Upgrading the Drive System for a REMUS 100 AUV Hydroid

Abraham Feldman
Christopher Fitzhugh
Clayton Gimenez
Morgan Lavine
Gray Thomas

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1 Executive Summary

Following work done in ENGR 3390: Design For Manufacturing at Franklin W. Olin College of Engineering, a group of four senior students, later five, was tasked with upgrading the drive and maneuvering systems of a Hydroid REMUS 100 Autonomous Underwater Vehicle (AUV). To date, Hydroid and the REMUS are global leaders in AUV sales and production, with applications spanning military, industrial and scientific pursuits. In the AUV market, REMUS is synonomous with robustness and reliability. As such, this project set goals to decrease cost to manufacture and assemble while maintaining reliability and improving performance.

This report details the current final iteration for this design cycle, including full system descriptions of fin actuation, propulsion and electronics. It also contains documentation for manufacture and assembly, as well as up to date cost reports and verifications for design decisions made.

In summary, a final tail assembly design has been completed. It follows a tri-fin configuration for stability utilizing a variation on the fin motor setup developed by Harris, Higgins and Martelaro for ENGR 3390 while the propulsion sub-system is a logical continuation of the concept developed by Carlson, Koukina and Schmidt utilizing their novel motor configuration concept. Significant changes have also been made to the tail hull section to decrease cost to manufacture while ensuring the mechanical system will continue to integrate seamlessly with the rest of the REMUS 100.

The initial designs of the ENGR 3260 electrical team have also been reworked , notably switching micro-controllers given poor early test results. The switch from building the thruster motor driver in house to using a prepackaged motor controller is also of note, since it eliminates a complicated and potentially problematic back emf sensing circuit which compensates for the lack of a hall effect sensor encoder. Based loosely on the original package's specifications the electrical team built a motor control circuit for a single fin motor in isolation, with the noted change to a PIC18F4550 which has the advantages of USB debugging and familiarity to the team. The circuit was capable of spinning the motor in either direction while varying the duty cycle of the enable pulses, which correlates to torque. This required reading the hall effect sensors, but not the magnetic encoder. A quick probe with the oscilloscope revealed that the sensors were correctly hooked up and ready to be interfaced to the PIC, but that task is yet incomplete. Thus the circuit is currently awaiting the closing of fin control loop. The thruster driver is expected to be controlled by a PWM signal off of the PIC. The serial interface to the existing Hydroid hardware has also yet to be done, but we have acquired the documentation of the protocol.

Currently, a propulsion sub-system testing jig is being manufactured and assembled to prove the new inverted motor configuration. At the completion of its testing and any redesign, a full prototype will be manufactured and assembled at Olin College before another round of testing commences in the Massachusetts Institute of Technology Tow Tank.

2 Proposal

The Hydroid REMUS 100 is the most successful autonomous underwater vehicle on the market currently. However, it is unfortunately quite dated. In its current state, the REMUS 100 tail assembly costs 18,000 USD to manufacture with 6,000 for the fin actuation assembly and 12,000 for the hull and propulsion system. These costs are distributed over 151 parts, with the majority allocated to manufacturing costs and specialized components such as ceramic bearings and the custom propulsion motor.

From the forward section aft, the main tail hull section is a billet of black anodized 6061-T6 Aluminum. It provides a double o-ring seal to the main submarine hull section and mounting points for the fin actuation assembly, the electronics assembly and the propulsion assembly. Its current configuration requires multiple complicated machining setups to provide the described mount points.

The fin actuation assembly (Fig 1) utilizes two Faulhaber 1628B DC brushless motors with a 246:1 planetary gearhead (350 USD) mounted in the forward section of the tail hull. The 42.5mm length of these motors requires more space than is allowable next to the fin shafts, so a complicated chain drive is required to transmit torque to the fins. The fins themselves are a NACA-0012 wing section of an unknown polymer mounted to a titanium shaft, setup in a four-fin configuration and driven in opposing pairs with a coupling mechanism. Finally, the motor loop is closed by a potentiometer mounted to the spur gear motor output. In total, the two fin actuation assemblies contain 56 parts.

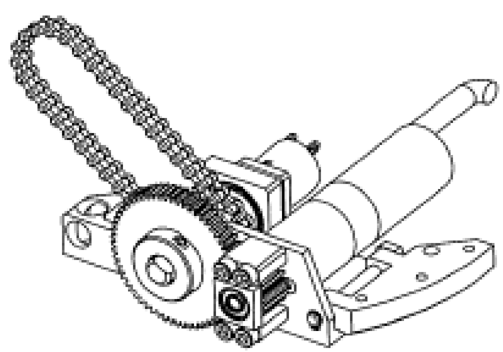


Figure 1: Example fin actuation assembly from the current REMUS 100 AUV

The current REMUS 100 propulsion system is a standard propeller drive using a wet brushless DC motor. The motor is set up such that the stator coils are sealed behind a Delrin sleeve against against a pair of Aluminum sections and bolted to the main body. There are two double o-ring seals for the stator coils and another to the main body. The rotor is a potted section around a titanium shaft pressed into two ceramic bearings using a final Aluminum section, while the propeller is held onto the rotating shaft assembly with a nut. Details outside of the dimensions were difficult to come by, with solid numbers only for RPM (600) and top speed (5 knots).

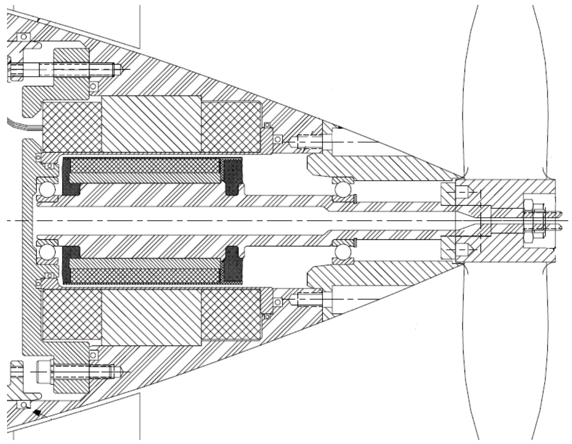


Figure 2: Propulsion motor assembly from the current REMUS 100 AUV

2.1 Previous Upgrade Progress

As the REMUS 100 is already fully function and an extremely successful market item, Professor Andrew Bennett of Olin College proposed a redesign of the tail assembly to reduce manufacturing cost and improve performance, with the stipulation that any changes made would not affect the overall submarine architecture - either mechanical or electrical. The design requirements are as follows:

1. Hull profile, hull mounting method and section seals remain unchanged
2. Electrical subsystem integrates seamlessly with REMUS architecture
3. At minimum, preserve fin and propulsion functionality
    a. Fins must sweep a net displacement of 20 deg using current REMUS fin design
    b. Fin transmission must output greater than 20 mNm of torque
    c. Propulsion system must operate at approximately 600 rpm using the current REMUS propeller
4. Increase depth rating from 100m to 200m
5. Decrease parts count
6. Decrease overall system cost

The ENGR 3260 Design for Manufacturing course was tasked with developing a set of cost efficient redesigns for the REMUS 100 tail section within this design space. At conclusion of the course, they proposed two solutions: one, a nearly fully realized design for a new fin motor assembly, and the other, a concept for a more pressure resistant propulsion system.

2.1.1 Fin Actuation

The fin actuation assembly is built around a base motor platform that can be easily modified into three different configurations, allowing for a tri-fin, independent four-fin and coupled four-fin assemblies with minimal modification to the existing outer hull section. The system is designed around a low profile Faulhaber 2622 brushless DC motor with a 33:1 planetary gearbox, allowing the motor to be placed much closer to the fin shafts. A direct 3:1 gear reduction using stock 25 and 75 tooth brass gears applies 90mNm of continuous torque and 300mNm of intermittent torque between the motor and the fin shaft; much greater than the 20mNm required to rotate the fins. A US Digital MAE3-A10-118-220-7-B magnetic encoder closes the feedback loop and is mounted directly to the motor output gear.

The motors and encoder are mounted to a 1in x 1in Aluminum L bracket and custom Delrin C-channel. A pair of alignment pins ensure the 6-32 screw holes between the L bracket and the main hull section are concentric, while a pair 4-40 screw bolts the encoder to the Delrin C-channel to the bracket, as seen in Figure (3).

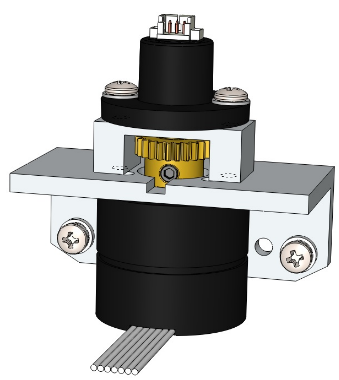
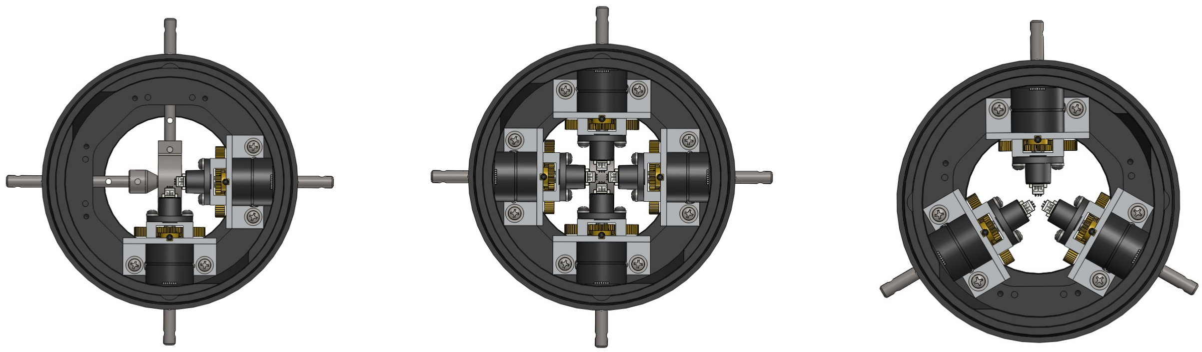


Figure 3: Fin Motor Block complete with mounting brackets

The main advantages to this assembly are cost, ease of manufacturing and assembly and modularity. ENGR 3260 estimated a total cost of 830 USD for the coupled 4-fin configuration, compared with the current 6000 USD for the same. With only two machined parts, it is also estimated that a full build would only take a couple of hours to assemble from start to finish, and the design can be fit to three different overall configurations, as shown in Figure (4).

2.1.2 Thruster Concept

The propulsion system redesign proposed by the students of ENGR 3260 involved inverting the wetted section of the brushless DC motor that drives the current REMUS. Rather than a fixed outer ring of stator coils and a rotating inner ring of potted magnets, this design would use a rotating outer ring of magnets and a potted, fixed inner stator. This would remove the



(a) 4 Fin Coupled (b) 4 Fin Independent (c) 3 Fin

Figure 4: Available fin actuation assembly configurations

o-ring sealed, deformable Delrin sleeve surrounding the current stator, and replace it with a much more structurally stable pressure hull, reducing the number of seals required by the system by 3.

Though their concept was not fully realized, the students were able to configure a test platform and estimate the efficiency for a basic design. Using an E-Flite Power 60 brushless outrunner motor, they turned a Delrin sleeve to house the inner stator and embedded the magnets in an FDM printed ABS rotor, as seen in Figure (5). After appropriately placing bearings, they estimated the motor efficiency at roughly 40%, half of the published value for the motor, but within the range of the current REMUS.

Figure 5: Components for testing the thruster concept

Based on these tests, the team proposed use of a Scorpion HKII-2216 outrunner motor, with the stator potted in an appropriately heat resistant material. An aluminum outer housing would provide sufficient mounting for the magnets and the propeller.

2.2 Proposed Deliverables

Building on the work done by ENGR 3260, this team was tasked with developing a final product that could replace the current REMUS tail section. The fully realized assembly would include a complete CAD model, drawing package, analysis, test data, and finally, a built prototype with DFMA documentation.

To date, we have developed a complete CAD model and drawing package of the final system including sufficient analysis to prove its structural and mechanical stability. We have also begun fabrication of a test rig for the propulsion assembly.

3 Mechanical System

In keeping with the proposed design requirements, we have maintained the overall hull contour and length, and retained the same mounting and sealing methods for the outer shell. The fins and propeller are also identical to those in the current REMUS 100 AUV, but on the encouragement of Chris von Alt, President of Hydroid, we opted to pursue a tri-fin configuration for its greater stability and roll control underwater. Nearly all of the internal components have been changed.

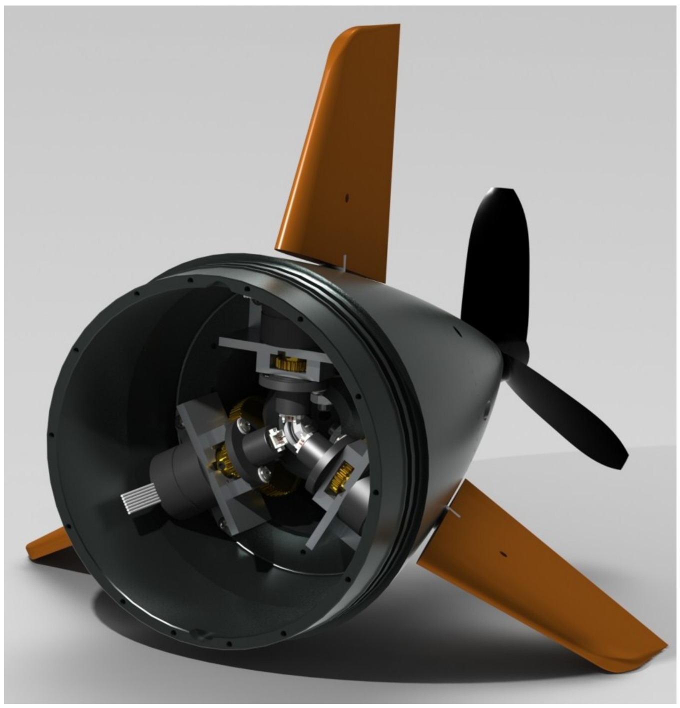


Figure 6: Finalized tail section design

3.1 Maneuvering

The fin actuation assembly is built around the designs produced by ENGR 3260. Their motor choice and mounting setup were expertly chosen and we saw no reason to re-do their work. We did, however, drastically change the outer shell, significantly reducing the machined feature count to reduce cost.

The majority of these features are necessary to mount the current REMUS 100 fin actuation assembly, but the small profile and tri-fin configuration of the proposed redesign negate their inclusion. Thus, the interior of the new shell is a smooth cylinder with conical sections to match the outer contour when required. The hexagonal mounting cut for clearance at the

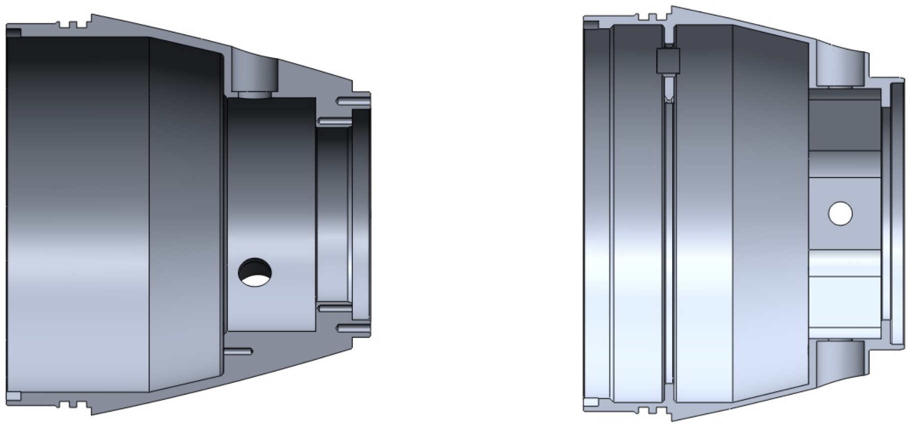


Figure 7: Comparison of proposed (left) and current (right) outer shells. Both are fabricated from 6061 Aluminum and anodized for corrosion resistance.

fin mounts was removed for another cylindrical section, and a new aft bulkhead design was introduced to provide a second point of contact for the fin shafts. Appropriate mounting was also added for the fin motor blocks and associated electronics in the configuration shown by Figure (8).

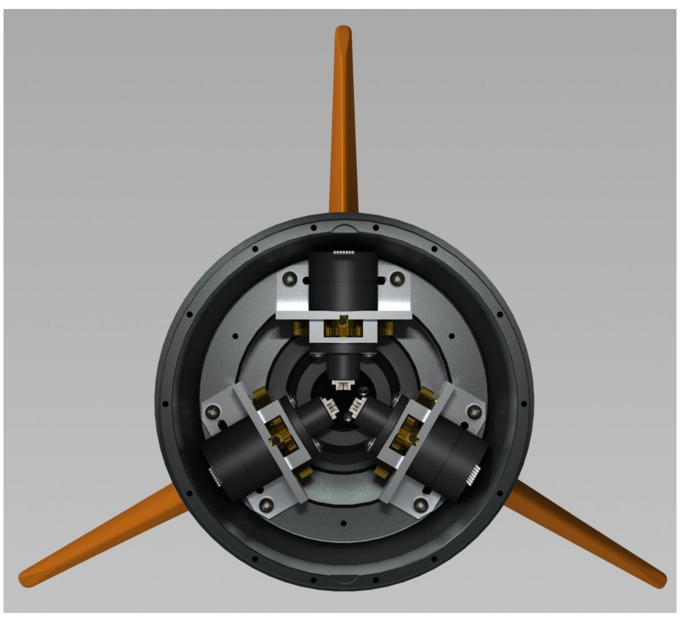


Figure 8: Front on view of proposed redesign showing fin actuation configuration

The fin shafts (Grade 2 Titanium) are mostly the same, but have been lengthened to accommodate another point of contact on the central bulkhead by way of a second bearing, as seen in Figure (9). Also added to the shafts are a set of retaining rings, one standard and one E-type for each, to hold the 75 tooth gear in place on the shaft, and a threaded end to accommodate a nut and washer to cross-load the two bearings. The outer of these two bearings is pressed in from the outside of the main shell below the same o-ring shaft seal used in the original REMUS assembly. The inner is pressed into the central bulkhead up against an inner retaining ring.

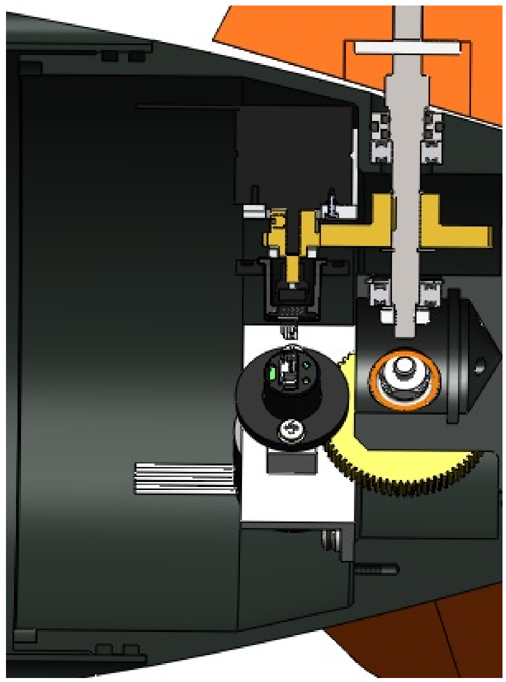


Figure 9: Cross section of the fin actuation assembly

3.1.1 Assembly

In terms of assembly, the motor block is built first and set to the side. Next, the fin shaft is pressed in to the o-ring seal block and the outer bearing before the upper retaining ring is mounted. The inner retaining ring is then mounted to to the bulkhead and its associated bearing is pressed against it. This is done for all three. Once the rest propulsion system is mounted to the bulkhead, it can be mounted to the outer shell at which point the fin shafts and their mounted bearing-o-ring assembly can be pressed into the outer bearing lands and the shaft passed through the 75 tooth gear and into the second bearing. At this point the e-type retaining ring is snapped onto the shaft and the inner nut is tightened to exert a slight pre-load on the bearings to prevent slop. Finally, the motor block can be aligned and screwed in such that the gears mesh properly.

Further details can be found in Appendix 1.

3.2 Propulsion

Based on the outrunner concept developed by the students of ENGR 3260, we created a brushless DC motor assembly that retained a nearly identical outer profile to that of the current REMUS. At its heart is the stator from a Scorpion HKII-2216 outrunner brushless DC motor.

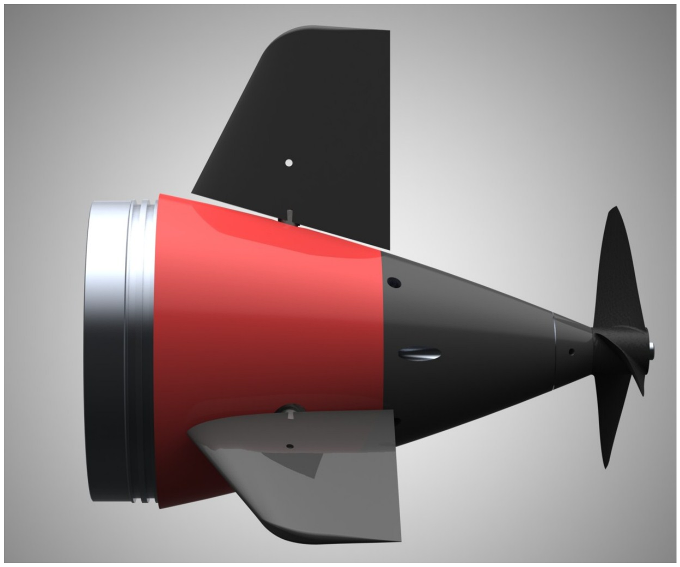


Figure 10: Side profile of the REMUS 100 redesign

We begin at the aft bulkhead, which seen in Figure (9), mounts the second point of contact for the fin shafts. A pair of alignment pins locate the bearings in relation to the fin shafts, while a Trelleborg energized seal ensures a watertight section (light blue in Figure 11). Onto this bulkhead we bolt a 316 Stainless Steel shaft on which mounts the stator and its housing. The housing is a high-strength, oil-filled Nylon and is sealed to the shaft and the bulkhead with a pair of o-rings. Four outlets through the shaft and the bulkhead allow the stator wires to pass through into the main hull section and a counterbore ensures that when the housing is potted through those same outlets, there is room for backflow. A widened groove acts as a retaining ring when the pottent sets to prevent outer pressure from squeezing the material through the outlets. The aforementioned potting material, once set, will act both as a seal and as a solid as it is expected that it will press up against the o-rings when we pressurize it during fabrication. This will ensure a high resistance to deformation due to pressure outside the hull, as well as watertightness to both the stator and the main hull section.

The potting material we have specified to be extremely low viscosity, very hard, with a very high very high thermal conductivity. With a low viscosity, it will permeate all of the stator coils, filling in every available air pocket, and a high thermal conductivity will ensure the heat generated by the stator during operation will be transferred out to the Nylon housing and then to the sea-water.

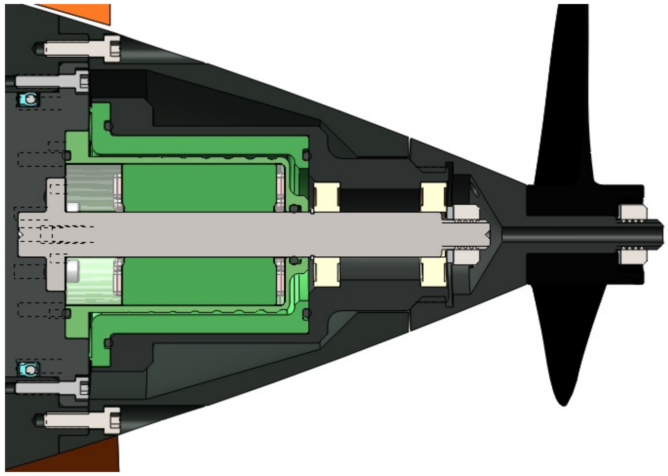


Figure 11: Cross section of the propulsion assembly

A pair of ceramic bearings on the aft end of the shaft locate the anodized 6061 Aluminum rotor housing while a nut and Belleville spring washer pre-load the bearings against a retaining ring just behind the stator housing. Moving radially from the stator housing, we find another oil-filled Nylon shell, this time containing the stator magnets. It is bolted to the aforementioned rotor housing and sealed on either end with an o-ring to prevent undue corrosion of the magnets.

The last rotating sub-assembly is an anodized 6061 aluminum mount for the propeller which is left hand threaded onto the end of the rotor housing. Four pins allow transmission of torque between the mount and propeller, and the propeller is constrained axially by a nut and washer. This sub-assembly can be seen on its own in Figure (12).

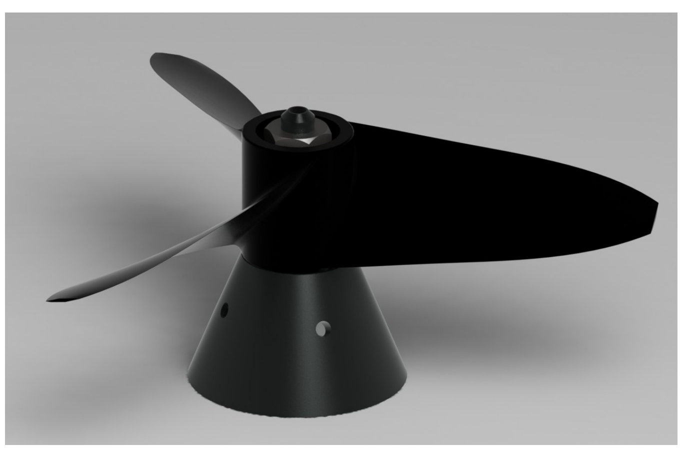
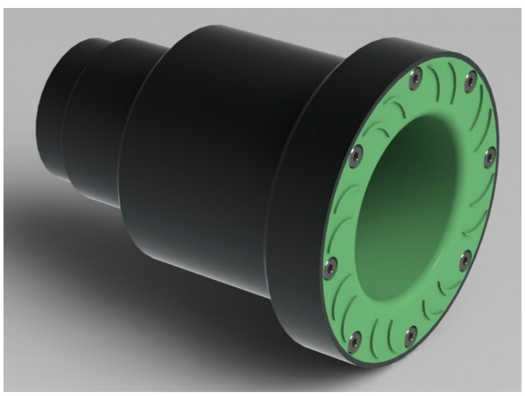


Figure 12: Propeller sub-assembly

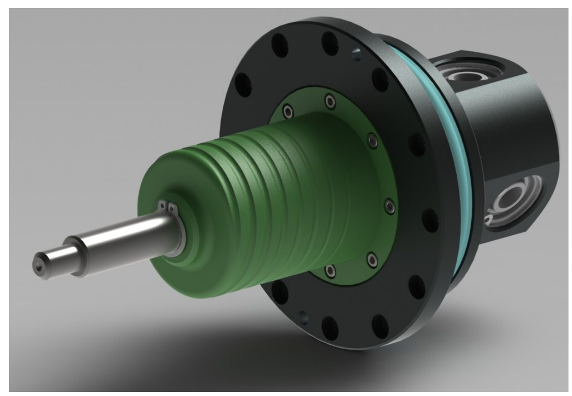
As all of these components are submerged in sea-water, there is a high degree of fouling from dirt and debris. To alleviate this problem, we have devised a system of passive flow-through from the fore end of the propulsion assembly, aft, as well as access to flush the system manually.

The final component in the propulsion sub-assembly is another anodized 6061 shell whose only purpose is to protect the inner rotating components from debris. It is located concentrically to the main outer shell and bolts on with four bolts, alongside which we find four inlet ports for flow through. These inlets can be covered with a small screw in mesh that will prevent objects larger than 0.01in in any dimension from getting through. A set of outlets on the propeller sub-assembly will provide a pressure drop through the interior, as the propeller creates a massive low-pressure zone just before its blades.

In the event there is not a sufficient drop in pressure to excite flow, we have included two forcing features within the rotating assembly. The first is a radial impeller pattern along the fore end of the rotor, as seen in Figure (13A). This will create a pressure gradient across the inlets, drawing water in. A set of thread patterns on the stator housing (Figure 13B) will then interact with the boundary layer of the rotor, forcing water aft and out. This has the added benefit of cooling the stator housing during operation.



(a) Rotor Assembly



(b) Stator Housing Assembly and Bulkhead

Figure 13: Flow forcing sub-assemblies

The manual flushing system utilizes a through hole along the main axis of the the propeller sub-assembly as a nozzle, such that water could be pumped in and out the inlets.

3.2.1 Assembly

The propulsion sub-assembly is broken further into three more assemblies - Propeller (Figure 12), Rotor (Figure 13A) and Stator Housing (Figure 13B) with several extraneous components.

The Propeller sub-assembly is made up of eight components - the propeller, the propeller attachment, a nut, a washer and four pins. Construction sees pins aligned in the attachment block, the propeller seated on the central shaft, aligned by the pins, and the nut and washer screwed onto the end to constrain the prop axially.

The Rotor consists of the motor magnets, the rotor housing, the magnet housing, two o-rings and a bolt pattern. To assemble, the magnets are first glued in to their slots in the magnet housing. The two o-rings can then be placed in the appropriate grooves in said housing before everything is bolted into the rotor housing.

The final sub-assembly, the Stator Housing, must be completed before any of the others, including those in the fin actuation assembly, as it begins with the main aft bulkhead. First, the 316 Stainless shaft is aligned and bolted to the bulkhead. Then, the stator is mounted to the shaft, with its wiring running out the access holes and the o-rings are placed in the appropriate grooves on the stator housing. Once the housing is slipped over the shaft and bolted to the bulkhead, the system can be potted before being used in the fin actuation assembly.

To finish the full assembly, the Stator Housing assembly is mounted and sealed in conjunction with directions given in the Fin Actuation assembly instructions. Next, a retaining ring is clipped to the shaft, before a bearing is pressed against it. The Rotor sub-assembly fits over this bearing and a second presses into its other land. These are pre-loaded with the aforementioned nut and Belleville washer. At this point, the thruster shell is aligned and mounted to the main outer shell and finally, the Propeller is left hand screwed onto the Rotor, pressing up against a conical face for alignment.

For a visual aide, see Appendix 1.

3.3 Analysis

Given the nature of some of the changes made, significant analysis was required to prove the system will still perform to specification. Stress analysis was performed for the main components under load: the main outer shell, the rotor shell and the Nylon magnet housing. A vibration analysis was done to calculate the natural frequencies of the 316 Stainless Steel shaft and a mass balance was performed to calculate center of gravity, center of buoyancy and density. The fluid flow problems posed by our assembly have either already been solved in the case of the fins and the propeller, or are too difficult to calculate in the case of the internal rotating components. Validation of those designs will require significant testing in a tow tank.

3.3.1 Stress Analysis

We intend for our new design to dive to 200m where it will sustain approximately 300 PSI of pressure. Figure (14) illustrates results from a pressure analysis where we applied 900 PSI of pressure to the outer surfaces of our thinnest walled main outer shell design. At this 3x Factor of Safety, the hull showed a maximum stress of roughly 137 MPa, half of 6061 Aluminum's yield strength of 275 MPa. This gives a 6x FOS for the outer shell, significantly more than is needed, allowing more material to be removed in the event of poor balancing when integrated into the main submarine assembly.

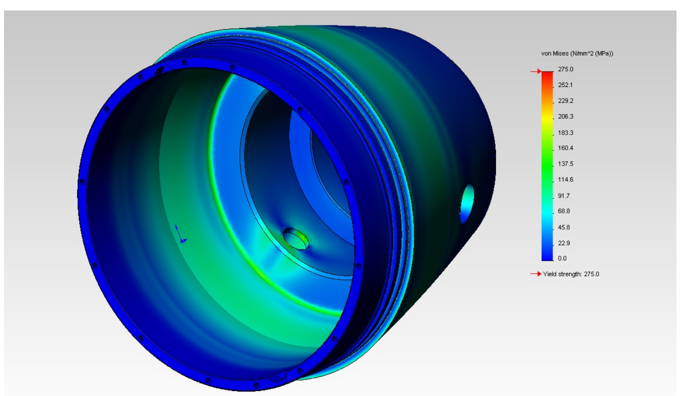


Figure 14: 6061 Aluminum main outer shell pressure analysis with results from 0-275 MPa.

A major concern is the force exerted by the stator on the magnets during operation. It was posed to us that under load the cantilevered magnets could exert enough force to throw the rotor out of concentricity and damage the system. A study was performed on the Nylon magnet housing (Figure 15) assuming 50lbs of force from each magnet on its slot. Results demonstrate a FOS of nearly 3, indicating that the magnet housing will not experience significant deformation under load.

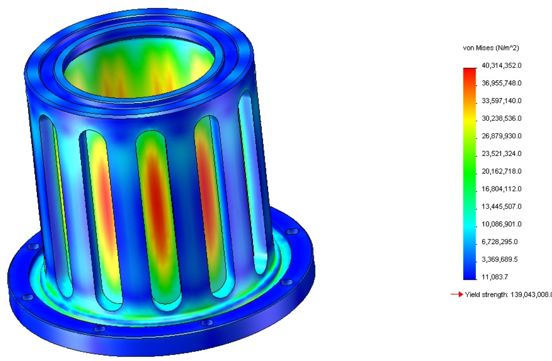


Figure 15: Nylon magnet housing stress analysis with results from 0-40 MPa.

A similar study was performed for the 6061 Aluminum rotor housing (Figure 16), assuming 50lbs of force uniformly distributed along the inside face of the housing. In this case, the FOS was unbelievably large - nearly 500x. However, our first tests will indicate whether or not this simulation was accurate.

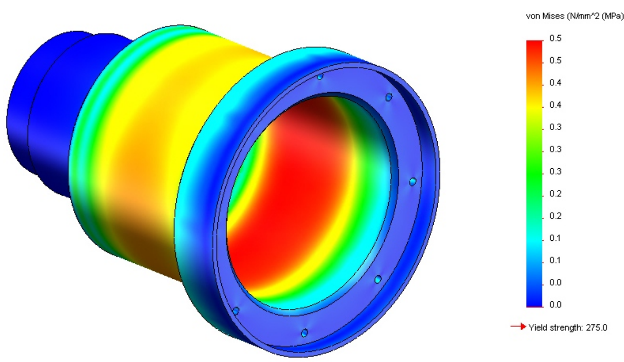


Figure 16: 6061 Aluminum rotor housing stress analysis with results from 0-0.5 MPa

3.3.2 Frequency

The current REMUS 100 assembly utilizes a Grade 2 Titanium shaft for their spinning rotor assembly. This allows them to flush the system manually and still retain the same structural strength. As we are utilizing a different flushing system, our shaft need not utilize titanium for its strength. Instead, we opted to use a less expensive 316 Stainless Steel shaft as its strength does not matter and its natural frequencies are approximately the same. The study results in Figure (17) the Stainless shaft experiencing its first natural frequency at approximately 900Hz, while the Titanium experiences its first at 850Hz. Greater stiffness in the stainless will also allow for less deflection at the first mode.

(a) 316 Stainless Steel Shaft (b) Grade 2 Titanium Shaft

Figure 17: Shaft vibration comparison of two materials

3.3.3 Balance

The tail assembly is radially symmetric in its tri-fin configuration, so there is no need for balance calculations along that axis. However, there is concern that the change in mass and watertight volume will drastically alter the center of gravity (CoG) and the center of buoyancy (CoB) of the REMUS overall.

Calculating the mass and watertight volume gave the overall density, found in Table (3.3.3) and a mass balance across the assembly gave the axial CoG and CoB, found in Figure (18). However, until we get more information from Hydroid about the weight balance in the current REMUS, we will be unable to apply this knowledge in a useful fashion.

Mass	$2.25kg$
Volume	$1900cm^3$
Density	$1.18g/cm^3$

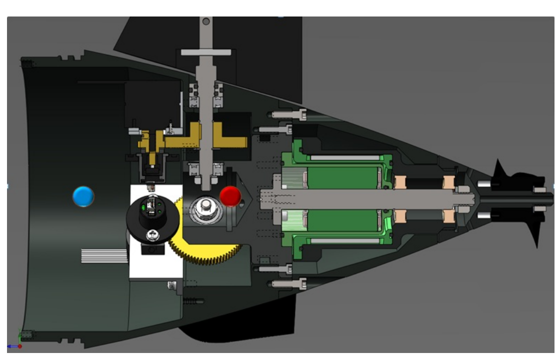


Figure 18: CoB (blue) and CoG (red) for new REMUS 100 tail

4 Electrical System

4.1 Overview

The new electrical system for the REMUS 100 continues the work begun by the ENGR 3260 electrical team with some major design modifications. Currently only partially complete, the electrical system is intended to interface the redesigned tail section with the current REMUS's serial interface, allowing a "plug-and-play" replacement. The majority of the work to date has been focused on fin actuation. An off-the-shelf hobbyist brushless DC motor controller is being used in the interim for main thruster control, but will be replaced with an optimized custom solution in the future.

4.2 Propulsion

The propulsion system is built around a standard Scorpion Motor HKII-2216 kit as mentioned previously. For the moment, it is controlled by an off-the-shelf solution: the Phoenix IceHV 60 Motor Controller, shown in Figure 19, is a 60 Ampere, 50 Volt, PWM controlled, data-logging motor controller designed for use with model helicopters and large airplanes. This motor controller was selected because of its cost, power, ease of use, and its data logging capabilities, allowing us to easily record important performance information in testing. Figure 21 depicts the flow of information to and from the microcontroller at the core of the electronics system.

Since the motor gap in the redesign is larger than the intended gap built into the motor kit (fig 20), it will be less efficient than the original kit. Based on the experiments of the ENGR 3260 Propulsion Team, who found their test motor to be approximately 40% efficient, we will see comparable efficiencies to Hydroid's current design. Testing is critical, however, and will be conducted in the spring.

Once the thruster motor is appropriately characterized, the control system will be replaced with a superior COTS or custom solution tuned to the application.

Figure 19: Phoenix Ice HV 60 Motor Controller

Figure 20: Scorpion motor kit

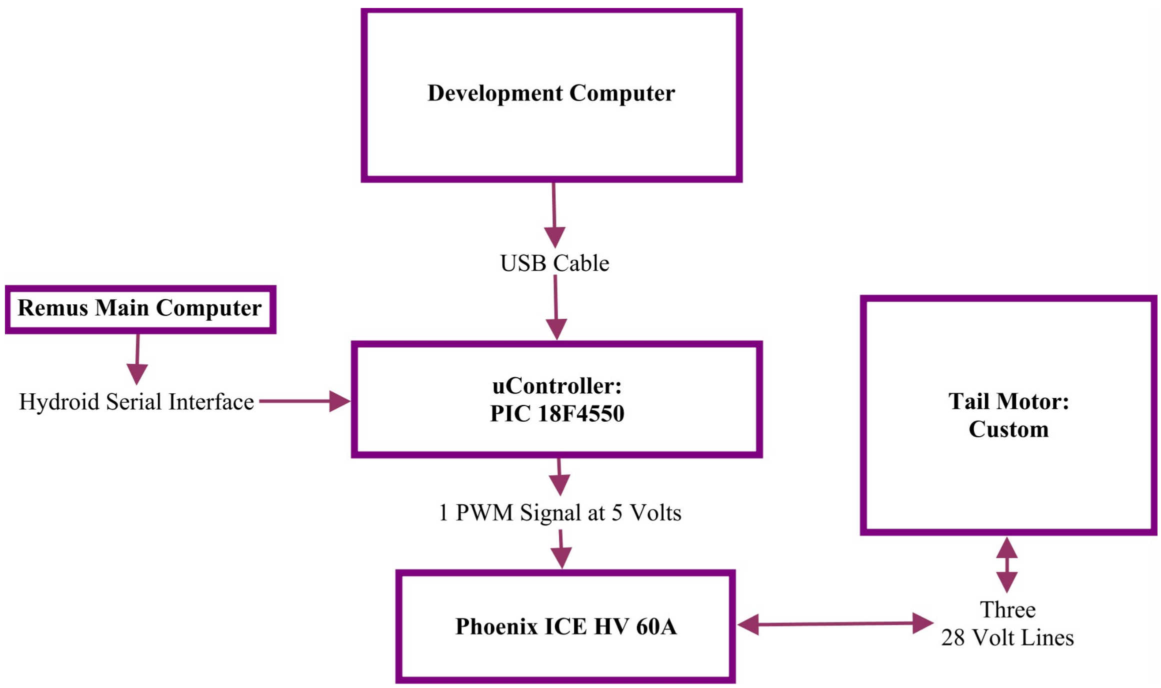


Figure 21: Propulsion overview

4.3 Maneuvering

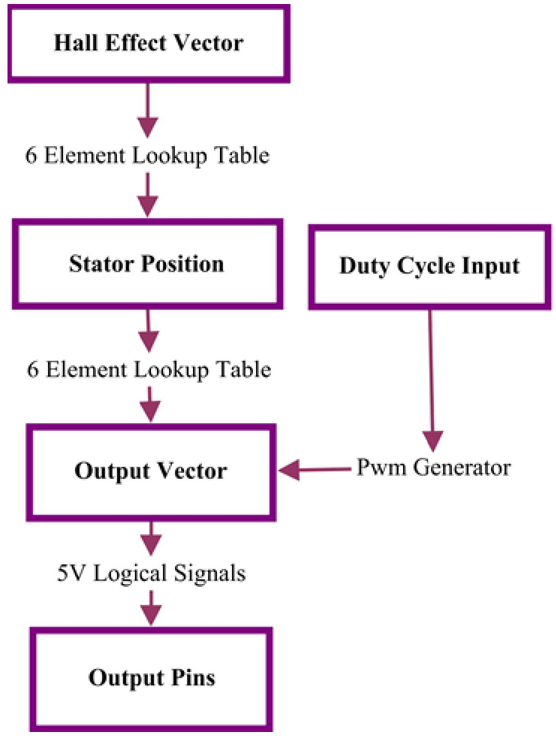


Figure 22: Maneuvering motor control algorithm overview

The goal of the fin motor controllers is to convert commands coming in through a defined serial connection from the main REMUS computers to appropriate fin positioning. To do so, the system must interpret serial commands from Hydroid's defined protocol, read signals from an absolute encoder, and drive the motor. Considering the simplicity of the algorithm used to control brushless motors using hall effect sensors shown in Figure 22, we opted to simply specify an H-bridge driver and control the motors directly using a microcontroller.

The L6226 dual full bridge chip was selected due to its current limit and price. The specific chip is out of production, but newer generations of the chip perserve identical functionality. The chips used by the electrical team are all DIP packaged chips which allow solderless breadboarding, though surface mount chips on a production board would be used in the full design to reduce board area, volume, and weight. Note that the chip requires a charge pump to function, and the full circuit diagram for motor control tests to date can be seen in Figure 24.

At the time of writing, the board is capable of rotating the motor in either direction with varying degrees of force. Efforts are directed toward reading the MAE3 encoder shown in Figure 23 and using this input for a simple PID feedback control compensator. The most current progress has demonstrated that the encoder returns pulses the length of which correlate to rotation.

Ultimately our design is still in prototyping, but we understand that cost is a major concern when designing a production circuit board. A preliminary costing of the electrical system would include: three PIC18f4550 TQFP at $6.68 a piece, three PowerSO L6226s at $7.87 a piece, approximately five dollars of passive components, three MAE3 encoders at $18.04 a piece, and board production for an approximately six square inch area which is $4.20 at `custompcb.com`. All values assume a production run of 34 boards and leaves the cost per board at approximately 107 dollars. However, it is far too early to determine how much the cost could be reduced with the focuesed attention of an experienced senior electrical engineer.

Figure 23: MAE3 absolute magnetic kit encoder

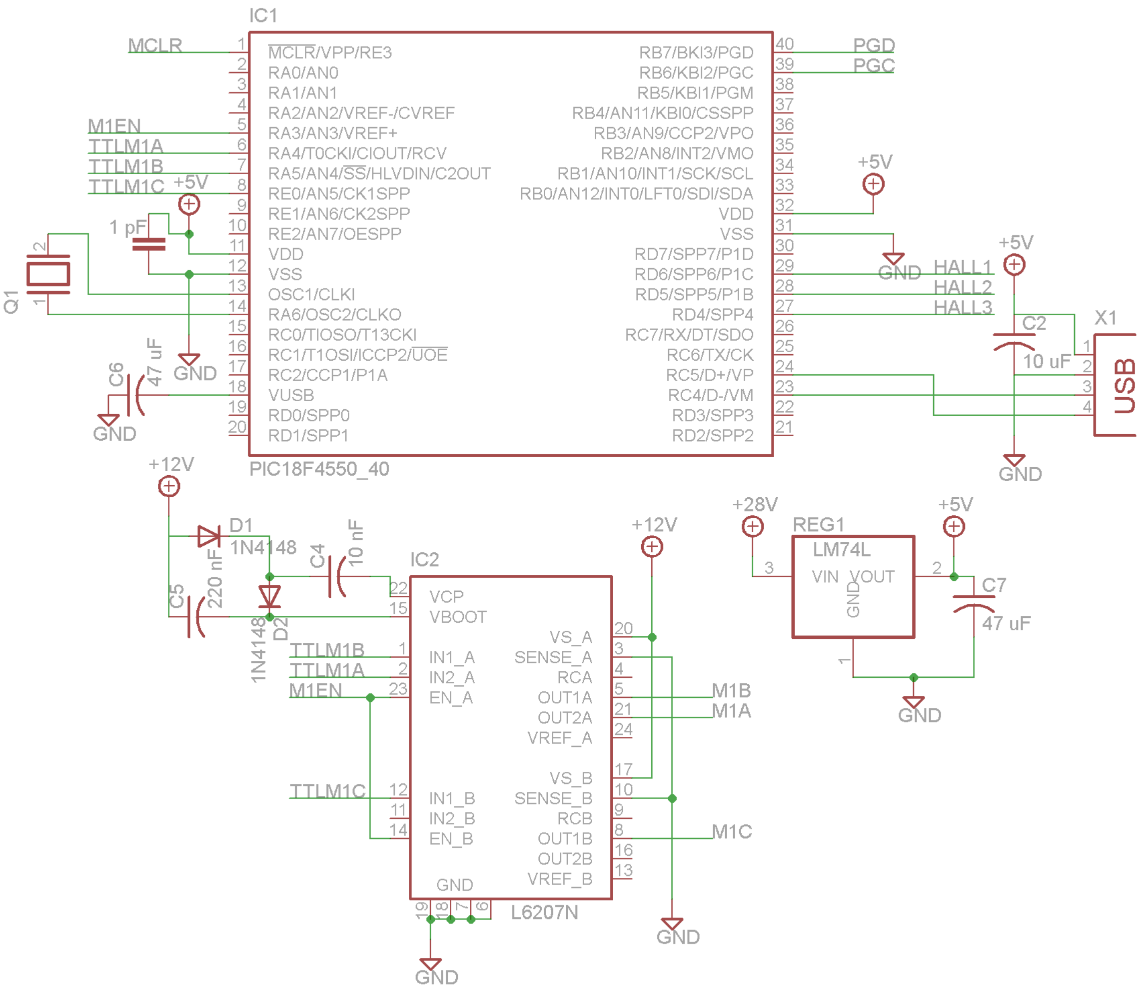


Figure 24: Motor Control Board Schematic

5 Testing

Again on advice from Chris von Alt at Hydroid, we have opted at this time to not pursue a final system assembly. Too many variables are unknown concerning our propulsion system, so putting the time and money into fabricating the entire system only to change it again does not make sense. Instead, we have opted to build a test jig for the aft outrunner for performance evaluations of the Scorpion motor. The material set will be exactly the same and we intend to test our potting techniques on this first assembly as well.

In lieu of constructing a circular test stand, we opted to replace the aft bulkhead with a square block of aluminum, easily mounted in a vise for construction and testing. This block contains all of the same features, allowing us to test the vast majority of our assumptions on the propulsion system. The entire rig can be seen in Figure (25).

This setup is currently being fabricated and will be ready for assembly at the start of next

(a) Test Jig external view

(b) Test Jig cross section

Figure 25: Test rig assembly for the propulsion system

semester.

At the conclusion of this coming round of testing we intend to construct a full assembly and test it in the MIT tow tank. This will allow us to answer questions about flow through in the propulsion section, as well as validate the design of the fin actuation assembly. Further trials after that will involve purchase or loan of a REMUS 100, or development of our own AUV body for autonomous testing.

6 Conclusions

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Appendix

1. Mechanical Drawing Package
2. Faulhaber 2622 Documentation
3. US Digital Encoder Documentation