Efficient numerical coupling strategy for evaporating polydisperse sprays in unsteady multi-species flows: Application to solid rocket motor simulations

A. Sibra[a,b,c], J. Dupays[a], F. Laurent[b,c] and M. Massot[b,c]

[a]Département d'Énergétique Fondamentale et Appliquée, ONERA 91120 Palaiseau FRANCE
[b]CNRS, UPR 288 - "Laboratoire d'Énergétique Moléculaire et Macroscopique, Combustion"
[c]École Centrale Paris, Grande Voie des Vignes 92295 Châtenay-Malabry FRANCE

In solid rocket motors, aluminum particles are included in the propellant with a significant mass fraction to improve the global performances. The distributed combustion of these droplets strongly coupled to the unsteady gaseous flow is suspected to have a remarkable impact on the motor behavior by amplifying flow disturbances. As one of the potential driving mechanisms of these instabilities, interactions between the spray combustion and the acoustics of the chamber could be a key issue. To improve solid rocket motor design, performing unsteady reactive two-phase flow computations with a reliable prediction of spray-acoustics interactions is a determining step to estimate flow instability levels [2, 4]. In the context of industrial computations, constraints such as an optimization of the cost/accuracy ratio have to be taken into account. An efficient numerical coupling strategy which can be easily implemented in an industrial code is a challenge for both computing and scientific computing. Here we limit our study to evaporating polydisperse two-phase flows since the context is particularly relevant to highlight thermoacoustics instabilities. This framework is sufficiently simplified not to take into account the complexity of a multispecie gaseous combustion but significantly instructive since it has been theoretically proved that mass release from an evaporating spray can drive acoustic waves [1].

In order to treat polydisperse sprays, we choose a kinetic approach where the spray is described by a number density function (NDF) and its evolution follows the William-Boltzmann transport equation [5]. Several approaches are possible to solve the NDF itself such as the Lagrangian approach. In the context of industrial simulations, the Eulerian description is chosen considering the advantages to scale up on parallel architectures and to render two-way coupling effects. Then we use an Eulerian Multi-Fluid model [3] which results in a system of conservation equation for a set of fluids constituted of droplets in discretized size intervals called sections, assuming size/velocity and size/temperature correlations to reduce the size space dimension. A second order Multi-Fluid model is derived choosing an appropriate size distribution in each section. These sections are coupled together and to the gas through source terms accounting for the gas-particle and the particle-particle interactions.

Recently we have implemented in the industrial-oriented code CEDRE developed at ONERA a numerical strategy based on a time operator splitting method for inert polydisperse sprays coupled with unsteady flows. Such an approach proves its efficiency on inert acoustics cases and on a solid rocket motor configuration. The purpose of the present contribution is twofold: 1- we introduce an adaptable splitting strategy designed to capture all reactive multiphase flow interactions and we prove its potential on simplified but challenging evaporating two-phase flow acoustics cases. 2- We use the CEDRE code and demonstrate its feasibility and performance for industrial computations in solid propulsion. As a first validation we evaluate the method's ability to perform evaporating polydisperse spray computations on a simplified solid rocket motor case with no flow instabilities. Then we present more complex simulations on a realistic solid rocket motor configuration featuring acoustics and hydrodynamics instabilities. For each computation, we assess the proposed strategy by making comparisons with classical coupling approaches and previous Eulerian descriptions of the spray. We finally highlight the robustness and the accuracy of the strategy to predict complex two-phase flow interactions for a reasonable computational cost.

References

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