COMPARISON OF SOURCE ESTIMATION ALGORITHMS / METHODS IN CLOSED TUNNEL NOISE MEASUREMENTS

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ABSTRACT

The Markham aerodynamic wind tunnel at Cambridge University has been modified to include two nested, 48 microphone arrays. The setup has been designed by the Nationaal Lucht- en Ruimtevaartlaboratorium in the Netherlands (NLR) and has been used to support the design of landing gear fairings for the Silent Aircraft Initiative.

Source power estimates have been computed using a power integration method (POWINT) and verified using the CLEAN source identification method. These are included as part of the NLR beamforming suite. POWINT computes the integrated source power over a specified grid containing the model. The CLEAN algorithm identifies the maximum source on the plot and removes it together with appropriate side lobes. It continues to compute and remove successive maximum sources which can later be added together to give an overall noise measure.

In the case where there are background sources or side-lobes visible on source plots, the use of the CLEAN algorithm to estimate source levels allows the user to choose which sources to integrate. The effect of background noise or sources exterior to the model can therefore be rejected. This technique may be of particular interest for array measurements in aerodynamic tunnels which are typically of higher background noise.

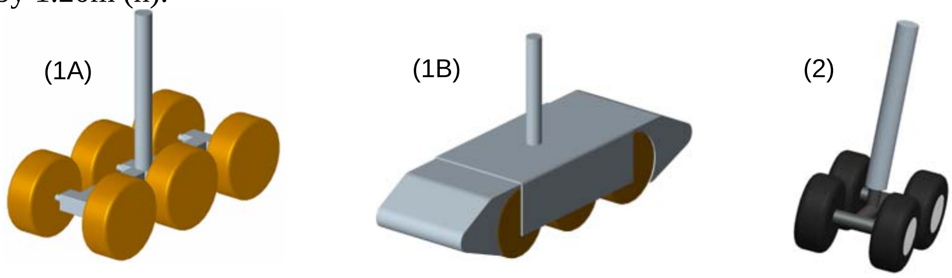
1 INTRODUCTION

Two nested microphone arrays have previously been fitted to the Markham closed-section aerodynamic wind tunnel at Cambridge University, in partnership with NLR. These have been used to measure landing gear noise as part of the Silent Aircraft Initiative [1]

In conventional beamforming, estimated source autopowers are generated using the sound pattern anticipated from a point monopole for each point on a scanning grid. Interpretation of the total noise from a given model is often achieved by addition of the sources in a particular subset of the scanning area.

2 EXPERIMENTAL SETUP

Experimental data have been collected on the aerodynamic noise of landing gear models in the Markham aerodynamic wind tunnel using a 48 microphone acoustic array, measuring 1.8m x 1.0m [2]. This fits in the floor of the wind tunnel which has a working cross section of 1.75m (w) by 1.20m (h).



1a) 6 whl bare gear; 1b) 6whl faired gear; 2) 4 wheel smooth gear

Figure 1: Models examined in the wind tunnel.

The models of figure 1 were attached to the tunnel ceiling so that the model centre was 60cm above the midpoint of the array. The models are approximately 1/12th full size and have wheel diameter 0.12m. Initial tests examined models 1a and 1b and were designed to provide an indication of measurement capability. More refined models (model 2) were examined with adjustable geometry, smoother surface features and a more realistic shape for a low-noise landing gear. In addition, the sample time of the acoustic array was increased from 2 minutes to 10 minutes with a sample frequency of 30kHz. For all experiments the flow speed was 50m/s as this was found to be the optimum, giving maximum Reynolds number without excessive tunnel background noise. The Reynolds number based on wheel diameter was 4.8×10^5.

3 RESULTS & DISCUSSION

3.1 Source Estimation

A beamforming algorithm provided by NLR [3] to accompany the array installation was used to estimate source autopower at each point on a 40cm x 40cm scanning grid. The scanning grid was in a horizontal plane through the centre of the models. Microphone autopowers were eliminated from the beamforming equation because of the high level of uncorrelated background noise in the aerodynamic, closed section tunnel [3]. Sample outputs from this method are shown in figure 2 for the 1250Hz 1/3 octave band (model scale). Flow is from left to right in each case.

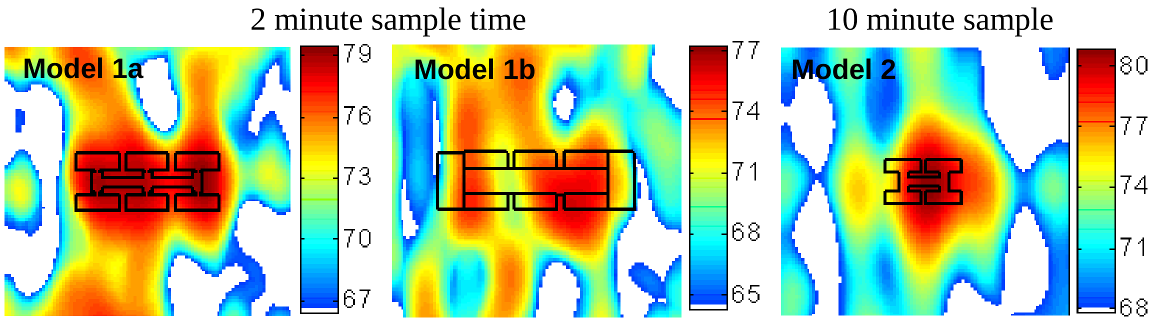


Figure 2 – Source autopower estimates for the models of figure 1, at 1250Hz.

The source plots of figure 2 estimate the strength of a point monopole at each location on the scanning grid. For true monopole sources, local maxima then identify the source strengths. Clearer results are seen in figure 2(c) with a much longer measurement time.

3.2 Source Integration

To obtain an overall assessment of the noise from each landing gear model, a source power integration method (POWINT), developed by NLR, was used [3]. As an output, POWINT gives the strength of an equivalent monopole which would develop the same integrated source level as found by integration of the experimental source autopowers.

Various integration areas enclosing the landing gear were examined to understand the effect of chosen area on the source power estimate. Example integration areas are shown in figure 3.

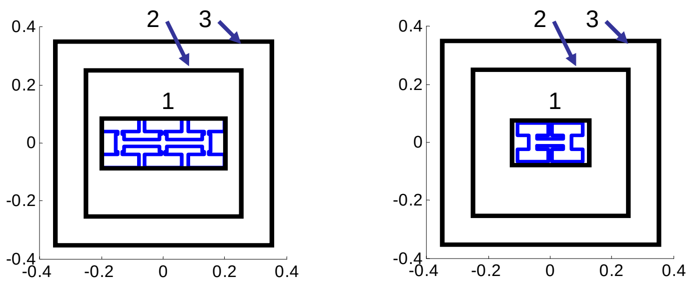


Figure 3 – Selected integration areas around models 1 and 2.

Definition of a suitable integration area is important when applying the POWINT method. For any real experiment, increasing the size of the integration area will increase the source power estimate. This is particularly noticeable where the background level is of a similar order of magnitude as model noise. Figure 4 shows the effect of applying the integration regions of figure 3 to model 2. The corresponding source autopower map for the 1250Hz band is shown on the right of figure 2.

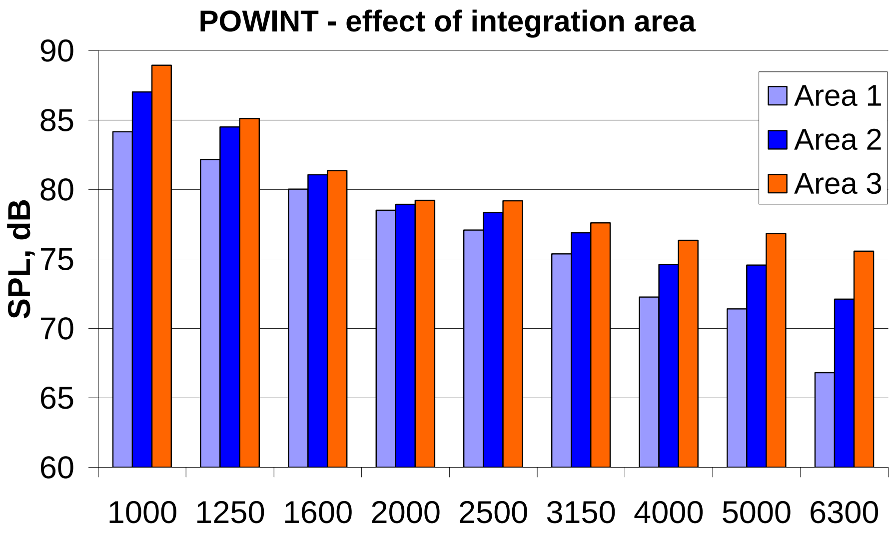


Figure 4 – POWINT levels for the three integration regions around model 2.

The effect of integration area is not common across the frequency spectrum. At lower frequencies (below 1600Hz), the POWINT method underestimates the source strength with a small integration area. The array resolution is relatively poor (in comparison to integration box size) at these frequencies, as seen from figure 2. At mid-frequencies the estimates are fairly consistent across different integration areas. At higher frequencies (above 2500Hz), the divergence of the results has been attributed to integration of additional tunnel background noise within larger integration areas (figure 5). At still higher frequencies, side-lobes from the main model begin to interfere with the integrated totals and must be carefully eliminated from the integration region.

3.3 Source Simulation

Simulations of the microphone output from any combination of monopole point sources can be generated using a suitable algorithm [3]. The use of POWINT was investigated using this tool. For a simulated point source close to the centre of the scanning grid, there is no difference in estimated level when a wide range of integration areas are used.

When additional, low level sources are present inside the integration area, POWINT interprets them as part of the total noise. This is part of the design of the POWINT routine, so that an integrated total can be obtained from the model as a whole. A requirement of this method is therefore that the background noise from a real experiment is well below the level of noise from the model. The simulation of figure 5 demonstrates the problem. A low level background noise is superimposed on the main, central source. The additional background noise makes a major contribution to the total noise estimate.

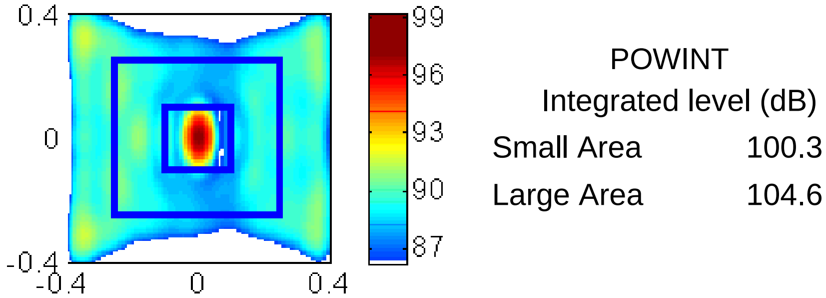


Figure 5 – Simulated background noise (101x101 grid of point monopole sources) with superimposed ‘model’ sources 10dB above (2x2 central grid).

3.4 ‘CLEAN’ Source Estimates

The CLEAN algorithm is an extension of conventional beamforming and was developed to aid the elimination of side lobes from radio telescopes [4]. This has been implemented for acoustic array experiments by NLR as a diagnostic tool to understand the influence of side-lobes on experimental measurement [3]. The method identifies the maximum source and computes the predicted interpretation of that source by the acoustic array. A fraction of the sound field from this source is extracted from the original data and the procedure repeated – identifying successive sources on the scanning grid.

The CLEAN method computes and extracts sources in a narrow frequency band (here 30Hz). To provide 1/3 octave band estimates, narrow band estimates are ‘clustered’ together using an estimate of array resolution. This is necessary because narrow band estimates will not necessarily position the same source in exactly the same place. The array resolution is taken to be the radius at which the sound level from a monopole source is 3dB lower than at the peak. After the first source is identified, subsequent sources are either added to the first (and position of the two modified according to relative strength) or treated as part of a separate ‘cluster’, allowing the separation of different sources.

Figure 6 shows a four source simulation. Figures 6(b), 6(c) show analysis using beamforming without autopowers and the CLEAN method. This application demonstrates the ability of the CLEAN method to reject sources which are not of primary interest to the user, without having to carefully select integration boundaries. The method is also highly effective at eliminating sidelobes, which can cause difficulty for fixed integration areas.

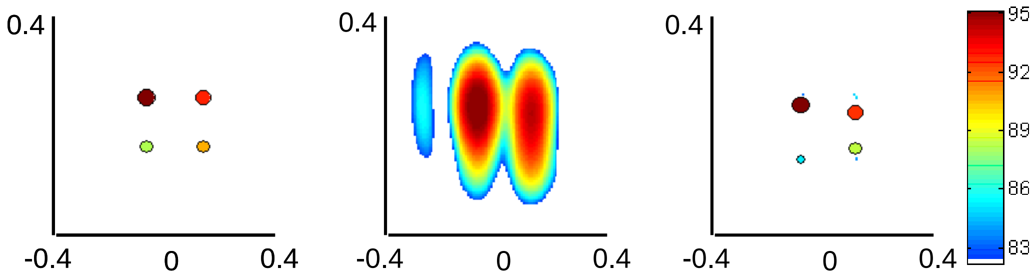


Figure 6 – (a) Simulation input (b) Beamforming (c) output from CLEAN

3.5 CLEAN Analysis of Experimental Data

In the case of experimental data, CLEAN can be used to identify sources associated with the model or part of the model. Additional sources can be rejected from the final integration. Since only a few sources will typically be of interest to the user, the method offers a way of identifying the intensity of those sources in isolation.

Figure 7 shows the CLEAN algorithm applied to data from figure 2. The sources identified by CLEAN are shown superimposed on the source pattern remaining after subtraction.

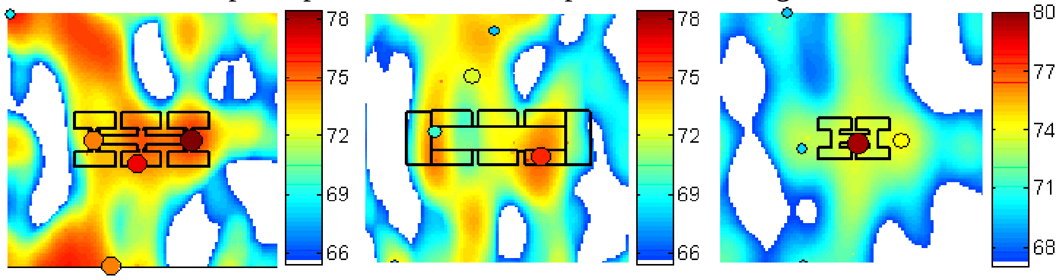


Figure 7 – Data from figure 2, processed using CLEAN

4 CONCLUSIONS

Two methods have been used to evaluate integrated totals from an acoustic array. The methods give similar results where sources can be clearly identified and the integration region chosen to exclude surrounding background noise at each frequency. By removing a proportion of the highest sources and re-evaluating the source map, the CLEAN algorithm allows successive sources to be identified and interpreted using knowledge of the model position. Using a source power integration method without carefully selecting the integration area for each frequency band concerned can lead to errors in source estimation, particularly where background tunnel noise is high. The CLEAN method is also excellent at rejecting sidelobes at higher frequencies, extending the useful frequency range of a given array.

REFERENCES

[1] CMI, "Silent Aircraft Initiative: http://www.silentaircraft.org," 2006.

[2] H. Shin, W. Graham, and A. Faszer, "Design and Implementation of a Phased Microphone Array in a Closed-Section Wind Tunnel " in 12th AIAA/CEAS Aeroacoustics Conference (27th AIAA Aeroacoustics Conference), vol. AIAA-2006-2651. Cambridge, Massachusetts: AIAA-2006-2651, 2006.

[3] P. Sijtsma, "Elements of acoustic array data processing, NLR-CR-2004-487," National Aerospace Laboratory NLR, Emmeloord, Netherlands 2004 2004.

[4] J. A. Högbom, "Aperture synthesis with a non-regular distribution of interferometer baselines," Astron. Astrophys. Suppl., vol. 15, pp. 417-426, 1974.