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EVALUATION OF ROWING SPEED AND EFFECTIVENESS USING THE INNOVATIVE "LAURA" BOAT COMPARED TO OTHER RESCUE BOATS

Andrzej Ostrowski [1 ABCDEF], Marek Strzała [1 BCDE], Arkadiusz Stanula [2 ABCD], Aleksander Skaliy [3 ABCF], Marek Makowiec [4 BCDF], Andrzej Swinarew [2 CEF]

[1] Faculty of Physical Education and Sport, University of Physical Education in Kraków
[2] Faculty of Physical Education, Academy of Physical Education in Katowice
[3] Institute of Sport and Physical Culture, University of Economics in Bydgoszcz
[4] Department of Organisational Behaviours, University of Economics in Kraków

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B. Data collection/entry
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D. Data interpretation
E. Preparation of manuscript
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Abstract:

Aim. The objective of this work was evaluation of rowing speed and effectiveness using the innovative "Laura" boat compared to other rescue boats.

Basic procedures. The research was conducted in July 2017 on Rożnów Lake amongst 20 men within the age of 20-22 years, students of the University of Physical Education in Kraków. Their task was to cover a 100-m length in "Laura", "Iwona" and "Mazurek" row boats. The evaluated items were speed of swimming by measuring the time to cover the route and the effectiveness by counting executed rowing cycles while rowing in a straight line – from halfway (50 m) to the buoy located in the middle of the return route (25 m before the finish).

Results. Based on the calculations, it was concluded that the fastest boat was "Laura" (average time: 105.22 sec) and the slowest was "Iwona" (average time: 143.74 sec). Also, basing on an analysis of rowing straight and round a buoy, it was proved that the subjects rowed the most effectively using the "Laura" boat, making less paddle movements than in the other vessels.

Main findings. The results of the research authorize the statement that the innovative "Laura" boat, apart from its many pros connected with its design, allows efficient and fast rowing both in a straight line and when turning.

Introduction

Pursuant to the Act from August 18th, 2011 on the safety of persons in water and bathing areas as well as places designated for both inland and marine bathing, rowing boats constitute the basic rescue equipment [1]. They are used for patrolling, and in the event of a rescue operation, for quickly reaching the scene of an accident to provide effective assistance by pulling the victim on board, to apply rescue procedures during a simultaneous, quick return to shore to continue assistance or transfer the victim to medical services.

The speed of reaching someone drowning and returning to shore with rowing rescue boats depends, to a large extent, on the lifeguard's efficacy and skills, as well as on the vessels used, which to a greater or lesser extent, may be limited by the resistance of the underwater part of the hull resulting from the boat's movement in water and by external resistance related to water level (ripples) and current weather conditions. The weight of the unit, the size of the hull surface, the crew and equipment load, also play a significant role. To swim faster using the given boat, the above restrictions must be minimised.

Optimal hydrodynamic properties of the underwater hull of the boat is the primary goal when designing new boats. Based on research and computer programs, designers determine the hull resistance depending on its shape at different levels of immersion. They also calculate the amount of flow, turbulence, pressure field distribution and the image of the wave system during hull movement at a given speed, which is a guide for constructors [2]. The boats most commonly used by water rescuers in tourism and water recreation are such types as: the "Mazurek," Jacek "," Cyranka "," Romana ", the "Iwona " and "Perkoz ". In some of them, in the bow section, at the expense of the cockpit, a resuscitation deck is created, making them more useful in water rescue. These are the "Grebe 3R" "Cyranka R", "Jacek R" and "BL". These boats are small, light, manoeuvrable and unsinkable, but they have a sloped bottom, which makes them easy to tip over, threatening to tip over or fall overboard, limiting effective and safe rescue operations [3].

In order to meet the expectations of numerous masses of lifeguards, the innovative "Laura" boat was designed, with a modelled flat bottom, a spacious cockpit and an open stern [4,5]. On May 14th, 2014, Andrzej Ostrowski obtained protective rights for a utility model entitled "Multifunctional boat" marked with the number W.121888 at Patent Office of the Republic of Poland. The design of this fast and useful boat for rescuers considered the latest design trends related to hull hydrodynamics known from sailing theory [6,7], as well as the postulates and needs of lifeguards using rowing rescue boats at bathing areas and areas designated for bathing.

Study aim

The speed of reaching someone drowning using a rescue boat and returning to shore with the injured person in order to continue the rescue operation by specialised medical rescue services depends, to a large extent, on the equipment used as well as on the rescuer's efficiency and skills. The use of a boat for this purpose, which can be used to reach the injured person more quickly, is safer and easier when rescuing a person awaiting help, and thus, limiting the risk of loss of health or life seems fully justified.

The purpose of the work was to assess the speed and effectiveness using selected rowing boats used for water rescue, and, as a consequence, to indicate the most favourable boat in terms of time to reach the place of rescue and to return to shore with a series of manoeuvres consisting of straight rowing, turning and returning. The following specific questions were posed:

1. How fast did the participants travel the route using individual row boats?
2. What was the effectiveness of the subjects in straight-line rowing using individual row boats?
3. What was the effectiveness of the subjects in performing turns and returning using individual row boats?

Selected aspects of hydrodynamics of the boat hull

The basic geometrical and hydrodynamic parameters characterising the boat hull, which determine not only resistance during movement, but also the speed or stability, are smooth hull line shapes, displacement and its distribution, mass, as well as lateral stability related to these parameters, its distribution along the structural waterline, especially in the fore and aft parts and the cylindrical coefficient [8].

Boat hull shapes are constantly evolving. The aim of the designers' continuous efforts is to reduce movement resistance while maintaining usability. Designers creating hulls of both sailing and motor boats, seeking greater rowing speed, regardless of the area of navigation, prefer flat-bottomed "irons" with a very wide stern. Shifting the centre of buoyancy of the unit backwards causes it to act as if its water line was extended at higher speeds, which in turn, causes the stern to displace the stream of water from the plating, and the wide, flat stern part facilitates the boat to slide [10,11].

Underwater hull shapes

The most important boat parameters are length (L), maximum width ($B_{max)}$, displacement (D) or displacement (V) in m^3 and immersion ($T_{c)}$. Equally important parameters are the length of the water construction line (L_{wl}) and its width (B_{wl}). These parameters result from the intersection of the hull with the water surface, when the hull displaces its mass, which corresponds to the assumed displacement (D), however, hulls of identical length, width and displacement can significantly differ in shape, especially the slenderness of the bow and stern, and thus, immersion (T_c). The shape of the buoyancy curve allows, at least partially, to decipher the course of the water lines of the hull, which according to classical sailing theory, should have a shape such as a wave profile. The height of the broadside (H_b) is also important, mainly for functional as well as stability reasons [8].

The shapes of the underwater hull are expressed in the so-called cylindrical (prismatic) (C_p) coefficient resulting from the buoyancy curve (V), and have a clear connection with total hull resistance. This is calculated by dividing the underwater volume of the hull (buoyancy) - V by the volume of the cylinder with waterline construction length (L_{wl}), described on the chain with the largest cross-section - the base equal to the surface of the largest chain limited by the water line [9,10].

The dimensionless cylindrical coefficient (C_p) cannot exceed unity, and this value could come close at the price of a very blunt, deeply submerged bow and a wide, equally deeply "sunken" stern of the boat. This extremely important factor for the hull characteristics in the case of modern sailing yachts is within the range of 0.45 to 0.55, while fast speedboats are above these values. Based on the cylindrical coefficient (C_p), it is possible to predict the resistance of boat movements in various wind conditions [11].

The influence of the shape of cross-sections of the underwater hulls on the size of their wetted surfaces is assessed on the basis of calculating the wetted coil circumference (O_w) ratio to the surface of its submerged part (z). The least favourable in this respect turns out to be the triangular (sharpie) cross-section, and the most - the round bottom. A smaller ratio of the wetted circumference (O_w) to its submerged surface (z) is generated by rectangular shape. The most favourable, however, is definitely the semi-elliptical shape, while for larger waterline width ratios (B_{wl}/z) - trapezoidal, characteristic for the skipjack hull type [12]. Quite good results occur in rectangular sections with rounded corners. The desired minimum resistance for almost all shapes is achieved when the waterline width (B_{wl}) is two times greater than the submersion value (z). For the semi-elliptical cross-section, this is obtained when it becomes a semi-circle [13].

Hull resistance

Total hull movement resistance is: friction resistance, resulting from the basic water quality, which is viscosity, and residual, especially wave resistance, resulting from the movement of water molecules during hull movement. Residual resistance is, in practice, wave resistance responsible for generating waves on the water surface by the hull [12,14].

Resistance to boat movement increases with speed but to an uneven degree - at lower speeds, friction resistance prevails, while at higher speeds, wave resistance dominates [15]. The value of the total resistance of hull (R) against the water and air at a given speed of movement is the basic parameter for the design of any propeller: water-screw propeller, sail, etc. This includes resistance in the water of the bare hull and parts protruding beyond its contour (e.g. column outboard motor) and the resistance of the water part [14]. There is also a relationship between one of the components of total hull resistance and its shape expressed by the coefficient of pressure (C_p) [7].

The greatest impact on the amount of **friction resistance** regards the wet surface of the underwater part of the hull, calculated in relation to its displacement. The minimum value of this parameter is characterised by the submerged hemisphere. Increasing immersion and rounding the cross-sections of the underwater part of the hull minimises the ratio of the wetted surface to buoyancy, reducing its resistance at lower speeds, but only to certain limits, depending on the type of hull.

The frictional resistance resulting from the viscosity of water also depends on the nature of the flow around the hull. It turns out that this resistance can be reduced by trying to maintain laminar flow, counting from the bow on the longest possible part of the hull. In the further part of the hull, turbulence called turbulent flow occurs. Thus, overpressure is generated on the bow and stern, the greater the more curved bottom lines there. In the middle of the hull, the pressure decreases due to the acceleration of the flow. Due to the stratification of the plane in the area of laminar zone and limitation of transverse movements of water molecules, the hull "tugs" it along less, thus losing less energy [9].

The differences in energy absorbed by the two types of flow are surprisingly large - turbulent flow "consumes" up to 5 times more than laminar. Unfortunately, laminar flow can only be maintained on a short hull length, counting from the bow, the shorter, the faster the yacht. Laminar or turbulent fluid movement is determined by the **Reynolds number**. This number allows to estimate the ratio of inertia to viscosity forces occurring during fluid movement. The transition of laminar into turbulent flow around the hull becomes inevitable after crossing the so-called critical Reynolds number ($Re \sim 10^6$). The paths of water molecules then become disordered, chaotic, creating vortices. This means that the hull, colloquially speaking, is more inhibited and more energy is needed to overcome the resistance arising from water viscosity. They depend not only on the surface on which they interact but also on surface roughness, resulting in thickness of this turbulent boundary layer [14,16,17].

Wave resistance included in the residual resistance results from the speed of the unit which, when moving, produces a wave. The course of the wave resistance curve depends on the displacement and shape of the underwater part of the hull. The full sterns and pointed ends of the boat increase wave resistance, especially at higher speeds [1,18].

The waves break up at the same speed, radiating from the disturbance site that is in the bow section of the boat. The distance travelled by the waves is proportional to the square of time from the beginning of the disturbance. The wave-fronts of successive waves begin to overlap, forming a kind of transverse wave, which begins to have greater amplitude than the rest of the waves and its creation requires more energy, resulting from the speed of the boat. Thus, the greater the transverse wave produced, the greater the resistance of the water is towards the boat movement [15].

The transverse wave system is associated with the hull of the boat and moves with it at the same speed. The stern also generates a transverse wave. It sometimes occurs that at a certain boat speed, the bow wave become long enough to cover the stern wave. The wave resulting from this interference becomes much higher than its components, which results in a sharp increase in resistance. The implementation of an appropriate bow design and stern shape reduces or completely reduces the bow wave, reducing hull resistance during movement [19].

The relationship between transverse wavelength and boat speed was determined by physicist William Froude living in the 19th century. He also formulated one of the most important criteria for hydrodynamic similarity, called the **Froude number**. It is like a dimensionless speed related to the length of the hull water line. It can be easily converted to speed for a specific length of the water line (L_{wl}). The highest speed that boats can develop in so-called buoyancy sailing depends on the length of their water lines (L_{wl}) and occurs when the produced waves are equal to the length of their water lines [20]. Therefore, shorter boats should be slower than longer boats. However, this rule does not always work for units of the same length, but with different buoyancy resulting from the shape of the hull [14,20]. In both cases, achieving threshold speed requires different energy expenditures depending on the weight of the boat, which translates into resistance to movement. Boats of lower value, i.e. light, place less resistance on water than heavy vessels [9,20].

The Froude number is also used to determine the number of waves that a boat's hull produces at a given speed. For example, $Fr = 0.4$ indicates that the hull generates only one wave along its entire length [18]. The ridges of the adjacent waves are then around the bow and stern. Two waves are within the hull length at relative speed, corresponding to the Froude number of 0.28 [7].

Materials and methods

The study was conducted on July 15th, 2017 at Rożnowskie Lake at the Water Sports Centre of the Kraków University of Physical Education. The study involved 20 men aged 20-22, students of the University of Physical Education in Kraków, with similar physical fitness levels, assuming that these variables similarly determine the predispositions of the subjects to use row boats.

The participants covered the obstacle course with consecutive rowing boats 30 minutes apart (each time a different type of boat: 1. "Mazurek", 2. "Laura", 3. "Iwona" - a modernised version of the "Cyranka" boat. To obtain objective results, none of the individuals had previously rowed any of the tested boats, nor had they used other rowing boats, which was why their rowing performance before testing was similar.

In order to eliminate the ordering effect, the subjects were randomly assigned to tests using individual boats. The task of each of subjects was to overcome the obstacle course in the shortest time possible.

The participants covered the obstacle course along the lake shore according to the regulations of the International Life Saving Federation, which consists of rowing a boat in a straight line, covering a distance of 50 m, performing a 180^{0} turn, and covering the 25-m straight return path, rounding the buoy ($360^{0)}$ and returning to the starting line. The whole distance totalled 100 m. The tests were carried out in calm weather with no rippling.

The research team consisted of 3 people: a starter measuring the time of the test, an observer located on the shore in the middle of the distance measuring the number of rowing cycles in straight-line rowing (50 m), an observer measuring the number of rowing movements with the external upper limbs in relation to the buoy during its 3600 circling.

All of the results were collected and ordered using a Microsoft Excel 2010 spreadsheet (Microsoft Corporation, Redmond, WA, USA). To compare the parameters depending on the type of boat, one-way analysis of variance was used, preceded by checking the relevant assumptions (normality of distribution, homogeneity of variance). When the F test reached statistical significance, Tukey's post-hoc RiR tests were carried out to identify differences between the boats. Each time the decision to reject the null hypothesis was taken, the level of alpha significance was 0.05.

Photo 1. Rowing boats used for speed and efficacy testing; from left to right "Iwona", "Mazurek" and "Laura" – front view

Photo 2. Rowing boats used for speed and efficacy testing, from left to right "Iwona", "Mazurek" and "Laura" – rear view

Photo 3. Row boat speed and efficacy testing using "Laura"

Results

1. Characteristics of the row boats

Rowing boats used in water rescue, and at the same time, used in the research, are the round-bottom "Mazurek", the triangular-bottom (sharpie) "Iwona" and trapezoidal-bottom (skipjack) "Laura". Their external appearance is shown in Fig. 1-2, and the parameters in Table 1.

According to the theory of hydrodynamics [7], the "Laura" boat had the most favourable bottom shape, the "Mazurek" bottom was slightly worse while the worst was "Iwona". The round-bottom boat "Mazurek" was the shortest and narrowest both in the middle of its length and at the transom. The amount of space in the cockpit was also the smallest, additionally limited by a rowing bench separating it. Instead, it had the highest freeboard and the greatest immersion. The bottom shape as well as the above-mentioned parameters determined its low transverse stability, with relatively high directional stability.

The "Iwona" boat with a triangular-bottom profile was characterised by intermediate length and width parameters among the tested boats, while the "Laura" boat was the longest and widest. It also had the largest surface in the cockpit, while it had the lowest side height and depth in the cockpit and the lowest immersion without load. The oars were chosen according to the length and width of the boat. The shortest were used for the "Mazurek" boat and the longest for "Laura". The tested boats were similar regarding many of their parameters. This particularly concerned the height of the oarsman's bench and weight.

Table 1. Parameters of the "Mazurek", "Iwona" and "Laura" row boats

Basic parameters in cm	"Mazurek"	"Iwona"	"Laura"
Type of bottom	round	triangular	trapezoidal
Length [cm]	310	378	426
Max. width [cm]	135	153	200
Stern width [cm]	90	143	200
Length of rows [cm]	180	210	260
Bench, seat height [cm]	43	40	40
Max. depth in cockpit	54	50	20
Max. height of broadside to waterline	50	45	35
Length of cockpit in stern part	110	120	160
Length of cockpit in bow part	165	93	60
Max. width in cockpit	100	120	160
Seat width	110	140	50
Length of back bench	28	46	none
Length of bench by the bow	50	60	110
Immersion without load	20	10	5
Weight [kg]	80	90	95

2. Row boat speed

The speed of overcoming the designated obstacle course by individual boats used in water rescue by the subjects is presented in Figure 1, while detailed test results are presented in Tables 2 and 3.-

The 100-m distance of the designated track was covered the fastest by students rowing the "Laura" boat and was, on average, 105.22 sec. Next, 11.6% slower was the "Mazurek" boat, covering the distance, on average, in 119.30 sec, and the slowest, by 28.6%, was the "Iwona" - in the average time of 143.74 sec. Furthermore, the best individual time to cover the route - 76.90 sec, was obtained by the "Laura" row boat. This time was 3.50 sec better in relation to the best time obtained

Table 2. Row boat speed of the "Laura", "Iwona" and "Mazurek" for the 100-m distance

Boats	N	Mean ± Std. dev.	Range
„Laura"	20	**105.22** ± 14.14	**76.9–**131.2
„Iwona"	20	**143.74** ± 38.96	96.6–**226.0**
„Mazurek"	20	119.03 ± 22.97	80.4–176.4

Table 3. Differences in row boat speed for the "Laura, "Iwona" and "Mazurek" for the 100-m distance in [sec] and [%] as well as their corresponding significant differences

Boats	**Time**	**„Laura"**		**„Iwona"**		**„Mazurek"**	
		sec	**%**	**sec**	**%**	**sec**	**%**
„Laura"	105.22			-38.52†	-28.60	-13.81	-11.60
„Iwona"	143.74	38.52†	26.80			24.71*	20.76
„Mazurek"	119.03	13.81	11.60	-24.71*	-20.76		

* $p \leq 0.05$; # $p \leq 0.01$; † $p \leq 0.001$

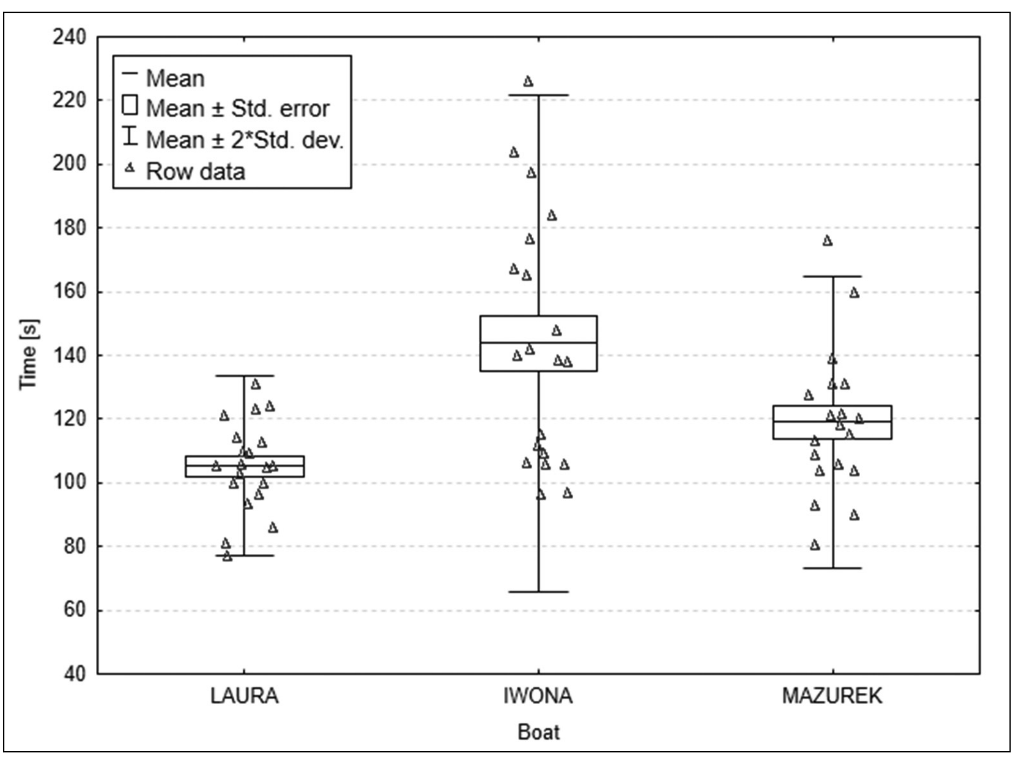

Figure 1. Speed of "Laura", "Iwona" and "Mazurek" rowing boats for the 100-m distance

by the “Mazurek” boat and as much as 19.70 sec better than the record time obtained by the “Iwona” boat. Also noteworthy is the fact that the time of the slowest boat “Iwona” (226.00 sec) was almost twice as long as the slowest time for the “Laura” (131.20 sec), and the difference between the fastest time for “Laura” (76.90 sec), and the slowest boat “Iwona” (226.00 sec) was as much as 149.10 sec.

The results obtained by the “Laura” boat were statistically significant ($p = 0.0002$) in relation to the “Mazurek” boat. The results also obtained by the “Mazurek” boat were statistically significant ($p = 0.018$) in relation to the “Iwona” boat.

Based on observation of the concentration of individual results obtained by the subjects rowing the “Laura”, “Iwona” and “Mazurek”, it may be concluded that the “Laura” was the fastest, the “Mazurek” was slower, while the “Iwona” was definitely the most difficult and slowest boat to row.

3. Efficacy of using row boats for straight-line rowing

The type of bottom, broadside profiles, and thus, the size of the wetted surface as well as the transition of laminar flow into turbulent flow are the main factors of wave resistance. The result of these parameters, along with fast paddling in order to obtain the shortest possible time to cover the distance, is rowing efficiency expressed in the number of performed rowing cycles (table 4-5). Therefore, during the timed test, their number was also calculated during the 50-m straight row.

Differences in the efficiency of rowing individual boats used in water rescue expressed in the number of rowing cycles in order for the subjects to overcome a 50-m straight section of the obstacle course are presented in Figure 2, while detailed test results are given in Tables 4 and 5. For the distance of 50 m, the least rowing cycles were made by students using the “Laura” boat - on average 20. The values for the ”Mazurek” boat were similar, while the number of cycles performed in the case of the “Iwona” were definitely greater - on average by 26.43%. The participant rowing the straight section using the “Laura” boat proved to be the most effective for all of the assessed parameters, covering the route with 11 rowing cycles, while the worst result, 38 rowing cycles, was recorded for a student rowing the “Iwona”. Analysing Figure 2, it was also noticed that during straight rowing, the concentration of results obtained for the “Laura” and “Mazurek” boats was similar and ranged from 15 to 23 cycles, while when rowing the “Iwona” boat, the results were definitely higher and more dispersed - from 20 up to 28 cycles. The results obtained by the “Laura” boat were statistically significant in relation to the results obtained by the “Iwona” ($p = 0.0002$). When comparing the number of rowing cycles with the “Iwona” and “Mazurek” boats, it should also be noted that when rowing the “Mazurek” boat, the subjects performed significantly less rowing cycles ($p = 0.0008$).

Based on the obtained results, it can be concluded that after the subjects performed a similar number of rowing cycles, the “Laura” and “Mazurek” boats covered a similar distance, however, the “Laura” boat was faster (see Tables 2 and 3, and Figure 1). The results obtained by those rowing the “Iwona” definitely departed from the-above. These results confirmed the dominance of the trapezoidal bottom profile over the rounded, and especially, the triangular one.

Table 4. Number of rowing cycles in straight line rowing using the “Laura”, “Iwona” and “Mazurek” boats

Boats	N	Mean ± Std. dev.	Range
“Laura”	20	**20.10** ± 3.93	**11**–30
“Iwona”	20	**26.15** ± 5.17	20–**38**
“Mazurek”	20	**20.68** ± 3.79	16–30

Table 5. Differences in the number of rowing cycles rowing in a straight line using the “Laura”, “Iwona” and “Mazurek” boats in [N] and [%] as well as their corresponding significant differences

Boats	**Number of cycles N**	**“Laura”**		**“Iwona”**		**“Mazurek”**	
		N	**%**	**N**	**%**	**N**	**%**
“Laura”	20.10			**-6.05†**	**26.43**	-0.58	-2.82
“Iwona”	26.15	**6.05†**	**26.43**			**5.47†**	**23.14**
“Mazurek”	20.68	0.58	2.82	**-5.47†**	**23.14**		

* p≤0.05; # p≤0.01; † p≤0.001

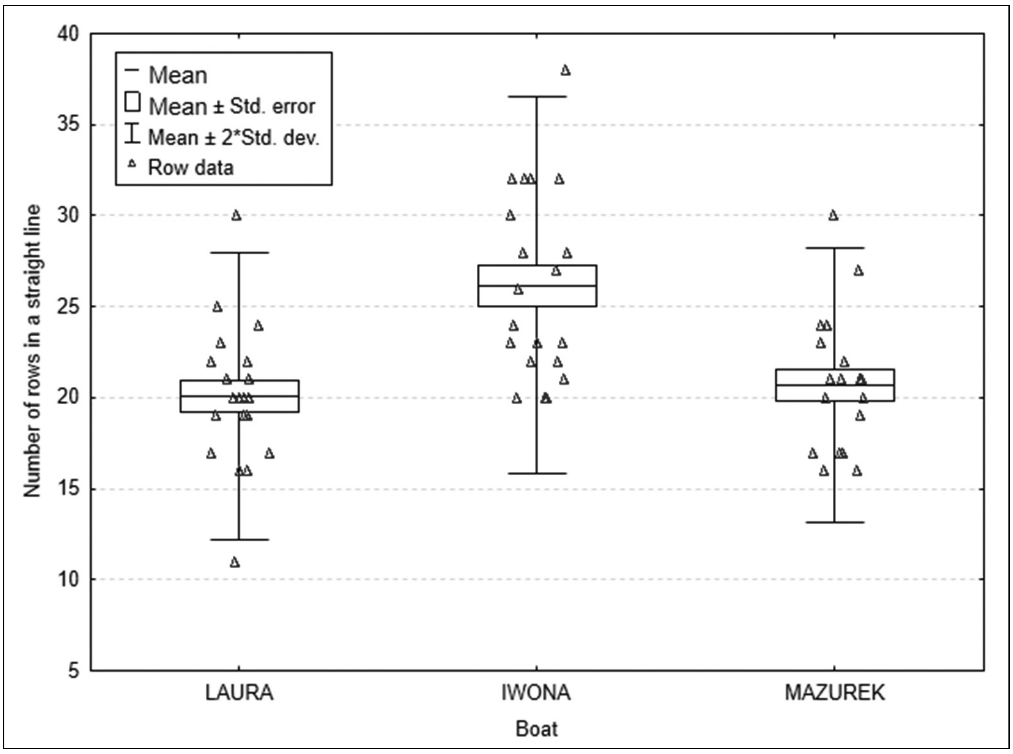

Figure 2. Number of rowing cycles for straight-line rowing using the "Laura", "Iwona" and "Mazurek" boats

4. Efficacy of row boat turns and returns

Boat bottom profiles, external dimensions of the boat determine the manoeuvrability of the unit, including its turning radius, and thus, the effectiveness of overcoming the route in the event of the need to avoid obstacles. It is generally accepted that with similar bottom profile, smaller boats are more manoeuvrable.

Differences in rowing efficacy with change of direction expressed in the number of rowing movements with the external upper limb in relation to the buoy with the intention of its circling, located in the middle of the return route using individual boats used in water rescue are presented in Figure 3, while the detailed results are in Tables 6 and 7. In order to circle the buoy, the least

Table 6. Number of external upper limb rowing movements w regard to buoys during their rounding using the "Laura", "Iwona" and "Mazurek" row boats

Number of movements – rounding buoys	N	Mean ± Std. dev.	Range
"Laura"	20	**14.10** ± 3.58	8–19
"Iwona"	20	16.1 ± 4.35	**6–28**
"Mazurek"	20	15 ± 3.05	10–19

Table 7. Differences in number of external upper limb rowing movements with regard to buoys during their rounding using the "Laura", "Iwona" and "Mazurek" row boats in [N] and [%]

Boats	Number of cycles N	"Laura"		"Iwona"		"Mazurek"	
		N	%	N	%	N	%
"Laura"	14.10			-2.00	-12.42	-0.90	-6.00
"Iwona"	16.10	2.00	12.42			1.10	7.33
"Mazurek"	15.00	0.90	6.00	-1.10	-7.33		

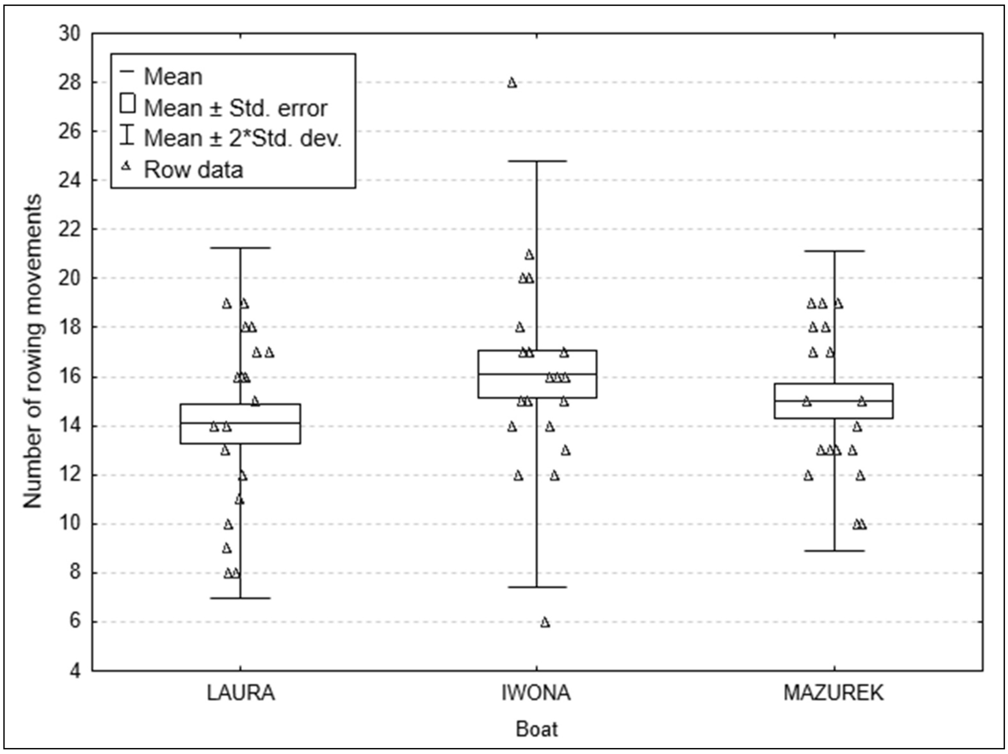

Figure 3. Number of external upper limb rowing movements during buoy rounding using the "Laura", "Iwona" and "Mazurek" row boats

rowing movements - on average 14, were made by students rowing the "Laura" boat. For the other boats, the average results were slightly worse: within 15-16 rowing movements. It is worth noting that the best (6 rowing movements) and the worst (28 rowing movements) results were obtained by the "Iwona". In general, there were no statistically significant differences in the number of rowing movements for the studied boats while circling the buoy.

In general, rejecting the extreme results obtained by the subjects, it should be noted that the above test resulted in all three boats performing a similar number of rowing movements.

Discussion

The hull parameters, especially of its underwater part, determine many different features, such as the speed and initial stability of the vessel. They form the basis for calculating resistance to movement in various water conditions. One of the most important parameters in assessing the efficiency of the underwater part of the hull is the waterline, i.e. the theoretical plane crossing the hull on the water line.

The shapes of the underwater hull of the boat have evolved since the dawn of sailing. In the past, builders favoured mackerel-like hull shapes. Thus, they were characterised by a pudgy bow, large overhangs and a stern with a residual transom. After numerous experiments, observations and other research methods, it turned out that the least favourable waterline occurs on units with a triangular (sharpie) cross-section of the underwater part of the hull, most preferably with a round bottom. Smaller ratios of the wetted periphery to its submerged surface are generated by a rectangular-like shape. The semi-elliptical shape is definitely the most advantageous, however, with larger waterline to draft ratios - trapezoidal, characteristic for the skipjak type hull [12].

Currently, designers wanting to construct faster units, while guaranteeing safe lateral stability and relatively low immersion, have moved away from traditional shapes, opting for hulls resembling an iron from a bird's-eye view. When building modern, fast boats, they additionally take into account their low weight and hull shapes, which shift towards small curvatures of the keel line, wide transom and relatively flat bottom [21,22]. According to the theory of hydrodynamics [7], the most favourable bottom shapes could be seen in the case of the "Laura" boat, and slightly worse the "Mazurek", while the worst was the "Iwona". As a consequence, the fastest participants sailed using the "Laura", slower by the "Mazurek" and by far the slowest - the "Iwona". After performing a similar number of rowing cycles by the subjects, the boats "Laura" and "Mazurek" covered a similar distance, however, the "Laura" boat was faster. The results obtained by those tested using the "Iwona" boat definitely departed from the above. These results confirmed the dominance of the trapezoidal bottom profile over the semi-circular and especially the triangular one. On all three boats, paddle movements were performed in a similar number around buoys. Thus the statement that the least manoeuvrable was the round-bottomed boat, represented by the "Mazurek", followed by the triangular bottom profile, represented by the "Iwona", and the most manoeuvrable with the trapezoidal bottom profile was the "Laura" boat.

In summary, based on the obtained research results and analysing the main trends used in the construction of new hulls, it can be stated that they lead to a reduction in resistance to reduce energy consumption. By searching for the optimal length of the watercraft unit and the fullness coefficient, an adequate reduction of hull resistance in motion is obtained, and by using an increasing value of the length-width ratio indicating the slenderness of the hull line, lower resistance values on the wave are obtained [23]. Thus, the basis of the economic effects of the vessel's operation is the use of scientific achievements and the introduction of technological innovations in the construction of new hulls, increasing propulsion efficiency by reducing hull resistance [19].

Conclusions

1. The bottom shapes of the boat determined the speed of rowing, as a result of which, it was found that the subjects were the fastest to cross the obstacle course using the "Laura" boat with the trapezoidal bottom profile even though it was the longest and widest, while the slowest was slightly smaller with a triangular bottom profile - the "Iwona" boat, and the time to cover the test track with the studied boats showed statistically significantly differences.
2. The results evaluating the efficiency of straight rowing also confirmed the dominance of the boat with a trapezoidal bottom profile over the others, because the number of rowing cycles performed using this boat significantly differed in relation to the others, which may indicate the role of hydrodynamic resistance of the bottom of the hull in individual units.
3. Although the boats were characterised by different length parameters and bottom profiles, there were no significant differences in the efficacy of circling the buoy, and the results did not demonstrate statistical significance. In order to determine the causes of dependence, further research should be conducted among a larger study population.

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Author for correspondence:

Andrzej Ostrowski
E-mail: andrzej.ostrowski@awf.krakow.pl
Orcid: https://orcid.org/0000-0003-3075-093X