BENCHMARK FOR EXPERIMENTATION OF ACOUSTIC TRANSMISSION LOSS APPLIED TO HELICOPTER TRIM PANELS

R. Wijntjes[1], F. Simon[2], T. Haase[3], O. Unruh[3], E. Tijs[4]

[1] NLR, Netherlands Aerospace Centre, e-mail: rik.wijntjes@nlr.nl
[2] ONERA, Office National d'Etudes et Recherches Aérospatiales, e-mail: frank.simon@onera.fr
[3] DLR, German Aerospace Center, e-mail: thomas.haase@dlr.de, e-mail: Oliver.Unruh@dlr.de
[4] Microflown technologies, email: Tijs@microflown.nl

The acoustic Transmission Loss (TL) of a vibrating structure, like a sample of helicopter trim panel, is generally measured in a laboratory set-up within controlled conditions. It represents the ratio between the incident acoustic power and the acoustic power radiated by the panel. To estimate its vibro-acoustic behaviour, it is essential to know precisely the nature of incident pressure field and to distinguish the influence of panel size and boundary conditions. Moreover, the relevance of the outputs depends on the experimental surroundings and instrumentation.

The aim of this paper is to present an experimental benchmark study involving different laboratories and operating processes (in laboratory or "in situ ") of "Helicopter GARTEUR (Group for Aeronautical Research and Technology in Europe) *Action Group AG20" and relative to the measurement of TL applied to reference trim panels.*

1 INTRODUCTION

For several years, aeronautical industries have wished to improve internal acoustic comfort. This is particularly true within the cabin of a helicopter, where passengers are in close proximity to disturbing sources that contribute to interior noise: main and tail rotors, engines, main gearbox (tonal noise) and aerodynamic turbulence (broadband noise).

Several European projects have as objectives the reduction of cabin noise and vibration levels: i.e., RHINO (Reduction of Helicopter Interior NOise), FRIENDCOPTER (FRIENDly HeliCOPTER), CREDO (Cabin noise REduction by experimental and numerical Design Optimization) or HELINOVI (HELIcopter NOise and VIbration reduction).

The purpose of this paper is to present an experimental benchmark study involving different laboratories and measurement techniques relative to the measurement of TL applied to reference trim panels.

It is based on a think tank, "Helicopter Garteur Action Group", devoted to "Design and characterization of composite trim panels" (AG20).

2 TRANSMISSION LOSS MEASUREMENTS

2.1 Standard Transmission Loss method

At ONERA, DLR and NLR the acoustic Transmission Loss (TL) is measured according to the method described in ISO Standard 15186-1[1].

The TL of a material is defined as the logarithmic ratio of incident sound power (W_i) to the amount of transmitted sound power (W_t) (Figure 1):

$$TL(\omega) \equiv 10\log_{10}\left(\frac{W_i}{W_t}\right) \text{ [dB]} \quad (1)$$

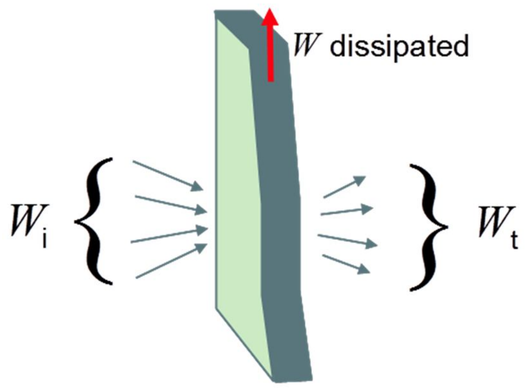


Figure 1: Schematic representation of the transmission loss

The test panels are clamped in an aperture between a reverberant room and a (semi-) anechoic room. Excitation is generated by broadband noise to produce a diffuse acoustic field in the reverberant room. The incident power is determined by sound pressure measurements. The transmitted power is obtained in the (semi-) anechoic room with a sound intensity probe moved on a meshed plane surface. The TL in dB being determined from:

$$TL = SPL_{send} - 6 - SIL_n - 10\log\left(\frac{S_m}{S}\right) \text{ [dB]} \quad (2)$$

where SPL_{send} is the sound pressure level in the sending room (in dB re 20 µPa), measured with a microphone on a rotating boom, SIL_n is the sound intensity level (in dB re 1 pW/m²), normal to and averaged over the measuring surface S_m, and S is the area of the test specimen (i.e., the part radiating sound to the receiving room).

At DLR and ONERA a clamping size of 0.84 x 0.84 m^2 is used. At NLR the clamping size for this experiment was 0.82 x 0.82 m^2 (instead of the normal 1.0 x 1.0 m^2).

The standard TL test set-up is shown in Figure 2. The reverberation rooms of ONERA and NLR have respective volumes of 45 and 33 m^3, resulting in a diffuse sound field for frequencies higher than 200 and 500 Hz. Nevertheless, in order to reduce the measuring error below 500 Hz, the TL is determined from successive measurements for three different loudspeaker positions, according to the procedure, described in Annex D of ISO 10140-5[2].

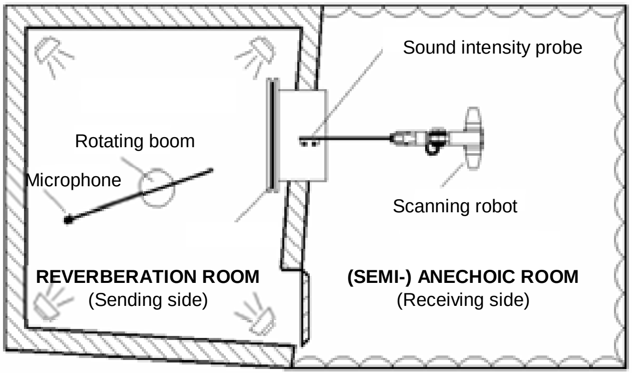


Figure 2: Schematic of standard TL measurement setup

Contrary to the previous laboratories, the DLR receiving room is a perfect anechoic room, justifying the standard ISO 3745[3] Class1. Moreover, the minimum frequency of interest (depending on the characteristics of reverberant room) is reduced to 100 Hz. Examples of the test setup of the different partners are shown in Figure 3.

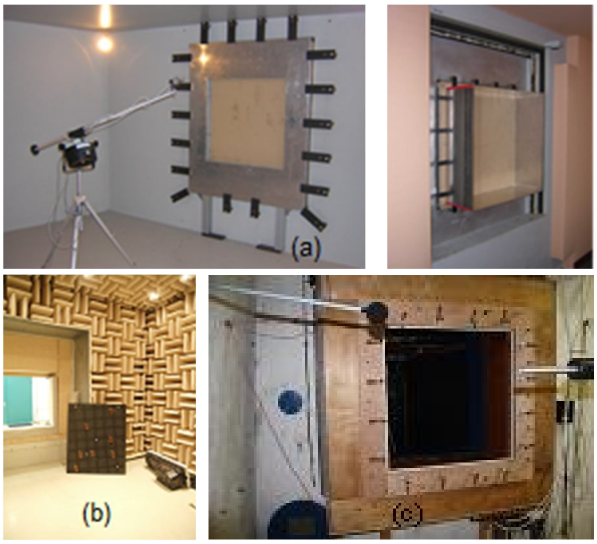


Figure 3: (a) ONERA Reverberant and Soundproofing room with typical clamped panel and lateral protections - (b) DLR Anechoic room with typical panel - (c) NLR Reverberant room with panel test section.

At NLR the panels can be clamped or suspended on springs, free from the surrounding structure (Figure 4). The reason for choosing a free-free set-up is to have well defined boundary conditions, in order to preclude possible difficulties to formulate the boundary conditions correctly in a FEM model. Flanking noise has been suppressed adequately by a special designed panel support structure. On all four sides of the test opening a U-shaped sound insulating structure is mounted, filled with sound absorbing foam. This free-free set-up has been tested and validated extensively in the European project FACE[[4],[5]].

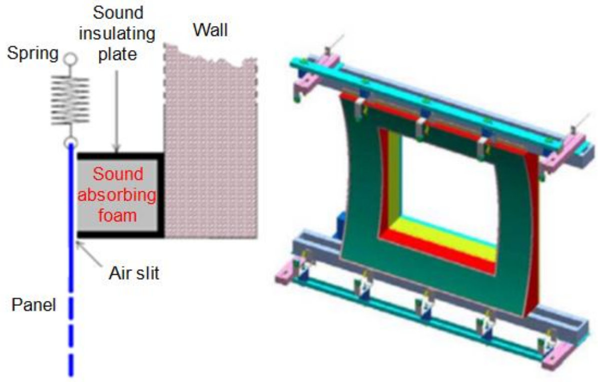


Figure 4: Principle (left) and CATIA picture (right) of the NLR flanking noise suppression structure, red = sound insulating plate, green = sound absorbing foam.

2.2 PU free field method

The standard method for transmission loss measurements uses two adjacent rooms with an adjoining transmission path. The standard method avoids the direct measurement of the sound energy transmitted in the material by using a reverberation room. This method is defined, time tested, and reliable. However, a transmission loss testing procedure that is more convenient and less costly would be of interest.

The radiated power can also be determined "in situ" and straightforwardly with a single probe called Microflowns containing a particle velocity sensor combined with a conventional microphone in a so-called PU probe. So, intensity measurement are acquired by PU probes to differentiate radiation of various parts of a panel and to extract Transmission Sound power (novel Microflown enabled based Transmission Loss method) but also acoustic reflection and impedance.

The difficult part in the transmission loss definition is the determination of the sound power going into the material (W_i). This is because the sound intensity measured at the inward side, is the net intensity, which is the inward intensity minus the reflected intensity (Figure 5).

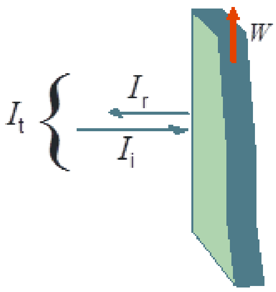


Figure 5: The measured sound intensity at the inward side

It is possible to measure the reflection coefficient "in situ" (which is the ratio of the inward intensity and the reflected intensity $|R|=I_r/I_i$). If this value is known, the inward intensity can be calculated from the net intensity.

The transmitted intensity is measured with an intensity probe on the backside of the sample. If the source signal is used as a reference signal, the measurement is unaffected by background noise.

3 TEST PANEL DESCRIPTION

Two types of trim panels have been tested, a "standard" trim panel (panel 1) with honeycomb and an "optimized" trim panel (panel 2), with thick foam to have a "dilatation effect" in the medium frequency range. Both panels have a surface of 0.90 x 0.90 m^2. The "standard" trim panel (Figure 6) reaches 3.4 km/m^2 for a thickness of 11.7 mm. The "optimized" trim panel (Figure 6) reaches 5.6 km/m^2 for a thickness of 21.7 mm. Both panels have been tested in the different laboratories. The two panels were made available by ONERA.

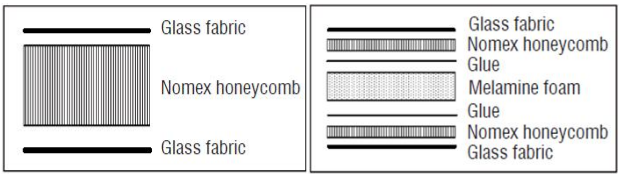


Figure 6: Composition of trim panels, left: "Standard" trim panel, right: "Optimized" trim panel

4 EXPERIMENT RESULTS

4.1 Deviation within a single facility

Figure 7 and Figure 8 show the deviation between measurements of the same panel. At NLR, the TL has been measured six times for each panel. The facility, measurement equipment and data processing are kept equal. Only the effect of repeatability is evaluated.

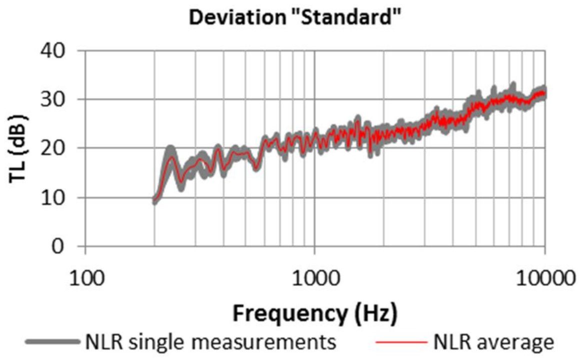


Figure 7: Deviation between repeat measurements panel 1

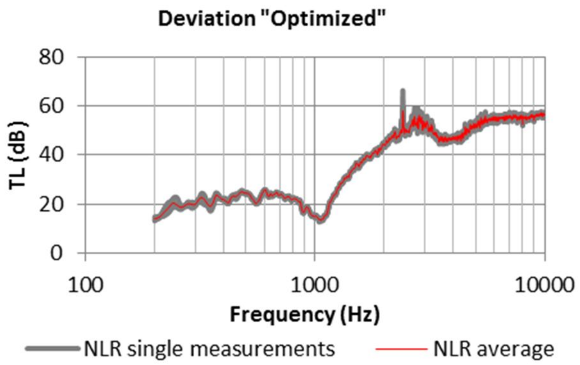


Figure 8: Deviation between repeat measurements panel 2

For each frequency (frequency step size = 10 Hz) the maximum difference between the repeat measurements and the standard deviation is calculated according to equations 3 and 4. Table 1 shows the statistics of the repeatability. For the "optimized" trim panel, one measurement was discarded due to extreme outliers.

$$\Delta TL_{freq\,bin} = \max\begin{pmatrix} TL_1 \\ . \\ . \\ . \\ TL_n \end{pmatrix} - \min\begin{pmatrix} TL_1 \\ . \\ . \\ . \\ TL_n \end{pmatrix} \quad (3)$$

$$\sigma_{freq\ bin} = \sqrt{\frac{\sum_{i=1}^{n}\left(TL_i - TL_{avg}\right)^2}{n}} \quad (4)$$

Table 1: Repeatability statistics

	"Standard"	"Optimized"
max($\Delta TL_{freq\,bin}$)	5.0 dB	14.8 dB
median($\Delta TL_{freq\,bin}$)	1.1 dB	1.0 dB
max($\sigma_{freq\ bin}$)	2.0 dB	6.0 dB
median($\sigma_{freq\ bin}$)	0.4 dB	0.4 dB

The measurements of the "optimized" trim panel show more deviation between the measurements. Especially, in the region 2 kHz – 3 kHz, there are large deviations. In general, the amount of scatter is within limits, 95% of the data is within a maximum difference of 2 to 3 dB.

4.2 Facility comparison

The two test panels were measured at ONERA, DLR and NLR according the standard TL method. At this stage the test panels were clamped to have the same boundary conditions. No additional restrictions were specified to be able to investigate the difference between the facilities and way of operation. Figure 9 shows the results of the "standard" trim panel and Figure 10 the "optimized" trim panel.

For the "standard" trim panel the three facilities show a similar behavior. The TL increases with approximately the same slope. 95% of the data is within a difference of 5 dB. These differences are due to measurement errors, measurement equipment (microphone size, spacer etc.) and data processing (frequency spacing, type of windowing etc.).

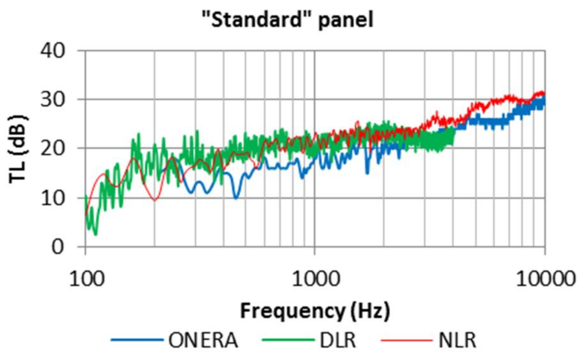


Figure 9: TL measurement results of panel 1

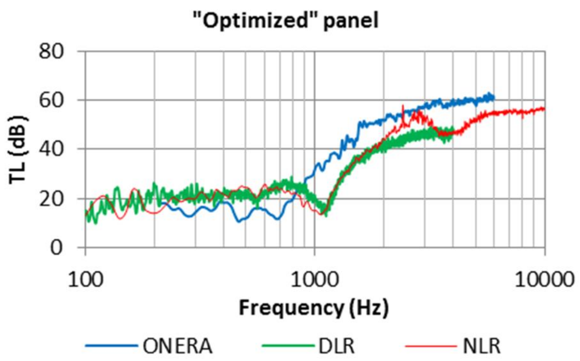


Figure 10: TL measurement results of panel 2

For the "optimized" trim panel the measurements of DLR and NLR are, within limits, equal. The majority of the measurement results show a difference within the repeatability error. In the frequency region of 2 kHz to 3 kHz the difference increases. Also in the repeat measurements at NLR this combination of trim panel and frequency range gave a high dispersion.

The measurements of ONERA and DLR/NLR show a large difference. A shift in frequency is visible where the dilatation effect starts. This shift is generated by the properties of Melamine foam which change over time.

4.3 Clamped v.s. free-free suspension

As described in paragraph 2.1, the free-free suspension was extensively tested in the European project FACE. The structure was designed to suppress flanking noise for large curved samples, extending the test window between the reverberation and semi-anechoic chambers. The GARTEUR samples are small compared to the test window, therefore a new window was manufactured to clamp the samples and a simple method was tried to have a free-free suspension. Figure 11 shows the clamped and free-free suspension. For the free-free suspension, all the clamps and wooden ring are removed. Fishing line is used to keep the sample on its place and sound absorbing foam is placed around the sample. Figure 12 shows the measurement results for the clamped and free-free suspension cases for the two trim panels.

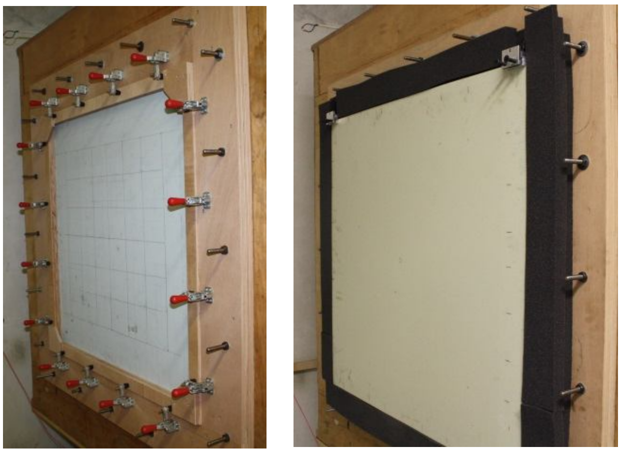


Figure 11: Clamped (left) and free-free suspension (right)

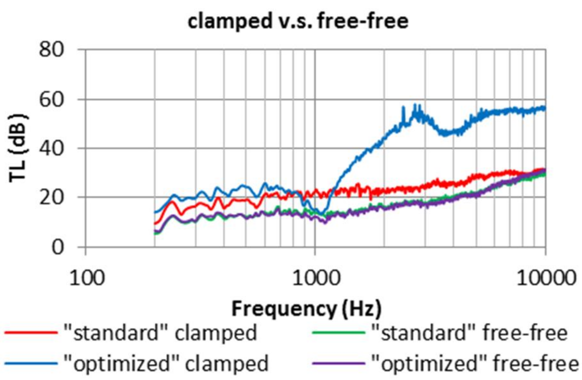
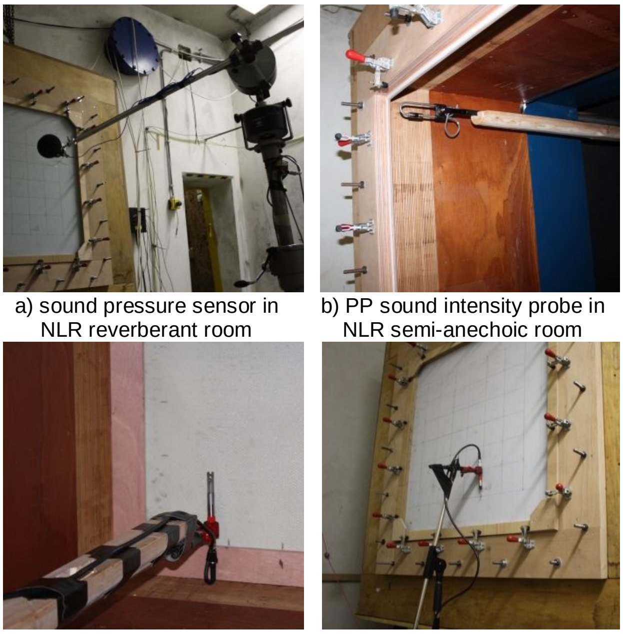


Figure 12: TL results for the clamped and free-free suspension cases

The measurements with the free-free suspension are not correct. The results for both panels are equal and well below the measured TL in the clamped case. The diffraction around the panel is measured instead of the TL of the panel. This is due to flanking noise. The used method to suppress flanking noise was not sufficient.

4.4 In situ v.s. standard method

The feasibility of in situ transmission loss tests are explored within the GARTEUR project. As such testing methods are still in development, it is best to take a step-by-step approach. Conditions used for standardized transmission loss tests were analyzed, i.e. sample mounted in between a reverberant room and a semi-anechoic room. The intensity was measured with a PP probe and a PU probe on the backside of a sample in the anechoic room. Secondly, the intensity was measured with a PU probe on the front side of the material inside the reverberant room. The ingoing sound power estimated from this measurement should approximate the ingoing sound power measured with the standard procedure involving sound pressure measurements in the reverberant room. The used sensors are depicted in Figure 13.



a) sound pressure sensor in NLR reverberant room

b) PP sound intensity probe in NLR semi-anechoic room

c) Microflown sensor (PU) in NLR semi-anechoic room

d) Microflown sensor (PU) in NLR reverberant room

Figure 13: sensors used for in-situ feasibility study

For the in situ transmission loss measurement, the sample was installed in free field conditions (i.e. in a room with few reflections). A sound source was placed at one side of the material, and the ingoing and transmitted intensity were measured with PU probes on both sides of the sample. The boundary conditions and incident sound field for the in situ measurements are different compared to the standard TL measurements. Figure 14 depicts the scheme for the in situ transmission loss measurements and Figure 15 shows an example of a measurement and its 3D intensity result.

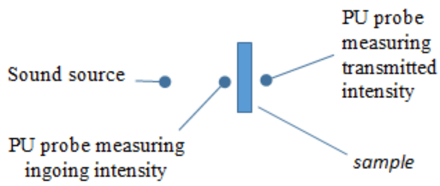


Figure 14: Overview of the measurements performed with PU probes in free conditions

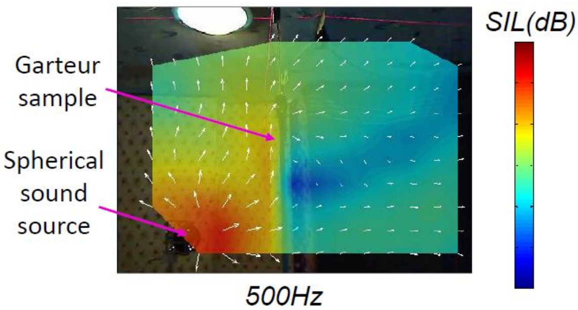


Figure 15: Example of color map of intensity levels and normalized intensity vectors

The in situ measurement method has been tested on multiple samples. Figure 16 shows the transmission loss results for a 6mm MDF plate for different sample sizes. The larger the sample the better the measurement follows the mass law.

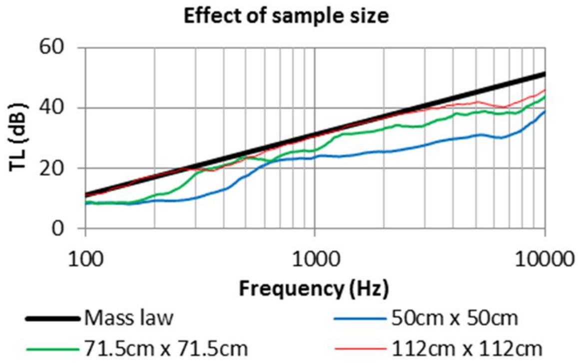


Figure 16: in situ measurements on a 6mm MDF plate for different sample sizes

In total three measurement methods (Table 2) were used to check the feasibility of in situ transmission loss testing. The obtained results for the different measurement methods are shown in Figure 17.

Table 2: Measurement methods for in situ feasibility study

Sensors	Description
p - pp	Sound pressure sensor in NLR reverberant room Sound intensity probe in NLR semi-anechoic room
pu - pu	Microflown sensor in NLR reverberant room Microflown sensor in NLR semi-anechoic room
in situ	Microflown sensor in front and behind sample in free field conditions

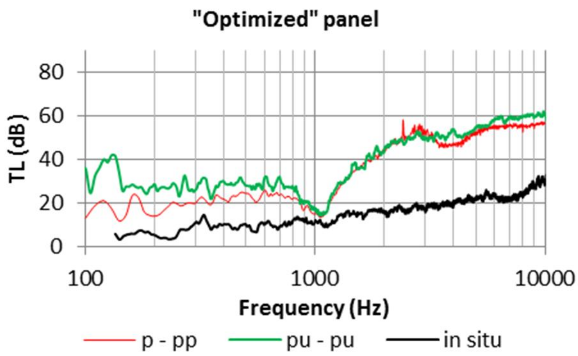


Figure 17: TL measurement results for different techniques

The obtained results at the facility of NLR show good comparison. The two measurements are within the repeatability error with some small outliers. In front of the sample, PU probes can be used because they do not have P/I index problems. Behind the sample, particle velocity is less affected by reflections than sound pressure or intensity.

The in situ results for the “optimized” trim panel show rather large differences. The results of the “optimized” trim panel are very similar to the results of the “standard” trim panel and the free-free suspension. This makes it plausible that the tested GARTEUR samples were too small to be tested with the in situ insertion loss method. The presence of acoustic propagation around the panel reduces the TL.

5 CONCLUSIONS

This paper has presented a comparison between different facilities (NLR, DLR and ONERA) and measurement techniques (conventional and in situ) to measure the Transmission Loss (TL) applied to two reference trim panels.

Repeat measurements at a single facility showed that the amount of deviation is within limits, 95% of the data is within a maximum difference of 2 to 3 dB.

Between facilities the deviation is higher (about twice as high), although the same ISO standards are used to perform the measurements. It is possible to compare trends in the data. But the results are not accurate enough to compare absolute values between different facilities.

The PU probes of Microflown showed good results when used in the conventional TL measurement setup. The same results are obtained with a sound pressure sensor - sound intensity probe combination and two PU probes.

The possibility of measuring transmission loss in situ has been investigated for several sample types. If the sample is large enough it is possible to measure the TL correctly. The used reference trim panels were too small resulting in a reduction of the measured TL. This makes it impossible to compare the results with the conventional TL method.

ACKNOWLEDGEMENTS

We thank the GARTEUR (Group for Aeronautical Research and Technology in Europe) for allowing the cooperation between authors of different laboratories in the helicopter domain (GoR-HC).

REFERENCES

[1] ISO 15186, “Acoustics -- Measurement of sound insulation in buildings and of building elements using sound intensity. -- Part 1: 2000, Laboratory measurements”.

[2] ISO 10140-5, "Acoustics – Laboratory measurement of sound insulation of building elements" -- Part 5: "Requirements for test facilities and equipment ".

[3] ISO 3745, “Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Precision methods for anechoic rooms and hemi-anechoic rooms”

[4] F.P. Grooteman, “Transmission Loss analyses on fuselage panels; Approach, numerical results and validation”, NLR-TP-2006-479.

[5] H.M.M. van der Wal, A.C. Nilsson, “Sound-transmission measurements on composite and metal fuselage panels for different boundary conditions”, NLR-TP-2005-570.

NOMENCLATURE & ABBREVIATIONS

I_i	inward intensity	(W/m^2)
I_r	reflected intensity	(W/m^2)
n	number of repeat measurements	(-)
$\|R\|$	reflection coefficient	(-)
S	area of the test specimen	(m^2)
S_m,	measuring surface	(m^2)
SIL_n	sound intensity level (re 1 pW/m^2)	(dB)
SPL_{send}	sound pressure level in sending room (re 20 μPa)	(dB)
TL	transmission loss	(dB)
TL_{avg}	average transmission loss of six repeat measurements	(dB)
$\Delta TL_{freq\,bin}$	maximum difference between the six repeat measurements for a single frequency bin	(dB)
TL_i	transmission loss of measurement i	(dB)
W_i	incident sound power	(W)
W_t	transmitted sound power	(W)
$\sigma_{freq\,bin}$	standard deviation for the six repeat measurements for a single frequency bin	(dB)

DLR	Deutsches Zentrum für Luft- und Raumfahrt
GARTEUR	Group for Aeronautical Research and Technology in Europe
NLR	Netherlands Aerospace Centre
ONERA	Office National d’Etudes et Recherches Aérospatiales