Journal of Sound and Vibration 431 (2018) 88–104

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

A convected frequency-domain equivalent source approach for aeroacoustic scattering prediction of sources in a moving medium

Leonidas Siozos-Rousoulis [a,*], Orestis Amoiridis [b], Zhongjie Huang [a], Tim De Troyer [a], Anestis I. Kalfas [b], Ghader Ghorbaniasl [a]

[a] Vrije Universiteit Brussel (VUB), Pleinlaan 2, 1050 Brussels, Belgium
[b] Aristotle University of Thessaloniki, Department of Mechanical Engineering, Thessaloniki 54124, Greece

ARTICLE INFO

Article history:
Received 10 November 2017
Received in revised form 21 April 2018
Accepted 28 May 2018

Handling Editor: J. Astley

Keywords:
Computational aeroacoustics
Acoustic scattering
Moving medium
Equivalent sources
Acoustic pressure gradient

ABSTRACT

In this paper, a convected frequency-domain approach for acoustic scattering prediction is suggested, for sources and scattering surfaces in a uniform constant flow. Frequency-domain moving-medium formulations are used for prediction of the incident acoustic pressure and acoustic pressure gradient. The latter is required for evaluation of the hardwall boundary condition in a moving medium and allows a convected definition of the equivalent sources. The scattering approach is validated by the analytical case of scattering of a pulsating monopole source by a rigid sphere. The applicability of the methodology to moving-medium problems is demonstrated for rotating and pulsating monopole point sources in a uniform flow, located near an infinite flat scattering surface. The suggested approach allows frequency-domain scattering predictions for sources in a uniform constant flow of any subsonic velocity, enabling direct inclusion of convection effects on incident and scattered acoustics. The hardwall boundary condition is thus evaluated directly in a moving medium. The need for a Lorentz transform is obviated, overcoming the complexity it introduces and the limitations it imposes.

1. Introduction

Aerodynamic noise generated from rotors, wings, and airframe components in a uniform flow comprises of incident and scattered acoustic fields. The presence of neighboring bodies may result in reflected and scattered sound waves of greater amplitude than the incident acoustic field [1]. Moreover, acoustic levels may be amplified due to uniform flow effects. Numerical methodologies capable of simulating convection effects are thus necessary for accurate aeroacoustic scattering prediction in realistic configurations.

Efficient aeroacoustic scattering prediction for sources in a uniform flow can be realized by boundary methods, such as the boundary element method (BEM) [2,3] and the equivalent source method (ESM) [4–6]. These methods are generally preferred over finite difference or finite element methods since they only require evaluation of the hardwall boundary condition on a discrete number of points on the scattering surface. The ESM provides specific advantages over the BEM, since

* Corresponding author.
E-mail address: leonidas.siozos-rousoulis@vub.ac.be (L. Siozos-Rousoulis).

https://doi.org/10.1016/j.jsv.2018.05.044

it allows choosing less source points than scattering points, whereas it does not suffer from the numerical singularity at interior resonance frequencies occurring in the BEM. The hardwall boundary condition can be satisfied by enforcing zero acoustic velocity or, equivalently, zero acoustic pressure gradient normal to the surface. This boundary condition is valid for a stationary scattering surface or a surface in rectilinear motion, as long as the surface has a very small slope in the direction parallel to its motion [7]. The ESM has been developed in the time domain [5] and in the frequency domain [4]. A frequency-domain solution is particularly advantageous for periodic noise problems, such as rotating sources.

Frequency-domain aeroacoustic scattering predictions for a source and scattering surface in uniform flow can be realized by considering convected or non-convected acoustic waves. Scattering prediction can be divided into propagation from the source to the scattering surface (incident field) and propagation from the scattering surface to the observer (scattered field). Incident predictions can be obtained by integral acoustic formulations whereas the scattered field may be efficiently computed using the ESM. As shown in the flow chart of Fig. 1, two main categories of methodologies can be identified for frequency-domain scattering predictions in a uniform flow.

The first category, seen on the left-hand side of the flow chart displayed in Fig. 1, relies on non-convected acoustic waves and consists of the ESM proposed by Dunn and Tinetti [4], the derivation of which is based on a Lorentz transformation. Due to the requirement of such a transformation, this approach will be referred to hereafter as ESM-LT. In the ESM-LT, the hardwall boundary condition is evaluated by computing the incident field on the scattering surface (see Refs. [8–10]), by acoustic pressure gradient or acoustic velocity formulations derived in a stationary medium (i.e. [11–14]). After incident acoustics on the scattering surface are computed, the boundary condition is evaluated in a stationary medium and subsequently equivalent source strengths are computed. Propagation of the scattered field is finally realized by a methodology based on a Lorentz transform. The transformation adds complexity to the approach. It also tends to elongate the scattering surface geometry in the direction of the flow, which can in turn lead to erroneous acoustic characteristics for specific surface shapes. Moreover, the application of the ESM-LT should be limited to low-speed flows as mentioned in Ref. [4].

The second category of methodologies, depicted on the right-hand side of the flow chart shown in Fig. 1, is based solely on convected acoustic waves, where uniform flow effects are considered directly during the evaluation of the boundary condition, as well as during scattered field propagation. This is possible by a solution of the convected FW-H equation. Ghorbaniasl et al. have recently derived a moving-medium formulation for acoustic pressure and acoustic pressure gradient prediction, in the frequency domain [15]. Application of these formulas was shown for acoustic scattering of sources in stationary media [16,17]. To the authors' knowledge, the acoustic pressure gradient formula suggested in Ref. [15] is the only formulation which is based on the convected FW-H equation and can be used for evaluation of the hardwall boundary condition in a moving medium. It also allows to define convected equivalent sources, and thus a convected ESM, in the frequency domain.

Purpose of the present paper is to suggest a convected frequency-domain equivalent source approach capable of simulating the scattered field directly, along with uniform constant flow effects of any subsonic flow velocity. The suggested

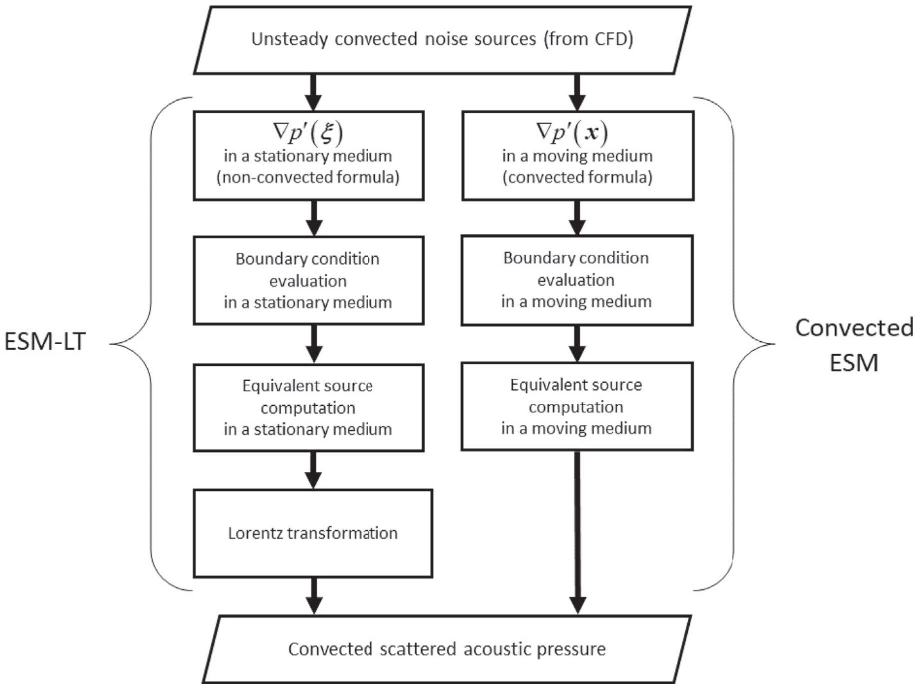

Fig. 1. Placement of the main contribution of the present work within the current state of art of frequency-domain equivalent source methodologies, for sources and surfaces in uniform flow. The proposed convected approach is depicted on the right-hand side, whereas the ESM-LT of Dunn and Tinetti [4] is depicted on the left-hand side.