

# Noise Source Localization and Optimization of Phased-Array Results

Patricio A. Ravetta\*

AVEC, Inc., Blacksburg, Virginia 24060

and

Ricardo A. Burdisso<sup>†</sup> and Wing F. Ng<sup>‡</sup>

Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

DOI: 10.2514/1.38073

A new approach to the deconvolution of acoustic sources has been developed and is presented in this work. The goal of this postprocessing is to simplify the beamforming output by suppressing the side lobes and reducing the sources' main lobes to single (or a small number of) points that accurately identify the noise sources' positions and their actual levels. In this work, a new modeling technique for the beamforming output is proposed. The idea is to use an image-processing-like approach to identify the noise sources from the beamforming maps: that is, recognizing lobe patterns in the beamforming output and relating them to the noise sources that would produce that map. For incoherent sources, the beamforming output is modeled as a superposition of point-spread functions and a linear system is posted. For coherent sources, the beamforming output is modeled as a superposition of complex point-spread functions and a nonlinear system of equations in terms of the sources' amplitudes is posted. As a first approach to solving this difficult problem, the system is solved using a new two-step procedure. In the first step, an approximated linear problem is solved. In the second step, an optimization is performed over the nonzero values obtained in the previous step. The solution to this system of equations renders the sources' positions and amplitudes. In the case of coherent sources, their relative phase can also be recovered. The technique is referred as noise source localization and optimization of phased-array results. A detailed analytical formulation, numerical simulations, and sample experimental results are shown for the proposed postprocessing.

## Nomenclature

|   |   |
|---|---|
| $a(\mathbf{x}'')$                       | = source strength for a source at $\mathbf{x}''$  |
| $b(\mathbf{x})$                         | = beamforming output power at the point $\mathbf{x}$  |
| $b_R(\mathbf{x}_i)$                     | = reconstructed beamforming output at the point $\mathbf{x}_i$                                    |
| $b'(\mathbf{x})$                        | = linear approximation to the actual beamforming output $b(\mathbf{x})$ at the point $\mathbf{x}$ |
| $C$                                     | = correlation coefficient   |
| $C_j(\mathbf{x}')$                      | = complex array response for microphone $j$ for a source at $\mathbf{x}'$                         |
| $\text{cpsf}(\mathbf{x}, \mathbf{x}'')$ | = complex point-spread function at the point $\mathbf{x}$ for a source at $\mathbf{x}''$          |
| $\hat{\mathbf{E}}$                      | = matrix of complex point-spread functions  |
| $f(\mathbf{b}, \mathbf{a})$             | = error function  |
| $J$                                     | = total number of microphones   |
| $K$                                     | = wave number   |
| $M$                                     | = actual number of sources  |
| $N$                                     | = number of grid points   |
| NZ                                      | = number of nonzero sources from approximated solution  |
| $\mathbf{p}$                            | = vector containing the for each of the array microphones   |

|  |  |
|--|--|
| $\text{psf}(\mathbf{x}, \mathbf{x}'')$ | = point-spread function at the point for a source at $\mathbf{x}''$                      |
| $p_j$                                  | = frequency-domain pressure at microphone $j$  |
| $s(\mathbf{x})$                        | = source distribution function   |
| $\mathbf{w}(\mathbf{x})$               | = array weighting factor, also known as steering vector                                  |
| $\mathbf{x}$                           | = position vector  |
| $y(\mathbf{x})$                        | = complex beamformed pressure at the point   |
| $\delta(\mathbf{x}' - \mathbf{x}'')$   | = Dirac's delta function   |
| $\xi_n$                                | = error between actual and modeled beamforming output for a grid point at $\mathbf{x}_n$ |
| $\langle \rangle$                      | = time-averaged of short-time Fourier transform signals                                  |

## I. Introduction

**D**URING the past years, microphones phased-array measurements have become a common practice in aeroacoustic testing. The use of this technology allows creating a sound picture at each frequency of interest showing the most significant noise sources. However, one of the problems with phased-array measurements is that the beamforming maps are usually contaminated by side lobes (i.e., lobes not associated with actual sources). Thus, it could be difficult to clearly identify the noise sources' positions and actual levels from the beamforming maps. This problem is especially true for complex source distributions, for coherent sources, and when some of the sources are at or under the array signal-to-noise ratio (SNR) (i.e., side lobes that can be assumed to be noise sources and vice versa). As a consequence, the interpretation of the beamforming maps has to be performed with care to properly identify the real noise sources, in which case some sources that look like side lobes might be overlooked.

To overcome these issues, a beamforming postprocessing technique called DAMAS (deconvolution approach for the mapping of acoustic sources) was developed by Brooks and Humphreys in 2004 [1]. This technique represented a breakthrough in array processing and led the way for future phased-array analysis. The DAMAS

Presented as Paper 2713 at the 12th AIAA/CEAS Aeroacoustics Conference (27th AIAA Aeroacoustics Conference), Cambridge, MA, 8–10 May 2006; received 14 April 2008; revision received 21 November 2008; accepted for publication 25 November 2008. Copyright © 2009 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved. Copies of this paper may be made for personal or internal use, on condition that the copier pay the \$10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0001-1452/09 and \$10.00 in correspondence with the CCC.

\*Chief Research Engineer, 3154 State Street Suite 2230. Senior Member AIAA.

<sup>†</sup>Professor, Mechanical Engineering Department, Mail Code 0238. Member AIAA.

<sup>‡</sup>Chris Kraft Endowed Professor, Mechanical Engineering Department, Mail Code 0238. Associate Fellow AIAA.