Retardation of a sphere settling in a vertically oscillating fluid

Master's Thesis Computational Science and Engineering

Carried out at the Department of Mechanical Engineering University of California Santa Barbara
Supervised by Prof. Dr. E. Meiburg and Prof. Dr. A. Soldati

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- **Bachelors:** Mechanical Engineering
- **Key Area Informatics**
  - Machine Learning (Chalmers)
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- **Key Area Fluid Dynamics**
  - Compressible Flow (Chalmers)
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- **Current Occupation:** Patent Attorney Candidate, SONN
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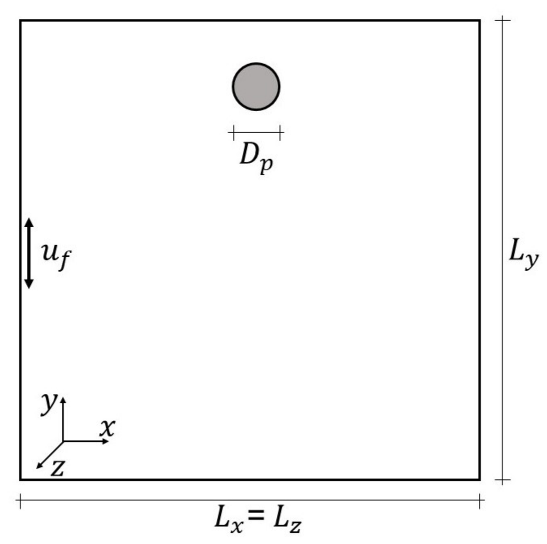
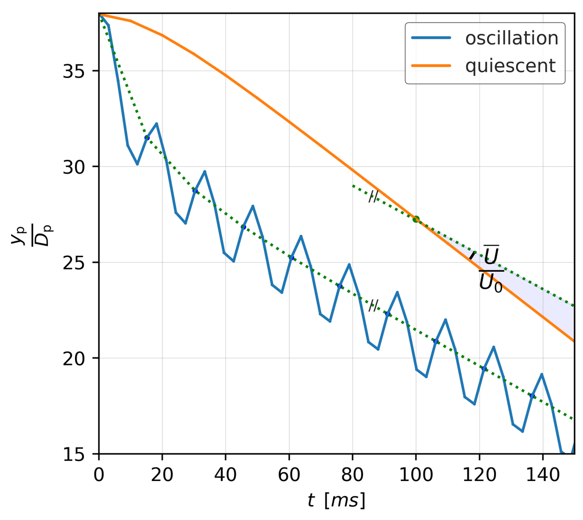
Introduction

A particle settling through a vertically oscillating flow settles more slowly than through a quiescent fluid.





The mechanism (=particle retardation) is not fully understood. Relevant material properties be particle to fluid density ratio ρ_s, fluid kinematic viscosity ν. Relevant flow characteristics be oscillation frequency ω, ratio of amplitude to particle diameter β.

$$\omega\ \left[\frac{1}{s}\right], \quad \beta = \frac{A}{D_p}, \quad \rho_s = \frac{\rho_p}{\rho_f}, \quad \nu\ \left[\frac{m^2}{s}\right], \quad g\ \left[\frac{m}{s^2}\right]$$

Questions

1) Can we find a dimensionless number that captures the retardation magnitude $\frac{\overline{U}}{U_0}$

2) What is physically causing particle retardation?

Method & Implementation

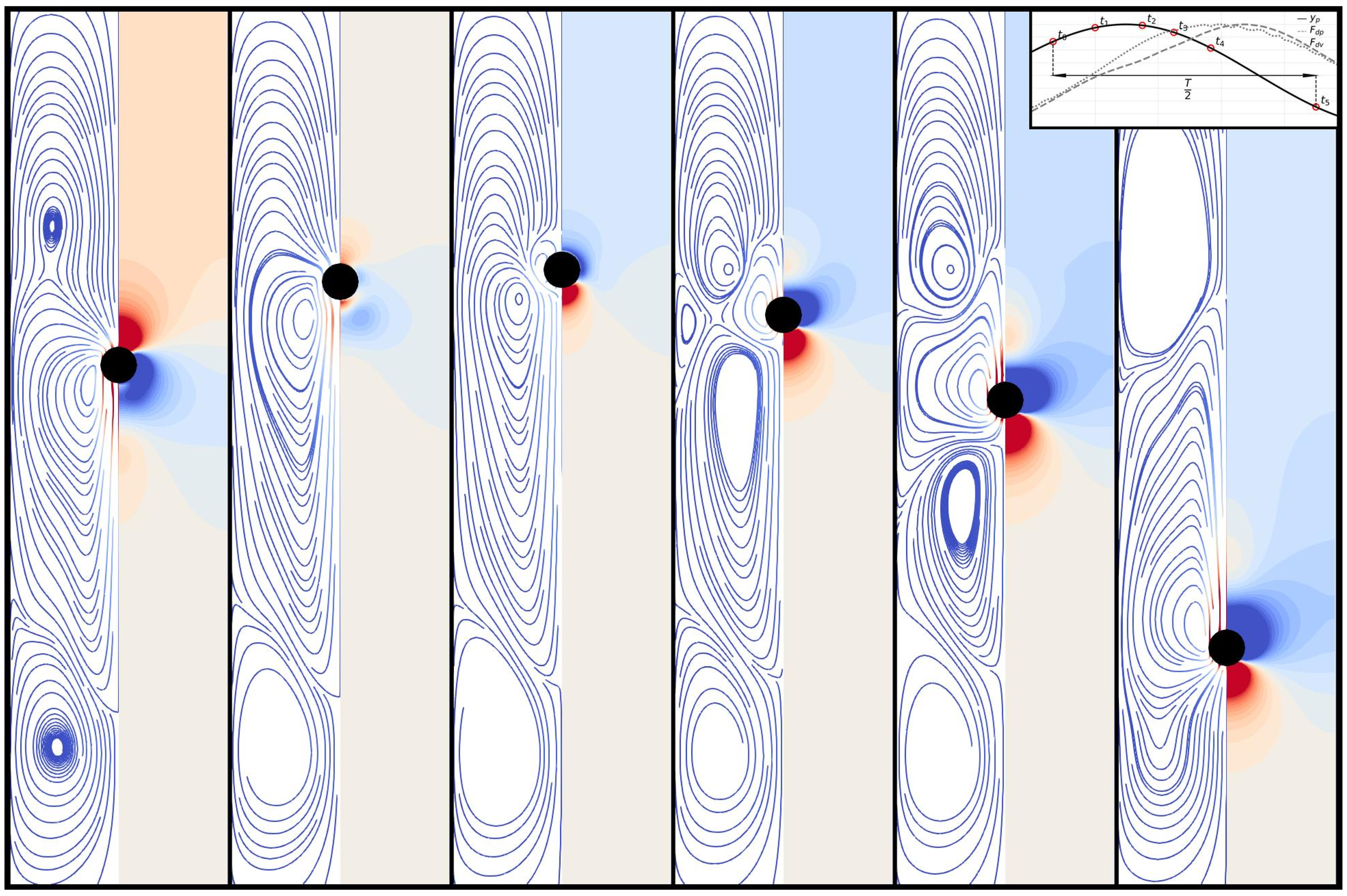
A grain-resolved Direct Numerical Simulation was applied (DNS). The according dimensionless set of governing equations (Navier-Stokes, Continuity and Newton-Euler) solved for, reads:

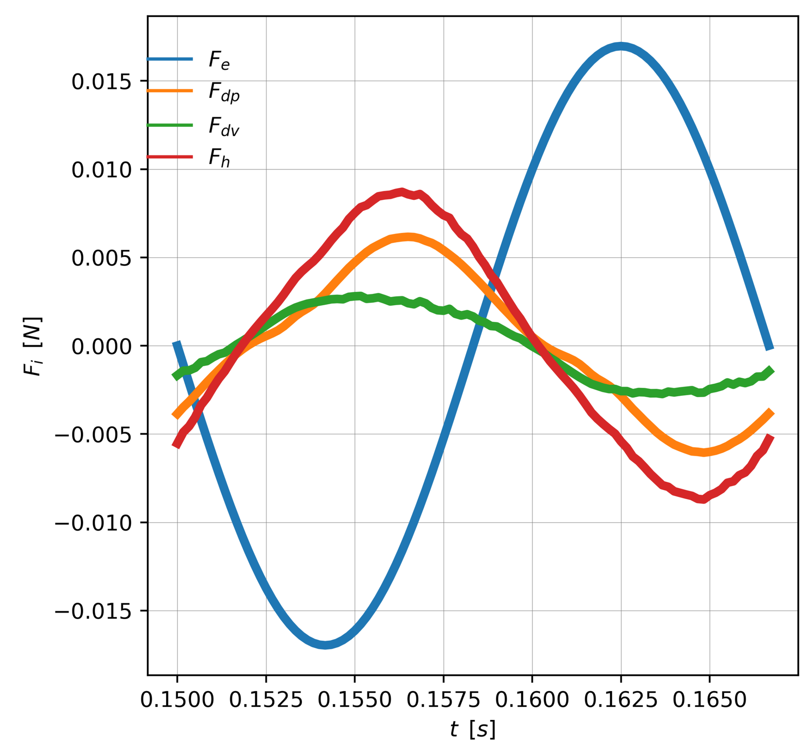
$$\frac{\partial \tilde{\mathbf{u}}}{\partial \tilde{t}} + \tilde{\nabla} \cdot (\tilde{\mathbf{u}}\tilde{\mathbf{u}}) = -\tilde{\nabla}\tilde{p}' + \frac{1}{Re}\tilde{\nabla}^2\tilde{\mathbf{u}} + \tilde{\mathbf{F}}_{IBM}$$

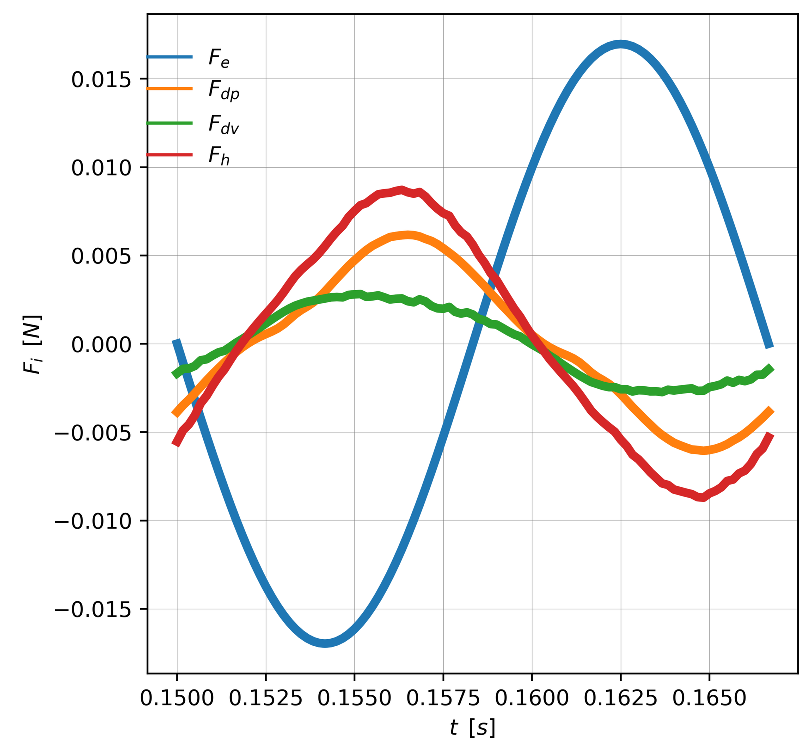
$$\tilde{\nabla} \cdot \tilde{\mathbf{u}} = 0$$

$$\tilde{m}_p \frac{\mathrm{d}\tilde{\mathbf{u}}_p}{\mathrm{d}\tilde{t}} = \tilde{\mathbf{F}}_g + \tilde{\mathbf{F}}_h + \tilde{V}_p(\tilde{\rho}_p - \tilde{\rho}_f)\,\tilde{\mathbf{F}}_o$$

Where $\tilde{\mathbf{F}}_{IBM}$ is the force on or from the particle, $\tilde{\mathbf{F}}_h$ the hydrostatic force, $\tilde{\mathbf{F}}_o$ the oscillation force and $\tilde{\mathbf{u}}_p$ the particle velocity. The flow data around the oscillated particle obtained by this method allows precise measurement and detailed description of the pressure and skin drag force.







Drag and flow-field Analysis

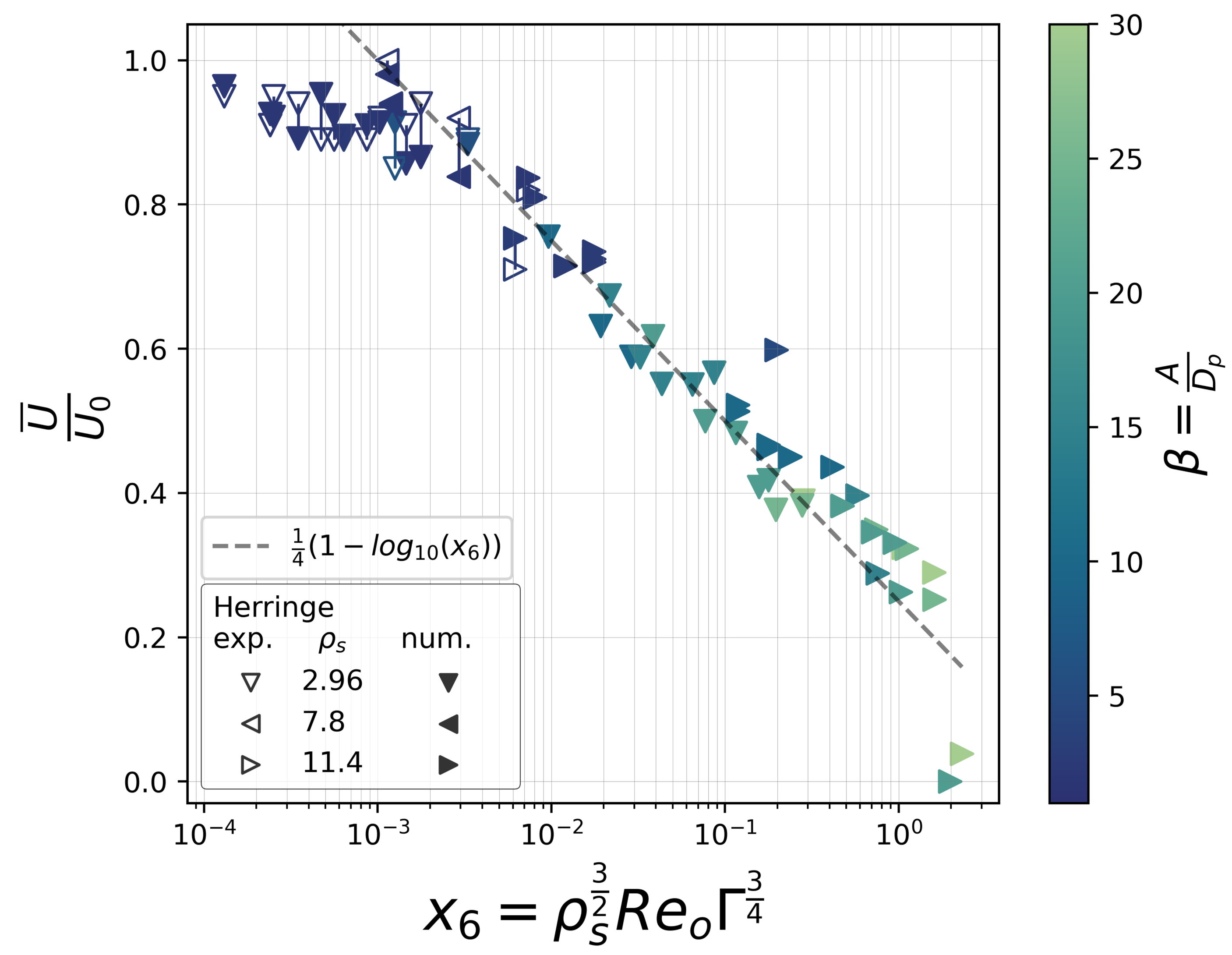
The contribution due to pressure difference F_{dp} to the reactionary force F_h compared to the viscous drag F_{dv} increases with the retardation effect, and higher energy configurations (high β, ω) cause vertically further stretched vortex structures which upon separation (as the particle changes direction) sustain longer and cause **longer periods where the particle works 'against' a heading vortex in the downwards-movement**.

Conclusion

A strong link between retardation magnitude and the pressure force $\mathbf{F}_{dp}$ contribution to net lift was identified. Differences in flow structures during upward and downward motion reveal an asymmetry in $\mathbf{F}_{dp}$ that increases with retardation, while a horizontally confined domain significantly affects particle retardation. A novel dimensionless parameter, $\Gamma = \frac{g\,D_p^3}{\nu^2}$, is proposed, for which both prior experimental data and the present simulation results collapse. [1].

Real feel

1. Make some theoretical considerations
2. Adapt existing C-code stack
3. Lay out plans for parameter study
4. Run a ton of simulations
5. Analysis
6. **Go surf!**



References

[1] Benjamin Gruber. *Retardation of a sphere settling in a vertically oscillating fluid*. eng. Wien, 2024.