A hybrid experimental-numerical approach for the determination of interior panel contributions in an aircraft cabin

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Abstract

A hybrid experimental-numerical approach for Panel Contribution Analysis has been implemented in the Airbus Acoustic Flight Lab to identify the dominant noise-radiating panels of an aircraft cabin. The vibration of principal interior components (floor, sidewalls, ceiling, etc.) was experimentally characterized using accelerometers positioned with a spatial resolution necessary to capture the structural response up to 150 Hz. These measurements were used as boundary conditions for a numerical acoustic cavity model of the aircraft, supporting the simulation of the interior sound field. The contribution of every panel to the overall cabin noise was independently computed, and the superposition of all simulated fields was validated against in-situ acoustic measurements. The comparison confirmed the validity of the method to reconstruct the interior sound field from measured accelerations. Finally, the relative ranking of the contributions of interior components was established for two representative load cases.

Introduction

Low-frequency aircraft cabin noise is driven by a limited set of efficient vibro-acoustic transmission mechanisms, typically dominated by interior panel vibration and radiation into the passenger cavity. A practical engineering question is therefore not only *how much* sound is produced, but *which panels* are responsible and how their contributions vary with frequency.

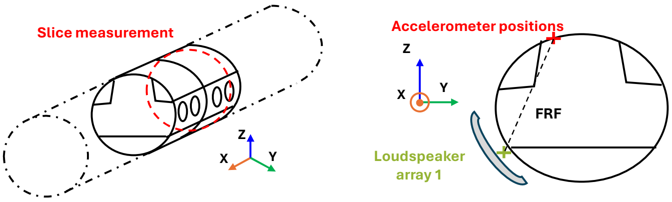
Panel Contribution Analysis (PACA) can be performed numerically using coupled vibro-acoustic finite element (FE) models [1]. However, in large cabin assemblies, uncertainties in geometry, boundary conditions, and material properties may lead to significant errors in absolute levels and spatial patterns. This work addresses this by confronting PACA results through three complementary approaches:

- **Experimental approach**: direct measurement of the cabin acoustic pressure field.
- **Full simulation approach**: coupled vibro-acoustic FE simulation excited by a measured primary acoustic field on the fuselage.
- **Hybrid approach**: acoustic FE simulation driven by *measured panel accelerations* used as boundary conditions.

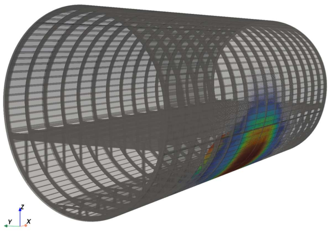
The core hypothesis is that the hybrid approach reduces modelling uncertainty by (i) using a purely acoustic FE model that closely matches the experimental cabin cavity, and (ii) injecting measured structural dynamics directly at the radiating panels. The goal of this paper is twofold: (1) validate the hybrid methodology against measurements in the Acoustic Flight Lab (AFL), and (2) use the validated hybrid model to provide PACA results and interpretation in the 50–120 Hz band.

Experimental setup at the Acoustic Flight Lab

The Airbus Acoustic Flight Lab (AFL) [2] is a full-scale fuselage-cabin demonstrator excited by an external loudspeaker array. In the considered campaign, the cabin acoustic field was measured using microphone arrays, while interior lining panels were instrumented with accelerometers along multiple longitudinal slices.



(a) Measurement segment. (b) Loudspeaker position.

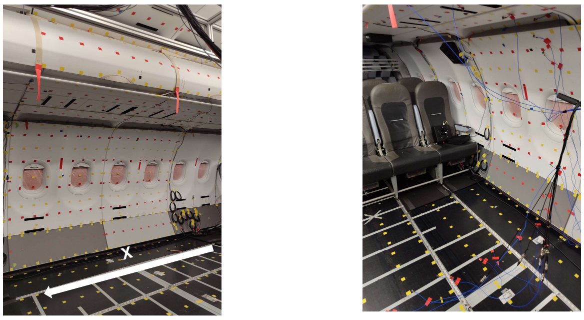


(c) Load studied in full simulation approach.

Figure 1: AFL loudspeaker configuration.

To increase robustness and interpretability, the experimental and modelling strategy follows this reasoning:

- Only **two longitudinal rows of panels** closest to the loudspeaker excitation are instrumented and analysed, since they are expected to dominate the noise in the nearby cabin region.
- The cabin volume between those rows is kept **free of seats** to better reproduce the acoustic FE geometry (noting that the numerical acoustic model does not include seats).
- The accelerometer mass is assumed negligible due to the distributed sensor grid and the slice-based acquisition.

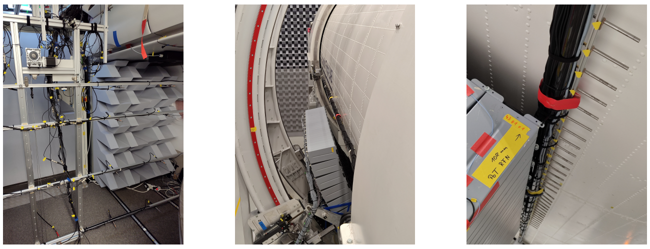


(a) Panel instrumentation.

(b) Slice measurement concept.

Figure 2: Accelerometer layout concept used in the campaign. Image credit by Airbus

The acquisition includes a microphone array inside the cabin, a loudspeaker array outside the fuselage, and fuselage microphones used to characterize the full simulation excitation. Data are processed in Simcenter Testlab and acquired with SCADAS.



(a) Cabin microphones.

(b) Loudspeakers.

(c) Fuselage mics.

(d) Simcenter Testlab.

(e) SCADAS LMS.

Figure 3: Measurement hardware and software used in the campaign. Image credit by Airbus

Hybrid PACA methodology

The hybrid approach applies experimentally measured *panel accelerations* as boundary conditions in a purely acoustic FE model of the passenger cavity. The cavity geometry closely matches the experimental configuration.

The analysis workflow is:

1. **Measurement of panel accelerations:** 68 accelerometers per transverse slice, repeated for 18 longitudinal slice positions along the cabin. The measured data consist of FRFs between each accelerometer and a reference at the loudspeaker array. The instrumentation covers sidewall, floor, ceiling, dado, cowl, and overhead compartment panels. The grid targets panel dynamics up to 150 Hz.
2. **Application as acoustic loads:** accelerations are interpolated to the acoustic mesh and used to define equivalent nodal acoustic loads via

$$F_f = S_n \, a_n, \tag{1}$$

   where S_n is the nodal surface weight and a_n the interpolated panel acceleration. Separate simulations are run for each panel group.
3. **Superposition:** the total cabin response is reconstructed by superimposing the acoustic pressure fields produced by each panel group excitation.
4. **Experimental reference:** the cabin pressure field is measured with microphones and interpolated to the FE evaluation grid for comparison.

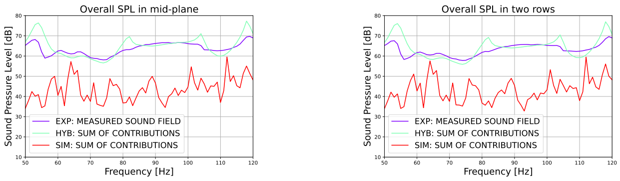
The frequency range analysed here is 50–120 Hz to focus on the low-frequency deterministic regime.

Validation metrics

Validation is performed using both *level* and *shape* metrics:

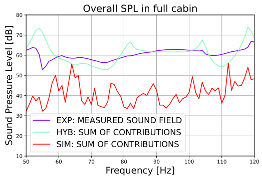
- **Average SPL**: spatially averaged sound pressure level in different cabin regions.
- **FRAC**: Frequency Response Assurance Criterion to quantify similarity of spatial acoustic shapes at each frequency (analogous to MAC [3], but applied to response patterns).

To test sensitivity to modelling assumptions, the comparison is performed in three regions: (i) **mid-plane** between the two instrumented rows, (ii) **two-row volume** spanned by the instrumented rows, and (iii) the **full cabin**.



(a) Mid-plane.

(b) Two-row volume.

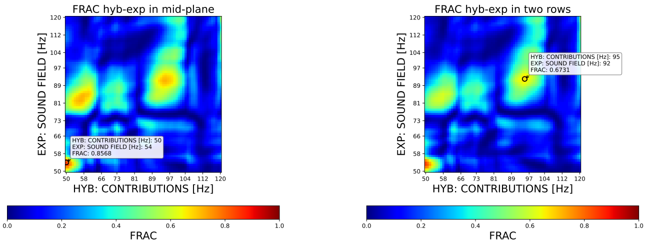


(c) Full cabin.

Figure 4: Average SPL (50–120 Hz) for experimental, hybrid, and full simulation approaches in different regions.

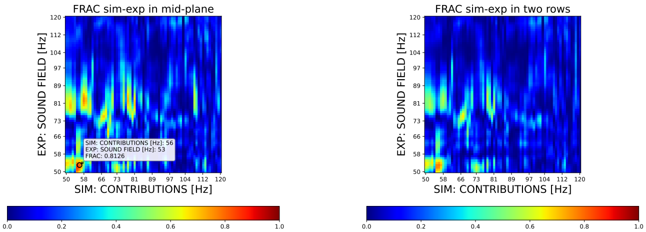
Validation results

The average SPL results indicate that the **hybrid approach** exhibits good agreement with the measured



(a) Hybrid vs. exp.: mid-plane.

(b) Hybrid vs. exp.: two rows.



(c) Sim. vs. exp.: mid-plane.

(d) Sim. vs. exp.: two rows.

Figure 5: FRAC comparison for hybrid and full simulation approaches against experimental measurements.

acoustic field, with the strongest agreement at the **mid-plane** region. In contrast, the **full simulation approach** (excitation via measured primary field on the fuselage) shows significant discrepancies, highlighting current limitations of the full vibro-acoustic model and motivating a hybrid strategy for PACA in complex cabins.

The FRAC trends are consistent with these observations. The hybrid approach shows relatively high correlation with measurements around **50 Hz** and again near **90 Hz**. While correlations are moderate overall, several spatial response patterns are correctly captured. The full simulation approach yields very low correlation across the frequency range, with only limited reproduction of the acoustic shape near 50 Hz.

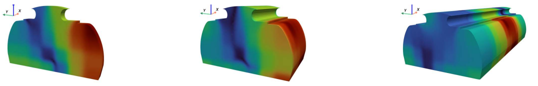
Importantly, for both approaches, agreement is consistently better at the mid-plane than within the two-row volume, which is consistent with the expected validity region of the hybrid assumptions (dominant contribution from the two instrumented rows).

Shape comparison at 50 Hz

To support the FRAC-based interpretation, Figure 6 compares measured, hybrid and full simulation acoustic pressure distributions around 50 Hz. Experimental and hybrid results exhibit very similar spatial patterns, particularly at the mid-plane location, while the full simulation model captures only the general trend with weaker agreement.

Hybrid and full simulation loads

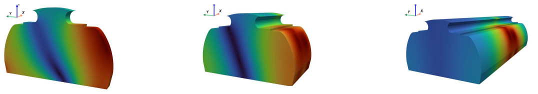
A key reason for the better performance of the hybrid approach is that its acoustic excitation is directly derived from the measured panel dynamics, whereas the full simulation approach depends on the accuracy of the vibro-acoustic coupling and the applied fuselage excitation mapping. Figure 7 compares the *acoustic load distributions* (amplitude) in the acoustic FE model at 50 Hz within the two instrumented rows, showing that the hybrid model produces a load pattern more consistent with the measured acoustic field reconstruction. The vibro-acoustic loads created by the panels in the full simulation approach were obtained using a modification of the FE-based Transfer Path Analysis methodology introduced in [4] adapted to vibro-acoustic simulation models.



(a) Exp.: mid-plane

(b) Exp.: two rows

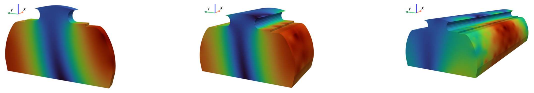
(c) Exp.: full cabin



(d) Hybrid: mid-plane

(e) Hybrid: two rows

(f) Hybrid: full cabin

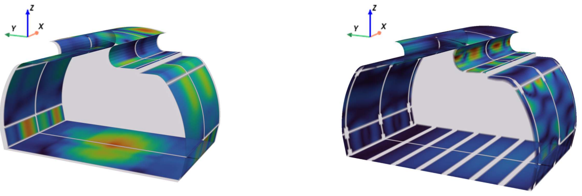


(g) Sim.: mid-plane

(h) Sim.: two rows

(i) Sim.: full cabin

Figure 6: Acoustic pressure distributions (amplitude) around 50 Hz: experimental vs. hybrid vs. full simulation.



(a) Hybrid model.

(b) Full simulation.

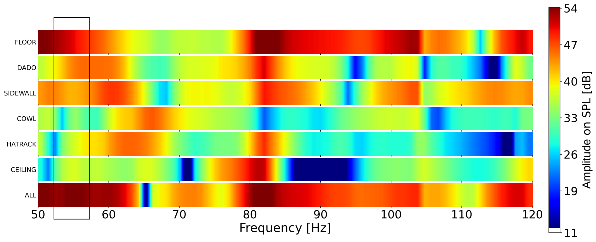
Figure 7: Comparison of acoustic loads (amplitude) at 50 Hz within the two rows of panels.

Panel Contribution Analysis

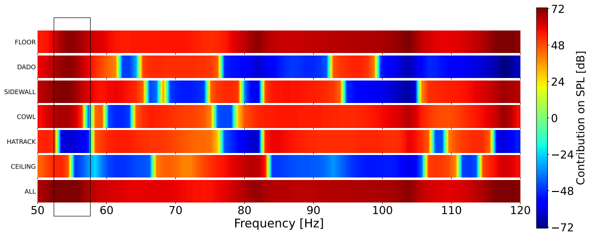
Based on the validation results above (good SPL agreement at the mid-plane and consistent acoustic shape similarity), the hybrid approach can be considered suitable for conducting PACA in the analysed band.

Figure 8 summarizes the hybrid PACA results at the mid-plane: absolute SPL amplitudes of individual panel paths, corresponding SPL contributions, and one-sixth octave contributions. The frequency around 55 Hz is highlighted for interpretation, since it corresponds to the most pronounced local SPL peak in the validation results.

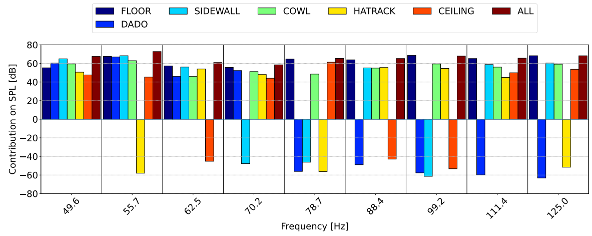
At ≈ 55 Hz, the amplitude plot indicates that the *floor* panels generate the highest absolute levels. However, the *relative* contributions reveal a more nuanced and physically meaningful result: *floor*, *sidewall*, and *dado* contribute in a very similar manner to the overall SPL. This is confirmed by the one-sixth octave representation, where these three components exhibit nearly equal con-



(a) Absolute amplitudes (hybrid, mid-plane).



(b) Relative SPL contributions (hybrid, mid-plane).



(c) One-sixth octave contributions (hybrid).

Figure 8: Panel contributions to SPL at the mid-plane obtained using the hybrid approach.

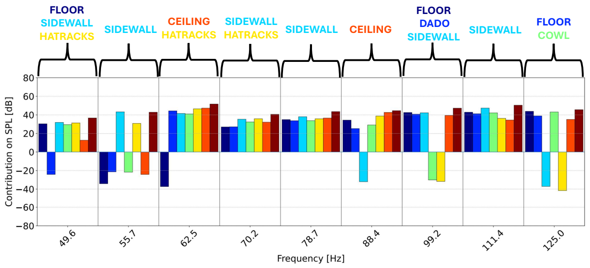
tributions around the 55.7 Hz band. At the same frequency, the *hatrack* panels show a *destructive* contribution (reducing total SPL), indicating partial cancellation in the superposition of panel-induced acoustic fields.

Comparison of contributions among approaches PACA results obtained from the full simulation approach yield markedly different patterns compared to the hybrid method. Figure 9 compares one-sixth octave contribution bars at the mid-plane. In the full simulation, dominant contributors vary strongly across frequency bands. In contrast, the hybrid approach yields a stable trend where floor, sidewall and dado consistently dominate in the band of interest.

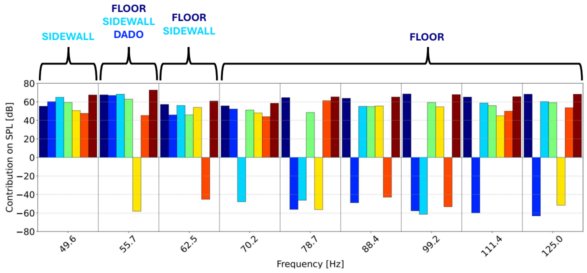
Conclusions

This paper presented an experimental validation of a hybrid Panel Contribution Analysis methodology on the Acoustic Flight Lab cabin demonstrator in the 50–120 Hz range.

The hybrid approach, which applies measured panel accelerations to a purely acoustic FE model, showed: (i) good agreement with measured average SPL, particularly in the mid-plane region between instrumented rows, (ii) moderate but consistent reproduction of acoustic response shapes quantified via FRAC, notably around 50 Hz and near 90 Hz, and (iii) physically interpretable and stable PACA results, where floor, sidewall, and dado panels dominate the contribution over the analysed band, including the observation of destructive contributions from hatrack panels near the main SPL peak.



(a) Full simulation contributions (one-sixth octave).



(b) Hybrid contributions (one-sixth octave).

Figure 9: Comparison of SPL panel contributions at the mid-plane: full simulation vs. hybrid approach.

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