Influence of VIP floor setups on noise reduction in aircraft cabin

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Introduction

In today's VIP aircraft, high demands are placed on acoustic comfort compared to standard aircraft, while the sound absorption is lower than in standard cabin layouts with many seats and passengers. For this reason, a larger mass of noise control components is used in the VIP cabin to reduce cabin noise. However, this additional weight means that more fuel is consumed, which affects the efficiency of the aircraft. The joint project ENTIRETY (Engineered TailoREd TranquilitY) aims to develop technologies to reduce noise levels in VIP cabins while reducing the overall weight of the cabin. The LuFo-Project ENTIRETY is funded by Bundesministerium für Wirtschaft und Klimaschutz. The main goals of the projects are:

- Identification and quantification of airborne and structure borne sound transfer paths in VIP aircraft cabins, which have been insufficiently researched to date
- Development of optimized sound reduction concepts for cabin components that are particularly critical for noise transfer
- Doing away with "heavy construction" in noise reduction
- Experimental validation of the concepts in a realistic environment
- Learning and developing from the VIP cabin what also works in serial production of standard aircraft

As part of this project, the measurements campaigns [1] [2] were carried out in the HCAT (Hamburg Centre of Aviation Training), where the cabin of Airbus A320 segment is located in the acoustic chamber. The primary focus of these measurement campaigns was to assess the overall sound power entering the cabin and to identify dominant sound paths by analysing the percentage contributions of individual paths to the total sound power level. To achieve this, the aircraft fuselage was divided into 13 segments, as shown in Figure 1. Additionally, octave bands at 1000 Hz, 2000 Hz, and 4000 Hz were calculated from third-octave bands (as illustrated in Figure 2) to evaluate the dominant sound paths. These octave bands play a critical role in determining the SIL (Speech Interference Level) rated sound pressure level, commonly used to specify sound pressure levels in VIP aircraft. It is clearly visible in Figure 2, segments such as the outboard floor panel consistently demonstrated significant contributions, irrespective of frequency, while lower and upper sidewall panels also emerged as dominant sound paths.

Since the outboard floor panel was identified as a significant contributor to cabin noise levels, implementing preventive

Segment/Panel	Größe [m²]
1. Floor Panel Inboard	0,53
2. Floor Panel Middle	0,53
3. Floor Panel Outboard	0,47
4. Dado Gap	0,06
5. Dado Panel	0,42
6. Lower Sidewall Panel	0,55
7. Window (-Panel)	0,20
8. Upper Sidewall Panel	0,55
9. ECS Gap	0,03
10. Closure Panel	0,42
11. Service Area Panel	0,41
12. Ceiling ECS Gap	0,05
13. Ceiling	0,53

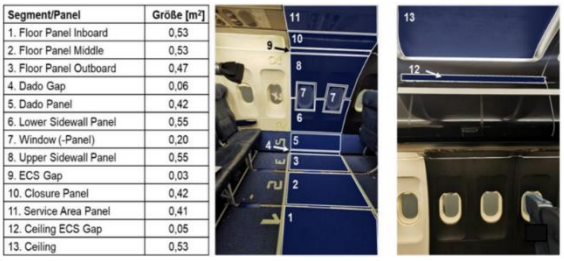

***Figure 1** : Defined segments of the measuring surface[1].*

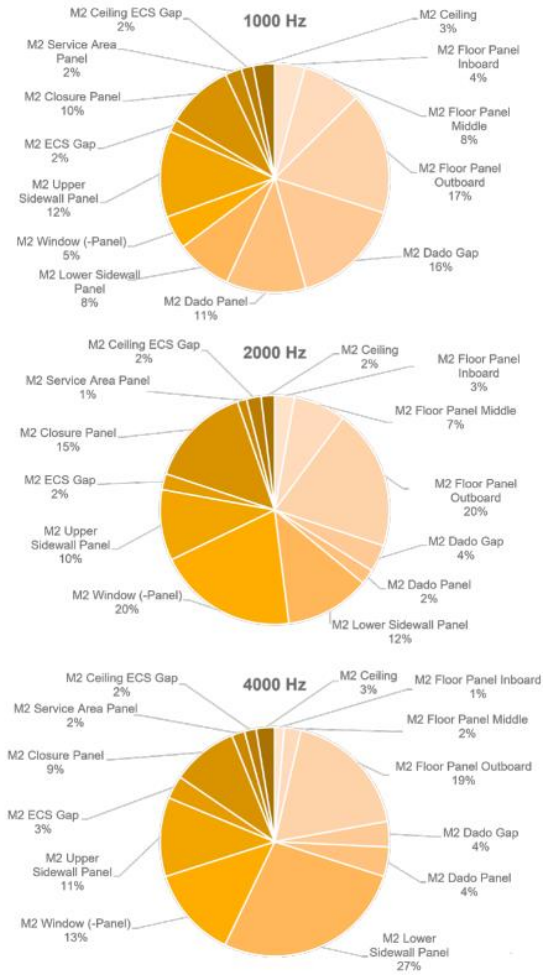

***Figure 2** : Sound power contributions for three third-octave bands[1].*

measures such as sound absorption materials becomes crucial. This research presents deeper into the impact of various floor carpet setups on cabin sound levels. The measurement campaigns were conducted at HCAT with 10 different carpet setups such as different VIP carpet with foam layer and VIP

carpet with mass layer as well as foam layer. In the measurement, the sound intensity and overall sound pressure of the cabin were measured for the different carpet configurations. The results of this study will make it easier to choose carpet setup in VIP cabins that are both lightweight and reduce the sound level in the cabin.

Measurement setup

Excitation in acoustic climate camber (Klima-Akustik-Kammer) of HCAT

Excitation was generated by three octahedral loudspeakers within the acoustic climate chamber, as shown in Figure 3. The loudspeakers were mounted on stands at different heights on one side of the aircraft fuselage in order to generate as homogeneous and diffuse sound field as possible on the reference side chosen for the investigations. This sound field was investigated by measuring the sound pressure level at a distance of 10 cm from the aircraft fuselage at different heights. The sound pressure level was also measured on the side of the aircraft fuselage opposite the loudspeakers and at various positions in the cabin.

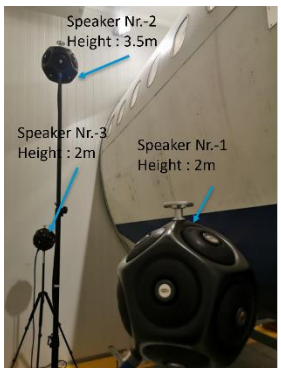

Figure 3 *:Excitation in acoustic chamber with three loud speaker.*

Slightly different levels on the left and right side in the acoustic climate chamber also led to correspondingly different levels on both sides in the cabin, as illustrated in the Figure 4. Because the excitation was only applied to the side of interest to reduce reflections in the cabin for sound intensity measurements. However, it was found that the differences between the two sides were minimal. Unwanted reflections in the cabin were not desirable for the intensity measurements and had to be further minimized by other measurements such as an intensity box.

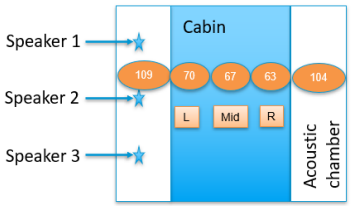

Figure 4 *: Sound pressure distribution in the cabin and acoustic chamber of HCAT.*

Different carpet setups with measurement type

The basis of all aircraft floors is the standard floor panel, which can be found in every aircraft, whether it is a VIP cabin or not. Therefore, the standard floor panel of the A320 classic cabin was analysed in this study. In this measurement, 10 different carpet setups with the VIP carpets (Cutpile and Looppile) and standard carpets with different combinations of mass layers and with more absorbent material such as foam were used, and the sound intensity and sound pressure in the cabin were measured. Table 1 shows different carpets setups with their weight. As the outboard floor panel and the middle floor panel are the main sound source for the cabin, all carpet setups are tested on these two floor panels.

Nr.	Carpet setup	Weight (kg/sqm)
1	Standard carpet	5.7
2	Only Panel	3.7
3	Cutpile carpet	8.7
4	Looppile carpet	8.7
5	Cutpile carpet + Foam with cover fabric	10.2
6	Looppile carpet + Foam with cover fabric	10.2
7	One layer mass	5.5
8	One layer mass + Cutpile carpet + Foam with cover fabric	12.0
9	Two layer mass	7.3
10	Two layer mass + Cutpile carpet + Foam with cover fabric	13.8

Table 1*: Different carpet setups with weight.*

Measurement procedure

1. **Sound intensity measurement** : According to the standard regulations, noise insulation must be used if there is a high level of ambient noise in the measurement environment. As this is particularly the case during measurement, a device called an "Intensity box" was built that can be placed on the segment to be measured. It has internal dimensions of 40 cm x 25 cm and consists of commercially available sandwich panels covered on the outside with semi-felt and on the inside with 40 mm thick open-cell foam (material: Basotect®). The intensity probe is inserted into the intensity box through a split, which is closed with a flexible cell foam seal. This split makes it possible to take a sample along a defined path. As can be seen in Figure 5, the sound intensity has been measured for all the carpet setups on the outboard floor panel and middle floor panel. The sound intensity was measured for 15 seconds by moving the intensity probe inside the box at a constant speed from one end of the split to the other.

Figure 5 *: Sound intensity measurement on standard carpet.*

2. **Overall sound pressure measurement** was conducted for all carpet setups in the absorption cave (bear cave), as depicted in Figure 6, to assess their influence on the overall sound pressure within the cabin. An absorption cave is built from the foam(Basotect®), with the assumption that the rest of the cabin except for the input paths is absorbing. The microphone with hand-held analyser is

Figure 6 *: Sound pressure measurement in Bear cave on panel without carpet.*

mounted on the stand at the height of the passenger's ear, and sound pressure was measured in bear cave for 15 seconds.

Results and Discussion

Sound intensity measurement

In this research sound interference level 3 (SIL3) is used for the analysis, because it is commonly used to specify sound pressure levels in VIP aircraft[1]. SIL3 measures the extent to which a certain noise spectrum can interfere with or disrupt clear voice communication[3]. SIL3 is derived as the arithmetic mean of three octave bands 1000, 2000, and 4000 Hz within their respective third-octave bands. Figure 7 illustrates the SIL3 levels for different carpets on the outboard floor. Both VIP carpets have almost equal sound reduction on the floor. In addition, the VIP carpet in combination with foam has almost identical SIL3 values. It can be clearly seen that *2*Mass layer + Cutpile carpet + Foam with fabric cover* has the lowest SIL3 value. Taking the *only panel* as a reference, the sound reduction is around 21dB. However, this combination is not so optimal in terms of sound insulation and weight on the floor. Plotting the SIL3 against the weight (kg/sqm) in Figure 8, it is clear to see that Cutpile and Looppile carpet with foam has reduced sound in the cabin and also has a lower weight per square meter, while adding the extra mass is not as effective. It can also be observed that the SIL3 value decreases with increasing mass.

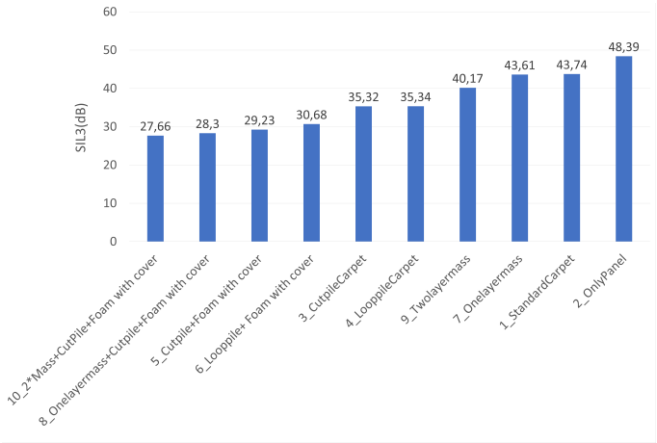

***Figure 7**: Sound intensity at outboard panel.*

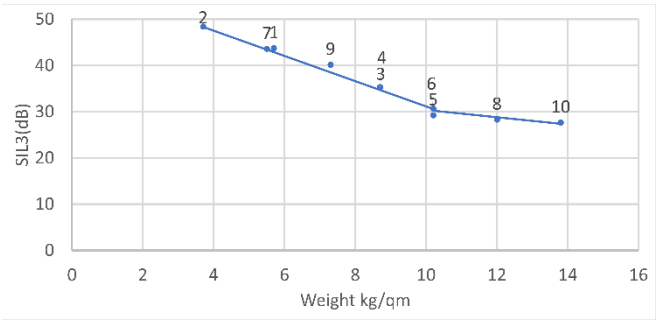

***Figure 8** : Relationship between SIL3 and Weight of different carpet setups on outboard panel.*

Analysing the SIL3 values for various carpet setups on the middle panel depicted in Figure 9 shows that *2*Mass layer + Cutpile carpet + Foam with fabric cover* has the lowest SIL3 level, which is 18 dB with reference to *only panel*. When looking at the SIL3 values of the Cutpile and Looppile carpet setups, discrepancies are found. This discrepancy is due to measurement errors; in particular, the Cutpile carpet and Looppile carpet have a higher Pressure-Intensity (PI) index at higher frequencies. Figure 10 illustrates also that the VIP carpet in combination with foam achieves optimum sound insulation at an optimum weight.

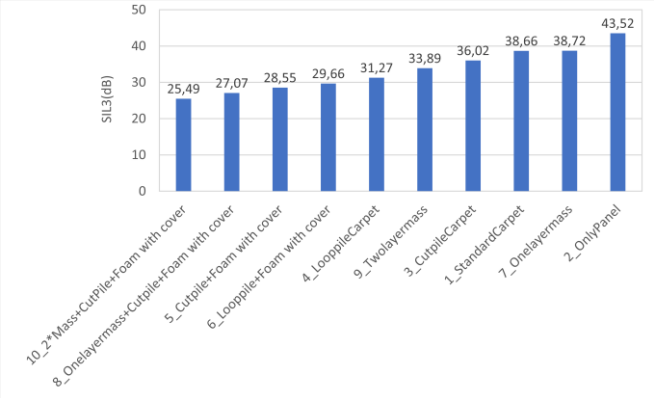

***Figure 9** : Sound intensity at middle panel.*

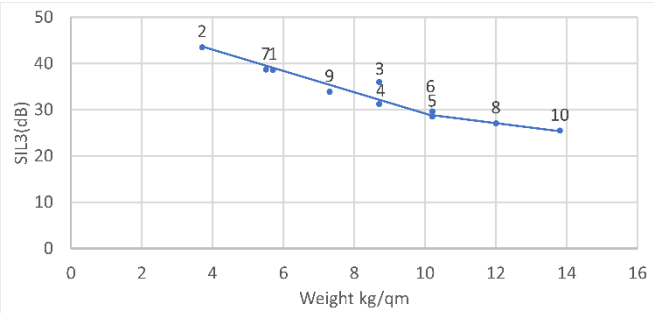

***Figure 10** : Relationship between SIL3 and Weight of different carpet setups on middle panel.*

Overall sound pressure measurement

The Figure 11 presents that the octave bands for the overall sound pressure measurement for the different carpet setups. It can be distinctly seen that the sound pressure levels in the bear cave are almost the same across all octave bands for all carpet setups. The sound pressure difference between the heaviest

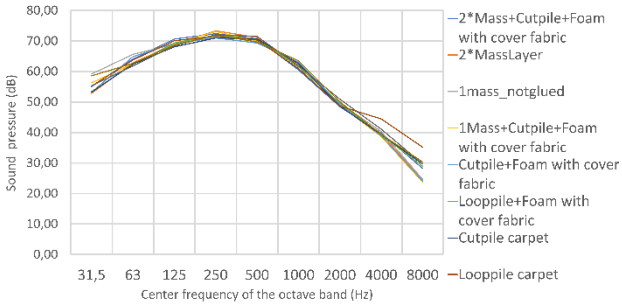

***Figure 11** : Octave band of overall sound pressure in cabin for different carpet setups.*

carpet and the only panel is 1.77 dB, as depicted in Figure 12. This is because many sound transmission paths contribute to cabin noise and the large effect cannot be observed if preventive measures are only taken for one sound

transmission path. Therefore, to observe the overall effect on sound pressure, preventive measures for all sound transmission paths in the cabin need to be taken. Also, an assumption of absorption in the absorption cave was too

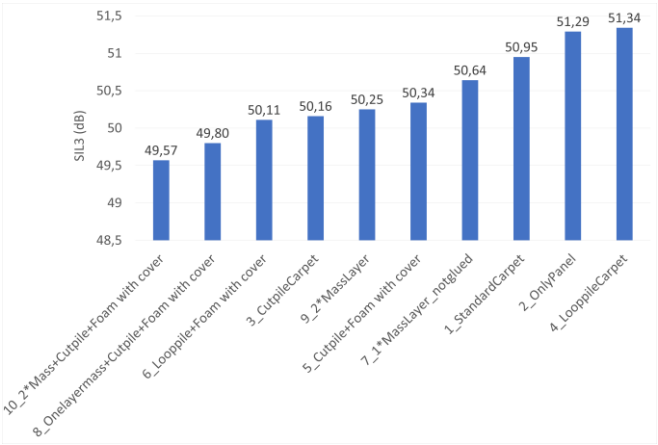

***Figure 12** : Overall sound pressure in cabin for different carpet setups.*

conservative for a real cabin with many reflections, where slight increases in sound contribution have a larger effect than studied.

Limitation of measurement

During the measurement, the intensity box was used to measure the sound intensity. Ideally, the intensity box should not change the sound field measured by the box. But in reality, the box distorts the sound intensity. To check how good the intensity box is, a measurement campaign was carried out in the laboratory of the Research and Transfer Centre for Technical Acoustics (FTZ-Akustik) at HAW Hamburg. The point sound source was placed in the free-field room and the sound intensity was measured as shown in Figure 13. The sound intensity was then measured in the box, which was located in the same place where the sound intensity was previously measured without the box. As can be derived from the Figure 14, the sound

***Figure 13** : Sound intensity measured without box in free field room of FTZ -Akustik laboratory.*

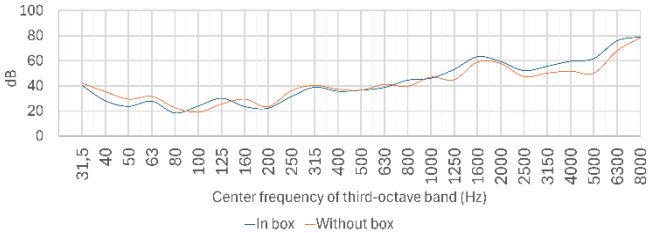

***Figure 14** : Measured sound intensity in the box and without box in free field room.*

intensity in the SIL3 area is about 5 dB higher with the box, so that some reflection in the box is expected.

In addition, the intensity box should have a higher transmission loss of the ambient sound so that it cannot be influenced by the ambient noise. To check the transmission loss of the intensity box, the box was placed in the reverberation room of the FTZ-Akustik laboratory, where the sound pressure outside and inside the box was measured. It was found that the transmission loss in the SIL3 range was around 25dB. As a result, the measured sound intensity on carpet setups might be lower, as the ambient noise could influence the quality of the measurement results at lower sound intensities.

Conclusion

The sound intensity and the overall sound pressure was measured for different carpet setups on floor, by generating the sound excitation at the outer surface of the A320 segment. As the mass on the floor is increased the sound insulation increased. By investigating different carpet setups, it is possible to choose between different carpet alternatives such as standard, VIP carpet and carpet with different combination of mass layer and foam for a specific sound pressure reduction. However, the overall sound pressure levels in the bear cave are almost the same for all setups despite the different masses and materials. Therefore, sound reduction concepts need to be found for all main sound paths in order to achieve a large effect on the overall sound pressure.

By checking the measurement accuracy for the intensity box, the intensity box distorts the sound field and increases the levels in the SIL3 range by 5 dB, suggesting internal reflections. In addition, with a transmission loss of around 25 dB in the SIL3 range, the box can attenuate ambient noise but affect measurement accuracy, especially in carpet setups, which affects the measurement of lower sound intensities.

Das LuFo- Projekt ENTIRETY wird Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages

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