Vol.55, n. 6: pp.851-856, November-December 2012
ISSN 1516-8913 Printed in Brazil

BRAZILIAN ARCHIVES OF
BIOLOGY AND TECHNOLOGY
A N I N T E R N A T I O N A L J O U R N A L

Effect of Wearing a Swimsuit on Hydrodynamic Drag of Swimmer

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ABSTRACT

The purpose of this study was to analyse the effect of wearing a swimsuit on swimmer's passive drag. A computational fluid dynamics analysis was carried out to determine the hydrodynamic drag of a female swimmer's model (i) wearing a standard swimsuit; (ii) wearing a last generation swimsuit and; (iii) with no swimsuit, wearing light underwear. The three-dimensional surface geometry of a female swimmer's model with different swimsuit/underwear was acquired through standard commercial laser scanner. Passive drag force and drag coefficient were computed with the swimmer in a prone position. Higher hydrodynamic drag values were determined when the swimmer was with no swimsuit in comparison with the situation when the swimmer was wearing a swimsuit. The last generation swimsuit presented lower hydrodynamic drag values, although very similar to standard swimsuit. In conclusion, wearing a swimsuit could positively influence the swimmer's hydrodynamics, especially reducing the pressure drag component.

Key words: Human body, Numerical simulations, Computational Fluid Dynamics, Forces, Female

INTRODUCTION

Swimming velocity depends on the interaction between the hydrodynamic drag force and propelling force. Aiming to achieve higher velocities, the swimmer should reduce the hydrodynamic drag force resisting forward motion and increase the propelling force. Regarding the first aim, several studies have analysed the effect of wearing different equipment on hydrodynamic drag, with special attention to the use of swimsuits (Toussaint et al. 2002; Mollendorf et al. 2004; Pendergast et al. 2006). Recently, companies turned to covering the human skin with a technologically advanced fabric that aims to be an efficient performance enhancer. Swimsuit fabric has progressed from wool to cotton, silk, Nylon, Lycra and finally polyurethane based products (Davies 1997; Montagna 2009).

The popularization of polyurethane swimsuits has got a large media and sports attention around the pools in the past couple of seasons. In the World Championships held in Rome, in 2009, swimmers used swimsuits produced partially or entirely with the industrial polymers, and 43 world records were broken in such time frame. This record rush never happened before, and these "rubber" swimsuits could be part of the explanation for this

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performance enhancement (Neiva et al. 2011). Indeed, International Swimming Federation (FINA) banned this type of suits in January 2010, a decision that was involved in great polemic and controversy.

The manufactures claimed these suits have features such as ultra-light weight, water repellence, muscles oscillation and skin vibration reduction by the compression of the body (Marinho et al. 2009a). However, little scientific evidence was reported in main literature about such relationship for this type of polyurethane swimsuits (Neiva et al. 2011). Much of the data relating to the use of body suits to performance is based on comparison of Speedo Fastskin^{TM} and traditional suits (Rogowski et al. 2006). A study carried out by Toussaint et al. (2002) reported no statistical difference in the friction drag between the full-length Fastskin^{TM} swimsuits and standard swimsuits, but recorded lower active drag values. This finding was consistent with the previously published results comparing the passive drag of the swimmers wearing a traditional swimsuit with Speedo Fastskin^{TM} (Sanders et al. 2001; Benjanuvatra et al. 2002). Accordingly, the comparison of a traditional swimsuit with the TYR Aquapel^{TM} suit observed a rise in the velocity values when wearing the TYR Aquapel^{TM} suit (Smith et al., 2007). Similar results on the effects of bodysuits on swimming performance were also reported by Chatard and Wilson (2008). Other authors suggested that the use of full body suits could reduce the total drag (pressure, wave and friction) (Toussaint et al. 2002; Pendergast et al. 2006). Friction drag seems to be largely influenced by the use of swimsuits; however, it represents only 10-15% of total drag (Mollendorf et al. 2004; Bixler et al. 2007). Added to that, these new swimsuits are very thigh fitting, thus compacting the body, eliminating air pockets (Mountjoy et al. 2009) and improving the swimming coordination (Chollet et al. 2010). Nevertheless, further research under this field is required to better understand the importance of swimsuits on the hydrodynamics enhancement. Computational fluid dynamics methodology can be used to accomplish this goal. This methodology is currently one of the best-established numerical tools in the field of biomechanical engineering (Silva et al. 2005) and has been used with success in the computational analysis of the fluid flow around human structures (Marinho et al. 2010a). Hence, the purpose of this study was to analyse the effect of wearing different swimsuits on swimmer's passive drag using the computational fluid dynamics methodology. It was hypothesised that wearing a polyurethane swimsuit might decrease the hydrodynamic drag in comparison to a standard swimsuit and to a light underwear.

METHODS

Three-dimensional model

The three-dimensional surface geometry model was acquired through standard commercial laser scanner *Vitus Smart XXL 3D* body scanner (Human Solutions Company, Kaiserslautern, Germany), as used previously (Bixler et al. 2007; Leong et al. 2007). The subject of this study was an Olympic level female swimmer (height 1.66 m, weight 55.0 kg, age 23 years-old). The swimmer was fully informed of the aims of the participation in the investigation and voluntarily agreed in participation, with the signing of written informed consent. The appropriate ethical committee of the institution in which it was performed has approved this protocol. The swimmer was in rest along the body scans. Each scan took an average of 20 minutes. Care was taken to limit the differences in alignment of the individual scans for the two situations, by fixing the position of feet, maintaining similar vertical and horizontal alignment in respective scans and also the stationary pose with control of breadth during the actual moment of acquiring the scan (Lashawnda and Cynthia 2002). The swimmer presented her arms extended above the head (shoulders flexed), with one hand above the other (streamlined position). The three-dimensional geometric models were used later for the analysis through the computational fluid dynamics simulation (Cavalcanti et al. 2005).

The swimmer was scanned in three situations: (i) wearing a standard swimsuit, with no legs; (ii) wearing a last generation swimsuit, with legs and; (iii) with no swimsuit, wearing light underwear (Fig. 1). All the scans were performed with the swimmer wearing a swim cap (Marinho et al. 2011).

Figure 1 - Female swimmer wearing a standard swimsuit (i), a last generation swimsuit (ii) and, light underwear (iii).

Computational fluid dynamics model

The numerical simulation of the fluid flow around the three swimmer's models was carried out in Ansys Fluent™ 6.3 commercial software (Ansys, Canonsburg, Pennsylvania, U.S.A.). The simulations were based on the Finite volume method of discretization. The quadrilateral computational domain of 20 m length, 1.5 m breadth and 1.5 m height with inlet at 5 m upstream of the swimmer model was prepared in Gambit™ preprocessor (Ansys, Canonsburg, Pennsylvania, U.S.A.). The computational domain consisted of about 11 thousand tetrahedral grid cells. The passive drag was determined with the swimmer model at a depth of 0.75 m. Drag force and drag coefficient were computed for a steady flow velocity of 2.0 m/s (Marinho et al. 2009b). Pressure drag component and skin friction drag component were also computed. Figures 2 and 3 show the surface meshing of the swimmer's body and a cross-section of the fluid area around the swimmer, respectively.

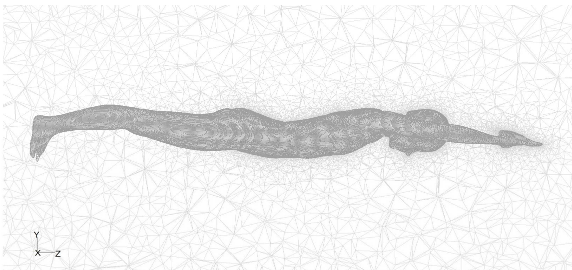

Figure 2 - Surface meshing of the swimmer's model.

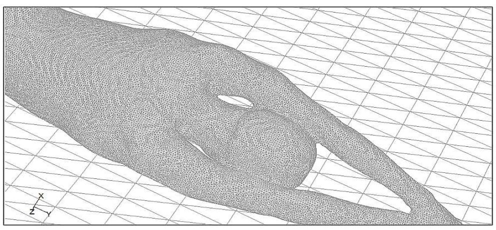

Figure 3 - Cross-section of the fluid area around the swimmer.

The fluid domain was specified as incompressible water, with the density of 998.2 kg/m^3 and dynamic viscosity of 1.004 x 10^{-6} m^2/s at 27º Celsius. The boundary conditions adopted for the numerical simulations were: (i) at the entrance of the fluid domain, a longitudinal uniform average velocity profile (2.0 m/s) was imposed; (ii) at the exit of the fluid area, mass conservation law was respected (all the gradients equal to zero); (iii) on the upper and side surfaces of the fluid domain, symmetry condition was imposed and; (iv) on the surface of the swimmer model and bottom surface of fluid domain, the no-slip wall boundary condition was imposed.

RESULTS

Table 1 shows the drag coefficient and drag force values of each swimsuit condition. The percentage and the absolute values of total drag due to skin friction and pressure drag are also presented. Total hydrodynamic drag when the swimmer was wearing no swimsuit (light underwear) was higher than the drag of the swimsuit conditions (~ +40%), where values were very similar, although the new generation swimsuit presented slightly lower drag coefficient and drag force values (~ -1%).

Moreover, the pressure drag was dominant, with a percentage of about 82 and 88% of the total drag, with swimsuit and with no swimsuit, respectively. The absolute values of skin friction drag were quite similar in all the conditions.

Table 1 - Drag coefficient and drag force values and contribution of pressure and skin friction drag for the total drag to each swimsuit condition: (i) standard swimsuit; (ii) new generation swimsuit and; (iii) underwear.

	Drag coefficient					**Drag force (N)**				
Swimsuit condition	**Total drag**	**Pressure drag**		**Friction drag**		**Total drag**	**Pressure drag**		**Friction drag**	
Stand. suit	0.325	0.270	83.08%	0.056	16.92%	76.23	63.20	82.91%	13.03	17.09%
New suit	0.323	0.266	82.35%	0.058	17.65%	75.82	62.31	82.18%	13.51	17.88%
Underwear	0.453	0.397	87.64%	0.056	12.36%	105.84	92.74	87.62%	13.09	12.38%

DISCUSSION

The main aim of this study was to analyse the hydrodynamic drag arising from the use of different swimsuit conditions, through the computational fluid dynamics. The results pointed out that there was an advantage of wearing a swimsuit on swimming performance, although minor differences were obtained between a standard suit and a new generation swimsuit. Computational fluid dynamics methodology and reverse engineering procedures were used to carry out this study with accurate digital models of the female swimmer. These procedures allowed improving the prediction of hydrodynamic forces in swimming (Lecrivain et al. 2008; Marinho et al., 2010b), being scientifically assumed to have the ecological validity for swimming studies (Bixler et al. 2007; Marinho et al. 2010a).

The drag coefficient values were very similar to the ones presented by Bixler et al. (2007), using numerical simulations on a three-dimensional model of the human body of an elite male swimmer (0.30 for 2.0 m/s velocity). Concerning drag force, similar data was also obtained. Lyttle et al. (1999), at 1.9 m/s, and at the deepest studied towing position (0.6 m deep), found experimental values slightly higher than the current study (80.4±10.0 N), although adult male swimmers were used, which could explain the differences. Bixler et al. (2007) reported drag force values of 55.57 N for a flow velocity of 2.0 m/s, with the human model at a prone position with the arms extended at the front. In this position, the drag force values were 76.23 (standard swimsuit) and 75.82 N (new generation swimsuit) for the same velocity. Since the same methodology was used in both the studies (computational fluid dynamics), this difference could be attributed to the particular body position of the swimmer's model, that was expected to be reflected in a higher cross-sectional area for all the swimsuit conditions under study, when compared to the fundamental and streamlined gliding position (Vilas-Boas et al. 1999).

The swimmer model with no swimsuit (underwear) presented the highest values of hydrodynamic drag compared to the models wearing the swimsuit, which gave rise to higher drag of about 40%. Bixler et al. (2007) experimentally analyzed the drag force in a male mannequin with and without a swimsuit and interestingly they found an additional 6% drag caused by the swimsuit. The authors reported that this result was probably caused by the waistband of the suit that was projected into the flow stream and many parts of the suit could be seen to be fluttering under the flow. Nevertheless, it was reported that even a brief swimsuit could play a significant role in swimmer's drag. Indeed, swimsuits, especially female swimsuits, seemed to allow reducing water resistance due to a decrease of the frontal surface area, with great compression of body masses (Kainuma et al. 2009).

Even with the ban on the use of the polyurethane swimsuits, in 2008 and 2009, several world records were established in major international swimming competitions, and it seemed important to better understand this so-called techno-suits and the correspondent "techno-doping" effect (Neiva et al. 2011). Although the mechanism of the improvement by the use of polyurethane swimsuits is not well-known and studies regarding this matter are still scarce, these results could contribute to support (or not) the FINA decision regarding this issue.

As observed, the standard swimsuit presented almost similar competitive edge to the swimmers, as compared to the new generation of banned swimsuit. Previous studies (Toussaint et al. 2002; Sanders et al., 2001; Roberts et al. 2003) have shown inconclusive results, although the last generation of swimsuits was not studied. Toussaint et al. (2002), studying the active drag, and Sanders et al. (2001), on passive drag, reported lower drag values for the swimmer wearing the Speedo Fastskin^{TM} swimsuit. However, Roberts et al. (2003) observed no statistical benefit when the swimmers used the Speedo Fastskin^{TM} during sub-maximal freestyle swimming.

There was very low variability of friction drag parameters compared to their pressure counterparts among the tested situation, which indicated that the main influence of swimming suits, both full body and conventional suits, seemed to be on pressure drag, probably due to selective compression of body volume. The reduction of wobbling masses is also an important parameter to be considered when analyzing these suits. However, steady state computational fluid dynamics cannot study this effect. If this effect could be measured, higher differences would occur between the standard and new generation body suits, especially when the legs (mainly thighs and gluteus) were covered, as it was the case of the swimsuit tested in the current study.

Following could be considered as the main liming points in this study: (i) the lower limbs and knee position of the swimmer model were not in streamlined glide position. Since the position of the entire swimmer models under study were exactly the same, it was assumed that comparisons were feasible, and that the relative hydrodynamic effect was expected to be comparable of the one observed in the fundamental gliding position normalized for carrying out the comparative studies; (ii) this numerical study was carried-out with the swimmer gliding underwater. Future studies could improve this computational fluid dynamics results by analysing the passive drag of a swimmer at the water's surface and including the wave drag in the measurements; (iii) only passive drag was analyse. During the underwater phase, only a small part of this task was performed passively without the kick actions. Thus, the evaluation of the active drag while the swimmer was kicking must also be attempted in the future; (iv) this study was performed with one single female swimmer, hence this study should be confirmed with other studies, analysing the swimmers of different level and different gender.

From the results, it could be concluded that the swimsuits presented performance-enhancing characteristics when compared to wearing no swimsuit (only light underwear). The standard swimsuit presented similar hydrodynamic advantages to the swimmers, as compared with the banned swimsuits. The possible hydrodynamic effects of wearing a swimsuit seemed to be particularly related to the factors affecting pressure effects rather than the friction.

ACKNOWLEDGMENTS

The Portuguese Government supported this work by a grant of the Science and Technology Foundation (PTDC/DES/098532/2008; FCOMP-01-0124-FEDER-009569). The authors would like to thank the important contribution of the swimmer Sara Oliveira.

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Received: May 15, 2011;
Revised: April 13, 2011;
Accepted: July 03, 2012.