Free Surface Flows

Introduction

Many problems of practical importance involve the low-speed flow with two phase fluids which have large phase density ratio and a moving interface. This type of flows exists in many industrial applications. The examples can be found in the studies of droplet dynamics, capillarity, hydrodynamic stability and so on. In such flows, the fluid interfacial motion induced by surface tension plays a fundamental role. The current work extends the PHOENICS to simulate free surface flows with surface tension. To calculate the surface tension at free surface, we use the continuum surface force (CSF) model [1]. This model interprets surface tension as a continuous, three-dimensional effect across an interface, rather than a boundary condition on the interface.

CSF Model for Surface Tension Force

In CSF model, instead of a surface tensile force or a surface boundary condition applied as discontinuity, a volume force due to surface tension on fluid elements lying within a finite thickness transition region replaces the discontinuities.

CSF formulation makes use of fact that numerical models of discontinuities in finite volume and finite difference schemes are continuous transitions within which the fluid properties vary smoothly from one fluid to another. The volume force in CSF model is calculated by taking first and second order spatial derivatives of the characteristics data, which in here is the color function value. At each point within the free surface transition region, a cell-centered value is defined which is proportional to the curvature κ of the constant color function surface at the point. Using the formulation given in the reference [1], we have:

$$F_{st} = \sigma\kappa \frac{\nabla C}{[C]} \frac{\rho}{\left(\frac{\rho_1 + \rho_2}{2}\right)} \delta$$

Where, F_{st} is the surface tension body force, C is the filtered color function, σ is the fluid surface tension coefficient, ρ is the density, ρ_1 and ρ_2 are the densities of phase 1 &2 respectively, δ is the Kronecker delta function, κ is the free surface mean curvature defined as:

$$\kappa = \frac{1}{|\vec{n}|}\left[\left(\frac{\vec{n}}{|\vec{n}|}\cdot\nabla\right)|\vec{n}| - (\nabla\cdot\vec{n})\right]$$

[C] is the difference of the color function across the interface and

$$\vec{n} = \nabla C$$

Practically, the term F_{st} is a vector source force decomposed in three components in 3D along X, Y & Z. Each component is a source term for the corresponding velocities similarly to the gravity force except that is always for the three components of velocity.

References

1. J.U. Brackbill, D.B. Kothe and C. zemach, “A continuum Method for modeling surface tension”, J. of Computational Physics, Vol. 100, p. 335, 1992.