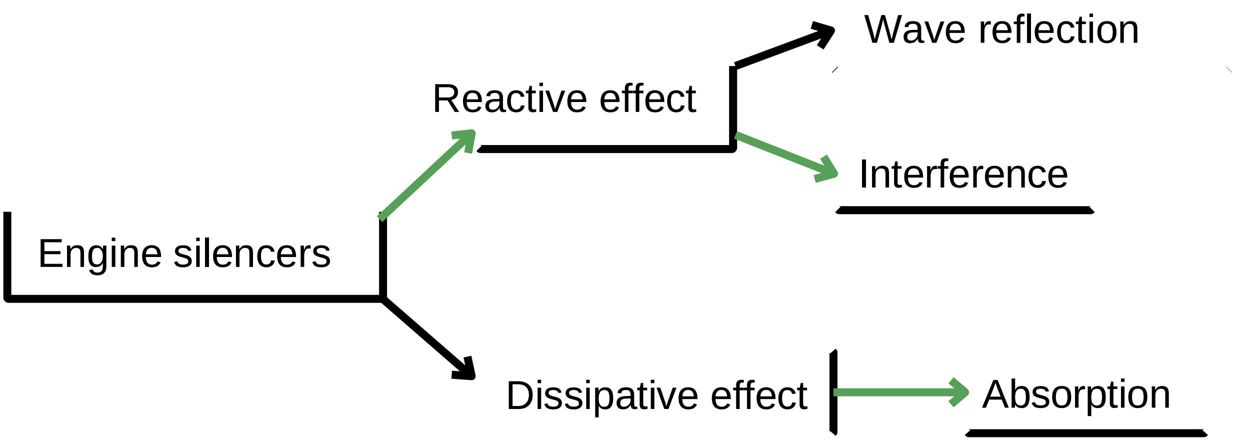
OPERATING PRINCIPLE

ENGINE SILENCER

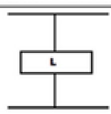
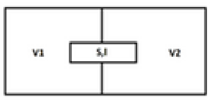
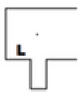
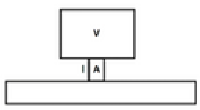
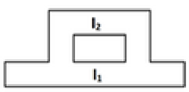
Engine silencers are devices integrated into the exhaust line of internal Combustion engines. They are designed to reduce the noise emitted by the engine while minimising pressure losses. These are known as passive silencers.
Unlike active silencers, which use electrical and electronic components to reduce noise by wave interference, passive silencers are purely mechanical devices. They use two operating principles to achieve this acoustic objective. Reactive attenuation and dissipative attenuation.
This note covers the theoretical bases of these 2 physical phenomena.



Mitigation by reactive effects :

Wave reflection is caused by reflective surfaces, changes in cross-section, or changes in the medium in the silencer. This causes an impedance break in the silencer and some of the incident acoustic energy is reflected back towards the source.
When two sound waves meet with a certain phase shift, constructive or destructive interference is created, which can lead to an increase or decrease in sound amplitude depending on the phase shift angle. Resonators such as Helmholtz resonators, quarter-waves and Herschel-Quincke resonators use this principle to generate destructive interference at specific frequencies.
It is important to note that the reactive effect in engine silencers is highest at low frequencies, where sound waves can be considered as plane waves. Its effectiveness is very high over restricted frequency ranges centred on the resonance frequencies of the various resonators present in the silencer. This is why it is crucial to 'tune' silencers correctly to the fundamental frequencies that need to be treated to achieve effective noise attenuation.

Below are some equations valid in the plane wave domain for calculating the frequencies mentioned below (Helmholtz frequency, closed bottom, open tube, etc.):

	Géométrie	Formule
Fréquence d'un tube ouvert		$f=n.\frac{c}{2.L}$
Fréquence d'Helmholtz		$f=\frac{c}{2.\pi}.(\frac{S1}{V1.l}+\frac{S2}{V2.l})^{0.5}$
Fréquence d'un fond fermé		$f=(2.n+1).\frac{c}{4.L}$
Fréquence d'un résonateur d'Helmholtz		$f=\frac{c}{2.\pi}.(\frac{A}{V.l})^{0.5}$
Fréquences de Herschel-Quincke		$f_1=\frac{c}{2.(l_2-l_1)}$ $f_2=\frac{c}{l_1+l_2}$

Attenuation by dissipative effect :

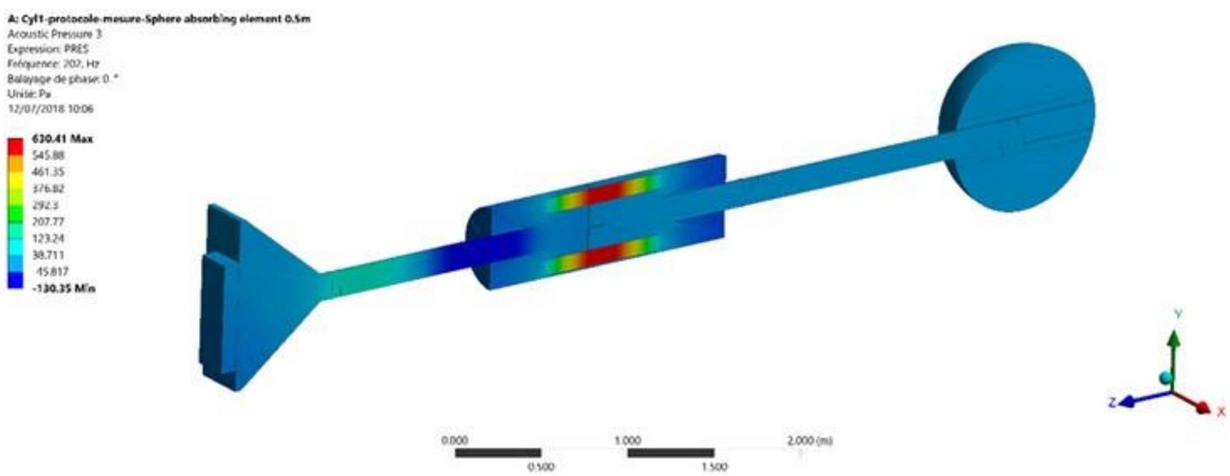
Dissipative attenuation

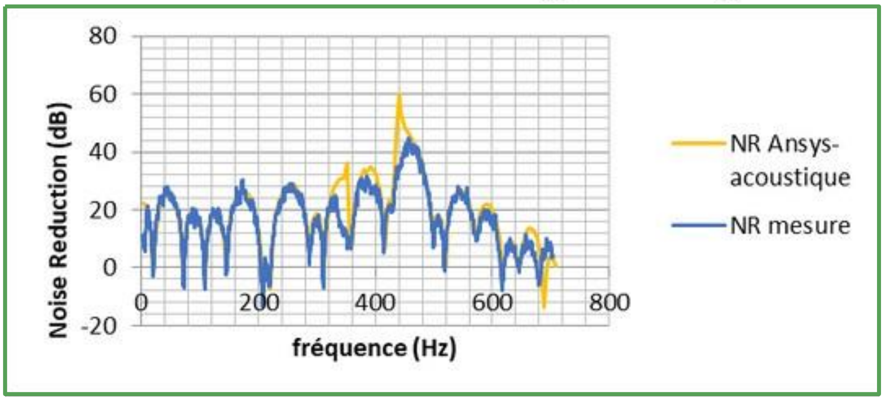
Engine silencers also use fibres to absorb part of the sound waves. As these waves pass through the fibres, they cause the fibre skeleton to vibrate, resulting in mechanical dissipation of the sound energy and, consequently, conversion of the energy into heat. In addition, the friction of the air molecules in the porous medium leads to visco-inertial dissipation of the acoustic energy.

Absorption is effective at medium and high frequencies. It is important to choose the right absorbent material and its correct installation in the silencer to obtain optimum attenuation. Generally, it is used as a lining, core or ring for cylindrical ducts. For rectangular ducts, it is arranged in parallel baffles.

Perforated sheets and/or glass cloth can be added to prevent defibration.

Boët StopSon silencers have been designed using finite element and fluid simulation software. This software has enabled us to take proper account of both reactive and dissipative effects, while minimising pressure losses.





In order to model a fibre correctly, it is necessary to know various intrinsic parameters of the porous material :

- Porosity
- Tortuosity
- Resistivity
- Viscous characteristic length
- Thermal characteristic length

Under certain conditions, the mechanical properties of the skeleton may be necessary.

These parameters are then used in various models (Delany-Bazley-Miki, Johnson-Champoux-Allard-Lafarge, Limp, Biot-Allard) and enable us to tune our silencers as precisely as possible to the sound spectra of the engines.

$$\tilde{\rho}(\omega) = \frac{\alpha_\infty \rho_0}{\phi}\left[1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty}\sqrt{1 + j\frac{4\alpha_\infty^2\eta\rho_0\omega}{\sigma^2\Lambda^2\phi^2}}\right]$$

$$\widetilde{K}(\omega) = \frac{\gamma P_0/\phi}{\gamma - (\gamma-1)\left[1 - j\frac{\phi\kappa}{k_0' C_p\rho_0\omega}\sqrt{1 + j\frac{4k_0'^2 C_p\rho_0\omega}{\kappa\Lambda'^2\phi^2}}\right]^{-1}}$$