THE EFFECT OF DEPTH ON THE DRAG FORCE DURING UNDERWATER GLIDING: A CFD APPROACH

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INTRODUCTION: Swimming events are the sum of a gliding part and a swimming part. The gliding is used after the start and turns, and this phase typically corresponds to 10-25% of the total event time (Chatard et al., 1990). Taking this into account, one can notice that gliding is very important in swimming events and, therefore, its biomechanical study in order to make it more efficient is also very relevant.

The gliding can be studied experimentally, by using voluntary subjects gliding in a controlled manner in a swimming pool (using video or velocimetry, for instance), or by using Computational Fluid Dynamics (CFD). Although the experimental method gives "real" values it also presents some drawbacks, like usually imposing a heavy setup and also the fact that it is difficult to control all variables, like depth, attitude or intersegment positions of the swimmer. The CFD method does not have these limitations and its results are comparable to those obtained by the experimental method (Bixler & Riewald, 2002; Silva et al., 2005; Bixler et al., 2007; Vilas Boas et al., 2010).

This work aims to study the effects of the depth and velocity on the drag force experienced by a swimmer during gliding using the CFD method.

METHOD: A 3D scanning of a male swimmer in a streamlined position, with the arms extended above the head, was performed. The resultant 3D image was processed and converted to a format compatible with the CFD program Flow 3D (Flow Science, New Mexico - USA). The simulation domain is a parallelepiped with 11m length, 3m wide and 1m deep, simulating a swimming pool lane. The General Moving Object Model (part of Flow 3D) was used in the computations, with the water static and the swimmer model moving through it at constant longitudinal speed. The other swimmer velocity components were zero.

The model solves the Navier-Stokes equations, with turbulence governed by the Standard k-ε model (with parameters: $C\mu = 0.09$; $C1=1.44$; $C2=1.92$; $\sigma k=1.0$; $\sigma\varepsilon=1.3$) – see for example Silva et al. (2005) for the equations used and the meaning of the symbols. The surface viscosity of the swimmer was 0.5; the initial turbulence was fixed at 1% with a scale of 0.1m. The water has a temperature of 28ºC, a density of 998.2 kg/m^3 and a viscosity of 0.001kg.m/s.

The simulations were performed for the swimmer speeds of U=1.5, 2.0 and 2.5 m/s, resulting in a value of about 10^6 for the Reynolds number. This value places the flow in a turbulent regime, as the critical value is about 5×10^5 (Toussaint and Truijens, 2005). The swimmer model was "placed" horizontally on the computational domain. Considering the swimmer midline as the reference, the simulations were performed for the depths of 0m (swimmer half submerged), 0.1m (swimmer fully submerged, just below the water surface), 0.5m (middle of the swimming pool depth) and 0.9m (bottom of the simulation domain).

Since the swimmer was moving from the beginning of the simulation, the first two seconds of the simulation have a transient flow, with values fairly constant and stable afterwards. In this work the average results for the time interval between 2 and 3 seconds are presented.

RESULTS: The mean values for the drag force as function of speed and depth are shown in Table 1, for the time interval between 2 and 3 seconds.

Table 1. Mean values for the drag force

Depth (m)	Speed (m/s)	Drag force (N)	Depth (m)	Speed (m/s)	Drag force (N)
0	1.5	14.5	0.5	1.5	41.2
0	2.0	25.5	0.5	2.0	68.1
0	2.5	80.6	0.5	2.5	112.8
0.1	1.5	42.5	0.9	1.5	33.7
0.1	2.0	70.9	0.9	2.0	58.3
0.1	2.5	123.5	0.9	2.5	100.7

DISCUSSION: As shown in Table 1, the drag force for the half submerged swimmer is much lower than for the fully submerged swimmer at any depth, and for each speed. This arises from the fact that only half of the swimmer body is subjected to the water drag force, while the other half is subjected to the air drag force which is substantially lower due to its low density. For the fully submerged body simulations, the drag force decreases with increasing depth. This is probably due to a lower contribution of the wave drag force arising from the creation of waves at the air-water interface, as the disturbances caused by the swimmer at the air-water interface decrease with increasing depth. These results agree with the experimental results of Toussaint et al. (2002). As expected, the drag force increases with speed for all depths.

CONCLUSION: In this work we studied the effect of depth and speed on the drag force experienced by a swimmer moving in a streamlined position. Due to some limitations on the software, we were not able to separate the different components of the drag force (friction, pressure and wave), although from the analysis of the results we may conclude that the drag force due to waves decreases with increasing depth, while the other forms remain constant (except for 0m). These results may be useful for coaches and swimmers, as the gliding should be performed as deep as possible, although not so deep that the following rise to the surface for the swimming phase becomes too steep.

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