Journal of Sound and Vibration 411 (2017) 328–345

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Numerical eduction of active multi-port data for in-duct obstructions

Stefan Sack [a,*], Michael Shur [b], Mats Åbom [a], Michael Strelets [b], Andrey Travin [b]

[a] KTH Royal Institute of Technology, Linne FLOW Centre, The Marcus Wallenberg Laboratory, Stockholm, SE-100 44, Sweden
[b] Saint-Petersburg Polytechnic University, New Technologies & Services (NTS), Saint-Petersburg, 195220, Russia

ARTICLE INFO

Article history:
Received 24 April 2017
Received in revised form 23 August 2017
Accepted 14 September 2017

Keywords:
Multi-ports
Aeroacoustic
Duct acoustic
Linearized Navier Stokes
IDDES
Source
Orifice
Computational method
Turbulence modeling
Network modeling
Scattering

ABSTRACT

A numerical method for aeroacoustic source characterization of in-duct components at frequencies beyond the cut-on frequencies of several acoustic modes is presented. Assuming linearity and time invariance, any ducted component can be fully characterized using a network (multi-port) model including source strength and scattering. A two-step multi-source approach is applied to numerical data in order to educe the multi-port characteristics. First, a scale resolving compressible flow simulation, here the Improved Delayed Detached Eddy Simulation (IDDES), is run to compute the channel flow that also contains the acoustic sources. Second, a linear acoustic computation, here the Linearized Navier Stokes Equations (LNSE), around a mean flow is solved for different acoustic loads to determine the component's scattering. The work uncovers the high potential of two-step numerical multi-port eduction methods. Particularly, it is shown that the acoustic source power spectra can be accurately extracted from IDDES data and the total acoustic power prediction is very good. Furthermore, a good result in the scattering data obtained from a second computationally inexpensive LNSE computation is achieved. The approach is interesting when describing mid-size duct systems, for example ventilation systems in aircraft and buildings, with a moderate number of higher order modes propagating in the considered frequency range. Therefore, the increasing availability of compressible flow data opens a wide field of applications.

1. Introduction

REDUCING environmental noise disturbance caused, for example, by ventilation systems, air conditioners, and exhausts, necessitates models to describe aeroacoustic duct components in terms of their noise sources ('active' properties) and their sound scattering ('passive' properties). A well-established model is the so-called 'two-port' model [1,2] which can be generalized as the 'multi-port' model [3,4] including higher order acoustic modes and components with multiple inlets/outlets. Multi-ports present acoustic data in the form of duct eigenmodes under reflection free conditions, which makes them useful for a direct comparison of measurement and computational data. A large proportion of the literature on two-ports and multi-ports only presents experimental applications (see Refs. [5–9] among many others). Such experiments are particularly

* Corresponding author.
E-mail address: ssack@kth.se (S. Sack).

https://doi.org/10.1016/j.jsv.2017.09.012

elaborate especially for higher order modes as numerous pressure probes and external sound sources are needed to decompose the in-duct sound into its acoustic modal content. However, only a few approaches that extract multi-port data from numerical computations have been documented, as described in the following paragraph.

For the scattering, encouraging results for planar waves (low frequencies) have been achieved with the Linearized Navier-Stokes Equations (LNSE) [10–13] and the Linearized Euler Equations [14] in the frequency domain. Such methods are convenient, as they decouple the acoustic computation from the background flow and allow there to be coarse aeroacoustics meshes. The results are a combination of acoustic and hydrodynamic fields clean of 'turbulence' yielding scattering data of low random uncertainties. The challenge of such approaches is, however, to find accurate solutions for the stationary background flow field and the turbulent variables especially in the vicinity of separated shear flows where acoustic-flow interactions occur. For that purpose, usually, the Reynold Averaged Navier-Stokes (RANS) equations with turbulence modeling are solved assuming an incompressible flow.

More computationally expensive (though less empiric) approaches are scale-resolving computations in the time domain that naturally contain parts of the (otherwise modeled) turbulent content. Large Eddy Simulations (LES) of compressible flow excited with external sources were successfully tested on single orifices [15,16] and tandem orifices [17] to extract both, the source and the scattering for the low frequency plane wave range. Such 'pure' LES approaches, however, are exacerbated by the need of uncorrelated, external sound sources either as part of the LES computation or in an additional scale-resolving computation in order to extract the component's scattering.

The present study aims to combine a set of computationally inexpensive LNSE solutions for precise scattering determination with accurate source data, extracted from scale-resolving compressible flow simulations. This novel approach allows it to obtain comprehensive multi-port data whilst retaining the advantages of the two numeric methods. The approach is very intuitive as noise source and sound scattering are solved in separate (though connected) steps, comparable to the measurement procedures.

First, direct computations of the flow and sound field created by the duct component are carried out with the use of compressible scale-resolving simulations based on the Improved Delayed Detached Eddy Simulation method (IDDES) [18]. Using special post-processing and modal decomposition procedures, the acoustic source cross-spectra can be extracted from an unsteady pressure field gained from the computed flow data. Earlier work has already proven the high potential of IDDES data combined with modal eduction techniques [19]. This work is extended here to remove the effects of internal scattering, using the passive properties of the multi-port computed, in the second step.

Second, the scattering of the component is computed, using the LNSE in the frequency domain combined with the time averaged solution from the IDDES serving as an accurate background flow. A remaining problem in LNSE methods is the correct prediction of the acoustic attenuation especially in turbulent regions of the flow. The paper, in hand, computes the scattering using different turbulence models, namely the quasi-static model, the quasi-laminar model, and a transmission model proposed by Weng et al. [20] to compare the differences in the results.

The numeric multi-port eduction presented in this paper is tested on the scattering and source prediction of a single thin orifice plate and a tandem orifice configuration in a distance of two duct diameters (2D) in low Mach number flow ($M < 0.1$) for frequencies above the cut-on of up to six acoustic modes. For validation of the computational models, very accurate measurement data on identical components are available, which was presented in Ref. [21]. To compute the scattering of the tandem orifice configuration, a multi-port network model as presented in Ref. [22] is used. For measurements, it demonstrated good performance for the scattering prediction, but the sources of coupled components were greatly underestimated. Therefore in the approach presented in this paper, the scattering of the tandem orifice case is predicted using multi-port cascading, whereas the source is extracted from a direct IDDES of the coupled system.

The paper, in hand, presents a full set of multi-port data (passive and active properties), which was gained with numerical methods and subsequently compared to measurements. The test cases were defined within the scope of the EU-funded project IdealVent ('Integrated Design of Optimal Ventilation Systems for Low Cabin and Ramp Noise') [23]. The first test case is a single thin orifice plate with a single sharp edged circular hole. The second test case is a combination of two such plates with an axial separation of two duct diameters (2D). The duct diameter is $D = 0.15$ m; the thickness of the orifice plate (t) is $t/D = 0.053$; the diameter d of the orifice is $d/D = 0.77$ and an area expansion ratio of $(d/D)^2 = 0.6$. A sketch of the system is presented in Fig. 1.

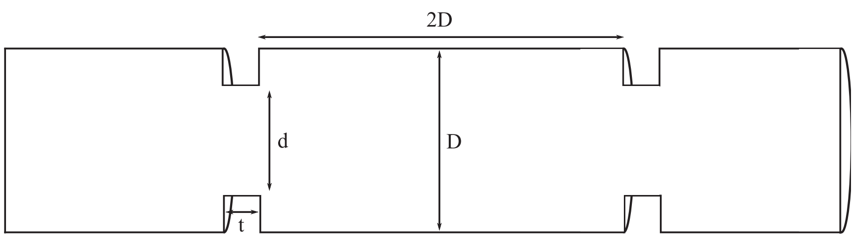

Fig. 1. Overview of the geometry of the tandem orifice plate configuration. The plate in the single orifice configuration has the same dimensions.