Nearfield Acoustical Holography measurement inside a helicopter cabin

J. Caillet[1], F. Marrot[2], P. Dupont[2], F. Malburet[1], J-C.Carmona[1]

1: LSIS, 2, cours des Arts et Métiers, 13617 Aix-en-Provence
2: EUROCOPTER France, Aéroport international de Marseille-Provence 13725 Marignane Cedex France

Abstract: This work aims to present the method used to localize noise sources inside a helicopter cabin from in-flight tests. The measurement method relies on the theory of Nearfield Acoustical Holography, which is evaluated for a noisy environment. The results obtained consist in a spatial representation of the sound field on the panels of the cabin.

Keywords: Helicopter, Nearfield Acoustical Holography, Noise Source Localization

1. Introduction

The work presented in this paper settles in the general framework aiming to improve acoustical comfort in helicopter cabins by use of passive techniques (insulating, damping, and porous materials).
Cabin noise level in helicopters is mainly due to transmission gearbox, rotor, engines and aerodynamic excitation (See Fig. 1 below).
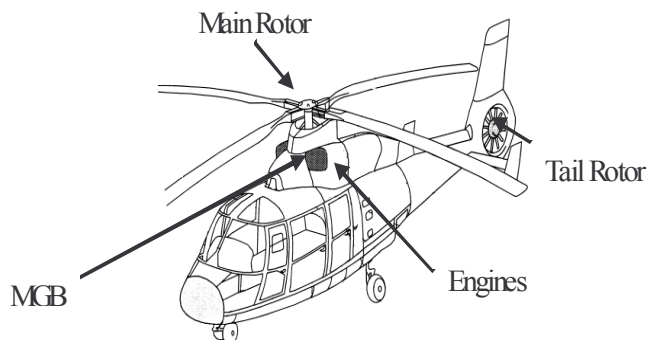

Figure 1 : Main Noise Sources

These sources cover a broad frequency range (typically 20Hz-12 kHz) as shown on Fig. 2. The majority of these sources are tonal in nature, extending into the mid-to-high frequency range, within the range of dBSIL4 (Speech Interference Level, 4-octave average), which is the frequency band at stake here. This noise-measurement metric rates steady noise, according to its relative ability to interfere with conversation between people. The leading detriment brought about by the high amplitude tonal content of helicopter cabin noise is the negative psycho-acoustic effects it has on passengers. Disturbances generated by these sources propagate through the airframe and reach into the cabin via airborne and structure-borne energy paths, thus producing radiated noise by the panels of the cabin, acting as apparent correlated noise sources. What we want to determine here is how these energy paths propagate and which are the most radiating panels in the helicopter cabin in order to propose some efficient noise reduction technique (trim panels, joints).
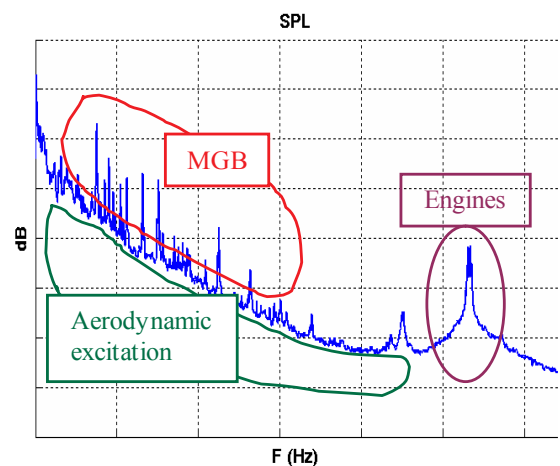

Figure 2 : Noise PSD inside a helicopter cabin

Because of the numerous reflexions of the acoustic waves in the cabin, the diagnosis cannot be done with a simple microphone measurement. The problematic here is to locate the noise sources and leaks in the cabin and to rank the vibrating panels according to their effect upon the inside noise level. As a consequence, the use of an acoustical imaging technique is proposed.
This paper is organized as follows: first a short preview of the way to carry out a Nearfield Acoustical Holography (NAH) measurement is given. This concerns both theoretical aspects and practical implementation to an in-flight test. In the following section, NAH is assessed on validating examples. Actually, acoustic measurements inside a helicopter pose a few difficulties. This section presents the different way to overcome the latter by estimating NAH robustness to difficult measurement conditions. Then, more realistic test constraints are realized by testing the acoustical radiation of system components through a measurement series made inside the cabin with artificial excitation situated on the outside. Finally, the application to an in-flight test is assessed and conclusions and perspectives are drawn.

2. Nearfield Acoustical Holography

2.1 Fundamentals of NAH

Recently, the evolutions in intensimetry and antenna techniques brought new capabilities in vibro-acoustic experiments. The spectral analysis can now be completed by the spatial structure analysis of the sources. J-C Pascal [1] proposes three main methods enabling to spatially represent an acoustical field radiated by a source: optical methods like vibrometers leading to a vibration field, intensimetry techniques enabling to locally determine the acoustical intensity vector, and microphone array techniques such as beamforming and Nearfield acoustical holography. In the case of a helicopter, many constraints (measurement length, complex environment, cost) are to be taken into account by the measurement system. In [2], the principles of the methods briefly discussed above were compared in order to derive the best one according to its constraints and capabilities. Finally, the measurement method chosen relies on the theory of Nearfield Acoustical Holography, which has become a powerful tool for the study of noise sources for both exterior and interior problems, such as interior noise in aircrafts. For example, the reference [3] presents an application of NAH to the interior of an airplane Beech 1900D.

The fundamentals of Nearfield Acoustical Holography may be found in many scientific publications. Among them, the references [4] and [5], and more recently [6] are certainly the most cited in the literature. The goal of the method is to solve the inverse problem consisting in rebuilding the acoustical field on the interior surface of the cabin from measurements of the pressure on a handy 2-D microphone antenna handled close to the studied panel.

The basic idea is to take advantage of the complexity and richness of the source nearfield information. This is performed by realizing a set of acoustical measurements in a plane which should be parallel and cover the radiating source. The measured signals are supposed to be stationary during the acquisition so that, thanks to the use of a fixed set of references, a complete fictive antenna is artificially built. A diffuse interpolation technique eases the operator from measurement requirements according to regular geometry's. From this complete fictive array measurement, NAH can be divided into three main steps:

-First, the acoustical field measured on the antenna is decomposed in plane waves by application of the two-dimensional (spatial) Fourier transform.

$$P_A(k_x,k_y,z=z_A,\omega) = SFT(P_A(x,y,z,\omega))$$

$$= \frac{1}{(2\pi)^2} \iint_{x,y} P_A(x,y,z=z_A,\omega)e^{(k_x x + k_y y)}dxdy \qquad [1]$$

-then, the different waves are back-propagated to the source plane with a back-propagating operator G:

$$P_S(k_x,k_y,z=z_S,\omega) = P_A(k_x,k_y,z=z_A,\omega)G(K,d) \qquad [2]$$

This operator enables the separation of propagative and evanescent components in the sound field:

$$G(K,d) = \begin{cases} e^{j\sqrt{k^2-k_x^2-k_y^2}\ d} & propagative\ waves,\ k_x^2+k_y^2 \le k^2 \\ e^{j\sqrt{k_x^2+k_y^2-k^2}\ d} & evanescent\ waves,\ k_x^2+k_y^2 > k^2 \end{cases} \qquad [3]$$

Filtering operations in the wavenumber domain are necessary in order to avoid the extra-amplification of noise with evanescent components. This performed by means of a Veronesi filter which acts as a low-pass filter in the wave-number domain. Moreover, a Wiener filter is applied to remove uncorrelated noise from the references, which are supposed to represent totally the radiated sound field. The parameters used to choose these filters implies a priori knowledge on the sound pressure field measured.

-finally, the inverse spatial Fourier transform is used to rebuild the acoustical field on the source plane with a good resolution:

$$P_S(x,y,z,\omega) = SFT^{-1}\{P_S(k_x,k_y,z,\omega)\} \qquad [4]$$

One of the advantages of NAH is that the following results can be obtained: pressure, velocity, intensity, power and coherence with a fixed reference.

2.2 Practical Considerations

Practically, measurements are made with a handy array. The latter is compact and easy to handle, particularly adapted to the specific situation inside the vehicle. It is a squared antenna of 8 by 8 microphones spaced out of 2.5 cm. This geometry governs the frequency range available for the measurement results (until 6300Hz). One of the advantages of using a handy array limit transmitted vibrations from the helicopter framework and prevent from the complexity of using a robot inside a helicopter cabin in-flight.
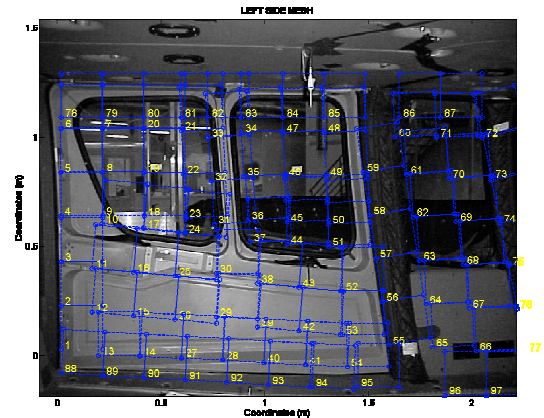

Figure 3. Antenna positions mesh

The microphone array is positioned successively in front of the cabin panels 7cm away from the source plane, each position being located thanks to adhesive marks. The references [7] and [8] discuss the limitations implied by the positioning of antenna. The conclusions drawn are taken into account here. The example of the left-hand side of a helicopter cabin is shown on figure 3.

The measurement series are carried out by using the DATaRec A480 Recording system[1] and the results are stored on a high storage capacity AIT Band, allowing the simultaneous acquisition by the antenna combined to 6 multiple reference (maximum total bandwidth : 1280kHz), as illustrated on Fig. 4 .
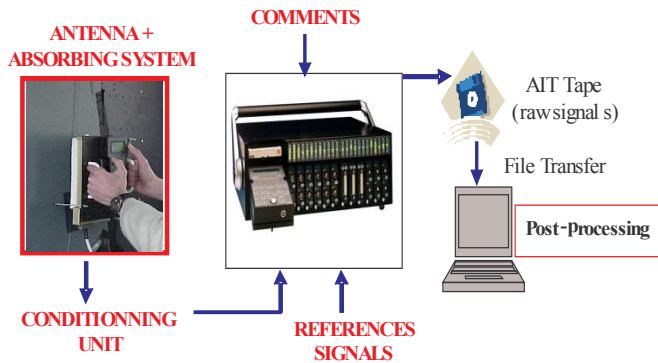

Figure 4 Microphone Antenna and Acquisition System

However, the manual positioning of the antenna is getting more and more difficult with the measurement length. An absorbing and isolating system was designed to ease the handling of the antenna and to protect the microphones from parasite reflexions on other surfaces. It consists in a rigid plate protected with a foam panel disposed behind the antenna. Another advantage of this system lies in the facility to trigger acquisition and to increment antenna positions. Actually, for each new antenna position, an event is triggered which is easy to locate on the AIT tape.

The cartographies are made in a post-processing step. It can be shown that NAH is very sensitive to microphone calibration. Actually, the post-processing made relies on a good relative measure between antenna microphones. Moreover, the microphones used are bad-quality transducers. Hence, the calibration process is carried out before each test (See Fig. 5).
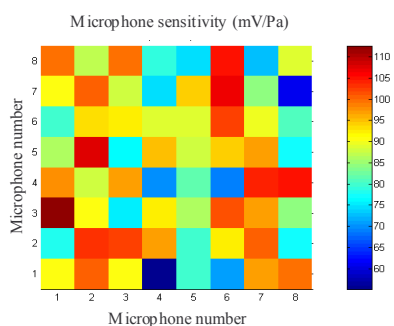

Figure 5. Result of the calibration process

3. Validation on test cases

3.1 Free-field spatially coherent sources

The measurement method used is validated on simple test cases for which numerical results are available.

---

[1]Registered Trade Mark from HEIM Systems GmbH

These validating results consist in the measurement on 2D isotropic and orthotropic plates used for sound insulating purposes in helicopter cabins. Several simulation codes and particularly the geometrical acoustics one used to model the scattering in helicopter cabins ([2], [9]), require Neumann boundary conditions for solving the problem of radiating panels. This can be done with NAH which provides access to the vibration velocity field on the measured surfaces. The example below presents the velocity field of an aluminium plate excited with a shaker. It permits to focus on the case of broadband spatially coherent sources. The vibration velocity field on the plate is calculated numerically by using a finite element code. It is then compared with the results of a measurement with NAH (See Fig. 6).
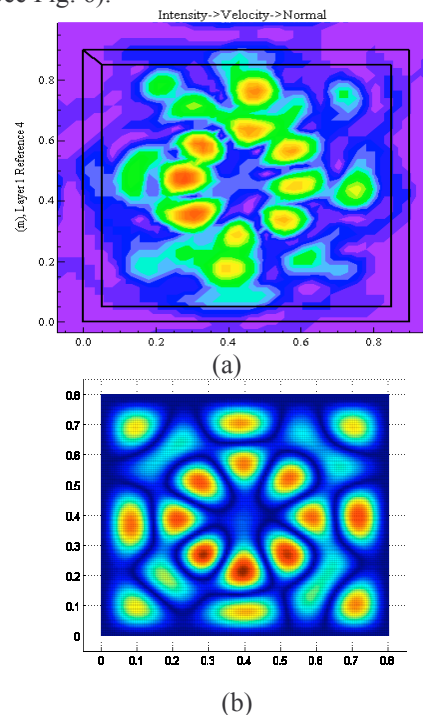

(a)

(b)

Figure 6. Comparison Measure (a) / Simulation (b) on an aluminium plate (1060 Hz)

Measurements are carried out in an anechoic chamber and the results prove to be in good agreement with the numerical results for the whole frequency range (300Hz – 6000Hz). Nearfield Acoustical holography also gives access to the acoustic power radiated by the measured structure. This allows for the calculation of the Transmission Loss of acoustic panels. Thus, NAH can also be used to improve cabin panels' definition.

3.2 Noisy measurement conditions

NAH is originally based upon a measurement of the whole source, in free-field conditions. Nevertheless, for the case of a vehicle interior, this hypothesis can not be checked. In [10], this hypothesis is made true by masking the other faces in order to minimize the acoustic energy coming elsewhere from the face of interest. However, in case of an in-flight-test inside a helicopter cabin, this kind of measurement is not possible for obvious safety conditions. NAH must then be robust to the noisy conditions of a helicopter cabin.

This was assessed during a measurement campaign with ONERA in an anechoic chamber on a structure consisting in several loudspeakers excited with a broadband white noise (fig.7).
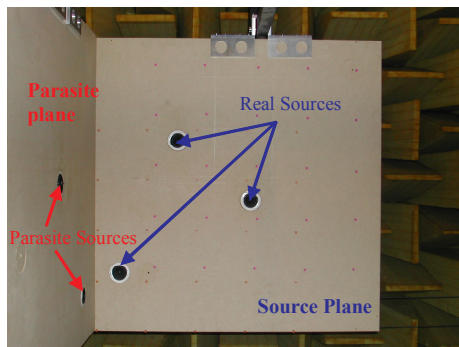

Figure 7. Test Structure

The three loudspeakers in the source plane act as compact sources to detect, and the two sources in the parasite plane generate a perturbation noise. The panels are made of a highly reflective material which tends to increase this background noise. This case simulates the case of an interior vehicle measurement submitted to sound reflexions on side panels.

As a reference, a measurement is performed with the 2 parasite sources set inactive (fig.8).
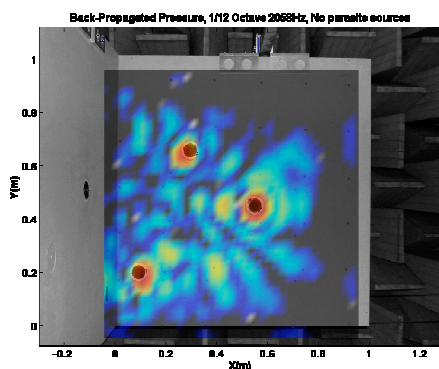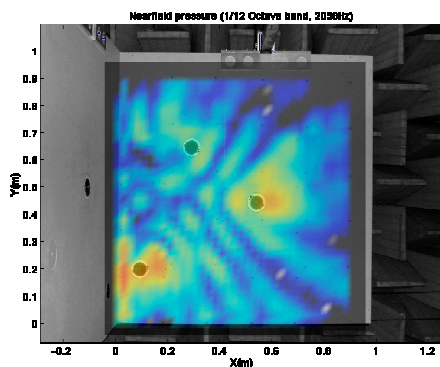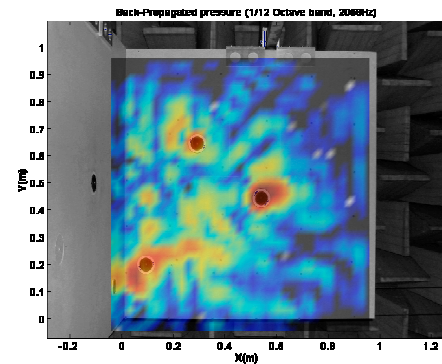

Figure 8. Back-Propagated pressure, 1/12 Octave 2058Hz, without parasite sources
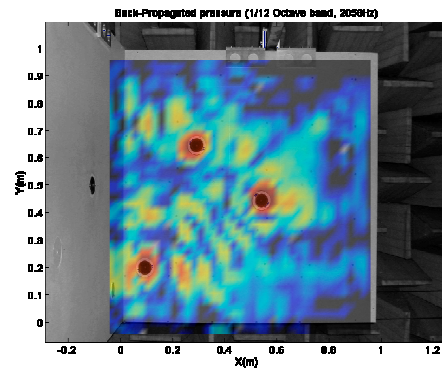
In the case presented below, the 3 loudspeakers in the source plane and the 2 loudspeakers in the parasite plane are excited with a white noise. The results with a SNR of 0dB are presented in the following Fig. 9:
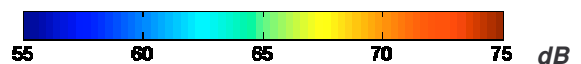

(a)

(b)

(c)

Figure 9. All Sources correlated (SNR= 0dB). Comparison between Nearfield measurement, back-propagated pressure without (b) and with (c) the absorbing system

This test provides good information concerning the contribution of NAH to a detailed localization of noise sources in presence of background Noise. The use of the absorbing system slightly improves the localisation of the sources. The quantitative obtained results are quite good since the max level measured in the source plane without the parasite sources is 74.7 dB (1/12 Octave 2058Hz).

This test also highlights a limitation of NAH: when the Signal-to-Noise ratio is too low, the source localisation is not relevant. The example below (Fig. 10) shows the source localization with a SNR of -10dB.
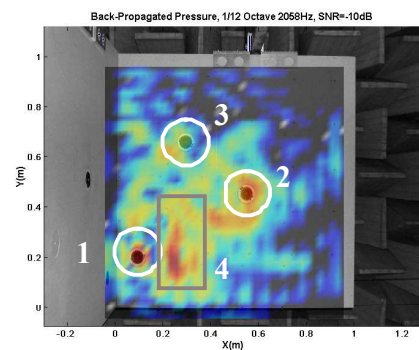

Figure 10. Source Localization, SNR=-10dB

With the use of the Wiener filter, the 3 sources (1, 2, 3) are detected, but it appears another one (4) due to a parasite source. Nevertheless, this is a critical measurement condition because one of the advantages of near-field acoustical holography is that the measurement is realized in the nearfield of the sources, what tends to increase the signal-to-noise ratio.

Another advantage of NAH (compared with other acoustical imaging techniques such as beamforming) relies on the high resolution of the analysis made. The latter is illustrated on Fig. 11 showing the separation of two correlated sources spaced by 10cm (located by squares), perturbed by the same reflective panel as above.
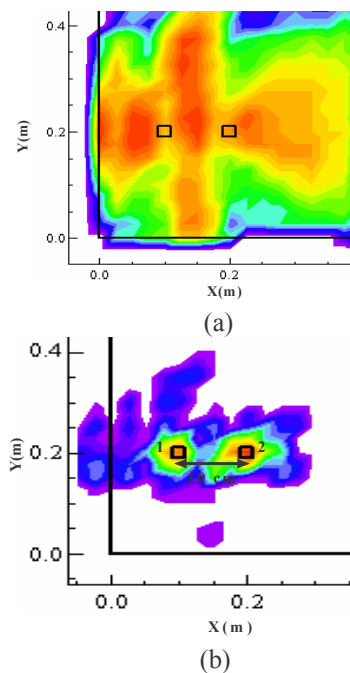

(a)

(b)

Figure 11. Source Separation (Third-Octave band 4000Hz) (a) Nearfield pressure, (b) Back-propagated pressure

In Fig. 11.a is shown the nearfield pressure (pressure in the antenna plane) which does not allow to detect the true sources number and locations. Conversely, after the back-propagation process, the noise sources are well identified.

Another problem is the sensitivity of NAH to vibrating measurement conditions. This problem has been studied through a measurement series on a loudspeaker with an increasing vibration magnitude of the antenna during acquisition. The results are not presented here, but they tend to prove that no significant measurement error is done provided the acquisition is long enough and the vibration level is acceptable.

The results shown here prove the robustness of Nearfield Acoustical Holography to noisy measurement conditions, provided wavenumber filters described above are applied before back-propagation.

4. Inside Helicopter cabin measurement

4.1 Physical artificial excitation measurement :

NAH was then tested for ground measurements on a whole helicopter. One of the interests of these tests was to

assess the behaviour of NAH in realistic reverberant conditions. Another objective was to access to the acoustical radiation of system components, through a measurement series made inside the cabin, with a physical artificial excitation situated on the outside. The goal was to locate the weakness points and to compare them with the localized sources in operating conditions.

Different kinds of excitation were checked. We present here the results of a measurement on the rear panel of the cabin submitted to a broadband excitation in the baggage compartment (see Fig. 12).
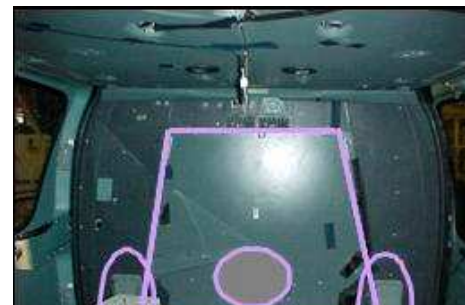
Holography->BackPropagate->Back

Wide Band (UBA) [502.6-6398.3]Hz Ph:577.6Hz D=0.07m,SNR=15dB V,X

-band Pressure (dB)
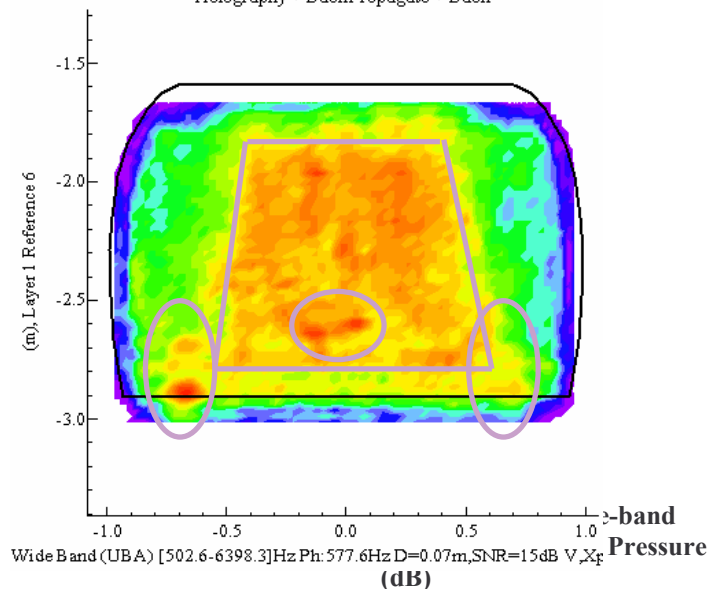
The expected noise sources are well detected, and it allows for a good knowledge of the sources in the SIL4 frequency range.

4.2 In-flight tests :

Finally, NAH was applied to an in-flight measurement. Reference transducers are positioned around the main sources according to the results obtained from a previous microphone measurement campaign. The references which present the best coherence with the cabin microphones are used as fixed references for the holographic treatment. Moreover, extra microphones are positioned inside the cabin at passenger's ears location in order to capture a fully coherent acoustic field.

The entire cabin is meshed with stickers and all the panels are measured (See Fig. 3). It represents 405 antenna positions (or 25920 microphone positions), for a measurement lasting approximately 1.5 hours. Time

signals are acquired and the holographic treatment is applied in post-processing.

The stationarity of signals is studied for the length of each plane acquisition. Some thresholds are put to detect non-stationary conditions. To reduce non-stationary limitations, a high average number (about 100) is used for each antenna position. Nevertheless, to prevent from bad measurements due to that kind of problem, we have proposed a normalization method: it consists in replacing the pressure input signals with signals normalized by one of the fixed reference signal acquired during the same measurement position.
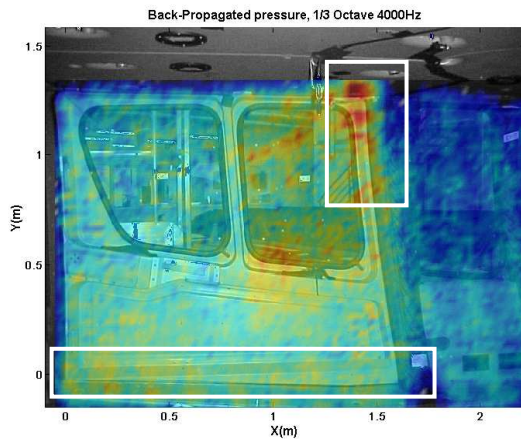
Figure 13. Back-Propagated pressure (dB), 1/3 Octave 4000Hz

The results obtained (see Fig. 13) allow a detailed localization of noise sources or leaks for the whole desired frequency range.

5. Conclusion

This paper presents the method used to detect noise sources in helicopter cabins. The theoretical approach is presented as well as its practical implementation. Nearfield Acoustical Holography is then validated on different test conditions, from less perturbed ones to very noisy conditions. It is shown both the abilities and the limitations of NAH in difficult measurement conditions. Sensitive parameters for holographic back-propagation have been discussed and conclusions have been drawn with respect to the application in a helicopter cabin. The technique is then applied to interior measurements inside a helicopter for both on-ground and in-flight tests. The results allow for a good knowledge of the acoustic energy distribution on elementary radiating surfaces such as roofs and openings. Finally, the energy radiated by these surfaces will be defined as an input to predict the acoustic pressure at pilot and passengers ears with geometrical acoustics techniques. This global methodology should lead to a better choice of passive treatments to improve comfort in helicopter cabins.

6. Acknowledgment

7. References

[1]   J-C Pascal, "*Les techniques d'imagerie acoustique et l'holographie acoustique*", Journée imagerie acoustique appliquée, CRITT-M2A (Le Mans, France), 2002.

[2]   J. Caillet, F. Malburet, J-C.Carmona, F. Marrot: " *Diagnosis, analyse and modelling of noise paths in a helicopter cabin* ", 2ème colloque d'analyse vibratoire expérimentale (Blois, France), 2003.

[3]   E.G. Williams, B.H. Houston, P.C. Herdic, R. Raveendra, B. Gardner, "*Interior near-field acoustic holography In flight*", Journal of Acoustical Society of America 108, 1451-1463, 2000.

[4]   Maynard, J.D, Williams, E.G. and Y.Lee, "*Nearfield Acoustical Holography: 1.Theory of generalized Holography and the development of NAH*", J.Acoust.Soc.Am, 1395-1413,1985.

[5]   J. Hald, "*STSF - a unique technique for scan-based Near-field Acoustic Holography without restrictions on coherence*", B&K Technical Review No. 1, pp 1-50, 1989.

[6]   E.G. Williams, "Fourier Acoustics, Sound Radiation and NAH", Academic Press, 1999.

[7]   S.M Dumbacher and D.L Brown, "*Practical Aspects of making NAH measurements*", Society of Automotive Engineers, 1998.

[8]   S.-C. Kang, J.-G. Ih, Y.-J. Park, "*Near-field limit in positioning the microphone for pressure measurements in using the nearfield acoustical holography*", Inter-noise 2000 (Nice, FRANCE), 2000.

[9]   P. Jean, "*Coupling integral and geometrical representations for vibro-acoustical problems*", Journal of Sound and Vibration 224(3), 475-487, 1999.

[10] D.Vaucher de la Croix, P.Chevret, F.Perrin, "*Use of Acoustical Holography in 3D Interior measurements*", Internoise 2002 (Dearborn, MI, USA), 2002.

8. Glossary

NAH: Nearfield Acoustical Holography

MGB: Main Gearbox

SIL4:   Speech Interference Level, 4-octave average

AIT: Advanced Intelligent Tape

SNR :   Signal-to-Noise Ratio

ONERA: The French Aeronautics and Space Research Center