Evolution of the contact line during the water exit of flat plates

Alan Tassin[1]*, Thibaut Breton[1,2], Nicolas Jacques[2]
[1]IFREMER, Marine Structures Laboratory, Z.I. Pointe du Diable, France
[2]ENSTA Bretagne, FRE CNRS 3744, IRDL, 29806 Brest Cedex 09, France
***alan.tassin@ifremer.fr**

1 Introduction

We investigate experimentally and numerically the evolution of the contact line during the water exit of flat plates (circular disc and square plate). The water exit problem, or the lifting of a body initially floating at the water surface, has regained attention and motivated a number of studies in the last years (Korobkin, 2013; Tassin et al., 2013). The evolution of the contact line is a central part of the analytical models proposed by Korobkin (2013) and Tassin et al. (2013), which are based on a linearisation of the boundary conditions on the initial flat free surface ($z = 0$). In Tassin et al. (2013), a modified von Karman (geometrical) condition is used during the exit stage for the water entry and exit of two-dimensional bodies, whereas Korobkin (2013) employed a condition which states that the speed of contraction of the wetted surface is proportional to the speed of the water particles located at the contact point:

$$\dot{c}(t) = \gamma \cdot \varphi_x(x = c(t), z = 0, t), \tag{1}$$

where $c(t)$ is the location of the contact point on the horizontal x-axis, φ is the linearized velocity potential and γ is a factor of proportionality. Korobkin (2013) obtained good results in terms of force prediction with $\gamma = 2$ when comparing with CFD results. Note that this model is suitable both for two-dimensional and axisymetric cases and that it can deal with flat bodies. The choice of the value of $\gamma = 2$ remains however based on comparisons in terms of force prediction but might not give the best results in terms of contact point position. The lack of experimental results motivated the present experimental investigation. Given the importance of the contact point location, we aimed at measuring the wetted surface during the water exit of flat bodies. However, in contrast to previous water-entry experiments during which the wetted surface was obtained from a bottom view of the mock-up, we observed during preliminary experiments that it was difficult to follow the wetted surface from bottom views during water-exit experiments. In order to overcome this limitation, we are developping a new technique based on the use of transparent mock-ups and the diffusion of light in the material. We show that with a single LED light source placed at the centre of a circular disc with a diameter of 20cm, it is possible to illuminate the contact line and to follow the contact line location with a high-speed video camera at 1000fps. In order to validate the measurement technique, we performed experiments with a draughtboard located at the bottom of the tank similarly to Scolan et al. (2006), showing a good agreement between the two techniques. The evolution of the contact line is obtained by a contour tracking algorithm and compared to the model of Korobkin (2013). In parallel, we performed numerical simulations with the ABAQUS CFD software for a circular disc exiting water at infinite Froude number and a constant acceleration. We also present experimental results obtained during the water exit of a square plate with a tangential LED lighting system. These results show the complexity of the shape of the contact line during the water exit of a square plate and demonstrate the performance of the tangential LED lighting system for such a complex case.

2 Experimental set-up

A sketch of the experimental set-up is drawn in Fig. 1. One can see a transparent mock-up made out of PMMA fixed to a rigid frame by high stiffness strings. The rigid frame is lifted by an eletric actuator. A highspeed camera (Photron Fastcam MiniAX50) records the scene from the top via a mirror. The water tank (1 m long, 0.8 m high, 0.6 m wide) was filled up to a level of 40 cm. In the following, we report experiments obtained with a circular disc and a modified square plate. The

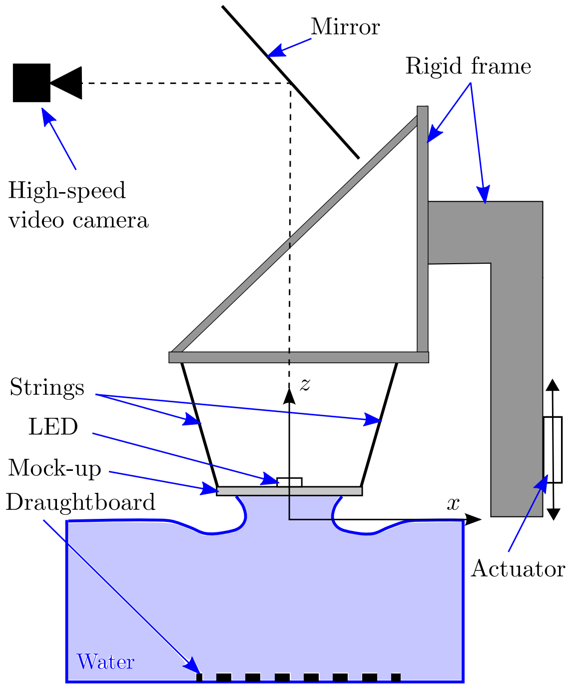


Figure 1: Description of the experimental set-up

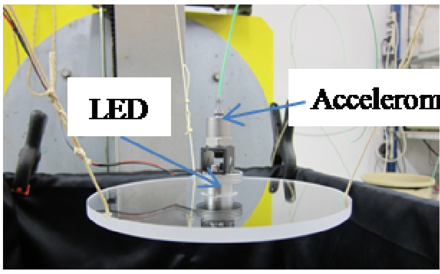


Figure 2: Circular disc

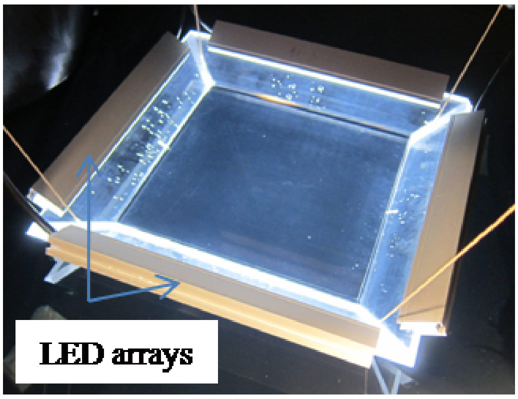


Figure 3: Modified square plate

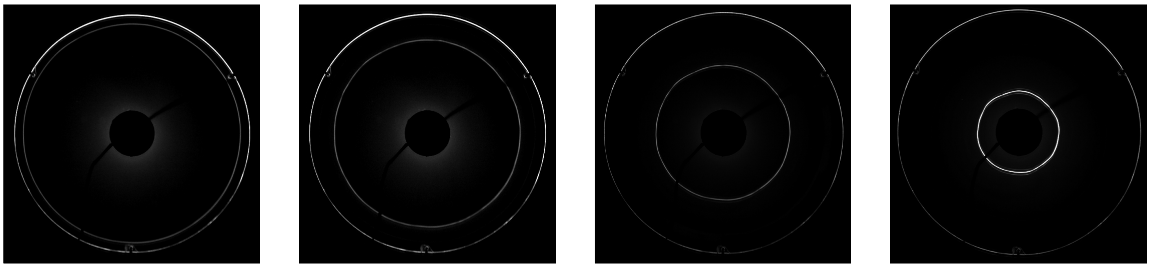
circular disc was cut out of an 8 mm PMMA board. A high-power LED facing downwards is fixed at the centre of the disc (see Fig. 2) and an accelerometer is fixed on top of the LED light. The upper surface of the disc under the LED light was roughened to help the diffusion of light in the material. The modified square plate (Fig. 3), machined in PMMA, is constituted of a 20 cm$\times$ 20 cm square central part of thickness 15 mm and of four inclined sides which have a slope of 30° (with respect to the horizontal plane) and a thickness of 12 mm.

3 Numerical simulations

Numerical simulations were performed using the Eulerian module of the Finite Element software ABAQUS/Explicit. The simulations are based on a non-viscous approach and the Volume-Of-Fluid method. The equations were solved in a moving coordinate system attached to the moving body in order to avoid re-meshing in the calculations (see Tassin et al. (2016)). The effect of gravity was not taken into account in the calculations presented in the present paper.

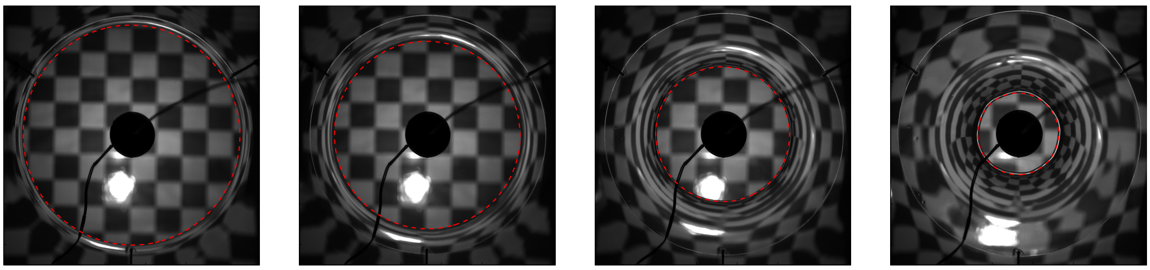
4 Results

A sequence of images obtained during an experiment of water exit with the circular disc is plotted in Fig. 4. One can observe two concentric bright circles, the exterior circle corresponding to the contour of the disc and the interior circle corresponding to the contact line which contracts towards the centre of the disc during the exit. In order to demonstrate that the illuminated contour delimits the surface of contact between the liquid and the disc, we also performed experiments during which a draughtboard was placed at the bottom of the water tank. A sequence of images obtained with the draughtboard technique, and for similar elevations as in Fig. 4, is plotted in Fig. 5. The contour observed in the different pictures of Fig. 4 has been extracted with a contour detection algorithm and superimposed to the images with the draughtboard in Fig. 5. This comparison clearly shows the close connection between the illuminated contour and the contact line. Small discrepancies can nevertheless be observed, probably because of the imperfections of the set-up. We adjusted the altitude of the mock-up such as to minimize the penetration depth before the experiments, but it is difficult to control the initial penetration depth given that the mock-up is held by strings and is not perfectly horizontal. The evolution of the relative radius of the contact surface as function of the elevation is plotted in Fig. 6. In the experiments, the value of $c(t)$ (resp. c_0) is the average value of the semi-axes of the ellipse obtained with the contour detection algorithm when fitting the contact line (resp. the contour of the disc). A record of the acceleration during the water exit of the circular disc is plotted in Fig. 7. The acceleration curve exhibits important oscillations because of the compliance of the strings. The elevation curve plotted in Fig. 7 was obtained by a double time integration of the measured acceleration. Note that these new experimental results are more accurate than those presented in Tassin et al. (2016), thanks to the use of a more appropriate accelorემeter. The results obtained from the numerical simulations and the analytical model of Korobkin (for 2 values of the parameter γ) for the water exit of a circular disc at constant acceleration and infinite Froude number are also plotted in Fig. 6. A sequence of images obtained (at 1000 fps) during the water exit of the modified square plate is plotted in Fig. 8, showing the complexity of the shape of the contact line for an initially square wetted surface. Note the very elongated regions of the contact line along the diagonals of the square in Fig. 8



(a) h(t)=2.8mm (b) h(t)=9.7mm (c) h(t)=30.1mm (d) h(t)=59.3mm

Figure 4: Sequence of images obtained during the water exit of a circular disc for different values of the elevation $h(t)$. (a-b): grey levels multiplied by 3, (c-d): original grey levels



(a) h(t)=2.7mm (b) h(t)=9.5mm (c) h(t)=30.4mm (d) h(t)=59.7mm

Figure 5: Comparison between the contours extracted from Fig. 4 (red dashed line) and images obtained with the draughtboard technique during the water exit of a circular disc

5 Conclusion and discussion

An original technique has been proposed for the measurement of the contact surface during the water exit of flat plates. The central LED technique has been used to measure the evolution of the contact surface during the water exit of a circular disc. Preliminary numerical results for a circular disc exiting water at constant acceleration and without gravity have been presented. New simulations will be run in order to simulate the experimental conditions (including gravity and viscosity). The edge lighting technique is a promising technique for more complex cases. The quality of the resuts obtained for the modified square plate are very satisfactory for image processing. We believe that this technique is likely to be extended to mock-ups of bigger size and to three-dimensional bodies.

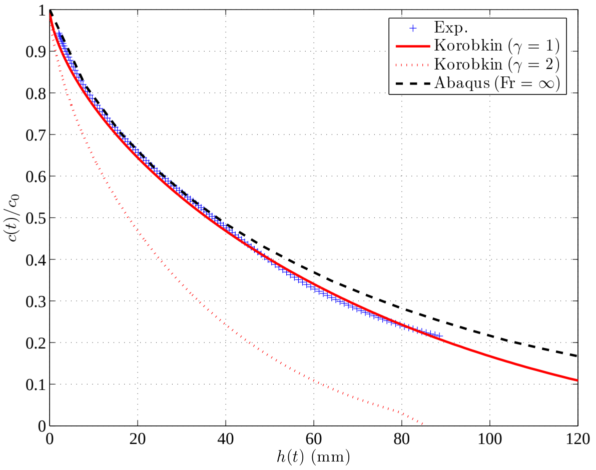


Figure 6: Measured and calculated relative radius of the contact point as a function of the elevation

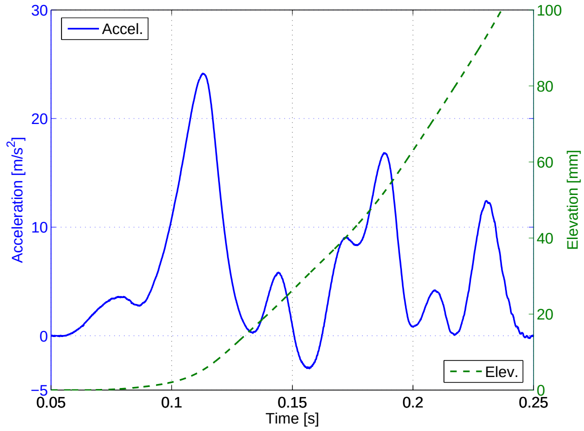
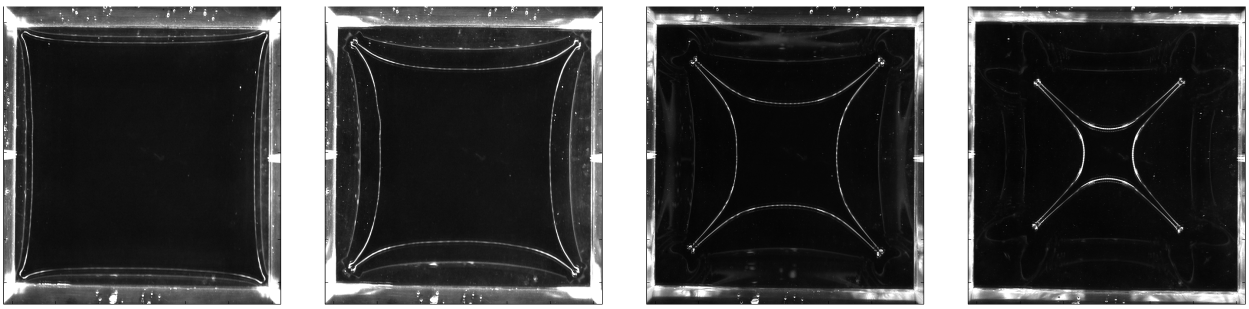


Figure 7: Acceleration and elevation



(a) h(t)=5.7mm (b) h(t)=17.4mm (c) h(t)=45.4mm (d) h(t)=78.9mm

Figure 8: Sequence of images obtained during the water exit of the modified square plate for different values of the elevation $h(t)$

Acknowledgements

We would like to thank Sébastien Chalony for his help in the construction of the circular disc mock-up and Dominique Le Roux for his help in the design of the modified square plate mock-up.

References

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

Scolan, Y., Remy, F., and Thibault, B. (2006). Impact of three-dimensional standing waves on a flat horizontal plate. In 21st *International Workshop on Water Waves and Floating Bodies*, 2-5 April 2006, Loughborough, U.K.

Tassin, A., Jacques, N., Forest, B., Chalony, S., Ohana, J., Le Roux, D., and Tancray, A. (2016). Etude expérimentale et numérique du phénomène de sortie d'eau. In 15ème *Journes de l'Hydrodynamique*, 22-24 Novembre, Brest, France (in french).

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.