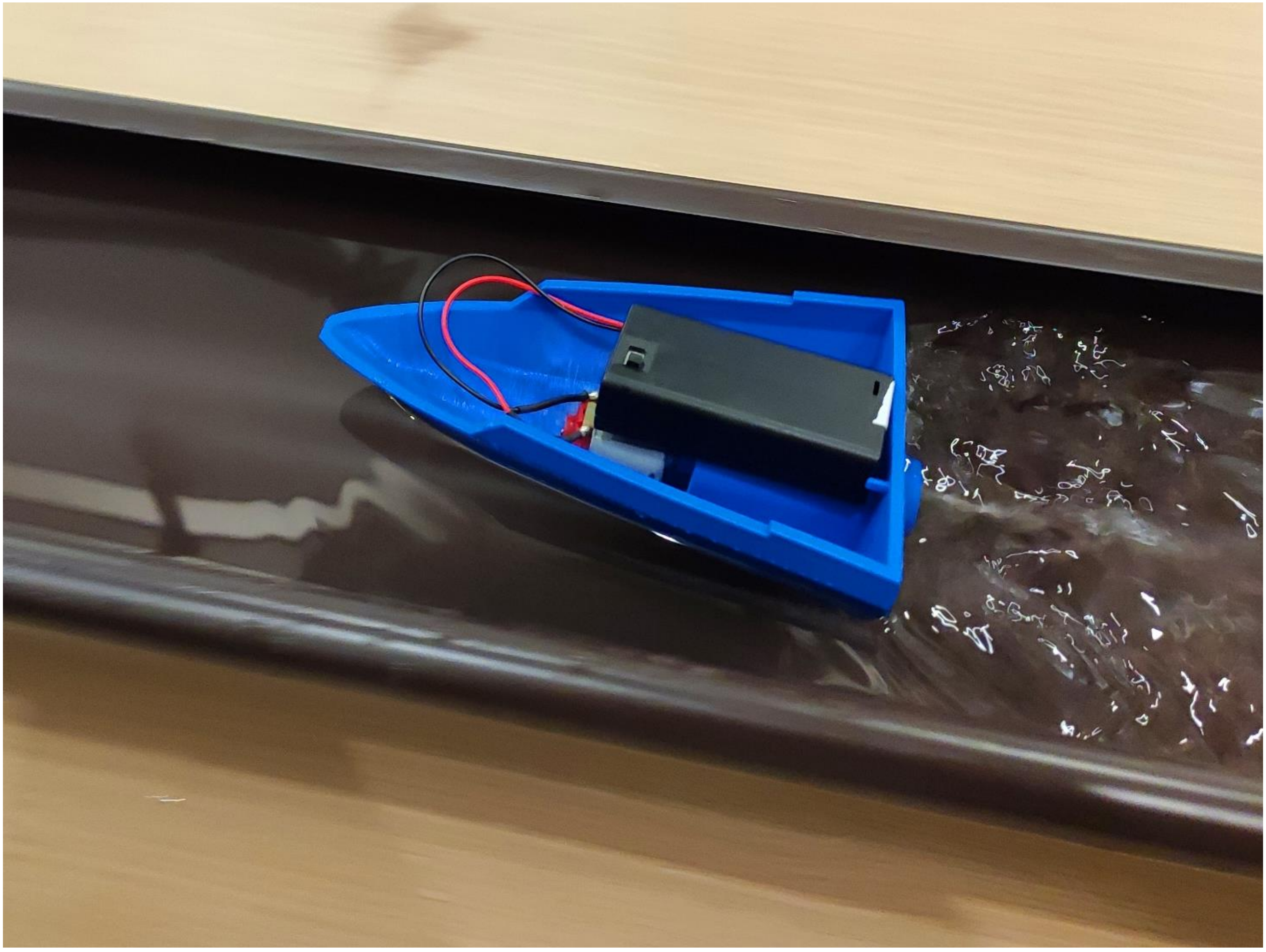
Additive Manufacturing 2021/2022

Lab 1 – AM for boat racing

WATERCRAFFFT



POLITECNICO
MILANO 1863

Another problem was finding a cross belt to guarantee a counter-rotation of the 2 propellers: if that condition is not guaranteed, the boat is not able to go straight.

Considering all these premises, the hydrojet boat seemed a good compromise between the constraint of velocity, printability and feasibility but still considering performance.

CAD design

Once the hull design was chosen, the next step was to make a printable CAD model. As a first try the dimensions were roughly decided only based on the constrains imposed by the rules of the race:

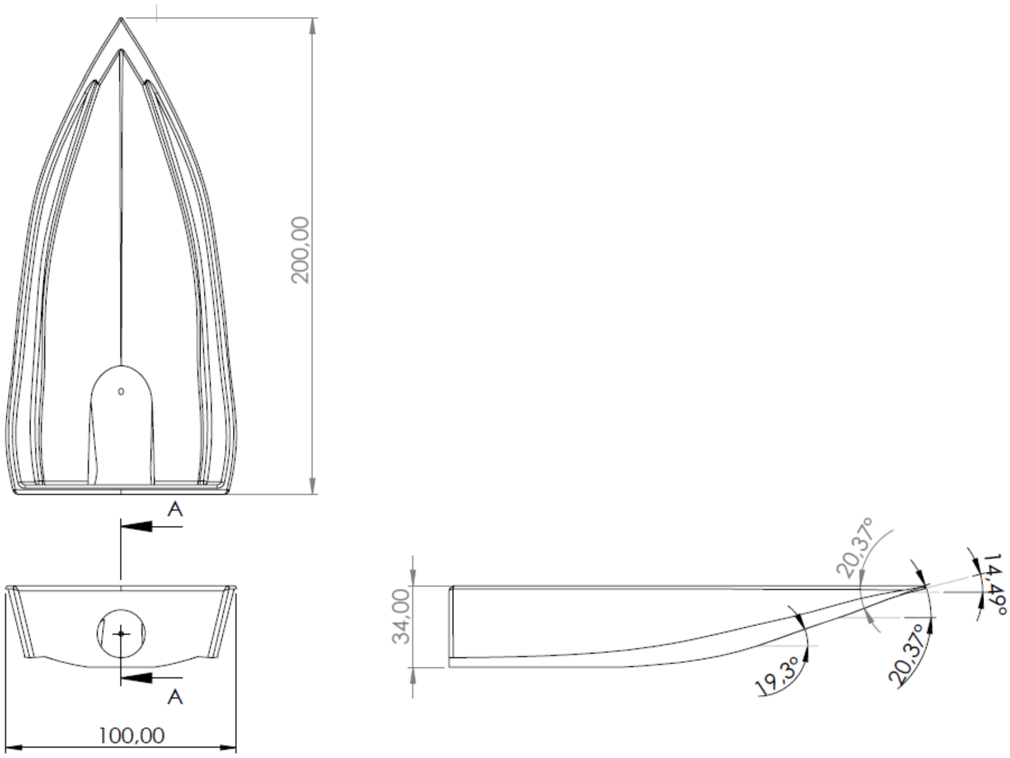


Figure 2- CAD design (with dimensions in mm) of the first boat prototype.

Then the shape has been designed roughly in function of typical proportions of hydro-jet boats, with a specific focus on the angles of the bow: if the cross section reduces rapidly, causing an overhang, it is necessary to use supports to print it. The more supports are generated, the longer the print takes.

Considering printing the boat horizontally, we wanted to avoid angles higher than 45° to avoid supports at all. However, because some angles exceeded this limit, the boat wouldn't be able to support itself during the print, so the addition of supports was necessary.

a reduction of the dimensions has been performed: to stay inside the time limit the length was reduced to 160mm and all the other dimensions were reduced to maintain the initial proportions.

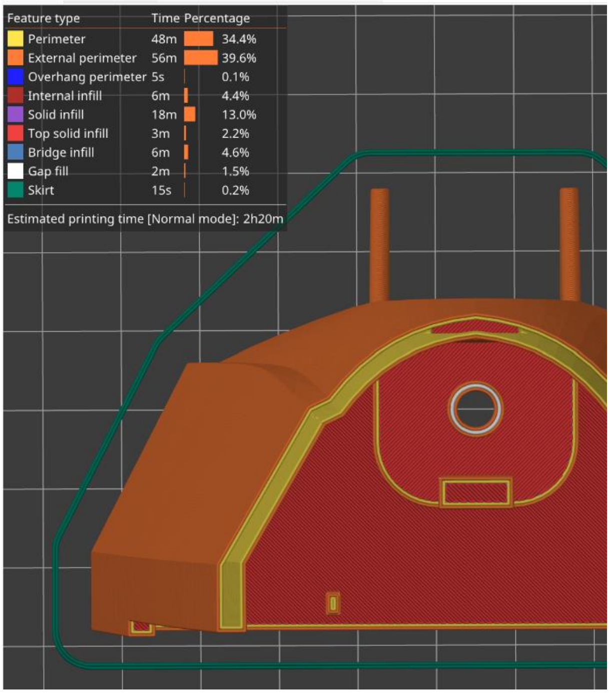


Figure 5- Hull with 3mm thickness and 2 + 2 layers. This simulation has been done for all the prototypes.

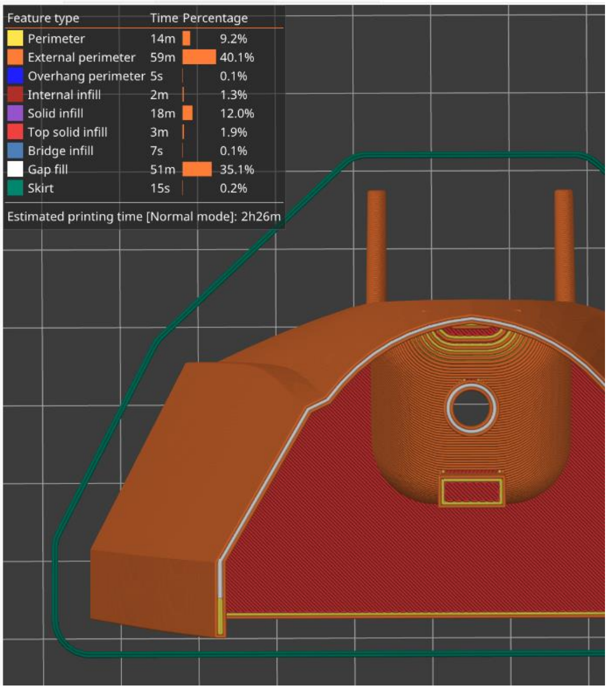


Figure 6- Hull with 1.2 mm thickness and 3 layers. This simulation has been done for all the prototypes.

Regarding the hull thickness, after a first comparison it has been decided to choose the "double perimeter" design instead of the thinner shell. This choice, ceteris paribus, enables to have a shorter printing time and a much higher stiffness and torsional rigidity of the hull.

<u>Printing sessions</u>

1st printing session: printing parameters

It was not allowed to change setting parameters without previous tutor's consent. The only one that was modified was the infill density in order to reduce the printing time.

- Layer height: 0,2mm
- First layer height: 0,3mm
- Numbers of perimeters: 2
- Infill density: 4% Infill pattern: rectilinear
- Automatically generated supports
- Estimated printing time: 2h 49min

Considering the boundary conditions (weight of bodies, surface in contact with water, max height of the boat, printability of a small component, arrangement inside the boat) a diameter of 20mm was considered. At the end, to have a printing time lower than 3h, only one propeller was printed.

Nozzle design improvement

The internal nozzle design tried in the last print presents some issues, mainly regarding the final assembly of the boat. Because of its small diameter it would be necessary to have multiple parts for the propeller and, in order to put it together, it would be mandatory to adapt the lower part of the hydrojet intake accordingly.

So, it has been decided to opt for the external nozzle design and, subsequently, change the design of the stern of the boat. Thanks to this design choice the assembly procedure became easier and the propeller could be printed as a single piece with its shaft, as in the design reported above. Moreover, this solution enabled the possibility to integrate a fixed rudder.

The rudder is an additional feature with the aim of reducing the momentum caused by the rotation of the single propeller; it’s paramount to compensate this momentum since it’s impossible to control the orientation of the boat once it starts moving.

However, this choice implies a more complex design in terms of coupling the hull and the nozzle and a more complex print both for the hull and the nozzle.

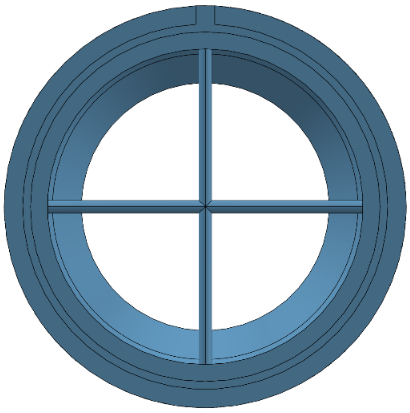


Figure 31- Final nozzle. Notice the two rudders to keep the direction and create a more laminar flow.

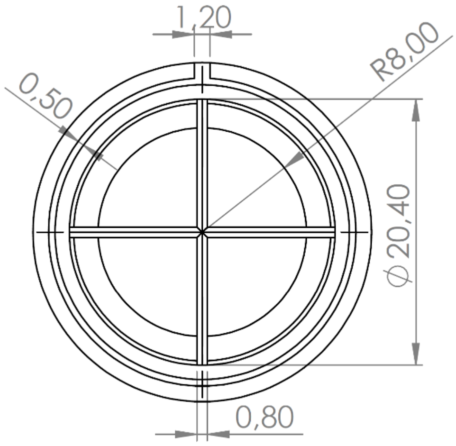


Figure 32- Final nozzle. Notice the different input and output dimensions.

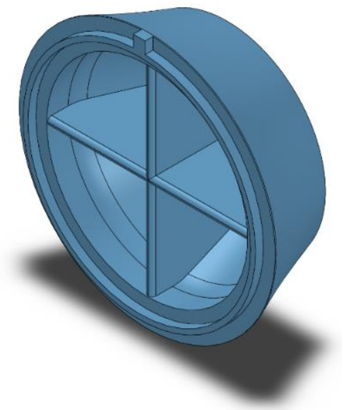


Figure 33- Final nozzle. Notice the pin and coupling system to plug it with the hull.

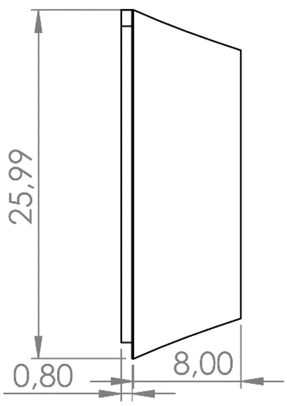


Figure 34- Final nozzle, lateral view. Notice the length and the angle, suitable to be printed without any supports.

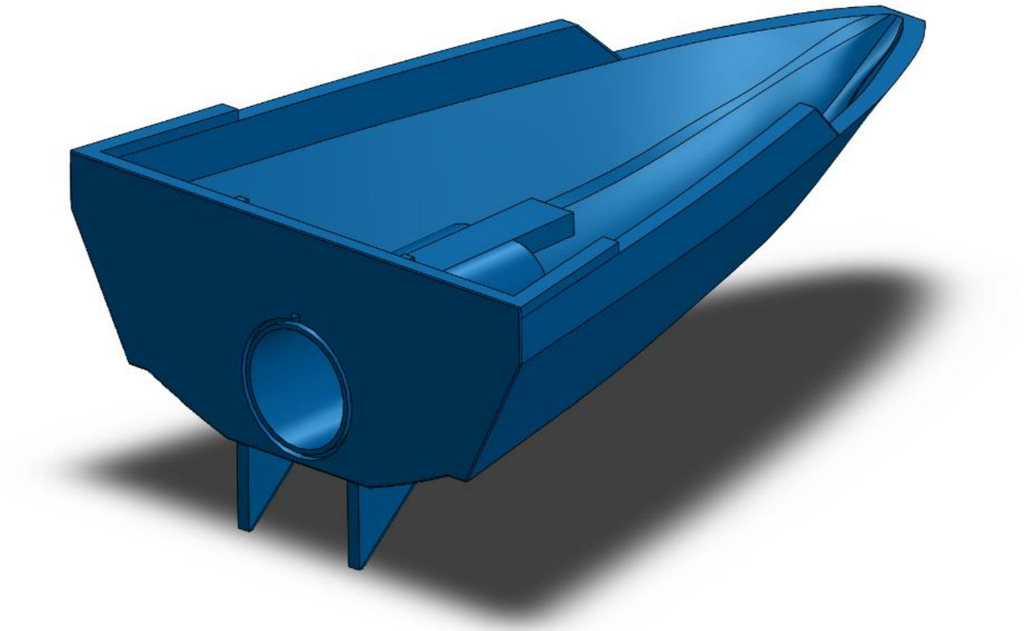


Figure 35- Final hull design. Notice the coupling system between hull and nozzle and the spacer, used both to keep the motor in place and support the battery pack. New engine slot angles prevented the use of any support.

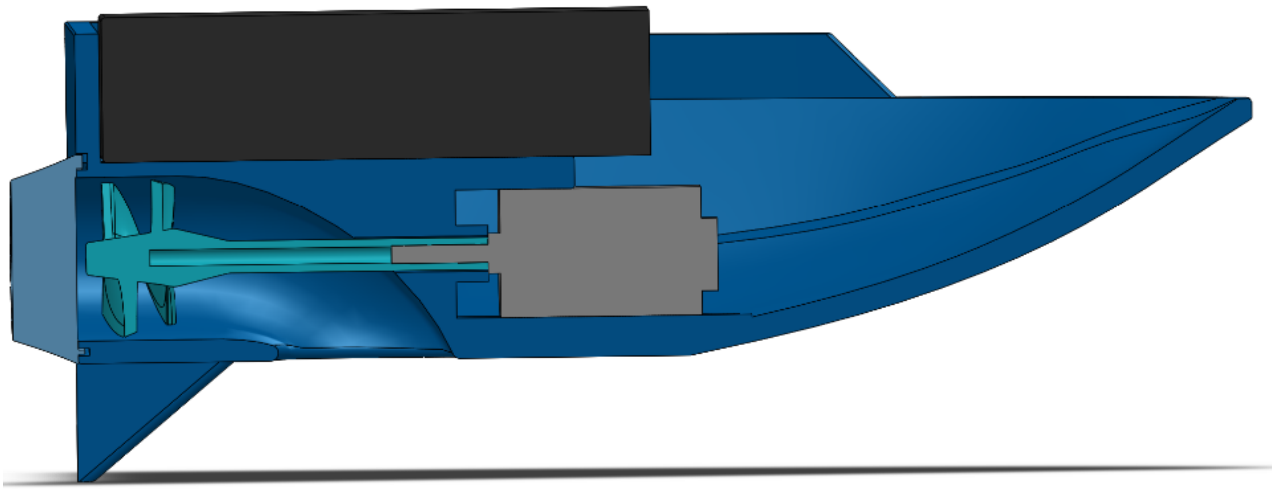


Figure 36- Final boat design, section view. Notice the final assembly of all components and in particular the motor-shaft connection. It has been decided to create a longer channel to prevent the water to enter the hull. As regards dimensional issues, in order to correctly couple hull and shaft, has been decided to have a 0,4mm gap between the two diameters, preventing the water entrance but avoiding too much friction. To reduce printing times, the shaft is hollow.

For the boat it was chosen a standard rectilinear infill, since the hull doesn't require any particular internal support structure and impact strength wasn't an important constrain, considering the slow speed at which the boat would move. This choice, when compared to the other available options, was the best trade-off between printing time, structural support during the print and weight of the boat.

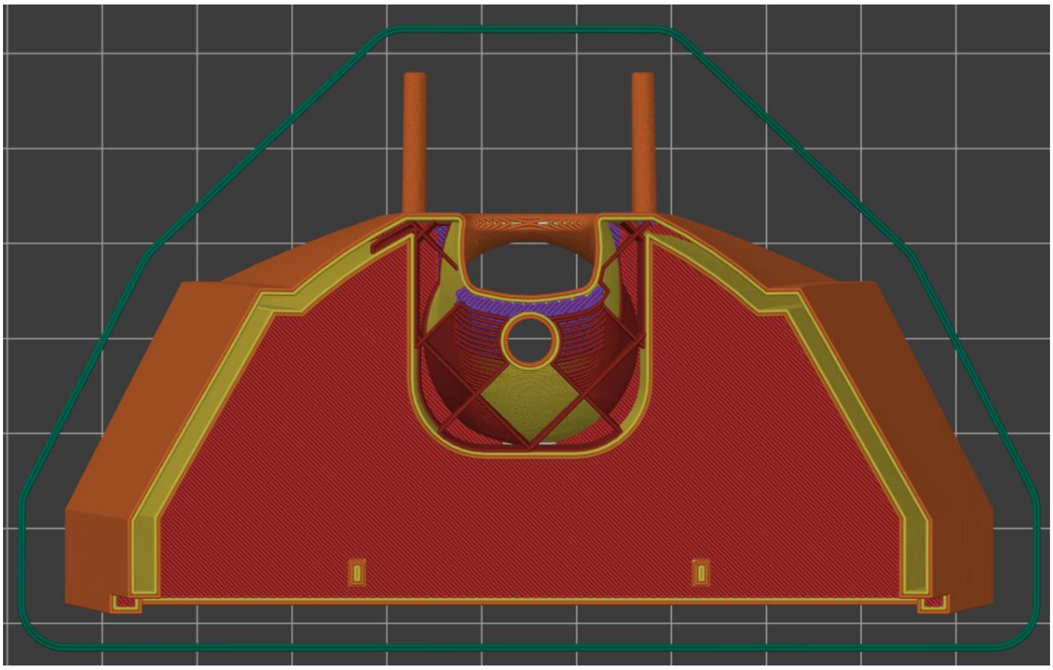


Figure 41- Final design. Hull slicing. Infill analysis.

Once everything was ready, we printed all the parts as stated above: during the print itself there wasn't any issue, all the parts sticked to the bed correctly and the predicted printing time was achieved.

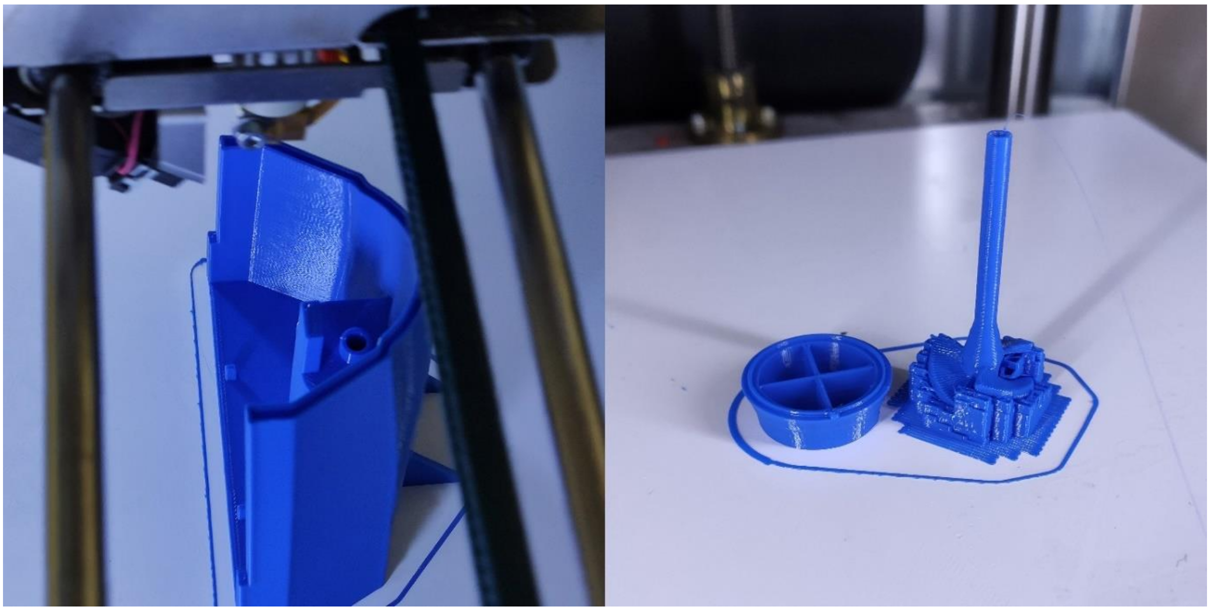


Figure 42- 3rd printing session. Hull *Propeller/shaft and nozzle.*

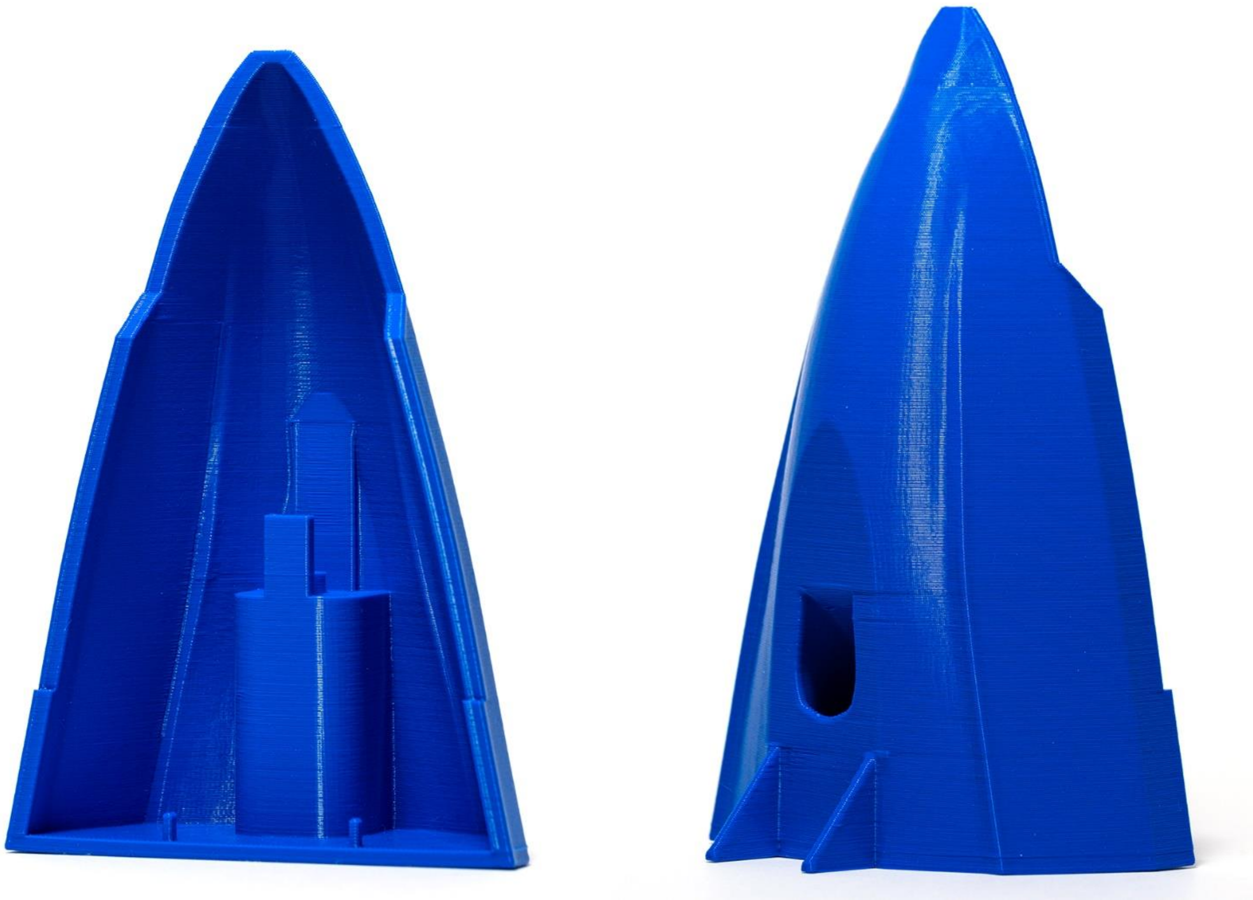


Figure 46- Final racing boat. Notice the overall good final quality. Front and Bottom view.

Figure 47- Propeller/shaft and nozzle. Notice the good quality of the coupling system of the nozzle and the slightly lower quality of the propeller blades, due to supports detachment and printing layer height.

Future development

Considering future possible improvements on design and performances, there are some key areas which can be considered:

- Surface finish of the propeller: the blades of the propeller don’t have a really smooth finish, surely impacting negatively the performances of the boat introducing turbulences in the water flow.

On the other hand, it has been noticed that other boats with a more streamlined design completed the race in less time, although bouncing between the walls. In fact, the biggest difference with respect to this kind of boats, mainly printed horizontally, was the way the Archimedes' principle was exploited: having a similar weight but with a larger surface, the height of the displaced water was reduced.

Because of the working principle of the hydrojet, a part of the boat is occupied by water, thus the duct doesn't contribute to the water displacement. The other interesting finding is related to the propeller dimensioning: the fastest boats were the ones with the smallest propeller, allowing the motor to run at higher RPM and closer to its nominal power.

Conclusions

In facing this project, the most important objective was to fully exploit the possibilities offered by additive manufacturing technologies, in particular the FDM. In doing so, the team tried to develop a boat using the "complexity for free" characteristic: in this sense, the choice of an hydrojet, characterised by many holes and particular shapes, gave an important opportunity, allowing the very peculiar components and solutions.

In addition, the goal of designing a "zero-support" structure has been achieved: in fact, both the hull and the nozzle were printed net shape, while the propeller needed deeper knowledge to be designed for a no-support print.

Considering the experience gained seeing the other prototypes during the race gives the possibility to grasp some final hints. Without the printing time constraint, the boat would have been longer and narrower, maybe by printing it horizontally instead of vertically.

The boat would have performed much better with a more powerful motor, which better fits this propulsion system; this characteristic would have also allowed a higher reduction ratio for the nozzle, increasing even more the thrust.

However, only using a hydrojet there was the possibility to mount a proper rudder, guaranteeing the desired rectilinear path. Among all competitors, this boat was the only one exploiting a such a different idea.