A New Hydrodynamic/Acoustic Splitting Method for Aeroacoustic Noise Prediction of Low Mach Number Flows

Jung-Hee Seo and Young J. Moon
Department of Mechanical Engineering, Korea University, Seoul, 136-701, Korea

Corresponding author ***Young J. Moon (yjmoon@korea.ac.kr)***

1. Introduction

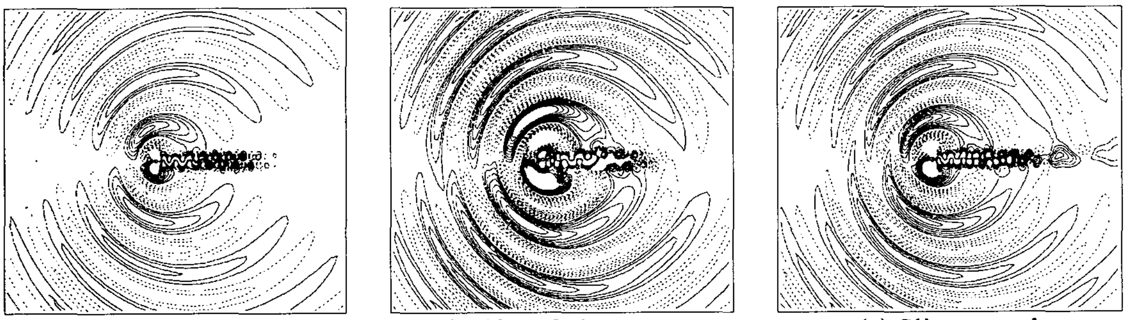
The aeroacoustic noise prediction method for low Mach number shear flows has been investigated by several researchers. Hardin and Pope [1] originally proposed a hybrid method, employing a viscous/acoustic splitting concept, and Shen and Sorenson [2] and Slimon et al. [3] further proposed similar hybrid CFD/CAA methods. These methods have well been verified for a quadruple noise generated by a spinning vortex pair [2,3]. Shen and Sorenson and Slimon et al. also tested an aeolian tone generated from a circular cylinder by Karman vortex sheddings but none of their methods have been quantitatively validated yet.

In the present study, accuracy assessments of these two methods are pursued for this cylinder aeolian tone problem by comparing with a DNS solution. The DNS computation was performed by solving the full compressible Navier-Stokes equations, using a sixth-order compact scheme with a fourth-order Runge-Kutta method. The DNS solution was verified by the two-dimensional Curle's acoustic analogy solution [4]. Based on observations of false solutions produced by these two methods, a new hybrid method is proposed to correctly handle the near-field compressibility effects, especially for the wall-bounded shear flows. The present splitting method yields solutions in excellent agreement with the DNS solutions.

2. Previous Splitting Methods

In the previous viscous/acoustic splitting methods (Hardin and Pope [1], Shen and Sorenson[2], and Slimon et al.[3]), the compressible flow variables are decomposed into the incompressible flow variables and the perturbed compressible variables, and the acoustically perturbed Euler equations were obtained by inserting the decomposed variables into the full compressible Navier-Stokes equations and subtracting the incompressible Navier-Stokes equations from them with dropping the viscous terms. The acoustically perturbed equations are also solved by a sixth-order compact scheme on the same grid used in the DNS calculations. The hydrodynamic calculation was also performed on the same grid by using a projection method based algorithm. The sixth-order compact scheme is used for the spatial discretization, while a second-order fractional-step method is used for the time integration.

The acoustic pressure fields of Slimon et al. and Shen & Sorenson are shown in Fig. 1, compared with a DNS solution. The solution of Shen & Sorenson, in fact, becomes unstable after ten thousand iterations.



(a) DNS (b) Shen & Sorenson (c) Slimon et al.

Fig. 1 Contours of $\Delta p' / \rho_\infty a_\infty^2$ (20 levels between -0.002 and 0.002).

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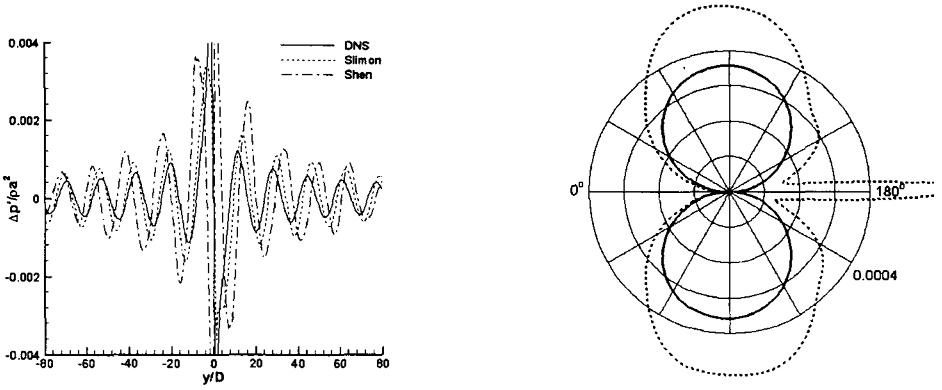


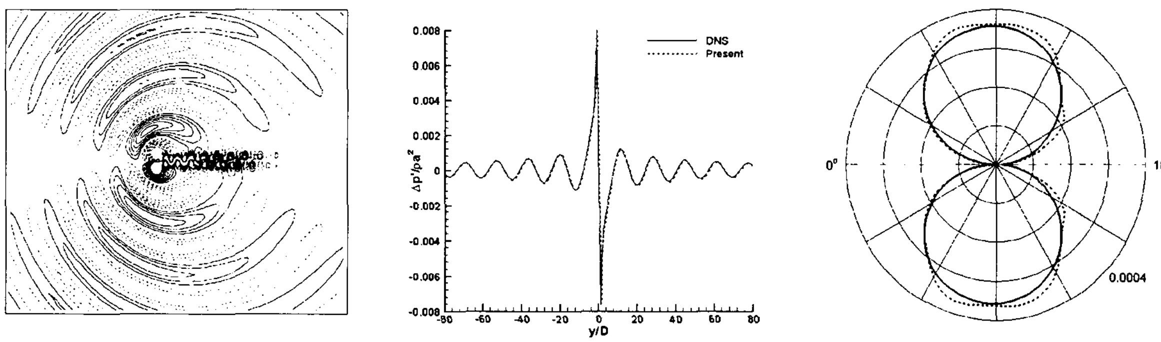
(a) Acoustic pressure (b) Directivity of $\Delta p'_{rms} / \rho_\infty a_\infty^2$

Fig. 2 Comparison of the previous splitting methods.

Although Slimon et al.'s solution remains stable, one can notice that it over-predicts the acoustic pressure field in comparison with the DNS solution. Figure 2(a) compares the acoustic pressures along the $x=0$ line of Shen & Sorenson, Slimon et al., and DNS solutions. The previous splitting methods severely over-predict the amplitude of acoustic pressure in the near-field as well as in the far-field. Figure 2(b) also shows that the acoustic pressure directivity at $r=60D$ is considerably over-predicted by Slimon et al., resulting in over-prediction of SPL by 5-10 dB compared to that of the DNS solution.

3. A new splitting method

Although the perturbed quantities are the acoustic properties in the far-field, they are not the ones in the near-field, especially for the wall-bounded shear flows. Therefore, the acoustic field becomes unstable and is also over-predicted. To resolve this matter, previous researchers used an artificial damping term [2] or invoked some numerical diffusion with very coarse mesh modeling [3] in the near field. In the present study, new source terms are obtained for properly handling the near-field effect, by introducing the perturbed viscous/heat flux terms into the acoustically perturbed momentum and energy equations. Figure 3 shows comparison of the present method compared with the DNS solution.



(a) Acoustic pressure contours (b) Acoustic pressure (c) Directivity of $\Delta p'_{rms} / \rho_\infty a_\infty^2$

Fig. 3 Comparison of the present splitting method.

References

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