INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

This thesis is devoted to the development of a robust and accurate Immersed Boundary/Finite Volume (IB-FV) framework for compressible flows and their applications to design and optimisation. The framework is devised by combining an unstructured data based finite volume flow solver with a sharp interface immersed boundary method. The finite volume flow solver employs limited linear reconstruction in conjunction with vanLeer and AUSM schemes for convective fluxes while central differencing is employed for viscous fluxes. A new approach to compute gradients, which are critical to the computation of inviscid and viscous fluxes, based on a variant of Gauss divergence theorem is proposed. The strategy referred to as Modified Green Gauss (MGG) reconstruction is a one-step approach but leads to marginally lesser dissipation and allows for the use of marginally higher Courant number than existing reconstruction techniques. A novel non-iterative variant of MGG reconstruction for non-orthogonal meshes is also described and its robustness in high-speed flows has been studied. A sharp-interface Immersed Boundary (IB) technique based on local reconstruction of the solution has been proposed for inviscid and viscous flows. The boundary conditions are imposed directly at the geometry interface and is employed to obtain the solution in the near vicinity of the solid(s). This reconstruction approach which also employs the finite volume solutions obtained away from the solid, is effectively an interpolation technique that does not strictly conserve the mass, momentum and energy. Two different strategies, based on inverse distance weighting (IDW) for inviscid flows and one-dimensional reconstruction (HCIB) for viscous flows are described and explained in this work. We show that the finite mass conservation errors diminish linearly with grid refinement and that the reconstruction approach does not degrade the nominal second-order accuracy of the flow solver. The IB-FV solver computes wall pressure and skin-friction distributions quite accurately, although the latter requires sufficient fine meshes in the vicinity of the body. However, finite levels of mesh refinement does not produce accurate heat flux estimates in laminar hypersonic flows past blunt geometries. We probe the possible causes of this under-prediction using an in-depth diagnostic analysis. The investigations indicate that errors due to temperature reconstruction which are linked to a loss in energy conservation are primarily responsible for the inaccurate estimation of wall heat-flux and stagnation point heat transfer. We prove using numerical experiments that the use of adaptive meshes and non-linear/non-polynomial interpolations do not improve the heat flux estimates and that the errors are larger as Reynolds and Mach numbers become higher. The utility of the FV and IB-FV frameworks proposed in this work are highlighted by their application to three selected problems of design and optimisation. These frameworks are employed in conjunction with variable fidelity approaches for the design of minimum drag geometries, scramjet intakes and supersonic nozzle. The large spectrum of canonical problems in this thesis over a wide range of Mach and Reynolds number indicate the efficacy of the IB-FV solver while also highlighting some of its drawbacks. The IB-FV framework, despite its limitations, is also found to be a promising tool to evolve multi-fidelity optimisation frameworks that can accelerate the design and optimisation in hypersonic flows.