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ACOUSTIC NOISE GENERATED FROM A HEATED CYLINDER IN MIXED CONVECTION

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Abstract. This work presents a hybrid aeroacoustic methodology which couples a CFD solver, to resolve the Navier-Stokes equations for the flow field, with a linearised acoustic solver, based on the acoustic perturbed equations, for the noise propagation. The framework is applied to investigate the effect of the mode E transition, which is typical of a heated cylinder in mixed convection regime, on the acoustic propagation.

1 INTRODUCTION

Transition to 3-D for a circular cylinder in cold flow has been observed for Reynolds numbers $180 \leq Re \leq 250$ [1, 2] (Re is based on the cylinder diameter and the incoming velocity). Two modes for the transition have then been identified. Mode A, which occurs up to $Re \approx 200$ is linked to instabilities of the primary core vortex of the von Kármán's vortex street. Mode B occurs at $Re > 200$ and is related to instabilities of the shear layer. However, in the case of a heated cylinder a new mode has been also observed [3], which is known as mode E, where transition occurs at lower Reynolds numbers (i.e. from $Re \approx 80$). In our earlier work [4] we have shown that the mode E transition is not only influenced by the Reynolds and Richardson numbers, but important roles are also played by the Prandtl number and the angle of attack of the incoming flow. The Prandtl number has a large influence on the Reynolds and Richardson numbers at which the transition occurs, whereas the angle of attack impairs, when positive, or enhances, when negative the chaotic behaviour of the 3-D flow.

The mode E transition has also an effect at higher Reynolds numbers, where transition is also naturally occurring for the cold flow (i.e. $Re \geq 200$). In the mixed convection regime, the effect of the buoyancy is to enhance the transition to turbulence, resulting in an almost fully turbulent state already for a relatively low Reynolds number (i.e. $Re = 250$) together with a Richardson number $Ri = Gr/Re^2 = 0.5$, with Gr being the Grashoff number. However, in comparison with with the forced convection regime the vortex shedding from the cylinder is largely affected, resulting in a different wake structure. Therefore the acoustic field generated by the vortex shedding is quite different from the conventional of cold flow and the subject to this paper investigation.

This work focuses on applying a hybrid aeroacoustic model, where an incompressible Navier-Stokes solver (i.e. *Code_Saturne* [7]) is coupled with a linearised acoustic solver (i.e. Nektar++ [8]) based on the acoustic perturbed equations (APE4) [5]. The coupling is performed using the Multiscale Universal Interface (MUI) [6], which handles the transfer of the noise sources from the CFD to the APE4 solver as a volumetric source term.

2 METHODOLOGY

The fluid simulations are performed using the open source finite volume based software *Code_Saturne* that is developed and maintained by EDF R&D [7]. The code is second order accurate in space and time and the velocity-pressure coupling is ensured through a prediction/correction method based on a SIMPLEC algorithm.

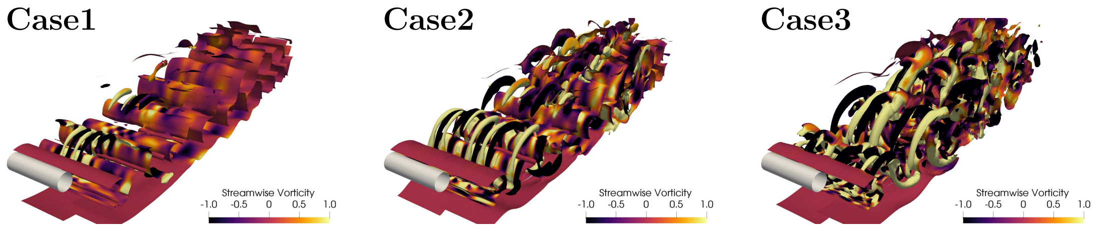
The acoustic propagation is carried out with the spectral/hp element framework Nektar++ [8], which uses low order h-type polynomial, and high order p-type polynomial, and spectral methods. One, Two and Three dimensional fields are represented as a collection of piecewise continuous or discontinuous polynomial domains using continuous or discontinuous Galerkin formulations. For this work polynomials up to order 6^{th} have been used.

Both CFD and acoustic solvers are fully MPI parallelised, with *Code_Saturne* having also a hybrid MPI/OpenMP pragma.

The coupling between the CFD and the acoustic solver is performed using the open source Multiscale Universal Interface (MUI) [6] library, which abstract the noise sources from the CFD into a point-cloud space and interpolate into the quadrature points used by the acoustic solver. Three spatial interpolations have been tested using a nearest neighbour, a Gauss and a Shepard quintic. The performances and accuracy of the data exchange have also been compared with another library named CWIPI and results will be presented at the conference.

3 RESULTS

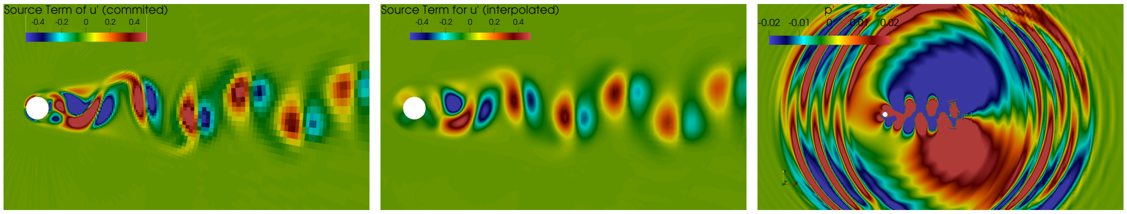
The study under consideration is the flow around a heated cylinder characterised by a temperature T_W, a diameter D, a uniform current across it and an incoming velocity U_∞. The temperature T_W is such that $T_W > T_\infty$, where T_∞ is the temperature of the undisturbed current. The Reynolds number range is $200 \leq Re = U_\infty D/\nu \leq 250$, with ν being the kinematic viscosity. The temperature at the wall is varied to have the Richardson number as $0 \leq Ri \leq 2$. The Grashof number is defined as $Gr = g\beta\left(T_W - T_\infty\right) D^3/\nu^2$ where g is the gravity and β the coefficient of thermal expansion. Figure 1 shows the wake behind the cylinder at $Re = 250$ for different Richardson numbers. As the Ri increases more structures are appearing in the wake and indeed the wake tends to become more turbulent. The acoustic propagation for the a 2D flow in force convection regime is presented instead in Figure 2. The left and middle figures represent the u (i.e. stream-wise) component of the Lamb vector which is used as source term of the APE4 equations. The effect of the interpolation is very prominent and it tends to spread out the peaks and smooth the field.


Case1

Case2

Case3

Figure 1: Visualisation of the wake behind the cylinder at $Re = 250$ and different Richardson numbers: **Case1**: $Ri = 0.0$; **Case2**: $Ri = 0.1$; **Case3**: $Ri = 0.5$


Source Term of u' (commited)

Source Term for u' (interpolated)

Figure 2: Source term for u' and relative acoustic pressure fluctuations p'. On the left the source term computed and committed by the CFD, in the middle the source term interpolated and used by the APE4 solver. The interpolation uses a Gauss filter.

4 CONCLUSIONS

This work presents a framework for the simulation of hybrid aeroacoustic problems coupling a CFD solver to resolve the noise sources together with a high order discontinuous Galerking code for acoustic propagation. The framework is applied to study the acoustic propagation of a heated cylinder in mixed convection regime. More results on the framework performance, the flow field and the acoustic propagation will be presented at the conference.

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