Innovative liner concept using friction powder for increasing of broadband noise absorption. Applications for broadband noise absorption in fan duct.

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Abstract. This paper presents research related influence of friction powders on enlarging the absorption band of acoustic liners used for reduction of tonal noise in fan duct of aero-engine. Kundt tube measurements done at COMOTI using fine powders (granules) made of various lightweight materials placed in the honeycomb cells of SDOF liners have shown a considerable broadening of the absorbed band of frequencies without a significant decreasing of absorption at the resonance frequency. Although the phenomenon is generally present for any type of powder, it was observed that for some powders the absorption is higher than for others. On the other hand, it was observed that the effect of the filling percentage of the cavity is important. Then, experiments done at the grazing flow facility of CNRS-Le Mans University have shown that the phenomenon is also present for high acoustic incident levels (up to 140dB) and M=0.13 while it still depends by the nature of powder material. The best results were obtained for the cork powder when the honeycomb is filled with powder at 66% of its height. For this material, the broadening of the transmission loss well was maximum. This phenomenon could be explained by the apparition of friction between powder granules which are taking place at very low scale consuming the noise power on a broader range of frequencies. It is supposed that the friction between the particles of powder have major influence because the best noise absorption was obtained for powders with a large distribution of particles’ dimensions while for particles with a small dimensional distribution (expanded polyester balls, for example) the transmission well broadening was smaller. The friction powders technology is simple and can be easily adapted to existing acoustic liner technologies with small manufacturing costs. This feature is conferred by the fact that powders can be easily poured in the honeycombs at the required height. The friction powder technology can be applied not only for the fan duct. In future, it could also be applied for reduction of jet noise reflected by pressure side of wing and for cabin noise reduction.

1. Introduction
As is well known, the need to reduce fuel consumption in jet engines applications has led to the adoption of engineering solutions that in recent decades have moved towards increasing the bypass ratio. Even if there are other important sources of noise, high-performance aircraft engines radiate noise through the fan both through the intake and exhaust area [1]. Solutions for reducing this noise are diversified and can be active or passive. One of the simplest passive methods for reducing fan noise is to use an acoustic liner. Usually, the acoustic liners are used for dissipation of aero-engine noise (reduction of certain frequencies) usually in the intake and bypass duct regions [2]. However, fan noise is a broadband noise. The present paper presents the result of research done in WP1-Reduction Technologies for Sound Radiation of European project ARTEM (Aircraft noise Reduction Technologies and related Environmental iM pact), Topic MG-1-2-2017, Call Identifier H2020-MG-2016-2017.
The main idea is that fine friction powders introduced in the acoustic liner cells should lead to changes in noise absorption characteristics of those acoustic liners (similar to porous metamaterials behaviour [3]). The experiments done using the Kundt tube shown that filling of honeycomb cells with various types of powders at certain percent of height much increases the noise absorption coefficient in broadband. The types of powders analyzed in the paper have the advantage that have a low weight (unlike the solution with glass beads proposed in [4]) and some of them can be waterproof. Subsequent experiments done in grazing flow shown that the transmission loss well width is much increased in broader band of frequencies while the maximum absorption at resonance frequency is about the same as in the case of empty acoustic liner. The conclusion is that using of this technology could lead in future to absorption of fan noise in broader band using these types of acoustic liners with low production costs.

2. The basis of concept
The action of sound on powders is known for a long time. This influence of sound on powders was observed by Kundt who obtained standing waves patterns in a horizontal glass tube containing a small quantity of cork powder when a sound was radiated into the tube. When the tube length was adjusted for resonance, the powder was accumulated in the nodes of the standing wave. While this method was mainly used for sound wavelength measurement, it shows the strong action of sound on powder particles.[5]

On the other hand, it is known that sound attenuation is used for dust concentration measurement in some current technologies [6]. Surprising, it was found that for reduction of reverberation, in the walls of in some old churches from Denmark and Sweden (15-16-th century) bottles made of glass filled with wood ash were [7]. These facts led to the idea that a special effect should happen when noise interacts with powder introduced in the acoustic liners leading to a more efficient noise absorption in the fan duct of aero-engines.

3. The basis of concept
A total of 17 materials were selected for testing in Kundt impedance tubes. These materials are: micanite, polyurethane, spheres of expanded polystyrene, cork, balsa wood, colophony resin, talcum, fomalux (plastic material), cinder, fluff of bird. A part of powders/granules were bought from market and others were produced using a fine milling machine. Some of these powders/granules are presented in Figure 2. The apparent density of tested powders is between 0.0032g/cm³ and 0.7072g/cm³ function of the nature of material.

![Figure 1. Resonance cavities full with ash found in the walls of old Danish and Swedish churches [7]](image1)

![Figure 2. Various types of powders selected by COMOTI for tests](image2)
3.1. Absorption measurements in impedance Kundt tubes

The dimensions of honeycomb test samples used for measurements in impedance tubes Kundt are: honeycomb (height - 35mm) (resonance height - 33.9mm), distance between honeycomb sides – 10 mm, thickness of honeycomb wall - 0.05mm (aluminum) honeycomb diameter of large samples - ΦL 100 mm, diameter of small samples - ΦS = 28 mm. The covers have the thickness - 0.5mm, hole diameter 1.9mm, porosity 28.5% (Figure 3).

![Figure 3. Example of sample used for noise absorption measurements in Kundt Impedance tubes](image1)

The small (Φ 28 mm) and large (Φ100 mm) test samples were manually filled with powders at 33%, 66% and 100% of height. One small and one large sample were kept empty being the base test samples for comparison. A total of 84 samples filled with powders in the indicated percent + 2 empty samples were prepared for measurements in the Kundt impedance tubes (the samples with Φ28 mm were prepared for frequencies in the range 500–6300 Hz and with Φ100 mm for frequencies in the range 100 to 1600Hz (Figure 4). On the basis of measurements results, 6 powders were selected as having a potential to be used on aircraft (Figure 5). The selection criteria were: maximum absorption of noise in broad band, minimum density of powder, low manufacturing costs and easy adaption of current manufacturing technology of acoustic liners for using these kinds of powders. These powders are balsa wood, cork (granulation p6), expanded polystyrene balls (1.3 and 2.3 mm in diameter) and grinded Fomalux (granulation P6). [Note: granulation P6 is the finest granulation produced by the used milling machine]

![Figure 4. Kundt tubes used for noise absorption measurements](image2)

![Figure 5. Powders with potential to be used on aircraft](image3)
Looking on these graphs one can see that noise absorption is high in broad band and depends by the nature of powders and the percent of honeycomb filling with powder.

3.2. The test samples for measurements in grazing flow at CNRS and results
All the 6 selected materials were tested in grazing flow at CNRS: Grinded balsa wood powder, grinded cork powder, $\Phi_{\text{med}} = 2.3\text{mm}$ expanded polystyrene balls, $\Phi_{\text{med}} = 1.3\text{mm}$ expanded polystyrene balls, grinded Fomalux powder and grinded fluff of bird. The air speed was set at a corresponding Mach 0.13. The filling percentage of the prismatic samples ranges from 33 to 100%.

The tests were performed by the CNRS researchers Thomas HUMBERT and Yves AUREGAN in the wind tunnel of CNRS. They did both arranging of powders in the prismatic honeycomb samples and the noise measurements in the wind tunnel. The geometry of prismatic sample and of the cover used during tests at CNRS is presented in Figure 6 and the CNRS wind tunnel is presented in Figure 7.

Figure 6. The geometry of cover and sample used for powder tests in grazing flow at CNRS

Figure 7. The CNRS wind tunnel for tests in grazing flow

The cover used for tests in grazing flow (holes diameter $\Phi 1.38$ mm, porosity 20%, thickness 1.08mm (material-steel, Figure 6) was preferred to the cover used during the Kundt tubes tests done in COMOTI (holes diameter $\Phi 1.8$ mm, porosity 28.5%, thickness # 0.7 mm (material-aluminum) because this cover was considered more rigid. Measurements shown that this change does not have a major influence to measurement results. The test conditions are presented in Figure 8. During tests, air speeds were $M=0$ and $M=0.13$.

Figure 8. CNRS test conditions

3.2.1. The effect of filling. The characteristics (Resistance, Reactance and Transmission) of samples when they were filled with cork powder at 66% and 100% of honeycomb height are presented in Figure 9. It was observed that Transmission increases when filling percentage of honeycomb with powder increases and that there are great differences between the values of Resistance for 66% filling and 100% filling and relatively small differences between the values of Reactance.
In the case of balsa powder one can better observe the effect of powder filling percentage which mainly consists in shifting the minimum transmission loss point to higher frequencies simultaneously with the enlarging the transmission loss well on a larger frequency field. Remarkable, the enlarging of transmission loss in broad band corresponds to the increased noise absorption in broad band measured in Kundt tubes at COMOTI (Figure 5).

The same effects were observed for Fomalux, too, i.e., extending of the transmission loss well to in broader frequency band and shifting of minimum value of transmission loss to higher frequencies (Figure 9). Similar to the first two presented powders, one can observe the correspondence between the measurements done in CNRS wind tunnel (Transmission loss) and the high valued of absorption coefficients measured in the Kundt tubes of COMOTI.

![Figure 9. The effect of honeycomb filling with cork powder on Resistance, Reactance and Transmission](image)

### 3.2.2. The effect of incident signal power

The characteristics (Resistance, Reactance and Transmission) of sample when it was filled with different powders at multiple percentages of honeycomb height and various signal powers (120, 130, 140dB) were excited in the flow duct are presented in Figure 10. It can be specified that the influence of signal power to the Transmission is not significant. In the case of Fomalux powder, the effect of the incident signal power in flow duct is low, too. Regarding filling with polystyrene balls, both for \( \Phi_{med} \) 1.3mm and \( \Phi_{med} \) 2.3 mm, when the honeycomb is filled at 66% of height, the effect of extending the Transmission well over a broader frequency field is much smaller than in the case of the rest of powders (Figure 10g and Figure 10h).
Looking at the figure 10, one can observe that shifting of the minimum value of Transmission is to lower frequencies than the case of empty liner. Such effect was observed only in the case of cork powder. In the rest of cases (balsa powder, Fomalux powder and expanded polystyrene balls, Φmed2.3mm and Φmed1.3mm, the minimum value of Transmission is to higher frequencies than the case of empty liner. The effect of enlarging the transmission well over a broader field of frequencies is also present.

a) 100% cork powder

b) 33% balsa powder
c) 66% balsa powder
d) 100% balsa powder
e) 33% Fomalux powder
f) 66% Fomalux powder
g) 66% 1.3mm polystyrene balls
h) 66% 2.3mm polystyrene balls
i) fluff of bird

Figure 10. The effect of incident signal power
3.2.3. Direct comparison between various powders. For a better image on the difference between some powders, the Resistance, Reactance and Transmission are presented on the same graphs for the case when 66% honeycomb height was filled with powder (Figure 11). One can remark the low values of Transmission for a very large range of frequencies in the case of cork, Fomalux and balsa-wood powders.

![Figure 11. Comparison of Resistance, Reactance and Transmission measured in grazing flow](image)

3.2.4. Comparison between various powders when a Kevlar mesh was added over the existing perforated cover for measuring the effect of porosity. For measuring the effect of porosity on Resistance, Reactance and Transmission, a Kevlar mesh was applied over the existing perforated cover. The measurements with Kevlar mesh applied over the existing perforated cover were done for samples filled at 33%, 66% and 100% of honeycomb height with balsa-wood powder (Figure 12a) and for the empty liner (Figure 12b). As observed by CNRS researchers, the decreasing of porosity does not reduce significantly the effect of powder, enlarging even more the transmission well over a broader band of frequencies.

![Figure 12. Values of Resistance, Reactance and Transmission measured in grazing flow at CNRS](image)

4. Conclusions and recommendations
The measurements shown that friction between powder granules should be a cause of the increasing the noise absorption by the acoustic liners filled with various powders at certain percentage of honeycomb height. The nature of material and dimensions of granules seems to be important. Really, in the case of expanded polystyrene balls which have about equal dimensions, the noise absorption in broad band (Transmission loss enlarging) is much smaller than in the case of the rest of powders because the number of contact points between the particles is small. Using of friction powder inside acoustic liners leads to:

- extending the transmission well over a broader frequency;
- shifting of the minimum value of Transmission well to higher frequencies in the case of balsa powder, Fomalux powder and polystyrene...
balls (Ф 1.3 and Ф 2.3 mm); - shifting of the minimum value of transmission well to lower frequencies in the case of fluff of bird powder and cork powder.

It can be evaluated that the absorption of noise is influenced by the irregularity of shape and the large variation of dimensions. Resistance, Reactance and Transmission depends by the nature of material. The influence on Resistance, Reactance and Transmission depends by the percentage of filling with powder of honeycomb combined with the nature of material: -Increasing the filling % induces greater Resistance (more losses in the material) and lower Reactance due to the smaller and smaller cavities; - Reactance lowering induces enlarging of the Transmission well; -Although increasing of Resistance leads to less absorption, it can be advantageous in practical applications depending by duct size.

It was observed that the smaller grains, the larger the Resistance. The small grain powders (cork and balsa-wood) have an increase impact on Reactance. Effect of expanded polystyrene balls is small in comparison with other powders. The influence of incident signal power is not significant. In the case of cork powder, increasing of reactance leads to a relatively constant low Transmission in a broad band being interesting to continue the investigation of the cause which generate this effect. The decreasing of cover porosity does not reduce significantly the effect of powder, enlarging even more the transmission well over a broader band of frequencies (effect simulated by Kevlar mesh applying over the existing perforated cover).

The cork can be considered the best powder suited for application on aircraft although balsa-wood and Fomalux are good too. It is recommended to: - continue the investigation of the phenomena which are taking place in the case of cork powder; - investigate the possibility to increase the absorption of cork powder at low frequencies; -develop the technology which could be used by companies for manufacturing the structures containing friction powders.

5. References
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