8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

Development and comparison of different spatial numerical schemes for the radiative transfer equation resolution using three-dimensional unstructured meshes.

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Key Words: *Radiative Transfer, Participating Medium, Unstructured Grids, Three-dimensional, Numerical Schemes, Finite Volume Method, Discrete Ordinates Method.*

ABSTRACT

Most of the engineering applications where computation of radiative heat transfer in participating medium is important, such as furnaces, combustors and solar energy devices, are 3D with complex-shaped geometry. The resolution of the integro-differential RTE for these multidimensional cases is very costly from a computational point of view. However, the increase of the computational power in the last decade has made feasible solve 3D radiative cases [1, 2]. Unstructured grids have been widely used in CFD for handling real shape cases due to their geometrical flexibility. Recent numerical works also employ unstructured grids for solving RTE in 2D and 3D [1, 2, 3, 4].

Several methods have been developed for solving the RTE in multidimensional situations. The DOM [5] and FVM [6] have emerged as two of the most popular techniques due to their ability to solve many radiative situations with relatively good accuracy and moderate computing resources. In both methods, the domain is spatially discretized in control volumes, which makes these methods easy to integrate into control-volume CFD codes. The main difference between them lies on the angular discretization. One of the most important shortcomings of the FVM and DOM, altogether with the *ray-effect*, is the *false-scattering*, which is due to spatial discretization [7]. This drawback can be reduced using finer grids or more accurate spatial numerical schemes [6, 8, 9]. However, most of these works investigate cases in 2D orthogonal grids. To the authors' knowledge, Joseph et al. work [4] is the only work that analyses different numerical schemes for the resolution of the RTE using DOM with unstructured meshes in 3D cases. The paper compares three numerical schemes: the exponential scheme proposed by Sakami et al. [1], which is a sophisticated *skew* scheme based on the formal solution of the RTE and developed specifically for 3D unstructured meshes; the *step* scheme, which is a low order scheme and is the analogous of *upwind* scheme in the CFD community, that has been used for many authors in the radiative scope; and a *mean flux scheme*, cited in [4].

In the present work a radiative heat transfer library with both DOM and FVM has been developed and coupled with TERMOFLUIDS code which is an intrinsic 3D parallel CFD code applied to unstructured meshes[10]. Discretized algebraic radiative transfer equations are solved by means of parallel iterative

solvers (GMRES and BIGSTAB) employed on a low cost PC cluster. These solvers have also been successfully tested in several CFD problems [10].

For the discretization of the convective term of the RTE five different numerical schemes have been developed and compared in several 3D benchmark cases. These schemes have been designed specifically for unstructured meshes by means of the projection of nodal values of intensity on the studied radiative direction, accordingly they are of *skew* type schemes. Three of them take also into account the formal solution of the RTE leading to schemes that bear a resemblance to modified and high-order exponential schemes [1, 6]. Nevertheless, their implementation on 3D unstructured grids is easier than the exponential scheme proposed by Sakami et al.[1].

The benchmark cases that have been studied include both transparent and non-transparent grey medium. Furthermore, several situations have been considered in non-transparent medium: absorbing-emitting and non-scattering medium, purely scattering medium and absorbing-emitting and non-scattering medium with a uniform heat source.

REFERENCES

[1] M. Sakami, A. Charette, and V. Le Dez. Radiative heat transfer in three-dimensional enclosures of complex geometry by using the discrete - ordinates method. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 59(1/2):117–136, 1998.

[2] G.D. Raithby. Discussion of the finite-volume method for radiation, and its application using 3D unstructured meshes. *Numerical Heat Transfer, Part B*, 35:389–405, 1999.

[3] J.Y. Murthy and S.R. Mathurt. Finite Volume Method for Radiative Heat Transfer Using Unstructured Meshes. *Journal of Thermophysics and Heat Transfer*, 12:313–321, 1998.

[4] D. Joseph, M. El Haifi, R. Fournier, and B. Cuenot. Comparison of three spatial differencing schemes in discrete ordinates method using three-dimensional unstructured meshes. *International Journal of Thermal Sciences*, 44:851–864, 2005.

[5] W.A. Fiveland. Discrete Ordinates Methods for Radiative Heat Transfer in Isotropically and Anisotropically Scattering Media. *Journal of Heat Transfer*, 109:809–812, 1987.

[6] G.D. Raithby and E.H. Chui. A Finite-Volume Method for Predicting a Radiant Heat Transfer in Enclosures With Participating Media. *Journal of Heat Transfer*, 112:415–423, 1990.

[7] J.C. Chai, H.S. Lee, and S.V. Patankar. Ray effect and false scattering in the discrete ordinates method. *Numerical Heat Transfer, Part B*, 24:373–389, 1993.

[8] P.J. Coelho. Bounded skew high - order resolution schemes for the discrete ordinates method. *Journal of Computational Physics*, 175:412–437, 2002.

[9] J.P. Jessee and W.A. Fiveland. Bounded, High-Resolution Differencing Schemes Applied to the Discrete Ordinates Method. *Journal of Thermophysics and Heat Transfer*, 11(4):540–548, 1997.

[10] O. Lehmkuhl, C. D. Perez-Segarra, R. Borrell, M. Soria, and A. Oliva. TERMOFLUIDS: A new Parallel unstructured CFD code for the simulation of turbulent industrial problems on low cost PC Cluster. In *Proceedings of the Parallel CFD 2007 Conference*, pages 1–8, 2007.