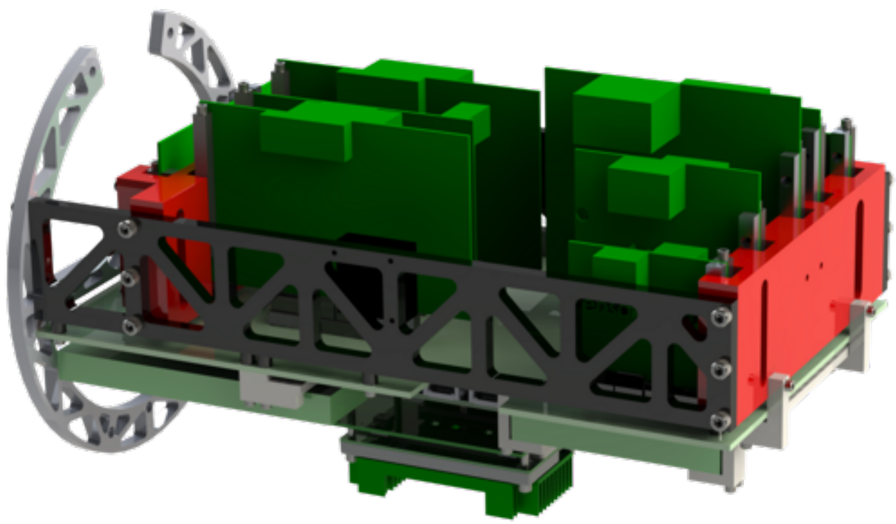
Cornell University Autonomous Underwater Vehicle Team

Fall 2019

Leviathan Racks



Technical Report

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1 Abstract

Since 2016, our team has built a minisub to aid our main sub in its tasks during the RoboSub competition. The upper hull pressure vessel (UHPV) of the minisub has been redesigned for our 2020 minisub, Leviathan. As a result of the change from a rectangular to a cylindrical UHPV design, the electronics racks have been redesigned. The electronics racks are structural components that hold all the printed circuit boards (PCBs) as well as off-the-shelf electrical components including the computer, USB hub, and Ethernet switch. The racks both secure these components while the sub is in motion and organize the components in a way that is easily accessible. This year's racks have an upper area, which secures the PCBs on a backplane, and a lower area, which secures the off-the-shelf components. The boards are secured using two aluminum towers that are mounted to trusses, which in turn mount to the backplane. The computer and Ethernet switch are mounted to a sliding plate under the backplane to allow for easy access, while the USB hub is mounted directly to the backplane. This racks design makes all necessary ports and boards accessible while remaining mounted to the UHPV.

2 Design Requirements

Constraints:

- Must hold the PCBs, SEACON backplane, computer, Ethernet switch, and USB hub
- Must fit inside the Leviathan UHPV
- Must make all the components easily accessible
- Must mount to the UHPV
- Must be machinable and structurally sound

Objectives:

- Maximize ease of access to components
- Minimize weight
- Optimize board placement for cooling, wire organization, and visibility
- Route wires towards the sides of the UHPV
- Allow for cooling of components through fans and heat sinks

3 Previous Designs

3.1 Odysseus (2019)

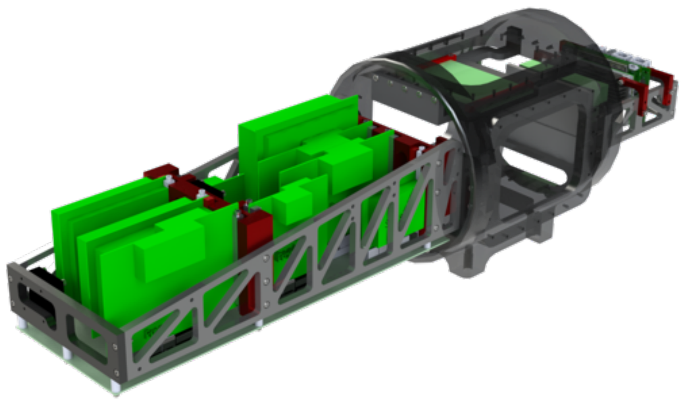

Figure 1: Odysseus racks

The Odysseus racks, like other main sub racks designs, had fore and aft racks. The fore racks contained all the PCBs, while the aft racks held off-the-shelf components. The fore racks had a two-tower, three-row design which housed between two and four boards per row. Cantilevers supported the towers and were connected to the backplane using standoffs. These cantilevers interfaced with an adapter plate that mounted to the midcap of the sub. The aft racks used aluminum brackets to mount the off-the-shelf components to trusses. The boards and off-the-shelf components were easily accessible without the use of a sliding mechanism. This design proved to be effective for a double-hull design. Although the design included room for fans, an objective going into 2020 was improving thermal regulation without the use of fans; as a result, the electrical sub-team determined new objectives for board arrangement. Additionally, the USB hub was not securely fixed to any structure on the Odysseus racks.

3.2 Ajax (2019)

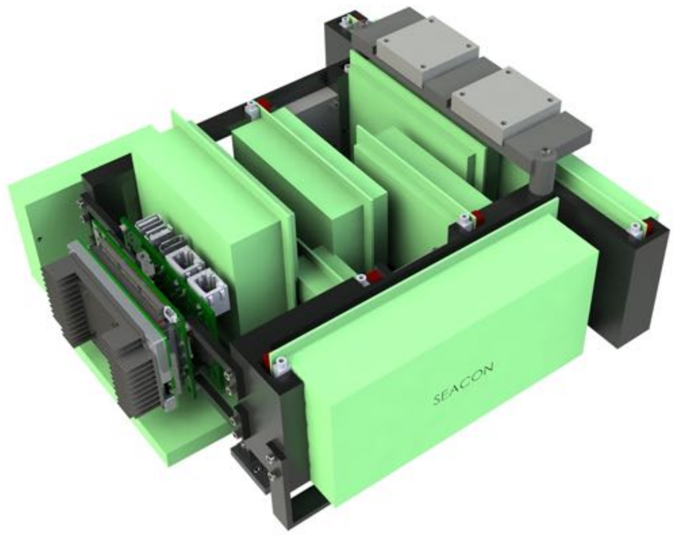

Figure 2: Ajax racks

The Ajax racks were designed to fit inside a rectangular minisub design. The racks were held in place using four mounting brackets, making the racks removable with the removal of eight screws. Like other racks designs, the Ajax racks utilized towers and wedgelocks to hold the boards in place. Separate mounting systems were put in place for the thruster boards, SEACON backplane, and computer. Four fans were placed in the sub, two of which were mounted directly to the towers, and two of which were mounted using a 3D printed bracket. One concern with the Ajax design was the use of many different L brackets and mounting systems. While the brackets ended up being easily machinable, mounting systems could be integrated better to support more components. As with other racks designs, thermal management continued to be an issue, especially in the small minisub enclosure.

3.3 Castor (2018)

Figure 3: Castor racks

As in past years, Castor featured a sliding rack system for the aft racks while the fore racks held the off the shelf components. In addition, the fore racks held the fore camera. Reusing Thor's midcap meant that the overall size constraints stayed the same. Castor's racks were certainly more robust than past years. The only problem with the aft racks was a miscommunication in manufacturing where tapped holes and clearance holes were switched, but that was able to be easily fixed. In the aft racks, the wedgelock and tower system remained effective. The boards were easy to access, and it was easy to implement. The brackets attaching the backplane were difficult to machine because they were so small and easy to deform if machined improperly. Some complaints on the aft racks were that there were no specific mounting places for fans, they were too condensed, and that the end cap did not have a heat sink. Considering all of these complaints would greatly improve thermal management over the electrical boards. In addition, more space between boards would allow the electrical team to more easily access and view their boards. The sliding mechanism did not end up getting widely used as the wires limited the movement of the racks. In addition, it took up space that could be used to space out the boards. More space is a major goal moving forward.

3.4 Pollux (2018)

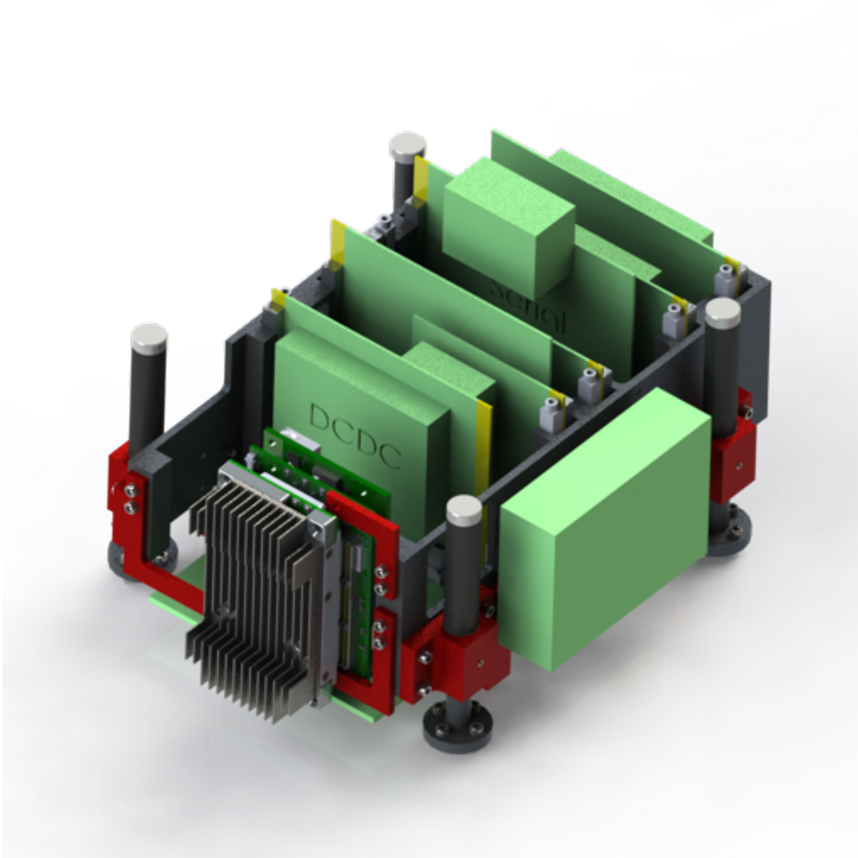

Figure 4: Pollux Racks

The racks for Pollux were designed specifically for the new UHPV manufactured in the same cycle. Thus, the UHPV's rectangular geometry has influenced the racks design for Pollux. It consisted mainly of two towers that hold the boards, four sliding bars, and auxiliary mounts for the Jetson computer and backplane board. All parts connect in some form to either of the main towers which have the ability to slide up to two inches out of the UHPV to allow for better access to the components. Clearances for the boards was based upon how tall a specific element or component is on each board and how much heat a specific board might emit. Explicit places for fans weren't directly addressed, and the use of a sliding feature for ease of access and easy debugging for the electrical team was rarely used. This was because of the large amount of wires that occupied the inner hull. In addition, it was much easier to remove the boards individually and then test them, as opposed to lifting the racks up. Therefore, Ajax's racks will not include a sliding feature and will address other shortcomings from Pollux's racks.

4 High Level Description

The minisub racks consist of three primary mounting systems: the mounting plate and trusses, which connect the racks to the UHPV; the towers, which secure the PCBs on the top of the racks; and the sliding plate, which makes the components on the bottom of the racks accessible. The mounting plate mounts to the end cap of the UHPV, and the trusses support the backplane and towers. There are two main towers that each hold four or five PCBs, and an attachment was made for the back tower to secure the SEACON backplane. The sliding plate on the bottom of the racks mounts to the front tower; the screws holding it in place are easily removable, allowing for quick access to the computer and Ethernet switch.

The boards were arranged with the constraint of the variable height of the top half of the UHPV and the objectives of organizing the wires and allowing for adequate cooling of all the components. To further organize the wires, a cutout was made in the backplane to allow wires from the serial board to connect to the components on the bottom of the racks. Furthermore, holes were added to the mounting plate to hold wires to the sides of the UHPV.

Multiple considerations were made to prevent overheating. The trusses support fans placed near two of the hottest boards; additionally, hotter boards were separated when designing the board placement. Finally, the computer was placed under the racks to separate its heat sinks from the boards.

4.1 Board Layout

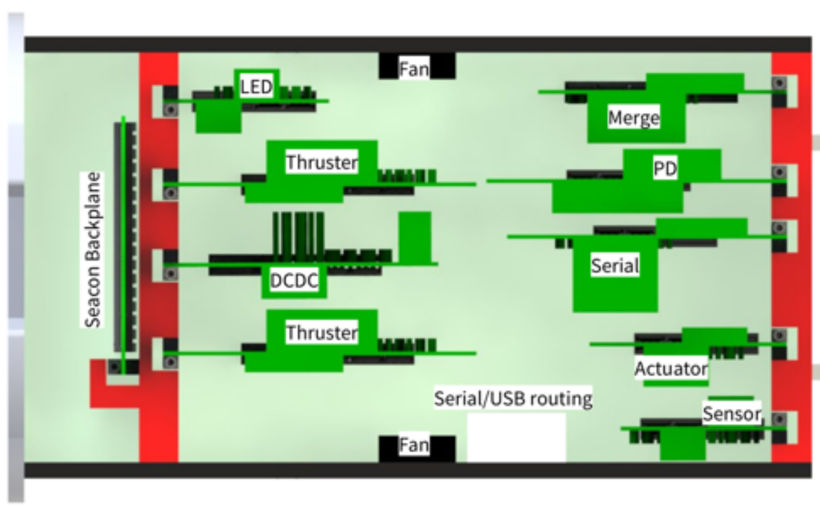

Figure 5: Board layout

The boards were placed parallel to the length of the sub with enough clearance between each of the boards for the largest components of each board. The boards were organized to fit into two towers to maximize use of the diameter of the sub and minimize the length of the sub. Boards were arranged to easily organize wires and separate hotter boards. The thruster boards were placed as far off to the sides and as close to the end cap as possible, as the end cap was designed to route the thruster wires to the sides. The merge, serial, and thruster boards were kept as far away from each other as possible to reduce overheating. The serial and power distribution (PD) boards were placed near the middle because of their height, but smaller boards were placed next to them to make the indicator LEDs on the boards visible.

Additional objectives, such as placing the DCDC board next to the merge board or keeping the sensor, actuator, and PD boards near the SEACON backplane were rated lower priority. As a result of the higher-priority objectives and the need to place taller boards near the middle of the racks, the lower-priority objectives could not be accomplished. These remaining objectives are detailed further in Section 6.

4.2 Mounting Plate

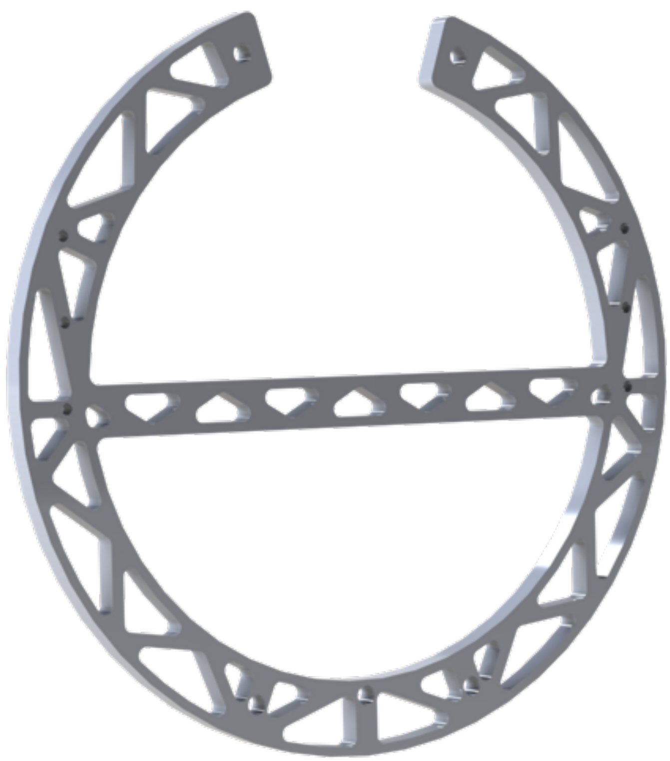

Figure 6: Mounting plate

Because Leviathan's end cap has mounting holes on the top and bottom, a mounting plate was made to secure the trusses in a configuration that leaves space for the top and bottom areas of the racks and maximizes the width of the racks. The mounting plate was designed around the 8-32 mounting holes on the top and bottom of the UHPV. The plate has a cutout at the top to accommodate the depth sensor that protrudes from the end cap. The plate also features three 4-40 holes on each side that allow the trusses to be mounted to it. To save weight, the aluminum plate has large cutouts around the center as well as triangular weight savings throughout. These weight savings also allow wires to be easily routed to the sides of the sub, as zip ties can be used to secure them to the sides.

4.3 Fore Tower

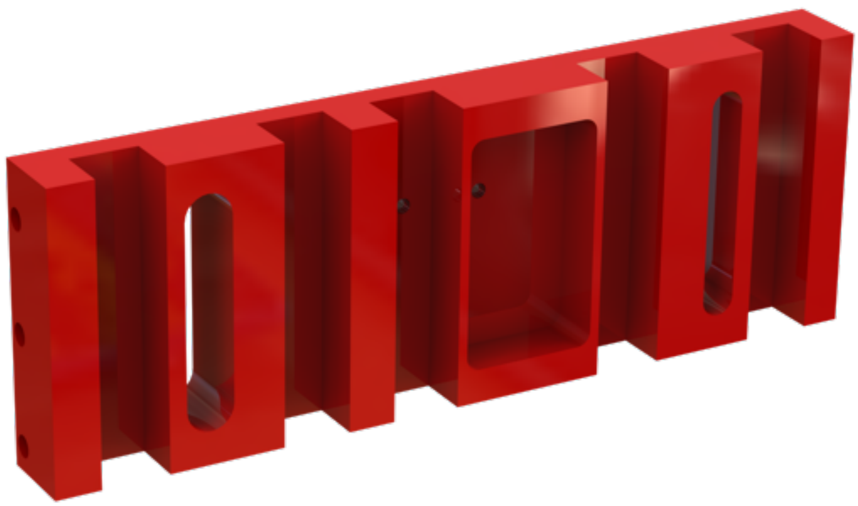

Figure 7: Fore tower

The fore tower is mounted to the trusses at the front side of the UHPV and secures five boards, the fore camera bracket, and the sliding plate. Because this tower is placed at the end of the backplane, it is not only secured by the trusses but mounted directly to the backplane. The boards the fore tower secures are the sensor, actuator, serial, PD, and merge boards. The cutouts for the boards are 0.5 inches wide and 0.4 inches deep to leave room for the spacers and wedgelocks that hold the boards in place. Holes are placed on the fore side of the tower to mount the camera bracket. Slots are used to reduce weight; the large rectangular slot near the center of the tower is 0.4 inches deep instead of through-all to leave room for the camera mounting holes. There are also holes near the bottom of the tower to which the brackets for the sliding plate are mounted. The ways in which the fore tower interfaces with the sliding plate are detailed more in Section 4.7.

4.4 Aft Tower

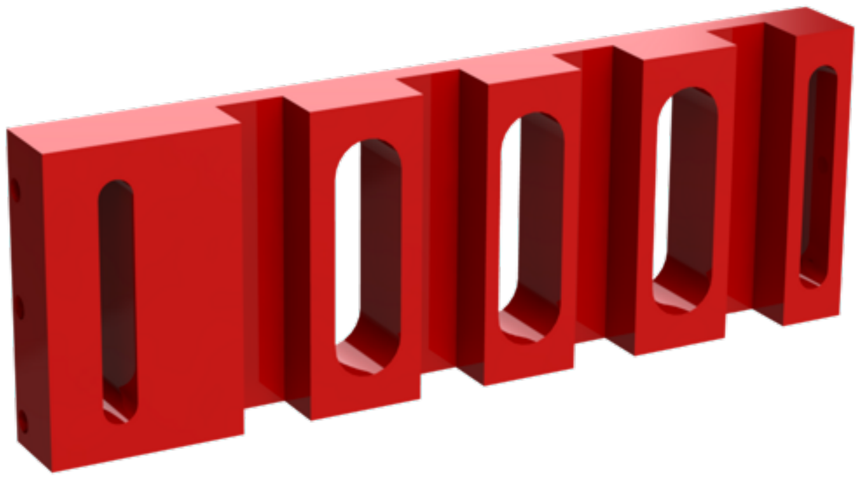

Figure 8: Aft tower

The aft tower is similar to the fore tower in its dimensions and purpose; it holds four boards and the SEACON backplane. Unlike the fore tower, it only interfaces with the trusses, as it is not near the edge of the backplane. The slots have the same dimensions as those on the fore tower and hold the two thruster boards, the DCDC board, and the LED board. It features more extensive weight savings than the fore tower, as it houses fewer boards and does not need to accommodate the camera mounting holes. Three holes near the side of the aft tower secure the SEACON tower (Section 4.5).

4.5 SEACON Tower

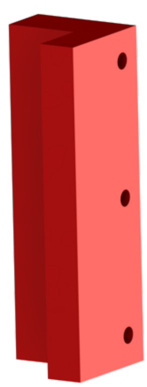

Figure 9: SEACON tower

The SEACON tower was designed to keep the SEACON backplane as close to the SEACON connectors as possible. Because the height of the SEACON backplane is greater than the vertical distance between the sides of the racks and the hull, the SEACON backplane was centered, and an additional tower was necessary to secure it. The tower interfaces with the aft tower using three mounting holes and shares the dimensions of the slots on the fore and aft towers. Because the tower is not near an edge of the backplane, it does not interface with the backplane itself.

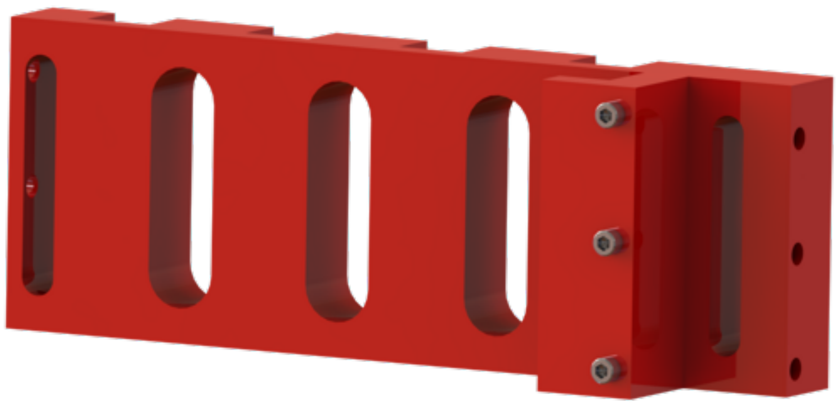

Figure 10: SEACON tower mounted to the aft tower

4.6 Trusses

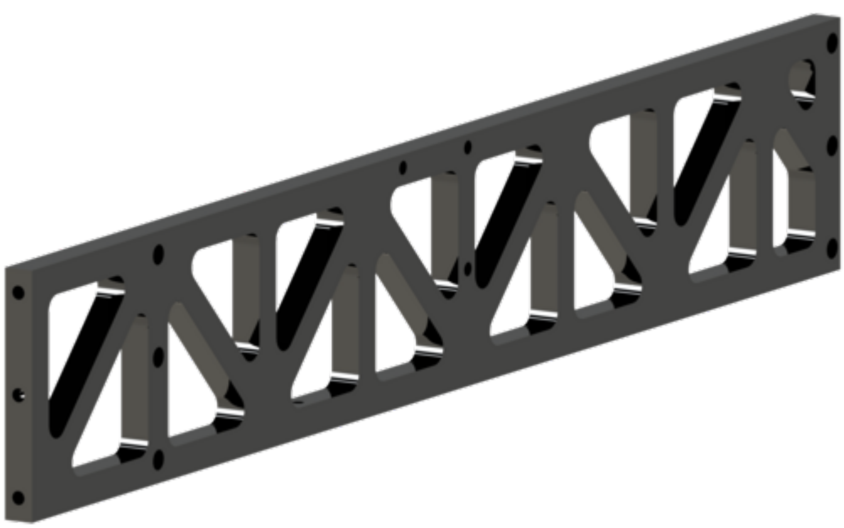

Figure 11: Truss

The trusses are structural components that are mirrored on both sides of the sub. They interface with both towers, the backplane, and the mounting plate. They support the aft tower completely and provide additional support for the fore tower. The backplane is mounted to the trusses using three holes on its sides. The brackets that support the sliding plate on the bottom side of the racks are also mounted to the trusses using standoffs. The trusses also have holes that allow fans to be mounted on each side of the racks. Extensive weight savings make the trusses lightweight but structurally sound. The trusses were placed as far off to the sides of the sub as possible while still allowing them to be as tall as the towers. Because the components on the top and bottom of the racks need both ample vertical room and to maximize use of the width of the sub, the trusses have very little room between their outer edges and the 7.5-inch-diameter collar of the UHPV. As a result, the outer edges of the trusses may have to be chamfered to fit.

4.7 Sliding Plate

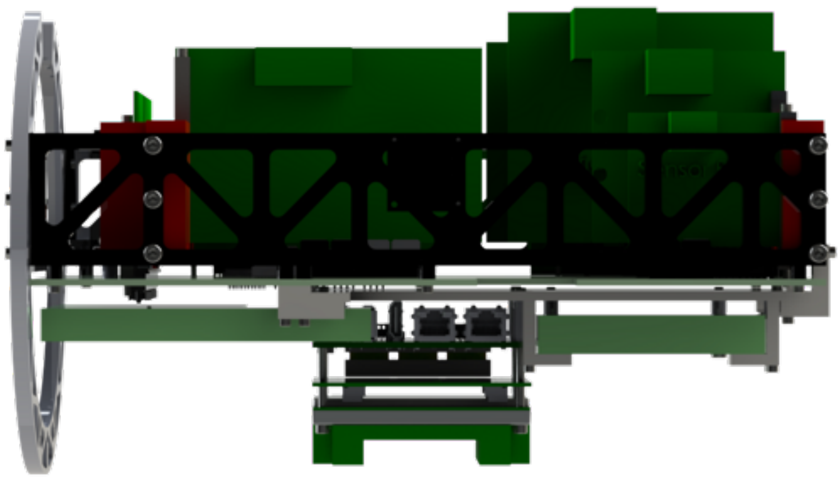

Figure 12: Sliding plate

The sliding plate was designed to make the Ethernet switch and computer accessible. The computer, Ethernet switch, and USB hub are placed on the bottom of the racks to maximize use of the diameter of the sub and minimize the length of the sub. Static mounting to the bottom of the racks would make the computer and Ethernet switch largely inaccessible for maintenance. The sliding plate secures the computer and Ethernet switch while the sub is in motion but allows both components to be removed from the bottom of the sub when the software sub-team needs access. While the sub is in motion, the lights on the Ethernet switch are still visible through the hull, and the ports on all the components on the bottom of the sub face towards the cutout in the backplane to optimize wire routing.

It was found that the USB hub did not need to be removed; as a result, it is mounted directly to the backplane using Velcro. To maximize use of the length of the UHPV, the

USB hub is mounted to be slightly lower than the sliding plate, allowing the plate to slide back and forth above the hub without interference.

To mount the Ethernet switch, L-brackets are mounted to the sliding plate. Like the aft mounts for the sliding plate, the Ethernet mounts allow the Ethernet switch to slide into place. The switch is then mounted using standoffs and holes on the opposite side of the UHPV. This design makes the Ethernet switch easily removable from the sliding plate assembly.

The computer is mounted using standoffs. Screws hold the computer together while screwing into the standoffs, and screws at the top of the sliding plate hold the sliding plate and computer together. The computer can therefore be removed from the sliding plate without disassembling the computer itself.

The arrangement of these off-the-shelf components is shown in Figure 13 below.

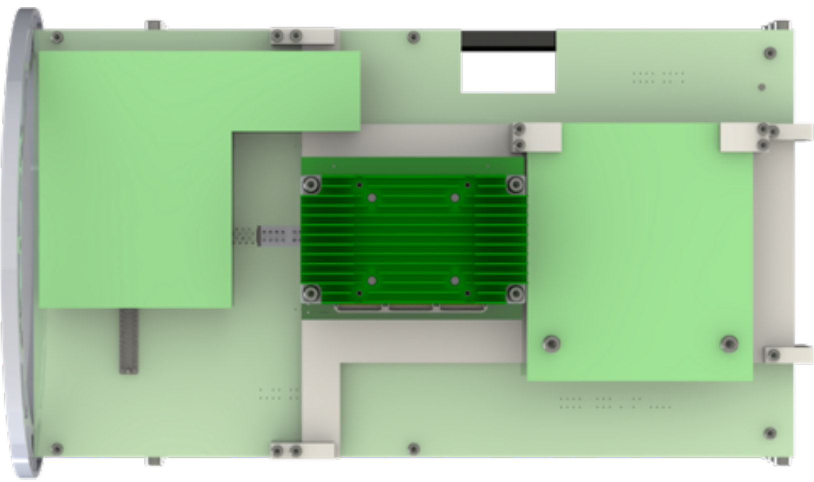

Figure 13: Layout of off-the-shelf components below the racks

Mounting components of the sliding plate interface with the fore tower and the trusses. At the fore end of the sliding plate, the mounts are directly attached to the plate, and the mounts attach to the fore tower using easily accessible and removable screws. The mounts on the aft side of the plate remain in place, and the plate is placed in position without any screws. No parts of the aft mounts are removed when the sliding plate is removed. The configuration of the plate and the off-the-shelf components when the plate is slid out is shown in Figure 14 below.

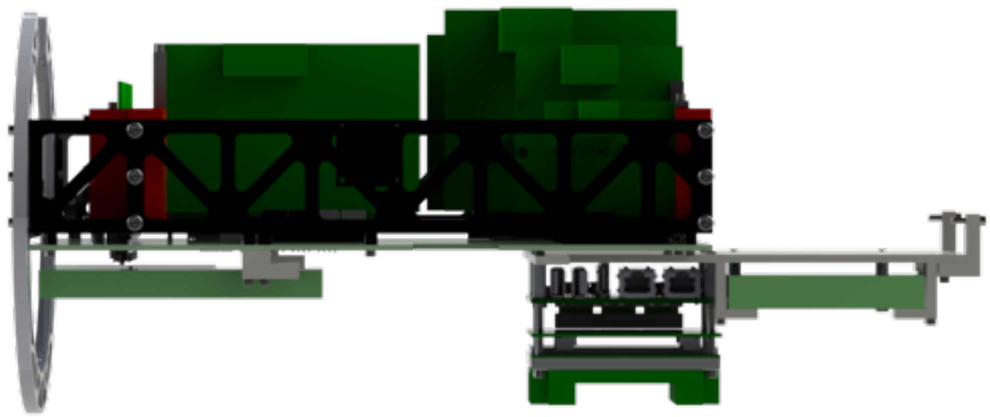

Figure 14: Sliding plate

5 Current Status

The design for the racks has been finalized, but manufacturing will not begin until the spring semester. The electrical sub-team has received the dimensions, hole placement, and cutout placement for the backplane and is finalizing board layouts that fit the racks. Drawings for all the parts that will be manually machined have been uploaded to Jira. The trusses and mounting plate will be manufactured using a CNC mill because of the complexity of the weight savings.

6 Future Improvements

Because of various constraints and some higher-priority objectives, the board arrangement did not meet all of the electrical sub-team's objectives. Because the serial and PD boards have important indicator LEDs on them, these boards would ideally be placed off to the sides; however, because of the boards' height, this goal was not accomplished. Likewise, the PD, DCDC, and merge boards could not be placed as close together as desired, and the sensor, actuator, and PD boards were not near the SEACON backplane. In the future, it would be useful to explore changing the dimensions of the boards to fit an ideal board arrangement instead of arranging the boards based on predetermined board dimensions.

Furthermore, while placing the off-the-shelf components on the bottom of the racks is very spatially efficient, the components are all very tightly packed in the UHPV. As a result, parts such as the trusses may have to be modified slightly to fit better.

Appendices

A Finite Element Analysis

To ensure the Leviathan racks are structurally sound, a 90 Newton force was applied to the racks, and both displacement and stress on the racks were modeled. Additionally, a first mode analysis was conducted to observe the effects of vibrations on the racks.

A.1 90 Newton Force Test

The 90 Newton load simulated a "toddler test," or a model of the load the racks might be under. For these simulations, the holes by which the mounting plate would be attached to the end cap of the sub were fixed. When a 90 Newton force was applied to the racks, the maximum deformation was found to be on the fore end of the racks at .1113 inches. The maximum stress occurred on the mounting plate at 239 MPa, which yielded a factor of safety of 1.13. While this is a fairly low factor of safety, the maximum stress occurred at a location on the mounting plate where it should not have occurred, so the maximum stress and factor of safety values are likely inaccurate.

Max Stress	2.393×10^8 Pa
Factor of Safety	1.13
Max Deformation	.1113 in

Table 1: 90 Newton Force Test

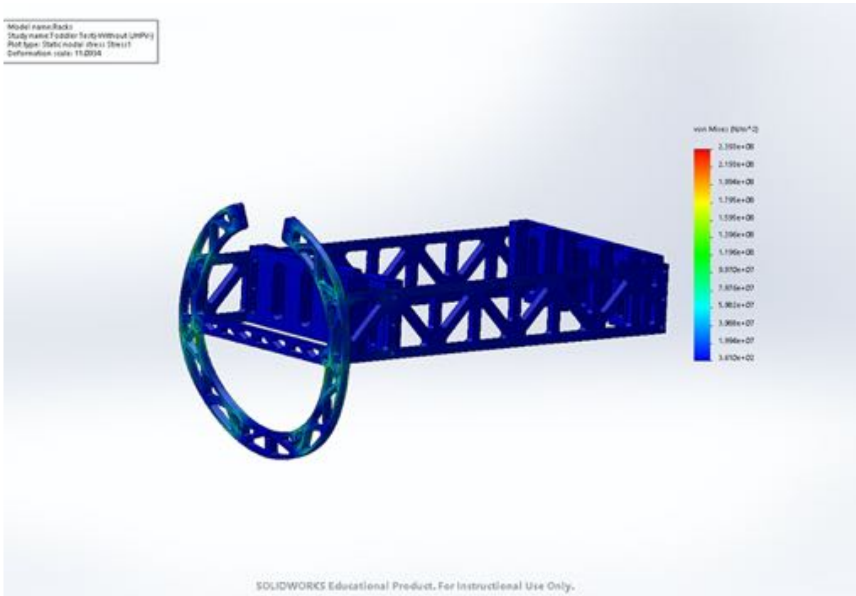

Figure 15: 90 Newton displacement test

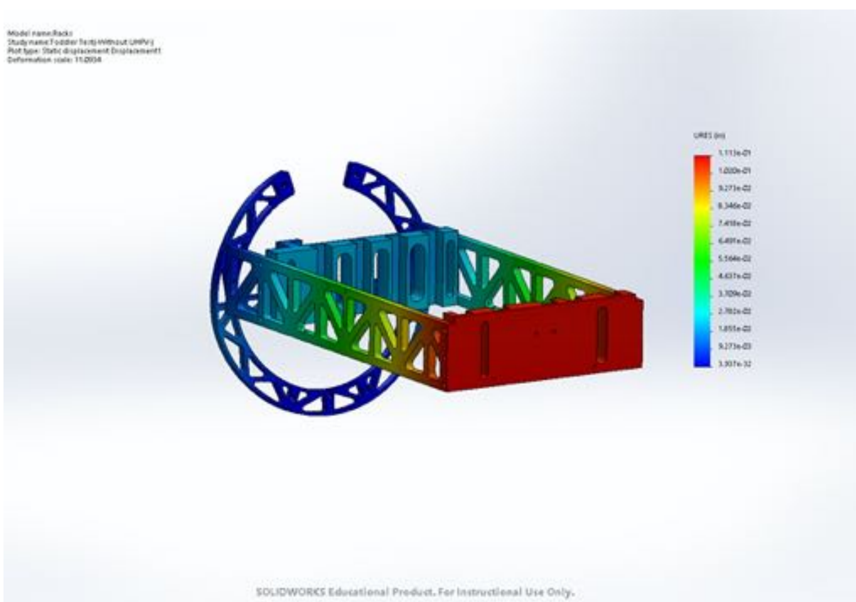

Figure 16: 90 Newton stress test

A.2 First Mode Frequency Analysis

Mode analysis was conducted to see how the racks would fare under vibrations. We want to achieve a first-mode frequency of at least 30 Hz. This is a relatively standard vibration comparable to the vibration in a car driving down a smooth road. To maximize how robust the racks are, however, our target is 50 Hz. The Leviathan racks had a first-mode frequency of 39.581 Hz. This is acceptable but not optimal.

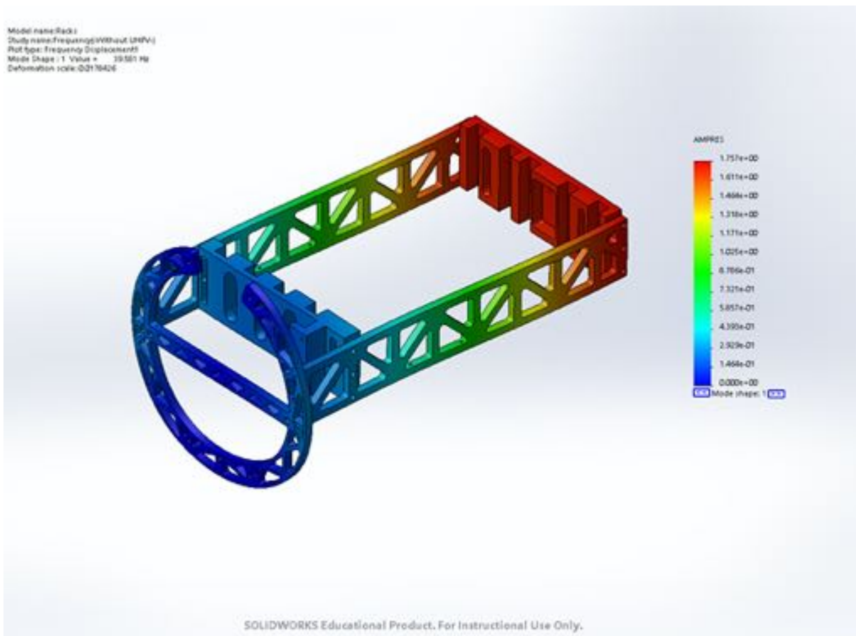

Figure 17: First mode frequency analysis