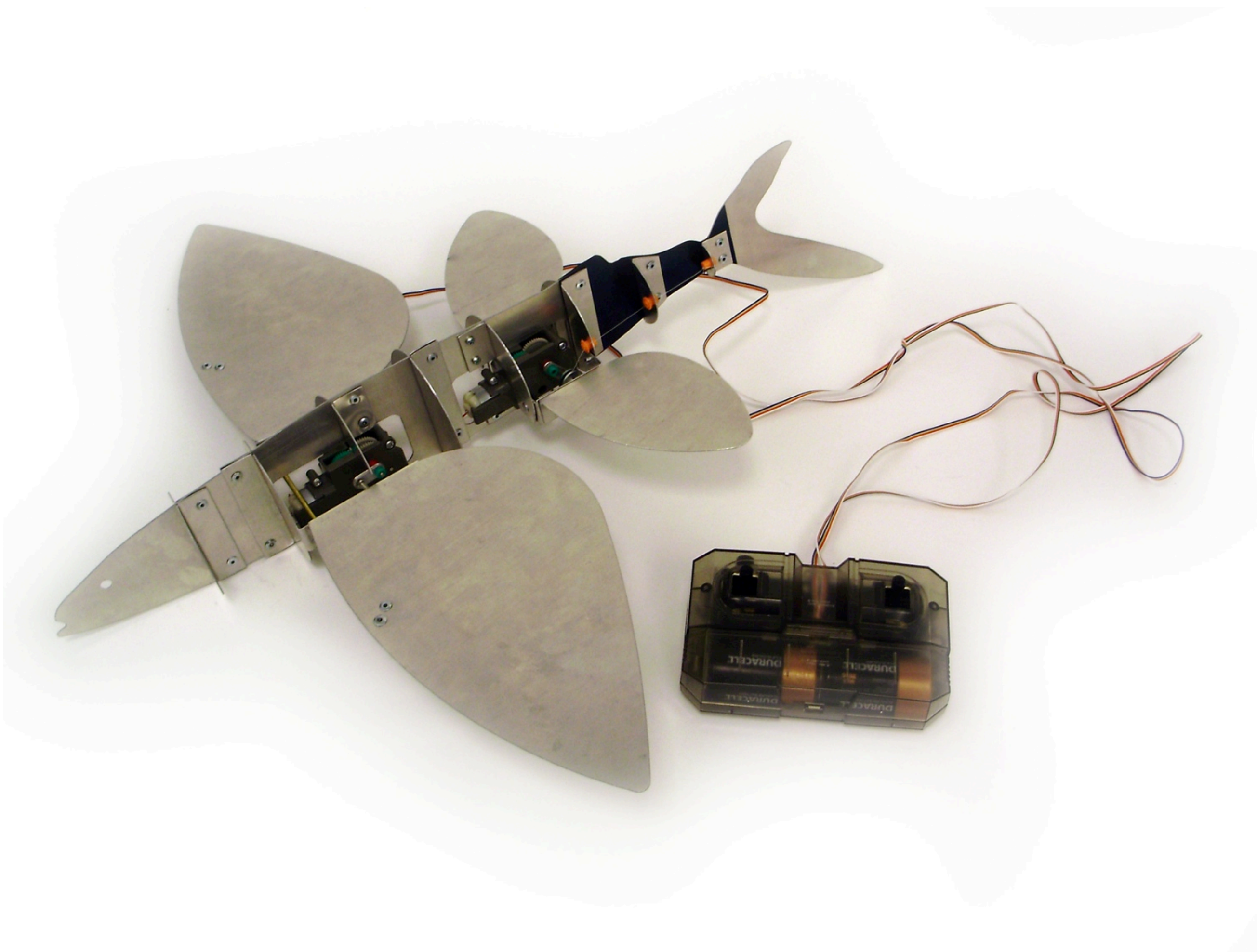
Franklin W. Olin College of Engineering

Robotic Flying Fish

ENGR 2330: Intro to Mechanical Prototyping



Raphael Cherney and Team Fish
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Table of Contents

List of Figures

Executive Summary

As an exercise in mechanical prototyping, teams of five designed and constructed robotic fish out of sheet metal over the course of three weeks. Team Fish decided to create a biomimetic flying fish that could actuate its tail and rotate its pectoral fins for gliding control. After initial background research, the fish was modeled in SolidWorks. After building a paper prototype to test actuation methods, parts were sent to the Olin College Machine Shop to be manufactured. The parts were then bent and assembled into the final prototype. The fish is made mostly 0.05" 6061 aluminum sheet metal, with the tail being made of robust 0.005" spring steel. The robot uses two single-motor Tamiya gearboxes powered and controlled via a wired remote control. The final prototype is fully functional and exhibits a nice biomimetic motion. This report details the design of the robot.

Design

We began by researching the shape, motion, and behavior of actual flying fish. We assembled a collection of pictures and videos to base our design on. We noticed that flying fish propel themselves by moving their tail back and forth in a sinusoidal pattern. If they pick up enough speed and jump out of the water – such as when they are avoiding predators – they can spread out their pectoral fins and glide (hence the name flying fish). Upon falling back to the water, they can continue to glide and push themselves forward with only a small part of their tail submerged. Figure 1 shows an actual flying fish in flight. Notice the splash pattern behind showing the sinusoidal motion of the tail.

Figure 1: Example of Flying Fish Motion

Based on our observations, we decided to actuate the tail of the fish (while remainder of the body remains relatively stable) and also to allow the pectoral fins to rotate (mirroring the gliding control of the fish). With this in mind, we began creating the body of the fish. To do so, we imported images of flying fish into SolidWorks and traced the contour of the body. Figure 2 clearly shows the final shape of the fish as modeled from our research.

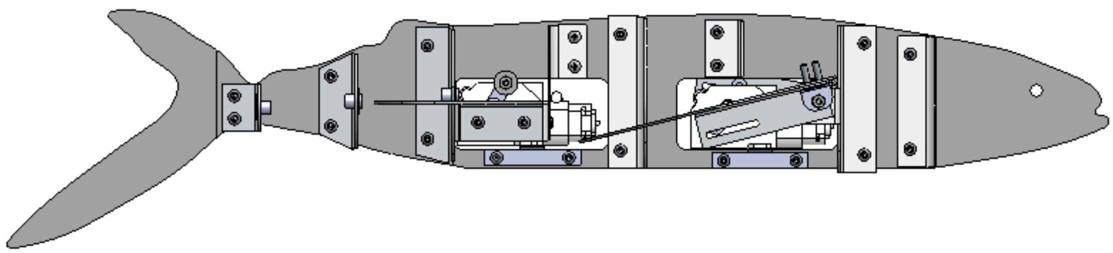

Figure 2: Side View of Robotic Fish

Using this basic body shape, we added bulkheads, or "ribs," to give the fish a defined shape (as seen in Figure 3). These features give the robot some volume and make it much more closely resemble an actual fish.

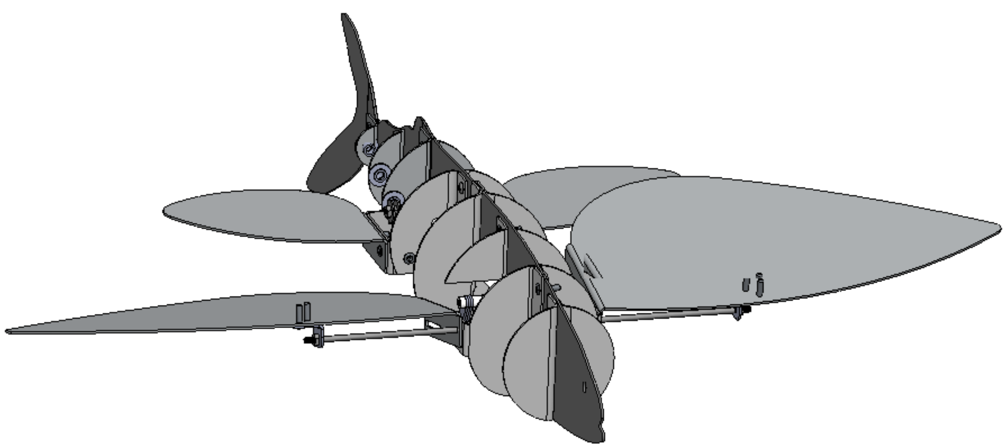

Figure 3: Shaped Body of Fish

Finally, we designed the fins and tail mechanism. At this point, we wanted to get an idea of the physical size of the robot to make sure that we could fit all that we needed to inside. We also wanted to ensure that our pectoral fin/tail mechanisms would work and that we could actually manufacture the device. To do this, we constructed several paper prototypes by printing the sheet metal parts on cardstock and assembling it with tape. These resulted in redesign of the wings and ribs and finalization of the travel distance of the cable cam used in the read. Our second paper model is shown in Figure 4.

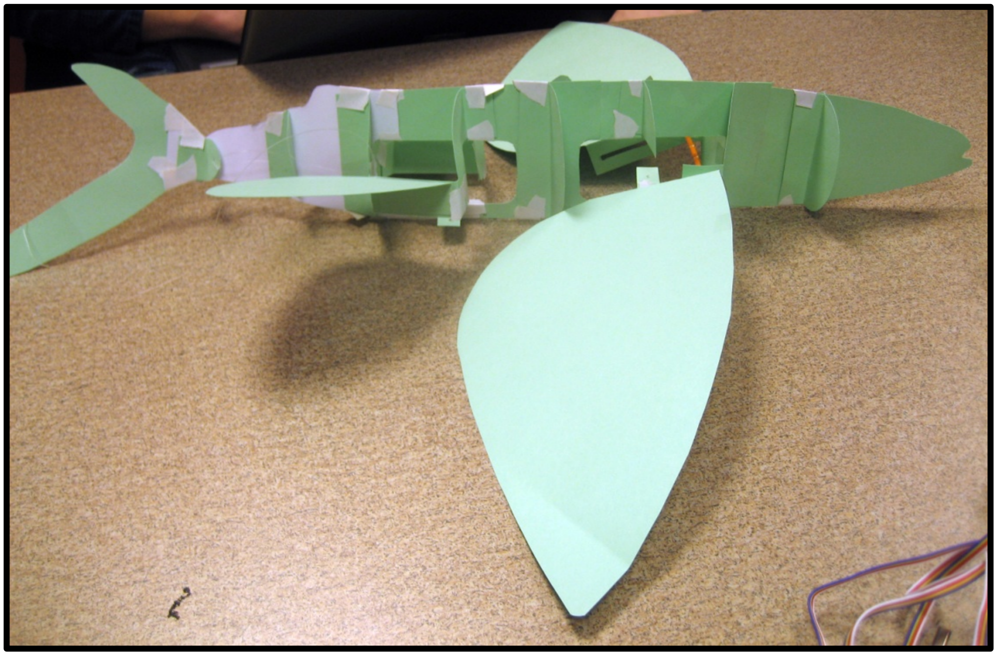

Figure 4: Paper Prototype

With our design finalized, we moved onto manufacturing and construction.

Structure

Our robotic flying fish is made mostly of 0.050” 6061 aluminum sheet metal. This is good material to work with because it is stiff but still very workable and easy to bend/machine. The various parts are held together by 1/8” blind rivets (also known as “pop” rivets). The tail is made of 0.005” spring steel because of its resilience to repeated bending. All parts were waterjet cut in the Olin College Machine Shop and then bent into their final configurations.

The basic structure of the robot is quite simple as seen in Figure 5. It consists of a base plate (the spine) with various “L” brackets attached to it (the ribs). There are also a couple “U”s that act as mounts for the anal fins. The pectoral and anal fins are all large “L” brackets. The design is purposely kept quite simple to ensure that it can be manufactured on site with our limited ability to bend sheet metal parts. There are almost never problems bending “L”s and “U”s, while more complex shapes can quickly become impossible to manufacture with our tools.

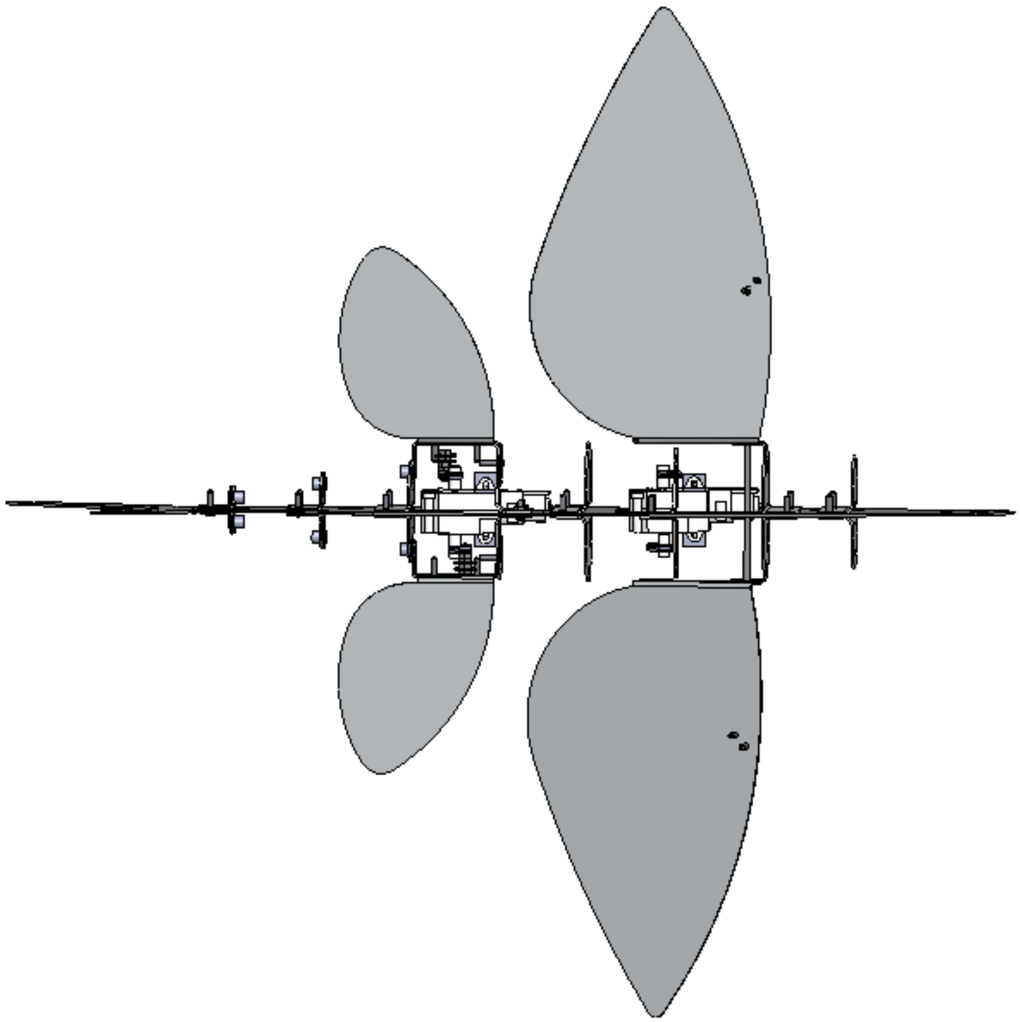

Figure 5: Robotic Fish Structure

There are a few additional things to note about the structure. Namely, we designed our robot such that we could get both gearboxes out if necessary. The sheet metal surrounding the transmissions is bolted on instead of riveted together. This allows us to, for example, remove one of the anal fins and replace/adjust the motor. In the front, there is a shaft that runs through the fish that supports the pectoral fins and acts as a hinge. It is threaded on the ends and held on with a nut, so that it can be removed for motor access.

Note: All parts that we didn't design are simply stock parts or from the Tamiya Remote Control Robot Construction Set. These include the two gearboxes, 4-40 screws and nuts, and some fender washers.

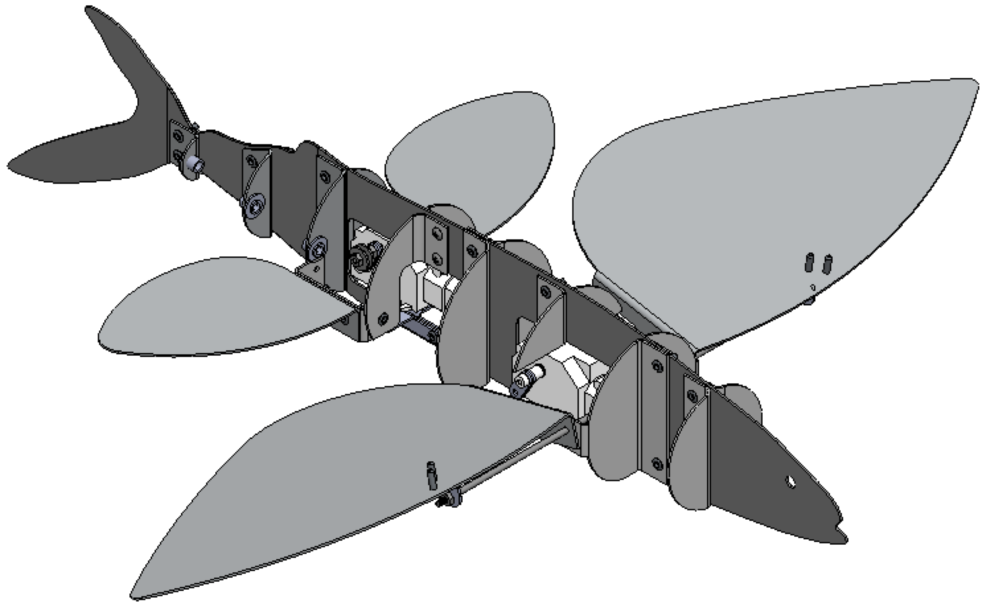

Figure 6: CAD Model of Flying Fish

Power

The robot is controlled and powered through a wired remote control that connects to two small brushed DC motors. The controller has joysticks that act as switches to turn the motors on and off or change direction. Inside the controller (Figure 7) are two D batteries. These large batteries provide 3V DC to the two small DC motors (one in each gearbox) based on the joystick position. DC motors do not require an elaborate clutch or transmission to get started; instead the voltage directly correlates to speed (and current to torque). Normally these two motors would spin very fast and not provide enough torque to be useful; however, with the Tamiya gearboxes, we can step down the speed to a reasonable value and increase the torque.

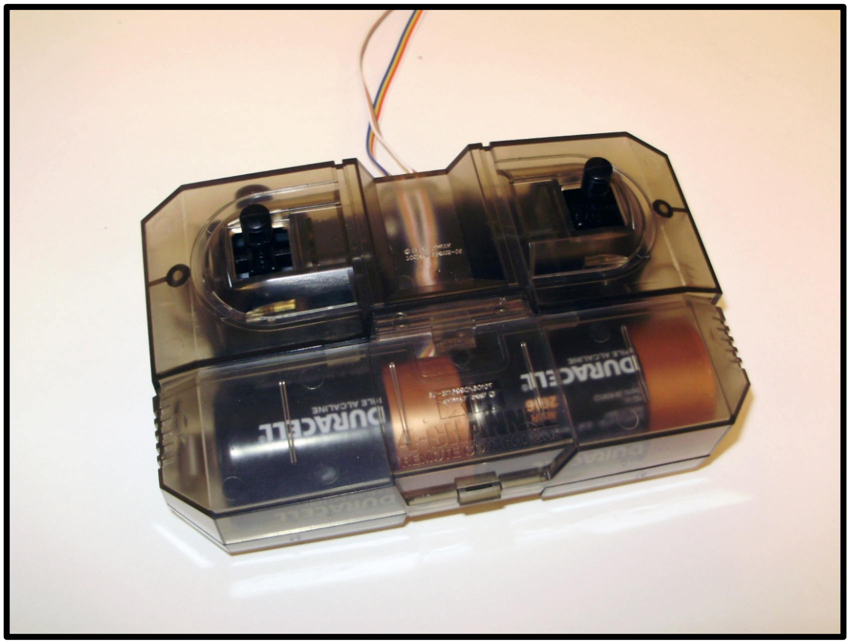

Figure 7: Controller and Power Source

Transmission

As mentioned before, our robotic flying fish uses two single-motor Tamiya gearboxes (another team was kind enough to donate their unused single-gearbox). These nicely designed ABS gearboxes can be easily adjusted for several different speeds. We took advantage of this by setting up our tail shaft to spin much faster than the pectoral fin shaft. As seen in Figure 8, the gear reduction in these boxes begins with a worm gear attached to the motor output shaft. This spins a series of gears that further reduces the shaft speed and increases the torque. In the rear gearbox we removed some of the intermediate gears to sacrifice torque for a faster speed of rotation (which results in a more lifelike motion). We calculated ratios of 1429:1 and 123:1 for the front and rear gearboxes respectively. Note that the gearboxes provided by Tamiya simply allow us to use a small, low-power motor to move our device, but they do not actually translate rotational motion into something that directly moves the wings. Instead we came up with two different mechanisms create a swimming motion with the tail and to rotate the front wings.

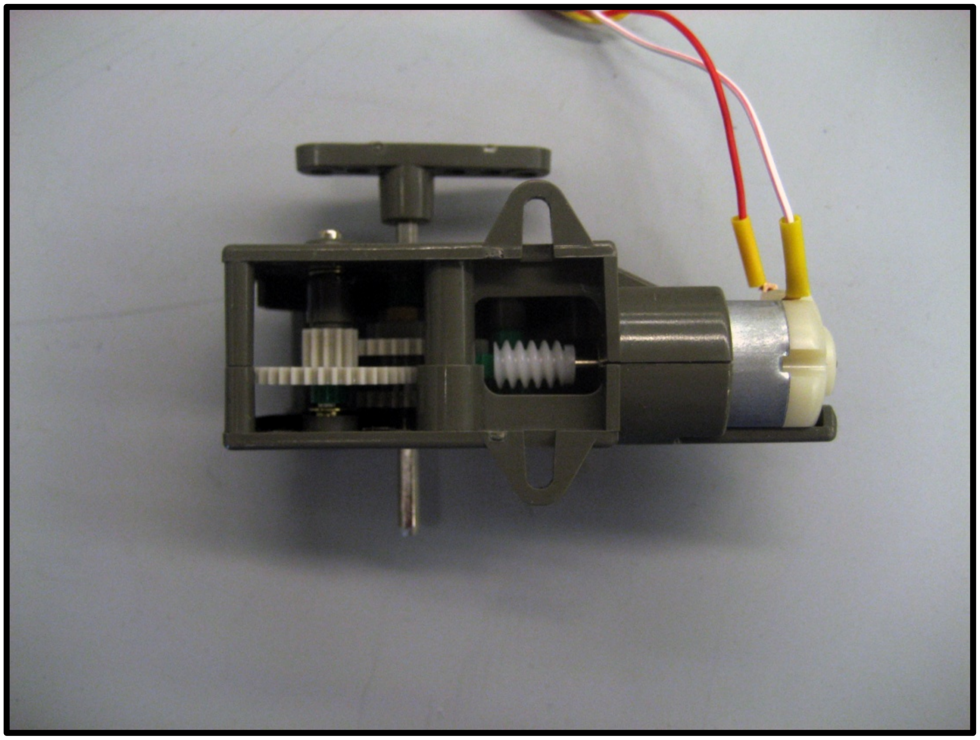

Figure 8: Single-Motor Tamiya Gearbox

Figure 9 shows the full rear tail transmission. Energy is transmitted from the motor through the gearbox to a cable cam. The cable cam consists of a rotating arm attached to some fishing line in tension. As the arm turns, it will pull the fishing line (and release it) in a sinusoidal pattern. There are two tendons running down the tail of the fish controlled by cable cams that are 180° out of phase. This way, when one tendon releases, the other tightens – causing the tail to go back and forth like a fish. There are also bushings that smoothly guide the fishing line "tendon" to the end of the tail.

Figure 10 shows the pectoral fin mechanism. Again, using the Tamiya gearbox (though at a greater gear reduction) we rotate an arm around in a larger circle. Using something similar to a scotch yoke mechanism, we transfer this rotational movement into smaller rotational change in the wing. This gives the effect of the robotic fish trying to maneuver and control its glide.

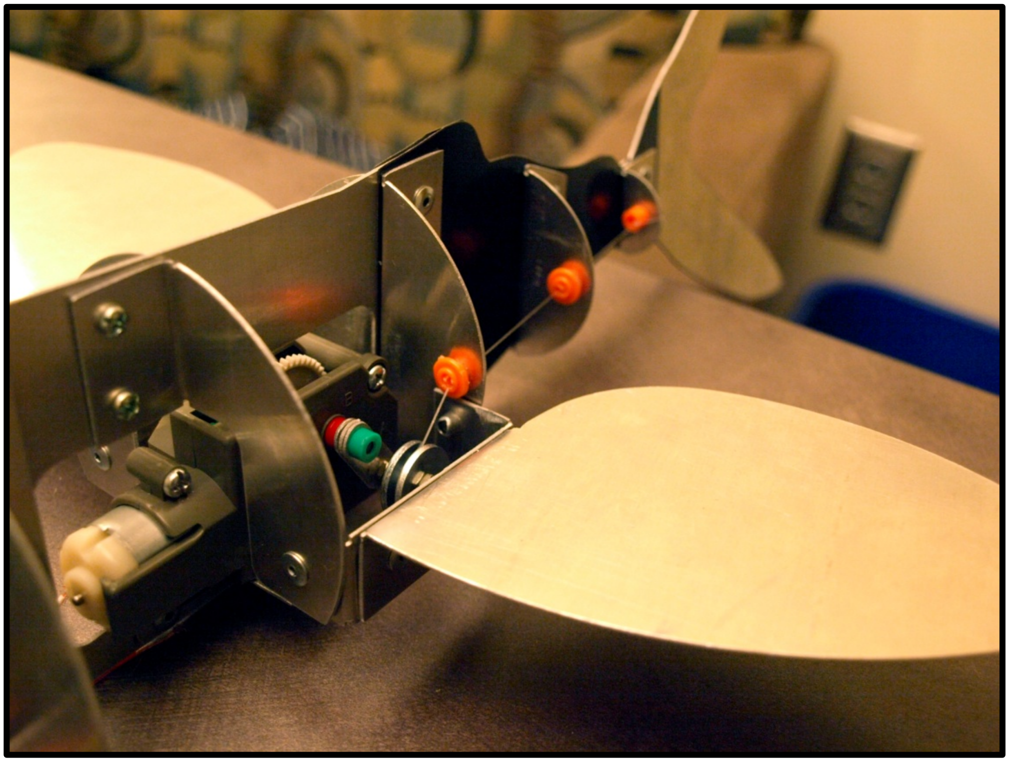

Figure 9: Rear Drive Mechanism

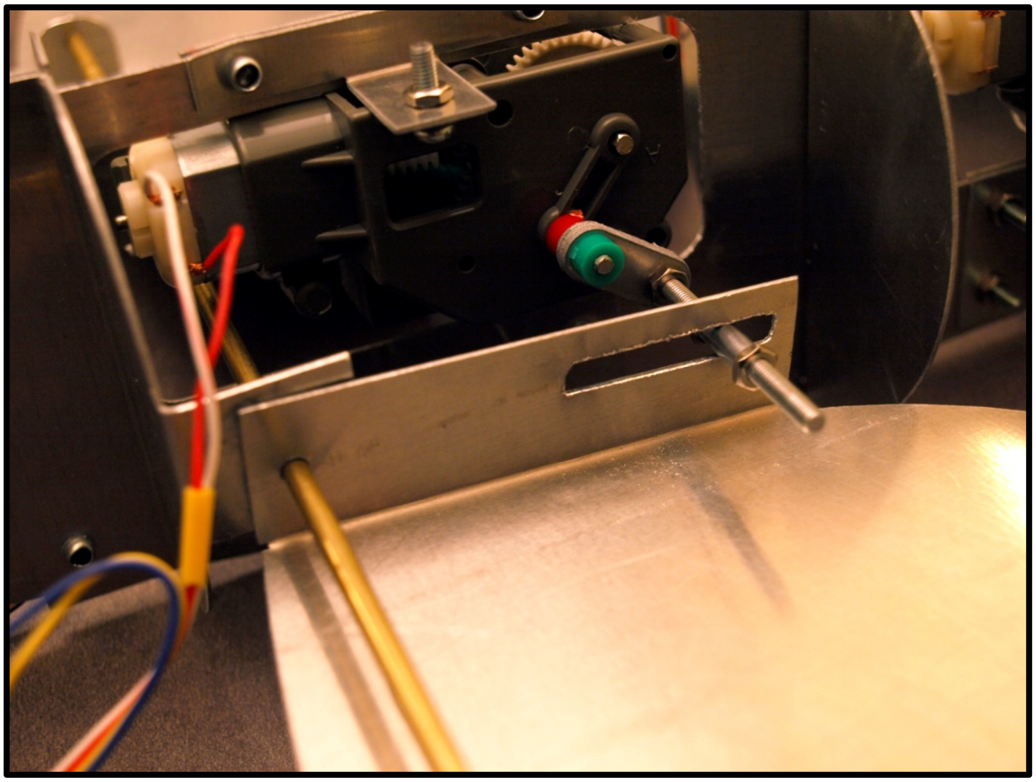

Figure 10: Pectoral Fin Mechanism

Conclusion

The project was a valuable experience in prototyping on a short timeline. It exposed everyone on the team to project management, designing for manufacturing, advanced CAD techniques, and how to properly use the machine shop. Our final, assembled robotic flying fish is shown in Figure 11. It has a bioinspired appearance and biomimetic motion.

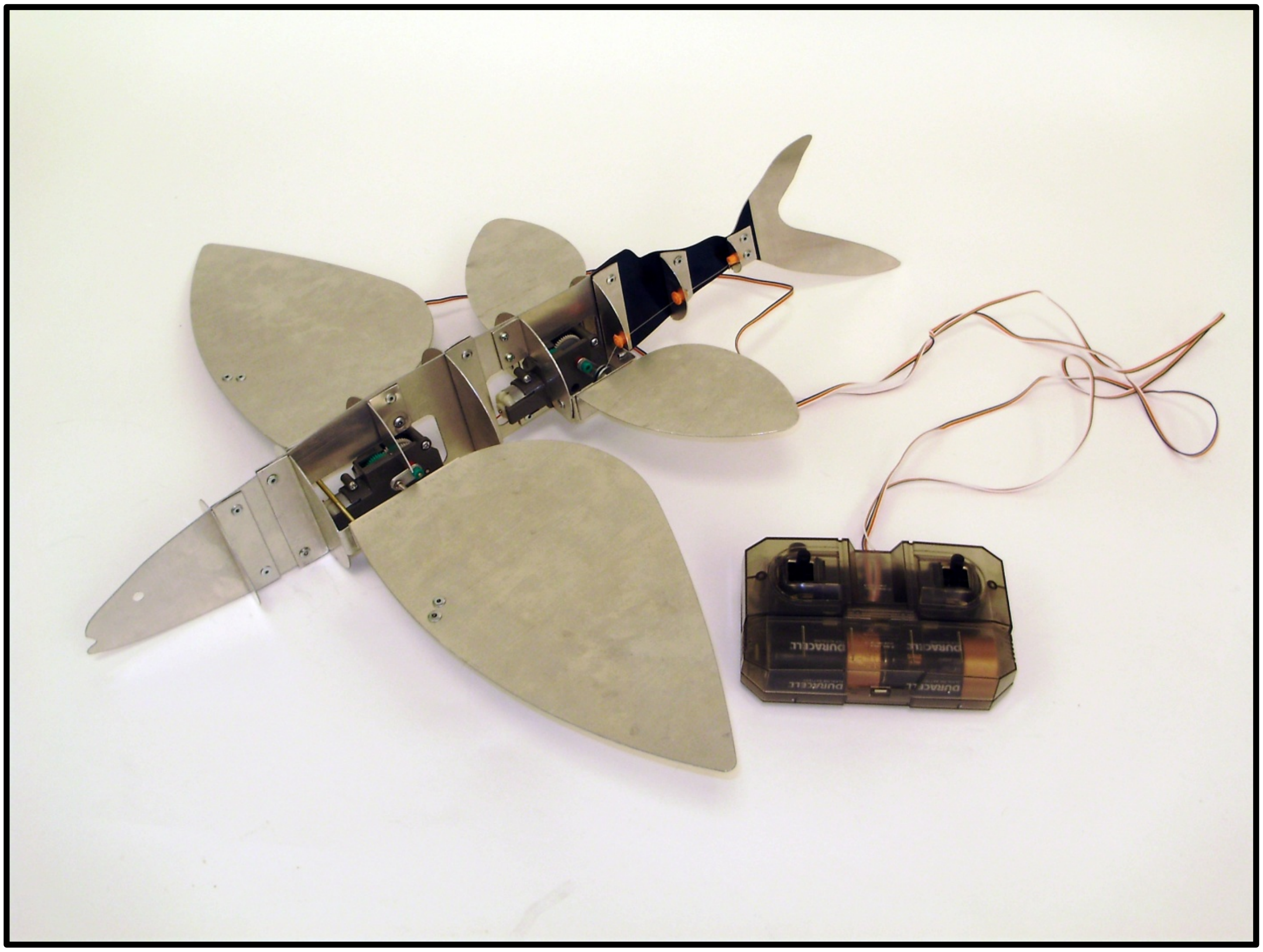

Figure 11: Final Assembled Flying Fish

Appendix

If there are any questions about this report or my knowledge of the contained material, please email me at raphael.cherney@students.olin.edu.

Drawings

The attached package contains all necessary technical drawings to construct the robotic flying fish presented in this report.