

ACOUSTIC ANALYSIS OF A TURBULENT FLOW AROUND A BLUFF BODY

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A body in a fluid flow gives rise to a vortical and turbulent three-dimensional field, whose structure depends on the shape of the body itself and the Reynolds number. Then, density/pressure fluctuations occur in the field and propagate far away as noise. The direct computation of such (acoustic) pressure disturbance is not practicable, due to the generally high propagation speed of sound, the spatial and time scale differences between the acoustic and fluid dynamic phenomena and the limits of the numerical domain. Within this context, the acoustic analogy based on the Ffowcs Williams-Hawkings (FWH) equation [1] undoubtedly represents the most rigorous way to deal with the problem. In fact, it directly derives from the fundamental conservation laws of mass and momentum and allows separation between the acoustic and fluid dynamic solutions, thus enabling the evaluation of noise through a rather simple post-processing of fluid dynamic data. Moreover, the presence of separate source terms, theoretically allows to identify the dominant generating noise mechanisms taking place in the flow, which, of course, represents a key information in view of any possible reduction or alteration of the acoustic field.

Our case of study concerns a turbulent flow around a stationary bluff body, the turbulent fluctuations occurring on the wake and the fluid dynamic forces interacting with the body surface are sources of noise. To predict the far field noise different integral formulations of the FWH equation can be adopted, we use the so-called *porous formulation* [2], which in our case reduces to the following:

$$\begin{aligned}
 4\pi p'(x, t) = & \frac{\partial}{\partial t} \int_S \left[\frac{\rho_0 u_n}{r} \right]_{\tau} dS(y) \\
 & + \frac{1}{c_0} \frac{\partial}{\partial t} \int_S \left[\frac{pn_r + \rho_0 u_r u_n}{r} \right]_{\tau} dS(y) \\
 & + \int_S \left[\frac{pn_r + \rho_0 u_r u_n}{r^2} \right]_{\tau} dS(y)
 \end{aligned} \tag{1}$$

where: the term on the LHS is the pressure disturbance in the far field, p and u on the RHS are pressure and velocity of the flow, n is the outward normal to the surface S , $r = |x - y|$ is the source-observer distance, $\tau = t - |x - y|/c_0$ is the compressibility delay, and the integration domain S is a surface that aims to enclose the immersed body and the main turbulent phenomena taking place in the downstream region.

The fluid dynamic solution is obtained through Large Eddy Simulations carried out using a standard Smagorinsky model at different Reynolds numbers. We use the `pisoFoam` solver. As a post processing we extract in time the flow data (p and u) on a suitable surface S and we compute the integral form described in (1). For this purpose we have considered convenient to use Python scripts that can take advantage of some utilities already implemented and available. It is necessary to take into account two main aspects during the set-up of the fluid dynamics simulation: the domain must be large enough to contain as much as possible the effects of turbulence and the time step must be able to capture the high frequencies of pressure fluctuations. Adopting the porous formulation (1) which consists of surface integrals, the main time expenditure is due to the collection of data on an appropriate surface S .

By positioning some measurement points very close to the source body (as to account for negligible effects of the compressibility delays), it is somehow possible to validate the noise predictions through a direct comparison with the pressure provided by the LES (incompressible) solver. As an example, figure 1 shows a preliminary comparison between the LES *fluid dynamic* pressure and the FWH *acoustic* pressure in the case of a small, rigid cube ($L=0.02m$) placed in a uniform flow with $U=10$ m/s ($Re=20000$), at a point P located upward $Z_p=10L$ and downstream $X_p=2L$ of the body. The very satisfactory agreement between the signatures demonstrates the congruence of the two solutions and the robustness of our FWH solver in providing a reliable prediction of the overall pressure disturbance.

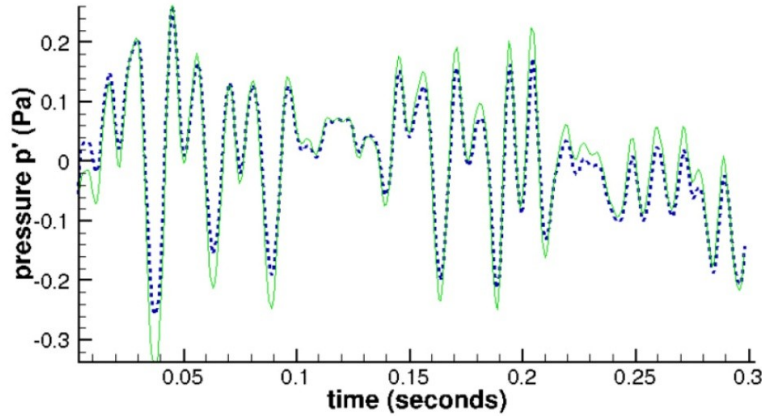


Figure 1: Comparison between LES (green) and FWH (blue) pressure at a measurement point located upward and downstream the source body.

The good agreement shown in figure 1 may notably deteriorate, by changing the location of the measurement point, the integration domain and, not last, the boundary effects arising in the fluid dynamic simulation. However, just accounting for all these effects, the comparison between the computed LES and FWH pressure at different, suitably located points (as well as at different Reynolds number) may provide very useful information about the nature of the acoustic field and help assessing the actual role played by the different noise sources present in the flow. The overall noise may be compared with a direct computation of the separate FWH source terms (in particular, the nonlinear *quadrupole* noise and the so-called *loading* component of Farassat formulation 1A [3]), in order to understand their relative weight and to achieve a full comprehension of the behavior of the acoustic numerical solution.

References

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