Application of Aero-Acoustic Analogy to Industrial problems

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1. Introduction

Due to the expertise built in the vibro-acoustic area and the structure borne noise reduction, flow-induced noise is becoming more and more a critical parameter in high-performance designs in automotive, aeronautic/aerospace and turbomachinery application and constitutes one of the major noise sources the industrials have to face. Different methods are used to predict this phenomenon. The direct approach solves acoustic and flow field at the same time using Navier-Stokes (NS) equations, but becomes problematic in high Reynolds number turbulent flows, due to computer limitations and poor accuracy. A more pragmatic approach is predicting flow and acoustics separately, using the Aero-acoustic Analogy methodology (Lighthill, Ffowcs Williams- Hawkings), where the NS equations are rearranged to yield the wave operator with on the right hand side aero-acoustic sources that are the converted outcome of CFD simulation. Based on this methodology, LMS International is extending his vibro-acoustic software SYSNOISE and developing interfaces with major CFD codes.

Different test cases ranging from academic to industrial have been considered for the validation of the software. In this paper, the sound emitted from a strut in a turbulent flow coming from a nozzle-jet are presented and discussed as part of ALESSIA results.

2. The methodology

The approach used in this paper is based on a generalised form of Lighthill (Ffowcs Williams & Hawkings) [1,2,3,4] acoustic analogy where Navier-Stokes equations have been re-written under the form:

$$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2}-\frac{\partial^2 p}{\partial x_i \partial x_j}=\frac{\partial \dot{Q}}{\partial t}-\frac{\partial F_i}{\partial x_i}+\frac{\partial^2 T_{ij}}{\partial x_i \partial x_j} \qquad (1)$$

The source terms on the r.h.s. of the equation are obtained from a CFD computation that provides time series of the flow pressure and velocity. Next the flow data are transformed into frequency domain and used within SYSNOISE to predict the noise.

3. Sound emission from a thin strut in a turbulent flow

Within ALESSIA, the methodology was applied to different test cases ranging from academic to industrial.

In this paper, the sound emanated from an airfoil fixed in a turbulent flow of finite lateral extent is considered. This example is of a great interest because it relates to the broadband sound emission from flap segments under the wings of aircraft, struts and splitters etc…

The configuration and the dimensions for the CFD simulation are described below:

Nozzle diameter:	Nd = 0.1m
Nozzle Length:	Nl = 0.3 m
Strut Span	Ss = 0.6 m
Strut Chord	Sc = 0.04 m
Domain Dimension	L x W x H = 2.4x0.6x0.5

A tetrahedral mesh was used with a total number of elements of 183031. A velocity boundary condition (U = 90 m/s) was set on the inlet side of the nozzle. Periodic boundary conditions were imposed in the orthogonal strut direction and relative pressure zero was set on the outlet side of the domain.

The turbulent viscosity on the walls was weighted with the Van Driest wall damping

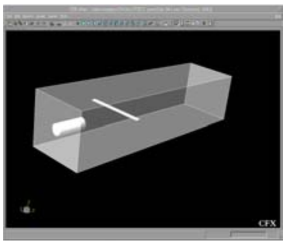
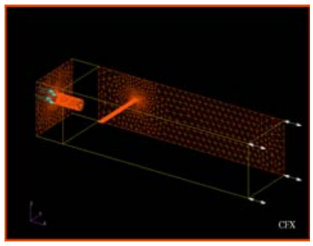



Figure 1. Block structure of the simulation domain for calculating the flow around the strut. CFX5.5.
Figure 2. Fluid dynamic mesh and boundary conditions. CFX5.5

Figures 3 and 4 represent the flow velocity and show the influence of the strut on the jet propagation. Indeed the flow downstream the strut is turbulent and vertices are developed.

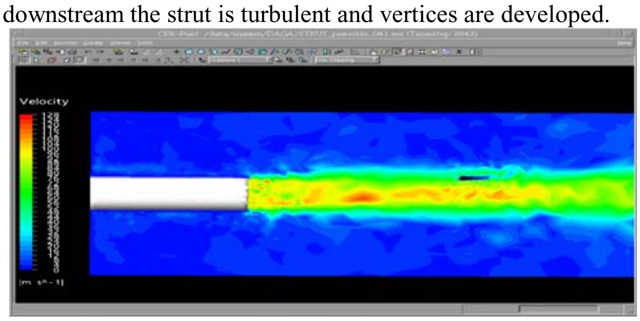


Figure 3 Flow Velocity. CFX5.5

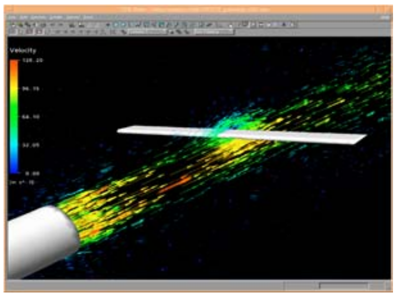
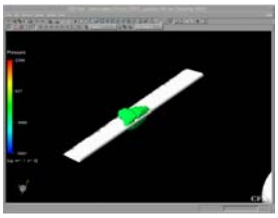


Figure 4. Flow Velocity. CFX5.5

Figure 5 shows a high-pressure level in the region of the strut located in the jet area (hot-spot region). For the acoustic simulation, it is very important to stress that identifying the hot-spot areas enables to reduce the number of equivalent sources that have to be taken into account, reducing therefore the computation time.



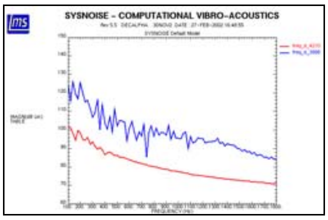
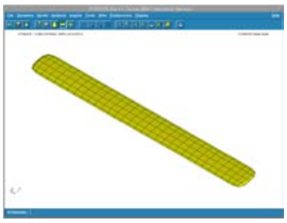


Figure 5 Hot-spot region on the strut. CFX5.5
Figure 6 Pressure fluctuation evaluated in the hot-spot region and away from it. SYSNOISE Rev5.6

To compute the radiated noise, the time fluctuating pressure has been transformed into frequency domain with SYSNOISE and equivalent dipole sources were defined on the strut (Figure 8). The DBEM module was used with 400 elements.
Figure 9 shows the radiated sound emanated from the strut at 280HZ. The dipole behaviour is well represented.



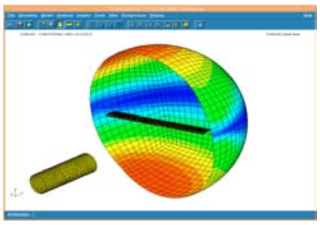
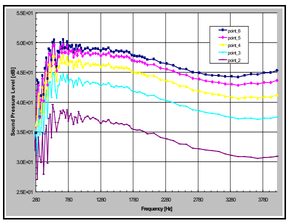


Figure 7 Dipoles distribution at 280 Hz on the acoustic mesh. SYSNOISE Rev5.6
Figure 8 Radiated sound from the strut at 280 Hz. SYSNOISE Rev5.6

The spectra of the SPL evaluated at different positions around the strut are plotted in Figure 14. The results show broadband noise behaviour between 450-950 Hz. The microphones are located 0.4 m away from the strut (microphone 1 being in front of the nozzle, Fig11).



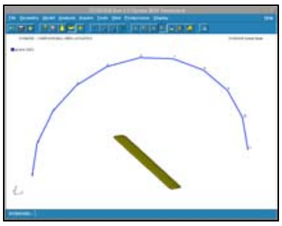


Figure 9 SPL spectrum at different positions. SYSNOISE Rev5.6
Figure 10 Microphone position around the strut. SYSNOISE Rev5.6

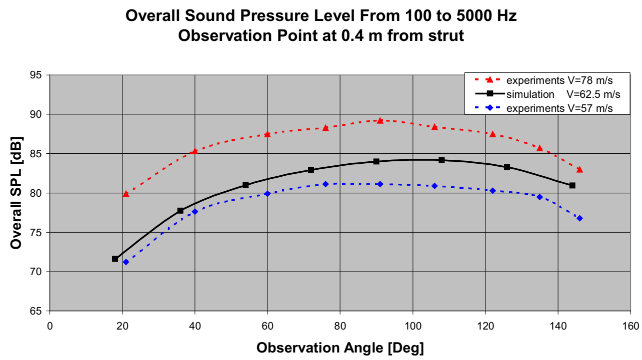


Figure 11 Comparison of overall SPL between numerical simulation and experimental measurements

A comparison of the overall SPL obtained with CFX/SYSNOISE coupling was made with the experiments. Figure 12 shows the numerical results obtained at an impingement velocity equal to 62.5m/s compared to the measurements carried out by W.A.Olsen [5] in the Lewis Research Center corresponding to impingement velocities equal to 78 m/s and 57m/s. The comparison shows a very good trend for the numerical results.

4. Conclusion and future work

In this paper, results have been presented on the noise radiation from a strut in a turbulent flow coming from a nozzle-jet. These results were obtained from the solution of the Ffowcs-Williams Hawkings analogy using the CFD software CFX5.5 coupled to the acoustic software SYSNOISE Rev5.6.
The LES results of CFX5.5 on the surface of the cylinder and the strut have been used to define the sources inside SYSNOISE and the radiated noise was calculated using the Direct Boundary Element Method.
Comparison of the results obtained for an impingement velocity equal to 62.5m/s (90m/s at the inlet) with the measurements carried out by W.A.Olsen [Ref] showed a very good trend.
For a better comparison of the results with the measurements and as a future work, it could be very interesting to re-do the simulation with an impingement velocity of 57m/s or 78m/s.

References

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