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Report

PhR26-011

Acoustic and aerodynamic design of dissipative silencers: the status of the Art

Corresponding features of the software SILDIS (*)

** Sound Impact Limitation : Design for Industrialized Solutions*

Ph. Reynaud, May 2026

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Dissipative silencers: introduction

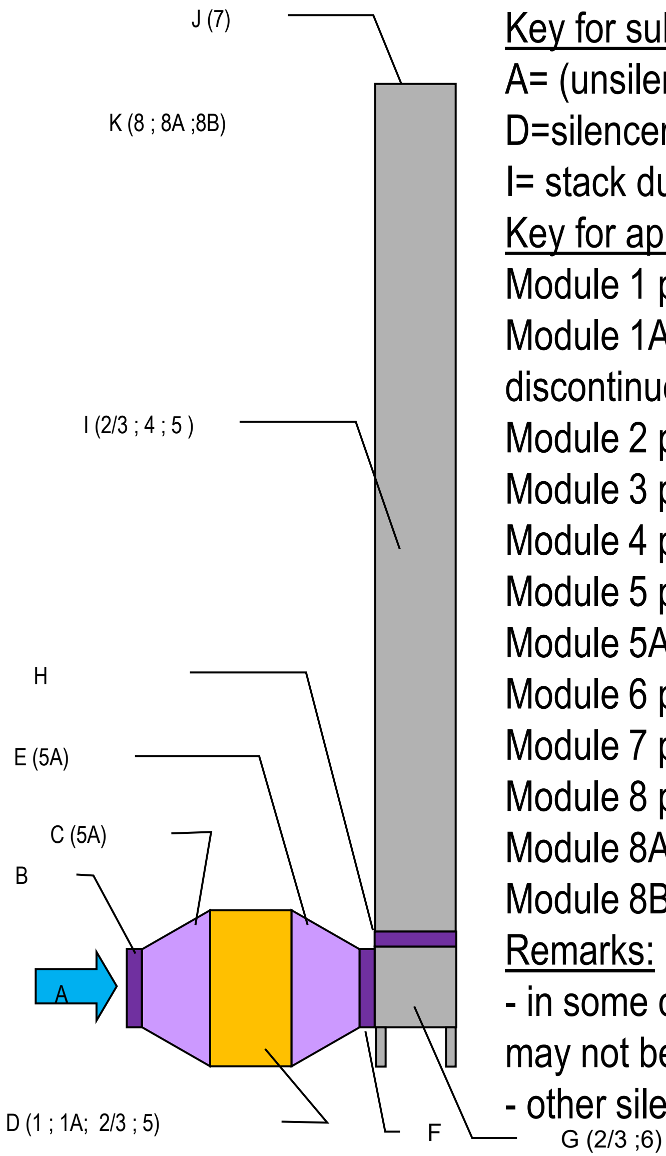
➢ Terms and definitions (according NF EN ISO 14163 Acoustics - Guidelines for noise control by silencers, 1999):

Silencer: device reducing the acoustic transmission in a duct, a pipe or an aperture, without preventing the carriage of the fluid

Dissipative silencer: silencer attenuating the wideband sounds with a relatively low pressure loss and converting partially the acoustic energy into heat by friction on tubes having a porous or fibrous structure

➢ Standardized measurement: according NF EN ISO 7235 Acoustics - Laboratory measurement procedures for ducted silencers and air terminal units- Insertion loss, flow noise and total pressure loss (2004).

Example of silencing arrangement HB: corresponding modules of the software SILDIS



Key for subsets of the aeraulic system from A to J and K = atmosphere):

A= (unsilenced) noise source e.g. fan outlet ; B= expansion joint ; C= transition D=silencer ; E= transition ; F= expansion joint ; G=bend/diverter/T-box, H=expansion joint; I= stack duct ; J= nozzle

Key for applicable Modules of SILDIS (from 1 to 8B):

Module 1 prediction of acoustic and aerodynamic performance of silencers

Module 1A prediction of acoustic and aerodynamic performance of silencers with discontinued splitters

Module 2 prediction of acoustic performance of plane partitions

Module 3 prediction of acoustic performances of duct walls

Module 4 prediction of acoustic performance of straight ducts

Module 5 prediction of break-out noise

Module 5A prediction of break-out noise of ducts with variable cross-section

Module 6 prediction of acoustic performance of bends

Module 7 prediction of nozzle reflection

Module 8 prediction of the sound impact of duct systems

Module 8A prediction of stacks directivity

Module 8B prediction of atmospheric sound absorption

Remarks:

- in some cases, some subsets (e.g. transition, expansion joints) of the aeraulic system may not be present or with different geometries
- other silencing arrangements can be accounted

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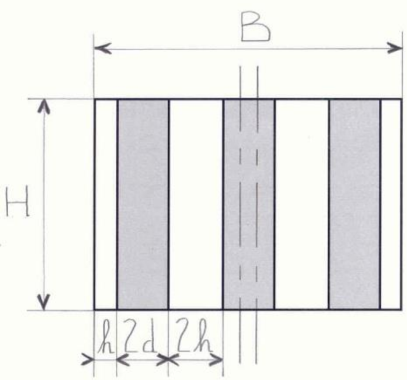
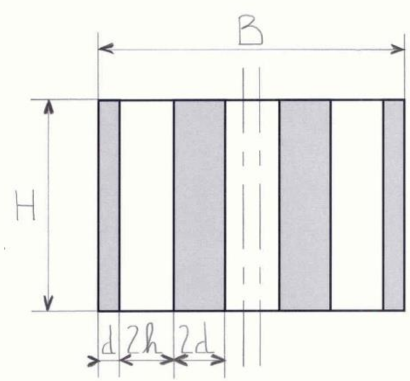
Key-points and routines for Module 1

Dissipative silencers: mountings

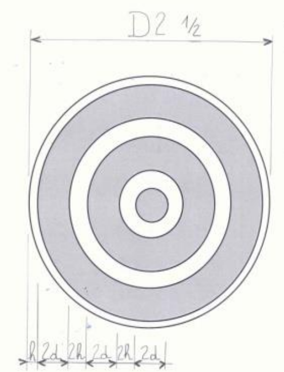
➢ Dissipative silencers having various cross sections are used for building or industrial applications, requiring appropriate predictions of performance.



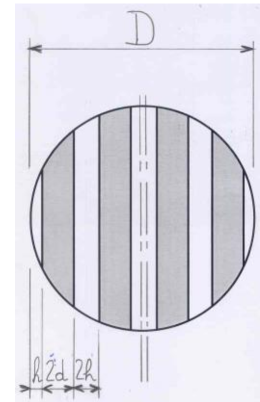
mounting R"



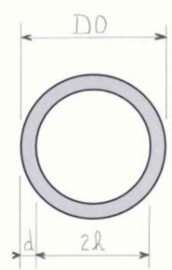
mounting R



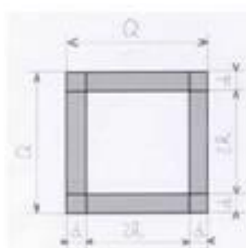
mounting Cx & Cx ½



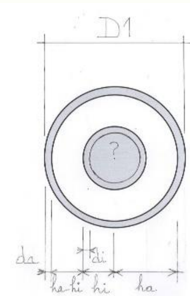
mounting CR



mounting C0

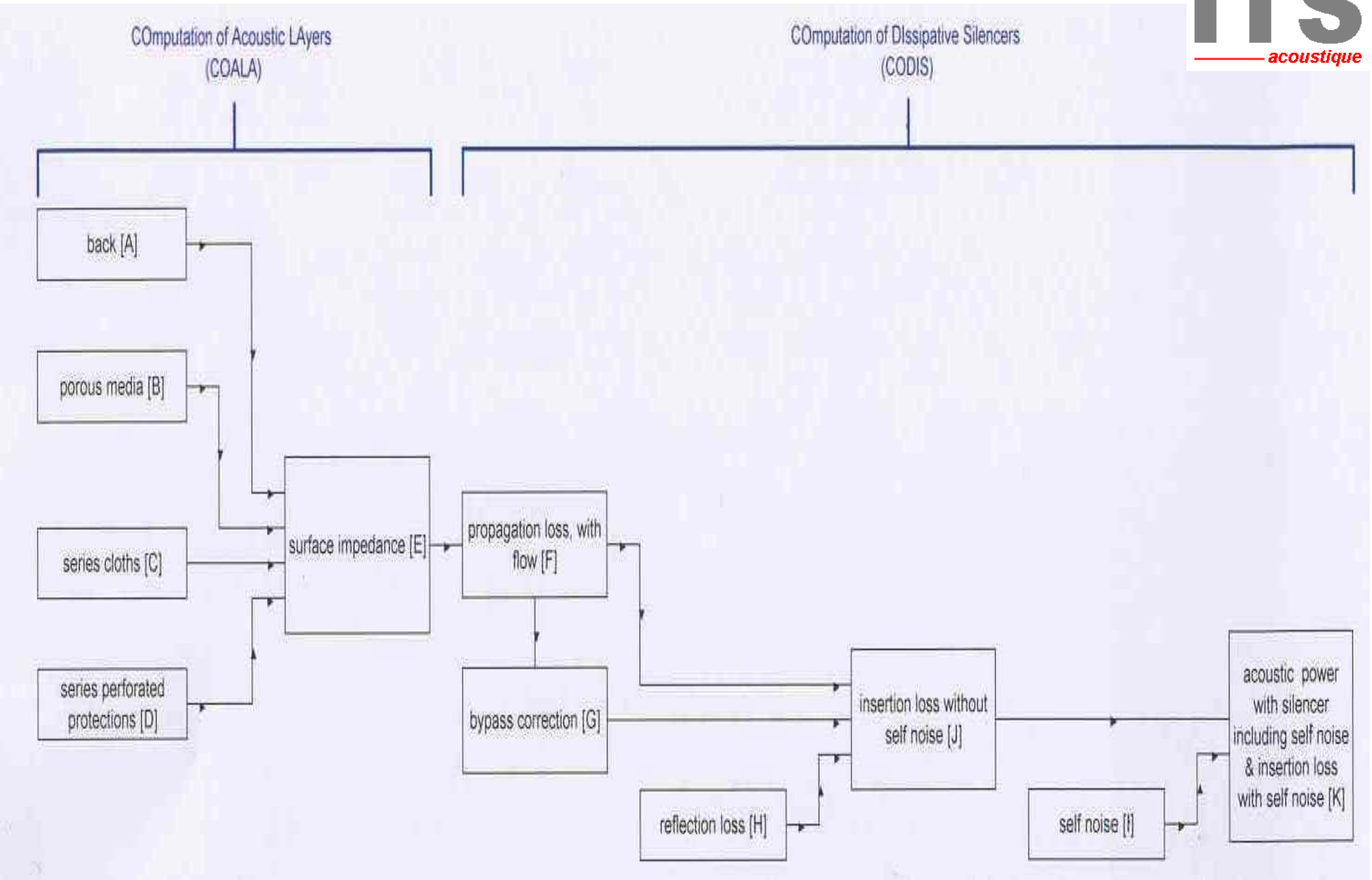


mounting Q



mounting C1

Dissipative silencers: computation scheme



Lining: the foreseen applications

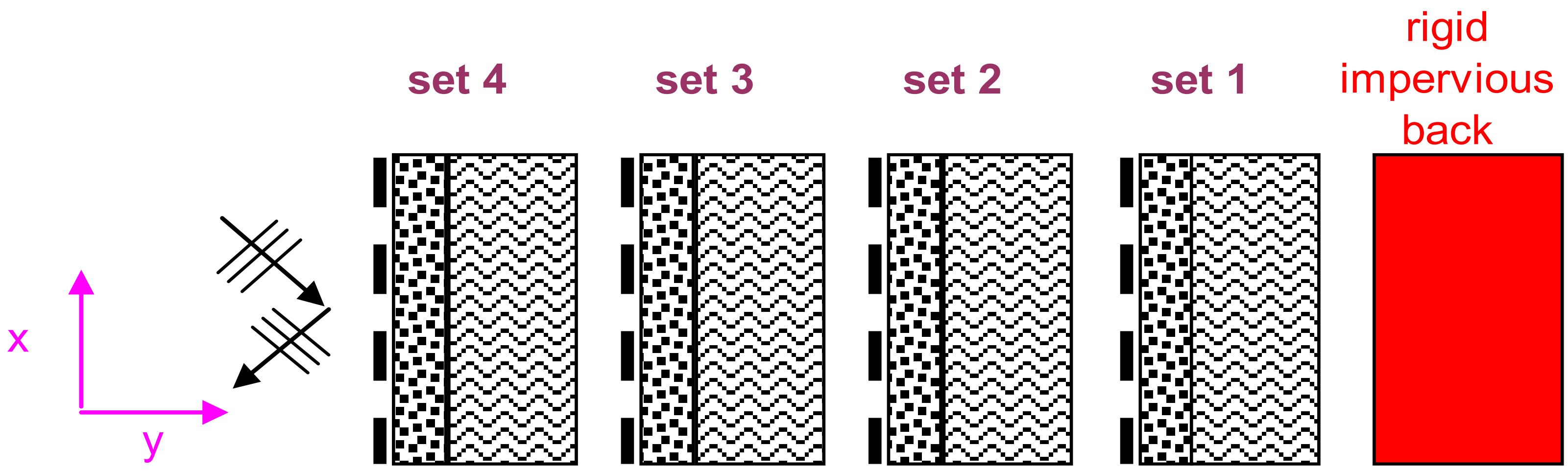
- The most sophisticated lining of interest for the applications foreseen at ITS consists in a **4 layers** filling:

  - 1 core layer of porous medium e.g. rock wool, basalt wool of variable thickness
  - 1 intermediate layer (e.g. needlemat, etc…) of variable thickness
  - 1 layer of cloth (e.g. fabric) of variable thickness
  - 1 layer of perforated sheet (e.g. with diameter of holes 3 or 5 mm in a hexagonal array with a perforation rate above 30 % thickness 1.5 mm or 2 mm)

- Lining different for adjacent baffles (rectangular silencer): possibly accounted

Lining: the combination of sets

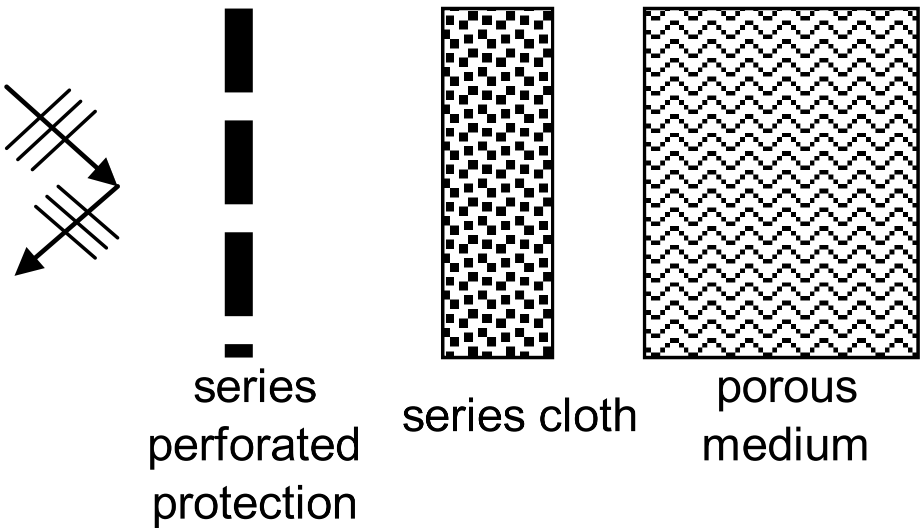
➢ In order to allow the corresponding computation to be done for such a combination of acoustic layers (and taking into account other predictions to be done in relation with the COmputation of Acoustic LAyers), it has been considered the propagation of sound in sets being indexed from an impervious rigid back at the rear to the front: 1 to 4. The surface impedance of the lining is calculated above the set **imax** with **imax** (selected) **from 1 to 4 .**



Lining: the elementary set

➢ Each set consists (from the rear to the front) of a up to 1 **porous medium**, up to 1 **series cloth** (i.e. a cloth acting as a series impedance using electro acoustic analogies), up to 1 **series perforated protection** (i.e. a perforated protection acting as a series impedance using electro acoustic analogies)

detail of each set (1 to 4)



Lining: the routine COALA (1/3)

COmputation of **A**coustic **LA**yers: in order to answer to the question (in terms of acoustic impedance)

Impervious rigid back (or rear symetry plane)

+

Porous media (of sets from 1 to imax≤4)

+

Series cloths (of sets from 1 to imax≤4)

+

Series perforated protection (of sets from 1 to imax≤4)

=

?

Lining: the routine COALA (2/3)

- various models have been analyzed and selected among the models known and used - almost - worldwide for porous media, series cloths, series perforated protections of variable thickness

- depending on the used models some of the following parameters are taken into account in relation with the properties of a **porous medium** (sometimes only in a direction parallel to or perpendicular to its surface):

σ (Nsm^{-4}) airflow resistivity, **Φ** porosity, α_∞ tortuosity, **Λ'** (m) thermal characteristic length, **Λ** (m) viscous characteristic, **RG** (kg/m3) density

Lining: the routine COALA (3/3)

- depending on the used models, some of the following parameters are taken into account in relation with the properties of a **series cloth**:

  Rs (Nsm^{-3}) airflow resistance, **ms** (kgm^{-2}) surface density of the filling

- depending on the used models, some of the following parameters are taken into account in relation with the properties of a **series perforated protection**:

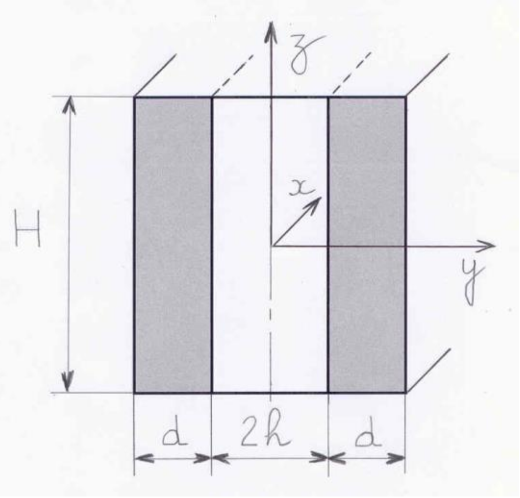
  geometry of perforation**,** ε open area ratio, **t** thickness (the interaction with porous media is also taken into account sometimes)

- some **cloths** and some **perforated protections** can also be modeled as **porous media** (« new wave approach »)

Lining: homogeneity (or not)

- Some absorbers (including some stone wools, some glass wools) are known to be non homogeneous in directions parallel to and perpendicular to the surface materials having (in particular) an airflow resistivity normal to laminae of fibers $\boldsymbol{\sigma_N}$ and an airflow resistivity parallel to laminae of fibers $\boldsymbol{\sigma_P}$ that can notably differ (with $\boldsymbol{\sigma_P}$ reaching only 0.5*$\boldsymbol{\sigma_N}$ sometimes). A difference along the direction normal or parallel to the laminae is also the case for other properties of numerous materials.

- In the software SILDIS, a possible inhomogeneity in directions parallel to and perpendicular to its surface (i.e. different properties - depending on the used model - in directions **x** and **y**) is considered (for the routine **CO**mputation of **DI**ssipative **S**ilencers) for the porous medium of set 1 (porous media for sets 2 to 4 being considered homogeneous in directions parallel to and perpendicular to the surface)



Lining: propagation inside

- The direction parallel to the axis of the duct being referred **x**, the direction normal to the axis of the duct being referred **y** (as for example of an R mounting just above), a sound propagation exists in the lining of a dissipative silencer, in a direction **y** (taken into account in the software SILDIS), depending on **σy** that is the flow resistance of the lining in the direction **y** : the attenuation of a dissipative silencer is always depending on this phenomenon (not only sometimes).

- Without transverse sufficiently thick metal sheets (with a very short distance between them: below 1/4 (maybe 1/6 ?) of the wavelength corresponding to the frequency of interest) acting as partitions, a sound propagation exists in the lining, in a direction **x**, depending on **σx** that is the flow resistance of the lining in the direction **x**

- 3 cases of propagation inside the porous media are to be considered **σx/σy**=∞ or **σx/σy=1** or **σx/σy=variable**

The routine CODIS (1/4)

COmputation of **DI**ssipative **S**ilencers:
in order to answer to the questions

given a considered lining as known thanks to the routine **COALA**
and
given the homogeneity (or not) of the lining
and
given the conditions of propagation inside the lining
and
given the aeraulic conditions of use of the silencer:

what about insertion loss ?
what about flow noise ?
what about total pressure loss ?

(given models analyzed and selected among various models known and used – almost – worldwide)

The routine CODIS (2/4)

- The propagation loss (**Da** in dB/m) is basically computed at frequency steps of 1/21 octave (then averaged per 1/3 octave frequency band) for the fundamental mode (being considered as the least attenuated mode), the cut off frequency for the first higher mode **fc** depending on the speed of sound **c**, the Mach number in the airways **M**, and the geometry of the duct . The longitudinal attenuation **Da.L** is proportional to **L,** the length of the silencer (m)

- A bypass correction (i.e. limitation of the longitudinal attenuation) (**Dc** in dB) is basically computed at frequency steps of 1/3 octave:

  if $L \leq L^*$ then $Dc = 0$
  if $L > L^*$ then $Dc = \Delta D * (1 - L)$ with ΔD in dB/m

- A reflection loss (**Dr** in dB) is basically computed at frequency steps of 1/21 octave (then averaged per 1/3 octave frequency band)

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The routine CODIS (3/4)

- The insertion loss without taking into account the self noise (**Di’** in dB) is basically computed at frequency steps of 1/3 octave (then calculated per 1/1 octave frequency band in reference to a reference acoustic power spectrum **Lw0** in dB ref 1E-12W):

Di’ = Da.L + Dc + Dr

- The acoustic power level with silencer including self noise (**Lw1** in dB ref 1E-12W) is basically computed at frequency steps of 1/1 octave (in reference to a reference acoustic power spectrum **Lw0** ref 1E-12W).

Lw1 = 10 * log [10^ (0.1 * (Lw0 – Di’)) + 10^ (0.1 * Lw)]

Lw being the self noise (acoustic power of flow noise in dB ref 1pW)

- The insertion loss taking into account the self noise (**Di** in dB) is basically computed at frequency steps of 1/1 octave (in reference to a reference acoustic power spectrum **Lw0** ref 1pW) **Di = Lw0 – Lw1**

The routine CODIS (4/4)

- The total pressure loss is computed from **$\Delta pt = \zeta * 0.5 * r * (Vf)^2$**

  ζ: coefficient of friction (6 models depending on geometry)
  Δpt: total pressure loss (Pa)
  r: density of fluid (kgm^{-3})
  Vf: speed in the area S (ms^{-1})
  S: area of the duct upstream / downstream (m2)

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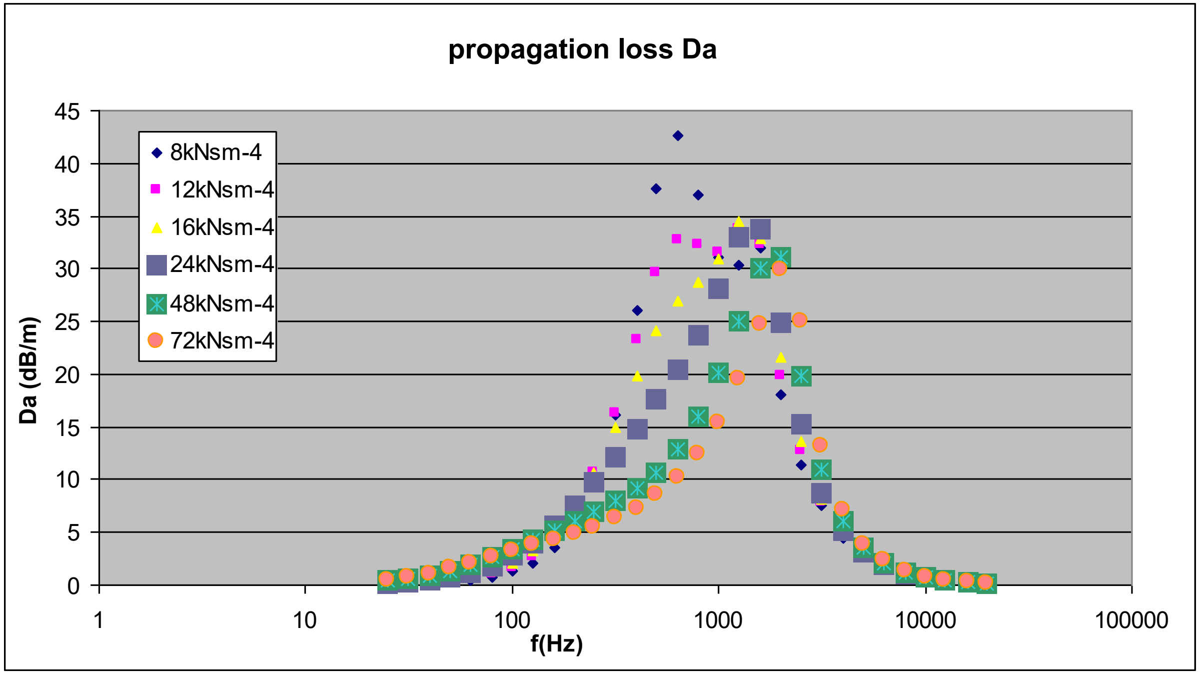
Illustrations of particular effects taken into account for the prediction of acoustic performances with SILDIS

Properties of a porous medium in a non-laminated lining

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1** variable from 8 to 72 kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m. No series cloth is considered, no series perforated protection is considered.



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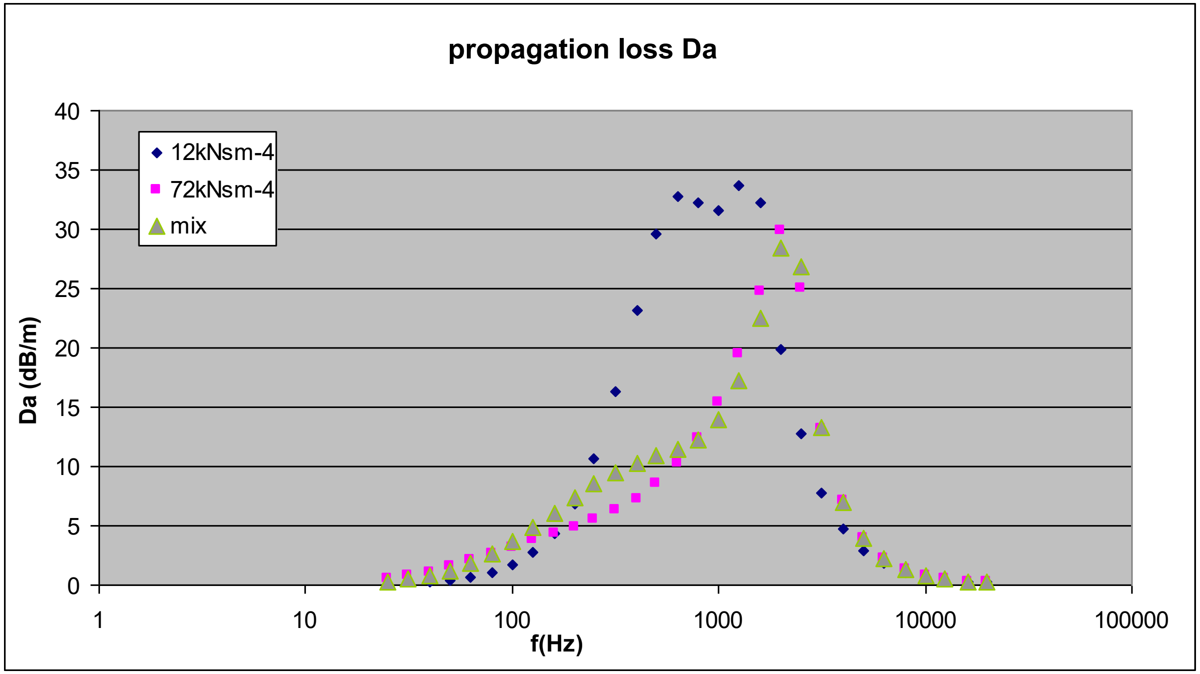
Properties of a porous medium in a laminated lining

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the laminated lining consisting of:

- a surface layer being a porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1**=72 kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **ds**=0.02m. No series cloth is considered, no series perforated protection is considered.
- a core layer being a porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1**=12 kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **dc**=0.08m. No series cloth is considered, no series perforated protection is considered.



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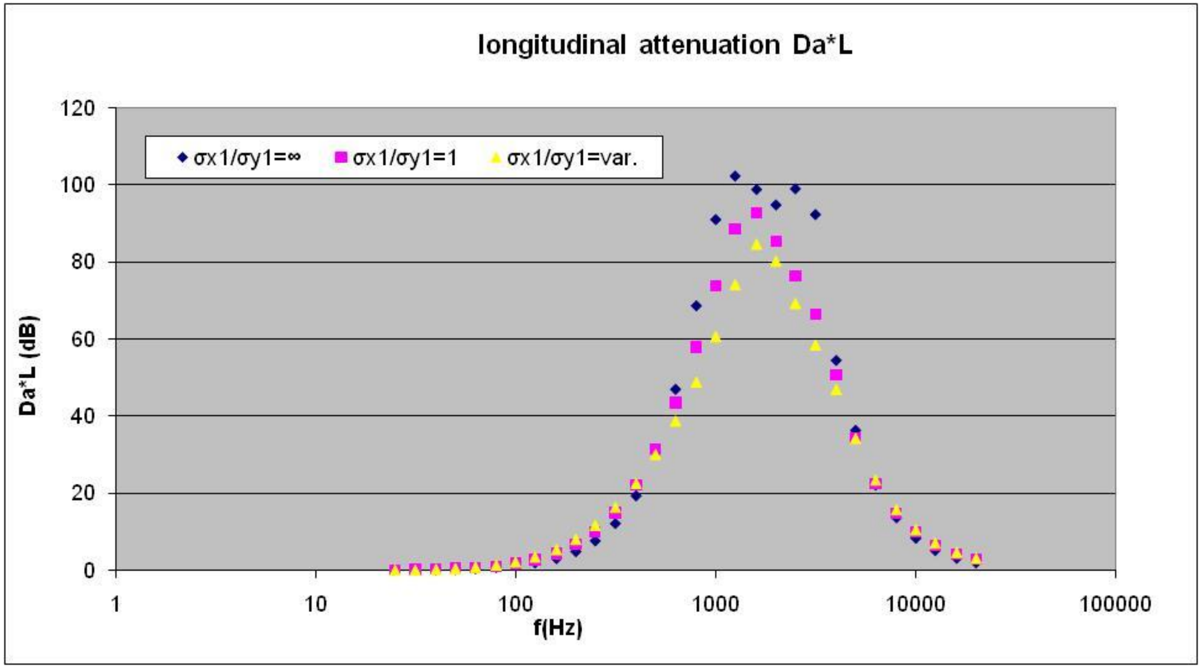
Conditions of propagation of sound inside the lining

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters being filled with a single porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1=**22332Nsm-4, a porosity Φ=0.95 (model M76), with a thickness **d**=0.05m. No series cloth is considered, no series perforated protection is considered. The longitudinal attenuation with a length **L**=1.5m is considered for the following cases, **σx1** being the flow resistivity of the porous medium in the direction parallel to the axis of the duct: **σx1/σy1**=∞ (absorber locally reacting), **σx1/σy1**=1 (absorber bulk reacting), **σx1/σy1**=var. with var.=0.5



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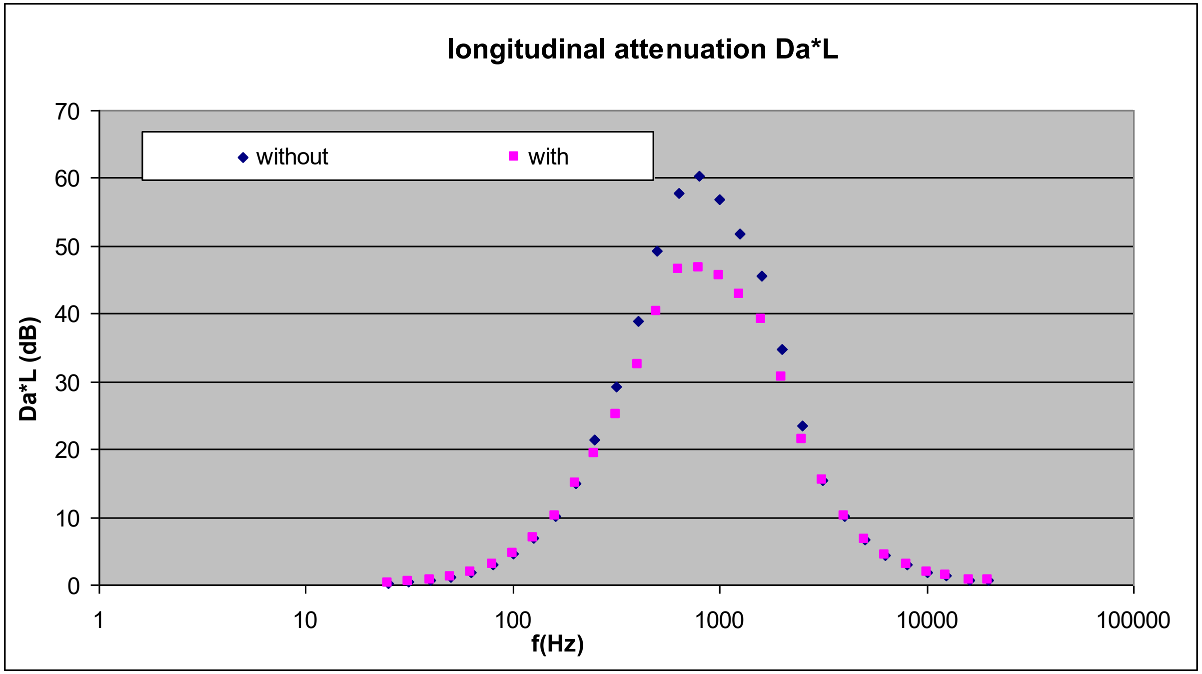
Limitation of the propagation loss

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having **no** transverse solid partitions being filled with a single porous medium homogeneous in directions parallel to and perpendicular to its surface, having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1=**12000Nsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m and a length **L**=2m. No series cloth is considered, no series perforated protection is considered. The longitudinal attenuation is considered with or without the limitation of the propagation loss.



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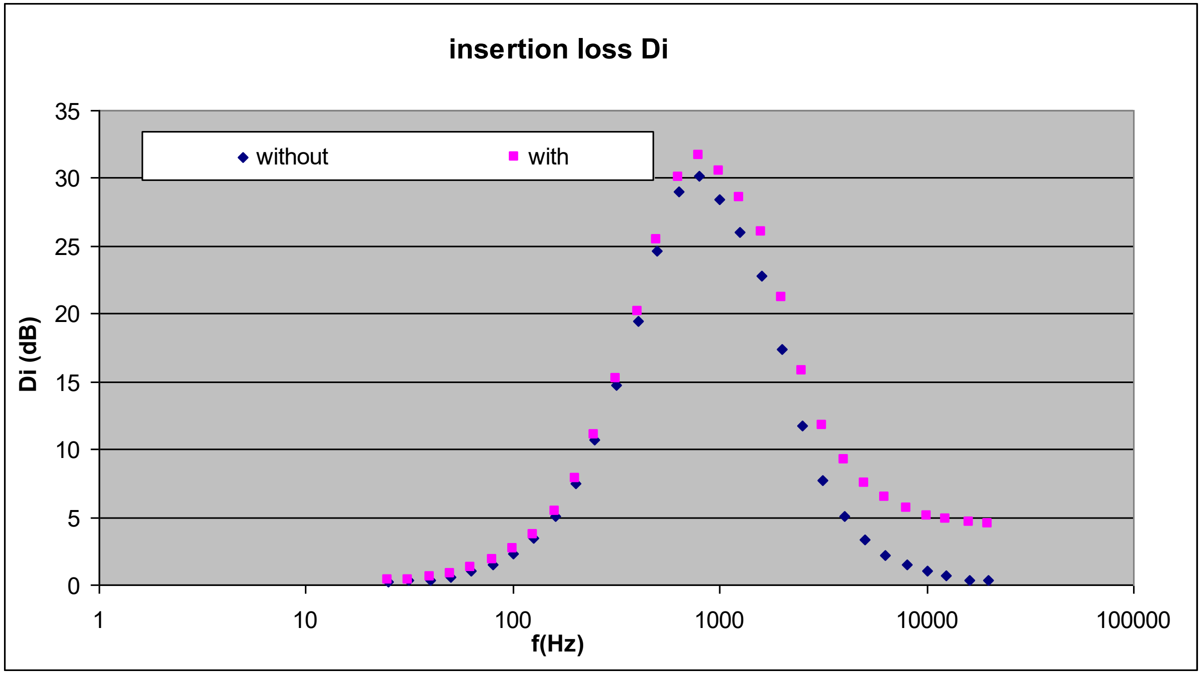
Reflection loss

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having **no** transverse solid partitions being filled with a single porous medium homogeneous in directions parallel to and perpendicular to its surface, having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1=**12000Nsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m and a length **L**=1m. No series cloth is considered, no series perforated protection is considered. The insertion loss is considered with or without the reflection loss.



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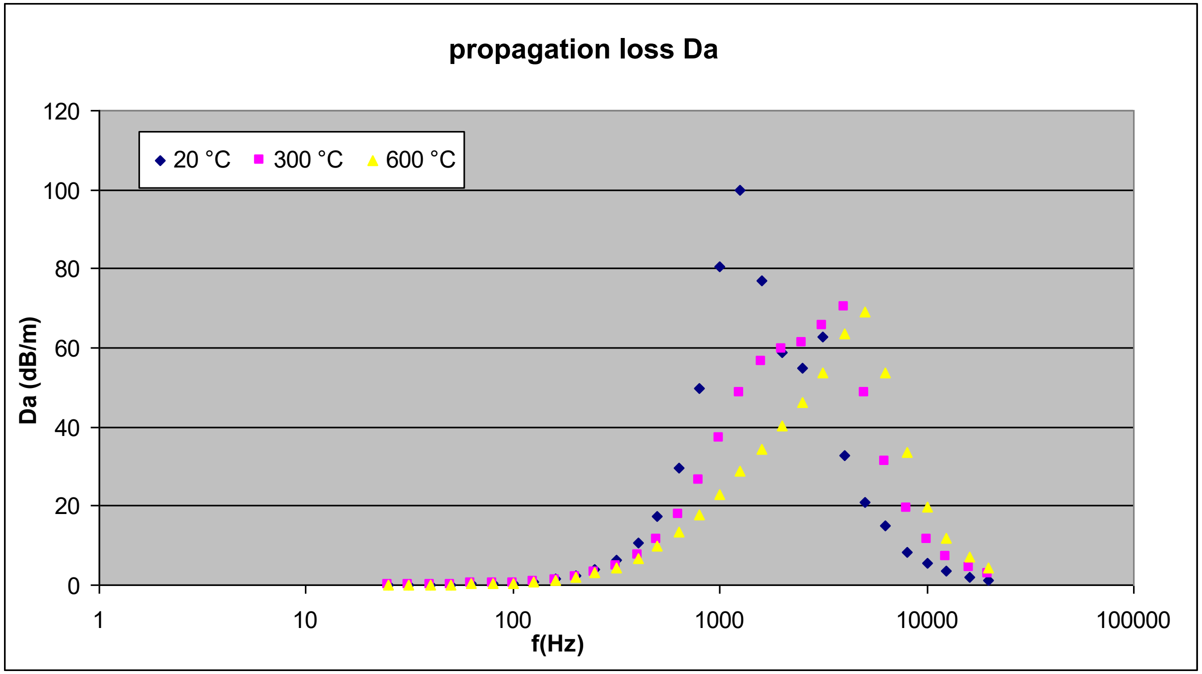
Temperature

a silencer is considered at (test) room pressure: from the one hand at (test) room temperature and from the other hand at high temperature with an open area ratio of 50%, the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1**=12400 Nsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.05m. No series cloth is considered, no series perforated protection is considered.



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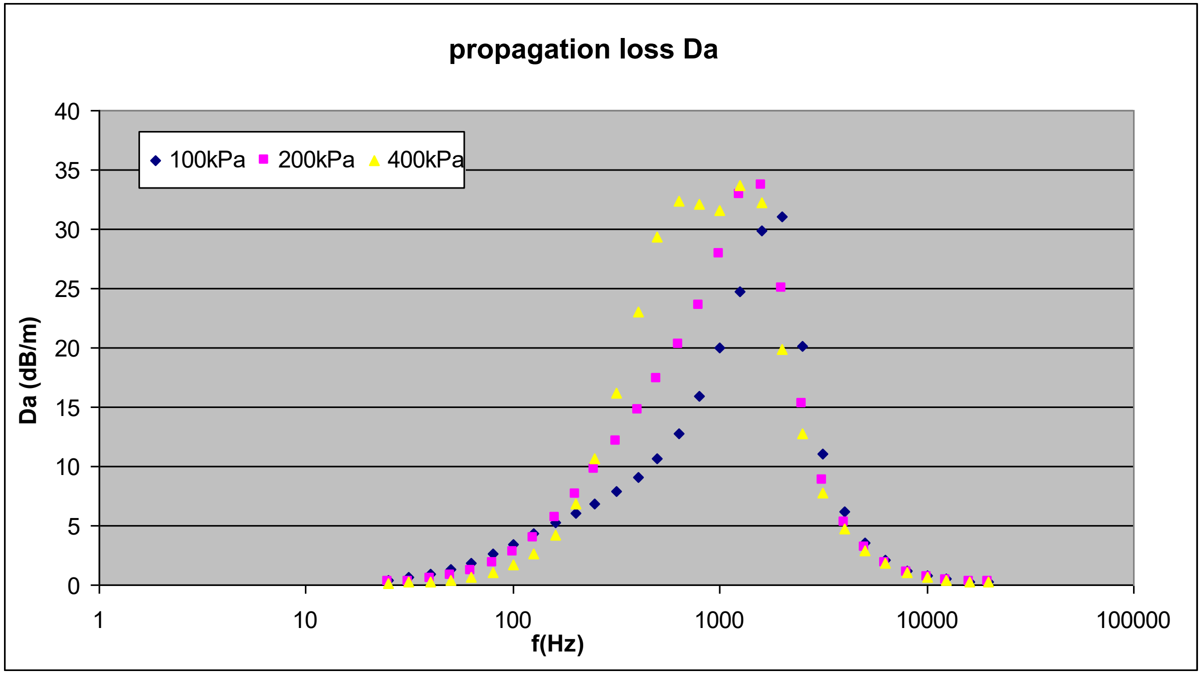
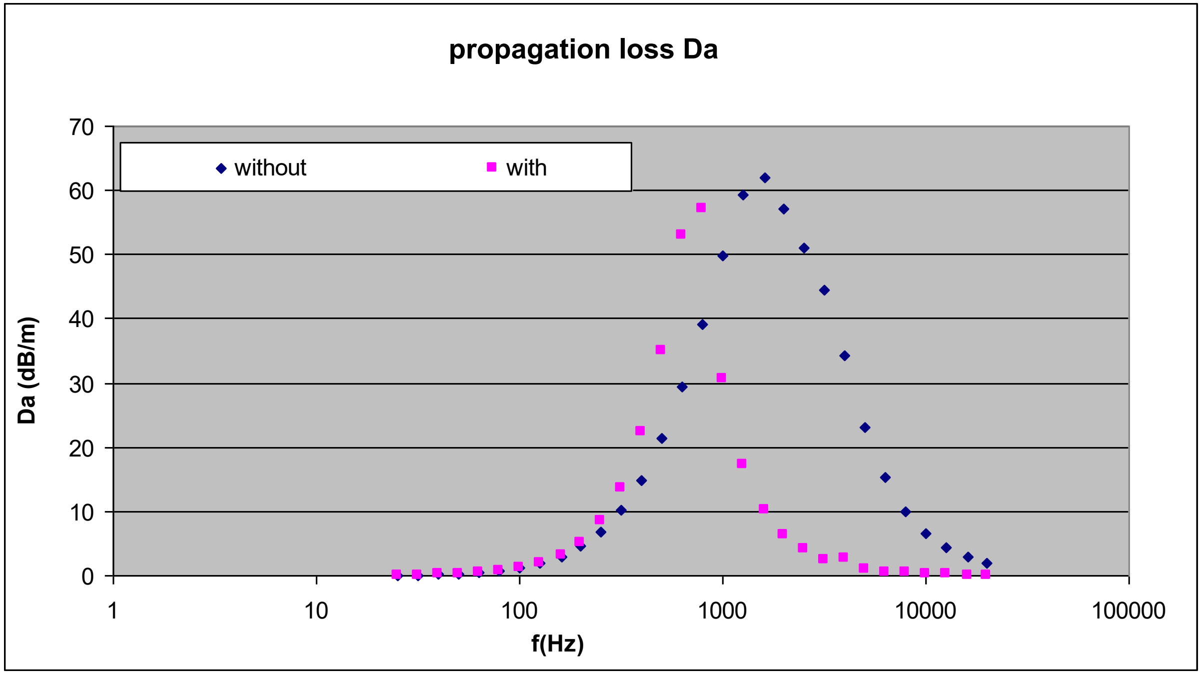
Pressure

a silencer is considered at (test) room temperature and at a pressure from 100 to 400kPa with an open area ratio of 50%, the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1**=48000 Nsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m. No series cloth is considered, no series perforated protection is considered.



Series cloth

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having **no** transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium homogeneous in directions parallel to and perpendicular to its surface, having a flow resistivity **σy**=22332Nsm-4, a porosity **Φ**=0.95 (model M76) with a thickness **d**=0.05m. The cloth consists of an impervious membrane (surface density 125 g/m2)



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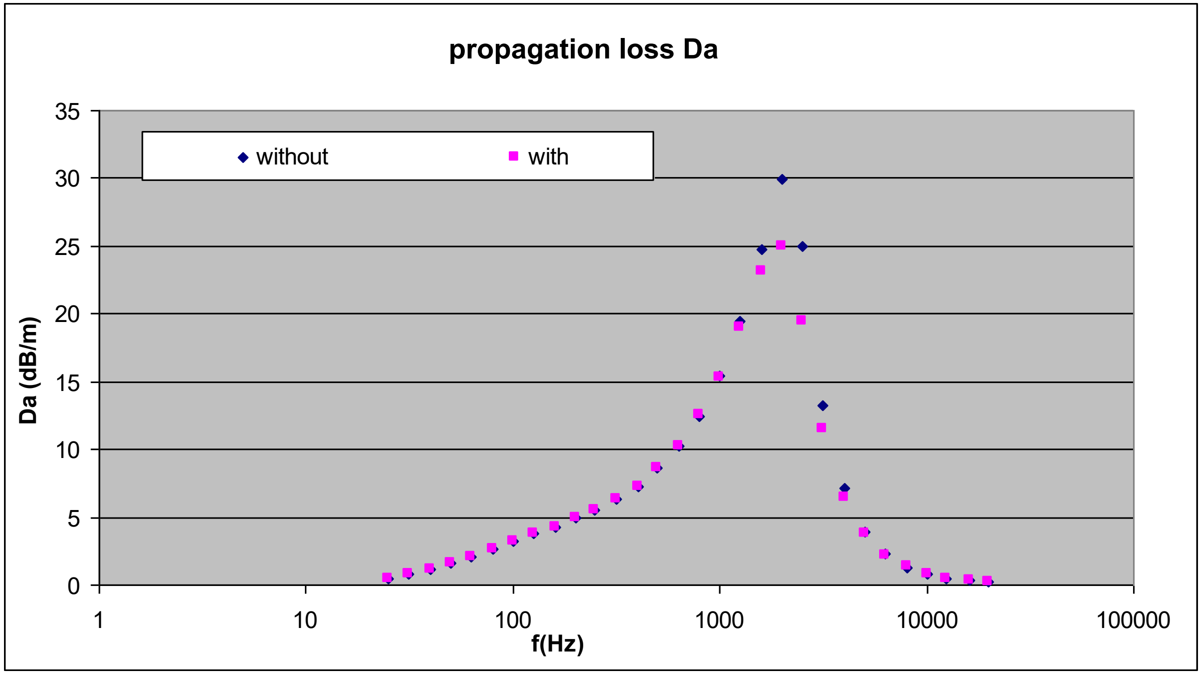
Series perforated protection

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium having a flow resistivity **σy**=72kNsm-4, a porosity **Φ**=0.95 (model M76) with a thickness **d**=0.1m. The perforated protection consists of a sheet R3T5 (round holes with an hexagonal arrangement, diameter 3 mm, open area ratio **Σ**=0.3265) of thickness 1 mm (general model MOI, model for the added impedances ROA)



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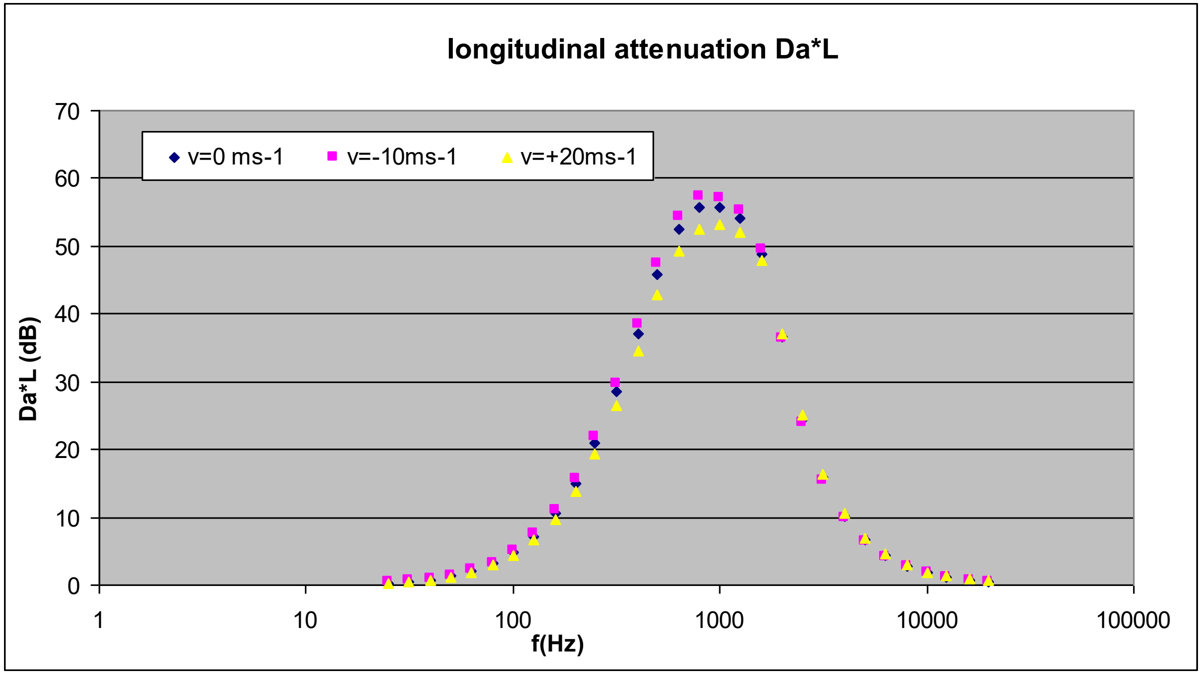
Velocity of air flow (effects other than regenerated noise)

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having **no** transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium homogeneous in directions parallel to and perpendicular to its surface, having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1=**15kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m and a length **L**=2m. No series cloth is considered, no series perforated protection is considered.



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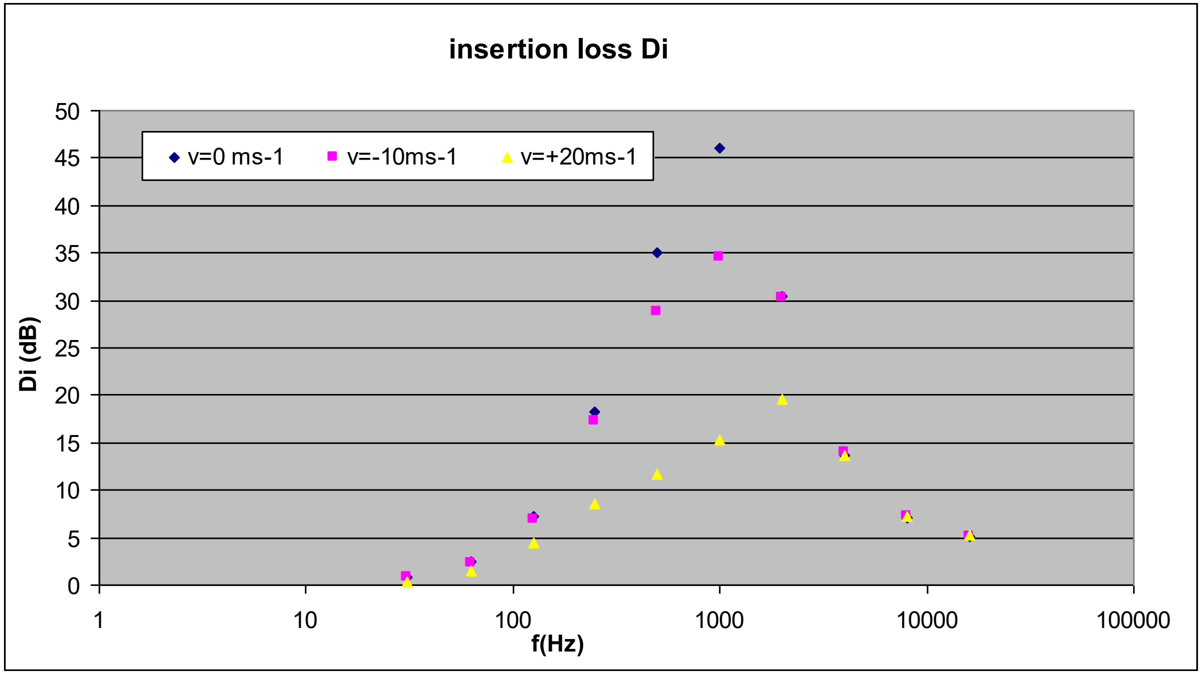
Velocity of air flow (regenerated noise)

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having **no** transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium homogeneous in directions parallel to and perpendicular to its surface, having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σy1=**15kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m and a length L=2m. No series cloth is considered, no series perforated protection is considered. A reflection loss and a limitation of the propagation loss are considered. The considered front section of the silencer is 2.5 m2. A noise source with an acoustic power of 80 dB/oct is considered



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Unsilenced sound power spectrum (and other uncertainties)

a silencer is considered at (test) room pressure and temperature, with an open area ratio of 50%, the splitters having transverse solid partitions inhibiting the sound propagation along the duct axis inside the non-laminated lining consisting of a single porous medium having (at room temperature) a flow resistivity in the direction normal to the axis of the duct **σ_{y1}=**12kNsm-4, a porosity **Φ**=0.95 (model M76), with a thickness **d**=0.1m and a length **L**=1m. No series cloth is considered, no series perforated protection is considered. The longitudinal attenuation for the 1/1 octave band of central frequency 250 Hz is considered for various sound power spectra of the unsilenced source **Lw0**, taking into account the propagation loss **Da** computed for the corresponding 1/3 octave bands: 6.8 dB/m at 200 Hz,10.7 dB/m at 250 Hz, 16.3 dB/m at 315 Hz.

		1/3 octave frequency band central frequency (Hz)			1/1 octave band central frequency (Hz)
		200	250	315	250
Case 1	Lw0 (dB ref1E-12W)	75.2	75.2	75.2	80
	Da*L (dB)	6.8	10.7	16.3	
	Lw0 - Da*L (dB ref1E-12W)	68.4	64.5	58.9	70.2
	longitudinal attenuation for the 1/1 octave band				**9.8**
Case 2	Lw0 (dB ref1E-12W)	68.0	75.0	78.0	80
	Da*L (dB)	6.8	10.7	16.3	
	Lw0 - Da*L (dB ref1E-12W)	61.2	64.3	61.7	67.4
	longitudinal attenuation for the 1/1 octave band				**12.6**
Case 3	Lw0 (dB ref1E-12W)	78.0	75.0	68.0	80
	Da*L (dB)	6.8	10.7	16.3	
	Lw0 - Da*L (dB ref1E-12W)	71.2	64.3	51.7	72.0
	longitudinal attenuation for the 1/1 octave band				**8.0**

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Appendix 1
Example of computation with SILDIS (*)

*** see the examples given in user's manual**
(training for users of the software)

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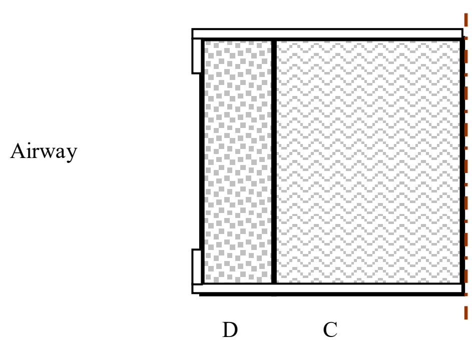
Example 1.4.1 (in User's manual) dissipative silencer with a rectangular cross section

It is wished to compute the acoustic and aerodynamic performances of a **dissipative silencer with a rectangular cross section** (width B=1200mm [1], height H=2000mm [2], length L=1500mm [3]), having rectangular edged [4] splitters of thickness 2d such as 2d-2d'1=200mm [5] with a open area ratio of 50% [6] made of one [7] homogeneous in directions parallel to and perpendicular to its surface bulk absorber [8] having the reference DEMO in the database for porous media of SILDIS [9] with [10] a cloth of thickness d'1=5/100 mm [11] having the reference DEMO in the series cloths database of SILDIS [12] without perforated protection [13]
It is foreseen to use the silencer with an air flow rate of 24.1 kg/s [14] at 20 °C [15] at a pressure of 101325 Pa [16].
It is decided to take into account a limitation of the propagation loss for L>1m [17] and to take into account the reflection loss [18].
The reference spectrum is supposed of the type "pink noise" [19] with a sound power level of 130 dB/oct [20]
It is chosen to predict the self noise of the silencer in the way described with the model referred to as 2081B [21]
It is chosen to predict the back pressure with the model referred to as FRO [22]

Sketch:



Nomenclature

land mark	element
D	series cloth
C	porous medium

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Thank you for your attention

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