Abstract #
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Direct numerical simulation of sloshing and phase change in LH2 tanks.

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Abstract
Sloshing of liquid hydrogen (LH2) during transportation or in micro-gravity conditions can lead to important issues in aerospace applications and, more recently, in its development as an energy vector in the transport industry. Since the work of Abramson [1], who proposed several analytical models to predict sloshing in tanks with different geometries, there have been a lot of studies on sloshing, but few that considered sloshing of vaporizing/boiling cryogenic fluids (for instance [2]). Besides the forces exerted by the liquid on the tank's walls, sloshing induces changes in the thermodynamic behavior of the liquid, leading to significant pressure changes when phase change occurs. This phenomenon, called boil-off, may lead to a release of the gaseous hydrogen during transportation to avoid the self-pressurization of the tank. The subsequent mass loss is considered one of the most severe drawbacks of this energy [3].
The LH2's boil-off can be triggered and enhanced by many processes, such as an increased surface area due to the sloshing, the heat flux entering through the walls, etc. These reasons prompted us to investigate this phenomenon using our in-house DNS code ARCHER[1]. In this work, the mass-conservative interface capturing (Coupled Level Set/Volume Of Fluid) method is adapted to account for the liquid mass variation due to phase change. In addition, the compressible Navier-Stokes equations are solved using a projection method based on two velocities, which allows us to capture the Stefan flow at the liquid/gas interface, acoustic effects and the thermal dilatation of both phases. Furthermore, the method can handle several gas structures captured inside the liquid, each with independent temperature, density, and pressure. A detailed description of the system of equations solved, the implemented numerical methods, and their application can be found in our previous work [4].
In this work, a configuration of a half-filled LH2 container is simulated, where the sloshing is represented by a sinusoidal acceleration in the x-axis. Results about the temporal evolution of the surface area, boil-off rate, temperature, and velocity field for 2D and 3D simulations are represented and analyzed. These results can be used to propose models dedicated to the estimation of the boil-off rate and pressure variations in an LH2 container subject to sloshing.

References

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