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Aerodynamics of a Wheelchair Sprinter Racing at the 100m World Record Pace by CFD

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Abstract. The aim of this study was to analyze aerodynamics in a racing position of a wheelchair-racing sprinter, at the world record speed. The athlete and wheelchair were scanned at the beginning of the propulsive phase position (hands near the handrims at 12h) for the 3D model acquisition. Numerical simulation was run on Fluent, having as output the pressure, viscosity and total drag force, and respective coefficients of drag at the world record speed in T-52 category. Total drag was 7.56N and coefficient of drag was 1.65. This work helped on getting a deeper insight about the aerodynamic profile of a wheelchair-racing athlete, at a 100m world record speed.

INTRODUCTION

Computer Fluid Dynamics (CFD) is a numerical simulation technique that provides insightful information on the sport performance [1] namely for wheeled vehicles. It allows to test different equipment's and provide useful information's about riding postures that users must adopt [2-4]. Even more, a better understanding of the resistive forces, allow to estimate the mechanical work produced during a race [13,5] Variables such as drag force and coefficient of drag are possible to obtain with CFD, and can also be separated in pressure and viscosity drag and coefficient of drag. This technic is recommended for aerodynamics access. With this methodology it is possible to control aerodynamics for the exact defined speed [1].

In wheelchair racing sprinting events, aerodynamics plays a critical role, accounting about 35% of the total resistive forces [6]. Variations in the rider's position may induce variations in the drag force [7]. Equipment, such as helmets, have also influence on the wheelchair aerodynamics [8,9]. Thus, athletes must know the influence of resistive forces at their target speed, and with their racing suits. The world speed record in wheelchair racing is 6.08m/s and it is unclear the amount of drag that is produced by a specific position in wheelchair racing at the world record speed. Thus, the aim of this study was to access aerodynamics of a wheelchair racer in a racing position, at the world record speed by CFD.

METHODS

A Paralympic wheelchair racer (category T-52) participated in this research. At the data collection time point he was a European medalist in sprinting events and a world championships finalist. The participant wore his competition suit and helmet.

To perform the numerical simulation, a geometry was obtained with a 3D scan Artec (Artec-L, Artec Group, Inc., USA). The scan was performed by Artec Studio 0.7 (Artec, USA) with the subject in a racing position.

Fluent (Fluent, Inc., USA, New York) code, allowed computing the numerical simulations, in a specific 3D domain with 3m x 2m x 1.5m (box form) and 35 million of subdivided prisms and pyramids cells representing the fluid flow around the subject and wheelchair [10]. For the simulations, realizable k-epsilon turbulent model was applied. Realizable k-epsilon was much more efficient in computation economy compared to others available in fluent hence it usually converged after 1404 interactions [11]. The set of equations that is solved in CFD are: (i) - the fluid flow behavior (equation 1); (ii) - Reynolds stress (equation 2); (iii) - temperature (equation 3); (iv) - mass transfer (equation 4).

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial u_i}{\partial t} \pm U_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j} (2\nu S_{ij} - \overline{\mu_j' \mu_i'}) \quad (2)$$

$$\frac{\partial \theta_i}{\partial t} \pm U_j \frac{\partial \theta}{\partial x_j} = \frac{1}{\rho c_p} \frac{\partial}{\partial x_j} \left(k \frac{\partial \theta}{\partial x_j} - \overline{\mu_j' \theta'} \right) \quad (3)$$

$$\frac{\partial c}{\partial t} \pm U_j \frac{\partial c}{\partial x_j} = \frac{\partial}{\partial x_j} \left(D \frac{\partial c}{\partial x_j} - \overline{\mu_j' c'} \right) \quad (4)$$

The fluid flow velocity was set in inlet portion of the dome surface at the world record speed, 6.08 m/s. Drag force was computed by the following equation:

$$F_D = 0.5 \rho A_d v^2 C_D \quad (5)$$

Where F_D is the drag force (in N), ρ is the air density (in kg/m³), A_d surface area (in m²), v the velocity (in m/s) and C_D represents the drag coefficient (dimensionless) [8].

RESULTS

The total drag force at the selected speed was 7.56N, and drag coefficient was 1.65. The effective surface area was 0.33m². Table 1 presents the total, pressure and viscosity drag and coefficients of drag. The pressure and viscosity drag and respective coefficients accounts about 67% and 33% of the total drag and coefficient of drag.

TABLE 1. Total, pressure and viscosity drag and coefficient of drag.

Variables	Drag [N]	Coefficient of Drag [dimensionless]
Total	7.56	1.65
Pressure	5.03	1.10
Viscosity	2.53	0.55

DISCUSSION

In our study, drag was 7.56 N and the coefficient of drag was 1.65. Barbosa et al. [5] also performed an aerodynamic analysis by a cost-down technic. In this analysis the authors noted a ACd (effective area) for the identical racing position was 0.1456 m². Considering our participant effective surface area his drag force was near 6.16 N. However, his speed was lower than 5.5 m/s and ACd was roughly half of our study. That might be due to measurement

procedures, which was made by photogrammetry technic. A lower speed also generates a lower drag; hence it is speed dependent. However, Hoffman et al. [12] corroborated our effective surface area result with 0.37m^2 .

A kinetic analysis by Barbosa and Coelho [13] also considered the partial contribution of the resistive forces. The authors reported that at the end of the race, the wheelchair-racing subject achieved a maximal speed of 6.97 m/s . At this speed aerodynamics contribution for resistive forces was near 46%. Thus, wheelchair-racing athletes must practice at a higher load than the required to surpass the resistive forces at the world record speed. The required mechanical power to overcome drag can be calculated from the product between the drag and the target speed [5].

CONCLUSION

In a wheelchair racing 100m event, at the world record speed, the total drag was 7.56 N . Wheelchair racing athletes must be aware of the produced amount of drag at their racing position, and aim to reduce it as much as possible. Pressure drag is mainly reduced by the body alignment and viscous drag can be reduced with light and tight clothes. Their training sessions should be prescribed considering the necessary mechanical power to overcome drag only represents roughly 35% to 46% of the resistive forces.

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