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Adaptive High–Order Finite–Volume Approach for Direct Numerical Simulation of Turbulent Flames

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Direct Numerical Simulation of combustion requires high numerical accuracy combined with acceptable computational cost. Reaction zones are often thin relative to the length scales of the computational domain, and Adaptive Mesh Refinement (AMR) becomes especially useful in providing adequate spatial resolution for the small–scale features. Considerable cost savings are realised by avoiding the need for fine mesh in regions where the solution is smoothly varying. In the present work, pointwise AMR is used on a three–dimensional cubic Cartesian mesh with Morton spatial indexing [1] and automatic parallel load balancing.

The continuity, momentum and energy equations are solved in a fully compressible formulation together with balance equations for chemical species mass fractions. Detailed chemistry and molecular transport is included. High accuracy is achieved on the locally adapted mesh using a spatial reconstruction scheme based on a high–order finite–volume approach with good conservation properties [2]. Third–order explicit Runge–Kutta time stepping [3] is used with adaptive step control.

In AMR algorithms reconstruction requires a well–formulated stencil around every cell to ensure the accuracy and stability of the solution. The stencils must be rebuilt on–the–fly every time the mesh is adapted and this requires a robust and efficient stencil construction algorithm. Here, an approach based on the mathematical structure of the Singular Value Decomposition (SVD) is used to link the numerical properties of each stencil to its geometrical configuration. This ensures that all stencils are correctly configured, even in the presence of boundaries and different scales of adapted mesh.

The stencil construction algorithm is implemented within the combustion DNS code HAMISH [4] which has been used to obtain results for a range of combustion test cases including three–dimensional turbulent flames. The robustness, accuracy and economy of the approach has been demonstrated.

References

[1] G.M. Morton, A computer oriented geodetic data base and a new technique in file sequencing, IBM Tech. Report, 1966.

[2] L. Ivan, C.P.T. Groth, High-order solution–adaptive central essentially non—oscillatory (CENO) method for viscous flows, J. Comput. Phys. 257 (2014) 830-–862.

[3] C.-W. Shu, S. Osher, Efficient implementation of essentially non—oscillatory shock-–capturing schemes, J. Comput. Phys. 77 (1988) 439–471.

[4] R.S. Cant, U. Ahmed, J. Fang, N. Chakarborty, G. Nivarti, C. Moulinec, D.R. Emerson, An unstructured adaptive mesh refinement approach for computational fluid dynamics of reacting flows, J. Comput. Phys. 468 (2022) 111480.