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VIBRO-ACOUSTIC RESPONSE OF A TURBOPROP CABIN WITH INNOVATIVE SIDEWALL VISCOELASTIC TREATMENT

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In recent years, it's considerably grown the market demand for increasingly performing and comfortable aircrafts as a new mandatory design target. Among the determining factors for the internal comfort, are included the noise and vibrations, the source of which is detected mainly in the propulsion unit especially in the case of turboprop category: the most significant component of the noise perceived inside a cabin is undoubtedly the blade-passage load exerted by the propeller. Recently were therefore tested techniques, both active and passive, of vibration emission reduction and sound absorption, however the goal remains to find solutions by extremely low-weight and easy to apply on the real mock-up. As known, a damping treatment is typically used to reduce noise coming from fuselage structure vibration under acoustic loading excitation. In such research context, the vibro-acoustic performance of the viscoelastic material for replacing the conventional interior blanket of the fuselage sidewall have been investigated for the well-known higher dissipation capacity and energy storage. Starting from experimental tests by means of different measurement techniques carried out on an innovative foam sample, the dynamic parameters were estimated according to identify suitably the material performance database for further finite element analysis on a turboprop fuselage model. The outcomes achieved have emphasized a significant role of the viscoelastic foam than the standard blanket with respect to the internal sound pressure levels abatement as well as the thermal insulation. The developed foam prototype is also easily integrable with an outer layer ensuring a fully removable embedded solution for the maintenance inspections.

Keywords: Damping Foam, Noise, Sound Intensity, Turboprop, Viscoelasticity.

1. Introduction

The foams whose damping properties are going to be discussed in this assessment can be labelled as viscoelastic materials. Viscoelasticity is a property of certain types of materials whose behaviour stands halfway between the viscous and the elastic ones, as the name suggests. The purpose of this assessment is to show the insulating properties of new viscoelastic foams designed specifically to have a high acoustic absorption coefficient and how they can be used effectively in aeronautical applications in order to enhance acoustic comfort by focusing on reaching high performances while always keeping an eye on lightweight materials [1-2].

2. Innovative viscoelastic foams overview

Usually the sound damping materials used in aeronautical applications to insulate the cabin from external noise sources are the so-called blankets which consist of an assembly of two materials, one with viscoelastic properties that reduce the structure vibration by muffling the structure-borne noise transmission and one with a relatively high acoustic absorption coefficient – like fiberglass fabrics – that ensures a dampening of the airborne noise transmission. The viscoelastic foams that are going to be examined in this assessment offer the great advantage of combining both insulating properties into one material which is still lightweight, thus resulting easier to produce and highly efficient at the same time. The foam used in the tests is made of polyurethane. The production process involves first the formation of the polyurethane polymer and then the injection of gas bubbles inside the polymer matrix which creates cavities (or cells) throughout the whole material. Said injection must be carefully balanced since if the bubbles are injected too fast, the whole foam could collapse because the matrix is not stiff enough to hold the gas and if the bubbles are injected too slowly, chances are that the foam will not develop correctly. Specifically, the foams examined hereby are the 65-30 type and the 90-10 type whose properties are listed in Table 1.

Table 1: Examined materials properties

Data	Foam 90-10	Foam 65-30	Polyester Blanket
Elastic Modulus, E [MPa]	0.017	0.012	0.172
Shear Modulus, G [MPa]	0.0057	0.0046	0.0622
Poisson ratio,	0.3	0.3	0.3
Density, ρ [Kg/m^3]	65	90	45

On the other hand, the blanket-like setup was obtained by assembling a viscoelastic foil directly fixed on the structure and foam-like polyester panels attached on one side of the foil. In such framework, each foam has been tested using a linear stiffened panel, expressly designed and manufactured, in order to simulate a portion of the fuselage shell, Fig. 1 [3].

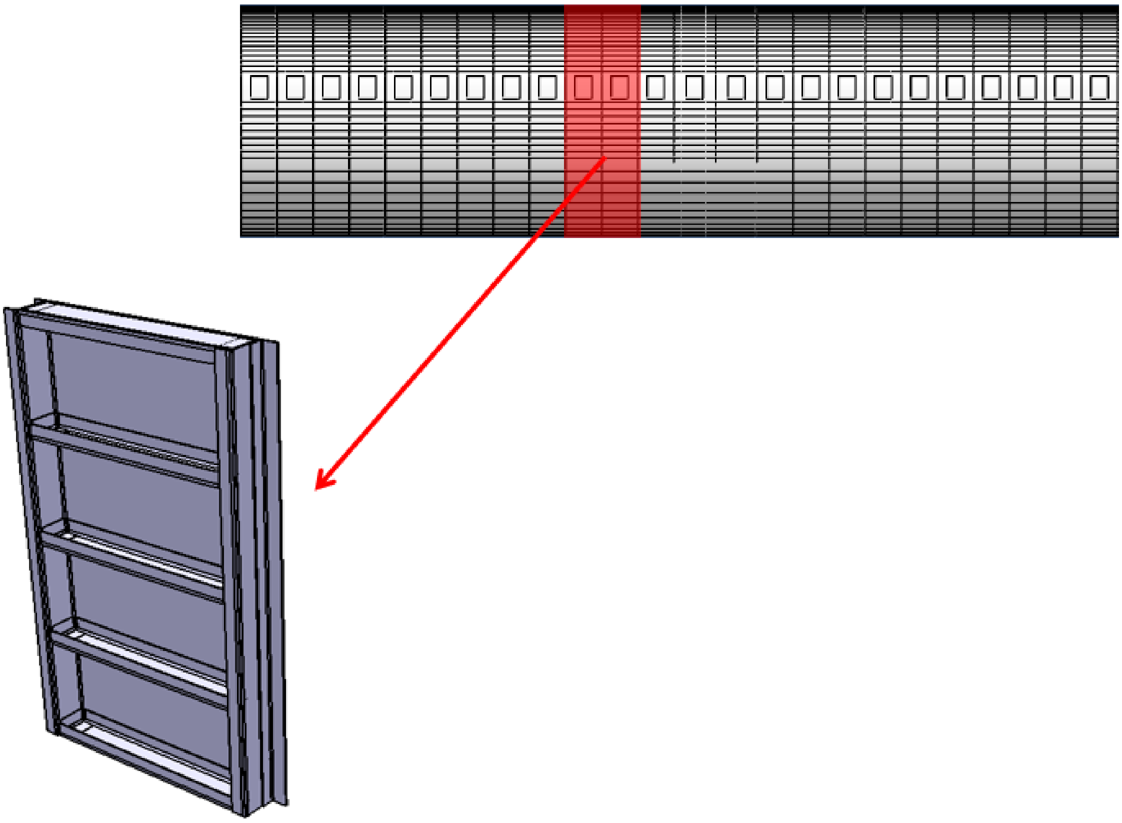


Figure 1: 3D CAD of the fuselage linearized panel.

3. Dynamic test

3.1 Testing strategy

The structural test – as well as the acoustic test – was made on a panel with stringers to mock up the outer skin of a fuselage and the stiffening structure beneath. The panel was hung from a beam with two supports to simulate a free-free condition, Fig. 2.

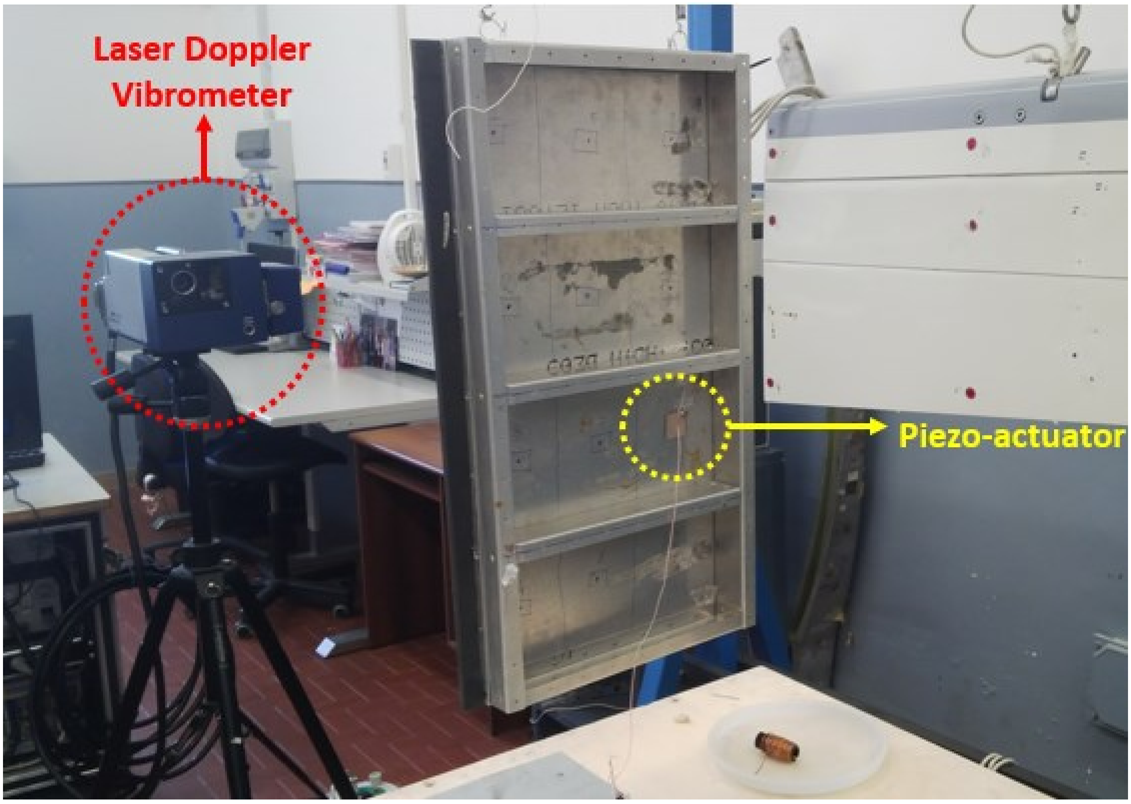


Figure 2: Vibration test set-up, Baseline configuration.

The Laser Doppler Vibrometer (LDV) Polytec 400®, was placed 1.5 m away from the panel [4]. The vibrating load was applied by means of a piezoelectric transducer which excited the structure, when undergoing a difference in electric potential (voltage). The test has been performed on five different configurations (all shown in Fig. 3, with the exception of the Baseline condition) in according to the following test matrix, Table 2:

Table 2: Test matrix, vibro-acoustic characterization

Case ID	Configuration	Test
Case 1	Baseline	LASER VIBROMETRY AND TRANSMISSION LOSS ASSESSMENT
Case 2	Foam 65-30	
Case 3	Foam 90-10	
Case 4	Viscoelastic sheet	
Case 5	Viscoelastic sheet and polyester panel	

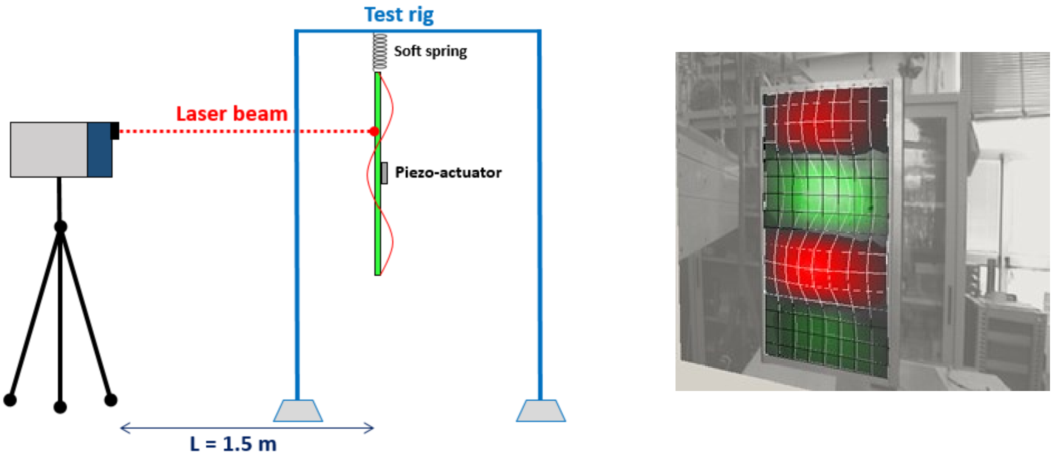
(a) Foam 65-30 (b) Foam 90-10

(c) Viscoelastic sheet (d) Viscoelastic sheet and polyester panel

Figure 3: Tested configurations.

3.2 Operational Deflection Shapes (ODS)

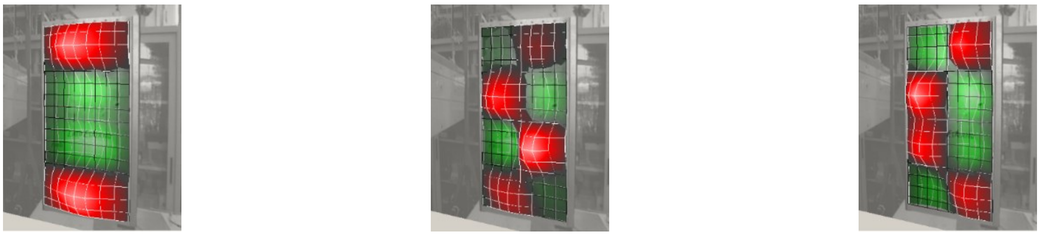
The output results of the LDV was the vibration velocity magnitude, averaged on all the single-point measurements, detected on a grid representative of panel surface. Seven Operational Deflection Shapes (ODS) have been achieved within the spectral range [100 Hz; 1000 Hz], as shown in Figs. 4-5. However, the parameter shown in the plots as a function of frequency, is the ratio output/input, which allows for the obtaining significant information about the transfer function of the system and separate the magnitude from the external load that caused it, Fig. 6. Generally, such dynamic gain is measured as a ratio between two engineering units but in this case, the input force, has been evaluated by only its electrical voltage to the terminals of the piezo-actuator.



(a) Conceptual layout

(b) Output vibrometry: ODS I

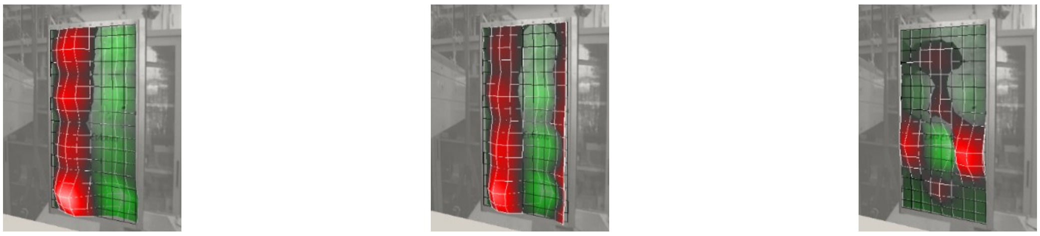
Figure 4: Vibration test execution.



ODS II

ODS III

ODS IV



ODS V

ODS VI

ODS VII

Figure 5: Operational Deflection Shapes.

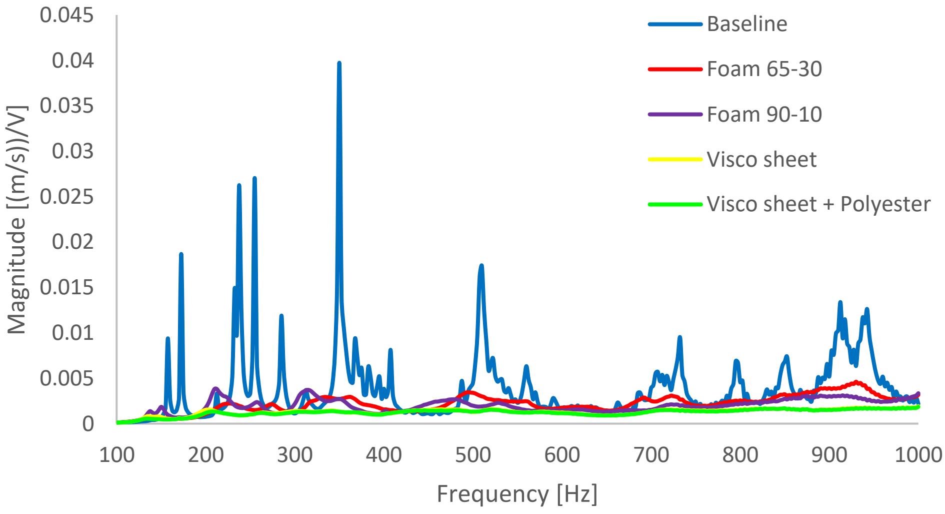
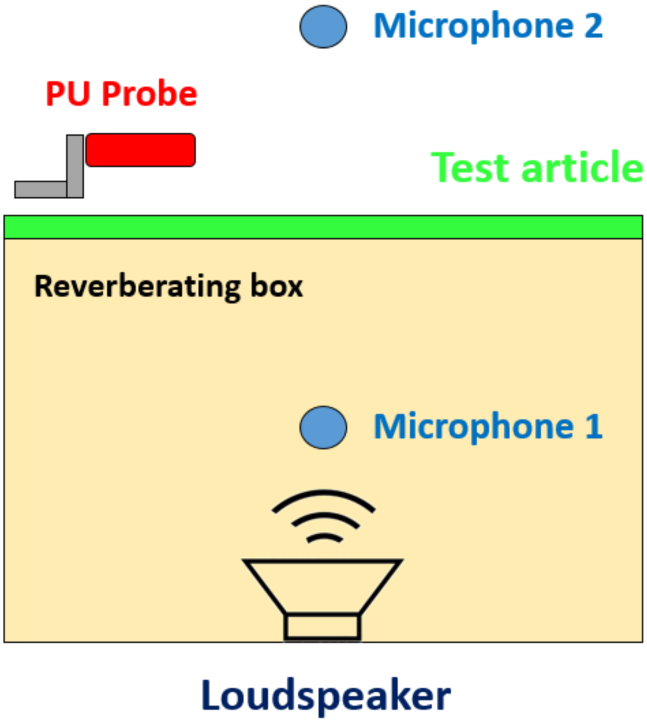


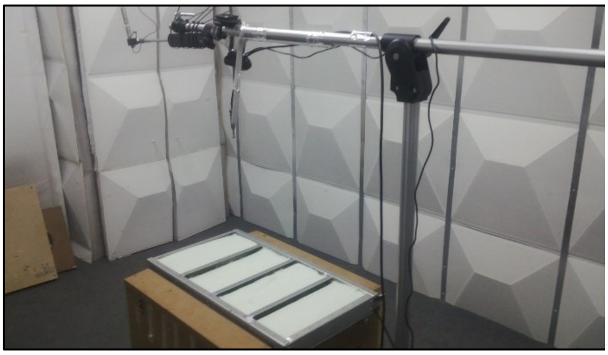
Figure 6: Vibration velocity magnitude normalized to the piezo-signal.

4. Acoustic test

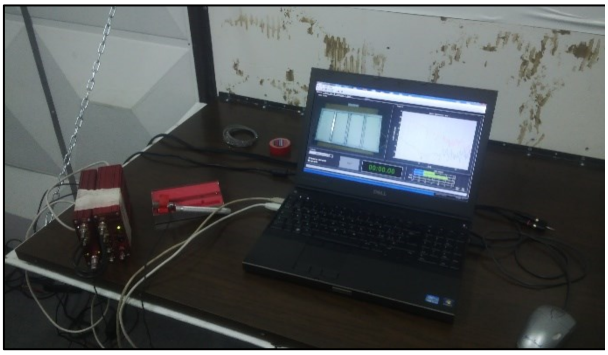
The acoustic test has been carried out in order to define the transmission loss level with reference to each structural configuration. Therefore, the test has been performed as follows:

- The sound source must be placed in an environment that ensures a reverberating acoustic field so that there is no influence from the direction of the measurement. Therefore, a loudspeaker has been placed to the bottom, inside a reverberating box, Fig. 7(a);
- The receiving environment should be an anechoic chamber so that the sound intensity level measured by the PU Probe and/or sound pressure level measured by means of a microphone are not due to any reverberation that might invalidate the measure, but only to the transmitted sound that managed to go through the object, whose absorption properties are being examined, Figs. 7(b), 7(c). The experimental campaign has been carried out in an anechoic chamber at CNR (Consiglio Nazionale delle Ricerche, Napoli - Italy).





(b) External microphone installation



(a) Experimental scheme

(c) PU Probe workstation

Figure 7: Acoustic test set-up.

4.1 Noise insulation assessment

The sound intensity levels measured by the microphones have been used to evaluate the acoustic absorption properties in two different ways [5-7]. In the first one – and for all set-ups – the acoustic absorption has been calculated as a ΔL_p, i.e. the difference in SPL between the inside of the box (the source) and the outside (the receiving environment) measured by two microphones, respectively SPL_{IN} and SPL_{OUT}. In the second one, the acoustic absorption has been evaluated as a R factor, in according to ISO 15 186/2, which is the difference between the sound pressure level inside the box (the source) and the sound intensity level, I_{PU}, measured by the Microflown® PU probe [8-10]. The spectrogram in Fig. 8 shows the global comparison of all the configurations results, evaluable both in terms of ΔL_p and R.

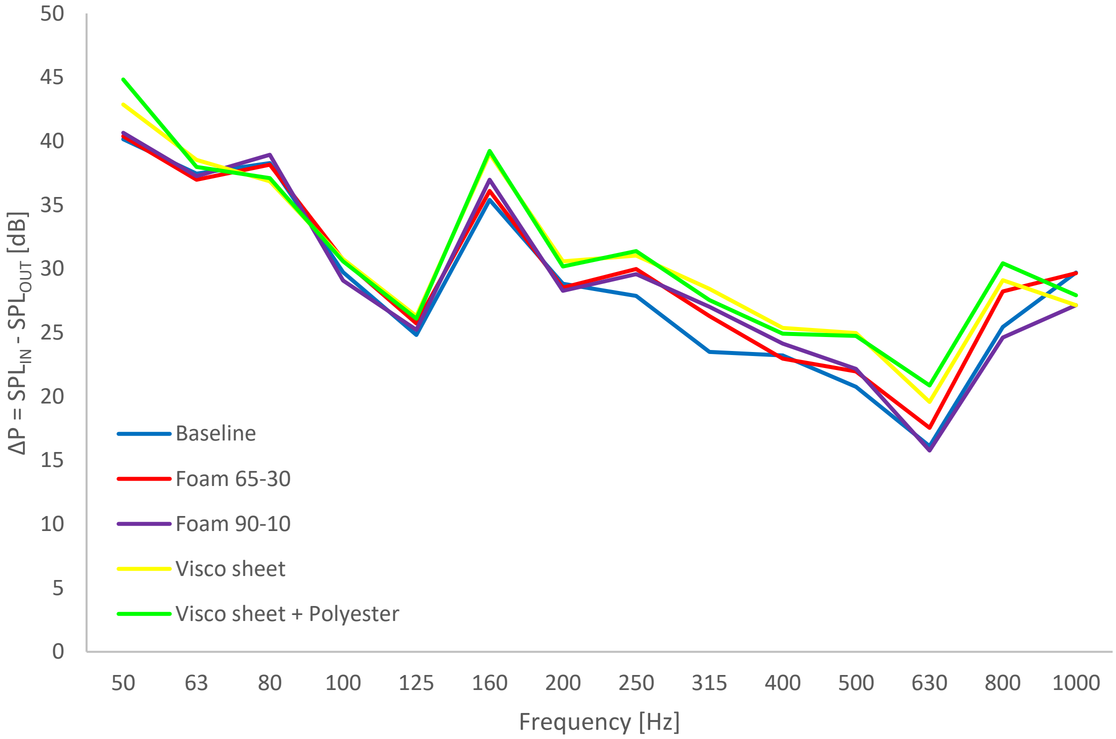


Figure 8: Transmission loss comparison.

5. Conclusions and further developments

The tests have shown that the viscoelastic foam hereby examined exhibits good insulating properties in a certain range of frequencies [250; 630 Hz]: the foam is clearly very effective, since it manages to reduce the noise level by up to 5 dB. In the low-frequency range [0; 250 Hz], the foam seems to have the same acoustic absorption than the baseline panel. That is due to the anechoic chamber which ideally prevents reverberation at any frequency but in reality, it manages to do so only from a certain frequency. At high-frequency range [630; 1000 Hz], the innovative foams do not much contribute to the acoustic absorption of the panel; in that spectral section, the acoustic absorption properties depend mainly on mass addition, and the weight added by such foams was a smaller fraction of the panel itself than the configuration including the viscoelastic layer with the standard polyester: the panel weighed actually 1.8 Kg while the total mass added with the foam was 230 g, i.e. only 13%. Furthermore, the test have been carried out by covering the whole panel with four viscoelastic sheets (globally 0.5 Kg); in the actual operative case, these foils, used for the structure-borne noise damping, are applied only in some specific areas. These results were collected in a numerical database, and addressed to the further noise prediction on a full-scale fuselage model, by finite element analysis [11-22].

REFERENCES

1 Viscardi, M., Arena, M. and Siano, D. Experimental and numerical assessment of innovative damping foams, *International Journal of Mechanics*, **10**, 329-335, (2016).

2 Viscardi, M., Arena, M. and Siano, D. Design and testing of a prototype foam for lightweight technological applications, *International Journal of Mechanics*, **10**, pp. 383-395, (2016).

3 Vanore, G., Paonessa, A. and Arena, G., Improved testing methods for structural damping evaluation, *AIDAA Congress*, Milan, June 29–July 3, (2009).

4 www.plm.automation.siemens.com (LMS SCADAS Data Acquisition Systems).

5 Fuller, C.R., Elliot, S.J. and Nelson, P.A. *Active Control of Vibration*, Academic Press, London, (1996).

6 Beranek, L. *Noise Reduction*, Mc Graw-Hill, (1960).

7 Beranek, L. and Ver, I. L. *Noise and Vibration Control Engineering: Principles and Applications*, Whiley & Sons, New York, NY, USA, (1992).

8 www.polytec.com (Polytec 400®).

9 www.microflown.com (PU Probe).

10 Viscardi, M., Arena, M. Barra, G. and Guadagno, L. Structural Performance Analysis of Smart Carbon Fiber Samples Supported by Experimental Investigation, *International Journal of Mechanics*, **10**, 376-382, (2016).

11 Viscardi, M., Arena, M. Barra, G. and Guadagno, L. Smart carbon-epoxy laminate with high dissipation properties for vibro-acoustic optimization in the turboprop aircraft, *International Journal of Mechanics*, **11**, 51-57, (2017).

12 Di Giulio, M., Arena, G. and Paonessa, A. Vibro-acoustic behaviour of composite fuselage structures using embedded viscoelastic damping treatments, *AIDAA Congress*, Milan, June 29-July 3, (2009).

13 Jones D. I. G. (2001). Handbook of Viscoelastic Vibration Damping. Whiley & Sons, New York, USA.

14 Vaicaitis, R. and Slazak, M., *Design of Sidewall Treatment For Cabin Noise Control of a Twin Engine Turboprop Aircraft*, NASA Contract Report 172245, Modern Analysis Inc., Ridgewood, New Jersey, December, (1983).

15 Carbone, A., Paonessa, A., Lecce, L. and Marulo, F. Cabin noise reduction for a new development turboprop commuter aircraft, *AGARD CP-366 on Aerodynamics and Acoustics of Propeller*, Toronto (1984).

16 Arena, M., De Fenza, A., Di Giulio, M., Paonessa, A. and Amoroso F. Progress in studying passive and active devices for fuselage noise reduction for next generation turboprop, *CEAS Aeronautical Journal*, (2017). doi: 10.1007/s13272-017-0242-7.

17 Sen Gupta, G. *Low frequency cabin noise reduction based on the intrinsic structural tuning concept*, NASA CR-145262, (1978).

18 Marulo, F., Lecce, L., Buono, G., Carbone, A. and Cianciaruso, M. Theoretical studies on frame applied dynamic absorbers to reduce cabin vibration and noise of turboprop aircraft, *L'AEROTEC. MISSILI SPAZIO*, **64**(4), 230–231, (1985).

19 Sollo, A., Lecce, L., Quaranta, V. and Doelman, N. Active Noise Control on ATR Fuselage Mock-Up by Piezoceramic Actuators, *4th AIAA/CEAS Aeroacoustics Conference*, (1998).

20 Paonessa, A., Sollo, A., Lecce, L. and Marulo, F. Optizimation of a System for the Reduction of Noise and Vibration inside a Turboprop Aircraft, *XI AIDAA Congress*, Forlì, (1991).

21 Viscardi, M., Leo, R.D. , Implementation of an Electronic Circuit for SSSA Control Approach of a Plate Type Element and Experimental Match with a Feed-Forward Approach, (2016) Archive of Mechanical Engineering, 63 (4), pp. 665-677.

22 Magliacano, D., Viscardi, M., Dimino, I., Concilio, A., Active vibration control by piezoceramic actuators of a car floor panel (2016) ICSV 2016 - 23rd International Congress on Sound and Vibration: From Ancient to Modern Acoustics, .