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EXPERIMENTAL EVALUATION OF THE INFLUENCE OF SURFACE ROUGHNESS ON A MODEL OBTAINED BY DIFFERENT CASTING PROCESSES IN THE DEVELOPMENT OF FLOW PROFILES

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Abstract. *This work has the purpose to analyze how the water flows through a boat. By aluminum casting two boats by utilizing two methods, such as green sand and die-casting, the surface demonstrated different patterns of roughness. In order to have the best finishing possible for each casting technique, a CNC machine was used to create the molds. The total resistance of a ship increases as hull surface roughens, which means more drag and vorticity (Usta e Korkut 2013). To prove it, the models were taken to the water channel. The visualization method chosen was the die injection and soap injection. In addition to the experiment, a Computational Fluid Dynamics was performed to ensure that surface roughness plays an important role in resistance characteristics of the boat.*

Keywords: *flow, drag, roughness, casting, CFD*

1. INTRODUCTION

In engineering applications, the roughness aspects of a body immersed in a flow are important in terms of the efficiency of heat transfer processes, the performance of ship propellers, aerodynamics of sports materials, the performance of wind turbines and aerodynamics of bodies (Bimbato 2012).

Casting is the manufacturing process in which the solid-state metal is cast into a cavity that has the intended shape (Callister 2010). The four most common casting processes are described in the literature: green sand, micro fusion, gravity casting and die-casting. The different finishes generated by the casting processes used lead to different roughness patterns, which can influence the location of the runoff and formation of the turbulence zones. A suitable experiment can produce revealing images of the flow of a fluid, which may show the evolution of the flow, the transition between regimes, laminar and turbulent, and the region of formation of vortices, recirculation and wake.

Flow visualization techniques, such as the direct injection of liquid tracer, make it possible to study the behavior of fluids in different flow regimes, either in a free stream, in closed ducts or in submerged bodies. Alé V. J. (2001) proposes the use of such techniques for the better learning of Fluid Mechanics, since they allow the observation of phenomena that are studied in a theoretical way, complementing the learning with qualitative and quantitative information of the flow fields. Such benefits extend to the field of research, where the view of flow profiles influenced by the most diverse factors contribute to improving the level of phenomenological understanding that is currently in this area of knowledge, including obtaining data for the development and validation of mathematical models.

The aim of this paper is to experimentally research the flow around a model made from different foundry processes. From that, it is possible to know better the flow behavior when surface roughness exists, through visualization techniques of flow, allowing comparing different manufacturing processes, since modifications in the flow pattern tend to affect parameters such as material wear, for example.

2. EXPERIMENTAL PROCEDURE

2.1 Obtaining the model

The study model was obtained from the following casting processes: green sand and cast-in-shell. The mold for such processes was fabricated using nylon 6.0 material. This choice was made due to the availability of this material in the laboratory and because of the ease of machining. It passed through a Romi machining center, model Discovery - 4022, where it was machined and acquired the desired shape (Figure 1). The programming for machining was performed using Edgecam software (Figure 2). It was possible to start the casting processes with the finished model.

(a) (b)

Figure 1. Obtaining the mold. (a) Machining center. (b) Mold being machined.

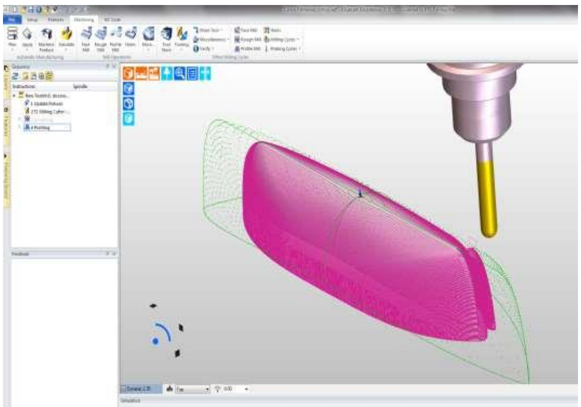


Figure 2. Edgecam project of the study model.

The casting process for green sand was divided into two stages. The first one was based on the manufacture of the molding box, which can be visualized in Figure 3. The second stage was carried out after sand casting and was based on casting the molten liquid (aluminum alloy 5052) into the mold at a temperature of 800 ° C with the help of a ceramic crucible, as can be seen in Figure 4. The solidification time for the alloy used was 20 minutes, after which it was possible to carry out the demolding of the study model manually.

Figure 3. Preparation of the molding box.

(a) (b)

Figure 4. (a) casting aluminum alloy melt. (b) Model already cast.

For the permanent casting, the mold was made of a gray cast iron ND 45012 because of its thermal fatigue resistance propriety (Degarmo, Black e Kohser 2003). This casting process was also subdivided into two parts. The first one consisted of machining the cavity where the boat would be cast, and the two halves of the material were machined with two mirrored cavities. The second action was the pouring of the molten aluminum alloy into the wells of the shell, which occurred after preheating the shell to 350 °C. The opening of the shell took place after a period of 30 minutes. Figures 5 and 6 show the die-casting process carried out in the design.

Figure 5. Aluminum solidification after pouring.

Figure 6. Opening the mold.

The cast models were characterized according to their roughness by the use of a Surface Roughness Tester, model Mitutoyo Surftest SJ-301, which is located in metrology laboratory where Ra and Rz of each model was measured at nine different points, with three measurements to the same point, with the aid of an altimeter.

2.2 Adaptating the didactic workbench

The laboratory of fluids at federal institute of science and technology education – Farroupilha campus has an open channel didactic workbench that allows water scaled experiments. However, a specific support was developed to hang the study model as well as to a liquid tracer injector.

For the development of the support, nylon 6.0 and aluminum were used, and it can be better visualized in Figure 7. In addition, the tracer fluid injector was made from bent copper tubes in which flow control valves are coupled to control the proper flow of tracer fluid. Figure 8 shows the adapted workbench that has the length and width of 3 m and 0.1 m respectively.

Figure 7. The hanging support.

Figure 8. Adapted open channel workbench.

2.3 Experiment setup

To run the experimental tests, the study model was set in the adapted workbench in a region where the input effects were negligible and this was 2.3 m away from the entrance of water in the channel. The water column was kept at a height of 30 cm by maintaining constant the water flow to a velocity of 0.013 m/s.

From this, flow visualization techniques, food dye injection and soap bubbles were used to verify the development of the flow around the study model, the vortex formation sites and the effects generated by the presence of roughness. The choice of these techniques is justified by the ease of implementation, the low operating cost and wide application (Mansur e Vieira 2004).

The alternative of food coloring was also because its density is close to water, which avoids variations in the flow regime when it is inserted. In addition, the dye is easy to clean, which allowed several experiments to be carried out without contamination of the water used. To perform this experiment, about 25 grams of Arcolor® food color in blue and red colors were diluted in 500 ml of water.

In the case of soap bubbles, liquid laundry soap was used due to the density of the soap. A disadvantage of its use is the amount of waste deposited in the water, which made it difficult to perform several experiments in sequence, requiring constant water exchange. On the other hand, due to the density of the soap, it presents excellent visibility characteristics, allowing its movement along the fluid lines. The amount of soap used was about 250 ml of soap, deposited next to the tank of 400 L of water.

The recording and processing of images was done by photographic means with conventional camera brand GoPro model Hero 4 Silver Adventure.

2.4 Computational Simulation

Parallel to the development of this proposal, it was also chosen to make use of Computational Fluid Dynamics (CFD) in order to simulate the test conditions and thus obtain a comparison with the experimental tests. Thus, the FlowSimulation package of SolidWorks software, available in Campus laboratories, was used to simulate fluid flow through the study model, taking care to maintain some characteristics used in workbench, including the speed of the fluid used and the geometric dimensions of it. The drawing in SolidWorks® software can be seen below in Figure 9.

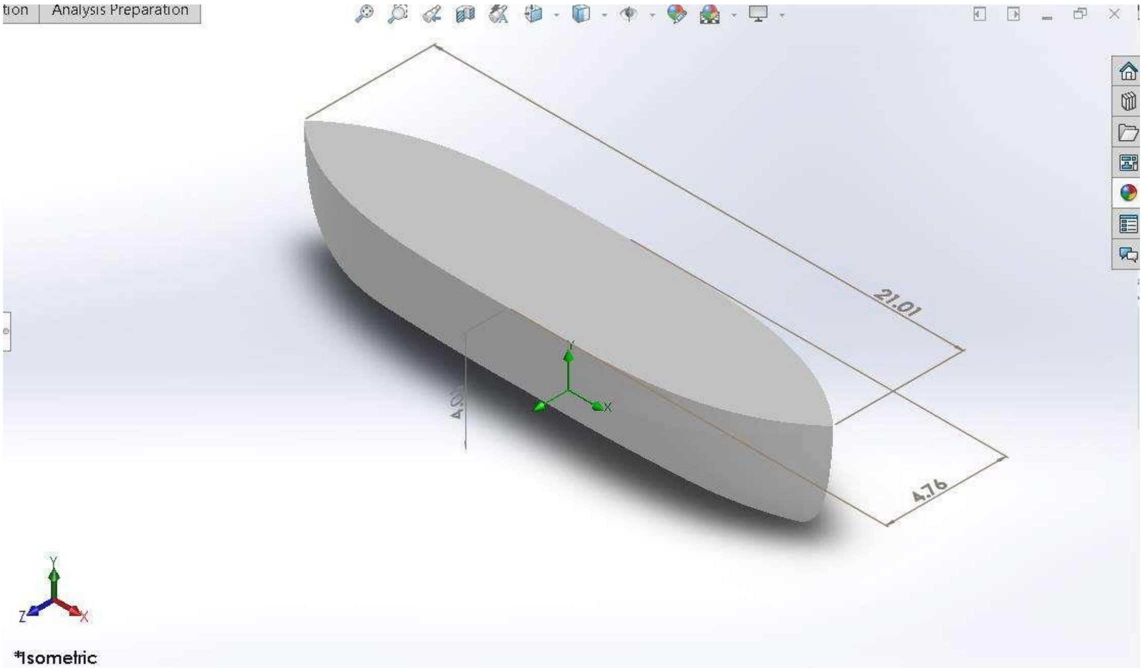


Figure 9. Perspective design of the study model used.

The data used for this simulation are presented in Table 1 below.

Table 1. Data used in the simulation step, according to the analysis experimental.

Model Length	210 mm
Model Width	40 mm
Model Height	47.5 mm
Bench Length	3000 mm
Bench Width	100 mm
Bench Height	300 mm
Fluid Speed	0.013 m/s
Total of mesh points	22000

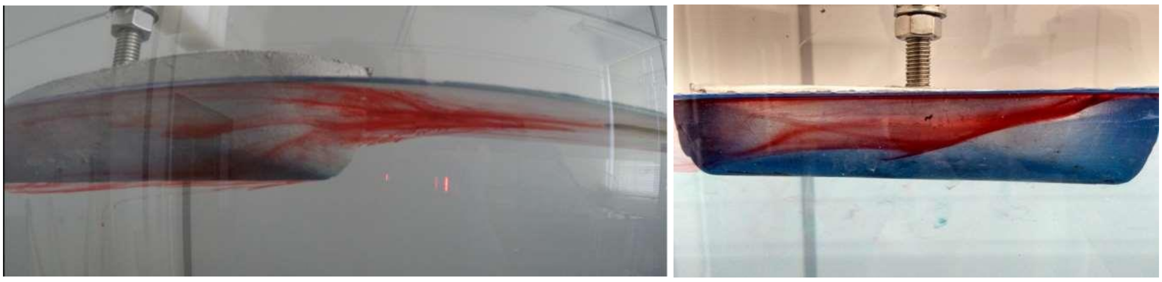
3. RESULTS AND DISCUSSION

The figures 10, 11 and 13 show how the techniques used allowed the visualization of the flow around the study model, while Figures 12 and 14 present the results of the computational simulation stage.

(a) (b)

Figure 10. Side view of the flow output with blue food coloring.
(a) Green sand-cast model. (b) Permanent casting mold model.

In Figure 10, a photo taken at the back of the model demonstrate a vortex formation. This generated vortex wake has the effect of speed reduction, and its presence is in agreement with the results obtained by the simulation. In addition to the formation of the vortex wake, it is possible to visualize the current lines along the bench, allowing observing the behavior of the fluid flowing. Also, notice that the flow develops more smoothly, without the occurrence of turbulence, in the permanent casting mold model.



(a) (b)

Figure 11. Side view of the entrance of the flow with red food coloring.
(a) Green sand cast model. (b) Permanent casting mold model.

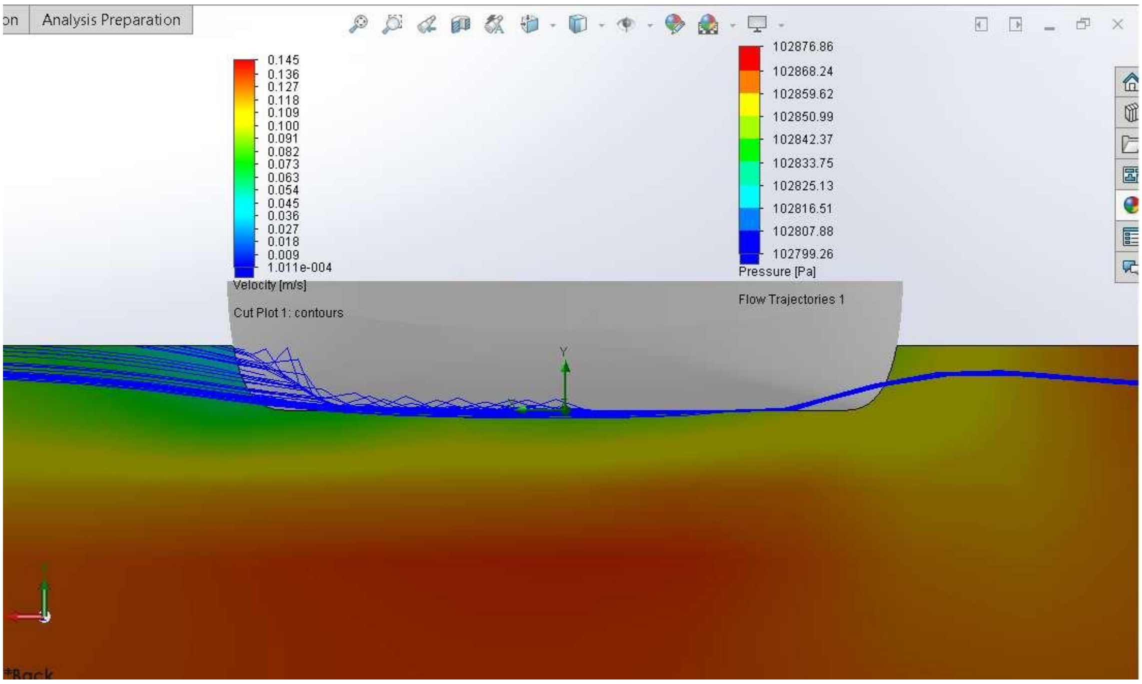


Figure 12. the speed profile view in detail the side of the model.

Figure 11 is the view of the contour motion that the water, with the dye, makes along the boat and the detachment of fluid at the bottom, moving slightly away from the edge of the boat. These results are in agreement with both the simulations (Figure 12) and with the literature used. Again, the development of a smoother flow in the die-cast model is observed.

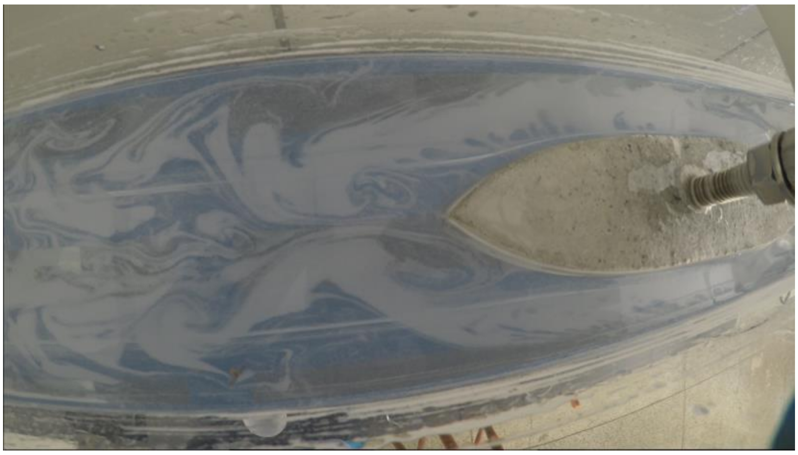


Figure 13. Top view of model outlet with soap bubbles.

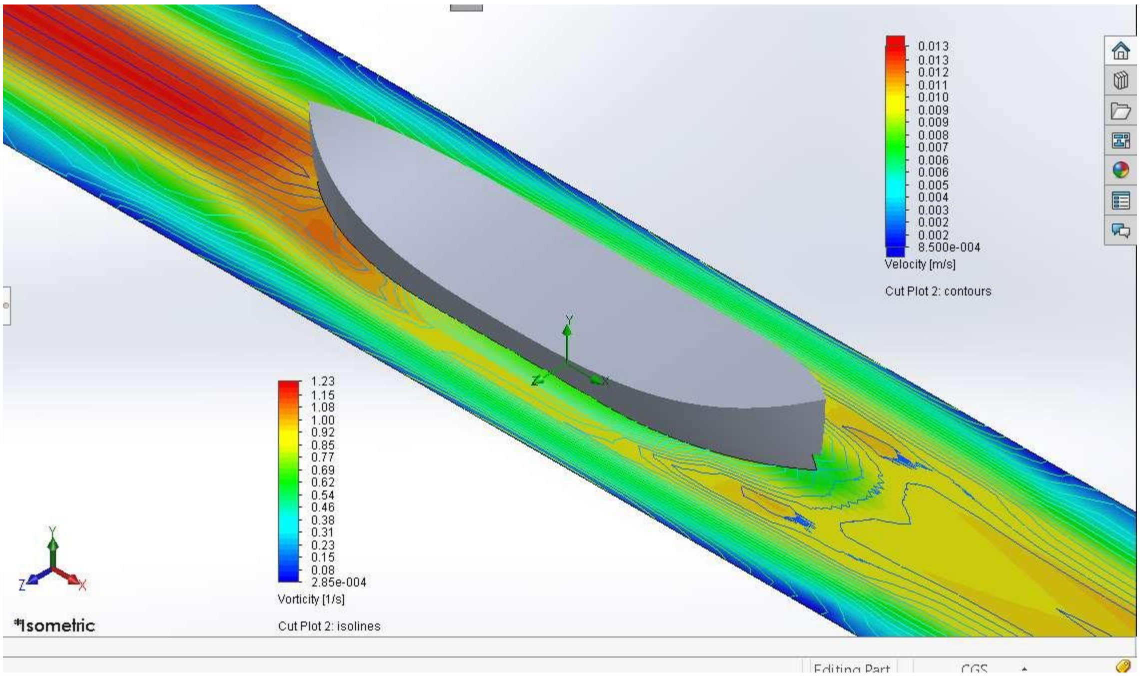


Figure 14. Isometric view of the velocity profile of the model.

Figure 13 that allow the understanding of how the fluid is initially forced to pass around the study model, and after the end of it, the fluid acquires turbulent characteristics, forming a vortex wake of Von Karman. Through the visualization technique used, it is possible to detect the profile of the flow as well as the formation of vortices, as mentioned, but its applications are limited to situations in two dimensions. These results are in agreement with the literature analysis and with the computational simulations performed in the figure 14. In addition, both the walls and the blockage that the study model causes in the fluid generate a very significant loss of velocity of the fluid.

Initially the fluid meets the workbench thus suffering a deceleration along the same. This loss of velocity results in the formation of a boundary layer on the sides of the bed. While in the wall the velocity of the fluid tends to zero, in the center the speed of the fluid tends the maximum speed. This situation is confirmed by observing the colors demonstrated by the fluid in Figure 14, where in blue, slower and red, higher velocities, and according to the literature analyzed.

Upon contact with the study model, the fluid is forced through the sides of it. Therefore, at this point, a new boundary layer forms around the model. With the combined effects of loss caused by the walls and the model, the speed reaches lower values, especially along the sidewalls of the water channel.

The roughness data show that the cast in green sand presented very high values and with great variation. This is because the mold preparation, which has been manually shaped, the molding green sand, may have eroded and some grains of sand have loosened and additionally to its large porosity, thus generates some non-conformity on the surface of the boat.

Figure 15 shows the roughness of the bottom of the boat cast in green sand. Note that closer to the middle of the boat the roughness increase, due to the central position where the aluminum alloy was poured.

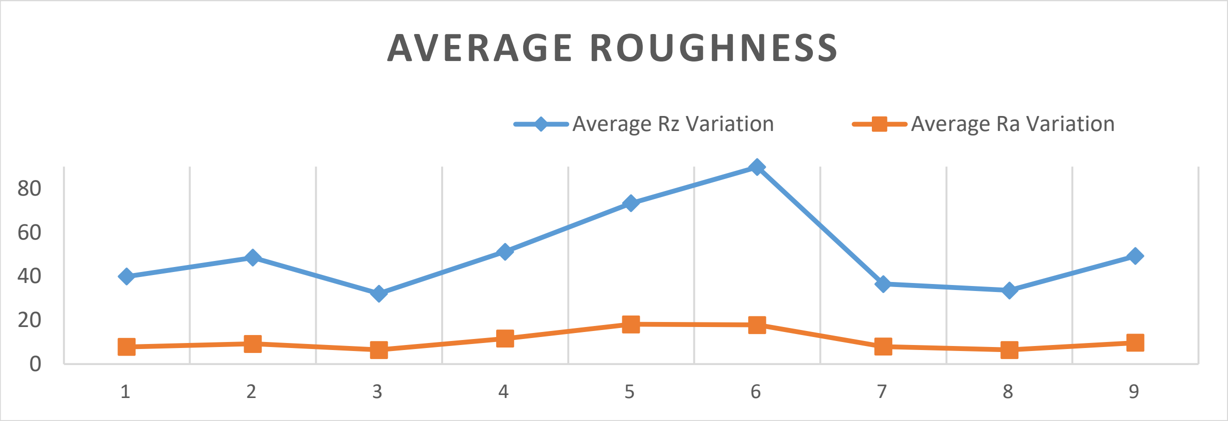


Figure 15. The roughness variation at the lower part of the model cast in green sand.

However, the roughness in the boat cast in a permanent mold has almost constant results, Figure 16 shows the mean variations of each point along the bottom of the boat.

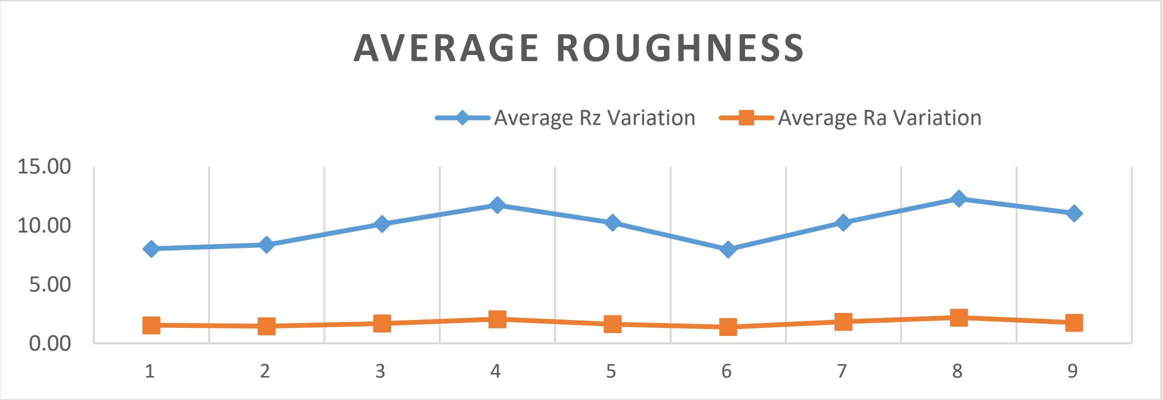


Figure 16. The roughness variation at the lower part of the model cast in a permanent mold.

This constancy is due to good machining quality because what will be represented in the mold is the quality of the shell and the aluminum alloy to be cast. It should also be noted that the porosity in the shell is negligible because the material is a cast iron.

4. CONCLUSION

According to the bibliography found, it was not possible to parameterize only the roughness with the flow. It is known that roughness when controlled and uniform can generate less friction, improving fluid flow around a study model (Leer-Andersen e Larsson 2003). However, it is not possible to predict and control the roughness only with the casting methods, especially the green sand casting. Each method of casting had a different result of roughness, being the sand casting green presenting greater roughness when compared with the permanent mold, but quantitatively it was not possible to measure the difference between the flows when the boat is in the water channel.

Computational simulation results show that there are differences in speed parameters on the surface of the boat when the roughness is altered, but it was not possible to reproduce the exact rough surface that the casting processes generate. Although the simulation is able to take into account the roughness, it is not possible to specify the geometry of this roughness (ITTC 2011). Thus, it can be inferred that the lower the roughness, the die-casting process, the study model generates less friction and less detachment of the boundary layer, but it is not the only parameter to be considered, since the roughness geometry, if machined, can generate better results at certain flow rates.

For the experiment, the results obtained were in agreement with the literature and with the simulation, which guarantees that, for similar applications, with this level of complexity, the software is a good initial analysis tool.

In general, it is not a question of eliminating the need for experimental tests, but rather a combination of both, in order to use the best characteristics of each one, resulting in less time and costs for developing new projects, but maintaining a high level of quality in it.

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6. RESPONSIBILITY NOTICE

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