ARTICLE IN PRESS

Wave Motion ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Wave Motion

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

A simulation-based analysis of the effect of a reflecting surface on aeroacoustic time-reversal source characterization and comparison with beamforming

Akhilesh Mimani [a,*], Ric Porteous [a], Con J. Doolan [b]

[a] *School of Mechanical Engineering, The University of Adelaide, South Australia 5005, Australia*

[b] *School of Mechanical and Manufacturing Engineering, University of New South Wales, New South Wales 2052, Australia*

HIGHLIGHTS

- Influence of a rigid-wall on aeroacoustic TR source characterization is analyzed.
- Wave reflection partially compensates for absence of acoustic data at rigid-wall.
- TR simulations show only one line array needed to localize and characterize idealized sources.
- CB used Method of Images to model the rigid-wall, CB and TR results are very comparable.
- Simulation results show a significant potential for application in experimental aeroacoustics.

ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form 25 May 2016
Accepted 4 June 2016
Available online xxxx

Keywords:
Idealized aeroacoustic sources in shear flows
Moving sources and Doppler effect
Aeroacoustic Time-Reversal
Reflecting boundary condition
Method of Images
Cross-spectral Conventional Beamforming

ABSTRACT

This paper presents a simulation-based analysis of the effect of a reflecting surface on aeroacoustic Time-Reversal (TR) source localization/characterization and compares the results of TR with those obtained using cross-spectral Conventional Beamforming (CB). The TR technique is shown to require the use of at least two line arrays of microphones to accurately characterize the nature of aeroacoustic sources. This work, however, shows that in the presence of a rigid surface, only one line array of microphones is sufficient to accurately localize and characterize idealized aeroacoustic sources. Forward simulations were carried out using the 2-D Linearized Euler Equations on a rectangular domain with a rigid bottom boundary (modeling a 2-D semi-infinite space) for the test-cases of stationary idealized tonal aeroacoustic (monopole, dipole and lateral quadrupole) sources located in a fully-developed mean shear flow field wherein the acoustic pressure time–history was stored at the computational boundaries. A set of TR simulations are implemented that show for each test-case that only the top line array is required to accurately characterize the idealized aeroacoustic sources in the presence of a reflecting bottom boundary, thereby suggesting the redundancy of acoustic pressure measurement at the rigid surface. The test-case of convecting (moving) idealized aeroacoustic source was also considered and the TR simulation using only the top line array in the presence of reflecting bottom boundary was able to accurately retrieve the source trajectory and simultaneously characterize its nature. This numerical experiment demonstrates in principle that when a rigid surface is mounted on the floor of an Anechoic Wind Tunnel, the use of only one (top) line array of microphones should be sufficient to characterize the nature and location of experimental flow-induced noise source. Acoustic source maps were also obtained using the CB method based on the Method of Images (to model the reflecting surface) and incorporation of the Ray-Tracing

* Corresponding author.
E-mail addresses: akhilesh.mimani@adelaide.edu.au (A. Mimani), ric.porteous@adelaide.edu.au (R. Porteous), c.doolan@unsw.edu.au (C.J. Doolan).

http://dx.doi.org/10.1016/j.wavemoti.2016.06.003

algorithm necessary to account for the effect of mean flow. The CB results were found to be highly comparable to those obtained using TR for the test-cases of non-convecting sources; thereby demonstrating the conceptual equivalence of the Method of Images and directly implementing the rigid-wall condition during TR for source localization/characterization.

1. Introduction

Acoustic Time-Reversal (TR) proposed by Fink et al. [1] is a promising method operating in the time-domain used for solving inverse problems of sound source localization. The TR method finds application in diverse fields such as ultrasound medical imaging, diagnostic and non-destructive testing [1], long-range communication in deep underwater acoustics [2], structural dynamics for health monitoring [3], electromagnetic wave propagation [4] and recently, in the field of aeroacoustics for studying flow-induced noise problems [5–7]. The TR technique implemented in a free-space, i.e., in a domain with non-reflective or anechoic boundaries typically employs the following two-step approach.

(1) In the first step, the acoustic pressure field radiated by source(s) is recorded by a microphone array in a Time-Reversal Mirror (TRM) during experiments or stored at the boundary nodes (virtual microphones) during forward simulations, either (a) over an array completely enclosing the source (see Fig. 1(a) of Ref. [8]), or (b) over an array with a limited aperture only partially enclosing the source.
(2) In the second step, the recorded acoustic pressure time–history is reversed in time and is enforced at the boundary nodes (corresponding to the microphone location) as numerical sources in a high-resolution numerical algorithm which initiates back-propagation of acoustic waves into the domain that converge at the source [1]. This step constitutes the TR source localization method.

When the microphone array completely encloses a time-harmonic source located in a free-space, it can account for almost the total acoustic power radiated from the source [9], and yields the most accurate prediction of the location and nature of the source [10] as well as the shape and strength of a transient signal such as a Gaussian pulse [11–13]. However, the use of such an array configuration is often limited. This is because its setting-up may be difficult (or perhaps, impossible) in certain experiments such as during aeroacoustics experiment carried out in a wind tunnel because the microphones must be located outside the flow field in order to prevent the generation of noise due to interaction of flow field with the microphones [11]. Furthermore, a large number of microphones are required (increasing with source frequency due to Nyquist–Shannon spatial-sampling criteria [1,14]) to completely enclose the source, often rendering the use of such a configuration impractical.

In view of the aforementioned difficulties, a microphone array that partially encloses the source, is often used for aeroacoustic TR [5–7,10,11,15], notwithstanding its limited focusing ability as it accounts for only a fraction of the acoustic power radiated. For instance, Padois et al. [11] used the experimental acoustic pressure time–history measured over one Line Array (LA) of microphones located above a wind tunnel test area and outside the mean shear flow field for localizing a time-harmonic monopole source (simulated by a loudspeaker) and a dipole source (simulated by two out-of-phase loudspeakers in proximity with their axis parallel to the flow) using a 2-D TR simulation based on the numerical solution of Linearized Euler Equations (LEE). The tube-end of the loudspeaker(s) was flush-mounted on a rigid plywood plate to ensure that the mean flow does not interact with the source(s). However, the rigid-wall boundary condition due to the plywood was not taken into account during the 2-D TR simulations; rather, the Anechoic Boundary Conditions (ABCs) were implemented at all boundaries allowing the back-propagated waves to pass through the bottom boundary without undergoing reflection. The error in the predicted location was shown to be less than a half-wavelength, however, the main limitation of their work was use of one LA which cannot characterize the idealized sources and flow-induced noise sources such as multipole sources [16–22].

The present authors had previously demonstrated through a simulation-based analysis that use of a minimum of two LAs of virtual microphones located at the top and bottom boundaries of a 2-D free-space during TR is necessary for characterizing the idealized aeroacoustic sources [10,15]. It was noted that the TR source maps indicate an error of one-tenth of a wavelength in the predicted location of the idealized sources. This result was later corroborated through an application of the TR technique to the experimental data of the flow-induced noise source; it was shown that the use of experimental data recorded at two co-planar LAs of microphones located at the top and bottom boundaries of an Anechoic Wind Tunnel (AWT) during 2-D TR simulations was able to characterize the *lift-dipole* nature of the flow-induced noise source generated at the Aeolian tone of a full-span cylinder [5,6] and by a full-span symmetric flat-plate throughout the broadband frequency range [7]. (The plane containing the two LAs was aligned perpendicular to the test-model span). It is noted that the microphones recorded the 3-D acoustic pressure field radiated by the flow-induced sources; however, the TR simulation was implemented over a 2-D domain (on the plane containing the LAs) because the span of both test-models extends beyond the width of the contraction-outlet which eliminates the end-effects [21], thereby signifying that a 2-D representation was sufficient for these experimental flow-induced noise problems. For the Aeolian tone, the experimental