Design and Development of Waterbikes at the Faculty of Engineering - University of Rijeka

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The undergraduate university study program for attaining the bachelor’s degree together with the graduate university study program for attaining the master’s degree of Naval Architecture at the Faculty of Engineering of the University of Rijeka can be defined as a classical naval architecture program. The completion of these programs enables students upon graduation to find jobs in companies that design and construct various ship types, develop and manage technological processes and build and maintain ships and offshore units, i.e. to get employed in a very wide field of shipbuilding and ocean engineering industries. In the process of professional training, besides a theoretical knowledge, practical experience is certainly essential for the students. In order to gain their first experience, students have the opportunity to join the student project "RITEH Waterbike Team – RWT". The basic task is the design and construction of a waterbike to participate in international waterbike regattas in Europe. By taking part in this project, students gain their first experience in the profession because they pass all stages of the waterbike development, which includes the conceptual design, the construction of parts and waterbike assembly, testing and sea trials and finally the participation in the regattas where all the possible drawbacks cannot be completely avoided. Besides these noticeable activities, there is a whole group of other activities which includes definition of the budget, marketing, contacting sponsors, project applications for funds, the purchasing and manufacturing of parts and organizing the multitude of tasks. This paper will discuss the development of several waterbikes since 1998 when the RWT was founded till the present. A case study of the present waterbike and a proposed new and improved design will be presented and an insight into design decisions will be explained. The main goal is to continually improve waterbike designs in order to maintain as well as to increase competitiveness in the waterbike regattas.

KEY WORDS: waterbike, design and building, development

INTRODUCTION

The waterbike team of the Faculty of Engineering, University of Rijeka, Croatia includes a group of approximately 15 students which are gathered in order to design and build a waterbike [1]. The name of the team is “RITEH Waterbike Team - RWT” where the word “RITEH” refers to the compound of “RIjeka” (name of the city) and “TEhnički” (meaning technical). The team is lead by a student team leader and all is supervised by a mentor who is a naval architect and a professor from the Department of the Naval Architecture and Ocean Engineering. All of the students are volunteers and the importance of teamwork is paramount. The main goal of the team is to build a waterbike and to participate in the International Waterbike Regatta (IWR). The IWR exists since 1980 and has taken place through many different locations mostly over Europe. The first IWR was in 1980 in Hannover. Initially, it was composed of students from various German universities. In 1988, the regatta has become international since it was held in the Netherlands, i.e. for the first time outside of Germany. The aim of IWR is to enable students to put theoretical knowledge into practice and to advance exchange among students. In various disciplines, waterbikes designed and built by students race against each other. The students are primarily naval architectural and marine engineering students from engineering faculties.

There are a total of seven disciplines:
- sprint 100 m,
- slalom 100 m,
- acceleration 10 m,
- forward - stop - backwards 50 m,
- long distance race (1 hour or 10 km),
- bollard pull where the average pulling force produced by waterbike in a period of 30 seconds is measured,
- surprise race which is not tallied for the competition except in the case of the same number of points between two teams.

The winner of the IWR is the team that has the least number of negative points. The events bring together a couple of hundred students each year and is a great platform for them to combine creative work, exchange with colleagues from other countries and have a lot of fun racing the waterbikes. The competition between the different universities has lead to high-tech waterbikes, lightweight constructions made of carbon fiber reinforced plastics, easily reaching speeds of more than 10 knots.

Waterbike is a kind of boat which is powered exclusively by the power of human muscles. According to the IWR rules, waterbikes must be designed, manufactured and driven by students themselves. There are no specific rules about the look of the waterbikes so solutions depend only on the team innovations, knowledge and capabilities. IWR rules are:
- maximum two people are allowed on board,
- maximum length is six meters,
- breadth always has to be smaller than the length,
- maximum draft is 1.5 meters,
- stored energy as batteries, springs, fly-wheels, etc., is not allowed,
- all parts at the waterbike are allowed to be changed during regatta, but must be kept on board,
- repairs are always allowed.

RWT THROUGH THE PAST
The beginnings of RWT originate in 1998, when a group of students of naval architecture gathered together with the idea of building a waterbike in order to participate in the IWR. The team existed for about three seasons, and after that team activities were interrupted because students graduated and started their own life outside the Faculty. The idea for the team's renewal appeared in 2009 and since then the RWT is continually participating in IWRs and in all probability this practice will continue in the future. By participating in IWRs, the Faculty of Engineering, the University of Rijeka, city of Rijeka, Croatia and, of course, the sponsors are promoted.

Since 1998, a total of four waterbikes were designed and constructed by RWT: “Esmeralda”, “Zvizda” (eng. star), “Kajzer” (eng. emperor, tsar) and “Šijun” (eng. tornado). The names of the waterbikes were created spontaneously like many other things that are related to the RWT’s work. The “Esmeralda” was built in 1998 and basically was a canoe for rowing on the calm water. The hull was built from fiberglass and the propulsion was based on pedals, gear mechanism and the screw propeller. Unfortunately, no photograph of this waterbike has been saved.

The catamaran “Zvizda” (Fig. 1) was constructed in 2009. The fiberglass hulls were adopted from two single kayak hulls. The hulls were connected with the steel and aluminum construction. Two drivers were sitting on two bicycles and by turning the pedals a screw propeller was rotating on the stern. This waterbike was in operation until the end of 2012.

The “Kajzer” (Fig. 2) was built in 2010 and also was a catamaran, but the hulls were made of carbon fiber reinforced plastic. The construction was sandwich with polyurethane core. The bulkheads were made of marine-grade plywood. The propulsion was achieved through a pedals and bicycle chains, multiplicator, angled shaft and the screw propeller. Since the end of 2013 “Kajzer” is no longer operable.

The present waterbike “Šijun” (Fig. 3) was built in 2013 and is a catamaran as well. The hulls are made of carbon-aramide fiber reinforced plastic. The construction is made of aluminum. The propulsion is achieved over the steerable strut with the screw propeller. The screw propeller is driven over pedals, bicycle chains, multipliers and a cardan shaft. The maximum speed is 9 knots. The best performance was fourth place in the IWR in Vienna in 2016.
Table 1 shows the characteristics of all waterbikes while the Table 2 gives the locations of IWRs where the waterbikes took part.

**SCREW PROPELLER MANUFACTURING**

It is well known that the engine does not propel the boat, the propeller does. In the past the RWT had permanent problems with screw propellers. Usually the propeller was ordered from the specialized companies in the neighborhood that repair and produce boat propellers. However, due to their technology, the propellers were too heavy and as a rule completely unsuitable for waterbikes. That is why RWT was constantly thinking of making an in-house propeller. In the spring of 2015, the first propeller was manufactured. It was casted from aluminum alloy obtained from used cans of sparkling beverages. A simple furnace was prepared for casting in the sand mold while the propeller model was made using a 3D printer (Fig. 4).

However, the development did not stop here. Since a 3D printing technology had been adopted, there were thought that casting might be avoided in a way to directly install the 3D printed propeller. Several propellers were made but due to low strength the propellers were not satisfactory. Finally, a technology in which the propeller is made by 3D printing and then overlaid with the carbon reinforcement was adopted. The epoxy resin is used and for quality bonding between the carbon reinforcement and the model, a vacuum bagging technique is used (Figs. 5, 6 and 7).

The propeller manufacturing involves four steps. The first step is 3D printing of the propeller blades and a hub. The second step is an assembly of these parts over a dovetailed groove. The third step is overlaying the composed propeller with carbon reinforcement. The fourth step is impregnating the reinforcement with the epoxy resin and curing it with the vacuum bagging. As a result, a very light propeller with thin blades, but strong enough to withstand the loads is obtained. The adopted technology allows the RWT to manufacture more propellers that can then be tested in real-life waterbike conditions.

Fig. 8 shows four 3D models of propellers that were designed using the computer CAD-CAM program SolidWorks [2]. As can be seen, the propellers differ in number of blades, blade area ratio, diameter, pitch, section shape, hub length, etc. The propellers were manufactured according to the above mentioned technology and then tested on the waterbike “Šijun” in the water (Fig. 9). Each propeller was tested in similar conditions - sprint...
100 m, acceleration and bollard pull - in order to define which propeller is best suited for each discipline. All of the propellers demonstrated good overall characteristics, but some are better suited to the corresponding discipline. The testing is not completed and will be done in spring 2018. The Fig. 10 shows one of the tested propellers.

Fig. 8. 3D model of propellers

Fig. 9. Testing of “Šijun” on the lake

DESIGN OF THE NEW WATERBIKE
After the last IWR in May 2017 in Poland, the RWT has started a designing of a new waterbike. The objective is to construct a waterbike which will be competitive in most of disciplines in IWR. In order to realize this objective, the following requirements are set:
- A hull form designed to attain semi-displacement speeds,
- A hull construction should withstand all loads while minimizing the mass.

Since the existing waterbike “Šijun” is a catamaran, it was decided to design and build a monohull waterbike. The hull form is intended for the sailing in a semidisplacement mode and the chosen design speed is 11,5 knots. After some analysis, finally it was decided to accept the following hull dimensions:
- Length = 5,80 m,
- Beam = 0,60 m,
- Depth = 0,40 m.

The 3D model of the new waterbike prepared in SolidWorks is shown in Fig. 11. The hull has almost vertical sides and a transom stern. The sides are not exactly vertical in order to allow the removal of the hull from the female mould. The midship section is almost rectangle with the small bilge radius. The stem is angled with the lightly rounded transition to the hull bottom. The propulsion is provided with a screw propeller installed on the stationary strut while the stern rudder is used for steering.

Fig. 10. One of the tested propellers

Fig. 11. 3D model of the new waterbike

The expected mass of the hull is 30 kg and mass in the empty waterbike condition is expected to be approx. 45 kg. The expected canoe body draft is 0,10 m while the expected
maximum draft which includes the screw propeller would be 0.85 m. The drivers will be sited inside the hull and facing each other. The hull will be made from carbon fiber reinforced plastic with epoxy resin. The vacuum bagging technique with postcuring at elevated temperature will be applied. The expected total mass together with drivers is estimated to be 185 kg. The waterbike stability was checked with the Orca 3D, marine design plug in for the computer program Rhinoceros [3]. The position of the center of gravity of the full loaded waterbike was calculated assuming the masses and the positions of centre of the gravity of all waterbike components. Two drivers were assumed to have the mass of 70 kg each. In Table 3 the values of righting arm for various heel angles are presented.

Table 3. Righting arm vs heel angle

<table>
<thead>
<tr>
<th>Heel angle, degree</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Righting arm, m</td>
<td>0.00</td>
<td>0.008</td>
<td>0.017</td>
<td>0.012</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The flow characteristics around the waterbike and the total resistance were obtained from Computational Fluid Dynamics (CFD) simulations done using the Reynolds Averaged Navies Stokes Volume of Fluid method within the commercial software package NUMECA Fine/Marine 5.1 [4]. Two different hull lengths were considered together with two different bow and stern shapes. The stems differ in angles while the one stern is transom and the other is rounded. The “Bow 1” has more angled stem as well as more rounded transition to the bottom while the “Bow 2” has more vertical stem with less rounded transition. The considered speed range was from 9.0 to 11.5 knots. The generated mesh is shown in Fig. 12. The wave elevations for “Bow 1” and “Bow 2” at 11 knots are shown on Figs. 13 and 14.

Table 4 shows the values of the total resistance (forward) obtained from CFD simulations for two bow configurations while the Table 5. gives the total resistance (astern) for two stern configurations.

Table 4. Total resistance from CFD simulations (forward)

<table>
<thead>
<tr>
<th></th>
<th>“Bow 1”</th>
<th>“Bow 2”</th>
<th>“Bow 1”</th>
<th>“Bow 2”</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = 9 kn</td>
<td>131.4</td>
<td>130.9</td>
<td>179.4</td>
<td>174.1</td>
</tr>
<tr>
<td>V = 11 kn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Total resistance from CFD calculations (astern)

<table>
<thead>
<tr>
<th></th>
<th>Transom stern</th>
<th>Rounded stern</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = 11 kn</td>
<td>3812.4</td>
<td>2239.7</td>
</tr>
</tbody>
</table>

Finally, it was decided to accept the “Bow 2” although the resistance difference itself is not large, but the spray at bow is smaller. As for the stern, it was decided to adopt a transom stern because of the expected semidisplacement speeds. However, the stern would have a rounded folding part that would be raised during the sailing forward in order to maximize the effects of the transom. For the sailing astern this part would be lowered in order to achieve the less resistance. This is the reason why the hull length is 5.8 meters. With the folding part the waterbike length will be just a little bit less than 6.0 meters which is the maximum value allowed.

Whereas the waterbike hull design may be optimized, if the propeller is not able to generate the required thrust, the waterbike will move at relatively non-competitive speeds. That is why a special attention will be paid to screw propellers. Several screw propellers will be manufactured and then tested with the waterbike in the water. The propellers will be manufactured according to the technology described above - a 3D printed model will be overlaid with the carbon reinforcement.

The screw propeller will be installed at the bottom of the stationary strut. For the manufacturing of the strut, the experience gained from the design and manufacturing of the propeller steerable strut done in the season 2016/2017 for the waterbike “Šijun” will be utilized (Fig. 15). This component was entirely made up with the team’s own strengths.
At the time of writing this article, the process of purchasing materials for the building of the new watercraft is ongoing. A file with the hull data has been already sent to a company that will sponsor the production of a two-piece female mould. The edge of the mould will have a flange due to the application of the vacuum process. In addition, activities on drafting the laminate plan are also in course. The hull will be completely made of carbon reinforcements. The consideration is given to the possibility of using the sandwich construction only for the bottom of the waterbike. The deck will be a single skin laminate, and there will be two bulkheads outside the sitting area of the drivers. Also, the ergonomic features of the driver seats are considered.

The RWT expects that everything will be completed in time for the IWR in Zagreb, Croatia in May 2018.

CONCLUSIONS

In the paper the history of RITEH Waterbike Team, its current and future activities are briefly described. The RWT behind itself has four waterbikes which were designed and built for the participation in international regattas in Europe. It is clear that through the years, the RWT waterbikes have become more sophisticated and their competitiveness has been largely improved. Over that time, a lot of experience has been accumulated and much knowledge and skills have been adopted, which are not purely engineering like finances, marketing, logistics and particularly teamwork, all of which are important for future employment. At this moment, all this knowledge and skills are directed towards the creation of a new waterbike which is naturally expected to be the best so far.

As of today, the fundaments of RWT are stable despite the ever-present fluctuations of the students which are due to variety of reasons, primarily because students graduate and leave the faculty. A mix of students from different years of study gives the belief that the RWT will exist for a whole number of years.

REFERENCES


AUTHOR BIOGRAPHIES

Prof. Roko Dejhalla, PhD., Nav. Arch., is a full professor at the Faculty of Engineering, University of Rijeka. For many years he is a Head of the Department of Naval Architecture and Ocean Engineering. He teaches courses related to the ships resistance and propulsion and building of small craft and his research activities take place within the scientific area of naval architecture, in particular the marine hydrodynamics (ship resistance and propulsion). Roko Dejhalla is a mentor of two student projects: “RITEH Waterbike Team” and “Adria Hydrofoil Team”.

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Darin Majnaric, Univ. Bacc. Ing. Nav. Arch. earned his bachelor’s degree in 2017 from the Faculty of Engineering, University of Rijeka. Presently he is in the second and final year of the Naval architecture Master’s degree program at the same institution. Darin is presently the team leader of the “RITEH Waterbike Team” for over a year and has been a member since his undergraduate years. Likewise, Darin is an active student member of SNAME since 2017.

Ivor Majnaric is an undergraduate student at the Faculty of Engineering, University of Rijeka. He is enrolled in the third year mechanical engineering program and plans to enter the Master’s degree program and specialize in marine engineering. Ivor is a student member of SNAME since 2017 and also a member of the “RITEH Waterbike Team” since 2016, where his main contribution is the design of a management and propulsion system.

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