

Drag Force On Janus Sphere: Effect Of Particle Position

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Drag on Janus Sphere in a Channel: Effect of Particle Position

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Potential use of Janus spheres in novel engineering applications is being explored actively in recent years. Hydrodynamics around Janus spheres is different from that around homogeneous sticks or slippery spheres. Instantaneous motion of a sphere in channel flow is governed by hydrodynamic forces experienced by the sphere, which in turn depends on the particle to channel size ratio, its instantaneous position, hydrophobicity of its surface, and the particle Reynolds number. We investigate numerically the drag experienced by a Janus sphere located at different off-center positions in a square channel. Two orientations of Janus sphere consisting of a sticky and a slippery hemisphere with the boundary between them parallel to the channel midplane are studied: (1) slippery hemisphere facing the channel centerline and (2) sticky hemisphere facing the channel centerline. The flow field around Janus sphere is found to be steady (for $Re \leq 50$) investigated in this work and asymmetric. Based on the data obtained, a correlation for drag coefficient as a function of particle Reynolds number and dimensionless particle position is also proposed. (DOI: 10.1115/1.4048928)

Keywords: Janus particle; square channel; drag coefficient; CFD; off-center

1 Introduction

Janus spheres are typically the particles which have hydrophobic as well as hydrophilic properties on its surface. These are named Janus after the Roman God having two faces [1]. Recently, these amphiphilic Janus spheres having both stick and slip boundary conditions on their two hemispheres have found applications as water repellent films in textile industry [2], switchable screens [3], and as self-propelling particles [4]. They are also used as stabilizers in Pickering emulsions for use in food and pharmaceutical industries [5]. The above-mentioned applications involve the hydrodynamics of Janus spheres in Stokes flow while there are no instances where understanding the hydrodynamics around such particles, at high Reynolds numbers is required. For example, the problem of drag reduction over bodies using hydrophobic or hydrophilic surfaces is studied in internal [6] as well as external flows [7–9].

The forces on Janus particles of the size of nanometer in a fluid medium were investigated using molecular dynamics by Safin et al. [10]. They varied the orientation of the Janus sphere and suggested that the forces are function of orientation of the Janus sphere. Das et al. [11] observed self-propulsion of Janus sphere experimentally. They found that the Janus particles when moving in close proximity to a solid surface exhibited an arbitrary trajectory. The “self-swim” behavior of Janus particle is also observed when the chemical composition of the solution in which the particles are immersed is altered [12]. Recently, the quantification of forces and torques on different aspect ratios of rigid Janus particles and Janus droplets in a uniform flow field is studied [13,14]. The low Reynolds number hydrodynamics for a slip-stick sphere in a uniform as well as linear shear flow is investigated by Swan and Klase [15]. They suggested that the particle responds parallel to the velocity gradient in a linear shear flow. Tada et al. [16] predicted the trajectories of Janus particle by varying the

position, orientation, slip parameter, and confinement ratio in a cylindrical microchannel. They observed two regimes: periodic oscillation for particle positioned far from the confining and migration towards the tube axis for those near the confining.

The brief review suggests that there is no study in the literature that investigates the drag on the Janus particles in a low to medium Reynolds number. Therefore, in our previous work [17], we investigated the flow field and drag over Janus sphere having sticky and slippery hemispheres placed at the centerline of a square channel. The effect of particle to channel size ratio (R) is explored, and it is observed that drag force on Janus sphere reduces when compared to that for stick sphere. We employ free-slip and no-slip boundary conditions on the slippery and sticky surfaces of the Janus sphere, respectively.

Therefore, the effect of wall on the hydrodynamics around off-centered Janus particles is investigated in this study. The remainder of this paper is organized as follows: In Sec. 2, we present the formulation of the problem. Section 3 describes the governing equations, boundary conditions and numerical schemes to solve the system of equations. In Sec. 4, we present the pressure and velocity distributions on and around the Janus sphere, and drag experienced by it. The drag coefficient obtained for Janus sphere is compared with that for no-slip homogeneous sphere and free-slip homogeneous sphere. Based on the data obtained from computational fluid dynamics (CFD) simulations, a correlation is proposed for the drag coefficient. Finally, in Sec. 5 we state our conclusions.

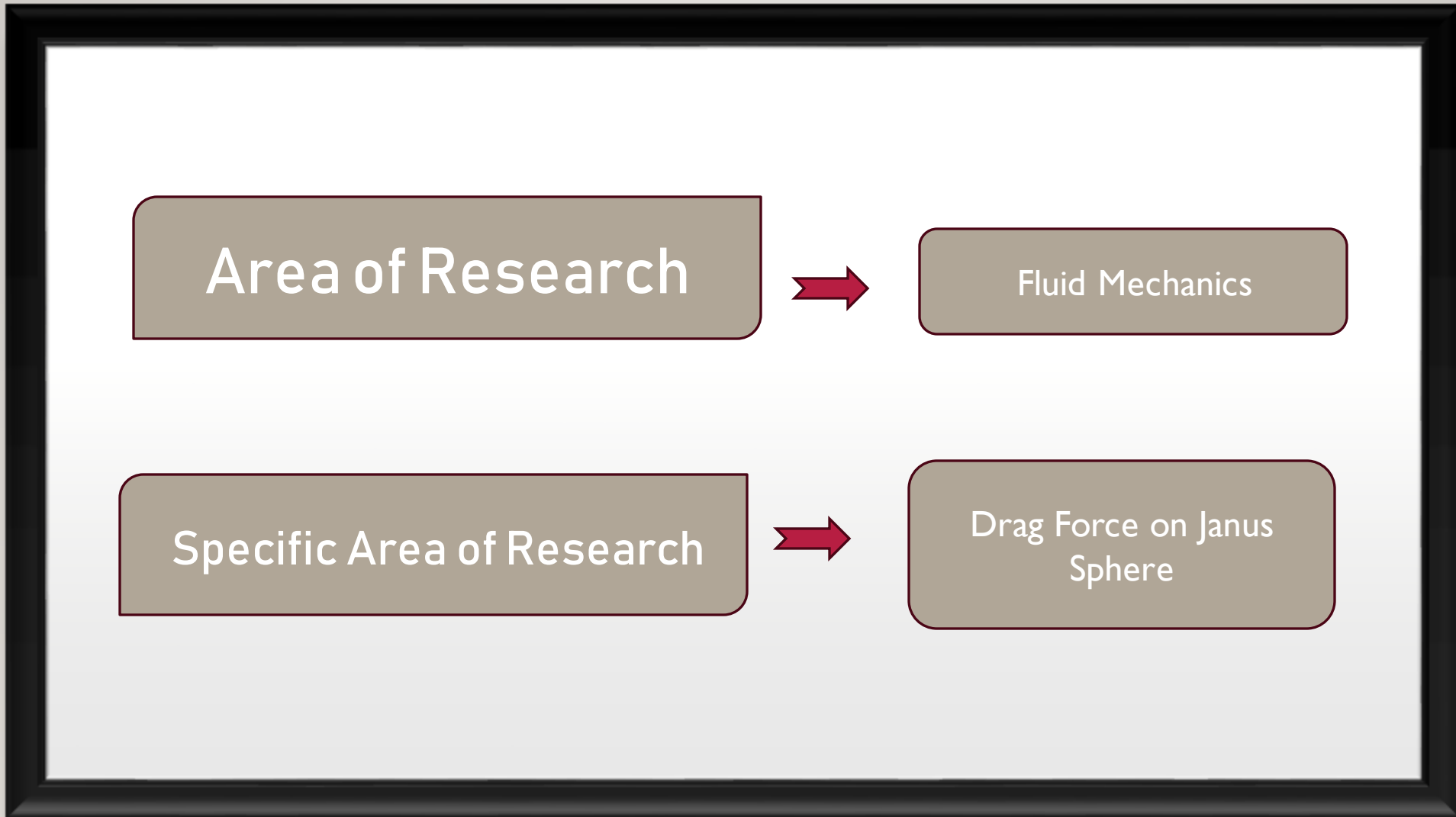
2 Problem Definition

Computational fluid dynamics simulations are performed in a channel of square cross section (in plane of side H as shown in Fig. 1). The Janus sphere of diameter d remains fixed in the channel and the liquid flows along positive x -direction. The Janus sphere is located at a distance Y from the channel centerline on the xy plane located at the middle of the channel for all the cases. The sphere is located sufficiently away from the solid boundary so that the flow becomes fully-developed before it reaches the sphere. The length of the channel is $L = 400d$.

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3 Content



Objectives



Introduction



Methodology



Novelty



Parameters



**Result And
Discussions**



**Literature
Reference**

Objectives

Investigate the drag experienced by a Janus sphere placed at different off-center positions in a square channel.

Computer stimulation to quantify the drag force experienced .

Understand the hydrodynamics around Janus spheres and compare it with homogeneous sticky or slippery spheres .

Introduction



Presence of a sphere and its effect on the velocity and flow in the channel.



Investigates the pressure distribution, drag reduction, and the influence of different parameters on the flow characteristics.

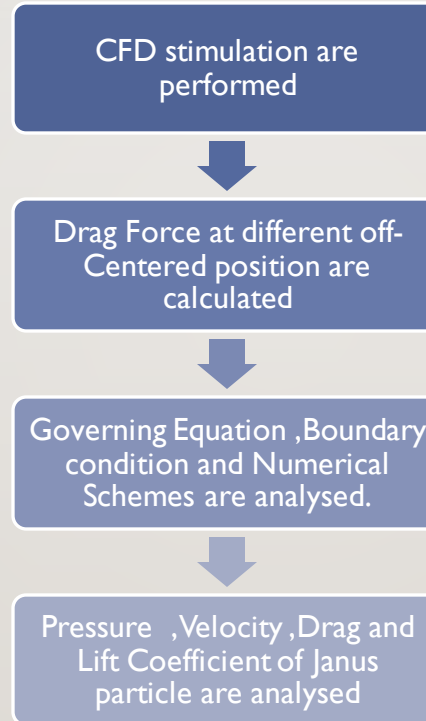


Motion affected by the particle to channel size ratio, position of sphere, hydrophobicity of its surface and Reynolds number.



Correlation between the particle Reynolds number and the particle position and the drag coefficient.

Methodology

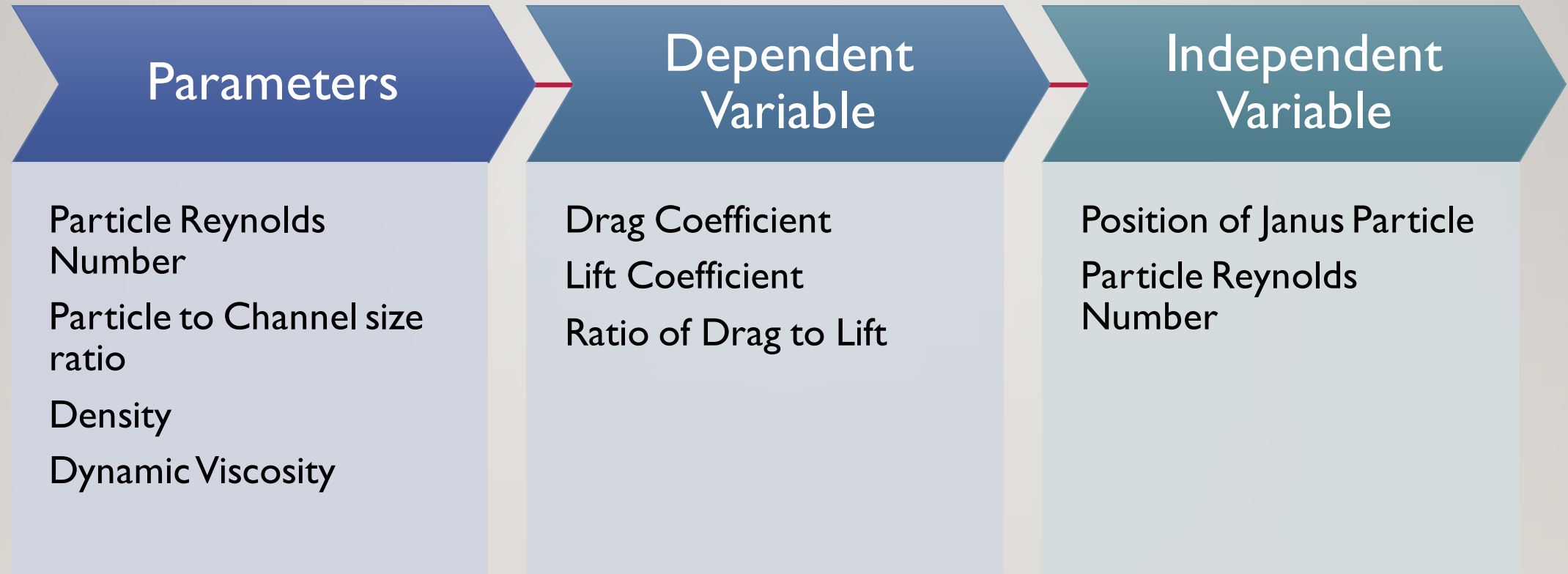


Targeted Novelty

- Previous research explored particles behavior at low to medium Reynolds Number
- Other research observed movements near surface at various flow condition.
- Focus on Drag Force on Off-Centered Janus particle

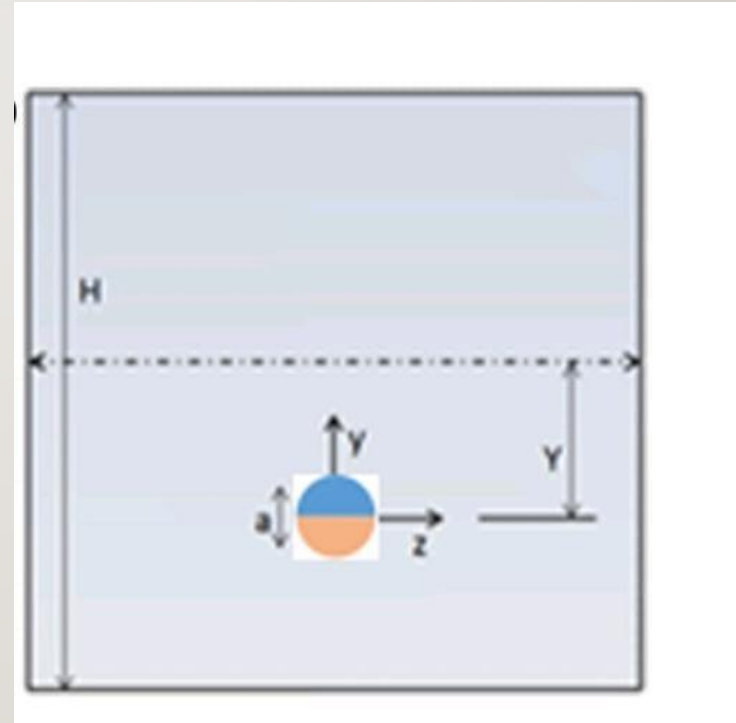
Subjective Novelty

- Drag Force in low to medium Reynolds number on Janus Particle
- Effect of free-slip and no-slip boundary condition on the slippery and sticky surface of the particle



RESULTS AND DISCUSSION

- ❖ Computational fluid dynamics (CFD) simulations conducted to calculate Drag force.
- ❖ Two orientation possible:-
 1. Free-slip hemisphere faces the channel centerline and case
 2. No-slip hemisphere faces the channel centerline



Pressure and Velocity Field

➤ POSITION OF PARTICLE INFLUENCES SURROUNDINGS FLOW FIELD

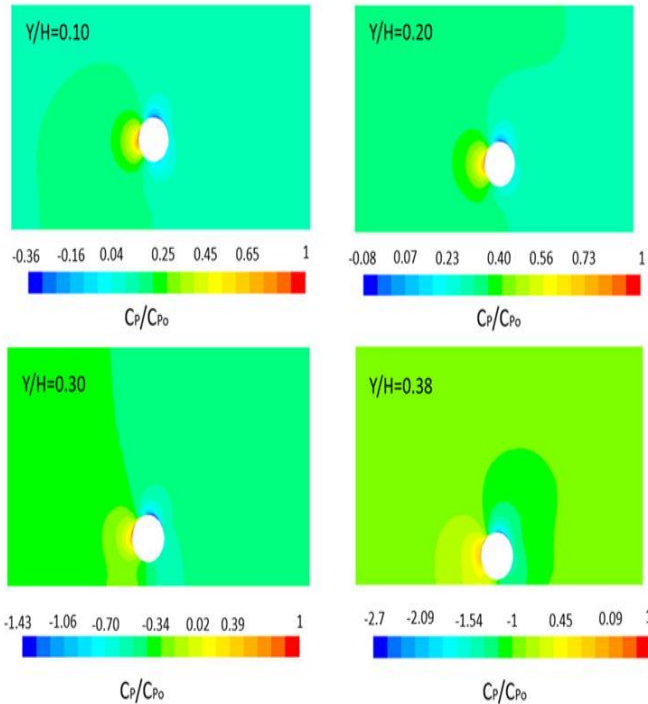


Fig. 3 Nondimensional pressure distribution $\left(\frac{C_p}{C_{p0}} = \frac{P - P_{min}}{P_0 - P_{min}}\right)$ on the xy plane for $Y/H = 0.10, 0.20, 0.30$ and 0.38 at $Re_P = 10$ for case 1

Case 1

Minimal Impact on velocity beyond Midplane

Free slip hemisphere allows flow passage

Case 2

Flow separation on no-slip hemisphere, formation of Vortex at $Re_P = 50$

Closer to channel centerline Vortex magnitude and Size are Higher

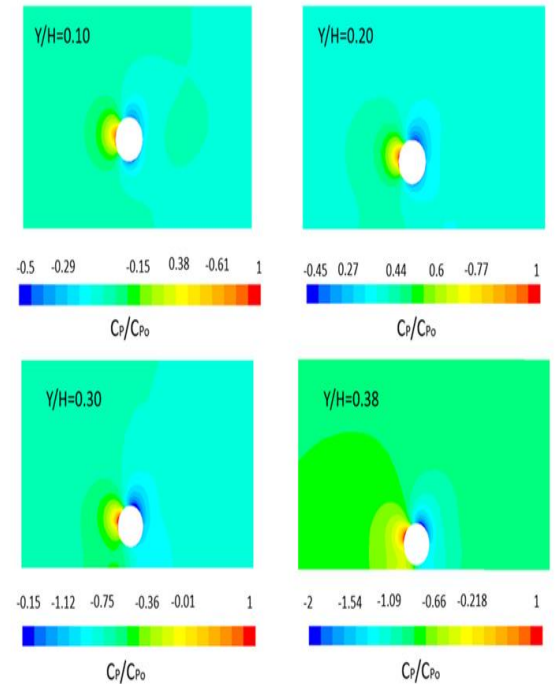


Fig. 4 Nondimensional pressure distribution $\left(\frac{C_p}{C_{p0}} = \frac{P - P_{min}}{P_0 - P_{min}}\right)$ on the xy plane for $Y/H = 0.10, 0.20, 0.30$ and 0.38 at $Re_P = 10$ for case 2

Drag Coefficient

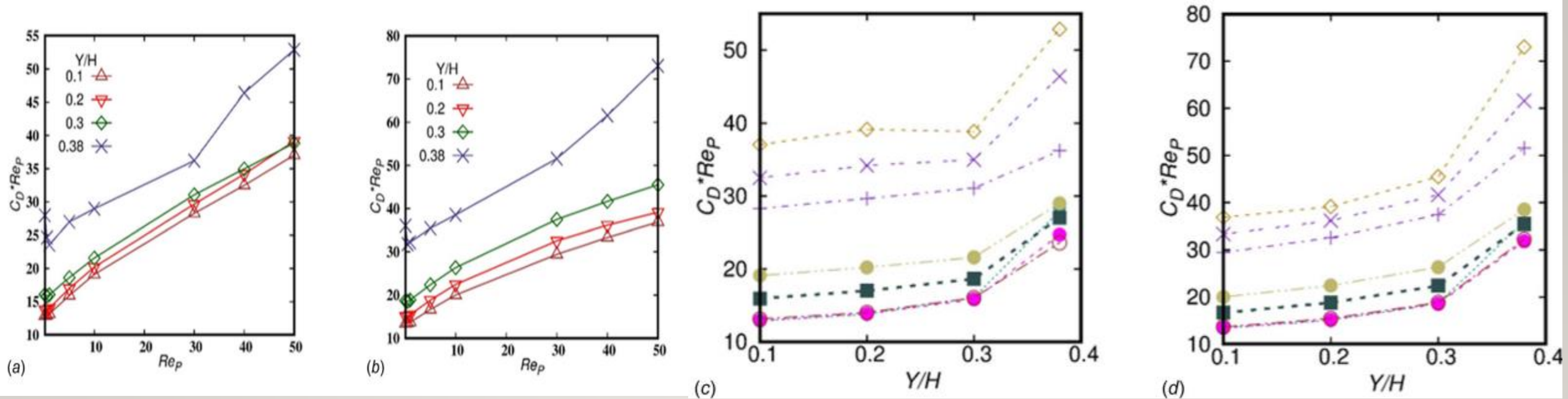
Case 1

- Drag Coefficient Decreases as Reynolds Number Increases
- CD appears larger at position closer to Centerline
- Viscous Drag decreases as particle move from centerline to wall

Case 2

- CD is higher than case 1 at high Reynolds No.
- Higher Viscous Drag than case 1 at same Y/H and Reynolds No.
- Force acts along Tangential and Normal to surface due to Viscous and Pressure Drag

Local Drag Coefficient Variation



Case1

Case2

Case1

Case2

Reynolds Number

Janus Position

Drag Coefficient and Lift Coefficient

Case 1

- Exhibit nonzero lift force directed toward centerline
- All C_D/C_L are positive indicating lift force always towards Centerline
- At higher Reynolds No. Lifts force comparable to Drag force in magnitude

Case 2

- Direction of Lift force is not fixed , varies with position in channel.
- Change in sign of C_D/C_L indicates direction of Lift force changes
- C_D decreases monotonically with Y/H

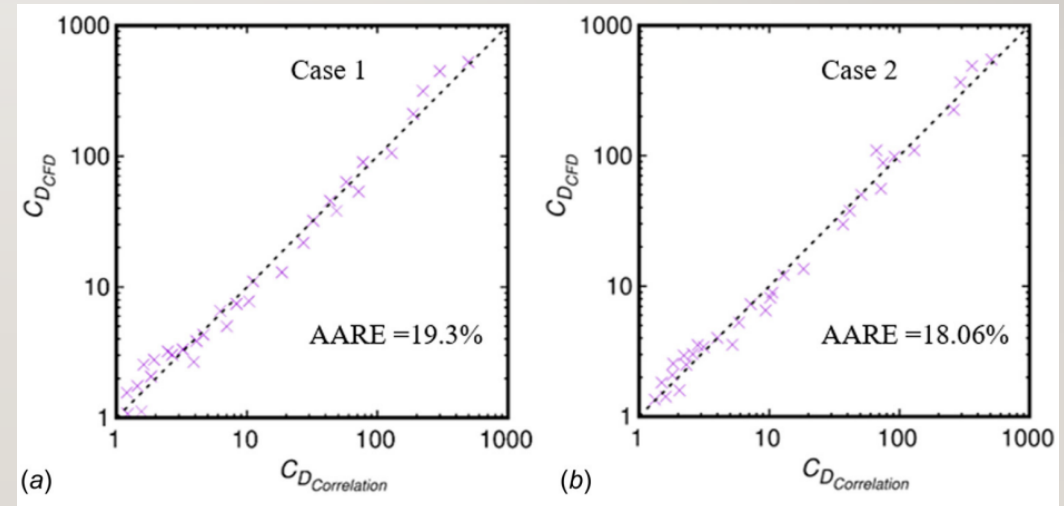
DRAW COEFFICIENT CORRELATION

Case 1

- Correlation Equation : $CD = 13.4 \cdot (Y/H)^{0.73} \cdot Re^{0.84}$
- AARE = 19.3%

Case 2

- Correlation Equation $CD = 22.69 \cdot (Y/H)^{0.50} \cdot Re^{0.85}$
- AARE : 18.06 %



CONCLUSION

- Janus sphere placed between channel centerline and wall at Two different orientation
- Drag Coefficient ,Viscous and pressure decreases when position is changed to wall
- Local drag Coefficient independent of Y/H but increases near wall.
- Lift coefficient is negligible at low Reynolds No. compared to high Reynolds No.

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THANK YOU
