Comparison of Porous and Direct Volumetric Integration FW-H Formulation for Acoustic Prediction

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ABSTRACT

In the present work, two integration methods of FW-H formulation for hydroacoustic prediction are adopted and compared. One of the methods uses porous surface integration method, the other is direct volumetric integration with a dual mesh technique. The numerical model is the flow past a circular cylinder. The setup of simulation case of the two methods keeps the same. The near-field and far-field sound pressure level are compared between these two methods. It is shown that peak value frequency of sound pressure level of both methods is around the shedding frequency of the cylinder. The near-field sound pressure level of those two methods has small differences while the far-field sound pressure levels are large. At last, the efficiency and disk storage of these two methods are also compared. With the dual mesh technique, the volumetric integration method shows small time cost in the simulation.

KEY WORDS: Ffowcs Williams-Hawkings analogy; OpenFOAM; libAcoustics; Dual mesh technique

INTRODUCTION

Nowadays, the sound problem in hydrodynamics became essential. Many numerical methods have been done to solve these kinds of problems. A popular numerical method to predict fluid noise is coupled Computational Fluid Method (CFD) with acoustic analogies. One of the widely used numerical approach to simulate acoustic analogy is the Ffowcs Williams-Hawkings (FW-H) analogy. The contribution of Lighthill stress tensor which is a quadruple source term can be directly calculated with volumetric integration, or it can be calculated on a porous surface.

These two methods both have their own advantages and disadvantages. For example, the porous surface integration method is sensitive to the choice of porous surface as well as the fluid data on the porous surface. Rahier et al (2015) pointed out that a spurious noise would be generated when the turbulent flow crossed through the porous surface. They thought the spurious noise generated due to the lack of volumetric terms. Cianferra et al (2019) compared porous surface integration method with volumetric integration method, and found out that under the low frequency, the accuracy of porous surface integration method is lower than both volumetric integration and linear Curle method. If only considered far-field noise, the nonlinear term of the sound decreased rapidly.

Therefore, to choose a suitable method to predict the quadruple source term is nonnegligible in hydrodynamic noise. Meanwhile, Cianferra et al (2019) didn’t mention the huge storage in computers and large cost in simulation time of volumetric integration method. Wang et al (2022) provided a new method with a dual-mesh technique to solve this problem. The method is carried out with a fine CFD mesh and a relatively coarser acoustic mesh which is used for acoustic calculation. They thought this method can reduce the computational disk storage and simulation time cost.

In this paper, two different solving methodologies are adopted to find out a powerful tool for the noise prediction. The calculations are carried out coupled CFD method for the acoustic assessment. The fluid field simulation chooses Large-Eddy Simulation (LES). The porous FW-H methodology is achieved by an open-source package OpenFOAM implemented the libAcoustics library (Epikhin et al, 2015). The direct FW-H methodology is applied through a dual mesh technique. The sound source information is mapped onto acoustic mesh to reduce the simulation time. A flow past a circular cylinder is considered to be the numerical model. The near-field and far-field acoustic pressures are calculated, as well as calculation time is included to compare the accuracy and efficiency of these two methods.

METHODOLOGY

Ffowcs Williams-Hawkings analogy

The Lighthill analogy (Lighthill, 1954) is derived from Navier-Stokes equation. The FW-H equation (Ffowcs, 1969) is based on the Lighthill equation:

\[
\left(\frac{1}{\epsilon_{\text{a}}} \frac{\partial^2}{\partial t^2} - \nabla^2 \right) \rho = \frac{\partial}{\partial t} (Q \delta(f)) - \frac{\partial}{\partial x_i} (F_i \delta(f)) + \frac{\partial^2}{\partial x_j \partial x_i} (H(f) \Gamma_{ij})
\]

(1)