



HAL
open science

Vortices and mechanics around the swimmer

R Guignabel, A Eon, A Decatoire, T Monnet, L David, M Samson

► **To cite this version:**

R Guignabel, A Eon, A Decatoire, T Monnet, L David, et al.. Vortices and mechanics around the swimmer. Second direct in-person colloquium on vortex dominated flows (Discover), Delft University of Technology, May 2023, Breckenridge, Colorado, United States. <hal-05033212>

HAL Id: hal-05033212

<https://hal.science/hal-05033212v1>

Submitted on 14 Apr 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Vortices and mechanics around the swimmer

R. Guignabel*, A. Eon, A. Decatoire, T. Monnet, L. David and M. Samson

Pprime institute, CNRS – University of Poitiers – ENSMA, UPR 3346, Futuroscope Cedex, France¹

*Correspondence: raphael.guignabel01@univ-poitiers.fr

1 Introduction

Performance in competitive swimming relies in part on the propulsive force that swimmers can generate. This force is mainly provided by arm movements [1]. Pioneering work in the evaluation of swimmer-generated forces is based on a quasi-static approach. The underlying assumption of this approach is that the kinematic parameters of the flow (in particular velocity and angle of attack) do not vary over time. However, it has now been demonstrated that the flow is unsteady [2–4]. It is therefore necessary to assess the flow from unsteady modelling. In recent years, devices and knowledge have been developed in ways that make such studies feasible. Our experimental and numerical studies carried out at the Prime Institute fall within this framework. The emphasis is on measurements of the propulsive force of the swimmers' upper limbs. Our methodology deals with flow measurements, which have been carried out with PIV methods and compared to CFD calculations. Nonetheless, experimental measurements of force and kinematics of the arm enables us to strengthen our understanding. The main unsteady mechanisms studied are the spatio-temporal analyses of vortex structures, but also the Kramer, axial flow, added mass or delayed stall effects [5]. Previous very promising studies have been carried out using a robotic arm to understand some of the propulsion mechanisms in swimming based on unsteady fluid studies [6]. We have also developed a robotic swimming arm device. This allows the kinematic parameters of the swimming motion to be varied such as the angle of attack or the velocity of the hand. A study using this device was carried out to investigate the relationship between propulsive force and swimming frequency [7]. Acceleration has been deemed important in the force generation process [3]. Which is why we would like to study its role in propulsion.

2 Methods

The robotic system described in Figure 1 is based on the swimmers' kinematics that we tend to reproduce by varying the angular acceleration of the arm $\ddot{\theta}$ in $rad.s^{-2}$. On the one hand, the aim is to produce a parametric study assessing key parameters such as arm angular accelerations and propulsive

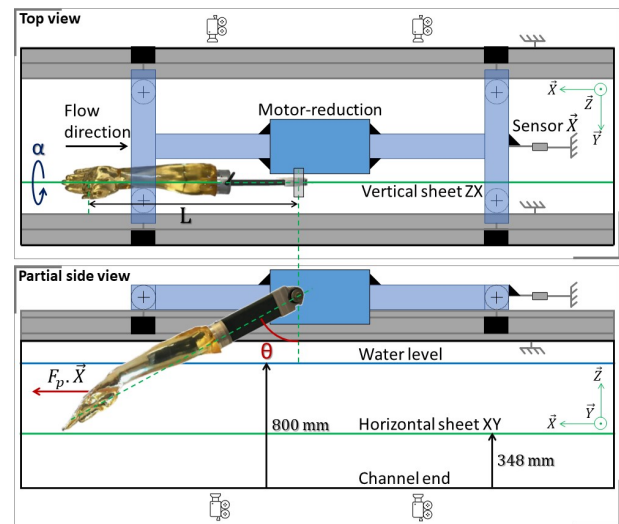


Figure 1: Schematic device of the robotic arm

forces. On the other hand, to compare these parameters with various phenomena such as vortex development and detachment. The experimental study was carried out in a laboratory, in an open channel. The forearm and hand were molded on an elite swimmer's model and built in epoxy resin (density of 0.98 kg/L similar to the human body). The mold was attached to a motor that allowed the forearm to produce aquatic movements. The motor was attached to a frame resting on two rails with four guide rollers providing a virtually slippery connection. We used a level to align the (\vec{X}) axis and calibrated the system with a device comprised of weights, belt and pulley, identifying frictional forces of 2.3 N. The frame was held with a monoaxial force sensor, measuring the force generated by the reaction of water on the arm, which represents the arm's propulsive force $\vec{F}_p = F_p \vec{X}$ (Figure 1). The sensor was connected to the motor's servo-drive from where data were extracted. The results were obtained in the cartesian frame of reference related to the earth $R(\vec{X}, \vec{Y}, \vec{Z})$. The arm's angular acceleration $\ddot{\theta}$ varied between 1 to 15 $rad.s^{-2}$ with a step of 1 $rad.s^{-2}$. The relative flow of the flume regarding the cartesian frame of reference related to the earth was 0.3 m/s, although it should have been around 2 m/s [1], but we couldn't go higher at this stage. The experiments were coupled with PIV measurements in two planes. In the vertical laser sheet, we can follow and evaluate the behavior of the fluid around the arm in the median plane. For the horizontal plane, vortex slices can be observed at different depths of the laser sheet crossing the arm. Two Phantom v2640 cameras were used to reconstruct the image for the whole motion θ in degrees from 20 to 160.

¹Authors would thank Patrick Braud, Jean-Carl Rousseau, Richard Tessier and Jessy Cantet as well as the Pprime Institute for the financial support provided (ACI project), and the French government aid managed by the National Research Agency (ANR) under the Future Investment Program (PIA) with the reference ANR-19-STHP-0001. This work pertains to the French government program "Investissements d'Avenir" (EUR INTREE, reference ANR-18-EURE-0010).

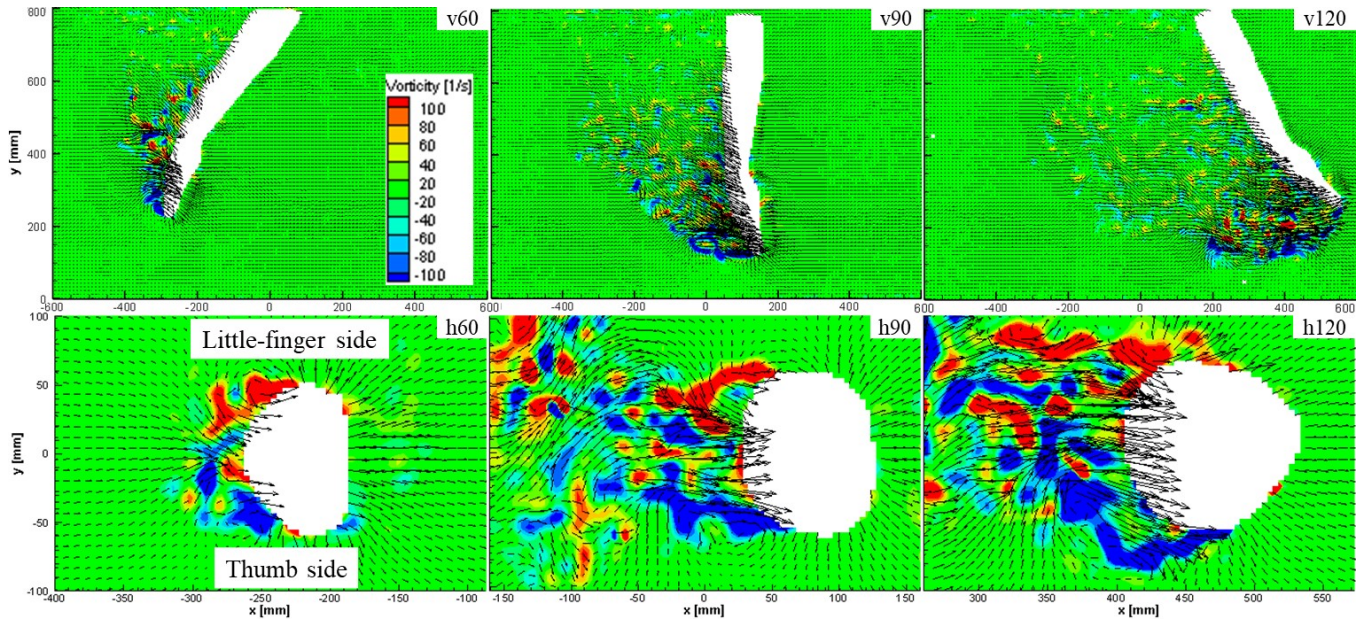


Figure 2: Experimental 2D PIV fields for $\ddot{\theta} = 10 \text{ rad.s}^{-2}$; $\theta = [60^\circ, 90^\circ, 120^\circ]$ for the ZX and XY laser sheets

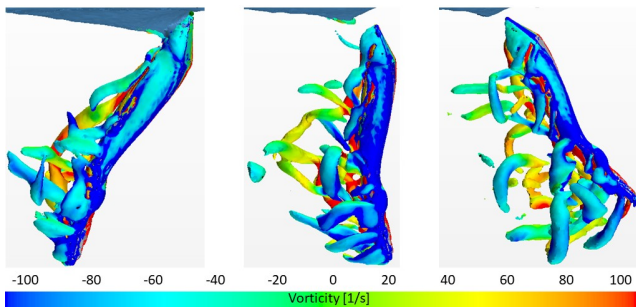


Figure 3: Spatio-temporal evolution of the vortex structures around the hand and the forearm, from the Q criterion and vorticity at different angles $\theta = [60^\circ, 90^\circ, 120^\circ]$, for $\ddot{\theta} = 10 \text{ rad.s}^{-2}$

3 Results

Post-processing of the data clearly shows that the higher the angular acceleration, the greater the propulsive force (Figure 4). A peak of strength can be observed around 90 degrees which matches our former study [7]. These data are to be compared with PIV fields from both vertical and horizontal laser sheets (Figure 2). For $\theta = 60$ degrees, we can see two vortex structures being formed on the edges of the thumb and little-finger (Figure 2). These leading-edge vortices grow and develop behind the hand and are then gradually shed in the wake ($\theta = 90$ deg). From $\theta = 90$ to 120 degrees, the wake becomes increasingly turbulent. To strengthen our understanding of the flow, we performed the same tests under numerical conditions (Figure 3), using the URANS methodology [8]. This study is promising because of the unsteady model and its confrontation with the fluid's behavior. We will present the effects of the arm's angular acceleration on propulsion in front crawl swimming in unsteady condition. The evolution of the propulsive force regarding acceleration and vortex formation will be analyzed under several conditions.

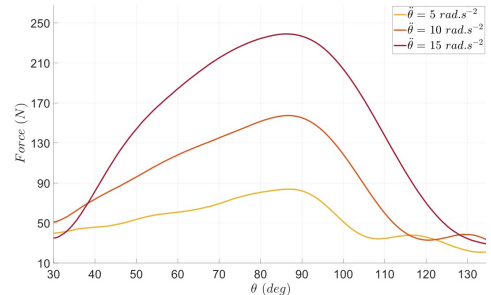


Figure 4: Evolution of the sensor's measured force according to the angular position of the arm. For three angular acceleration values

References

- [1] Ernest W. Maglischo. *Swimming fastest*. Human Kinetics, Champaign, IL, rev. edition edition, 2003.
- [2] Huub M Toussaint, Coen Van den Berg, and Wiero J Beek. "Pumped-up propulsion" during front crawl swimming. *Medicine and science in sports and exercise*, 34(2):314–319, 2 2002.
- [3] Shigetada Kudo, Ross Vennell, and Barry Wilson. The effect of unsteady flow due to acceleration on hydrodynamic forces acting on the hand in swimming. *Journal of Biomechanics*, 46(10):1697–1704, June 2013.
- [4] Mathias Samson, Tony Monnet, Anthony Bernard, Patrick Lacouture, and Laurent David. Kinematic hand parameters in front crawl at different paces of swimming. *Journal of Biomechanics*, 48(14):3743–3750, 11 2015.
- [5] Mathias Samson, Tony Monnet, Anthony Bernard, Patrick Lacouture, and Laurent David. Comparative study between fully tethered and free swimming at different paces of swimming in front crawl. *Sports Biomechanics*, 18(6):571–586, 11 2019.
- [6] Hideki Takagi, Motomu Nakashima, Takashi Ozaki, and Kazuo Matsuuchi. Unsteady hydrodynamic forces acting on a robotic arm and its flow field: application to the crawl stroke. *Journal of Biomechanics*, 47(6):1401–1408, 4 2014.
- [7] Raphaël Guignabel, Antoine Eon, Arnaud Decatoire, Achraf Outada, and Mathias Samson. Parametric study of propulsive forces in front crawl swimming. *Computer Methods in Biomechanics and Biomedical Engineering*, 25(sup1), 8 2022.
- [8] Mathias Samson, Anthony Bernard, Tony Monnet, Patrick Lacouture, and Laurent David. Unsteady computational fluid dynamics in front crawl swimming. *Computer Methods in Biomechanics and Biomedical Engineering*, 20(7), 5 2017.