Design and development of silencers for F2C team race.
Rob Metkemeijer.
December 2013

1. Introduction

From 2015 engines in F2C will need to be equipped with exhaust systems that give 14 dB(A) reduction of noise measured on an electroacoustic noise generator. For this procedure see annex M.

In this paper a design approach will be given to develop exhaust systems that meet this requirement and at the same time suit the currently used engine types.
It is important to say is that the approach given here is without doubt just one of the possibilities. I think that there may also be other ways to go.
However this approach has been tested and it works, but further development and optimization is possible.
The reason for publishing this information is to give competitors and manufacturers a starting point for design and development.

2. General characteristics.

Current F2C engines are all of the 2 stroke compression ignition (diesel)type. The back pressure at the exhaust port from any exhaust system will influence the scavenging process and the initial pressure in the combustion chamber.

1. When an exhaust system changes this initial pressure (which is very close to a (constant)1 atmosphere in an open exhaust engine) the effective compression ratio is changed, usually in an rpm and gas temperature dependent way. A temperature and rpm dependent compression is something we are not used to and this may give problems in setting the engine and getting a constant run. In the approach discussed here, the aim is to minimize this back pressure and to make it independent of rpm in order to be able to use the same compression settings as used with an open exhaust engine. This is done by using a "neutral mini pipe" principle. See below.

2. Influencing the scavenging process can result in either more or less fresh mixture, and more or less"spoiling"(going out without being burned) of fresh mixture.
   We all know the effects of a properly working tuned pipe, giving more mixture, a higher initial pressure and more fuel efficiency compared to the open exhaust engine. The fact is, in"real" two stroke engines the exhaust system is an important factor in fuel economy and carbon hydrate (waste fuel) emissions. There is a lot of room for development to optimize the combination of scavenging and exhaust systems.

3. The neutral mini pipe principle

   The mini pipe is well known for model engines and is based on the principle that, with a short pipe connected to the exhaust port, the positive pressure wave from the exhaust will be reflected as a negative pressure wave to the exhaust port. This speeds up the scavenging process and will usually have the effect that the ratio between old gas and fresh mixture in the combustion chamber is improved. The price we pay is that more fresh mixture will be going out and fuel consumption will go up. The energy in the exhaust gas is used to speed up the scavenging.

The effect of the mini pipe for engine behaviour is depending on its length and diameter. When we reduce the diameter or make the pipe longer, the flow resistance of the pipe will increase which gives a positive back pressure to the exhaust.
When we increase length the negative pressure will also come back to the exhaust a bit later and will be less strong (less negative back pressure) and also the flow resistance increases, which makes the positive back pressure higher.
By proper dimensioning of length and diameter it will be possible to get the back pressure to approximatly zero, so the engines “sees” approximately the same as it sees without the mini pipe. That is what I call a neutral mini pipe. In this case the compression setting of the engine will be the same with and without this pipe over quite a broad rpm range.
Starting from the 60 mm^2 (diameter 8.7 mm) that is in the rules for the maximum exhaust area of the cylinder as well as for the gas outlet of the silencer, the length that provides this is in the order of 120 mm for an exhaust timing around 150 degrees and rpm’s between 24.000 – 30.000. Uncertainties in the calculation of back pressure are the gas temperature and the side holes (used for the silencing effect, see further).
Experiments have shown that this approximation worked quite well.
However, there is a lot to play for inside the rules by adjusting the length, diameter and geometry of the pipe.

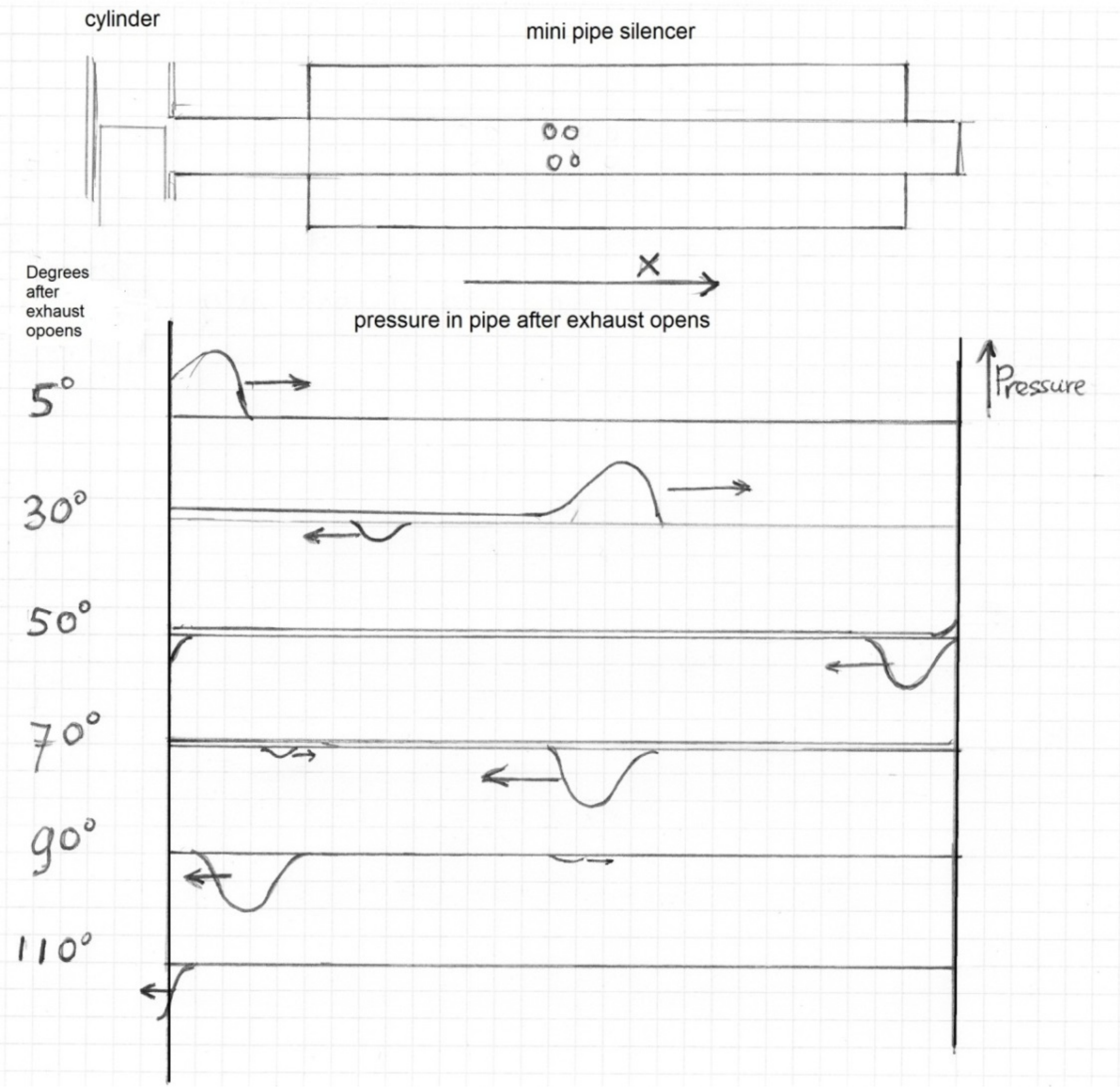


Fig 1. Pressures in a straight pipe with single side resonator behind the exhaust. Parameter is the crankshaft angle after exhaust opens.

The silencing effect is simply made by adding a number of so called side resonators to the pipe. These consist of holes in the pipe wall connected to closed volumes in such a way that the appropriate frequencies are attenuated.

4. Silencer design.

An acoustic analysis of the noise from a team race engine shows that the noise attenuation needs to be in the 1500 – 5000 Hz range.
As a starting point I used a pipe with constant a constant cross section of 60 mm^2, an outside diameter of approximatly 22 mm and 3 side resonant chambers with resonance frequencies of approximatly 2000 Hz, 3000 Hz and 4000 Hz.
If a larger outside diameter of the silencer is chosen, e.g. 28 mm, then the number of chambers may be reduced to 2, one at 2300 Hz and one at 3500 Hz. This is because larger volume chambers have a higher acoustic effect and can absorb sound in a wider band.

For the attenuation characteristics of side resonant silencers the program 8.2 of Blair can be used, see annex?.

A possible silencer design for a side exhaust engine with 3 chambers and an outside diameter of 22 mm is given below. This one was calculated with the Blair program and fulfils the requirement of 14 dB(A) insertion loss as measured with the standard noise generator.

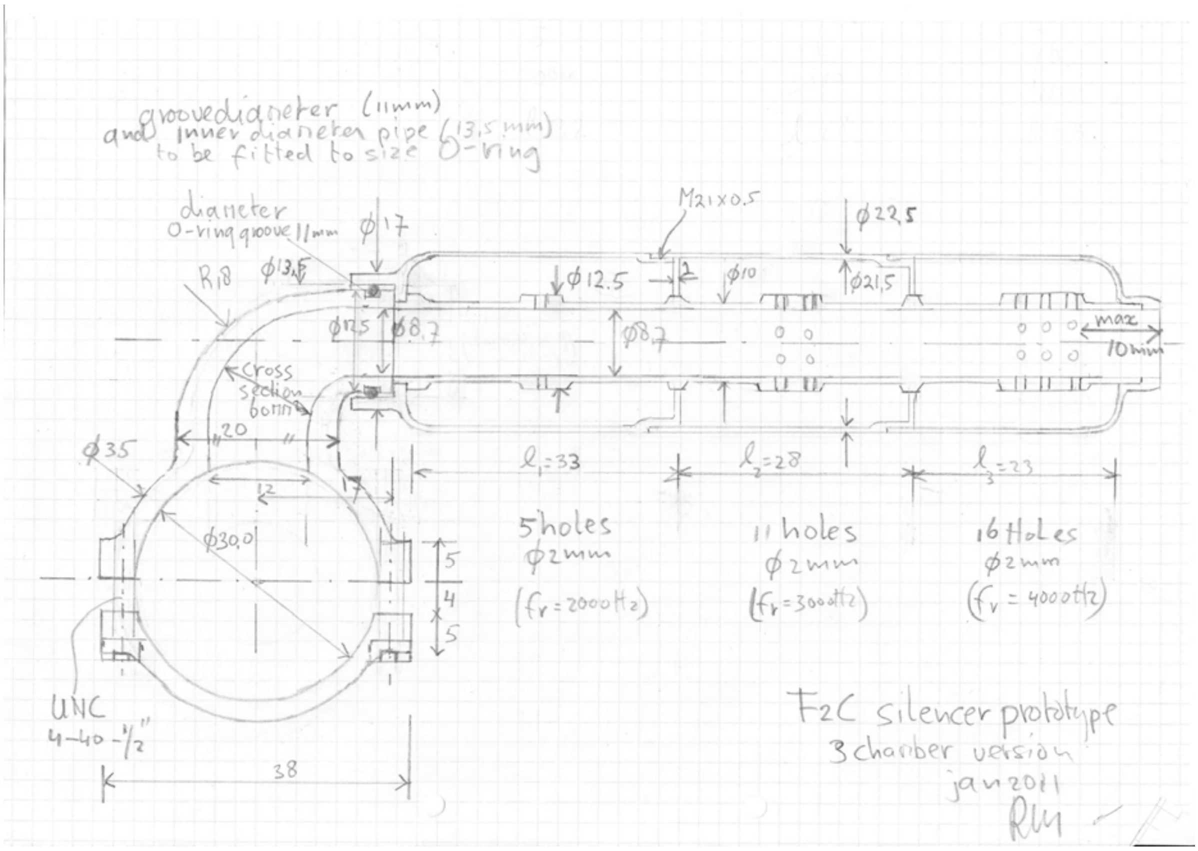
Note that for gas flow (and thus power) the total length and inside diameter of the tube are of main importance and for the acoustic performance the volumes of the side chambers and the number, diameter and length of holes.

This implies that engine performance and acoustic performance can be developed more or less independently; the number of possible variations and combinations to find the optimum is almost infinite; the challenge is to find an optimum for both.

The connection between the exhaust port in the cylinder and the silencer (manifold or rear exhaust shape) is important for gas flow.

There may be scope to adjust the diameter and volume of the pipe in the local area near the exhaust port and/or to play locally with the pipe diameter in order to optimize the initial phase of exhaust gas expansion and to regulate the back pressure wave.

Annex 1. Example F2C silencer



A few parameters:

Total mean length of pipe from side of the piston to exhaust gas outlet L	125 mm
ID inner pipe, D_{ii}	8.7 mm (60 mm^2)
OD inner pipe at position of side holes D_{io}:	12.5 mm
ID silencer chambers D_o:	21.5 mm

Length chamber 1 L_1 33 mm, number of holes N =5, diameter 2 mm
Length chamber 2 L_2 28 mm, number of holes N =11,diameter 2 mm
Length chamber 3 L_3 23 mm, number of holes N =16,diameter 2 mm