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Computational Fluid Dynamics Models Combined with Acoustical Models to Design Accurate Solutions to Reduce Noise Emission through Underground Railway Ventilation Systems

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ABSTRACT

Acoustics solutions are frequently dependant on ventilation working conditions requirements. Hence, the growing possibilities to practical use of computational fluid dynamics (CFD) models justifies its incorporation to the acoustics studies in order to get a more accurate and multidisciplinary assessment of the real situations, considering the different variables relevant to the solution projects.

This paper presents the methodology applied to find accurate acoustical solutions to solve the noise annoyance generated due to the underground train noise emitted outside, propagated along big ducts aimed to fulfil the ventilation needs in emergency situations. The design phase to guarantee the best solutions, requires the combination of outdoor and indoor acoustic models, adjusting the indoor model to some relative complex "rooms" with specifically planned acoustics measurements, combined with the CFD models for each ventilation system.

During the study different alternatives have been analysed, looking for the most optimum solution for each case study, including a cost analysis, assuring that the minimum required noise attenuation are reached while maintaining the specified ventilation conditions. Furthermore the solutions have to secure that no additional risks appear in case of an emergency situation besides its practical execution due to access limitations.

Keywords: Acoustic, Solutions, CFD
I-INCE Classification of Subject Number: 06, 02

1. INTRODUCTION

Noise sources generated by fluids are quite relevant in the industry, but also in different situations related with noise in the environment or in buildings. To be able to evaluate theses sources it is important to understand how the noise is created or affected by the fluid, especially to improve the design phase in order to reduce the main effects that are generating the noise and to avoid that the acoustics solutions do not respect the needed flow conditions.

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Sometimes it is the own fluid that generates the noise due to its behaviour, while in other cases a duct, which in some situations could have an internal flow, is the path where noise propagates, connecting a noisy place or machine with another place that could have a higher sensitivity to the noise.

Regarding the first scenario, it would be vital to understand how the fluid behaves and identify the origin and main causes where the noise is generated in order to be able to find the most effective solution design.

However the second case is completely different, and hence the solution study needs a different approach. Generally the solutions introduced in such a problematic affect directly to the internal flow of the conduct, since it usually tends to reduce the duct area with different types of acoustic barriers, and therefore the pressure loss induced by the acoustic solutions has to be verify in order to assure that the minimum ventilation operation conditions are satisfied.

In order to have the technical basis for the analysis of the above mentioned problematics and to define supported solutions, a precise study of the fluid must be made using Computational Fluid Dynamics (CFD) models, which relevance is growing as part of the global acoustics studies, to have a complete assessment and increase the accuracy in many noise problems generated by fluids.

CFD simulations are able to analyse how the design or noise reduction solutions are affecting to the fluid behaviour and are also able to identify when the fluid is itself a noise source, offering valuable information on how the solutions integrates in the system. There are many scenarios where acoustics methods and models and CFD should be combined to really have an adequate knowledge for a specific study case.

This paper presents the case of an underground railway line where noise is propagated outside through the emergency ventilation conduct. The emergency ventilation system must be able to remove the air or smoke in the railway tunnel and in the underground stations through the ventilation conduct which counts with two fans. Generally this fans don't work, and only get into operation during the periodic maintenance checks, in order to assure that everything is working perfectly in case they have an emergency.

The emergency duct has quite big dimensions to provide an effective ventilation flow in case of an emergency and, of course, this ventilation tunnel is connecting the underground railway tunnel with the outside environment above the underground train, being such a tunnel a perfect path where pass-by train noise propagates to the residential area, producing annoyance in the nearest dwellings of the urban environment.

To solve this situation in three ventilation tunnels with different shapes, characteristics and length, AAC combined acoustics methods (measurements and models) with the application of CFD to each specific case.

2. METHODOLOGY

To reduce the noise emission in the exterior ventilation grill, the solution was to introduce along the ventilation tunnel different noise attenuation elements which reduce the propagation along the tunnel, but considering that any obstacle to the flow will generate a pressure loss in addition to other effects on the fluid behaviour which will have a direct repercussion on the working conditions. Here is where CFD plays a major role in the project.

From the CFD point of view, the methodology of the project followed the succeeding steps:

1. Develop an accurate model of the actual situation with the help of a 3D software, which will then be imported into the CFD analysis.

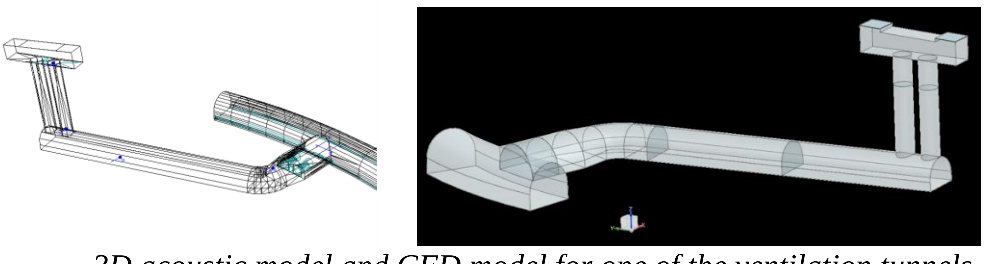
2. Preliminary CFD study of the most critical sections that require a very small cell size, in order to simplify the real model substituting these elements for an equivalent filter reducing the needed cell number for the whole project and hence the computational power and calculation time, to be acceptable to the project time schedule without losing the required accuracy.
3. CFD simulation of the whole ventilation system of the actual situation, using the simplified filter result from the above mentioned step. After analysing the result, it will be possible to define the maximum pressure loss the system could support in order to satisfy the minimum operating conditions.
4. Based on the flow analysis along the actual conduct, some conditioners are stated, which will have to be consider during the solution design phase.
5. Introduction of the different solutions designs in the actual 3D model.
6. CFD study of various scenarios which will state which solutions are affordable and which exceed the aforementioned maximum pressure loss.

The same study has been completed for each of the three specific ventilations, since dealing with different conduct geometries the conclusion from one study is not applicable to the other situations. Consequently, assuring that the CFD study represents faithfully the real scenario and how the acoustics solutions disturbs the flow behaviour in order to conclude whether if they are valid or not after post-processing the results.

To define the solutions AAC combined measurements, to describe the noise arriving to the ventilation tunnel from the train pass by, the propagation along the tunnel and the sound power at the outside grill, which is used as the noise source to assess the noise levels in the residential area.

With the measurements, the acoustics models for indoor and outdoor propagation were adjusted to the existing situation, providing the reference to assess the acoustic effectivity of the different alternatives for solutions and generating the tools for each ventilation tunnel to carry out the studies to design the solution focusing in reducing enough the noise levels in the most exposed dwellings.

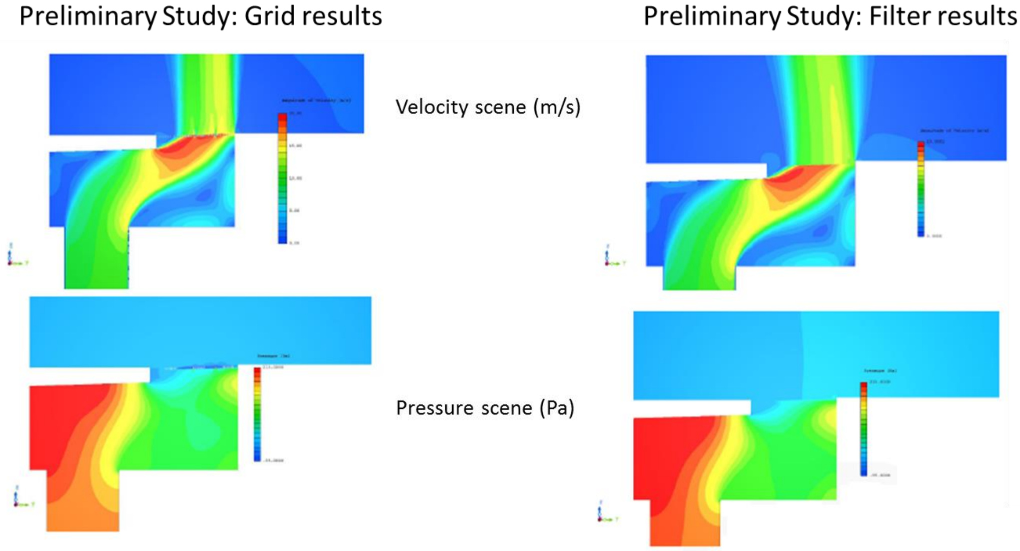
Pictures describing the situations



3D acoustic model and CFD model for one of the ventilation tunnels

The study for possible alternatives combines acoustic models and CFD, looking for the most optimum solution for each case study, including a cost analysis, assuring that the minimum required noise attenuation is reached while maintaining the specified flow conditions at each of the ventilations systems.

Furthermore the studied solutions have to secure that no additional risks appear in case of an emergency situation, which added additional requirements to the design phase. Besides the consideration of the limitations during the practical execution of the solutions due to access restrictions to introduce the needed tools and materials to build the final solution in the ventilation tunnels.

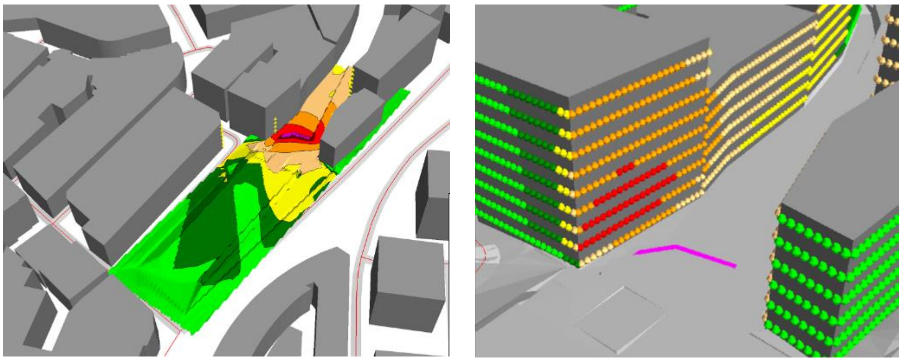


Example of preliminary CFD study at critical areas of the system to simplify the model: at the left the results obtained using the real grid model and at the right the results for the same scenario but replacing the grid for a filter.

Due to the combination of both, acoustic and CFD, analyses, the final solutions were optimized to reach the maximum noise attenuation with respect to the cost study together with the minimum incidence on the ventilation systems, assuring that once the solutions are implemented in all three conducts the minimum operation conditions are satisfied .

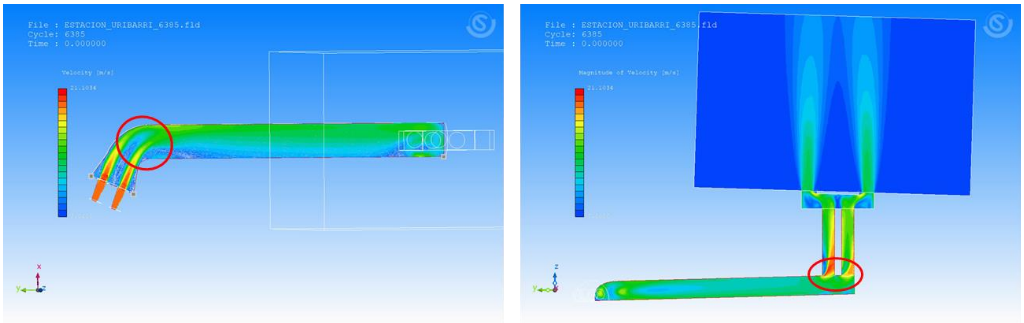
3. RESULTS

Based on the environmental noise assessment in each residential area the attenuation requirements for the outdoors grills sound power in each ventilation tunnels was defined. These attenuations were taken as references for the solution studies inside the tunnels, combining indoor acoustic analysis model and CFD.



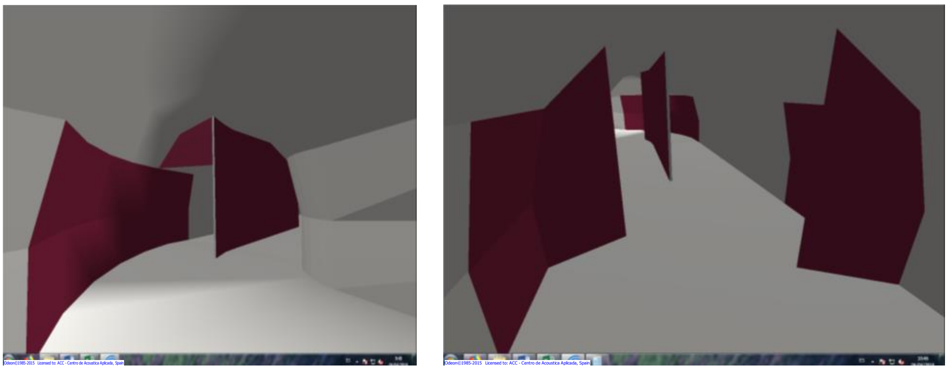
Example of outdoors noise levels studies

A procedure was developed for the selection and study of possible solutions types: barriers, absorption panels, etc. where CFD calculations were considered as the key reference to decide the geometry, position and dimensions of the solutions based on the maximum pressure loss calculated after post-processing the present scenario simulation.

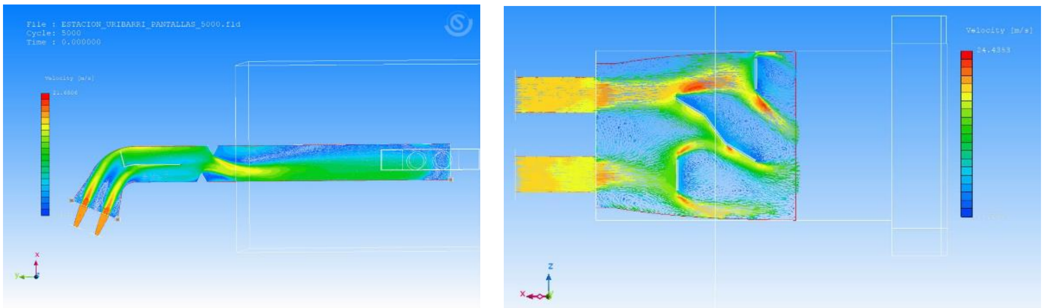


Examples of areas of interest that could be considered from the actual situation when designing the solutions.

The study procedure was based on AAC experience to propose different alternatives, doing general assessment on the acoustics and the CFD side, in order to select the best type of solutions and the main factors to consider in each case, in order to get practical analyses to arrive to the best solutions. An important part of the study is to reduce calculation time on CFD models without losing relevant data or calculation accuracy that could have incidence on the results.

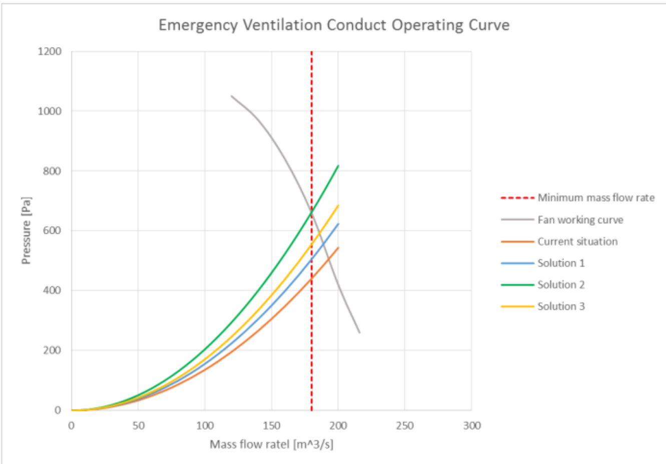


Some of the possible solutions analysed with acoustics and CFD models



Example of the CFD study in a tunnel with solutions

After verifying in the acoustic model that the solutions behave in the expected manner and present an attenuation level similar to the estimated one, the 3D model with the solutions is imported into the CFD to assure that the new entire system is still working inside the optimum operating condition range. After post-processing the results, the following plot has been created in order to compare the pressure loss each solution has generated and conclude which ones are feasible and which ones don't. From the plot it can be seen how the pressure along the conduct has increased for the solution cases with respect to the actual situation. This is mainly due to the pressure loss that generates all the obstacles along the conduct.



Effect of the acoustics solutions on the pressure of the system and hence the pressure loss.

Solution 1 and 3 form the plot satisfy the minimum working condition and therefore the solution with the best effectiveness to cost ratio will be considered while solution 2 has been rejected since it slightly exceeds the maximum working point the conduct supports, meaning that the system would not be able to evacuate sufficiently in case of an emergency situation.

4. CONCLUSIONS

Due to the combination of acoustics methodologies (measurements and models) with CFD it was possible to obtain a technically supported solution in the three ventilation tunnels. As frequently happens, acoustic studies must consider also other variables to get representative results and conclusions.

Acoustics and CFD models together allowed to efficiently design solutions, adjusting them to the best relationship between costs and benefits, including the lower incidence of the solutions in the flow and consequently reducing the risk of not satisfying the minimum operating conditions of the emergency ventilation system.

The integration of CFD models on daily acoustics problems is justified because having a CFD study proportionates in many cases the needed tools, in order to acquire the knowledge to understand how the noise is generated or propagated. This allows a more accurate assessment, including different variables that specific noise software don't take into account and hence proportionating an optimized solution for each case, while reducing the cost considerably.

This study also highlights the importance of introducing CFD analysis when dealing with both external and internal flow in various situations: developing new products in the early design stage to reduce production costs or, in the other hand, in existing scenarios where action measures have to be taken to solve a specific problem. This is applicable to a large variety of fields such as: product developments, installations, automotive sector, wind turbine blades, etc.

5. ACKNOWLEDGEMENTS

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