From engine integration to cabin noise: drivers to accurate interior noise evaluations

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ABSTRACT

The present paper addresses the topic of end-to-end cabin noise aero-vibro-acoustic prediction for civil aircraft. Through an overview of Airbus cabin noise prediction means and related investigations, the sensitivity of cabin noise to key parameters at engine and aircraft levels is demonstrated, highlighting the need for high fidelity numerical and experimental capabilities as well as integrated ways of working between engine and aircraft manufacturers in the frame of engine design to cabin noise.

Keywords: Engine, aeroacoustics, transmission
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1. INTRODUCTION

In line with Airbus product strategy, significant efforts are being invested in the development of aircraft design means covering short term incremental improvement as well as longer term disruptive concepts as a way to cover the air transportation market needs in the coming decades.

Among the various disciplines involved in present and future aircraft design processes, cabin acoustics stands at the crossroad between aerodynamics, aeroacoustics, structure and vibration while being fully dependent on engine, aircraft and cabin designs.

This multidisciplinary character makes it necessary to clearly define the essential parameters and physical phenomena to be accounted for in order to achieve appropriate cabin noise predictions with well-dimensioned modeling efforts for short to long term-oriented activities.

The present paper focuses on the best practices developed by Airbus with respect to their end-to-end aero-vibro-acoustic prediction process for engine cabin noise.

The drivers to successful experimental and numerical aero-acoustic predictions with regards to cabin noise are first presented in §2.

These drivers and their quantified effect on the aero-acoustic field impinging a flying aircraft are further quantified in §3 through the example of the early development of Contra Rotating Open Rotor (CROR) integration for single aisle aircrafts.

Finally, the sensitivity of cabin noise to fuselage aero-acoustic excitations is roughly quantified, which highlights a strong interdependency between engine and aircraft acoustic design and an increasing need for integrated ways of working between engine and aircraft makers in the field of engine design to cabin noise.

2. DRIVERS TO ROBUST ENGINE AEROACOUSTIC PREDICTIONS FOR CABIN NOISE

This section consists in three parts respectively addressing the aeroacoustic quantities required for an accurate cabin noise evaluation and the experimental and numerical best practices for the prediction of such quantities.

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2.1 Aero-acoustic quantities required to predict engine cabin noise

The process of modeling engine cabin noise is strongly dependent on the nature of the engine sources which drive the physical phenomena underlying noise transmission through the fuselage structure and the cabin. In the present paper, engine noise sources are split into three categories: low frequency tonal noise, high frequency tonal noise and broadband noise.

a) Low frequency tonal noise (open rotor noise or turbofan Buzz Saw Noise (BSN))

For an open rotor equipped aircraft, tonal noise radiating between 100Hz and 500Hz is one of the dominant cabin noise sources in cruise. In this frequency range - especially around its lower limit where the acoustic wavelength is of the order of magnitude of the cabin inner diameter - the aircraft’s fuselage structure response and interior noise levels are particularly sensitive to the local characteristics of the fuselage acoustic excitation. The resulting structure vibrations are of such nature that they can be modelled by use of Finite Element Models (FEM) aiming at simulating the structure response of the aircraft to an aeroacoustic excitation and its propagation through a detailed environment inside the cabin.

Feeding a cabin noise FEM prediction model with relevant aeroacoustic data is challenging in the sense that it requires a detailed description of the complex pressure field on a dense grid covering a wide part of the fuselage skin. Such information can only be accessible by use of aeroacoustic numerical models. Figure 1 displays an example of surface domain where aeroacoustic inputs to FEM computations are stored. It consists in several thousand nodes shells on which the amplitude and the phase of the aeroacoustic complex pressure are stored.

![Figure 1 – Input to cabin noise FEM prediction: SPL (left) and Phase (right) in several thousand points grid.](image)

While it is naturally admitted that the amplitude of the aeroacoustic excitation significantly drives interior noise levels (for a given frequency, the interior Sound Pressure Level (SPL) evolves as a linear function of the exterior SPL), the role of the phase can happen to be less intuitive. The phase distribution on the fuselage skin characterizes the wave vector of the aeroacoustic excitation travelling along the fuselage structure. From a structure dynamics point of view, critical acoustic cases can occur when the local wavelength of the excitation is of the order of magnitude of the fuselage bending wavelength for a given frequency.

This makes it easily understandable that cabin noise levels for a given frequency band are not a linear function of the phase or wave-vector distribution on the fuselage.

For this reason, the sensitivity of cabin noise to the excitation phase is considered as a challenging phenomenon when it comes to influence engine or aircraft design processes.

b) High frequency tonal noise (open rotor and forward/rearward fan noise)

For higher frequency tones, the sensitivity of the fuselage structure response to the external excitation decreases and the use of aero-vibro-acoustic numerical tools becomes awkward due to the required models sizes. This makes it possible - and necessary - to make use of empirical or experimental data to model aeroacoustic excitations and their transmission inside the cabin.

c) Engine broadband noise (jet noise, open rotor broadband noise, fan broadband noise)

The modeling of engine broadband aeroacoustic excitations in high speed has still not reached a maturity level compliant with industrial design processes. This is related, on one hand, to the cost and complexity of unsteady Navier Stokes turbulence modeling, and on the other hand, to the fact that
physical phenomena occurring at engine level in cruise stand beyond the assumptions on which state-of-the art analytical tools are based. Nonetheless, considering the nature of these sources and the frequencies at which they radiate, it is possible – as for high frequency tonal noise – to model their external and internal contributions using experimental and empirical means.

d) Summary

The aeroacoustic quantities required for an accurate prediction of engine cabin noise are, according to Airbus prediction process:
- For low frequency tonal noise: a full complex pressure distribution on a fuselage FEM grid fine enough to tackle frequencies of interest;
- For high frequency tonal noise and broadband noise:
  o Measured (or measurements based) SPLs on a set of near-field microphones;
  o Empirical cabin noise data related to parent aircrafts and/or engines.

The development of both aeroacoustic numerical and experimental means therefore appears to be a pre-requisite to successful cabin noise predictions.

2.2 Driving criteria for robust experimental aero-acoustic evaluations

At the early development stage of a new aircraft, experiments are often the very first reliable mean to evaluate design concepts and validate related prediction tools. For aero-acoustic purposes Wind-Tunnel Tests (WTT) consist in a good cost/representativeness compromise to account for complex flow effects without requiring a full scale flight test demonstrator.

This section aims at providing an overview of key quality criteria to be taken into account in the frame of cabin-noise-oriented WTT.

a) Engine inflow representativeness

For open rotors or new turbofan architectures featuring shorter inlets and closer vicinity to the aircraft solid bodies, the presence of the aircraft strongly influences the Mach number field ingested by the engine’s fan or blades and generates an increasing engine-aircraft interaction noise contribution. As an example, Figure 2 displays a comparison between the inflow ingested by an isolated propeller flying at Mach 0.75 and the same propeller installed behind a pylon on a generic aircraft. Significant Mach number differences are observed locally which is expected to induce additional interaction noise sources and to significantly alter the isolated propeller self-noise. In order to correctly account for such effects, it is convenient to make use of an influence wind-tunnel model to appropriately reproduce the aeroacoustic behavior of a propeller in standard operations.

![Figure 2 – Inflows ingested by an isolated (left) and installed rear-mounted (right) propeller](image)

b) Wind-tunnel performances: blockage

Testing an influence model in a WTT section is not the only required condition to reproduce the desired aircraft flow. The size of the model with respect to the tunnel section should be adequately selected to be small enough to avoid blockage effects - i.e. a contamination of the propeller inflow by the presence of the tunnel walls - and large enough to embed all physical phenomena expected in a real
aircraft. In case these constraints are not reachable, it is recommended to carefully calibrate the upstream tunnel Mach number according to the geometry of the model to obtain inflow conditions which are as close as possible to the ones which would be achieved in free field conditions and actual flight Mach number. Such calibration can be achieved by the use of pre-test CFD simulations allowing the definition of reference Mach numbers and pressure coefficients to be targeted during tests.

c) Wind-tunnel performances: anechoicity

Although, it results in a reduction of wind-tunnel test sections and potentially increased blockage effects, measuring in an anechoic environment is considered by Airbus as a pre-requisite to a successful aeroacoustic test.

In Figure 3, the acoustic effect of a generic non-treated square wind-tunnel section is numerically assessed against a free field model for the first Blade Passing Frequency (BPF) of a generic rear-mounted propeller model. These features make it obvious that, even in a large wind-tunnel section, acoustic measurements in non-treated areas are hardly exploitable.

Combining the present results with the ones from a) and b) shows how constrained the definition of an appropriate high speed wind-tunnel model can be: the wind-tunnel shall be large enough to accept realistic influence model and appropriately treated whilst inducing minimum blockage effects.

![Figure 3 – Computed SPL distribution in non-treated wind-tunnel (middle) and free-field (right)](image)

d) Instrumentation and post-processing

One of the characteristics of high speed acoustic measurements on an aircraft model skin is the significant spurious contribution of Turbulent Boundary Layer (TBL) fluctuations. In a real aircraft operating in cruise conditions, the amplitude of this TBL component may happen to stand beyond the one radiated by the engine. Nonetheless, due to its space-correlation characteristics, engine noise is propagated more efficiently inside the aircraft cabin and remains one of the main contributors in cruise for a significant part of current civil aircraft fleet. This yields a strong need to acquire instrumentation and post-processing means enabling the extraction of engine noise out of flow noise contributors.

Furthermore, as explained in §2.1, cabin noise evaluations require the prediction of the acoustic wave vector on the fuselage skin which, experimentally, can only be tackled with the use of a sufficient amount of appropriately chosen sensors in well-defined locations.

e) Summary

It is shown in paragraphs a) to d) that robust experimental engine noise characterization for cabin acoustics inevitably implies strong technical challenges and subsequent financial investment. Although it is clear that such efforts have to be sized with respect to target technology readiness levels at various program development stages, it is necessary to master some essential parameters to ensure that the outcome of the tests does not turn out to be misleading.

Subsection §2.3 describes how Airbus has undertaken the aeroacoustic evaluation of an open rotor equipped single aisle at the early stage of the aircraft viability assessment.
2.3 A dual (experimental numerical) approach for the prediction of engine noise in cruise at early aircraft development stage

In the frame of the feasibility assessment of a CROR-equipped single aisle aircraft, a project has been undertaken by Airbus with the objective to evaluate CROR-related cabin noise taking into account all aeroacoustic driving phenomena whilst minimizing time and cost efforts. The project involved a wind-tunnel test campaign aiming at characterizing the noise generated by a simplified installed powerplant system as well as a numerical simulation campaign allowing an acoustic projection to realistic geometrical and flight operating conditions.

a) Experimental characterization

The CROR test rig, Rig 145, was tested in ARA transonic wind-tunnel during September and October 2011. The tests were undertaken in a partnership between Rolls-Royce and Airbus. The two parts of the test involved an isolated open rotor configuration controlled by Rolls-Royce, and an installed configuration (with the addition of a pylon and a rear fuselage representation) controlled by Airbus. The main objective of the test was the characterization of the full set of aero-acoustic phenomena driving cabin noise (including complex engine-aircraft interactions) within limited means and time. During the installed test preparation, a number of compromises had to be met in order to fulfil most of the quality criteria presented in 2.2.: 
- **Wind-tunnel performances**: the treated 2.44*2.13m acoustic section of ARA transonic wind-tunnel was used allowing covering Mach numbers representative of take-off to cruise;
- **Propeller inflow representativeness**: as the size of the tunnel did not allow using a fully representative aircraft model, a fuselage panel representation was designed by Airbus in order to best reproduce the aerodynamic flow in the propeller vicinity whilst minimizing blockage effects. Figure 4 features the tested fuselage model equipped with a Rolls-Royce CROR engine.

![Figure 4](image-url)

**Figure 4** – Open rotor mounted on an instrumented fuselage panel as tested in ARA 2011 Rig 145 campaign

- **Blockage effects**: in addition to using a panel mock-up to reduce blockage, a pre-test CFD campaign was carried out allowing appropriate calibration of the wind-tunnel flow taking into account the presence of the fuselage thanks to a set of static pressure taps, as shown in Figure 5.

![Figure 5](image-url)

**Figure 5**: Reference CFD pressure; pressure taps on model; free-field versus wind-tunnel inflow
Figure 5 shows that a very satisfactory agreement is obtained between the free field reference propeller inflow and the calibrated wind-tunnel inflow.

- **Acoustic instrumentation and post-processing**: in addition to safety monitoring instruments and Rotating Shaft Balances, about 100 acoustic sensors were installed over the model in order to cover a 3D fuselage SPL directivity, to characterize the acoustic wave vector at well-chosen locations and to allow the use of post-processing techniques aiming at extracting engine noise from TBL noise.

Although not fully representative of a flying aircraft due to test means limitations, the present test campaign is believed to embed most of the physical phenomena of interest for the prediction of engine cabin noise in cruise. In order to minimize the uncertainties related to the experimental model representativeness, any remaining deviation between the test and a flying aircraft – fuselage geometry effects, Reynolds number and scale effects, thermodynamic conditions effects, etc – are covered in a second step by the use of numerical tools.

b) **From experimental data to numerical in-flight prediction: low frequency range**

As stated in §2.1, the high sensitivity of low frequency tonal noise transmission towards the cabin makes it necessary to provide a detailed aeroacoustic excitation as input to a cabin noise FEM model. As sketched in Figure 6, the relating prediction process is built upon a reference experimental campaign - such as the one described in a) - and can be detailed as follows:

i. A chorochronic URANS CFD coupled with a CAA propagation simulation is carried out on the tested isolated engine configuration;

ii. The numerical settings of the CFD/CAA computations are iteratively defined thanks to comparisons to test results and up to convergence with respect to key settings (see Ref. 1);

iii. Based on the defined numerical settings, a 3D CFD/CAA computation is carried out on the tested installed engine configuration;

iv. A detailed comparison between the results from iii. and the test results is carried out to allow a judgment on the accuracy of the numerical prediction. If needed, a refined computation may be launched to reach an acceptable accuracy level;

v. Based on the numerical settings resulting from iv., a 3D CFD-CAA computation is done on a fully representative aircraft flying in standard cruise conditions;

vi. The resulting amplitude and wave-vector distributions on the fuselage are fed in the FEM cabin noise simulation model to derive cabin noise levels.

![Figure 6: Low frequency tonal noise prediction](image-url)
c) From experimental data to numerical in-flight prediction: broadband noise and high frequency tonal noise

As stated in §2.1, the semi-empirical approach used to model the transmission of engine high frequency noise from the fuselage outer surface to the cabin is based on the assumption that for the considered sources and related frequency range - cabin noise is not sensitive to local details of the acoustic field impinging the fuselage. This makes it possible to carry out cabin noise simulations in a global manner – as opposed to the very detailed and local FEM prediction approach. In practice, aeroacoustic SPLs are directly derived from WTT data and projected to flight according to correct aircraft and flight conditions using either numerically or analytically defined corrections. The correction process involves:

i. Reynolds number effects at engine level due to the relative thickening of the propeller or pylon wake at small scale leading to an energy transfer from high to low frequencies;
ii. Blades and pylon boundary layer transition effects driving the frequency content and the energy of rotor-rotor and pylon-rotor interaction noise;
iii. Thermodynamic conditions corrections from wind-tunnel to flight;
iv. Aircraft boundary layer effects influencing the engine noise propagation towards the aircraft.

2.4 Summary

What is considered by Airbus to be key drivers for a successful prediction of engine noise impinging an aircraft in cruise was presented in the present section together with an overview of the experimental and numerical prediction means developed by Airbus accordingly. In the sequel, analyses of experimental and computational results are undertaken to assess the relevance of the proposed approach and the sensitivity of aeroacoustic predictions to key parameters.

3. RESULTS OF AERO-ACOUSTIC PREDICTIONS & SENSITIVITY ASSESSMENT

In the present section, experimental and numerical predictions are analyzed with respect to key aero-acoustic parameters and benchmarked in order to assess the relevance of the overall aero-acoustic prediction process.

3.1 Experimental results: blade design effects

The rig145 tests carried out at ARA allowed assessing the sensitivity of CROR noise in cruise to blade design. In Reference 2, Parry et al. compared the aeroacoustic behavior of two Rolls-Royce blade designs in isolated configuration: an original blade design referred to as design 1 and an aero-acoustically optimized design referred to as design 2.
Figure 7 shows measured Near-Field-Noise (NFN) isolated blade design effects for the front rotor BPF (low frequency) and its third harmonic (medium frequency), both designs operating at their cruise nominal conditions. The noise differences displayed in Figure 7 are based on the maximum SPLs measured in the vicinity of the propeller planes.

![Figure 7: Measured noise reduction from Rolls-Royce original blade design 1 to optimized design 2 (front rotor BPF and third harmonic)](image)

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Figure 7 shows tremendous blade design effects reaching more than 10dB for the front rotor BPF and more than 35dB for its third harmonic.

3.2 Experimental results: aerodynamic installation effects

The two Rolls-Royce blade designs presented in §3.1 were compared in semi-installed configuration, i.e. installed behind a pylon with no fuselage model included. Figure 8 shows how different the impact of blade design is when switching from an isolated engine to an installed engine.

For the front rotor BPF, the measured noise reduction of 10dB for an isolated engine is reduced down to 6dB due to the presence of the pylon while the 35dB improvement measured in isolated configuration is drastically reduced to 2dB with a pylon in place.

The present results demonstrate the criticality of propeller inflows accuracy and highlight the need for harmonized installed engine design processes involving aircraft and engine manufacturers.

3.3 Experimental results: acoustic installation effects

In this subsection, the sensitivity of engine noise to its propagation flow field in cruise conditions is assessed. Figure 9 displays the directivity measured for the third front rotor BPF harmonic during rig 145 tests for 3 model configurations: an isolated engine in light blue, an engine installed behind a pylon in dark blue and an engine installed on the fuselage panel behind a pylon in red.

Note that in the figure 9, all curves are corrected from pressure doubling effects on instrumented surfaces.

The difference between isolated and semi-installed results clearly demonstrates that the dominant
source for the design 2 – which was optimized as an isolated engine - is related to pylon-rotor aerodynamic interaction effects which are expected to remain unchanged when a fuselage is added. Consequently, the measured differences – more than 10 dB in the forward sections of the fuselage - characterize the impact of the flow gradients induced by the presence of the fuselage in the acoustic propagation towards the fuselage skin.

In addition to the criticality of aerodynamic installation effects addressed in §3.2, this subsection highlights tremendous acoustic installation effects occurring through the modification of the propagation flow by the presence of the fuselage.

In §3.4, the capabilities of Airbus aeroacoustic prediction tools with regards to aerodynamic and acoustic installation effects are assessed.

3.4 Numerical account for full aircraft configurations and assessment against measurements

As explained in §2, numerical aeroacoustic simulation is an essential mean for robust engine cabin noise prediction for two reasons:
- The local behavior of the fuselage aeroacoustic excitation over several thousand locations is a driver to the FEM prediction of tonal noise transmission towards the cabin;
- Numerical simulation is needed to correct for deviations between WTT and flight tests.

In this sub-section, the impact of the fidelity of CFD/CAA numerical models on the quality of the noise predictions is assessed using a step-by step approach thanks to comparisons with WTT data. Reference WTT data are those resulting from the installed measurements carried out in the frame of Rig 145 tests in 2011 (see Figure 4).

a) SPL prediction

The results from three different numerical prediction processes of increasing level of maturity are displayed in Figure 10 and compared to reference WTT data:

i. A chorochronic URANS computation of an isolated engine is carried and coupled to a Fowcs Williams Hawkings propagation solver. In this approach the propeller is assumed to “see” an axisymmetric inflow and the propagation field is assumed homogeneous. The acoustic results are corrected by a 6dB SPL increase to account for pressure doubling on a virtual fuselage and are displayed in blue color in Figure 10;

ii. A 3D URANS computation taking into account the aerodynamic effect of the aircraft on the engine sources is undertaken as a second step. The resulting sources are propagated towards the fuselage assuming a uniform propagation flow but taking into account the reflecting effect of the fuselage solid boundaries. The results are plotted in red color in Figure 10;

iii. Finally, the thorough source model described in ii. is propagated towards the aircraft taking into account pressure gradients induced by the fuselage and the reflecting behavior of the fuselage solid boundaries. The results are plotted in green color in Figure 10.

Three frequencies are considered: the front rotor BPF, the first rotor-rotor interaction tone and the third harmonic of the front rotor BPF.

The results are displayed as polar directivities over axial fuselage lines. Due to the very interferential character of an installed tonal noise source, the simulated results are not extracted from a single line but from 10 parallel lines spaced by 3mm which leads to a maximum scattering of about 2dBs. For all plotted cases, a significant sensitivity to the fidelity of the numerical model is exhibited. As expected, a good match with reference data can only be achieved by a proper account for all aerodynamic and acoustic interaction phenomena occurring between the aircraft and the engine.

Furthermore, the agreement between the full computations plotted in green and the reference test data is very satisfactory and demonstrates the potential of numerical means for the aero-acoustic design and prediction of integrated engines.
b) Wave vector prediction

In addition to the assessment of SPL predictions presented in a), a small study was undertaken to evaluate the ability of numerical tools for the prediction of aeroacoustic wave-vectors on the fuselage. Figure 11 displays axial wavelength directivities for the front rotor BPF. The following data are compared:

- Cyan: measured NFN wavelength directivity for the installed configuration;
- Red: repeat of the measured wavelength directivity for the installed configuration;
- Green: computation of the tested configuration using a full CFD/CAA calculation;
- Black: computation of the tested configuration using a full CFD/CAA calculation with a refined microphone grid in order to check the relevancy of the sensors spacing set in wind-tunnel.

The features exhibited in Figure 11 show a rather good agreement between all compared configurations, proving that state-of-the-art numerical tools have good capability for the prediction of local space dynamics of engine noise on the fuselage skin for frequencies of the order of magnitude of the first BPF. Nonetheless, it can be seen that very local discrepancies inevitably occur between simulations and experiments due to the interferential behavior of tonal engine noise. The sensitivity of cabin noise to such variations is currently under investigation. Furthermore, a validation at higher frequencies is currently undergoing thanks to a recent WTT with enhanced acoustic instrumentation.
4. **SENSITIVITY OF CABIN NOISE TO AERO-ACOUSTIC EXCITATIONS**

The capability of state of the art numerical tools for the prediction of engine noise on the fuselage skin was presented in §3, highlighting high aeroacoustic sensitivity to aircraft integration. The present section aims at providing examples of the sensitivity of interior noise levels to the fidelity of aeroacoustic predictions feeding FE cabin noise models. Assuming that for a given frequency and a given trace-wavelength on the fuselage, interior engine noise levels vary as a linear function of exterior engine noise levels, the aeroacoustic results presented in §3 are self-explaining in terms of interior noise sensitivity to SPL aeroacoustic modeling. However, the sensitivity of interior noise to the space dynamics of the aeroacoustic field exciting the fuselage requires further attention.

In Figure 12, a dummy test case allowing appraising such sensitivity is built. A generic cylindrical fuselage section is excited with three different aeroacoustic signals under the following assumptions:

- The signals are generated analytically assuming free field and isolated engine conditions;
- The considered frequency is close to a usual CROR BPF;
- The three aeroacoustic signals have strictly the same SPL distribution over the fuselage;
- The axial wave vectors of excitations b) and c) are changed with respect to the reference a) in order to virtually model the effect of a different engine position or operating condition.

![Figure 12: Sensitivity of cabin noise to the aeroacoustic space dynamics on the fuselage skin; a), b) and c) cases excited with same aeroacoustic SPL distribution.](image)

FEM computed cabin noise levels feature up to a 20dB difference between case a) and case c), both cases being representative of realistic operating conditions. Straightforward Fourier transforms allow establishing a clear link between the acoustic levels computed inside the cabin and the bending wavelength of the fuselage. Such results clearly highlight the necessity to consider the structural properties of the aircraft and the efficiency of the coupling between the structure and its aeroacoustic excitation when running a propeller aero-acoustic design optimization targeting cabin noise.

For fully integrated engines, the sensitivity of cabin noise to the impinging aeroacoustic space dynamics turns out to be even more complex. Figure 13 features aeroacoustic phase distributions on the fuselage resulting from numerical computations in free-field and installed configurations together with the resulting impact on cabin noise for a rotor-rotor interaction frequency of 350Hz. It shows as expected that acoustic installation effects induced by the presence of the aircraft have a strong impact on the aeroacoustic phase distribution on the fuselage and consequently on resulting cabin noise levels.

The results displayed in the present section open a room for further investigations on the characterization of aero-vibro-acoustic coupling phenomena at aircraft structure level. In particular, significant efforts are currently being invested at Airbus to thoroughly validate vibro-acoustic models for the prediction of engine cabin noise and to define installed design cost functions allowing engine
design-to-cabin noise taking into account the complexity of aero-vibro-acoustic physical phenomena.

Figure 13: Sensitivity of aeroacoustic phase to installation and resulting impact on cabin noise.

5. CONCLUSION AND WAY FORWARD

An end-to-end engine cabin noise prediction process involving numerical and experimental aero-vibro-acoustic means was presented with an emphasis on the essential parameters and physical phenomena to be taken into account for a robust engine cabin noise prediction in cruise. It was shown that the account for integration aspects as aerodynamic installation effects, acoustic installation effects and noise-to-structure coupling were crucial for successful acoustic engine design. Such observations together with the trend towards stronger engine-aircraft interaction in the coming years leads to a need for close cooperation between aircraft and engine manufacturers as initiated in the frame of CROR and UHBR (Ultra High ByPass Ratio) technologies development.

In order to ease future collaborative work, Airbus is currently heavily involved in investigations aiming at defining relevant aeroacoustic design criteria embedding vibro-acoustic considerations. Two main axes are being developed accordingly:
- Enhancement and validation of vibro-acoustic modeling means: in the frame of a Lufo 4 funded project, a full scale fuselage demonstrator equipped with a loudspeaker system representing engine acoustic excitations have been developed in order to characterize the transmission of engine noise from the fuselage to the cabin and validate related prediction tools (Ref.3);
- Definition of simple cabin noise design criteria to be shared with engine manufacturers: a statistical condensation approach based on the U-vectors from Singular Value Decomposition is being developed to reduce the complex aeroacoustic information driving cabin noise to a limited set of scalar numbers. This approach will be used as a mean to set installed engine acoustic cost function allowing clear and efficient way of working between Airbus and engine manufacturers.

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