New method to evaluate the drag coefficient" of 100-m runners"

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Abstract

This study presents new method used to evaluate the variation of the drag coefficient with the runner's relative velocity. Approximated shape of the runner's body of seven parts was used. Drag coefficient and projected area of each part was evaluated and used to find the runner's body drag coefficient. The results of this method show that the total projected area of the approximated runner's body was 0.6824 m\ The ratio of this area to the square of the height of runner (1.85 m) was 0.2. The drag coefficient of the sphere was constant with the relative air velocity. For cylinders, the drag coefficient decreases with the air velocity. The drag coefficient of the runner's body varied from 0.867 to 0.968. The results showed the reduction of the drag coefficient with the relative air velocity.

Introduction

In the sport activities, all types of motion are affected by the environment of the fluid in which these activities occur (1:178). During the sport activities, the term fluid resistance is usually used in order to express the type of force, which is technically known as the drag force. According to the type of fluid, this force, in case of air, is termed as the aerodynamic drag force (2:414). Drag acts directly opposite to the direction of motion of the body and depends on the size, shape, and position of the body, the velocity of fluid flow past it and the density of the fluid (2:419). The drag is the main air resistance force that affect on skiers, cyclists, runners and all projectiles (2:417). Moreover, drag is the component of the resultant dynamic fluid force which tends to slow down the relative velocity of the body moving through the fluid, in case it is the only force acting on the body (4:200). Drag pulls and pushes on an athlete. For example, if an athlete runs to the left, the drag forces are expected to act to the right. If an athlete sprints faster, the air is going to push and pull at him more (5:109). The drag is based on several factors

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including the drag coefficient, projected area of the body, air density and the relative velocity of air passing by the moving body (3:486). The drag coefficient, Cj, for the human body must be found experimentally in wind tunnels because it changes for every change of the orientation of the body relative to the flow (2:419). However, the reported values of the drag coefficient seem open to discussion because it varies from 0.7 to 1.2 (6).

Research Problem

The sprinting activities are very sensitive so that the differences in the records can be as little as fractions of seconds. Therefore, any parameter can affect the performance during the event must be considered. One of the important parameters is the aerodynamic drag force that faces the sprinter and tries to reduce his spiriting performance. This force depends on several parameters including the value of the drag coefficient. The drag coefficient still until now of conflicting values. None, to the knowledge of the author, has reported definite value or definite method to evaluate the value of the drag coefficient for sprinter performing sport activities. Most of the reported drag coefficient values were constant, which is believed by the researcher to be far away from the true condition.

According to previous studies published by the author (7) (8) and as a result of the author comprehensive search on this subject, noticeable differences were found in evaluation of the drag coefficient. Also, search on this topic in the literature that concern of the Engineering in Sports (9) (10) has reflected the difficulties of measuring the drag coefficient using the wind tunnel measurement and most the reported experiments have been conducted using approximation that can significantly affect the reported values of the drag coefficient.

Therefore, this study presents new method that can be used to evaluate the variation of the drag coefficient according to the sprinter's relative velocity. In this method, the author approximated the shape of the runner's body to known shapes of known drag coefficients and make use of them to evaluate the drag coefficient for the runner. More precisely, to the knowledge of the author, this is the first study that makes use of approximating the human body into predefined shapes to be used to evaluate the drag coefficient.

Research Objectives

This aim of this study is to evaluate the drag coefficient variation with the sprinter's relative velocity in sprinting activities. Accordingly, the objectives of this study include the description of a new method to evaluate the drag coefficient, the evaluation of the drag coefficient variation patterns with the relative velocity of the runner and to obtain correlations relating the drag coefficient with the relative velocity of the sprinter.

Definitions

Drag

It is defined as a resistance force that slows the motion of a body moving through a fluid

(3:486)

Drag Coefficient

It is defined as the drag force (D) divided by the product of the frontal area of the body

(A) and the free stream dynamic pressure (0.5 p V^2) (11:133).

Reynolds Number

It is defined as the ratio of the inertial forces in the fluid to the viscous forces (11:128).

Kinematic viscosity

It is property of the fluid (air in this study), which is the ratio of the absolute dynamic

viscosity to the fluid density (11:125).

Previous Studies

There are several studies reported the evaluation of the drag coefficient of human's

body from wind tunnel measurements. Hill (1927) estimated the drag coefficient from the measurements made on a 0.20 m tall model of a runner. He reported drag coefficient of 0.45 for the running position and 0.49 for the erect position. He also approximated the projected area of the runner during these experiments to be 0.15 times the square of the runner's height (12).

Pugh (1971) conducted experiments also in wind tunnel to evaluate the drag coefficient on life sized models. One of the models was a plywood cutout of a runner in the shape of the projected area as close as possible to the real condition. The other tested model was a rectangular plywood board which had same projected area as the first model. For both models, the researcher reported same drag coefficient of 1.5. In addition, the researcher measured the drag coefficient of an upright elliptical cylinder (one cylinder) having approximately the same projected area as,that of a runner and this model resulted in drag coefficient of 1.04 (13).

With the use of a wing tunnel, Van Ingen Schenau (1982) measured the drag coefficient for six skating players of different body builds. He also investigated the relationship between the drag coefficient and the air velocity. His results suggested that the drag coefficient was approximated to be in the range of 0.79 to 0.99 and that the drag coefficient is decreasing with the increased air velocity in the range of 6 to 12 m/s (15).

Walpert and Kyle (1989) performed wind tunnel experiments on both a lifelike model .and a human in order to evaluate the aerodynamic drag of different body positions in sport activities. The experiments were conducted in wind tunnel using different air speeds of 10, 15, 20, 25, and 30 mile per hour (4.47, 6.7, 8.94, 11.18 and 13.4 m/s). They measured the drag force for more than forty different positions for the model and the human. They reported various values for the drag coefficient according to the type of sport. For example, they reported drag coefficient of 0.64 to 0.79 for the running and 0.73 to 0.85 for the long jumping. In this study, they concluded that the drag coefficient is constant as the speed varies (14), which is not the case in other studies.

Murakami et al. (1999) analyzed the dynamic effects of wind on a human body by means of computational fluid dynamics (CFD) technique. They examined the wind effects on a human body under various wind conditions and evaluated the drag coefficient. The reported values of the drag coefficient in this study ranged from 1.08 to 2.06 (16).

Research Procedures

Research Methodology

In order to conduct this study, the researcher has selected the in purpose approach. This approach has proved to be the most suitable to the nature, problem and the objectives of the research.

Data Collection Tools

- Published literature and previous researches
- Measuring tape and digital scale
- Proposed new method

Research Samples

The researcher made use of the measurements of the physical dimensions of six players of 100-m sprint activities (all volunteers). The mean age of the participants was 22.5 years (SD = 1.64), the mean weight was 73.5 kg (SD = 1.87) and the average height was 1.85 m (SD = 1.43).

Method of Drag Coefficient Evaluation

Approximation to known shapes

The first step of the drag coefficient evaluation was to approximate the body of the runner into shapes of known and established aerodynamic characteristics so that each shape is having a measured and defined value of the drag coefficient along with its variation with the speed of the air flowing past it.

The average height of the body of the runner was used as 1.85 m. For each of the participants the circumference of the head was measured and then used to evaluate the diameter of the equivalent sphere, as the ratio of the circle circumference to the diameter is constant ratio equals to 3.14 (17:43). Also, the average circumference of the arm. chest, thigh and leg were measured and then used to evaluate the equivalent diameter of the cylinder as these elements were approximated as cylinders, as shown in figure 1.

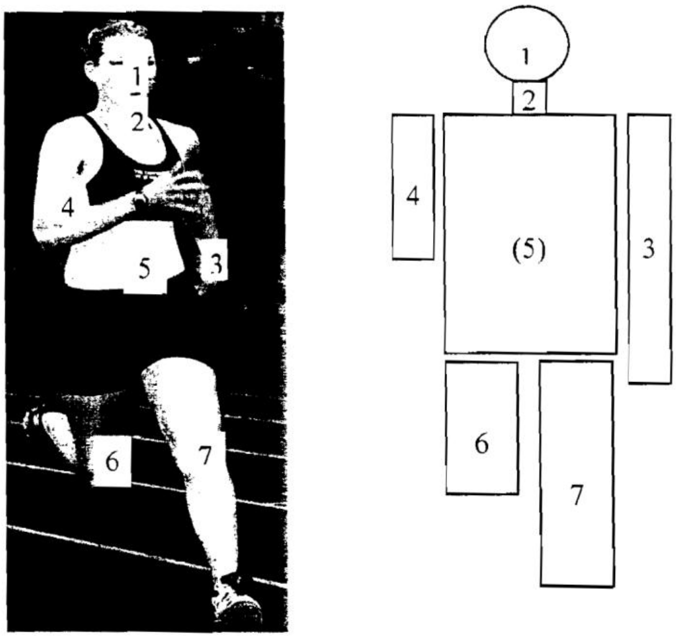

Figure 1 Approximation of the runner's body to known shapes

The average measurements and dimensions of each element of the shapes that are described and shown in figure 1 are listed in table 1. In case of the sphere representing the head, there is no value for the height. Each part used is given a number and its approximated shape is defined either sphere or cylinder.

Table 1 Description and average dimensions of each part

Number	Type	Shape	Circumference (m)	Diameter (m)	Height (m)
1	head	sphere	0.77	0.25	------
2	neck	cylinder	0.47	0.15	0.10
3	Left arm	cylinder	0.35	0.11	0.73
4	Right ami	cylinder	0.40	0.13	0.40
5	trunk	cylinder	1.10	0.35	0.80
6	Right leg	cylinder	0.62	0.20	0.40
7	Left leg	cylinder	0.55	0.18	0.70

Evaluation of Reynolds number

- Reynolds number is recognised as the important parameter in all fluid flow in sports. It was calculated from the expression (13:128):

$$Re = \frac{\rho l V}{\eta} = \frac{l V}{\nu} \qquad (1)$$

in this equation:

- I is the characteristic dimension of the flow
- V is the flow velocity relative to the body
- v is the coefficient of kinematic viscosity of the fluid (air)

In this study, the characteristic dimension of the sphere and cylinder is represented by the diameter (£>). The relative velocity V_r of the air moving past the runner was evaluated from the equation:

$$V_r = V_B \pm V_W \qquad (2)$$

where:

- V_B is the velocity of the runner's body, which is evaluated as the average distance of 100m divided by the average records of the event (7). It is used as 10.0 m/s.
- V_w is the wind speed in case of head wind and tail wind. According to the limits of the sprinting events, the wind speed is limited to ± 2 m/s.

In this study, the coefficient of kinematic viscosity (1.56xl0"^{5} m^2/s) was evaluated as the ratio of the coefficient of absolute viscosity of air (1.92xl0"^{5} Pa s) and the air density (1.23 kg/m^3) (13:125 & 158).

Evaluation of the drag coefficient of each part

- The head of the runner was approximated as sphere of diameter 0.25m.
- In order to evaluate the drag coefficient of the sphere, published data in a form of graph relating the drag coefficient to Reynolds number were used (18).
- The other parts are approximated as cylinders with the diameters listed in table 1.
- The wind speed was varied from 0.0 to 2 m/s (event limits) in both directions i.e. the head wind and the tail wind, with 0.25 m/s step of variation.
- The body velocity of 10.0 m/s was used along with the wind speed to evaluate the relative velocity required for equation (1).
- Then, Reynolds number was evaluated and used to check the graphs (18) to obtain the drag coefficient for each shape at the corresponding relative velocity.

Evaluation of the drag coefficient of the runner

- The value of the drag coefficient of each part of the seven parts forming the runner's body was evaluated at different relative air velocity.
- The projects area of each part was evaluated, using the dimensions listed in table 1, as (A = (TT/4) D^2) for the sphere and of the cylinder it was (A- D L) where n is 3.14, D is the diameter and L is the cylinder height.
- The product of the drag coefficient times the projected area of each part was evaluated.
- The total projected area was evaluated by summing the areas of the seven parts.
- The runner drag coefficient was then evaluated, at the different relative air velocity, from the expression:

$$C_d = \frac{\sum_{i=1}^{i=7} C_{d_i} A_i}{A_{total}}$$

Results

The projected area

The projected area of each part was evaluated and the results are shown in table 2.

Table 2 Projected area of each part

Head	Neck	Left Arm	Right Arm	Trunk	Right Leg	Left Leg	Total
A,	A_2	A_3	A_4	A_5	A_6	A_7	A_{tot}
0.0491	0.015	0.0803	0.052	0.28	0.08	0.126	0.6824

Drag coefficient of each part

The drag coefficient of each part was evaluated as a function of the relative air velocity. The results are shown in table 3.

Table 3 Drag coefficient of each part

Relative velocity	Head	Neck	Left Arm	Right Arm	Trunk	Right Leg	Left Leg
V_r (m/s)	C_{d1}	C_{d2}	C_{d3}	C_{d4}	C_{d5}	C_{d6}	C_{d7}
8.00	0.515	1.005	1.080	1.043	0.969	1.010	1.008
8.25	0.515	1.005	1.075	1.040	0.962	1.010	1.008
8.50	0.515	1.005	1.070	1.038	0.955	1.010	1.008
8.75	0.515	1.005	1.065	1.035	0.942	1.010	1.008
9.00	0.515	1.005	1.060	1.033	0.928	1.010	1.008
9.25	0.515	1.005	1.055	1.030	0.923	1.005	1.005
9.50	0.520	1.005	1.050	1.027	0.916	1.005	1.005
9.75	0.520	1.005	1.045	1.025	0.889	1.005	1.005
10.00	0.520	1.005	1.040	1.022	0.864	1.000	1.002
10.25	0.520	1.000	1.035	1.017	0.857	1.000	1.000
10.50	0.520	0.999	1.035	1.017	0.852	0.995	0.997
10.75	0.520	0.998	1.030	1.014	0.840	0.990	0.994
11.00	0.520	0.996	1.030	1.013	0.828	0.985	0.991
11.25	0.520	0.994	1.025	1.010	0.815	0.985	0.990
11.50	0.520	0.992	1.025	1.008	0.796	0.980	0.986
11.75	0.520	0.989	1.020	1.004	0.782	0.980	0.984
12.00	0.520	0.985	1.020	1.003	0.770	0.975	0.980

Drag coefficient of the runner

The drag coefficient variation of the runner as a function of the relative air velocity and wind speed is shown in table 4. The positive values of the wind speed referred to the tail wind condition and the negative values are for the head wind conditions.

Table 3 Drag coefficient of each part

Wind speed V_w (m/s)	**Relative velocity V_r (m/s)**	**Drag coefficient of runner**
2.00	8.00	0.968
1.75	8.25	0.964
1.50	8.50	0.961
1.25	8.75	0.954
1.00	9.00	0.948
0.75	9.25	0.944
0.50	9.50	0.941
0.25	9.75	0.929
0.00	10.00	0.916
-0.25	10.25	0.912
-0.50	10.50	0.909
-0.75	10.75	0.902
-1.00	11.00	0.896
-1.25	11.25	0.889
-1.50	11.50	0.880
-1.75	11.75	0.873
-2.00	12.00	0.867

Correlation of the drag coefficient with relative velocity

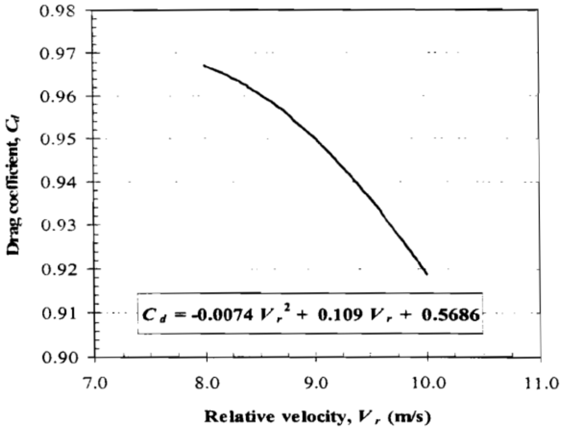

Figure 2 Variation of the drag coefficient of runner with relative air velocity (tail wind)

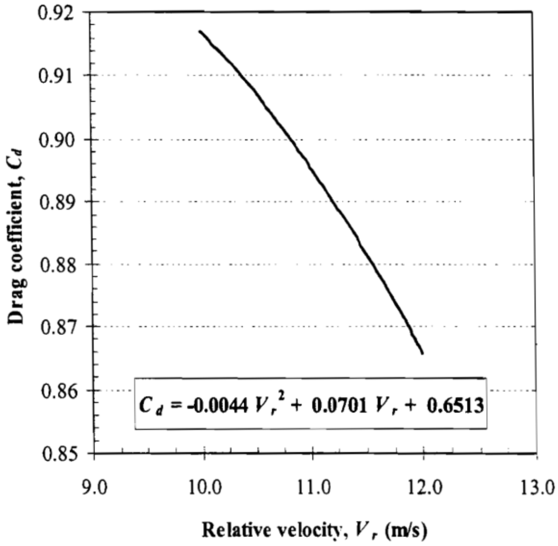

Figure 3 Variation of the drag coefficient of runner with relative air velocitj' (head wind)

Discussion

Projected area

The total projected area, table 2, of the approximated runner's body is evaluated as 0.6824 m^2. This area comes close to the value of the runner's projected area of 0.5 m^2 reported by Frohlich (19) and 0.51 m~ of Quinn (20). Also, the ratio of this area to the square of the height of runner (1.85 m) is found to be 0.2, which is about 30% higher than the value of 0.15 reported by Hill (12).

Drag coefficient of each part

The results of the drag coefficient shown in table 3, shows nearly constant drag coefficient of the sphere (representing runner's head) with the relative air velocity. In case of each part represented by cylinder, the drag coefficient was found to decrease with the air velocity. These values are based on the experimental results of wind tunnel experiments.

Drag coefficient of the runner

The values of the runner's drag coefficient are listed in table 4. The results show that the drag coefficient varied from 0.867 to 0.968. These values shows that some of the previous studies produced overestimated values such as Pugh who reported drag coefficient of 1.5 (13) and Murakami et al. who reported higher values ranged from 1.08 to 2.06 (16). On the other hand, other studies produced underestimated values such as Walpert and Kyle who reported drag coefficients in the range of 0.64 to 0.79 (14) and Hill who reported considerably lower value of 0.45 (12). The findings of this study are therefore in good consistency with the findings of Van Ingen Schenau who reported drag coefficient in the range of 0.79 to 0.99 (15).

The results also show that the drag coefficient varied from 0.968 at tail wind of 2 m/s to 0.867 for head wind of the same magnitude. This clearly shows the reduction of the drag coefficient with the relative air velocity, which is consistent with the finding of Van Ingen Schenau (15) and contradicts the findings of Walpert and Kyle who claimed constant drag coefficient throughout (14).

Correlation of the drag coefficient with relative velocity

The values of the drag coefficient were used to correlate the variation of the drag coefficient with the relative air velocity in both cases of the tail and head wind conditions, as shown in figures (2) and (3). The results of the tail wind conditions show reduction of the drag coefficient with the relative air velocity which was described by the relation:

$$C_d = -0.0074\ V_r^2 + 0.109\ V_r + 0.5686 \qquad (4)$$

Also, the results of the head wind conditions show same behaviour with the relative air velocity which was described by the relation:

$$C_d = -0.0044\ V_r^2 + 0.0701\ V_r + 0.6513 \qquad (5)$$

Conclusions

This study presents new method used to evaluate the variation of the drag coefficient with the runner's relative velocity. The results of this method show that:

1- The total projected area of the approximated runner's body is 0.6824 m2. The ratio of this area to the square of the height of runner (1.85 m) is 0.2.
2- The drag coefficient of the sphere (representing runner's head) is constant with the relative air velocity. For cylinders, the drag coefficient decrease with the relative air velocity.
3- The drag coefficient varied from 0.867 to 0.968.
4- The drag coefficient varies from 0.968 at tail wind of 2 m/s to 0.867 for head wind of the same magnitude. This clearly shows the reduction of the drag coefficient with the relative air velocity.

Recommendations

5- The results of this study can be used to evaluate the drag forces acting on athletes in sprinting events.
6- Other wind speeds can be used to evaluate the drag coefficient.
7- The correlations in this study can be used to investigate the effects of the drag forces on the runners' performances.
8- Other positions during the running event can be studied using the new method.

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طريقة جديدة لتقدير معامل الإعاقة لمتسابقي ١٠٠ متر عدو

أ.م.د انتصار عباس خوجلي محمد نور

أهداف البحث

- وصف طريقة جديدة لتقدير معامل الإعاقة
- تقدير نماذج تغيير معامل الإعاقة مع السرعة النسبية للعداء
- الحصول على العلاقات التي تربط معامل الإعاقة مع السرعة النسبية للعداء

إجراء البحث

استخدمت الباحثة المنهج الوصفي نظراً لملائمته لطبيعة ومشكلة وأهداف البحث

استخدمت الباحثة ٦ لاعبين متطوعين من متسابقي ١٠٠ متر عدو للحصول على القياسات الجسمية اللازمة لتنفيذ طريقة تقدير معامل الإعاقة

النتائج

١. المساحة الإسقاطية لجسم العداء المقرب لأشكال معلومة معامل الإعاقة كانت ٠.٦٨٢٤ متر مربع. والنسبة بين هذه المساحة وبين مربع الطول المتوسط للاعب (١.٨٥ متر) هي ٠.٠٢.

٢. معامل الإعاقة ثابت للكرة (التي تمثل رأس العداء) مع السرعة النسبية. أما في حالة الأسطوانة (التي تمثل باقي أجزاء الجسم) فإنه يقل مع زيادة سرعة الهواء النسبية.

٣. معامل الإعاقة يتغير من ٠.٨٦٧ إلى ٠.٩٦٨.

٤. معامل الإعاقة يتغير من ٠.٩٦٨ في حالة رياح خلفية مقدارها ٢.٠ م/ث إلى ٠.٨٦٧ في حالة رياح أمامية مقدارها ٢.٠ م/ث.