Correlation of transmission loss of simple representative sidewall to full scale fuselage demonstrator

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Introduction

Recent developments in advanced material technology such as acoustic metamaterials seem to have potential to replace the traditional glass wool technology for thermal and acoustic insulation in aerospace vehicles. However, due to inherent challenges to derive material properties of metamaterials, small scale measurements to predict vibroacoustic response of material sample are favorable and cost effective. This paper discusses such small scale vibroacoustic measurements to predict transmission loss using p-u probe [1]. A test bench to represent the double wall cavity as seen in a typical aircraft is developed and sound transmission tests are performed using p-u probe in-house and a p-p probe at acoustic lab of Hamburg University of Applied Sciences (HAW). A measurement methodology is being developed to first correlate p-u measurement in alpha chamber and p-p measurement in a full-scale test facility. Subsequently, the goal of this work is to develop correlation between simple transmission loss (or insertion loss) test using p-u probe to full scale A320 type simplified fuselage located in acoustic flight lab of ZAL. Furthermore, numerical simulation using finite element method in Actran will be performed to complement the efforts to develop the correlation methodology between small scale and large-scale measurements.

Development of Double Wall Cavity

Aircraft fuselage structures combined with cabin side wall components are a typical leaf partitions [2] which has been investigated significantly in the literature. For an efficient noise control concept development for current as well as future aircraft, it is extremely useful to have a simplified representation of aircraft double wall where advanced noise control concept can be investigated at an early design phase of the development process for a new cabin type or for a completely new aircraft architecture. To address this challenge, the authors have developed a double wall cavity which is an engineering representation of the double wall cavity as seen in a single aisle aircraft side wall near window area. The developed double wall cavity installed in alpha cabin can be seen in Figure 1. The wall facing towards the alpha cabin interior is of aircraft grade aluminum and the wall facing to exterior is of honeycomb sandwich material as used in the sidewall of AIRBUS single aisle aircraft. The cavity depth between two wall can be varied and adapted to the various region of an aircraft side wall.

Transmission Loss (TL) Measurement

Transmission loss characteristic of double wall configuration is one of the most resorted vibroacoustic parameters widely used in assessing the acoustic environment of the cabin of an automobile, ship or an aircraft. The current study addresses the sound transmission loss of a double wall cavity for aircraft cabin. However, findings of this work can be applied to any double wall scenarios similar to aircraft double wall concept. Transmission loss discussed in this work is is measured as per ISO 151861:2000 [3] and can be computed using the following simplified formulation in Equation 1 when the measurement area is same as the area subjected to acoustic diffuse field.

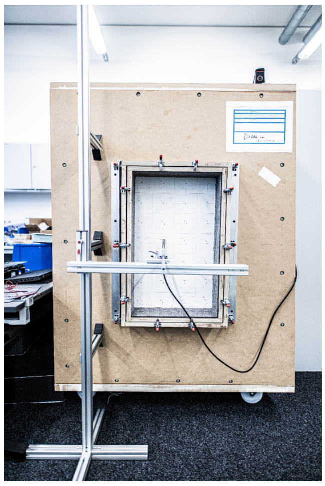

Figure 1: Alpha cabin with attached double wall cavity at ZAL Acoustics and Vibration Lab.

$$TL(dB) = L_p - L_I - 6 \quad (1)$$

Where, L_p is average sound pressure level in dB in reverberation room. L_I is radiated sound intensity level by the second wall of the double wall configuration either in semi-unechoic room or to the exterior in case of alpha cabin measurement. The average sound pressure level, L_p, is measured inside alpha cabin using two microphones placed randomly and the radiated sound intensity is measured using p-u probe on the radiating side facing outside of the alpha cabin. The usage of p-u instead of p-p probe makes it possible to measure radiated intensity in a noisy environment [4].

Small Scale Test at Alpha Cabin and HAW

Four loudspeakers and two diffusers are used inside the alpha cabin for generating semi-diffuse field which is subjected on to aluminum panel of the double wall configuration. The radiated sound power is computed using p-u probe on the second wall of the double wall model facing to exterior domain. Figure 2 shows the measurement grid used to compute radiated sound intensity using p-u probe. The measurement grid is generated by dividing the whole measurement surface into 28 rectangular sub-surfaces with p-u probe located at the center of these rectangles. The radiated intensities are measured at these 28 points to compute the total radiated sound power. This radiated sound power is then used to compute the average intensity level, L_I to compute the sound transmission loss using Equation 1.

Transmission loss tests are also performed at HAW using the same double wall as used in alpha cabin. However, an adapter is developed to fit the alpha cabin double wall into the transmission loss window at HAW. The measurement setup for TL test at HAW is shown in Figure 3. The comparison of both transmission loss measurements show an encouraging match and thus builds confidence in simplified transmission loss measurements performed in alpha cabin using p-u probe. To build further confidence in TL measurements, both TL test results are also compared with transfer matrix method (TMM) [5] applied to double leaf partition with finite size correction. All three TL results as shown in Figure 4 show good agreement and are encouraging for the development of correlation of TL test from alpha cabin to full scale demonstrator. The following subsection addresses the transmission loss type test (i.e., noise reduction) in a full scale demonstrator under random acoustic field.

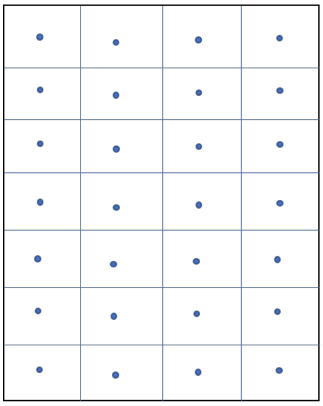

Figure 2: Measurement grid for radiated sound power computation using p-u probe

Noise Reduction Test at Acoustic Flight Lab

This subsection addresses the noise reduction tests performed in a full scale A320 type fuselage demonstrator located in acoustic flight lab at ZAL. Random acoustic loads are generated using array of loudspeakers on the outside as shown in Figure 6. The sound radiation measurements are performed inside the cabin using p-u probe scanning the Fomalux sidewall of the cabin (see Figure 6). Fomalux sidewall is used as it is light weight and flexible to adapt to the curved surface of the fuselage. The material properties of aluminum and Fomalux foam PVC sheet used as the flexible cabin wall mounted on the curved fuselage wall are shown in Table 1. The comparison of TL test result with noise reduction type test in acoustic flight lab is shown in Figure 7 and it can be seen

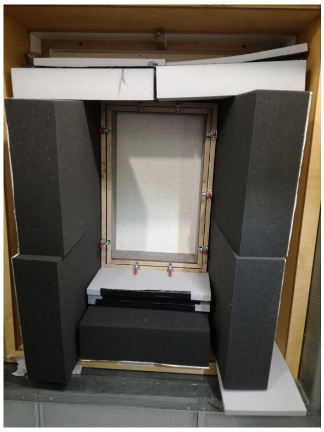

Figure 3: TL test set-up at HAW.

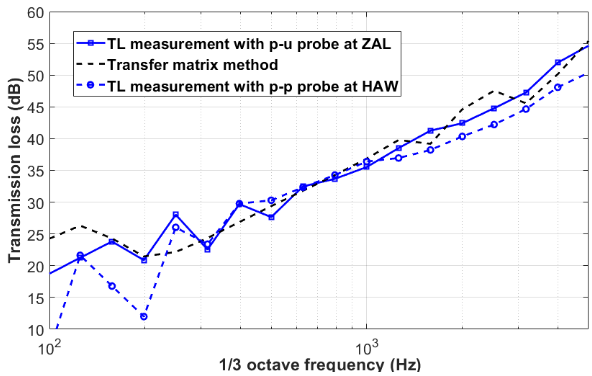

Figure 4: Comparison of transmission loss test results at HAW and ZAL; transfer matrix method (TMM) is used as a reference.

that there is a strong mismatch between alpha cabin test and acoustic flight lab measurement. There are many phenomena and parameters (e.g., structure-borne versus air-borne noise, global versus local fuselage response, boundary conditions, damping, etc.) which can be the potential reason for such strong mismatch. However, at very high frequencies where air borne noise through fuselage skin pockets start to have dominance, it can be seen that the two measurements start to show a good match. The good correlation at very high frequencies shows that there is a potential where correction terms can be derived to capture global structural dynamic response in a local simplified component measurements in alpha cabin or in transmission loss window. Considering the flexibility in modeling large scale structure, finite element analysis is considered to develop such correlation. The following subsection addresses the finite element based modeling and analysis of double leaf partitions.

Finite Element Analysis of Double Wall

Numerical studies using finite element method come handy in addressing complexities involved in correlating small scale measurement results to full scale test in an aircraft demonstrator. Therefore, finite element model of the double wall cavity for alpha cabin is developed and fully coupled fluid-structure interaction analysis is performed with acoustic diffuse field as the source of ex-

Figure 5: Location of array of loudspeakers on fuselage used for random acoustic excitation on external fuselage skin

Figure 6: Installed sidewall panel inside the acoustic flight lab demonstrator for Transmission loss type (i.e. noise reduction) test under random acoustic loads.

citation to primary structure. In finite element analysis context, following system of algebraic equations are solved in finite element based software Actran [6] and displacement and acoustic pressure vectors are computed for structure and fluid component, respectively.

$$\begin{bmatrix} K_s + i\omega C_s - \omega^2 M_s & D \\ \omega^2 D^T & K_a + i\omega C_a - \omega^2 M_a \end{bmatrix} \begin{pmatrix} u(\omega) \\ p(\omega) \end{pmatrix} = \begin{pmatrix} f_s(\omega) \\ f_a(\omega) \end{pmatrix} \quad (2)$$

Table 1: Material properties of the double wall material

Type	Parameter		
	Modulus of elasticity (E), GPa	Density (ρ),kg/m^3	Poisson's ratio
Aluminum	71.0	2810	0.33
Fomalux PVC foam	3.38	482.8	0.32

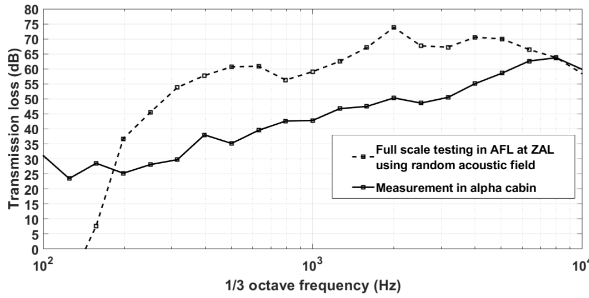

Figure 7: Comparison of transmission loss type quantity (i.e. noise reduction) measured at Acoustic Flight Lab in ZAL to TL measurement in Alpha cabin.

Where, K_s, M_s and C_s are structural stiffness, mass and damping matrices, respectively. Whereas, K_a, M_a and C_a are acoustic stiffness, mass and damping matrices, respectively. In Equation 2, the coupling between fluid and structure is given by the coupling matrix,D. The load vector on structure is represented by f_s and the acoustic load vector is given by f_a. The structural displacement vector, u and acoustic pressure vector,p are the set of structural and acoustic unknowns which are obtained by solving Equation 2, respectively. Figure 8 shows the finite element model of the double wall cavity as shown in Figure 1 Fully coupled fluid-structure interaction analysis is

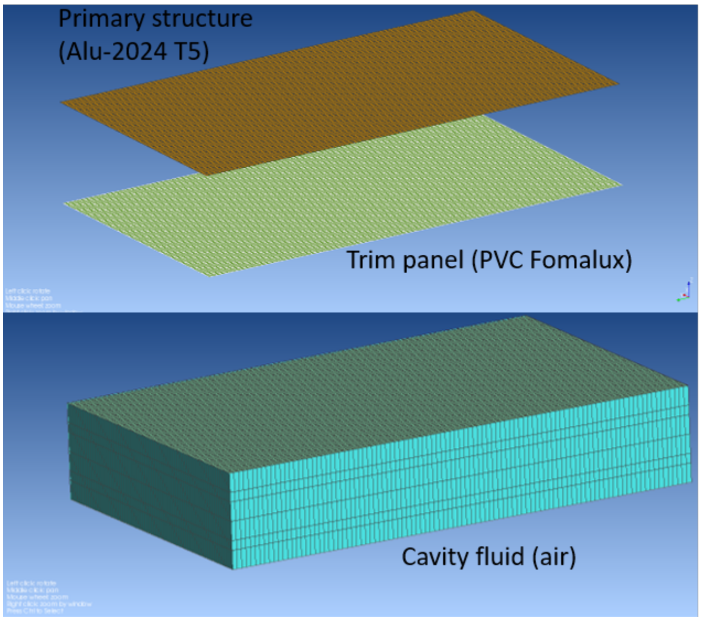

Figure 8: Finite element model for fully coupled fluid-structure interaction analysis of double wall subjected to acoustic diffuse field; Top: fuselage side wall ($0.40m \times 0.66m \times 0.0015m$) and trim panel ($0.40m \times 0.66m \times 0.003m$); bottom: the cavity ($0.40m \times 0.66m \times 0.125m$) fluid between fuselage and trim panels.

performed using developed finite element model of double wall. Due to higher computational burden of finite element analysis, a frequency range from 50 Hz to 1000 Hz with 1.0 Hz step is selected for the numerical studies

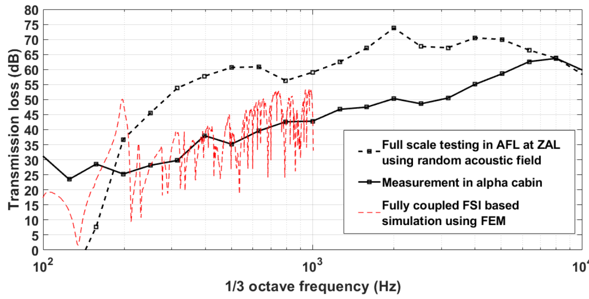

Figure 9: Comparison of transmission loss type quantity (i.e. noise reduction) measured at Acoustic Flight Lab in ZAL to TL measurement in Alpha cabin.

addressed in this subsection. The primary structure side of the Finite element model is subjected to acoustic diffuse field and radiated sound power is computed for the trim panel using Rayleigh surface approach [7] for planar structure. Figure 9 compares the TL results based on finite element analysis to the TL measurement performed at alpha cabin. The finite element based TL result shows qualitatively good agreement with TL measurements in alpha cabin. Further investigations are ongoing to measure right input parameter for finite element model which will lead to a quantitative estimate of transmission loss. Once quantitatively validated, the current finite element based TL prediction will complement the TL measurement results in deriving appropriate correlation methodology to have a reliable prediction for aircraft level without conducting a full scale measurement at demonstrator or aircraft level.

Conclusion

A representative but simple double wall test setup as observed in the side wall of a single aisle aircraft is developed. A reliable but simplified approach for transmission loss measurement using p-u probe in alpha cabin is also developed. To validate the developed approach for double wall TL measurement using p-u probe in alpha cabin, initial validation TL tests are performed at HAW using p-p probe and the same double wall cavity as used in alpha cabin. The comparison of TL test results in alpha cabin to the TL measured at HAW show encouraging agreement. Additionally, the TL computed using transfer matrix method is also shows a very good agreement with both TL tests in alpha cabin at ZAL and the acoustic lab at HAW, respectively. The developed TL measurement approach using alpha cabin is then used to capture the correlation with noise reduction in a full scale aircraft demonstrator subjected to random acoustic noise. The preliminary comparison of transmission loss/noise reduction show the inherent complexities in developing such correlation between vibroacoustic measurements at component and demonstrator levels. Finite element based fully coupled fluid-structure interaction analysis of double wall cavity is also performed for TL prediction. The finite element based TL results from 100.0 Hz to 1000.0 Hz show good qualitative agreement with the TL measurement in alpha cabin.

Future Work

In near future, we will derive correlation approaches which can be used to extrapolate component level vibroacoustic measurements to full scale demonstrator level. The developed correlation methodology will be validated on industry relevant use cases for vibroacoustic testing. Furthermore, FEM based numerical approaches will be used to compliment the measurement based method for transposition of component level test in alpha cabin to full scale demonstrator.

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