An Adaptive Finite Element Technique with Dynamic LES for Incompressible and Compressible Flows

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Large-eddy simulation (LES) is a technique intermediate between the direct simulation of turbulent flows and the solution of the Reynolds-averaged Navier-Stokes (RANS) equations. In LES the contribution of the large, energy-carrying structures to momentum and energy transfer is computed exactly, and only the effect of the smallest scales of turbulence is modeled. Small scales tend to be more homogeneous and universal, and less affected by the boundary conditions than the larger scales. LES models can be simpler and require fewer adjustments when applied to different flows than similar models for the RANS equations. Moreover, for fluid flow applications involving chemical reactions, which take place in the small scale structures of the turbulence, LES including species and particle transport naturally constitutes a more accurate model. Here we present our methods and results for an LES turbulence model that was developed for the KIVA combustion software, which is part of a larger effort to enhance combustion predictability and efficiencies within engines.

In this study, the Vreman dynamic LES approach is implemented in a Predictor-Corrector Split (PCS) *h*-adaptive Finite Element Method (FEM) for modeling combustion [1]. The PCS *h*-adaptive FEM model achieves 2^{nd} and higher order spatial accuracy, with a minimal amount of computational effort [2]. In our formulation, the Vreman dynamic LES model is able to solve compressible and incompressible fluid flow without any wall damping function or ad-hoc clipping to prevent an unstable (negative) eddy viscosity, unlike the Smagorinsky subgrid model [3]. Furthermore, it provides measurement of the actual error in the discretization, and can adjust spatial accuracy to minimize the error to some specified amount. By utilizing the dynamic model, the flow can be automatically classified as laminar or turbulent as it develops, improving the resolution of eddy viscosity.

The goal is to use this dynamic LES PCS *hp*-adaptive FEM code known as KIVA-hpFE for reacting flows with complex geometries found in internal combustion engines [2]. In the present paper, the dynamic Vreman LES approach is described in a simpler geometry concerning the discretization schemes for the mass, momentum, energy and species transport equations and for SGS stress modeling. The model is validated by solving an 18 degree ramp problem with Mach number 2.2 as well as an unsteady turbulent flow problem, i.e., flow over a backward facing step (BFS). The high Mach number ramp problem demonstrates the ability of the model to capture shocks and shock-wave/boundary layer interactions, and simulations are in a good agreement with experimental data. In the high Reynolds number BFS problem, large eddies are resolved without the requirement of a fine mesh, in contrast to DNS. The reattachment length and instantaneous flow results compare well with published simulations and experimental data.

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