System for flow visualization in swimming

van Houwelingen, J.; Van De Water, Willem; Kunnen, R.P.J.; van Heijst, GJF; Clerx, H.J.H.

DOI
10.1016/j.proeng.2016.06.286

Publication date
2016

Document Version
Final published version

Published in
Proceedings of The Engineering of SPORT 11

Citation (APA)
van Houwelingen, J., Van De Water, W., Kunnen, R. P. J., van Heijst, GJF., & Clerx, H. J. H. (2016). System for flow visualization in swimming. In A. J. Jansen (Ed.), *Proceedings of The Engineering of SPORT 11: 11th Conference of the International Sports Engineering Association, ISEA 2016* (pp. 288-292). (Procedia Engineering; Vol. 147). Elsevier. https://doi.org/10.1016/j.proeng.2016.06.286

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 147 (2016) 288 – 292

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

System for flow visualization in swimming

Josje van Houwelingen[a], Willem van de Water[a,b], Rudie P.J. Kunnen[a], GertJan F. van Heijst[a], Herman J.H. Clercx[a]

[a]*Eindhoven University of Technology, Dept. of Physics, Fluid Dynamics Laboratory, P.O. Box 513, 5600 MB Eindhoven, The Netherlands*
[b]*Delft University of Technology, Dept. 3ME, P.O. Box 5, 2600 AA Delft, The Netherlands*

Abstract

Understanding the power balance of a swimmer, who needs to overcome power losses to drag and to water set in motion, requires detailed insight into the hydrodynamics of the flow around the swimmer. This will be done from a hydrodynamic point of view with techniques familiar from fluid mechanics. One of our objectives is to develop a system to visualize the flow around a swimmer in practice. Currently, the visualisation system is designed and built and we will present the underlying ideas of the experimental setup.

Keywords: swimming, hydrodynamics, flow visualization

---

1. Introduction

The goal of a swimmer is to swim the race distance in the shortest amount of time, thus to swim as fast as possible. To achieve this the swimmer has to convert his mechanical power into forward motion by pushing-off against the water. The power balance of a swimmer can be written as $P_s = P_d + P_p$, where P_s is the mechanical power produced by the swimmer, P_d is the power loss to drag (related to the speed of the swimmer), and P_p is the power loss related to the push-off against the water. Compared to terrestrial sports the aquatic sports (swimming, rowing, etc.) are unique. While in most sports a term like P_p can be neglected, this term is relevant in the description of swimming, [1,2]. With the push-off water is set in motion. It is not possible to swim without setting the water in motion. Kinetic energy will always be transferred towards the ambient water. Of course, a technique exists whereby this term is minimized. That does not mean that all generated flow motions, such as vortices, produced by a swimmer are a waste of energy. Vortices are of importance in gaining propulsion. That flow visualization helps in understanding the principles behind propulsion has been shown by studies like reported by Takagi et al. [3]. In this study the propulsion of two front

---

[*] Josje van Houwelingen. Tel.: +31-(0)40-247-3241
E-mail address: j.v.houwelingen@tue.nl

doi:10.1016/j.proeng.2016.06.286

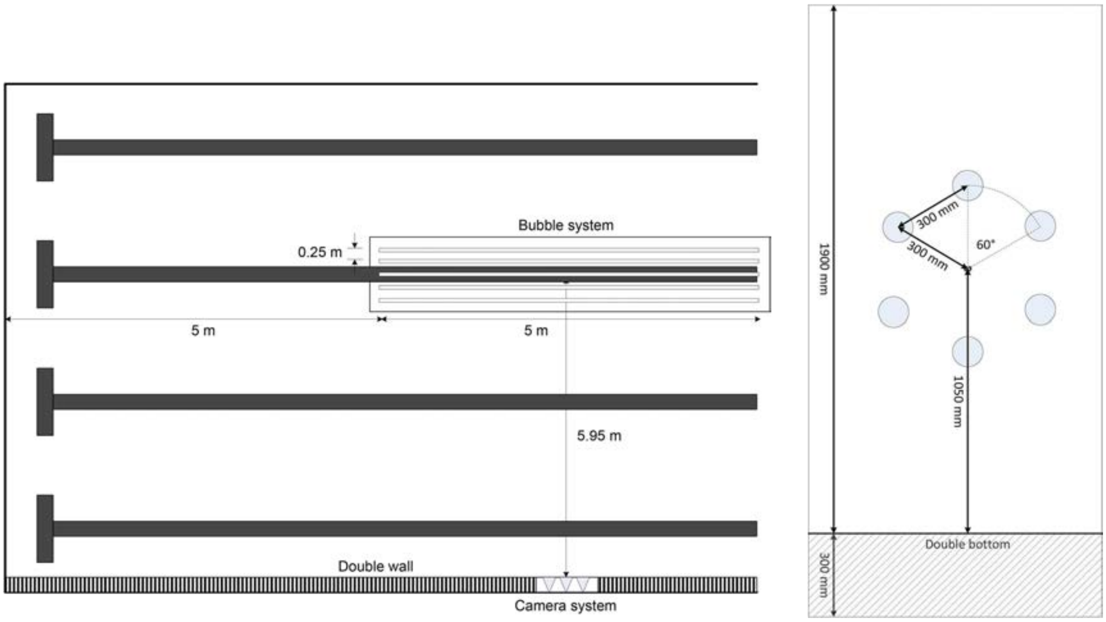


Fig. 1: (a) Schematic plan view of the bubble system placed in the swimming pool. (b) Schematic side view of the camera system.

crawl techniques was investigated by flow visualization using PIV (Particle Image Velocimetry). This study is very illustrative about how lift- and drag-based propulsion arises during the arm stroke, understood from the water motion.

One of the goals of the present study is to develop a system to visualize the flow (i.e. vortices) around the swimmer. The system is inspired by experimental techniques applied in the fluid dynamics community like PIV. For operation use, the system was placed in a regular swimming pool, which entailed a number of challenges.

2. Experimental setup

2.1. Bubble system

Since the visualization system is placed in a regular swimming pool, neither the use of tracer particles is allowed nor the use of lasers to illuminate the tracer particles. Therefore, as alternative small air bubbles have been chosen as tracers. They are not harmful for the swimmer and the swimming pool, disappear from the pool by themselves and they can be produced continuously and in sufficient amount. The air bubbles, with a diameter of approximately 4 mm, are produced by a 'bubble system', consisting of a set of five parallel tubes of 5 m length with a series of small holes at separation distances of 2 cm along its length. The tubes are placed 25 cm apart. Locally, the double bottom in the swimming pool has been adjusted, allowing the bubble system to be implemented inside the bottom of the swimming pool. In this way the experimental setup can meet the safety requirements of the swimming pool. With a pump and a flow meter for each tube the flow can be set for the appropriate amount of bubbles needed in the measurement volume. Figure 1 shows a schematic view of the bubble system.

2.2. Camera system

Another challenge is related with the camera system. Most components have to be resistant to (chlorine) water. Furthermore, a large field of view is necessary to study the flow around the whole swimmer. The cables define the bandwidth of data transfer and thus the particular choice of cameras that can be used. Finally, the chosen camera system consists of six 2 mega pixel cameras with a frame rate of 50 fps. All cameras have a 16 mm lens and are placed

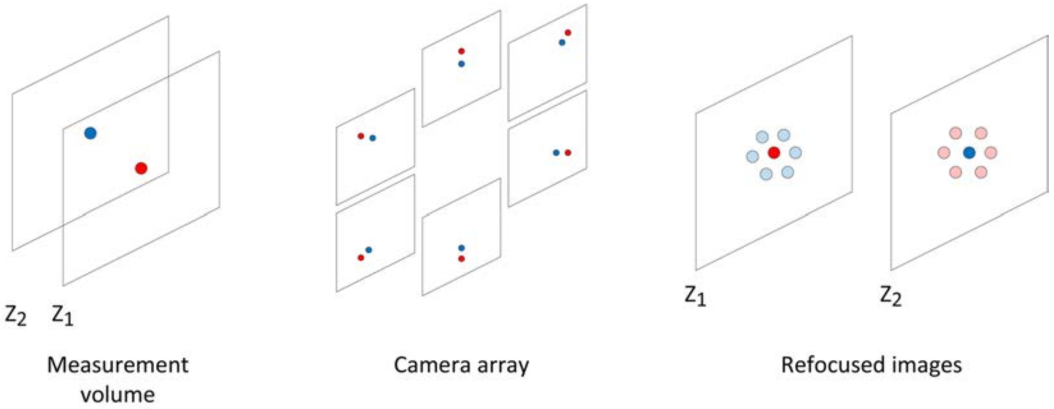


Fig. 2: The principle of the SA method. Left: Measurement volume with two planes of interest (Z_1 and Z_2). Middle: Images captured by the camera array. The red and blue points are shifted on every camera. Right: Images are shifted to align on a plane of interest to refocus. The schematic view is based on a figure by Belden et al. (2010) [4].

in under-water casings. The cameras are placed in a hexagon frame with a 30 cm spacing, which is implemented in a special double side wall in the swimming pool. A schematic side view of the camera system is provided in figure 1.

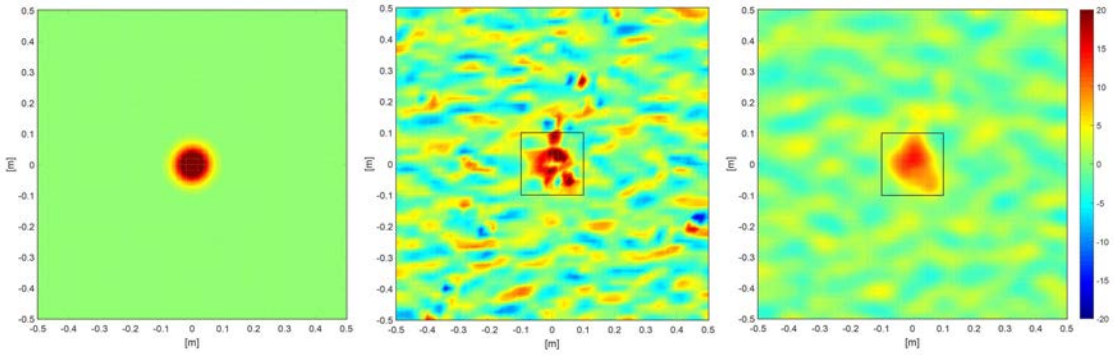
3. Visualization

3.1. Synthetic Aperture refocusing method

Six cameras are used to apply the so-called Synthetic Aperture refocusing method (SA method) [4]. Figure 2 shows the principle of this method. In the post-processing of the images, this method can be used to refocus on certain planes (determined by the tube positions releasing the bubbles) in the measurement volume. Because cameras with different locations view the same measurement volume, the bubbles from different planes in the measurement volume are displaced compared to each other on the images. With a calibration the shift per plane can be determined. By putting the images on top of each other and “shifting them back”, the bubbles of one plane coincide. Therefore, the intensity of the bubbles in a certain plane becomes much stronger compared to all other bubbles in the measurement volume. This result can be filtered and data from one plane of the volume is retained. The quality of this algorithm depends on the exposure of the measurement volume. The exposure must be homogeneous across the entire volume, to obtain a clear plane of interest when putting the images on top of each other. The quality of the algorithm increases when more cameras are used (there is an optimum [4]), because a larger intensity difference between the plane of interest and the rest of the measurement volume can be obtained.

3.2. Bubbles

The use of bubbles as tracer particles is not ideal, since bubbles have their own dynamics. Besides reacting strongly to an external flow field, bubbles also have interactions with each other. Even single bubbles show a spiralling or zigzagging motion when rising to the water surface. The velocity field generated by the swimmer should be distilled from the velocity field of the bubbles. To examine to what extent this is possible, simulations are performed on a (two-dimensional) bubble swarm rising through the velocity field of a prescribed vortex structure (figure 3a). A point-particle approach with modelled forces [5] is used to simulate the bubble motion. The physics behind the interactions and zigzagging of the bubbles is not taken into account directly in these simulations, but a zigzagging motion has been applied during the simulations as a proxy of the distortion of the bubble trajectory. This is sufficient for our purpose, since the bubble dynamics itself is not the subject of study. From the results of the simulations artificial images are created on which PIV is performed. The raw PIV results (mean vertical velocity is subtracted) display disturbances



(a) theoretical

(b) PIV data with distortion, $A_{zz} = 0.0065$m

(c) filtered PIV data, $R_{filt} = 0.038$m

Fig. 3: PIV analysis of artificially generated images of 2D bubble swarms rising in the prescribed velocity field of a Lamb vortex (radius R_{vor} = 0.05 m, circulation $\Gamma_{vor} = 0.28$ m^2/s). In this case the bubbles zigzag with an amplitude $A_{zz} = 0.0065$ m. (a) Prescribed vorticity distribution. (b) Vorticity field as reconstructed from the raw PIV results with clear distortions due to the bubble zigzagging. (c) Filtered vorticity field. A spatial circular top-hat filter with a radius $R_{filt} = 0.038$ m is applied. The black square indicated the integration area for vorticity ($4R_{vor} \times 4R_{vor}$), to be used in figure 4.

due to the zigzag motion of the bubbles (figure 3b). Therefore, filtering algorithms to remove the distortion have been examined.

Filtering the results clearly enhances the reproduction of this vortex from PIV. Figure 4 shows the integrated absolute vorticity as a function of distortion amplitude and filter size. The inaccuracy of the data increases with increased distortion. The filtering reduces the effect of spurious vorticity generated by the bubble zigzagging. However, there is an optimal filter size (in this case $R_{filt} \approx 0.038$ m). Above this filter size the entire vortex is reduced in strength by the filtering. In conclusion, based on these tests with artificial bubble images we are confident that we can use bubbles for reliable velocity and vorticity reconstruction of the flow field around a swimmer.

4. How to continue?

The setup has been built at Innosportlab De Tongelreep (Eindhoven, The Netherlands) and recordings of the swimmer and the bubbles can be made. Experiments with PIV analysis of a cylinder wake flow are in preparation to validate the procedure and to assess the quality of the images. The filtering methods will be optimized taking the length and time scales of the flow into consideration. Additionally, we will explore complementary solutions to explicitly visualize the vortices generated by the swimmer. Possibly, vortices may be recognized by the tendency of bubbles to concentrate in the vortex cores. In the end, visualization of the vortices can contribute in the understanding of (unsteady) force generation and the kinetic energy given to the water during the push-off.

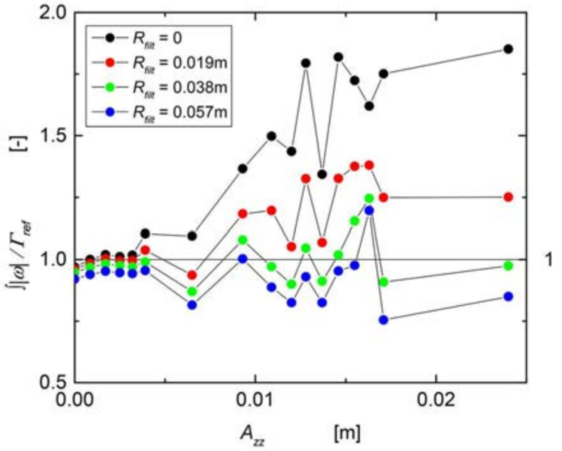


Fig. 4: Integrated absolute vorticity as a function of the amplitude of distortion A_{zz} and filter radius R_{filt}. The integrated vorticity is non-dimensionalized with a reference circulation $\Gamma(R_\infty)$, which should yield 1 when matching the theoretical circulation.

Acknowledgements

This project is supported by the Dutch Technology Foundation STW (project # 12868). We would like to thank the partners and collaborating universities of this project: the Dutch swimming federation (KNZB), Innosportlab De Tongelreep, TU Eindhoven (TU/e), VU Amsterdam and TU Delft for making this project possible.

References

[1] G.J. Ingen Schenau, P.R. Cavanagh, Power equations in endurance sports, J. Biomech. 26 (1990) 865–881.
[2] H.M. Toussaint, P.J. Beek, Biomechanics of competitive front crawl swimming, Sports Med. 13 (1992) 8–24.
[3] H. Takagi, M. Nakashima, T. Ozaki, K. Matsuuchi, Unsteady hydrodynamic forces acting on a robotic arm and its flow field: application to the crawl stroke, J. Biomech. 47 (2014) 1401–1408.
[4] J. Belden, T.T. Truscott, M.C. Axiak, A.H. Techet, Three-dimensional synthetic aperture particle image velocimetry, Meas. Sci. Technol. 21 (2010) 125403–125421.
[5] E.A. van Nierop, S. Luther, J.J. Bluemink, J. Magnaudet, A. Prosperetti, D. Lohse, Drag and lift forces on bubbles in rotating flows, J. Fluid. Mech. 571 (2007) 439–454.