

Measurement of Absorption Coefficient, Surface Admittance, Radiated Intensity and Absorbed Intensity on the Panels of a Vehicle Cabin using a Dual Layer Array with Integrated Position Measurement

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ABSTRACT

In some cases it is important to be able to measure not only the total sound intensity on a panel surface in a vehicle cabin, but also the components of that intensity due to sound radiation and due to absorption from the incident field. For example, these intensity components may be needed for calibration of energy flow models of the cabin noise. Two different methods are introduced in the present paper: one based on surface absorption coefficient and one based on surface admittance. The two methods are compared in terms of underlying assumptions and through simulated and real measurements. The method based on absorption coefficient appears to be the more robust.

INTRODUCTION

The present paper is based on work done in the European Union research project CREDO, which deals with noise in aircraft and helicopter cabins. Since the radiated intensity is often seen from the perspective of the cabin, it will be sometimes called Entering Intensity (EI).

Consider the radiation of sound from a small surface segment in a cabin environment. Such a surface segment may radiate sound energy because of external

forcing, causing the surface to vibrate, and it may absorb energy from an incident sound field because of finite surface acoustic impedance. When measuring the sound intensity over the surface segment with an intensity probe, the total intensity I_{tot} will be measured. Assuming the radiated field and the incident field to be mutually incoherent, the total intensity is equal to the sum of the radiated sound intensity I_{rad} that would exist with no incident field and the sound intensity component I_{abs} due to absorption from the incident field:

$$I_{\text{tot}} = I_{\text{rad}} + I_{\text{abs}} \quad (1)$$

Considering the intensity in the outward normal direction on the panel surface, the radiated intensity will typically be positive, while the component due to absorption will typically be negative. So for vibrating panels with an absorptive surface, the total measured intensity may be small although the radiated intensity is relatively high. Often it is of interest to know not only the total intensity, but also the components due to radiation and absorption. For example, this kind of information is needed in energy based modeling that describes the energy flow between sub-systems, [1].

The assumption of incoherent radiated and incident field components is probably reasonable for Turbulent Boundary Layer (TBL) noise in an aircraft cabin, where

there is a huge number of incoherent excitations. A first idea could therefore be to estimate the radiated intensity as the product of total intensity and the coherence with a reference vibration signal measured under the position of the intensity probe. However, with finite surface impedance, the surface velocity and thus the reference signal will contain a component due to the incident field. Also, one reference may not be sufficient to completely represent the radiated field at the measurement position.

The methods to be investigated in the present paper are not based on correlation, but on separation of different sound field components via the spatial sound field information provided by an array. The radiated intensity is estimated as the intensity that would exist, if the incident and scattered field components could be taken away. So a free-field radiation condition is simulated. The idea is to first separate the incident field component, then use separately measured information about the scattering properties of the panel to calculate the scattered field, and finally subtract the incident and scattered fields from the total sound field. Two different ways of characterizing the scattering properties have been investigated. Both methods need the panel geometry, which is either imported as CAD or measured with a 3D digitizer. One method then uses a measured map of complex surface admittance, while the other method uses a measured map of absorption coefficient. The separate measurement of the surface admittance and/or the absorption coefficient is taken with loudspeaker excitation.

DESCRIPTION OF METHODOLOGY

The array measurements considered here are cross-spectral measurements. Separate reference signals could be measured to provide phase information between different array positions, but because of the large number of independent sources of TBL noise we have chosen to measure "only" the full cross spectral matrix between all array microphones, and then derive a Principal Component sound field representation based on that [2]. As a consequence no phase information is available between different array positions, so a separate patch holography calculation has to be performed for each position. We used a Double Layer Array (DLA), and the processing was performed using Statistically Optimized NAH (SONAH), [3-4]. In the following we will consider only a single Principal Component, i.e. a spatially coherent sound field with coherent sources. We shall use a complex time harmonic representation with the time variation $e^{j\omega t}$ suppressed.

EXTRACTION OF THE INCIDENT FIELD

A basic array processing task is that of extracting the incident sound field from the total sound field. Considering the sound field on a small panel segment in a cabin, the distinction between the incident field and the radiated field is, however, not obvious, even when we

look at the field very near the panel segment. Because of coherent vibration components and significant mutual radiation impedances between neighboring panel segments, some neighboring segments should be included as sources of the radiated field. Figure 1 illustrates, how this distinction can be made in practice with a DLA. Using SONAH holography on a DLA measurement, the sound field components $(p^-, \mathbf{u}^-)$ and $(p^+, \mathbf{u}^+)$ with sources on different sides of the array plane can be separated, [3,4]:

$$(p_{total}, \mathbf{u}_{total}) = (p^-, \mathbf{u}^-) + (p^+, \mathbf{u}^+) \quad (2)$$

The array must then be used in such a way that the pressure p^- and the velocity vector $\mathbf{u}^-$ represent the field incident on the source area of interest, while the outward propagating field component $(p^+, \mathbf{u}^+)$ is the sum of the scattered and radiated fields:

$$(p^+, \mathbf{u}^+) = (p_{sct}, \mathbf{u}_{sct}) + (p_{rad}, \mathbf{u}_{rad}) \quad (3)$$

Figure 1a illustrates the case of an isolated source object, where the incident and outward propagating field components are well defined. They could be determined for example based on measurements across two concentric spherical surfaces that enclose the test object. Figure 1b illustrates the case of measurement with a DLA on a panel section in a cabin. Here, the measurement plane will define the distinction between sources of the incident field and sources of the outward propagating field. The distinction will, however, not be sharp due to the limited angular resolution of a practical array.

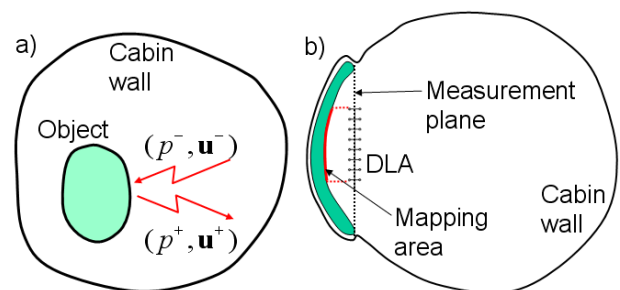


Figure 1: Separation of inward (incident) and outward propagating field components $(p^-, \mathbf{u}^-)$ and $(p^+, \mathbf{u}^+)$: a) Clearly separated sources. b) Smooth transition between sources.

Figure 2 shows the angular resolution at 2 kHz for the applied 2x8x8 element DLA with 3 cm microphone spacing and 3 cm layer separation. Here, the x-axis shows the incidence angle of a plane wave relative to the array normal, and the curve shows the calculated average pressure on the array centre plane relative to the true pressure of the plane wave. The SONAH calculation was set up to estimate the field component with sources on one side of the array, and a 20 dB dynamic range was used in the SONAH calculations, [4].

Clearly there is a smooth angular cut-off over an angular interval of approximate size 40° .

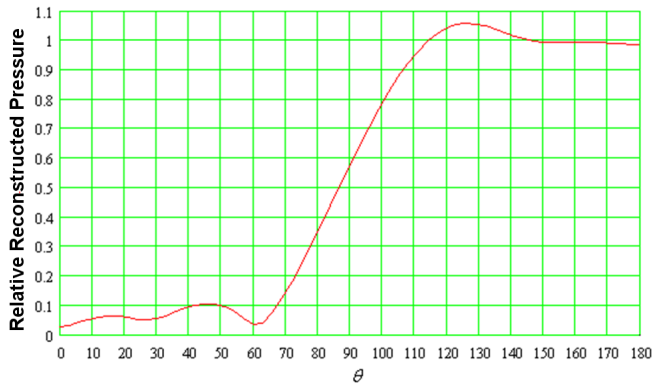


Figure 2: DLA/SONAH separation of the field component with sources on one side of the array, illustrated through its performance as an angular plane wave filter.

SOLUTION OF THE SCATTERING PROBLEM

If the source surface is locally reacting with a surface admittance $Y(\mathbf{r})$ that is known at all positions $\mathbf{r}$ on the surface, then the scattered field $(p_{\text{sct}}, \mathbf{u}_{\text{sct}})$ can be completely determined based on the extracted incident field $(p^-, \mathbf{u}^-)$. Subtraction of the scattered field from the outward propagating field $(p^+, \mathbf{u}^+)$ then provides the desired radiated field. The method requires a separate measurement of the admittance, which is a quantity that typically changes quickly along the surface normal, [5]. Small positioning errors in either the admittance measurement or the operational measurement could therefore have a big impact on the result.

Provided the incident and radiated fields are mutually incoherent, then Eq. (1) is the basis for a simpler and perhaps more robust energy based method. The basic assumption is that we can measure a local absorption coefficient α at each point $\mathbf{r}$ on the source surface such that that the normal components I^- and I_{abs} of the incident and absorbed intensities are related by:

$$I_{\text{abs}}(\mathbf{r}) = \alpha(\mathbf{r})I^-(\mathbf{r}) \quad (4)$$

In general the ratio $I_{\text{abs}}(\mathbf{r})/I^-(\mathbf{r})$ between the two intensities will depend on the form of the incident field. If, however, the coefficient $\alpha(\mathbf{r})$ is measured with an incident field that is sufficiently similar with the incident field under operational conditions, then Eq. (4) can provide good results with the operational field. This will be shown in both the simulated and the real measurements.

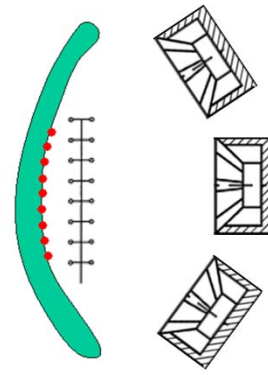


Figure 3: Cabin panel section with surface calculation points covered by a specific array position. Speakers for measurement of surface properties are shown.

Both methods require a separate set of DLA measurements with artificial speaker excitation. Figure 3 illustrates a set-up with a set of incoherently excited speakers to create an incident field similar to the field incident under for example flight conditions in an aircraft. As mentioned already, the DLA/SONAH measurement can provide the total and incident components of the loudspeaker-generated sound field on the panel surface. The complex surface admittance is then obtained as the ratio between the normal velocity and the pressure of the total field on the surface. An averaging can here be performed over the principal components. Since in this case the absorbed intensity is equal to the total intensity, then in accordance with Eq. (4) the absorption coefficient is calculated as the ratio between the total and the incident intensities. Accurate measurement of the array positions relative to the panel geometry using an integrated position measurement system allows the admittances and absorption coefficients to be calculated at pre-defined points on the panel surface, see Figure 3.

For the case of aircraft cabin application, the surface property measurement will typically be performed on the ground, while the operational measurement will be performed during flight. Often, a single surface property measurement will be applied with several operational measurements, corresponding to different operational conditions.

Once an operational measurement has been taken, the associated total, incident and outgoing field components on the panel surface can be estimated using SONAH. Considering first solution of the scattering problem via the absorption coefficient, the absorbed intensity is estimated using Eq. (4), and the radiated intensity is then obtained using Eq. (1). This method will be called the Energy Method.

The solution of the scattering problem via surface admittance is more complicated, and space does not allow a full derivation here. SONAH provides the pressure and particle velocity of the incident and outgoing fields on the surface. We need to calculate the pressure and particle velocity of the scattered field. For this, the surface admittance provides a set of equations, while SONAH can provide another set of