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P. Forte; D. A. Marinho; P. Morouço; P. Pascoal-Faria; T. M. Barbosa

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Comparison by Computer Fluid Dynamics of the Drag Force Acting Upon two Helmets for Wheelchair Racers

P. Forte[1, 2, a)], D. A. Marinho[1, 2, c)], P. Morouço[3, b)], P. Pascoal-Faria[3,4], T. M. Barbosa[2, 5, d)]

[1]*University of Beira Interior, Covilhã, Portugal.*
[2]*Research Centre in Sports, Health and Human Development, Vila Real, Portugal.*
[3]*Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Marinha Grande, 2430-028, Portugal.*
[4]*Department Mathematics of Engineering, School of Technology and Management, Polytechnic Institute of Leiria, Portugal.*
[5] *Nanyang Technological University, Singapore.*

[a)]Corresponding author: pedromiguelforte@gmail.com
[b)] pedro.morouco@ipleiria.pt
[c)] marinho.d@gmail.com
[d)]tiago.barbosa@nie.edu.sg

Abstract. The aim of this study was to compare the drag force created by two helmets (time trial and road)used by a wheelchair racer. The head and helmet of the racer were scanned to obtain the3D models. Numerical simulation was run on Fluent, having as output the drag force for both helmets (road and time trial) in two different positions (0º and 90º) and increasing velocities (from 2.0 to 6.5 m/s). The greatest aerodynamic drag was noted wearing a time trial helmet in 90º ranging from 0.1025N to 0.8475N; this was also the position with the highest drag. The velocity with higher drag for booth helmets was at 6.5 m/s. The time trial helmet at 0º had the lower aerodynamic drag, compared with the same position of road helmet. The drag force seems to be lower wearing the time trial helmet and keeping the 0º position and, thus, should be considered for sprinting events.

INTRODUCTION

Computer Fluid Dynamics (CFD) is an area under Computer-Aided Engineering and provide insights on 2D and 3D digital geometries. This methodology has been applied to assess competitive sports such as cycling, swimming, golf or ski jumping. It also allows to assess variables such as drag force, coefficient of drag and pressure, of gears, equipment and apparel in these sports [1].

Aerodynamics plays an imports role in sprinting events. It represents more than 90% of the resistive forces at speeds higher than 5m/s [2]. This analysis was done as well at greater speeds, such as 15m/s, 20m/s or even higher [3].In sports like cycling, the rider's posture could be evaluated. Small variations in the rider's position could account for 10% variation in the drag force [4]. Being based on the same rational, the helmet used and the position of a wheelchair racer may have a meaningful effect on the resistance, notably in racing sprinting events.

CFD presents concordance between the numerical simulations and experimental testing. A 3D model obtained with specific 3D scan is needed for the computer simulations. Software's such as Artec Studio 0.7 (Artec, USA), Geomagic (3D Systems, USA) and Maya (Autodesk Inc., USA) allows model digitalization, and scans merge and

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editing. Upon merging the scans and editing, it is possible to generate a3D mesh, and areas and elements definition [5].

This methodology consists in the discretization of Navier-Stokes equations by the finite volumes methods. This set of equations encompass the Newton's second law of motion. The fluid stress, resulted from an applied pressure term and it comes from the sum of diffusion of its viscosity. Reynolds-Avareged Navier-Stokes equations decompose instantaneous values into means and/or fluctuation compounds [6, 7]. The fluid flow behavior (equation 1), Reynolds stress (equation 2), temperature (equation 3) and mass transfer (equation 4) could be solved with resource to this methodology.

$$\frac{\partial_{\mathrm{Ui}}}{\partial_{\mathrm{xi}}} = 0 \tag{1}$$

$$\frac{\partial_{Ui}}{\partial_t} \pm U_j \frac{\partial_{Ui}}{\partial_{x_j}} = -\frac{1}{\rho}\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j}\left(2vS_{ij} - \overline{\mu_j{}'\mu_\iota{}'}\right) \tag{2}$$

$$\frac{\partial_{\theta i}}{\partial_t} \pm U_j \frac{\partial_\theta}{\partial_{x_j}} = \frac{1}{\rho_{cp}}\frac{\partial}{\partial x_j}\left(k\frac{\partial\theta}{\partial x_j} - \overline{\mu_j{}'\theta'}\right) \tag{3}$$

$$\frac{\partial_C}{\partial_t} \pm U_j \frac{\partial_C}{\partial_{x_j}} = \frac{\partial}{\partial x_j}\left(D\frac{\partial C}{\partial x_j} - \overline{\mu_j{}'c'}\right) \tag{4}$$

Therefore, this technique can be used to learn the effects of different helmets and positions by the wheelchair racer, as the racer can wear either a road helmet or a time trial helmet. It is unclear which model will impose a lower aerodynamic drag. Thus, the aim of this study is to compare two different helmets (road vs time trial) at different speeds and head positions by CFD.

METHODS

A Paralympic wheelchair racer (category T-52) was recruited for this research. He is a European medalist in sprinting events and a world championships finalist. The subject wore two different models of helmets. One is a road helmet (LAS, Istron) and the other a time trial model (LAS, Cronometro).

The geometries were obtained by a 3D scan Artec (Artec-L, Artec Group, Inc., USA). The scans were performed by Artec Studio 0.7 (Artec, USA) (Figure 1).

Fluent (Fluent, Inc., USA, New York) code, allows to compute numerical simulations applying a mathematical model to the fluid flow, at a created domain with discretized algebraic expressions of the Navier-Stokes equations. Fluent software solves the equations with a finite volume approach [7]. The domain is represented by a 3D mesh of subdivided cells representing the fluid flow around the head and helmets in the different positions.

Realizable k-epsilon was the applied turbulence model, this one, is much more efficient in computation economy and converged after 1404 interactions [9].

The 3D mesh was made with more than 6 million cells for booth helmets domains. The angles of attack were set as 0º (i.e., looking forward, with the opposite direction of the fluid flow) and 90º (looking downwards, perpendicular to the fluid flow direction).

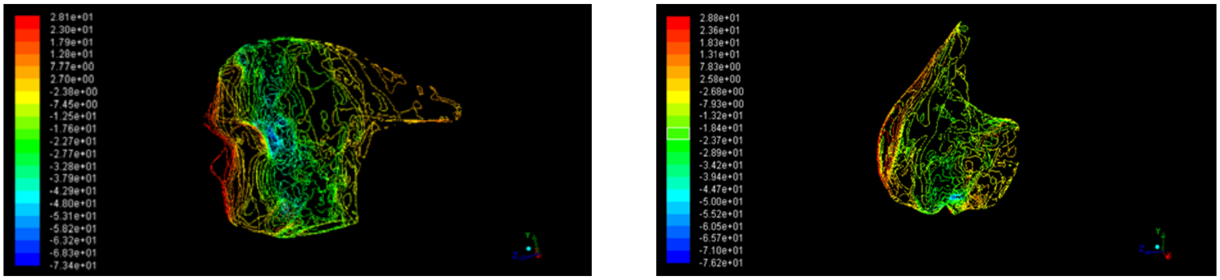
The fluid flow velocity was set in inlet portion of the dome surface at 2m/s, with increments of 1.5 m/s up to 6.5 m/s. Typically the wheelchair racer will reach these range of speed over an event. The aerodynamic drag was computed as:

$$F_D = 0.5\rho A_d v^2 C_D \tag{5}$$

Where FD is the drag force, CD represents the drag coefficient, v the velocity, Ad surface area and ρ is the air density [8].

RESULTS

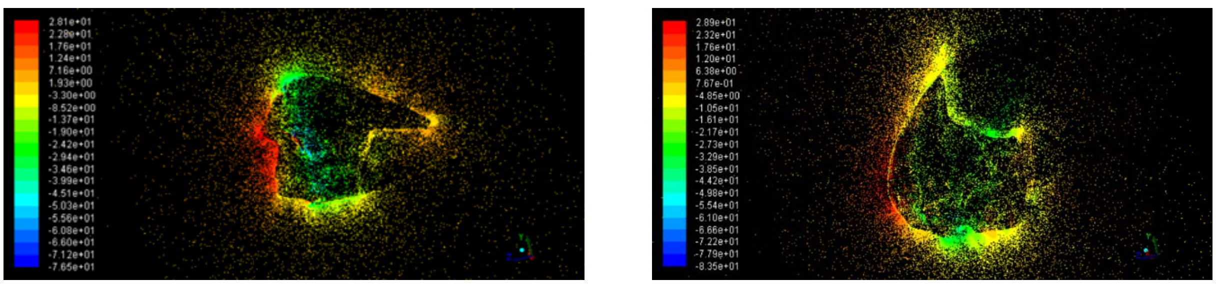
The contours of static pressure obtained in fluent, represents the pressure zones (Pa) in the helmets at 6.5m/s. Zones with red colour indicate high pressure and low pressure with blue colour (figure 1). It is possible to observe that the helmet at 90º increases the surface area and consequently the pressure zones.



(a) (b)

FIGURE 1. Static pressure zones of the time-trial helmet at 0º (a) and 90º (b) position, at 6.5 m/s.

It is also possible to recreate the fluid flow velocity simulation around the object at 6.5 m/s. With this simulation it is possible to observe the velocity vectors coloured with the static pressure around the surface area of the geometry (figure 2).



(a) (b)

FIGURE 2. Flow velocity vectors at 6.5 m/s colored by static pressure on the surface area in time-trial helmet at 0º (a) and 90º position (b) respectively.

Aerodynamic drag is prone to increase for booth helmets with increasing velocities. The drag force ranged between 0.0660 N and 0.8475 N (table 1).

In both helmets, a higher drag was noted at 90º angle of attack, when compared to a 0º angle.

The time trial helmet presented higher aerodynamic drag compared to the road model at 90º. These are kept for all velocities selected though. However, at 0º time trial helmet presented lower drag compared with the road one.

TABLE1. Drag force at different velocities and attack angles.

Velocity [m/s]	**Road Helmet (F_D) [N]**		**Time trial Helmet (F_D) [N]**	
	0º	90º	0º	90º
2.0	0.0884	0.0899	0.0660	0.1025
3.5	0.2139	0.2474	0.1615	0.2659
5.0	0.4012	0.4607	0.3116	0.5423
6.5	0.6675	0.7323	0.4667	0.8475

DISCUSSION

The obtained aerodynamic drag ranged from 0.0660 and 0.8475 N. Some authors presented similar results, near 1 N. However, reports in the literature assessed the performed at velocities higher than 6.5 m/s and the rider shoulders were also included in the simulations [3]. A higher surface area (because the shoulders were scanned) will contribute for a higher aerodynamic drag.

Others reported 0.319N of drag force for a time trial helmet. This data is in accordance to our outputs. However, it should be noted that they run the simulation only for the helmet (i.e., without scanning the head) but at a higher velocity (13.4 m/s or faster) [10].

CONCLUSION

Wheelchair racing athletes might wear time trial helmets when they keep looking forward. In the event of looking downwards, the aerodynamic drag will increase meaningfully in comparison to road helmet. Thus, racers should be aware of this drawback wearing time trial models.

CFD methodology might be useful for better understanding the technical features intending to optimize athlete's performance. Namely with, different helmets, speeds and angles of attack study. Futures researches could evaluate and create customized helmets for each athlete in agreement with his characteristics.

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