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INVESTIGATION OF DISPERSION-RELATION-PRESERVING SCHEME AND SPECTRAL ANALYSIS METHODS FOR ACOUSTIC WAVES

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Important characteristics of the aeroacoustic wave propagation are mostly encoded in their dispersion relations. Hence, a computational aeroacoustic (CAA) algorithm, which reasonably preserves these relations, was investigated. It was derived using an optimization procedure to ensure, that the numerical derivatives preserved the wave number and angular frequency of the differential terms in the linearized, 2-D Euler equations. Then, simulations were performed to validate the scheme and a compatible set of discretized boundary conditions. The computational results were found to agree favorably with the exact solutions. The boundary conditions were transparent to the outgoing waves, except when the disturbance source was close to a boundary. The time-domain data generated by such CAA solutions were often intractable until their spectra was analyzed. Therefore, the relative merits of three different methods were included in the study. For simple, periodic waves, the periodogram method produced better estimates of the steep-sloped spectra than the Blackman-Tukey method. Also, for this problem, the Hanning window was more effective when used with the periodogram method than with the Blackman-Tukey method. For chaotic waves, however, the weighted-overlapped-segment-averaging and Blackman-Tukey methods gave better results than the periodogram method. Finally, it was demonstrated that the representation of time domain-data was significantly dependent on the particular spectral analysis method employed.

1. INTRODUCTION

Computational aeroacoustics (CAA) may loosely be defined as the employment of computational fluid dynamics (CFD) techniques in the direct calculation of all aspects of sound generation and propagation aeronautical applications.[1] Most CFD schemes, however, are not adequately accurate for solving the acoustics problems; these problems are time dependent, their amplitudes are often several orders of magnitude smaller, and yet the frequencies are several orders of magnitude larger than the flow field variations generating the sound. Hence among the requirements that should be placed on a CAA algorithm are the minimal dispersion and dissipation features. This often conflicts with the requirement of "mainstream" CFD, which is to reach steady states, by either damping out or removing from the domain the transient disturbances created during the start-up of the computation. High-fidelity is paramount for the resolution of acoustic problems; but, a consistent, stable, and convergent high order scheme is not necessarily dispersion-relation preserving and thus does not necessarily guarantee a good quality numerical wave solution for an acoustic problem. Demonstrated in the present paper is a validation of a dispersion-relation-preserving (DRP) scheme, first introduced by Tam and Webb,[2] and a compatible set of radiation and outflow boundary conditions.

In the recent past, most commonly used computational methods have been of the acoustic analogy type. With such a method, the aeroacoustic problem is reduced to a non homogeneous wave equation for the noise, with its right side equal to a distribution of acoustic sources of strength related directly to the characteristics of the flow. A good example of acoustic analogy application to helicopter aeroacoustics was given by Farassat and Brentner.[3] Another commonly used method is the Kirchhoff approach, where the solution is obtained by integrating the wave equation external to some real or imaginary surface on which the relevant acoustic data is known. Among the applications of this method is by Hawkings,[4] who used a stationary-surface Kirchhoff formula to predict the noise from high-speed propellers and helicopter rotors.

Linear perturbation potential methods have also been applied for the aeroacoustic problems. Since a quiescent or a uniform flow is generally assumed, the potential methods are similar to the acoustic analogy equations except that the dependent variable in the wave/convective-wave operator is the perturbation velocity potential. Atassi et al.,[5] for example, used this method to study the far field acoustic radiation from a lifting airfoil in a three-dimensional gust. Perturbation Euler techniques have recently received attention from the acoustic community and also the unsteady-flow community at large. Hariharan and Bayliss[6] computed the acoustic radiation in cylindrical ducts by using the linearized Euler equations in a quiescent field. Meadows et al.[7] solved the nonlinear Euler equations to compute unsteady shock waves.

The direct simulations of acoustic wave propagation have also been tried by solving the Navier-Stokes equations. For example, Ridder and Beddini[8] integrated the axisymmetric Navier-Stokes equations for the acoustic radiation of sound from resonance tubes. Baysal et al.[9] investigated two devices to suppress the high tones generated by a high-speed cavity flow by solving the two-dimensional Navier-Stokes equations using a second-order accurate method.

What is almost always common to these CAA solutions is the enormous amount of data generated. One way of reducing this data to understand the underlying physical phenomena is analyzing their spectrum, i.e. spectral analysis. A variety of methods are available to perform this task and their overviews can be found in reference books on time series analysis (e.g., by Hardin[10]). The spectra obtained from such analyses, however, often depend on the particular method that has been used.

Therefore, considering this "numerical data reduction" as an integral part of CAA, three spectral analysis methods were included in the present study. These are the Blackman-Tukey,[11] the periodogram,[12] and the weighted-overlapped-segment-averaging (WOSA)[13] methods. The former two of these methods were implemented using box-car and Hanning windows. The latter method was compared for different

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