The retrospective comparison of Olympic rowing results considering weather

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Abstract. The purpose of the paper is comparing the rowing results in different aero- and hydrodynamics conditions. We analyzed the winners' results of the single sculls (1x) men finals at the Olympic Games regattas from Sydney to Tokyo. We used precise weather hour diary and satellite maps to reconstruct the exact weather race conditions.We found data on the sport results and parameters of the rowers on the official websites of the competitions and the WorldRowing website. The created physical and mathematical model of the weather conditions influence is based on the second law of mechanics and includes 22 variables which characterise environment and features of the rowing biomechanical system. The physical and mathematical model was implemented in the form of a computer application. The computer application made it possible to accurately assess the preparedness of athletes by clearing the distance time off the environment influence. The pure characteristic time allowed comparing the results obtained in different weather conditions. Calculation reveals that the weather conditions have an effect on race time significantly. The weather influence on Olympic race was in the range of -10.10 to +5.94 seconds. The presented approach allows to register world and Olympic records for the first time in rowing history.

1 Introduction

Rowing is a sport where the competitions are held on open rowing channels. Nonconstant aero and hydrodynamic conditions can affect the time of passing the distance significantly. The meteorological air masses movement can promote the boat's progress with a tailwind, or, conversely, hinder it with a headwind. In the first case, the time of passing the distance will be better, in the second – worse. The inability to hold competitions always in the same conditions makes it impossible to compare the time results of different regattas and does not allow to fix world records [1]. The variability of the environment introduces uncertainty in the assessment of the level of crew readiness to competition, complicates the prediction of the target result and planning of the training process. The purpose of the study is to

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perform the comparative retrospective analysis of the results in rowing taken in various meteorological conditions.

There are enough scientific papers based on mathematical and computer modeling in rowing [2, 3]. Such models are based on an understanding of the mechanics and biomechanics of rowing [4]. For example, a mathematical model is used to compare the effectiveness of various oar blade designs [5] and to calculate the expediency of modifying paddles due to speedstrips [6].

The original mathematical model of rowing is described in paper [7]. This model allows to calculate the wind effect on the distance time. The influence of external factors on rowers is so significant that it does not only affect the results but also does not allow to create standard conditions for an objective study of the physiological parameters of rowers [8, 9]. The variability of the distance time leads to a change in the athletes' physiology.

The works [10, 11] provide experimental data on the influence of wind on the 2000 meters racing time. However, the methodology of the study is not specified. Presented nomograms (Fig. 1) do not include the characteristics of the crew (mass), aero- and hydrodynamic coefficients and midsection. Graphical approach is unable to consider the variable nature of the wind, for example, when the distance begins with a headwind and ends with a tailwind.

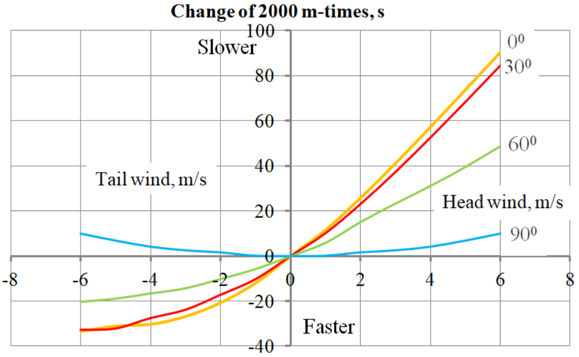

Fig. 1. Dependence of the boat speed on the wind parameters (1x): experimental data of Klaus Filter [10].

2 Materials and methods

The study is based on 2 methods: data collection and computer simulation.

2.1 Data collection

To conduct the study we collected all necessary information. The database includes information on the Olympic Games winners' time results (Tables 1), weather conditions on the days of the races (Tables 2, 3), the geography of the rowing channels, the orientation and direction of the race (Fig. 2). We have used the official website of the International Olympic Committee https://www.olympic.org/rio-2016/rowing/single-sculls-1x-men and the official website of World Rowing https://worldrowing.com/ to collect data on the competitions results. The weather diary was used to restore the weather conditions of the races https://www.gismeteo.ru/diary and https://www.wunderground.com/. The orientation of the channels was determined due satellite maps https://www.google.ru/maps.

Table 1. Rowing canal locations.

Olympic Games	Date	Latitude, longitude
Sydney, 2000	22/09	-33.7229, 150.6718
Athens, 2004	21/08	38.1419, 24.0168
Beijing, 2008	16/08	40.1705, 116.6905
London, 2012	03/08	51.4940, -0.6610
Rio, 2016	13/08	-22.9739, -43.2085
Tokyo, 2020	30/07/21	35.6024, 139.8092

The official competition protocols do not contain information about the race meteorological conditions.

Table 2. Weather conditions on the days of the race

Olympic Games	Weather Diary
Sydney	https://www.gismeteo.ru/diary/10719/2000/9/
Athens	https://www.wunderground.com/history/daily/LGAV/date/2004-8-21
Beijing	https://www.wunderground.com/history/daily/cn/beijing/ZBAA/date/2008-8-16
London,	https://www.gismeteo.ru/diary/744/2012/8/
Rio	https://www.wunderground.com/history/daily/br/rio-de-janeiro/SBRJ/date/2016-8-13
Tokyo	https://www.gismeteo.ru/diary/5924/2021/7/

The direction of boats movement was determined by video recordings of the Olympic Games broadcasts. In addition, we studied scientific articles about rowing biomechanics to determine the coefficients for computer simulation.

We determined the air masses speed relative to the rowers' movement through comparing the information about the canals orientation and meteorological conditions on the day of the race (Fig. 2).

Fig. 2. Determining the mutual orientation of the rowing canal and wind direction during the Olympic regatta in Tokyo.

We initially selected the single sculls (1x) main class in order to avoid additional complications associated with algorithm of crew strokes synchronization [12].

Table 3. The Olympic champions time results in the single sculls (1x) men class and meteorological conditions of the races.

Year	Athletes	Results	Wind[1]		Air Temp., Celsius
			m/s	deg.	
2000	Rob Waddell	6:48.90	3.13	4	18
2004	Olaf Tufte	6:49.30	2	var[2]	31
2008	Olaf Tufte	6:59.83	3.13	160	28
2012	Mahé Drysdale	6:57.82	9	82	32
2016	Mahé Drysdale	6:41.34	6	143	25
2021	Stefanos Ntouskos	6:40.45	4	57	25

[1]The wind parameters are indicated relative to the boat movement direction: 0 deg. – tailwind, 90 deg. – crosswind, 180 – headwind. [2]Variable wind.

2.2 Computer simulation

We created a computer model of the interaction of the biomechanical rowing system with the aero- hydrodynamic environment. Similar models are used in athletics [13, 14, 15].

The computer model (physical and mathematical) is based on a recurrent algorithm which is a consequence of the second law of dynamics and the law of conservation of momentum. The algorithm includes two parts: the adjustment unit and the calculation unit.
The physical and mathematical model is based on the following formulas:

$$\Delta T = \frac{\Delta S}{\overline{v}} \quad (1)$$

$$\Delta S = (d - \sum_{i=1}^{ngr} v_i \times dt) \quad (2)$$

$$\overline{v} = \frac{\sum_{i=1}^{ngr} v_i}{ngr} \quad (3)$$

$$v_\iota = v_{\iota-1} + \frac{F_\iota \times dt}{m} \quad (4)$$

$$F_\iota = F_{\iota(traction)} - F_{\iota\,(resist)} \quad (5)$$

$$F_{i(resist)} = F_{i(aero)} + F_{i(hydro)} \quad (6)$$

$$F_{\iota\,(traction)} = F_{i(Hill)} \times F_{i(geometry)} \quad (7)$$

$$F_{Hill} = (((F_{stat} + a) * b) / (v_{(i-1)} + b) - a) \quad (8)$$

The stroke force curve is significantly affected by the weather conditions, the wind and the current [17]. The validity of the application of the A.V. Hill equation had been repeatedly proven in rowing and kayaking so it was introduced into the algorithm. The physical meaning is a strong headwind leads to the boat speed drops, at the same time increases a possibility to apply additional force in the stroke. And vice versa during a tailwind, the speed of the boat increases but a possibility of applying force decreases (Fig.3).

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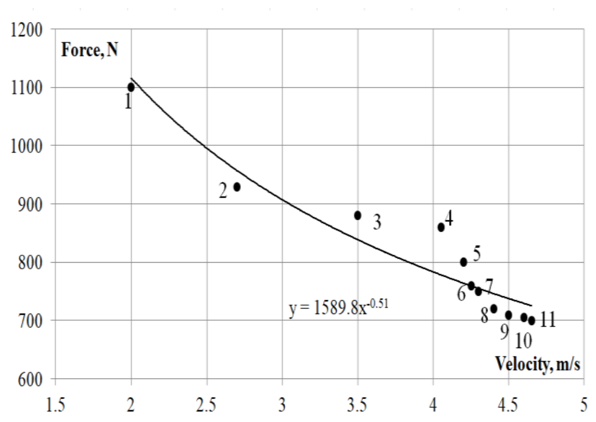

Fig. 3. The possibility of applying the stroke force depending on the boat speed, experimental data of start strokes [16].

We did not include the fatigue function, i.e. the reduction of the stroke force from the time of work in the algorithm. However, the available experimental data is enough to supplement the algorithm by the metabolism block [8].

$$F_{geometry} = SIN(3.14 / 180 * ((stroke_{moment} / stroke_{rhythm}) * 180) \quad (9)$$

$$F_{i\,(aero)} = C_{air} \frac{\rho_{air} \times v_{i-1}^2}{2} \times S_{air} \quad (10)$$

$$F_{i(hydro)} = C_w \frac{\rho_w \times v_{i-1}^{\frac{3}{D}}}{2} \times S_w \quad (11)$$

The researches [10, 11] contain experimental data on the influence of water temperature on the boat speed (Fig.4). However, it must be taken into consideration that the temperature through a change in viscosity affects not only the hydrodynamic resistance of the boat but also the strength of the stroke.

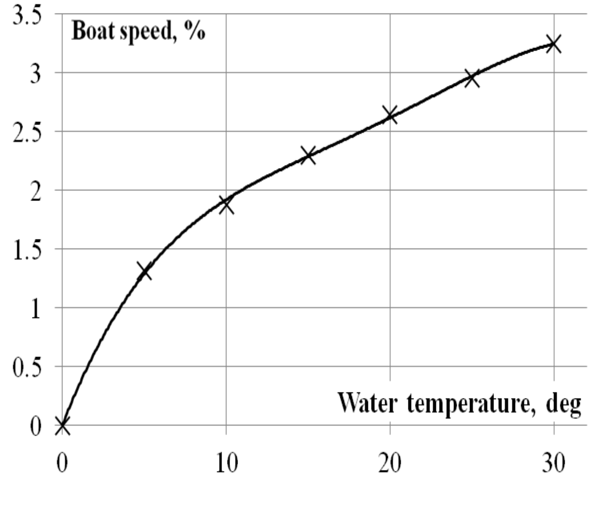

Fig. 4. Dependence of the boat speed on water temperature. Points – experimental data of Klaus Filter, line .

In our simulation the influence of water temperature (tc) was realized through viscosity changing according to the Poiseuille formula. Formula for calculating the dependence of viscosity of water on the temperature is: pu = 1.8 / (1 + .0337 * tc + .00022 * tc ^ 2).

Symbols and notation:

ΔT– increment/decrement of the race time under the influence of aerodynamics and hydrodynamics factors.

ΔS – changing the distance which oarsman can overcome for the entered time in modified conditions.

$\mathrm{d}t$ – elementary time interval.

ngr – the number of intervals into which the time of passing the distance is divided

d – distance (2000 meters)

v_i – instantaneous speed on elementary time interval.

$\overline{v}$ – average boat speed.

F_i – superpositional force at the i-moment of time

m – mass of the biomechanical rowing system. The mass of the athlete in the calculations was entered individually according to the data from official websites.

The mass of the athlete was added to the mass of sports equipment. Minimum 1x boat weight is 14 kg.

a, b – coefficients of the A.V. Hill's equation of muscle dynamics.

$\mathrm{stroke}_{\mathrm{moment}}$ – the ordinal number of the elementary interval in a particular stroke.

$\mathrm{stroke}_{\mathrm{rhythm}}$ – the ratio of the contact period time to the total stroke time.

Rowing is characterized by significant fluctuations of intra cyclic speed. The fluctuations can reach 25% of the average boat speed [18]. An increase or decrease in the instantaneous boat velocity immediately leads to changes of aero and hydrodynamic resistance.

C_{air}, C_w – resistance coefficients. The coefficient of hydrodynamic resistance depends on the shape and the coating of boat [19].

ρ_{air}, ρ_w – density.

S_{air}, S_w – mid-section area.

The total aerodynamic drag consists of the resistance of a boat and riggers - 15%, crew - 35%, oars - 50% [10]. However, it is obviously that during a crosswind ratio will change, in particular the aerodynamic midsection of the boat will increase significantly.

Table 4. Input and output variables of the model

INPUT VARIABLES	VALUE
Environment	
Wind speed [m/s] and direction [degrees]	uploaded from a file with a certain discreteness
Angle between the boat direction and water current [degrees]	uploaded from a file with a certain discreteness
Water current speed [m/s]	0
Water temperature [Celsius degree]	depends on the race, standard – 24
Coefficients	
Air resistance coefficient [$\mathrm{Nxs}^2 / \mathrm{m}^2$]	0.26
Race Time [s]	depends on the race
Crosswind action coefficient	0.85
Aerodynamic drag changing coefficient	0.5
Waves influence coefficient. The value of the waves influence coefficient is determined by a special algorithm depending on the bottom profile and depth	0.9
Keel and side pitching influence coefficient	1.11
Race	

INPUT VARIABLES	VALUE
The standard distance in rowing is 2000 metres	2000
The ratio of oar - water contact time to the full stroke cycle time	0.7
Biomechanical rowing system	
Rowing system mass [kg] average values: 1x – 14 kg (boat) + athlete mass + riggers, stretchers, shoes slides, seats	depends on the rower
Strokes amount	depends on the rower
Stroke quantization frequency	10-1000
Propulsive force is the projection of the stroke force on the boat movement direction. Peak paddle force in static [N]	depends on the rower, 800
The degree of dependence of hydrodynamic drag forces on the boat speed. Initial value.	2
Coefficient "a" A.V. Hill's equation	98.5
Coefficient "b" A.V. Hill's equation	3.75
Coefficient to the Poiseuille formula	1.02–(1/750)*tc
OUTPUT VARIABLES	**VALUE**
The degree of dependence of hydrodynamic drag forces on the boat speed, exact calculated value	
Instantaneous intra-cycle speed with a certain discreteness, graph	
Instantaneous stroke power, graph	
Time increment/decrement under weather conditions	
Characteristic (pure) time	

gm - the degree of dependence of resistance – speed. This value is specified in the first cycle of the program. A classic degree equal to 2 is defined for a ball completely submerged in water. So, it is not the exact value for rowing because the planing effect is observed.

For convenience, the described algorithm was implemented in C# in Pure Rowing Time 1.1 application (Fig. 5).

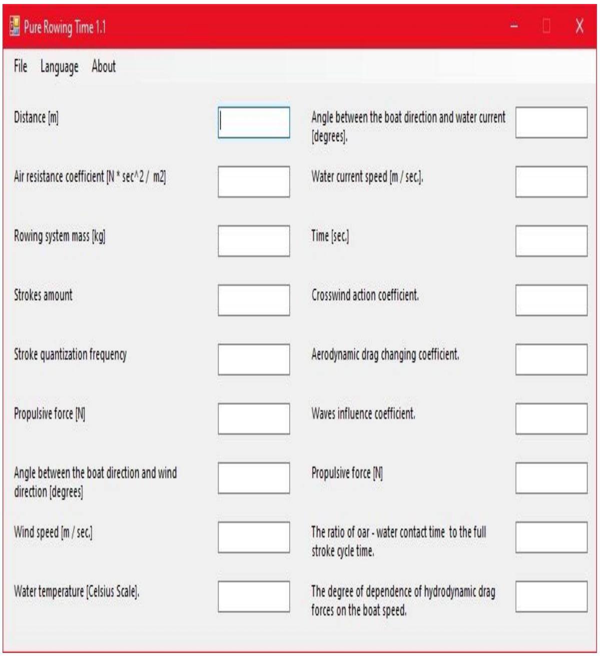

Fig. 5. Interface Pure Rowing Time 1.1 application with input characteristics.

3 Results and discussion

Using the computer program the Olympic finals meteorological conditions were simulated. The outputs of computer simulation indicated a change of boat speed and the thrust force under the influence of aero- and hydrodynamic factors (Fig.6,7).

The final result of the simulation is the calculation of the increment of the race time ΔT under the influence of meteorological conditions (Fig. 8).

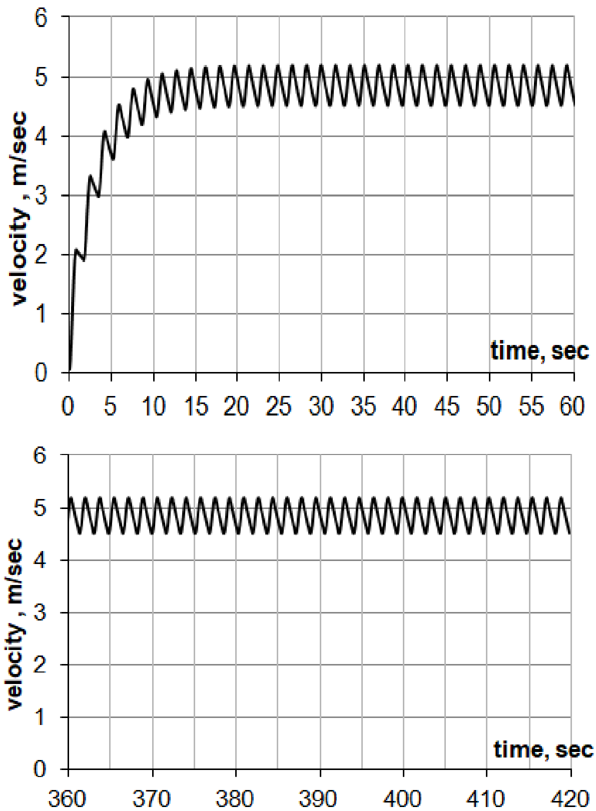

Fig. 6. The example of computer simulation for Olaf Tufte's race: intra-cycle speed of the boat during start (top) and finish (beneath) in real weather conditions.

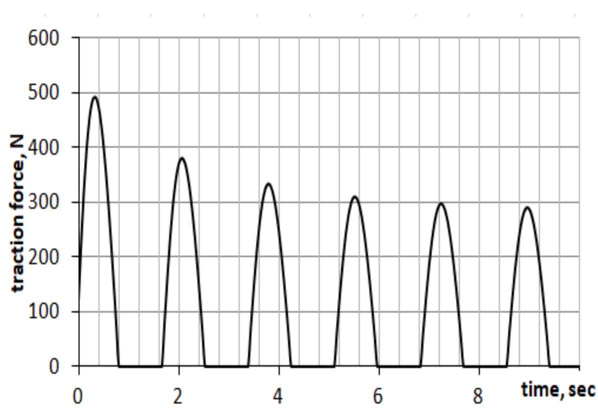

Fig. 7. The example of computer simulation for Olaf Tufte's traction force during start.

The data of computer simulation of the stroke force are in good agreement with the experimental data [20, 21].

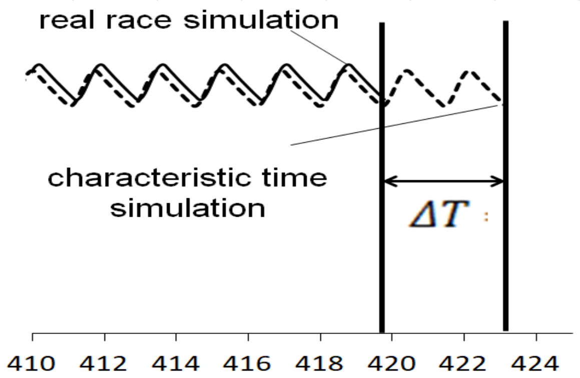

Fig. 8. Determination of the characteristic time based on calculation increment/decrement of the race time.

The simulation allowed to identify the characteristic (pure) time, i.e. the time that the athlete would have hypothetically shown under calm conditions (Table 4). A similar approach based on computer simulation was previously presented [22], but without describing the exact program code and clear algorithm.

The characteristic time is the time "cleared" from the action of the wind and the current. Certainly, both during the day and during the race, the weather conditions could change. However, our proposed approach is more accurate in estimating sports results than by simply ignoring the aero-and hydrodynamic conditions.

Table 5. Olympic Champions' characteristic race times

Olympic Games	**Athletes**	**Real time**	**Δ*T***	**Character. time**
Sydney, 2000	Rob Waddell	6:48.90	+5,94	6:54.80
Athens, 2004	Olaf Tufte	6:49.30	0[1]	6:49.30
Beijing, 2008	Olaf Tufte	6:59.83	-5.96	6:53.87
London, 2012	Mahé Drysdale	6:57.82	-10.10	6:47.72
Rio, 2016	Mahé Drysdale	6:41.34	-6.69[2]	6:34.65[2]
Tokyo, 2020	Stefanos Ntouskos	6:40.45	+1.75	6:42.23

[1]Low wind speed and variable direction make it possible not to take into account its influence. Revision of the competition broadcasting also allows stating the calm during the race. [2]Weather conditions of race in Rio were double checked by several sources.

The proposed approach based on physical and mathematical computer simulation allows to determine the influence of meteorological conditions on the race time in rowing. Comparison of the results based on characteristic (pure) times will allow to compare results objectively, to identify and to fix world records.

Conclusion

The paper presents an innovative approach to estimating the time of distance passing in rowing. The approach is based on the determination of the pure characteristic time cleared off the influence of the weather conditions. The characteristic time is the time that an athlete would demonstrate in standard conditions of absence of wind and current.

For the efficiency and convenience a physical and mathematical model of the interaction of a rowing biomechanical system with the environment was presented in the form of a computer application.

The retrospective comparison was based on hourly weather diaries for the cities where the Olympic regattas took place. Satellite maps were used to compare the wind direction and the rower's movement.

The paper analyses the time results of six Olympic regattas from Sydney to Tokyo. Studies revealed that weather conditions significantly affected the time of the distance passing.

The proposed approach will allow to objectively assess the time results and fix world and Olympic records.

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