University of British Columbia

Department of Mathematics

Dynamics and Wakes of a Fixed and Freely Moving Angular Particle in an Inertial Flow

Basilisk (Gerris) User's Meeting 2023

G. GAI, A. Wachs

Outline

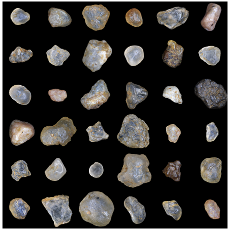
1 Introduction

2 Flow past An Angular Particle

3 Freely Settling of A Tetrahedron

4 Conclusions and Perspectives

Angular Particles in Fluids



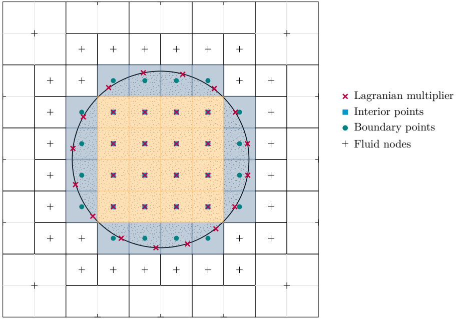
Particle-laden flows

- Sedimentation in rivers
- Particulate air pollution
- Coal & biomass gasification, etc.

Angular particles

- Complex shapes, sharp edges
- Broad range of size and density
- Rotation, unsteady dynamics

DLM/FD and Adaptive Mesh Refinement

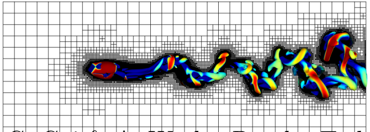


Combined weak formulation

- $\int_\Omega \left(\frac{\partial \vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\cdot\nabla\vec{v}\right)\cdot\vec{v}d\boldsymbol{x} - \int_\Omega p\nabla\cdot\vec{v}d\boldsymbol{x} + \int_\Omega \mu_f \nabla\vec{u} : \nabla\vec{v}d\boldsymbol{x} = -\int_P \boldsymbol{\lambda}\cdot\vec{v}d\boldsymbol{x}$
- $\int_\Omega -q\nabla\cdot\vec{u}d\boldsymbol{x}$
- $\left(1-\frac{\rho_f}{\rho_p}\right)M\left(\frac{d\vec{U}}{dt}-\vec{g}\right)\cdot\vec{V} - \vec{F_i'}\cdot\vec{V} = \int_P \boldsymbol{\lambda}\cdot\vec{V}d\boldsymbol{x}$
- $\left(1-\frac{\rho_f}{\rho_p}\right)\frac{dI\vec{\omega}}{dt}\cdot\xi - \vec{T'}\cdot\vec{\xi} = \int_P \boldsymbol{\lambda}\cdot(\xi\times\vec{r})d\boldsymbol{x}$
- $\int_P \vec{v}\cdot(\vec{u}-(\vec{U}+\boldsymbol{\omega}\times\vec{r}))d\boldsymbol{x}$

Octree mesh refinement

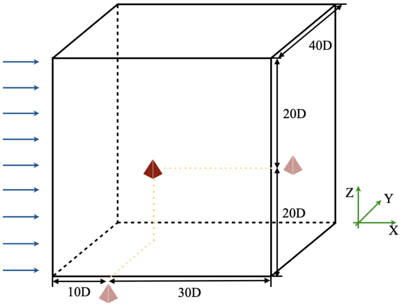
- Criterion: velocity gradient
- Smallest grid size on surface

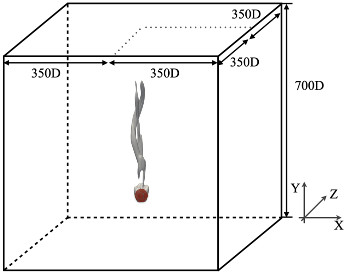


G. Gai & A. Wachs, Powder Technol., 2023

Flow past An Angular Particle

Fixed (left) and Settling (right) Particle

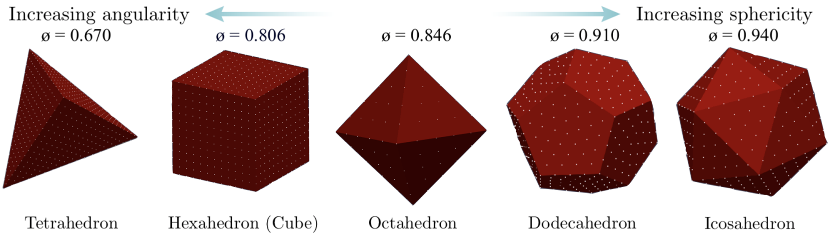




Numerical set-up

- Cubic computational domain of size $40D$ (fixed) and $700D$ (settling)
- Octree refinement level: $n_l = 12 \sim 15$, $32 \sim 100\ pts/D$

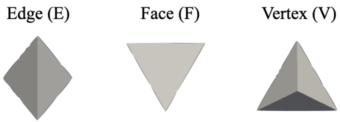
Platonic Solids



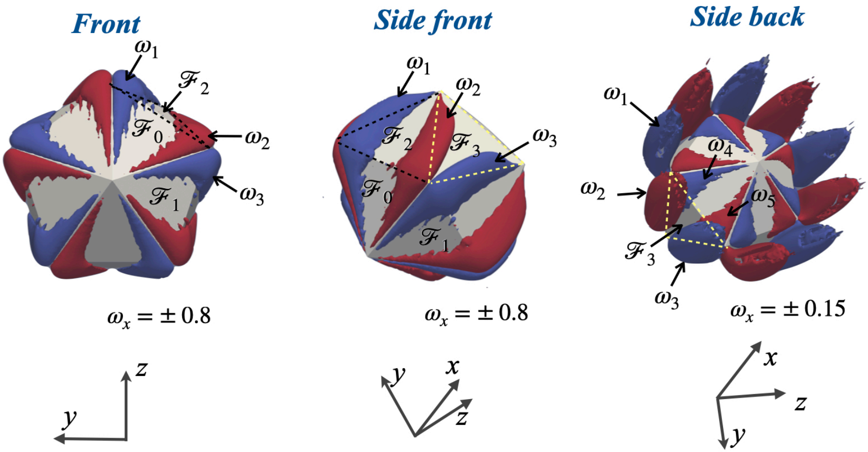
Lagrange multiplier distribution

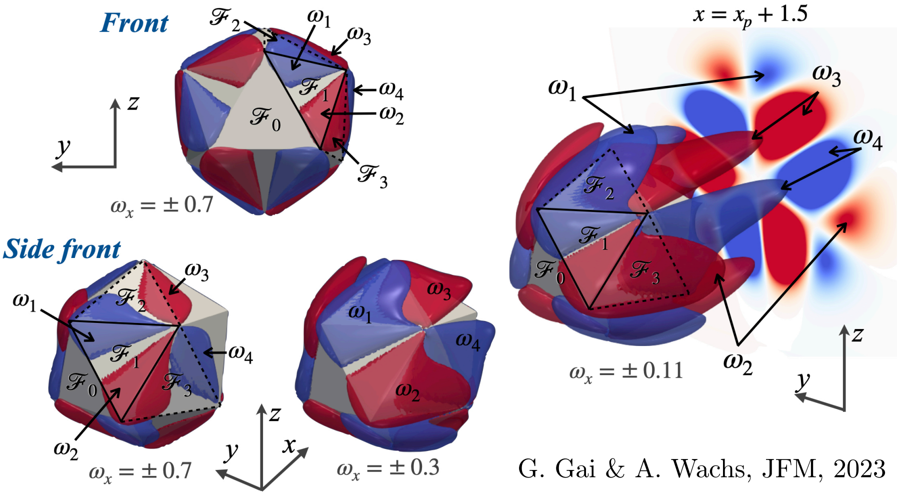
- Platonic solid with increasing sphericity
- Homogeneous distribution

Three angular positions



Vortex Generation on An Angular Particle





G. Gai & A. Wachs, JFM, 2023

Analogy to Optic Diffraction

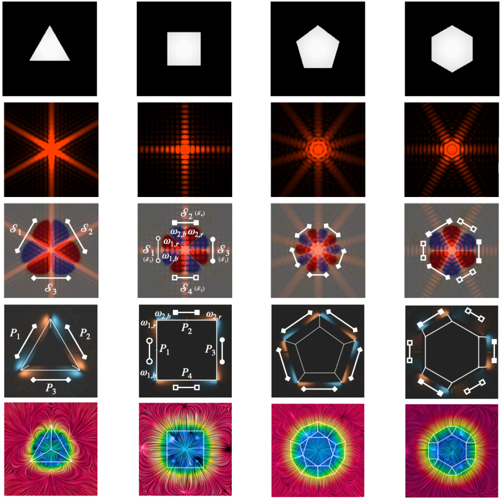
Aperture

Far-field Pattern

Wake vorticity

Front vorticity

Wake streamline



Analogy to Optic Diffraction

- Same symmetry axes
- Imaging of opaque particle
- Deterministic pattern dependent on front surface

Symmetry Breaks: Interaction of Face Induced Vortices

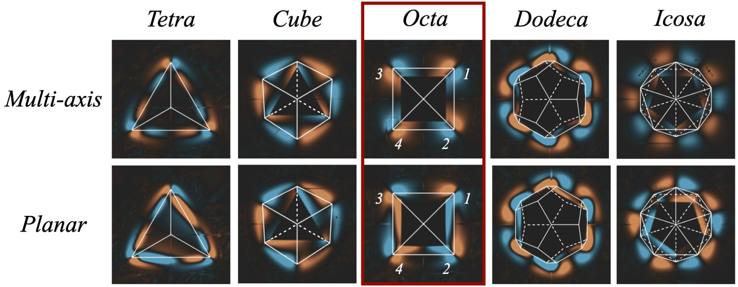
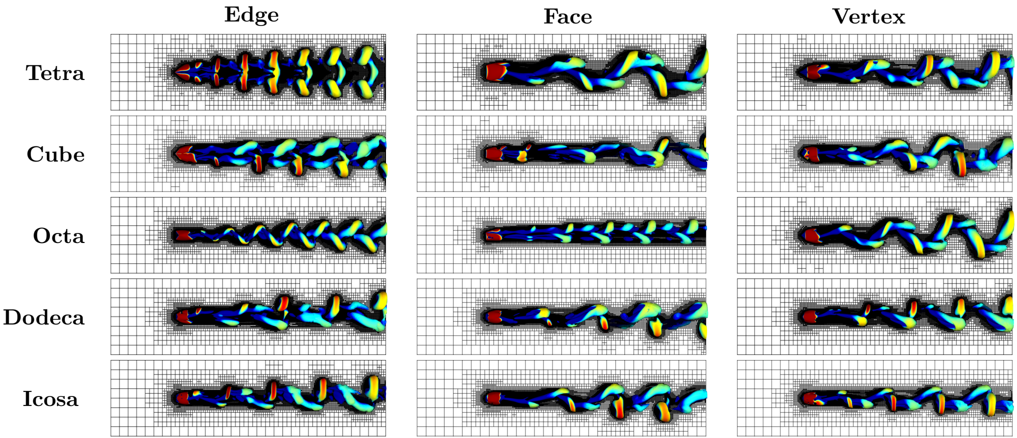


Figure: Stream-wise component of vorticity $-0.5 < \omega_x < 0.5$ on the rear surface of the Platonic particles: from multi-axis symmetry to planar symmetry; $\omega_x > 0$ in orange and $\omega_x < 0$ in blue.

Symmetry breakup mechanism

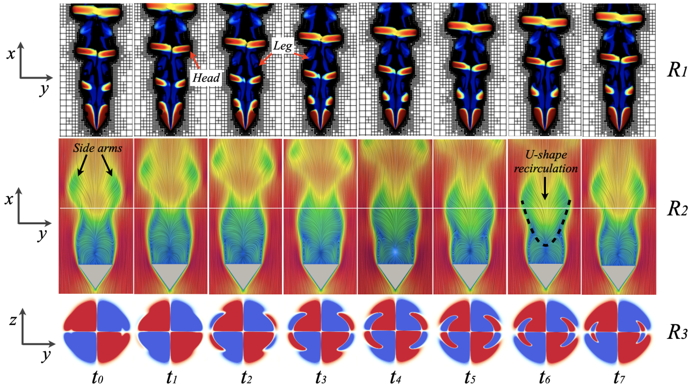
- Opposite-signed vortex pairs from front surface leading edges
- Repulsion of opposite sign, fusion of the same sign
- Vortex arm on the particle rear surface

Vortex Shedding Patterns



G. Gai & A. Wachs, Part1 & Part2, PRF, 2023

Double-Hairpin Vortex Shedding



Double symmetric shedding

- Edge tetrahedron
- Twice shedding frequency
- Planar symmetric

Shedding dynamics

- Front surface splitting stream
- Rear surface converging
- Unique shape of recirculation

Drag and Lift Coefficients

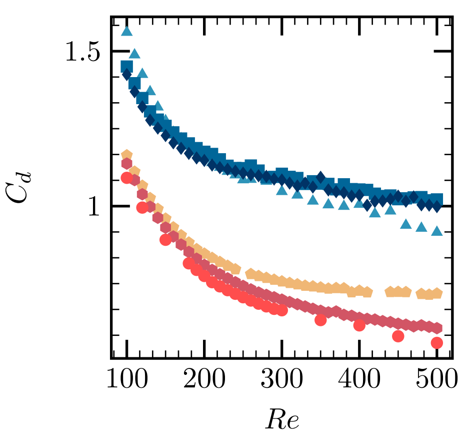


Figure: Drag coefficient C_d evolution in Re: TV (▲), CV (■), OV (♦), DV (⬟), IV (⬢) and S (●).

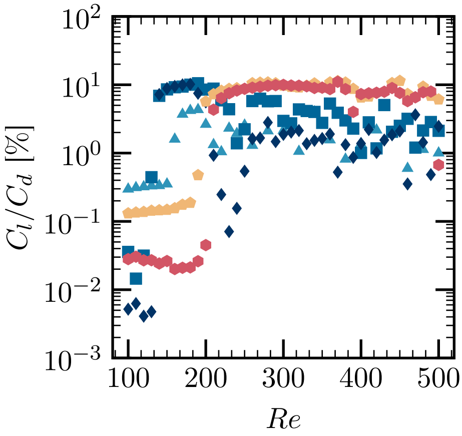
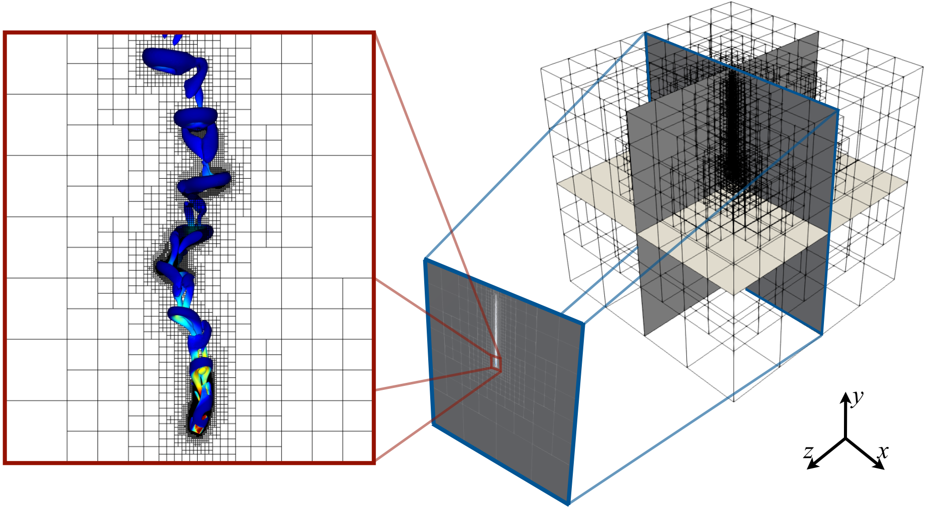


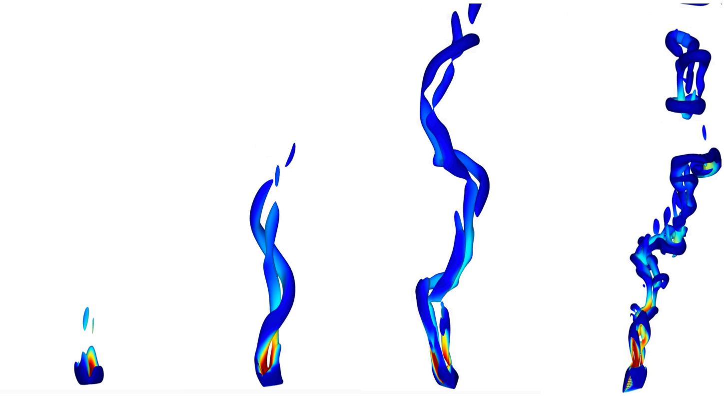
Figure: Lift-drag ratio C_l/C_d as a function Re: TV (▲), CV (■), OV (♦), DV (⬟), IV (⬢).

Freely Settling of A Tetrahedron

A Settling Platonic Particle in an Unbounded Fluid



A Settling Tetrahedron



$Ga = 50$ $Ga = 90$ $Ga = 140$ $Ga = 300$

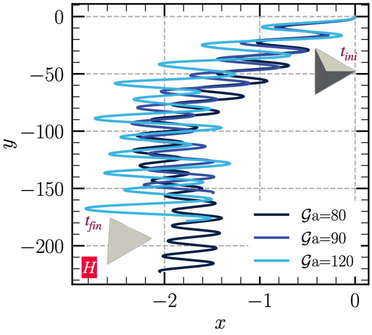
Steady settling

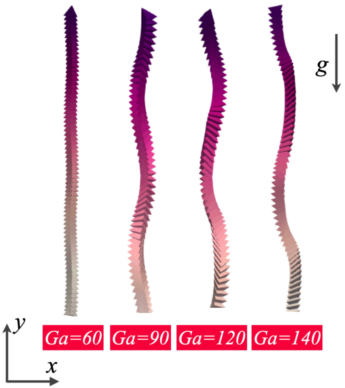
- Stable: face downwards
- Maximize drag
- Minimize settling velocity

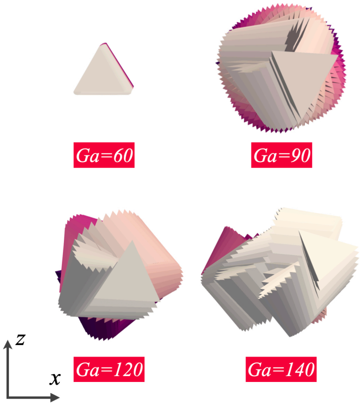
Double helix vortex

- Rotation enhanced
- Strands elongated with Ga

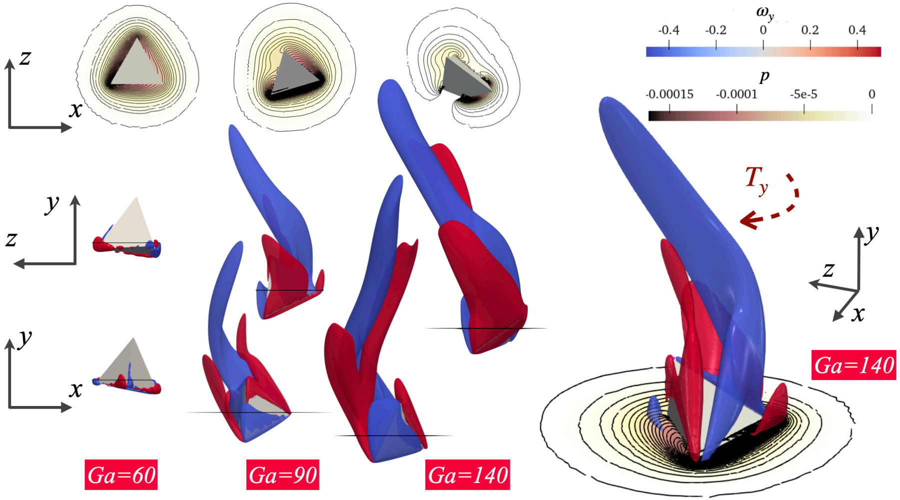
Stable Angular Position in the Helical Settling







Helical Settling and Vortex Structure

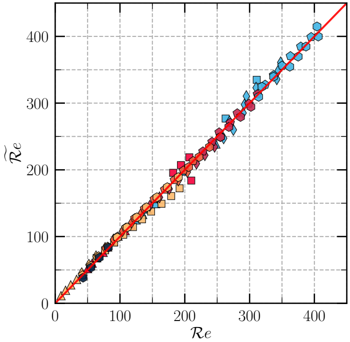


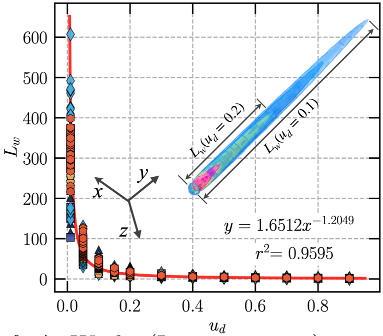
Settling $\mathcal{R}e$

- $\widetilde{\mathcal{R}e} = 2.573\phi\mathcal{G}a - 0.916\mathcal{G}a - 0.032\exp(7.503\phi)$

Wake length L_w

- $L_w = 1.6521 u_d^{-1.2049}$, $u_d = u_{crit}/u_{set}$





G. Gai & A. Wachs (In preparation), 2023

Conclusions & Perspectives

Conclusions:

- Vorticity structure serves as image of the front surface
- Wake symmetry breakup due to vortex merging
- Rich vortex shedding patterns
- Rich path instability and settling regimes

Perspectives:

- Magnus effect of a rotating Platonic particle
- Free/turbulent suspensions of Platonic solids

Thank you!