THE METHOD OF LINES SOLUTION OF DISCRETE ORDINATES METHOD FOR TRANSIENT SIMULATION OF RADIATIVE HEAT TRANSFER

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Solution of the time-dependent conservation equations of mass, momentum, energy and species in conjunction with the radiative transfer equation (RTE) is indispensable for the complete simulation of turbulent, reacting and radiating flows and understanding the interactions among these complicated phenomena. Accurate modeling of turbulent flows necessitates implementation of direct numerical simulation (DNS) in which all space and time scales are resolved and computed directly without using any turbulence models. On the other hand, this rigorous, accurate and straightforward treatment requires a lot of grid points and time steps and hence the computational effort is highly intensive. Moreover, coupling a transient computational fluid dynamics (CFD) code based on DNS with an RTE solver is expected to increase the computational cost enormously. Therefore, it is essential to develop efficient codes based on accurate models as well as efficient coupling strategies to overcome this difficulty. Applying compatible solution methods for the CFD and radiation codes is a promising approach to maintain computational efficiency. The method of lines (MOL) is an alternative approach that meets this requirement for time dependent problems. The MOL consists of two stages. First, the dependent variables are kept continuous in time and the partial differential equations (PDEs) are discretized only in space on a dimension by dimension basis using any readily available 1-D spatial discretization package such as finite difference, finite volume or finite element based schemes. This leads to a system of ordinary differential equations (ODEs) to be integrated in time using any readily available explicit or implicit ODE solver, constituting the second stage. By this way, MOL not only offers accurate and stable solutions but also flexibility to incorporate any desired package with ease.

Radiation models most suited to treatment by the MOL approach are the ones which involve PDE formulation. Flux models, also called differential approximations, satisfy this requirement. Discrete ordinates method (DOM), which conceptually is an extension of flux models, was tested in various multi-dimensional radiative heat transfer problems and found to be an accurate and computationally efficient technique. These studies provide steady state solution of discrete ordinates equations. However, application of the DOM to transient problems necessitates representation of discrete ordinates equations in transient forms by using false transients approach. In this approach, the integro-differential equation representing RTE is converted into a system of PDEs by the application of DOM. Implementation of false-transients approach to the resulting equations, followed by discretization of spatial derivatives transforms system of PDEs into an ODE initial value problem. Starting from an initial condition for radiation intensities in all discrete directions the resulting ODE system is integrated until steady-state by using a powerful ODE solver. The most important advantage of MOL solution of DOM is the use of ‘pseudo-time’ iteration widely used in CFD applications.

Predictive accuracy of the MOL solution of DOM was validated against exact solutions, Monte Carlo and zone method solutions, as well as measurements on a wide range of one-dimensional and multidimensional problems in rectangular and cylindrical coordinates including absorbing, emitting, isotropically and anisotropically scattering grey media. Upon encouraging performance of MOL solution of DOM in grey media reported in the previous studies, the method was extended to treatment of one-dimensional and multidimensional non-grey media by incorporation of wide band correlated-k (WBCK) and spectral line-based weighted sum of grey gases (SLW) models compatible with MOL solution of DOM. More recently the method was used in conjunction with a computational fluid dynamics (CFD) code based on the MOL approach for modeling transient, reacting, radiating flow of grey/nongrey absorbing, emitting media in a confined laminar methane –air diffusion flame.

Overall evaluation of the MOL solution of DOM points out that it provides accurate and computationally efficient solutions and can be used with confidence in conjunction with CFD codes based on the same approach.