13th International Symposium on Particle Image Velocimetry – ISPIV 2019
Munich, Germany, July 22-24, 2019

Modeling iceberg dynamics in a laboratory experiment: PIV analysis of a free floating cylinder in waves

Yiyi Whitchelo[1], Jean Rabault[1], Atle Jensen[1]

[1] University of Oslo
Department of Mathematics, section for Mechanics
Oslo, Norway

Abstract

Experimental studies on the flow field under the circular cylinder are investigated. The buoyant circular cylinder is placed at the center of a wave tank and around 4 meters away from the wave maker. A set of monochromatic waves is generated by the wave maker to model one mode of the ocean waves. This causes the circular cylinder to oscillate up and down and to travel in the direction of wave propagation. A PIV analysis is performed in the flow region directly under the cylinder.

1 Introduction

In recent years, the behavior of icebergs in the polar regions, and especially in the Arctic, has been the focus of increased research interest (Marchenko, 1999; Eik et al., 2009; Andersson et al., 2016). A detailed understanding of the interaction between icebergs and ocean waves can be helpful to design better models that will help predict icebergs drift. This is important to help better describe the Arctic environment and to allow safer human activities in this region. However, the models developed so far have only taken into account inviscid dynamics and ignored the effect of viscosity and eddy structures on the motion of icebergs. The effects of viscosity could limit the heave response of the floating geometry, it can also create drag and reduces the drift motion. The eddy structures in a fluid can introduce mixing, which is an important aspect highly stratified oceans. In the present work, we present direct measurements of the full velocity field under a floating cylinder in waves in a reduced scale laboratory experiment, in order to help investigate the effect of such dynamics.

For this, we have modeled icebergs using a circular cylinder. The buoyant circular cylinder is placed at the center of a wave tank and around 4 meters away from the wave maker. A set of monochromatic waves is generated by the wave maker to model one mode of the ocean waves. This causes the circular cylinder to oscillate up and down and to travel in the direction of wave propagation. A PIV analysis is performed in the flow region directly under the cylinder, using a methodology similar to Rabault et al. (2016, 2018). The interaction between the incoming waves and the circular cylinder produces eddy structures that are particularly visible at the edge of the cylinder base. Similarly to what has been observed under a grease ice cover (Rabault et al., 2018), this could be an important mechanism for energy dissipation and water mixing.

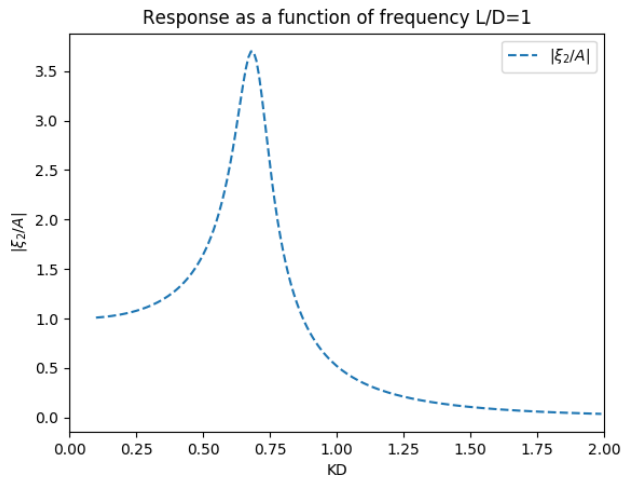


Figure 1: The response as a function of frequency for equal length and height

2 Methods

2.1 The experimental setup

The experiments were carried out in a wave tank in the Hydrodynamics Laboratory at the University of Oslo. The dimensions of the tank are 25 m in length, 0.5 m in width and 1 m in height. The tank was filled with fresh water of depth around 0.7 m which was kept constant throughout the experiments. The wavemaker was positioned at one end of the tank and an artificial beach was placed at the other end to dampen the incoming waves. The beach was found to reduce the amplitude of the reflected waves to less than 3% for waves of 1.5 Hz. The wavemaker is of the piston type, and the waves are therefore generated by moving a vertical plate driven through a computer controlled hydraulic piston. An ultrasonic gauge was used to measure the amplitude of the generated waves. An illustrative example of the data for all experiments collected by the gauge is shown in Figure 3.

In potential theory, the response amplitude of the heave motion of an equal length and height cylinder in 2D can be calculated using discretisation method(see Figure 1). From Figure 1 the response amplitude is maximum at around 0.68, this is also the eigenfrequency of the geometry. Ideally, if the incoming wave is set to have a frequency equal to the geometry's eigenfrequency, it is expected that the floating geometry will experience a drastic heave response compared to all the other incoming wave frequencies. The downside to this estimation is that it is only a 2D estimation and the 3D estimation will likely to deviated from this value. For the present experiments, we have generated only linear monochromatic waves of 1 Hz. The setup for the experiments is shown in Figure 2.

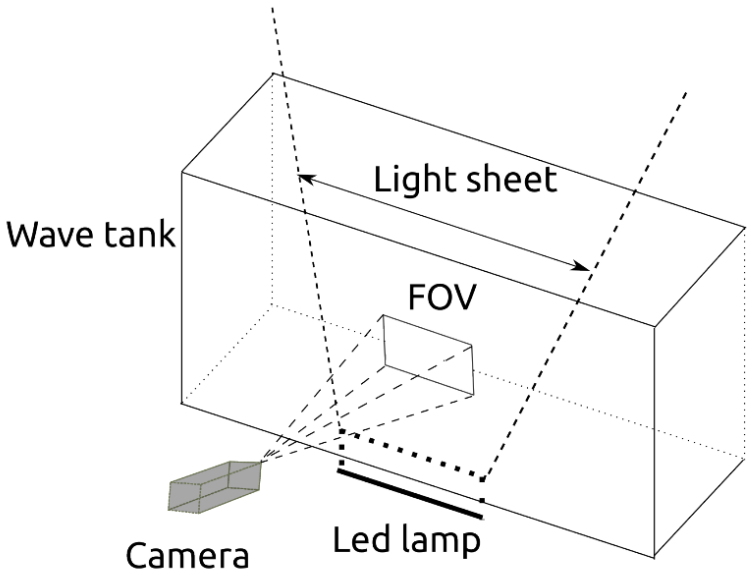


Figure 2: Experimental setup, figure reproduced from (Rabault et al., 2016).

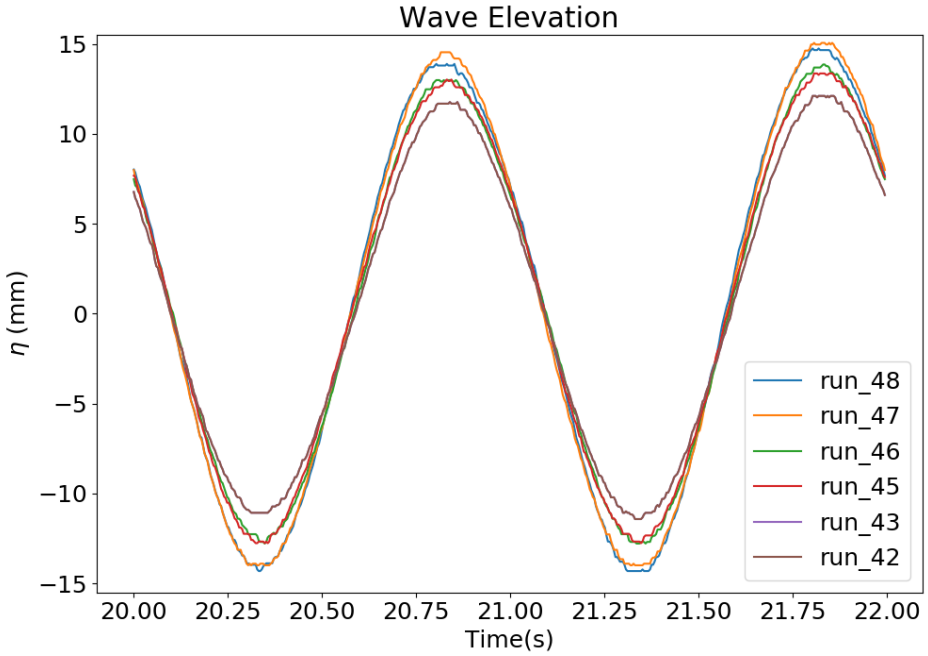


Figure 3: Illustration of the water wave elevation used for the incoming wave field in one experiment run. The wave frequency is 1Hz. The measurements are performed using an ultrasonic gauge measuring wave elevation at a frequency of 250Hz. Monochromatic waves corresponding to a single mode are used in all experiments.

2.2 The floating objects

To imitate the characteristics of an iceberg, the material of the circular cylinder was chosen so that it is naturally buoyant in water. The dimensions of the cylinders were chosen so their height is the same or greater as the diameter of the top section. Initially, we discovered that due to the height of the cylinder, the center of mass was above the buoyancy center, and therefore, this would make the cylinder tilt and float sideways. To prevent this, some modifications were done; a circular lead plate was added to the base of the cylinder and a small section on the top were drilled out and covered with tape. After the modifications, the center of mass was shifted down and the cylinder was able to float upright with 10% of the height above the water. The base of the floating cylinders was painted with a non-reflective black paint to avoid light reflection during the experimental runs. For all the experiments conducted in this study, two circular cylinders of different size were used and their dimensions are shown in Table 1.

Table 1: Dimensions of the circular cylinder

Shape	Height(mm)	Diameter(mm)	Weight(g)
1	131.1	88.5	723
2	88.3	87.1	493

2.3 Measurement techniques

During all PIV measurements, a vertical section in the mid-plane of the tank was illuminated. This was achieved by placing a LED light sheet below the transparent base of the tank. We have chosen a red LED light sheet over the traditional white LEDs as, given the hardware available in our laboratory, the light intensity is stronger for the red LED over a short distance. The LED light sheet had a thickness of approximately 1 cm and it illuminated a section of the tank around 1m long. The side of the tank on the opposite side to the cameras was covered with black (non-reflective) paper so the background of the lab would not interfere with the visualisation of the wave motion in the tank.

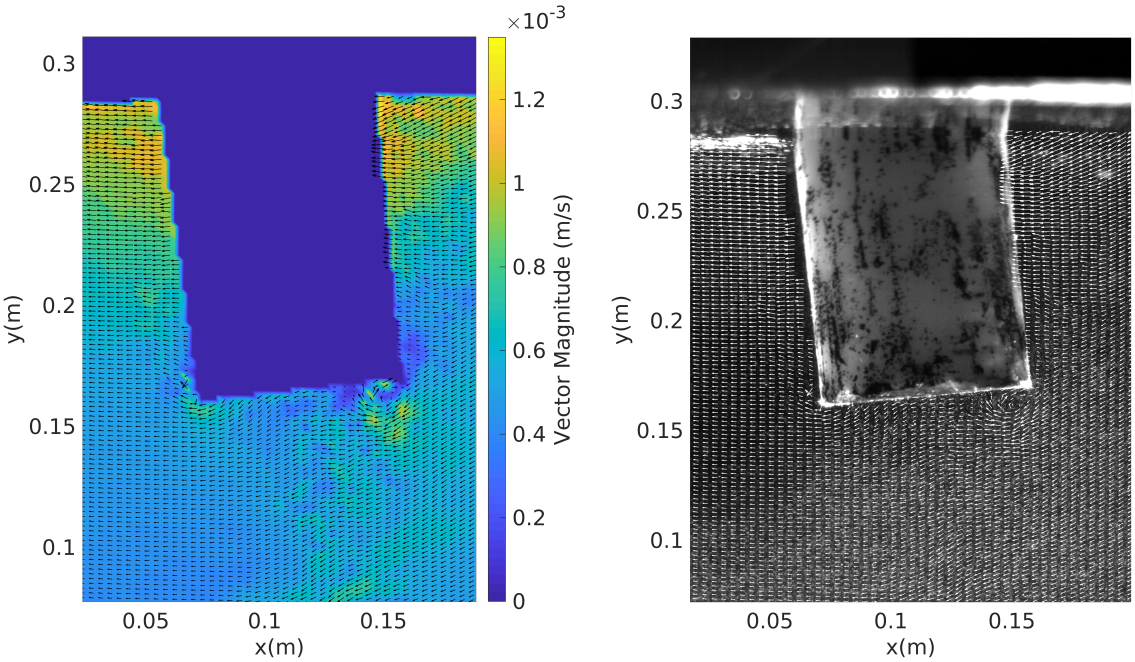
We have used ”Polyamide”, neutrally buoyant light-reflecting tracer particles with diameter 50 μm to seed the illuminated area. Motion within the illuminated area was recorded by a Falcon 2 4M camera at a fixed position relative to the tank. The Falcon 2 4M camera was used at a resolution of 1728 x 2400 pixels and a frame rate of 80 frames per second. The flow dynamics around the floating object in the illuminated section of the tank is then processed using the software package DigiFlow (Dalziel, 2006). To process the images, we need to specify the coordinates of the camera's field of view. To set the coordinates, a plastic grid marked with a predetermined referential frame was then placed in the tank and in view Following PIV processing and calibration, the images are processed to mask the area of the cylinder and above the free water surface. For the PIV analysis the interrogation window size was 28 pixels with 50% overlap and the search range is set to 12 pixels with 3 multipass.

An additional camera was used to capture the mean drift velocity of the floating cylinder. This second camera was used at a resolution of 1280 x 1024 pixels and a frame rate of 25 frames per second. The videos captured by this camera were used to estimate the drift speed of the cylinder. An image of a ruler captured by the second camera was used to give the distance the cylinder traveled. This image was first cropped and then mounted to the videos. We are able to estimate the drift speed by distance traveled divided by time. The estimated drift speed for each run are shown in Table 2.

3 Results

From the PIV analysis, we are able to visualise the velocity fields around the floating cylinder. The camera captures the cylinder motion in sway, heave and roll mode(2D motion). As the wave approaches the cylinder from the right, it starts to roll and heave then sway to the left. We have found that the occurrence of the eddies depends on the upwards heave motion of the cylinder and at the position of the maximum amplitude of the incoming wave. For all the experimental runs for shape 1, the effect of eddies have been observed at the lower left of the cylinder, this is illustrated in Figure 5. However, no eddies have been observed for shape 2. This is perhaps due to the value of the eigenfrequency for shape 1 is close to the wave frequency and therefore produces a larger heave response compared to shape 2. The drift velocities for each run are shown in Table 2. From the table, it is inconclusive in whether the effects of eddies slows down the cylinder. Therefore, the method of obtaining drift speed needs to be improved and more experimental run needs to be done.

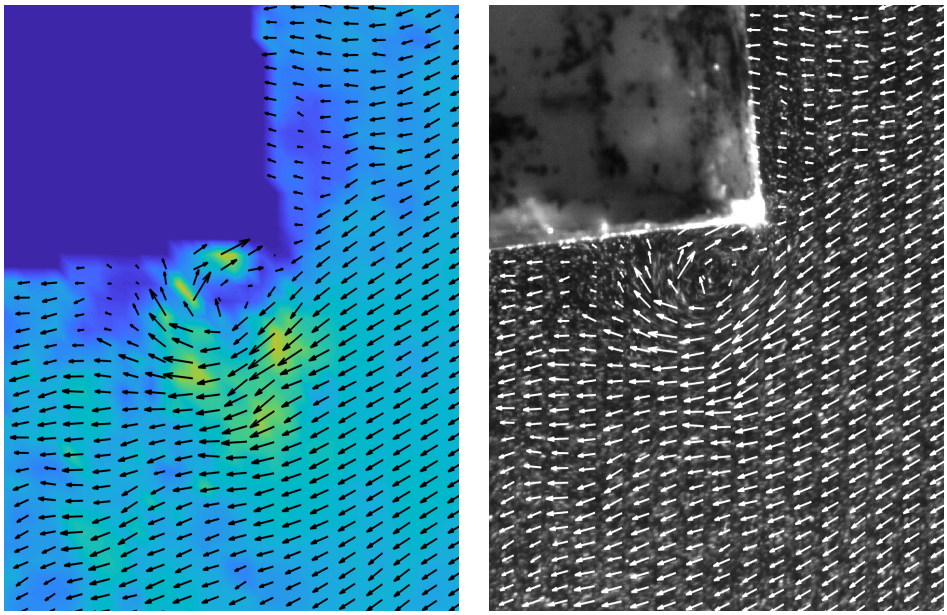
One of the difficulties of the post-processing of the images was the masking for the PIV measurements. Generally, image masking was done automatically on a computer, however, in our case due to the texture of the cylinder the script would fail to mask the images. All the images used for PIV in this set of experiments were masked by hand. One way of improving this is to paint the cylinder a bright colour and using a third camera to track the position of the coloured block relative to the PIV camera. Once the coordinated of the block is known the masking process becomes easier for the computer to handle.



(a) Velocity field over vector magnitude

(b) Velocity plot over lab image

Figure 4: PIV analysis of experimental run 43. Eddy effects are apparent at the edge of the cylinder base.



(a) Velocity field over vector magnitude (b) Velocity plot over lab image

Figure 5: PIV analysis of experimental run 43 zoomed in.

Table 2: Experimental runs

Run	Shape	Drift speed(m/s)	Frequency(Hz)	Amplitude(m)	Wavenumber
42	2	0.01875	1	0.01123	4.0161
43	1	0.01400	1	0.01127	4.0167
44	1	0.02100	1	0.01257	4.0141
45	1	0.02238	1	0.01257	4.0141
46	2	0.02409	1	0.01257	4.0141
47	2	0.02625	1	0.01305	4.0133
48	1	0.02767	1	0.01337	4.0128

4 Conclusion

Out of the two shapes of the geometry chosen for this set of experiments, the eddy structure is only apparent in shape 1. This is perhaps because the eigenfrequency of shape 1 is closer to the generated wave frequency compared to shape 2. Although the results of the drift speed are inconclusive in the effects of the eddy structure. It is undeniable that when investigating the motion of a floating geometry the effect of viscosity should not be neglected. For future work, more results need to be obtained from experiments and these results need to be compared with simulation obtained from CFD.

References

Andersson LE, Scibilia F, and Imsland L (2016) An estimation-forecast set-up for iceberg drift prediction. *Cold Regions Science and Technology* 131:88–107

Dalziel SB (2006) Digiflow user guide. *DL Research Partners, Version* 1

Eik K, Marchenko A, and Løset S (2009) Wave drift force on icebergs–tank model tests. in *Proceedings of the International Conference on Port and Ocean Engineering Under Arctic Conditions*. POAC09-86

Marchenko A (1999) The floating behaviour of a small body acted upon by a surface wave. *Journal of Applied Mathematics and Mechanics* 63:471–478

Rabault J, Halsne T, Sutherland G, and Jensen A (2016) PTV investigation of the mean drift currents under water waves. in *Proceedings of the 18th Int. Lisb. Symp.*

Rabault J, Sutherland G, Jensen A, Christensen KH, and Marchenko A (2018) Experiments on wave propagation in grease ice: combined wave gauges and piv measurements. *arXiv preprint arXiv:180901476*