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Research Article

THE CALCULATION OF HYDRODYNAMIC RESISTANCE EXERTED BY THE WATER AGAINST THE SWIMMERS MOVEMENT USING COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT
In this paper, the application of Computational Fluids Dynamics (CFD) in computation of components water resistance force against the swimmers movement have been studied. Understanding the resistance components and the percentage of their role in total resistance of swimmer leads significantly to better records in the competitions. Obtaining the pressure and velocity distribution in different parts of swimmer's body, we can take measures to prepare the swimmer's body form, and improve its function. In this research, the distribution of the fluid flow around the swimmer's body was compared in two different states: the first state refers to the time he is swimming in the surface of water, and the second refers to the movement in diving state in the water depth. The calculations show that in Front Crawl, and in the limitation of swimming velocity of official competitions, the resistance exerted by water in diving state is nearly 50% less than the state that the swimmer moves on the surface of water. Therefore, according to research findings, the swimmer should attempt to transverse the path in diving state and has a subtle schedule for coming out of the water and perform the competition in swimming state.

Keywords*: *Professional Swimming, Computational Fluids Dynamics, Water Resistance Force, Sport Engineering

INTRODUCTION
Achieving the high velocity to transverse the path, and obtaining less time, are the main objectives of the swimmer in the competitions. The swimmer faced two factors to achieve the objective. If he cannot overcome to any of them, he will not achieve the maximum velocity. One of the factors is drag exerted by movement under water, and the other one is the swimmer skill in implementing the swimming movements and taking hydro dynamic shape to decline the drag (Cossor and Mason 2000; Vilars-Boas *et al.*, 2008).
In modern swimming, the swimmer attempts to pass a long path of the race in underwater diving to reduce the drag force exerted by the water (Marinho *et al.*, 2009).
The calculation of drag force by many researchers has been studied since many years ago. For example (Jiskot and Clary, 1975) calculated the resistance force exerted to swimmer's body in stretching state underwater. (Bixlure and Shuldhur, 1966) have studied the effect of the moving parts velocity in swimmer movement using the CFD trough arm modeling and the hand movements with one disk for the first time. CFD also was used by "Roboya, 2006" for computation of steady and non-steady propulsion force created by swimmer hand.
In this research, we have calculated the components of resistance force exerted by water to swimmer's body with different velocities in the state that the body parts are non-moving in relation to each other in two different positions: when the swimmer is fully diving in the water, and when he is swimming on the surface of water.
The purpose of the research is totally comparing the resistance force exerted by water in two mentioned states. Obviously the better understanding of the nature of these forces would help the swimmer and coaches to advance their strategic and training programs in preparing and training of athletes through engineering approach.

The Components of Hydrodynamic Resistance Force

The components of the hydrodynamic resistance force are categorized as follow and the relationship between them is shown in figure 1.

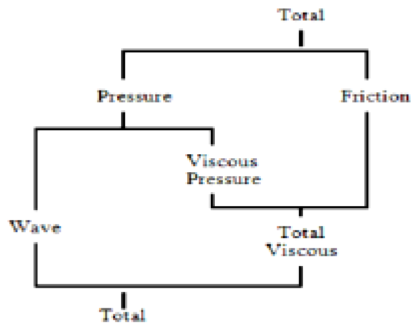


Figure 1: The Categorization of Hydrodynamic Resistance Components

As shown in the figure, hydrodynamic resistance components are divided in two categories: Skin friction resistance caused by shear stresses on wet surface, and compressive strength calculated by normal stresses integral on total surface of the object. The compressive resistance by itself includes the wave making resistance and the pressure viscosity resistance, and we can write:

$R_{\text{total}} = \mathrm{R}_{\text{wave}} + \mathrm{R}_{\text{viscous pressure}} + \mathrm{R}_{\text{frictional}}$ (1)

The wave making resistance caused by pressure difference of the object and occurs when the pressure difference causes making ups and downs of water surface; therefore, when the object placed in enough depth, there is not enough force to make ups and downs on the surface of water, so the wave making resistance would be equal to zero for the objects moving deeply (Webb *et al.*, 2014; Marinho *et al.*, 2011).

Wave Making Resistance

Generally we can use the following equation for calculating the resistance force specially wave making resistance:

$\mathrm{R}_{\text{wave}} = {}^{1}\!/_{2}\, \mathrm{C_w} \rho \mathrm{V}^2 \mathrm{A}_{\text{wetted}}$ (2)

Where ρ is density, $\mathrm{C_w}$ is drag coefficient of wave making resistance, V is the velocity of swimmer move, and $\mathrm{A}_{\text{wetted}}$ is the wet surface of swimmer body. The wet surface may be estimated carefully by the following formula:

$$\mathrm{A}_{\text{wetted}} = 0.2024\mathrm{H}^{0.725}\mathrm{W}^{0.425} \qquad (3)$$

Where H is the swimmer height, W is the swimmer weight (kg) (Marinho *et al.*, 2011).

Frictional Resistance

We can use the ITTC 1957 formula, applied in calculation of skin resistance of hulks, to calculate skin friction resistance (Molland *et al.*, 2011).

$\mathrm{R}_{\text{frictional}} = {}^{1}\!/_{2}\, \mathrm{C_f}\, \rho \mathrm{V}^2 \mathrm{A}_{\text{wetted}}$ (4)

Where $\mathrm{C_f}$ is the skin friction coefficient which calculated through the following formula:

$$\mathrm{C_f} = \frac{0.075}{(\mathrm{Log}_{10}\mathrm{Re} - 2)^2} \qquad (5)$$

Where Re is **Reynolds** number which equals with:

$$\mathrm{Re} = \frac{\mathrm{V.L}}{\vartheta} \qquad (6)$$

Where V is velocity (m/sec), L is the swimmer length; ϑ is Kinematic viscosity which is equal about 10^{-6} for sweet water in 25º C.

Pressure Viscous Resistance

$$\mathrm{R}_{\text{viscous pressure}} = {}^{1}\!/_{2}\, \mathrm{C_{DP}} \rho \mathrm{V}^2 \mathrm{A}_{\text{projected}} \qquad (7)$$

Research Article

Where C_{DP} coefficient of is drag pressure, and $A_{projected}$ is the projected area of object.
The main problem in above formulas is coefficient of resistance, and except skin resistance coefficient in which we can suitably use ITTC 57 formula, it is impossible to calculate for other components of resistance, and generally for complex objects; therefore, the resistance should be obtained either directly by the testing in laboratory or by using the new methods, such as computational fluid dynamics, and this the matter is discussed in this article.

Modeling

For numerical modeling, we have used the Standard physique of the human body, the geometry of which has been extracted of CATIA designing software (figure 2); then the geometry has been meshed in ICEM CFD software- one of the powerful modules of Ansys software package used in the field of meshing of CFD.
The diameters of computational fluid field is assumed so large that we can consider the around flow field as developed (figure 3).
Regarding the geometry complexity, we used unstructured triangle-type mesh. The required compression of mesh on the swimmer body, free surface, and the borders have been considered so that the mesh can show the details of body geometry and flow field changes. In Figures 3 and 4, we have used the tools available in software package to produce the mesh with high possible quality, and the mesh quality is less than 0.3 which is an important factor in computation precision, convergence, and constancy of solution in solvent software (figure5).

Figure 2: Human Standard Body for Modeling

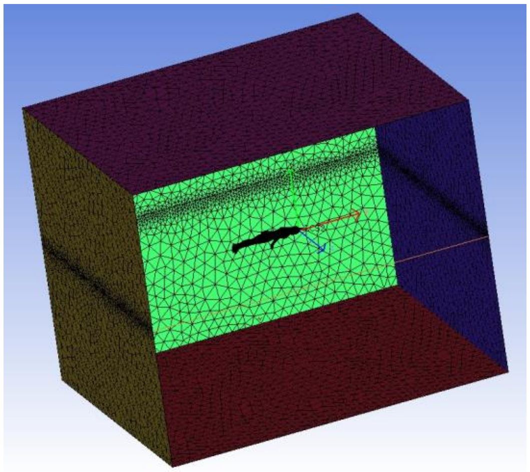


Figure 3: Computational Field, and the Compression of Mesh on Borders

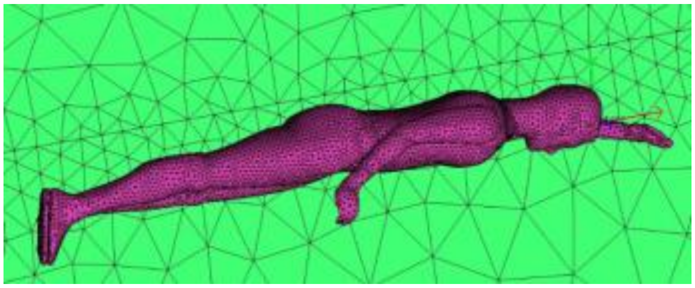


Figure 4: Mesh Compression on and Around of the Swimmer's Body

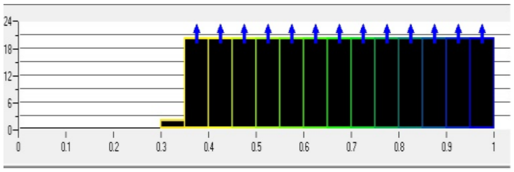


Figure 5: Mesh Resolution

Modelling in Fluent Software

We have used Ansys Fluent software for numerical solution. Also we have used Open Chanel Flow model with Mass flow inlet, and Pressure outlet in the state that the swimmer is on the water surface, and the remained borders were considered as symmetry. The setting related to solvent listed below:

Table 1: The Solvent Setting in Fluent Software

Setting	**Case**
Simple	Solution Method
Least Squares Cell Based	Gradient
Presto	Pressure
Second Order Upwind	Momentum
Modified HRIC	Volume Fraction
First Order Upwind	Turbulent Kinetic Energy
First Order Upwind	Turbulent Dissipation Rate

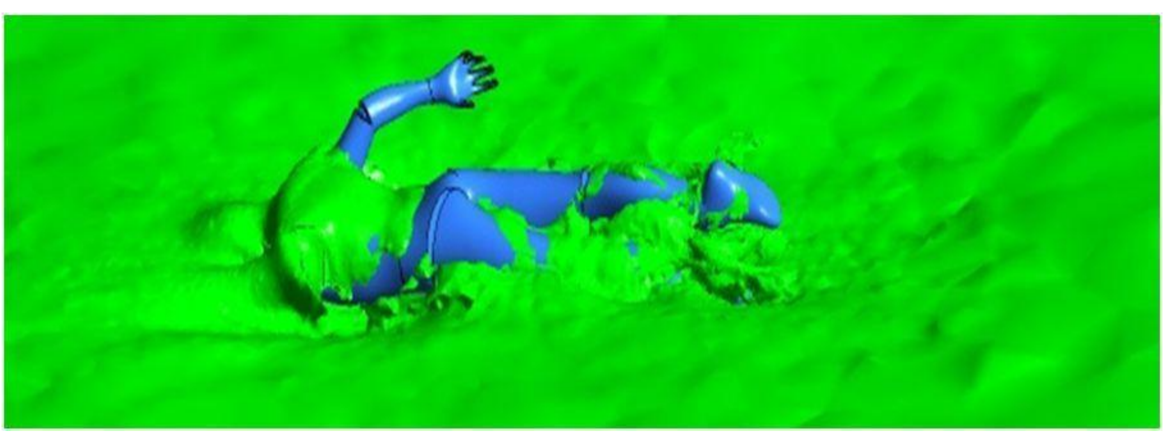
The fluent flow regime has been considered transient and the scale of convergence is monitoring the drag force on the swimmer's body in addition to stability and monitoring the remaining. The computations have been continued so long as the drag force changes in time are fixed, and temporal steps for the stability of solution with trial and error method have been found, and the best finding has been obtained in period of about 0.005 sec.

Also the modeling and related computation have been done both for swimming on water surface, and deeply in diving state.

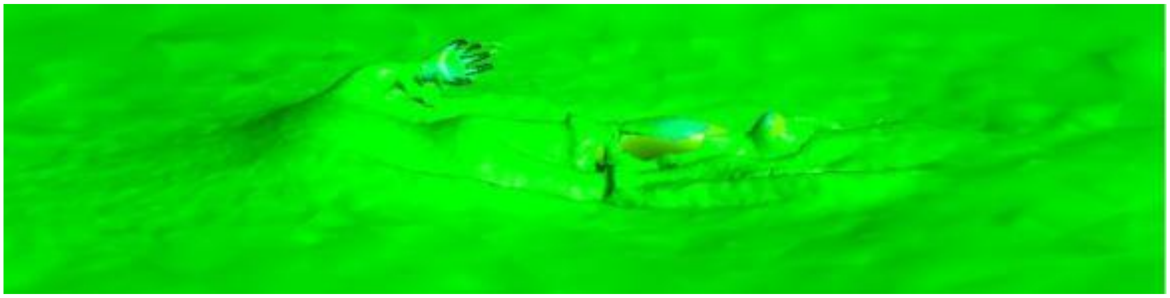
RESULTS AND DISCUSSION

Results

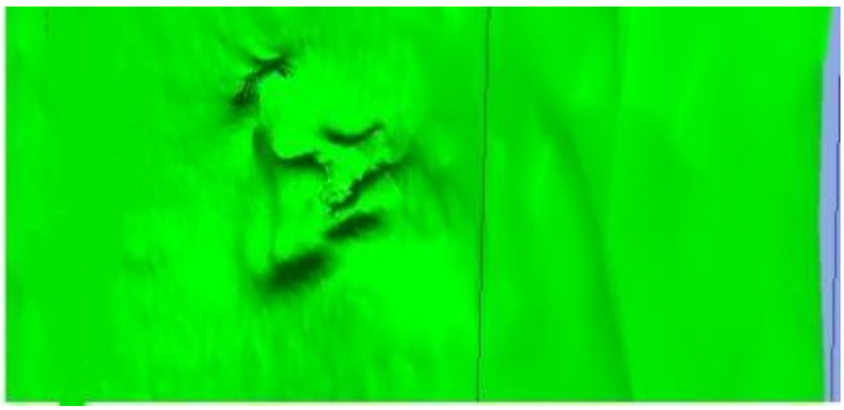
Free surface profiles at different speeds is shown in Figure 6. As it can be seen, with the increase of water pressure, the surface of swimmer's body is more exposed to water, and this is the significant factor of increase in the exerted drag force.



A: Swimming with Velocity of 1 m/sec



B: Swimming with Velocity of 1.5 m/sec



C: Swimming with Velocity of 2 m/sec
Figure 6 ???

The contours with the same velocity have been shown in figure 8. The wake level formed in the behind of the swimmer is distinguishable from other parts in blue. The wake range caused by increasing the fluid velocity, has the significant role in pressure resistance. The red area seen in front of the swimmer is the area in which the fluid velocity is high. In figure 9, the lines of fluid flow on free surface have been drawn in forwarding velocity of 1.5 m/sec.

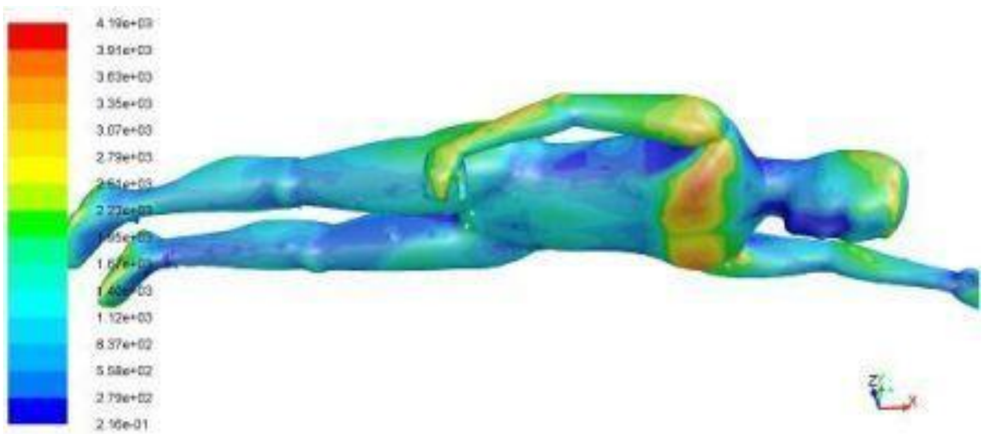


Figure 7: Dynamic Pressure Distribution on Swimmer's Body with the Velocity of 2m/sec

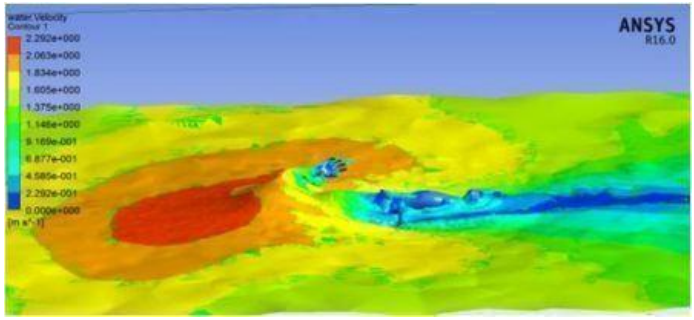


Figure 8: Velocity Connectors with Velocity of 1.5 m/sec

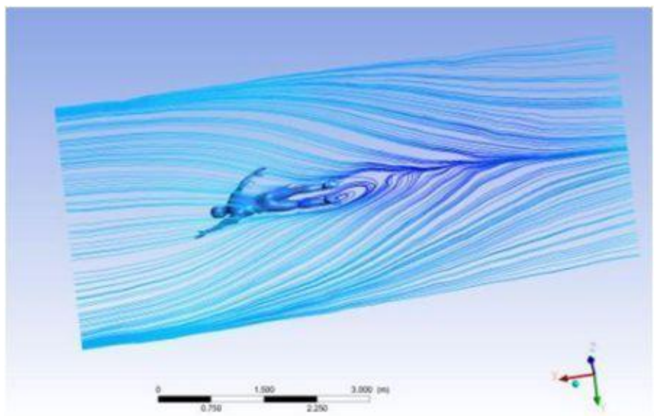


Figure 9: Flow Lines on Free Surface with Forwarding Velocity of 1.5 m/sec

In figure 10, the drag force exerted to swimmer's body in different velocities in two states of flowing on water surface and deeply diving have been drawn. The drag force in the fully diving state is less than the state in that the swimmer moves on water surface. The main reason is the increase in the residuary resistance caused by wave making resistance, and significant increase of pressure resistance.

Although, the contact surface of swimmer with water in the state that he is moving on water surface is less than his diving state, which causes the significant decrease of frictional drag, the total drag of swimmer is more than diving state due to great residuary drag components.

Therefore, the swimmer should has an appropriate schedule for coming out of the water and continue the path swimming on the surface which is a very important factor in obtaining appropriate records in competitions. According to findings, the resistance force exerted to swimmer in swimming state on free surface is averagely 50% more than diving state. Also the research results are confirmed by empirical results extracted from (Vennell *et al.,* 2006) reference.

Conclusion

The new methods of engineering have been expanded in various disciplines, and one such method is sport engineering. In records including running and swimming, since the velocity is important, CFD can help coaches and swimmers do their training programs and sport strategies based on engineering principles. In this paper also, one of the CFD usages in swimming was explained.

According to the research findings, the resistance exerted to swimmer's body in diving state in the scope of velocities related to international records is about 50% less than swimming state on the surface. So, the swimmer should have the subtle schedule for coming out of the water. Also as the drag force is increased progressively, the swimmer should act quite deliberately in resistance swimming which need much energy.

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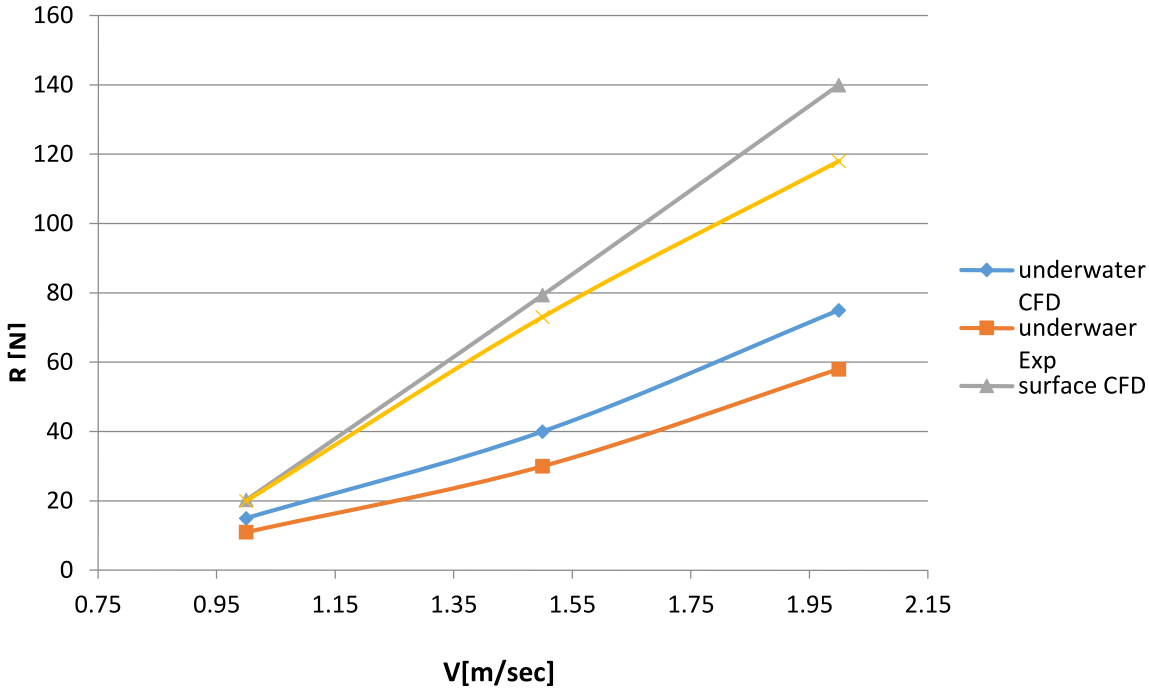

Figure 10: Drag Force Exerted to Swimmer's Body in Different Velocities

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