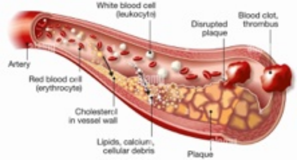
The effect of droplet coalescence on drag in turbulent channel flows

OIST internal seminar

2022 March 4

Ianto Cannon, supervised by Marco E. Rosti
Complex Fluids and Flows unit

Wall bounded flows with droplets



Blood plasma + lipids

Water + air

Water + organic matter

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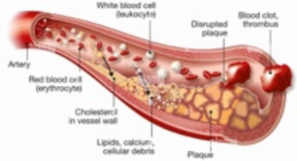

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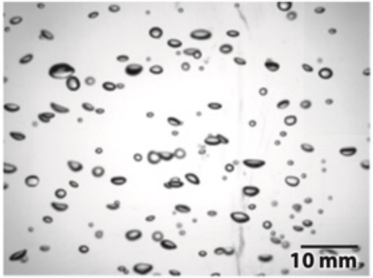
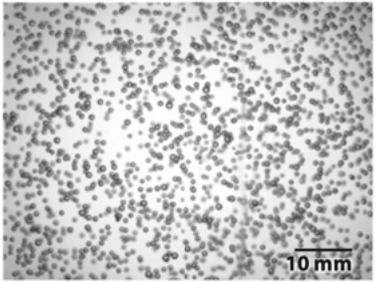
Previous studies

Due to **steric hindrance**, the **coalescence** of bubbles hardly occurs in the presence of surfactant[1].



Bubbles in tap water.



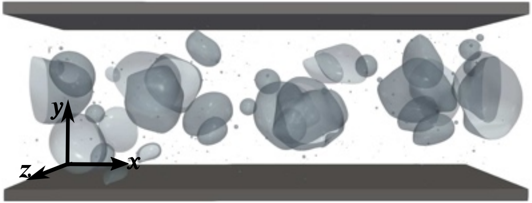
Bubbles in tap water with 2ppm Triton X-100 solution.

[1] Takagi & Matsumoto 2011 *Annual Review of Fluid Mechanics* 43, 615–636

Methods

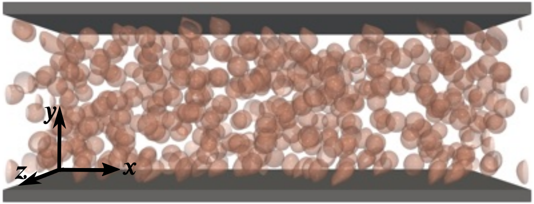
In the **volume of fluid** (VOF) method, an indicator function H is advected with the fluid,[2]

$$\frac{\partial H}{\partial t} + \mathbf{u} \cdot \nabla H = 0. \qquad (1)$$



In the **front tracking** (FT) method, the velocity of the interface is a sum over fluid velocities at nearby grid points,[3]

$$\mathbf{u}^{(l)} = \sum_i D(\mathbf{x}_i - \mathbf{x}^{(l)})\mathbf{u}_i. \qquad (2)$$



[2] Unverdi & Tryggvason 1992 *Journal of Computational Physics* 100, 25–37.

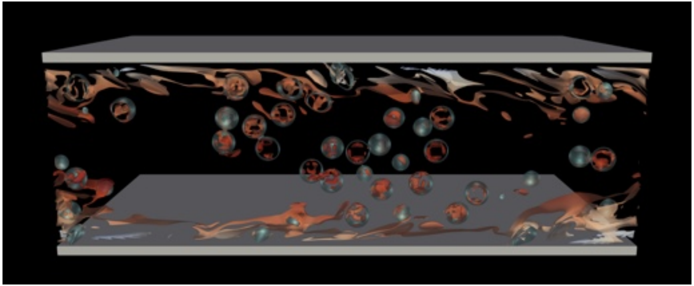
[3] Ii, Sugiyama, Takeuchi, Takagi, Matsumoto & Xiao 2012 *Journal of Computational Physics* 231, 2328–2358.

Setup: pressure driven channel flow

The Navier-Stokes equations, $u_{i,i} = 0$, and

$$(\rho u_i)_{,t} + (\rho u_i u_j)_{,j} = (\mu u_{i,j} + \mu u_{j,i})_{,j} - p_{,i} + \gamma \kappa n_i \, \delta_S(\boldsymbol{x}), \qquad (3)$$

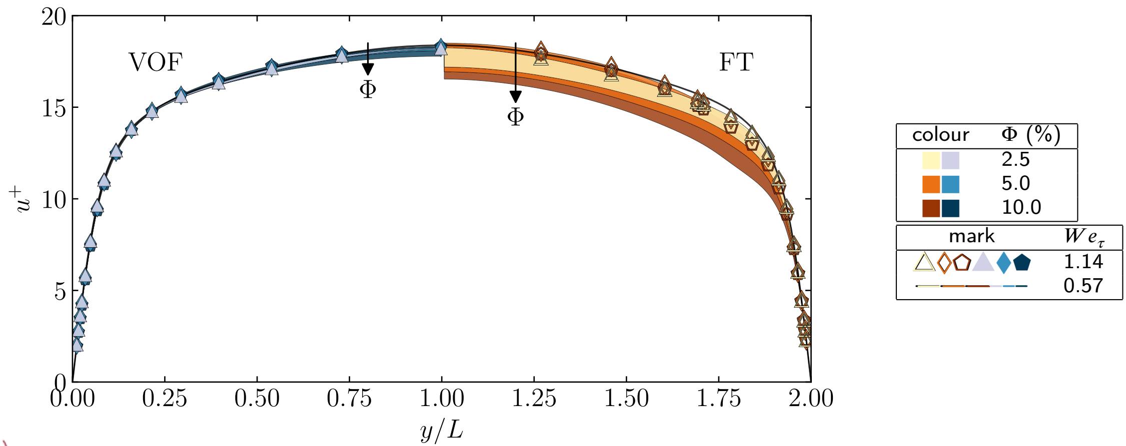
are solved on a grid of size $1296 \times 432 \times 648$



Friction Reynolds number	$Re_\tau \equiv u_\tau L/\nu = 180$
Four volume fractions	$\Phi = 0\%,\ 2.5\%,\ 5\%,\ 10\%,$
Two values of surface tension	$We_\tau \equiv \rho_c u_\tau^2 L/\gamma = 0.57,\ 1.14$

Flow profile

As the volume fraction of droplets increases, the **flow rate is reduced**.
Non-coalescing droplets have a much greater effect.



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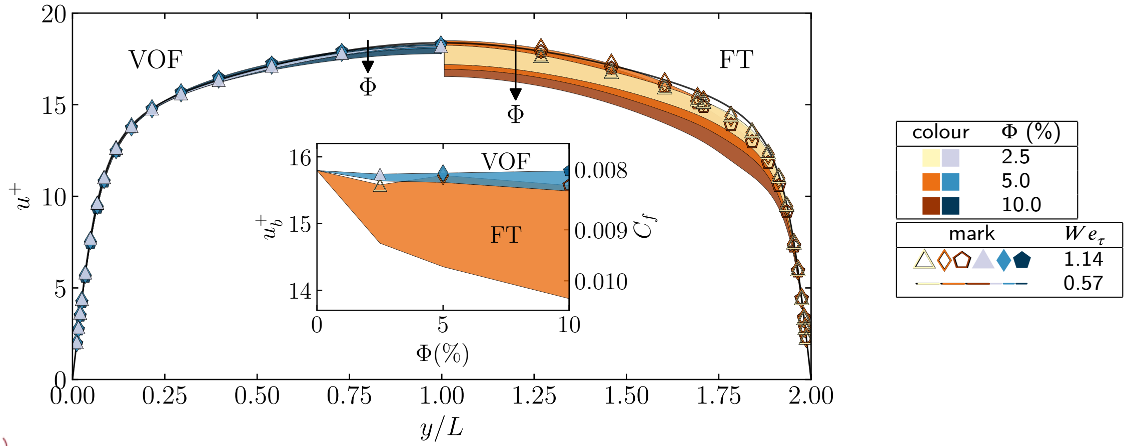
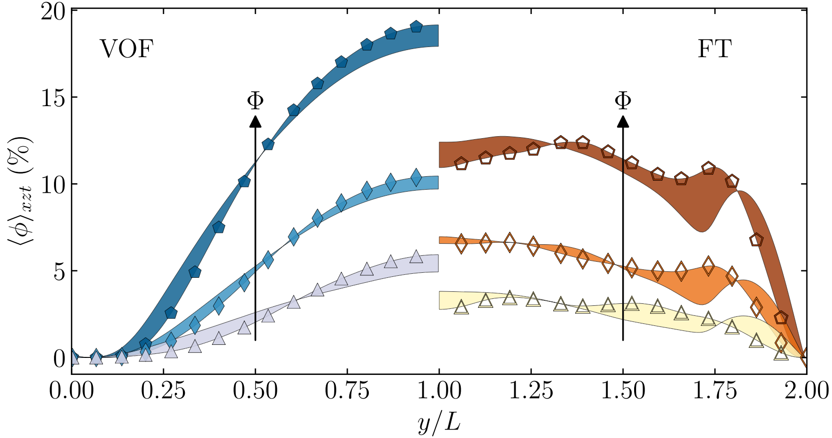
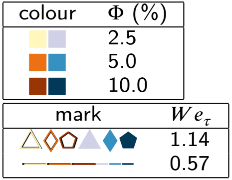
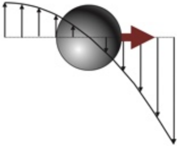


Volume fraction of dispersed phase







Martel & Toner 2014 Ann. Rev. of Bio. Eng. 16, 371–396

Volume of fluid droplets are able to coalesce and move to a region of low shear[4].

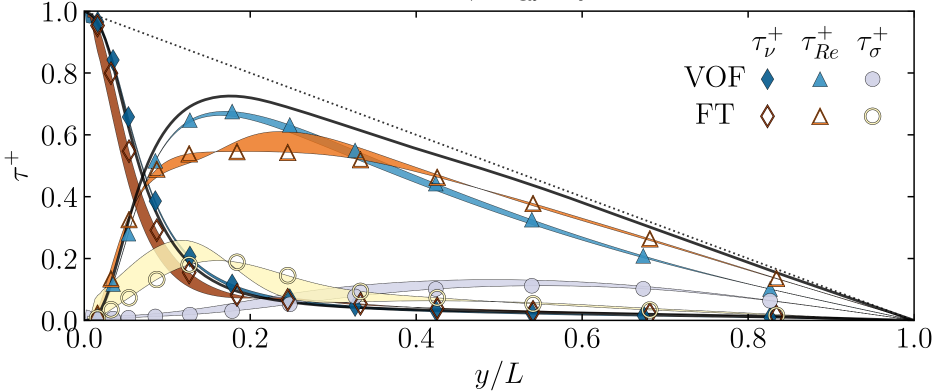
Front tracking droplets experience a **shear-gradient lift force**, pulling them toward the wall.

[4] Alghalibi, Rosti & Brandt 2019 Phy. Rev. Fluids, 4(10):104201

Shear stresses

The shear stress is a sum of the viscous, inertial, and surface tension parts,

$$1 - y/L = \tau_\nu^+ + \tau_{Re}^+ + \tau_\sigma^+ \tag{4}$$



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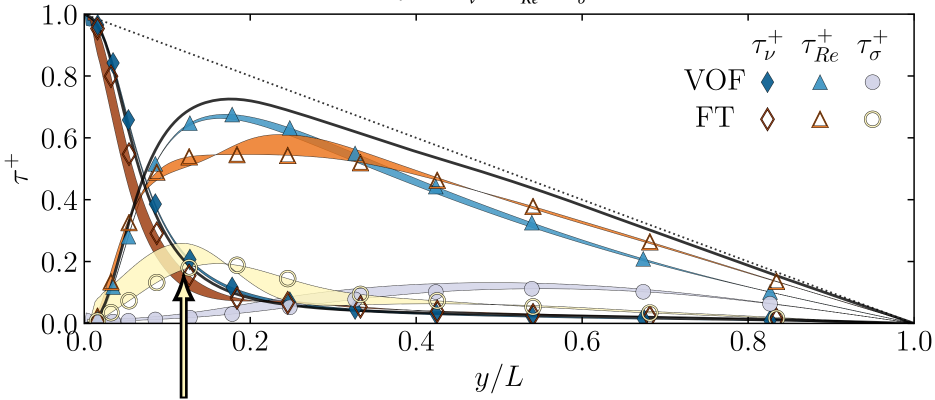
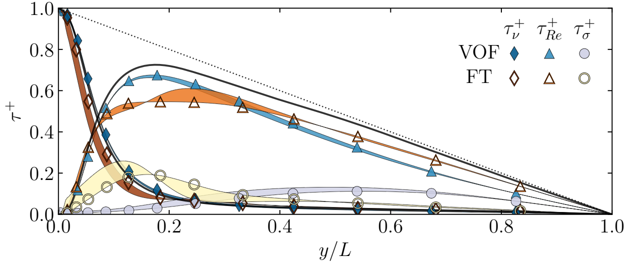
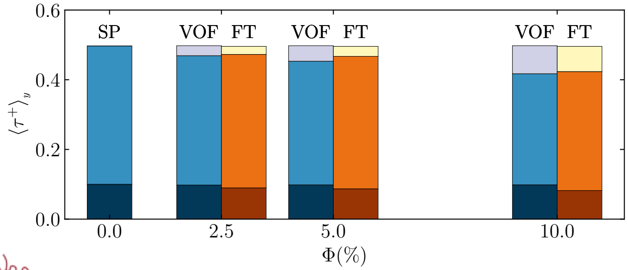


The front tracking **surface tension stress** has a peak near the wall.

Shear stresses



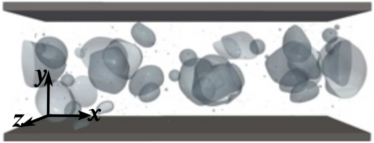


The mean viscous stress is reduced in the flows with non-coalescing droplets. This stress is proportional to the flow speed in the centre of the channel,

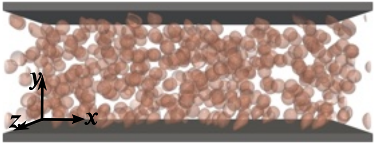
$$\langle\tau_\nu^+\rangle_y = \frac{1}{L}\int_0^L \frac{du^+}{dy^+}dy = \frac{\delta_\nu}{L}u_{cen}^+. \tag{5}$$

Hence the flow velocity is reduced in the front tracking simulations.

Conclusions



Volume of fluid method

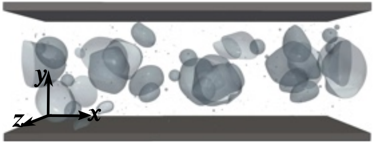


Front tracking method

1. Non-coalescing droplets produce a significant **drag increase** compared to coalescing droplets.
2. The non-coalescing droplets experience a **shear-gradient lift force**, which attracts them to the channel wall.
3. This leads to large surface tension stresses near the channel wall, **reducing the budget for viscous stress**, and increasing drag.

I. Cannon, D. Izbassarov, O. Tammisola, L. Brandt, and **M. E. Rosti**, *The effect of droplet coalescence on drag in turbulent channel flows*, Physics of Fluids, 33.8, p85112, Aug. 2021, 10.1063/5.0058632.

Conclusions



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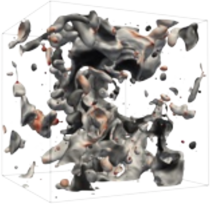
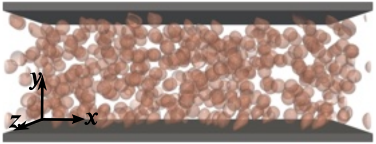

Surfactant model



Front tracking method

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4. Currently working on a model of surfactant as a **third fluid phase**

Thank you! Questions?

I. Cannon, D. Izbassarov, O. Tammisola, L. Brandt, and **M. E. Rosti**, *The effect of droplet coalescence on drag in turbulent channel flows*, Physics of Fluids, 33.8, p85112, Aug. 2021, 10.1063/5.0058632.