



Biomechanics and Medicine in Swimming XI

Per-Ludvik Kjendlie, Robert Keig Stallman, Jan Cabri (eds)



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The Gliding Phase in Swimming: The Effect of Water Depth

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The aim of this study was to analyse the effect of depth on drag during the underwater gliding. CFD simulations were applied to the flow around a 3D model of a male adult swimmer in a prone gliding position with the arms extended at the front. The domain to perform the simulations was created with 3.0 m depth, 3.0 m width and 11.0 m length. The drag coefficient and the hydrodynamic drag force were computed, using a steady flow velocity of 2.50 m/s for depths of 0.20, 0.50, 1.0, 1.50, 2.0, 2.50 and 2.80 m. As the depth increased, the drag coefficient and drag force decreased. The water depth seems to have a positive effect on reducing hydrodynamic drag during the gliding after starts and turns, although a compromise between decreasing drag (by increasing water depth) and gliding travel distance should be a main concern of swimmers.

Key words: CFD, Hydrodynamics, Simulations, Human model

INTRODUCTION

Aiming to achieve higher performances, swimmers should take full advantage of each component of swimming race to stand out in swimming competitions. During starts and turns, the gliding phase represents a determinant race component. During the crucial gliding phase, swimmers must minimize the hydrodynamic drag force resisting forward motion. The position adopted by the swimmers under the water represents an important concern and seems to determine the success of the start (Vilas-Boas et al., 2000). Another interesting and less studied issue is related to the ideal depth to perform this underwater gliding. Vennel et al. (2006) showed that to avoid significant wave drag, a swimmer must be deeper than 1.8 chest depths and 2.8 chest depths below the surface for gliding velocities of 0.90 m/s and 2.0 m/s, respectively, which corresponds to water depths of 0.45 m and 0.70 m, respectively, for a swimmer with 0.25 m of chest depth. Lyttle et al. (1999) also showed that there is no significant wave drag when a typical adult swimmer is at least 0.60 m under the water surface. In both studies, at water depths higher than these values, hydrodynamic drag was almost constant, depending only on viscous and form drag. However, one can notice that new swimming pools attempted to incorporate some key elements that characterize a “fast swimming pool”, as the Beijing 2008 swimming pool (The Beijing Bubble Building, “The Ice Cube”), with its 3.0 m depth, is a good example. Additionally, one can also observe some elite swimmers performing this underwater gliding at higher depths. Thus, using computational fluid dynamics methodology one can compute the hydrodynamic drag when gliding at different water depths (Bixler et al., 2007). Hence, the aim of this study was to analyse the effect of depth on drag during the underwater gliding in a swimming pool of 3.0 m depth, using computational fluid dynamics.

METHODS

To obtain the geometry of a male human body, a model was created through computer tomography scans techniques (Marinho et al., 2010). The surfaces of the swimmer were then developed using ANSYS-FLUENT 6.3 pre-processor GAMBIT, (Ansys Inc[®], Canonsburg, USA). The entire computational domain was volume meshed and solved through FLUENT solver.

The three-dimensional computational domain representing a part of swimming pool was about 3.0 m in depth, 3.0 m wide and 11.0 m in length. The entire computational domain consisted of 900 millions cells of hybrid mesh composed of prisms and pyramids.

Computational fluid dynamics simulations were carried out to simulate the flow around a three-dimensional model of a male adult swimmer in a prone gliding position with the arms extended at the front (Marinho et al., 2009). General Moving Object (GMO) model was used to model the body as the moving object. During the gliding, the swimmer model's horizontal axis line running lengthwise was placed at different water depths viz., (i) 0.20 m (just under the surface), (ii) 0.50 m, (iii) 1.0 m, (iv) 1.50 m (middle of the pool), (v) 2.0 m, (vi) 2.50 m and, (vii) 2.80 m (bottom of the pool), respectively. The drag coefficient and the hydrodynamic drag force were computed using a steady flow velocity of 2.5 m/s for the different depths in each case.

RESULTS

Table 1 presents the drag coefficient and the drag force values when gliding at a water depth of 0.20 m, 0.50 m, 1.0 m, 1.50 m, 2.0 m, 2.50 m and 2.80 m. These values were computed at the time of 2 seconds when the swimmer was approximately at the middle of the computational pool.

It was observed that, both drag coefficient and drag force values fall with increase in depth of swimming tank, which swimmer model is chosen for simulation of gliding.

Table 1. Drag coefficient and drag force values for different water depths during gliding at the time of 2 seconds.

Water depths (m)	Drag coefficient	Drag force (N)
0.20	0.67	100.20
0.50	0.62	92.30
1.00	0.53	80.50
1.50	0.44	65.40
2.00	0.36	53.40
2.50	0.30	44.70
2.80	0.28	42.00

DISCUSSION

The aim of this study was to analyse the effect of depth on drag during the underwater gliding, using computational fluid dynamics. It was noticed that hydrodynamic drag decreased with depth increase, presenting the lowest hydrodynamic drag values near the bottom of the computational swimming pool (water depth of 2.80 m).

Computational fluid dynamics methodology has been shown to be a reliable tool to examine the water flow around a submerged human body model (Bixler et al., 2007). Thus, an attempt was performed to analyse the hydrodynamic drag during the underwater gliding, simulating a swimming pool with 3.0 m depth and to verify if drag values remained constant at depths higher than a critical point, beyond which wave drag seems to be almost null (Lyttle et al., 1999; Vennel et al., 2006).

The water depth seems to have a positive effect on reducing hydrodynamic drag during the gliding. Moreover, gliding near the bottom of the pool also presented lower drag values compared to gliding at a water

depth, for instance, in the middle of the swimming pool. This finding could suggest that the positive effects of water depth are more powerful than the possible negative hydrodynamic effects of turbulence near the bottom of the pool, expected when the simulations are not carried-out with a moving model. In fact, one of the innovations of this study was the possibility to carry-out the simulations and the drag analysis with a moving human body, as performed by Lecrivain et al. (2008) in the analysis of the upper arm propulsion.

The values found in this study, concerning hydrodynamic drag, were very similar to others presented in CFD studies (e.g., Bixler et al., 2007; Marinho et al., 2009), using similar velocities and similar water depths. Nevertheless, in opposition to what occurred in the studies of Lyttle et al. (1999) and Vennel et al. (2006), hydrodynamic drag decreased with depth, in the entire range of depths computed in FLUENT 6.3 (0.20 m to 2.80 m). These differences signify an interesting aspect for future investigation and to further analysis with computational fluid dynamics simulations. However, one can attribute these differences between the experimental analysis and computational fluid dynamics could be one of the reasons not to find good match of data. Indeed, although significant improvements on computational fluid dynamics simulations, it raises the question, whereas this methodology truly represents the real swimming conditions. In this paper, a significant effort was performed to diminish this difference, using a moving human body. We believe this approach could lead to obtain more accurate results. In the future, it should be also attempted to perform the same analysis with the swimmer kicking (underwater dolphin kicking), since the time when the swimmer is passively gliding is very short comparing with the total underwater distance. Moreover, active drag can be significantly different from passive drag values (Kjendlie & Stallman, 2008), thus generalizing these data to the underwater dolphin kicking should be made with careful.

CONCLUSIONS

Reducing the drag experienced by swimmers during the glide of the wall can enhance start and turn performances. Therefore, a compromise between decreasing drag (by increasing swimmer's deepness from water surface) and gliding travel distance should be a main concern of swimmers and an important goal to be studied in future investigations. Although increasing depth position could contribute to decrease drag force, this reduction seems to be lower with depth, especially after 2.0 m depth, thus suggesting that possibly performing the underwater gliding (and the underwater dolphin kicking) more than 2.0 m depth could not be gainful for the swimmer.

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A Method to Estimate Active Drag over a Range of Swimming Velocities which may be used to Evaluate the Stroke Mechanics of the Swimmer

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This research project aimed to estimate values of active drag over a range of swimming velocities. The data required to do this was the passive drag values for the swimmer at various swim velocities, together with the active drag force value for the individual at their maximum swim velocity. The drag force is represented by an exponential equation $F = a \cdot e^{(bV)}$, where a and b are constants for a particular swimmer. The constant a_p (passive) reflects the more innate characteristics of the individual swimmer and their suitability to aquatic motion. The constant a_{a-p} (active-passive) reflects the efficiency of the swimmer's technique. In both cases, the lower the constant's value, the better suited the swimmer is to aquatic motion or to technical efficiency. The a_{a-p} and the a_p provide an index to evaluate a swimmer's capabilities.

Keywords: Biomechanics, swimming, active drag, passive drag, stroke mechanics

INTRODUCTION

A swimmer's ability to swim faster is dependent upon an increase of propulsive force, which exceeds the drag force presently acting on the swimmer's motion. However, active drag increases exponentially with a progressive increase in the swimmer's mean velocity. When the active drag and mean maximal propulsive force generated by the swimmer reach equilibrium, the swimmer attains their mean maximum swim velocity. However, at any constant swim velocity, mean active drag is equal in magnitude to the mean propulsive force exerted by the swimmer. Knowing the magnitude of the mean active drag opposing the forward motion provides information that may be used to evaluate the swimmer's mean propulsive force.

Initially it was thought that tethered swimming would provide a reasonable measure of the swimmer's propulsion. Researchers have discounted this theory (Mason et al, 2009a). The MAD system developed in the Netherlands provided a measure of active drag at different velocities (Toussaint et al, 2004). However, researchers have questioned whether the swimming actions using the MAD system represent swimming propulsive technique. The major challenge researchers faced was the ability to measure total propulsive force generated by the swimmer during the free swim phase. Therefore, methods were developed to estimate the swimmers' mean propulsive force. The Velocity Perturbation Method provided a value for active drag, however only at the swimmer's maximum velocity (Kolmogorov & Duplishcheva, 1992). Similarly, a method developed at the Australian Institute of Sport also identified the magnitude of active drag at maximum swim velocity (Formosa et al., 2009). Both these methods used to evaluate active drag were dependent upon the assumption that the swimmer applied equal power while swimming at their maximum velocity during the free swim and assisted/resisted conditions. Passive drag is measured at various velocities by towing the swimmer in a streamline position. Researchers have identified that the measurement of passive drag was highly correlated to that of active drag at the swimmer's maximum velocity (Mason et al, 2009b). This high relationship between active and passive drag justified the procedures used in this present research project. The aim of this study was to develop a method to estimate the active drag of the swimmer over a full range of swimming velocities. The method developed relied upon having mean passive drag measures of the swimmer over a range of velocities, as well as the mean active drag of the swimmer at the swimmer's maximum swim velocity.