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DETERMINATION OF ACOUSTIC ARRAY CONFIGURATION FOR OPTIMAL BEAMFORMING USING GENETIC ALGORITHMS: PART II – APPLICATION TO WIND TUNNEL TESTING OF SCALED MODEL OF A REGIONAL AIRCRAFT WITH COUNTER-ROTATING OPEN-ROTORS

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Abstract. *In this paper we present the very first experimental results from wind tunnel experiments of a scaled model of a regional aircraft with counter-rotating open-rotors and the application of beam-forming techniques to detect the noise sources. In addition, a Genetic Algorithm optimization tool is used to optimally reduce the number of elements of an acoustic array, without reducing its specific performance required for the series of experimental tests. The results show that the a priori selection of the optimal configuration using the GA tool could contribute to the reduction of the number of channels while improving the pattern of the beam and the overall performance.*

1 INTRODUCTION

Far field beamforming for sound/noise source localization, is an expanding application field today. The quality of the source detection and the direction of arrival (DOA) estimation, especially when multiple sources are present, depend highly on the response pattern of the acoustic array.

A way to improve the response pattern is to design an appropriate array geometry and configuration for the application in hand. But, array construction and geometry configuration is not an easy or inexpensive task. Therefore, an early study of all possible array configurations, to achieve the desired array performance, is required before constructing an array.

Several restrictions and requirements are posed to the designer about the array size, geometry, number of sensors, distance, direction, positioning, etc, leading to a large number of alternative designs with comparable characteristics (figure 1). Alternative designs can be simulated and compared by the array designer, using specially designed tools like AABA [1].

For larger number of candidates, more thorough search and detection tools applying optimization techniques such as Genetic Algorithms (GA) can be used, as the one developed in [2]. These tools use an optimizer to calculate the best configuration, based on the designer’s criteria, requirements and goals.

In this paper, the case of acoustic experiments in a Wind Tunnel using the acoustic arrays already installed and functioning is presented. The problem faced is that the microphone configuration of an installed array has been designed to perform optimally for all cases and therefore is not optimally-best for each case. Each experiment may need different array layouts, external arrays or sub-arrays or other re-configurations of the installed equipment, leading often to a need of extra acquisition channels, thus making necessary to either connect external equipment, or reduce the required time & space for processing and storing the acquisition data sets.

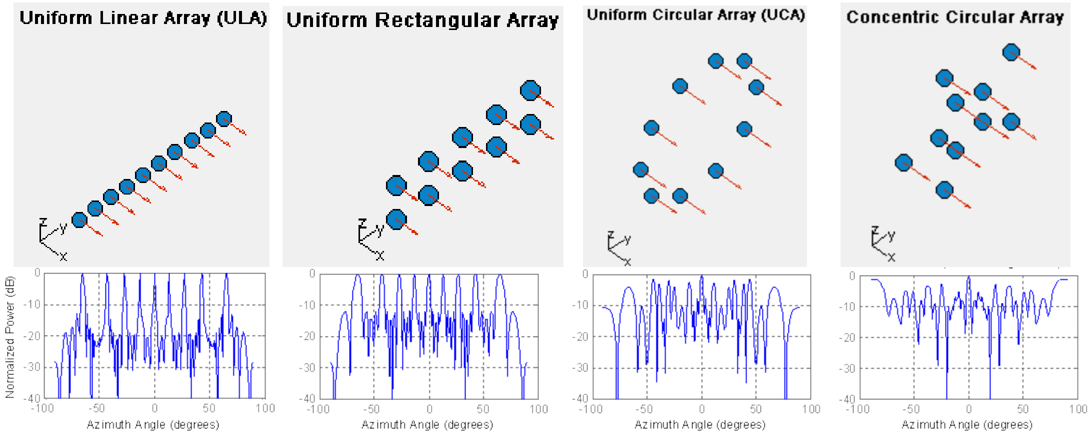


Figure 1. Four different array geometries using the same number of MICs and their responses (Azimuth cuts at elevation angle (0^{o}): a) ULA, b) URA, c) UCA, d) CCA

The aims of the present work are, first to map the emitted noise and also to locate the direction of the noise emission sources based on the experimental scale model of a regional aircraft with counter-rotating open-rotors. The second objective, as shown in figure 2, is to find an optimal reduction of the existing arrays in order to reduce the number of microphones or channels, without compromising performance, i.e., keeping low side lobe level, narrow beam width and accurate source detection (DoA) and also to verify that the optimal solution is correct under the real conditions of the Wind Tunnel experiments.

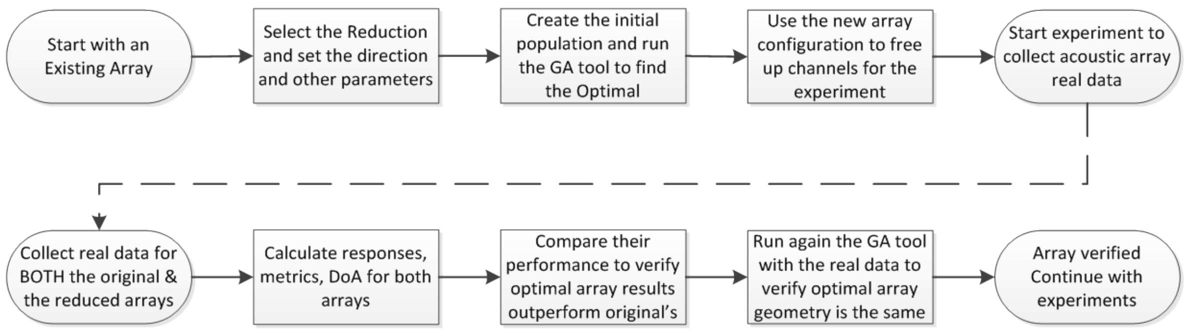


Figure 2. The two stages: Array Design Optimization and Experimental Verification.

As the decision about the optimal solution is usually made at design stage, i.e., before constructing and using any array, the question about the correctness of the optimal solution remains, until the array is finally used in the field with real data. In our case, the experimental data from the Wind Tunnel tests of sound emissions from an airplane model engine will be used to test and verify the optimization results.

2 THE WENEMOR PROJECT EXPERIMENTS

2.1 The Aircraft Model

As presented in detail in [3] by the WENEMOR consortium, the principal goal of the WENEMOR project is to assess experimentally the noise shielding effectiveness of classic airframe components for different Open Rotor aircraft configurations. A complete 1/7th scale aircraft has been designed and built for installation in the Pininfarina Aerodynamic and Aeroacoustic Research Center Wind Tunnel (figure 3a). The model has two Counter-Rotating Open-Rotors, at the same scale as the airframe (figure 3b). Various positions of the ORs with respect to the airframe will be tested with noise measurements being performed both in the near and the far field.

(a) (b)

Figure 3. The aircraft model (a) and the engines (b) installed in the wind tunnel [3].

2.2 The Far Field Experimental Facilities

The far field sound measurements were acquired by three (3) 2-D microphone arrays ('Top', 'Lateral' and 'Front') and one (1) 1-D/linear array (figure 4) with the following details:

- Top array (78 microphones), circular in 4 concentric circles
- Lateral array (66 microphones), semi-circular
- Front array (30 microphones), circular
- Linear Array (13 microphones) centered on the front blade plane covering angles from 30 to 150 about the blade side-line axis

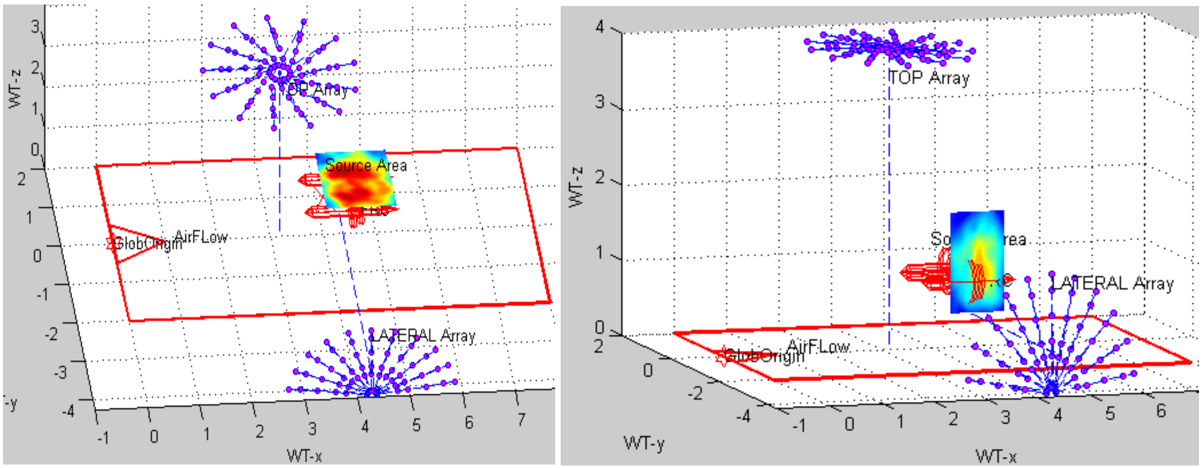
Data were acquired simultaneously on all systems for the far field measurements at a data rate of 32,768Hz for 10s duration. A total of 16 aircraft configurations were tested consisting of 9 pusher and 7 tractor configurations. Each aircraft configuration could in turn be modified to a take-off or approach setting. Using automated systems in the wind tunnel, each of these set-ups was then tested at a variety of angle of attack settings: 6o, 8o, 10o, and flow speeds: 20m/s, 24m/s, 28m/s. This led to a total of 288 unique test set ups consisting of changes in model geometry, take off/approach setting, angle of attack and wind tunnel flow speed. The outputs of the WENEMOR project will form a database through which the other Green Regional Aircraft partners can validate the developed software codes.

Figure 4. Pininfarina's wind tunnel: a) the 'top' and 'lateral' arrays [3], and,
b) setup of the 'lateral', 'linear' & Univ.PM 'front' array.

3 OPEN-ROTORS NOISE EMISSION DETECTION

The final set of experimental data is collected using the airplane & engine models shown in figure 3, and, a separate sequence of data was recorded by the acoustic arrays for each one of the 288 test setups.

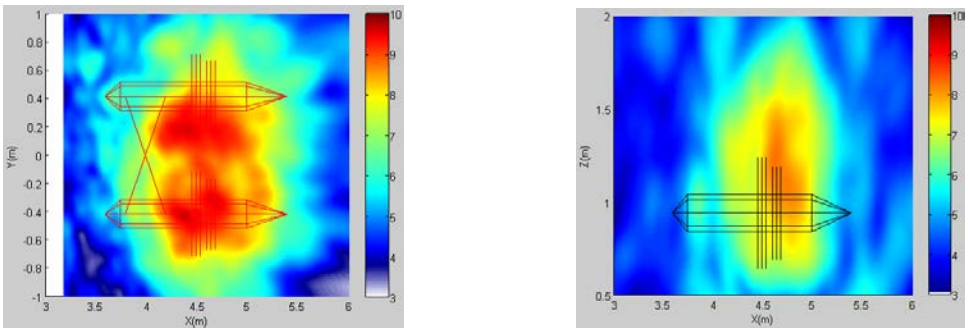
Here, a subset of the results is presented, i.e., the test sequence PTE1_T_FF_00_28_0, with the responses of both the Top 78mic array (figure 5a) and the Lateral 66mic array (figure 5b). The response is projected at the location of the noise source and a wireframe drawing of the engines & rotors is added to the plots for reference.



(a) (b)

Figure 5. Top (a) & Lateral (b) array responses, averaged over the 400-3600Hz frequency range. The engines-rotors position is also shown for reference.

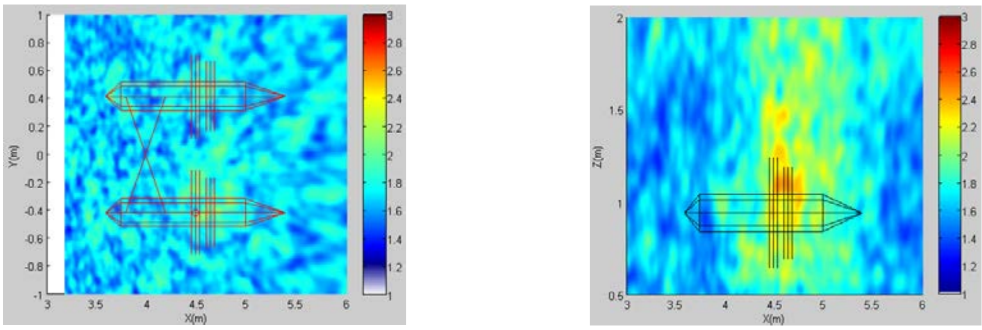
The Top & Lateral array responses were filtered and summed over the 400-3600Hz frequency range. The detailed vertical and horizontal views of the above responses are shown in figure 6.



(a) (b)

Figure 6. Noise received at the Top (a) and the Lateral (b) arrays (lower frequencies).

The noise levels at higher frequencies, from 4000 to 8000 Hz, (figure 7) are significantly lower as it becomes is clear from the values of the colorbar.



(a) (b)

Figure 7. Noise received at the Top (a) and the Lateral (b) arrays (higher frequencies).

Using conventional beamforming and direction of arrival (DOA) techniques the acoustic arrays were used to detect the origins of the emitted noise. There are slight variations on the estimated DOA depending on the frequency but the overall results over a wider range (400-8000Hz) showed that the highest source is on the direction of the rotor blades (red lines in figure 8).

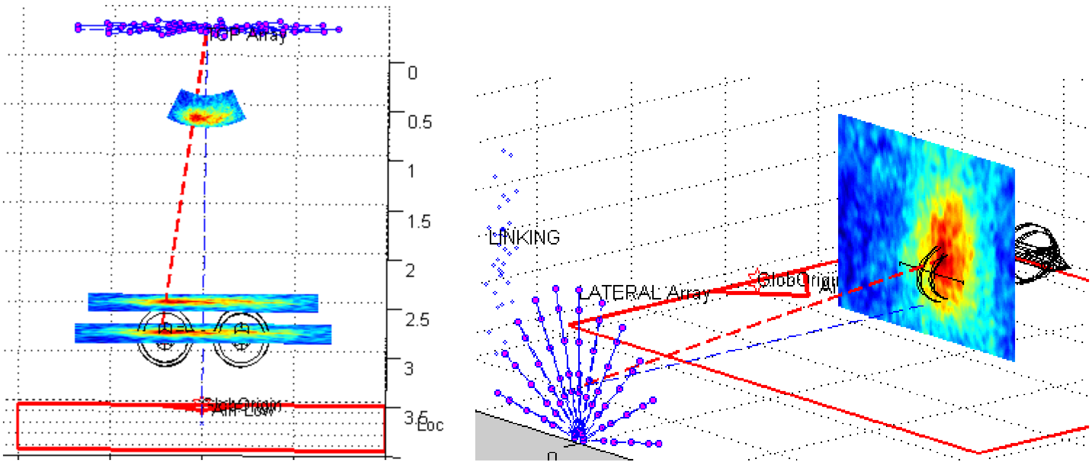
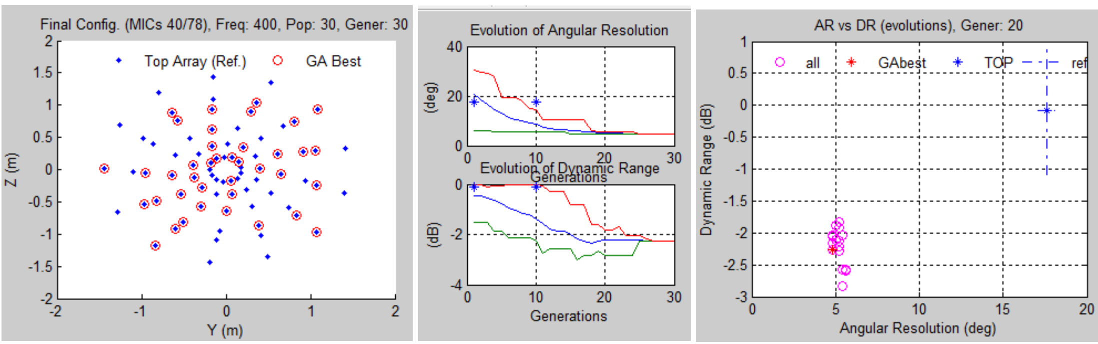


Figure 8. Averaged DOA estimation (dotted red) from the Top (a) and the Lateral (b) array.

4 ACOUSTIC ARRAY OPTIMIZATION

Finally a part of the experimental data was used to select an optimally reduced configuration of the Top array with fewer (40) elements. Following the method presented in [2], starting with an initial population of 30 arrays and after 30 generations, the result was the array shown in figure 9.



(a) (b) (c)

Figure 9. Optimal selection of a reduced array with improved characteristics (AR, DR). a) geometry, b) GA evolutions, c) final population and original array metrics.

The resulting array was applied to the rest of the data over the frequency range of 400-8000Hz and the results are shown in figure 10 where the pattern of the reduced array (b) demonstrates a higher dynamic range and better angular resolution than the response pattern of the original array (a).

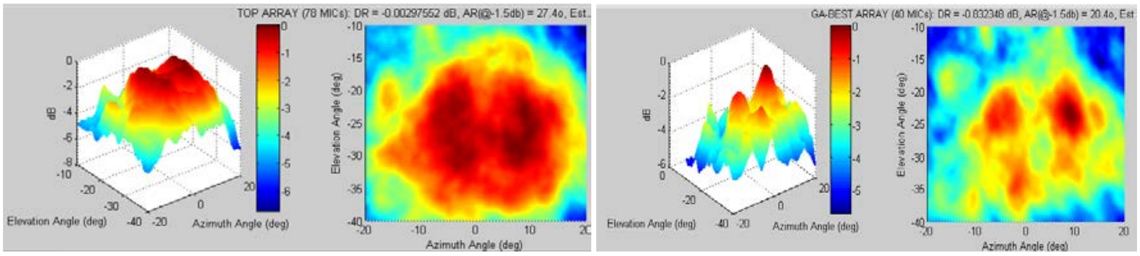


Figure 10. Response pattern of (a) the original and (b) the optimally reduced array.

The reported results were produced from the very first available datasets from the wind tunnel experiments performed in Pininfarina's installations. A large amount of data follows for some hundreds of test conditions, that will produce more concrete and detailed results on the emitted noise and on the configuration and combination of the available acoustic arrays.

5 CONCLUSIONS

In this paper, the very first experimental results from the wind tunnel experiments of a scaled model of a regional aircraft with counter-rotating open-rotors and the application of beam-forming techniques to detect the noise sources were presented. A Genetic Algorithm optimization tool was applied to reduce the number of elements of the acoustic array, in an optimal way without reducing its specific performance required for the series of experimental tests. The results show that the a priori selection of the optimal configuration using the GA tool could contribute to the reduction of the number of channels while improving the pattern of the beam and the overall performance.

6 ACKNOWLEDGMENTS

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