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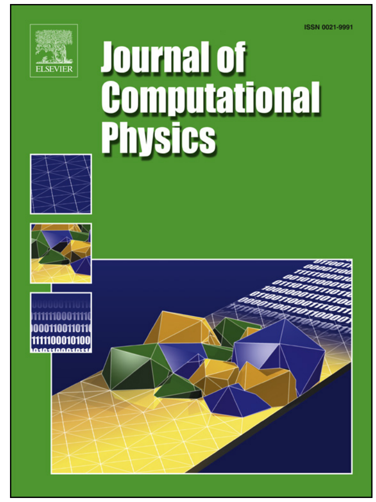

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Incompressible-compressible flows with a transient discontinuous interface using smoothed particle hydrodynamics (SPH)

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Abstract

A new two-phase incompressible-compressible Smoothed Particle Hydrodynamics (SPH) method has been developed where the interface is discontinuous in density. This is applied to water-air problems with a large density difference. The incompressible phase requires surface pressure from the compressible phase and the compressible phase requires surface velocity from the incompressible phase. Compressible SPH is used for the air phase (with the isothermal stiffened ideal gas equation of state for low Mach numbers) and divergence-free (projection based) incompressible SPH is used for the water phase, with the addition of Fickian shifting to produce sufficiently homogeneous particle distributions to enable stable, accurate, converged solutions without noise in the pressure field. Shifting is a purely numerical particle regularisation device. The interface remains a true material discontinuity at a high density ratio with continuous pressure and velocity at the interface. This approach with the physics of compressibility and incompressibility represented is novel within SPH and is validated against semi-analytical results for a two-phase elongating and oscillating water drop, analytical results for low amplitude inviscid standing waves, the Kelvin-Helmholtz instability, and a dam break problem with high interface distortion and impact on a vertical wall where experimental and other numerical results are available.

1. Introduction

Multi-phase flows are common, in fact quite general, in environmental and industrial processes. Broadly these may be modelled as continuous problems where phases are mixed (e.g. oil-water homogenisation [36], sediment transport [18]) or interface problems where phases are distinct and interact at the interface (e.g. gas-assisted injection moulding [21], liquid jet breakup [40]). In some cases flows start as interface problems but as mixing occurs at the interface they become effectively continuous, at least locally. Air entrainment, perhaps due to wave breaking, is an obvious example. We consider here two-phase interface problems where the interface remains distinct and the density difference is high, e.g. air and water, and where one phase may be considered incompressible. The interface is transient and may become highly distorted and interconnected. Such problems have been tackled with mesh-based methods using periodic (or adaptive) re-meshing or additional phase tracking functions [40]. However, these approaches can be time-consuming to implement and prone to errors in surface representation [50] or mass conservation [34].

Lagrangian particle methods are ideally suited to multi-phase flows as they are naturally surface or interface following and conservative: here we employ the smoothed particle hydrodynamics (SPH) method. SPH has been previously applied to such problems either in (weakly) compressible form or incompressible form, but not a combination of the two. Here we impose the incompressible divergence-free condition for one phase while the other phase is compressible. This requires a new interface treatment which is the subject of this paper. **The air phase of interest here is weakly compressible, but, in SPH, this term generally refers to the form with a stiff equation of state to represent incompressible flow (originally due to Cole [8], but often attributed to Tait [46]). Here we refer to compressible SPH or CSPH to distinguish the method as the physics of compressibility is**

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