CEAS-ASC WORKSHOP 2019

Experimental validation of an ultra open metamaterial which uses the acoustic black hole principle

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Abstract

Ultra open metamaterials (UOM) represent a recent class of acoustic metamaterials with subwavelength structure which attenuates transmitted sound in pipes but allows air circulation with minimum restrictions. Such metamaterial based on asymmetric transmission, similar to the Fano-like interference demonstrated a reduction of acoustic energy of 94% , keeping 60% the open area for air passage(Ghaffarivardavagh et al.,2019). A different option to obtain an UOM is to apply the acoustic black hole principle (ABH) which slows down the sound velocity up to a value of zero and undergoes a total wave absorption by interacting with varying wall admittance. This paper firstly describes the theoretical background of this phenomenon and presents several research contributors. Further on, results from numerical simulation of different configurations are presented and discussed. The last part of the paper presents the experimental validation using the impedance tube of an ABH device which have been fabricated using 3D printing technology. Results confirm the numerical simulation and proves that ABH based device is a valuable UOM solution with applications in various industries including aero engine core or fan noise reduction , industrial or engine mufflers and HVAC installations.

Outline

- Theoretical background for Acoustic black hole (ABH) principle
- Results from numerical simulations
- Fabrication of an ABH muffler using 3 D printing
- Experimental test bench presentation
- Validation results
- Conclusions and remarks

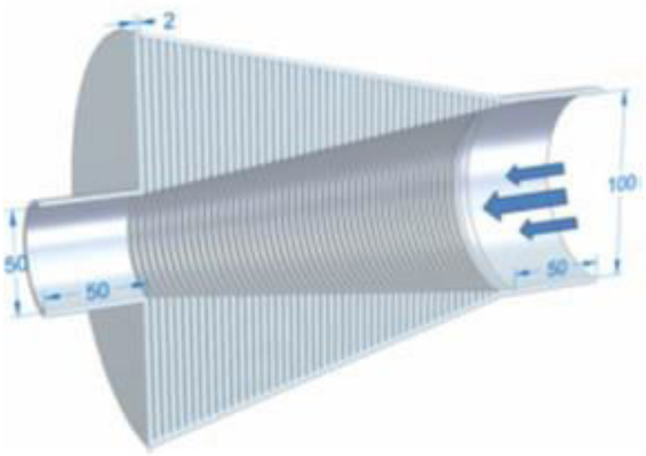
Design options for UOM (1)

- Ultra open metamaterials (UOM) : allows air to pass but not the sound
- Design options include:

- based on asymmetric sound transmission similar to the Fano-like interference (Ghaffarivaravagh et al, 2019)

- based on ABH principle : slowing down the speed of sound up to zero and getting total absorption by interacting with varying admittance (Sharma et al, 2016)

Design options for UOM (2)

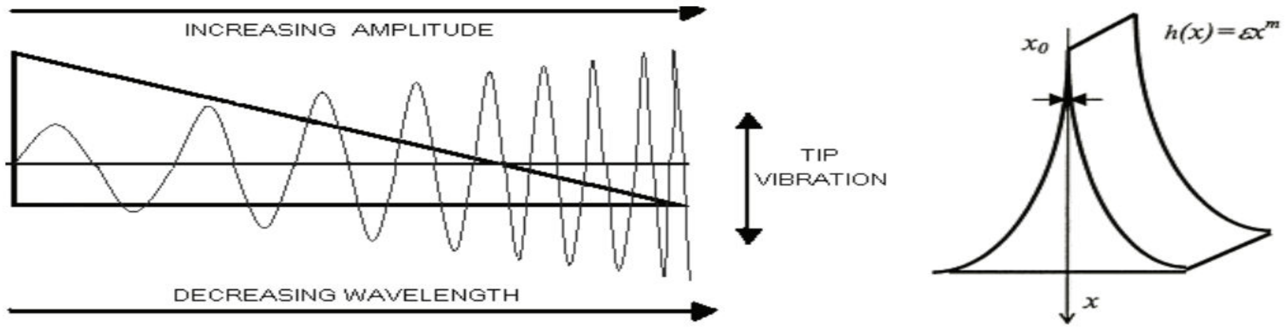


a) Fano-like interference design

b) ABH design

ABH effect

- ABH effect is a passive approach to control vibrations and sound
- The effect is achieved by means of a retarding structure that induces a power law decrease of incident wave velocity.
- Theoretically the wave never reaches the limit of retarding structure because the speed goes to zero, so no reflection can occur.
- In practice we deal with imperfect ABH and becomes necessary to place some damping material at the area of small velocity

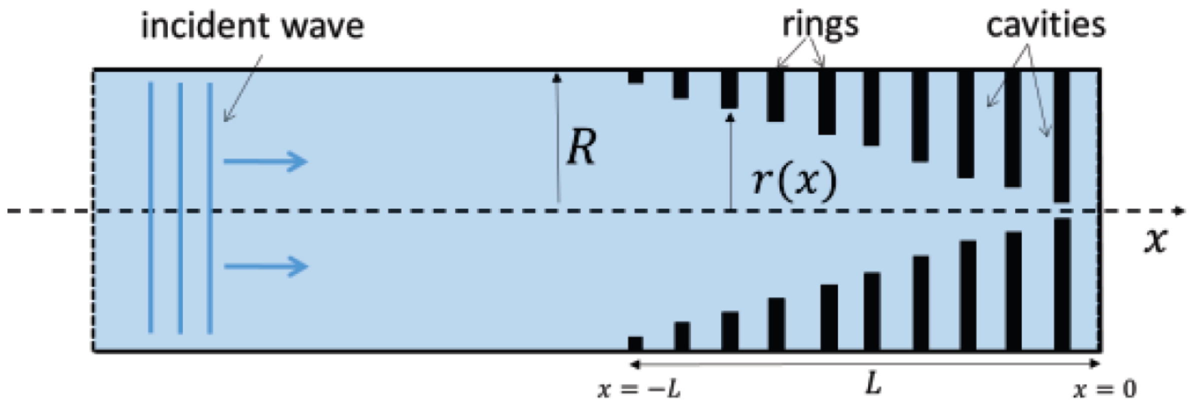


(a) (b)

ABH effect for terminating ducts

- ABH effect for sound absorption in duct terminations can be achieved by a combination of two features:

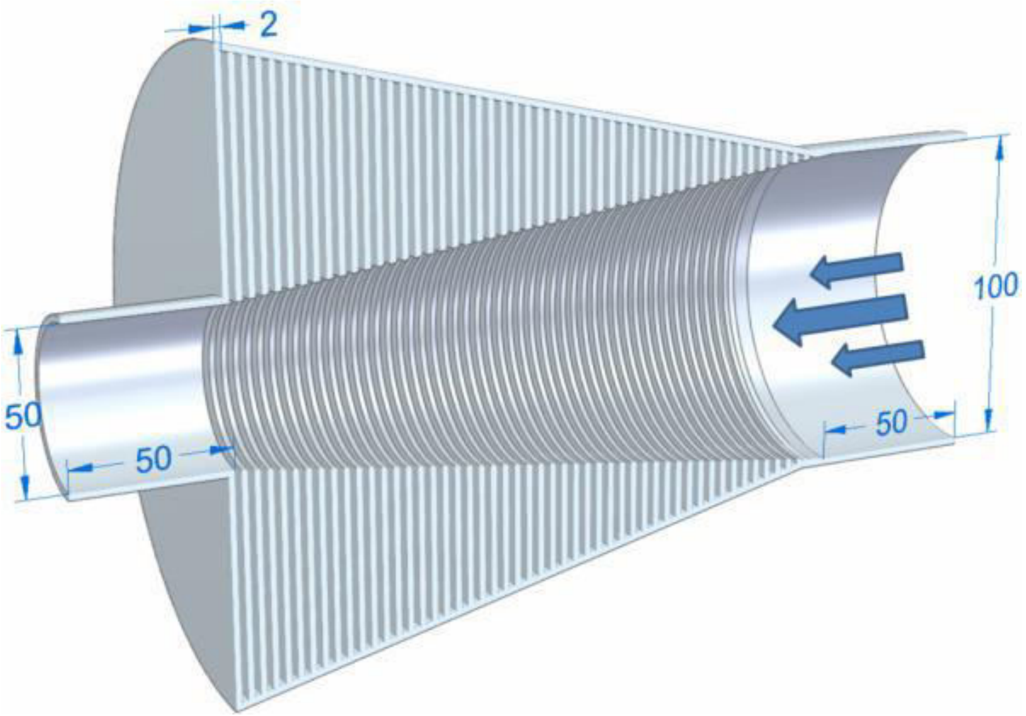
- The power law decay of duct radius
- An appropriate decay of wall admittance which can be achieved by inserting of rigid rings with inner area decreasing to zero.



Theoretical background for ABH concept

- Mironov and Pislyakov : ABH effect for terminating structures(2002) - vibrations
- El-Ouahabi,Krylov and O’Boy: ABH termination for cilindrical pipes (2015)- sound in terminating pipes
- Sharma,Umnova and Moorhouse: ABH muffler (2016)-sound in open pipes

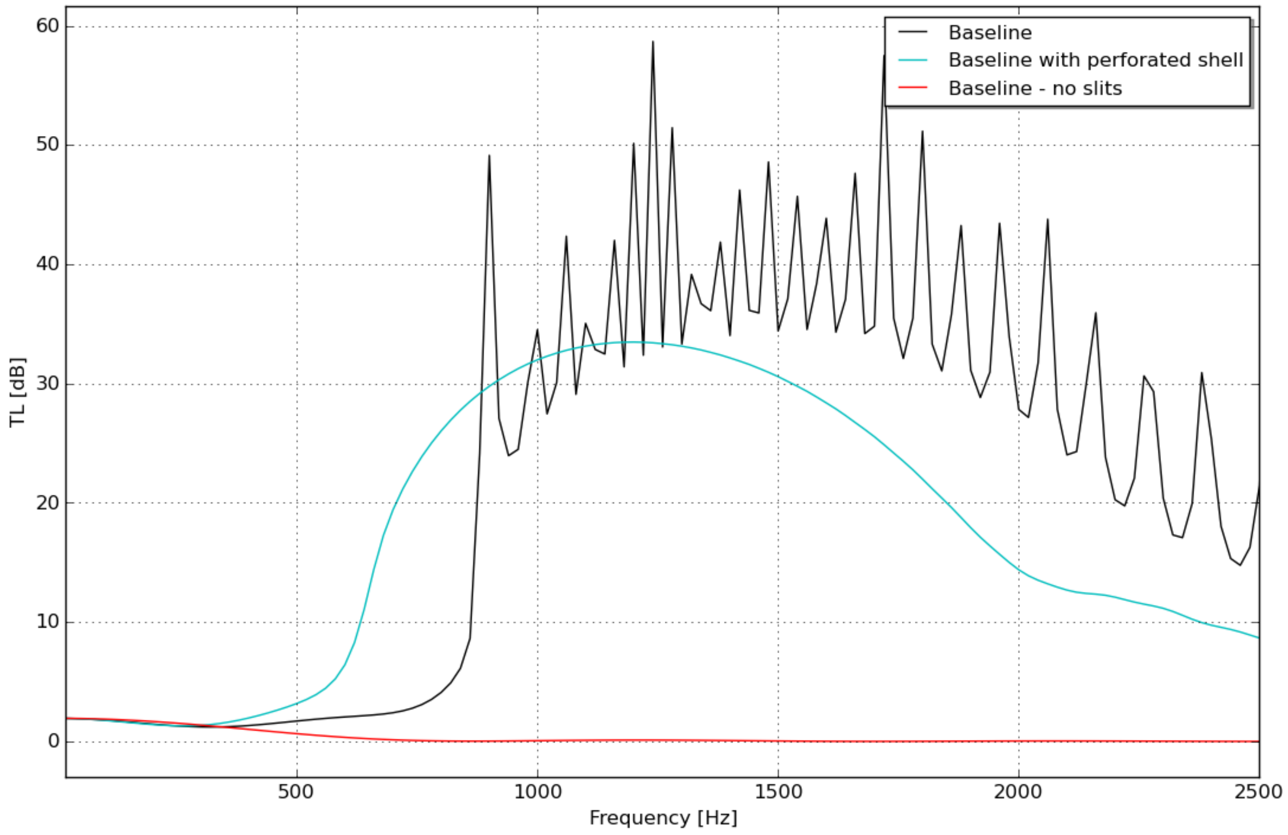
ABH muffler design



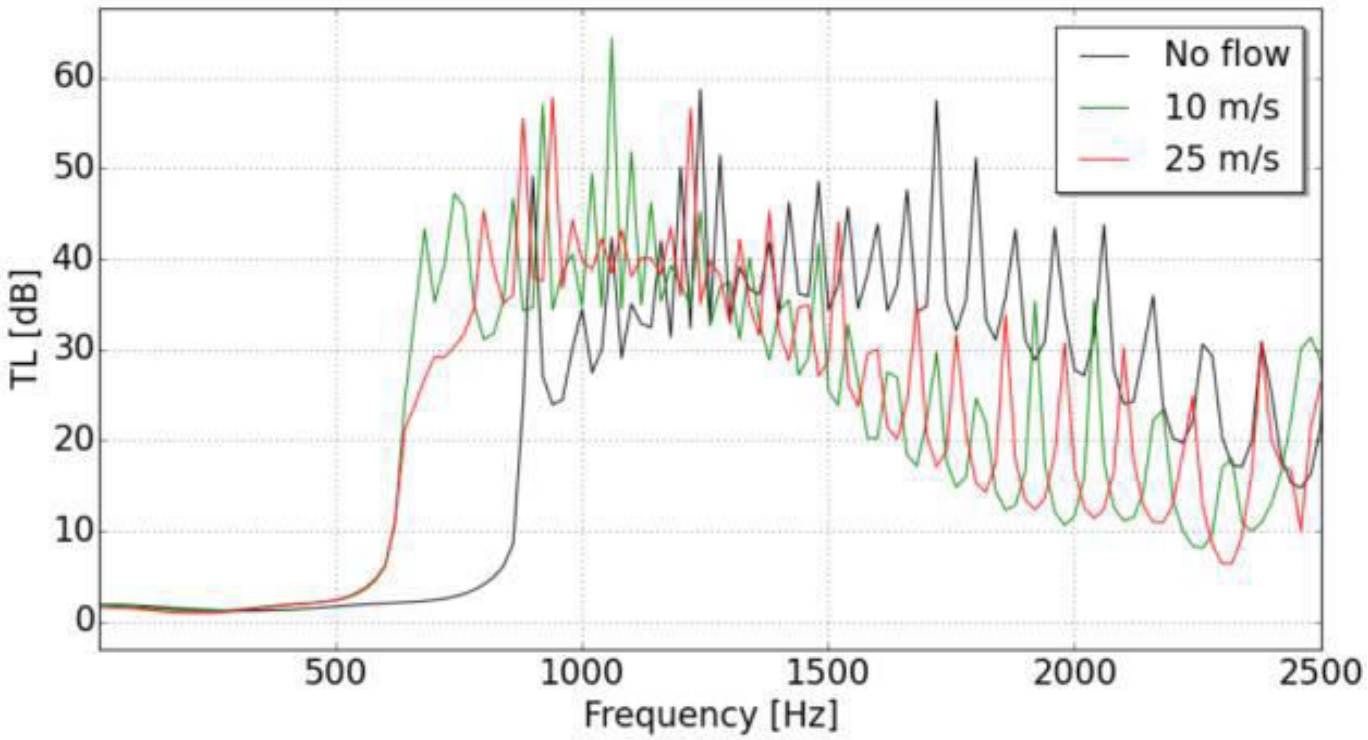
Basic design and dimensions

Numerical TL evaluation

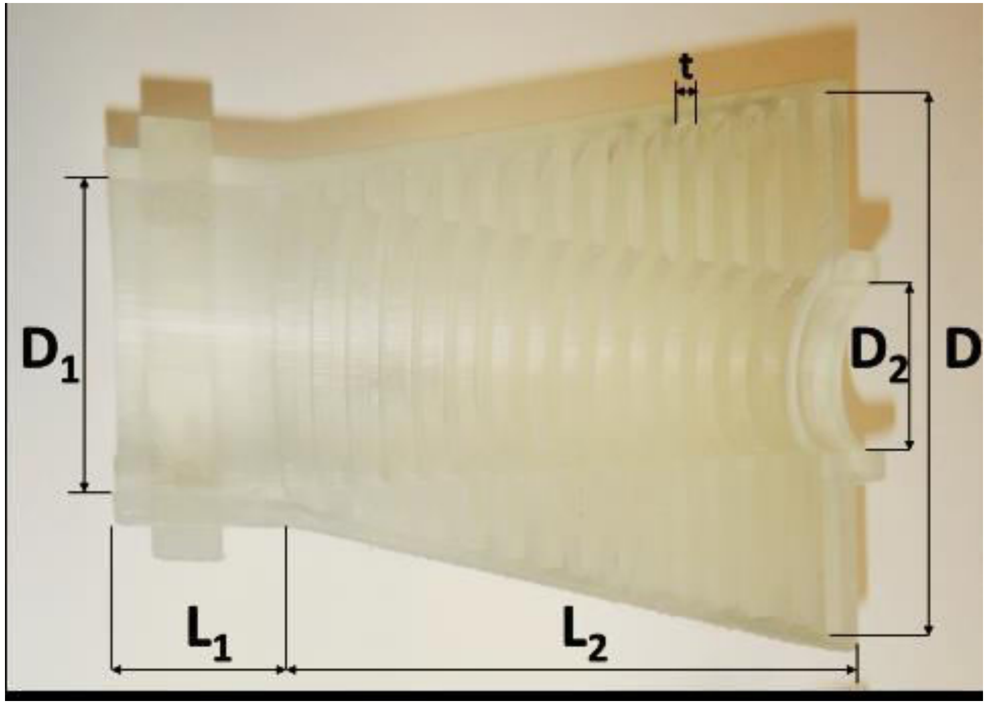
- Msc ACTRAN software
- Evaluation includes : base, base+ micro perforated cover, simple expansion chamber



Numerical simulations considering grazing flow



Fabrication of the ABH muffler using Formlab 2 printer

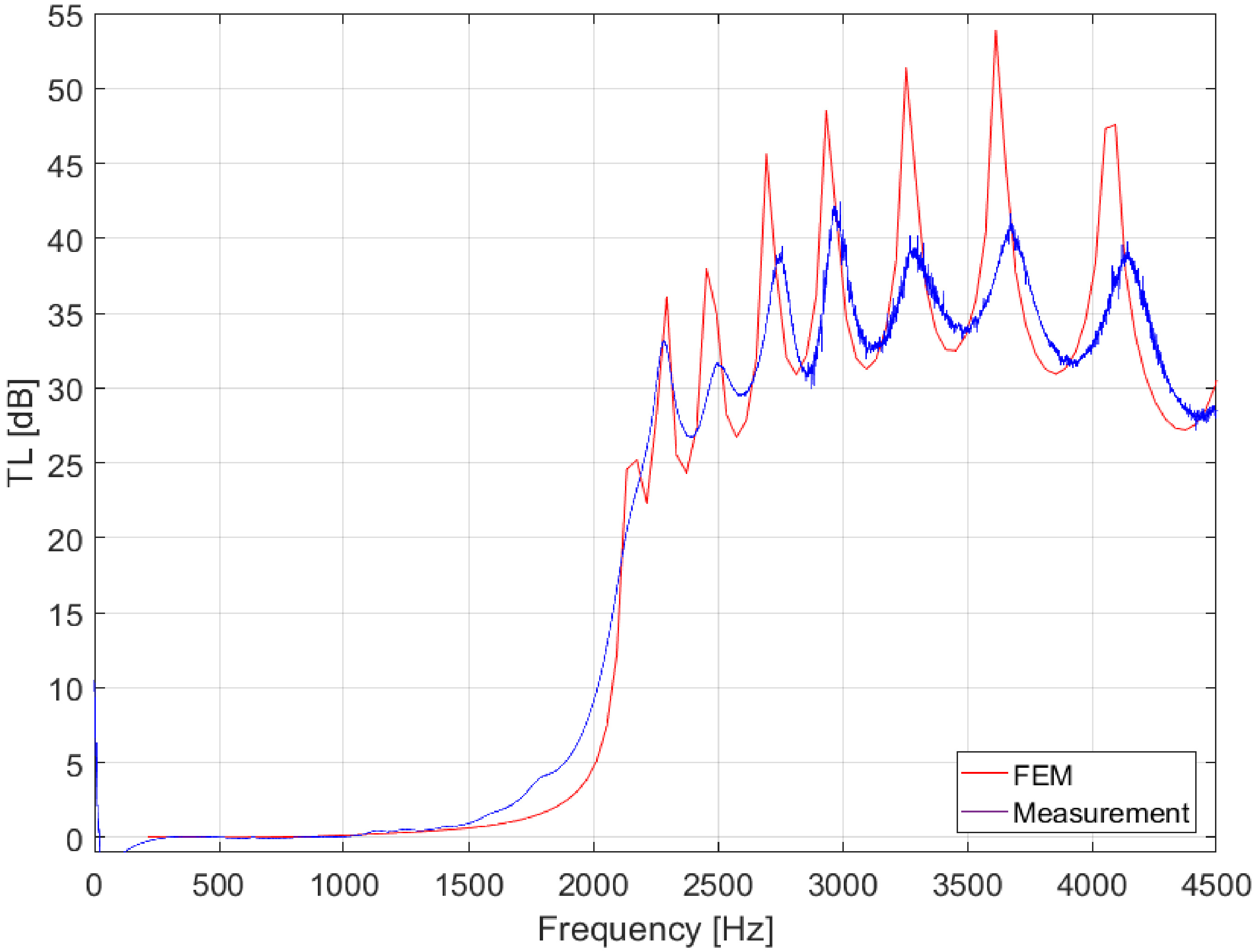


Dimensions: D =90 mm; D1=45 mm;L1+L2=110mm; t=3mm

Adapting the test bench

The measurement technique (two loads method) is based on the transfer function method described in ASTM E2611 with some correction techniques from ISO 10534-2 using an adapted impedance tube.

Validation results for the ABH muffler



Conclusions and remarks

- ABH muffler represents a very compact broad band solution suitable for various applications including aircraft engines
- There is no need for absorption materials in order to have good results
- Numerical results have been very well validated by experiments
- TL performance is improved if the lengths is increased or the internal profile follows the power law
- Performance for lower frequencies are increased if the diameter is increased

THANK YOU !