Experimental study of the fast exit of a plate lifting from a water surface

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Introduction

This experimental study aimed at measuring the hydrodynamic force experienced by a circular rigid disc which is lifted from the water surface and moves thereafter upwards at a nearly constant acceleration. The lack of experimental results regarding the water exit problem and the formulation proposed by Korobkin [1] have motivated this experimental investigation. Negative pressures are allowed and gravity, surface tension and viscous effects are neglected during the initial stage of the motion considered here.

We consider the axisymmetric unsteady problem of a rigid body which is initially in contact with the water surface and suddenly starts to move upwards with a constant acceleration much greater than gravity. The liquid is assumed to be ideal, incompressible and initially at rest. The experimental study is motivated by the need to validate experimentally the linearized model of water exit developed by Korobkin [1]. In this model, the hydrodynamic equations and boundary conditions are linearized, which is acceptable during the initial stage. The radius of the wetted area, $c(t)$, which shrinks in time, plays a crucial role. We assume that the speed of these contact points is proportional to the local flow velocity.

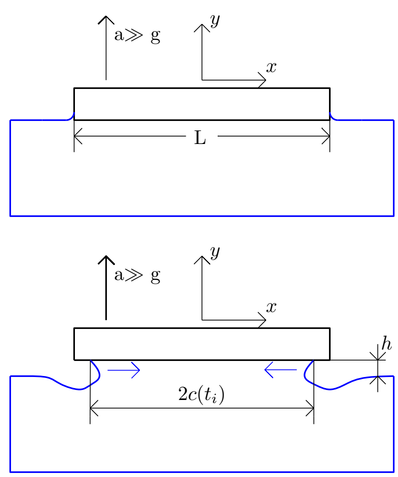


Figure 1: Initial position of the plate on the water surface which is at rest and expected shape of the water surface when the plate starts to move.

The water-exit problem has become significant in the last years [1,2]. Tassin *et al.* conducted experiments regarding the evolution of the contact line during the water exit of flat plates [3]. However, they did not measure forces, which are one of the most important results from the theory from the point of view of the applications.

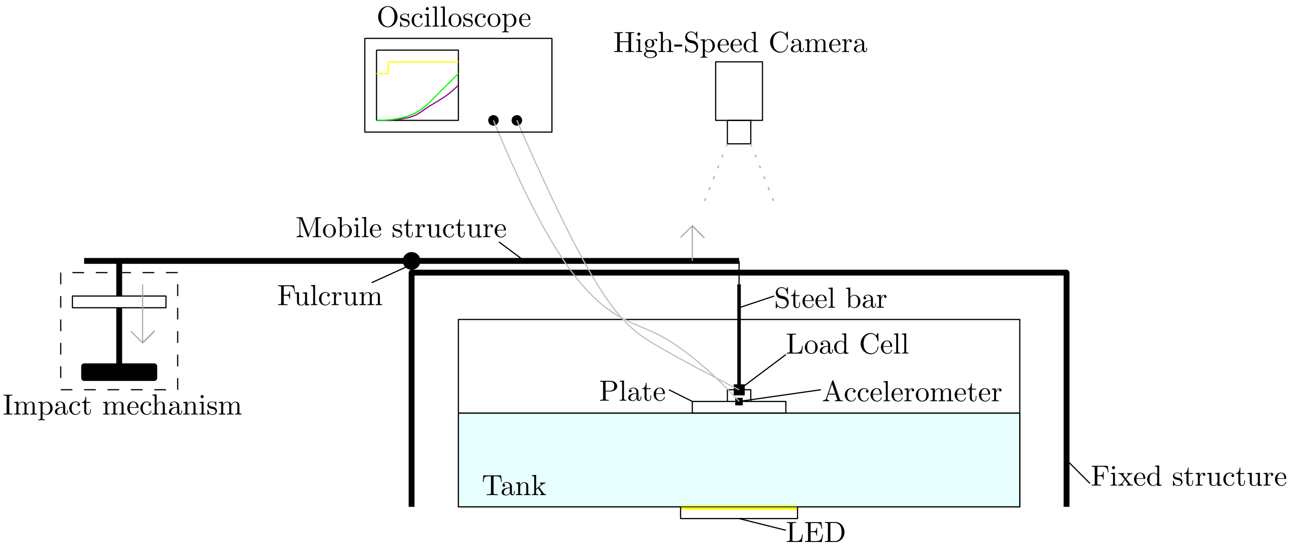


Figure 2: Layout of the experimental setup.

Experimental setup

The experiment consists in lifting a plate from a water surface with a sudden acceleration much greater than gravity, g, in order to measure the hydrodynamic force. The layout of the experimental set-up is shown in figure 2.

The plate is supported and set in motion by a catapult-like structure which has two parts: a fixed frame and a mobile arm (very much like a seesaw) that rotates around a fulcrum. The plate hangs from a steel bar fixed to the tip of the arm. Between the plate and the steel cable there is a load cell (Honeywell Model 31 mid, 100 lb). The other end of the arm contains the impact mechanism, which consists of a weight that slides along a rail and a base that stops the weight fall and thus transmits the impact to the mobile part of the structure.

The radius of the plate is 10.8 cm and the thickness is 1 cm. It is made of acrylic, thus it is transparent and permits us to observe the liquid-solid contact line. Furthermore, an accelerometer (Honeywell model JTF, +-50G) has been placed at its center.

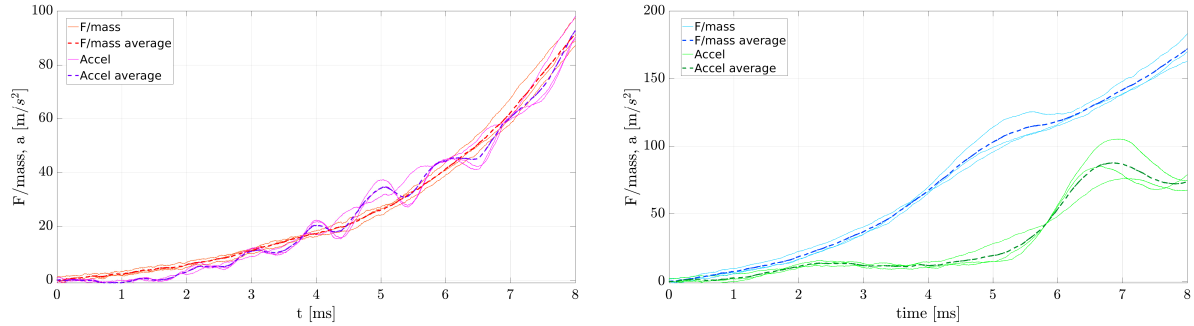
Each experiment implies two realizations, one where the disk is touching the water surface of the tank (wet experiment), and another one, identical in everything, except that the disk does not touch the water surface (dry experiment). The dimensions of the tank, 100 $\times$ 40 $\times$ 40 cm, are much larger than the size of the disk, thus it can be considered as in contact with an infinite water.

At the beginning of the experiment, the weight is released and allowed to fall freely, sliding down the rail, until it impacts the base. When this happens, the mobile arm is set in motion in a time much shorter than any other time scale of the experiment, thus this instant can be regarded as our time origin, $t = 0$.

The motion of the contact line during the exit is recorded by a high-speed camera (MEMRECAM HX-3, working at 15000 fps) and the measurements from the load cell and the accelerometer are acquired with a digital oscilloscope (Tektronik TDS3014c). Before acquisition, their signals have been pre-conditioned by amplifiers (ADAM3016).

Results and Conclusions

The main aim of this study is to measure the hydrodynamic force experimentally in order to validate the predictions by the linear theory in Korobkin [1]. As we said in a previous section, each experiment implies two realizations: dry and wet case. In figure 3, we show a comparison between the acceleration measured by the accelerometer and the force, measured with the load cell, divided by mass of the instrumented plate ($m = 0.630$ kg) felt during the experiment in both cases. In the dry case, the agreement is fairly good despite of the oscillations in the acceleration.



(a) Dry case. (b) Wet case.

Figure 3: Set of the measurements of the acceleration and force in both cases. The dashed line corresponds to the average of the force and acceleration. Notice that the experiment is fairly repeatable.

In the wet case, the hydrodynamic force can be calculated by

$$F_{h,exp} = F + m(a - g) \tag{1}$$

where F is the force measured by the load cell, m is the mass of the plate, a is the acceleration measured by the accelerometer and g is the gravity. Then, the linear theory [1] proposes the following expression:

$$F_{h,theo} = \frac{4}{3}\rho a c^3 \tag{2}$$

where ρ is the density of the water and $c(t)$ is the radius of the contact region of the wetted area of the plate. The evolution of the contact line , $c(t)$, is measured using high-speed imaging. The impact time (t_0) is determined manually in this analysis matching the data of the height obtained from image analysis of the high-speed movies and the integration of the acceleration read by the accelerometer.

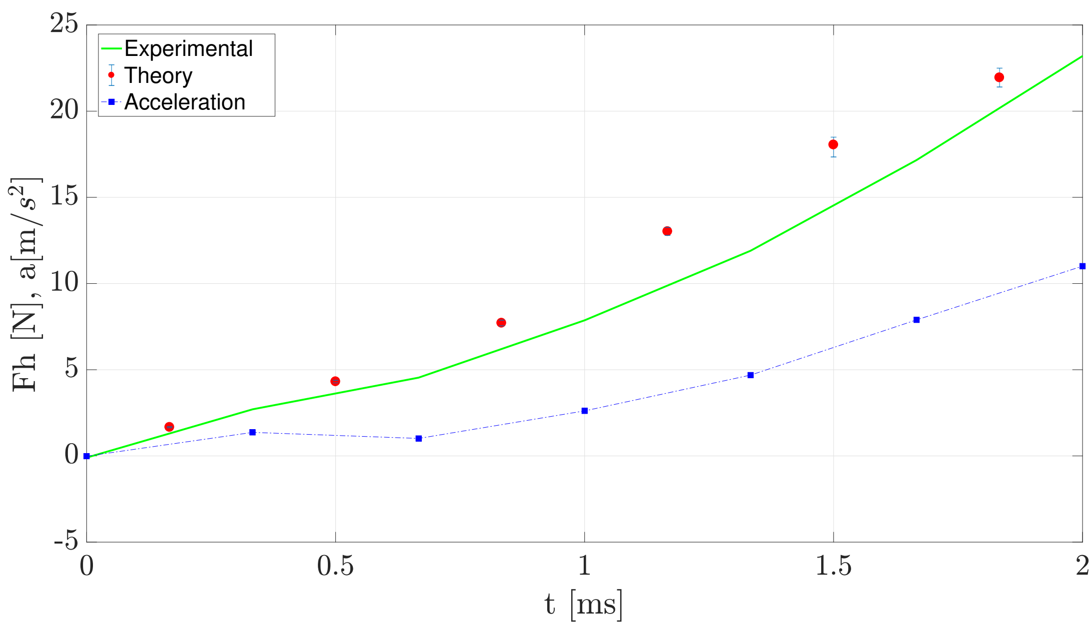


Figure 4: Comparison between theory and experimental hydrodynamic force computed with the average acceleration measured in the wet cases over time.

The theoretical and experimental results follow very similar trends, and are quantitatively close (fig. 4). Thus, the preliminary results of this experimental study suggest that the hydrodynamic force can be estimate according to the linear theory formulated by Korobkin [1]. However, a more quantitative comparison has not been possible due to the fact that the acceleration achieved in the experiment is not constant.

At the moment, some improvements have been made in the experimental setup to avoid the oscillation in the measurements. Thus, we expect to achieve more accurate data in the near future. The next step is to synchronize two high-speed cameras in order to get more quantitative data of the height and the contact line dynamics during the initial stages of the problem.

Acknowledgements

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References

1. Korobkin A. A. (2013). A linearized model of water exit. *Journal of Fluid Mechanics*, **737**, 368-386.

2. Tassin A., Piro D., Korobkin A., Maki K. and Cooker M. (2013) Two-dimensional water entry and exit of a body whose shape varies in time. *Journal of Fluids and Structures*, **40**, 317-336.

3. Tassin A., Breton T., Forest B., Ohana J., Chalony S., Le Roux D., and Tancray A. (2017) Visualization of the contact line during the water exit of flat plates. *Experiments in Fluids*, **58**(8), 104-.