VORTEX-INDUCED VIBRATIONS OF A TETHERED SPHERE WITH NEUTRAL BUOYANCY

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Summary Recent preliminary experiments have indicated that a vertically-tethered sphere develops a large diameter quasi-circular trajectory, unlike the oscillations observed for buoyant horizontally-tethered spheres. The previous study of the same authors numerically identified that there exist six different flow regimes within the range of the Reynolds number (*Re*) = [50, 800], which is based on the mean flow velocity (U) and sphere diameter (D), in the case of a tethered sphere with neutral buoyancy. A series of experiments are carried out in a water channel to verify and support the numerical findings. The experiments covered the range of the Reynolds number = [700, 4000] which is higher than those of the numerical study, and the position of the sphere was recorded during the experiments. Within the Reynolds range = [700, 800], which covers simulations and experiments, and corresponds to the Regime VI, it is observed that the response of the sphere is irregular. This verifies the existence of Regime VI which has been found in the numerical study. It is also observed that the sphere shows quasi-circular motion in the plane normal to incoming flow as the Reynolds number is increased further.

BACKGROUND

The practical significance of vortex-induced-vibration (VIV) has led to a large number of fundamental studies, especially regarding a rather simple form of bluff body like cylinder. Some comprehensive reviews in the field are [1] and [2].

The majority of early work on tethered spheres was concerned with the action of surface waves on tethered buoyant structures ([3], [4]). The tethered sphere was found to vibrate vigorously due to the waves as expected. However, the coupling of the wave motion and the dynamics of the sphere made it difficult to understand the underlying dynamics of the sphere motion.

The research concerning fully submerged tethered bodies was first examined by Govardhan and Williamson [5] who found that non-neutrally buoyant a tethered sphere does indeed vibrate in a uniform flow. In particular, they found that it will oscillate vigorously at a transverse peak-to-peak amplitude of about two diameters. In the Reynolds number range of their experiments (*Re* = [1000, 13000]), the response amplitude was a function of the flow velocity.

Pregnalato [6] numerically found that a buoyant tethered sphere oscillates at large amplitude over a wide range of normalised velocity, which is similar to the previous studies ([5], [7]). Even though the flow is within laminar regime whose Reynolds number fixed at 500, he observed some modes shown in [8].

RESULTS

The experiments were conducted in a recirculating free surface water channel at Monash University, Melbourne, Australia. Water is recirculated through the channel using a centrifugal pump controlled by an electronic controller to give flow speeds between 0.047 and 0.456m/s in the glass working section. The working section has a width of 0.6 m, a height of 0.8m and a length of 4.0m and is positioned between two large tanks of water. Upstream of the working section water flows through a honeycomb and thin wire mesh before going through a 9:1 contraction to the working section. The combination of the screens and contraction yield a turbulence level of less than 1.0%.

A sphere made with Perspex and the diameter of 16mm was used for the experiments. The sphere was made to be separated in half and hollowed out to adjust its buoyancy by adding some types of material inside. For the experiments, a piece of sponge was inserted to adjust its buoyancy and mass distribution. A thin string with the diameter of 0.1mm was connected to the sphere as a tether, and then the tether was attached to 0.315mm wire which was vertically tensionised between the bottom of the working section and the ceiling right above it as a support.

A series of images of of 8-bits grayscale were captured to locate the centre of the sphere. Each image has 1360x1024 pixels and the size of 1.4 megabytes. 2fps(frame per second), 4fps and 8fps were tested to record the images, and 4fps was used in most cases.

It has been found numerically that there exist six different flow regimes within the range of the Reynolds number = [50, 800]. From the experimental study of the Reynolds number = [700, 4000], It is veryfied that there exists the Regime VI which shows chaotic behaviour of the body. Moreover, it is found that there is another regime, Regime VII, which shows quasi-circular motion as the Reynolds number is increased above about 2000.

In summary both from numerical and experimental studies, Regime I (*Re* = [50, 205]) shows steady axisymmetry flow structure without body movement. Regime II (*Re* = [210, 260]) is also characterised by steady flow structure except the loss of axisymmetry. The sphere starts to oscillate at Regime III (*Re* = [270, 280]). Regime IV (*Re* = [300, 330]) shows suppressed body oscillation and the off-centered distance decreases rapidly. In Regime V (*Re* = [335, 550]), the sphere

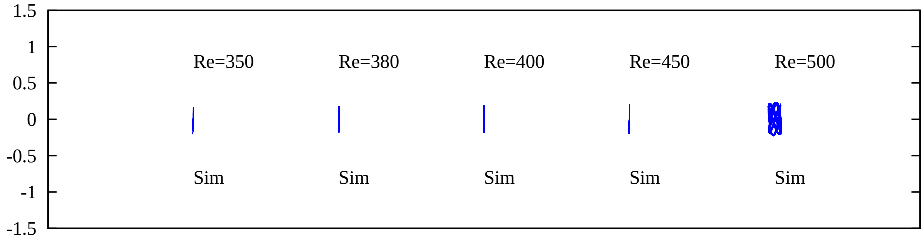

Figure 1. Trajectory in the plane normal to the stream. Regime V. Both axes are of the same scale. The unit of the number in y axis is the diametre of the sphere. All from the simulations(Sim).

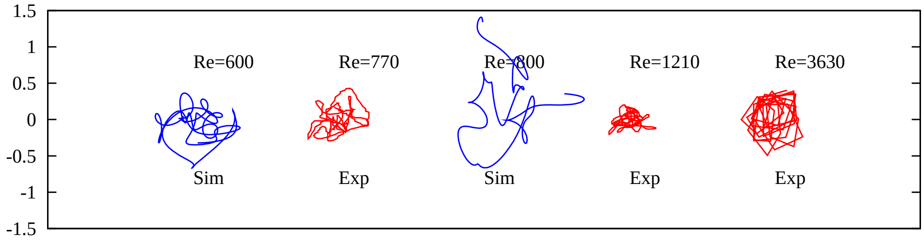

Figure 2. Trajectory in the plane normal to the stream. Regime VI. Both axes are of the same scale. The unit of the number in y axis is the diameter of the sphere. From the simulations(Sim) and the experiments(Exp). Irregular motion observed from the experiment at *Re*=770 shows good agreement to that from the simulation at *Re*=600. The case of *Re*=3630 starts to show a quasi-circular motion, which corresponds to Regime VII.

vibrates around the centre of the plane normal to the stream (Figure 1). In Regime VI (Re = [600, 800]), the sphere oscillates rather irregularily at larger amplitude than other regimes. The body motion in Regime VI is predicted from the simulation and observed in the experiments (Figure 2). In Regime VII ($Re > 2000$), the oscillation becomes quasi-circular from irregular pattern and has a preferred direction of rotation

It is expected that detailed analysis of the experimental data with additional sets of experiment will verify the existence of the other regimes predicted from the numerical simulations and also reveal additional regimes beyond Regime VII. Those results will be shown at the conference.

References

[1] T. Sarpkaya: A critical review of the intrinsic nature of vortex-induced vibrations. *J. Fluids Struct.* **19**:389–447, 2004.
[2] C. H. K. Williamson & R. Govardhan: Vortex-induced vibrations. *Ann. Rev. Fluid Mech.* **36**:413–455, 2004
[3] D. Harlemann & W. Shapiro: The dynamics of a submerged moored sphere in oscillatory waves. *Coastal Eng.* **2**:746–765, 1961
[4] H. Shi-Igai & T. Kono: Study on vibration of submerged spheres caused by surface waves. *Coastal Engineering Japan* **12**:29–40, 1969
[5] R. Govardhan & C. H. K. Williamson: Vortex-induced motions of a tethered sphere. *J. Wind Eng. Ind. Aerodyn.* **69-71**:375–385, 1997
[6] C. J. Pregnalato: The Flow-Induced Vibrations of a Tethered Sphere. *PhD Thesis* Monash University, Melbourne, Australia, 2003
[7] C. H. K. Williamson & R. Govardhan: Dynamics and forcing of a tethered sphere in a fluid flow. *J. Fluids Struct.* **11**:293–305, 1997
[8] N. Jauvtis, R. Govardhan & C. H. K. Williamson: Multiple modes of vortex-induced vibrations of a sphere. *J. Fluids Struct.* **15**:555–563, 2001