DRAG FORCE RELATED TO BODY DIMENSIONS IN BUTTERFLY SWIMMING

[1]Morteza Shahbazi-Moghaddam and Safoora Sabbaghian[2]
[1]Physics Department of Tehran University and Centre for Aquatic Research and Education of Edinburgh University, UK
[2]Physical Education Department of Amirkabir University, Iran

During four last decades, a great deal of attention has been given to the presupposed relationship between body dimensions and hydrodynamic resistance related drag for actively swimming subjects to anthropometrical variables. The development of a new indirect method of determining active drag (IMAD) warranted a reevaluation of this relationship, which was the aim of present study. Twenty female swimmers with different body shape and experience ranging from 13 to 19 years and in mass from 42 to 68 kg have volunteered in this study. They were requested to swim a 10-m distance as fast as they could and three trials with enough rest in between. They have also been instructed to glide at the end of 10-m swim, by whistling, until still position. The time of 10-m swim and the glide distance were measured with reasonable precision. The variables were mass, height, upper limit length, arm, forearm, hand lengths, and torso, arm, and head circumferences. Very high and significant correlations were found between active drag and anthropometric variables. The drag force for advanced swimmers was ranging from 26 to 36 N, while for other swimmers was ranging from 16 to 32 N. The results achieved from this study agreed well with the results obtained by other researchers using direct measurement systems.

KEY WORDS: anthropometric variables, drag force, butterfly swimming

INTRODUCTION: So far a great deal attention has been given to the presupposed relationship between body shape and dimensions and hydrodynamic resistance (Clarys, 1976, 1979; Clarys et al., 1974; Councilman, 1971; Gadd, 1963; Jaeger, 1937; Jurina, 1972; Karpovich, 1933; Miyashita and Tsuoda, 1978; Tilborg et al., 1983; Zaciorski and Safarian, 1972. Clarys, (1976, 1979) was the first who related drag for actively swimming subjects (active drag) to anthropometric variables. Contrary to expectations, Clarys (1976, 1979) found only few correlations between active drag and anthropometric variables, which forced him to conclude that the shape of human body has hardly any influence on active drag and that other factors are therefore more important.
Many researchers have been encouraged to use MAD system (Measurement of Active Drag), which is only suitable for front crawl (Hollander et al., 1986). MAD system consists of a variable number of push-off pads mounted on a 23-m long horizontal rod attached via a computer-linked force transducer to the wall of a swimming pool, 0.8m below the water surface. Propelling forces of the arms in only front crawl swimming can be measured during each stroke. The other limitation of the system is that the subject should swim at a constant speed and using the arms only, the mean propelling force equals total drag at any given speed.
The development of a new indirect method of determining active drag IMAD)(Shahbazi and Sanders, 2002, 2004) warranted a reevaluation of this relationship, which was the aim of present work.

METHODS: The subjects in this study were 20 female butterfly swimmers in three categories: advanced (5), intermediate (7), and beginners (8). The mean propulsive forces were obtained by using indirect measurement method (IMAD) developed by Shahbazi and Sanders, (2002, 2004). This indirect method has the advantage of being used for all four strokes.
The swimmers performed three 10-m trials with enough rest in between and with zero initial velocity over which average velocity was calculated. The swimmers began to swim from still position after whistling, and stopped swimming at the end of 10-m swim again by whistling and kept gliding until still position. The time of 10-m swim and the glided distance were

measured with reasonable precision (10^{-2} Sec. And 10^{-2} m respectively) and then used in the established formulae for determining the drag force.

FORMALISM: The equation of motion of the swimmer in water was proposed by Shahbazi and Sanders (2002, 2004) as followings:

$$F_P - (C_1 V_L + C_2 V_L) = Mdv/dt \quad (1)$$

V_L is the maximum speed the swimmer can reach in 10-m swim, C_1 and C_2 are the hydrodynamic coefficients, which are given as:

$$C_1 = \frac{2MV}{X+10} \quad (2)$$

V is the mean velocity in 10-m swim, X is the glided distance, M is the swimmer mass, and

$$C_2 = M/X \quad (3)$$

The limit speed V_L is given as:

$$V_L = 0.5[C_1 / C_2 + \sqrt{(C_1/C_2)^2 + 4MV/C_2.t}] \quad (4)$$

By inserting these values in the following relationship, the propulsive force, which at limit speed equals the drag force, can be obtained:

$$F_P = C_1 V_L + C_2 V_L \quad (5)$$

Table 1 Mean ± SD of swimmers kinematic and kinetic values.

Subjects	M (Kg)	T(Sec.)	V(m/s)	X(m)	C_1(kg/s)	C_2 (Kg/m)	V_L (m/s)	FP(N)
A(5)	55.4±4	8.3±0.3	1.2±0.1	6.8±1.3	7.9±0.8	8.5±2.1	1.6±0.22	33.9±3.5
B(7)	53.1±6.9	8.7±0.1	1.15±0.01	5.3±1.1	8.0±1.2	10.2±2.2	1.3±0.23	28.2±4.3
C(8)	51.8±8.3	9.4±0.5	1.06±0.05	5.1±1.4	7.3±0.9	10.6±2.7	1.2±0.22	23.5±5.4

Table 2 Mean ± SD of anthropometric variables values in (cm).

Subjects	Height	Arm Len.	Forearm	Wrist Thic.	Torso Cir.	Arm Cir.	Head Cir.
A(5)	164±3.08	30.7±1.44	31.5±1.52	5.34±0.28	86.1±2.27	26.7±2.1	54.9±1.2
B(7)	162±5.76	30.5±2.81	31.4±1.44	5.23±0.24	85.2±3.85	26.6±3.7	53.9±1.5
C(8)	160±5.43	29.7±2.08	30.5±1.87	5.18±0.37	84.5±4.8	26.1±2.8	52.8±2.2

RESULTS AND DISCUSSION: By measuring the anthropometric variables directly on the body such as: body height and weight, biacromial distance, arm length (i.e., distance between acromion and most distal part of the hand), upper and lower arm length (i.e., distance between acromion and caput radii, distance from caput radii to processus styloideus radii, hand length (i.e., distance from processus styloideus radii to most distal part of the hand), torso, arm circumferences and wrist thickness. Very high and significant coefficients of correlation were found between active drag and anthropometric variables.

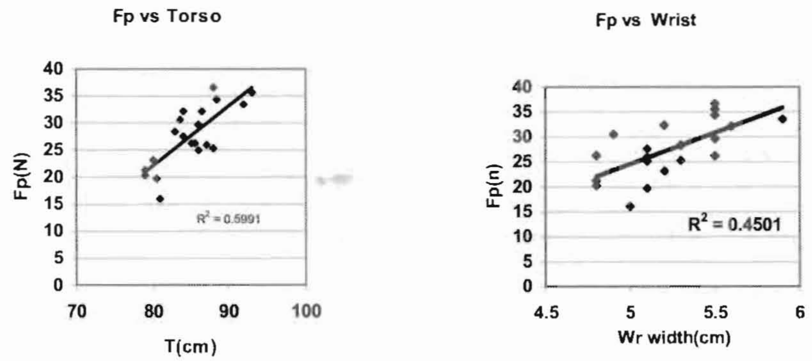

Figure 1 Correlations between torso circumference and wrist width and FP.

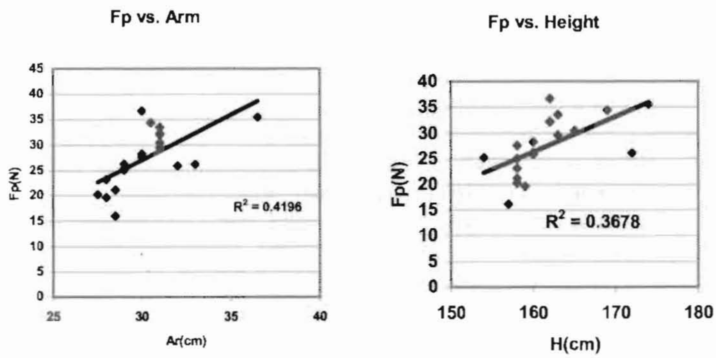

Figure 2 Correlation between arm length and height and propulsive force FP.

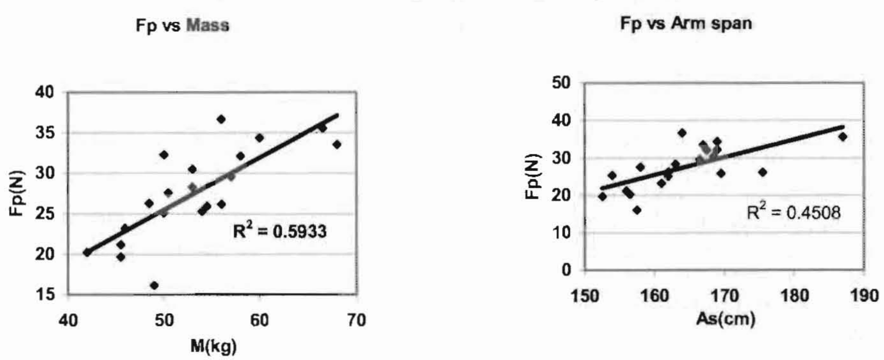

Figure 3 Correlation between mass and arm span and propulsive force FP.

It should be kept in mind that the methods employed in the present study (i.e., considering swimming speed and drag data with linear and quadratic functions and using proportionality coefficients C_1 and C_2 for active drag) are sensitive for skin friction as well as viscous pressure drag. No conclusions can be drawn regarding wave drag using the methods employed, even though the wave drag is included in the measurements performed in this study. In contrast with Clarys (1976, 1979) significant correlations were shown to exist

between selected anthropometric variables and a variable characterizing drag of the actively propelling swimmer.
In the present study, active drag was actually measured using IMAD method, while Clarys (1979) obtained estimates of the same order of magnitude as those calculated by Schleihauf et al., (1983) and Kolmogorov et al., (1998). In addition to a high degree of correlations were also found between several other anthropometric variables and drag.
In Figures1, 2, and 3 the correlations between some remarkable variables such as; mass, torso circumference, wrist thickness, height, arm length and span, and propulsive force are shown. In Table 1 and 2 the swimmers kinematic and kinetic parameters values and the anthropometric variables magnitudes are given.

CONCLUSION: With simple indirect measurement of drag force IMAD, we were able to find correlations between body variables and propulsive force, which at constant speed equals the drag force. Significant correlations between weight and height, arm, forearm, length, torso and arm circumferences and drag force have been found. The main advantage of IMAD method to MAD system is that the former can be used for all four strokes and is not expensive and easy to use.

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