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Coupling a hierarchy of diffuse interface model with kinetic-based moment methods for primary atomization simulations in liquid propulsion

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Diffuse interface models, robust and accurate MUSCL numerical schemes, primary atomization, separated and dispersed two-phase flow models, cryogenic combustion.

The reliability of rocket engines is one of the priorities given to the Ariane 6 European Space Agency program. A cryogenic combustion chamber faces many physical phenomena, which are interacting with each other and involve a large spectrum of length and time scales. Amongst them, the primary atomization plays a major role and should be investigated to understand its influence on high frequency instabilities developing in the chamber. Such instabilities have been encountered in the recent past and can cause highly destructive damages for cryogenic rocket engines. Whereas experiments are crucial in order to validate simulations and understand the physics of such phenomena, predictive numerical simulation are mandatory, at least as a complementary tool in order to understand the physics as well as to design new combustion chambers and predict their potential of developing instabilities in various configurations. In subcritical conditions, a co-axial injector involves liquid oxygen and di-hydrogen two-phase flow with three distinct topology regions. As described in **Figure 1**, at the injection, the two phases are separated with a smooth interface; it is the separated flow region. Downstream, one can observe a polydisperse spray of evaporating droplets carried by the gaseous flow field: the dispersed flow. In between, velocity shear stress tears the liquid jet, forming ligaments. This process is called primary atomization. The ligaments eventually break-up into droplets during secondary atomization. This region called mixed region is characterised by a very complex flow topology and physics.

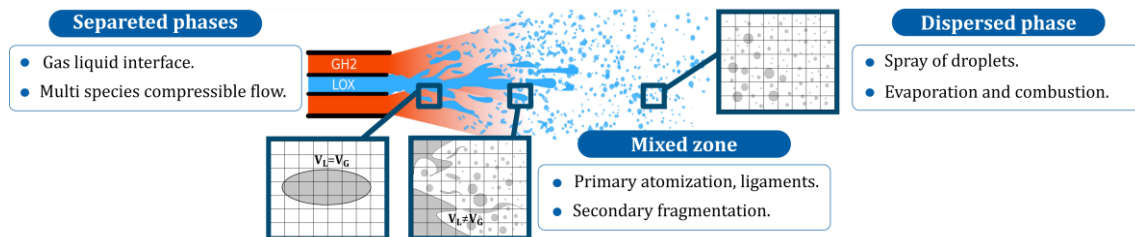


Figure 1 : Two phase flow topology of a coaxial jet in subcritical conditions

Since direct numerical simulations of such flows in realistic configurations are completely out of reach, predictive numerical tools have to rely on reduced order models and great care must be taken when modelling the flow in order to cover the three zones [1].

The contribution of this talk is three-fold. First we present an original fully Eulerian modelling strategy relying on the coupling of a hierarchy of diffuse interface models with an Eulerian

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kinetic-based moment method (KBMM) [2] in order to accurately describe the polydisperse evaporating spray generated through atomization [1]. The separated fluids and mixed zones are first modelled using the LHF diffuse interface model (Locally Homogeneous Flow) for which pressures, velocities and temperatures are instantaneously relaxed. A special attention is devoted to the coupling strategy with the dispersed phase flow. An extension to an enriched two-fluid diffuse interface model [3] is also proposed and investigated, as well as an extension to the recently high order geometrical moment approach in the dispersed phase zone [4], which is easier to couple to and can better describe the complex geometry of the interface.

Second, a novel accurate and robust numerical method is introduced to cope with the specificities of both coupled models, which can generate singularities in finite time and require dedicated schemes. A fully robust and accurate second-order multi-slope MUSCL technique on general unstructured meshes has been developed [5] and designed for both models. It is proved to be highly accurate on a large range of meshes and robust in the sense that it yields a realizable method for the KBMM approach [2]. This method has been successfully implemented in CEDRE code of ONERA [6] and tested on several spatial applications involving two-phase flow and turbulent combustion. It has solved robustness issues due to the presence of strong gradients and high-density ratios, which a classical mono-slope approach cannot overcome. The extension of the proposed strategy to the various levels of the diffuse interface models will be discussed.

Third, relying on the previous two points, large eddy simulations of a jet atomization in a cryogenic combustion chamber in subcritical conditions [1] are presented using various levels of modelling as represented in Figure 2. They are performed using CEDRE code [6] and rely on the robustness and accuracy of the proposed numerical strategy. Numerical results of jet atomization on the test bench MASCOTTE (ONERA) should eventually be obtained.

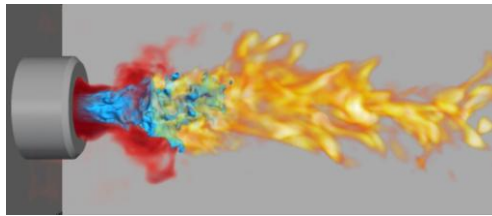


Figure 2 : Jet atomization simulation using CEDRE CFD code, MASCOTTE (ONERA) configuration. In blue, LOx iso-mass fraction. In red, H_{2(g)} volume fraction. In yellow, heat released.

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