

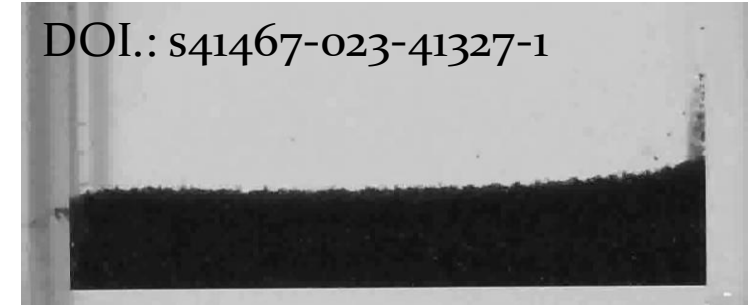
Choosing the Most Appropriate Drag Model for CFD-DEM Simulations

Sadaf Marami
Sadegh Nadimi



1 - 3 September 2026

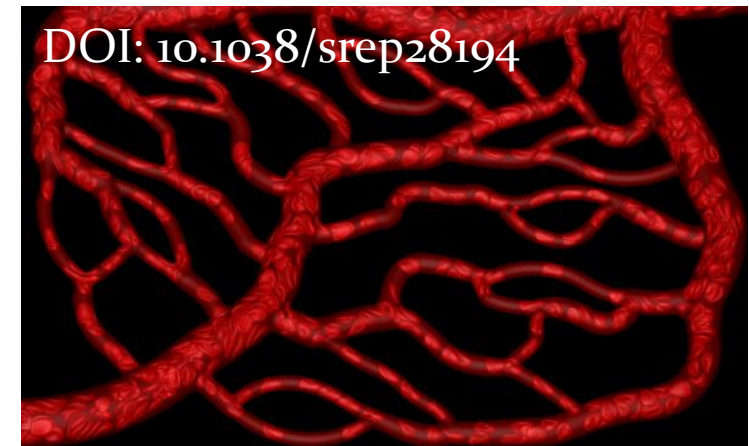
❖ Real non-spherical granular materials



❖ Drag force dictates particle dynamics

❖ A spectrum of methods for modelling the particle drag force:

- ◆ Direct Numerical Simulation (DNS) (fully resolved)
- ◆ Lattice Boltzmann Methods (LBM)
- ◆ Immersed Boundary Methods (IBM)
- ◆ CFD-DEM two-way coupling
- ◆ Empirical Drag Models & CFD-DEM one-way coupling

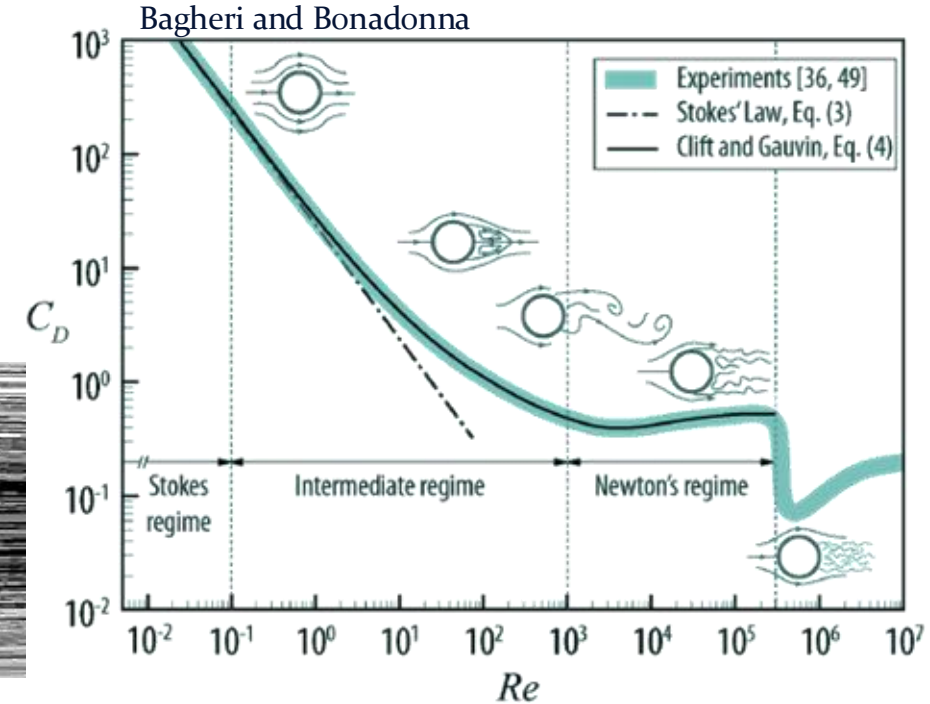
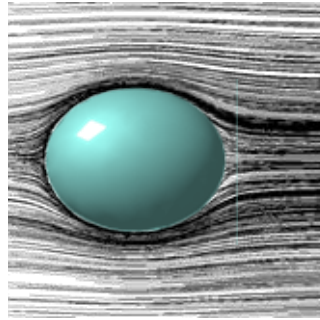


❖ Drag force $F_D = f(\rho_f, \mathbf{U}_f, A, \mathbf{U}_p) \times C_D$

$$F_D = \frac{1}{2} \rho_f C_D A |\mathbf{U}_p - \mathbf{U}_f| (\mathbf{U}_p - \mathbf{U}_f)$$

❖ For spherical particles $\rightarrow C_D = f(Re = \frac{\rho_f U d}{\mu_f})$

◆ Reynolds number defines the flow regime

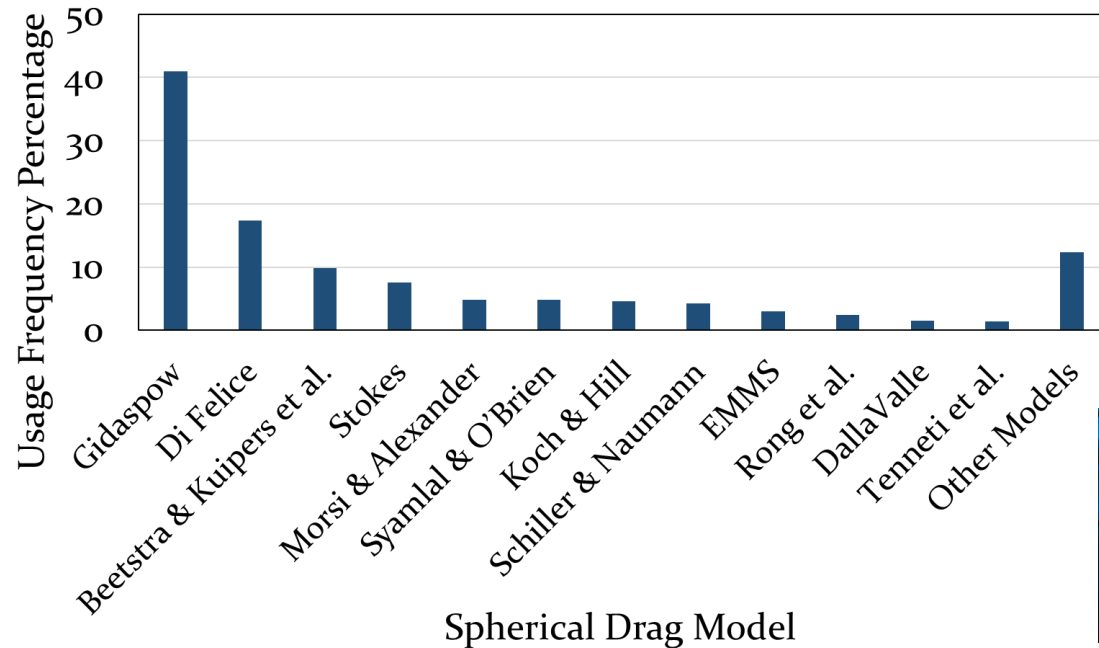


❖ For irregular particles $\rightarrow C_D = f\left(Re = \frac{\rho_f U d}{\mu_f}, \text{particle shape}\right)$ is challenging to calculate

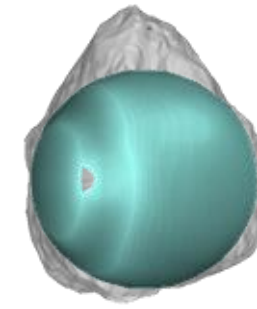


❖ Finding accurate drag force model for simulating irregular particles in DEM-CFD

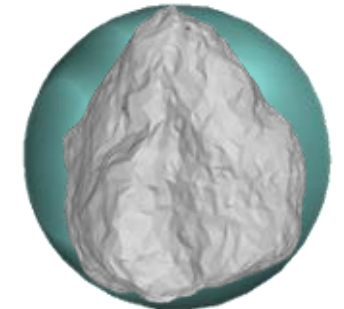
❖ 14 journals → 800 papers → 90 consider particle shape



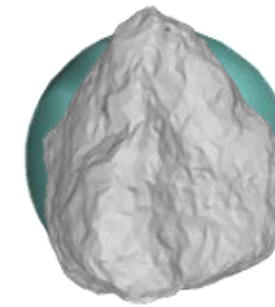
❖ Simplification to Sphere



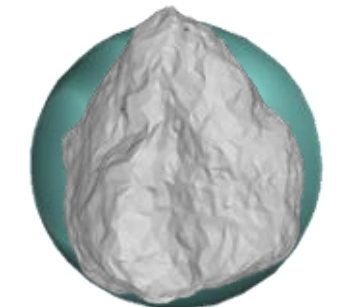
Inscribed



Circumscribed



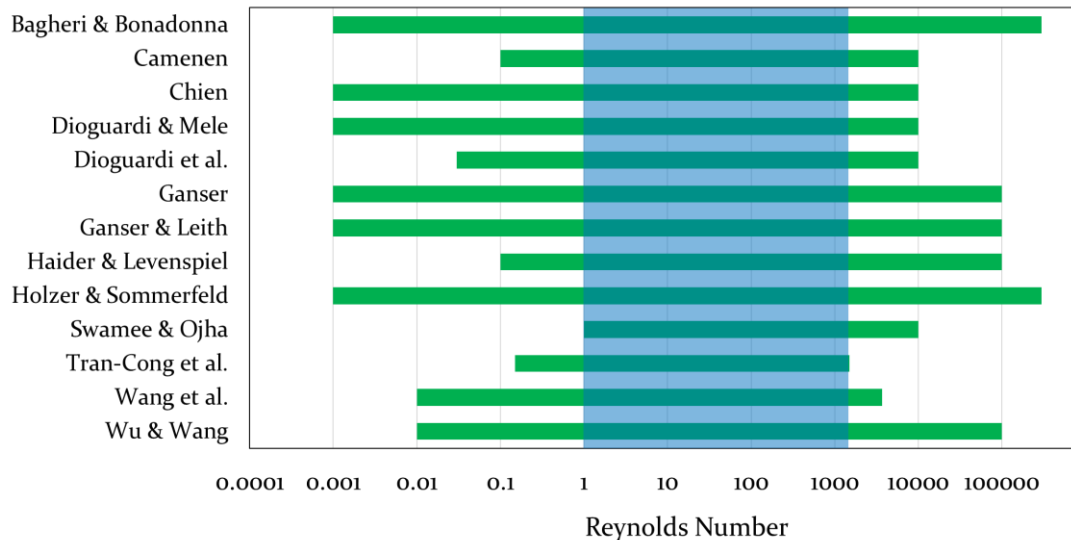
Volume Equivalent



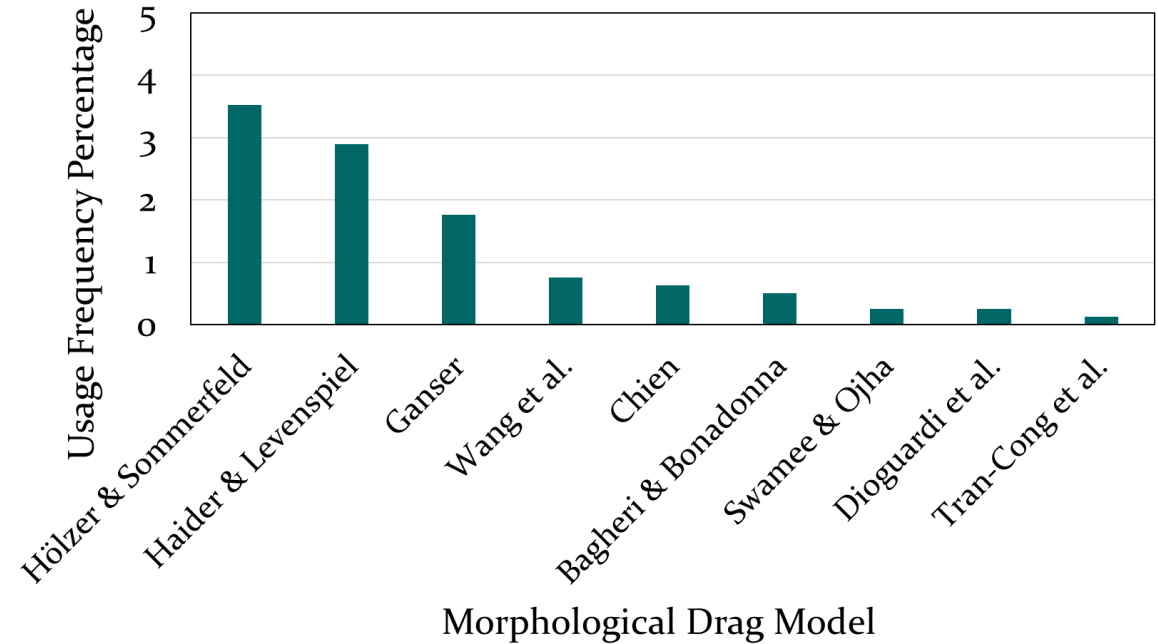
Surface Area Equivalent

❖ Non-spherical drag models

- ◆ Holzer and Sommerfeld
- ◆ Haider & Levenspiel
- ◆ Ganser (& Leith)
- ◆ Wang *et al.*
- ◆ Chien
- ◆ Bagheri & Bonadonna
- ◆ Swamee & Ojha
- ◆ Dioguardi *et al.*
- ◆ Tran-Cong *et al.*
- ◆ Camenen



Range of Reynolds number empirical drag coefficient models operate at

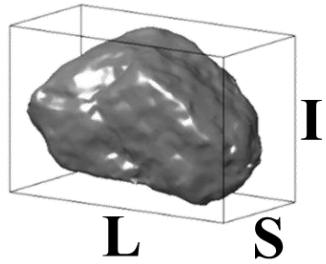


C_D dependent on Shape

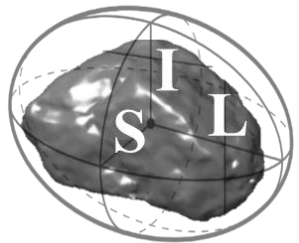
C_D dependent on Shape & Orientation

Hölzer and Sommerfeld
Ganser and Leith
Tran-Cong *et al.*

❖ Bounding Box

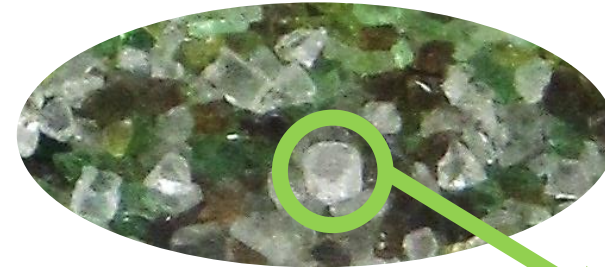


❖ Fitted Ellipsoid

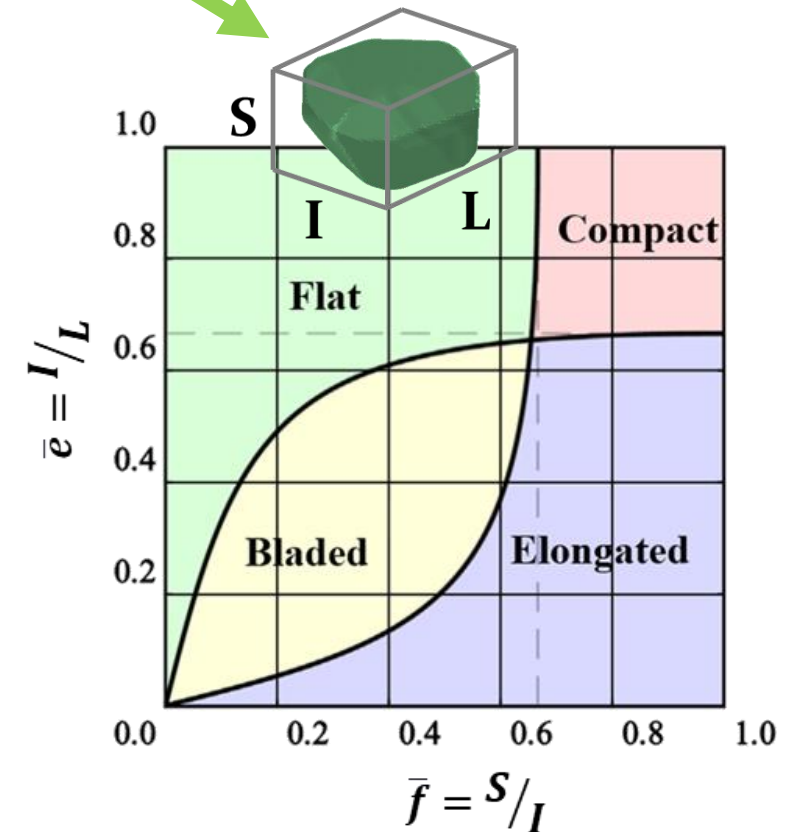


❖ 3D Particle Size Descriptors

- ◆ $S = \text{Short Dimension}$
- ◆ $I = \text{Intermediate Dimension}$
- ◆ $L = \text{Long Dimension}$
- ◆ $\text{Specific Surface Area} = \text{Volume} / \text{Surface Area}$
- ◆ $\text{Convexity} = \text{Volume} / \text{Volume of convex hull}$
- ◆ $\text{Wadell's Sphericity} = A_{sph} / \text{Surface Area}$
- ◆ $\text{Krumbein's Sphericity} = \sqrt[3]{S \times I / L^2}$

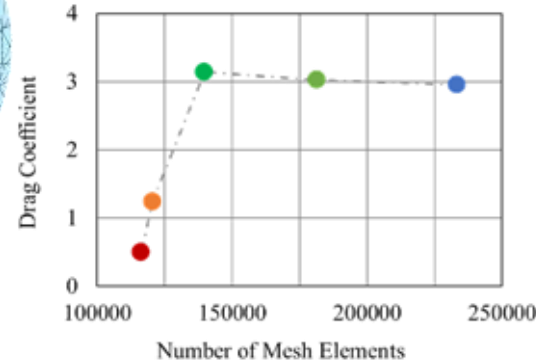
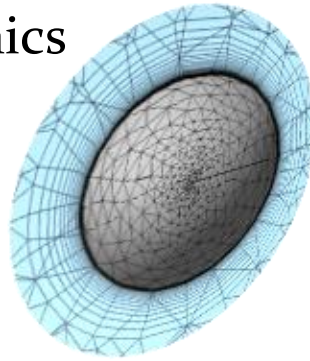
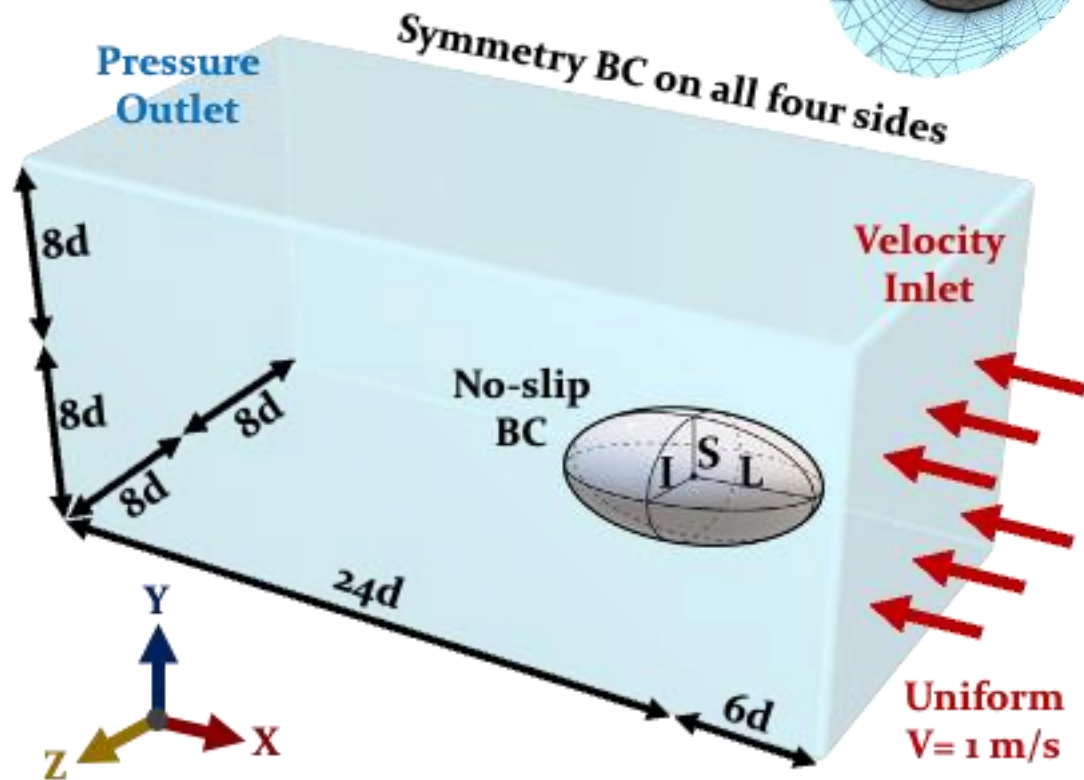


❖ Zingg Chart

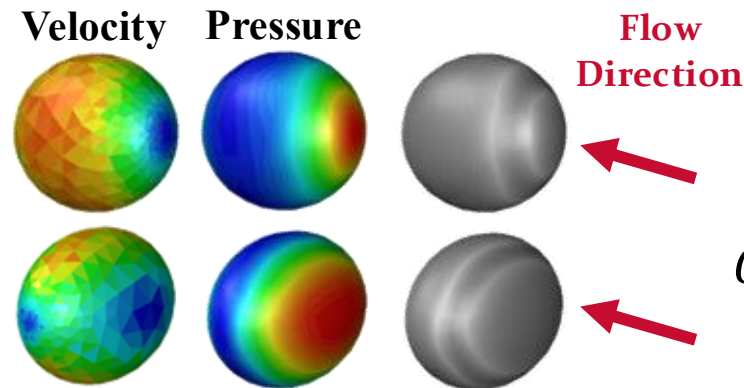
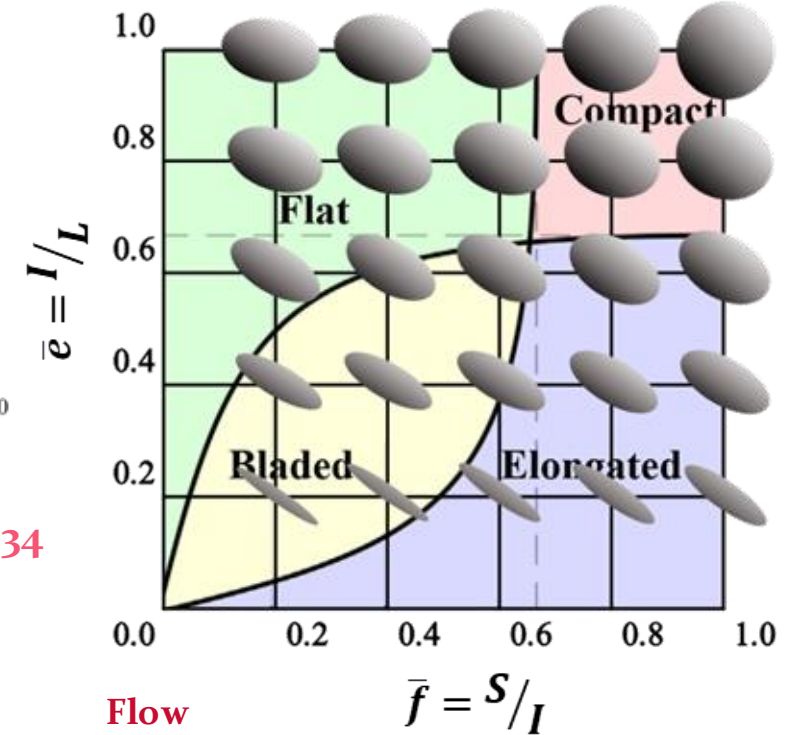


❖ Computational Fluid Dynamics

Simulations using ANSYS FLUENT



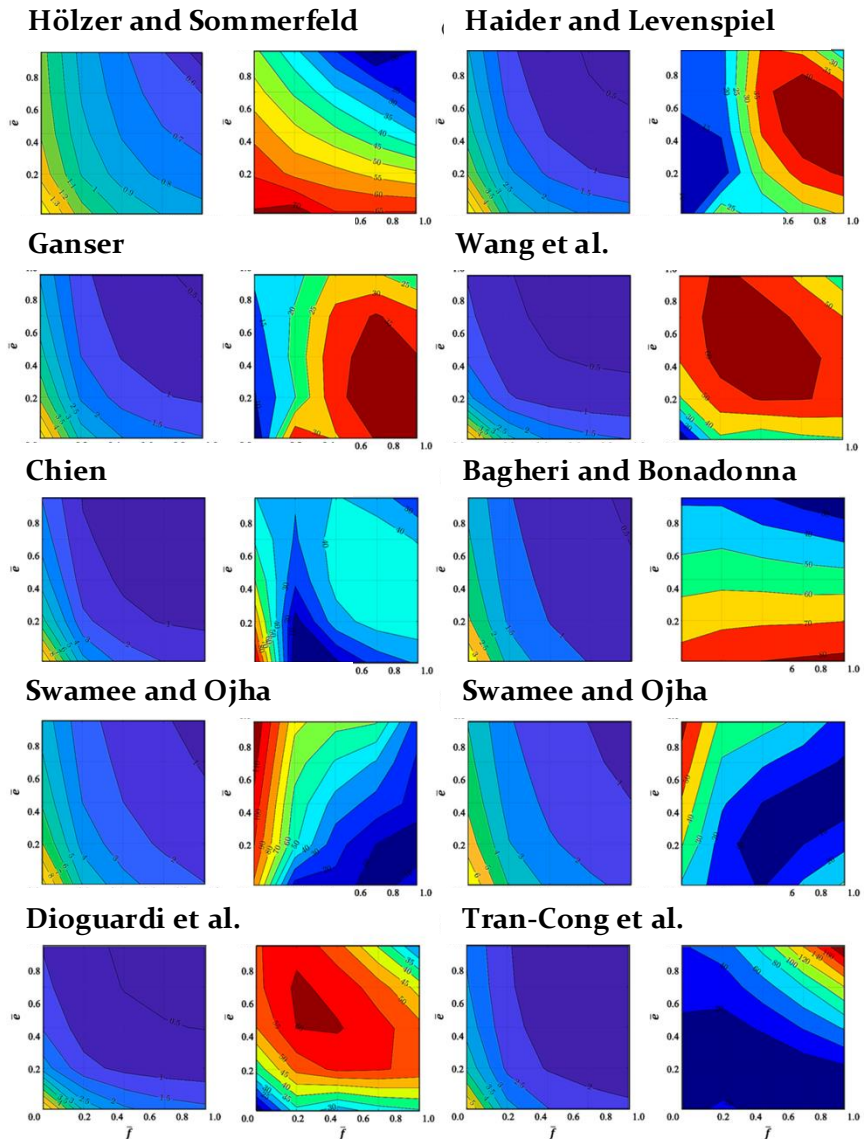
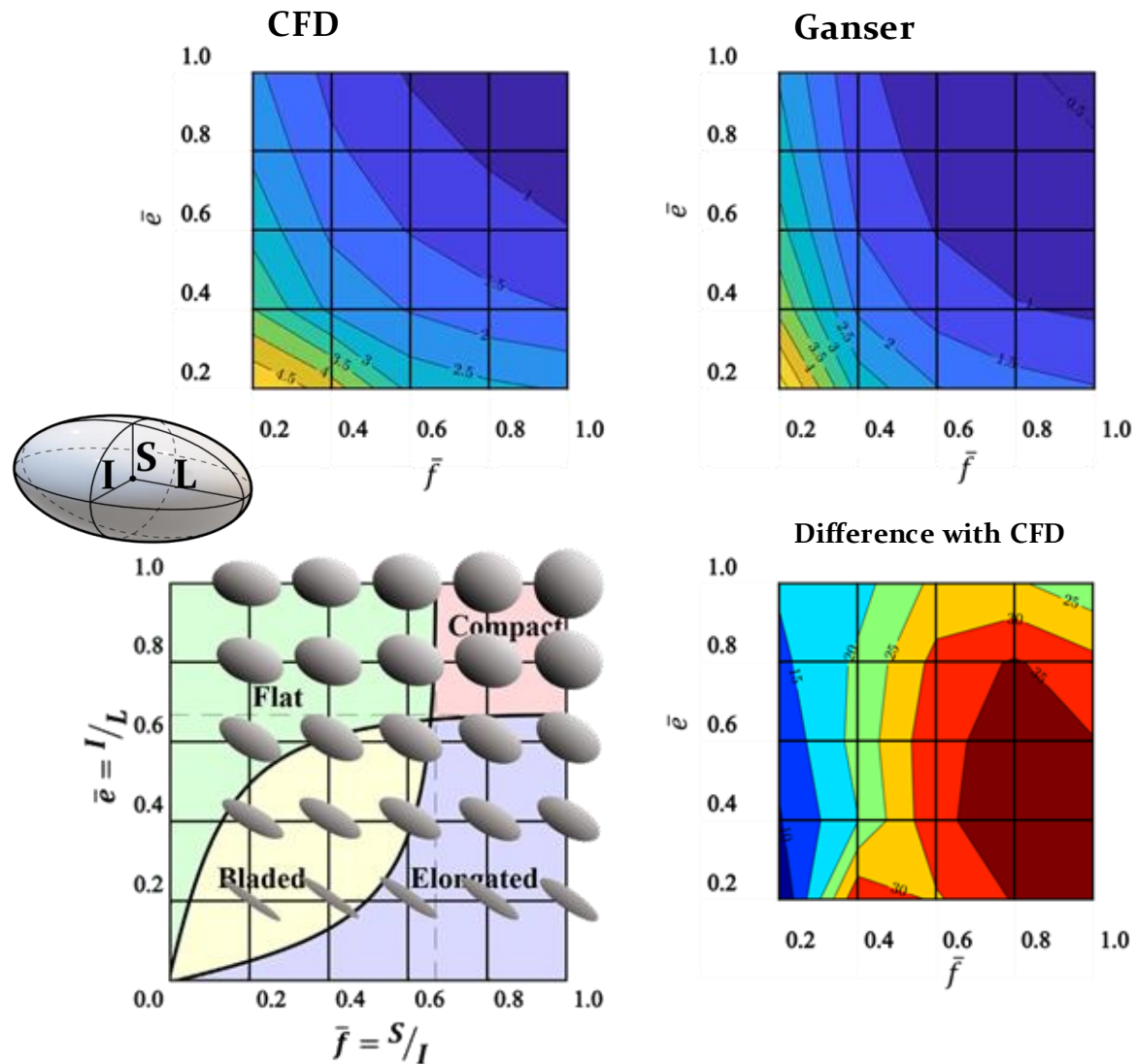
$137 \leq \text{Reynolds Number} \leq 234$



2 simulations per each ellipsoid

$$C_D = \frac{2\langle C_{D_{min}} \rangle \langle C_{D_{max}} \rangle}{\langle C_{D_{min}} \rangle + \langle C_{D_{max}} \rangle}$$

Empirical Drag Models vs. CFD

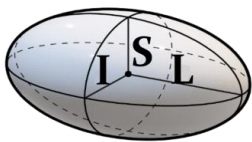
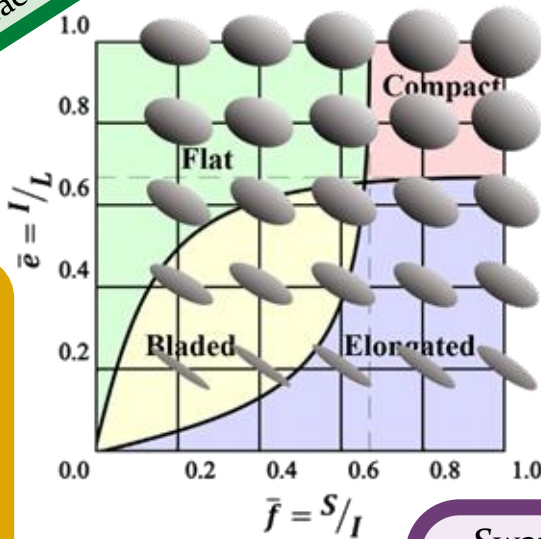


Regular Non-Spherical Particles: Ellipsoids

Swamee & Ojha
Wu & Wang
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)

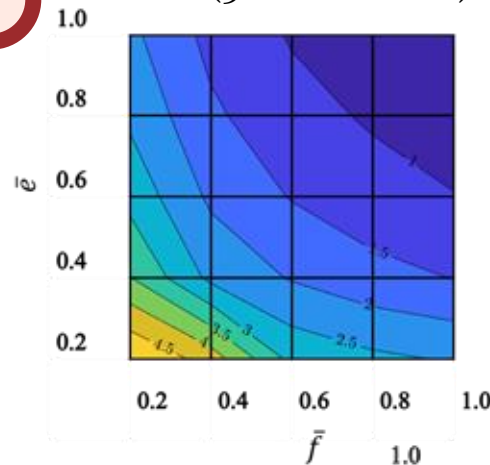
Camenen
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)

Ganser
Ganser & Leith
Haider & Levenspiel
(Wadell's Sphericity)

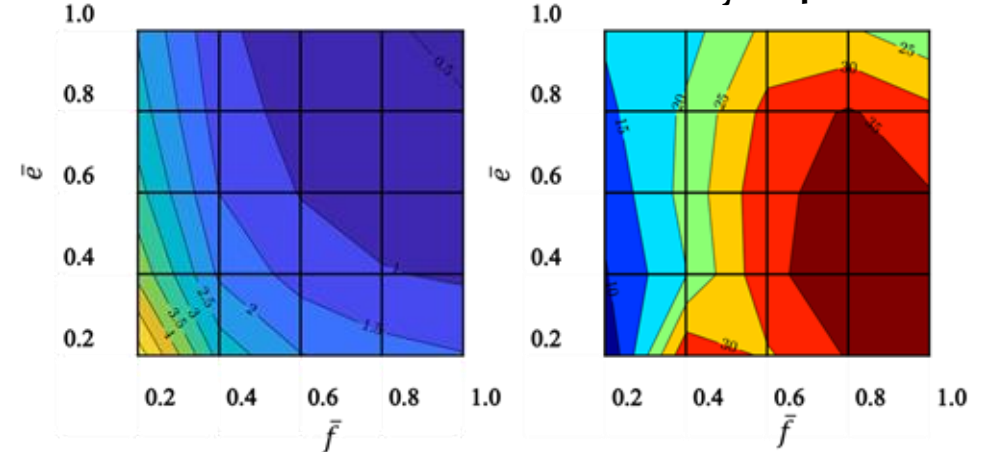


Swamee & Ojha
Wu & Wang
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)

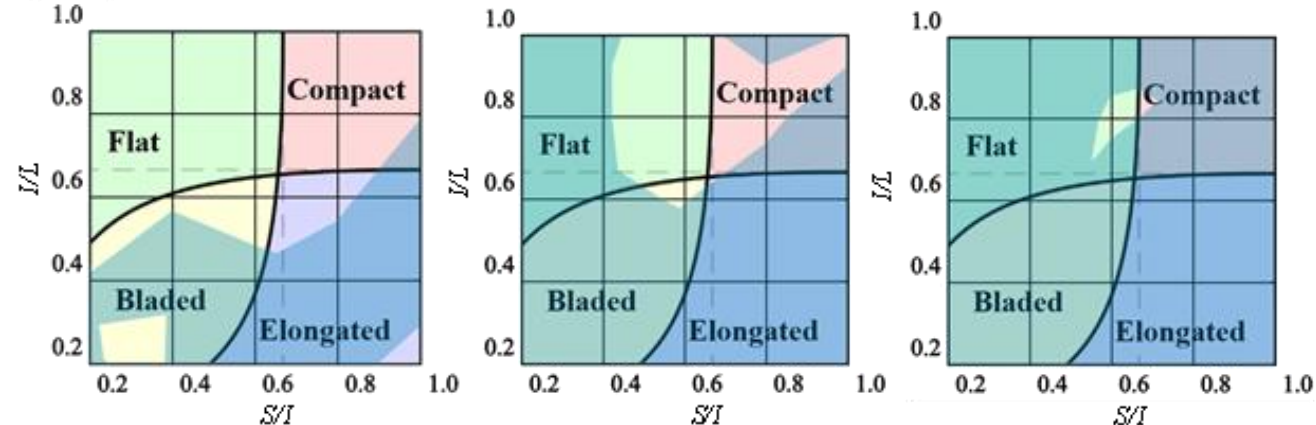
CFD (50 simulations)



Ganser model with an accuracy of 40%



Coverage of the drag models where at least one of which can estimate the drag coefficient for ellipsoids with an accuracy of 10%, 20%, and 30% difference relative to the CFD



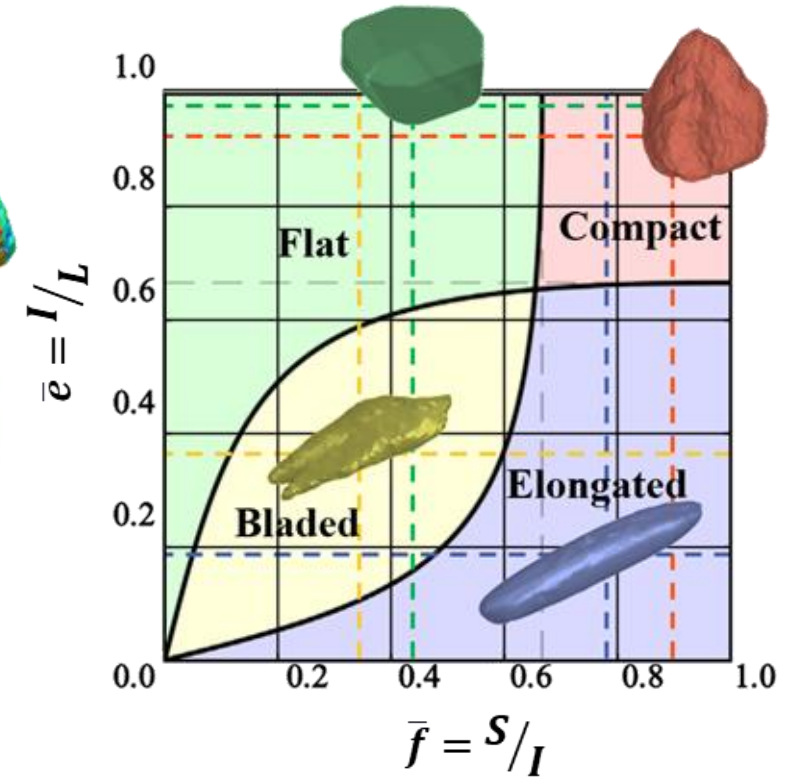
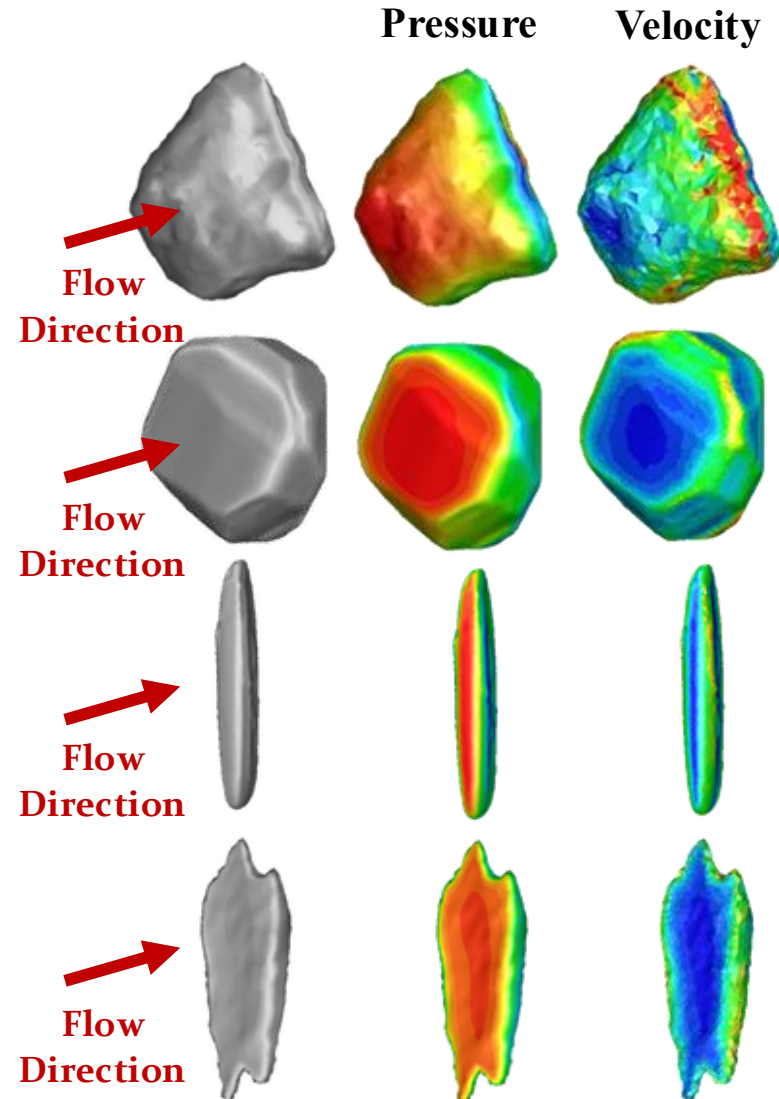
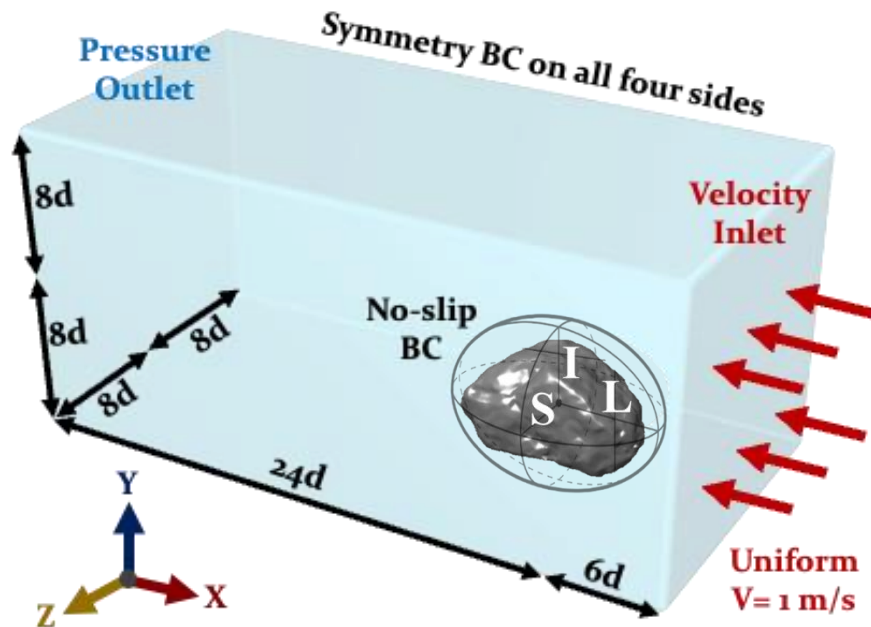
CFD as the Benchmark: Irregular Particles

❖ Computational Fluid Dynamics

Simulations using ANSYS FLUENT

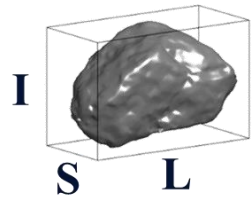
Similar geometry setup

Reynolds Number = 293.5



8 simulations per each particle
For 8 different orientations

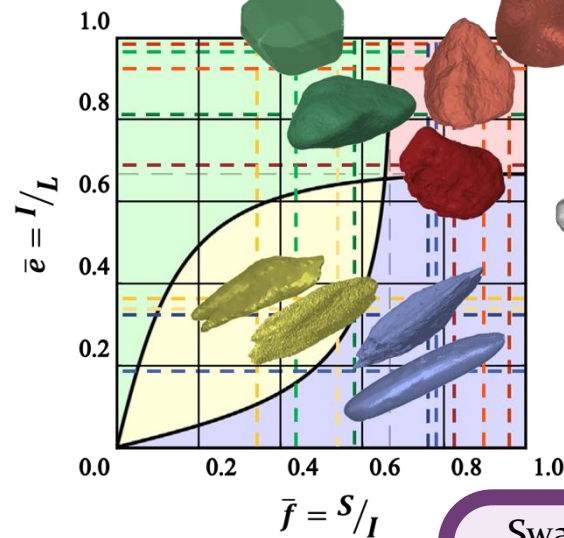
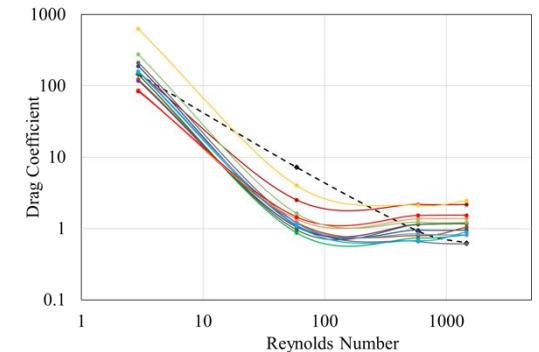
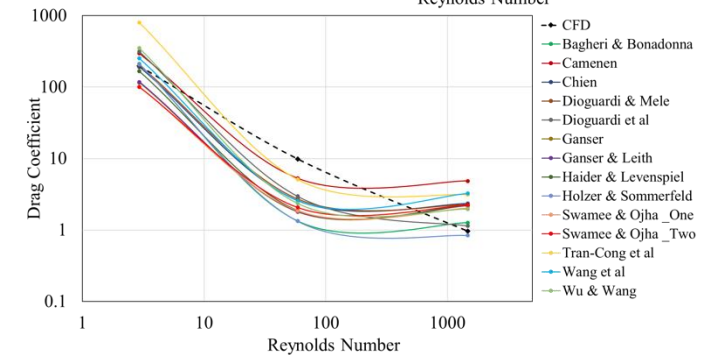
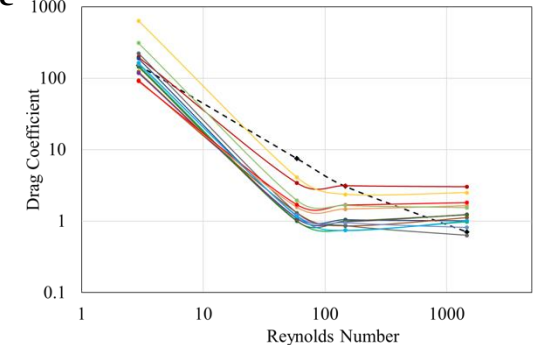
Irregular Particles



Swamee & Ojha
Wu & Wang
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)

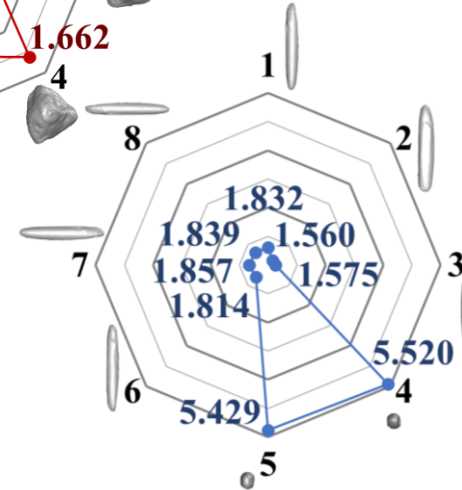
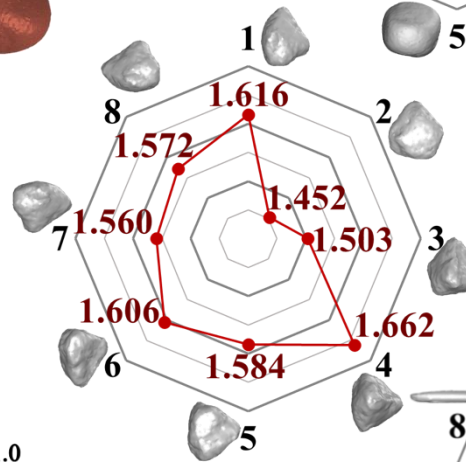
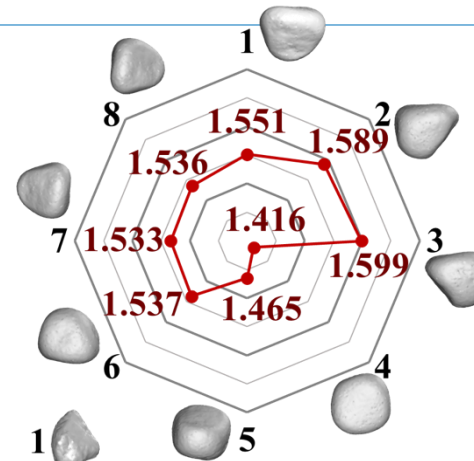
Camenen
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)

Comparison of the values of the drag coefficient obtained through CFD with the results of the empirical drag models versus the Reynolds number for compact, flat, and elongated particle



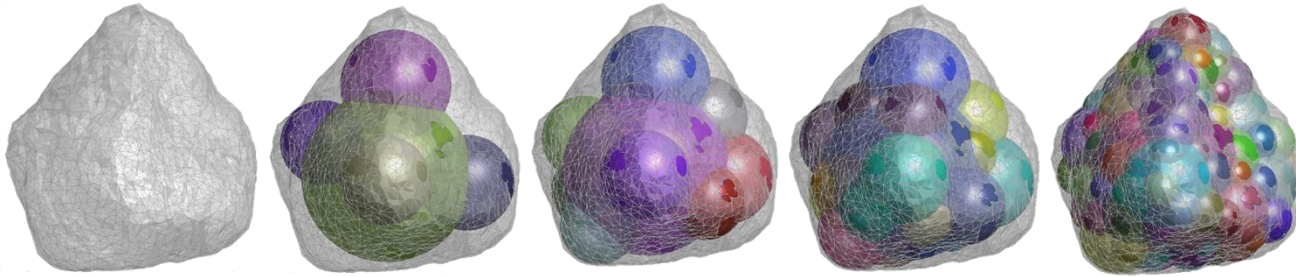
Ganser
Ganser & Leith
Haider & Levenspiel
(Wadell's Sphericity)

Swamee & Ojha
Wu & Wang
(Corey's Sphericity)
Tran-Cong *et al.*
(Surface Circularity)



- ❖ One approach to introduce shape in DEM:

Multi-Sphere Representations of Particles



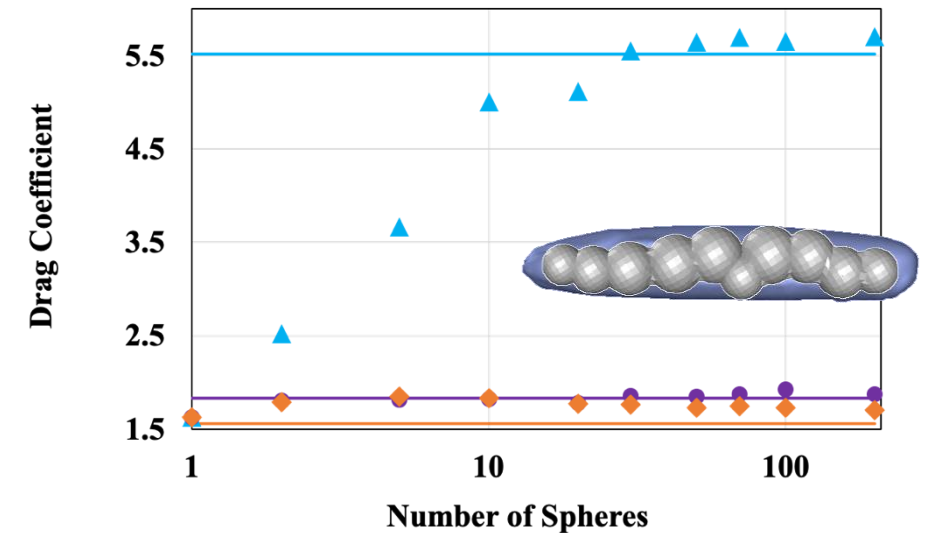
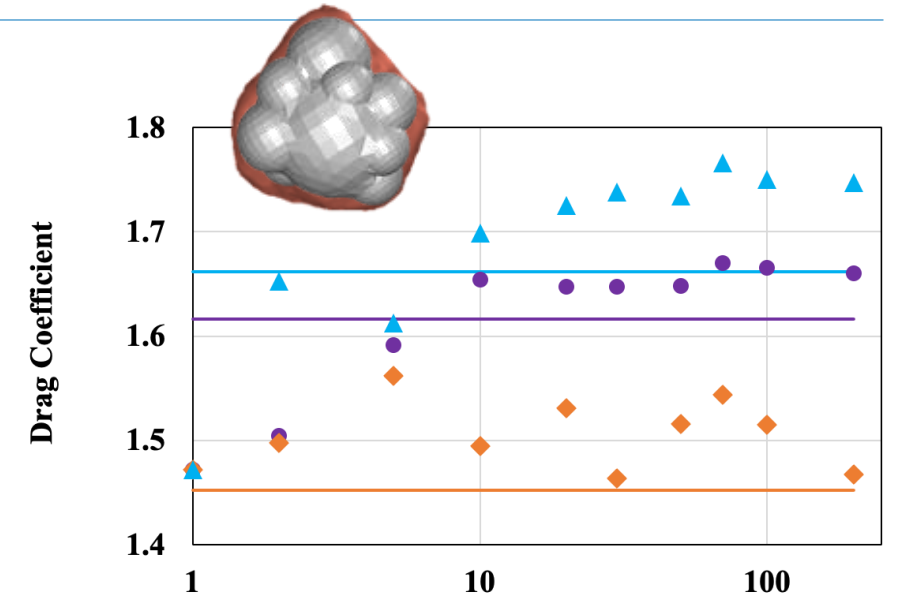
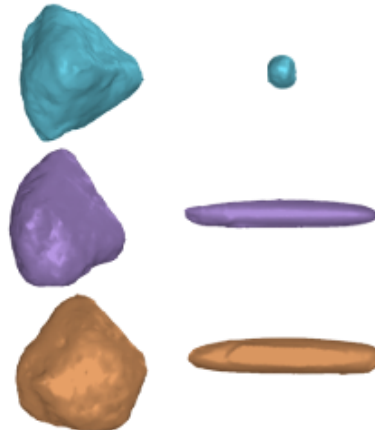
- ❖ Choosing the Number of Spherical Fragments

- ❖ Different particle morphologies at different orientations

▲ Maximum Drag Coefficient

● Median Drag Coefficient

◆ Minimum Drag Coefficient





Dr Sadegh Nadimi



ParaSols
Particulate Solids Simulations

More Information

- S. Maramizonouz, S. Nadimi, **Drag Force Acting on Ellipsoidal Particles with Different Shape Characteristics**, *Powder Technology* , 2022.
- S. Maramizonouz, S. Nadimi, **Are Drag Models Adequate? A comprehensive analysis of drag modelling for regular and irregular particles**, *Powders*, 2025.
- S. Maramizonouz, S. Nadimi, et al. **CFD–DEM Modelling of Particle Entrainment in Wheel–Rail Interface: A Parametric Study on Particle Characteristics**, *Railway Engineering Science*, 2025.

Thank You for Your Attention

