COMPARISON OF EXPERIMENTAL AND MODELED INSERTION LOSS OF A COMPLEX MULTI-CHAMBER MUFFLER WITH TEMPERATURE AND FLOW EFFECTS

Helen Ule[1], Colin Novak[1], Tony Spadafora[1], Ramani Ramakrishnan[2] and Robert Gaspar[1]
1. Dept. of Mechanical, Automotive and Materials Engineering, University of Windsor, 401Sunset Ave., Windsor, Ontario
2. Department of Architectural Science, Ryerson University, 35 Victoria St., Toronto, Ontario

1. INTRODUCTION

Due to both legislative and consumer demands, the need to attenuate noise emissions associated with the operation of today's automobiles has become paramount. Further to this, improvements in engine performance capabilities have resulted in the generation of greater noise propagation from the engine. Exhaust system engineers, therefore, must design mufflers that are capable of attenuating this higher amplitude noise propagation while at the same time not restricting engine performance by increasing flow resistance.

The complex multi-chamber muffler is the most common noise control filter used for automotive exhaust systems today. The design of these filters has always been a specialized field that involved a degree of experience and intuition along with an understanding of the fundamental design equations. With this, a prototype would be constructed, tested and improved as part of a trial and error process. This is both costly and time consuming. As a result, the design of such systems is now done with the aid of computer modeling programs. Care must still be taken in the implementation of such an approach to ensure good correlation between modeled and actual results.

For this investigation, a computer simulation program, Ricardo WAVE, is used to predict the insertion loss of an "off the shelf" multi-chamber muffler. Included in the investigation are the effects of both temperature and flow. These theoretical results are compared to experimental measurements of the same muffler design that was used in the computational model.

2. METHOD

The insertion loss of the muffler was determined both experimentally on an engine motored on a dynamometer as well as analytically using WAVE. The following is a description of these two approaches.

2.1 Experimental Approach

To experimentally determine the insertion loss of the muffler, it was attached to a Toyota 4A-GE engine motored on a DC dynamometer within a semi-anechoic environment. A cutaway view of the muffler showing the multiple chambers is illustrated in Figure 1. This filter is classified as a reactive muffler. Here, the multiple pipes and chambers provide an impedance mismatch for the acoustic energy traveling through it. This impedance mismatch causes some of the acoustic energy to reflect back to the source thus preventing some of the noise from transmitting through the muffler.

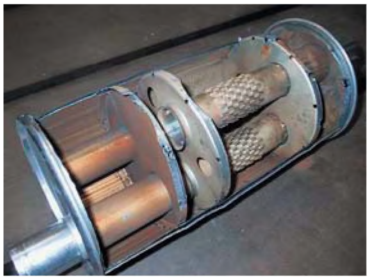

Fig. 1. Cutaway view of the muffler used showing the multiple passages and chambers that make up this reactive filter.

The engine was operated at engine speed from 100 to 4000 rpm in increments of 500 rpm. A microphone 100 mm from the exit of the exhaust pipe measured the resulting noise. Flow temperature and velocity data was also collected 0.5 metres before and after the muffler. The insertion loss was determined by comparing these results to similar measurements made with the muffler replaced by a straight section of pipe. The difference in realized sound pressure level represents the insertion loss of the muffler.

2.2 Analytical Approach

Using Ricardo WAVE, implementing a one-dimensional finite-difference formulation, the realized sound pressure level at the exit of the exhaust pipe was predicted with both the muffler and straight pipe in place. In order to accomplish this, both the Toyota engine that was used as the dynamic noise source and the muffler needed to be modeled. Figure 2 is an illustration of the WAVE model schematic showing the input building blocks of the muffler only.

3. RESULTS

Figure 3 shows the realized sound pressure level with and without the muffler installed for both the experimental and modeled analysis. It can be seen that an insertion loss of up to 20 dB is realized with implementation of the muffler in the experimental exercise with the maximum occurring at the higher engine speeds. While a positive insertion loss also occurred in the modeled results, the degree of insertion loss is much less. It is felt that the higher noise levels for the unmufflered experimental results were due to wind noise, which is not realized in the modeled results.

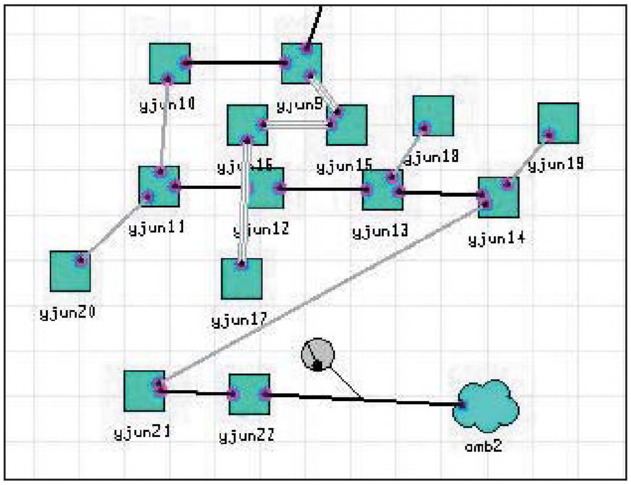

Fig. 2. Schematic of Ricardo WAVE model for the muffler used in this investigation illustrating the various input building blocks of the model.

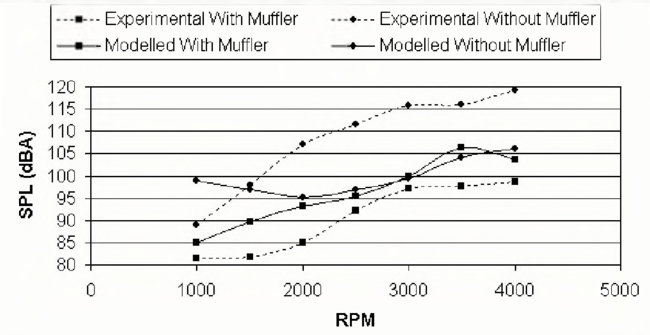

Fig. 3. Sound pressure levels with and without muffler for experimental and modeled engines illustrating realized insertion loss.

Figure 4 shows the experimental and modeled flow temperature determined 0.5 metres after the muffler exit location with and without the muffler installed. It can be seen that while the temperatures for both experimental results are approximately the same, they do increase with an increase in engine speed. It is assumed that this increase is due to frictional effects of the motored engine. This assumption is reinforced through examination of the modeled results. Here, the predicted temperatures not only remain constant, but also show no significant difference between the case with and without the muffler. This is due to the inability of the computational model to include any frictional effects

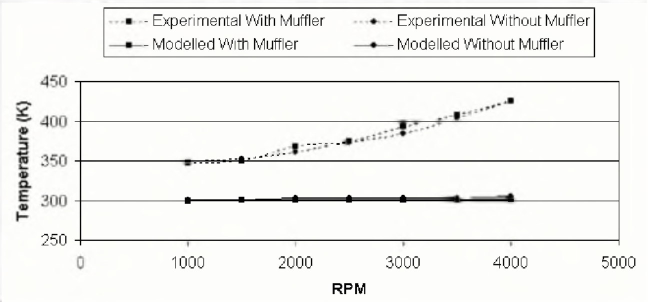

Fig. 4. Flow temperatures with and without muffler for experimental and modeled engines.

Figure 5 shows the gas flow velocity for the experimental and modeled flows determined 0.5 metres after the muffler exit location with and without the muffler installed. It can be seen for the most part that the flow velocity was higher for the experimental results in the absence of the muffler. This is to be expected since the presence of the muffler acts as a dampening reservoir. The results for the modeled results, however, do not follow this same trend. It was found that the modeled flow velocities without the muffler were unexpectedly low for engine speeds of 1000 and 3000 rpm.

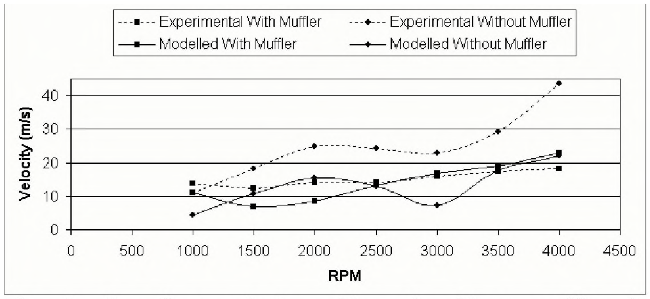

Fig. 5. Gas flow velocity with and without muffler for experimental and modeled engines.

4. CONCLUSION

The focus of this investigation was to investigate the difference in realized insertion loss of a motored engine using both experimental and modeled results. Also included were temperature and flow effects. It was felt that the experimental noise measurements were contaminated by wind noise over the microphone and that the temperature differences were due only to frictional effects of the motored engine. Good insertion loss results, however, were obtained by the computational model. As expected, no temperature changes resulted in the modeled output. It was further determined that the analytical model was not able to accurately predict the flow velocity for the case without the muffler installed.