GENERATION OF UNSTEADY AEROACOUSTIC SOURCE TERMS FROM STEADY CFD

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1. Introduction

This document deals with a time-based hybrid method for the computation of flow-induced noise. The method described is based on a reconstruction of the time-accurate turbulent field based on CFD results and a propagation of the resulting noise sources with Linearized Euler Equation. Examples of industrial applications are given. In the second lecture, the focus is on the extension by coupling to other methods.

The significant advances that have recently been made in numerical techniques and computer hardware have had a major influence on the approaches used to understand and predict noise generated by unsteady flows. Direct Numerical Simulations (DNS) numerically solve the Navier-Stokes equations directly by resolving all the scales in the flow from the smallest turbulent eddy to the largest scale of motion. Naturally this method will automatically handle all phenomena from flow instabilities, transition to turbulence and energy exchanges between the different turbulent scales to sound production due to the unstationary turbulent flow and propagation through a turbulent media. However, even with today's high-powered computing capabilities it is limited to low Reynolds numbers and simple flow geometries. For the typical applications of DNS (jets) Reynolds numbers are achievable in the order of Re=5000 to Re=10000 for supersonic jets. Other applications of noise prediction using DNS are still in development, but the computation of flow noise around complex geometries it is not expected in a close future. A bit closer to industrial applications, Large Eddy Simulations (LES) numerically solve spatially filtered Navier-Stokes equations. The filter is applied over each grid element and a turbulence model is required to account for the influence of the sub grid scale fluctuations on the rest of the flow. The advantage of LES is that the time dependent large-scale motions of the flow are still resolved. Hence, a large part of the unsteady features of the flow and the turbulence are still preserved, however without the extreme grid requirements that are associated to DNS.

Apart from the problem that all (DNS), or a large part (LES) of the hydrodynamic scales must be resolved, the demands on the accuracy of the discretisation schemes and integration schemes are severe. As indicated above the energy differences between the hydrodynamic pressure fluctuations in the near field and the acoustic pressure fluctuations scale with M^4, for jet-noise like mechanisms. In addition to this, owing to the multiple nature of the source, correctly representing the small retarded time differences is crucial for the correct source strength evaluation. Generally, DNS and LES approaches are not used for calculation of the long-range propagation to the far field. Owing to the severe grid-size demands, integration to the far field is extremely expensive. The source region can be surrounded by a Kirchhoff surface to calculate semi-analytically the acoustic far field from the acoustic field variable on this surface.

Furthermore, to predict the flow in the acoustically interesting region, often it is necessary to model a large part of the upstream flow as well. For example, to model the flow over a wind-screen wiper and to predict the noise production by a wind-screen wiper, probably the flow over the hood of car must be modelled in detail. Thus, even though the flow over the hood of the car does not generate any sound, it still needs to be modelled for an accurate noise prediction.

Several approaches are possible to reduce these problems. It is possible to make less accurate computations in the less interesting regions, hoping that this will not have any consequences on the acoustics sources. It is also possible to compute more economically the base turbulent flow on the complete geometry with CFD and to compute corresponding acoustic sources in the critical regions. Hybrid approaches are based on this principle. They use CFD calculations to define the equivalent steady source terms required for an acoustic theory. Unsteady CFD computations can also be used to predict the acoustic source terms. If the source region is compact, retarded time variations can be ignored and predictions based on this approach are reasonably successful (Lele 1997). However, this formulation will breakdown whenever significant refractive effects are present in the flow (Lele 1997). Furthermore, for aero acoustic problems including interaction with objects in the flow, to represent the diffraction by these objects, for each new geometry, a tailored Green's function needs to be developed.

Though a hybrid approach relieves some issues relating to the propagation of noise, the problem of defining the Lighthill Stress tensor remains. This often requires a major numerical effort, even when based on unsteady RANS computations. To overcome this issue, alternative approaches were developed in the last decade. They are based on models for the space-time correlation function of the turbulent velocity fluctuations (Bechera *et al* 1996). Lighthill theory (Lighthill 1952) is used to develop a relation between the far-field noise and correlation of the Lighthill Stress tensor. A model is assumed for this relation that is locally scaled using a eddy length scale, decay rate and turbulent kinetic energy, which can be obtained from a steady RANS computation. A similar approach was followed by Tam and Auriault (1999) for the prediction of small-scale turbulence. An extension to the approaches followed by Bechera and Tam and Auriault is given by Longatte (1998). Instead of formulating a model for the relation between the far-field noise and the Lighthill Stress tensor, Longatte uses statistical models, fed by information from steady RANS computations, to develop a time-accurate description for the acoustic source terms. The propagation from the source to the receiver is modelled using a linearized Euler formulation.

The time-domain formulation of Longatte (1998) is the starting point of the CAA approach presented further. Owing to its hybrid character, the source strength remains finite since the correct multiple nature of the sources is automatically specified correctly. Refraction and diffraction effects are handled automatically by the linerarized Euler formulation for the propagation and numerical problems related to the multiple scales are largely avoided.

2. Time dependant hybrid method

The approach is based on a hybrid approach where the acoustic calculations are separated from the flow (CFD) calculations, thereby assuming the turbulence to be an autonomous source of sound, only fed by the mean flow, see Snellen *et al* (2002) and Blom *et al* (2001b). This approach is aimed at predicting the **broadband** noise. It does not predict the tones resulting from a coupling between the flow and the acoustic field. Neither does it predict the