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TOOL FOR INTERIOR NOISE SOURCES DETECTION IN AIRCRAFT WITH COMPARISON OF CONFIGURATIONS

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ABSTRACT

Identification of interior noise sources during flight tests becomes a necessary step in aircraft industry to improve acoustic comfort. In the case of the cabin, it can be interesting to use mobile tools such as microphones rackets to explore all corners. In many other cases, a static tool can be more efficient, for example where access is prohibited during flight, when sources are transient, or when successive flight configurations are compared.

For several years Airbus and MicrodB have developed a spherical rigid antenna. It was used in trouble shooting activity and gave good results in presence of complex acoustic field thanks to favourable scattering effect on the sphere. In order to improve at same time detection performance and ability to be used in difficult access areas, Airbus and MicrodB recently developed a new tool, based on a multi-antenna concept. It is composed of a smaller spherical antenna and extension arms. Beamforming treatments had to be adapted to this special microphones layout. Different methods were explored in order to evaluate true levels of localized sources for the different types of sources encountered and their degree of correlation.

This tool was recently tested in flight and produced promising results.

1 INTRODUCTION

It can be interesting in some cases to use mobile tools such as time Beamforming rackets to explore all corners of a cavity, but usually these techniques are not designed to quantify precisely the acoustic power of the pointed sources. Scanning an entire cavity by making patches with a Nearfield Noise Holography racket can give access to sources levels, but this produces very long measurement time [1]. Static antennas are more adapted to the comparison of flight configurations.

For several years Airbus and MicrodB have developed a spherical rigid antenna. It was used in trouble shooting activity during flight to detect transient noises in cavities such like avionics bay cargo. This technique was efficient as regards to purely detection purpose. Beamforming was used as treatment of the microphones signals. Diffraction around the sphere was taken into account and had a beneficial effect for signal to noise ratio.

Now new treatments have been developed and this kind of system can be used with larger application field. It now gives an estimation of the energy distribution of the main sources all around the three-dimensional cavity. However, due to the free field assumption, the technique will not work in purely modal or diffuse fields.

The antenna has been improved in order to be better adapted to flight tests in aircraft cavities and also to have greater capabilities and performances. Other antennas with spherical geometry exist, but they are generally hollow spheres [2].

2 TOOL SPECIFICATION

2.1 Testing cavities

Airbus was seeking for a tool to localize and quantify acoustic sources in aircraft cavities such as cockpit or cargos. For some of these cavities, access is not easy and may be prohibited during flight or possible only during a short installation time. For these reasons the tool had to be very quick to mount and demount, and also to be of reduced size to get through small access doors of less than 40cm large. In the context of beamforming treatment, high frequency limit will impose the number of microphones and low frequency limit the size of the antenna.

On this project, the possibility to scan the entire cavity at once simultaneously was a strong wish: it enables to shorten measurement time in flight and to compare different aircraft flight configurations.

2.2 Antenna setup

The choice was made for a 48 ICP microphones static system comprising a 30cm rigid sphere and extension arms to enlarge the antenna size once positioned in the cavity.

On rigid sphere (C) microphones are mounted flush to the surface and distributed in a pseudo-random way. Extension arms create a virtual open sphere (O) of 80cm diameter around the rigid sphere and can be clipped directly in the sphere. Sub-antenna (C) is dedicated to high frequencies and sub-antenna (O) to low frequencies. For intermediate frequencies a specific treatment combining both (C) and (O) is operated [3].

2.3 Cavity meshing

In antenna processing domain, necessity to visualize results is of primary importance. Photos are not sufficient to deal with a complete three-dimensional cavity. A numerical mesh is interesting, but it is not always available, especially when a short delay happens between test request and test realization.

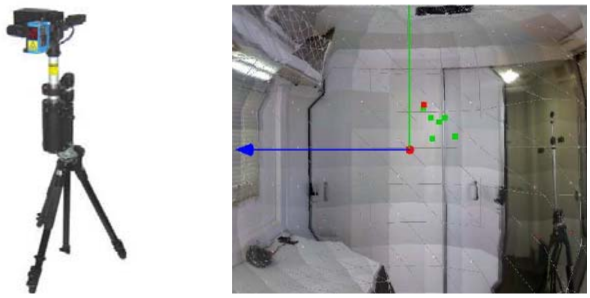


Figure 1- Geometry automatic mesher (left) and example of augmented reality mesh (right)

Airbus uses a system developed by MicrodB and adapted to Airbus special needs, which performs a scan of the cavity geometry before the acoustic test (Figure 1). It consists of a piloted robot equipped with a camera and a laser distance-meter, which is installed at the place of the antenna. This system produces a three-dimensional mesh with an “augmented reality” texture.

3 ANALYSIS METHODS

3.1 Calculation process

The first step of the process is to calculate beamformed pressure spectrum over the calculation mesh. Coherence between sources identified from beamforming then enables to choose the most suited quantification method. Equivalent Sources Modelling (ESM) has to be used when sources are strongly correlated, whereas it may be preferable to use Deconvolution Method (DCV) for its robustness when coherence is low.

Those two methods are differentiated by the way to solve the inverse problem. ESM consists in solving a linear system, having much more variables than equations [4], with SVD and Tikhonov regularization, combined with L-curve technique. DCV, developed initially by EADS-IW for flyovers analysis [5], is in the same class of methods as DAMAS algorithm [6] and has been recently adapted to 3D cavities [7].

3.2 Equivalent Sources Modelling

The principle of ESM is to replace an acoustic field by the superposition of fields radiated by a set of equivalent acoustic sources.

The direct formulation can be written as

$$\mathbf{p} = \mathbf{H}\mathbf{q}, \qquad (1)$$

where **q** is the volume velocity of monopoles distribution, **H** is a transfer matrix describing the propagation of acoustic field between a monopole and a measurement point, **p** is the pressure field measured on the array. The number of calculation points is superior to the number of measurement points, yielding to an under-determined system, whose inversion requires regularization procedure.

In the case of the open sphere, the free field Green function is considered yielding to the following transfer function

$$\mathbf{H} = \frac{j\rho ck}{4\pi}\frac{e^{-jkr}}{r}, \tag{2}$$

In the case of the rigid sphere with a radius a, the transfer function takes into account the scattering of the acoustic waves on the surface [8]:

$$\mathbf{H} = \frac{j\rho c}{4\pi a}\sum_{n=0}^{\infty}(2n+1)\frac{h_n^{(2)}(kr)}{h_n^{(2)'}}P_n(\cos\theta), \tag{3}$$

where $h_n^{(2)}$ and $h_n^{(2)'}$ are respectively the n-th order spherical Hankel function of the second kind and its derivative. P_n is the Legendre polynomial of degree n and θ is the angle between the direction of the incoming acoustic wave and the vector pointing from the sphere center and the measurement point.

3.3 Deconvolution method

DCV considers a spatially continuous source distribution $q(r,t)$ with spherical radiation. The beamformed signal $p(r_i,t)$ of a microphone array focused to a point r_i can be written in the frequency domain as

$$P(r_i,\omega) = \int_{-\infty}^{+\infty} G(r_i,r,\omega)Q(r,\omega)d^3r, \tag{4}$$

where $G(r_i,r,\omega)$ is the transfer function that includes the Green's propagation functions (2) and (3) and the beamforming focusing function between the sources located at r and the focus point located at r_i. If we consider an uncorrelated source distribution, the auto-power source density Ψ_n can be related to the focused pressure P_k by the following linear system

$$P_k = \sum_n H_{k,n}\Psi_n, \tag{5}$$

where the focused pressure P_k, the transfer function $H_{k,n}$ and the auto-power source density Ψ_n are given by

$$P_k = \left|P(r_k,\omega)\right|^2, H_{k,n} = \left|G(r_k,r_n,\omega)\right|^2, \Psi_n = \left|Q(r_n,\omega)\right|^2. \tag{6}$$

The inverse problem is solved with a non negative least squares (NNLS) iterative process.

4 METHOD VALIDATION

4.1 Test in laboratory

Many tests were carried on in laboratory to validate the system and characterize its performances. The measurement technique was first qualified in the free field conditions obtained in an acoustic room (see Figure 2).

Figure 2- Measurements in anechoic room with different sources locations

We show on Figure 3 an example illustrating the assumption that two correlated sources will have their beamforming images correlated and inversely. One point is chosen on each beamforming source image for coherence calculation.

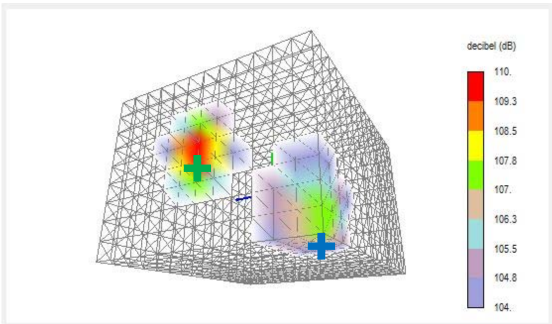


Figure 3- Location of points chosen for calculation of images coherence

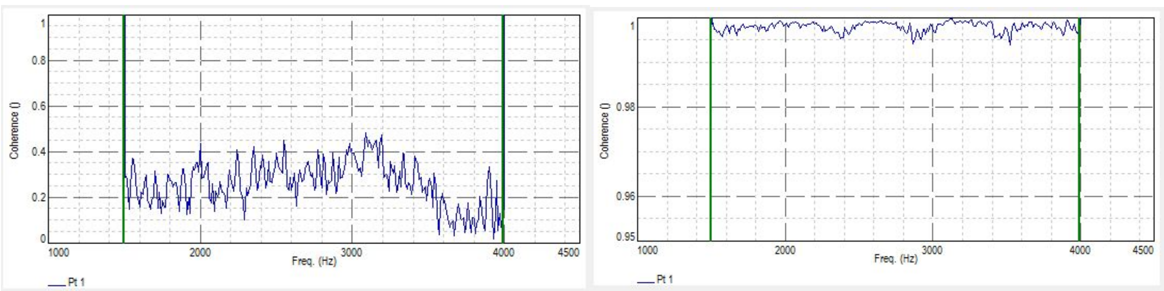


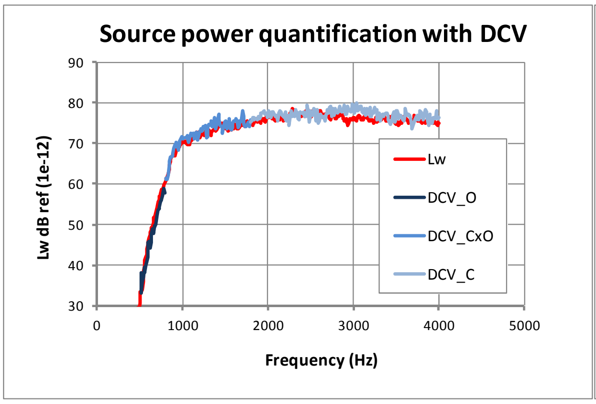
Figure 4- Correlation of images for uncorrelated sources (left) and for correlated sources (right)

On Figure 4, we see that coherence of beamforming images for the uncorrelated sources case is between 0 and 0.5: DCV can be used. For the correlated sources case, values are between 0.99 and 1: ESM is necessary!

4.2 Levels validation

Different tests were done to check the validity of the sources levels obtained by the quantification methods. Here we evaluate the power of a point source in free field with a microphone at 1 meter (Lw), and then we see with the antenna what levels give DCV and ESM on the frequency range (Figure 5).

ESM gives better accuracy at high frequencies, were only the rigid sphere is used, but the treatment between both rigid sphere and open sphere (extension) is not so accurate for mid frequencies. DCV seems on average more reliable.



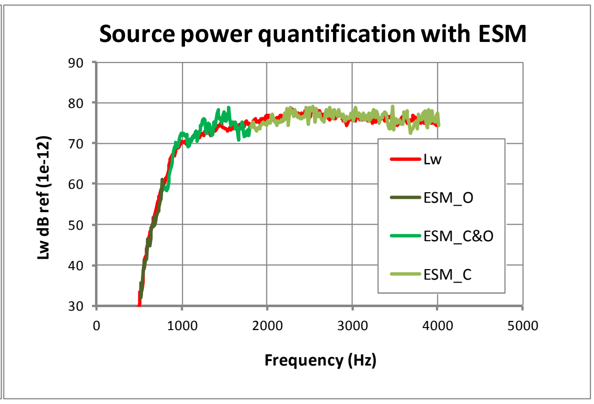


Figure 5- Energy recovery for Deconvolution (DCV) and Equivalent Sources (ESM) methods

In more complex environments like real cavities, it is not easy to verify if quantified levels are right or not, because it depends of the nature of the acoustic field. This work is carried on at the present time at Airbus. The assumption of free acoustic field in cavities is a strong approximation, but it gives already interesting results when coupled with the coherence analysis. Actually strong coherence between sources is often due to either a common origin or a reflection on rigid panel.

5 TESTS RESULTS

5.1 Beamforming and quantification

A flight test on an Aibus test aircraft was performed using this antenna system.

The system was installed and made recordings during several flight configurations. It was shown for these conditions that DCV gave better results than ESM, due to its better robustness to geometry inaccuracies.

Gain of quantification is not only to give true source levels, it also eliminates all secondary lobes and so increases drastically the maps dynamics. An example is given on Figure 6:

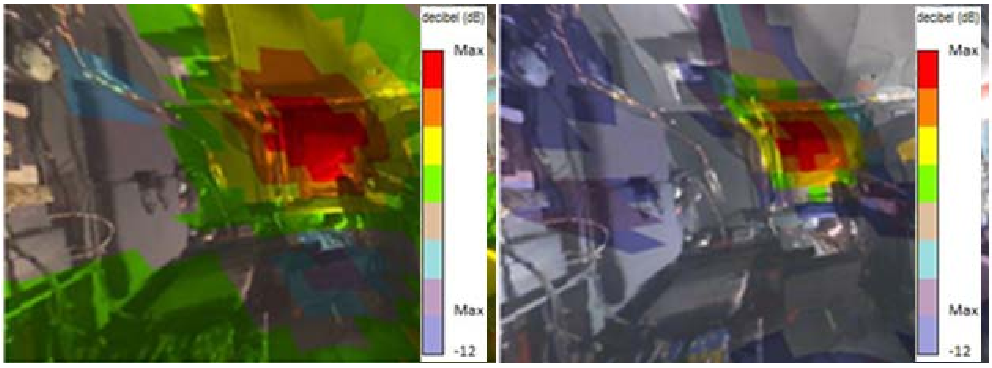


Figure 6- Comparison of beamforming (left) and quantification (right)

5.2 Coherence between sources

Coherence between global beamforming image sources is a way to choose between DCV or ESM. But once sources have been quantified, it is also interesting to analyse coherency between more precisely identified regions.

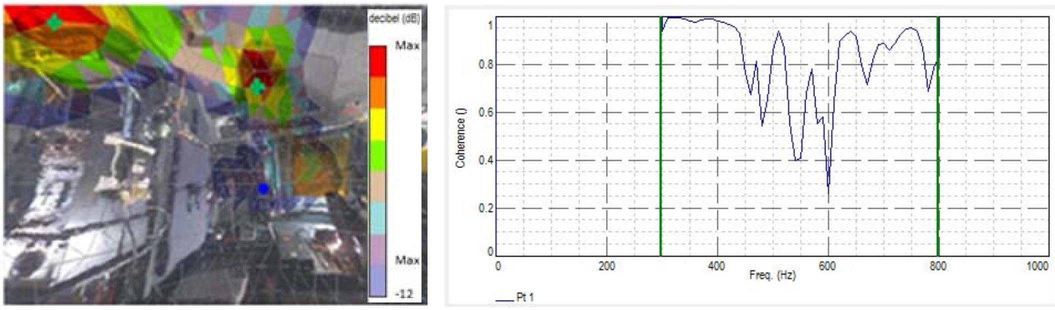


Figure 7- Coherence between two sources: calculation points (left) and coherence curve (right)

This was done on Figure 7 for two sources of the cavity: they are well correlated at low frequencies and less correlated above.

5.3 Comparison of configurations

Quantification results can be exploited in different manners. One interesting way is to define integration areas where acoustic power spectra can be evaluated. It enables to know the power of a given source versus different flight configurations. This was done on the example of Figure 8.

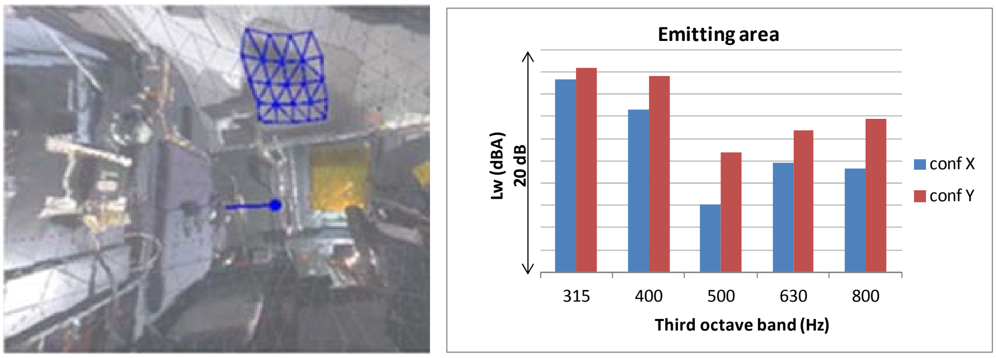


Figure 8- Acoustic power of a given source versus flight configurations

6 CONCLUSIONS

In this paper we presented the new tool developed by Airbus and MicrodB for noise sources localization in aircraft cavities. This tool was improved with two numerical methods to evaluate the levels of the identified sources. Although it is not easy to evaluate right sources levels in confined environment, the free field assumption in complex geometry cavities coupled with coherence analysis already gives useful flight test results.

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