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Rolling spheres down an inclined plane immersed in a Newtonian fluid and a Boger fluid

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Abstract— **The flow and vorticity fields surrounding a sphere sedimenting inside a rectangular shaped box with an inclination angle are characterized using particle image velocimetry (PIV). Two different fluids, a Newtonian fluid and constant (shear) viscosity Boger fluid are used to determine the effect of elasticity on the flow field, and significant differences on the flow structure are found for each fluid. In this work, the instantaneous two-dimensional (2D) vectors, velocity and vorticity contours are plotted to show some of the flow characteristics and to elucidate the effect of the fluid properties on the resultant flow structure and anomalous rolling.**

Key words— **Newtonian fluid, Boger fluid, PIV, Rolling sphere.**

I. Introduction

The sedimentation of a sphere through a quiescent polymer solution is a benchmark problem in non-Newtonian fluid mechanics [1]. A related problem to sedimentation along the axis of a fluid filled cylinder is sedimentation near a vertical plane. Several researchers have reported flow unique phenomena under these conditions. Liu et al. [2] found anomalous rolling of a sphere in viscoelastic liquids along an inclined path by varying the angle between the wall and the direction of gravity from zero to 45^{o}. Their results show that the sphere rotates upwards while falling down near the vertical plane and pointed out that a critical distance with respect to the vertical plane exists. Singh and Joseph [3] performed a three-dimensional (3D) numerical study of a sphere sedimenting near a planar wall in an Oldroyd-B fluid and predicted that depending on the type of fluid, if a sphere is near a planar vertical wall, it can exhibit anomalous rotation as long as it does not touch the wall. Becker et al. [4] used a reciprocal theorem to predict the steady 3D creeping motion of a sphere sedimenting near a single vertical plane wall. Their results show that at low Deborah numbers, the theoretical calculations indicate that fluid elasticity results in a migration of the sphere away from the wall and a drag decrease greater that that predicted in the unbounded case. Liu et al. [5] showed that anomalous rolling is a characteristic phenomenon which can be observed in every viscoelastic liquid and revealed the hydrodynamic mechanisms that make it happen. Harrison et al. [6] used a novel 3D PIV technique to measure the planar 3D flow field about the centerline of a sphere sedimenting in a rectangular shaped box. They presented results for a sphere falling in both a constant viscosity elastic (Boger) fluid and a shear-thinning elastic liquid, and pointed out that significant qualitative differences in the flow field for the sphere sedimenting in the shear-thinning and constant viscosity elastic liquids exist. Tatum et al. [7] studied the velocity fields surrounding a sphere sedimenting near a vertical plane wall using 3D stereoscopic PIV. Three different test fluids (Newtonian, Boger, and shear-thinning) were investigated, and their results showed that the presence of the wall has a significant impact on the velocity fields surrounding the sphere. Arigo and McKinley [8] studied experimentally the occurrence of negative wakes behind spheres settling along the centerline of a tube containing a viscoelastic aqueous polyacrylamide solution using laser-Doppler velocimetry (LDV) and PIV. Their results show that for a fixed aspect ratio, the magnitude of the most negative velocity in the wake is seen to increase with increasing Deborah number.

In the present work, the effect of elasticity on the resultant instantaneous flow field surrounding a sphere rolling down on an inclined plane for Newtonian and Boger fluids is studied experimentally using PIV. In the following section, the complexity of the flow behavior of the falling sphere is elucidated by presenting instantaneous 2D vectors, velocity and vorticity fields surrounding the falling sphere, and the main differences for each fluid are pointed out.