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Problems of a 3D VOF research code for confined geometries to compute bubble rise in an extended domain

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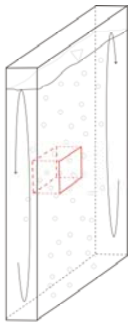
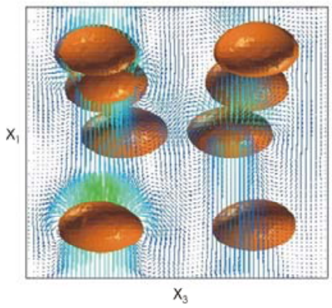
Overview

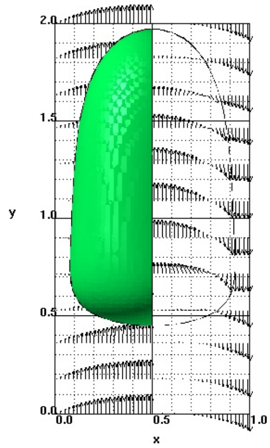
- Short description of in-house code
- Short description of test case 1
  - Spherical cap bubble in stagnant liquid
- Estimation of required grid size
  - Size of computational domain
  - Number of mesh cells
- Conclusions

In-house code TURBIT-VOF

- Designed to compute 3D bubble flow in confined rectangular geometries
  - Taylor-bubble in square mini-channels
  - Flat bubble column

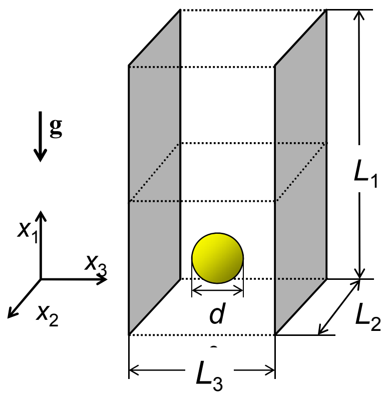






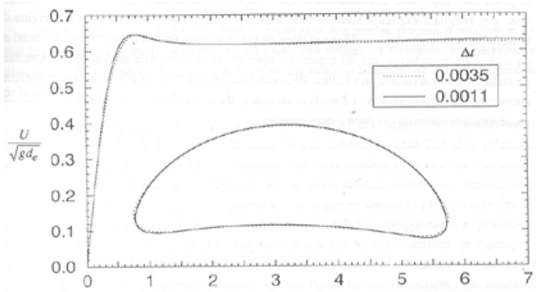
Features of TURBIT-VOF

- 3D PLIC-VOF method: interface is locally approximated by a plane
- Cartesian co-ordinate system
  - Rectangular 3D domain with two side walls (or four side walls)
  - *2D axi-symmetric coordinates are <u>not</u> implemented*
- Periodic b.c. in vertical and spanwise directions x_1 and x_2
- Grid spacing
  - Uniform in periodic directions
  - Optionally non-equidistant in wall-normal direction



Test case 1: Rise of a spherical cap bubble in a stagnant liquid

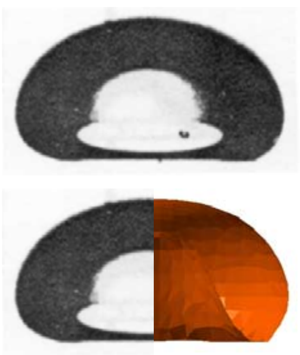
- Compute the displacement of an initially spherical inclusion with the following non-dimensional properties $Mo = 0.056$, $Bo = 40$, $\rho_L/\rho_V = 100$ and $\mu_L/\mu_V = 100$.



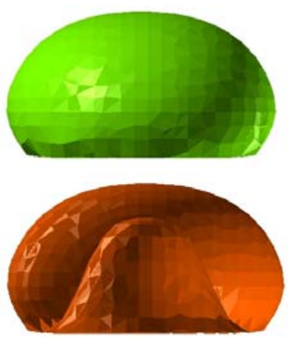
- As an example, we suggest the following physical properties: $\rho_L = 1000$ kg.m^{-3}, $\rho_V = 10$ kg.m^{-3}, $\mu_L = 0.273556$ Pa.s^{-1}, $\mu_V = 0.00273556$ Pa.s^{-1}, $\sigma = 0.1$ N.m, $g = 10$ kg.s^{-2}, $d_e = 0.02$ m.

Ellipsoidal cap bubble *Mo*=266, *Eö*=243

Experiment Bhaga & Weber
($\Gamma_\rho \approx 0{,}0008$; $\Gamma_\mu \approx 10^{-5}$)



TURBIT-VOF
($\Gamma_\rho = 0{,}5$; $\Gamma_\mu = 1$)



Estimate of size of computational domain for test case 1

- Test case requirements for horizontal directions (minimum): $L_2 = L_3 = 10d_e$
- Estimation of vertical distance of bubble rise

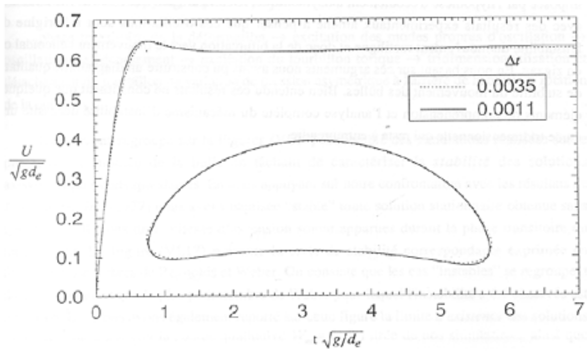
$$U \approx 0.6\sqrt{g d_e}$$

$$t \approx 7\sqrt{\frac{d_e}{g}}$$

$$\Rightarrow H = U \cdot t = 4.2 d_e$$

$$L_1 > 2H = 8.4 d_e$$

$$\Rightarrow L_1 = 10 d_e$$



Estimate of number of mesh cells

- The adequate representation of surface tension force requires accurate computation of the interface curvature
- For this the bubble diameter must be resolved by a minimum number of mesh cells
  - Number of mesh cells per bubble diameter $n_B \geq 16$
- Estimation of total number of mesh cells:

$$N = (10 d_e)^3 \cdot \left(\frac{n_B}{d_e}\right)^3 = 1000 n_B^3$$

$$n_B = 16 \quad \Rightarrow \quad N \approx 4{,}000{,}000$$

$$n_B = 20 \quad \Rightarrow \quad N \approx 8{,}000{,}000$$

- Largest grid used up to now: $N \approx 2{,}000{,}000$ cells

Conclusions

- For a purely 3D Cartesian PLIC-VOF code based on a structured grid test case 1 requires a large number of mesh cells
  - Most cells are spent in regions far away of the bubble where there is almost no liquid flow at all
- Test case 1 is well suited for codes with
  - 2D axi-symmetric coordinates
  - 3D codes which use an unstructured grid