ACOUSTIC COMFORT OPTIMIZATION IN A H175 HELICOPTER

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SUMMARY

Airbus Helicopters, Inc. offers the most complete range of corporate helicopters. These rotorcrafts combine smooth rides and luxurious interiors with industry-leading safety and low noise signatures, ensuring that operations are neighbor-friendly wherever they are performed. The combination of aerodynamic, acoustic and mechanical noise sources however typically leads to a rich spectrum with potentially very loud and annoying broadband and tonal components especially inside the helicopter. Moreover, strong mechanical coupling and complex noise transmission paths in the helicopter render acoustic optimization a challenging task. To achieve improved cabin comfort and apply efficient noise treatments, it is essential to identify the dominant noise sources and treat them in the right order of priority. Thus, having a tool to easily locate and rank the most contributing panels and sources in the cabin would be extremely beneficial to support comfortable helicopter design. Many works have already been published on such noise source separation technique and applications, especially in the automotive industry. Among available technologies, array techniques based on beamforming have been largely developed and used for interior noise analysis but rarely applied to interior aircraft or helicopter noise. This paper presents an interesting study carried out on a H175 helicopter and showing how the interior sound field is analyzed with an acoustic array technique.

The tool used in this project has been recently developed by MicrodB and his partner Siemens. It is based on a double layer spherical array placed at the center of the cabin and is able to provide a 360 degree “acoustic image” of the sound field in the cabin. A unique combination of two spherical arrays allows to cover a broad frequency range: one rigid sphere containing 36 or 54 microphones distributed on its surface covers the mid and high frequencies, whereas a second larger diameter open sphere with 24 microphones handles the low frequency part. The acoustic array is connected to a portable LMS SCADAS measurement system and the LMS Test.Lab software is used to process the data. Sound source localization results can be readily obtained in-flight after just a few seconds of measurements. Alternatively, the measurement system can be used autonomously to record the entire flight for different flight conditions and provide the source localization result at a later stage. As such, this is a revolutionary tool as it is extremely quick, is able to analyze transient phenomena and avoids lengthy and costly in-flight measurements as performed with traditional techniques like sound intensity measurement or holography. The combination of a dual spherical array and specific processing algorithms such as spherical beamforming and equivalent source method allows to extend the application range of beamforming and to successfully handle noise source identification in cavities. This technique has already proved its efficiency in non-reverberant environments such as automotive interior noise optimization in windtunnels. One challenge of the current project is to apply the technique to the helicopter cabin which is a more reverberant environment.

Noise source analysis has been performed in the cabin of the H175 helicopter for various flight conditions and will be illustrated in the paper. It is interesting to see how the noise sources vary as a function of thrust or flight speed. Noise spectrum is analyzed in detail and dominant sources are identified in the cabin for most critical frequencies. Some examples are illustrated in this paper. Source contribution results will also be shown where sound power is obtained by integrating the acoustic intensity over selected emission areas. This efficient measurement technique allows to get clear indications on possible noise treatments in the cabin to reach improved acoustic comfort. Best practices for such array measurements as well as advantages and limitations of this technique are clearly explained.

This study allows to confirm that such acoustic array technique is very well suited for helicopter interior noise analysis.

Key word: interior noise, noise localization, source contribution, microphone array, in-flight acoustic testing

1 INTRODUCTION

Helicopter customers demand more and more comfort, what requires continuous efforts on various fields such as vibrations, thermal, ergonomics, aesthetic and acoustics. Regarding the latter, and despite complex numerical models derived to optimize sound-proofing design, unexpected additional noise sources and transfer path might degrade the overall sound-pressure levels and comfort perception in the helicopter in some particular flight conditions. As an example, leakages cannot be accurately predicted before flight tests and there is a need to have fast and efficient means for trouble-shooting and final sound-proofing set-up and validation on helicopter.

It is common practice in the development of helicopter to test interior acoustic during flight to account for the combination of aerodynamic, acoustic and mechanical noise sources. While flight tests are generally expensive, it is of benefit to capture as much information as fast as possible. In the context of interior comfort optimization, the aim is to detect areas with acoustic weakness to be treated in priority.

The use of isolated microphones does not permit to localise them but microphone array technologies are well suited as far as they are not based on scanning technology which leads to long measurement time. These last techniques are used by Airbus Helicopter for determining the sound power of panels from acoustic holography [1,2]. Among available one-shot technologies, array techniques based on beamforming have been largely developed to achieve source ranking. The interior and reverberant environment imposes to use a measurement set-up able to separate wave directions. The Double Layer Spherical Array combined with spherical beamforming developed by MicrodB, patented with Airbus and included in Siemens product line offers a good dynamic and resolution over a very broad frequency range from 200 Hz to 8 kHz. Many works have been published in automotive and aeronautic industry where interior acoustic optimization is carried out in wind tunnel testing or on flight testing [3,4].

Since the objective of this project was to demonstrate the ability of this equipment to localise various noise sources in the helicopter cabin, the measurement system has been used during an in-flight measurement campaign for several flight configurations. The results prove the ability of the system to rank noise sources in a one-shot measurement of few seconds.

2 HELICOPTER PROBLEMATIC

2.1 Sound sources and transfer paths

The noise levels measured in helicopters are severely affected by several noise sources. Among the main sources, main gearbox (MGB), engines, rotors and turbulent boundary layer are classically depicted as the most significant. On top of these, environmental control systems and equipment may generate additional noise components that degrade interior acoustic comfort.

From these sources, the noise propagates to passengers ears through different noise propagation paths. As an example, mechanical noise originating from the gearbox propagates to the cabin through combination of structure borne propagation via MGB struts and suspension mounted on helicopter airframe, and airborne paths after radiation of MGB housing in the upper deck compartment.

On top of this, identification and ranking of these transfer paths is made rather complex due to the fact that helicopter cabin environments are generally highly reverberant environments.

Hence, the sound pressure level spectrum of a helicopter is characterised by a superimposition of several noise sources. The latter is illustrated on Figure 1.

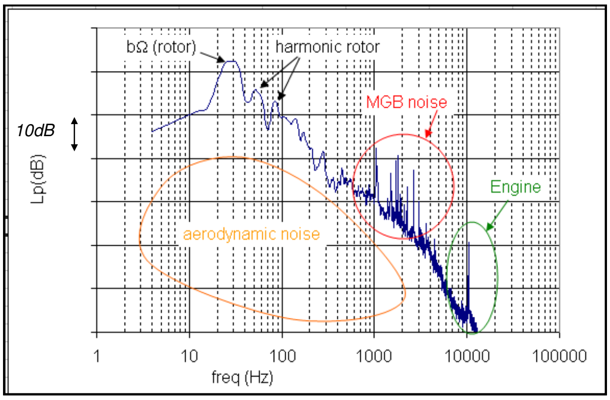

Figure 1: Typical sound pressure level spectrum inside helicopter

Main focus is generally brought on the mid and high frequency range, as intelligibility bandwidth remains of prime importance. Hence, internal noise levels are generally summarized in dBSIL4 (Speech Interference Level, 4-Octave average). Overall dB(A) noise levels are also generally analysed, with respect to upcoming standards on workers health protection.

2.2 Diagnosis process

Acoustic diagnosis process can be considered with two different objectives: detailed diagnosis and cabin acoustic modelling, and trouble-shooting.

During helicopter development phases, main target is to localize and rank main acoustic contributors such as radiating panels or windows, and leakages, so as to feed the numerical simulation models and develop appropriate sound-proofing solutions. Current process at Airbus Helicopters has been presented at ERF in 2009 [9] and relies on the combined use of Nearfield Acoustic Holography Measurements [1] and Ray-tracing simulations. This methodology has been widely validated in helicopter environments and benefit from all the advantages of measuring noise in the nearfield of acoustic sources. In particular, this method enables to accurately quantify pressure, acoustic velocity and sound intensity generated by radiating panels.

Main drawback of such a methodology lies in the long preparation and measurement time needed to perform in flight nearfield acoustic holography measurements in a complex 3D environment. As a consequence, measurements are generally performed in a single flight condition (generally in stabilized level-flight at standard cruise speed), thus limiting potential interest of such a complex measurement technique.

For trouble-shooting applications, target is to locate in a short measurement time frame the main noise sources that may exist only in some particular flight conditions, or associated with a given helicopter subsystem operation. It is then necessary to be able to investigate noise sources localisation in several flight conditions and for different operating conditions (e.g. ECS noise).

It is thus of strong interest for Airbus Helicopters to get a diagnosis tool that could be easily and rapidly installed in a helicopter cabin, which permits to localize and rank main acoustic contributors for a set of given flight conditions with a reasonable flight test duration.

The chosen methodology which is presented here is based on the use of a double layer spherical array positioned at a fixed position at the center of the cabin and provided by MicrodB, for which microphones signals are continuously recorded along a full flight representative of main flight conditions. The method doesn't require any operator on-board (recording is started/stopped on ground) and only 30 to 60 seconds are enough for characterizing each stabilized flight phase. Signals are then post-processed to create acoustic pressure maps on the cabin geometry. The measurement process is detailed hereafter.
Main target of the measurement presented here was to validate this fast measurement technique in comparison with a nearfield acoustic holography measurement, so as to consolidate the use of this tool for further trouble-shooting applications, and then quickly identify weak acoustic areas.

3 MEASUREMENT

3.1 Geometry scanning

A mesh of the cavity is required to obtain best localization results with the right propagation distance between each measurement point on the spherical array and each source point on the surface of the cavity. Because meshes obtained with CAD software are not always available, MicrodB has developed and patented [5] a dedicated measurement tool to allow fast measurement and processing of any cavity. It is composed of a laser sensor and a camera mounted on a robotised arm driven by the acoustic imaging software in LMS Test.Lab environment. It is positioned on the same pod as the microphone array for easy coordinate system positioning.

Figure 2: Laser scanning system mounted on the pod

Pictures and distance data are automatically acquired for each source node and assembled to generate a full 360 degree mesh of the cavity. This process is very quick as it takes for instance about 25 minutes to create a mesh of 1500 points for a volume of 2x2x3 m3. This part of the measurement is typically done on the ground since the meshing doesn't require to be done in testing configuration. The below figure 3 presents the result mesh.

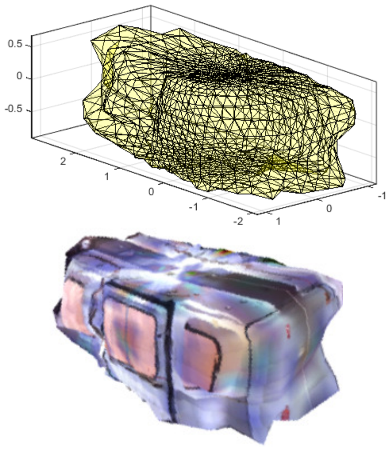

Figure 3: 3D photorealistic representation of the H175 cabin

The other great advantage of this technique compared to conventional CAD meshing is that reconstructed pressure field is displayed on the mesh with associated pictures, thus making identification of the equipment responsible of the sound emission easier. Thanks to the polar coordinate measurement methodology, a planisphere view is also available and makes comparison of configurations easier, by making all surfaces visible.
The mesh result of the H175 is displayed with such a planisphere view on Figure 4.

Figure 4: planisphere view of the H175 mesh carried out by innovative tool in LMS Test.Lab.

On this figure, the middle of the picture shows the front part of the cabin, while the left and right extremities are the opposite rear cabin panel. The laser sensors, and then the double layer spherical array, are voluntarily positioned in the middle, below main gearbox and close to passengers' doors.

3.2 Double layer spherical array

MicrodB and Airbus have developed and patented [6,7] a methodology based on a double layer spherical array to localize and quantify sources in cavities in one-shot measurement. The array is composed of a 30cm rigid spherical body on which 36 or 54 microphones are mounted flush to the surface and an 80cm open sphere created by 24 microphones positioned on removable extension arms fixed on the rigid sphere. The scattering of acoustic waves on the rigid body of the sphere drastically improves the directivity of the array in middle and high frequencies. To improve the poor resolution in the low frequencies without modifying the cavity volume, the extensions create an open spherical array with a larger diameter. Thanks to this complementarity and associated processing developed in next chapter, this measurement set up gives satisfactory results for frequencies from 200 to 6000 Hz. The measurement setup is illustrated on Figure 5, where the array is positioned in the middle of the cabin and is fixed on structure rails.

With integrated cabling between the array and data acquisition front-end, the complete system is mounted and dismounted in few minutes allowing it to be installed and/or removed during the flight if necessary.

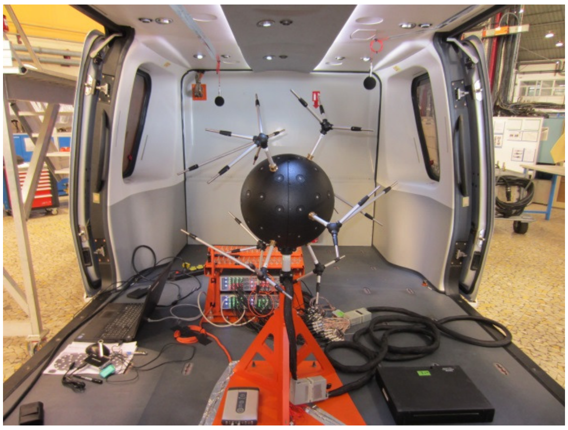

Figure 5: Measurement set-up with double layer spherical array in the H175 helicopter

3.3 Data acquisition

The LMS SCADAS mobile system is used for acquiring the signals from the microphones of the array. This portable data acquisition system features integrated signal conditioning and digitization capabilities which allow simplifying the instrumentation task. Its compact size and integrated battery also make it ideal for field measurements. The data acquisition system can be used in autonomous recording mode to write the data on a compact flash for the entire flight and allow further processing once on the ground. Alternatively, the front-end is connected to a tablet PC via a simple network cable allowing monitoring of the data during recording and on-the-spot analysis of the source localization results for various flight conditions.

4 ANALYSIS AND RESULTS

4.1 Processing

The different processing carried out from the measurement can produce different types of results: sound source localization maps, sound source contribution spectrum to measurement point or sound power spectrum. The localization indicates the position of the dominant source regions where the noise is coming from. From these maps, integration of the pressure or source density on specific areas of the mesh allows to estimate the relative or absolute levels of dominant sources. Using this technique, different configurations can easily be compared based on the calculated sound power spectra.

Source localization and quantification from array measurement in closed spaces is not straightforward since the free-field assumption commonly used to formulate the problem is violated due to reflection of sound waves on wall surfaces. Also, because the number of sources (around 5000 nodes) is typically much greater than the number of measurement points (78 microphones), resolution of the system must be done carefully.

The measurement set-up used here helps alleviating these limitations. On one hand, the automatic geometry scanning provides a better representation of the actual cavity volume and improves accuracy of the source localization. On the other hand, the acoustic scattering happening on the surface of the rigid sphere helps separating waves coming from different angles.

Moreover, several methods have been implemented in the software to reach best accuracy on a wide frequency range. These methods can be separated in two categories: beamforming and inverse method.

The principle of beamforming is to sum the measured pressures with a delay corresponding to the path between the measurement points and the meshing points. Performance of the source localization technique is typically estimated in terms of 2 criteria: spatial resolution and dynamic range linked to array pattern. But it has to be a compromise, the first one requiring a large array for a narrow main lobe and the second one, a high microphone density for lower secondary lobes. For this reason the double layer spherical array is a good solution. In low frequency, the open large sphere is preferred to improve noise source separation while the dynamic range is not so important. In high frequency, taking into account the SRTF (spherical related transfer function) of the rigid sphere with spherical beamforming improves the directivity for the best dynamic range. In middle frequency, a multiplicative processing based on the coherence of the results from the 2 spheres is the best compromise.

It is common to apply deconvolution on beamforming results to clean up the map and to obtain the source power quantification. However for interior applications, it is more difficult to apply as it is a long iterative processing due to the large number of calculation points and the algorithm also needs to be adapted to deal with coherent sources linked with acoustic reflections.

Due to above limitations, the equivalent source method (ESM) has been preferred. The principle of this inverse method is to replace a given acoustic field by the superposition of fields produced by a set of equivalent sources [8]. Compared to beamforming, the performance in terms of dynamic range and resolution is improved since this equivalent source method gives a distribution of sources without windowing by the array pattern. The main drawback of this approach is its sensitivity to system conditioning (poor conditioning can be linked to presence of cavity modes or noisy measurements).

For the application on the H175, the ESM has only been used to improve the localization results in low frequency since the environment is very reverberant and does not permit to get absolute sound power quantification of sources.
The beamforming processing is then preferred in middle and high frequencies (over 800 Hz) to get the sound pressure maps. In a second step, the pressure levels of sound map have been integrated on specific noisy areas to get source ranking with source contribution spectra.

3.2 Results

From the continuous recording of a whole flight, signals are then separated according to stabilized flight conditions (ground run, hover, level flight at 40/100/145kias with and without Environment Control System functioning were analysed).

Extracts of the results are presented below, enabling to draw main conclusions on the applicability of such a method for helicopter cabin environments.

3.2.1 Limitations

In the low frequency range (<500Hz), the method does not provide valuable results due to classical limitations of beamforming method particularly on the spatial resolution constraints. In this frequency range, excitations sources are mainly distributed aerodynamic sources and acoustic response is dominated by the modal properties of the cavity. An example of the mapping in the 125Hz-octave band is presented on figure 6 below.

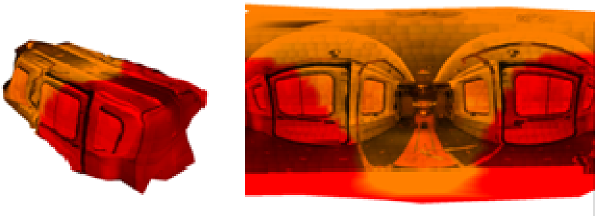

Figure 6: Acoustic pressure map, Octave band 125Hz

Another limitation has been identified on some acoustic maps (depending on frequency). Indeed, beamforming method may detect “ghost sources”. These pseudo-sources are not real ones and they are possibly due to noise reflections or post-processing errors. In particular, it was noticed during this measurement that cabin floor can be identified as a noise source at some main gearbox frequency, while this is unlikely the case. This issue is most probably linked to the fact that antenna is located quite close to the cabin floor which is a highly reflective area. Nevertheless, and for such a case, practical means such as absorption carpet below the antenna proved to significantly reduce this phenomenon. Still, as a consequence, interpretation of acoustic mappings shall be done carefully.

3.2.2 Mid and High frequencies results

On the contrary, the method proves to be very efficient at higher frequencies, and from octave band centered on 500Hz (figure 7).

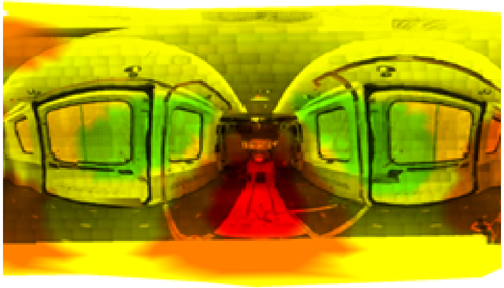

Figure 7: Acoustic pressure map, Octave band 500Hz

On the latter, the front part of the cabin is clearly pointed out as a dominating source area, as it was already identified on previous flight with microphone measurements. The hot point is physically identified as the cabin air recirculation inlet which proves to be a direct airborne path to the aeroacoustic excitation.

Figure 8: Acoustic pressure map, Octave band 2kHz, with FTI installation cable in RH sliding door.

Results are even more spectacular at higher frequencies at which the system resolution becomes very precise. As an example, a flight test installation cable was installed through RH cabin door frame for measurement purpose. This cable creates a small leakage at the door seal, which in turns becomes an additional acoustic source. The latter can easily be identified at frequencies above 2000Hz. One can notice that there is no cable in the LH door, thus leading to a dissymmetrical noise mapping (Figure 8).

An additional example is shown hereafter when environment control system is switched on. In this configuration, additional noise may arise from the heating and ventilation modules, which is propagated through the ducts and till the cabin through ambient and individual air outlets. The locations of these outlets are accurately identified on figure 9.

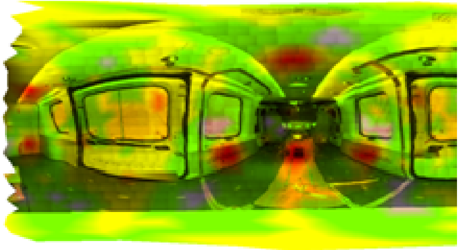

Figure 9: Acoustic pressure map, Octave band 4kHz, Environmental Control System On.

Finally, it is rather interesting to compare results of the double-spherical array with nearfield acoustical holography measurements performed on the same helicopter. An example is shown below with the 1kHz third-octave band frequency which is significantly dominated by a main gearbox gear tonal component. The latter propagates to the cabin through the main frames and reaches the cabin through the upper deck upper left area. Similar localizations results are obtained with Holography and beamforming treatments (figure 10).

It can be seen that the methodology developed here enables to quickly locate the main contribution area as a few seconds only in this flight condition are needed to get such a result, while the full nearfield acoustic holography measurement campaign took more than 2 hours for the complete EC175 cabin.

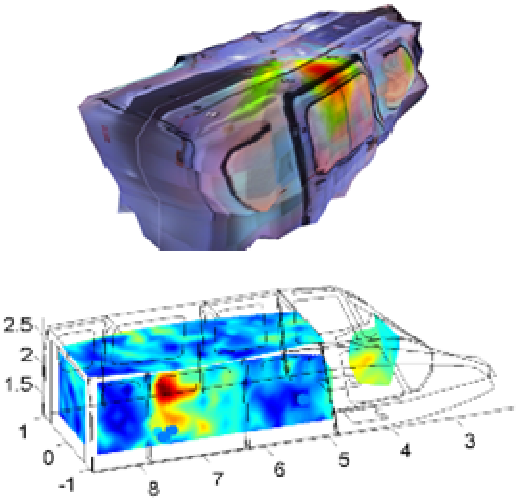

Figure 10: Comparison of MicrodB results (upper) with Nearfield Acoustical Holography measurements (lower).

3.2.3 Contribution analysis

In addition to the localization of noise sources, the acoustic maps allow to evaluate the acoustic contribution of areas on the overall noise level inside the cabin. Based on the noise sources reconstructed on the mesh, it is possible to propagate their sound pressure to a microphone in order to evaluate the contribution of this source or area on the noise level measured by the microphone.
To do so, the first step is to define specific areas on the meshing which are identified as radiating areas.

In the below example, and for a given flight condition, 4 different zones were identified. An illustration of results that can be obtained are presented on figure 11 below.

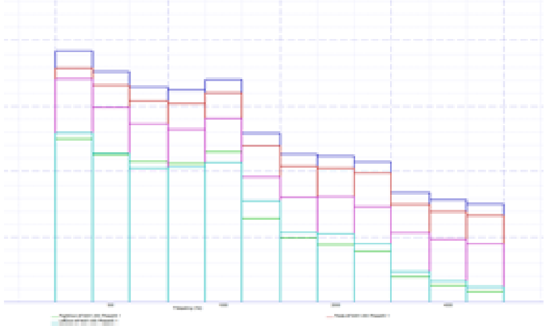

Figure 11: Source contribution analysis illustration

This kind of analysis confirms the results obtained with localization maps, though putting them in a different perspective. Note that this contribution is valid only for the microphone array location and that area of the considered zone play a significant part in their relative contribution.

This analysis can be easily used to have a rough estimation of potential benefit of modifying acoustic design at identified sources locations.

4 CONCLUSIONS

This paper presents the results of an experimental study in H175 cabin aiming at validating the use of MicrodB & Siemens tools for acoustic source localisation in flight.
In a first part, the targets and main challenges are presented, with a particular emphasis on the specific issues of helicopter cabin environment. The measurements and analysis methodology is then discussed. In a last part, the results are illustrated with specific examples of H175 cabin noise sources.
Though some limitations are identified and presented here, the results of this study show that spherical beamforming is a quick and industrial acoustic imaging methodology, with affordable measurements and analysis durations. Hence, it can be used as an efficient trouble-shooting means for cabin noise sources investigations.
Furthermore, estimations of sources contributions can also be obtained with the methodology, thus enabling to quickly investigate the potential benefit of design modifications. Though the results are not presented here, following this study, the method was further used for the final set-up of best-in-class H175 VIP interior

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