COMPARING COMPUTATIONAL FLUID DYNAMICS AND INVERSE DYNAMICS METHODOLOGIES TO ASSESS PASSIVE DRAG DURING SWIMMING GLIDING

Lígia Costa[1], João Ribeiro[1], Daniel Marinho[2,3], Vishveswar Mantha[3,4], João Paulo Vilas-Boas[1,5], Ricardo J. Fernandes[1,5], António Silva[3,4], Abel Rouboa[3,6] and Leandro Machado[1,5]

CIFI²D, Faculty of Sport, University of Porto, Porto, Portugal[1]
University of Beira Interior, Sport Science Department, Covilhã, Portugal[2]
CIDESD, Vila Real Portugal[3]
University of Trás-os-Montes e Alto Douro, Vila Real, Portugal[4]
Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal[5]
University of Pennsylvania, Mechanic and Applied Mechanic Engineer Department, Philadelphia, USA[6]

The purpose of the present study was to compare two different methodologies for passive drag evaluation considering two different swimming glide positions used in the breaststroke event: a prone position with flexed shoulders and arms extended above the head, and a prone position with arms extended along the trunk. Experimentally the passive drag was assessed by Inverse Dynamics from swim meter data, and numerical simulation by the Computational Fluid Dynamics. Similar drag and drag coefficient values were found for the first glide position with the two methods; however, for the second glide position, the drag and drag coefficients were higher using Computational Fluid Dynamic when compared with Inverse Dynamics for the same velocities.

KEYWORDS: biomechanics, hydrodynamic drag, breaststroke, glide.

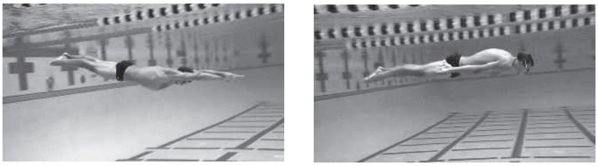
INTRODUCTION: Swimming performance is determined by the combined effect of propulsion, drag and technical skill (Chatard et al. 1990). Passive drag, it can be considered as a relevant predictor of gliding performance during the underwater phases of the starts and turns, which are important components of the overall swimming event (D'Acquisto et al., 1988). Lyttle et al. (1998) found the reduction of the hydrodynamic drag during the glide leads to reduced turning times. Cossor and Mason (2001) suggested that rather than the start technique, it is the swimmer's position underwater that mostly determines the success of a start.

The most common method used to study the passive drag acting in human swimming is by towing subjects - at various velocities, body positions and depths - using electro-mechanical motors or weights and pulley systems (e.g. Counsilman, 1955; Clarys et al., 1990; Kolmogorov et al., 1997; Lyttle et al., 2000; Toussaint, 2004). However, other methods are being used, like the Inverse Dynamics (Vilas-Boas et al, 2010; Costa et al, 2010) and Computational Fluid Dynamic (CFD) (Bixler et al., 2007, Zaidi et al., 2002, Marinho et al., 2009). The CFD method is a numerical modelling technique that can be applied to hydrodynamic phenomena, and may be used as an alternative approach to the experimental research regarding the determination of a swimmer's passive drag.

In this context, the aim of the present study was to compare experimental and numerical hydrodynamic data, particularly drag (D) and Drag Coefficient (C_D), obtained in the first and second gliding positions of the breaststroke underwater stroke used after starts and turns in breaststroke events. These data were obtained for the total range of common velocities available for each glide.

METHODS: For this purpose, inverse dynamics and CFD were used to obtain D and C_D for each glide positions. Six National level male swimmers voluntaries participated in this study. Planimetry was used to obtain the swimmer's body cross sectional area (S), as described by Vilas-Boas et al. (2010). Experimentally, the D and C_D were assessed through inverse

dynamics (for a more detailed description cf. Vilas-Boas et al., 2010), based upon the velocity to time curve of each glide, which were obtained by a swim-meter developed by Lima et al. (2006). From the curves of all swimmers, the common velocities for each pair of glide positions were determined and the D and C_D values were computed.
A real swimmer's 3D model, representative of the two gliding positions (figure 1), was used in computational simulations. The numerical simulation of the fluid flow around the 3D model of the swimmer was implemented with the CFD software FLUENT, applying the finite volume method. In the present study, the simulation was carried out on the meshed model consisting of 1 million of tetrahedral cells, with a uniform velocity equal to 1.00, 1.39 and 2.00 m/s. To compare the two methodologies (inverse dynamics and CFD) the D and C_D were interpolated for the velocities found experimentally: first glide v=1.3; 1.39; 1.5; 1.6; 1.7 and 1.8m/s and second glide v=1.0; 1.1; 1.2; 1.3; 1.39; 1.5m/s.



(a) (b)

Figure 1: Body position adopted by swimmers in first glide (a) and second glide (b) in breaststroke underwater stroke.

RESULTS: In the first glide position we found very similar D values assessed by Inverse Dynamics (D=33±7.96N to 58±12.73N) in comparison with D values assessed by CFD (D=29N to 52N). Similar C_D values were also obtained in both methods: Inverse Dynamics (C_D=0.52±0.04 to 0.46±0.09) and CFD (C_D=0.43 to 0.41), for velocities between 1.3m/s and 1.8 m/s In the second glide position we found significantly higher D and C_D values for CFD (D from 31N to 72N and C_D from 0.82 to 0.86) in comparison with values obtained through inverse dynamics (D from 26±9.83N to 44±6.97N and C_D from 0.69 to 0.47) for velocities between 1.0m/s and 1.5 m/s, respectively.

DISCUSSION: In a review of Clarys (1979), several authors have showed that Passive Drag depends on the body position and the head position. Our 3D model used in the CFD simulations did not assume elevated shoulders while in the experimental setup the swimmers adopted it. Being this position (second glide) considered as more resistive than the first one, with various pressure points, especially at the head and shoulders (Marinho et al., 2009, Vilas-Boas et al, 2010 and Costa et al., 2010), naturally the proper geometry of these points is essential to be considered in the simulations. The model 3D was obtained with a full body scan being the feet swimmer's in plantar flexed and the arms were not totally attached along the trunk. We believe that the differences found in the second glide position were caused by the differences between the real body shape assumed by swimmers and the body shape of the model.

CONCLUSION: Future CFD research in this area should consider different head and shoulder position, particularly in the second gliding position. The present work is an approach to the validation of CFD simulations, which showed very good agreement with experimental results for the first gliding position, and understandable differences for the second one.

REFERENCES:

Bixler, B.; Pease, D.; Fairhurst, F. (2007). The accuracy of computational fluid dynamics analysis of the passive drag of a male swimming. *Sports Biomechanics*, 6: 81-98.

Clarys, J., 1979. Human Morfology and Hydrodynamics. In: Terauds, J. (Ed.). *Swimming Science III*. University Park Press, Baltimore, pp. 3-41.

Chatard, J., Lavoie, J., Bourgoin, B., Lacour, J. (1990). The contribution of passive drag as a determinant of swimming performance. International Journal of Sports Medicine 11(2), 367-372.

Cossor, J., Masson, B., 2001. Swim start performance at the Sydney 2000 Olympic Games. In: Blackwell, J., Sanders, R. (Eds.), *Proceedings of Swim Sessions of the XIX Symposium on Biomechanics in Sports*. University of San Francisco, San Francisco, pp.70-74.

Costa, L., Ribeiro, J., Figueiredo, P., Fernandes, R.J., Marinho, D., Silva, A.J. Rouboa, A., Vilas-Boas, J.P., Machado, L. (2010). Hydrodynamic Characterization of the First and Second Glide Positions of the Underwater Stroke Technique in Breaststroke. In: P.L Kjendlie, R Stallman & J. Cabri (Eds), *Proceedings of Swim Sessions of the XI Symposium on Biomechanics and Medicine in Swimming*. University of Norway, Norway, pp. 62-63.

Counsilman, J. E. (1955). Forces in swimming two types of crawl stroke. *Research Quarterly, 26*, 126-139.

D'Acquisto, L.J., Costill, D.L., Gehtsen, G.M., Wong-Tai, Y., Lee, G. (1988). Breaststroke economy skill and performance: study of breaststroke mechanics using a computer based "velocity video". *Journal of Swimming Research* 4, 9-14.

Kolmogorov, S., Rumyantseva, O., Gordon, B., Cappaert, J. (1997). Hydrodynamics characteristics of competitive swimmers of different genders and performance levels. *Journal of Applied Biomechanics* 13, 88-97.

Lima, A.B., Semblano, P., Fernandes, D., Gonçalves, P., Morouço, P., Sousa, F., Fernandes, R., Barbosa, T., Correia, M.V., Tani, G., Vilas-Boas, J.P. (2006). A kinematical, imagiological and acoustical biofeedback system for the technical training in breaststroke swimming. *Portuguese Journal of Sport Sciences* 6(322 Suppl.1), 22.

Lyttle, A., Blanksby, B., Elliot, B., & Lloyd, D. (1998). The effect of depth and velocity on drag during the streamlined glide. *Journal of Swimming Research*, 13, 15-22.

Lyttle, A., Blanksby, B., Elliot, B., Lloyd, D. (2000). Net forces during tethered simulation of underwater streamlined gliding and kicking technique of the freestyle turn. *Journal of Sports Sciences* 18, 801-807.

Marinho, D. A., Reis, V. M., Alves, F. B., Vilas-Boas, J. P., Machado, L., Silva, A., Rouboa, A. I. (2009). Hydrodynamic drag during gliding in swimming. *Journal of Applied Biomechanics* 25, 253-257.

Toussaint, H. M., Roos, P. E., Kolmogorov, S. (2004). The determination of drag in front crawl swimming. *Journal of Biomechanics* 37, 1655-1663.

Vilas-Boas, J.P., Costa, L., Fernandes, R., Ribeiro, J., Figueiredo, P., Marinho, D., Silva, A., Rouboa, A., Machado, L. (2010). Determination of the drag coefficient during the first and second gliding positions of the breaststroke underwater. *Journal of Applied Biomechanics, 26: 324-331*.

Zaidi, H. Taiar, R. Fohanno, S. Polidori, G. (2008). Analysis of the effect of swimmer's head position on swimming performance using computational fluid dynamics. *Journal of Biomechanics* 41, 1350-1358