Use of a New Modified Acoustic Model to Investigate Mean Flow Effects on Underwater Sound Sources

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(Received 18 June 2013; revised: 17 October 2013; accepted: 28 October 2013)

In this investigation, by introducing a relatively comprehensive acoustic equations system, the possibility of a more precise time and spatial pattern for sound wave propagation in fluid was revealed. Since the conservation equation is known as a fundamental equation for obtaining the wave equation, initially, by using scale analysis, the differential terms and weight coefficients are converted into the dimensionless form. Then, by assuming the amplitudes of the sound sources are small and by utilizing the perturbation technique, these dimensionless equations are converted into different orders based on the order of acoustical fluctuations. Consequently, it was shown that the obtained first order equations are representative of acoustical equations. Also, the results are indicative of the first order equations being coupled with the leading order ones. Comparison of the obtained acoustic the equations of the present study are capable of considering velocity, viscosity, and density changes of the background fluid flow. In the end, the effects of the flow velocity with a different Mach number on the acoustical distribution pattern that stemmed from different sound sources have been studied for several benchmarks.

1. INTRODUCTION

The linear equation of the wave was founded on the basis of the linear constitutive theory in fluid mechanics and the assumption of sound waves with a small amplitude.[1] Linear constitutive theory of the fluid medium being used in the formulation of the linear equation of the wave includes the assumption of non-viscous and stationary background fluid flow with constant density. In light of these assumptions, linear wave equations in many fields of hydrodynamics and aerodynamics related to sound wave propagation are valid. Studies conducted on the noise generated by a hydrodynamic or aerodynamic occurrence in a time domain could be categorized into three groups.[2] The first group is based on the suggested acoustic analogy by Lighthill.[3] The linear acoustic wave which is placed on the left side of the Lighthill model is capable of evaluating wave propagation under the effect of sound sources placed on the right side of model. Ffowcs Williams and Hawkings (FWH) extended this analogy by adding the effects of unsteady surface pressure.[4] Seol and Salvator's studies are amongst those related to the FWH model in the investigation of the underwater propeller's noise.[5–8] Although by using such models it is possible to identify patterns of wave propagation and directivity in the far field, this type of noise estimation methodology presents many assumptions such as those considered in linear acoustics, a low Mach number, and compressed sound sources.[2]

Another group of noise estimation viewpoints includes research utilizing Direct Numerical Simulation (DNS) to model and simulate the hydrodynamics of fluid with its acoustic noise, directly and simultaneously. The advantage of using this method is in its limitless capability by which noise generated by all fluid flow such as a low Mach flow or a flow with a high Reynolds number could be obtained.[2] At the same time, scaled use in aerodynamics and hydrodynamics simulations have much difference with scaled use in acoustic simulation. This inequality of scales has caused the utilization of DNS in aerodynamic and hydrodynamic fields to be very difficult.[9] Moreover, using the DNS method is very time consuming. Seo, et.al chose the DNS method to find the noise of the cloud cavitation.[10] They used the compressible Navier-Stokes equations and a homogeneous equilibrium model based on fluctuating density to simulate noise generation in a flow field.

The third point of view is, in fact, a hybrid method between the two fields of hydrodynamics and acoustics or between the two fields of aerodynamics and acoustics. Some of these hybrid methods are formed based on dividing the flow field into compressible hydrodynamic and compressible acoustic perturbation equations (or Perturbed Euler Equations).[11–13] Seo and Moon present a set of revised Perturbed Euler Equations capable of calculating the effects of compressibility in the near field.[14] They also developed a set of linearized, perturbed, compressible equations to overcome the occurred instability in numerical calculations caused by perturbed vorticity.[9, 15] Ewert and Schröder formulated several acoustic perturbation models based on the different sound sources derived from compressible flow simulation.[3] They initially simulated the compressible flow and generated acoustic sources. Then on the basis of the type of formed sound sources, by using the suitable acous-