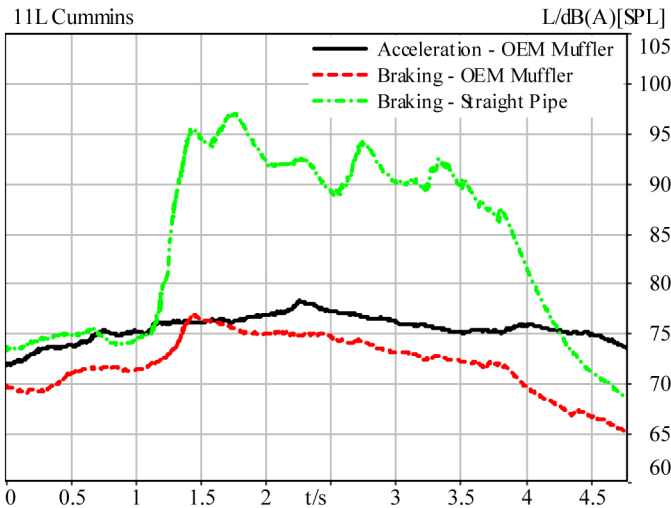


Figure 1. Fast response sound levels of a truck equipped with an 11L Cummins engine under acceleration and compression braking with the OEM muffler, and compression braking with a straight pipe.

For the 11 liter engine, the peak sound levels during acceleration and compression braking were 78.4 dB(A) and 76.9 dB(A) respectively. For this engine and muffler, the overall vehicle noise under braking was lower than under acceleration. The compression brake noise is still audible with the OEM muffler, but it is not the dominant sound. However, when the muffler was replaced by a straight pipe, the peak compression braking noise increased to 97.2 dB(A) and the noise became very objectionable.

The loudest vehicle tested in [5] was equipped with a 12.7 liter Detroit Diesel Series 60 engine. The results are shown in Figure 2. This vehicle represented a case where the acceleration noise level of 80 dB(A) was much lower than the 86 dB(A) noise level observed during compression braking

with the OEM muffler. During compression braking, the sound level rose from 86 dB(A) to 102 dB(A) when the muffler was replaced with a straight pipe. In this case, the sound of the compression brake was still dominant with the muffler installed, and although it still emitted a harsh staccato noise it was much less objectionable than the noise observed with the muffler removed.

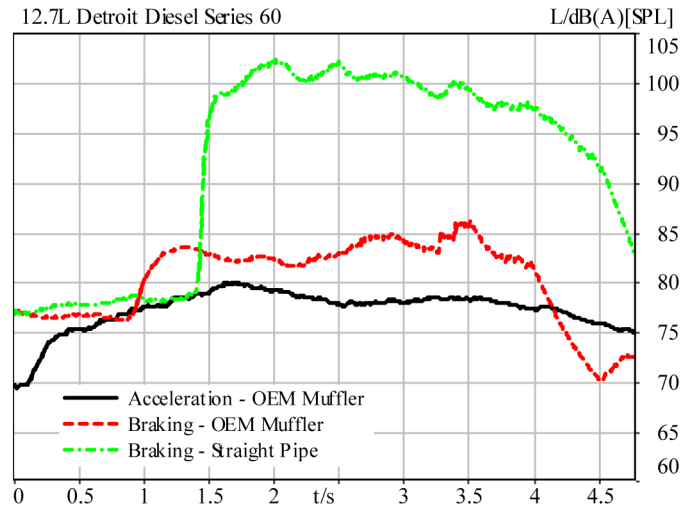


Figure 2. Fast response sound levels of a truck equipped with a 12.7L Detroit Diesel Series 60 engine under acceleration and compression braking with the OEM muffler, and compression braking with a straight pipe.

The frequency content of the compression brake pass by noise is shown for the 11 liter Cummins equipped truck with a straight pipe and with the OEM muffler in Figures 3 and 4 respectively. The spectrogram with the straight pipe shows the fundamental firing frequency of approximately 90 Hz at the beginning of the braking event at 1.3s, and many strong harmonics appear, as one would expect from such a raspy sound. There is a substantial increase in noise amplitudes at all frequencies up to 20 kHz during brake operation. The braking event ends at about 3.8 seconds. The spectrogram with the OEM muffler shows that the noise is significantly attenuated across the entire frequency range, explaining why both the level and sound quality of the compression brake noise is much less objectionable with a muffler in place. Even with the OEM muffler, however, it is possible to see higher levels of firing frequency and the first few harmonics of firing, and compression brake operation can be detected subjectively by listening to the recording.

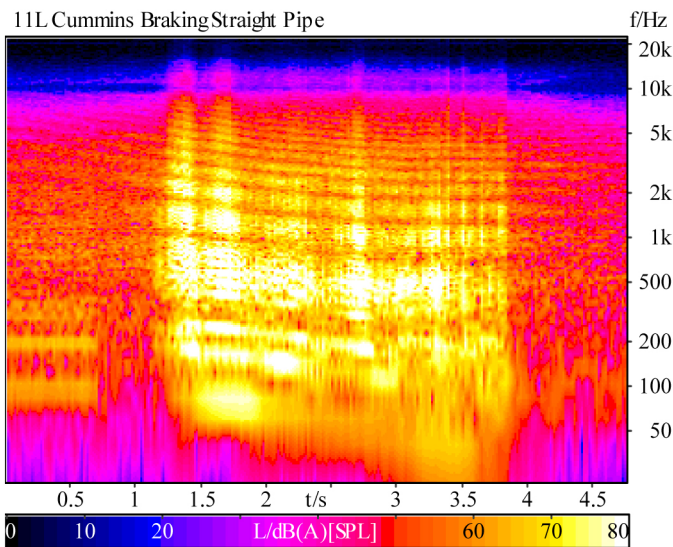


Figure 3. FFT versus time for the 11L Cummins data from Figure 1 during compression braking with the straight pipe.

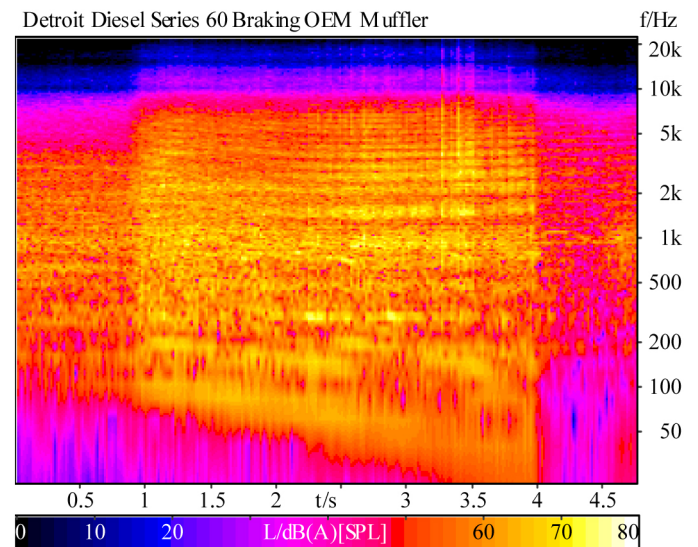


Figure 5. FFT versus time for the Detroit Diesel Series 60 data from Figure 2 during compression braking with the OEM muffler.

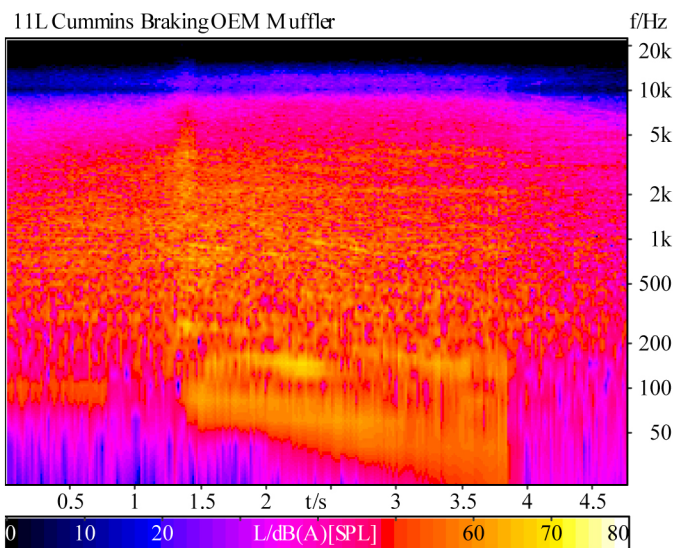


Figure 4. FFT versus time for the 11L Cummins data from Figure 1 during compression braking with the OEM muffler.

The frequency content of the compression brake pass by noise for the Detroit Diesel Series 60 equipped truck with the OEM muffler is shown in Figure 5. Comparing this spectrogram to the 11 liter Cummins in Figure 4 illustrates how much louder this vehicle's compression braking was with the OEM muffler in place. Comparing it with Figure 3, however, illustrates how much quieter it was than the Cummins equipped vehicle with a straight pipe.

INFLUENCE OF DPF AND SCR

All heavy-duty diesel engines in the US market since 2007 have diesel particulate filters (DPF), and selective catalytic reduction (SCR) systems were installed by most OEMs to meet 2010 EPA regulations. By the middle of 2013, SCR use will be universal in the US market. The noise attenuation properties of diesel particulate filters (DPF) has been recognized and studied for at least a decade. Allam and Åbom were among the earliest investigators, and they presented two acoustic DPF models in [6]. They modeled and measured an automotive DPF of 150mm diameter and 250mm length and showed transmission losses between 4-6 dB at 10 Hz and 7- 9 dB at 1.3 kHz depending on the filter media and condition. Elnady, et al. modeled and tested the acoustic performance of three aftertreatment devices for heavy-duty diesels [7]. They measured a minimum of 25 dB transmission loss above 1.2 kHz.

Noise Testing with DPF and SCR

Two trucks equipped with DPF and SCR aftertreatment systems were tested to record their acceleration and compression braking noise. One was a Kenworth T700 built in February 2012. This truck is EPA Smartway certified, with a Cummins ISX 450 and an Eaton Ultrashift 10 speed automated manual transmission. This truck has a vertical exhaust stack as shown in Figure 6. The other test truck was a Freightliner Cascadia built in April 2012 with a Cummins ISX 450 and an Eaton 10 speed manual transmission. This truck has a horizontal exhaust as shown in Figure 7. Both trucks have a high idle speed of 1,800 rpm during operation and were tested in 6th gear. The acceleration noise testing was conducted per EPA Title 40, Chapter 1, Part 205, section