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An improved localized radial basis function meshless method for computational aeroacoustics

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ABSTRACT

An improved localized radial basis function collocation method is developed for computational aeroacoustics, which is based on an improved localized RBF expansion using Hardy multiquadrics for the desired unknowns. The method approximates the spatial derivatives by RBF interpolation using a small set of nodes in the neighborhood of any data center. This approach yields the generation of a small interpolation matrix for each data center and hence advancing solutions in time will be of comparatively lower cost. An upwind implementation is further introduced to contain the hyperbolic property of the governing equations by using flux vector splitting method. The 4–6 low dispersion and low dissipation Runge–Kutta optimized scheme is used for temporal integration. Corresponding boundary conditions are enforced exactly at a discrete set of boundary nodes. The performances of the present method are demonstrated through their application to a variety of benchmark problems and are compared with the exact solutions.

1. Introduction

Computational aeroacoustics (CAA) is concerned with the accurate numerical prediction of aerodynamically generated noise as well as its propagation and far-field characteristics [1]. Numerical methods for problems of sound generation and propagation must overcome a host of difficulties that arise because acoustic waves are very weak compared to near-field fluctuations, and they must propagate with little attenuation over long distances.

Several computational methods, such as spectral and pseudo-spectral method, finite element method (FEM) and finite volume method (FVM), have been developed and applied in the CAA fields [2–4], the majority of CAA codes are based on finite difference method (FDM). During the last two decades, various FDM with optimized spatial discretization and temporal integration in conjunct with proper boundary conditions have been developed [5–8]. Many variations such as upwind scheme, explicit addition of artificial damp, have been tried with these methods. There were two fundamental papers, Lele [5] and Tam and Webb [6], that revolutionized this field, the former concerning with the optimization of the compact schemes and the latter with the optimization of the explicit schemes (the so-called dispersion-relation-preserving (DRP) schemes), respectively. Since these two papers have appeared in the aeroacoustics community a series of other proposals have entered in line.

All of the spectral method, FEM, FVM and FDM need mesh generation in the preparation of data, and a good quality mesh procedure is needed in order to get much more accurate results. However, this procedure must correspondingly increase much of the computational cost. Furthermore, these methods provide the solution of the problem on mesh points only and accuracy of the techniques is reduced in non-smooth and irregular domains.

Meshless methods have generated considerable interest recently due to the need to overcome the high cost of mesh generation associated with human labor [9]. Meshless methods avoid grid generation and the domain of interest is discretized by a set of scattered points among which there is no pre-defined connectivity. In addition, geometry discretization is updated by simply adding or deleting points in the domain of interest.

A number of meshless methods have been proposed [10,11]. Smoothed particle hydrodynamics method (SPH) [12], element-free Galerkin method (EFGM) [13], reproducing kernel particle method (RKPM) [14], finite point method (FPM) [15], hybrid boundary node method (HBNM) [16], boundary knot method (BKM) [17], meshless local Petrov–Galerkin method (MLPGM) [18], general finite difference method (GFDM) [19] and gradient smoothing method (GSM) [20–22] are the well known meshless methods considered for fluid flow problems. In the past two

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