TP – MASTER 2 TMA

Lagrangian tracking of bubbles: study of different regimes of rising bubbles in a water tank

I. OBJECTIVES

- Learn how to use an imaging system with a high-speed camera.
- Learn how to use python and matlab for image processing.
- Measure the size of bubbles.
- Find the trajectories of bubbles with different sizes.
- Study the different trajectories as a function of different parameters.

II. INTRODUCTION

II.1. Wake instabilities of spheres in a fluid

Whether a sphere vibrates as it rises or falls through a fluid is of interest in a number of practical applications. This phenomenon is known to affect drag as well as heat and mass transfer, which have important implications for sedimentation and other multiphase flows, while the oscillatory motion itself can influence atmospheric measurements using weather balloons. The earliest observation of the vibration of a rising or falling sphere was reported by Newton [1], who studied lead and wax spheres dropped in water, as well as glass spheres and inflated hog bladders falling through air. In the case of the bladders, he observed that they 'did not always fall straight down, but sometimes flew about and oscillated to and fro while falling [2].

In recent years, with the development of DNS (direct numerical simulation) at high Reynolds number and high-speed imaging techniques this problem received renewed attention [1,3]. A big variety of motions have been reported for such a system, that includes different regimes that can vary according to the falling object geometry (figure 1).

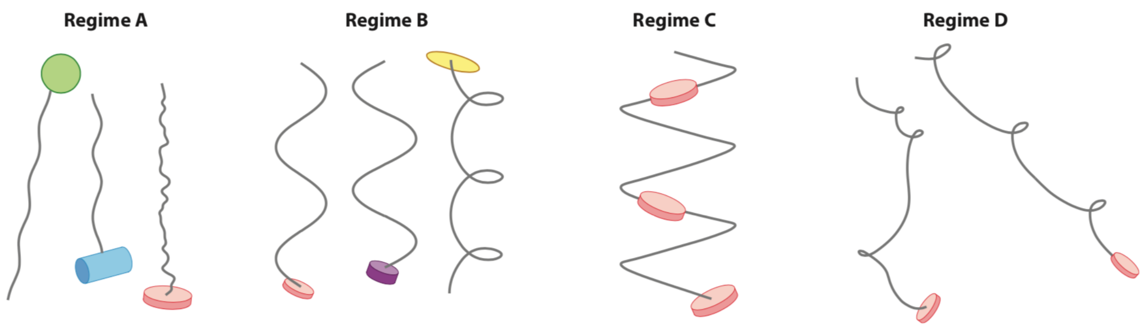

Figure 1: different trajectories for free falling/ascending objects (spheres, disks and cylinders). Image taken from [3].

For the particular case of freely falling/ascending spheres, three different parameters have to be considered:

1. The particle Reynolds number Re_p. It is defined as $Re_p = \frac{U_s \Phi}{\nu}$, with U_s the relative velocity between the fluid and the sphere, Φ its diameter and ν the kinematic viscosity of the carrying flow).

2. The density ratio $\Gamma = \rho_p/\rho_0$, where ρ_p and ρ_0 are the particle and fluid densities respectively

3. The Galileo number, defined as $Ga = \sqrt{\frac{g\Phi^3\rho_0|\rho_p-\rho_0|}{\mu^2}}$, where g is gravity acceleration modulus and μ the dynamic viscosity of fluid.

Dimensional analysis shows that the system is governed by only two parameters. It is therefore possible to work using only two of these parameters. Figure 2 shows the different family of trajectories for rising/falling spheres in the $\{\Gamma, Ga\}$ plane.

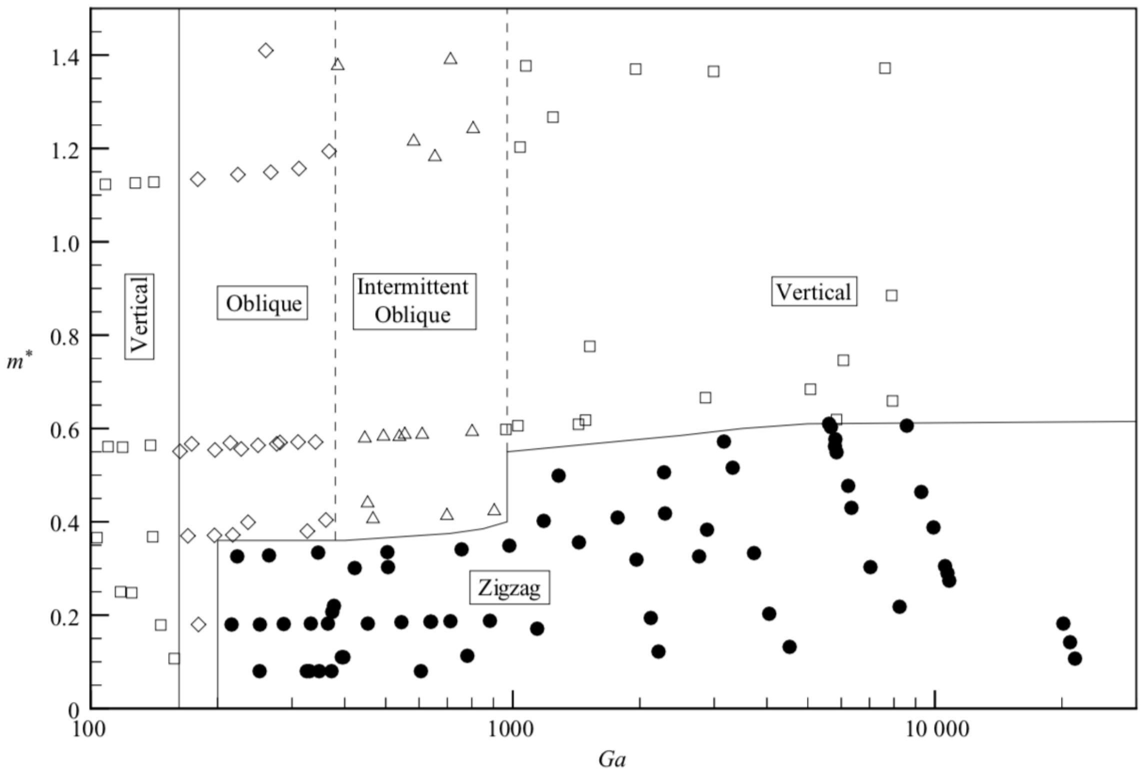

Figure 2: Map of regimes of sphere motion in the $\{\Gamma, Ga\}$ plane. Image taken from [2].

III. EXPERIMENTAL SET-UP

The experiment will be performed in a water tank that is $0.70m$ tal and has a cross section of $25 \times 25\ cm^2$. Bubbles are injected via a needle at the centre of the tank, from where air is injected with controlled pressure and flow rate (figure 3).

An USB high-speed camera from the image source (model DMK33UP1300) is available for recording the bubbles. It allows to record films at a maximum frequency of $175Hz$ with a resolution of $1280 \times 1024\ pixels^2$. As standard light sources have a frequency of $50Hz$, a continuous light source is needed. The camera is connected to a laptop and is controlled with the camera's manufacturer software (**IC Capture 2.4**). Image processing will be performed using matlab.

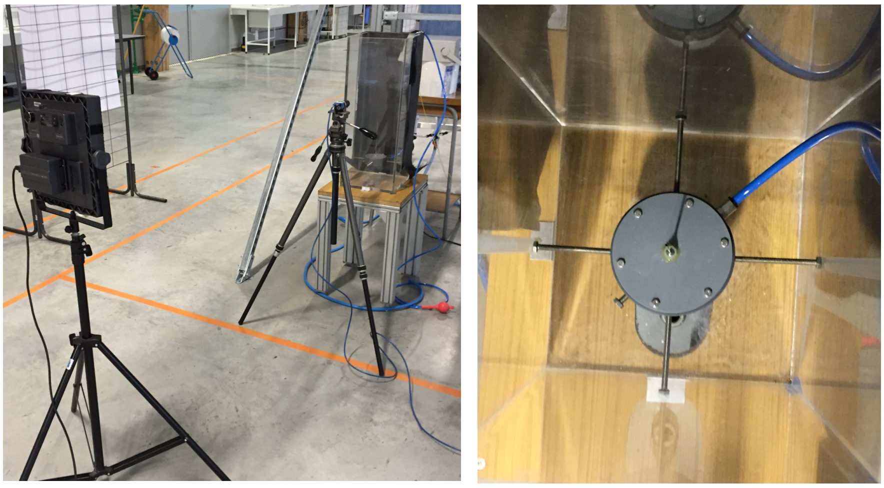

Figure 3: experimental set-up.

IV. MEASURES

III.1. Acquiring and analysing videos.

Use with the injection system in order to generate an isolated bubble in the tank. Once this is achieved, try to generate bubbles of different sizes. Once you manage to do this, you will:

- Record a video that includes the trajectory of a **single bubble**. If the video is longer than this trajectory, it can be then edited with the matlab codes detailed below. To see falling particles, there are also available some **plastic spheres**.
- Use the camera's software, or other software (matlab or ImageJ) to deduce the bubble's size. What would you do to obtain the sizes in mm?
- Use the matlab codes to obtain the trajectory of the particle (Lagrangian tracking).
- Deduce the values of Γ and Ga. Place the trajectory type in the diagram from figure 2.

III.2. Matlab codes

Different mtlab codes will allow to measure the bubble size and its trajectory. The codes available are:

- **TEC21_read.m:** this code reads the avi file and reformats it into a matrix that can be used for image processing in matlab. The matrix will be of size $Res_x \times Res_y \times N_{colours} \times N_{filmes}$, where the parameters are the resolution in x, the resolutions in y, the number of the RGB colours required and the number of films. Furthermore, it allows to crop the image and select a pertinent temporal range.

- **TEC21_black_reference.m:** this code allows to do a black reference. It consists in subtracting an image with no particles so all background details are eliminated from the video.

- **Track_ftpa1B:** this program performs the Lagrangian tracking of the bubble, and returns its trajectory.

V. CALIBRATION

Note that the previous analysis is done using only the raw images from the camera. Therefore, results are in pixel units. To convert them into real world units (such as mm), a calibration mask has to be used. A calibration mask has a known pattern that can be used to relate pixels and real word units. The code calib2DFTPA.m is capable o to find the transformation from $pixels$ to mm, that is represented by a transformation matrix T. Once the matrix is obtained, the vectors with the bubble's centre components can be converted into mm via the code line:

$$[x_{mm}, y_{mm}] = tforminv(T, [x_{pixel}\ y_{pixel}])$$

<u>Note</u>: a simpler calibration can be performed using a ruler on the field of view. Such approach would only work if the camera is not distorting the images. For that, a relation pixel/millimetre is obtained from the ruler's film.

VI. SUBSEQUENT DATA ANALYSIS

For this section, that comprises the work that have to be done later on the data analysis session, it is important to have the following data saved:

- Size and density of plastic particles.

- Matlab matrix with a snapshot of the bubble (to measure the size).

- The vectors with the trajectory of all particles (bubbles and solid spheres).

- The plots of velocity vs time for all particles.

The analysis that has to be performed later is:

1. Quantify the size and velocity of the bubbles.

2. Estimate the averaged velocity from all cases studied.

3. Calculate the Ga, Re_p and Γ for all cases.

4. Place the cases studied in the diagram of figure 2.

5. Estimate the amplitude of oscillation. Is there any trend with the non-dimensional parameters involved?

VII. REFERENCES

1. R. Clift, J. R. Grace, M. E. Weber, Bubbles, drops, and particles, Courier Dover Publications, 2005.

2. M. Horowitz, C. Williamson, The effect of Reynolds number on the dynamics and wakes of freely rising and falling spheres, Journal of Fluid Mechanics 651 (2010) 251.

3. P. Ern, F. Risso, D. Fabre, J. Magnaudet, Wake-induced oscillatory paths of bodies freely rising or falling in fluids, Annual Review of Fluid Mechanics 44 (2012) 97–121.