Sound Attenuation Analysis for an SCR Retrofit of a Quad-Engine Catamaran Ferry

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1.0 Abstract

A selective catalytic reduction (SCR) system has been designed to reduce NOx emissions on four diesel engines powering a catamaran ferry. The SCR system will replace the existing silencer and has been evaluated to determine the impact on output sound power output levels. The exhaust components relating to the SCR system will replace the existing silencer, and will include a forward mixing section (where aqueous urea is injected and mixed with the exhaust gas), and a rear catalyst section (comprised of the NOx reducing catalyst material). Since the exhaust components of the SCR system are to replace the existing silencer, an analysis of the changes to the sound attenuation properties was requested. Calculations of the exhaust components acoustic impedances were conducted to estimate the approximate insertion loss (sound attenuation associated with replacing an equivalent section of pipe) of the new SCR system. This calculated value was then compared to the reported sound attenuation properties of the existing EM Products JC Series critical grade silencer. As discussed in the following report, calculations showed that the expected sound attenuation of the new exhaust components exceed the performance of the existing critical grade silencer. The SCR system is expected to provide a sound attenuation of 30.8 dBA compared to the existing silencer sound reduction of 31.2 dBA. Calculations used herein to determine the performance of the new system components are believed to be conservative; actual sound attenuation values may be significantly higher than calculated, since several sound reducing features such as bends and reflecting plates were omitted in order to facilitate and simplify the calculations.

2.0 Introduction

The system consists of both electrical and mechanical components along with a new exhaust section which will replace the existing EM Products JC series silencer. The exhaust section is comprised of two main components: 1) The forward mixing chamber where aqueous urea is injected and mixed with hot exhaust gases and 2) The rear section consisting of blocks of the NOx catalyst (where NOx is reduced to N2). Data for the existing JC series grade silencer was obtained from published data available on the company’s website. Performance data for the

SCR exhaust components were obtained from calculations of the sound attenuation of the forward mixing section, and tabulated performance data from the catalyst manufacturer (Reference 2) for the rear catalyst section.

Noise is defined as sound levels above a comfortable hearing threshold for humans. Sound, however, is the pressure pulsation detected by the human ear. Throughout this report both terms sound and noise will be used synonymously in our discussion of sound attenuation. Furthermore, when evaluating noise of internal combustion (IC) engines it is necessary to specify the source. For IC engines, there are three (3) sources which can cause considerable discomfort to persons within range. These sources are: air inlet noise (Can be particularly important when evaluating the noise of turbo-charged engines), casing noise emanating from engine vibration, and exhaust noise induced by pressure pulsations in the exhaust gas flow.

Since the scope of work for this project relates only to changes in the exhaust system, both air inlet and engine casing noise will be omitted from this evaluation. Any controls currently in place for these particular noise sources will remain unaffected; therefore no increase or decrease in noise levels is expected for these sources.

Sound attenuation data will be provided in units of decibels (dB); A-weighted values may also be provided particularly when referring to human perceived noise levels. A-weighted sound values (dBA) utilize a scale which adjusts linear sound measurement to human perceived levels. Additionally, noise levels (dB or dBA) may be reported in terms of sound power level at an octave band, or at an overall level.

3.0 Results and Discussion

3.1 Existing Silencer

Sound attenuation characteristics for the existing EM Products JC Series Silencer were obtained from published data and are summarized in Table 3.1. The data is presented in terms of sound attenuated (dB) at the indicated octave band center frequencies. As shown the insertion loss of the silencer ranges from 20 to 34 dB, for the corresponding range of frequencies.

Calculations of the sound attenuation characteristics of the new exhaust components (Mixer and Catalyst unit) will be compared and contrasted to the reported EM data to evaluated potential increases or decreases in the overall exhaust sound levels.

3.2 SCR Exhaust Components

Table 3.1 - Existing Silencer Data

Octave Band Center Frequency - Hz	*Sound Attenuation (IL) - dB*
31.5	20
63	24
125	28
250	32
500	34
1000	33
2000	31
4000	27.5
8000	26

As previously discussed, changes to the existing exhaust system will include the removal of the existing silencer and the subsequent replacement with the catalyst assembly. The catalyst assembly is comprised of both a forward mixing section and a rear catalyst section. Exhaust gas will enter into the mixing section through a 12” ANSI flange located on the bottom of the mixing section. Exhaust gas then expands into the initial volume (V1) prior to passing through a perforated cone and entering a secondary volume (V2). The gas then undergoes a 90 degree bend and passes through a plate type mixer and into the catalyst blocks. At the outlet of the catalyst blocks, the exhaust gas flows into the existing 12” exhaust piping.

Generally, the front portion comprised of the mixer will reduce sound transmission by preventing sound propagation (Reactive muffling). The catalyst unit will also act as a reactive muffler while, in addition, providing some dissipative sound reduction (sound attenuated by the catalyst material itself). Sound attenuation through the mixing section will be determined analytically and combined with reported data for the catalyst section.

In order to calculate muffling parameters with respect to sound generated from the engine exhaust, the sound source must be defined. As found in Reference 1 (Bies, D.A.), internal combustion engines are characterized as fluid mechanical monopole sources. Furthermore, the resulting sound propagation is defined as a constant volume velocity flow; making the use of the following calculations possible. Since the mixing section is comprised of two volumes separated by perforated plate, the sound attenuation may be modeled through utilization of a lumped element analysis. In the model, a representative AC circuit is developed and calculations are performed accordingly (Each component within the "circuit" is defined as either an acoustic impedance or resistance). Additionally, since the electrical equivalent system mimics that of a lowpass filter (Also know as a Hemholtz filter), the insertion loss of the mixing section for a long pipe termination can be determined using the following equation:

Figure 3.1 – Insertion Loss of Existing Silencer

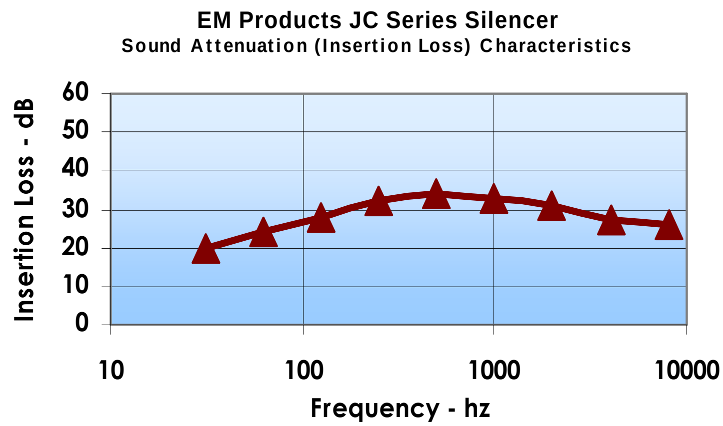
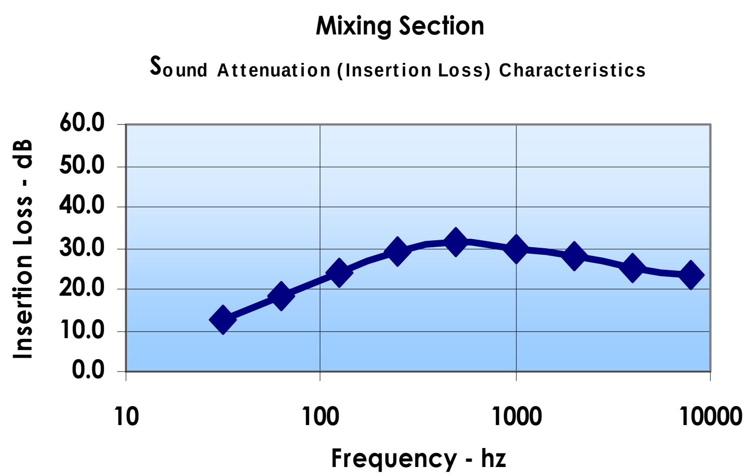


Figure 3.2 - Insertion Loss of Mixing Section



$$IL = 10 \cdot \log_{10}\left[\left(1 - \frac{V_b \cdot l_c}{A_c} \cdot \left(\frac{w}{c}\right)^2\right)^2 + \left(\frac{V_b + V_d}{A_l} \cdot \left(\frac{w}{c}\right) - \frac{V_b V_d l_c}{A_l A_c} \cdot \left(\frac{w}{c}\right)^3\right)^2\right]$$

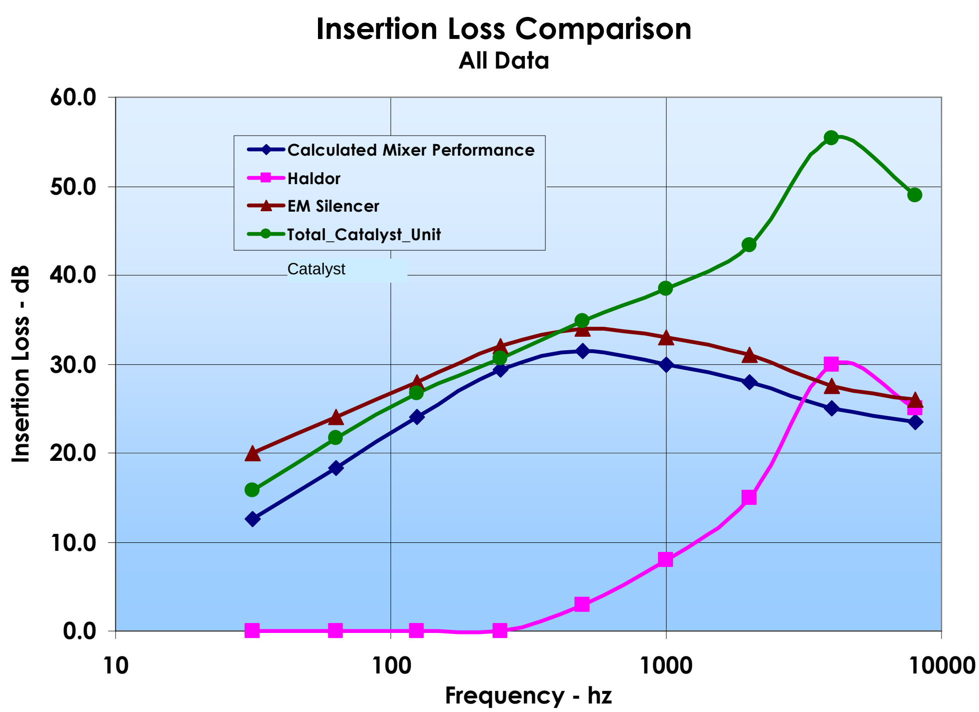
Where: V_b˜V_d=volumes before and after restriction
L_c=length of orifice (effective length)
A_c=area of perforation
A_l=area of outlet pipe
? =angular frequency of sound waves
c=speed of sound

This equation remains valid for frequencies up to the resonance frequency of the filter. After which the actual insertion loss decreases with increased frequency. This trend is shown in the log-normal curve of the existing silencer (Figure 3.2). Calculations of insertion loss (IL) were used to determine the magnitude of the insertion loss for low to mid frequencies while high frequency losses were interpolated. The resulting sound attenuation versus octave band center

Table 3.2 - Catalyst Section Data (1m)

Octave Band Center Frequency - Hz	*Sound Attenuation (IL) - dB*
31.5	0
63	0
125	0
250	0
500	3
1000	8
2000	15
4000	30
8000	25

Figure 3.3 – Insertion Loss Comparison



frequency characteristic of the mixing section is provided in Figure 3.3. The sound attenuation for the overall system is then computed by combing insertion losses for the mixer, catalyst section, and pipe losses. Insertion losses for the catalyst section (approx. 1 m long) are presented in Table 3.2. Provided in Figure 3.4 are the insertion loss characteristics for each component along with the resultant insertion loss curve.

3.3 Sound Power Output

To compare the relative change in sound power output level, we begin by calculating the output sound power level of the un-muffled engine using the following equation:

$$L_w = 120 + 10 \cdot \log_{10}(kW) - K - \left(\frac{l_{ex}}{1.2}\right)$$

Where: L_w = overall sound power output of engine
kW = engine power in kilowatts
K = adjustment factor (K=6 for turbo-charged engines)
l_{ex} =length of exhaust

The total output sound power is applied at each octave center band frequency, and further adjusted by adding subtracting an adjustment factor to provide the "Adjusted Linear Output Sound Power". A summary of the sound power output is provided below in Table 3.3.

Table 3.3 - IC Engine Sound Power Output

Octave Band Center Frequency - Hz	*Overall Sound Power - dB*	*Octave Band Freq Adjustment - dB*	*Adjusted Linear Output Sound Power – dB*
31.5	144.6	5	139.6
63	144.6	9	135.6
125	144.6	3	141.6
250	144.6	7	137.6
500	144.6	15	129.6
1000	144.6	19	125.6
2000	144.6	25	119.6
4000	144.6	35	109.6
8000	144.6	43	101.6

Calculated noise levels for both the existing and proposed SCR systems can then be determined by subtracting the appropriate insertion losses from the baseline adjusted linear output sound power. The resulting linear sound power output levels for the EM Products silencer and the SCR hardware are summarized in Table 3.4. To obtain noise level criteria which can be equated to tolerances of human hearing, the data must also be adjusted to A-weighted values, and further reduced to provide a sound power level over the entire audible range. A-Weight adjustment factors for each octave center band frequency are provided in Table 3.5 (See Figure 3.4 for A-weighted sound output characteristics for both the existing and proposed exhaust systems). After the adjustment factors are added, the overall sound power level (Lo) is found by adding the sound power at the incoherent octave band center frequencies. This logarithmic addition is performed using the following equation:

Table 3.4 - Attenuated Linear Sound Power Output

Octave Band Center Frequency - Hz	*SCR System*	*EM Products Silencer*
31.5	123.8	119.6
63	114.0	111.6
125	114.9	113.6
250	107.0	105.6
500	94.8	95.6
1000	87.2	92.6
2000	76.2	88.6
4000	54.2	82.1
8000	52.7	75.6

Table 3.5 - A-Weight Adjustment Factors

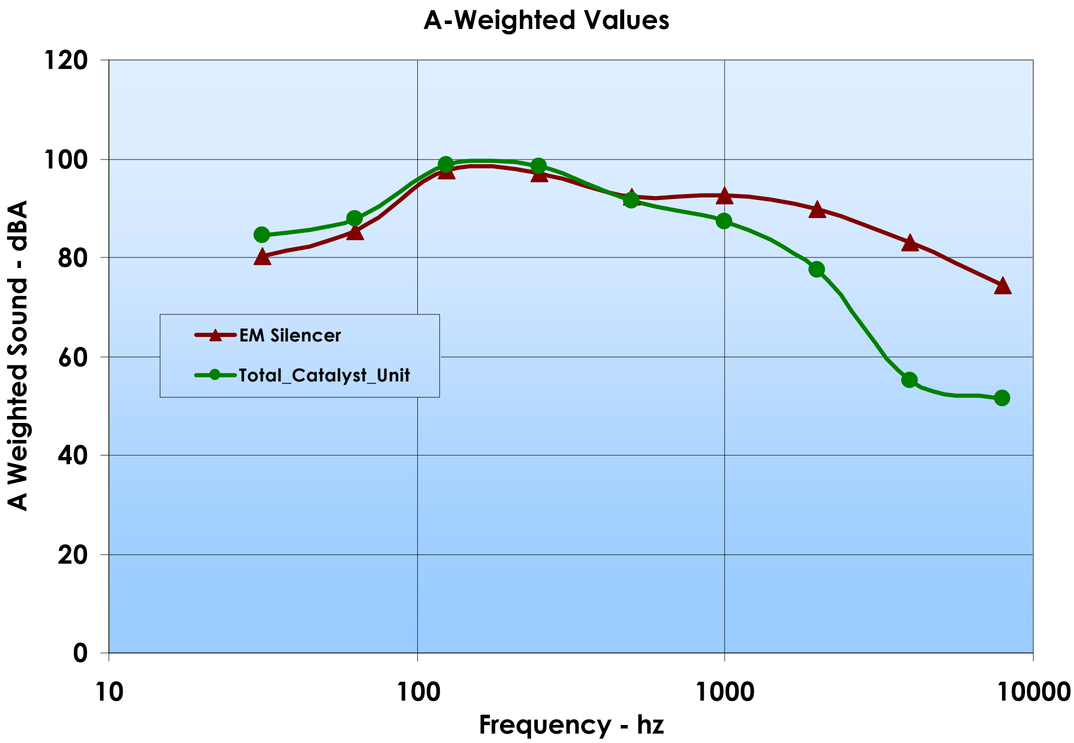
Octave Band Center Frequency - Hz	*A-Weight Adjustments*
31.5	-39.4
63	-26.2
125	-16.1
250	-8.6
500	-3.2
1000	0
2000	1.2
4000	1
8000	-1.1

$$L_o = \sum_{i=31.5}^{i=8000} 10 \cdot \log_{10}\left(10^{\frac{W_i}{10}}\right)$$

Where: W_i=sound power level at incoherent frequencies i, from i=31.5 to 8000 Hz.

Based on these calculations the attenuated sound power output levels for both the EM Products Silencer and SCR System are found to be 102.0 and 102.4 dBA, respectively. The SCR system provides slightly less attenuation than the existing silencer; resulting from a reduced attenuation at very low frequencies. However, since the deviation between pre and post retrofit is <0.4%, reasonable precision of the calculated values would suggest that the predicted levels are essentially equivalent. Furthermore, the calculations of the SCR system attenuation are thought to be conservative and additional attenuation is anticipated.

Figure 3.4 – Attenuated Sound Power Output for Existing and Proposed Exhaust Systems



4.0 Conclusions

Sound attenuation characteristics for the retrofit scr system have been calculated and compared to the existing critical grade silencer. As shown in Figure 3.4 the proposed SCR exhaust components are expected to provide equal sound reduction when compared to data for the existing silencer. A total insertion loss of 30.8 dB has been calculated for the retrofit system, compared to an insertion loss of 31.2 dB for the existing silencer. The calculated attenuation of the SCR system is believed to be conservative as there are additional noise reduction components such as bends and area changes which were omitted for simplification of the calculations. In addition to this report it may be desirable to perform measurements of the actual sound levels in critical areas both on and off the catamaran; this can be accomplished with the use of a sound level meter both before and after the retrofit. If field measurements are performed, adequate data to enable calculation of the difference attributable to the exhaust system changes should be taken. Also, it is advisable that sound measurements in the octave band center frequencies be recorded to aid in characterization of the sound source.

References

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