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Kinematical Approaches for Hydrodynamic Force Assessments

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Abstract: A new mathematical model for studying hydrodynamic force was developed. The purpose of this study was to present a simple, inexpensive, reliable and less complicated method. In order to verify the proposed model, 5 male recreational swimmers ranging in age from 20 to 25 years and in mass from 71 to 82 Kg. have been served in our study. They were requested to swim a 10-meter distance as fast as they could and three to five trials with enough rest in between. They have also been instructed to glide at end of 10m swim, by whistling, until still position. The time of 10m swim and the glided distance were measured with reasonable precision (10^{-2} Sec 10^{-2}m respectively). One of the elite subjects was requested to perform swimming with different speeds in order to achieve different characteristic curves as model. The data collected were then used in the proposed formulae in different approaches for achieving velocity, acceleration, propulsive or resistive forces of the subjects. The results obtained agreed well with the results obtained by the other researchers with complicated and expensive systems.

Key Words: Mathematical Model, Indirect, Velocity, Acceleration, Propulsive Force, Assessment

Introduction

Since the human body, like the shape of ship, presents an additional difficulty in the sense that it moves in the boundary plane between two media: water and air, whereby changes in flow also cause changes in the level of the boundary plane (waves). In other words, the problems are much more complex than those of a body moving in a single medium. If we add to these problems the uneven and poorly streamlined shape of the human body plus its possibility for self-propulsion, then the problems seem endless.

Resistance and propulsive forces that human body either undergoes and/or originates can be measured directly; the resistance can be derived from the propulsive force and vice versa and is always a function of the velocity. The forces of man's hydrodynamic locomotion can also be described in terms of mathematical analyses of the body's shape and movement (Seireg and Baz, 1971; Miyashita, 1974; Francis and Dean, 1975; Jensen and Blanksby, 1975). The complicated procedures of these studies deviate, however, from the direct hydrodynamic considerations of this discussion. Also, their results are still hypothetical and have not been tested against the actual hydrodynamic forces. Early measurements involved indirect calculations of active resistance with additional drag loaded onto the swimmer (Clarys, 1979; diPrampero *et al.*, 1974; Pendergast *et al.*, 1978; Rennie *et al.*, 1975). In the study of the hydrodynamic resistance of a moving human body, two types of resistance must be considered. Passive resistance, that is the amount of water resistance that a body experiences in an unchanged posture, during passive towing or during exposure to water flow in a water flume and when performing gliding without movements, while active resistance is the water resistance associated with the swimming motion.

Materials and Methods

Studies to determine the propulsive force of a moving body in water can be classified according to four different approaches as described below. The first approach is propulsive force recording of a body moving in one spot (at zero speed), which is also referred to as tethered swimming. (Houssay, 1912) studied the propulsive force of five untrained subjects, whom he connected to increasing amounts of weight via a rope and pulley system. Subjects had to swim until the added weights prevented them from moving forward. The principle of this method corresponds to the maximum force recording of a body moving at zero velocity and has been used subsequently to measure the force of arm and leg movements separately, together with the maximum propulsive force. The weight system, however was replaced by a spring dynamometer system, whereas a kymograph and more recently a series of potentiometers were used for recording. (Mosterd, 1960; Mostered and Jongbloed, 1962; Safarian, 1968; Gordon, 1969; Zaciorsky and Safarian, 1972; Malzahn and Stafenk, 1973).

The second approach to assess the amount of propulsive force developed is the measurement of energy consumption during locomotion. This technique can be either combined with previously mentioned propulsive force recordings or simply examined as a function of time and distance (without propulsive force recording). (Anderson, 1960; Adrian, Singh, and Karpovich, 1966; Costill, 1966; Magel and McArdle, 1970; Holmer, 1971, 1972, 1974a and b, 1975; Rennie *et al.*, 1972; Rennie Pendergast, and diPrampero, 1975; Kemper *et al.*, 1976).

The third approach is Measuring Active Drag (MAD) system (Toussaint *et al.*, 1988 and 1990). The MAD system is based on measuring the mean propulsive force only on front crawl. The swimmer pushes off against grips, which are attached to a tube located 0.8 m under the water surface. Tube being fixed to a force transducer thus the force a swimmer applies during push-off is registered. This system measures mean propulsive force, F_P , which is equal to the mean active drag force, F_{DA}, and the authors found the mean propulsive force at a swimming velocity of 1.48 $m.s^{-1}$ appeared to be 53,2 ± 5.8 **N**, which is in agreement with values reported for passive drag on a towed swimmer(Fig. 1).

The fourth approach is the Velocity Perturbation Method (Kolmogorov and Duplisheva, 1992). This method involves changing in maximal swimming velocity using added drag provided by hydrodynamic body of known resistance towed by the swimmer. Swimmers perform two maximal velocity swims of 30m with and without the hydro dynamic body. Hydrodynamic body is consisted of carrying body (made of foamplast); kniveposts; hydrodynamic cylinder (made of light metal); fixing hook for ropes. To avoid turbulent, the hydrodynamic body was at a critical distance of 3.5-4.5 swimmer body length Fig. 2.

Swimmer speed, and the resistance force, F, were measured during both swims. The assumption has been made by authors that the power output during swimming without the hydrodynamic body is equal to the power output delivered when swimming with it. The drag force is estimated by:

Where F_b represents the added drag due to the hydrodynamic body, V_1 and V_2 are the average 30m velocities of the first swim (without hydrodynamic body) and second swim (with hydrodynamic body), respectively.

Proposed Theoretical Indirect Measurement: The swimmers speed can be ranged from 0.8 $m.s^{-1}$ to 2.2 $m.s^{-1}$.Three theoretical approaches for determination of body characteristics are proposed and described below.

1-The first approach; water resistance proportional to Velocity, V

1-a: Determination of propulsive force; F_P

The differential equation can be written as:

$$F_D = F_b V_2 V_{1,} / (V_{1,} - V_{2,}) \qquad (1)$$

$$F_P - C_1V = M\ dV/dt \qquad (2)$$

At limit speed (the maximum speed attained by swimmer), $V=V_L$, the acceleration becomes zero, then we have;

$$F_P = C_1V_L \qquad (3)$$

Inserting 3 into 2 we get;

$$C_1(V_L - V)=M\ dV/dt \qquad (4)$$

In integral form;

$$\int_0^t C_1/M.\ dt = \int_0^v dV/\ (V_L - V) \qquad (5)$$

Integrating both sides (at t=0, V0=0);

$$C_1/M.t = - Ln\ [(V_L - V)/\ V_L] \qquad (6)$$

In exponential form is;

$$(V_L - V)\ /\ V_L = Exp\ (-C_1t\ /M) \qquad (7)$$

Solving for V, we get;

$$V=V_L(1-Exp-(C_1t/M)) \qquad (8)$$

This relation is showing that the behaviour of the body velocity in water is exponential and depending upon the maximum (limit) speed, and varies with time. After a certain time (with V0 = 0) the exponential term vanishes and the instantaneous speed is equal to limit speed. 8 can be written for V_L;

$$V_L=V/(1- Exp(-C_1t\ /M))=V(1+ Exp(-C_1t\ /M)) \qquad (9)$$

Because $C_1t\ /M>1$. Inserting 9, into the 3, we will get for the propulsive force as;

$$F_P=C_1\ V(1+ Exp(-C_1t\ /M)) \qquad (10)$$

Where V is the instantaneous velocity and 10, shows how the propulsive force is developing with time until the exponential term vanishes, but when it is considered as the mean velocity of the body in a 10m distance swim, then the mean propulsive force is estimated, t, is the time measured for this distance.

1-b: Determination of C_1

The swimmers are instructed so that, at the end of the 10m swim to stop swimming and just keep gliding until still position. They are also requested to stretch their body and get their body stream lined, to not introduce extra drag force. Since during gliding no propulsive force is exerted, the differential equation 2, becomes;

$$- C_1V=M\ dV/dt \qquad (11)$$

11 can be written in appropriate form for integrating;

$$-\int_0^t C_1/M.dt = \int_{V_L}^{V} dV/\ V \qquad (12)$$

Integrating, yields;

$$V=V_L\ Exp\ (-C_1t\ /M) \qquad (13)$$

This equation shows that when t becomes large (20 Sec.or more), the speed tends to zero, which is valid in reality. In order to determine C_1, we rewrite 13, as;

$$dX/dt = V_L\ Exp\ (-C_1t\ /M) \qquad (14)$$

integrating 14, we get;

$$X= (V_LM/C_1)(1- Exp(-C_1t\ /M)) \qquad (15)$$

Infact X is the glided distance and when t, tends to a larger values then X tends to; V_LM/C_1 from which we can extract C_1;

$$C_1=V_L.M\ /\ X \qquad (16)$$

Inserting the value of V_L into 16, we have;

$$C_1=(MV/X)(1+ Exp(-C_1t\ /M)) \qquad (17)$$

Expanding the term in potential, since (C_1t/M)>1, then we have;

$$XC_1/MV=2 - C_1t/M \qquad (18)$$

Solving for C_1, we will have;

$$C_1=2MV/(X + V t) \qquad (19)$$

Where t; time of 10m swim, X; glided distance,V; mean velocity in 10m swim. From dimensional point of view, 19 presents the same dimension as in, C_1V. In fact we can replace (Vt) by 10m,and 19 becomes;

$$C_1=2MV/(X + 10) \qquad (20)$$

2-The second approach; water resistance proportional to squared velocity, V^2

2-a: Determination of propulsive force; F_P

The differential equation is in the form;

$$F_P - C_2V^2 = M.\ dV/dt \qquad (21)$$

At limit speed the acceleration becomes zero, then;

$$F_P = C_2V_L^2 \qquad (22)$$

21 is then written as;

$$C_2(V_L^2- V^2) = M\ dV/dt \qquad (23)$$

23 can be rewritten as;

$$(C_2/M).dt = dV / (V_L^2- V^2) \qquad (24)$$

Integrating, we have;

$$\int_0^T(C_2/M).dt =\int_0^V dV / (V_L- V^2) \qquad (25)$$

At t=0, the swimmer's speed is considered zero. Integrating 25, yields;

$$C_2t/M = (1/2V_L)\ Ln((V + V_L) / (V - V_L)) \qquad (26)$$

26 can be written in exponential form as;

$$V_L-V = (V+V_L)\ Exp.(-2C_2V_Lt /M) \qquad (27)$$

Rearranging 27, we get;

$$V_L / V = (1+ Exp.(-2C_2V_Lt /M)) / (1- Exp.(-2C_2V_Lt /M)) \qquad (28)$$

We can again here notice that the behaviour of instantaneous velocity is exponential and that after certain time the exponential terms vanish and the limit speed is attained. As an assumption, we take the linear part of the exponential terms in both nominator and denominator , then we have ;

$$V_L / V = (1- (C_2V_Lt/M)) / (C_2VLt/M) \qquad (29)$$

Rearranging, we get;

$$V_L^2- V.V_L- M / (C_2t) = 0 \qquad (30)$$

Solving 30 for VL, we can have for limit speed the following relationship;

$$|V_L| =0.5\ \{V+ \sqrt{(V^2+4MV/(C_2t))}\ \} \qquad (31)$$

2-b: Determination of C_2

The swimmer is not applying force in gliding phase, therefore the differential equation 21, becomes;

$$- C_2V = M\ dV/dt \qquad (32)$$

in integral form;

$$\int_0^t - (C_2/M)dt =\int_{V_L}^{V} dV/ V^2 \qquad (33)$$

The integration yields;

$$C_2t/M=(1/V-1/V_L) \qquad (34)$$

Solving for V, gives;

$$V=MV_L/(C_2V_L\ t+M) \qquad (35)$$

Replacing V by dX/dt, 35 in integral form becomes;

$$\int_0^X C_2V_LdX= (M/C_2)\int_0^t C_2V_Ldt/((M/C_2V_L)+M) \qquad (36)$$

Integrating 36, gives;

$$X=(M/C_2)Ln(1+(C_2V_L\ t/M)) \qquad (37)$$

where X is the glided distance. Since $(C_2V_Lt /M)\gg 1$, then 1 is negligible and 36 can be written in exponential form and after expanding the exponential term we get;

$$M/(C_2.V_L\ .t)=1-(C_2X/M) \qquad (38)$$

Solving 38, for X, we will have;

$$X=(M/C_2)-M^2/(C_2^2V_L.t)=(M/C_2)(1-M/(V_L.C_2.t)) \qquad (39)$$

When t, tends to 30 Sec. or more, the second term on the right hand becomes negligible and therefore we can have;

$$C_2=M/X \qquad (40)$$

3- The third approach; the water resistance proportional to both, C_1V and C_2V^2.

The differential equation is presented under its general form;

$$F_P-C_1V-C_2V^2 =M.\ dV/dt \qquad (41)$$

At limit speed 41 becomes;

$$F_P=C_1V_L+C_2V_L^2 \qquad (42)$$

Inserting in 41, and arranging we get;

$$C_1(V_L-V)+C_2(V_L^2-V^2)=MdV/dt \quad (43)$$

In integrating form:

$$\int_0^t dt/M=\int_0^V dV/((V_L-V)(C_1+C_2(V_L+V)) \quad (44)$$

Integrating by part yields;

$$t/M=\int_0^V dV/((C_1+C_2V_L)(V_L-V))+\int_0^V dV/(V_L\,(C_1+C_2(V_L+V)) \quad (45)$$

$$t/M=(-1/(C_1+C_2V_L))\,[Ln(V_L-V)]_0^V + (1/(C_2V_L))[\,Ln(C_1+C_2\,(V_L+V))]_0^V \quad (46)$$

$$t/M=(-1/(C_1+C_2V_L))[Ln(V_L-V)-V_L]+(1/(C_2V_L)\,[Ln(C_1+C_2\,(V_L+V))-Ln(C_1+C_2V_L)] \quad (47)$$

Rearranging yields;

$$t/M=(-1/(C_1+C_2VL))Ln(1-V/VL)+(1/(C_2V_L))\,Ln[(C_1+C_2\,(V_L+V))/\,(C_1+C_2V_L)] \quad (48)$$

Second term on the right side can be ignored as in reality it is about one hundredth of the first term, therefore we can have;

$$t/M=(-1/(C_1+C_2V_L))Ln(1-V/V_L) \quad (49)$$

In exponential form:

$$(1-V/V_L)=Exp-(\,C_1+C_2V_L)t/M \quad (50)$$

Solving for V, we get;

$$V=V_L(1-\,Exp.-(\,C_1+C_2V_L)t/M) \quad (51)$$

51, shows that the subject's velocity, in this case has also an exponential behaviour which agrees well with reality. Developing the exponential term we get;

$$V=V_L(1-\,1+.(\,C_1+C_2V_L)t/M)) \quad (52)$$

Finally the limit speed can be calculated as;

$$|VL|=0.5\{C_1/C_2+\sqrt{((C_1/C_2)^2+(4MV)/(tC_2))}\} \quad (53)$$

C_1 and C_2 should be calculated as it was indicated before in their own phases, V is the mean velocity, t is the time measured for 10m swim. For determination of C_1 and C_2, we should use the same time and glide distance measurements for both cases in order to calculate the propulsive force. For each approach we could find the corresponding acceleration. In fact derivation of equations; 8, 28, 51, will give us the acceleration in each approach:

$$a_1=(C_1V_L1/M)(Exp-(C_1t/M) \quad (54)$$

$$a_2=(4C_2V_{L2}/M)(Exp-(2C_2V_L2t/M) \quad (55)$$

$$a_3=((C_1V_{L3}+C_2V_{L3}^2)/M)(Exp-(C_1+C_2V_{L3})t/M) \quad (56)$$

Time measurement was carried out by two skilled swimmers and with electronic Start-Stop watch with the precision of 10^{-2} Sec., the glided distance was measured with Tape measure with the precision of 10^{-2} meter.

Results and Discussion

A mathematical study allowed to define formulae in different approaches. The simple measurements of time of 10 m swim and the glided distance were necessary to be used in these formulae, in order to achieve the variations of velocity, acceleration and hydrodynamic force.

In Table 1, subject No. 1, is the lightest subjects in present study, has bigger values of mean and maximum velocities in first and second approaches and has still reasonably high value in third approach. His hydrodynamic force is also high in three approaches. Subject No. 5, who is 10 Kg heavier, has shown smaller mean. Maximum and hydrodynamic force magnitudes in all approaches. This means that the subject's mass is an important factor in hydrodynamic characteristics computations. No researchers have reported the possible effects of mass in their estimation of hydrodynamic forces.

In Table 2, the characteristics of a selected elite subject in different speeds are shown. He was requested to perform different types of swimming such as; legs only, hands only and both together and with and without fins and paddles. The subject could present the speed of 0.9 to 1.84 ms^{-1} as mean velocities. We can notice that in all three approaches the higher the speed is, the higher are the values of hydrodynamic force and the hydrodynamic coefficient C_1. On the contrary, the values of hydrodynamic coefficient C_2 , decrease with the increase of the speed.

In Fig. 1, the variation of velocities in different approaches are presented. In first approach (series 1), the swimmer actually reaches to his maximum speed after 17 seconds. This means that the swimmers in 10m swim, will never reach to their maximum speed. In second approach (series 2), the swimmer reaches actually to his maximum speed after 6 seconds, but the value of maximum speed seems to be high, such that the curve of first approach will never reach it. In the third approach (series 3), the swimmer reaches to his maximum speed actually after 7 seconds. The magnitude of the maximum speed is such that the curve of first approach can finally be reached. This means that the swimmer's maximum speed is definitly V_{L3} (Table 3), and is certainly reached by third approach in shorter time.

In Fig. 2, the variation of accelerations relative to time is presented. As can be seen in second and third approaches the swimmer swims with uniform velocity where according to the Newton's first law, he experiences no horizontal force, that is,

Table 1: Subjects Characteristics Values ± SD

Subjects No.	Body Mass (Kg)	Time of-10m Swim (Sec.)	Gliding-Dist. (m)	Mean-Velocity (ms^{-1})	Limit Speed V_{L1} (ms^{-1})	Limit Speed V_{L2} (ms^{-1})	Limit Speed V_{L3} (ms^{-1})	C1 $(N.S.Kg^{-1})$	C2 $(N.S^2.Kg^{-2})$	FP1 (N)	FP2 (N)	FP3 (N)
1	71	6.24	5.79	1.60	2.05	2.26	1.94	14.47	12.31	29.73	62.92	74.50
		0.03	0.34	0.01	0.01	0.03	0.48	0.33	0.70	0.58	2.20	0.43
2	73	6.25	5.74	1.60	2.05	2.25	1.93	14.75	12.63	30.23	64.15	75.50
		0.06	0.36	0.02	0.03	0.04	0.42	0.33	0.80	0.67	2.25	1.74
3	75	6.37	6.60	1.57	2.02	2.25	1.97	14.52	12.14	29.34	61.10	75.57
		0.10	0.28	0.02	0.04	0.05	0.30	0.17	0.55	0.64	1.18	2.57
4	79	6.72	5.98	1.49	1.92	2.12	1.84	14.70	13.20	28.18	59.10	71.58
		0.24	0.44	0.05	0.08	0.11	0.14	0.17	0.94	1.50	2.12	5.98
5	82	6.74	5.74	1.48	1.90	2.09	1.79	15.42	14.25	29.30	62.17	73.17
		0.14	0.36	0.03	0.04	0.05	0.06	0.48	0.90	1.32	3.33	3.16

Table 2: Characteristics of a Selected Swimmer ± SD

Type of Swimming	Body Mass (Kg)	Time of-10m Swim (Sec.)	Gliding-Dist. (m)	Mean-Velocity (ms^{-1})	Limit Speed V_{L1} (ms^{-1})	Limit Speed $V_{L2}(ms^{-1})$	Limit Speed V_{L3} (ms^{-1})	C1 $(N.S.Kg^{-1})$	C2 $(N.S^2.Kg^{-2})$	FP1 (N)	FP2 (N)	FP3 (N)
Legs-only	79	10.97	4.55	0.91	1.14	1.22	0.96	9.90	17.36	11.30	25.90	25.60
		0.03	0.34	0.01	0.01	0.03	0.48	0.33	0.70	0.58	2.20	0.43
Legs + Fins	79	9.09	5.10	1.i0	1.32	1.44	1.30	11.10	15.32	19.80	31.90	38.80
		0.06	0.36	0.02	0.03	0.04	0.42	0.33	0.80	0.67	2.25	1.74
Hands-only	79	7.86	5.71	1.27	1.63	1.79	1.53	12.79	13.48	20.82	44.25	51.87
		0.10	0.28	0.02	0.04	0.05	0.30	0.17	0.55	0.64	1.18	2.57
Hands+ Paddles	79	7.20	6.25	1.38	1.81	2.03	1.82	13.02	12.25	23.73	48.25	62.46
		0.24	0.44	0.05	0.08	0.11	0.14	0.17	0.94	1.50	2.12	5.98
Both (L& H)	79	6.72	6.15	1.48	1.91	2.12	1.87	14.72	13.20	28.20	59.10	71.58
		0.14	0.36	0.03	0.04	0.05	0.06	0.48	0.90	1.32	3.33	3.16
Both + Fins	79	5.60	6.48	1.78	2.31	2.58	2.30	17.11	12.20	39.60	81.35	103.9
		0.24	0.44	0.05	0.08	0.11	0.14	0.17	0.94	1.50	2.12	5.98
Both + (Fi+Pa)	79	5.34	6.34	1.84	2.38	2.65	2.34	17.84	12.50	45.52	87.89	110.4
		0.14	0.36	0.03	0.04	0.05	0.06	0.48	0.90	1.32	3.33	3.16

the propulsive force equals the resistive hydrodynamic force. On the contrary, in the first approach, the swimmer needs more time to reach his maximum speed. Second approach represents an incredibly big force for starting (4.5 x 79=355.5N), while in third approach the starting force is about (1.5 x 79=118.5 N) which seems to be reasonable, and can be expected as explosive force from swimmer.

In Fig. 3, 4, and 5, show the instantaneous variations of velocity and acceleration together with time. As can be seen, when the acceleration is zero, the uniform velocity commences.

Fig.6, represents the variation of propulsive or hydrodynamic force relative to mean velocity. This figure supports the fact that, the higher the speed is, the larger the propulsive force should be applied. Fig. 7 represents the variation of force relative to time. The upper curve corresponds to the second approach and shows that the swimmer should apply an immense force to start a 10m swim to reach 1.84 ms^{-1} as mean velocity. Table 3, presents a comparison between the hydrodynamic forces obtained in this study and those reported by other researchers. At the speed of 0.9 ms^{-1} the result obtained by present study agreed well with what has been obtained by Holmer (1974), and at 1.5 ms^{-1} with what was reported by Jiskoot and Clarys, (1974), but is much greater than the results obtained by Toussaint *et al*,. (1988-1990), with MAD system. The results obtained by this study disagreed with the results reported by Kolmogorov *et al.*, (1992-1997).

Conclusion

Comparison of the three approaches results showed that the maximum speeds and hydrodynamic forces are for higher mean velocities. The difference between limit speeds in first and third approaches were negligible and support the fact that third approach is one we should consider as a final tool for determination of swimmers characteristics. In addition comparison revealed that, although the curves of second and third approaches had the same general form, there were some marked difference between them. The mean velocity had a pronounced effect on the magnitudes of the hydrodynamic force and coefficients computed.

It seems obvious that additional research is necessary to establish the exact approach. A Three Dimensional Analysis would be enough to verify the subject's speed when arriving at the end of 10m swim. However, current information and empirical evidence indicate that third approach can produce results compared, at some stand, to the results reported by researchers with different methods.

Although there are a number of reasons which can account for superiority of third approach, a major problem deals with mechanical specificity. Considering the evidence that specificity of third approach results in a more reasonable data obtained, Three Dimensional Analysis should produce a more precise results with its complexity. The present study offers inexpensive, reliable, not complicated and very easy to use method.

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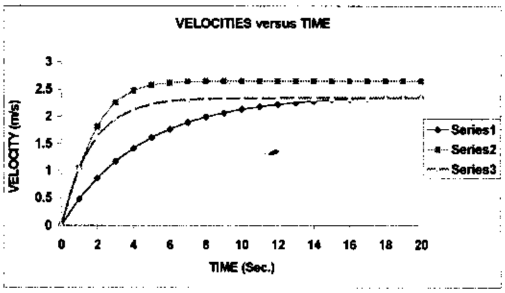

Fig.1: The Variation of Velocities in Different Approaches with Time

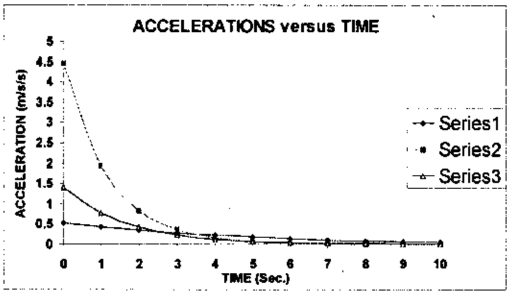

Fig.2: The Variation Acceleration in Different Approaches with Time

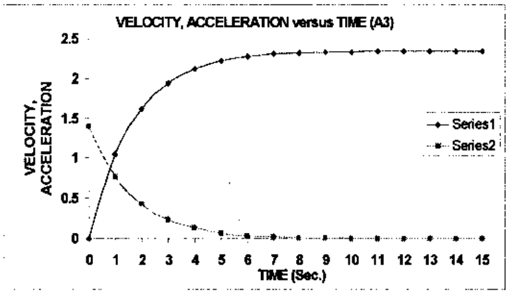

Fig. 3: The Variation of Velocity and Acceleration with Time in First Approach

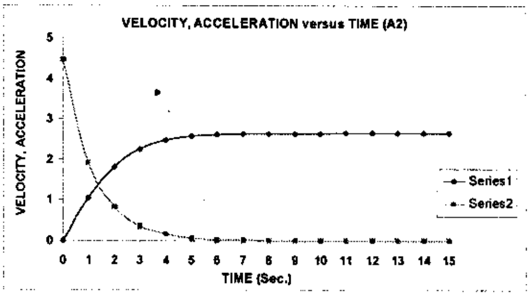

Fig.4: The Variation of Velocity and Acceleration With Time in Second Approach

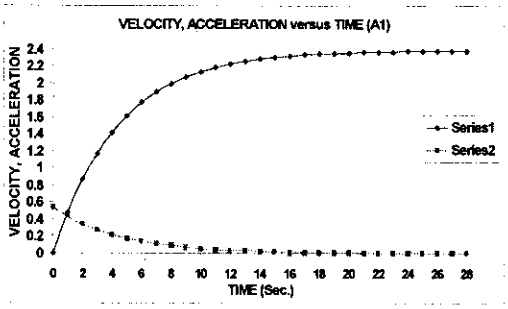

Fig. 5: The Variation of Velocity and Acceleration in Third Approach with Time

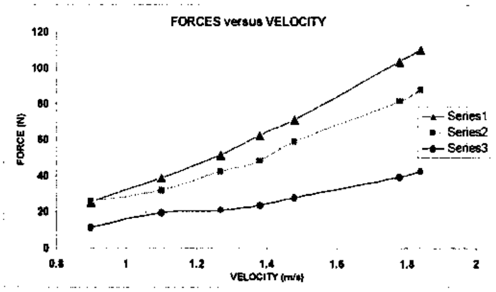

Fig. 6: The Variation of Forces in Different Approaches with Velocity

Table 3: Comparison Mean Drag Values Obtained by Different Methods

Type of Study	Year	Gender M/F	Drag Force (N)	Mean Velocity ms^{-1}
Passive Measurement:				
Schramm, E.	1958/1959	M	80.60	1.70
Zaclorsky and Safarjan	1972	M	64.30	1.60
Malzahn and Stafenk	1973	M	63.60	1.30
Jiskoot and Clarys	1974	M	65.70	1.50
Holmer, H.	1974	M	26.30	0.90
Estimate Active Drag				
Rennie *et al.*	1975	F	76.20	1.20
Rennie *et al.*	1975	M	89.30	1.20
Holmer	1974	M	36.70	0.90
Clarys, J., P.	1978	M	120.00	1.40
Film Analysis				
Schleihauf *et al.*	1983	M	75.40	1.70
MAD - System				
Hollander *et al.*	1986	M	62.80	1.50
Hollander *et al.*	1987	F	45.30	1.40
Van der Vaart *et al.*	1987	M	53.20	1.50
Toussaint *et al.*	1988/1990	M	53.20	1.48
Toussaint *et al.*	2002	F	25.49	1.10
//	//	M	29.95	1.10
//	//	F	37.45	1.30
//	//	M	43.79	1.30
//	//	F	52.22	1.50
//	//	M	60.63	1.50
//	//	F	69.97	1.70
//	//	M	80.70	1.70
Velocity Perturbation Method				
Kolmogorov *et al.*	1997	M	28.00	1.50
//	//	M	43.20	1.60
//	//	M	63.50	1.70
Theoritical Indirect	Present	M	25.60	0.90
Method	//	M	51.87	1.27
Shahbazi and Sanders	//	M	62.46	138.00
//	//	M	71.58	1.48
//	//	M	75.25	1.60
//	//	M	103.90	1.78

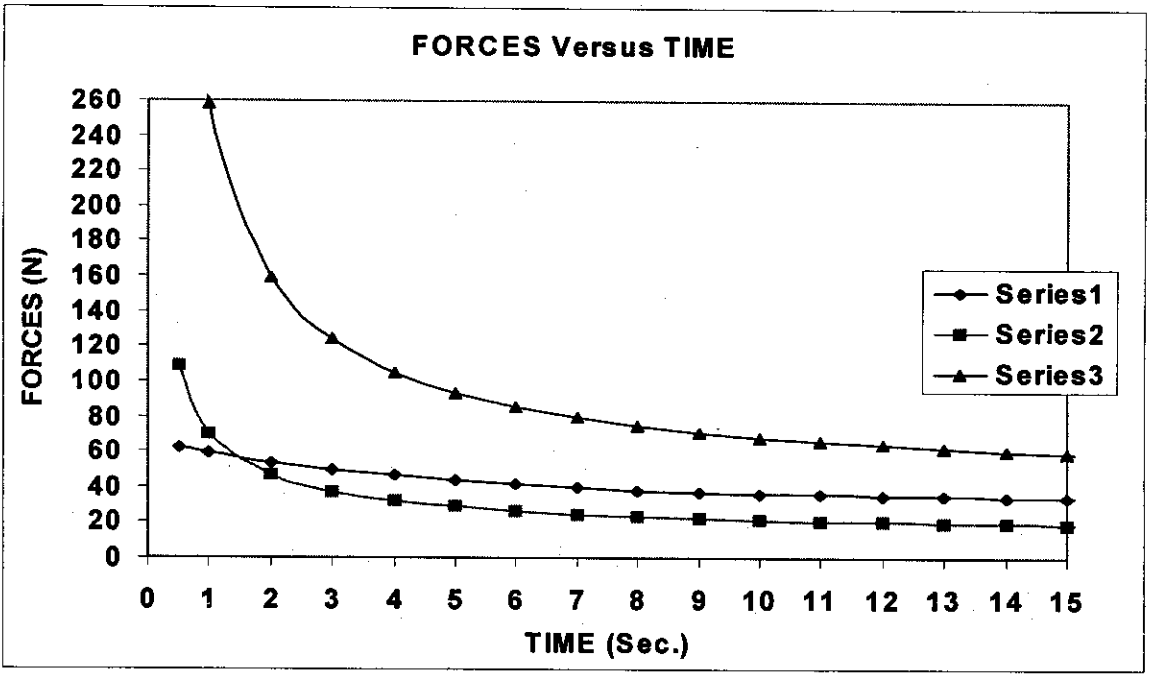

Fig. 7: The Variation of Forces in Different Approaches with Time

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