Operations Manual for Student-Team-Built Hybrid Power Source to Recharge an Unmanned Undersea Vehicle

by

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Abstract: Unmanned Undersea Vehicles (UUVs) have the potential to explore and monitor oceans in unprecedented ways, but their present batteries only allow them to operate for days at a time. A team of students designed and built a gasoline-hybrid recharging system for a Remus 600 UUV to extend its operating time from three days to four weeks. To facilitate the understanding, operation, and copying of the unit by the project sponsor, MIT Lincoln Laboratory, a thorough inventory of components was taken and explained according to subsystem, including fuel system, air snorkel system, engine system, electronics system, and cooling plumbing.

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

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Motivation

Unmanned Undersea Vehicles (UUVs) are submersible robots capable of exploring and monitoring the world's oceans. Their military, scientific, and commercial applications are vast, and their operating costs are a fraction of that to operate ships and submarines. The present drawback with UUVs is that their operating time is extremely limited by the capacity of their lithium ion batteries. The Remus 600 UUV for instance has a maximum battery operating time of only three days before it must return to a ship or port.

To advance the potential for UUV performance and promote its general use, the MIT Rapid Development Group (RDG), a class of MIT mechanical engineering students sponsored by MIT Lincoln Laboratory, designed and prototyped a power system to extend the operating time of a Remus 600 vehicle from three days to four weeks. The final product was a gasoline hybrid system that would burn gasoline to generate power to recharge the Remus batteries.

This was an exceptionally complicated project involving dozens of students designing and assembling an array of components including commercial, house made, and custom ordered parts. In order for the sponsor and others to understand the prototype and its subsystems, as well as be able to use and replicate them, the system needed to be concisely explained.

The document which follows explains in as clear terms as possible the different subsystems, their components, and functions.

Figure 1: Remus 600 with new power system shown (MIT RDG, 2011)

Introduction

Congratulations on your new gasoline-hybrid, at-sea recharging system for your Remus 600 unmanned undersea vehicle!

This document is designed to be an "at a glance" guide to help you familiarize yourself with the basic sub-systems of the Remus. It is not an exhaustive reference, but should provide a very good starting knowledge.

Major components in the text are listed in **bold** for convenience in browsing.

Integrated System Overview

The system operates in principle as follows. The vehicle surfaces and opens its snorkel to collect air in an internal plenum, which in turn delivers air to the engine. Gasoline from the fuel tanks is combusted with air in the engine, driving a generator which recharges the Remus's onboard batteries. Ocean water is run through a cooling system to prevent the electronics and engine from overheating. Ocean water is also taken into the fuel tanks to replace consumed fuel so as to maintain constant mass. An electronic controls system maintains the engine at a proper speed to produce voltage within proper operating bounds.

A visual outline of the sub-system locations within the overall device is given below.

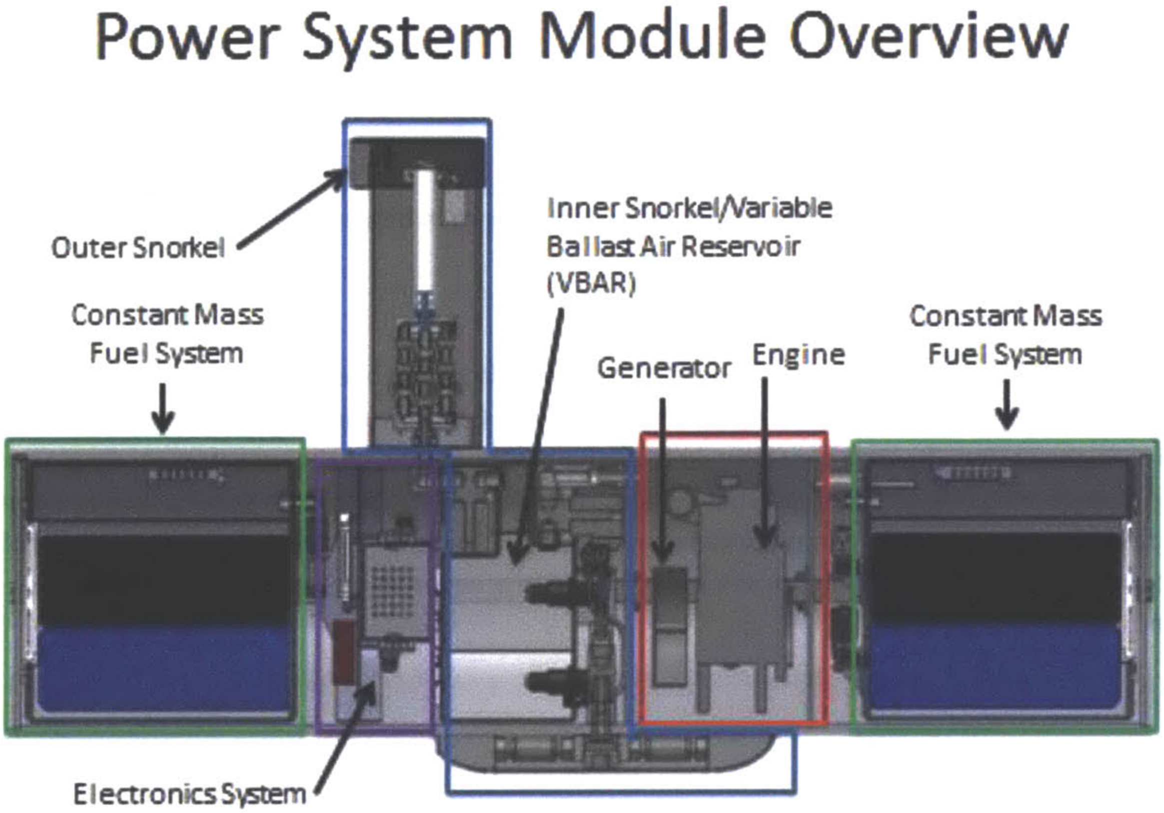


Figure 2: A solid model of an early version of the system very similar to the final product. (MIT RDG, 2011)

Rail System

The system is held together by **two metal rails** running along each side of it, spanning 61 inches in length, spaced 10.5 inches from interior portion to interior portion. This allows the entire system to fit within one Remus module compartment.

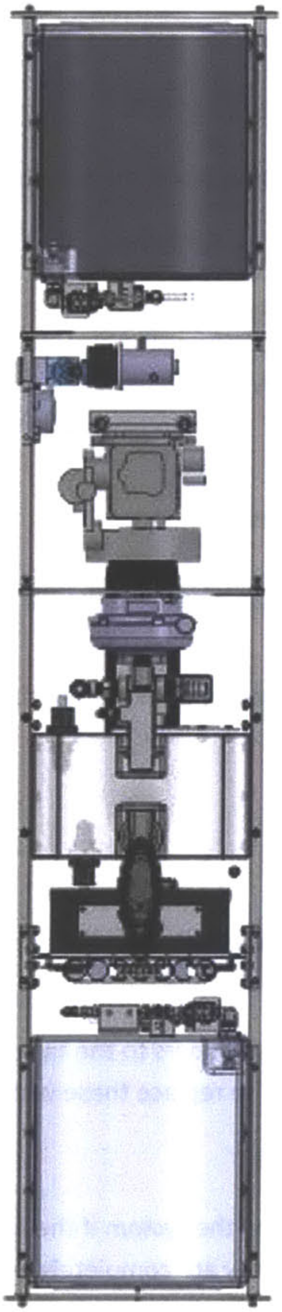


Figure 3: A top view of the entire system, with the rails visible on the sides.

Fuel Tank System

The two fuel tanks are composed of #300 epoxy resin fiberglass with #21 non-blushing cycloaliphatic hardener.

Each of the **two** fuel tanks contains:

1 **Black Water Bladde**r, custom manufactured by ATL.

1 **White Fuel Bladder** for use with **gasoline,** custom manufactured by ATL.

1 SC 8256A002 V-24/DC **fuel valve**, made by ASCO Valve.

1 VX2130M-02N-6G1 **air valve**, made by SMC Valve.

1 VX2130L-02N-6G1 **water valve**, made by SMC Valve.

In addition, the **entire system** also contains:

1 SLQ-HC60 **fuel flow meter**, manufactured by Sensirion, mounted on the engine-facing side of the forward tank.

1 30-3222 **fuel vapor sensor**, manufactured by OPWGlobal, also mounted on the engine-facing side of the forward tank.

Notes:

IMPORTANT! The bladders should **NOT** be velcroed to each other. Please do not use any velcro that appears to connect the two bladders.

The tubing connecting the fuel and water bladders to the tank attachments is fastened with a series of zip ties. At your discretion, you may wish to replace these with clamps.

The system is designed to run on ***gasoline***.

It is not recommended to continue running the system if the fuel bladders are nearing empty. Stop operation and refill the bladders before they are completely depleted.

Fuel Tank, Engine-Side View

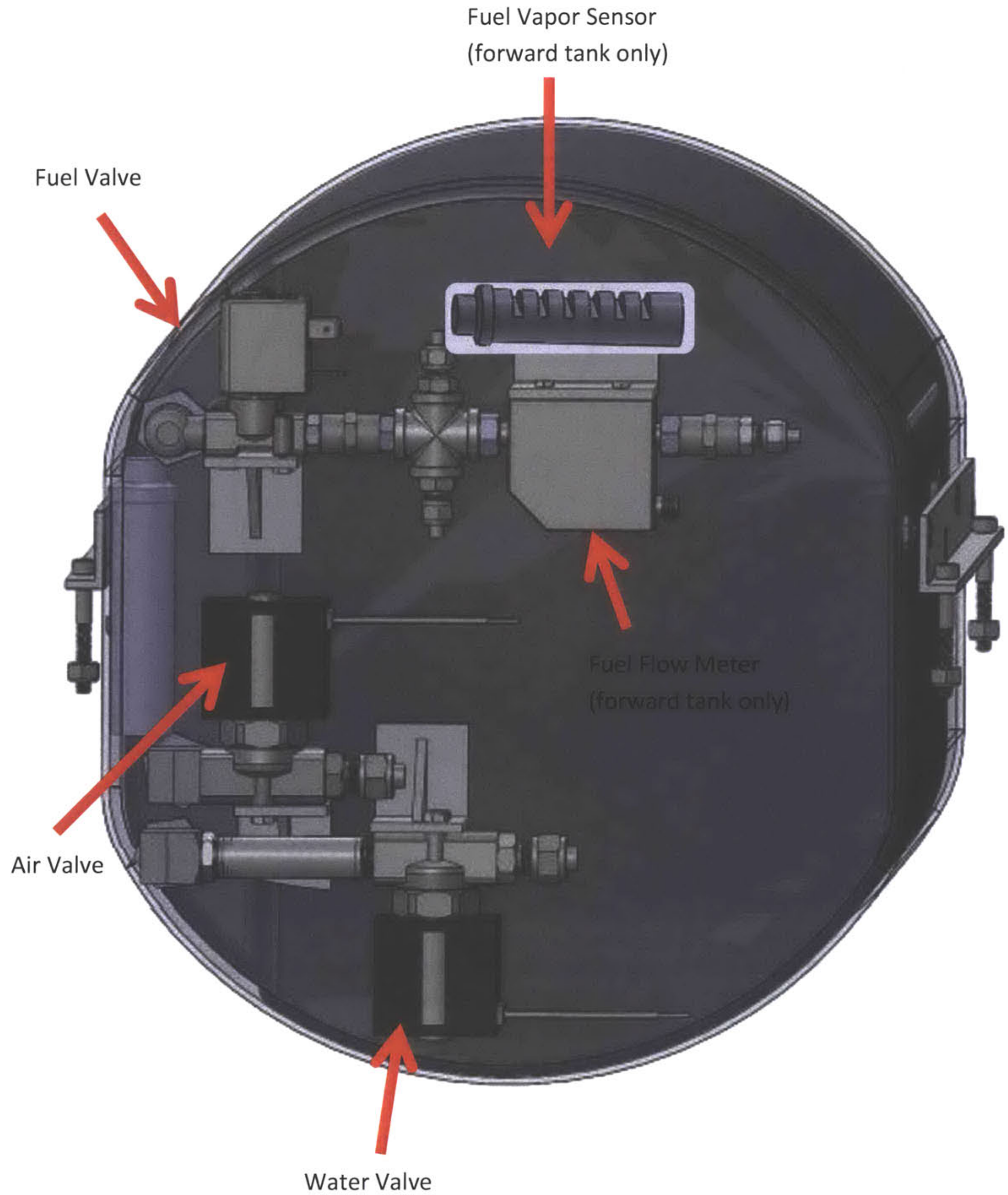


Figure 4: View of fuel tank from side facing towards the engine.

Fuel Tank with Full White Fuel Bladder

Note: Aside from the front screw-on porthole window, the containment tank itself is **NOT** pictured so as to show the white fuel bladder.

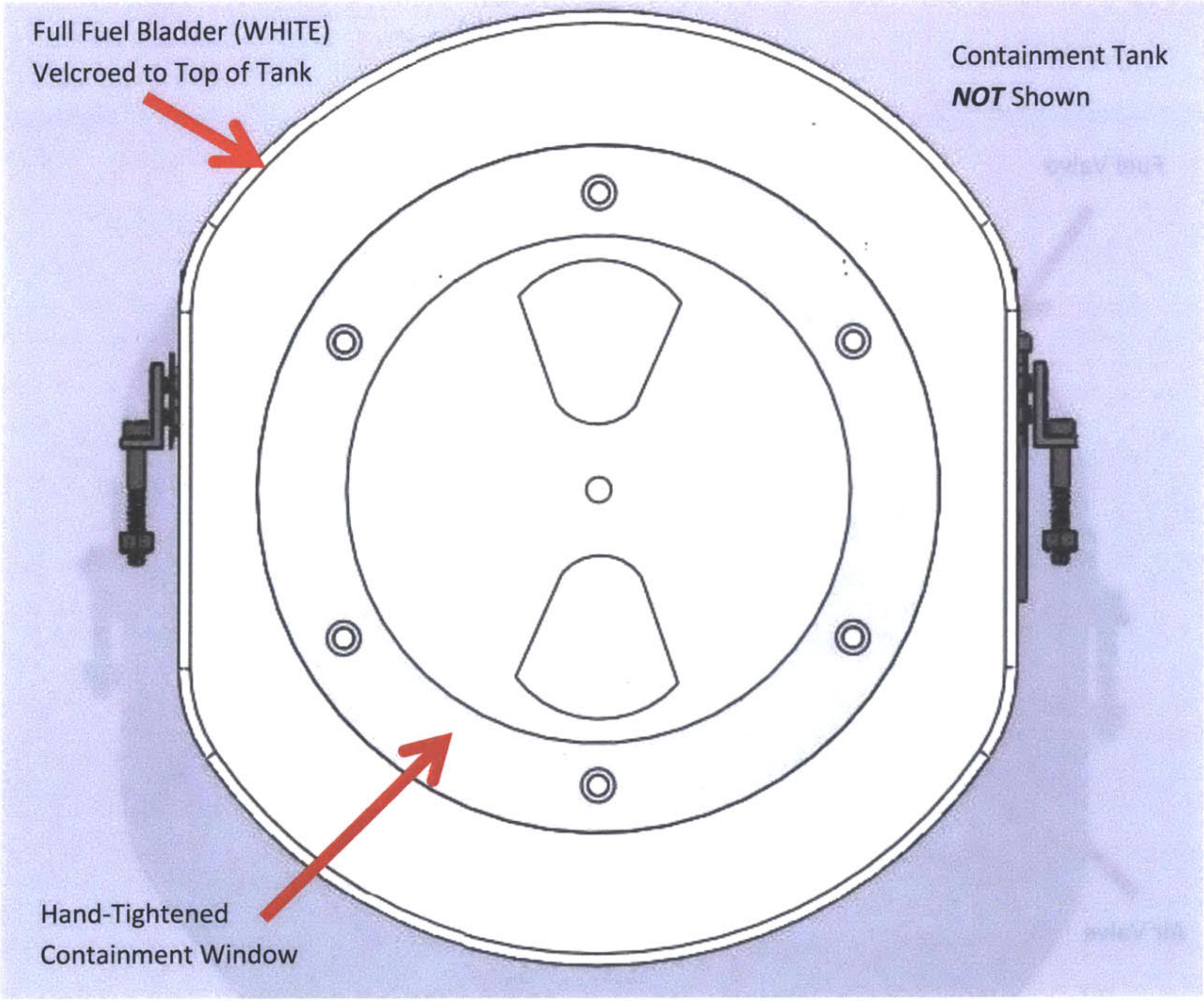


Figure 5: View of fuel tank from side facing away from the engine. The white fuel bladder is full at the start of the mission, while the black water bladder (not visible) is collapsed to very low volume. Containment tank is not pictured so as to show the bladder.

The white fuel bladder is velcroed to top of the tank, and when full, fills the entire tank. The black water bladder (not shown) is velcroed to the bottom of the tank. When the white fuel bladder is full, the black water bladder should be empty and pressed to a very low volume against the bottom of the tank by the weight of the full white fuel bladder.

Repeat: The bladders should **NOT** be velcroed to each other. Please do not use any velcro that appears to connect the two bladders.

During the recharging process, fuel is consumed, and the white fuel bladder velcroed to the tank top decreases in volume. Seawater is taken in via the cooling system plumbing to compensate for the lost fuel mass, increasing the volume of the black water bladder velcroed to the tank bottom. Because the sea water is denser than the fuel, a smaller volume of it is taken in, and air is taken and stored directly in the tank to compensate for the volume discrepancy. This means that as the fuel bladder becomes emptier and the water bladder becomes fuller, the gap between them becomes wider.

By the time the fuel is exhausted, the fuel bladder will be essentially collapsed and the water bladder will be filled to capacity as such (again, the containment tank itself (aside from the screw-on porthole window) is not pictured so as to make the bladders visible):

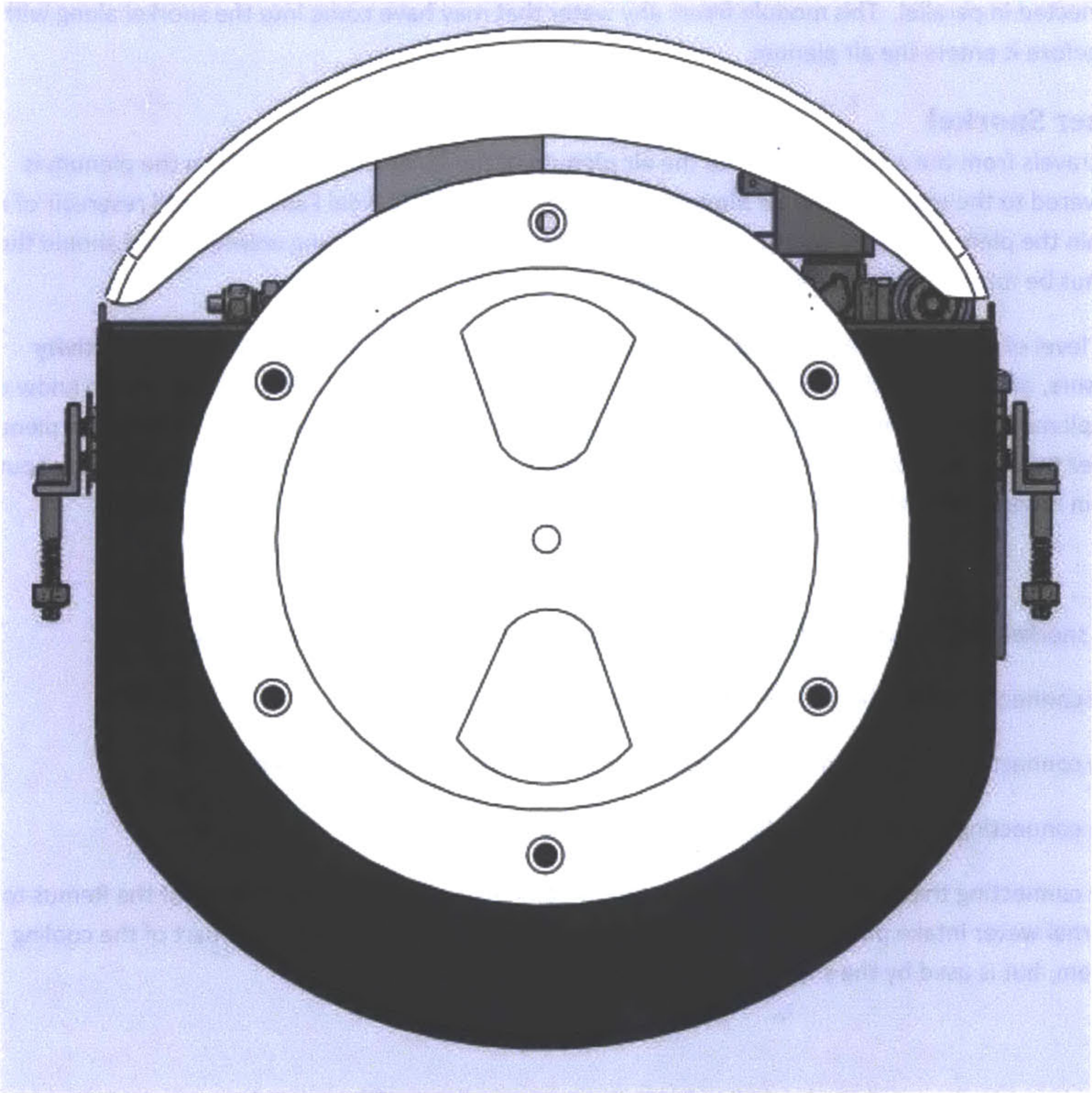


Figure 6: View of fuel tank from side facing away from the engine. The white fuel bladder is nearly empty at the end of the mission, while the black water bladder is filled nearly to its full volume. The containment tank itself is not pictured so as to show the bladders.

Snorkel Section

Outer Snorkel

The outer snorkel section is contained within a **fiberglass housing**. At the open point where air is received into the snorkel, a **series of baffles** helps deter water from entering the snorkel.

A **float mechanism** (a buoyant valve within the snorkel) will rise to the water level in the event that the Remus is submerged by a wave during refueling. This provides a loose seal to help deter water from entering the snorkel.

Inside the outer snorkel is a **filtering module** containing three Swagelok SS-8F-440 **water filters** connected in parallel. This module filters any water that may have come into the snorkel along with the air before it enters the air plenum.

Inner Snorkel

Air travels from the outer snorkel into the **air plenum** of the inner snorkel. Air from the plenum is delivered to the engine by the **air blower**, a Grainger made 5AFZ2 Axial Fan. The small reservoir of air within the plenum is large enough to allow the engine to continue running uninterrupted should the Remus be momentarily submerged by waves.

The level of water that has entered the plenum is monitored by two NEK-1136N20C **conductivity sensors**, made by Kobold, positioned at the bottom and top of the tank which let the system know when the plenum is nearly empty or nearly full. If, during recharging, there is too much water in the plenum, a **water pump** is activated to remove it from the system. When recharging is complete, the water pump is run in reverse to fill the plenum with water to reduce buoyancy for diving.

The snorkel system contains four SMC VXE2260L-04F-5G1 **high pressure solenoid valves**:

One connecting the outer snorkel and the plenum.

One connecting the bottom of the plenum to the internal water intake plumbing.

One connecting the plenum to the air blower for the engine.

One connecting the external water filter intake module extending from the bottom of the Remus to the internal water intake plumbing (this valve can more technically be thought of as part of the cooling system, but is used by the snorkel and fuel tank systems).

Also shown in the snorkel system diagram is the **seawater intake filter module**. It contains four Swagelok SS-8F-440 **water filters** (the same as the upper snorkel), and provides ballast water to both the plenum and the fuel tanks. This component may also technically be considered part of the cooling system but is used by the snorkel and fuel tanks systems.

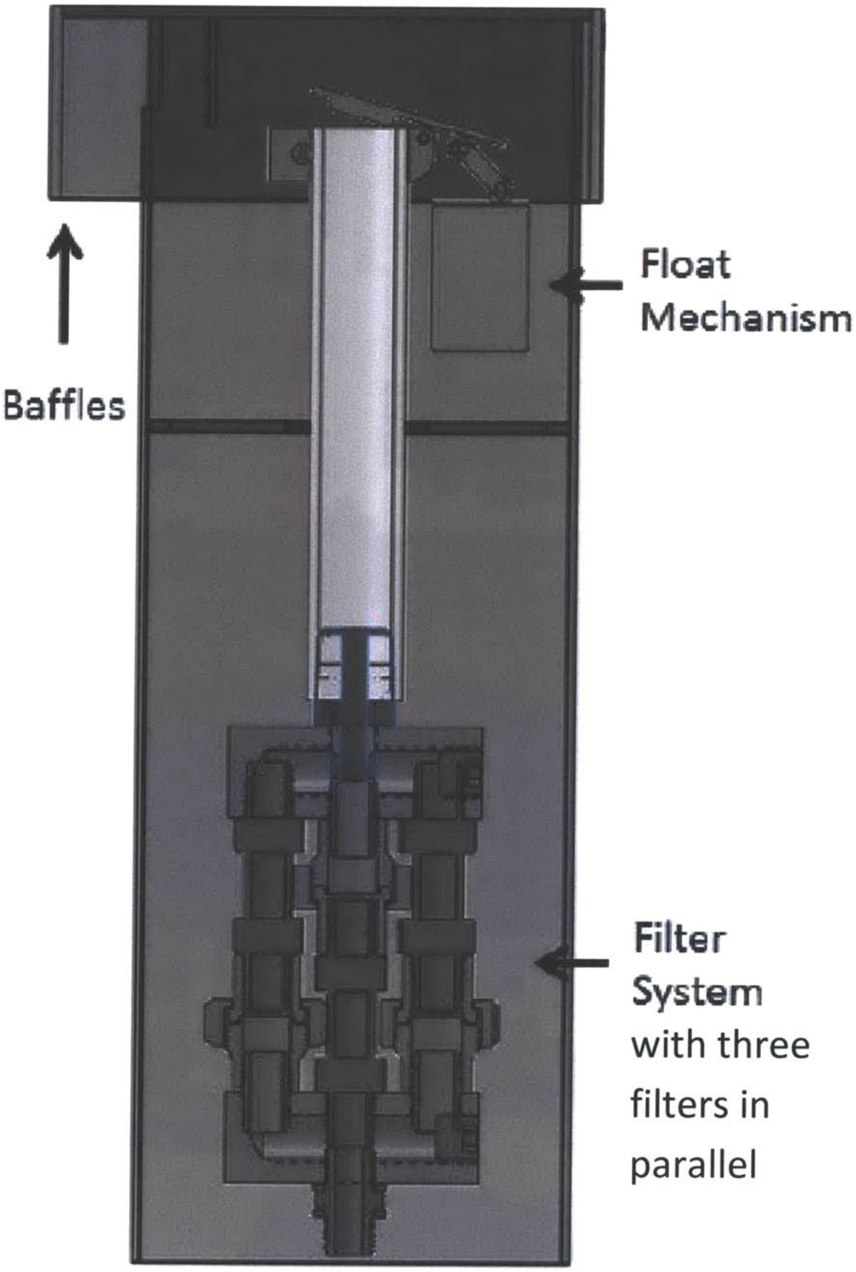
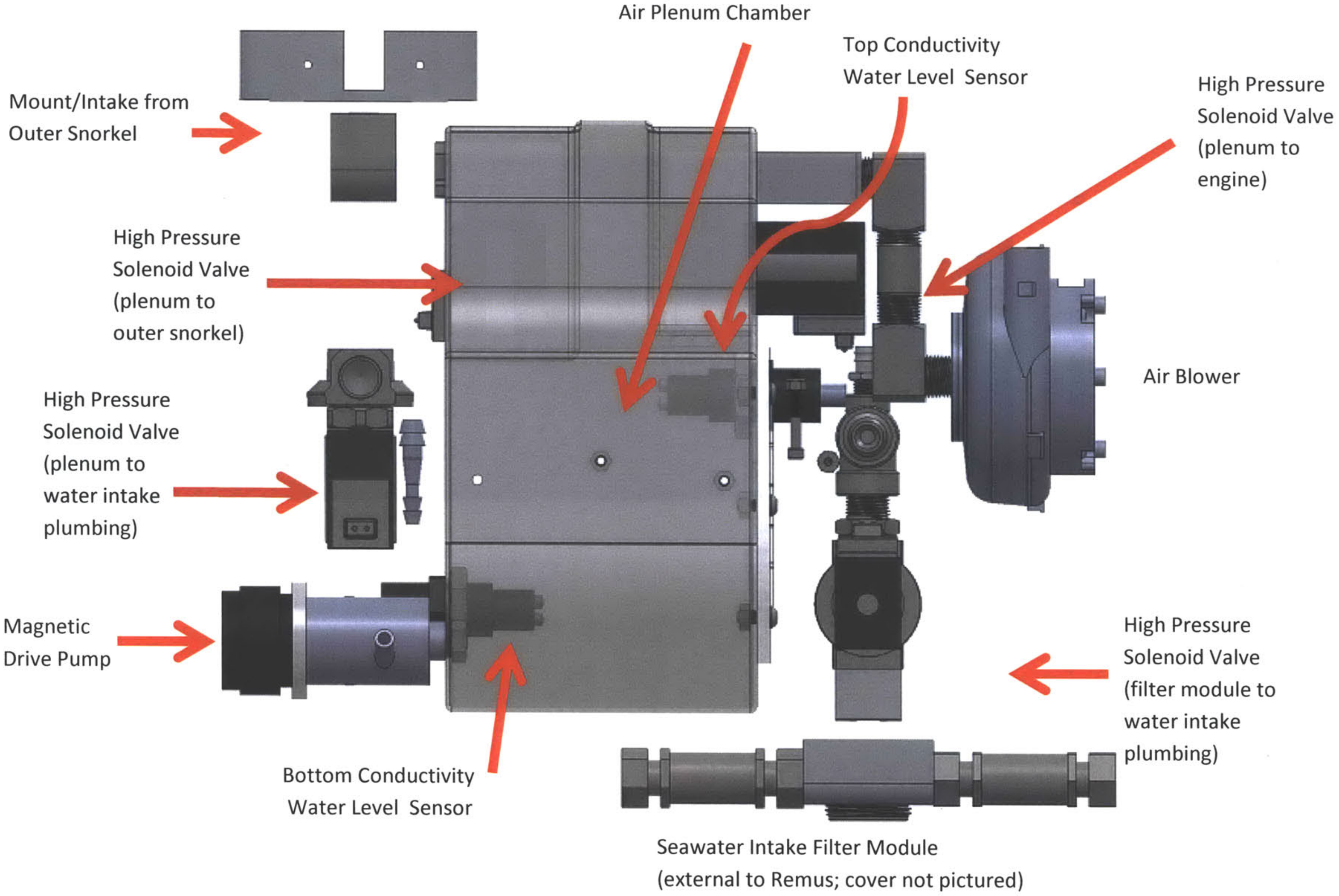


Figure 7: Outer Snorkel System Side View (Tia, 2012).

Figure 8: Inner Snorkel System Side View.



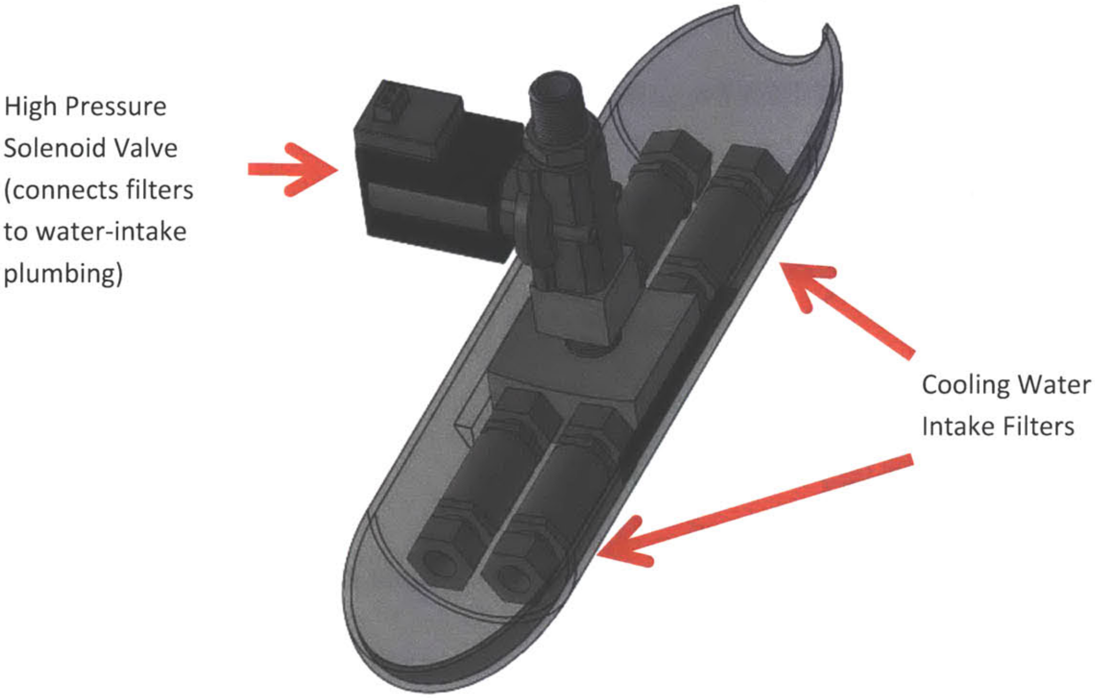


Figure 9: Seawater Intake Filter Module.

Engine System

The primary feature of the engine subsystem is the engine itself, a Honda GX50 gasoline engine taken and adapted from a Honda EU1000i generator.

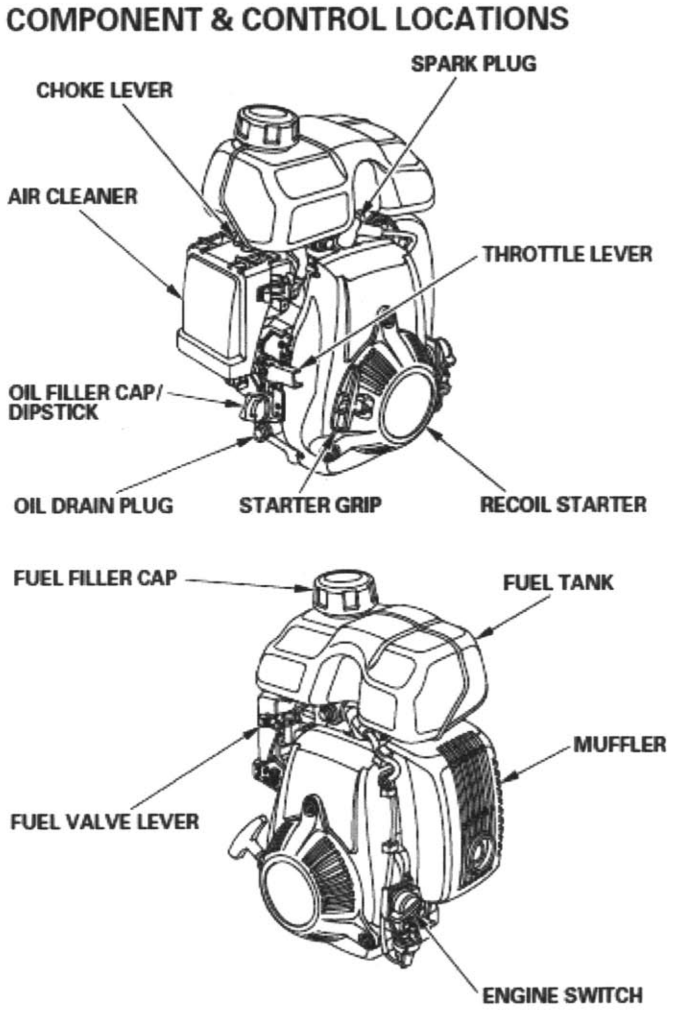


Figure 10: The Honda GXH50 Generator from which the engine was taken (Honda Motor Co., 2009).

The Honda GXH50 engine has been removed from the EU1000i generator and is being used as a standalone part. The generator component has been replaced with a customized generator.

The engine is started using a 170-6-0 Electronic **Ignition Module** DLE-170 (made by DLE Engines) and an ROB-10551 small **stepper motor** (made by Sparkfun Electronics).

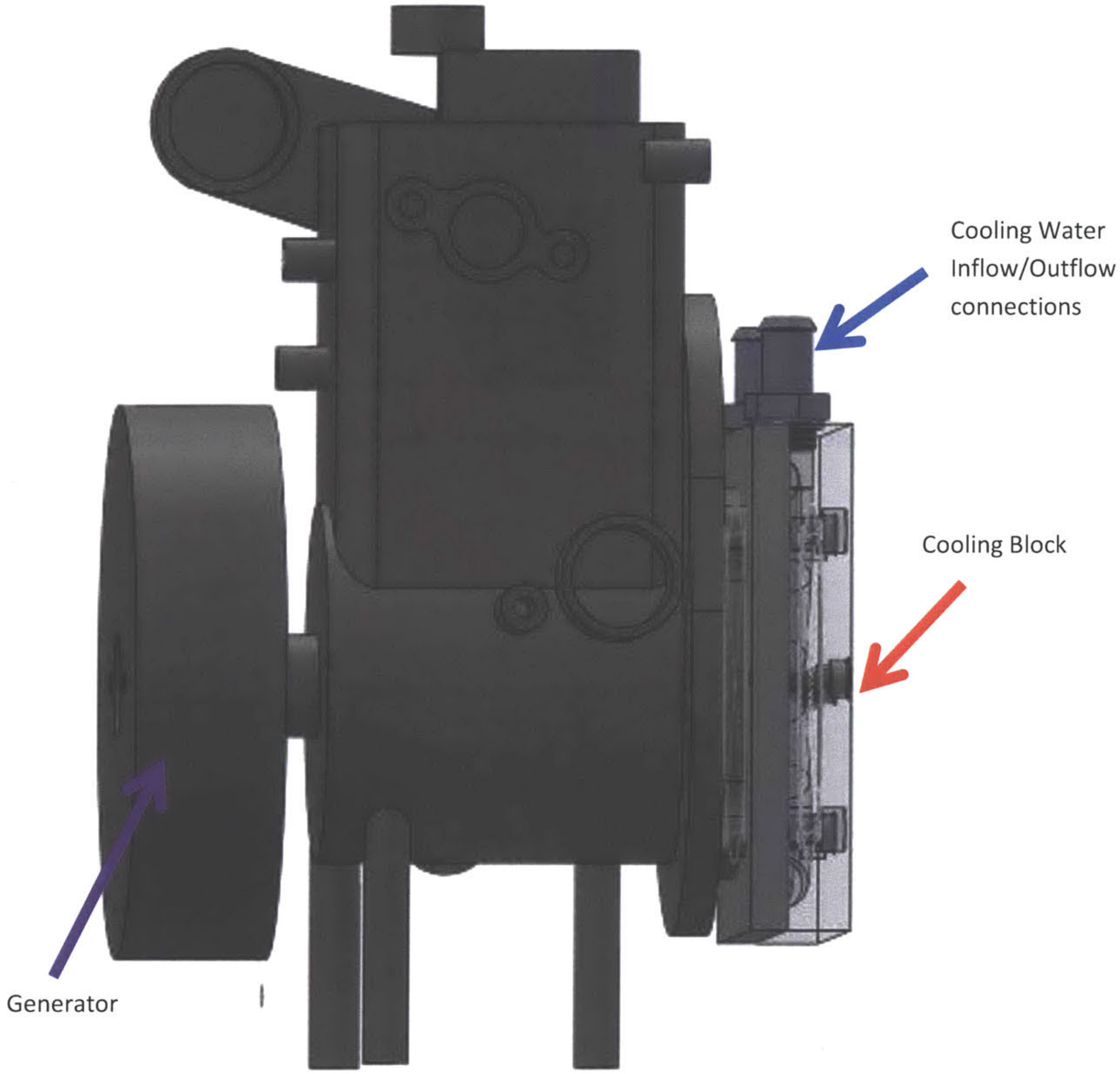


Figure 11: Honda GHX50 Engine taken from Honda EU1000i Generator with attached cooling block.

The engine is mounted to the railing system using four V10Z61MTHC silicone **vibrational mounts**. These mounts damp vibration from the engine to reduce the risk of damage to sensitive components in other systems.

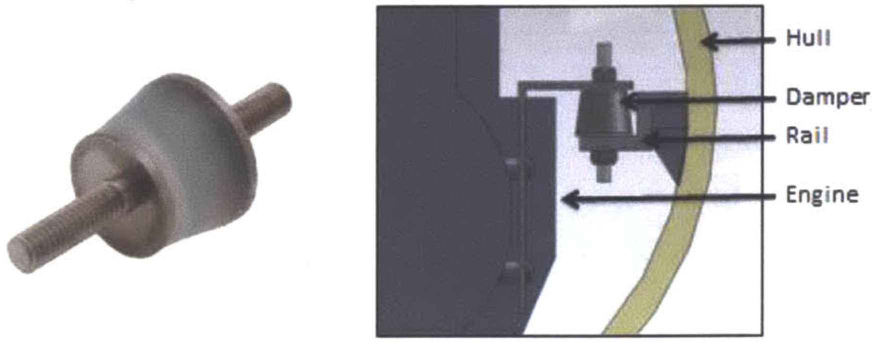


Figure 12: Silicone mounts help isolate the engine's vibrations from the rest of the system (MIT RDG, 2011).

To prevent damage to other system components from engine heat, thermal barriers help isolate the engine from other subsystems. These barriers are mounted onto the system rails on either side of the engine and exhaust assemblies.

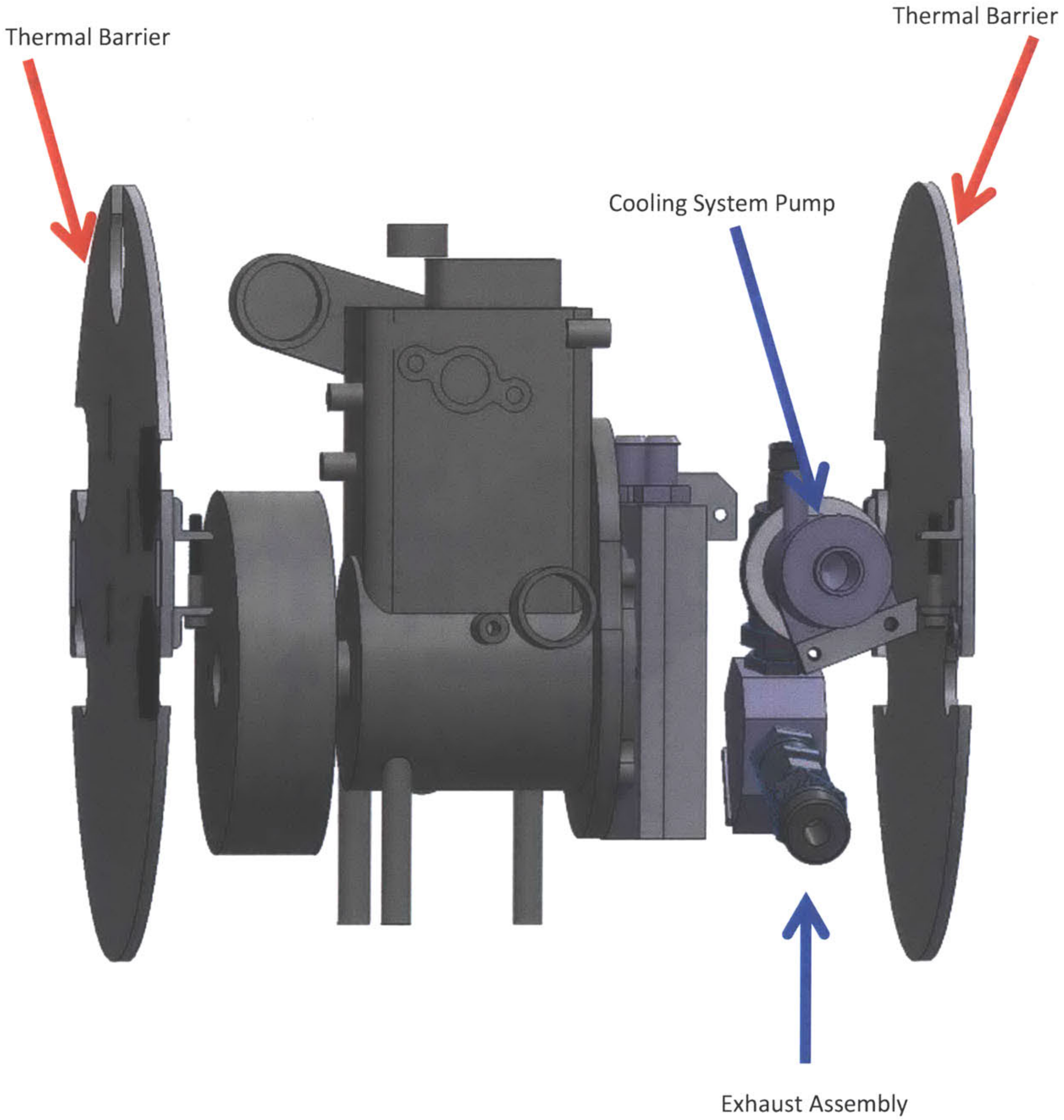


Figure 13:Engine with thermal barriers and some cooling system components.

A pump for the water cooling system is also located adjacent to the engine cooling block and the exhaust assembly.

Cooling System Overview

Sea water is taken in through the external filter module shown in the snorkel system layout. It is taken into the water intake plumbing and is then routed either (1) into the fuel tanks to replace the mass of consumed fuel, (2) into the air plenum to decrease buoyancy in preparation for diving, or (3) further along the cooling system.

The cooling water travels first through the electronics water block then through the plumbing into the engine cooling block. It shortly thereafter reaches the exhaust system just forward of the engine and is released back into the ocean.

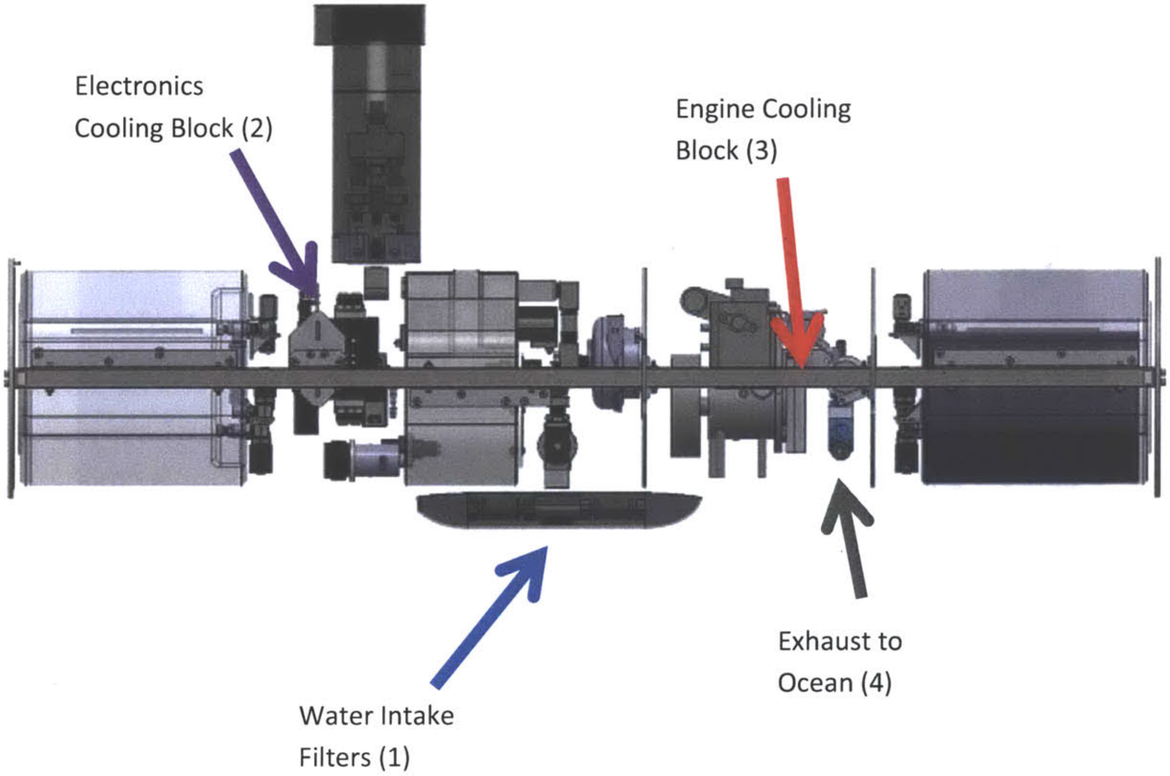


Figure 14: The path of sea water through the cooling system.

The exhaust assembly contains two **Swagelock SS-CHF6-1 poppet check valves**.

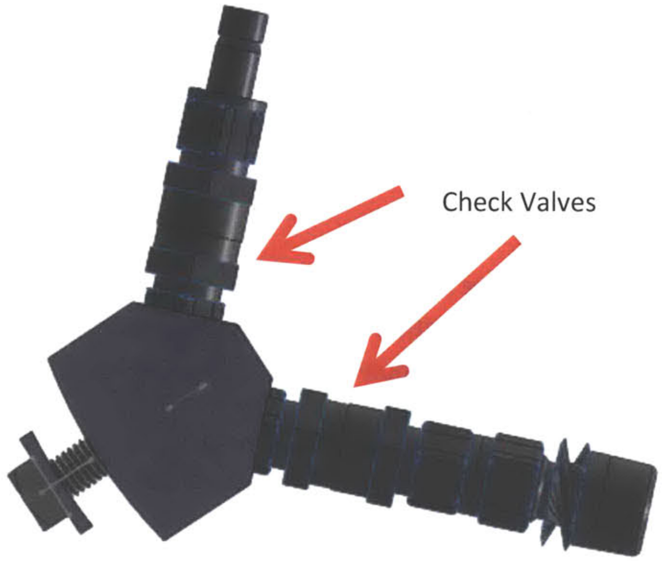


Figure 15: Cooling system exhaust assembly.

Controller and Electronics System

Battery charging, the opening and closing of pumps and valves, and electronic communication with the Remus native system are all accomplished by a **PIC24H microcontroller**.

Attached to the bottom of the electronics assembly which houses the microcontroller is a **power assembly box** which houses the **electronics water-cooling block** to prevent the electronics from overheating.

Engine Control

A **motor controller** is used to back-drive the generator to start the engine. A **Hall Effect sensor** adjacent to the generator reads the generator's position and speed using a magnet attached to it. The sensor signals a capacitive discharge ignition which powers **spark plugs** and ensures that they fire at the proper moment to ignite the fuel vapor in the engine.

A **choke** and **throttle** connected directly to the engine are regulated by a small controller board which is in turn controlled the central microcontroller.

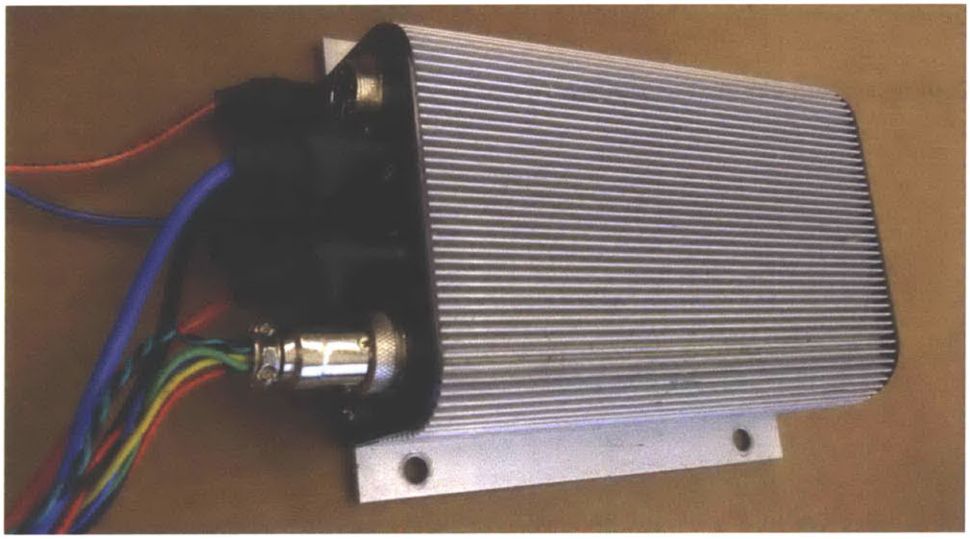


Figure 16: Motor controller box which receives power from the generator.

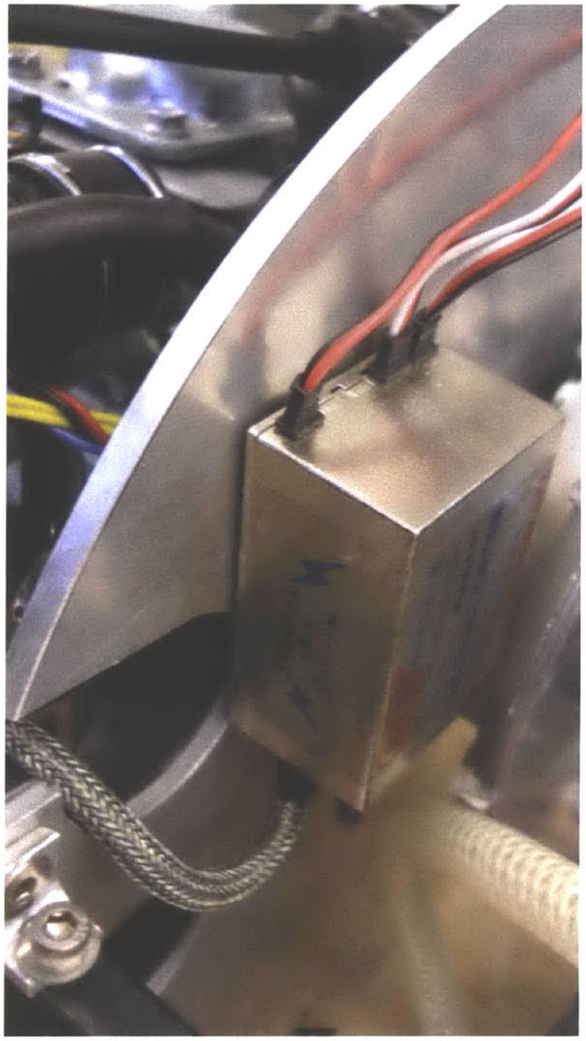


Figure 17: Capacitive discharge ignition ensure times ignition of engine spark plugs

Recharging

The generator is connected to the same **motor controller** which starts the engine. When in normal operation, this motor controller sends power to a **buck converter** which efficiently lowers the voltage to a standardized level of less than 32 volts. The electricity is then fed into the **charger** rated between 10 and 32 V to recharge the battery.

Power for Peripherals

Peripherals such as sensors and valves are powered using a **second battery**, ***not*** the one presently being charged. This battery is connected to three **boost converters,** which regulate the voltage to 5 V, 12 V, or 24 V. All peripherals operate at one of these three voltages. Peripherals which are always turned on, such as sensors are directly connected to the boost converters. Other peripherals that need to be turned on and off or reversed (such as valves or pumps) are connected to **switching boards** which regulate those changes in operation. Each peripheral, boost converter, and switching board is connecter to the microcontroller.

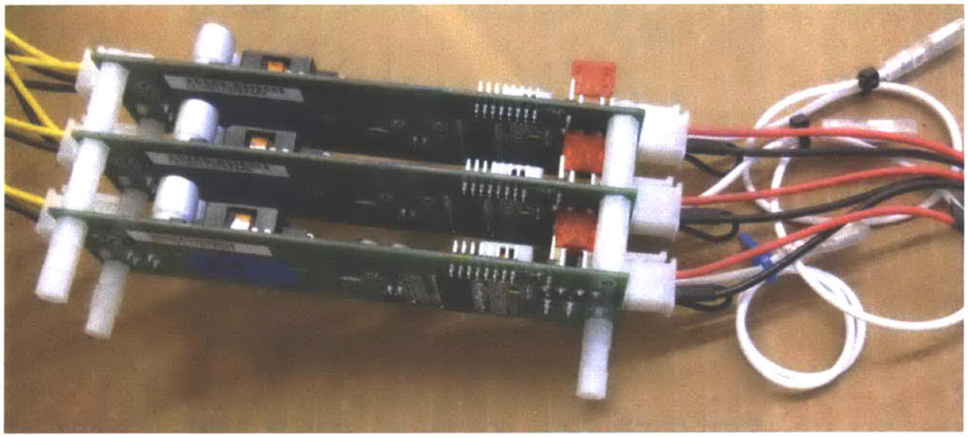


Figure 18: Three boost converters which regulate voltage to proper levels for each of the sensors and actuators.

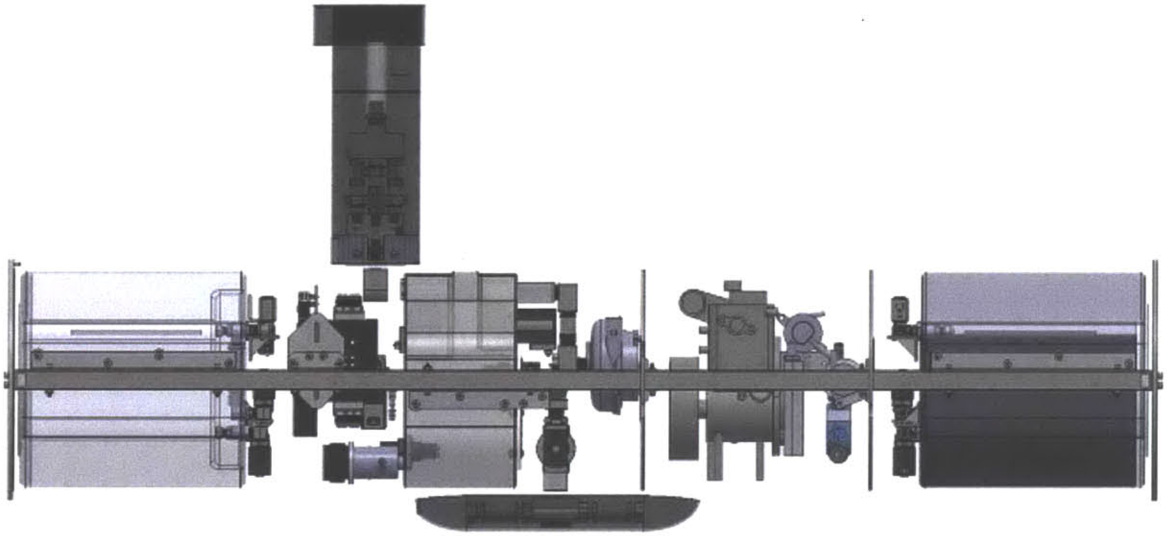


Figure 19: Side view of final sytem design.

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