12 Silencing

Work at Queen's University Belfast continued for many years on the basis that the only real way to predict gas behaviour is through the use of unsteady gas dynamics rather than acoustics, which they have done much to discredit. A number of papers by Coates and Blair give us some tools to work with, as opposed to putting a perforated steel tube in an aluminum can and stuffing with glass wool and hoping for the best.

What I would like to do is to understand what the exhaust sound properties are for my engine in its current state of tune with its existing exhaust. A tall order you would think especially if you do not want to spend much money, and indeed I did think that until 2010 when I finally understood This is one of the significant enhancements in theory and practice that I have added in 2012. The basic steps are to record the sound using a good microphone to tape or SD card, analyse the sound using free software, see what frequencies are dominant, apply the acoustic formulae, hopefully removing them with no reduction in power, repeat as necessary.

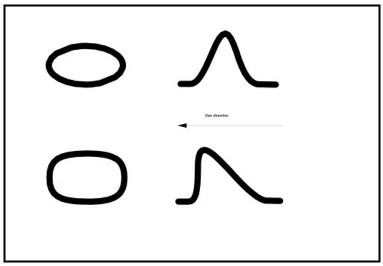

Figure 74 Exhaust port wave profile

As might be expected, the shape of the exhaust port has a significant effect on the exhaust note as well as on engine performance. The experimental data confirms this, with the "square" exhaust port profile giving a steep fronted wave compared with the gentler profile of the truly oval port shape, see Fig 74 . Research has shown that the soft oval port shape will give a primary sound frequency around five times the engine pulse rate, whereas the square-ish tuned exhaust port with its steep fronted wave will give a primary sound frequency at around twenty times the engine pulse rate.

Engine	Port shape		
RPM	Oval	Squared	
4000	267 Hz	1333 Hz	Primary frequency
6000	500	2000	
8000	533	2667	

Since all exhaust ports are somewhere between oval and square, this gives a rather large frequency band to target a silencer at, and the more unfortunate as the human ear is particularly sensitive in the 2000 - 2500 Hz range.

We have three basic techniques which we can use when designing a silencer

a) Frequency tuned diffuser (Fig 75)

b) Frequency tuned resonator (Fig 76)

The resonator is tuned by varying the number of holes, and the hole diameters pierced in a tube running through the centre of a canister on known volume. It is known that clean sharp holes will give a whistle, that is how many musical instruments work! Much better to drill or pierce the holes at an angle of 45 or 60 degrees.

c) Frequency absorption by certain materials, such as glass wool.

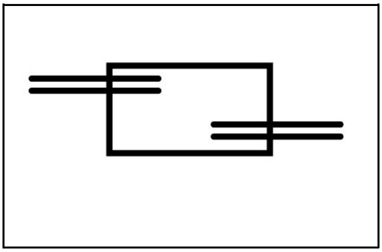

Figure 75 Frequency tuned diffuser

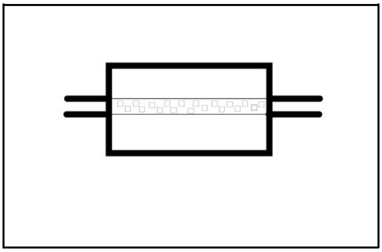

Figure 76 Frequency tuned resonator

A typical silencer will make use of some or all of these techniques. In a worked example, we will use each technique and predict the amount of sound that the silencer will absorb and at which frequencies. This example produces a silencer too long for some applications, but it does illustrate how some science may be applied to what was previously a black art form, our schematic design is shown in Fig 77 .

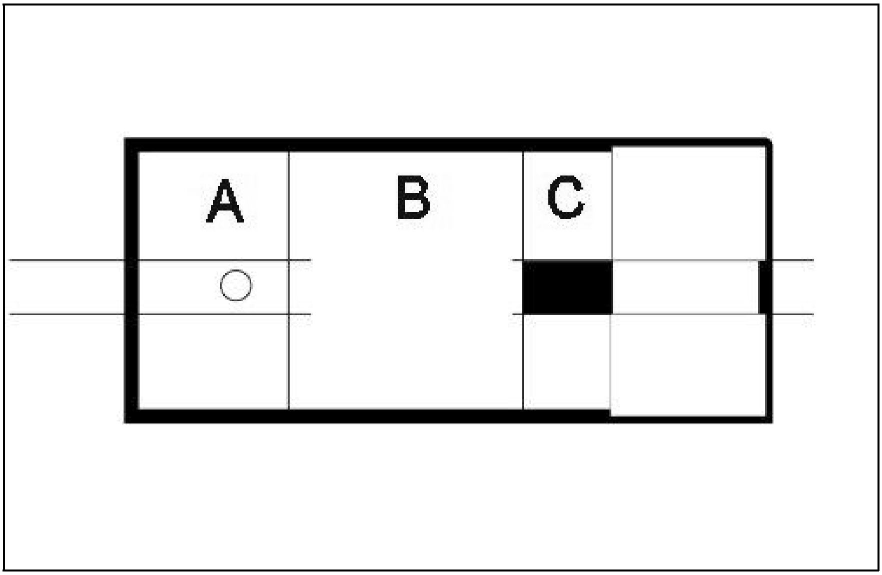

Figure 77 Silencer design

The dimensions assumed throughout are

Can diameter	76 mm	
Pipe diameter	32 mm OD, wall thickness	1.5 mm
Sonic speed	37,300 cm/sec (80 centigrade)	

The expansion chamber baffle cone bleeds away its pressure through the stinger pipe, and it is the stinger pipe which passes through the silencer. The gas passes through chamber A (resonance), then chamber B (diffuser), then chamber C (resonance) and then through an amount of perforated tube surrounded by glass wool, which tends to absorb the higher frequencies.

The design criteria for the three chambers are

	A(red)	B(blue)	C(yellow)
Chamber length (mm)	150	250	50
Number of holes	2		44
Hole diam (mm)	5.0		3
Max Attenuation (dB)	50	48	40

Green line is A,B,C root mean squared combined value
The PDF version is in colour, but for those with a book the chart is in B&W regrettably but the plots are labelled as A B C.

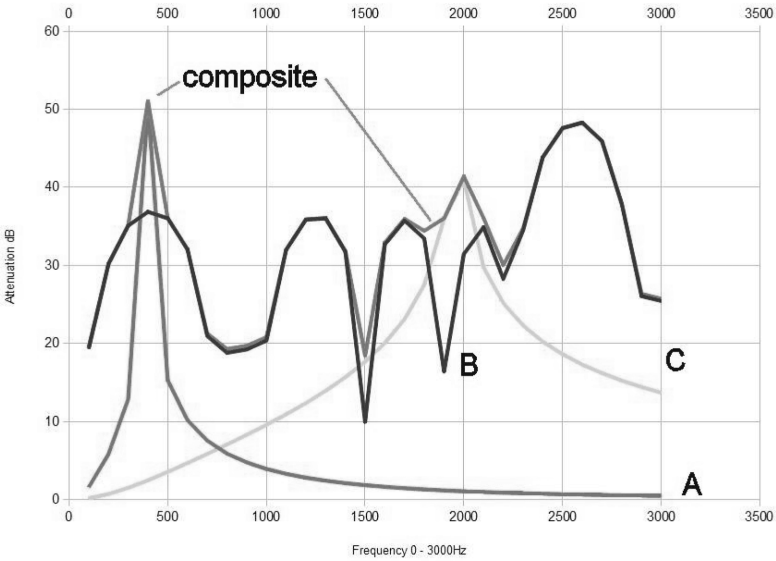

Figure 78 Example 1 : dB Attenuation prediction

We have tried to hit the dominant frequencies at 6000 rpm, that is 500 Hz and 2000 Hz, by a process that we will examine in two worked examples.

A word of explanation about sound measurement and decibels (dB). The human ear can hear a wide range of sound volume, from the almost imperceptibly wide quiet (1 Pico-watt per square metre) to the extremely loud (1 watt per square metre), a range of 12 orders of magnitude. Noise meters are pressure transducers, and measure the “effective sound level” which is the root-mean-square of the pressure fluctuations about the mean pressure level of the sound. As the range of value is so large, we use a logarithmic scale with units of “Bels”, but the unit is too large for everyday use, so we use a one-tenth unit named “deci-Bel” or dB. Since the scale is logarithmic (to base 10) then a change of loudness from 1 Bel to 2 Bels signifies an increase in loudness by a factor of 10. To combine two or more sounds, take the anti-logs of the Bel values, add them together, and take the log of that sum. Two sounds each at 100dB would combine to give a combined loudness of 103dB, a 90dB sound with a 100dB sound would give 100.4dB. The loudest noise in the exhaust will completely consume the lesser ones, so taking out that dominant frequency is the initial focus.

Now for some discussion about the diffuser and resonator chambers.

The resonator has a pipe with just a few holes in it, and it blows just like a whistle, the note is a function of the holes, the wall thickness of the tube, and