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Back-to-back comparison of impedance measurement techniques applied to the characterization of aero-engine nacelle acoustic liners

Piergiorgio Ferrante [a,*], Wim De Roeck [a], Wim Desmet [a], Nicola Magnino [b]

[a] Department of Mechanical Engineering, Katholieke Universiteit Leuven – Afdeling PMA, Celestijnenlaan 300 B, 3001 Leuven, Belgium
[b] Aeroacoustics Aerodynamic and Wind Tunnel, Alenia Aermacchi, Alenia Aermacchi S.p.A., via P. Foresio 1, 21040 Venegono Superiore, VA, Italy

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ABSTRACT

The aim of this paper is to assess three different measurement techniques applied to the characterization of the acoustic impedance of a Single-Degree-of-Freedom (SDOF) liner installed in nacelle ducts of turbofan engines. The "two-microphones" method, the "in-situ" impedance measurement technique and the "impedance eduction" approach are respectively compared in representative flight environment, characterized by normal and grazing incidence sound, with and without grazing flow. Goal of the study is to collect evidences of the unique and complementary features offered by these techniques, providing deeper insight into their strengths and limitations.

The experimental results obtained with the three methods are in global agreement. For the "two microphones" method it is demonstrated the necessity to insert the liner samples into the impedance tube in order to perform accurate measurements at low frequencies on low porosity liners. For the "in-situ" technique it is highlighted the feasibility of implementation on aeronautical liners and the reasonable correlation achieved with the "impedance eduction" approach and with the impedance tube.

1. Introduction

Acoustic liners [1] are largely exploited in aero-engine nacelles for noise reduction. Air intakes, fan cases and by-pass ducts are lined wherever possible in order to maximize the acoustically treated area. Typical liner configurations are composed by arrays of Helmholtz cavity resonators for the dissipation of the incident acoustic energy. Their structure is made by a porous facing-sheet and one or more honeycomb layers, with the overall panel being backed by a reflective solid backing-sheet.

Large efforts are being made by industries, research institutions and academies to deeply understand the physics underlying the sound absorption, in order to improve the mathematical models used to estimate the acoustic impedance. By relying on accurate impedance predictions, in fact, it is possible to optimize the physical and geometrical liner parameters and produce more efficient designs, providing higher sound attenuation. The development of accurate impedance models (analytical [2], semi-empirical [3,4], numerical [5,6]) relies on tests performed in representative flight environment, characterized by high sound pressure levels and grazing flow. For this purpose dedicated measurement techniques have been developed in recent years.

The goal of this paper is to assess the unique and complementary features of three different experimental approaches, providing deeper insight into their strengths and limitations when applied to the impedance characterization of a Single-Degree-of-Freedom (SDOF) liner with low porosity (lower than 7%). This type of liner is particularly interesting for its lightweight structure and simplified manufacturing process. However its impedance is largely sensitive to the incident sound pressure level and to the grazing flow velocity, hence adequate test benches are required to reproduce a representative flight environment with varying noise level and flow speed.

The test methods and the relative facilities investigated in this study have been selected by Alenia Aermacchi S.p.A (AAEM), aeronautical industry involved in nacelles design and manufacturing. They are respectively:

(1) The "two microphone method" implemented in the following impedance tubes:
   – AAEM impedance tube (Ø29 mm).
   – AAEM impedance tube with open flanged termination (Ø29 mm) [1].
   – Impedance tube operated by K.U. Leuven (KUL) (Ø45 mm) [7].

* Corresponding author.
E-mail addresses: Piergiorgio.Ferrante@student.kuleuven.be (P. Ferrante), Wim.DeRoeck@mech.kuleuven.be (W. De Roeck), Wim.Desmet@mech.kuleuven.be (W. Desmet), Nicola.Magnino@alenia.it (N. Magnino).

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Nomenclature

ISO	International Organization for Standardization
ASTM	American Society for Testing and Materials
KUL	Universiteit Katholieke Leuven
AAEM	Alenia Aermacchi S.p.A.
SDOF	Single Degree of Freedom
k	wavenumber (1/m)
x_1	distance of mic. 1 from the sample surface (impedance tube) (m)
x_2	distance of mic. 2 from the sample surface (impedance tube) (m)
s	microphones distance (m)
H_{12}	frequency transfer function between microphones 1 and 2
r	reflection coefficient
z	acoustic impedance (Pa s/m)
j	imaginary unit
p_s	acoustic pressure at the liner facing-sheet (Pa)
p_c	acoustic pressure at the liner back-plate (Pa)
p_0	amplitude of the acoustic pressure inside the liner cavity (Pa)
p	acoustic pressure (Pa)
h	liner cavity depth (m)
T	acoustic transfer matrix
T_{tr}	acoustic transition matrix
u	acoustic velocity (m/s)
ρ_0	air density (kg/m^3)
c_0	speed of sound (m/s)
ω	angular frequency (1/s)
z_0	air characteristic acoustic impedance (Pa s/m)
U	mean flow velocity (m/s)
M	mean flow Mach number
SPL	sound pressure level (dB)
R	acoustic resistance (g/(cm^2 s))
R_{lin}	linear acoustic resistance (g/(cm^2 s))
R_{nl}	nonlinear acoustic resistance (g/cm^3)
u_{rms}	root mean square acoustic velocity (cm/s)
X	acoustic reactance (g/(cm^2 s))
X_c	cavity acoustic reactance (g/(cm^2 s))
X_m	mass acoustic reactance (g/(cm^2 s))
a	dimensionless constant
μ	dynamic viscosity (dynes s/cm^2)
t	face sheet thickness (cm)
C_d	dimensionless orifice discharge coefficient
σ	dimensionless face sheet porosity
d	hole diameter (cm)
l	cavity depth (cm)
ε	dimensionless orifice end correction
POA	percentage of open area (%)
OASPL	overall sound pressure level (dB)

Subscripts

$(\cdot)_x$	value in the x-direction
$(\cdot)_y$	value in the y-direction
$(\cdot)_z$	value in the z-direction

Superscripts

$(\cdot)^+$	downstream or incident propagation value
$(\cdot)^-$	upstream or reflected propagation value
$(\cdot)^\wedge$	complex value

(2) The "in-situ" impedance measurement technique [8], implemented in the frame of this study at AAEM;
(3) The "impedance eduction" approach developed and implemented into the KUL flow duct facility [9,10].

These facilities enable the impedance characterization in the following basic environments

(1) No grazing-flow, Normal-incidence acoustic waves.
(2) No grazing-flow, Grazing-incidence acoustic waves.
(3) Grazing-flow, Grazing-incidence acoustic waves.

Even if impedance tubes cannot be applied in grazing flow conditions, they are widely used by aeronautical industries to test liners before/after installation on aircraft engines. Thanks to their compact and lightweight design, they can be operated directly in the manufacturing assembly line or inside the aircraft nacelle, for checks on the field. They provide an effective way to measure the surface impedance and represent an established reference for quality control. However, due to their limited diameter, they typically suffer of reduced accuracy and repeatability at the lowest frequencies when operated on low porosity liners. In these conditions the impedance accuracy is reduced by edge and cell volume effects. This aspect is specifically investigated in the present work.

The in-situ technique is particularly interesting for its potential application at full scale in ground/flight tests. However, this technique requires the complicated installation of miniaturized microphones inside the compact structure of the acoustic liner. In this study this technique is implemented in an aeronautical liner sample, tested with/without grazing flow and compared with impedance tubes and with measurements performed in an impedance eduction facility.

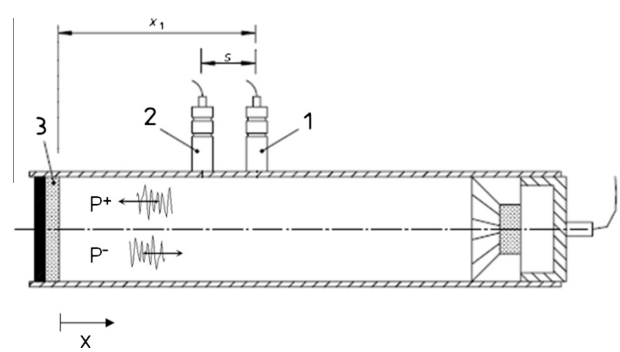

Fig. 1. Typical impedance tube scheme.

Finally an impedance eduction facility is considered in order to assess the capability to measure the impedance in grazing flow conditions, without the necessity to instrument the liner sample. A direct comparison with the in-situ setup allows to assess the consistency between lumped (educed) and local (in-situ) impedances.

The outline of this paper is the following: Section 2 provides an overview of the experimental methods considered. Section 3 describes the implementation of the selected methods in the test benches. In Section 4 the experimental results are discussed and compared with the impedance predictions provided by a standard impedance model (Motsinger and Kraft [3]). Conclusions are reported in Section 5.