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Experimental Acoustic Testing Of Alternative Ventilation Ducts

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ABSTRACT

Ducts of alternative materials to galvanised steel, are widely employed in residential buildings' mechanical ventilation systems in a bid to comply with the conservation of energy regulations in circumstances that prevent the use of natural ventilation.

The noise transfer predictions of systems with alternative ducts are still being based on data for galvanised steel due to the lack of acoustic performance data of alternative ventilation ducts tested in controlled conditions. To close this knowledge gap, a test rig was designed and built based on the test set up defined in ISO 7235. Alternative ventilation ducts and associated 90º bend samples were acoustically tested in controlled laboratory conditions utilising customized test rig developed to suit typically small duct profiles of alternative ventilation ducts. Test samples were tested using two methods: the substitution principle as outlined in BS EN ISO 7235 (2009) as well as applying a novel "zero substitution" conceptual approach.

The preliminary results of the "zero substitution" approach tests show indication of its validity.

1. INTRODUCTION

Ducts of alternative materials to galvanised steel, are widely employed in residential buildings' mechanical ventilation systems in a bid to comply with the conservation of energy regulations [1] in circumstances that prevent the use of natural ventilation. The noise transfer predictions of systems with alternative ducts are still being based on data for galvanised steel due to the lack of acoustic performance data of alternative ventilation ducts tested in controlled conditions [2].

To close this knowledge gap a programme of experimental tests was devised, involving the review of existing and relevant test procedures [3] creation of a dedicated test rig and the implementation of a series of laboratory based measurements. This paper aims to inform on progress to date on the experimental testing processes implemented and the conceptual stage of a novel test procedure approach.

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2. EXPERIMENTAL TESTING OVERVIEW

Samples of ventilation ducts of alternative materials (plastic and polystyrene) of straight and associated 90º bend configurations were acoustically tested in controlled laboratory conditions. The samples were representative of ducts employed in the residential ventilation industry.

Sound transmission loss and aerodynamic performance were investigated by means of experimental measurements utilising the substitution principle as outlined in ISO 7235 [4] test procedure.

The conceptual stage of a novel and alternate test procedure named as "zero substitution" was developed and preliminary validation tests were undertaken. A custom-built portable test rig was constructed to enable a comprehensive set of investigative tests in an acoustics laboratory.

3. STANDARDISED TEST PROCEDURE ISO 7235

This international standard provides guidance for laboratory testing procedures for determining the insertion loss, flow noise and total pressure loss for ducted silencers and air-terminal units utilizing the substitution principle. Following this method, the sound pressure levels (SPL) of the transmitted sound source are firstly obtained for the test sample and then the sample is replaced by the substitution piece and the SPL are measured again. The arithmetic difference between the two measurements represents the insertion loss of the tested sample. The measurements of the SPL can be made in a reverberation room, induct - in the test duct before and after the tested sample and also in the free field.

The test set up that follows the aforementioned standard as found at Lindab [5] and other testing facilities [6], [7], has elements on a large scale permanently fixed across many rooms allowing testing of ducted silencers and air-terminal units of large sizes. In the UK and mainland Europe it is the main testing procedure to obtain the performance of the passive type of silencers used in ventilation systems.

4. THE TEST RIG

The design of the test rig was based on the test set-up described in the ISO 7235 [4]. The alternative ventilation ducts typically used within residential ventilation have small profiles such as the rectangular ducts 220x90mm, 204x60mm, and the circular ducts with 150mm diameter and 125mm diameter meaning that a smaller, scaled down version of the traditional test set up would be better suited for conducting acoustic testing of the same. Furthermore, small test rig elements permitted the built up of the test rig in a compact as well as portable format.

The initial idea of having all rig elements in a long horizontal in-line format was abandoned for the vertical stack up formation (Figure 1). This compacted option, compared to the horizontal in-line approach, reduced floor footprint, prevented movement of individual test rig elements, reduced the number of uncertainty factors and provided good accessibility for the monitoring of different parts and sections.

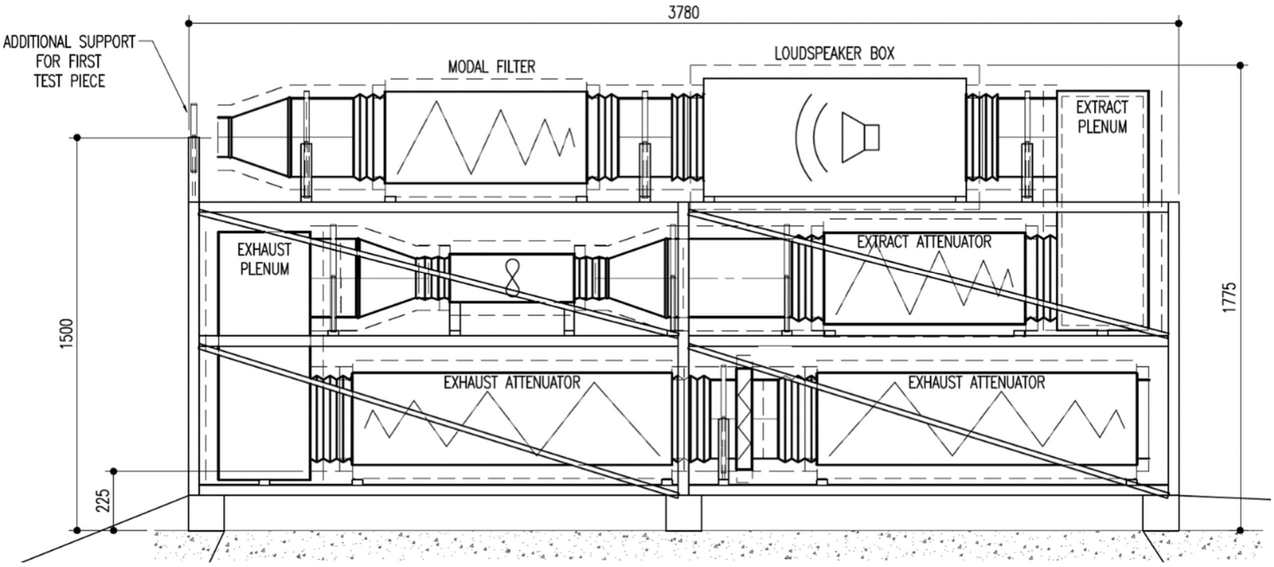

Figure 1 Test rig vertical stack up design side view

The test rig frame was made from 40x40mm Unistrut bars to keep the weight of the rig as low as possible. Rubber pads were installed between every bar connection for vibration isolation. The additional corners and reinforcement sidebars were added to enhance the strength and sturdiness of the frame and minimize unwanted re-radiated noise emissions.

Wheels were installed at each corner and in the middle sections of the rig frame to enable easy movement of the entire rig. Flexible connections were fitted between all air handling components to further control the propagation of structure borne noise and vibration. Tuned anti-vibration mounts were fitted on the extract fan's installation. The vibration isolation scheme was completed with the installation of selected rubber and foam pads applied underneath all other elements resting or connected to the rig frame.

The main elements that were installed in the building of the test rig included the modal filter, loudspeaker box, extract fan plus extract and exhaust attenuators and the selection of the duct connection pieces.

The modal filter selected for the test rig and as noted in ISO 7235 [4] was sized to have longitudinal attenuation of the fundamental mode of at least 3dB at the low frequency end and of 5dB above the cut-on frequency selected for higher order modes in the connected ducts.

Following the recommendation of the standard, the loudspeaker box was made of a large volume (1m L x 1m W x 0.4m D) with a 5:1 ratio between its cross-sectional area and the test duct (300mm dia / 150mm dia). In order to provide a high level of sound insulation, all sides of the loudspeaker box were made from 50mm double-skinned metal panels with 1.5mm steel skins.

One side was designed to be removable to allow access to the loudspeaker. All the sides of the box were cladded with a heavy mass damping layer to further avoid sound breakout, panel resonances and noise re-radiation from the box sides. Two small holes sealed with grommets were fitted for the audio signal and power cables to feed the self-amplified loudspeaker. The loudspeaker installed in the box was an 80W (RMS) studio quality unit capable to radiate a flat frequency response between 50Hz and 10kHz. Sound absorbent open cell polyurethane foam of 25mm thickness was used to line the inside of the loudspeaker box to prevent in-box resonances and unwanted buildup of reverberant sound.

The inline extract fan S2E-200 was selected and installed on the rig capable of doing a wide range of duties inclusive of high air volumes associated with overheating circumstances. A multi-leaf damper was introduced on the exhaust side between the two exhaust attenuators to create adequate system resistance when required.

An exhaust fan attenuator was selected to prevent/avoid the fan's outlet sound power levels detrimentally increasing the overall background noise within the main acoustic laboratory housing the test rig. To satisfy this condition the exhaust attenuator had to be long and hence was installed in two sections to fit the confines of the frame.

The size of the connecting sections of ducts between the main elements of the test rig, such as the loudspeaker box and the modal filter, has been selected of the large size as to assist with choosing the extract fan and modal filter and to avoid potential turbulence during dynamic tests at the bends and connecting sections. Furthermore, the plenums were employed rather than bends on either side of the extract fan. In this way, the airflow velocity in the system was reduced to 1.6m/s when testing at the highest air flow volume, see Figure 2.

Figure 2 Test rig at the factory before it was cladded with acoustic insulation

Acoustic cladding material of 10kg/m^2 superficial density was selected for covering all the test rig elements and duct pieces (Figure 3) to prevent rig sound breakout from increasing the laboratory room background noise which could in turn the break into the duct sample under test and feedback into the test rig via exhaust and inlet openings.

Three free standing supports were used to hold the test set up elements not part of the test rig. One support was used to hold the attenuator installed at the make up air hole made in the wall of the reverberation chamber. Second support was used to hold the transmission duct section formed by the duct element between the test sample and the reverberation chamber and the third support was used to hold the first duct section (duct element after the modal filter and the test sample) (see figure 4). During the testing sessions, the test sample was positioned above a hard board that replicates the hard ceiling in a real-world installation. Figure 3 shows the cladded test rig in its unconnected stand-alone form viewed from the side (left) and from the back (right).

Figure 3 Left: cladded test rig, Right: test rig in the main acoustic laboratory space

5. TEST FACILITY

London South Bank University (LSBU) possess a reverberation chamber of 202m^3, suitable for acoustic testing to ISO 3741[8] standard. In order to fulfil the conditions of the standard and connect the sample arrangement to a reverberant room, two 200mm diameter holes were made in the wall separating the main acoustic laboratory area and the reverberation chamber. One hole was used to connect the test set up and through which the sound signal was delivered to the reverberation chamber from the test rig when doing static tests (using loudspeaker as a sound source) and through which the air was extracted when doing dynamic tests. The second hole was needed for the make up air when doing dynamic tests. The main acoustic laboratory area housing the test rig is a large laboratory control room (see Figure 3 right) of semi reverberant characteristics and 524m^3 volume.

6. CUSTOMISED TEST PROCEDURE AND IMPLEMENTATION

In a systematic review of relevant standardised testing methods [3], it was found that no specific test procedure exists for the purpose of determining the acoustic characteristics of alternative ventilation ducts and their ancillaries. A customized test procedure was developed to suit testing of generally small duct profiles of alternative ventilation ducts based on the most relevant and applicable standardised test procedures available by adopting one of the existing testing principles and modifying it.

The sound generated by the test rig positioned within the main acoustic laboratory propagated via the test sample, connecting parts and through the wall hole and was measured within the reverberation chamber. ~~Figure 4~~ below shows the full test set-up within LSBU main acoustic laboratory and adjacent reverberation chamber with the test sample in position to be tested and the Figure 5 test set when following the zero substitution approach/substitution principle described in section 7.

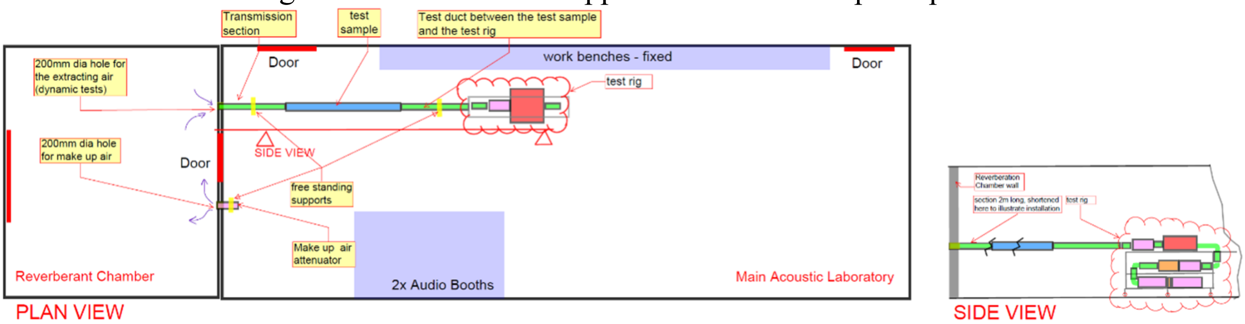

Figure 4 Test set up with the test sample in place

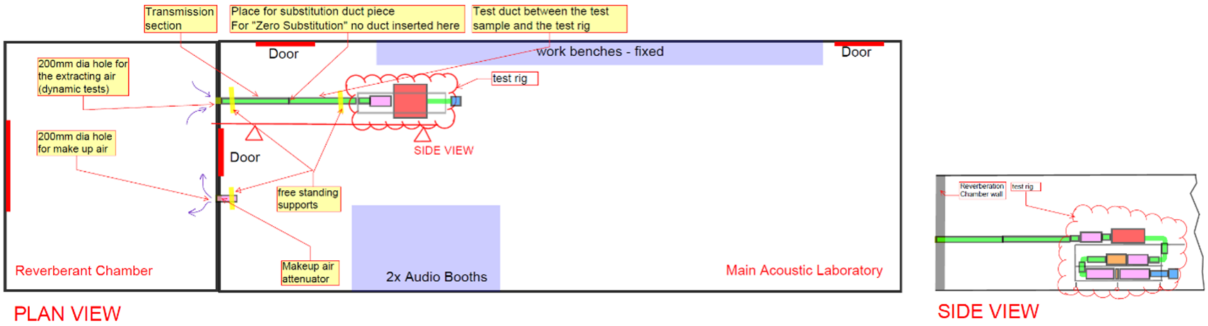

Figure 5 Test Set up for zero substitution approach test/substitution principle test

The ventilation duct sample test sizes selected were four of the most used plastic duct profiles in UK residential installations: 220x90mm, 204x60mm, 150mm and 125mm diameter and were supplied from three UK leading manufacturers with the intention to evaluate potential sample variability.

The straight sections of duct samples were tested using two methods. The first method followed ISO 7235 [4] standard and applied the substitution principle as described earlier in Section 3. A 3mm thick internally polished galvanised steel duct was used as a substitution piece for testing rectangular profiles of 200x90mm and 204x60mm and a 2mm thick stainless steel duct for testing circular profiles of 150mm and 125mm diameter. The second testing method employed followed the zero substitution approach explained below.

7. THE ZERO SUBSTITUTION APPROACH

ISO 7235 [4] test procedure is generally used for measuring insertion losses of silencers that have very high insertion losses – the key attribute of their performance. This standard includes the use of a substitution piece, a duct element with non-absorbing walls designed to avoid breakout of airborne sound and transmission of structure-borne sound. The arithmetic difference of sound power levels (obtained from measured SPL in the reverberation chamber) between the test sample and substitution piece (usually this is a high difference) would not affect the value of the silencer's overall insertion loss.

The main characteristic of this alternative test method is that it does not use the substitution piece prescribed in ISO 7235 [4]. This approach consists of two tests: one with the test sample in position and the second one with the test sample removed. The test rig is wheeled forward to close the gap left by the removal of test sample in the transmission section. This is an innovative and alternative testing concept used in this research for the first time and is currently in its preliminary development stage.

Alternative ventilation ducts on the other hand were expected to have comparatively much lower insertion losses than silencers. Hence it is hypothesized that the acoustic properties of alternative ducts would not be clearly determined through the substitution principle method as it involves subtraction of the sound levels of a duct element (substitution piece). It should be noted that the substitution piece is expected to have non-absorbing walls, in reality would have some inherent insertion loss potentially in the range of the alternative ventilation ducts. Therefore by applying the "zero substitution" approach and eliminating the subtraction with a substitution piece it was expected to obtain data that is purely due to the performance of the test sample itself.

8. TWO METHODS

For the calculation of transmission loss using any of the two methods, two sets of SPL measurements were taken in the reverberation chamber (in accordance with ISO 3741 [8]): set 1 with the test sample) see Figure 4 and set 2 employing either the substitution piece in the place when following ISO 7235 [4] or the absence of the test sample in the sound path in the case of following the "zero substitution" approach, see Figure 5.

The sound power level (Lw) based on the two measured SPL sets were determined following ISO 3741 [8] procedure which involved the calculation of the equivalent absorption area of the reverberation room.

The insertion loss (D_i) in decibels (dB) of the tested sample (see equation 1) was obtained by deducting arithmetically the sound power level obtained when the test sample was in the sound path (L_{WI}) from the sound power level obtained when the substitution piece or zero substitution was applied (L_{WII}),

$$Di = L_{WII} - L_{WI} \quad (1)$$

It should be noted that for measurements conducted in line with ISO 7235 [4], the standard states that the insertion loss of the silencer is equal to its transmission loss.

Making the relation to the alternative ventilation duct samples, the insertion loss of the test sample obtained through the testing represents the overall sound attenuating effect of the test sample when used in the ventilation system. The overall effect is made up of the breakout element – sound energy transmitting through the duct walls and the transmission element that occurs as the sound travels down the length of the duct.

Following existing industry guidance [9] for the acoustic performance of the ventilation ducts, the naming convention of using the term "attenuation per meter" will be adopted for the straight duct sections and "attenuation" for bends.

The majority of the acoustic tests conducted were of the static type, utilising a loudspeaker within the loudspeaker box as a sound source.

A range of dynamic tests using a fan as the sound source to also create airflow were carried out with the purpose to validate the use of the alternative ventilation ducts for overheating scenarios when high ventilation flow rates need to be utilised with the consequently higher duct velocities and aero dynamic noise. For these tests, the fan in the test rig was set up to extract air from the reverberation chamber with the intake air coming via the make up air hole in the wall. This make up air hole had an attenuator fitted to prevent noise from the main laboratory area from entering the reverberation chamber and vice versa, see Figures 4 and 5.

The dynamic test of the straight duct samples were measured employing the two methods as explained in section 7 for static testing. For each sample, dynamic tests were carried out using a range of air velocities with the intention to explore the acoustic behaviour of the alternative ventilation ducts in the circumstances of the overheating scenarios when higher air volumes and the higher air velocities exist in the ventilation system. In specific, air velocities of 4m/s, 6m/s, 8m/s and 10m/s were used to cover amply and exceed duct velocities likely to occur in the overheating scenario.

Static and dynamic tests for 90^0 bends sample ducts were identical as for the straight duct samples with the exception that no substitution samples were available; enabling only data to be obtained through the "zero substitution" approach.

The next stage of the project will involve the post processing, analysis and review of the experimental test data obtained and validation of the zero substitution approach.

9. CONCLUSIONS

A bespoke test rig was designed and built based on the test set up defined in ISO 7235 [4]. Small test sample profiles permitted having smaller version of the traditional test set up with all rig elements set up in the vertical stack up formation.

Test facility at London South Bank University has been set up to suit the test rig and subsequent acoustic testing to ISO 3741 [8].

A customized test procedure was developed to suit the test rig and explorative testing of typical alternative ventilation duct profiles utilising the standarised substitution principle and the innovative zero substitution approach.

The zero substitution approach has been devised in its conceptual stage and preliminary results show indications of its validity. Further validation tests will be conducted in the next stages of the research.

10. ACKNOWLEDGEMENTS

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