

Development of a Snorkel for Unmanned Underwater Vehicles

by
Peter Tia

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Mechanical Engineering

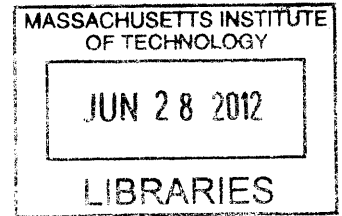
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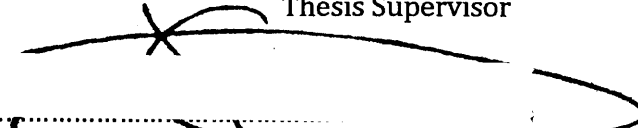


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Abstract

The development of unmanned underwater vehicles (UUV) has provided a bevy of opportunities for the exploration of the ocean. However, one limitation has kept UUVs from truly becoming mass produced, its limited range. The problem with traditional snorkel designs built for submarines is that they are far too large to be effective on a small underwater vehicle. This paper thus explores the design and development of an air snorkel for a hybrid power system for UUVs. The process beginning with concept generation and ending with manufacture will be discussed. Features discussed include the outer shell, float mechanism, and filtration system. The goal is to provide further advancement on snorkel design because through the development of a hybrid power system, UUVs will be able to perform a larger variety of tasks that are limited due to the low energy density of battery powered systems.

Thesis Supervisor: Douglas P. Hart
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Table of Contents

Development of a Snorkel for Unmanned Underwater Vehicles	3
Abstract.....	3
Acknowledgements.....	4
List of Figures	7
1 Introduction	9
1.1 Objective	9
2 System Requirements	9
2.1 Resistance Minimization	10
2.2 Airflow Maximization	10
2.3 Buoyancy Compensation	10
2.4 Vehicle Integration.....	10
3 Concept Generation	11
3.1 U-Tube Snorkel.....	11
3.2 Floating Intake	12
3.3 Dome Intake.....	12
3.4 Tub Fin.....	14
4 Design Considerations.....	14
4.1 Retractable Snorkel vs. Fixed Snorkel	15
4.2 Active vs. Passive System	16
5 Snorkel Design.....	17
5.1 Overall Outer Snorkel Design.....	17
5.2 Outer Snorkel Shell Design.....	18
5.3 Float Mechanism Design.....	19
5.4 Filtration System Design	21
6 Operation Modes	21
6.1 At Surface.....	22
6.2 Preparation to Dive	23
6.3 At Depth	24
6.4 Preparation to Surface	25
7 Snorkel Manufacturing	25

7.1	Molds	26
7.2	Material Selection	26
7.3	Intake Seal.....	26
7.4	Filter Manifold.....	28
7.5	Intake Collar	28
8	Snorkel Testing.....	30
9	Conclusion.....	30
	References	33

List of Figures

- Figure 1:** The U-Tube snorkel was one of the original ideas that led to the development of the current snorkel. The upper bend provided a barrier for water while allowing air in and the bend on the inside of the vehicle allowed water to collect preventing it from entering the engine..... 12
- Figure 2:** This figure illustrates the snorkel in action when a wave passes and submerges the vehicle. The black float device rises and seals the snorkel from the intake of water. The brown cap of the snorkel provides protection against free surface effects of the sea..... 13
- Figure 3:** This figure illustrates the snorkel in during a relatively stable sea state. The black float device floats on the surface of the water allowing air to enter the snorkel..... 13
- Figure 4:** The tub fin is a modification of the original u-tube snorkel that eliminates the lower bend in favor of a reservoir..... 14
- Figure 5:** The baffles provide a defense against free surface effects. Air is allowed to enter the snorkel while water will enter and exit through an orifice at the bottom of the outer snorkel (not shown in figure). The float mechanism provides another passive prevention system that keeps water from entering the system too quickly when the vehicle is temporarily overcome by a wave or other free surface effects. The filter system provides protection for the pumping system by removing particles that are too large to flow through the system. A parallel system was developed in order to minimize clogging of the system.17
- Figure 6:** The FEA shows that the snorkel shell can withstand a constant force of 1000N achieving a maximum stress of 23MPa compared to a yield stress of 48MPa of fiberglass. 19
- Figure 7:** The stress on the intake seal can be seen in this figure..... 20
- Figure 8:** The stress at the bottom of the intake seal is shown in this figure for when the float is pushed up by the water. 20
- Figure 9:** The snorkeling system of the Remus consists of two main parts, an outer snorkel that interacts with the environment and an inner plenum that acts as a safety when water bypasses the outer snorkel. Air enters through the intake and flows to the engine while water collects in the plenum and is then pumped out. 22
- Figure 10:** When a wave is encountered the outer snorkel will become completely submerged, however before being completely submerged a float mechanism will seal off the intake pipe, preventing large amounts of water from entering the system. 23
- Figure 11:** In preparation for diving, the Remus must become as neutrally buoyant as possible. This will allow the Remus to use a minimum of power to travel. To achieve this effect, the pump will send water in the reverse direction, thus pump water from the sea into the plenum..... 24
- Figure 12:** When the Remus is completely submerged, the entire plenum is filled with water to remain close to neutral buoyancy and the outer snorkel is filled with water to prevent damage due to high pressures at depth. All high pressure valves are closed, so that

the high pressure valves and the structural frame of the Remus are enduring the high pressures at depth. 25

Figure 13: The intake seal being CNC machined. 27

Figure 14: The completed intake seal..... 27

1 Introduction

The development of unmanned underwater vehicles (UUV) has provided a bevy of opportunities for the exploration of the ocean. However, one limitation has kept UUVs from truly becoming mass produced, its limited range. This range limits the types of activities that may be accomplished with a UUV, which leads to the use of manned vehicles. If the endurance of a UUV could be lengthened by a substantial amount then it would be possible to perform activities that would require manpower but would be dangerous. Not only would underwater vehicles be able to perform a larger variety of tasks, but they would also be much less expensive. The need to pay for wages for men on board as well as food and any ancillaries to support a crew is eliminated.

1.1 Objective

The goal of the Engineering Systems Design class was to develop a power system that would replace the current power system in the Remus 600 underwater vehicle. In order to achieve this goal, the students of 2.013 spent the Fall semester designing a novel power system with guidance from MIT Lincoln Lab. Throughout the design process constant communication was needed between the groups working on the different aspects of the power system; one aspect being the snorkel system. The objective of this thesis is to detail the design and development of a snorkel that will provide the interaction between an underwater vehicle and the environment. Specifically this paper focuses on the development of specifications, brainstorming of ideas, and selection methodology. After the initial concept was chosen, further analysis on hydrodynamic behavior was performed as well as finite element analysis to optimize the system.

2 System Requirements

The first step of any design process is to develop the requirements for the product, thus the system requirements must be examined in depth and chosen before any good design can be developed. To develop these requirements, the needs of the snorkel were analyzed along with the operating environment of the snorkel. The snorkel is the main interface between the Remus 600 and the environment, thus it must be able to operate in both sea and air. Its main functions are to take in air for the engine and buoyancy system and water for the buoyancy system and cooling system. The snorkel must withstand the conditions at 300m below the surface of the water, minimize resistance during travel, and minimize overall changes to the dynamics of the current Remus, such as changes in buoyancy or

maneuverability. This was accomplished through streamlined design and weight minimization.

In order to be a successful snorkel, the geometry of the system must not restrict flow so much that the engine is not able to intake a sufficient amount of air. The engine requires two liters of flow per second for peak operation. This requirement dictated the sizing of the pipes within the snorkel system. In order to prevent water damage to the engine the snorkel needed to prevent water from entering the engine intake while allowing a high flow of air.

2.1 Resistance Minimization

In order for the benefits of the hybrid power system to be substantial, the snorkel must not create resistance during operation the vehicle that would offset the benefits gained from the hybrid power system. The power loss due to the resistance from the snorkel was compared to the energy gained from the power system to ensure the power system met the endurance goal of the Remus which was to be able to operate at sea for a month without needing human intervention.

2.2 Airflow Maximization

The main system requirement for the snorkel is to provide air to the engine. Thus the engine can only operate at a certain head loss before flow is completely halted and the engine becomes choked. The pressure was experimentally determined to be approximately 2 psi. This requirement set the goal for head loss throughout the entire snorkel system.

2.3 Buoyancy Compensation

The entire vehicle must maintain a slightly positive buoyancy of approximately 1% when underwater. This ensures that energy is not wasted in trying to maintain the altitude of the vehicle underwater. The snorkel system therefore must not alter this positive buoyancy. The center of buoyancy of the system is also 1-2 inches above the center of mass of the vehicle to maintain maneuverability, thus the snorkel must maintain this relationship as well.

2.4 Vehicle Integration

The key aspect of the project that was needed throughout development was constant communication between the various groups working on the power system. This was essential in creating a product that was able to integrate properly with other systems. In order to accomplish this aspect, teams were required to present on progress every week to both show progress of each system, but mainly to ensure that the each subsystem was informed about the other subsystems. This communication led to both new innovations and to standards set forth for integration.

Thus the system requirements of the snorkel can be summarized as follows. The snorkel must be able to provide an amount of air that is devoid of moisture such that the engine is able to operate efficiently. The snorkel must not significantly alter the dynamics of the underwater vehicle such that the vehicle becomes difficult to maneuver. The snorkel must be able to maintain the constant buoyancy of the system at depth while providing enough buoyancy to the vehicle during operation.

3 Concept Generation

Once the needs of the system were defined, concepts were generated to visualize the possibilities of developing an active or passive system. Each member of the snorkel team was responsible for the generation of as many concepts possible. These concepts were developed using information from patents, existing products, as well as from personal experience.

3.1 U-Tube Snorkel

The U-Tube design was considered to prevent free surface effects of the water from entering the system. The lower bend was meant as a reservoir for water that would be pumped out. Potential problems with this design are the filling of the tube in the chance that the snorkel becomes submerged. The filled tube would prevent any flow of air into the engine unless the water was pumped out quickly enough so as to prevent a stoppage of flow.

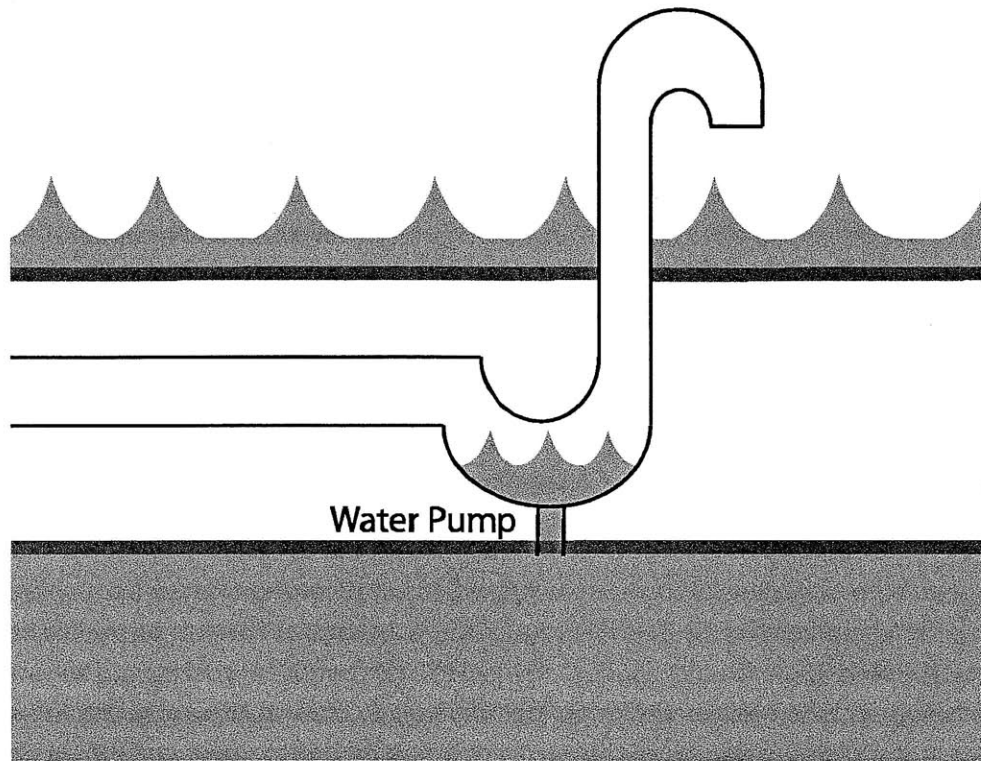


Figure 1: The U-Tube snorkel was one of the original ideas that led to the development of the current snorkel. The upper bend provided a barrier for water while allowing air in and the bend on the inside of the vehicle allowed water to collect preventing it from entering the engine.

3.2 Floating Intake

The next design that was considered was a system with a floating intake. This floating intake would eliminate the problem of the snorkel becoming submerged and taking in water because the buoyancy of the snorkel system would keep it afloat. One of the main problems with this design concept was the storage of the intake when not in use as well as the complication of having a snorkel that was not fixed to the vehicle.

3.3 Dome Intake

The dome intake was another consideration, which included a round dome above the intake pipe which would prevent splashing. In addition to preventing splashing from entering the vehicle, the dome intake was developed with the intent of preventing large amounts of water from entering the snorkel when a wave submerged the vehicle.

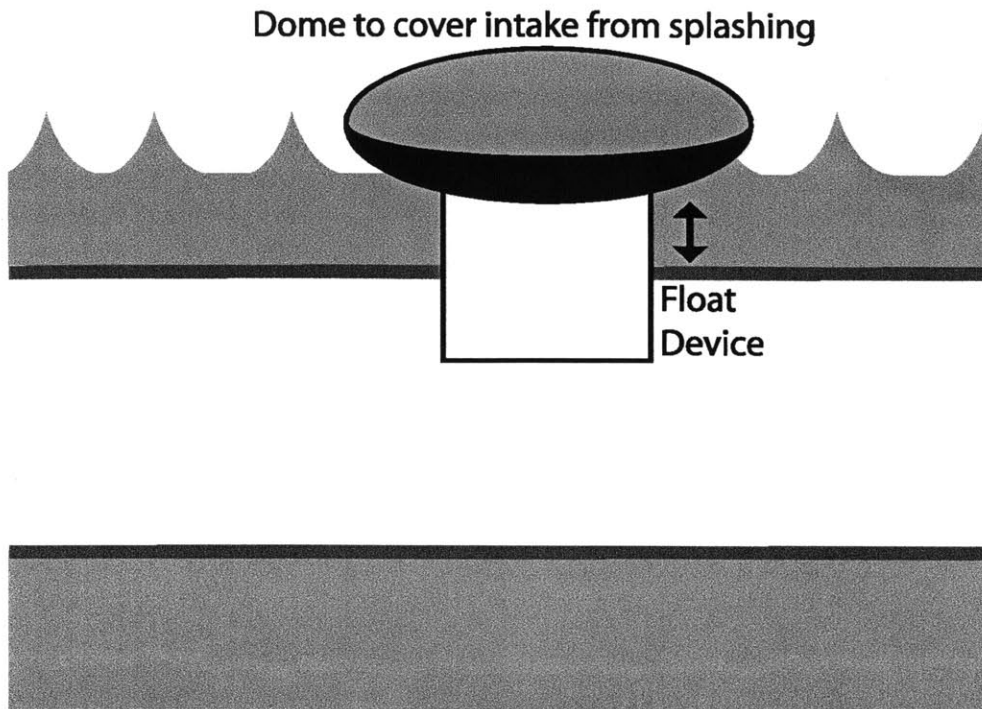


Figure 2: This figure illustrates the snorkel in action when a wave passes and submerges the vehicle. The black float device rises and seals the snorkel from the intake of water. The brown cap of the snorkel provides protection against free surface effects of the sea.

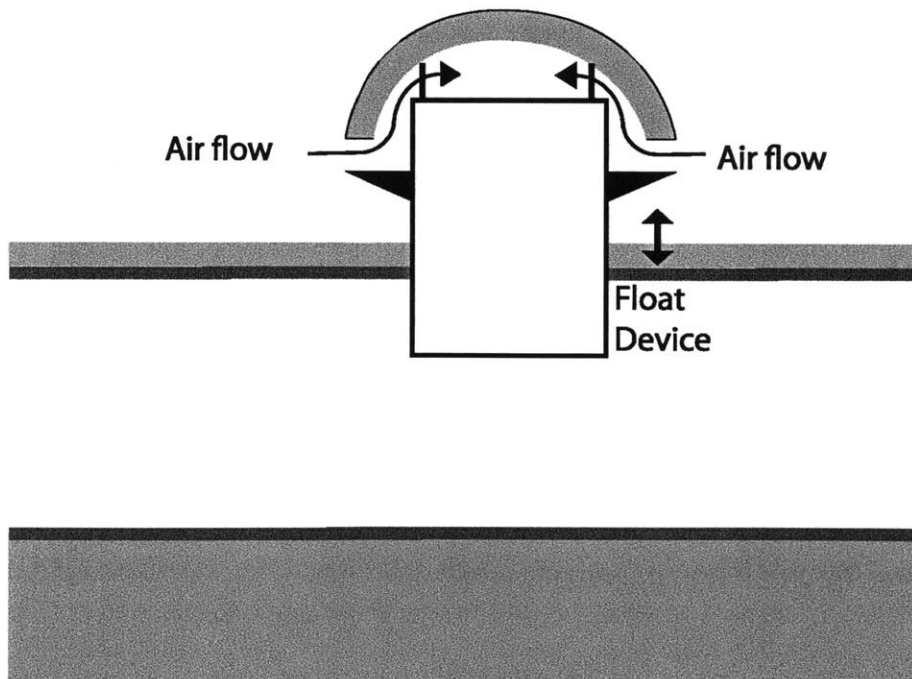


Figure 3: This figure illustrates the snorkel in during a relatively stable sea state. The black float device floats on the surface of the water allowing air to enter the snorkel.

A problem with the dome intake that prevented it from being further developed was developing a sealing mechanism between the intake and the float device so that the float would not be hindered by friction. This sealing mechanism also meant that the pipe would need to withstand high pressures if the seal were to completely limit the flow of water into the system.

3.4 Tub Fin

The tub fin was a modification to the original U-Tube snorkel. By eliminating the lower bend and instead replacing it with a reservoir, the chance of water preventing air from flowing into the system is minimized. Figure 4

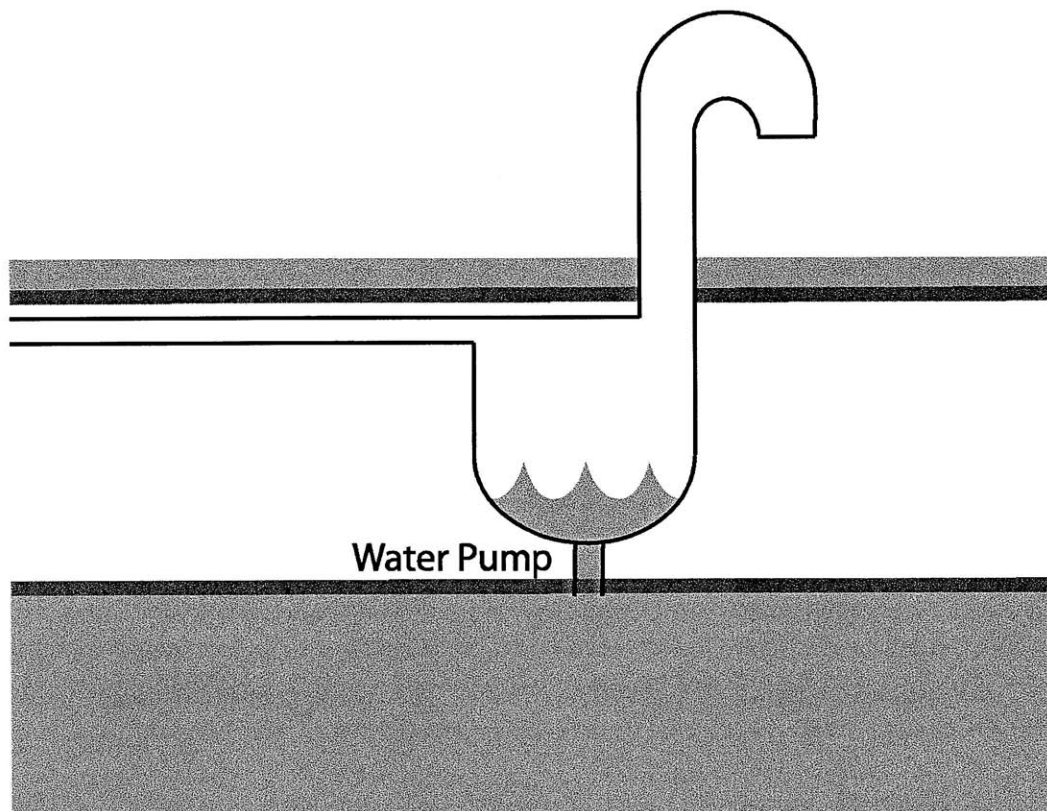


Figure 4: The tub fin is a modification of the original u-tube snorkel that eliminates the lower bend in favor of a reservoir.

4 Design Considerations

With the system requirements developed and some concepts to compare, the next step was to determine how to optimize the system and ensure it would be able to accomplish the goals set forth. The two main decisions for the design were having a fixed snorkel or a

retractable snorkel and deciding between a passive or active snorkel system. Each of these designs had their own costs and benefits which were weighed while concepts were being developed.

4.1 Retractable Snorkel vs. Fixed Snorkel

The retractable snorkel idea had many favorable features which were weighed with the risks associated with a retractable snorkel. Some of the benefits included the possibility of a snorkel that would allow the Remus 600 to maintain most of the dynamic properties, if the snorkel could be concealed properly. The retractable snorkel also eliminated a potential structure outside the vehicle that could add to the chances of the vehicle being hit by ships or being caught on a feature of the underwater landscape.

The disadvantages of the retractable snorkel include the added risk of moving parts, the changing buoyancy during the rise of the snorkel, and the size of the entire system. Considering the size of the Remus 600 vehicle, being able to conceal an entire snorkel within the vehicle would dramatically alter the entire weight of the system. This would prevent the vehicle from being neutrally buoyant in the allotted volume. The surfacing of the snorkel also raised concerns for the buoyancy of the system because of the portion that would rise out of water. Currently the Remus 600 is neutrally buoyant and having a mass rise outside of the water could cause the vehicle to sink back into the water. However, the main concern with the retractable snorkel was the reliability of the system. With a retractable snorkel, special care must be taken in designing the joints and interactions. Because the system will be operating in a sea environment, a large concern was the biomass, such as seaweed or animals, which could cause the snorkel to malfunction. Any jamming of the system would cause the end of the mission, thus offsetting the benefits of extended range of the hybrid power system.

The fixed snorkel offered many favorable features that the retractable snorkel was not able to offer. The fixed snorkel was much simpler in that it would not need moving parts to operate, thus failure due to biomass getting caught in a critical location was eliminated. Also because the fixed snorkel did not have as many parts, it would not affect the weight of the Remus 600 as much as the retractable snorkel.

The concerns with the fixed snorkel include the drag caused from having a structure increasing the surface area of the vehicle, the possibility of the snorkel being damaged by ships or the underwater landscape, and the buoyancy change due to surfacing. Further analysis was performed on a fixed snorkel that showed the extra drag due to a fixed snorkel was negligible compared to the payload of the electronic systems within the Remus. The next concern of the snorkel being damaged by the environment was accounted for so that the snorkel could be damaged as long as the structural integrity of the Remus was not

compromised. Since the buoyancy change due to surfacing was prevalent in both cases, it was not a deciding factor in the decision to choose a fixed or retractable snorkel.

Through the analysis of each system, the conclusion was made that the fixed snorkel proved to be a safer solution that would also be simpler to implement. The possibility of the retractable snorkel failing and compromising the entire mission was a risk much too large that the benefits did not outweigh. Thus the process proceeded to deciding between an active or a passive snorkel system.

4.2 Active vs. Passive System

The next important design decision revolved around choosing an active or passive snorkel system or a combination of both. Each system had its own strengths and flaws. The passive snorkel was ideal because of the nature of the project. Since the goal of the power system was to increase the range of the Remus 600, the passive system seemed optimal since no power would be required to operate. If designed properly, the snorkel would passively protect the main body of the vehicle from water while allowing air into the system. Being passive meant energy from the power system would be freed up for the other components of the vehicle.

One flaw with a passive system is it is much less reliable than an active system with sensors. It is difficult to trust a passive system that contains no feedback and since the system is passive, it is not possible to control the system even with feedback. Without sensors to monitor the conditions within the snorkel, it is much harder to determine the cause of failure in the occurrence of one.

The failures of the passive snorkel are not present with the active snorkel. However, the active snorkel requires power which decreases the duration that the underwater vehicle is allowed to stay out without needing human intervention.

With these facts considered, and the fact that reliability is of utmost importance, a snorkel that utilizes both passive and active elements was developed. The passive element provides a first line of defense against the factors of the environment such as free surface movements of water as well as initial biomaterial. The active system is meant to operate in series with the passive system to provide a redundant line of defense against too much water entering the system.

5 Snorkel Design

The final design of the outer snorkel was developed by combining and improving the concepts generated after brainstorming. The overall design of the outer snorkel consisted of designing the shape of the snorkel, the baffle placement, and the intake seal design.

5.1 Overall Outer Snorkel Design

The final design of the outer snorkel consisted of a passive baffle system and float system, while also utilizing a low power active solenoid valve system. The passive system will be the main focus in this paper; brief mentioning of the other subsystems will be mentioned to help understand the operation of the vehicle. Below in Figure 5 is an image illustrating the entire outer snorkel system including, baffles, float mechanism, and filtration system.

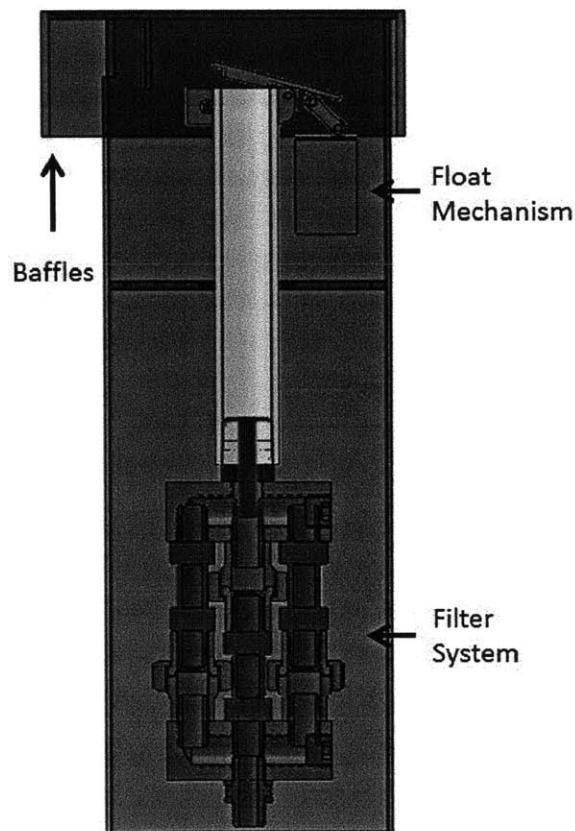


Figure 5: The baffles provide a defense against free surface effects. Air is allowed to enter the snorkel while water will enter and exit through an orifice at the bottom of the outer snorkel (not shown in figure). The float mechanism provides another passive prevention system that keeps water from entering the system too quickly when the vehicle is temporarily overcome by a wave or other free surface effects. The filter system provides protection for the pumping system by removing particles that are too large to flow through the system. A parallel system was developed in order to minimize clogging of the system.

5.2 Outer Snorkel Shell Design

In order to minimize the drag of the snorkel, calculations determined that having at least a ratio of 3:1 for the major to minor axis of the outer snorkel would not provide a significant amount of drag to the system. Currently a fin with GPS is located at the top of the Remus that is of approximately the same width of the snorkel. Therefore, the new snorkel should be in line with this fin so as to reduce the amount of drag. The outer cover of the snorkel was designed such that manufacturing of the entire shell would be simpler than having a solid outer snorkel.

The material of the snorkel will be fiberglass. This was decided because a lightweight and non-corrosive material was desired for the outer snorkel. Given that the product will not be mass produced, the labor costs of fabricating the shell were a secondary factor to the reliability of the system.

The thickness of the snorkel was chosen in order to minimize weight of the vehicle while maintaining structural integrity. To determine the structural integrity of the system a static force analysis was used to examine stress and deflection of the snorkel. A static force of 1000N was used to examine stress. This force was chosen as an estimate for a person who accidentally tries to lift part of the Remus by the snorkel. From the finite element analysis Figure 6 shows a maximum stress of 23MPa in the shell. This gives the snorkel a factor of safety of 2 before the outer shell will break off. It is also important to note that the snorkel must not hurt the structural integrity of the vehicle if it collides with an object, thus it must break off and not cause a large amount of stress on the Remus hull.

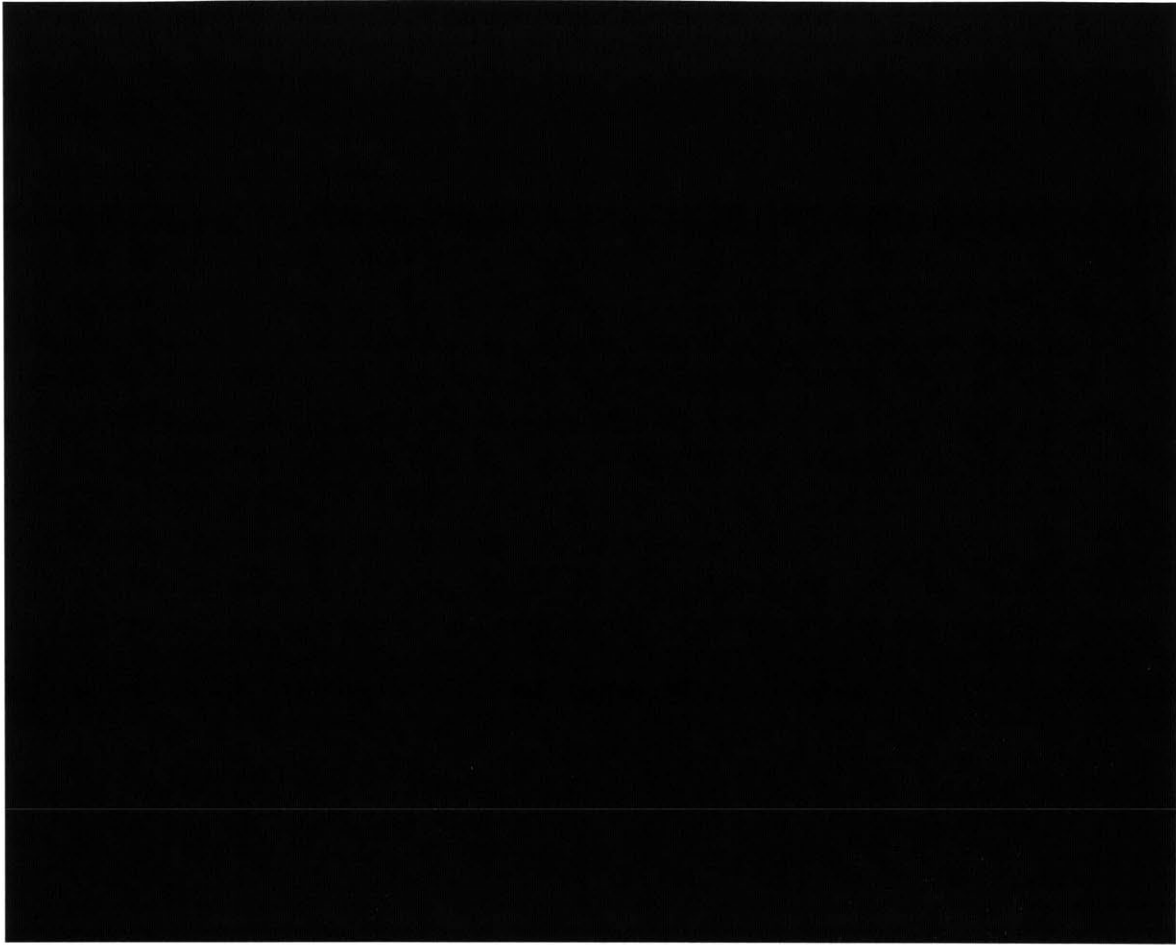


Figure 6: The FEA shows that the snorkel shell can withstand a constant force of 1000N achieving a maximum stress of 23MPa compared to a yield stress of 48MPa of fiberglass.

5.3 Float Mechanism Design

The next critical part of the outer snorkel was the float mechanism developed for the passive system. In order to properly function, the float must be able to quickly rise when a wave overcomes the snorkel so that water does not fill the tank within the vehicle. One problem with developing this system, was the balance of creating a system that was lightweight, but could withstand being at the operating depth of 300 meters. In order to solve this problem, the intake seal, which closes off water from entering the vehicle is purposely created with a loose seal. This loose seal means that water is able to enter the vehicle at a slow rate, however the pump system will be able to empty the water before the inner snorkel is full. This loose seal also serves another purpose, which is to prevent a vacuum from being drawn when the seal closes due to water rising.

The intake seal was designed to be lightweight and able to withstand the force due to the float rising because of water. Below is a figure showing the FEA for a force of 10N being applied on the seal upwards.

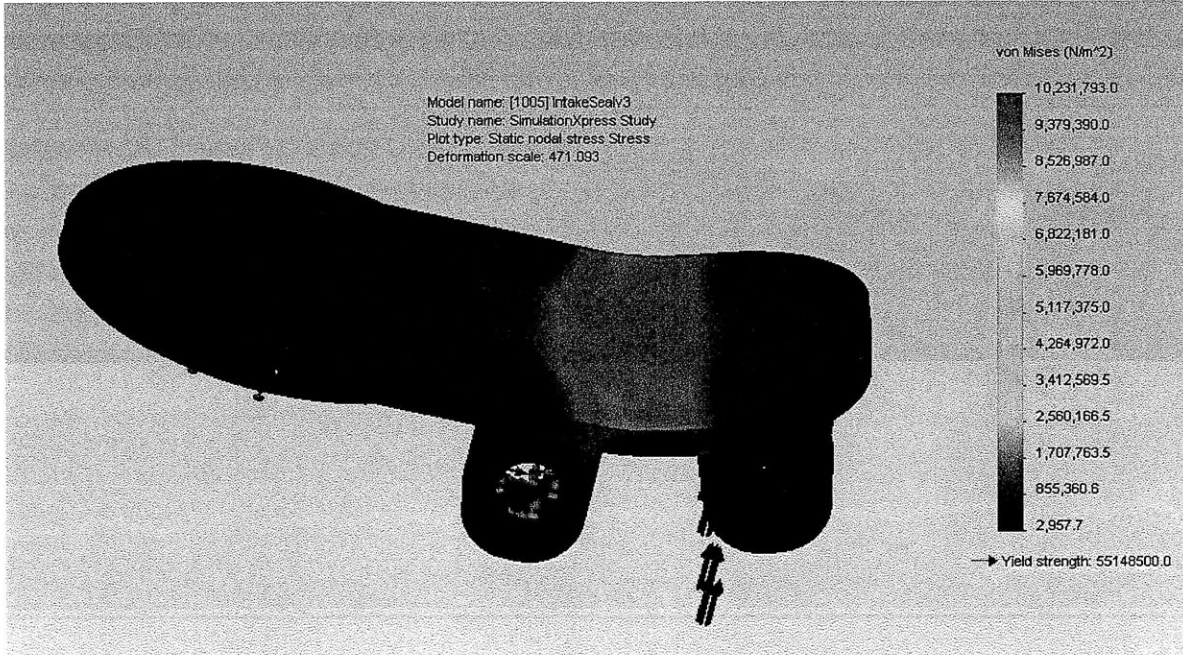


Figure 7: The stress on the top of the intake seal is shown in this figure.

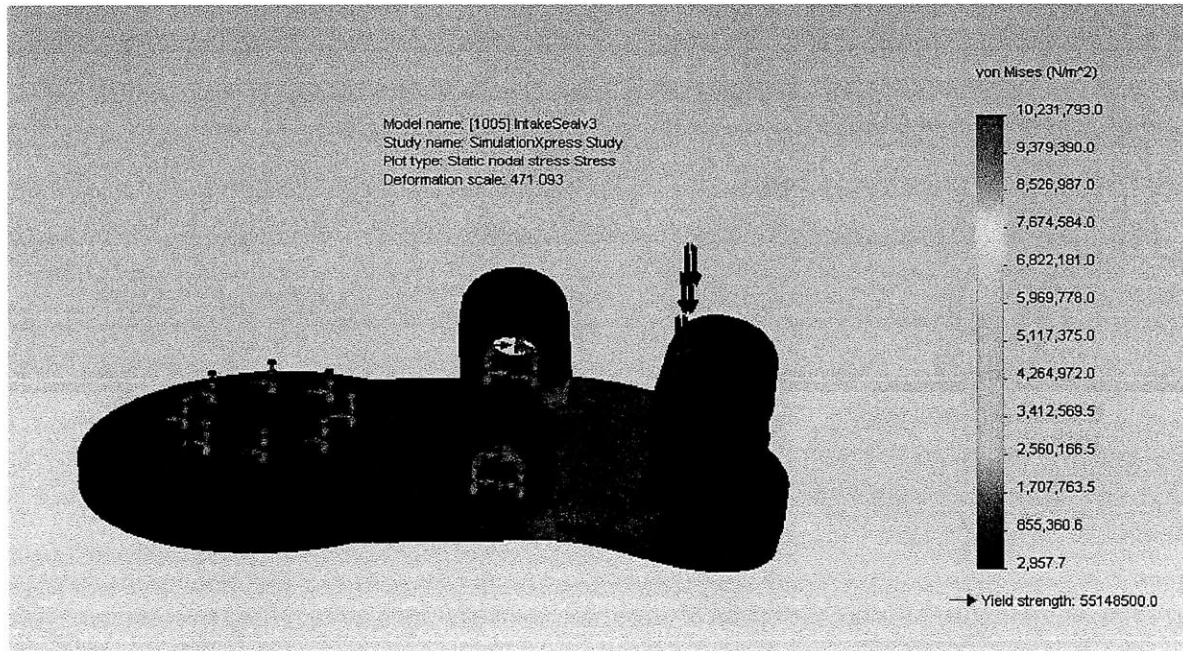


Figure 8: The stress at the bottom of the intake seal is shown in this figure for when the float is pushed up by the water.

5.4 Filtration System Design

The filtration system was developed in order to prevent biomaterial from clogging the pumping system of the inner snorkel which is meant to control buoyancy and cooling of the vehicle. The parallel filtration system was chosen to minimize risk of clogging individual filters and jeopardizing the entire vehicle. A 440 micron filter was chosen to allow saltwater and small biomass to enter the system and not interfere with the pump system. The head loss of the chosen components was calculated to make sure the pressure loss was not too high. The following equation for total head loss was used,

$$h_{l,total} = h_{l,major} + \sum_i^N h_{l,minor} \quad (1)$$

The major and minor head loss equations used were,

$$h_{l,major} = f \left(\frac{L}{D} \right) \left(\frac{v_{ave}^2}{2} \right) \quad (2)$$

and,

$$(h_{l,minor})_i = K_i \left(\frac{v_{ave}^2}{2} \right) \quad (3)$$

where f is the friction factor and K is the specific head loss coefficient for each component. For laminar flow the friction factor is defined as

$$f = \left(\frac{64}{Re} \right) \quad (4)$$

where Re is the Reynolds number. For turbulent flow the friction factor is defined as

$$f = (.790 \ln Re - 1.64)^{-2} \quad (5)$$

Combined these equations provided the basis for the pressure loss analysis to determine whether the snorkel system allowed a sufficient amount of airflow to the engine[3].

6 Operation Modes

The snorkel consists of two main components: an outer snorkel that interacts with the environment and an inner snorkel that ensures the proper operating conditions. The inner snorkel has two main functions, it acts as a reservoir for air when a wave temporarily submerges the vehicle, and it provides buoyancy during the snorkeling of air. The snorkel has four operating conditions: snorkeling air at the surface, encountering a wave,

submerged operation, and preparing to surface. Below are figures that summarize the operation of the snorkel and the various components.

6.1 At Surface

Figure 9 illustrates snorkeling air at the surface.

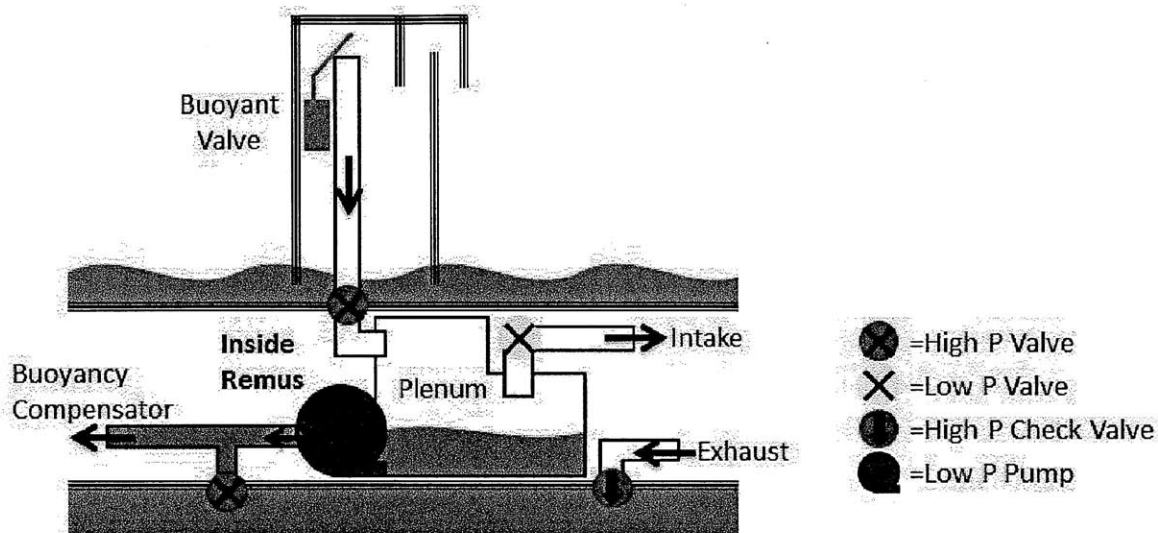


Figure 9: The snorkeling system of the Remus consists of two main parts, an outer snorkel that interacts with the environment and an inner plenum that acts as a safety when water bypasses the outer snorkel. Air enters through the intake and flows to the engine while water collects in the plenum and is then pumped out.

The outer snorkel mainly acts as a passive stop and prevents large amounts of water from entering the Remus. At surface, the engine intakes air through the snorkeling system as it prevents water from entering the intake of the engine. A series of baffles prevents free surface effects of water from entering the pipe leading to the Remus. However, this float mechanism only creates a loose seal that prevents most water from entering. A plenum collects the small amount of water that bypasses the baffle system and buoyant valve, thus preventing the water from adversely affecting the engine. While the plenum is collecting water, a pump either propels the water into the environment or brings water to the buoyancy system, depending on need.

When the vehicle descends or free surface effects submerge the vehicle, the junction between the snorkel and the Remus will have openings in the outer snorkel that allow water to flow out from the snorkel when the UUV resurfaces.

Figure 10 depicts buoyant valve mechanism rising to close the intake valve when a wave is encountered, and sufficient amounts of water flood the outer snorkel. This valve mechanism prevents large amounts of water from entering the Remus. If needed, the engine will continue running off the air in the plenum and the pump will remove any water from the plenum.

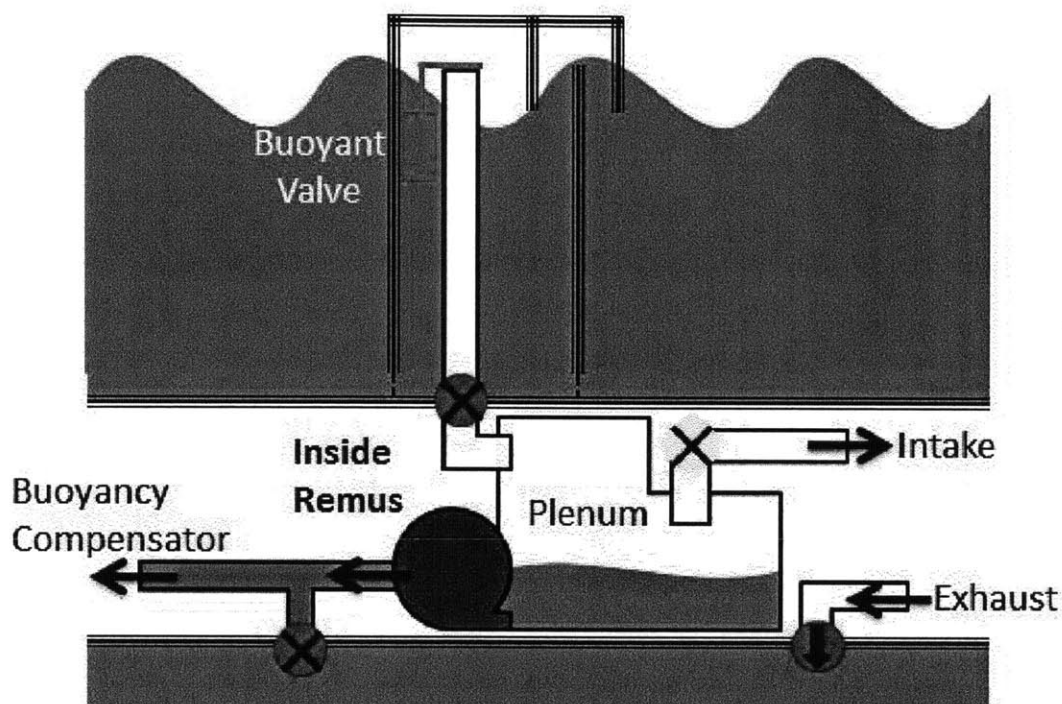


Figure 10: When a wave is encountered the outer snorkel will become completely submerged, however before being completely submerged a float mechanism will seal off the intake pipe, preventing large amounts of water from entering the system.

6.2 Preparation to Dive

When the Remus detects that the batteries are fully charged, the engine shuts off and it prepares to descend. Because the plenum provides a large amount of buoyancy force when filled with air, it fills with water to offset this force. As seen in Figure 11 the pump sends water in the reverse direction, thus filling the plenum with water. This allows the Remus to maintain its neutral buoyancy at depth while becoming positively buoyant at surface. This also prevents the need for power to overcome the extra buoyant force provided from the plenum. As the water level rises in the plenum, sensors will detect the water level and close the valve that allows flow into the engine. Once the plenum is completely filled with water

the high pressure valves at the top and bottom of the Remus are closed. This prevents any flow into or out of the Remus.

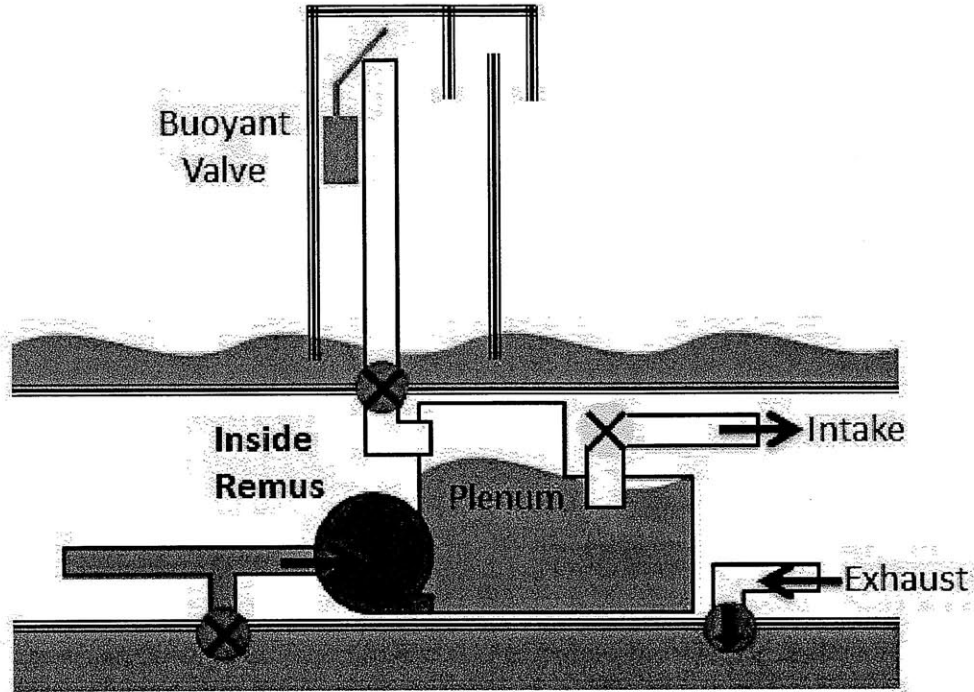


Figure 11: In preparation for diving, the Remus must become as neutrally buoyant as possible. This will allow the Remus to use a minimum of power to travel. To achieve this effect, the pump will send water in the reverse direction, thus pump water from the sea into the plenum.

6.3 At Depth

During descent, the choice of a loose (“sloppy”) seal becomes clear. The sloppy seal was chosen to allow the intake that is outside the Remus to completely flood when submerged. This prevents the intake from needing to be a pressure vessel. The walls of the intake are thus thinner and lighter which is in line with the goal of a light snorkeling system that will not substantially affect the dynamics of the Remus. As the Remus slowly descends, water will enter the pipe. As seen in Figure 12, when the vehicle is completely submerged, the entire section of the Remus that interacts with the atmosphere is flooded. This flooding allows the Remus to maintain its neutral buoyancy at depth while becoming positively buoyant at surface.

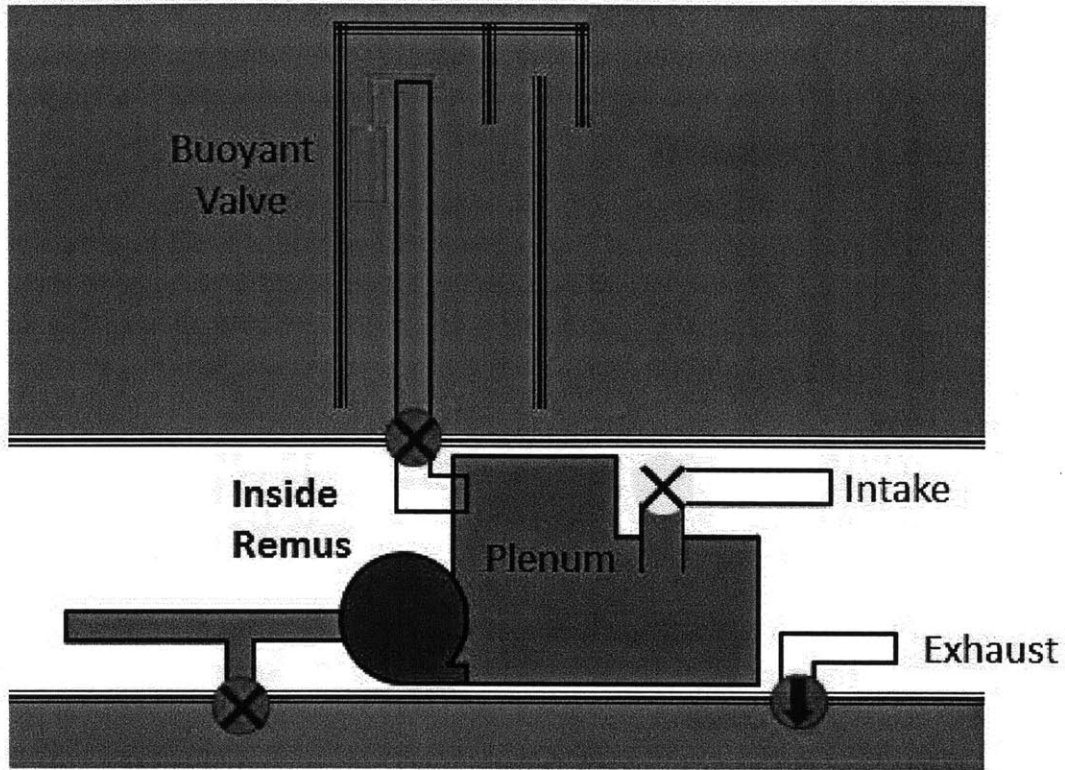


Figure 12: When the Remus is completely submerged, the entire plenum is filled with water to remain close to neutral buoyancy and the outer snorkel is filled with water to prevent damage due to high pressures at depth. All high pressure valves are closed, so that the high pressure valves and the structural frame of the Remus are enduring the high pressures at depth.

6.4 Preparation to Surface

Once the Remus is ready to charge again, the Remus will rise toward the surface. At the surface, water will leave the outer snorkel from the opening at the bottom of the snorkel and water will be pumped out of the plenum. After all water is removed, the intake valves are open and charging may convene. The cycle continues until the duration of the mission is complete or the Remus returns to base for other reasons.

7 Snorkel Manufacturing

During the spring 2012 semester much work was done on the system to ensure that it will be very easy to manufacture for future use. In this period the system was also fabricated and assembled.

7.1 Molds

For fiberglass construction of the outer snorkel, male molds were created with foam. A template of plastic in the shape of the snorkel was cut via a water jet machine and then foam was carved with hot wire using the template. Fiberglass was laid up onto the male mold and cured.

The intake collar was machine out of 6061 aluminum billet. In order to reduce the number of pieces a couple of components were combined to create a more complex part. This piece required extensive redesign because of the size of the original part. The small size made it difficult to machine because the clamping forces and milling forces would deform the piece. In order to protect against corrosion due to seawater, the part will be anodized.

One component that was replaced after analysis for manufacturing was the hinge pin of the float mechanism. The hinge pins required two different precise parts to be created that would be relatively difficult to machine, therefore sex bolts were used as replacements. These bolts mated with normal screws provided an easy to assemble part that was also easily purchased.

7.2 Material Selection

The material chosen for the majority of the snorkel subsystem is composed mainly of Aluminum 6061. Aluminum 6061 was chosen because of its corrosion resistant behavior as well as its machinability. The protective oxide layer on aluminum protects it from the environment. However, one concern with using aluminum is the possibility of galvanic corrosion. This can be eliminated with the use of a material that acts as a sacrificial anode, thus strengthening the aluminum during the galvanic reaction [1].

7.3 Intake Seal

The most complicated part to machine was the intake seal given availability of machines. When designing the seal, forces that were initially neglected include the force on the seal due to machining, thus minor modifications were needed to properly secure the part to be machined. Most of these modifications involved making the features on the seal thicker to prevent deformation. The piece was machined with tabs to keep the piece in place and with extra material to provide rigidity within the vice.

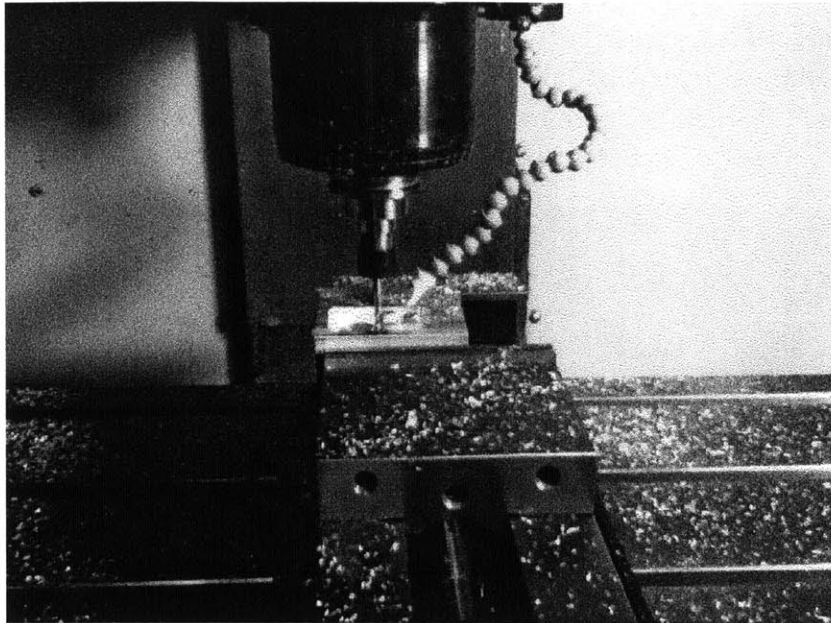


Figure 13: The intake seal being CNC machined.

After machining the profile and tabs, the part needed to be finished off using a manual mill to drill the holes for the tabs. In the original design the tabs were designed to be completely round however a flat surface was used to allow clamping for the process of machining the holes within the tab.

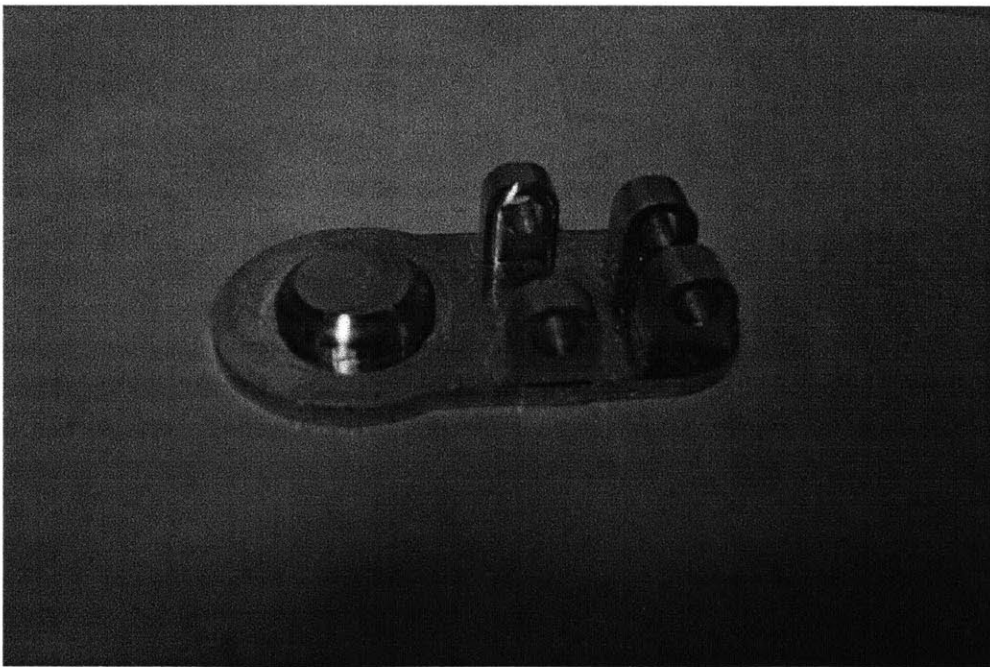


Figure 14: The completed intake seal.

7.4 Filter Manifold

The filter manifolds were essential to connect the filters to the intake and connect the filters to the inner snorkel. The outline of the filter manifold was water jet and then machined manually to obtain the other features of the manifold.

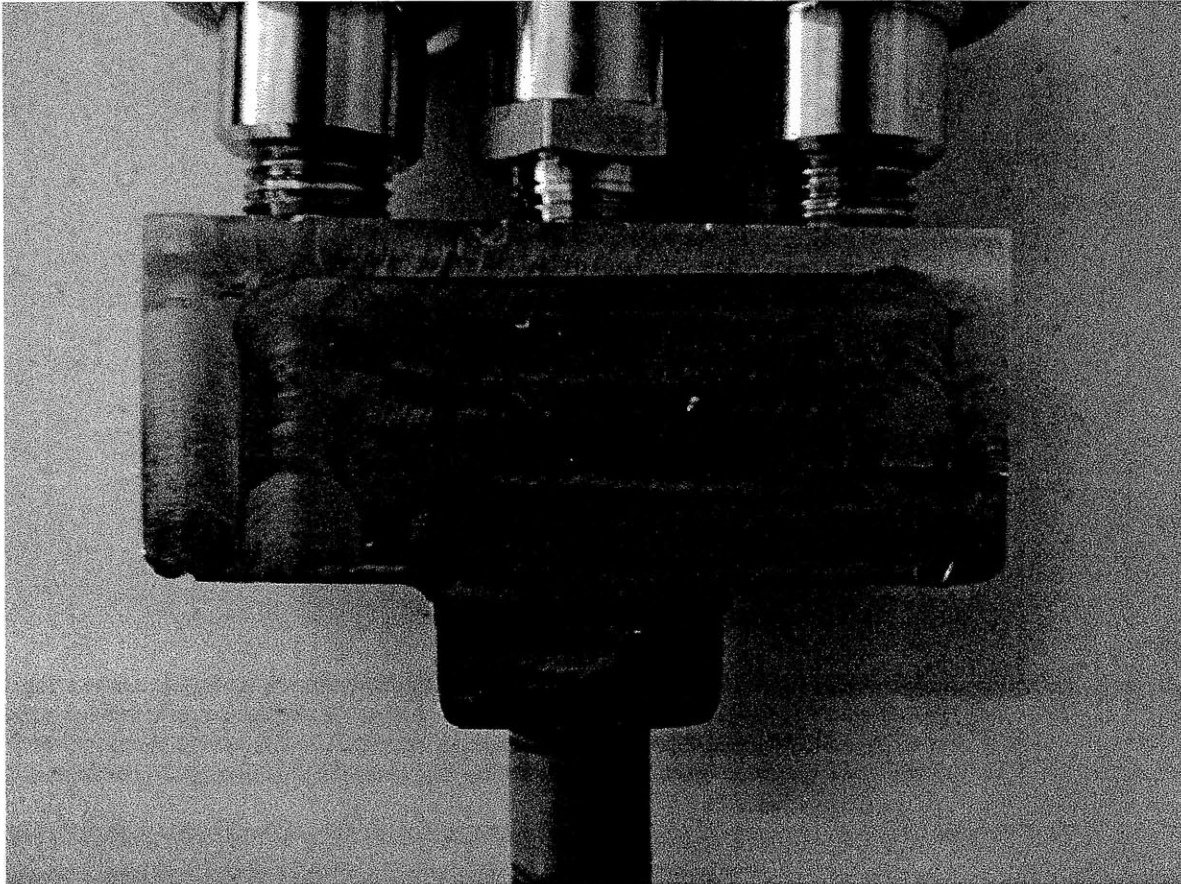


Figure 15: The complete manifold for the air intake.

7.5 Intake Collar

The intake collar outline was water jet and finished with manual milling. It was designed such that the collar would assemble and disassemble easily. The sizing of the hole for the collar was chosen to be a close fit with the intake pipe. The collar was meant to clamp onto the pipe to ensure at depth the collar would remain on the vehicle.

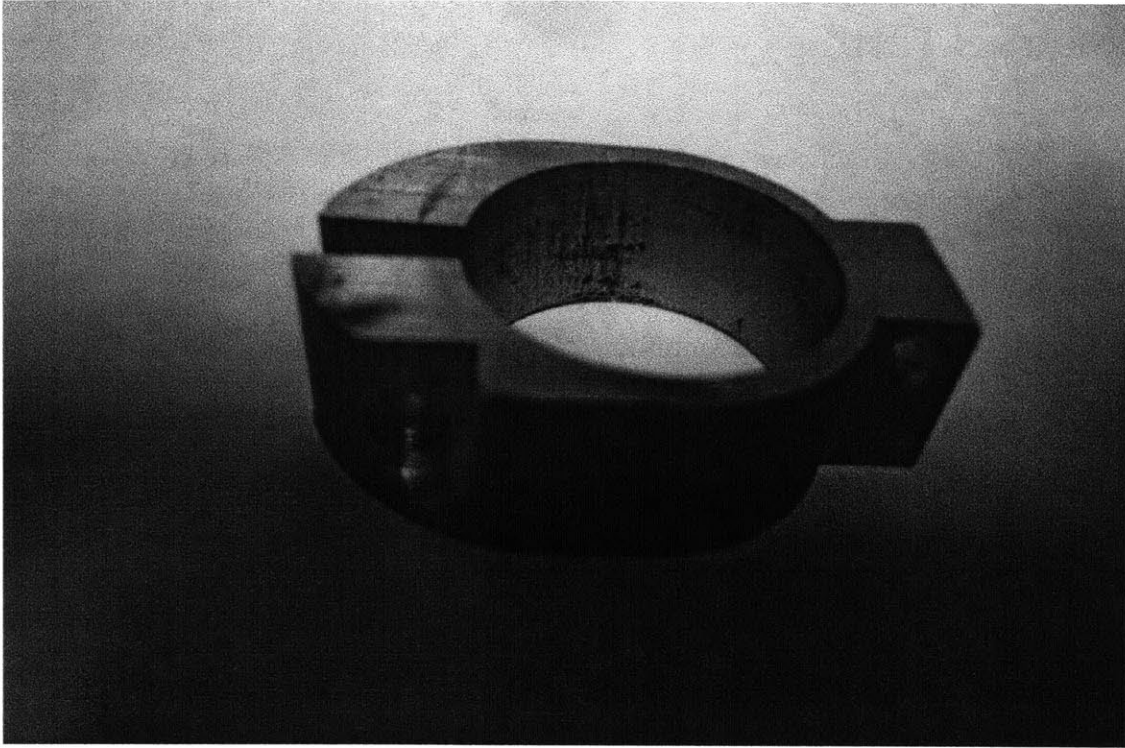


Figure 16: The completed intake collar.

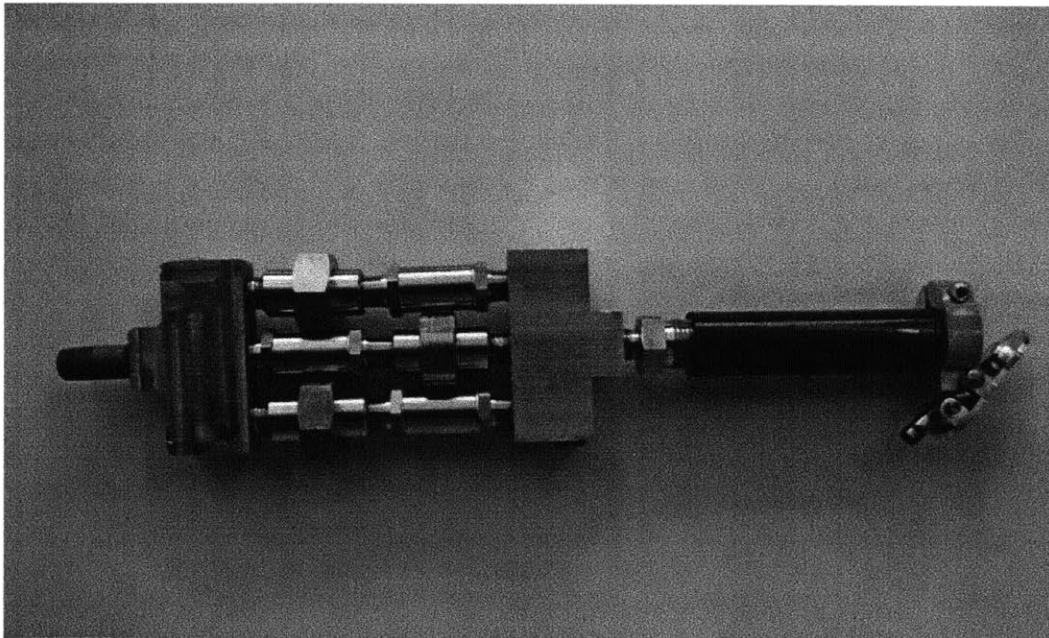


Figure 17: The assembled snorkel intake sans fiberglass shell.

8 Snorkel Testing

In order to test the snorkel system, the entire snorkel system was connected to the engine system. This meant connecting the engine intake to the inner snorkel (plenum), then connecting the inner snorkel to the outer snorkel. The test consisted of running the engine with the entire system assembled.

During testing a problem was encountered where the engine became choked after the inner snorkel was attached. This issue arose because the head loss due to an active solenoid valve was higher than anticipated. However to solve this problem, a supercharger was installed between the engine and the inner snorkel in order to increase the airflow into the engine system. The first installed supercharger did not provide enough of a pressure differential, so a higher power supercharger was installed. The new supercharger needed to be powered down in order to work properly because the pressure provided to the engine prevented fuel from being drawn from the fuel tank.

9 Conclusion

The hybrid underwater power system provides a great opportunity for underwater vehicles. The challenge will be implementing a system that is compact enough to bring widespread use to small unmanned underwater vehicles. This thesis discussed the process by which a new snorkel was designed and manufactured for an underwater vehicle. It provides a few possible methods for a new snorkel as well as compares the benefits and reservations of each design. This goal of this new snorkel is to provide a lightweight interface for underwater vehicles so that it becomes feasible for hybrid power systems to be used in underwater vehicles.

For future development of a snorkel, it is important to accurately test the pressure loss allowable for the engine before it becomes choked. This is to ensure that the intake system prevents a choked engine without a supercharger. More testing of the snorkel system to determine the airflow and pressure loss of the entire system is needed to optimize further development and locate the parts that could be modified and

Future snorkel design modifications that could be possible are eliminating the current float mechanism in favor of a simpler mechanism that relies solely on a lightweight foam material for sealing water because the seal does not need to completely restrict flow. This float could be used to seal a surface while allowing a small amount of water into the system.

This water would eventually be evacuated from the plenum via the water pumps installed. The new system would thus consist of only one moving part.

The proposed snorkel system provides a starting point for future systems, and could be improved upon further. It was successful in providing air to the intake of the engine while maintaining a small form factor. The significance of this report is to show that many possibilities for novel snorkels exist and that further development of the snorkel is needed in order to allow underwater vehicles to perform a larger variety of tasks.

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