UNIVERSITY OF MICHIGAN

WOLVERINE II:

DESIGN REPORT

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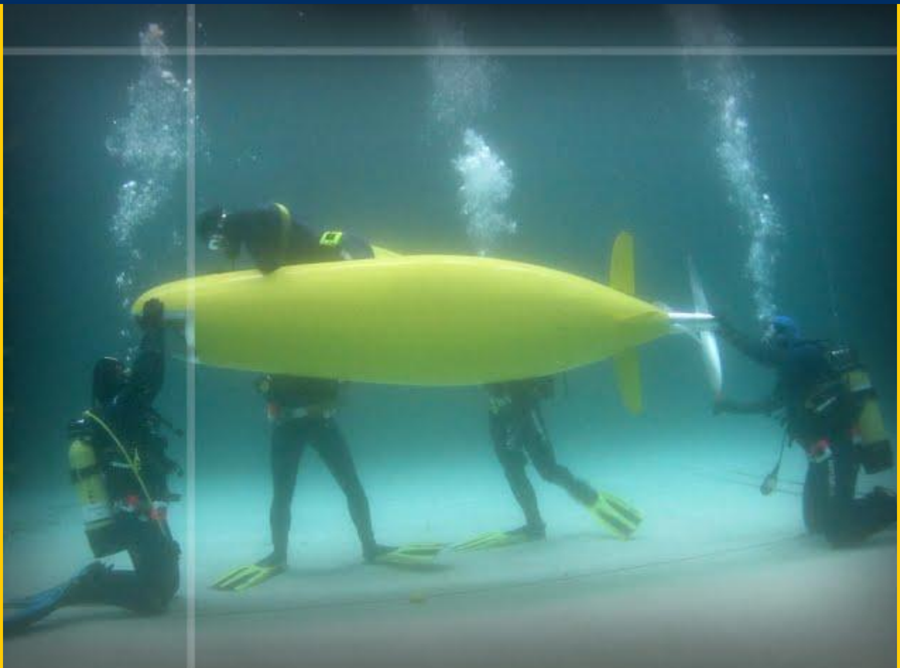

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Introduction

The University of Michigan Human Powered Submarine Team (U-M HPS) is proud to enter a Wolverine II into the 12th ISR. Wolverine II features several improvements over last year's sub, Wolverine, which we raced at the European International Submarine Races (EISR). Our drive train has been modified to be adjustable to different pilot body types, our propellers have been modified and re-made, our safety buoy now has a built-in redundancy and is designed to fail in our favor, the latch on our hatch is much stronger, and our new steering system has been designed so that the pilot has an easier time operating it.

Section 1: Drive Train and Propellers

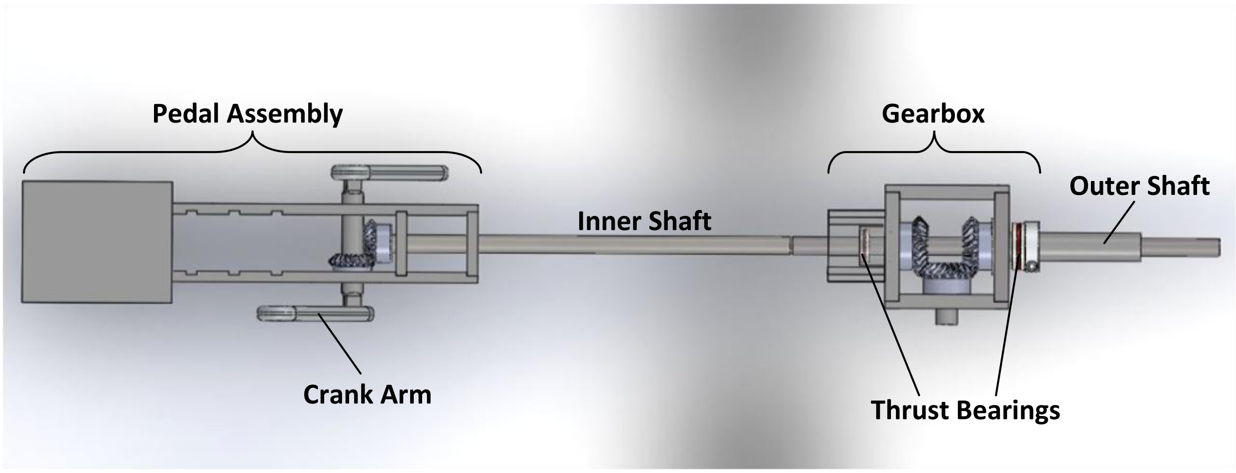

Figure 1.1 - Full diagram of drive train.

Our drive train is comprised of two modules and uses the pilot's power to turn two large diameter, low speed propellers, counter-rotating propellers. The forward module houses bike pedals and two spiral-cut miter gears that transmit rotation from the bike pedals to the inner shaft (Fig 1.1), which runs along the center of the sub from the pedals, through the gearbox, and is fastened to the aft propeller hub. Where the inner shaft enters the gearbox, it connects to a configuration of three miter gears, which transmits rotation to the outer shaft and gives us counter-rotation. The inner and outer shafts exit the gearbox on the aft side, go through a bearing in the transom plate, and couple with the propeller hubs. The gearbox also houses two thrust bearings; one each for the inner and outer shafts. The gearbox itself is braced against the hull by two bars that hold the thrust block on the front in a vise-like grip (Fig 1.2).

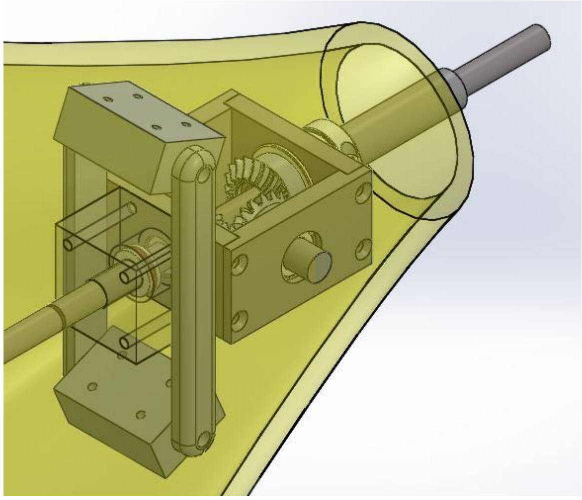

Figure 1.2 - Gearbox brace to transmit thrust to the hull.

The drive train was built to optimize several technical aspects of its performance. We measured the output power of our pilot for several crank arm lengths, and we found that reducing the crank arm would not hugely impact our output power, especially underwater, where viscous effects slow down the pilot's natural biking cadence. After conducting this study, we settled on a crank arm length of 4.5". Our gear ratio, which is simply the ratio of propeller speed to pilot's pedaling speed, is 1:1. This is a slight decrease from last year's gear ratio of 1:1.4. This low gear ratio can be accounted for by the relatively large diameter and steep pitch of our propellers (compared to other subs), as these factors give us a slower optimal rate of revolution. The table below features more technical data for the drive train and propellers.

Drive Train				
Crank Arm Length	**Gear Ratio**	**Pilot's Cadence**	**Propeller Angular Speed**	**Design Speed**
4.5 inches	1:1	70-80 RPM	75 RPM	7.3 knots

Propeller Blades					
Front Propeller			**Rear Propeller**		
P/D at 0.7R	**Pitch at 0.7R**	**Diameter**	**P/D at 0.7R**	**Pitch**	**Diameter**
3.71	126.2 in	34 in	3.49	118.57 in	34 in

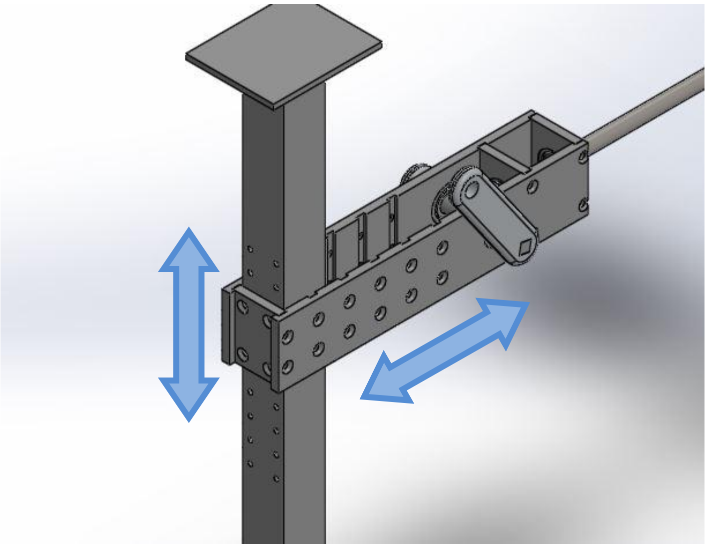
Figure 1.3 - Adjustability in Pedal Assembly.

We designed some very useful features into our drive train. Since our pilots come in different sizes, the pedals can be adjusted up and down as well as forward and backward in the sub (Fig 1.3). When adjusting the pedals longitudinally, the inner shaft is swapped out for a shorter or longer shaft, and when adjusting up or down, we can change the gearbox's pitch to accommodate the change in the shaft's angle. We are also using spiral-cut miter gears to make the gear train run more smoothly and efficiently. Since these gears were only available in steel, and since the body of our drive train is aluminum, we had to find a way to keep the gears from rusting. Our solution was to isolate the gears by chrome plating them, and we have magnesium anodes in our race kit in case we need further protection.

U-M HPS has traditionally used large diameter, low speed, counter-rotating propellers. This year is no different. However, instead of pouring resin propellers like we have in past years, Mercury Propellers machined them for us out of aluminum. Because of the change to this stronger, more flexible material, the engineers at Mercury were able to reduce the blade thickness on the propellers to improve their efficiency.

Section 2: Safety Buoy

The previous safety buoy was retained using a set of pins that slotted into the foam buoy. With this design, the buoy was prone to misalignment with the hull and accidental deployment. The system had also collected residue between the bike cable and its sheathe, which created friction in the system, making it inoperable. Another issue that this system has was that the high visibility line, which is positively buoyant, would unravel within the submarine and could become tangled on the moving drivetrain components. This system was designed to fail in the open/released position, a feature we carried over into the new design.

For the new design, a two-fold approach has been taken to secure and release the safety buoy. The first is a physical interlock with the buoy that keeps it flush with the hull. The physical interlock is mounted to the outside of the hull. It interlock breaks down into the buoy, buoy holder, catch, wedge, and containment case (Fig 2.1). The cone-shaped buoy nests into the buoy holder. Beneath the buoy holder is the containment case which houses the catch mechanism. Attached to the bottom of the buoy is a cone shaped wedge which is forced towards the bottom of the buoy by a compression spring and screw. The catch, which is housed in the containment case, is pushed to the open position by a compression spring. This setup puts the mechanism in the open/released position when the dead man's switch is open. When the dead man's switch is held closed, the cable pulls the catch into an interference position with the wedge (Fig 2.1 and 2.2). This then pulls the wedge down causing a compressive force to hold the buoy tight against the buoy holder (Fig 3.2). The wedge cannot pass the catch in the closed position.

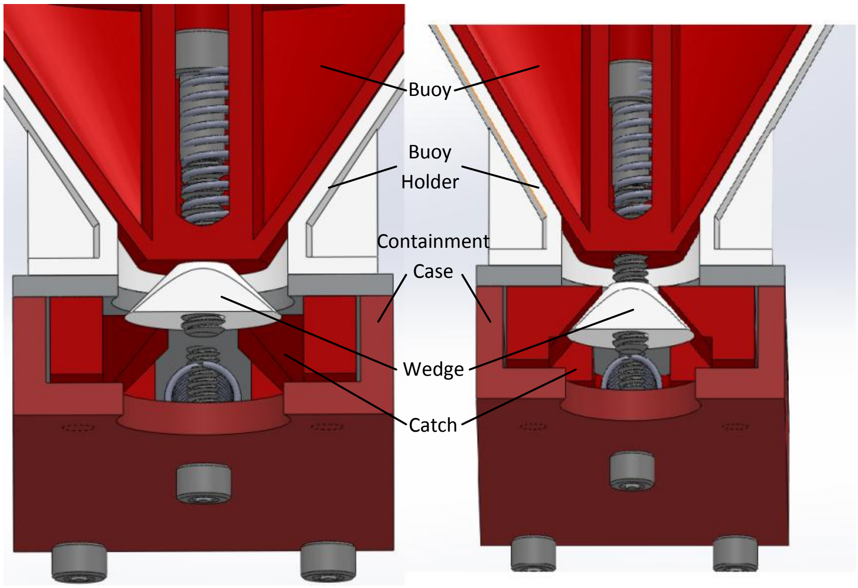

Figure 2.1 - Full diagram of physical interlock in both open (left) and closed (right) positions.

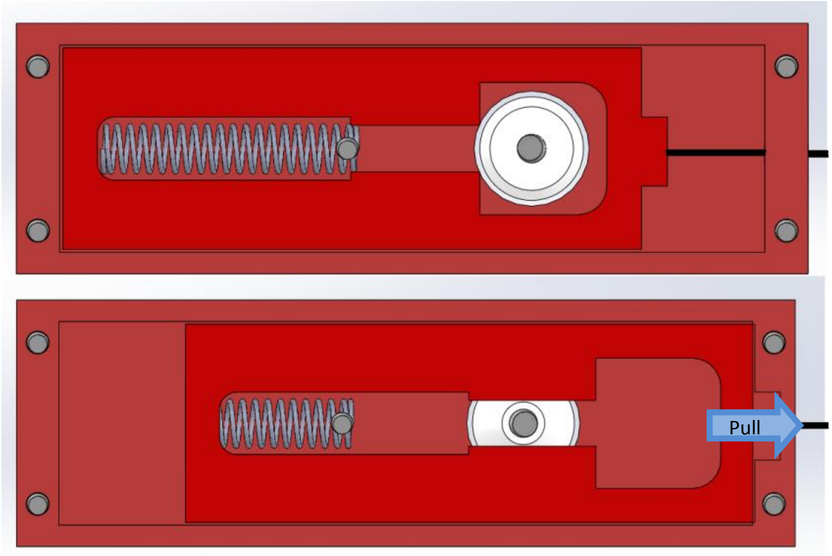

Figure 2.2 - Diagram of containment case in open (top) and closed (bottom) positions.

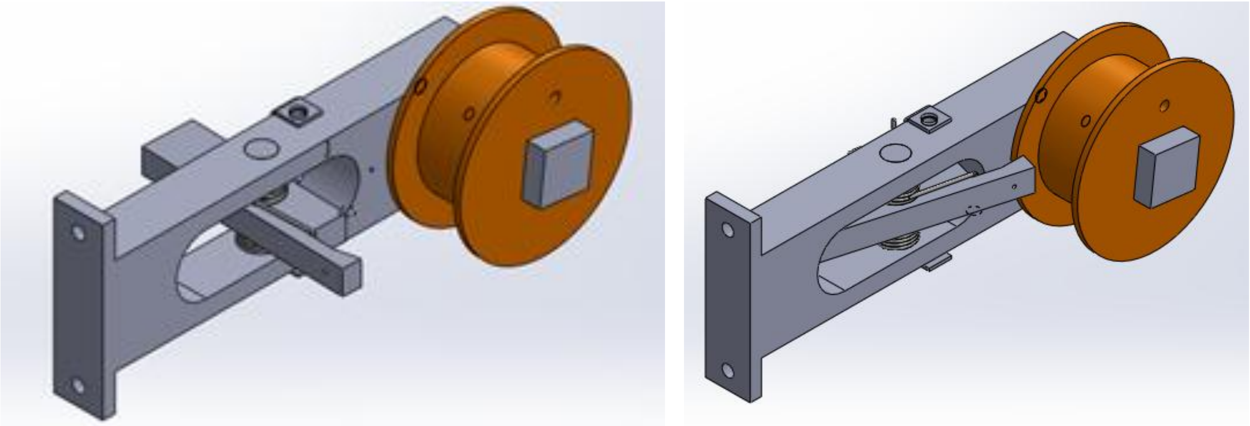

Figure 2.3 - Full diagram of secondary safety buoy system in both open (left) and closed (right) positions.

The secondary buoy retainment system is a frictional restraint on the spool of high visibility line. This back-up system keeps the spool from unwinding during runs, but it is also able to keep the buoy nested in its holder on its own. An arm with a rubber pad presses against the side of the reel when the dead man's switch is closed, keeping the reel from spinning. When the dead man's switch is open, two torsion springs force the pinching arm away from the reel (Fig 2.3).

The buoy, buoy holder, wedge, and catch have been 3D printed out of PLA and PVC plastics. This was an obvious choice for the buoy as it could be printed to have an internal cavity. Additive manufacturing techniques such as extruded plastic printing allow for the unique opportunity to easily manufacture a hollow, buoyant component.

Section 3: Steering Controls

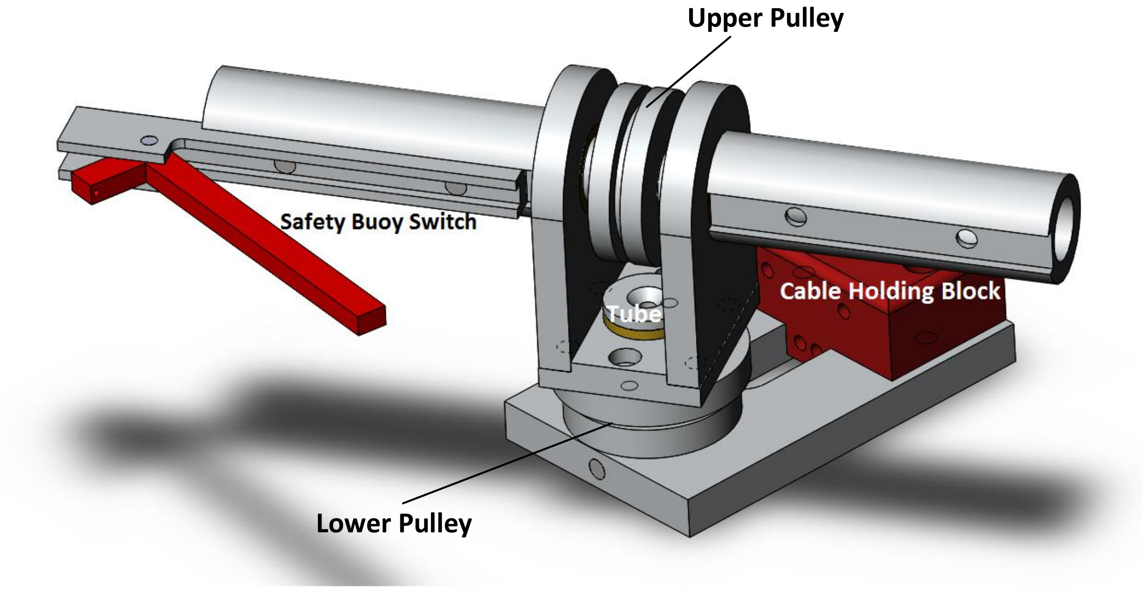

Figure 3.1 - Diagram of control mechanism with safety buoy switch.

Wolverine II's control mechanism was designed to be ergonomic and to allow for precise movement of the control surfaces. The control stick's handles turn left and right to control the rudders and twist fore and aft to control the dive planes (Fig 3.2). The handles are slotted to accommodate the safety buoy switch, which gives the pilot the option to either have both hands on the handles or to have one hand free (Fig 3.1). The cables on the lower pulley, which control the rudders, route directly to the cable holding block. The cables on the upper pulley, which control the elevators, route downward through a tube inside the shaft of the lower pulley, then into the cable holding block (Fig 3.3). With the elevator cables routed through axis of the pulley for the rudder cables, we have eliminated any incidental motion of the elevators when the pilot turns the stick left or right. From the cable holding block, the cables run back to the dive planes and connect to similar pulleys on the dive plane shafts.

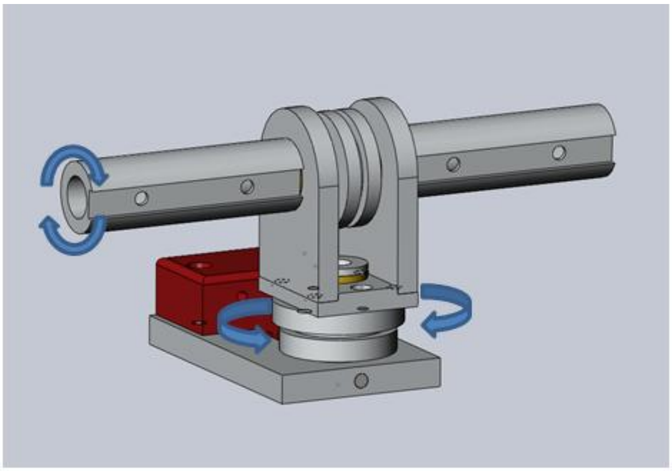

Figure 3.2 - Motion of control mechanism.

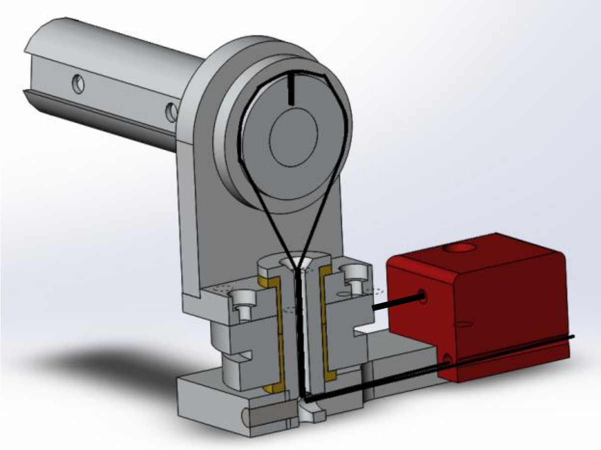

Figure 3.3 - Cable routing through the control mechanism.

The drive train uses a straight shaft to transfer torque from the pedals to the gearbox. If we used straight shafts for the dive planes, they would intersect with the drive shaft. To solve this problem, we interrupted the dive plane shafts with rings where they meet with the drive shaft (Fig 3.4). Although this does limit the maximum angle to which the control surfaces can be positioned, we have not found this to effect the maneuverability of the submarine because the limiting angle is still large enough for the controls to be effective.

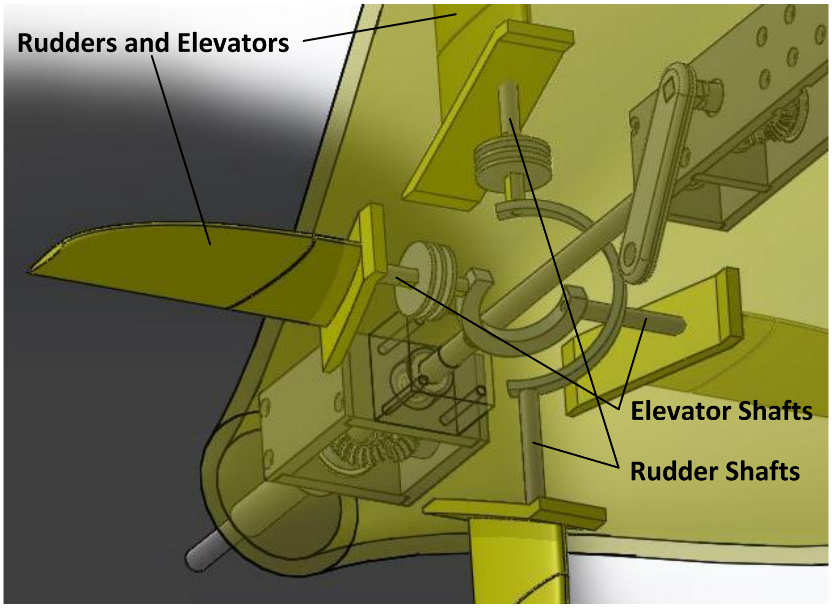

Figure 3.4 - Interaction between dive plane shafts and drive shaft.

Section 4: Latch for Pilot's Hatch

The latch for the pilot's hatch uses a rotational, self-centering interlock. The outer lever (red) and the pilot's/inner lever (yellow) rotate the interlock, a gray pipe with semi-circular tabs on the ends, around the locking bars. The Locking bars are mounted to the inside of the hull. The interlock mount, interlock, and both levers are mounted to the inside of the hatch. The latch is designed so that it can be opened from either outside or inside the submarine. The outer lever can be pulled in the -y direction to open the hatch, and the inner lever can be pulled in the +y direction if the pilot wants to make an unassisted egress. The inner lever is also designed so that it does not rotate when the outer lever is pulled. This prevents the inner lever from jabbing the pilot when someone outside the sub opens the hatch.

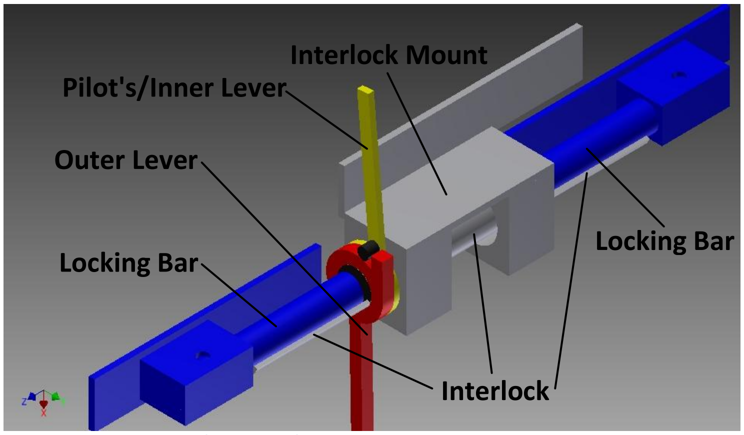

Figure 4.1 - Diagram of the latch for the pilot's hatch in the locked position.

Conclusion

Every one of Wolverine II's systems are new to the ISR, which has not been the case for our team in years. Even more significant, since we participated in the EISR, our the timeline for our design cycle was cut in half, condensing an increased amount of work into a smaller time frame. Despite this challenge, we have been able to include several innovations in our submarine's design, including chrome plating as a form of corrosion prevention, 3-D printing as a means of producing parts quickly, and redundancy in our safety system which, like our dive gear, is designed to fail in our favor by releasing the buoy. Much effort, care, and time have gone into Wolverine II, and we are excited to bring it to the race.