The Effect of Length to Height Ratio on Forces Produced by a Caudal Fin

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Abstract

Autonomous underwater vehicles (AUVs) are growing in popularity as they eliminate the need to put humans in potentially harmful situations during military, scientific, and commercial missions. These AUVs are typically powered by classic rotary propellers, but driving mechanisms modeled after fish fins could provide more efficiency, speed, and stealth than rotary propellers. One of the steps toward successfully implementing a bio-inspired propeller is understanding the morphology of a fish's caudal (tail) fin and how each of its parameters affects swimming. This project creates a platform for testing how force produced by a tail fin varies with the fin's length and height. This is done by 3D printing and attaching an Arduino to a mechanical fin that can alter this ratio via two servo motors while swimming. The fin also keeps other variables, such as area, constant.

Introduction

When it comes to underwater missions for the military or the scientific community, having a robot that can operate underwater autonomously is useful, especially when it eliminates the need to put a human in a hazardous situation. For this reason, autonomous underwater vehicles (AUVs) have become popular. Currently, classic rotary propellers are the most common form of propulsion through the water. However, it turns out that propulsion methods inspired by biology can be superior to the classic screw propellers in terms of speed, maneuverability, efficiency, and stealth[1]. The Gharib research group has set out to create a bio-inspired tail fin for an AUV.

Along the path from idea to actual AUV, they have explored methods to model optimal pathways and trajectories autonomously[2]. The research group is also interested in figuring out the best shape for this tail fin, so that it can be best fit for efficiently meeting trajectory requirements. There are many parameters that influence how a fish fin performs, such as flexibility, forking (aspect ratio), and the size of the caudal peduncle (the part where the fin attaches to the fish). We know from simulations that all of these affect the performance of the fin and thus, there is a merit to determining a "best" shape for the fin[3]. This project created a fin that can autonomously change its length and height (while keeping other variables like flexibility and area constant) by changing the sweep of the fin, so that the aspect ratio's effect could be closer studied.

Methods

Figure 1 *The experimental setup*

To test the fin, it is first attached to a force sensor via an adapter CADed on the top of the shell. The three robotic arms outside of the tank are the driving force behind the fin's movements. They can provide a large range of motion, so many types and variations of fin trajectories can be tested. During the movements, the forces on the fin are measured and recorded.

Control and Power Transmission

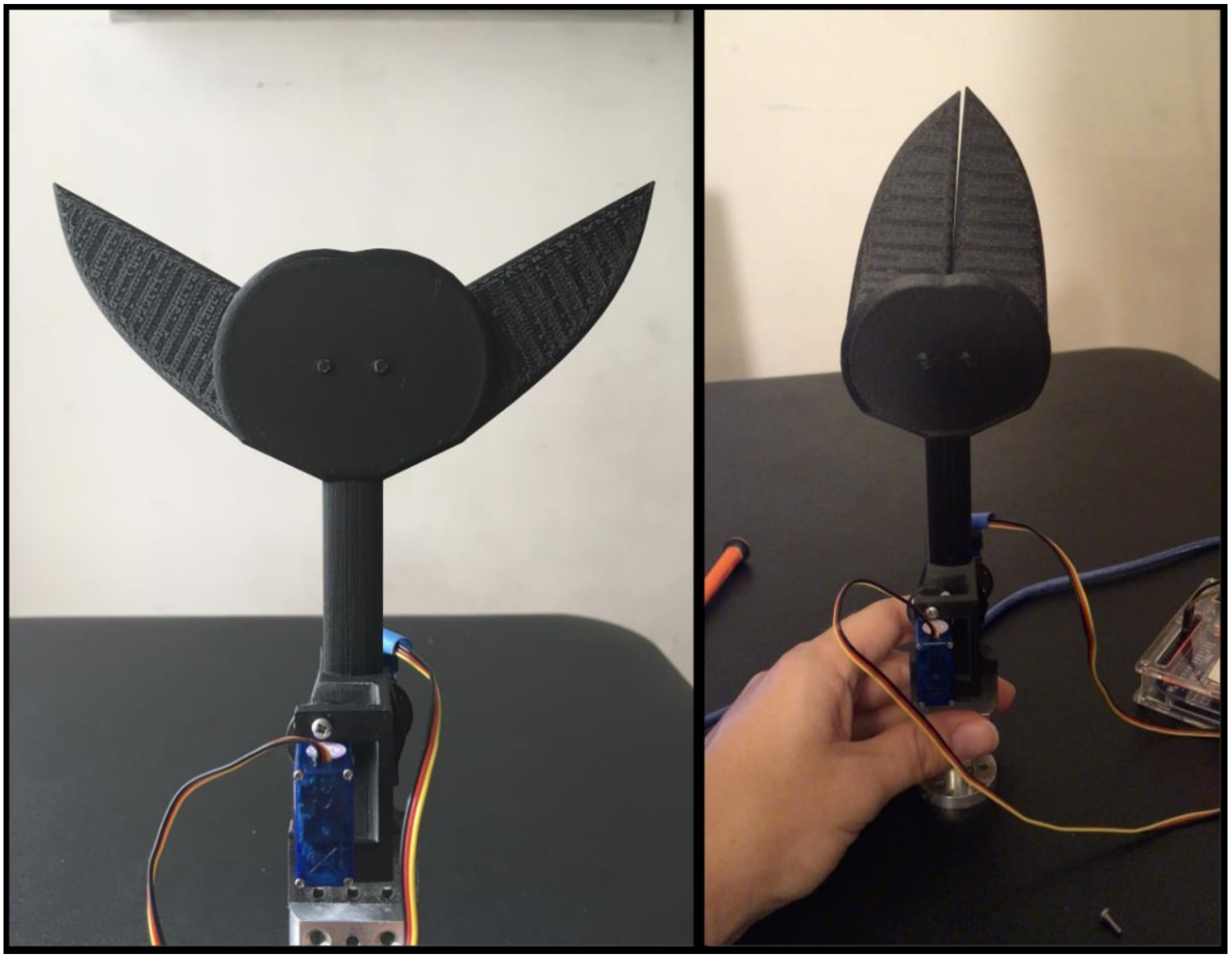

Figure 2 *On the left is the tail fully assembled and in its opened position. On the right is the tail in the closed position*

The tail is made up of several components which all work together to move the fins. At the bottom, there are two HS-5055MG servo motors. These motors are connected to an Arduino, which controls the motors' angles. The motor control software written for the Arduino uses both the servo library (which it uses to communicate with the servos), and serial library. The serial library allows the Arduino to read numbers from MATLAB, which is required because ultimately MATLAB will be responsible for providing angles to the servo. This functionality was also important to implement because the optimization code the fin could be tested with in the future is written in MATLAB.

When the servos finally move, they move 3D printed adapters attached to the servos, which connect the servos to gears. All of this is held into place with set screws. Each pair of gears moves a gear rack which is positioned inside the shaft of the tail. The moving gear rack then moves another set of gears on the bottom of the tail. The two pairs of gears are identical, meaning that the servos and the gears on the bottom move at the same rate. These gears are attached via a set screw to the fin lobes.

The Fin Lobes

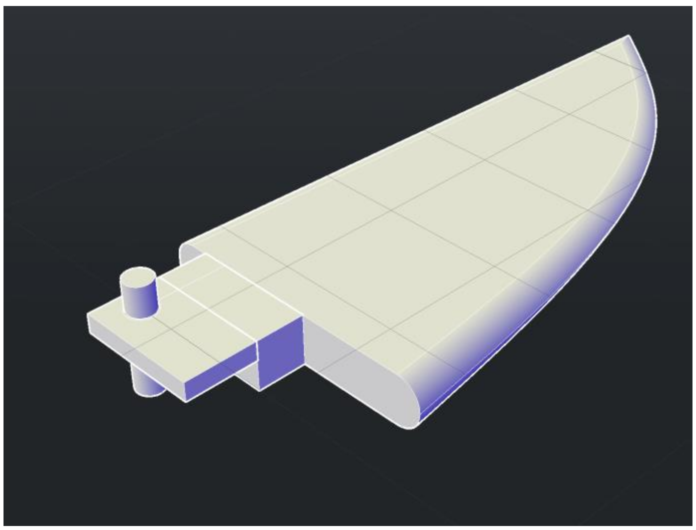

Figure 3 *A CAD of one of the fin lobes. The other is a mirrored version of this one.*

The fins are designed to have a much larger surface area than the shell. This is so that their change in position has a greater effect on the data. They have one flat edge so that when they are in their closed position, they mesh together well. The other edge is curved to mimic a real fish's fin.

The Shell

Finally, holding the whole thing together is the shell. The top of the shell features six holes, which is what the force sensor uses to connect to the fin and take measurements. This was used to get the pre-analysis data, and in the future it will be used to allow the forces to be measured when finding optimal angles. Moving down the shell, below the force sensor adapter, there are two servo holders. These are on opposite sides of the shell so that the center of mass remains centered. This will make calculations when measuring the forces easier. Additionally, there is a hollow area. This is where the gears attach to the servos and interact with the gear racks. Further down we reach the shaft, which has the main purpose of guiding the gear racks on a straight path to the bottom part of the shell. At the bottom part of the shell, there is a shape resembling two intersecting circles. This shape creates a space for the fins to move and maintain a constant area (which is important so the effects of length and height can be isolated).

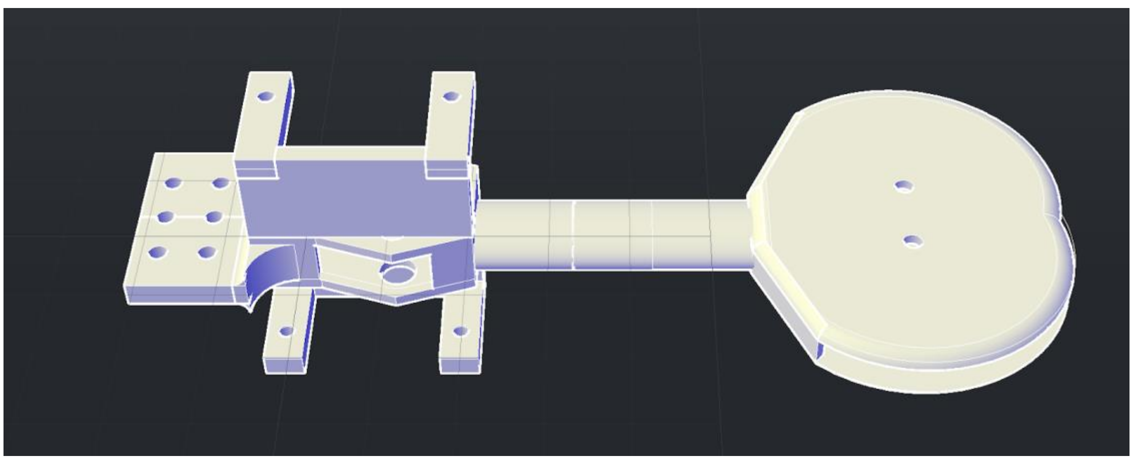

Figure 4 *A CAD of the shell.*

Design Reasoning

This overall design was decided upon for two reasons. First, it allows for each lobe of the fin to move independently of the other. In nature, some fish have uneven lobes, and so allowing for independent movement can explore the advantages of this ability. Secondly, this design was the thinnest. Other designs, like ones using a worm gear, take up so much space the fin can no longer be considered a flat plate. The data collected from such a shape would no longer be data from a fin in water, but rather from a 3D shape in water.

Results

The results shown in figure 5 are for the fin in an open position moving back and forth at 70 Hz through the oil tank. F_z represents the thrust generated by the fin and F_n is the force normal to the fin. As we can see here, the fin successfully generates forces that are able to be measured by the system.

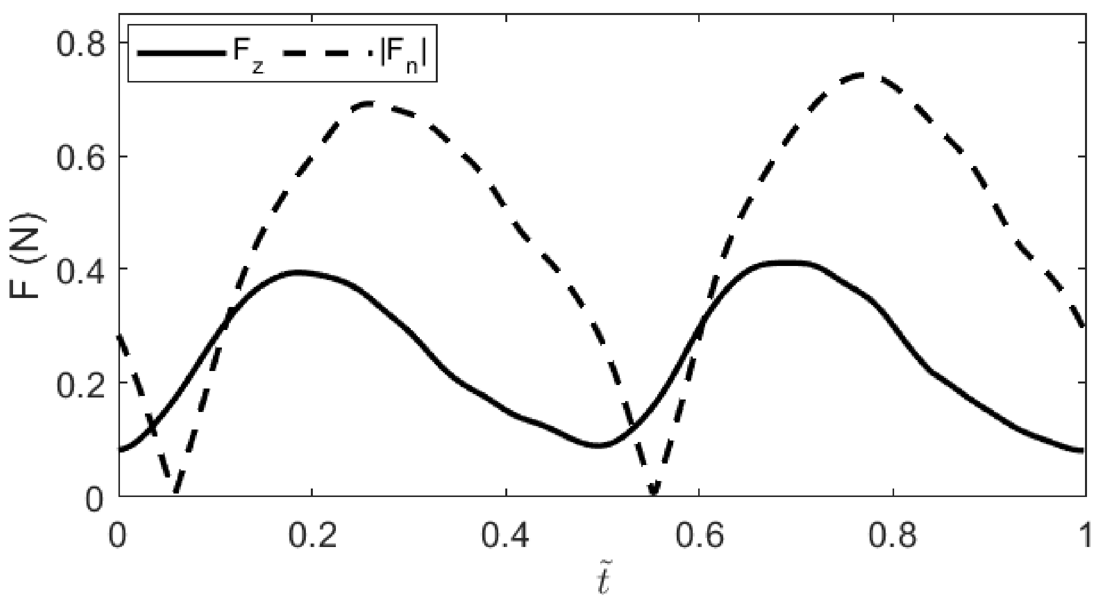

Figure 5 *The forces generated by the fin in the open position moving at 70 Hz through the tank.* F_Z *represents the thrust and* F_n *represents the normal force on the fin.*

Future Work

It is worth noting that the results gathered so far are only for pre-analysis to make sure that all aspects of the fin design will work, as there was not enough time to make the minor changes required to test the fin with the fin trajectory optimization code. If the fin gets tested with this code in the future, the data gathered will help determine optimal length and height ratios for different fin trajectories through the water. There are three minor changes that are needed for a future iteration of the fin to be compatible with the optimization code. First, the 3D printed adapter between the gear and servo bends too much to provide accurate angles, so in the future, this part should be machined. Doing so will make it more sturdy and accurate. Another issue is that currently the gears and gear racks are a little too far apart, which prevents reliable turning. This can be fixed by simply moving the holes that hold the gears in place slightly closer together. The third and final issue is that the Arduino does not have enough current to constantly power two servo motors. This is easily fixed with an external power source.

With these quick fixes implemented, the research group can use the methods used in creating this fin to study how other parameters affect swimming. The findings from this fin combined with the findings from other fins (which test other parameters) will allow the team to make a final fin inspired from the data accrued by the others. This fin will be optimal in many ways, such as aspect ratio, shape, and flexibility.

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