PROCEEDINGS of the
24th International Congress on Acoustics

October 24 to 28, 2022 in Gyeongju, Korea

ABS-0175

Measurement and estimation of the flanking impact sound transmission in timber frame building constructions

Maximilian NEUSSER[1]; Thomas BEDNAR[2]

[1] Technische Universität Wien, Institute of Material Technology, Building Physics, and Building Ecology, Austria

ABSTRACT

The K_{ij} vibration reduction index is the essential parameter for characterizing the flanking transmission of impact sound in buildings. The calculation method according to EN ISO 12354-2 based on K_{ij} has been established for many years for heavy homogenous constructions. For timber frame constructions, the determination of the vibration reduction index is not, with sufficient accuracy, possible. The parameter used for characterizing the flanking sound transmission in timber frame constructions to estimate the normalized flanking impact sound pressure level $L_{n,f}$ is the direction-averaged vibration level difference $D_{v,i,j}$. The paper discusses the applicability of this method for timber frame constructions by comparing the measured and the predicted normalized flanking impact sound pressure level $L_{n,f}$ of a timber frame T-joint. The direction-averaged vibration level difference $D_{v,i,j}$ was measured in a test facility in one T-joint configuration under different loads on the joint. The measurement result was used to calculate $L_{n,f}$. The results are compared with the measurement of the normalized flanking impact sound pressure level by shielding the direct transmission path. The results show that with minor modifications of the measurement procedure, a satisfactory agreement between the prediction model of the EN ISO 12354-2 and the measurement result can be achieved.

Keywords: Flanking Sound Transmission, Light weight constructions, Timber Frame Buildings

1. INTRODUCTION

An essential parameter in the planning of buildings and for predicting the flanking sound transmission of impact and airborne sound in the EN ISO 12354 series of standards is the vibration reduction index K_{ij}. [1] This calculation method has been established for many years for solid mineral constructions components and there are standardized prediction models for its input variables. The K_{ij} approach and the related measurement methods are only valid with the assumption of a diffuse structural field. [2] Therefore, it is not useable to measure vibration reduction indices for joints in lightweight constructions (type B components according to EN ISO 10848-1). The revision of DIN 4109 "Sound Insulation in Buildings" use a prediction Model based on the measurement of the flanking sound pressure levels. [3] This model shows reliable calculation results but the measurement of the necessary input parameter $D_{n,f,w}$ is a labor-intensive and complex task. The parameter used in EN ISO 12354-2 for the calculation of the standard flanking impact sound level is the normalized direction averaged vibration level difference $\overline{D_{v,ij,n}}$. From the authors' point of view, the applicability of EN ISO 12354-2 in timber frame construction has not yet been confirmed and is currently one of the current scientific issues. [4] In addition to the basic applicability, there are currently no standardized calculation models for the prognosis of, the essential input parameters, for lightweight timber construction. [5] The areas carried out in the paper put this applicability up for discussion by comparing the measured normalized flanking impact sound pressure level $L_{n,f}$ to the, in accordance with EN ISO 12354-2, predicted $L_{n,f}$. For this purpose, the normalized direction averaged vibration level difference of a T-Joint in timber frame construction was measured. For the same T-joint, the direct sound transmission path was shielded and the resulting normalized flanking impact sound pressure level was measured and compared to the calculation result.

---

[1] maximilian.neusser@tuwien.ac.at

[2] thomas.bednar@tuwien.ac.at

2. METHOD

The evaluation of the component and joint characteristics was carried out in accordance with the currently valid standards. The EN ISO 10848 series was used as the essential standard for measuring the vibration level differences and the flanking sound pressure levels. The quantities to be determined for the characterization of the joint are the normalized direction averaged vibration level difference $D_{v,ij,n}$ and the normalized flanking impact sound pressure level $L_{n,f}$. Both parameters can be used in accordance with ÖNORM EN ISO 12354-2 to calculate the normalized impact sound pressure level L'_n including the direct and the flanking sound transmission. The measurement of $L_{n,f}$ requires a closed recieving room and insulation of the flanking transmission path by shielding the direct sound transmission path, which makes the test setup significantly more complex than for the determination of $D_{v,ij,n}$.

2.1 Measurement

The spatial averaging of the vibration levels was carried out per excitation position at four measuring positions on the respective component surface. Structure-borne sound excitation takes place at four positions per transmission direction. The vibration levels measured on both components simultaneously perpendicular to the component surface are used to determine the vibration level difference according to equation 1.

$$D_{v,ij} = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}(D_{v,ij})_{mn} \tag{1}$$

In formula 1 M is the number of excitation points on component i, and N the number of measuring positions at each component. The vibration level difference $(D_{v,ij})_{mn}$ is calculated for one excitation point and a measurement position pair in dB. The excitation was carried out on the outside and underside of the components by means of a small hammer mill "System Gössele". The hammer mill uses a plunger to carry out a pulse-like excitation with a frequency of 10Hz. The nominal stroke hight of the 22g heavy hammer mass is around 5mm. According to EN ISO 10848-3:2018, the measurement was carried out in both transmission directions. The measurement was carried out with a calibrated measuring equipment of the type "Sinus Messtechnik Soundbook_octav with software SAMURAI 1.7.14, calibrated as a sound level meter of class 0.7". The vibration levels at the component surfaces were measured with accelerometers of the type "ENDEVCO ISOTRON 65-10-Z". According to Figure 1, the accelerometers were attached to the measuring positions of the respective component by means of beeswax.

$$\overline{D_{v,ij}} = \frac{1}{2}\left(D_{v,ij} + D_{v,ji}\right) \tag{2}$$

The normalized flanking impact sound pressure level $L_{n,f}$ and the normalized impact sound pressure level L'_n was determined by the spatial and temporal averaging of the sound level L_2 in the receiving room, which is generated by sound radiation of the wall and ceiling component of the T-joint. The ceiling was excited on the top surface by a tapping machine. The bottom of the ceiling in the receiving room was shielded for the measurement of $L_{n,f}$ by a self-supporting suspended ceiling (80mm airspace filled with mineral wool, 12.5mm gypsum fibreboard) in accordance with ÖNORM EN ISO 10848-1:2018. As a result, the direct sound transmission path is blocked and only the flanking sound transmission contributes to the sound pressure field in the receiving room. This shielding was dismantled again to determine L'_n. The measurement of L_2 is carried out by averaging the sound pressure level determined at three measuring positions of the rotary microphone boom. The equivalent absorption area A required for the calculation was determined by measuring the reverberation time in the receiving room according to EN ISO 10140.

$$L_{n,f} = L_2 + 10lg\frac{A}{A_0} \tag{3}$$

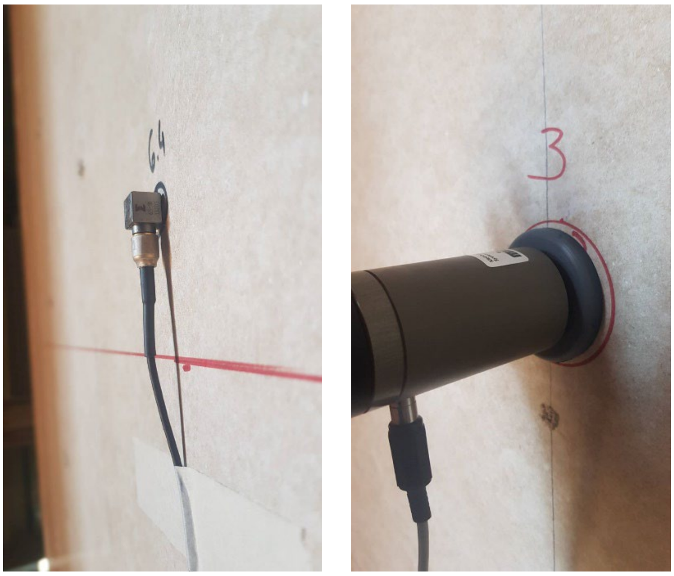

Figure 1 - (left) Attachment of the accelerometer to the component surface; (right) Excitation of the component by means of a small hammer mill "System Gössele"

The measurement of the normalized flanking impact sound pressure level $L_{n,f}$ was carried out in accordance with the EN ISO 10848 series of standards with calibrated measuring equipment of the type "Norsonic Dual Channel Real Time Analyzer Type 830". The impact sound excitation was carried out with a tapping machine of the type "Norsonic". The noise excitation for measuring the reverberation time was carried out with stationary, broadband noise. The measurement of the receiving sound pressure levels was carried out with a calibrated 1/2" condenser microphone ("Brüel & Kjaer Condenser Microphone Type 4165", "Brüel & Kjaer Preamplifier Type 2639" and "Brüel & Kjaer Microphone Power Supply Type 2804"). Before each measurement, the measuring chain was calibrated with a calibrated test sound source of the type "Norsonic Type 1251"; after each measurement, the calibration was checked.

Figure 2 - (Left) Tapping machine on the wooden frame ceiling; (Right) Rotary boom microphone for sound pressure level measurement in the receiving room

2.2 Prediction Model

The calculation of the normalized flanking impact sound pressure level $L_{n,f}$ is carried out according to EN ISO 12354-2:2017 from the direction averaged vibration level difference $\overline{D_{v,ij}}$ and the normalized impact sound pressure level of the ceiling $L_{n,i}$. Furthermore, the two component surfaces of the ceiling S_i and the wall S_j are included in formula 4. All other variables in formula 4 can be neglected in this case. There are no additional layers ($\Delta L_i = 0\ and\ \Delta R_i = 0$), and the airborne sound insulation measure of both components are about the same size ($\frac{R_i - R_j}{2} \approx 0$). Since the same configuration of the components and component dimensions was used to determine $\overline{D_{v,ij}}$ as well as $L_{n,f}$ the otherwise necessary conversion from $\overline{D_{v,ij}}$ to $\overline{D_{v,ij,situ}}$ is not necessary.

$$L_{n,f} = L_{n,i} - \Delta L_i + \frac{R_i - R_j}{2} - \Delta R_i - \overline{D_{v,ij}} - 10\lg\left(\sqrt{\frac{S_i}{S_j}}\right) \tag{4}$$

2.3 Test setup

The test setup was configured in accordance with the EN ISO 10848 series of standards. The test setup consists of a wall element (2530 x 3100mm, timber frame construction, 12.5mm gypsum fiber board, 160mm mineralwool/wooden beam, 12.5mm gypsum fiber board) and a ceiling element (3100 x 3550mmm timber frame construction, 18mm OSB board, 160mm mineralwool/wooden beam, 12.5mm gypsum fiber board). The edges of the test bench are decoupled from the load-bearing elements by means of elastic interlayers. Therefore, the edges do not contribute to the sound transmission behavior of the T-joint or the ceiling. The receiving room below the ceiling component is spatially closed on both sides by hollow brick walls and on one side by a wooden frame construction planked with gypsum fibers. This results in a receiving room volume of approx. 28 m³.

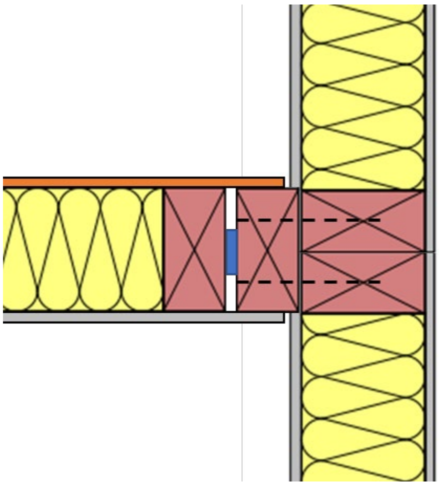

Figure 3 – Cross section of the investigated T-joint of timber a frame wall and a timber frame ceiling component

In order to simulate the building load acting on the node, 20t were applied to the node during the measurements. The attached 1200mm high wall stump in timber frame construction is primarily used to distribute the load applied to the node by the hydraulic stamps. A measurement of the flanking sound transmission wall-wall is not possible due to the small geometry and the resulting inhomogeneous vibration fields in the wall stump.

Figure 4 - T-joint and closed receiving room

To measure the normalized flanking impact sound pressure level $L_{n,f}$, it is necessary to shield off the direct impact sound transmission path through the ceiling so that only the sound pressure level in the reception room resulting from the sound power radiated from the flanking building component is measured. Based on the recommendations in EN ISO 10848-1:2018, a self-supporting suspended ceiling was installed below the ceiling construction. For this purpose, wooden beams (50mm x 80mm) were mounted on the laterally receiving room walls. There is no mechanical connection between the suspended ceiling and the ceiling construction. This wooden construction was planked with 12.5mm thick gypsum fiber boards ($m'=17kg/m^2$). The resulting cavity was dampened with mineral wool.

3. RESULTS

3.1 Normalized direction-averaged vibration level difference $\overline{D_{v,ij,n}}$

The normalized direction-averaged vibration level difference calculated by means of the measured vibration levels L_v (Figure 5a) is shown in Figure 5b. In the frequency range between 200Hz and 1250Hz, which is essential for the single-number evaluation, the curve with ±3dB runs horizontally, which allows the use of the single number value $\overline{\overline{D_{v,ij,n}}}$ according to EN ISO 10848-1. The fluctuations in the vibration levels may be caused to the modal vibration behavior of the components and the inhomogeneous vibration field in the different compartments.

Below and above this frequency range, the curve drops by about 7 dB. In the low frequency range, this can be concluded from the greatly reduced signal-to-noise level ratio, which is <6dB at 50Hz. Above 1250Hz, the velocity level difference decreases mainly due to the airborne noise caused in the reception room by small hammer mills. The ceiling, which is excited by means of a small hammer mill, radiates sound power into the receiving room and thus causes the wall surface to vibrate independently of the flanking transmission path. The structure-borne sound transmission is thus influenced by airborne sound transmission. This can be seen in Figure 5a that the average velocity level on the wall surface increases steeper from 1250Hz than that on the ceiling surface, when the ceiling is excited and the measurement of the velocity levels of the wall surface were carried out inside of the receiving room.

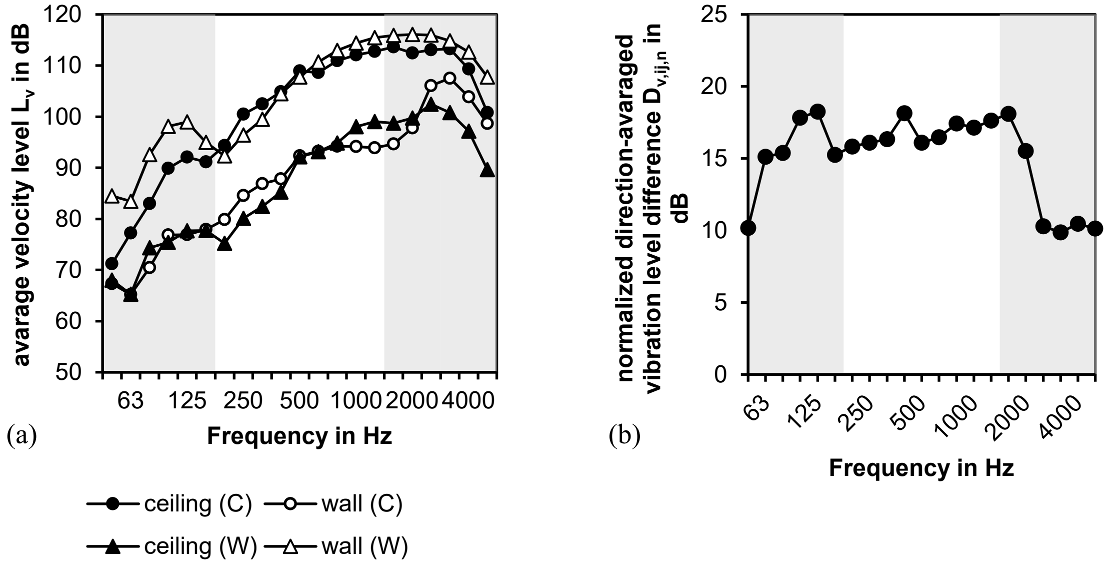

Figure 5 – (a) Frequency dependent trend of the average velocity levels on the building components surfaces with excitation of the wall (W) and the ceiling (C); (b) Frequency dependent trend of the normalized direction averaged vibration level difference $\overline{D_{v,ij,n}}$ of the investigated T-joint in timber frame construction for the ceiling-wall transmission path

3.2 Normalized impact sound pressure level L'$_n$

Based on EN ISO 10140-3, the normalized impact sound pressure levels L'$_n$ of the ceiling construction with and without self-supporting suspended ceiling were measured. With the assumption that with the shielded direct sound transmission path, sound power is only emitted by the flanking building component, this impact sound pressure level reflects $L_{n,f}$.

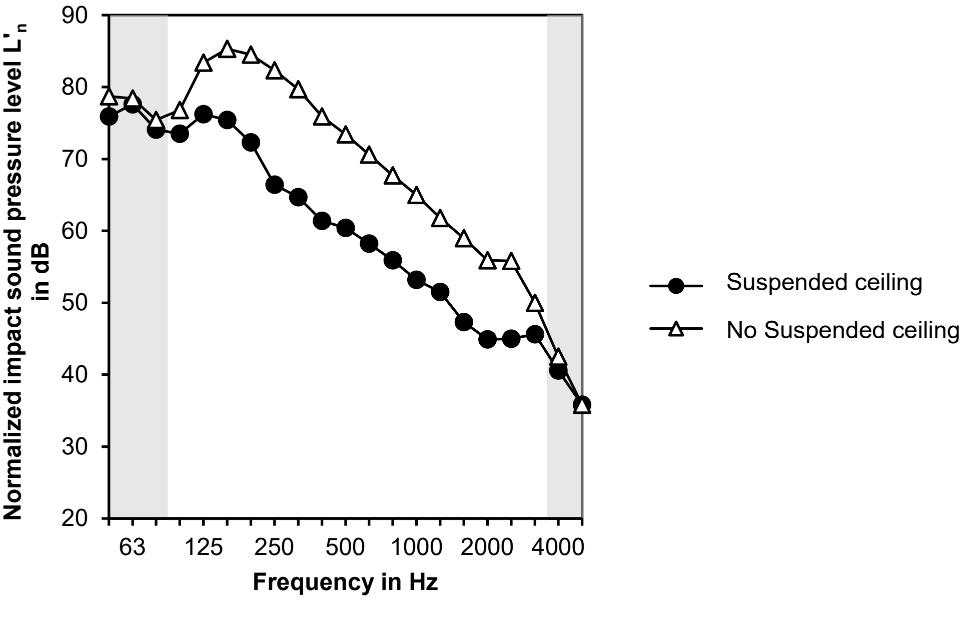

Figure 6 - Frequency dependent trend of the normalized impact sound pressure level L'$_n$ of the wooden frame ceiling with and without self-supporting suspended ceiling and with attached wooden frame wall

For the calculation of the normalized impact sound pressure level L'_n, according to ÖNORM EN ISO 12354-2, it is assumed for the measurement without suspended ceiling that the flanking sound transmission path to not have a significant influence on the overall impact sound pressure level and thus the measurement result can be regarded as the normalized impact sound pressure level L_n of the examined ceiling construction.

The comparison of the two impact sound pressure levels in figure 6 shows an effectiveness of the suspended ceiling construction beginning from 125Hz. Below this frequency, the impact sound pressure level for both ceiling constructions is almost the same and thus the suspended ceiling construction is ineffective. A comparison of the calculated and the measured flanking impact sound pressure levels is therefore not possible below 125Hz based on the measurement results shown.

3.3 Normalized flanking impact sound pressure level $L_{n,f}$

The comparison between the calculated and measured normalized flanking impact sound pressure level $L'_{n,f}$ in figure 7 shows that between 125Hz and 3150Hz a very good performance of the prediction model of EN ISO 12354-2. Below 125Hz, the measurement of $L'_{n,f}$ was not possible (see section 3.2), because the ineffectiveness of the shielding by the suspended ceiling. Therefore $L'_{n,f}$ is significantly underestimated in the calculation. From 3150Hz, the problem is that the measured direction averaged vibration level difference in this frequency range is influenced by the airborne sound induced in the receiving room by the sound radiation of the excited building component (see section 3.1). This could explain a deviation of the calculation result from the measurement result in this frequency range.

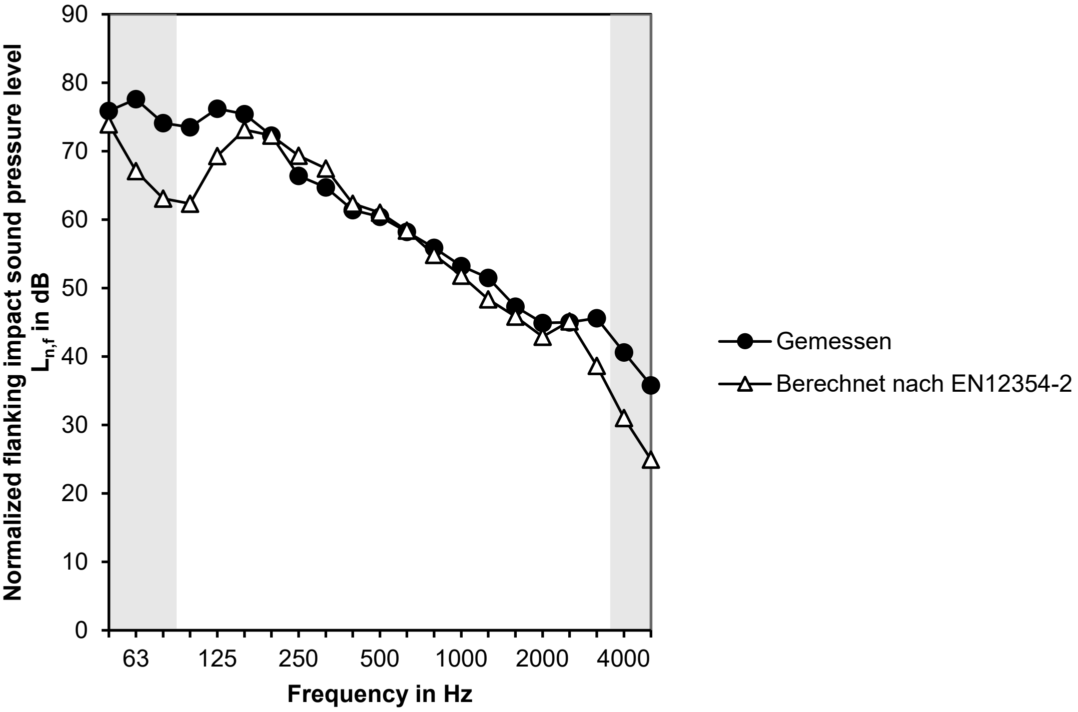

Figure 7 - Comparison between measured and calculated normalized flanking impact sound pressure level $L'_{n,f}$ of a wall-ceiling T-joint in timber frame construction

4. CONCLUSIONS

It could be shown that for a by the normalized direction averaged vibration level difference $\overline{D_{v,ij,n}}$ characterized T-joint in timber frame construction, a calculation of the normalized flanking impact sound pressure level $L'_{n,f}$ with the prediction model of the EN ISO 12354-2 with a sufficient accuracy (deviations <3dB) is possible. The calculation is limited by the accuracy of the measured input parameters. The measurement needs to take place as unaffected as possible by other transmission paths. A particular challenge in the measurement of $\overline{D_{v,ij,n}}$ is the airborne sound transmission path between ceiling and wall in the closed receiving room as well as the airborne sound power radiated by the building components effecting the vibration level measurements inside the receiving room. An improvement in the measurement accuracy is to be expected with the use of a “shaker” instead of the small hammer mill, whereby less airborne noise is induced in the receiving room, but the measuring effort is significantly increased.

ACKNOWLEDGEMENTS

The authors acknowledge the support of all project partners of the research project “Schall.Holz.Bau II”. The project was funded by the "NÖ Wirtschafts- und Tourismusfonds" in the funding track "Kooperation" under the number WST3-F2- 525823/007-2018.

REFERENCES

1. Neusser M., Bednar T. Construction details affecting flanking transmission in cross laminated timber structures for multi-story housing. Internoise 2022, Glasgow, Scotland.
2. Villot. M., Guigou-Carter, C. Measurement methods adapted to wood frame lightweight constructions. Build. Acoust. 2006, 13 pp. 189–198
3. Metzen A., Schumacher. Construction details affecting flanking transmission in cross laminated timber structures for multi-story housing. Forum Acusticum 2005, Budapest, Hungar.
4. De Geetere L., Ingelaere B., Rychtarikova M. Vibration level difference measurements on a timber frame mock-up. Project AH+, part 3, Proc. Inter-Noise 2013, Innsbruck, Austria.
5. Schönwald S, Flanking sound transmission through lightweight framed double leaf walls; Prediction using statistical energy analysis (SEA), Phd Thesis, Eindhoven, 2008
6. Schöpfer F., Mayr A., Schanda U. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise16, Hamburg GERMANY, pages 2862-3857, pp. 2862-2871(10)