Detection of acoustic radiating areas of a generic helicopter cabin by beamforming

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Improvement of the helicopter internal noise is essential to decrease the fatigue effects of passengers. This requires having a metrological tool, able to give information on acoustic radiating areas in cabin in order to target appropriate acoustic passive or active solutions.
In this context, the authors have shown, in previous papers, capability of modified beamforming using a cross-shaped array of microphones, associated with an acoustic mask, to localize isolated sources in a generic composite helicopter cabin (VASCo), thus, in spite of free field's hypothesis.
The present paper deals with the feasibility of this measurement method to identify main acoustic pressure areas radiated by an helicopter mechanical deck whose vibration is generated by gear box beams between 800 and 3000 Hz.
This configuration is performed, thanks to simulations and experiments on a sandwich composite panel of VASCo, excited by 4 correlated shakers.
It appears that beamforming can be used to identify main acoustic area coming from the radiating of many coupled vibration modes. Nevertheless, the dynamic range decreases with the number of pressure anti-nodes and it is necessary to introduce an inverse method to reject the ghost images and to reconstruct amplitude and phase of synthesized sources.

1 Introduction

Since several years, aeronautical industries have wished to improve internal acoustic comfort. Thus, acoustic localization tools are performed in order to determine what area of cabin sidewalls radiate noise in the cabin. Nevertheless, two problems must be solved. Firstly, classical localization techniques, like holography or beamforming, are based on free field hypothesis, while the medium is confined. Secondly, acoustic sources are partially or totally coherent. This implies to use reference microphones near sources to separate the contribution of each type of source or to solve an inverse method with a representation of these sources. So, the holography based on multiple references (STSF) is suited to radiating of vibrating panels but must be used in nearfield to reduce effect of reflections and takes a long time to scan large radiating surfaces. On the other hand, one can show that the beamforming, which is a very fast method, is able to localize a sum of uncorrelated sources (statistically independent) [1], with or without a reference microphone. Moreover, it is less sensitive to reflections than holography [2] and can be used in confined medium [3] if the array is coupled with an acoustic mask (to avoid back waves). But, in the case of close correlated (coherent) sources, the interferences between waves can be harmful to localization.

So, the present paper deals with the feasibility of this last measurement method to identify main acoustic pressure areas radiated by a vibrating panel. This configuration is performed, thanks to simulations and experiments on a sandwich composite panel (representative of a mechanical deck) of a generic helicopter set-up.

2 Principle of modified beamforming

A cross shaped array, composed of *N* microphones on each arm, is suited to localisation of sources assumed to be monopoles (in Fresnel region of the array).

After measuring acoustic pressure *P* on the array, localization consists on searching contribution of each possible source and finding the position of the source on a focused plane.

Then, a source of unit amplitude is assumed to be placed at the point *F*, which moves in the focused plane:

$$u_{Fi}(F) = \frac{e^{-jkR_{Fi}}}{R_{Fi}} \tag{1}$$

with R_{Fi} is the distance between *F* and the microphone number *i*.

The localization's function is the product of the pressure and the fictive monopole in F:

$$J_2(F) = \frac{\left|u_{Fi}^{+}(F)P\right|^2}{\left\|u_{Fi}\right\|^2 \left\|P\right\|^2} \tag{2}$$

where $^+$ is the conjugate transposate.

During a measurement, the cross-spectral matrix is estimated thanks to periodigram method :

$$\Gamma_{m,n}(f) = \left\langle p_m(f) p_n^*(f) \right\rangle \tag{3}$$

The localization's function, representative of a coherency, becomes:

$$\gamma^2 = \frac{u_F^{+}(F)\Gamma u_F(F)}{\left\|u_F(F)\right\|^2 Tr(\Gamma)} \tag{4}$$

where *Tr* is the trace operator.

The cross-spectral matrix can be expanded as:

$$\Gamma = \begin{pmatrix} 0 & \Gamma_{AB} \\ \Gamma_{AB}^{+} & 0 \end{pmatrix} \tag{5}$$

where A and B are relative to the two arms.

Performances of the cross-shaped array, in neglecting cross-spectral terms of microphones which are on the same arm (Γ_{AA} and Γ_{BB}), allows to have performances similar to a full square array [4].

This method is assimilated to a normalised cross-spectral imaging function.

The following figure (Fig. 1) shows an example of localization's function (scale 0-1) for an harmonic monopole source (frequency=2000 Hz, red circle) placed at 0.3 m from the cross-shaped array (in white). Each arm is 0.6 m length and contains 16 microphones. The focused plane is a square surface of 4 m side.

The localization's function field must not be interpreted as fields of acoustic pressure near the plan source (unlike the holography method). Only the position of local maxima, representative of pressure sources, must be considered.

The source is well localized at the maximum of the localization's function (=1), whatever its location in focused plane (even outside the surface of array). Nevertheless, more the distance to the middle of array increases, more the area of maximum is wide.

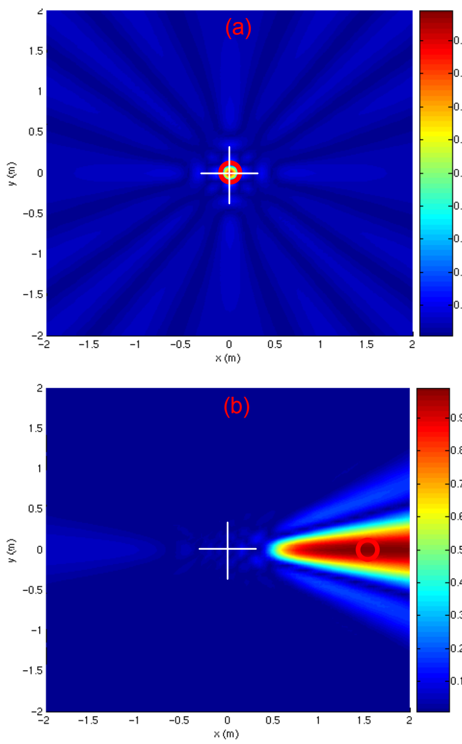

Fig. 1: Localization's function with a monopole at (x,y)=(0,0) (a) or (x,y)=(1.5, 0) (b) and z=0.3 m

To reduce the magnitude of side lobes (so-called ghost sources), a spatial filter (i.e. Hanning) depending on the distance between the microphone *i* and the center of the array can be applied. None less, the spatial resolution is also reduced.

3 Application

3.1 Simulation

Simulations are led with a vibro-acoustic model based upon modal basis to verify feasibility of modified beamforming to localize main acoustic pressure areas radiated by a vibrating panel, representative of a mechanical deck (Fig. 2 (a)) whose vibration is generated by gear box beams. This panel radiates acoustic pressure in cabin (Fig. 2 (b)).

The contest is difficult because the panel is a sandwich composite structure excited in bending by four correlated forces.

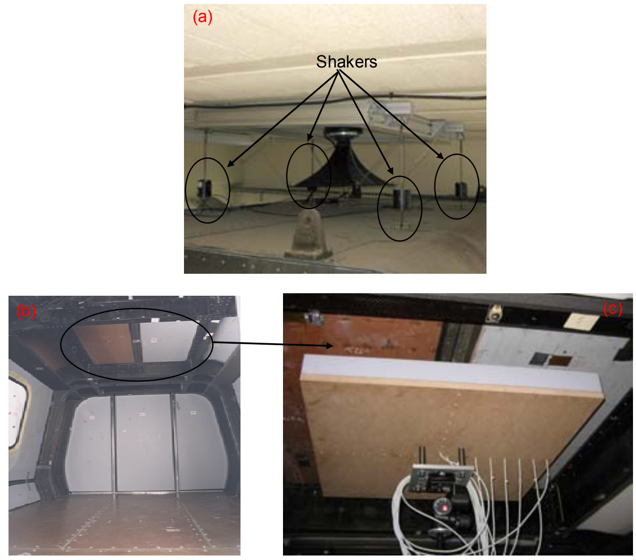

Fig. 2: (a) Helicopter mechanical deck of VASCo equipped with shakers (b) ceiling of cabin (c) cross-shaped array of microphones in an acoustic mask

Because of high damping and frequency range, the excited modes of mechanical deck are coupled and generate high number of pressure sources, naturally correlated.

The simulation is relative to a Nomex honeycomb structure placed fiber glass / carbon layers (surface: 0.98 x 1.07 m²). We compare the pressure field near panel (distance: 0.01 m) to localization's function field, obtained thanks to a cross-shaped array of 16 microphones for each arm (length: 0.60 m, distance between sensors: 0.04 m) placed at 0.07 or 0.26 m from panel (Fig. 2 (c)).

The fields are displayed at 1000, 2000, 3000 and 4000 Hz (Fig. 3 to 6). The main areas of radiating are localized by black circles.

It may be noted the presence of several central sources, 0.15 to 0.30 m away, and sources located near the corners of the panel where forces are applied.

The microphones of antenna are viewed on the localization's function fields.

It turns out that sources close to the middle of field produce:

- areas of high coherency dependent on the frequency resolution and interactions between sources

- significant sidelobes requiring additional analysis.

The other sources generate areas of large and strong coherency (continuous or discontinuous).

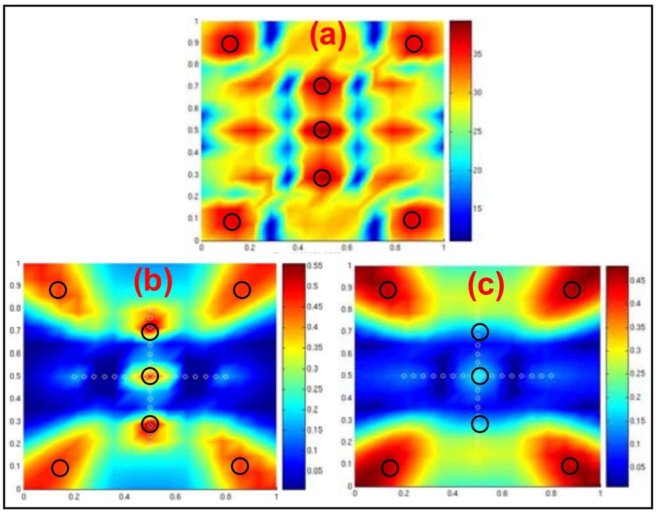

Fig. 3: Pressure field near panel (a) and localization's function fields with cross array at 0.07 m (b) and 0.26 m (c) at 1000 Hz

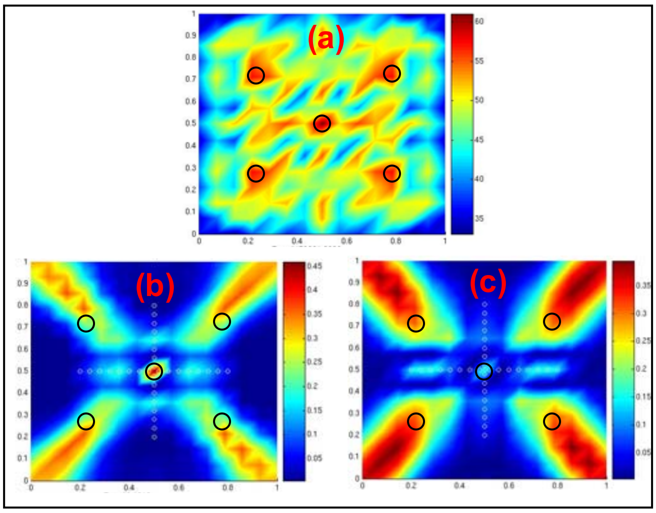

Fig. 4: Pressure field near panel (a) and localization's function fields with cross array at 0.07 m (b) and 0.26 m (c) at 2000 Hz

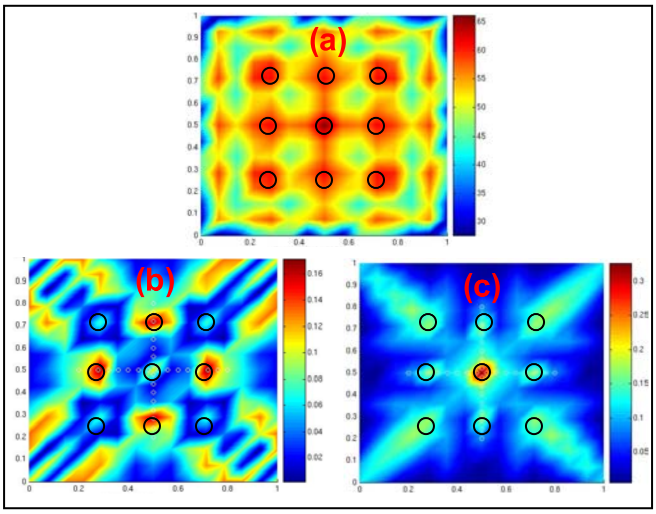

Fig. 5: Pressure field near panel (a) and localization's function fields with cross array at 0.07 m (b) and 0.26 m (c) at 3000 Hz

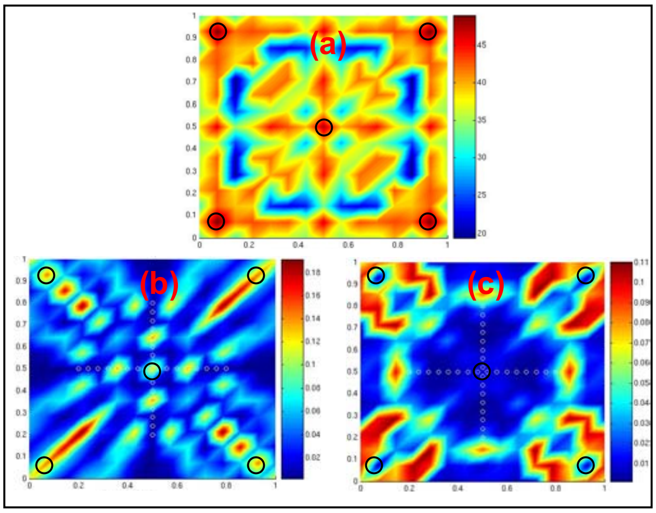

Fig. 6: Pressure field near panel (a) and localization's function fields with cross array at 0.07 m (b) and 0.26 m (c) at 4000 Hz

The configuration of the antenna located at 0.07 m appears more suited to localize radiating sources while showing sidelobes that predominate at higher frequencies.

It is more difficult to localize and separate sources precisely for the higher distance of antenna. This is due to the fact that the localization's function is determined in each point by making the assumption that the pressure field measured by the antenna comes from an alone monopole: the possible contribution of other pressure sources is neglected.

To double the number of microphones has not significant effect in the frequency band.

The following simulation is relative to a case of vibration excitation without symmetry (Fig. 7) at 1000 Hz. The main radiating areas (black circles) are localized less accurately if the sources are far from the middle of antenna, contrary to the case of an alone source (Fig. 1), which confirms previous comments.

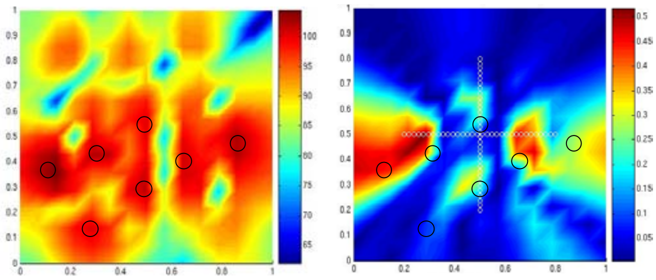

Fig. 7: Pressure field near panel (left) and localization's function fields with cross array at 0.07 m (right) at 1000 Hz.

To illustrate the performance of beamforming with correlated sources, the case of two monopoles in phase or in opposite of phase**,** 0.15 m away from one another (Fig. 8), is simulated at 1000 and 3000 Hz, with or without spatial filter (Hanning). The location of sources is displayed by black circles.

It appears that sources are distinguished or not at 1000 Hz according to the difference of phase. On the other hand, at 3000 Hz, sources are localized correctly for two cases, with nevertheless very different pressure fields measured by antenna.

The spatial resolution, generally associated to a monopole (equal to wavelength), is not valid to assure detection of sources.

The respective position of sources relative to the middle of antenna is also decisive on the feasibility of detection.

The spatial filter increases the dynamic range by substantially reducing the amplitude of sidelobes but reduces the amplitude of the real source which is not in the middle. It is so a weighting different according to the position of the source.

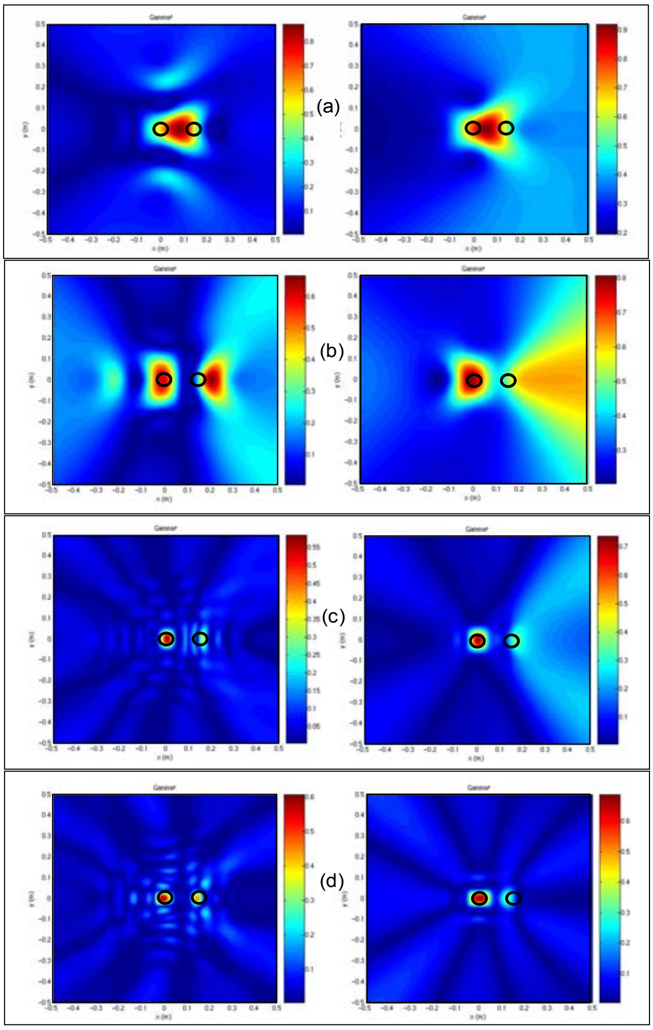

Fig. 8: Localization's function without / with spatial filter (left/right) - Sources (a) in phase or (b) in opposite of phase at 1000 Hz -Sources (c) in phase or (d) out of phase at 3000 Hz

3.2 Experimentation

The mechanical deck of VASCo is excited by the four shakers.

The pressure field obtained near panel is shown at 800 Hz and 2000 Hz, frequency for which the radiated energy is high.

At 800 Hz (Fig. 9), two main sources, 0.25 m away from one another, appear in a radiating area. On the localization's function fields with and without spatial filter, only one source is localized in the radiating area (white or blue circle according to signal processing).

One can notice two areas of low coherency (red and green circles,) with spatial filter. A way to verify if they are real or ghost sources, is to simulate the localization's function generated by a monopole at location of main source (Fig. 10).

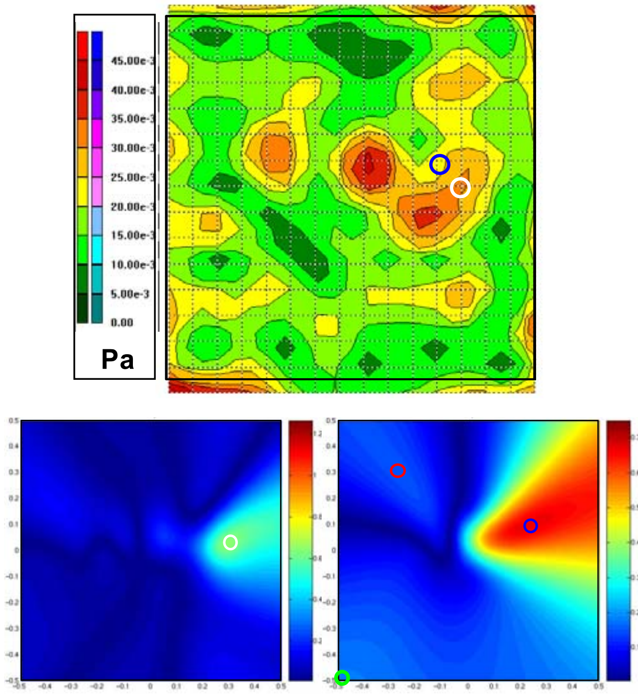

Fig. 9: Pressure field (up) and localization's function (down) without / with spatial filter (left/right) at 800 Hz

The measured and simulated localization's function fields have strong similitudes (Fig. 9 and 10) but the two previous areas do not appear in simulated field, that means that one or the two areas correspond to real source(s) of low contribution. Indeed, one can notice the presence of a high level of pressure in front of location of green circle.

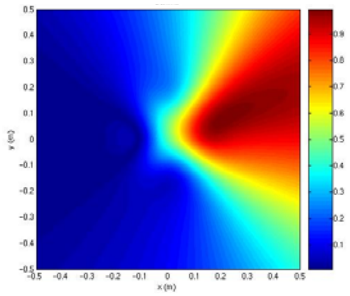

Fig. 10: Simulation of localization's function with spatial filter at 800 Hz

At 2000 Hz (Fig. 11), six areas of high pressure radiation; 0.30 to 0.4 m away, with variable amplitudes are present. The localization's function without filter shows a complex field difficult to analyze. One can notice nevertheless five area whose levels are above 0.25 (white lines). With spatial filter, two other areas (red lines) are brought to the fore. The different maxima of coherency are displayed in pressure field.

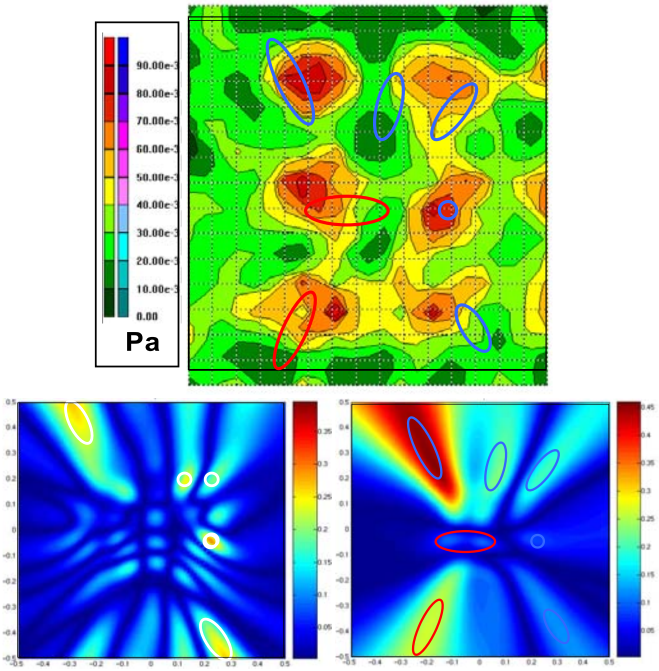

Fig. 11: Pressure field (up) and localization's function (down) without / with spatial filter (left/right) at 2000 Hz

The presence of sources is confirmed with nevertheless a gap of position between 0.06 and 0.17 m. Simulation of localization's function, with spatial filter, produced by six monopoles at location of real sources is carried out (taking into account amplitudes and phases between sources) (Fig. 12).

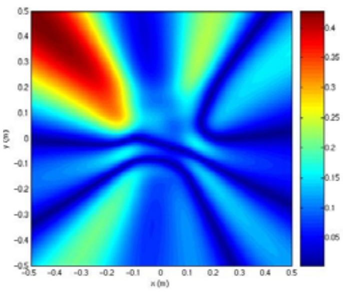

Fig. 12: Simulation of localization's function with spatial filter at 2000 Hz

The close similarity between experiment and simulation shows that one can "assimilate" the vibrating structure to a distribution of six monopoles.

5 Conclusion

Simulations and experiments have shown that modified beamforming with spatial filter can be used to identify main acoustic area coming from the radiating of a panel placed in a confined medium. But, interactions between coherent sources generate also sidelobes in the localization's function whose levels are higher than for uncorrelated sources. It is necessary to introduce an inverse method to reject these ghost images and to reconstruct amplitudes and phases of real sources obtained by the present method. The inverse methods that take into account *n* correlated or uncorrelated sources are solved by iterative schema (gradient method…) from any locations, realistic or not [1,5]. To couple an inverse technique of level estimation with the modified beamforming reduces the number of parameters (*n* possible locations), the computation time and improves the robustness of the algorithm.

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