A Coupled Level Set/Volume-of-Fluid (CLSVOF) Method for Target Flow Simulation

Yan Zhan

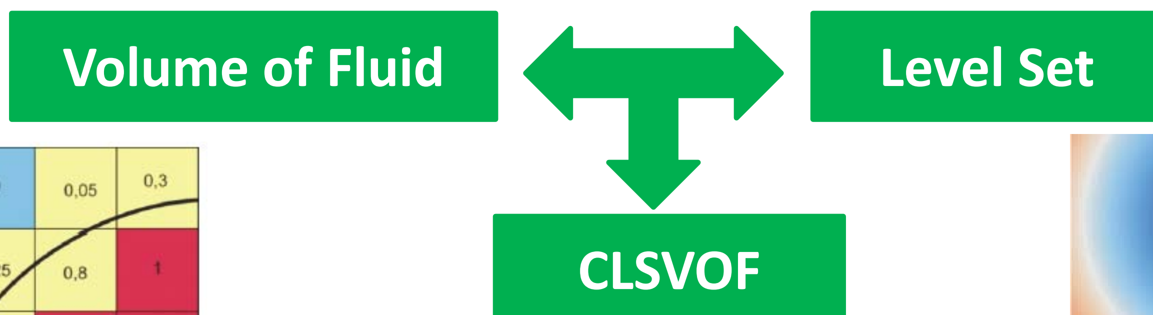
8-18-2011

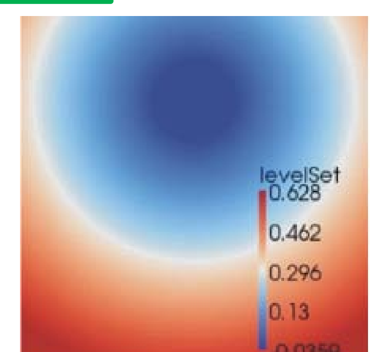
Outline

- What is CLSVOF?
- Why CLSVOF?
- How to implement CLSVOF?

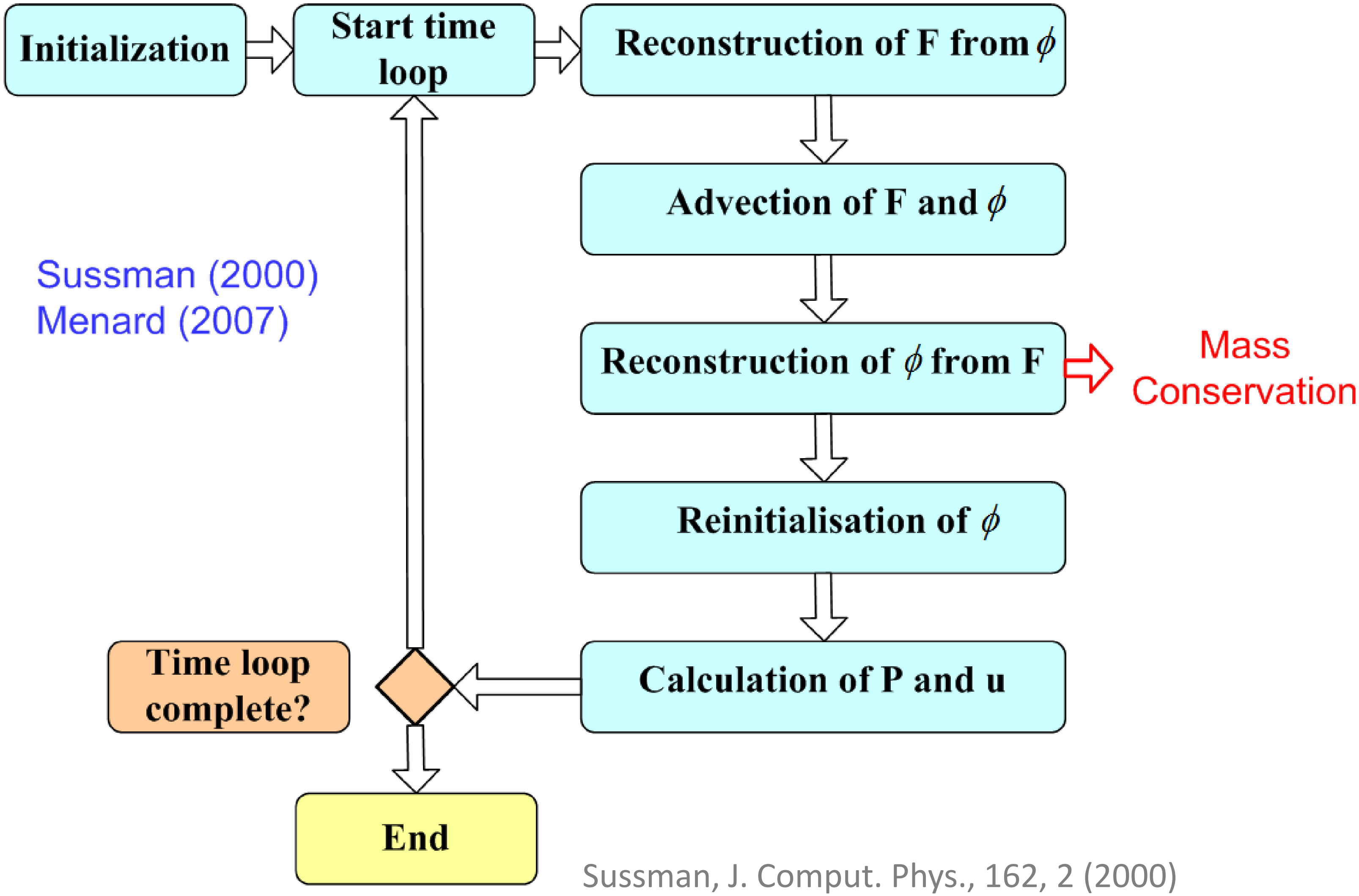
What is CLSVOF?

Volume of Fluid (VOF)	Level Set (LS)
• Volumetric phase fraction *F* Phase 1 *F=1* Phase 2 *F=0* Interface *0<F<1* • Transport of *F*: $(\rho F)_t + \nabla \cdot (\rho \tilde{U} F) = 0$ • Mass-conservative • Diffusion of the interface	• Level-Set function *Φ* Phase 1 *Φ>0* Phase 2 *Φ<0* Interface *Φ=0* • Transport of *F*: $(\rho \phi)_t + \nabla \cdot (\rho \tilde{U} \phi) = 0$ • Robust geometric information (normals and curvatures); automatic handling of topological changes (merging and pinching); • Not mass-conservative





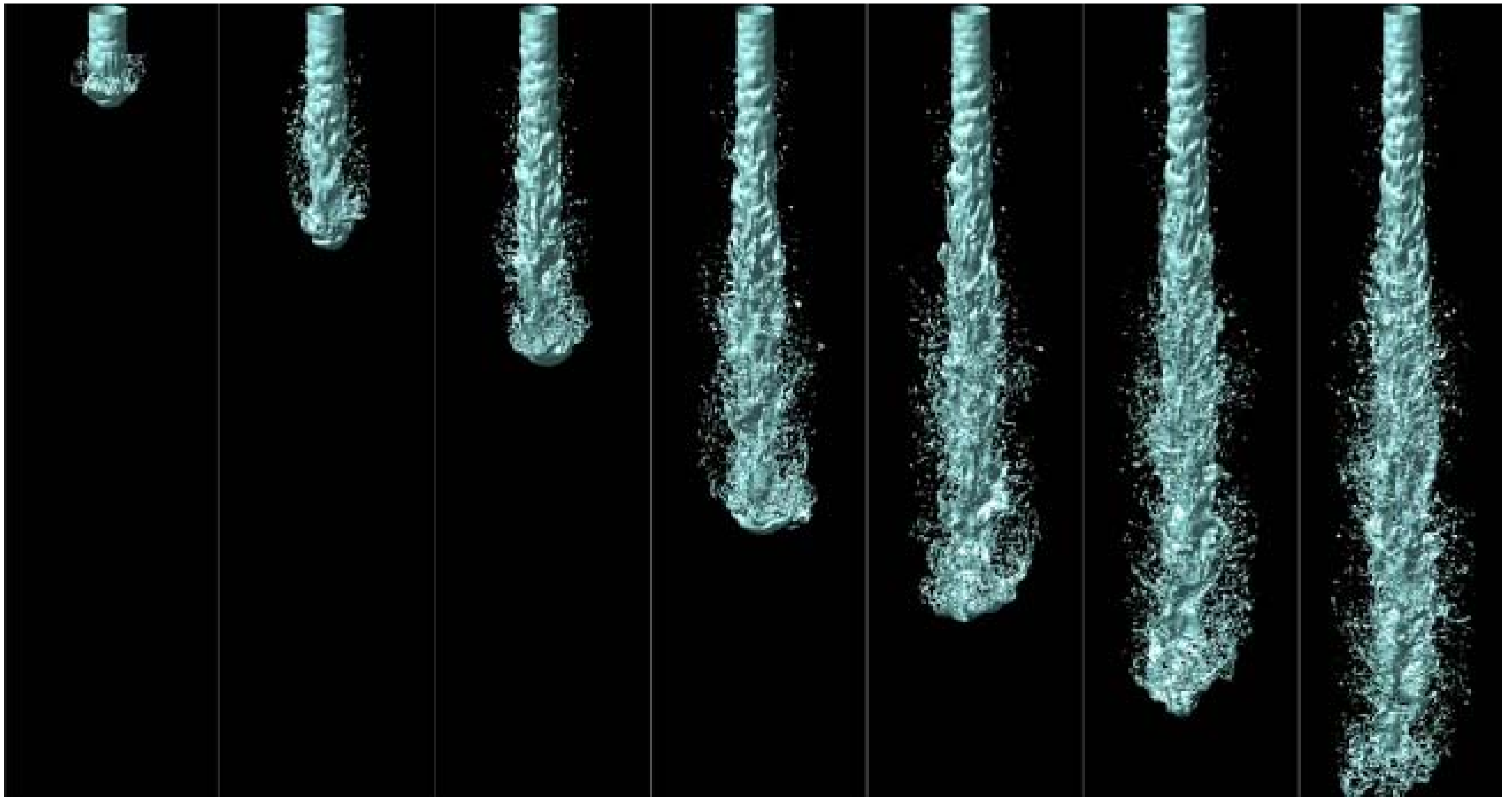
Why CLSVOF?



Sussman (2000)
Menard (2007)

Sussman, J. Comput. Phys., 162, 2 (2000)
Menard, International Journal of Multiphase Flow, 33, 5 (2007)

Why CLSVOF?



Development of the liquid jet (time step is 2.5 μm) (Menard, 2007)

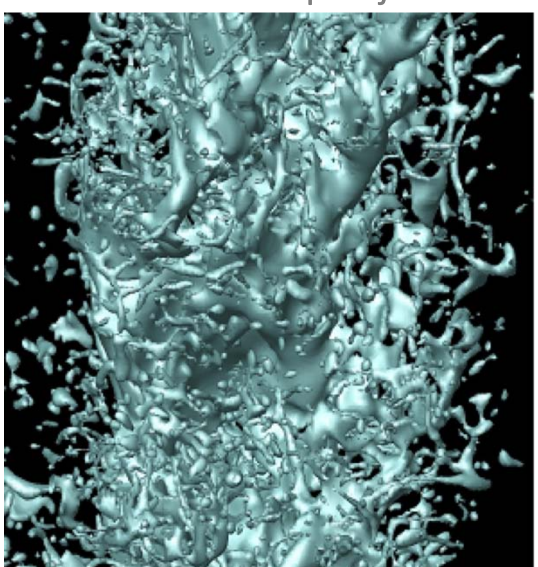
Jet characteristics

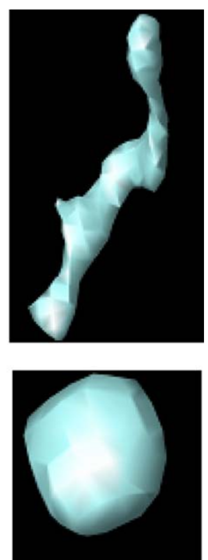
Diameter, D (μm)	Velocity (m s^{-1})	Turbulent intensity	Turbulent length scale
100	100	$u'/U_{liq} = 0.05$	0.1 D

Phase	Density (kg m^{-3})	Viscosity (kg $m^{-1}s^{-1}$)	Surface tension (N m^{-1})
Liquid	696	1.2×10^{-3}	0.06
Gas	25	1×10^{-5}	

Why CLSVOF?

Liquid jet surface and break-up near the jet nozzle



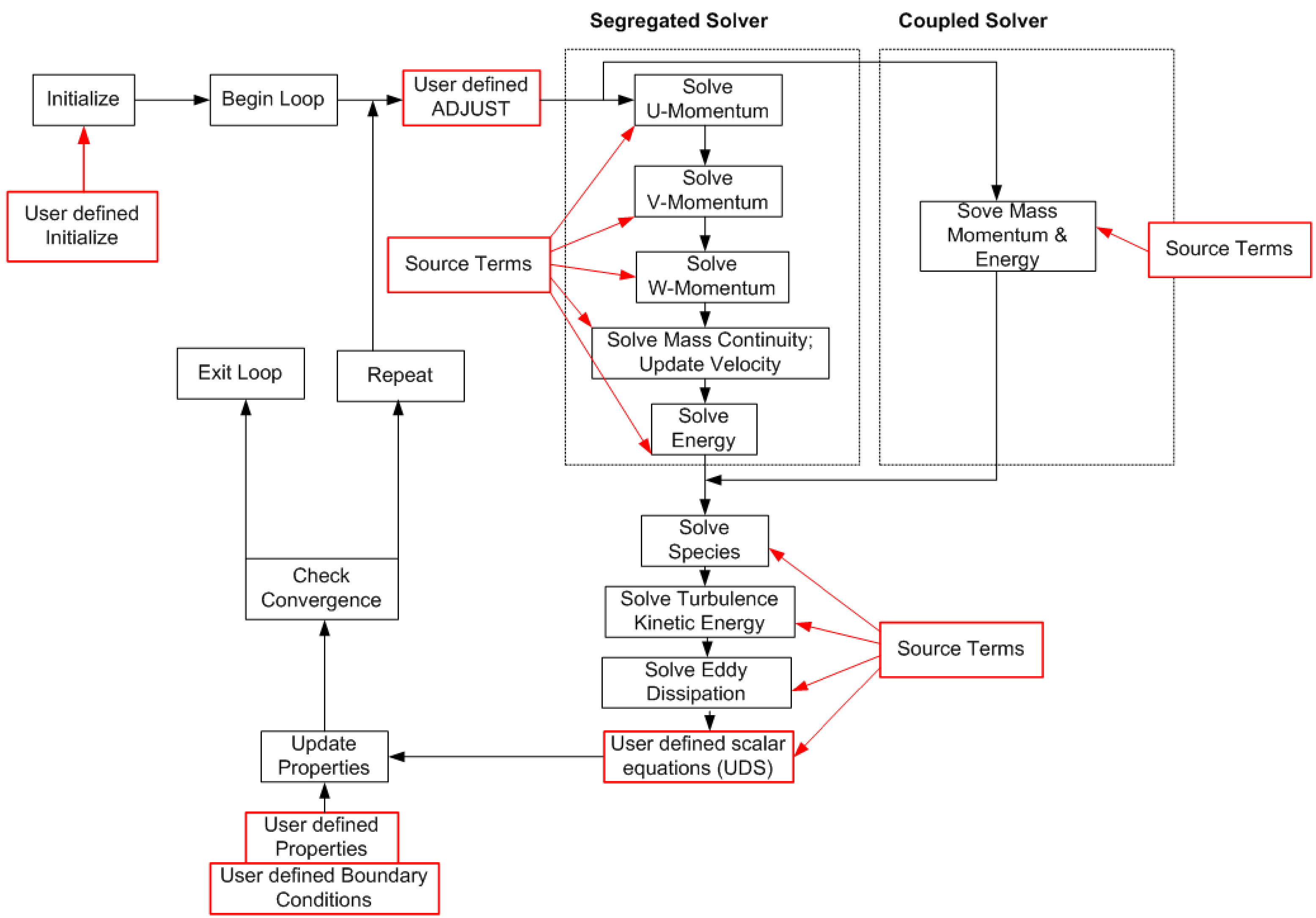


Liquid parcels

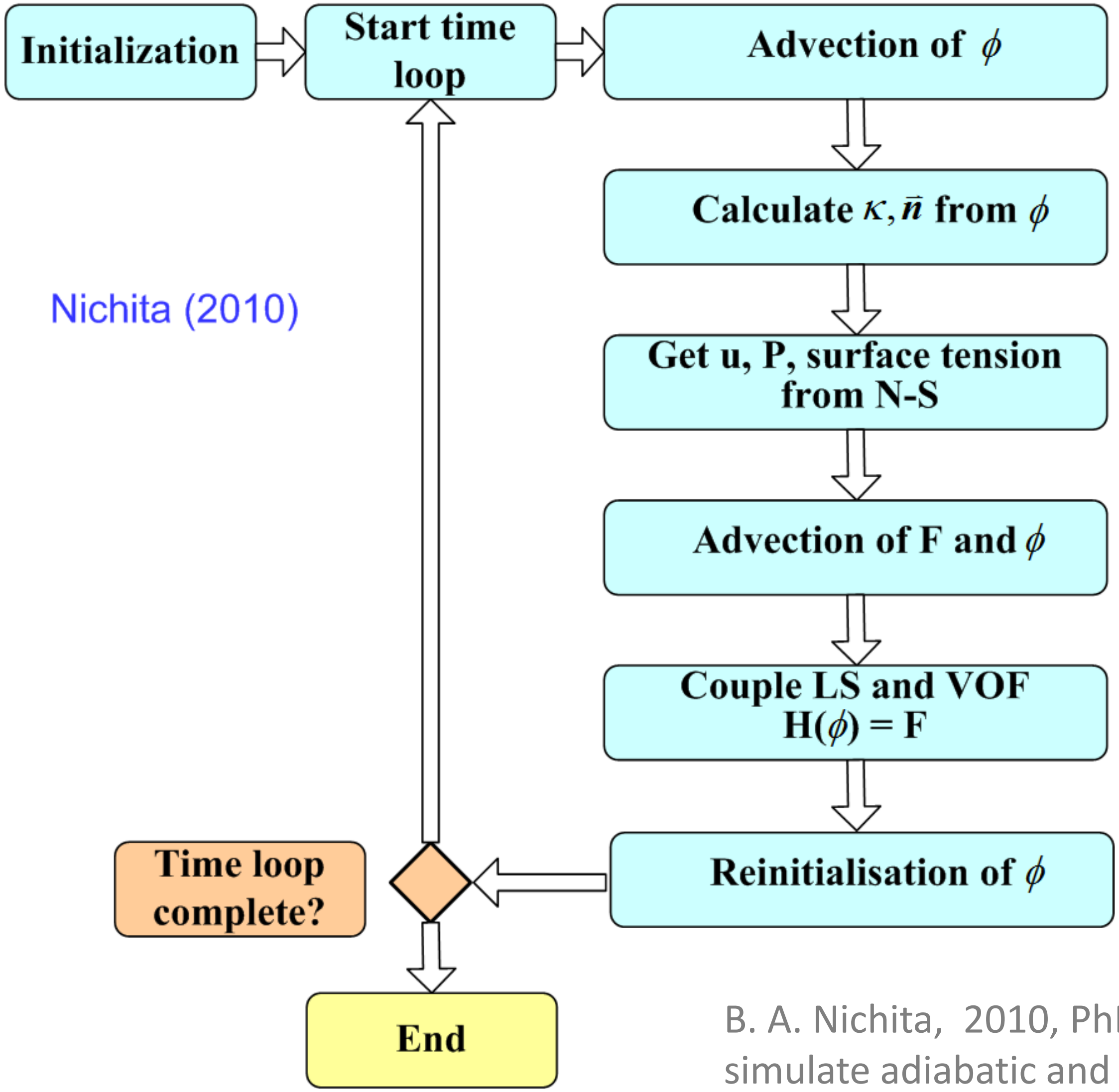
How to implement CLSVOF?

- Couple LS with VOF within the CFD code FLUENT by implementing user defined functions (UDF)
- UDF
  - User written program that can be linked with FLUENT at run-time
  - Programmed in C and FLUENT defined macros
  - User-defined scalar (UDS) transport modeling customize FLUENT for level set equation

How to implement CLSVOF?



How to implement CLSVOF?

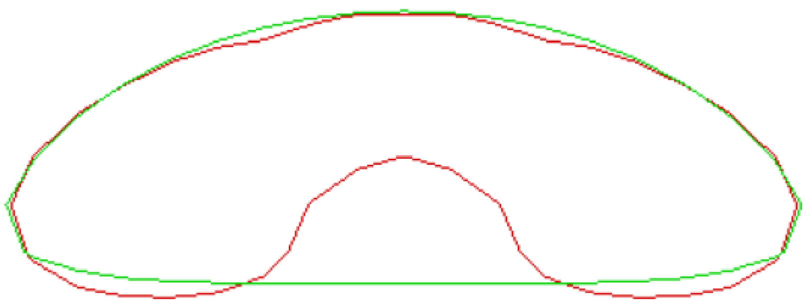


Nichita (2010)

B. A. Nichita, 2010, PhD thesis, An improved CFD tool to simulate adiabatic and diabatic two-phase flows

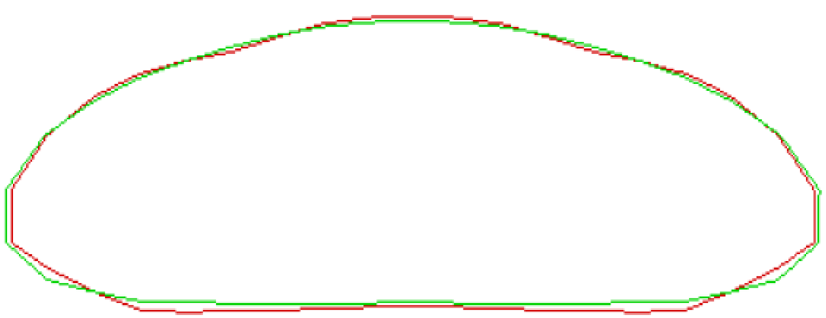
How to implement CLSVOF?

- B.A. Nichita’s test case
  - A bubble rising in a viscous fluid due to gravity



(t = 0.2s)

Level set contour (red) and volume-of-fluid contour (green) without coupling between LS and VOF (with large loss of mass).



(t = 0.2s)

Level set contour (red) and volume-of-fluid contour (green) after solving the coupling equation between LS and VOF.

How to implement CLSVOF?

- Setup UDS for LS in FLUENT

Scalar ø Transport Equation

$$\frac{\partial \rho \phi}{\partial t} + \nabla \cdot (\rho \tilde{U} \phi) = 0$$

- Unsteady term $\frac{\partial \rho \phi}{\partial t}$
- Convection term $\nabla \cdot (\rho \tilde{U} \phi)$
- Diffusive term 0
- Source term 0

Additional term appear for turbulent flow such as $-\rho \overline{u'_j \phi'} = \Gamma_t \frac{\partial \overline{\phi}}{\partial x_j}$

How to implement CLSVOF?

- Setup UDS for LS in FLUENT
  - Set number of UDS
  - Set UDS terms (Appendix A)
    - DEFINE_UDS_UNSTEADY
      - Get unsteady term for scalar equation
    - DEFINE_UDS_FLUX
      - Returns user specified flux
    - DEFINE_DIFFUSIVITY
      - Returns user diffusion coefficient (Γ)
    - DEFINE_SOURCE
  - Set UDS boundary conditions
    - Constant
    - UDF: DEFINE_PROFILE

Appendix Equations

- Incompressible two-phase flow

$$\nabla \cdot U = 0$$

$$U_t + U \cdot \nabla U = -\frac{\nabla p}{\rho(\phi)} + \frac{1}{\rho(\phi)} \nabla \cdot (2\mu(\phi) D) - \frac{1}{\rho(\phi)} \gamma \kappa(\phi) \nabla H(\phi) + F$$

$$\phi_t + U \cdot \nabla \phi = 0$$

$$F_t + \nabla \cdot (UF) = 0$$

Density $\rho(\Phi)$, viscosity μ (Φ), and curvature κ (Φ) are written as,

$$\rho(\phi) = \rho_g (1 - H(\phi)) + \rho_l H(\phi)$$

$$\mu(\phi) = \mu_g (1 - H(\phi)) + \mu_l H(\phi)$$

$$\kappa(\phi) = \nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}$$

D is defined as the rate of deformation tensor

$$D = (\nabla U) + (\nabla U)^T$$

Appendix Equations

- Incompressible two-phase flow

The surface tension force is

$$\frac{1}{\rho(\phi)}\gamma\kappa(\phi)\nabla H(\phi)$$

where *H* is the Heaviside function,

$$H(\phi)=\begin{cases}1 & \text{if } \phi>0\\ 0 & \text{otherwise.}\end{cases}$$

F will be initialized in each computational cell Ω_{ij}

$$F_{ij}=\frac{1}{\Delta r\Delta z}\int_{\Omega_{ij}} H(\phi(r,z,0))rdrdz$$

where Ω_{ij} is

$$\Omega_{ij}=(r,z)\big|\, r_i\le r\le r_{i+1} \quad \text{and} \quad z_j\le z\le z_{j+1}$$

Appendix Equations

- Re-Initialization
  - Reinitialize ϕ

$$\int_V \frac{\partial \phi}{\partial \tau} + \int_V w \cdot \nabla \phi = \int_V \text{sign } \phi_0$$

where w is the characteristic velocity pointing outward from the free surface

$$w = \text{sign } \phi_0 \frac{\nabla \phi}{|\nabla \phi|}$$

The sign function is

$$\text{sign}_\epsilon(\phi_0) = 2[H_\epsilon(\phi_0) - 1/2]$$