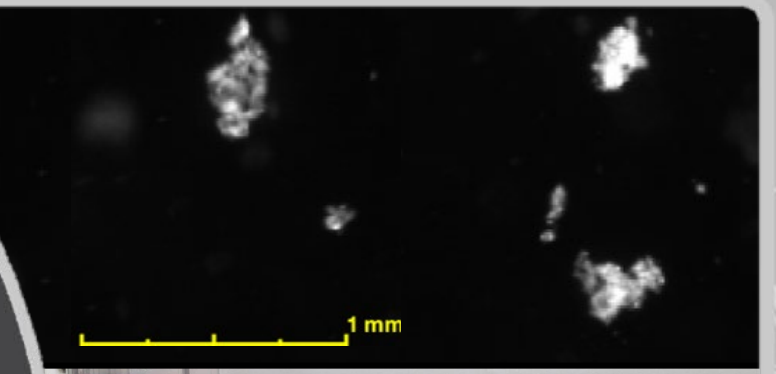
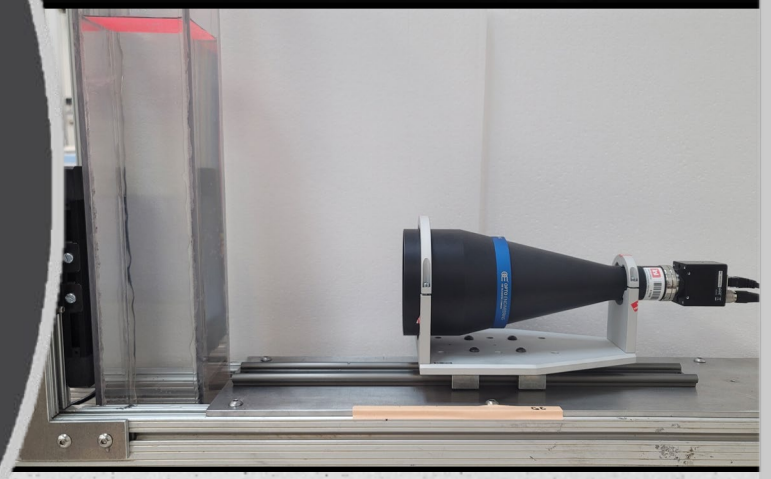
SHAPE AND PERMEABILITY EFFECTS ON FLOC SETTLING VELOCITY





KELSEY FALL, DANIELLE TARPLEY, & JARRELL SMITH

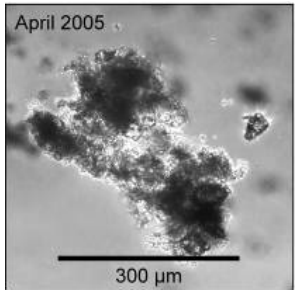
CIRP TECHNICAL DISCUSSION
MAY 9, 2023

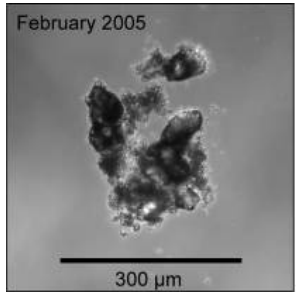
(FUNDED BY CODS, RSM, & CIRP)

US Army Corps of Engineers

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

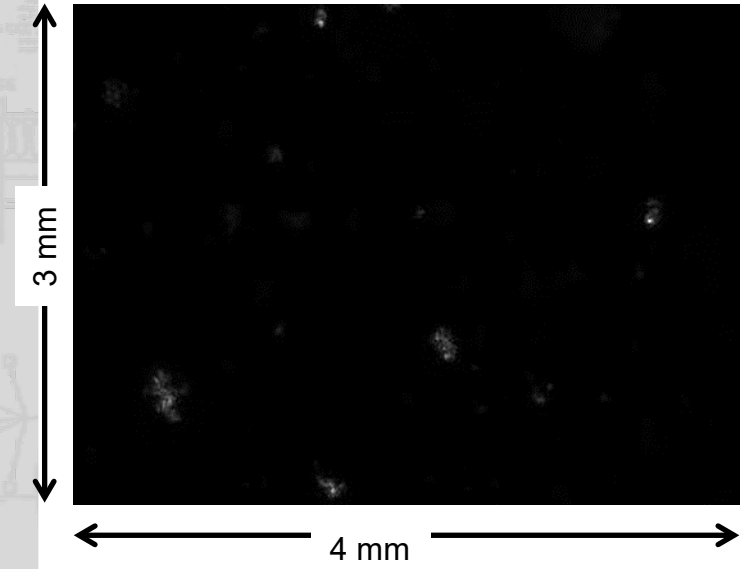
Motivation: Advance USACE sediment transport modeling capabilities to better represent dynamic systems .





In many USACE managed waters Suspended Particles=flocs (agglomerates of inorganic solids, organic solids and water), yet models do not account for dynamic flocculation.

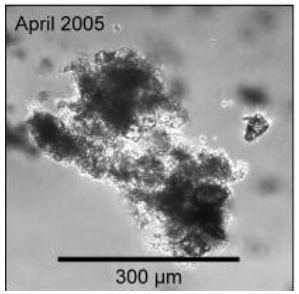
To develop a robust dynamic flocculation model, relationships between size, shape, density, and settling velocity are required.

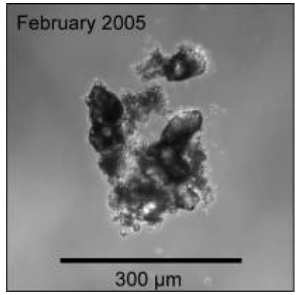


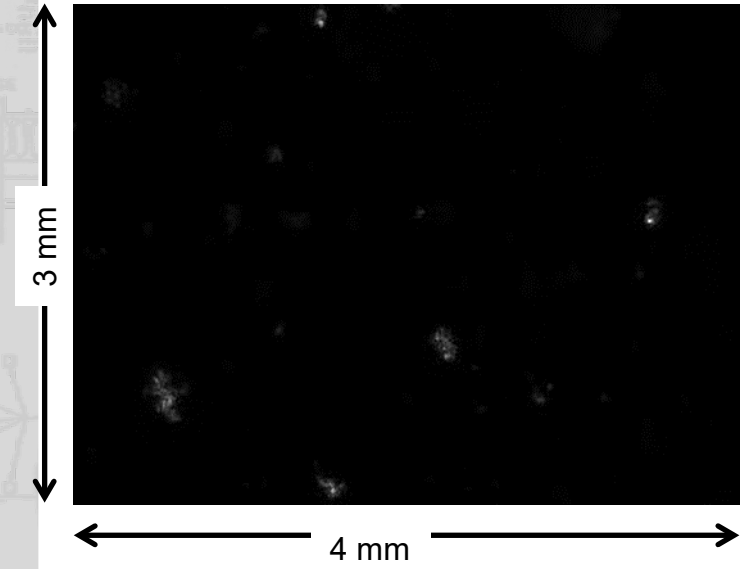
Video based techniques (e.g., PICS, Smith and Friedrichs, 2011; 2015) provide observations for model parameterization.

These techniques rely on size-settling expressions that assume particles are spherical & impermeable (non-porous).

Motivation: Advance USACE sediment transport modeling capabilities to better represent dynamic systems .







Problem (1): Real flocs are not spherical or impermeable.

Problem (2): Published modifications to account for irregular shaped particles depend on 3D shape properties; and video systems are often only configured to resolve 2D images.

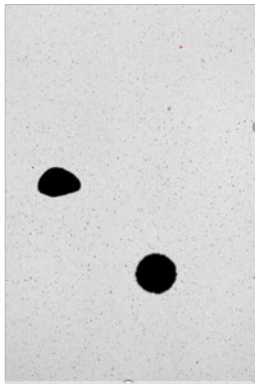
Problem (3): Assessments of the importance of floc permeability on settling velocity are mixed and largely argumentative with little to no experimental evidence to resolve the issue.

This project aims to develop a fundamental understanding of the influence of floc shape and permeability on settling velocity to inform development of dynamic flocculation algorithms in USACE sediment transport models.

Project Objective: Develop fundamental understanding of the influence of floc shape and permeability on settling velocity

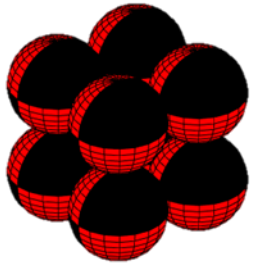
I. Laboratory Settling Experiments:

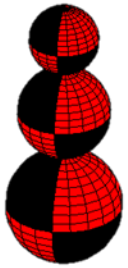
Build flocs using 3D printing

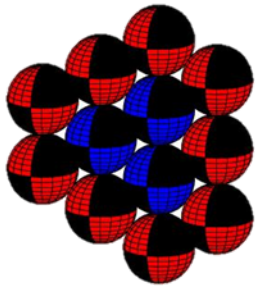


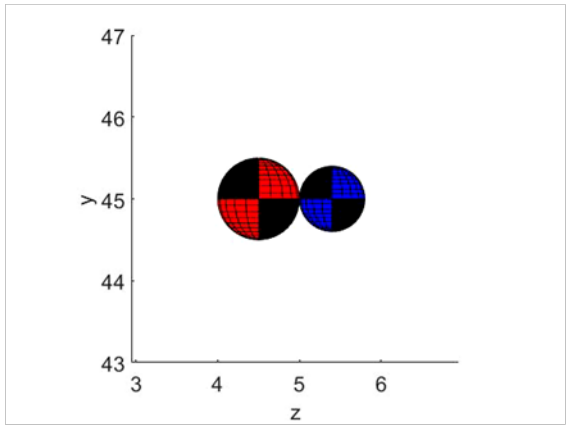
II. Particle Resolved Direct Numerical Simulations:

Build flocs by assembling primary particles.







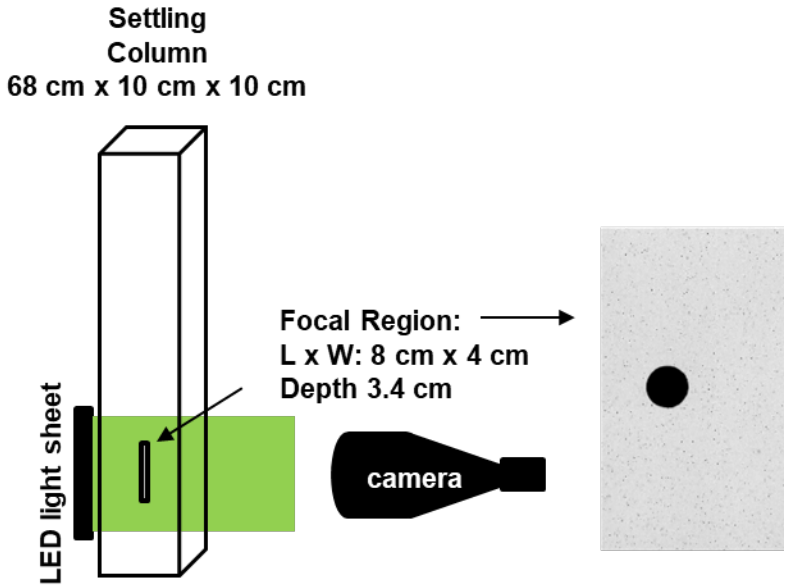


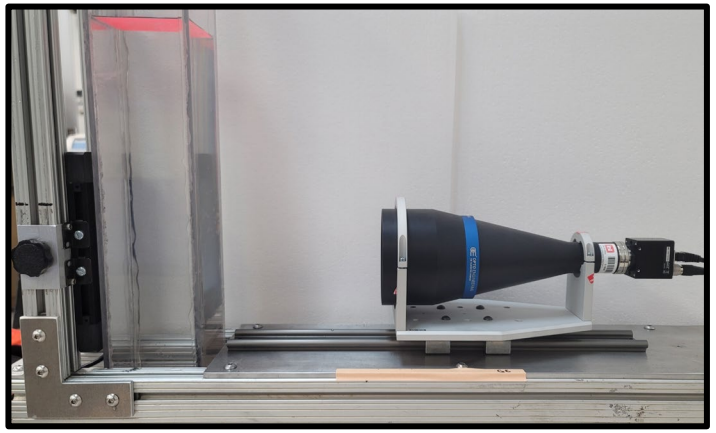
UC SANTA BARBARA mechanical engineering

BAA Computational Fluids Group

US Army Corps of Engineers • Engineer Research and Development Center

Laboratory Settling Experiments: Video Settling Column





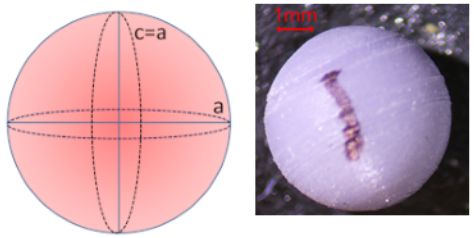
Experiments will focus on the following experimental variables:

- Particle shape (Idealized & “natural”). Particles will be scaled for 3D printing and property measurement.
- The viscosity (density) of the suspending fluid (glycerol-water mixture) will be adjusted to mimic drag felt by flocs.

Laboratory Settling Experiments: 3D Printed Particles

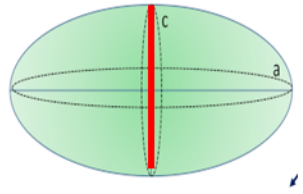
4 Idealized Cases (with variations)

Spheroid
a=b=c

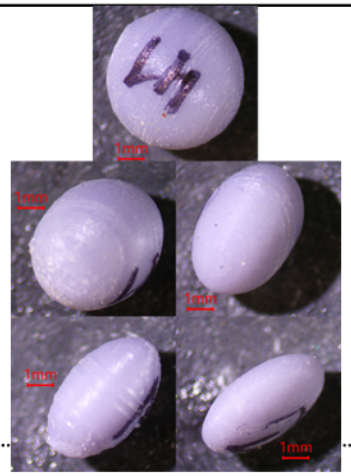


1 Variation

Oblate Spheroid
a=b>c

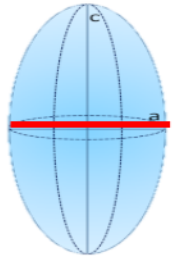


(m&m)

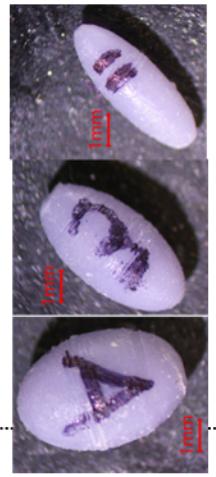


4 Variations

Prolate Spheroid
a=b<c

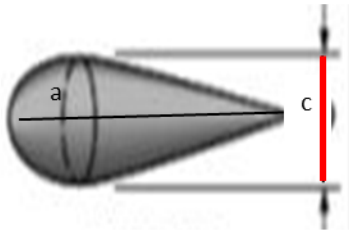


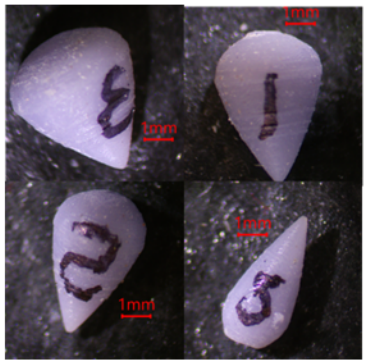
(football)



3 Variations

Streamline body ("stringer")

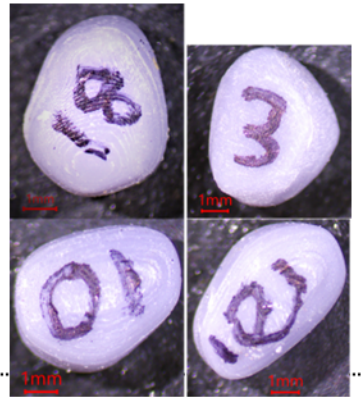




4 Variations

Irregular Case

Natural Particles



20 Variations

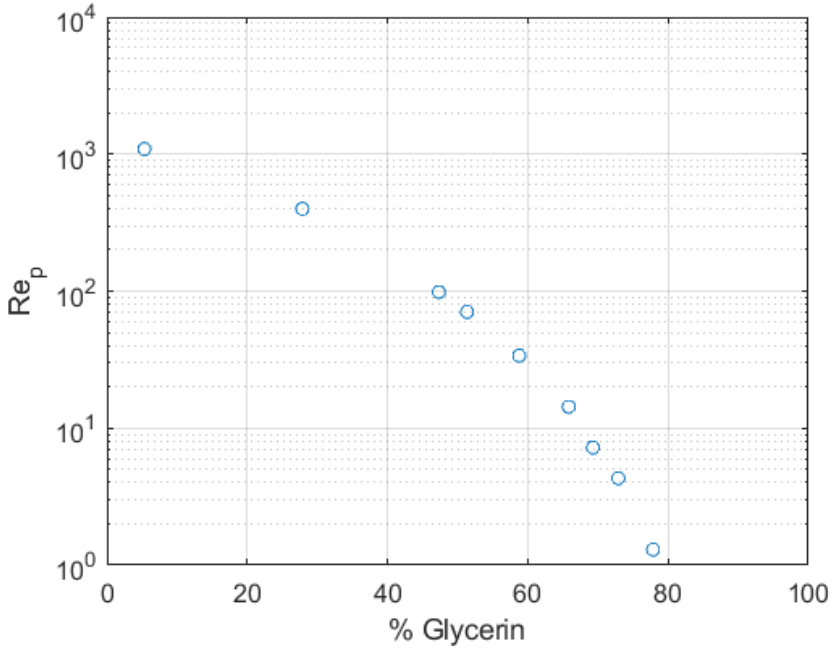
Particle Characterization:

- Shape
  - 3D: digital calipers & microscope
  - 2D: settling experiments
- Density (ρ_s)
  - Water Pycnometer (ASTM D-854.4939)
    - $\rho_s \approx$ 1225 +/- 3 kg/m^3

and Development Center

Laboratory Settling Experiments: Settling Solutions =Glycerin + Water Mixtures

Evaluated 9 different water-glycerin solutions

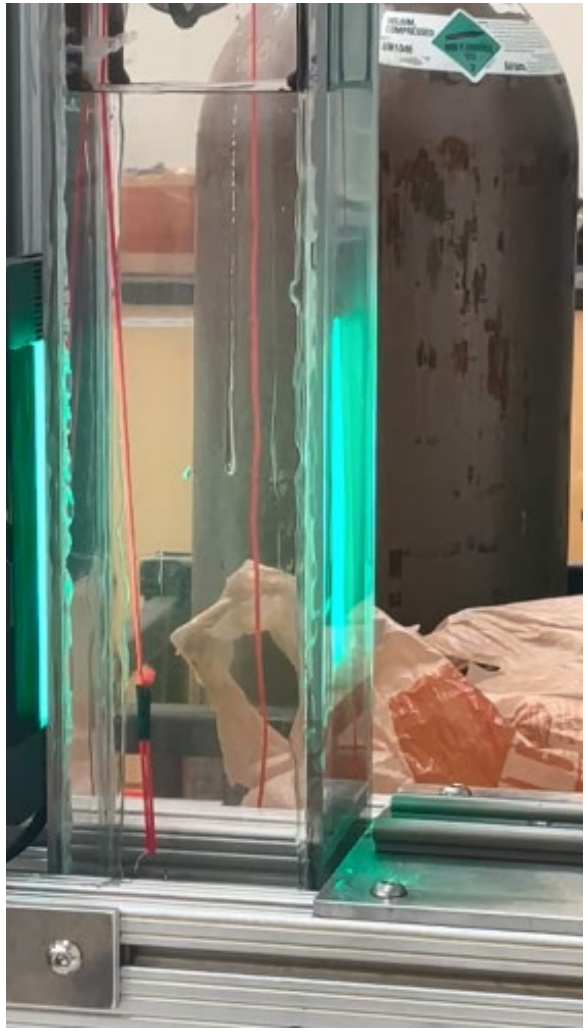


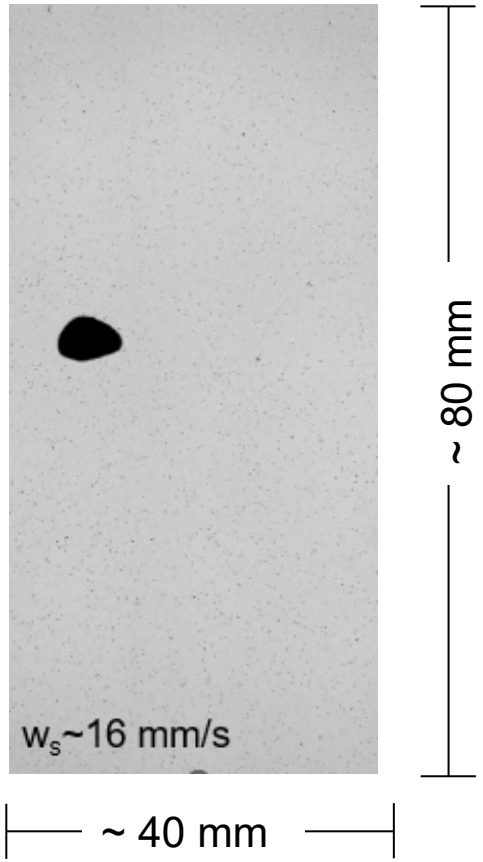
Re_p=Reynolds particle number
Non-dimensional parameter used to describe drag on the particle.

Measurement of Settling Solution Characteristics (factors influencing w_s):

- density (ρ_w): hydrometer
- dynamic viscosity (μ): viscometer
- Measured periodically during experiments.

Laboratory Settling Experiments:



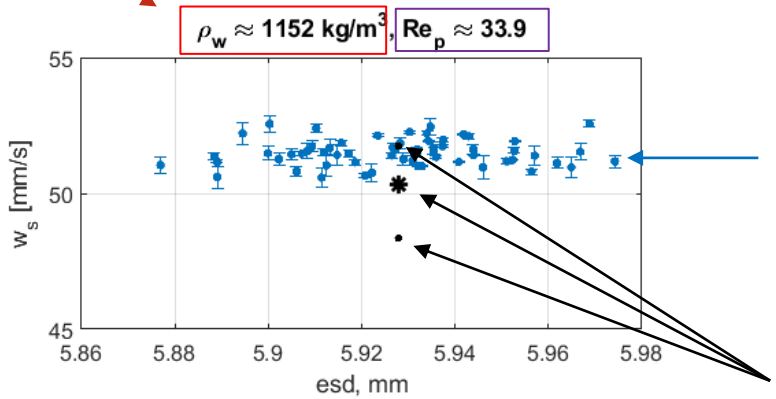


Automated image processing and particle tracking algorithms (Smith and Friedrichs, 2011; 2015; Fall, 2020) used to determine particle size, settling velocity and density.

Preliminary Results (Spheres): Measured (•) vs Theoretical (*)

Settling solution density

Reynolds particle number (function esd, w_s, μ, and ρ_w)



Measured esd vs w_s for all drops, error bars denote +/- standard error from 5 or more tracked frames.

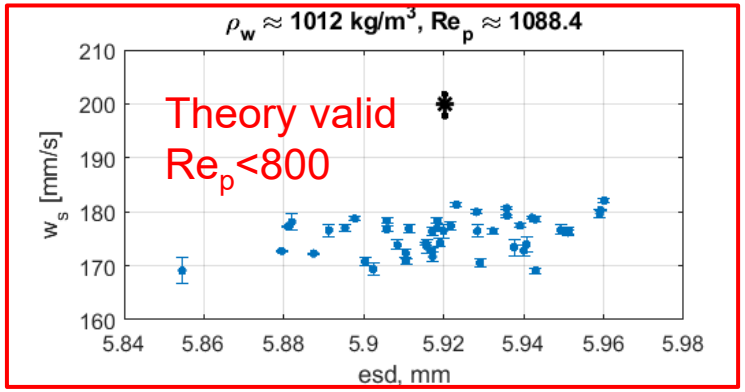
Schiller & Naumann (1933)

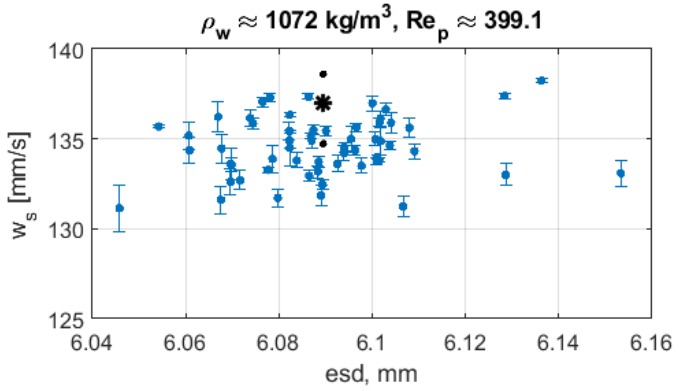
$$w_s = \frac{g \times esd^2}{18\mu} \frac{(\rho_s - \rho_w)}{\left(1 + 0.15 Re_p^{0.687}\right)}$$

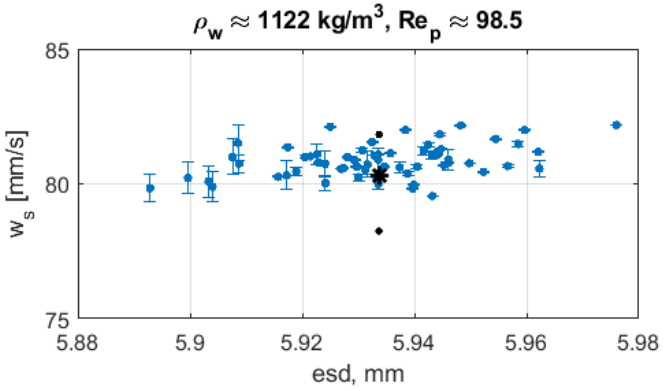
esd is particle size (esd)
ρ_s is particle density (1225 +/- 3 kg/m^3)
g is the acceleration due to gravity
μ is dynamic viscosity

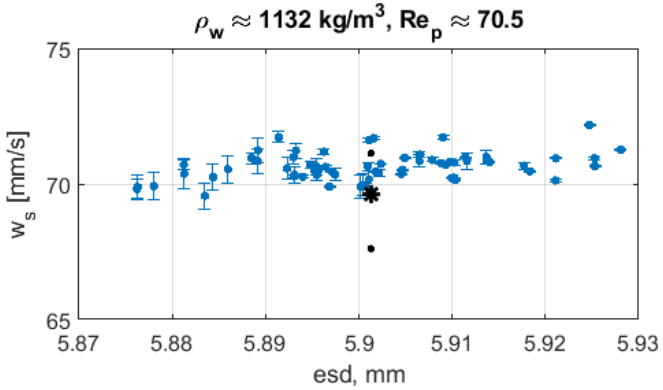
* Theoretical Expression applied= Schiller & Naumann (1933)

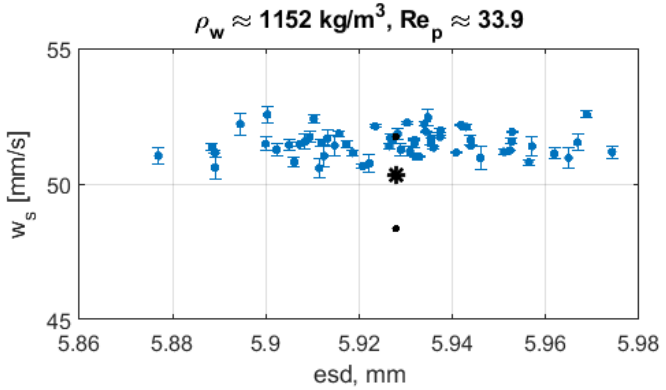
Preliminary Results (Spheres): Measured (•) vs Theoretical (*)

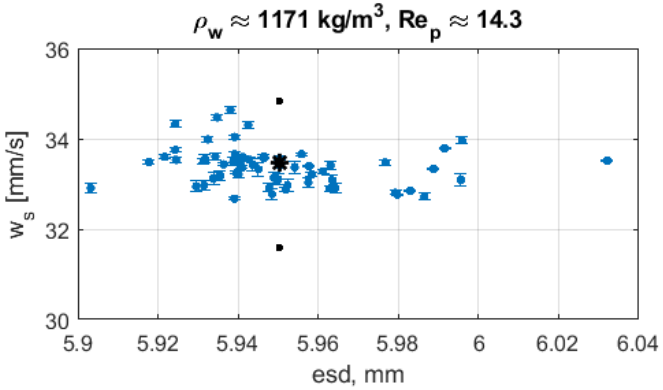


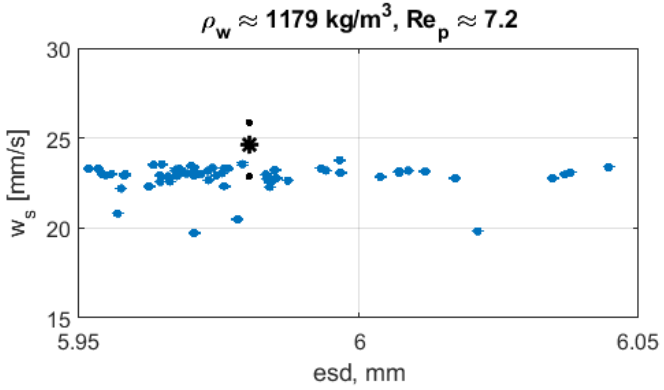


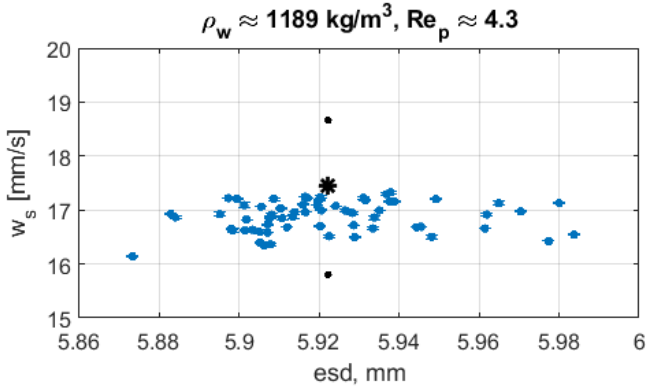


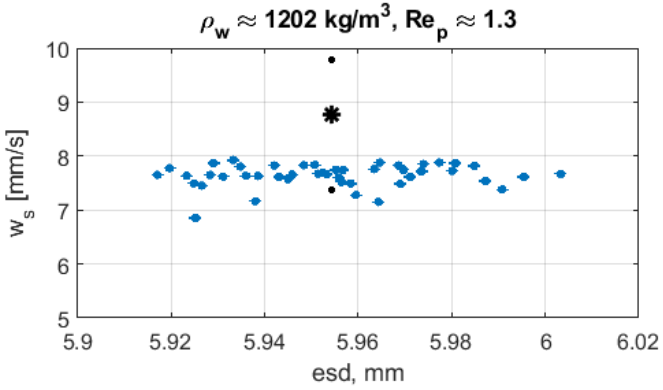










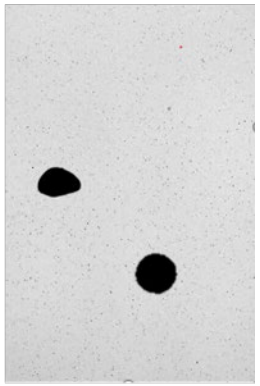


* Theoretical Expression applied= Schiller & Naumann (1933)

Project Objective: Develop fundamental understanding of the influence of floc shape and permeability on settling velocity

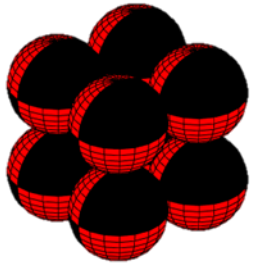
I. Laboratory Settling Experiments:

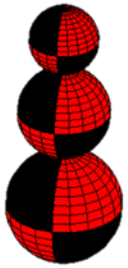
Build flocs using 3D printing

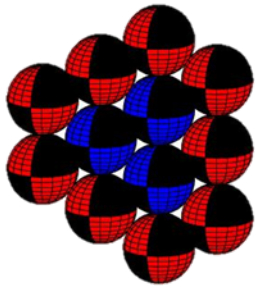


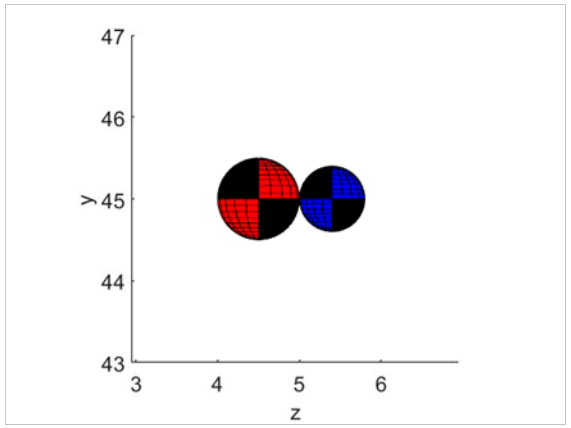
II. Particle Resolved Direct Numerical Simulations:

Build flocs by assembling primary particles.









UC SANTA BARBARA mechanical engineering

BAA Computational Fluids Group

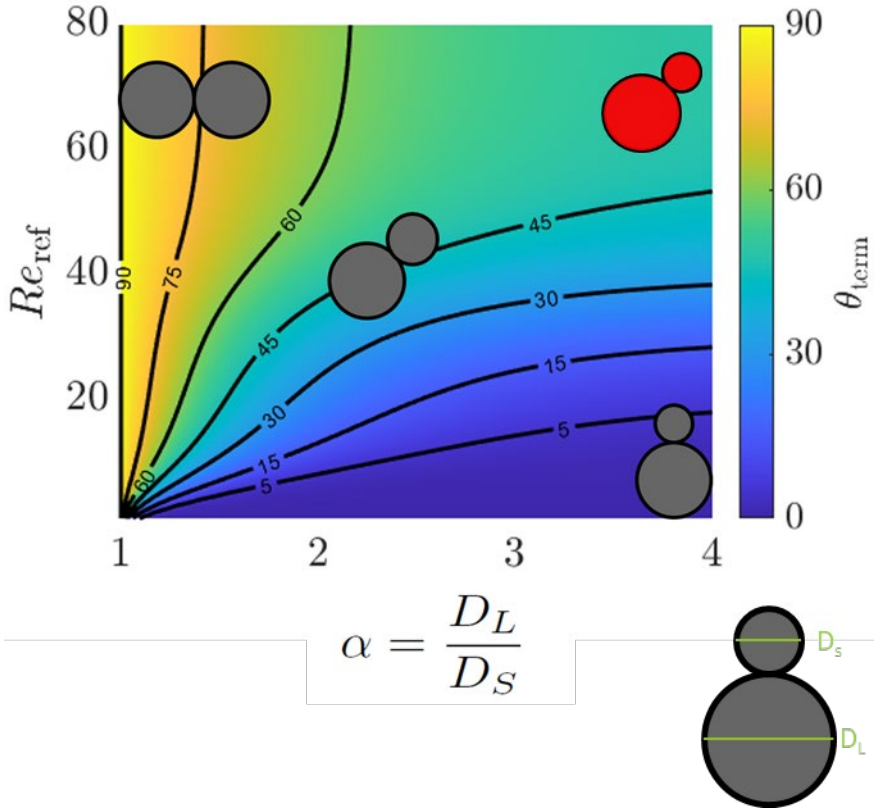
Preliminary Results: Particle Resolved Direct Numerical Simulation

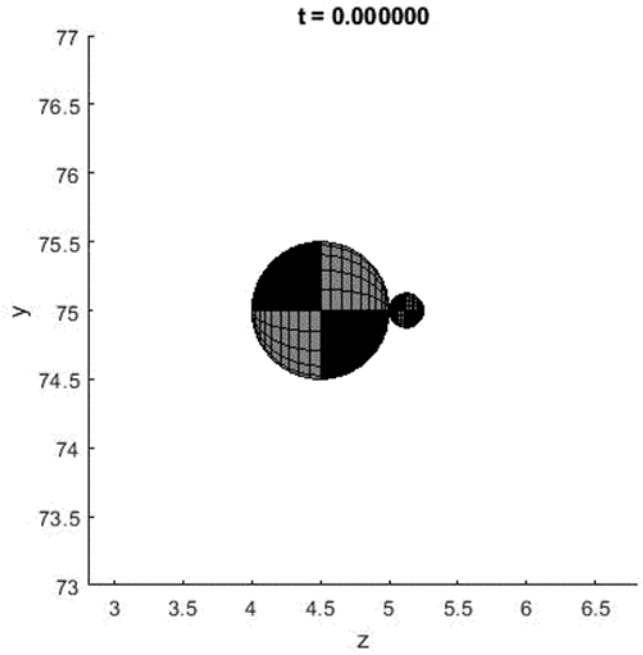
Work by Zachary Maches, UCSB PhD Candidate

UC SANTA BARBARA mechanical engineering

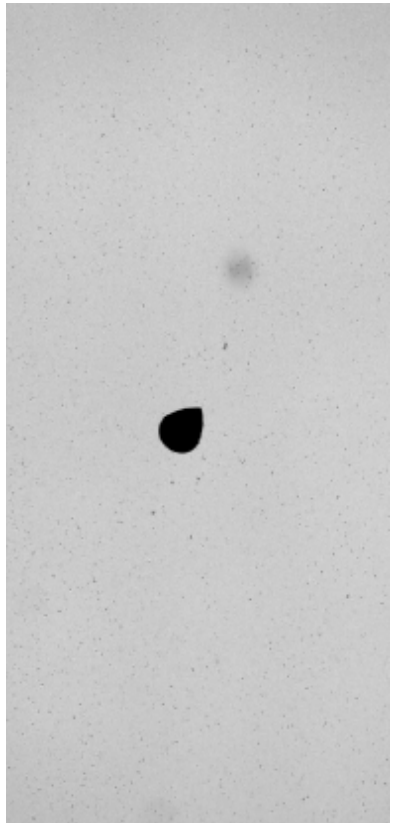
Computational Fluids Group

Case: Two spheres





CHL Lab Experiments



Preliminary Results: Particle Resolved Direct Numerical Simulation

Work by Zachary Maches, UCSB PhD Candidate

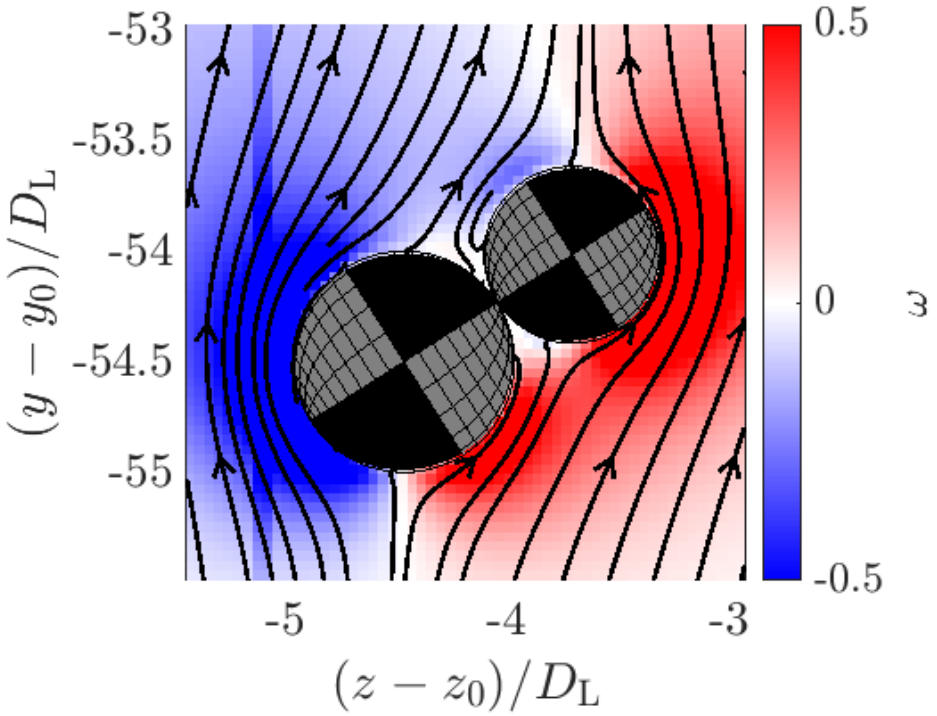
UC SANTA BARBARA mechanical engineering

Computational Fluids Group

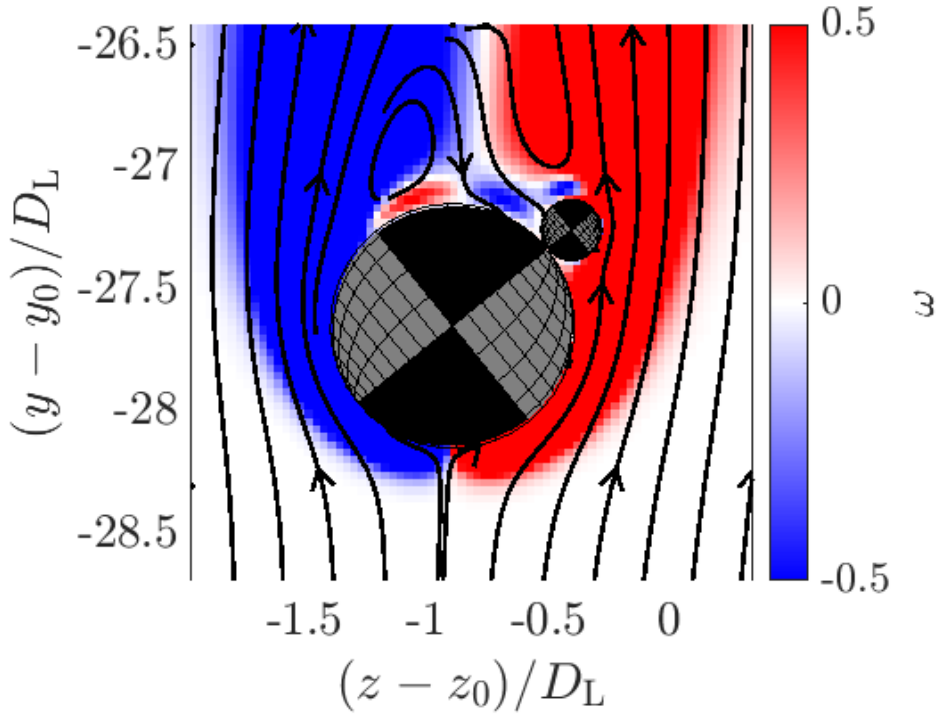
Case: Two spheres

With DNS we can quantify flow fields:

α = 2, Re = 13



α = 4, Re = 75



Preliminary Results: Particle Resolved Direct Numerical Simulation

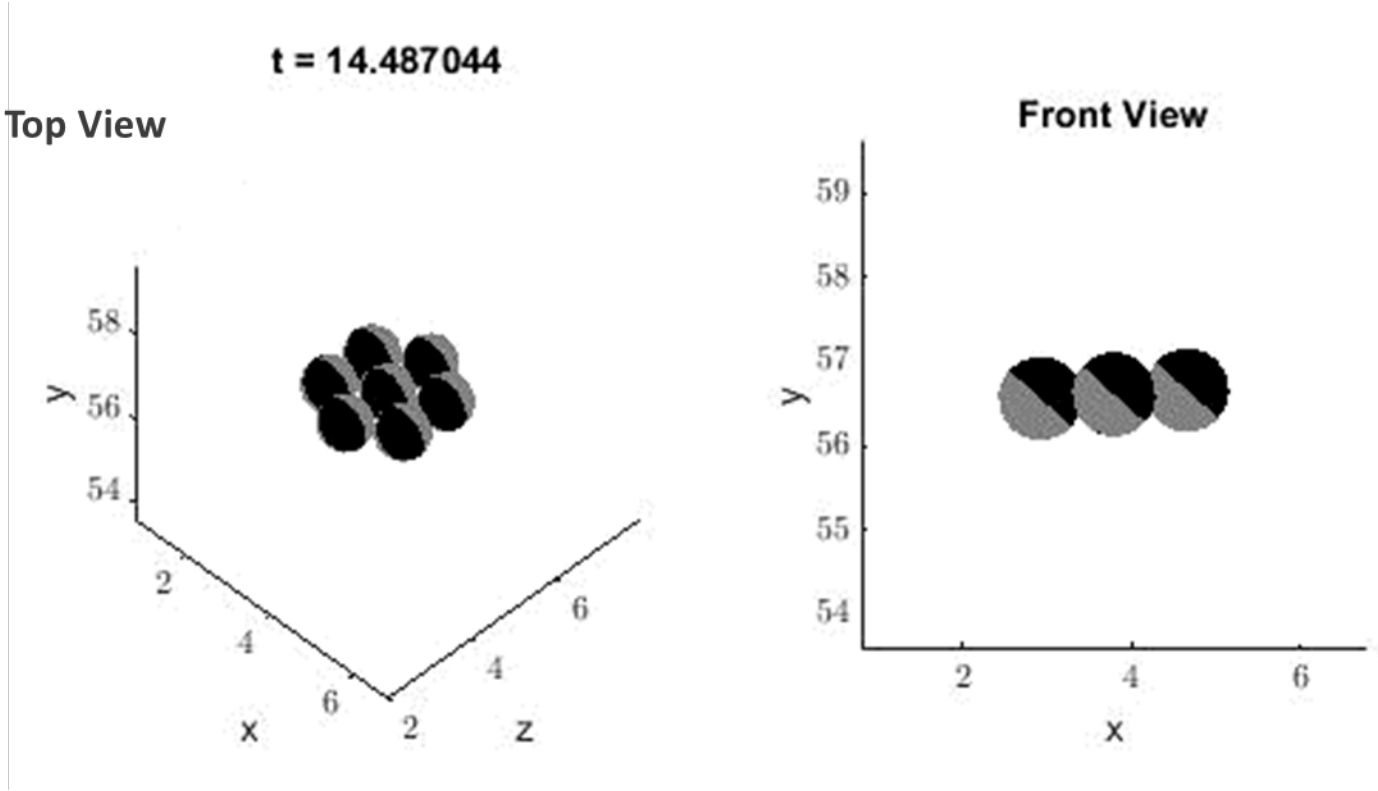
Work by Zachary Maches, UCSB PhD Candidate

UC SANTA BARBARA mechanical engineering

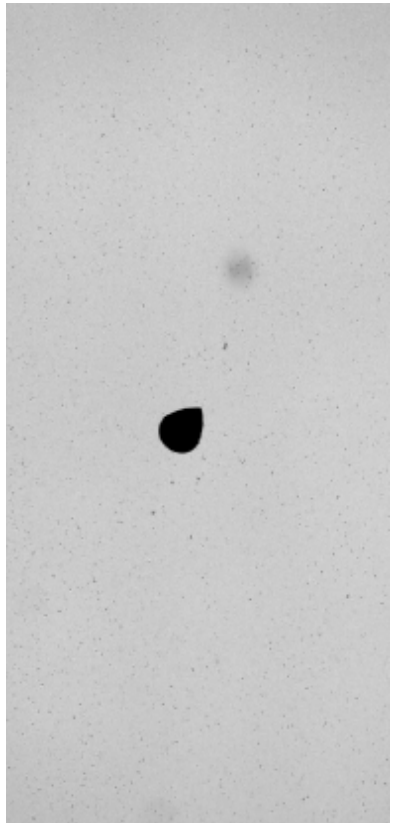
Computational Fluids Group

Case: Plate Dynamics

DNS and observations reveal orientation less stable at Rep >1

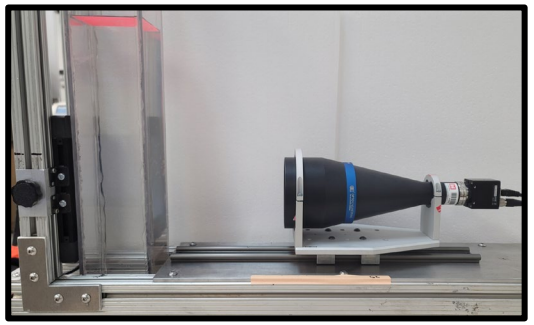


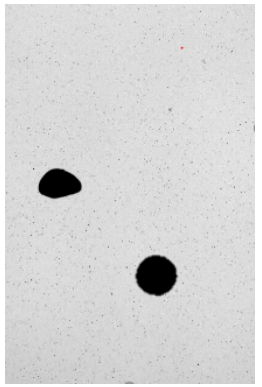
CHL Lab Experiments



* Theoretical Expression applied= Schiller & Naumann (1933)

Summary and Future Work

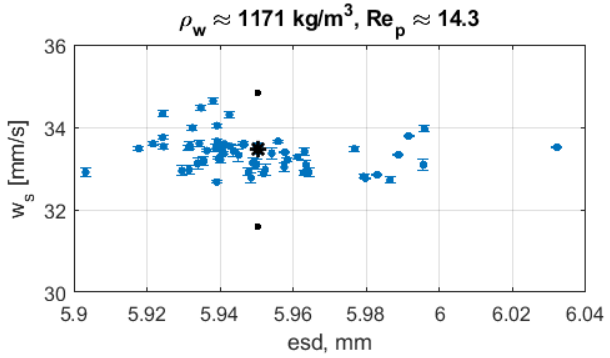


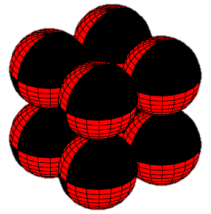


Influence of shape on settling velocity:

- Validated experimental setup & analysis algorithms. Found good agreement between spheres and theoretical approximations.

- Particle resolve DNS model (BAA with UCSB) created and preliminary results in agreement with lab experiments.





Next steps:

- Complete (shape) settling lab and numerical experiments and develop and validate method to approximate 3D shape from 2D images.

- Investigate influence of permeability on settling velocity:

  - Evaluate 3D printing capabilities to see porous “flocs” can be printed?
    **May require micron scale printing to appropriate represent external and internal (in pores) Re_p.*

  - Use validated DNS model to investigate - flow in pores, pore configurations, pore fillings (eps, water, air), etc.

- Investigate implementation of dynamic floc model for USACE.