A steady-state Eulerian-Lagrangian solver for non-reactive sprays

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Abstract

A steady-state RANS solver for sprays, based on fully coupled Eulerian-Lagrangian approach, was implemented in the framework of the open source CFD code called OpenFOAM. Because of the intrinsic unsteady nature of the Lagrangian tracking, the most straightforward approach to solve for droplet motion in continuous media is the fully unsteady method. However, since for many industrial purposes the focus is on the time averaged solution, steady state acceleration techniques are of primary interest.

The computational strategy, implemented to handle typical configurations encountered in liquid-fueled gas turbine combustors such as pressure swirler atomizers, consists in separately resolving the gas and the liquid phases exploiting respectively a standard steady-state pressure based solver and a pseudo-transient Lagrangian approach. The coupling between the two phases is achieved by means of time averaged source terms in the Eulerian conservation equations and by including gas-droplet interaction in the Lagrangian tracking to account for evaporation, drag, break-up and turbulent dispersion. The Lagrangian tracking is performed using a statistically representative number of parcels which are tracked over their entire history from injection up to either evaporation or computational domain exiting. Pseudo time integration employs a user-defined time-step chosen to obtain an optimal fuel mass injection to suitably represent droplet distribution. The obtained instantaneous solutions are then summed up to compute the Lagrangian solution and hence the steady-state spray-gas coupling source terms. In such a way the number of parcels necessary to describe the spray evolution, as well as the computational time to resolve the Lagrangian tracking of the liquid particles, is strongly reduced compared to standard unsteady approaches. In order to improve the stability of the coupling source terms, an averaging procedure among successive Lagrangian solutions is proposed instead of the classical approach which only considers the last available Lagrangian solution. Such averaging is performed using a moving average approach which only accounts for a given number of Lagrangian solutions. This technique allows us to increase the number of parcels considered in source term computation without increasing the computational efforts and to smooth out possible oscillations of the Lagrangian solution.

This paper describes the derivation and implementation of such numerical methods. Solver validation was performed against experimental data available from two well known literature test cases. The first one consists of an isothermal swirled flow with solid particles axially injected at the center of the vortical structure. In this case, the Eulerian-Lagrangian coupling is reduced to flow field interactions, thus only drag, particle dispersion caused by turbulence and turbulence generated by particle motion are to be considered. The solution obtained with the proposed coupling approach was compared with experimental measurements and numerical results obtained using classical approaches: detailed results in terms of gas phase velocity field, particle velocity and particle size-velocity correlation are presented. The second test case is an isopropyl alcohol spray generated by a hollow cone injector issuing into a co-flowing heated air stream. In this case the Eulerian-Lagrangian coupling is also extended to the mass and energy conservation equations and the convergence capabilities of the different approaches are further tested. Comparisons with experiments for both continuous and disperse phase are reported.

The newly implemented solver showed faster convergence rates compared to numerical approaches already available in the code, maintaining equivalent capabilities for mean flow field and particle distribution prediction.

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