THE INFLUENCE OF INERTIA ON TAYLOR COLUMN

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Introduction

In a uniformly rotating fluid, a slowly rotating($u<0.1\pi$/s) object generates an invisible wall extending from the bottom to the fluid surface around its axis of rotation. This wall is the so-called Taylor column. Typical discussions of Taylor column focus on the case of big Reynold number and small Rossby number(Ro<<1), which, respectively, neglect viscosity and the flow's inertia. Nevertheless, in our experiment, we take the inertia into account, and study its influence(s) on the column.

Experimental method

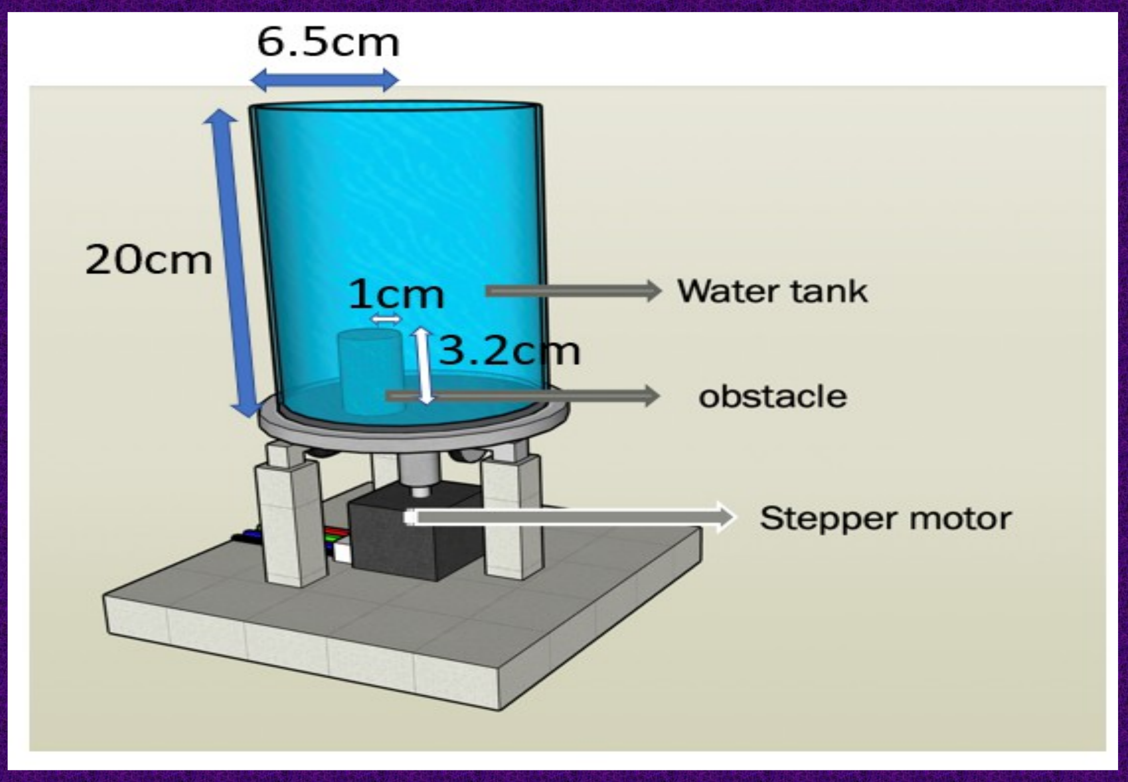

Fig. 1 Schematic diagram of our apparatus.

A cylindrical obstacle is fixed from bottom to the turntable driven by a stepper motor. A relative rotation between the obstacle and water is achieved by slowing down the tank's angular velocity after the water co-rotates with it at the initial velocity. In addition, a camera is fixed to the turntable to record the process and powder is added to the water to be tracked and give the flow field using the PIV approach.

Theoretical basis

Navier-Stokes Equations describes the motion of fluid and is give by

$$\frac{\partial\vec{u}}{\partial t}+(\vec{u}\cdot\nabla)\vec{u}+\vec{\Omega}\times(\vec{\Omega}\times\vec{u})=\frac{-1}{\rho}\nabla P+\nu\nabla^2\vec{u}-2\vec{\Omega}\times\vec{u}-\vec{g} \quad (1)$$

where $\vec{u}$ is the obstacle's velocity, ρ is the fluid density, P the pressure, ν the kinematic viscosity, $\vec{\Omega}$ the angular velocity of the system, and $\vec{g}$ the gravitational acceleration. For typical discussions, i.e. big Re and Ro<<1, viscosity and inertia can be neglected. Eq.(1) reduces to

$$\frac{-1}{\rho}\nabla P=2\vec{\Omega}\times\vec{u}-\nabla\Phi \quad (2)$$

Where $\nabla\Phi$ is the combination of gravity and the centrifugal force. In addition, for incompressible fluid, i.e., ρ is constant, eq.(2) can be simplified to

$$2\vec{\Omega}\cdot\nabla\vec{u}=\frac{\partial u_z}{\partial z}=0 \quad (3)$$

This is the well-known equation describing the typical Taylor column.

For higher Rossby number, the inertial effect should be taken into account. The resulting equation describing the fluid's motion should then be

$$\vec{u}\cdot\nabla\left(\frac{\partial u_y}{\partial x}-\frac{\partial u_x}{\partial y}\right)-\frac{\partial\vec{u}}{\partial y}\cdot\nabla u_x+\frac{\partial\vec{u}}{\partial x}\cdot\nabla u_y=-2\Omega_z\frac{\partial u_z}{\partial z} \quad (4)$$

Where, u_z may now be z-dependent. This means the fluid's velocities vary in different layers of the fluid, i.e., the Taylor column now has an inclined wall instead of the typical vertical one. We will explore the relationship between $\vec{\Omega}$ and $\vec{u}$ on the system through experiments.

Experimental Results

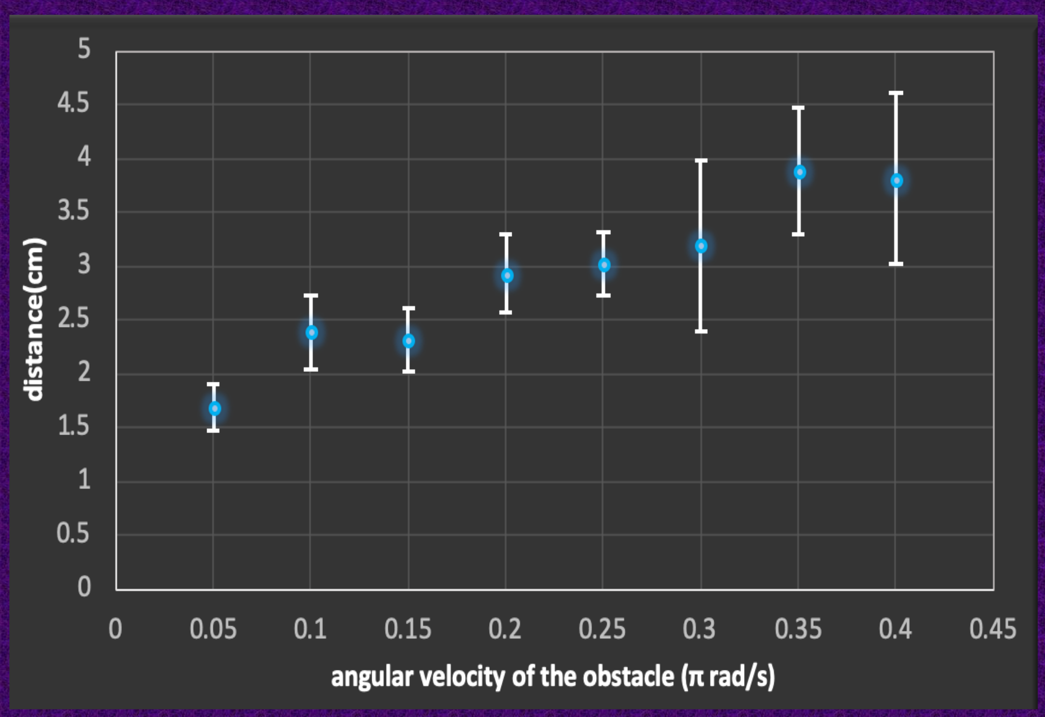

Fig. 2 The relationship between the deviation of Taylor column and the moving speed of obstacles.

- In the experiment, we found that the Taylor column will deviate from the original obstacle. Through the analysis, we found that the deviation is positively correlated with the speed of obstacle.

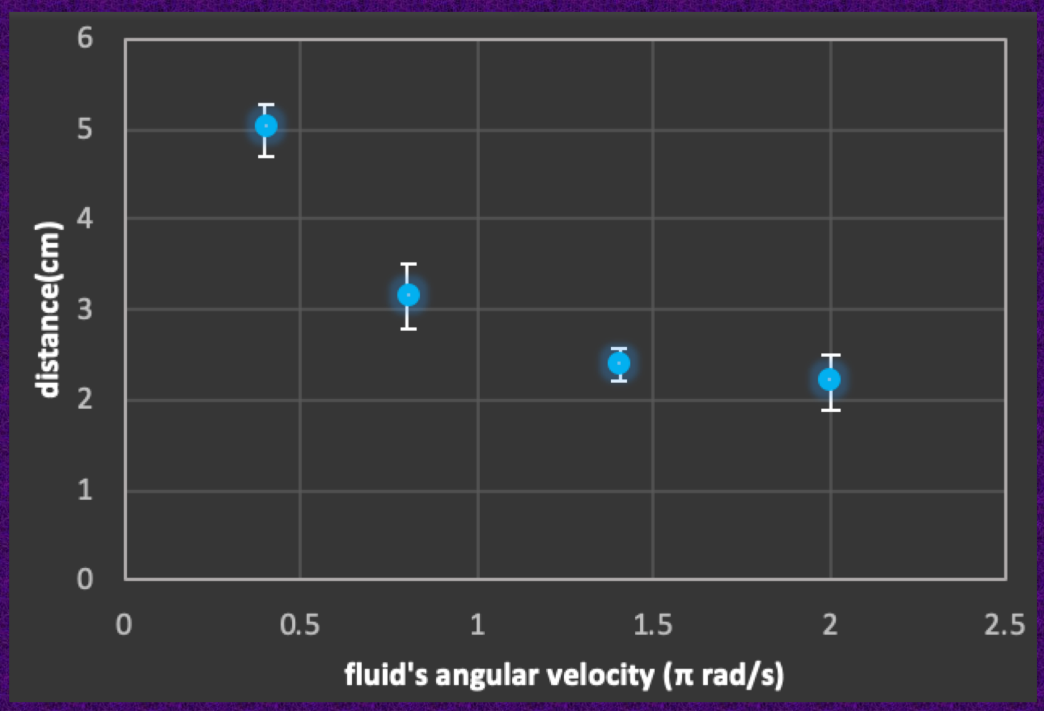

Fig. 3 The relationship between the deviation of Taylor column and the fluid's angular velocity.

- We fix the angular velocity of obstacle and observed the impact of flow field speed on the system. The faster the fluid rotate, the smaller the deviation is.

Conclusions

1. The deviation of the Taylor column increases as the obstacle's speed rises. This result is in line with the theoretical prediction of the relationship between inertia and the uniformity of the upper and lower layers of the flow field.
2. Due to the experimental setup, we can't test the excessive speed of fluid. In the experiment with the angular velocity below 2π/s, the larger the angular velocity, the smaller the deviation.
3. Experimentally, we find out that the deviation of Taylor column is more sensitive to the change in $\vec{\Omega}$ than that in $\vec{u}$.

Reference

[1] O.U.Velasco Fuentes. in European Journal of Mechanics B/Fluids 2008
[2] Martha W. Buckley. Notes on the Taylor Column Experiment 2004