# Experimental Setup

A Chrysler inline-4 SI engine was installed on an engine dynamometer at the Center for Automotive Research at the Ohio State University. Pressure transducers were installed in the exhaust system of the engine, both upstream and downstream of the muffler. The engine was run at wide open throttle while the dynamometer was held at 1000 and 2000 RPM and pressure traces were recorded as a function of crank-angle of the first engine cylinder by the transducers. Identical tests were run with the exception that the muffler was removed and replaced with a section of straight pipe.

# Results

## Part 1

Figure 1 shows the exhaust pressure traces in terms of time upstream and downstream of the muffler for the two engine speeds: 1000 RPM and 2000 RPM. The pressure traces upstream of the muffler contain large amplitude, low frequency oscillations and lower amplitude, higher frequency oscillations. As one would expect, the large amplitude oscillations in the downstream section are slightly out of phase from those in the upstream section due to travel distance. From the plots, it is clear that the muffler dampens the pressure fluctuations in the exhaust system. High frequency oscillations are almost entirely nonexistent downstream of the muffler and the amplitudes of the low frequency oscillations has been reduced considerably for both engine speeds. At the higher engine speed, the performance of the muffler is so great that the pressure downstream of the muffler is lower than the pressure upstream of the muffler for all times, suggesting that the muffler has been specifically tuned for this engine speed (as opposed to the lower engine speed).

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Figure : Upstream and downstream pressure trace across muffler for 1000 RPM (left) and 2000 RPM (right).

## Part 2

Figure 2 shows the downstream exhaust pressure traces in time for the straight pipe versus muffler, for both engines speeds. It can be seen from the plots that the muffler produces a significant attenuation of the oscillation amplitudes over that of the straight pipe. High frequency oscillations are still observable in the straight pipe spectra whereas in the muffler spectra they are of negligible amplitude. Interestingly, the higher engine speed results in a smaller spectral range of high frequency oscillations than the lower engine speed, even for the straight pipe section. This is likely due to the fact that the fundamental oscillations have doubled in frequency, as has the resulting higher order oscillations, and the dampening effect of viscosity increases with increasing wave frequency.

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Figure 2: Downstream muffler and straight pipe pressure traces for 1000 RPM (left) and 2000 RPM (right).

## Part 3

Figure 3 shows the downstream exhaust pressure spectra for the straight pipe versus muffler at both engine speeds, calculated via a discrete Fourier transform. The values at each order are also included in Table 1. As one would expect based on the pressure traces, the muffler produces increasing attenuation over the straight pipe as the frequency (or order) increases for both engine speeds. For the lower engine speed, near the fundamental firing frequency of the engine (corresponding to order of two) and its first harmonic, the muffler produces the weakest attenuation compared to the straight pipe; however the attenuation is still non-negligible. For the higher engine speed, only the fundamental firing frequency is weakly damped; the first harmonic is significantly damped as compared to the straight pipe. As before, this suggests that the muffler has been tuned to the higher engine speed.

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Figure 3: Downstream muffler and straight pipe pressure spectra for 1000 RPM (left) and 2000 RPM (right).

Table : Downstream muffler and straight pipe pressure spectra for 1000 RPM and 2000 RPM.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 1000 RPM | | 2000 RPM | |
| Order | Straight Pipe | Muffler | Straight Pipe | Muffler |
| 0.0 | 194 | 194 | 194.1 | 194.1 |
| 0.5 | 117.7 | 108.8 | 112.5 | 119.4 |
| 1.0 | 121.6 | 99.7 | 120.3 | 113.6 |
| 1.5 | 129.5 | 113.3 | 106.5 | 108.9 |
| 2.0 | 160.7 | 149.4 | 157.9 | 144.9 |
| 2.5 | 109.9 | 103.1 | 117.5 | 110.2 |
| 3.0 | 108.9 | 88 | 120.6 | 101.8 |
| 3.5 | 118.1 | 108.9 | 119.2 | 94.6 |
| 4.0 | 154.9 | 142.6 | 150.8 | 123.7 |
| 4.5 | 120.6 | 104.9 | 108.7 | 90.2 |
| 5.0 | 115.1 | 99.3 | 108.3 | 69.4 |
| 5.5 | 121.9 | 99.7 | 110.9 | 88 |
| 6.0 | 154.7 | 132.5 | 144.9 | 117.2 |
| 6.5 | 124.1 | 100 | 111.4 | 94.9 |
| 7.0 | 113.6 | 94.5 | 123 | 95.9 |
| 7.5 | 115.8 | 95.9 | 112.8 | 100 |
| 8.0 | 141.1 | 113.7 | 133.6 | 118.5 |
| 8.5 | 115.1 | 84.8 | 113.9 | 92.7 |
| 9.0 | 104.4 | 71.5 | 113.3 | 85.6 |
| 9.5 | 114.1 | 82.2 | 105.7 | 74.8 |
| 10.0 | 135.8 | 105 | 125.6 | 86.7 |
| 10.5 | 118.3 | 83.1 | 96.6 | 75.6 |
| 11.0 | 113.2 | 80.3 | 111.3 | 85.3 |
| 11.5 | 115.5 | 78.8 | 107.5 | 82 |
| 12.0 | 140.5 | 112.1 | 129.5 | 94.6 |
| 12.5 | 115.9 | 94.5 | 95.1 | 75.6 |
| 13.0 | 121.2 | 92.7 | 102.2 | 77.5 |
| 13.5 | 114.6 | 96.3 | 107 | 75.6 |
| 14.0 | 136.1 | 117.3 | 120.4 | 87.2 |
| 14.5 | 115.2 | 101.7 | 90.5 | 76.2 |
| 15.0 | 125.3 | 93.1 | 101 | 68.4 |
| 15.5 | 122.3 | 86.7 | 99.9 | 76.9 |
| 16.0 | 137.3 | 100.3 | 119.1 | 84.6 |
| 16.5 | 113.7 | 85.7 | 92.1 | 71.6 |
| 17.0 | 113.2 | 83.8 | 100.6 | 69.1 |
| 17.5 | 112.4 | 76.7 | 91.5 | 55.7 |
| 18.0 | 126.2 | 92.9 | 116.3 | 79.1 |
| 18.5 | 85.3 | 71.2 | 93.9 | 73.1 |
| 19.0 | 97.2 | 69 | 101.9 | 69.1 |
| 19.5 | 103.7 | 78.7 | 91.7 | 62.5 |
| 20.0 | 116.6 | 88 | 111.6 | 53.3 |

## Part 4

Table 2 shows the insertion loss in decibels for both engine speeds, calculated by subtracting the sound pressure level at second order of the muffler spectra from the straight pipe spectra. Clearly, the muffler produces greater attenuation at the higher engine speed, which agrees with previous observations.

Table : Insertion loss at second order for 1000 RPM and 2000 RPM engines speeds.

|  |  |
| --- | --- |
| RPM | Insertion Loss (dB) |
| 1000 | 11.334 |
| 2000 | 12.976 |

# Appendix

clear;clc;

fname = 'experiment3.xls';

sheetname = {'Straight Pipe (1000 RPM, WOT)', 'Straight Pipe (2000 RPM, WOT)', 'Muffler (1000 RPM, WOT)','Muffler (2000 RPM, WOT)'};

tmp = zeros(7200,3,4);

RPM = [1000 2000 1000 2000];

for j = 1:length(sheetname)

tmp(:,:,j) = xlsread(fname,sheetname{j});

time{j} = (tmp(:,1,j)/360/RPM(j))\*60;%check this

FS = mean(diff(time{j}))^-1;

N = length(time{j});

[f{j}, SPL{j}] = calcSPL\_v2(tmp(:,3,j),FS,N);

SPL{j} = 10\*log10(SPL{j}/4E-20);

O{j} = f{j}\*60/RPM(j);

end

%Part 1

h(1) = figure; j = 3;

plot(time{j},tmp(:,2,j),'k',time{j},tmp(:,3,j),'k--');title(sheetname{j});xlabel('Time (s)');ylabel('Pressure (bar)');legend('Upstream','Downstream');

filename = sheetname{j};

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

h(2) = figure; j = 4;

plot(time{j},tmp(:,2,j),'k',time{j},tmp(:,3,j),'k--');title(sheetname{j});xlabel('Time (s)');ylabel('Pressure (bar)');legend('Upstream','Downstream');

filename = sheetname{j};

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

%Part 2

h(3) = figure;

plot(time{1},tmp(:,3,1),'k',time{3},tmp(:,3,3),'k--');title('1000 RPM Pressure');xlabel('Time (s)');ylabel('Pressure (bar)');legend('Straight Pipe','Muffler');

filename = '1000 RPM Pressure';

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

h(4) = figure;

plot(time{2},tmp(:,3,2),'k',time{4},tmp(:,3,4),'k--');title('2000 RPM Pressure');xlabel('Time (s)');ylabel('Pressure (bar)');legend('Straight Pipe','Muffler');

filename = '2000 RPM Pressure';

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

%Part 3

h(5) = figure;

plot(O{1},SPL{1},'k',O{3},SPL{3},'k--');title('1000 RPM Pressure Spectra');legend('Straight Pipe','Muffler');xlim([0 20]);xlabel('Order');ylabel('SPL (dB)');

filename = '1000 Spectra';

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

fid = fopen([filename,'.txt'],'w');

fprintf(fid,'%6.1f \t %6.1f \t %6.1f \n',[O{1} SPL{1} SPL{3}]');

fclose(fid);

h(6) = figure;

plot(O{2},SPL{2},'k',O{4},SPL{4},'k--');title('2000 RPM Pressure Spectra');legend('Straight Pipe','Muffler');xlim([0 20]);xlabel('Order');ylabel('SPL (dB)');

filename = '2000 Spectra';

saveas(gcf,filename,'fig');saveas(gcf,filename,'png');

fid = fopen([filename,'.txt'],'w');

fprintf(fid,'%6.1f \t %6.1f \t %6.1f \n',[O{2} SPL{2} SPL{4}]');

fclose(fid);

%Part 4

fid = fopen('Insertion loss.txt','w');

fprintf(fid,'%6.1f \t %6.3f \n',[1000 SPL{1}(5)-SPL{3}(5); 2000 SPL{2}(5)-SPL{4}(5)]');

fclose(fid);

close(h);