# Array based aerodynamic noise source identification

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## Introduction

Areas where aerodynamic noise has high attention are passenger car driving comfort at cruising speeds, and wind turbine community comfort. The paper describes the applications of array systems in the process of minimising this noise exposure.
For car interior aerodynamic noise, measurements are performed on full sized vehicles in wind tunnels at different stages during the development. Exterior noise can be measured at a very early stage, starting with a solid, clay model. Both interior and exterior array systems and measurements will be presented, and an attempt will be outlined to find the correlation between the exterior and interior noise changes resulting from design modifications.
For the investigation of wind turbine noise, measurements are made in the field on full scale turbines, but also on scale models in wind tunnels. The paper describes a set of array systems to perform these measurements together with some typical results.
Finally, an overview is given of array designs and processing algorithms typically applied for Beamforming and Near-field Acoustical Holography measurements..

## Vehicles in wind tunnels: exterior methods

The two main methods for measurements on the exterior of vehicles in wind tunnels are near-field holography and beamforming. Other methods are also being used such as acoustical mirrors and surface pressure mapping.
For near-field holography a scanning method can be used where an array of measurement microphones has to be placed close to the vehicle under test and that is usually in the airflow region. A sufficient number of reference microphones is distributed near the vehicle in order to model the independent sound fields in the frequency range of interest. Cross spectra are measured between all the reference microphones and between each reference microphone and each scan microphone. This means that the sound field coherent between the reference microphones and the scan microphones is measured, whereas the self-induced noise in the microphones, manifest in the autospectra, is suppressed. The microphones must be equipped with windscreens and be positioned to face upwind  and any support they may have must be aerodynamically chamfered to minimised unwanted turbulence. If a full microphone array were used no reference microphones would be necessary. However placing such a large structure in the airflow would inevitably produce  turbulence. Fortunately, such measurements are usually made with constant wind-tunnel flow speed, therefore a robot-controlled, scanning method with a reduced number of microphones can be employed.. Judiciously positioned reference microphones can be used to reduce the effect of wind noise. For example, a reference microphone inside a motorcyclist's helmet can be used to map the sound field coherent with this reference. Other typical references are the pressure signals measured with a HATS (Head And Torso Simulator) placed inside the vehicle, or a microphone concealed behind the side mirror in order to be shielded from the turbulence.

## Vehicles in wind tunnels: interior methods

The results from the exterior measurements are frequently used in conjunction with those made inside the vehicle. A well-proven tool here is a spherical beamformer which is usually placed at head-height at an occupant's position. The spherical beamformer provides a directional map of acoustical quantities superimposed on a photograph made by stitching together the views seen from the cameras built into the sphere. Not only can quantities such as sound pressure and sound intensity be calculated but also sound quality metrics such as Loudness, Sharpness, Impulsiveness, Articulation Index etc.
For precise noise source localisation within the vehicle cabin, the spherical beamformer is usually used in conjunction with a conformal mapping technique whereby the sound pressure or other acoustical quantity is mapping on a 3-D CAD model of the vehicle interior.
The main sources of aerodynamic noise perceived by the driver are usually the A-pillar and the side mirror. Therefore, exterior beamforming focuses on these areas. Figs.1 and 2 show results using a full wheel, beamforming array hung above the roof of the vehicle and a half wheel array positioned facing the side of the vehicle respectively.

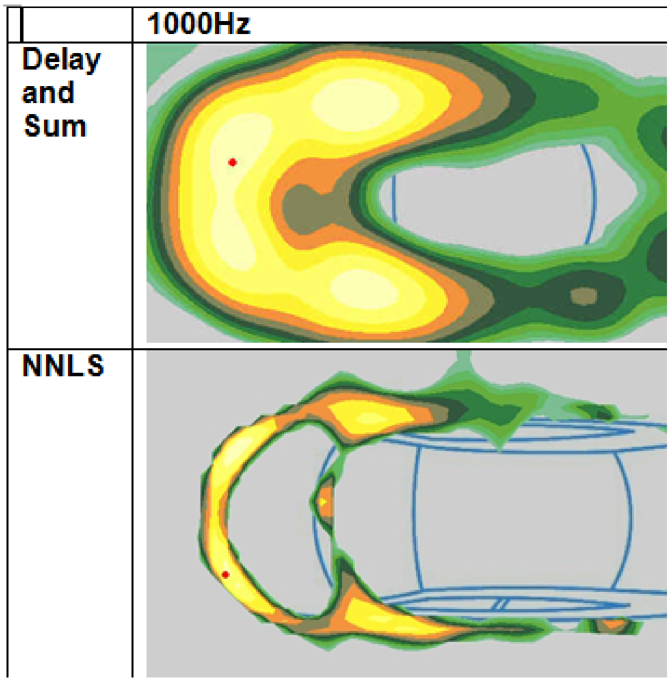


**Fig.1:** Wheel array supported above test vehicle in windtunnel. Top row: delay and sum results; bottom row: NNLS (Non-Negative Least Squares) deconvolution results. Display range 15dB**.**

The results were calculated for two different beamforming algorithms. Delay and Sum is the most commonly used beamforming algorithm. Whereas the Non Negative Least Squares algorithm is a deconvolution method well known in the aerospace industry. Fig.1 and 2 show how the spatial resolution of a Delay and Sum beamforming sound mapping is improved when NNLS is employed.

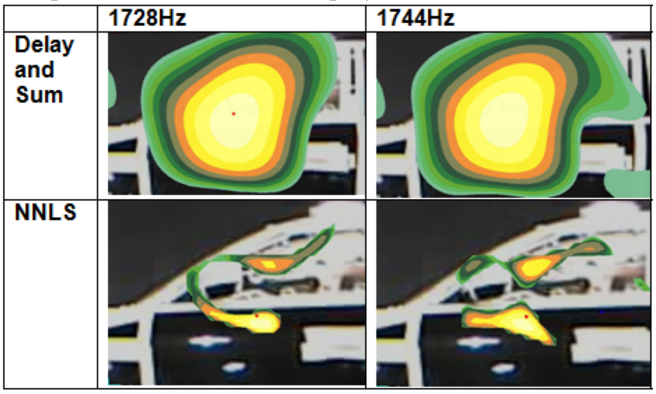


**Fig.2:** sound maps are shown for noise in 16Hz bandwidths. Virtually no difference is noticed for the Delay and Sum results whereas the NNLS shows considerable frequency related detail..

A crucial question for vehicle designers is whether the interior noise source ranking for particular A-pillar /side mirror configurations, can be deduced from measurements made at a very early stage in the development process when only a clay model of the proposed design is available for wind tunnel testing. To test this hypothesis, the source distribution over the side door window area was measured externally using planar beamforming and internally using spherical beamforming. The results were encouraging, in that the same source generating areas are located by means of the external half wheel array and by the internal spherical array and comparable relative changes in source strength are observed from inside and outside. Furthermore, the assumption that the A-pillar /side mirror design which produces the lowest exterior noise, will produce the lowest interior noise is supported.
To measure transfer functions from the indentified sources to the HATS on the driver's seat, a volume velocity source was then used. These transfer functions from an existing vehicle could then conceivably be used when pressure contributions at the driver's ear are required for a new but similar design for which only a clay model exists.

## Wind turbines

Acoustical arrays are used to measure on wind turbines in situ for noise source identification, and for the validation of CFD simulations. The most commonly used methods are based on beamforming. Due to the size of the wind turbines, the acoustical arrays have to be of considerable size to obtain an acceptable resolution of the noise generating regions. Wind turbines often produce tonal noise in the range 125Hz to 200Hz. To adequately locate such sources, large ground based ellipsoidal arrays are typically employed, with dimensions of up to 15m x 10m. For frequencies from 500Hz to 4kHz., much more portable arrays with a diameter of typically 3.5m can be used to give a rapid evaluation of the emitted noise by means of noise maps and a tonality value. A particular difficulty associated with array measurements on wind turbines is the air turbulence which decreases the coherence of the acoustical signal over the array area. Furthermore the fact that the array is not in the same plane as the blades and that the blades are in motion add to the complexity of the problem. Fig.3. shows sound maps made down stream from a wind turbine using a portable pentangular array. The improved spatial resolution attained with NNLS deconvolution is clearly seen.

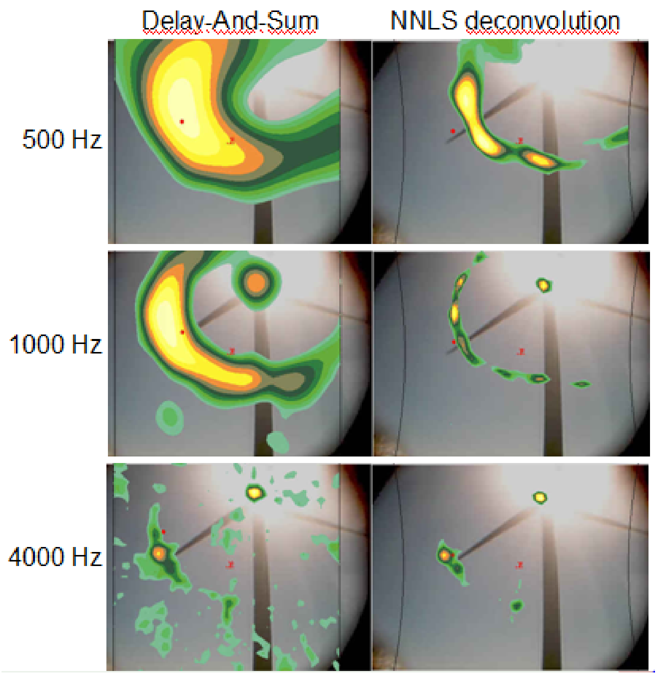


**Fig 3:** sound maps made down stream using a portable pentangular array. Delay and sum Beamforming results are on the left, NNLS deconvolution results on the right.

## Summary

An overview is given of acoustical array techniques used for aerodynamic noise source identification with practical examples from the automotive and windturbine industries. Correct array designs can yield a vast amount of information in frequency and spatial domains. Deconvolution algorithms can enhance spatial resolution on planar beamforming maps by a factor of 3.

## References

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