Abstract
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Multiphase MHD model for electric explosions: Application to lightning protection systems

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Abstract

The electrical explosion of metals due to very fast energy deposition mechanisms (laser beam, Joule heating), is at the core of many applications such as lightning protections for aircraft, pulsed power technologies, nuclear fusion (Z machines) or directed energy weapons. However, the modelling of such explosions is very difficult to address since matter, initially in the solid state, may experience rapid phase transitions to liquid state, gas, supercritical state, and finally to plasma state. Being able to compute the properties of matter, such as thermodynamic and transport coefficients, from cold solids to high temperature diluted plasmas is a big challenging issue in this field. The second challenge is to deal with bi-phasic regions, where for example the high density, nearly incompressible liquid state may coexist with a diluted compressible gas or plasma. In the literature, single-fluid resistive MHD approaches are usually being used to model wire explosions [1-2]. However, such single-fluid approaches cannot deal correctly with the bi-phasic regions and are limited to very high current pulses that allow metals to stay long above the critical point. Moreover, ideal gas equations of state (EOS) are usually considered that does not incorporate cohesion pressure, largely overestimating pressure at liquid or solid densities. For moderated current applications, such as the explosion of lightning protection devices, dealing correctly with the bi-phasic regions and the high-density states is mandatory.

In this work, we propose a multiphase model relying on a diffuse-interface multi-fluid, single-pressure solver based on [3-4]. This solver is able to deal with Stiffened Gas Equations of state (SGE), considering a cohesion pressure that makes it possible to consistently model both compressible gas or plasmas and fluids with a very low compressibility, such as solids or liquids. To compute the thermodynamic properties, coefficients of the EOS, and transport coefficients, a classical QEOS (Quotidian Equation of State) model inspired by the work of [5] and [6] has been employed for highly correlated regimes at high density and coupled with LTE (Local Thermodynamic Equilibrium) plasma calculations for low density and high temperature regimes.

As a validation test-case, the explosion of an Aluminum wire with a 20 µm radius has been simulated to compare with experimental and numerical results from the literature. Then, simulation results will be presented that focus on several aerospace applications such as lightning protection systems for aircraft.

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