SOURCE LOCALIZATION OF AIRCRAFT ENGINES WITH CIRCULAR MICROPHONE ARRAYS

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1. INTRODUCTION

Turbo-engines are an important of exterior noise of jet aircraft. Many researchers have attempted to develop methods to identify and locate the various noise sources of aero-engines (fan, compressor, turbine, combustion, jet exhaust). Among the acoustical localization techniques, the beamforming method [1] and Inverse method [2] are very common. In a recent past, hybrid methods using subspace analysis and beamforming have been particularly developed, such as the MUSIC [3] and ESPRIT [4] methods. The aim is to split relevantly signal and noise components into identified subspaces to attenuate the measurement noise. Sarradj [5] proposed a different subspace-based beamforming method focused on signal subspace and leading to a computationally efficient estimation of the source strength and location. The general idea of these approaches is to improve the performance of beamforming by estimating the assigned distribution of sources through the solution of an inverse problem. Recently inverse problems in acoustic imaging have been devoted to the selection of the optimal regularization parameter [6] which is a key aspect of inverse problems.

The goal of this research is the discrimination of inlet and exhaust sources in aircraft engines using far field microphone arrays. The proposed acoustic source identification method in this study is based on a combination of inverse modeling and conventional beamforming. It was initially investigated at university of Sherbrooke for sound field extrapolation in small, closed environments based on sound field measurement with a microphone array. The method has proven to provide source localization in free-field, diffuse field and modal situations with a better spatial resolution than conventional beamforming and inverse methods.

2. METHODS

This section discusses inverse problems in general as well as Tikhonov regularization theory and presents the beamforming regularization approach proposed in this research.

2.1 Inverse Method

We assume here that the acoustic sources are represented by a set of L point sources and also there are M microphones to measure the magnitude of the sound sources. The sampled direct radiation problem is written in matrix form

$$\mathbf{p} = \mathbf{G}\mathbf{q} \tag{1}$$

Where $\mathbf{p}$ is a $M \times 1$ vector of complex sound pressure values at the microphone locations, $\mathbf{G}$ is a $M \times L$ vector matrix of free-field Green's functions between the L point sources and M sound pressure measurement points, $\mathbf{q}$ is a $L \times 1$ vector of unknown complex source strengths. In the inverse method, the minimization of the 2-norm of the error between the reconstructed sound pressure $\mathbf{p}$ assuming a set of L point sources and the measured sound pressure $\widehat{\mathbf{p}}$ is calculated. The problem is then to find the optimal $\mathbf{q}$ for the minimization problem

$$\boldsymbol{q}_{opt} = arg\ min\{|\widehat{\mathbf{p}} - \mathbf{G}\mathbf{q}|^2\} \tag{2}$$

Most of the time the inverse problem is ill-conditioned, implying that the solution $\boldsymbol{q}_{opt}$ is very sensitive to measurement noise and model uncertainty. To prevent this problem, Tikhonov regularization method is used [6],

$$\boldsymbol{q}_{opt} = arg\ min\{|\widehat{\mathbf{p}} - \mathbf{G}\mathbf{q}|^2 + \lambda^2|\mathbf{L}\mathbf{q}|^2\} \tag{3}$$

where λ is the regularization parameter and $\mathbf{L}$ is the discrete smoothing norm used to shape the regularization. The solution of this minimization problem is

$$\boldsymbol{q}_{opt} = \frac{\boldsymbol{G}^H\mathbf{p}}{\boldsymbol{G}^H\mathbf{G} + \lambda\boldsymbol{L}^H\mathbf{L}} \tag{4}$$

2.2 Beamforming Regularization (Hybrid)

The main idea behind the proposed hybrid approach is to find a "best" smoothing norm $\mathbf{L}$ in our problem. This can be done by observing that part of the solution given by eq 4 involves a beamforming delay-and-sum operation. In this case the beamforming delay-and-sum operation is given by

$$\boldsymbol{q}_{BF} = \boldsymbol{G}^H\widehat{\mathbf{p}} \tag{5}$$

which is equal to the numerator of eq 4. The beamformer output is defined by

$$\boldsymbol{q}_{BF}{}^H\boldsymbol{q}_{BF} = \widehat{\mathbf{p}}^{\mathrm{H}}\boldsymbol{G}\boldsymbol{G}^H\widehat{\mathbf{p}} \tag{6}$$

An application of the general Tikhonov regularization [6] problem eq.4 is therefore to use the special case where the regularization matrix $\mathbf{L}$ is related to the beamforming output,

$$\boldsymbol{L} = [diag(|\boldsymbol{G}^{\boldsymbol{H}}\hat{\mathbf{p}}|/||\boldsymbol{G}^{\boldsymbol{H}}\hat{\mathbf{p}}||_{\infty})]^{-1} \quad (7)$$

So the minimization problem thus becomes

$$\boldsymbol{q}_{opt} = arg\ min\{|\hat{\mathbf{p}} - \mathbf{Gq}|^2 + \lambda^2|[diag(|\boldsymbol{G}^{\boldsymbol{H}}\hat{\mathbf{p}}|/||\boldsymbol{G}^{\boldsymbol{H}}\hat{\mathbf{p}}||_{\infty})]^{-1}\mathbf{q}|\} \quad (8)$$

2.3 Experiments

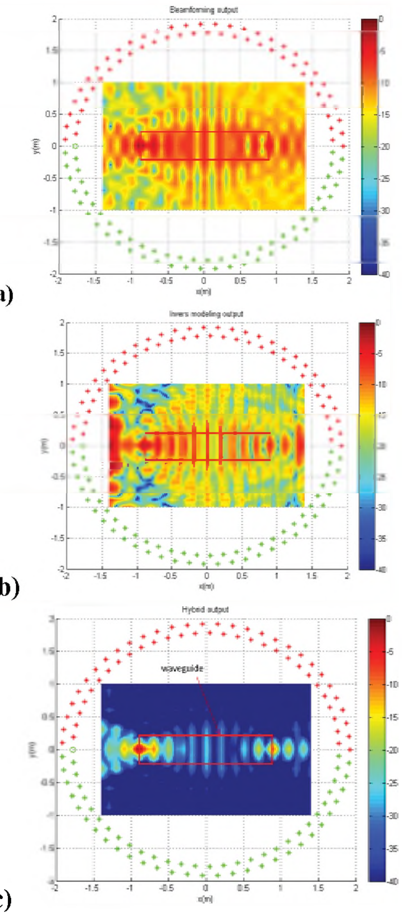
A laboratory test set-up was designed to validate the source identification approach. A small-scale replica of a free field static engine test was installed in a hemi-anechoïc chamber. The engine was experimentally modelled by two open cylindrical waveguides fitted with a loudspeaker at their ends (placed back-to-back to simulate inlet and exhaust noise) to measure the sound pressure field of the sources, a semi-circular configuration of microphones was set up around the small-scale engine.

3. RESULTS

Experiments were repeated for different inputs of the loudspeakers (tonal, band-limited white noise and combination of tonal and band-limited white noise). The experimental data were then post-processed using the various source identification approaches (Beamforming, inverse and Hybrid) to validate the best method. Figure 1 shows the output of the three methods for two broadband sources simulating the inlet and outlet of a small-scale engine. 60 microphones were set-up on two rings around the small-scale engine at an average radius of approximately 2m and axi-symmetry of the sound field was assumed. The Figure 1 shows that the Hybrid method can identify the location of the source in inlet and outlet of the engine.

4. DISCUSSION AND CONCLUSIONS

The results of experimental data show that the Hybrid method is an effective technique for discrimination of inlet and exhaust noise in aero-engines. Also, the results show that spatial source resolution in Hybrid method is better than with the beamforming method and inverse method.



(a)

(b)

(c)

Figure 1. Output of Beamforming(a), Inverse(b) and Hybrid method (c) for two broadband sources that the left source is 6db stronger that the right source, frequency=1Khz, 60 microphones

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