Propeller Based Human Powered Swimming Device

by

Kristine Bunker

Submitted to the
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ABSTRACT

Currently the only human powered swimming device widely sold on the market are swim flippers. However, flippers are not efficient for the human body, and there is a potential to increase the speed while swimming with a device. This thesis is the planning, design, construction, and prototyping of a new human powered swimming device which increases human efficiency and speed in water. This device uses a squatting motion to drive counter rotating propellers up and down a threaded shaft creating the propulsion force to move the swimmer forward. The design of this device is primarily geared towards scuba divers and swimmers moving beneath the water surface. Through various tests we were able to prove that the design concept is valid, but alterations are still necessary to reach optimal speed. One such improvement would be enlarging the size of the propeller to increase the force generated with each leg thrust.

Thesis Supervisor: Douglas P. Hart
Title: Professor of Mechanical Engineering

Acknowledgements

I would like to thank Professor Douglas Hart for all his help with my undergraduate thesis. Without his guidance, encouragement, and help throughout the year I would not have been able to design this innovative device. More importantly Professor Hart kept me excited about the project through the most demanding and challenging times of the semester. I am very grateful to have had such an enthusiastic, easy going, and involved thesis advisor.

I would also like to thank Bill Cormier and David Allaby for their help in the shop assisting me with machining of parts for my thesis, and my father, Thomas Bunker, for helping me assemble different components of the device whenever I came home to brainstorm and work on this project. Without all the support I had on this project I would not have been inspired to investigate several conceptual options nor have ultimately been as successful in creating this innovative human powered swimming device. Finally, many thanks to the staff at the Zesiger Center Pool for allowing me to test my thesis in the pool.

Table of Contents

1 Introduction

1.1 Motivation

Currently the only human powered swimming devices commercially available are swim flippers. However, the understanding of human biomechanics and fluid mechanics has greatly increased since flippers were first invented. Flippers in use today only allow swimmers to generate forward motion through the downward motion of the legs. Most of the leg and back muscles, which are the strongest in the human body, are not used at all. The idea of creating a new human powered device which integrates the potential of these currently underused muscles would not only be very beneficial to swimmers but to divers in particular who attempt to reach greater depths. In addition, with proper design features, this new device could have the potential of breaking the current swimmer's world record in speed.

1.2 Objectives

The goal of this project is to develop a new type of human powered swimming device that properly utilizes the mechanical build of humans. The current design of flippers are not an efficient use of human leg muscles or the amount of motion required to move forward. By examining the biomechanics of humans and the possible designs for human powered devices, it is possible to design a much more efficient piece of equipment to aid divers in swimming. The purpose and goal of my thesis is to design and build a new swimming and diving device which uses the human muscular system efficiently to create a propulsion force which exceeds the speed a swimmer currently achieves using conventional flippers.

2 Background

2.1 Swimming

Swimming is an inefficient movement for humans. In terms of energy output versus input, land sports tend to be in the range of 20-25% efficient whereas swimming is between 0.5 and 2.2% efficient [1]. Therefore, increasing efficiency is key to improving one's swimming ability. This can be done in a couple ways, most prominently decreasing drag and increasing the propelling force.

Two main forces act on a swimmers body: a propulsion force created by the swimmer, P, and an active retarding force due to movement, L. During any major part of a swimming stroke the force resulting in forward acceleration is equal to a combination of P, L, and R which is water resistance due to skin friction, which scales with velocity squared[2].

$$P_A = (P - L) - R = P - (L + R) = M\left(\frac{dV}{dt}\right) \tag{1}$$

A lot of effort has been put into determining the value of (L+R) in order to establish how much energy is lost to external forces. One method of determining L and R involved towing a swimmer through water with a constant velocity. The measured tension on the rope could be used to solve for P_A by substituting back into Equation 1 using the equation below [2]:

$$T = (L + R) - M\left(\frac{dV}{dt}\right) \tag{2}$$

There are three main types of drag that cause the loss of energy in swimming: friction drag, pressure drag, and wave drag [1]. Since my device will primarily be used by swimmers swimming below the surface of the water, wave drag, which is dependent on the Froude number, is ignored and only becomes a factor when the swimmer is within one meter of the surface [1]. Friction drag is a function of the surface area of the swimmer as well as the velocity. Adhesive forces act on the skin resulting in a no slip condition, so the velocity of the water in contact with the swimmer is at the swimmers velocity. However, the velocity of the water infinitely far away from the swimmer is theoretically zero. Therefore, every layer of water in front of the swimmer is acting to slow down the water, which is the force the swimmer has to counteract [1]. Pressure drag is caused by pressure differences along the length of the swimmer's body. These pressure differences can be caused through a number of factors including shape, size, and velocity of the swimmer, and they result in eddies [3]. Pressure drag, D_P, can be described with the equation:

$$D_p = \frac{1}{2} C_D A \rho v^2 \tag{3}$$

Where C_D is the coefficient of drag, A is the cross section area of the swimmer, v is the velocity of the swimmer, and ρ is the density of water. Drag which can be generalized as

$$D = Kv^2 \tag{4}$$

is the limiting factor in swimming [1]. The mechanical power required to overcome drag is proportional to the velocity of the swimmer cubed[2].

$$Power\ to\ Overcome\ Drag = P_d = Kv^3 \tag{5}$$

Since 1905 researchers have been developing methods to measure drag. It was long accepted that passive drag 'K' was equal to 29 [1]. However, swimmers are not passive, so this is not a sufficient model. In the 1970's more effort was put into measuring active drag, and in the 1980's Hollander et al developed the Measure Active Drag System (MAD) [1]. With this testing, the swimmer, with their hands in the water, pushed off stationary force plates which measured the force applied. After pushing off, the swimmers only used their arms to swim. Based on the assumption that at a constant velocity the mean propulsion force is equal to the mean active drag force, the coefficient of drag can be calculated. This yielded a 'K' of 30 for males and 24 for women [3]. Another method developed by Kolmogoroc and Puplisheva had swimmers swim 30m length twice at maximal effort. The first 30m they were freely swimming and the second 30m dragging an additional resistance. The benefit of Kolmogoroc and Puplisheva's method is that any stroke can be measured whereas with the MAD method, only front crawl can be evaluated. With Kolmogoroc and Puplisheva's method, 'K' was determined to be 24.5 [1]. Both researchers also re-measured the passive drag 'K' as previously described and found a value of 14.5 when the swimmer was streamlined. Furthermore, they also noted that any slight differences in body or head position can result in over 100% increase in 'K. [1]'

2.2 Human Power

The force applied during motion is constantly changing in direction and angle. Changing the position of one's body to optimize the direction of force becomes more natural the more experience a swimmer has [2]. The main propelling force for swimming is generated through the arms, approximately 85% [1]. The diagram below simplifies swimming by just looking at the effects of a swimmer's hand.

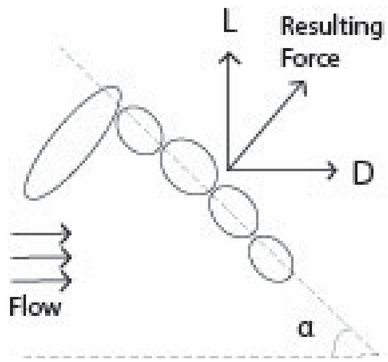

FIGURE 2-1: SCHEMATIC OF FORCES ACTING ON A SWIMMER'S HAND [1]

$$L = Lift\ Force = \frac{1}{2} C_l u^2 \rho S \tag{6}$$

$$D = Drag\ Force = \frac{1}{2} C_d u^2 \rho S \tag{7}$$

Where C_l and C_d are coefficients of lift and drag respectively, *u* is the velocity of the hand, *S* is the propelling surface of the hand, and α can be called the angle of attack which strongly affects the lift and drag coefficients. Therefore, the lift and drag forces are affected by the change in α, which changes the resulting force of the two vectors, the propelling force, F_P [1]. For this reason, humans have learned to alter the angle of their hand while swimming to keep F_P directed forward in order to gain the maximum amount of output by maximizing the contact surface area with the water in the proper direction.

Looking into the contribution from the feet for swimming several biomechanical disadvantages appear. Due to the inflexibility of the human ankle, there is not as much ability to change the angle of the foot as it moves in the water [4]. However, in test runs by Gatta et al, it was determined that the lower limbs do not actually have a direct propulsion action. Kicking actually acts to stabilize the trunk's position which results in approximately 9% increase in velocity [4]. For the experiment swimmers were asked to go through three tests at multiple velocities: a maximum flutter kick sprint for 15m, being towed passively for 25m, and towed with maximum flutter kick for 25m (lowest velocity being that found in test 1). These tests were performed at six different velocities. Test results showed that the power produced by flutter kick actually decreases as velocity increases, because as velocities increase, the path of the foot's angle becomes greater overall which in turn results in a lower power production. This is the direct result of the limited flexibility in the ankle [4].

2.3 Previous Designs

As stated earlier, the two ways to increase swimming speed is to decrease drag or increase propelling force. Flippers increase the propulsion power produced from the lower limbs by increasing the surface area of the foot and adding the flexibility we lack. In a study done by Pendergast et al in 1996 it was determined that flippers decreased the energy lost in swimming by 40% which resulted in a 0.2m/sec increase in velocity [5].

There have been attempts to design an alternative device in the past to further increase the benefits and efficiency of flippers. Some devices looked at animals and tried to mimic the mechanics found in their physical structure. In 2001, Milan Dennis Earl patented the Whaletail Swimming Device which allowed the hamstrings and back muscles to be involved in the swimming motion. Additionally, Earl's invention enlarged the surface area of the "tail" over the conventional flipper surface area and integrated a mechanism of steering. [6]

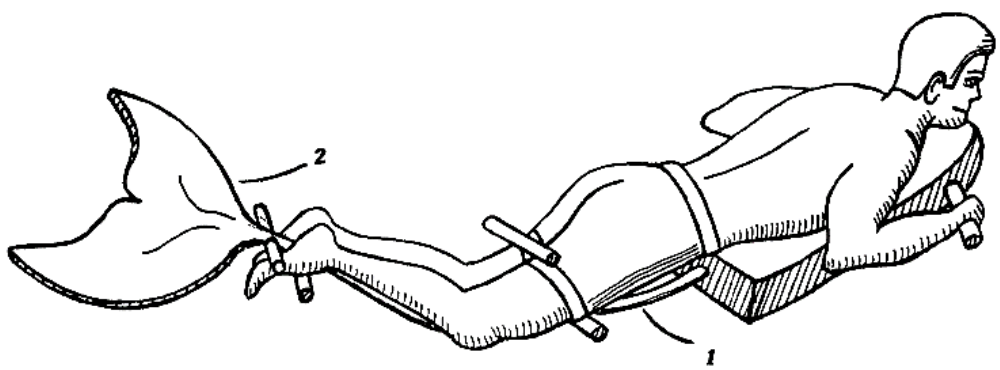

FIGURE 2-2: DRAWING OF THE WHALETAIL SWIMMING DEVICE [6]

In 2008, Deka Productions Limited Partnership invented a similar device but without the steering mechanism. Their swimming propulsion device locks the swimmer's lower legs into the device, connecting them to one fuselage but allowing some rotation for stabilization. [7]

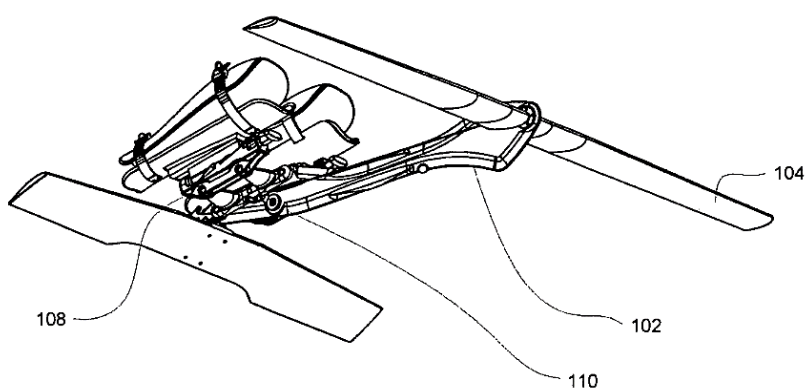

FIGURE 2-3: DRAWING OF DEKA'S SWIMMING PROPULSION DEVICE [7]

Designs by others kept the basic principal of the flipper with two independent parts for each foot, but they looked into increasing their efficiency. In 1996 Peter T. McCarthy altered the swim flipper design to decrease drag and increase lift by reducing the angle of attack and increasing the sweep angle of the hydrofoil [8].

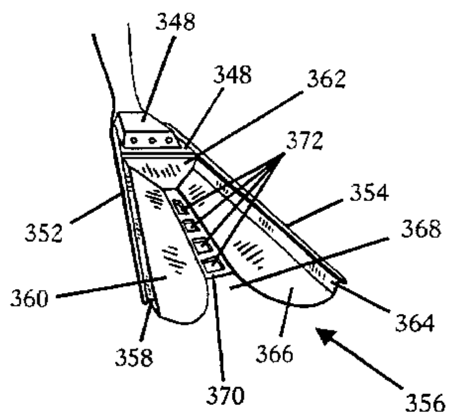

FIGURE 2-4: DRAWING OF ALTERED HYDROFOIL SWIM FIN DESIGN [8]

A design by Chun-Kai Wu, shown in Figure 2-5: Drawing of Oscillating Foil with Joint, created a rigid flipper which created propulsion in both the forward and downward motion of the legs which compensates for the inflexibility of the human ankle. Chun-Kai Wu's design uses a joint to connect an oscillating foil to the rigid part of the flipper that fits the foot. This allows the foil to take a different angular position depending on the direction of the swimmer's leg motion, creating propulsion force in up and down directions [9].

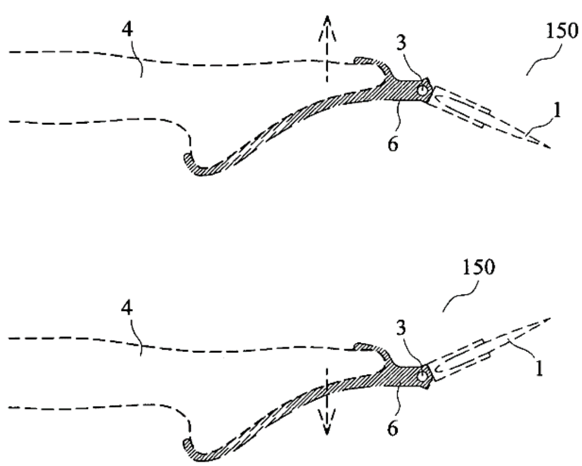

FIGURE 2-5: DRAWING OF OSCILLATING FOIL WITH JOINT [9]

All four of these designs use a hydrofoil to increase the surface area for propulsion to mimic the biomechanics of most aquatic animals. With the knowledge of those earlier designs, I also started with a hydrofoil based design to develop a human powered swimming device.

3 Design

3.1 Hydrofoil Design

Based on the research done on the human body and forces that act on swimmers, we decided to focus on increasing the propelling force because reducing drag is largely a function of experience in the water. My design was formed from both the Swimming Propulsion Device seen in Figure 2-3 and the Oscillating Foil with Joint as shown in Figure 2-5. By holding the legs together and using a single hydrofoil, the swimmer is able to better activate the back and abdominal muscles. A key difference of my design is to hold the swimmer's legs together at the ankles and knees. A rod extending from the swimmer's knee continues past both feet where it is connected to a hydrofoil which can rotate between two fixed angles above and below the rod. As the swimmer's legs switch from moving upwards to downwards (or vice versa), the water forces the hydrofoil to rotate between the two angles, similar to Chun-Kai Wu's design.

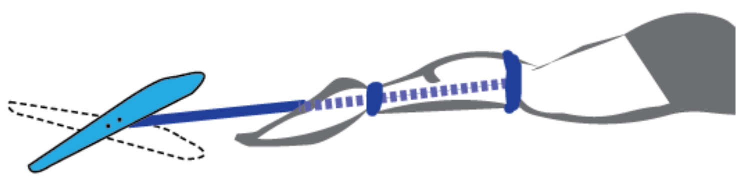

FIGURE 3-1: SCHEMATIC FOR BASIC HYDROFOIL DESIGN

The joint causes the hydrofoil to switch positions depending on whether the swimmer's legs are moving up or down due to water resistance. This increases efficiency because it uses both the quadriceps and hamstrings. More importantly this means that there are propelling forces throughout the swimming movement as opposed to flippers which primarily create propulsion as the swimmer is moving his or her legs downwards.

The first step for developing my thesis was to make sure the design was feasible. The force from the moving hydrofoil is perpendicular to its surface; this, in combination with the vertical motion of the legs and the angle of the hydrofoil in the water, gives a resultant force in the direction of the swimmer.

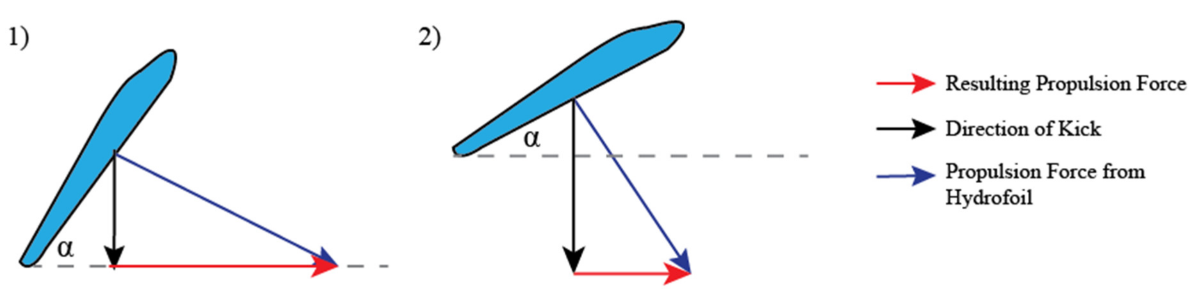

FIGURE 3-2: RESULTING PROPULSION FORCE WITH HYDROFOIL DESIGN

In order to generate a large enough force in the direction the user is swimming one of two things has to happen. One, α, the angle the hydrofoil is from horizontal has to be very large putting the majority of the generated force horizontally. However as α gets larger the surface area decreases, therefore decreasing the generated force. The hydrofoil becomes harder to balance and harder to flip when the kick direction switches. Two, with a reasonable α, the speed of the kicking has to be unreasonably fast to generate a large enough horizontal propulsion force. This is because a large portion of the force generated from the hydrofoil goes in the vertical direction. To remedy these problems I tried moving the hydrofoil farther away from the swimmer. This increased the force created by the kicking motion and decreased the frequency of kicking. Due to the large sweep of the kick the human body flips over rather than move forward creating the need for a counter weight. One possible counter weight is to add a second hydrofoil on the opposite side of the swimmer. This second hydrofoil switches the motion to a pushing motion, similar to squatting in the water, which allows a sweep of two hydrofoils simultaneously in opposite directions.

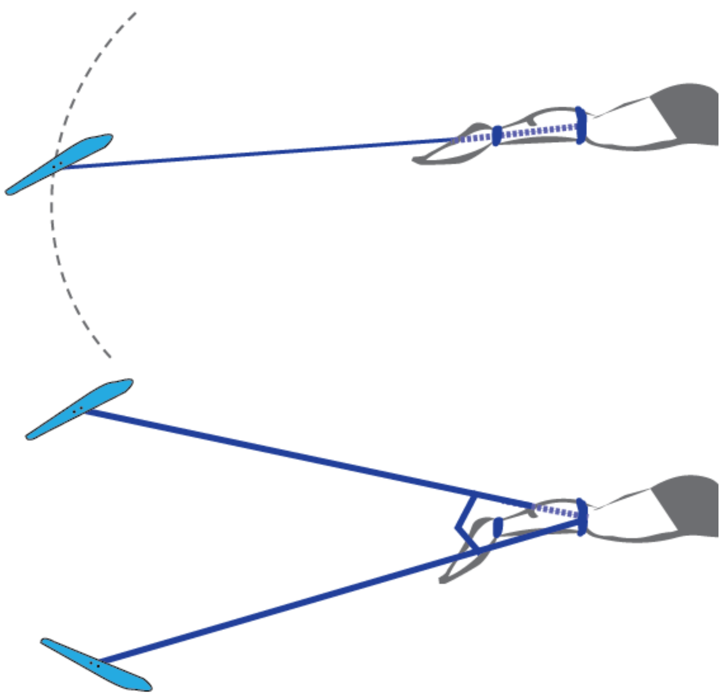

FIGURE 3-3: ITERATIONS ON HYDROFOIL DESIGN

There were still problems with the double hydrofoil design. First, the swimmer could only operate the device well beneath the surface of the water because the sweep of the hydrofoils is so large, and if one hydrofoil was exposed to the air rather than water, there would be an imbalance due to the difference in resistance. More importantly, figuring out how to design this device without crushing the swimmer's legs posed a problem. Since the size of the device was not particularly practical for general use, the direction of the design changed. The idea of squatting, however, continued to be part of my design concept.

3.2 Propeller Design

A climbing type motion (pushing down with legs) is the strongest everyday movement for the human body [10]. Standing up from a squatting position with both legs together allows a human to engage back and abdominal muscles, increasing power and efficiency. Although hydrofoils do increase the propelling force, they also increase drag because of their size. I switched my attention to a smaller device that increases propulsion not by increasing surface area but by creating a pressure difference between the water before and after it. Because propellers are relatively small, they can be placed directionally in line with the swimmer, therefore barely increasing drag.

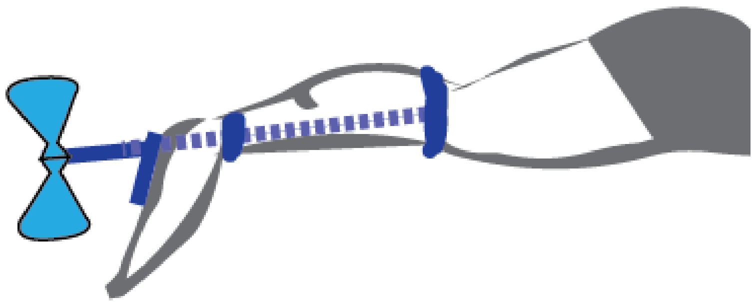

FIGURE 3-4: SCHEMATIC OF BASIC PROPELLOR DESIGN

The current world record speed for swimming is 2.39m/sec achieved in 2009 in the 50m freestyle [11]. I wanted my design to be used for extended periods of time, so I aimed for 2m/sec in initial calculations. Using Equation 4 and number estimates for K based on the research previously described, the drag was determined to be in the range of 80N to 112N depending on the position of the swimmer (bent legs or coasting). The power to overcome drag can be calculated using Equation 5 and is equal to 224Nm/sec. The efficiency for a highly trained swimmer is around 61% [1] meaning about two thirds of the output power goes to propulsion rather than overcoming drag. Calculating this out gives 350Nm/sec for propulsion. Given that a trained athlete can generate approximately 700Nm/sec consistently for over an hour [10], I felt that I could achieve the speeds I wanted with my design.

3.3 Yankee Screwdriver

As mentioned before, the strongest motion for humans is climbing or squatting so I wanted to keep this as the motion to power the device. I needed to develop a way to translate this linear motion into a rotation motion for the propeller. This concept brought to mind the Yankee screw driver. Yankee screwdrivers use a linear push to spin the head of the screw driver and it can be set to rotate in both directions. This is done with a slide selector and two pawls. The slide selector is set to disengage one of the pawls which then allows the nut to spin freely as the threaded rod passes through, see Figure 3-5. When engaged, the pawl catches on the sprockets lining the outside rim of the nut. Depending on which pawl is engaged, the rod will spin clockwise or counterclockwise.

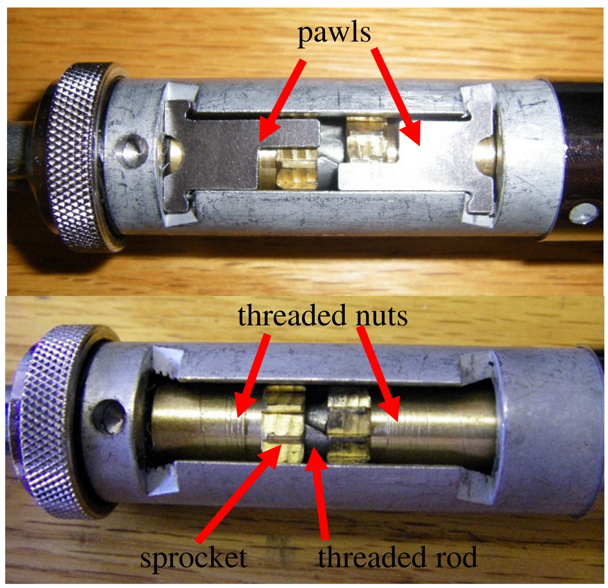

FIGURE 3-5: YANKEE SCREW DRIVER PAWL SYSTEM

Inside the housing of the Yankee screwdriver are bronze nuts which are threaded to match the harsh pitch of the rod, each threaded in opposite directions. If both pawls are disengaged (when retracting the rod) the rod can move without rotating, however if one pawl is engaged, it forces the rod to spin.

FIGURE 3-6: THREAD OF A YANKEE SCREWDRIVER ROD

Using the concept of the Yankee screwdriver, counter rotating propellers in my design can run on each track of an oversized Yankee screwdriver threaded rod. To return the propellers back to the top of the rod after pushing them down with a foot board, a spring will be added that can counter the drag force on the propellers.

For this iteration of the design, the propellers will only create a propelling force when the swimmer pushes down. The propellers will free wheel on the way back up the shaft using a one way clutch bearing. This is similar to the breaststroke in swimming: applying force with the push and gliding while "reloading."

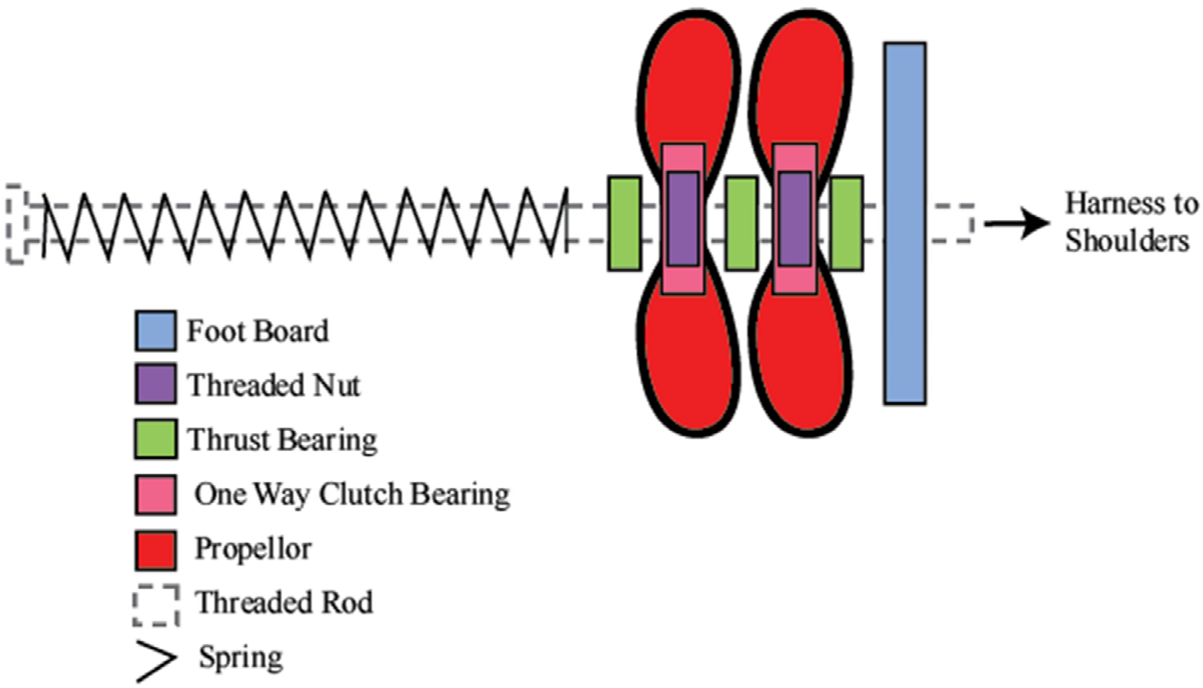

FIGURE 3-7: SCHEMATIC ILLUSTRATION OF PARTS IN DESIGN

FIGURE 3-8: FOAM CORE MOCK-UP SCALE MODEL

4 Building

To begin building, I performed a simple experiment to ensure the design could work with the power capabilities of humans. By doing body squats for 30 seconds I was able to determine the power requirements as well as the torque the rod would need to sustain.

Known	Value	Method
Work in 30 seconds	0.29J	18” leg drop 180lbs 19 squats completed
Power requirement	230W = 1/3hp	Work*Force=Power
Rotation Speed	36rad/sec	1” shaft diameter 45° thread
Torque Generated	6.4Nm	Power/Rotation Speed

TABLE 4-1: CALCULATIONS OF DESIGN PARAMETERS FOR ROD

The following specs were sent out to various manufacturers to determine the best option for making the nuts and rod. *(The following specifications were determined by building the device to fit my body)*

Specification	Value	Method
Rod Length	24”	Distance of push between fully bent knee to straight plus extra for components
Rod Material	Stainless steel	Noncorrosive and can handle torque requirement
Rod Diameter	1” OD 0.75” ID	Thick enough for stability by hallow to reduce weight
Nut Material	Bronze	Reduce friction with SS rod and noncorrosive

TABLE 4-2: DESIGN SPECIFICATIONS FOR ROD AND NUT

After hearing from four different manufacturers that the manufacturing of the threaded rod as designed was either not possible given the equipment they had available or would be too expensive. I investigated utilizing the newest manufacturing method: 3D printing. I sent a CAD model to Shapeways, a 3D printing company, to fabricate the rod and nuts out of plastic to determine the precision of the printing process used. Shapeways uses Selective Laser Sintering (SLS) printing. SLS printing is a powder based printing method in which powder is laid out on a printing bed. A CO_2 laser, which fuses the powder together, deflects off mirrors which control the X and Y print directionality. The print bed is then lowered (Z direction) and a new layer of powder is rolled out over the surface. This process continues until the entire part has been sintered together. One of the benefits of SLS versus other 3D printing methods is that no support material is required. This means that the only step in post processing is washing away any extra powder rather than dissolving or breaking off support material with the risk of breaking your actual part [12]. Shapeways provides a Material Data Specification Sheet (MDSS) for all materials they use, but they recommend their products only be used as decorative and cannot guarantee further performance abilities.

Figures 4-1 through 4-4 show CAD models and photographs of the plastic parts Shapeways manufactured.

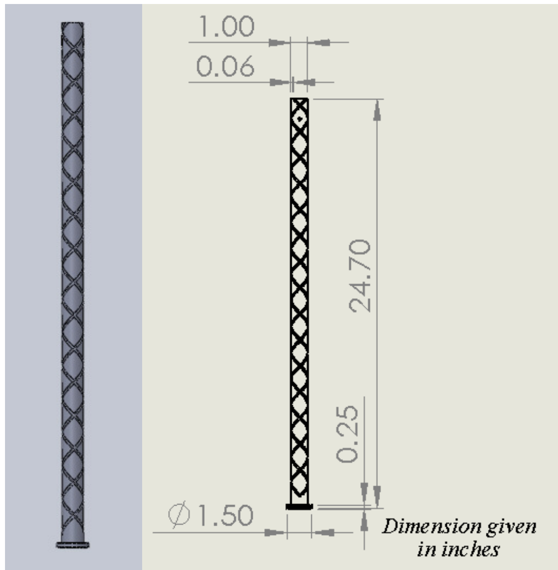

FIGURE 4-1: CAD MODEL OF PROPOSED THREADED ROD

FIGURE 4-2: PLASTIC 3D PRINTED ROD FROM SHAPEWAYS

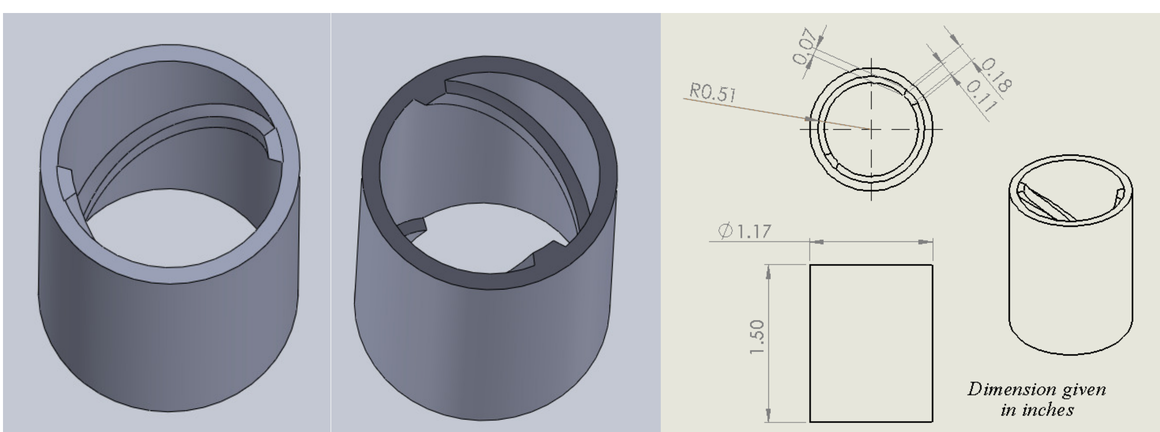

FIGURE 4-3: CAD MODEL OF PROPOSED THREADED NUTS

FIGURE 4-4: PLASTIC 3D PRINTED THREADED NUT

After receiving the rod and nuts from Shapeways, I tested them for fit. The nut slid up and down the rod, however there was an excess amount of friction. Additionally, the rod appeared to be printed as two parts and sintered together, this resulted in a slight offset in the rod, see Figure 4-5.

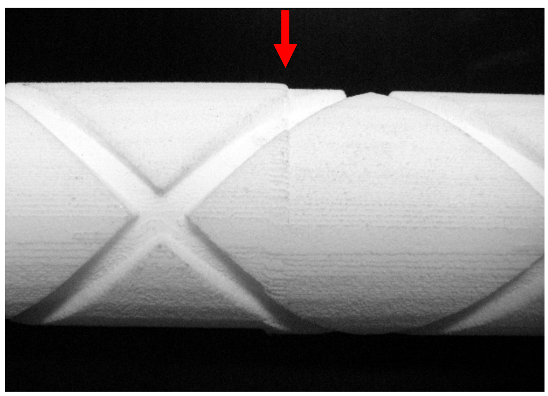

FIGURE 4-5: OFFSET IN PLASTIC PRINTED ROD

Based on the MDSS of the bronze infused stainless steel material used by Shapeways, the material could withstand the torque generated by the counter rotating propellers. After confirming with Shapeways that the threaded rod could be printed as one piece, the CAD file was sent to be printed out of stainless steel.

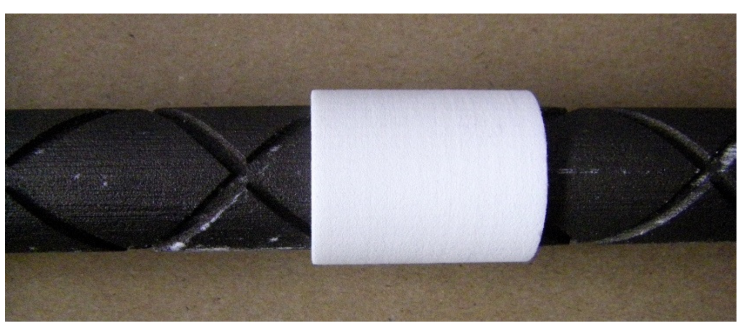

FIGURE 4-6: STAINLESS STEEL PRINTED ROD WITH PLASTIC NUT

Upon receiving the stainless steel rod and confirming the plastic nut fit the rod, the nuts were ordered to be printed out of bronze. However, when the nuts arrived they did not fit. As you can see in Figure 4-6, there is a white residue on parts of the rod, mainly showing in the grooves, resulting from the plastic rubbing off on the grit of the stainless steel rod finish. The poor tolerances of the printing process on the metal rod and nuts together caused too much friction and overlap for the nut to slide freely. To overcome this problem, I turned the rod on a lathe to take off the surface layer of the metal and I filed the grooves until the nuts slid freely up and down the rod.

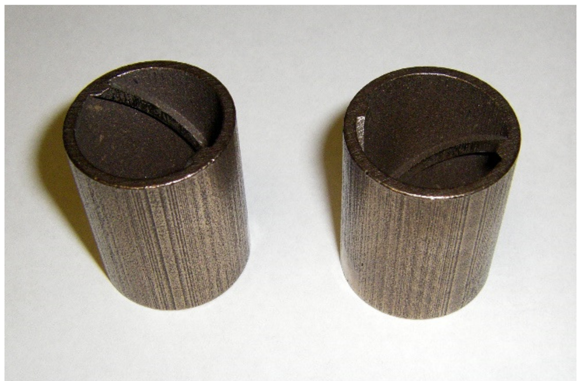

FIGURE 4-7: BRONZE 3D PRINTED THREADED NUTS

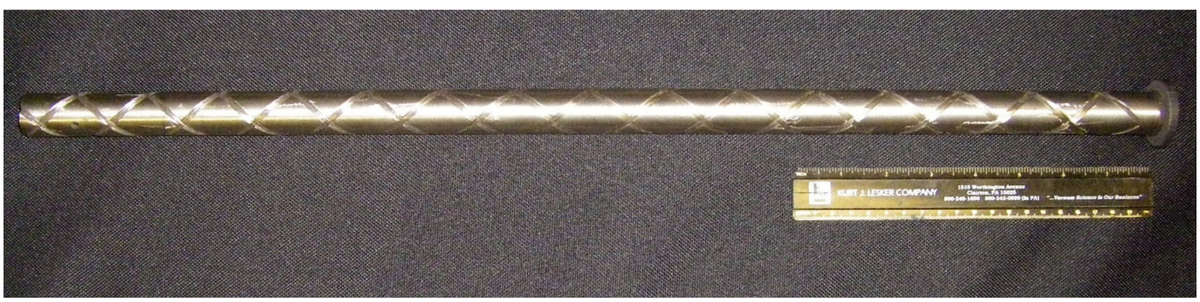

FIGURE 4-8: TURNED DOWN 3D PRINTED STAINLESS STEEL THREADED ROD

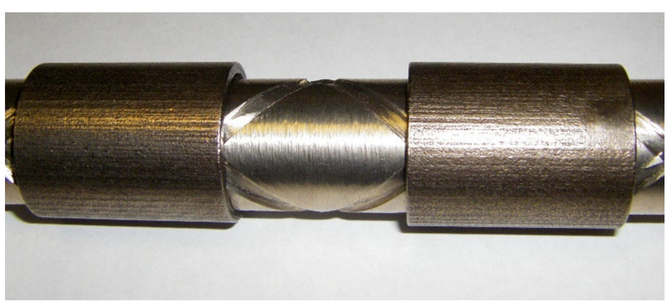

FIGURE 4-9: METAL THREADED NUTS ON ROD

Based on my estimate of 1/2hp capabilities of humans, the design of the swimming device requires propellers with a rating in the range of 248-372Watts. Because I was using two propellers, I can use ones that are rated for slightly less than 1/2hp each. Minn Kota, a manufacturing of trolling motors and propellers among other things, gives thrust and voltage ratings for each of their trolling motors. For my estimations I used the ratings for maximum force applied at 1knot to determine the power rating of the motor. Once I found a motor that met the specifications needed, we could order the propeller rated for that motor.

Motor	Max Thrust	Power
Endura C2 55	245N	122.5W
Terrova 112	498N	249W
RT 160	711N	355W

TABLE 4-3: MINN KOTA TROLLING MOTOR RATING

Both the Terrova 112 and RT 160 fell within the range of power I was looking for and both of these models used the MKP-32 Weedless Wedge propeller, Figure 4-10. In order to get counter rotating propellers, the propeller was scanned using a Microsoft Kinect Fusion, mirror imaged in Meshlabs and 3D printed on a Dimensions sst 1200 printer. The Microsoft Kinect Fusion uses a basic stereo imaging to create 3D renderings of objects. Stereo imaging is performed by taking single frame photographs from two cameras which are at known distance and angle apart. Each point in a picture is then matched up to its corresponding point in the second picture. The software goes through a process of triangulation to estimate a fixed position in 3D. The Kinect software uses a unique method to distinguish between similar objects. A pattern, which is not visible to the human eye, is projected onto the object being scanned. The pattern used by the Kinect is a scattering of dots where each subset of dots is unique. This way the software can tell when there is a shift in depth by comparing the locations of each subset of dots in the camera views [12]. Although this scan is not perfect it serves the purpose for this prototype.

FIGURE 4-10: ORIGINAL MINN KOTA PROPELLER

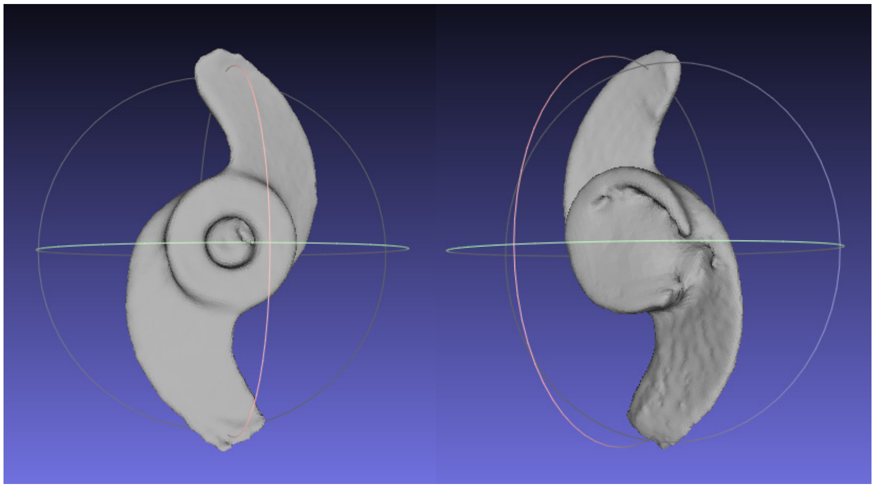

FIGURE 4-11: 3D SCAN OF PROPELLER USING KINECT SOFTWARE

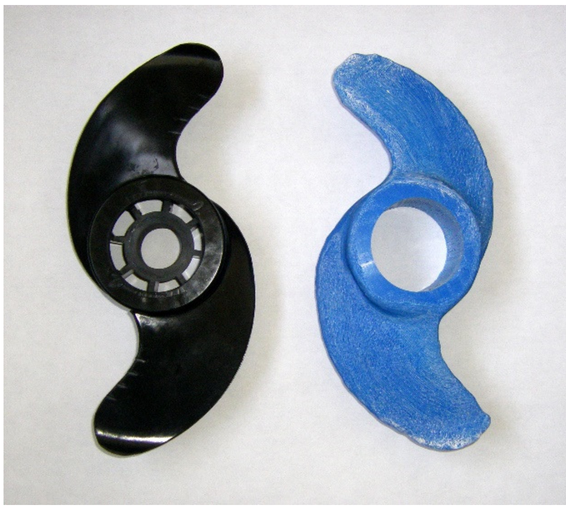

FIGURE 4-12: ORIGINAL AND PRINTED PROPELLER AFTER MACHINING

The alternating pushing and pulling motion of the legs when using this device is similar to pedaling a bike, so I used bike pedals and straps for the foot board, see Figure 4-13. This allows for a change in the angle of the swimmer's ankle when pushing versus pulling, putting the swimmer's leg in a better position.

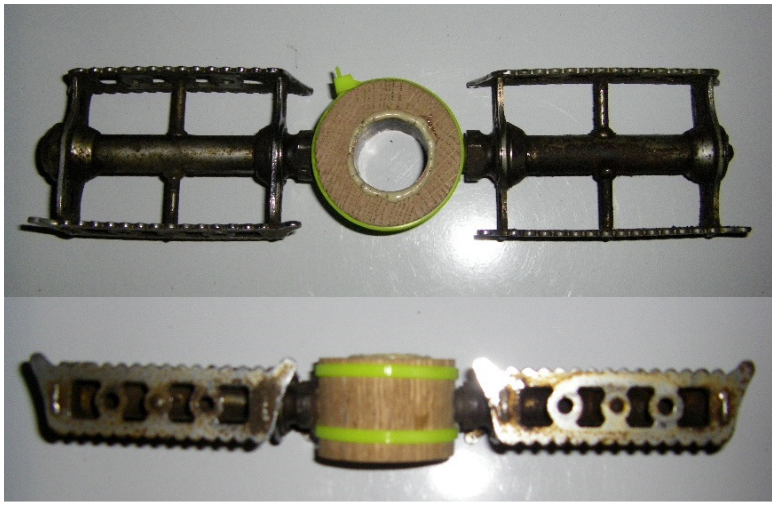

FIGURE 4-13: FOOT PIECE WITHOUT STRAPS

A spring is used to return the propellers and other components back to the top of the shaft when the swimmer returns to the squat position. Because swimmers primarily move horizontally in the water, the spring only needed to be strong enough to counter act the drag force felt by the propellers. Using Equation 3 the drag force was calculated to be approximately 154.2N/m resulting in a spring rate of a little less than 1lb/in. The following specifications were sent to W.B. Jones Spring Co. Inc. to make a custom spring.

Specification	Value	Method
Overall Length	18”	Span entire length of rod
Inner Diameter	1.050”	Fit over rod
Spring Rate	0.9lbs/in	Counter drag force

TABLE 4-4: SPECIFICATIONS FOR SPRING MANUFACTURER

4.1 Assembly

For the harness, a marching band drum carrying harness was used, the Pearl MX T-Frame Bass Drum Carrier. After removing several unnecessary components, I was left with a very sturdy harness which is comfortable to wear over long periods of time and is adjustable in height. To attach the harness to the threaded rod, a carbon fiber tube was used, which allowed for maximal strength while adding very little weight. This was attached to the rod and harness with parts 3D printed on the Up Mini which uses fused deposition model printing, a process in which plastic is extruded in the desired shape. These were all connected with stainless steel clevis pins on one end and DAP All-Purpose Adhesive Sealant on the other.

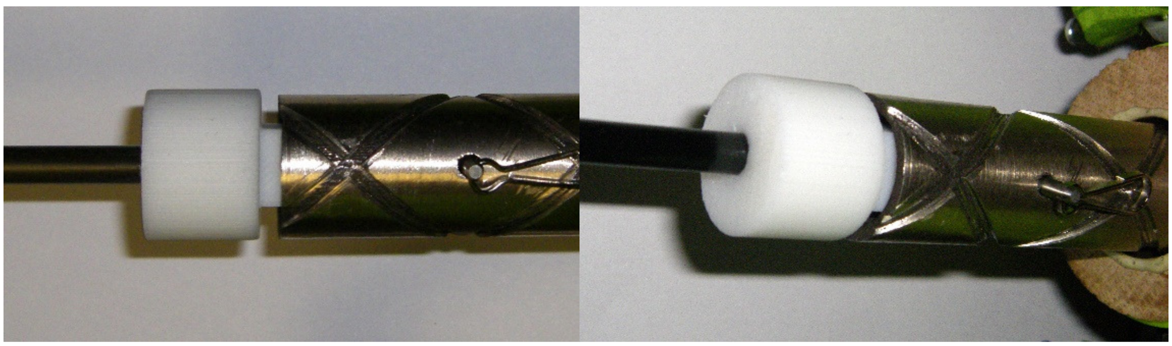

FIGURE 4-14: CONNECTION BETWEEN THREADED SHAFT AND CARBON FIBER TUBE

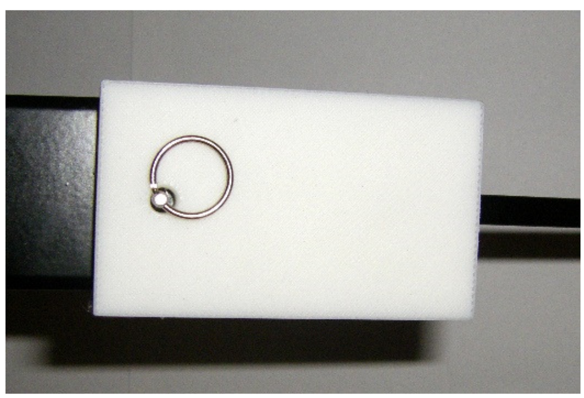

FIGURE 4-15: CONNECTION BETWEEN CARBON FIBER TUBE AND SHOULDER HARNESS

Next the propeller assembly was adhered together using Red Loctite. The threaded nut, one-way clutch bearing, and propeller were fixed together to prevent any rotation (except that allowed by the bearing).

FIGURE 4-16: ASSEMBLY PROPELLER ASSEMBLY (PROPELLER, ONE-WAY CLUTCH BEARING, THREADED NUT) USING LOCTITE

Thrust bearings were placed on either side of the propellers and in between the propellers to absorb some of the force along shaft. A buoy was added to the lower end of the shaft to counter the weight of the threaded steel rod using a 3D printed part and adhesive, enabling the user to focus on swimming rather than keeping the device from sinking. Finally fabric straps were added to the bike pedals and around the harness.

FIGURE 4-17: BUOY'S CONNECTION TO END OF ROD

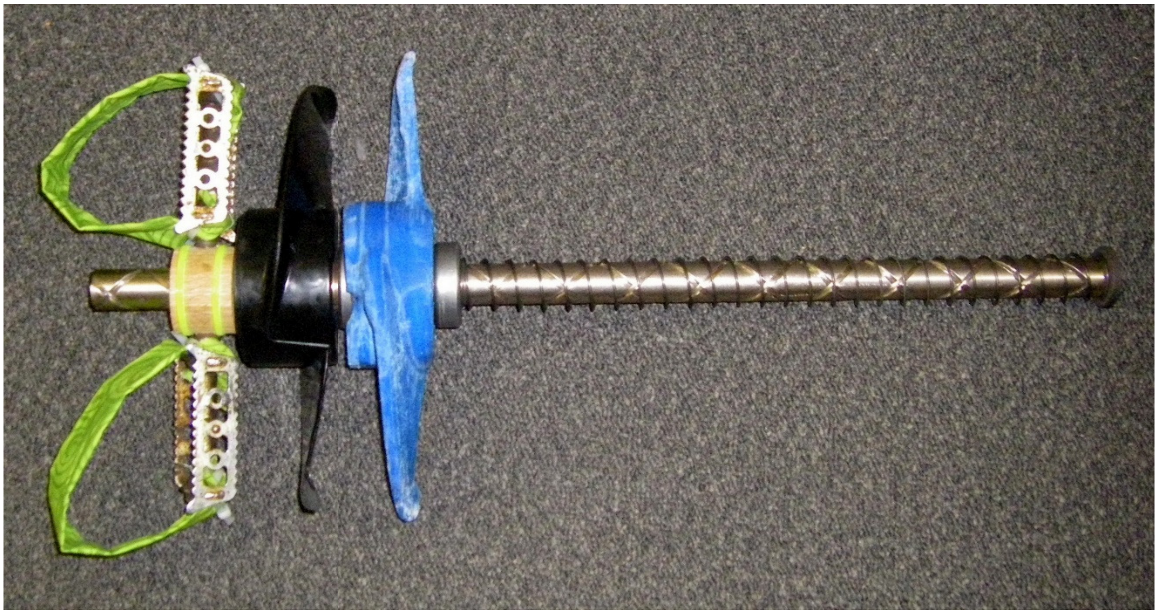

FIGURE 4-18: COMPLETED LOWER HALF OF DEVICE (WITHOUT PROPELLER)

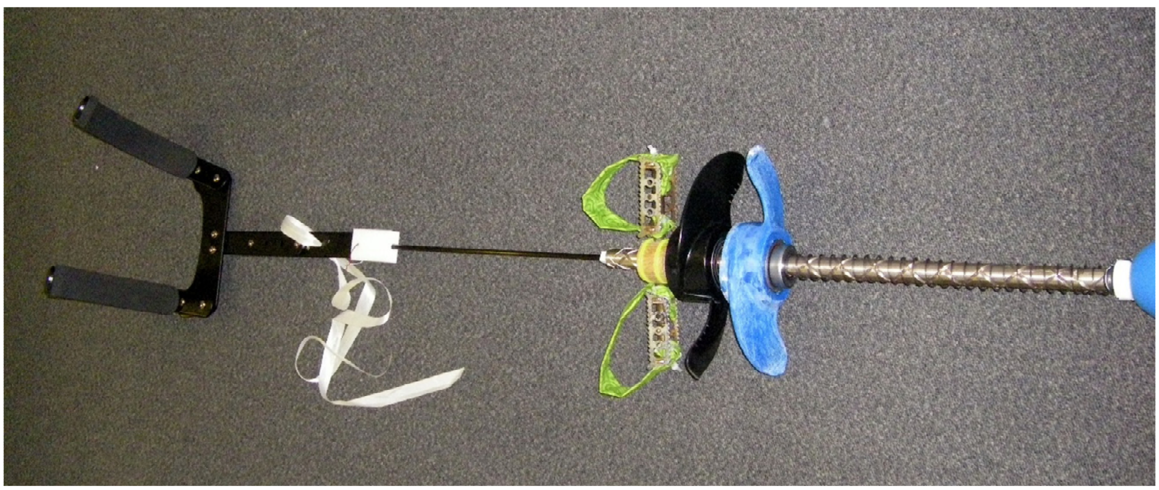

FIGURE 4-19: COMPLETED DEVICE (VERSION 1)

5 Testing

Testing was completed at the Zesiger Center Pool at MIT

5.1 Testing Round 1

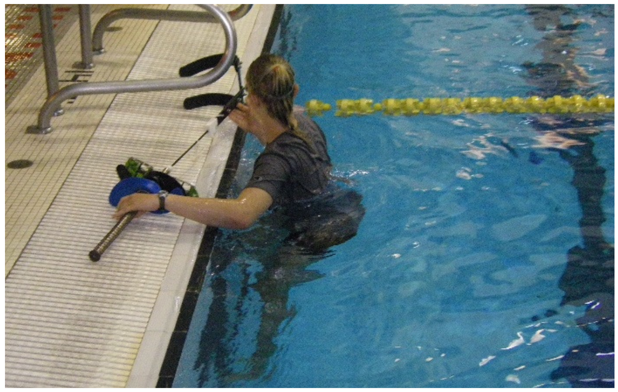

FIGURE 5-1: THE BEGINNING OF TESTING ROUND 1

The first round of testing did not go perfectly, but it did yield information to improve the device for the second round of testing. First, the adhesive on the 3D printed connections were not stable in the water and essentially broke as soon as I put on the device. Because both surfaces (printed part and carbon fiber tubing) were very slick, as soon as water was added to the bond, it immediately came apart. Additionally the thickness of carbon fiber used was not rigid enough in the water. Instead of using carbon fiber I switched to using an aluminum tube attached to the threaded rod and harness with clevis pins. This eliminated the point of weakness created by having multiple components and adhesive and added rigidity to the middle section.

FIGURE 5-2: PUTTING ON THE DEVICE DURING TESTING ROUND 1

FIGURE 5-3: UPDATED CONNECTION BETWEEN THREADED ROD AND ALUMINUM ROD

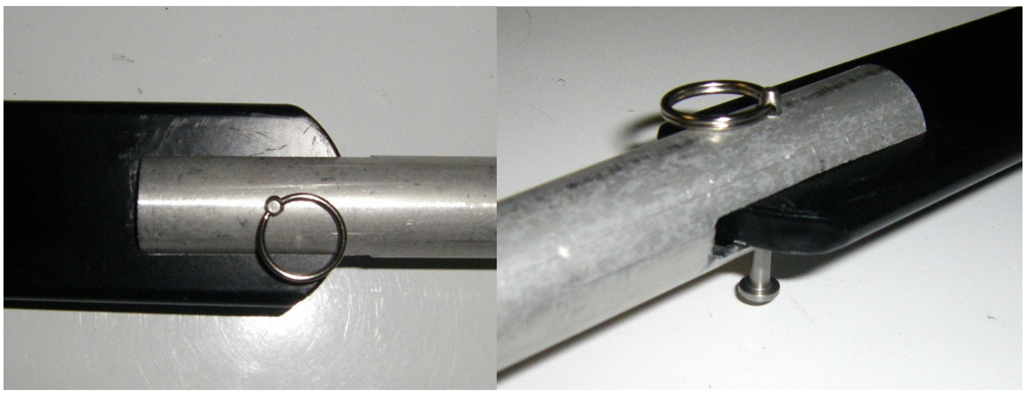

FIGURE 5-4: UPDATED CONNECTION BETWEEN HARNESS AND ALUMINUM ROD

Having the buoy rigidly attached to the end of the threaded rod also caused problems. The buoy continually tried to lift the threaded rod up, as it should have, but because of the rigidity, every movement changed the angle of the rod. This made applying force in one direction difficult. Additionally due to this continuous movement, the force felt by the connection between the rod and buoy was more than expected and the adhesive failed. To modify the design the buoy was attached with a rope. This meant the action of the buoy was more passive, limiting the movement directly felt by the threaded rod while still keeping it afloat.

Since all the attachments broke, I tested the lower half of the device with my hands pushing the device up against the wall. I found that the propeller train was jamming primarily on the return back to the squatting position as well as occasionally going down the rod. I believe this was occurring due to the fact that as the propellers moved back up, the thrust bearing between the two propellers was interfering with the back one-way clutch bearing. This interference was caused by the slop in the inner diameter of the thrust bearing verse the outer diameter of the shaft. By adding a bushing in between the two propellers, the thrust bearing was forced to keep its alignment and cleared up most of the jamming.

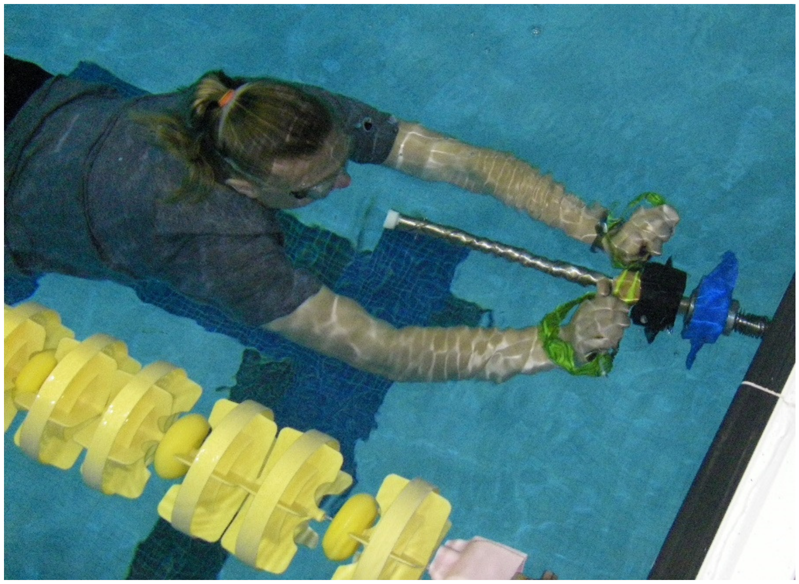

FIGURE 5-5: TESTING THE DEVICE AGAINST THE WALL

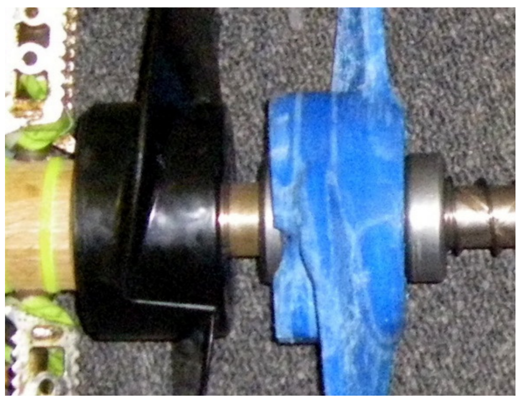

FIGURE 5-6: ADDED BUSHING IN BETWEEN PROPELLERS

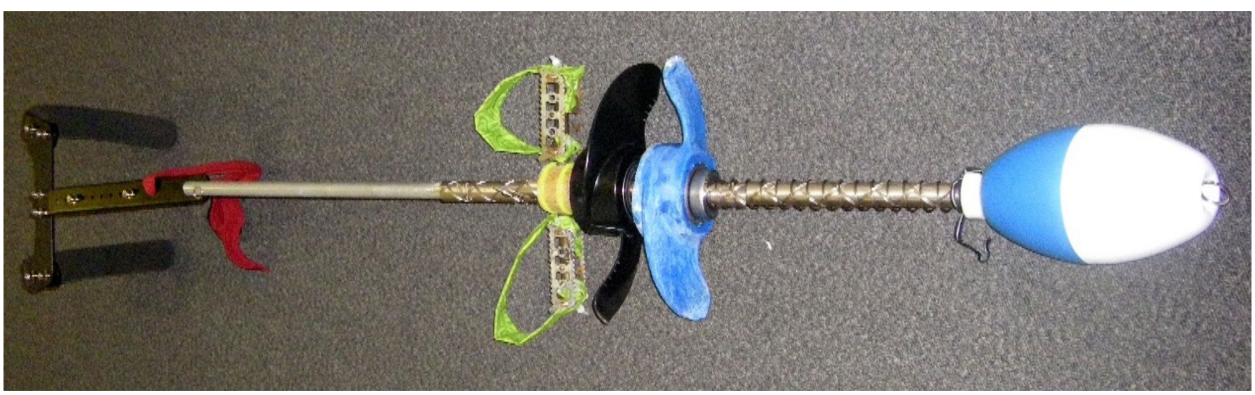

FIGURE 5-7: UPDATED DEVICE AFTER TESTING ROUND 1

5.2 Testing Round 2

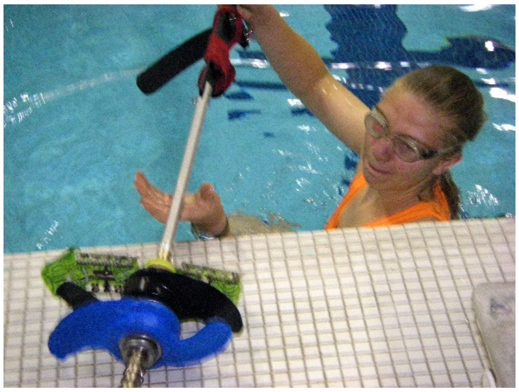

FIGURE 5-8: BEGINNING OF TESTING ROUND 2

During the second round of testing everything held together with just a few minor glitches. The aluminum rod and clevis pins were able to withstand the forces and the free hanging buoy design allowed for better control over the threaded rod. However there were still a few problems. First, because the base of the pedals was made with wood, as soon as they were in the water for about ten minutes the wood expanded and the pedals broke off as soon as force was applied. Luckily, I had a back-up make-shift foot piece made of a piece of sheet aluminum, however even this started bending after a few tests. The force being applied along the rod is very large, so when there is a moment arm in play as well, a much stronger design will have to be built to avoid a weak spot. Second, the spring occasionally jams. Again because of the slop in the dimensioning of the thrust bearings, the end of the spring can slip underneath one edge of the bearing, causing the system to jam. Simply retracting and pushing again cleared the jam but it made for some jerkiness in the operation.

Overall the design worked, however not nearly at the speed we were aiming for. I was able to chug along, pumping my legs as quickly as I could, moving at a slow crawl. In terms of a proof of concept, the project was a success, all the components work together the way they were designed to and it was not awkward to swim with, but it is definitely not a product yet.

6 Conclusion

Unfortunately I was not able to break the world record for swimming speed with the current device, but given the success of the design, with a few minor changes it is still possible! Because my design involved more muscles when in use as compared to conventional flippers, it is more efficient for the biomechanics of a swimmer. Additionally using propellers barely increases drag, so my device primarily increases propulsion force while the drag force the swimmer is opposing stays relatively constant. This means greater speeds can be attained than with conventional flippers. With these design ideas in mind and the proof of concept shown in this thesis, there is still the potential for this human powered swimming device to break world record speeds and become a widely used device due to its efficient use of the human muscular system.

Moving forward I am going to continue with the project. We believe that by increasing the propeller size to a two or two and a half foot diameter rather than a one foot diameter, the force necessary to generate speed is attainable. I am currently looking at large model airplane propellers as alternatives to the current trolling motor propellers being used in the device. Additionally, by adding a flanged sleeve bearing at the top of the spring, the jamming can be eliminated to make a smoother operation, and the pedals will have to be redesigned to withstand the moment applied. I am excited to continue working on this project through the summer and see it through to achieve the goal of breaking world record swimming speeds.

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List of Figures

List of Tables