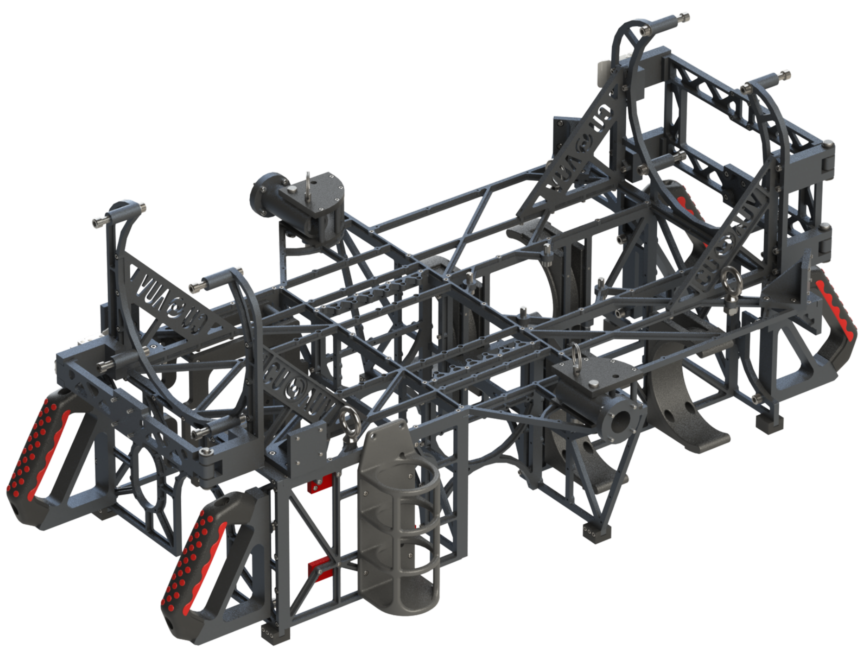
Cornell University Autonomous Underwater Vehicle Team

Spring 2019

Odysseus Frame



Technical Report

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Contents

1 Abstract

The frame is the backbone of each AUV's mechanical structure, dictating the locations of all enclosures, sensors, and actuators, and therefore the way which the vehicle will interact with its surroundings. Beyond a base level of being structurally sound, manufacturable, and mounting all required components, the frame's design is complex optimization problem which has to account for what is optimal for the submarine's function, what will be serviceable over the course of the season, and what is space efficient, among other factors. Since freshmen members were added to the team much later into the design cycle this year compared to previous years, a large amount of space and mounting flexibility was left around their projects compared to the tighter packaging elsewhere on the frame.

2 Design Requirements

2.1 Constraints

- Mount all enclosures (Table 1)
- Mount all additional components (Table 2)
- Be structural
- Be manufacturable
- Be assemblable
- Protect critical components
- Fit through Teagle Hall pool doorways ($\sim$ 25in.)

2.2 Objectives

- Have hydrophones in the front, away from thrusters, with the trigger element forwards
- Have helpful actuators placement relative to cameras
- Have dedicated space for trim weights and/or foam
- Leave more space for getting the hull on and off than on Castor
- Not require post-anodization modifications
- Have easily unmountable enclosures
- Provide space for clean cable routing
- Have comfortable handle placement
- Not obstruct access to the racks
- Fit through doorways *easily*
- Minimize overall weight

3 Previous Designs

3.1 Gemini (2014)

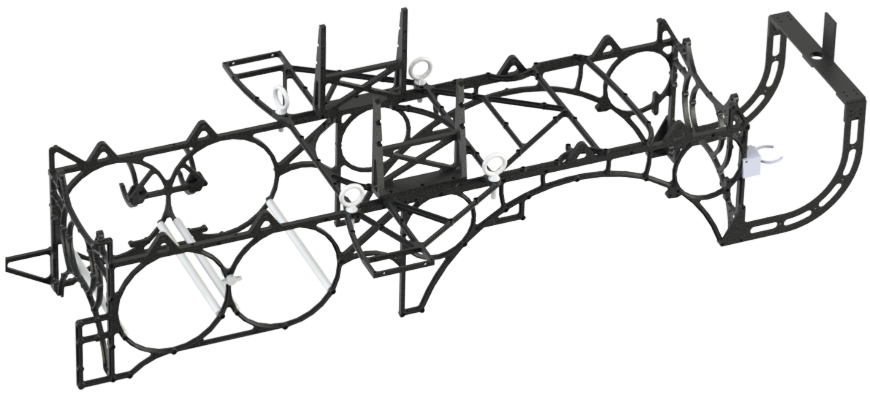


Figure 1: Frame from Gemini

The Gemini frame was the first frame for a dual-hull design. This departure from all past designs yielded significant design changes, especially evident in a large reduction in vehicle height and a slight decrease in width, largely because Gemini wastes less space than the final mono-hull mainsub, Ragnarök (2013). Aesthetically, the design utilizes more arcs than previous truss-based frames. It maintained the same thruster configuration as in Ragnarök and Argo, although it too lacked vector thrust. The frame was composed of just five main pieces, with hold down blocks for the endcaps hulls directly on the front and back pieces. There were additional brackets for the forward manipulator and for supporting the midcap.

Unlike past years, the design of Gemini emphasized forewards compatibility and involved additional holes specifically for unforeseen purposes. With its four handles, and the lightest and smallest design to date, the vehicle was easily picked up by two people. The battery pods were placed under the front hull, rather than on the sides, and secured with a simple thumb screw so as to avoid e-clips. Geminis design was able to stay rigid under deflection in large part due to heavy use of finite element modeling, and because of brackets which secured the midcap to the frame. Several issues presented themselves after the frame was designed; namely, the competition necessitated additional grabbers, which were placed outside of the surge thrusters and behind the vehicle. These grabbers needed delrin supports, because the rules changed quite radically, but Geminis extra holes made this design straightforward. Gemini's frame presented some means for improvement. Its pneumatic components were placed far from each other,and the valve enclosure had to be taken off to access the hydrophones enclosure. Also, Geminis DVL was high off of the ground, which meant that space under the vehicle could not be fully used in order to attempt avoiding interference with its beams. However, it is possible that Geminis frame was too close to these beams, so there may have been interference at several points. Gemini's frame was the last to be CNC machined, as all frames since Argo (2015) have been waterjetted.

3.2 Argo (2015)

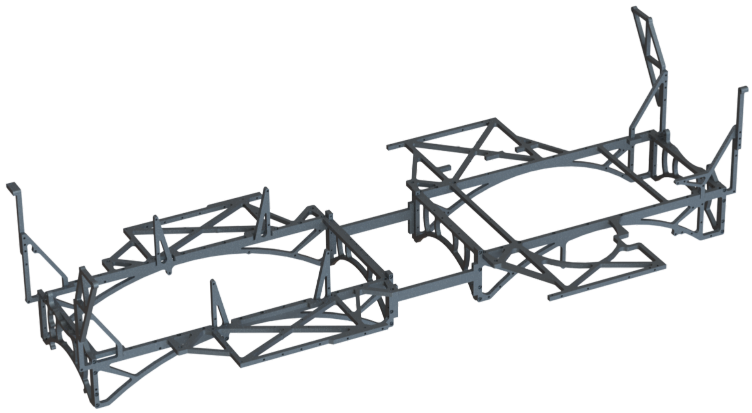


Figure 2: Frame from Argo

Unfortunately, Argo's frame may have been in many ways a step backwards. The frame, though very lightweight and extremely compact, bent excessively in its middle portion, resulting in a corresponding misalignment and unnecessary stress on the vehicles two main hulls, which somehow were still able to seal. The frame deflected around nearly every other enclosure as well - the eight thrusters were all poorly secured and vibrated easily. The largest design oversight was the lack of lifting handles. Several more components were either not designed with a mounting scheme in mind or were changed, which led to some hastily redesigned mounts and a few components being secured by cable ties and hose clamps. CUAUV paid out of pocket for most of these new mounts to be fabricated in the Clark Machine Shop,which contributed to a budget deficit which was then inherited by the 2015-2016 Team. Argos frame was initially planned to be roughly waterjet cut and then finish CNC milled, however because of time constraints the CNC milling did not occur, leaving a rough surface finish and many misaligned connections, such as those for the hinged sway thrusters.

3.3 Thor (2016)

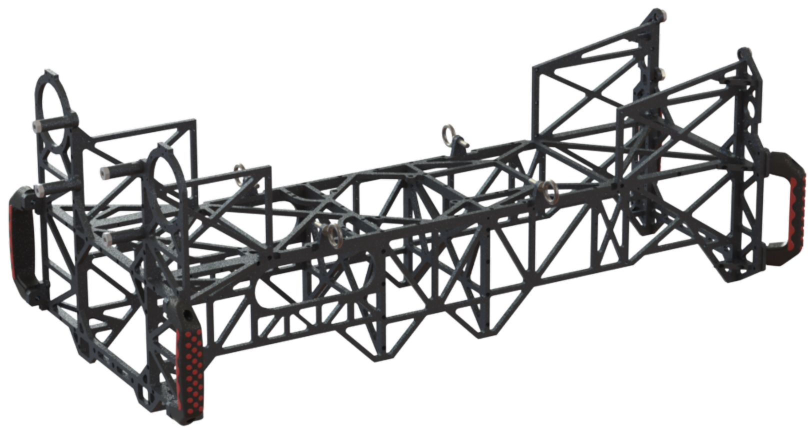


Figure 3: Frame from Thor

Thor's frame design aimed to fix the issues that were present in Argo's frame design, principally Argos frames large deformations, long manufacturing time, misalignment, and poor vehicle serviceability. Thors frame utilizes the spaceframe concept implemented from Killick (2012) onwards. The frame pieces however do not use the T-profile found in earlier frames in an effort to decrease manufacturing time by only requiring waterjetted parts and adding holes, since this was an issue last year and it is necessary that the frame be entirely completed in order to assemble the barebones AUV and perform the first in-water testing. This in addition to increased emphasis on stiffness and vehicle size came at the price of a heavier vehicle frame.

Thor's frame worked well in that it successfully avoided Argos problems of structural integrity. It was easy to carry though the vertical handles were uncomfortable at times, and most components were easy to mount and unmount, though some enclosures with dual purpose sealing/mounting holes proved problematic. Additionally, the thruster wings allowed the thruster streams to not interfere with each other or SEACON wires. The biggest complaint was that Thor's frame was fairly bulky, but getting the frame waterjetted allowed for ease of manufacturing.

3.4 Artemis (2017)

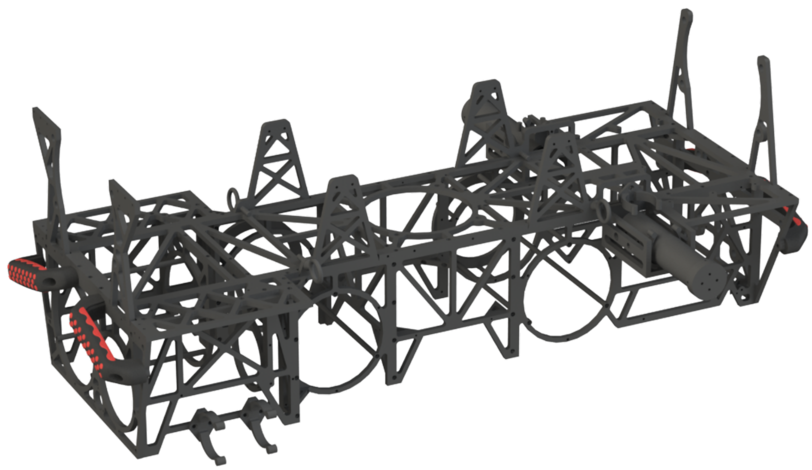


Figure 4: Frame from Artemis

Artemis' frame was a direct successor to and improvement upon Thor's frame. It was also designed to be manufactured by waterjet. Artemis featured many experimental projects such as vector thrust and active ballast causing the frame to be more constrained than in the past, though the projects were never fully implemented on the vehicle. The frame also featured connections to the UHPV that were meant to make removing the hulls easier. Due to misalignment the attachments never made it on the vehicle and made it harder to remove the hulls. The frames hold down blocks were also not well supported and bent when the bolts were tightened. Additionally, there were many interferences leading to parts being hack sawed so the frame pieces fit together.

One of the major successes of Artemis' frame is the implementation of pipe clips to hold the swinging surge thrusters in the upright position. The design change combined with locking pins to keep the arms in place when in use made putting the vehicle in water easier. Another improvement was the handle placement as it was a lot more comfortable carrying the vehicle with angled handles. With the return to removable battery pods from the battery enclosures present on Argo/Thor, Artemis' frame featured delrin sliding rods with a bungee cord locking mechanism in order to easily remove and replace pods.

3.5 Castor (2018)

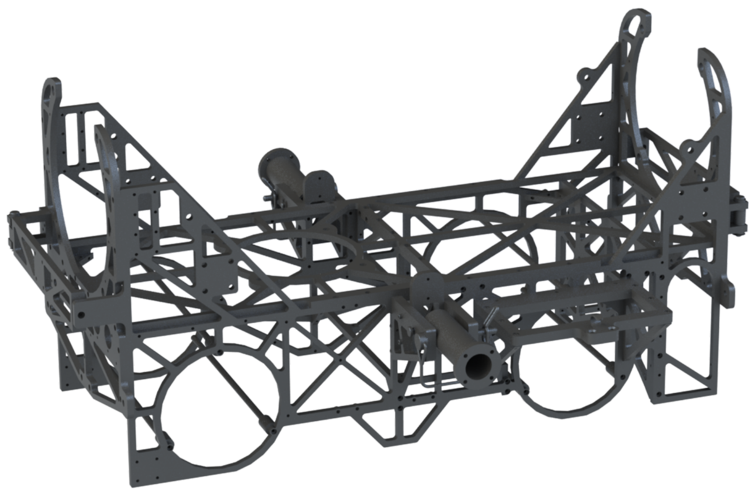


Figure 5: Frame from Castor

Due to a massive reduction ($\sim$ 8in) in UHPV length between Artemis and Castor, Castor's frame was in many ways an ultra-compact successor to Artemis' frame. With the major reduction in length, as well as temporary elimination of external camera enclosures on Castor (thanks to a clear fore endcap and repurposing of the midcap's DVL port), the packaging of components on Castor's frame was relatively dense; the end result of this packaging was a small and sleek submarine but at the cost of some serviceability and loss of space to add trim foam/weights. The frame also lacked space to mount manipulators due to the mid-design cycle revelation of a new recovery element, which caused the manipulator to be mounted below the ground plane of Castor and required them to be removed whenever the vehicle was out of the water. Castor also featured the delrin rod battery pods mounts from Artemis, as well as a delrin mount for the valve enclosure which slid in vertically on the side of the vehicle.

Castor's frame featured further refinement of the swinging thruster wings pioneered on Thor, with the entire arm being a single machined piece to eliminate the alignment issues present on Artemis' wings. These wings featured the same tube clips as on Artemis, but interference with SEACON wires once the collision mitigation shrouds had beed added meant the clip could not be engaged. Additionally, Castor's frame removed the need to attach thrusters to the UHPV's endcaps by implementing horizontal swinging thruster mounts for the sway thrusters which move out of the way in order to remove the hulls.

4 High Level Description

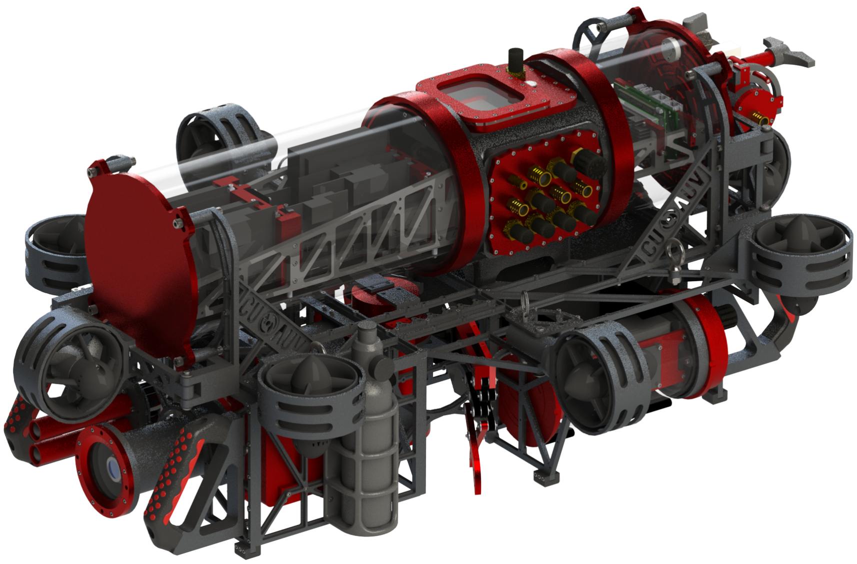


Figure 6: Odysseus

Odysseus's frame aims to improve upon Castor's frame's approach to packaging a shorter vehicle by drawing heavily upon the multi-width elements of Artemis' (2017) frame. This is in response to new mounting position requirements for the hydrophones enclosure as well as to maximize flexibility in terms of incorporating freshman members' designs as their timeline has been pushed back by a month and a half. Additionally, the frame sees a return of T-profile members last seen on Gemini thanks to manufacturing assistance from DATRON Dynamics West. Since having the frame pieces produced at DATRON reduces a significant portion of the frame manufacturing burden (since the only remaining in-house operation is to add tapped holes on their ends) as well as guarantees significantly better tolerancing than in-house or waterjetted parts, the number of main plates in Odysseus' frame can comfortably increase without much worry about tolerance stack issues.

Comprehensive lists of all enclosures and other components which mount to the frame, as well as their placement restrictions/desires are available below in Tables 1 & 2. All machined components referenced should be assumed to be 6061-T6 Aluminum unless otherwise specified.

[1] **Ground Plane:** the plane of the ground if the vehicle is sitting on a flat surface, clearance above it is required for fragile components in case there are objects on the ground (ie. screws, rocks, cables, etc.) which might damage them.

Enclosure	Qty.	Placement Restrictions
UHPV	1	Centerline of vehicle, clearance for removing hulls, clearance around SEACON panels
Hydrophones	1	Front of vehicle, elements pointing down but with clearance above the ground plane,[1]away from thrusters, trigger element in proper orientation relative to front of vehicle
Sensor Boom	1	Away from thrusters and other sources of electrical noise, aligned to main axes of vehicle
Foreward Camera	1	Front of vehicle, viewcone unobstructed
Downward Camera	1	Bottom of vehicle, centerline of vehicle preferred, viewcone unobstructed, clearance above ground plane
Killswitch	1	Aft of vehicle
Valve Enclosure	1	Anywhere the push-to-connects are easily accessible, must be easily removable
Battery Pods	2	Anywhere provided they are easily removable

Table 1: Enclosures List

Component	Qty.	Placement Restrictions
DVL	1	Bottom of vehicle, unobstructed sensing cone, clearance above ground plane
Handles	4	Fore and aft ends of vehicle, symmetric about midplane of vehicle, angled as to be ergonomic
Torpedo Tubes	2	Fore end of vehicle, near each other, close to fore camera, far enough from fore camera to not obstruct it (always or with bubbles)
Dropper Tubes	2	Bottom of vehicle, near each other, close to downward camera, far enough from downward camera and DVL to not get bubbles trapped on them
Manipulators	2	Symmetric relative to the downward camera and about the center plane of the vehicle, close to but with clearance above the ground plane
Thrusters	8	Preferrably coplanar about the center of mass of the vehicle, symmetry about the center plane of the vehicle (for depth thrusters), away from where SEACON protrude from the UHPV when in use (for surge thrusters)
Air Tank	1	Easily removable for refilling, somewhat near the valve enclosure
Eye Bolts	4	Spread out to the far corners of the vehicle, not obstructed after assembly and cable managment

Table 2: Non-Enclosure Components List

4.1 Plates

The following plates are the primary structure of Odysseus's frame.

4.1.1 Top Plate

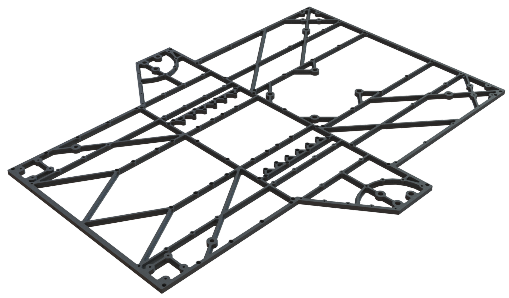


Figure 7: Frame Top Plate

The top plate is the primary interface between all of of the components of the frame, and as such all other pieces will be manufactured treating their interface with the top plate as a datum surface in order to minimize tolerance stacks. In addition to the other plates of the frame, the top plate also includes mounting holes for the UHPV, downward facing camera, sensor boom, and depth thruster blocks, with optional mounting holes for the manipulator and dropper assemblies. Since the top plate will interface with freshman projects and must be sent out for manufacturing before those designs are finalized, it includes a number of members which may ultimately be unused, but exist to give these projects flexibility in their final mounting to the frame.

4.1.2 Fore End Plate

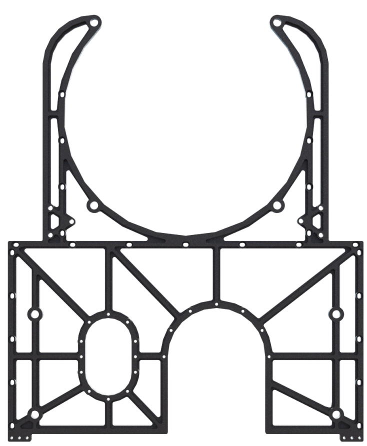
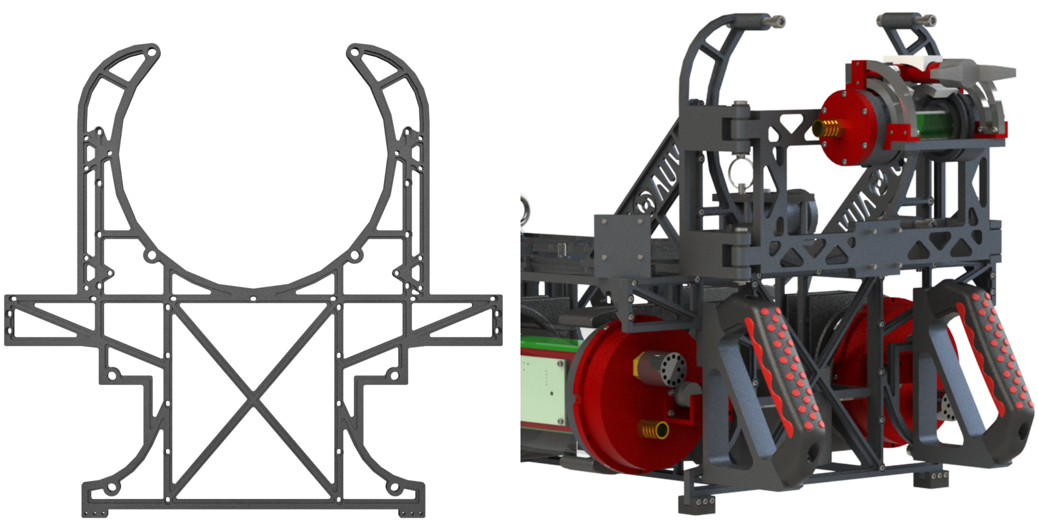


Figure 8: Fore End Plate

The fore end plate mounts onto the fore end of the top plate (Section 4.1.1), and interfaces with the foreward camera, torpedo tubes, fore sway thruster mount (Section 4.3), handles, and fore hull of the UHPV. The foreward camera mounts to standoffs which interface with the bolt circle on the port side of the front end plate, with a slot to the bottom allowing for the camera hull's rear flange to be within the frame while the rest of the camera and mounting are in front of it. The torpedo assembly interfaces with the other bolt pattern next to the camera mounting. The fore sway thruster assembly mounts to two sets of three mounting holes on either side of the large cutout for removing the UHPV's fore hull.

4.1.3 Aft End Plate



(a) Aft End Plate

(b) Aft End Plate and Enclosures

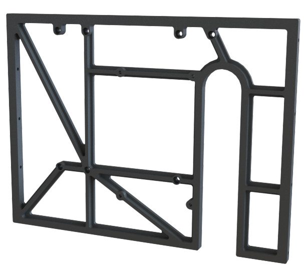
Figure 9: Aft End

The fore end plate mounts onto the aft end of the top plate (Section 4.1.1), and interfaces with the aft sway thruster/killswitch assembly (Section 4.4), handles, and the aft hull of the UHPV. The cutouts on the sides of the plate allow for the battery pods' SEACON connectors to pass through the plane of this plate, while their handles fit snugly behind it,[2] so some care must be taken when mounting them to ensure they are snapped into their clips (Section 4.6.1) in the correct orientation.

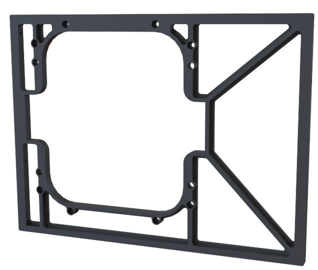
[2]Besides Hades, which may need to have its handle removed because it is mysteriously 0.125" longer than all of the other pods.

Figure 11: Enclosures, Plates, and Mounting at the Fore End

4.1.4 Fore Port & Starboard Plates



(a) Port Plate



(b) Starboard Plate

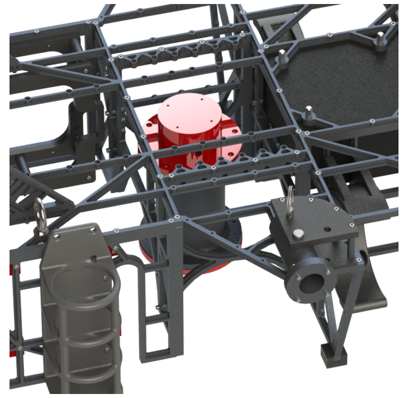
Figure 10: Fore Port & Starboard Plates

The fore port and starboard plates flank the sides of the enclosure mounting space at the for end of Odysseus. The hydrophones enclosure mounts to the fore port plate via a set of small blocks to avoid breaking more screws off in hydrophones enclosure mounting holes, while the valve enclosure mount (Section 4.5) attaches to the fore starboard plate. The fore port plate features a long slot in it for the transmit SEACON on the bottom of the hydrophones enclosure, and is long enough that the enclosure and its SEACON have clearance to be slid into position from below the frame.

The positioning of the hydrophones enclosure towards the front of Odysseus and orientation of its piezo elements was one of the first decisions in the frame which was finalized. Since the elements need to be in certain orientations to properly track the pinger in TRANSDEC (causing Castor to track better in reverse) as well as being far from thrusters, it was beneficial to decide on a location and orientation for the enclosure early on so that requirement would be satisfied through all stages of the design process.

4.1.5 Center Port & Starboard Plates

(a) Center Port & Starboard Plate

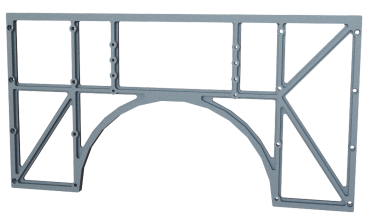


(b) Downward Camera and Droppers

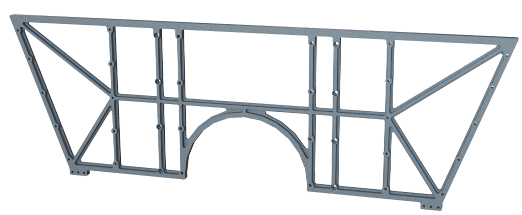
Figure 12: Center Port & Starboard Plates

The Center Port & Starboard plates flank the downward camera and dropper assemblies near the center of the vehicle. Unlike other plates on opposites of the vehicle, these two are completely identical since they are symmetric, though their part files remain separate in SolidWorks in case their designs diverge at a later date through post-manufacturing modifications like drilling out some holes. The arches at the bottom of each plate minimize possible conflicts with the camera viewcone or droppers launch path.

4.1.6 Crossbars



(a) First Crossbar



(b) Second Crossbar

Figure 13: Frame Crossbars

The crossbars provide an interface between the different widths of primary plate structure along the length of Odysseus. Besides this role they include a number of spare mounting holes for the sensor boom and manipulators. Though screws will pass through these plates from both directions, only the side visible from the outside of the frame has counterbored holes to save a manufacturing setup.

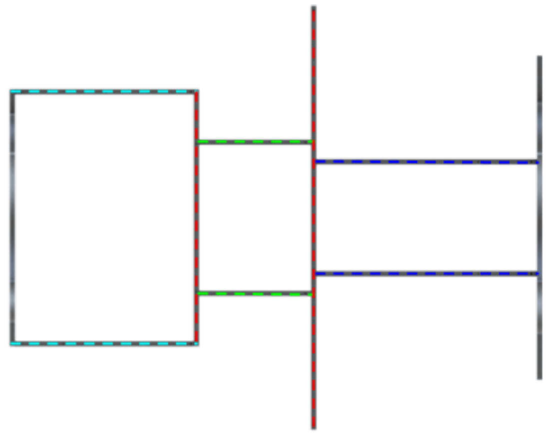
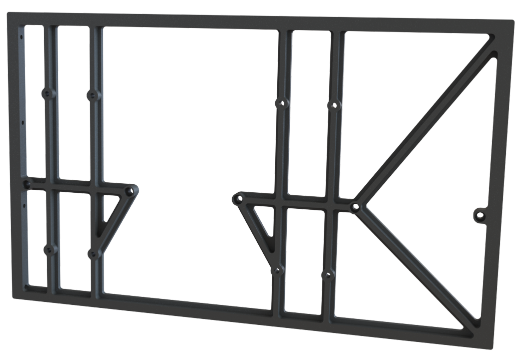
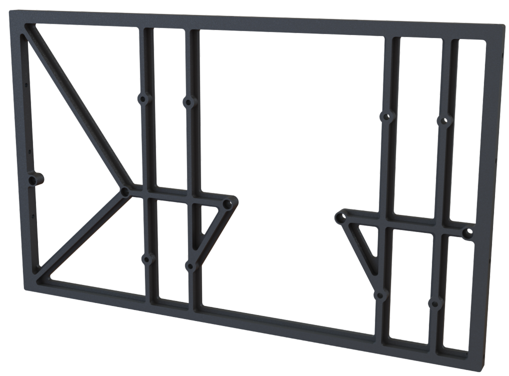


Figure 14: Crossbars (red) Changing Width of Frame Structure

4.1.7 DVL Plates



(a) Port DVL Plate



(b) Starboard DVL Plate

Figure 15: DVL Mounting

The DVL plates provide mounting holes for the DVL mount (Section 4.7.5) and the battery pods clips (Section 4.6.1) and are mirrored versions of each other (since their T-profile and counterbores are on opposite sides).

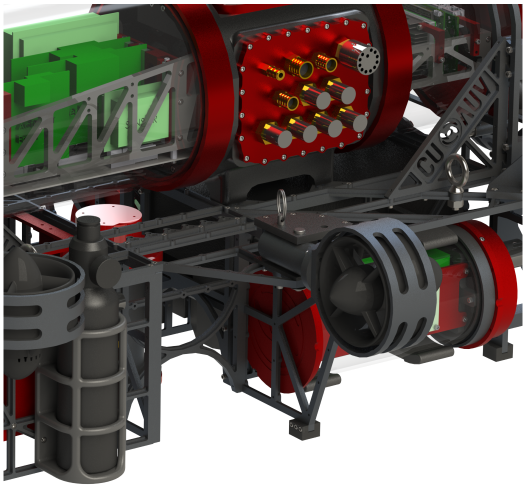
4.2 Surge Thruster Wings

Figure 16: Surge Wing Assembly

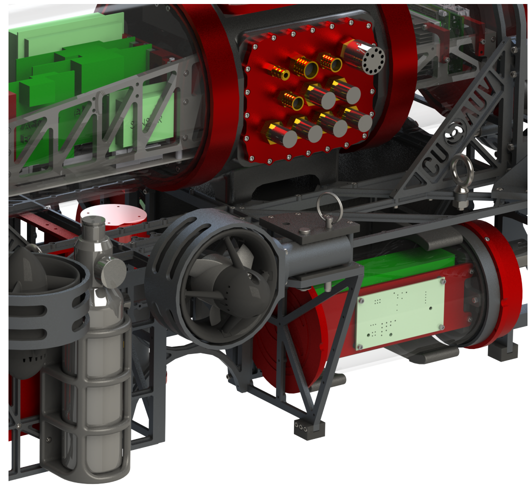
The surge thruster wings allow for the surge thrusters to be manually actuated between a stowed position for transport and an extended position where their streamlines will not conflict with other components or SEACON cables during operation. All three previous iterations of surge thruster wings (on Thor, Artemis, and Castor) have involved a vertical pivot, stowing the thruster wings upwards towards the side of the vehicle. Due to a combination of uncertainty regarding the position of the SEACON panels relative to frame components, conflicts between the cable and thruster on Castor, desire to keep all thrusters approximately co-planar, and blocking out space for the manipulators to the sides of the downward camera, a horizontal pivot was selected over the past vertical pivot.

The surge wing pivots on a clevis pin (McMaster 92735A260) between two sheets of delrin, and is locked into place by a quick release pin (McMaster 98404A960). The total distance which the surge thruster travels is lower than previous iterations, partially because the thruster wing is placed farther from the center plane of the vehicle in the first place, though the vehicle has a similar width in the stowed configuration. The pin locking mechanism should prove more easy to use and less likely to drop onto the bottom of Teagle pool than the previous locking mechanisms since the pin can be tied off onto a nearby piece of the frame. Additionally, the pivot and locking holes are machined into the top plate of the frame since that component will be manufactured by DATRON.

The fact that there are no components not attached to the frame (the quick release pin is tied off to a nearby plate) has made this new swinging thruster design very user friendly since there is no risk of losing the locking mechanism/dropping it to the bottom of the pool as there was on previous frames.



(a) Extended



(b) Retracted

Figure 17: Port Surge Wings Positions

4.3 Fore Sway Thruster Swinging Mount

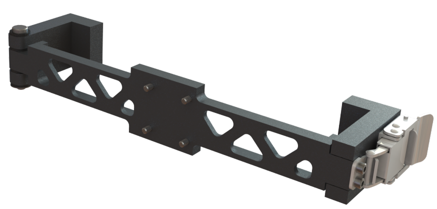
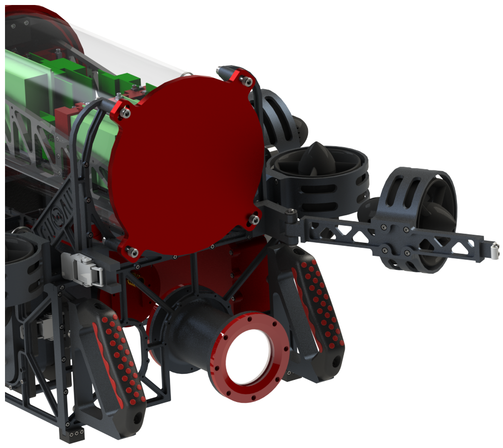


Figure 18: Fore Sway Thruster Mount Assembly

The fore sway thruster swinging mount is a continuation of the design first used last year on Castor. Most elements are similar, with the main difference being a change to the locking mechanism. Castor's involved a pin passing through part of one of the frame's large side plates and into the end of the swinging mount to lock it in place, which allowed for a decent amount of movement even in the locked position. The pin has been replaced by the locking grab latches used on the Pollux/Ajax UHPV (McMaster 1794A550) to securely lock the assembly into its closed position. The swinging mount attaches to the fore end plate with six 6-32 screws.

The version on Odysseus is also more reinforced than the one on Castor as there was evidence of plastic deformation of the bar over time, despite analysis of exaggerated load cases indicating there should be no issues (see Section D.3 for a more in-depth discussion).



(a) Opened (b) Closed

Figure 19: Fore Swinging Sway ThrusterAssembly Positions

4.4 Aft Sway Thruster/Killswitch Swinging Mount

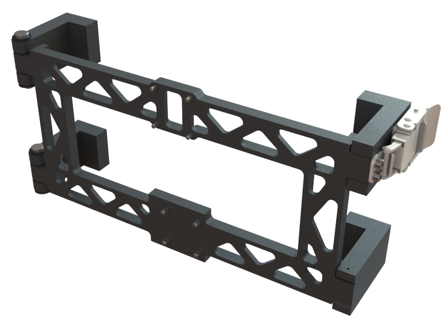
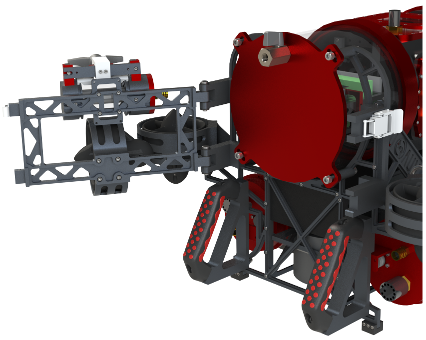
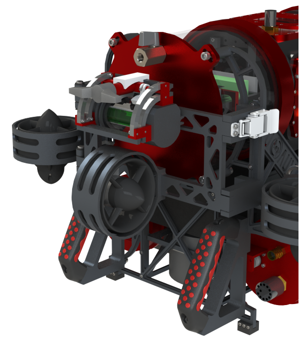


Figure 20: Aft Sway Thruster Mount Assembly

The aft sway thruster/killswitch swinging mount is similar to the fore sway thruster version (Serction4.3), just wider and with a second layer to mount the killswitch. The assembly locks in place with the same latch as the fore assembly on the upper block, but is only held in place by a ball detent (McMaster 3408A68) on the lower block as the position of the aft starboard depth thruster would conflict with a latch on the lower block. The killswitch was moved onto this assembly after is became clear that the space towards the bottom of the aft end of the vehicle was becoming too cramped, with the additional advantage of moving its handle far from Odysseus' actual lift points. The swinging mount attaches to the aft end plate with six 6-32 screws. Since the historical evidence indicates that our vehicles are much less likely to back into a wall at high speeds than they are to drive forwards into them, the aft swinging bar has not been reinforced in response to the deformation observed on Castor (Section D.3).



(a) Opened

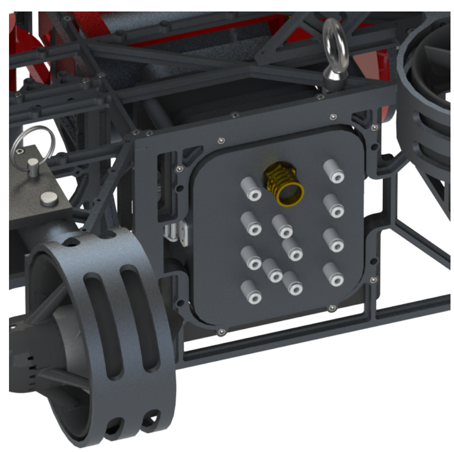


(b) Closed

Figure 21: Aft Swinging Sway Thruster/Killswitch Assembly Positions

4.5 Valve Enclosure Mounting

(a) Valve Enclosure Mount



(b) Valve Enclosure on the Frame

Figure 22: Valve Enclosure Mounting Assembly

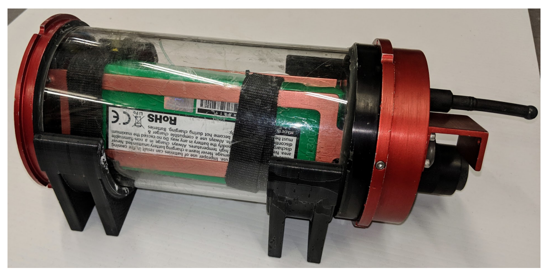
The valve enclosure mounting assembly combines the part two years of valve enclosure mounting with elements from Castor's laser cut rectangular delrin slot and Artemis' horizontal orientation, standoffs, and back plate. The valve enclosure mounts by sliding onto the two delrin pieces within the frame, then allowing the small bungee cords to fall in front of it, securing it in place. Unlike previous iterations of bungee cord mounting, these cords do not go around any of the tubing or wires attached to the enclosure, so it can be removed from the frame (a short distance) without disconnecting anything. Additional holes for more bungee cords have been included in case the initial holes are not sufficient for holding the enclosure in place.

4.6 3D Printed Mounts

3D printed components have made their way into the planned design of the frame this year, as opposed to as a stop-gap measure to fix issues over the summer. In order to raise our confidence level in these parts, prototype versions have been printed in order to determine whether or not the component will function as intended.

4.6.1 Battery Pods Clips

(a) Battery Pods Mounting Clip



(b) Printed Test Clips

Figure 23: Battery Pods Mounting

In order for the battery pods to be mounted parallel to the primary axis of the vehicle while retaining the slanted handle blocks on the aft handles, the battery pods needed to be attached from the sides rather than sliding in as they had historically. A pair of 3D printed clips accomplishes this, and despite initial skepticism test prints have demonstrated that they are capable of providing the right amount of force to hold the pods in while still allowing for easy swapping. What remains to be seen is how the clips will perform in terms of fatigue life, but their attachment points are easily accessible so replacements (or a revised version) could be printed if issues are encountered over the summer.

4.6.2 Paintball Tank Cage

(a) Paintball Tank Cage

(b) Printed Cage with Tank

Figure 24: Paintball Tank Mounting

After experiencing issues with our onboard paintball tank slipping out of its clips during testing on Castor, it was decided that exploring an alternate mounting method would be preferable. The mount operates by constraining the tank with a 3D printed cage, while a small length of bungee cord looped through the two holes at the end of the cage constrains the neck of the tank and prevent it from sliding out.

4.7 Miscellaneous

4.7.1 Handle Blocks

(a) Handle Block

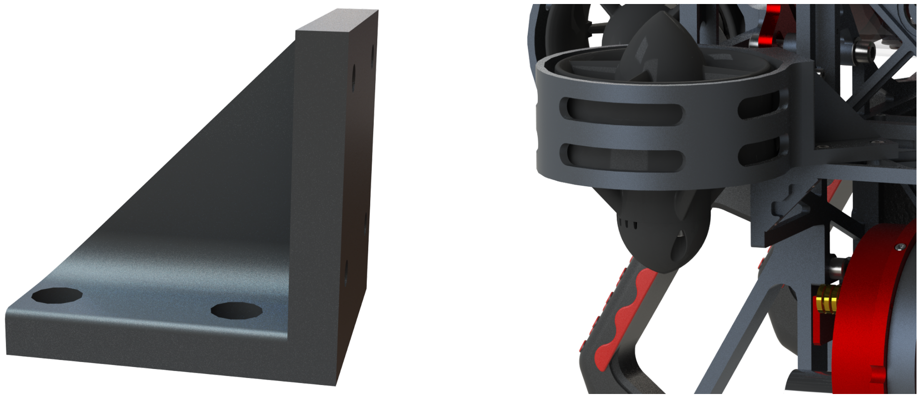
(b) Handle blocks on the aft end of the frame

Figure 25: Handle Blocks

The ergonomics of handle placements are a hotly debated topic during frame design reviews each yeah, and after the relatively comfortable grip which Pollux's slanted orientation provided, an attempt at recreating that orientation on Odysseus was selected. In order to have slanted handles on the ends mounting blocks are required, but they have the added advantage of moving the handles out from under the swinging sway thruster mounts (Sections 4.3 & 4.4). The comfort does come at a cost in terms of maneuverability, but since the main geometry will be done at DATRON there will just be a shift of strange setups on a mill to add the tapped 1/4"-20 holes which interface between these block and the handles/frame. The handles themselves are the same pull handles as every vehicle since at least Killik (McMaster 1950A5) since they've proven to not only be comfortable but also fit well into our vehicles' visual aesthetic.

Instead of using a sine block for the angled setups to add the holes, a pair of 3D printed fixtures were printed at the RPL which fit to the outer profile of the handle and kept the surface which needed holes added to it parallel to the vise. These 3D printed fixtures eliminated the need for a complicated setup and should be used in the future for holes in surfaces which do not have another surface square to them.

4.7.2 Depth Blocks



(a) Depth Block (b) Mounted on the Frame

Figure 26: Depth Thruster Mounting Blocks

Since the center of mass of the submarine lies a small distance above the top plate of the frame, there aren't any locations on the main frame plates to mount the depth thrusters to without sacrificing width of the vehicle or co-planarity with the center of mass. To solve this issue, the depth thrusters are mounted to small blocks which form an interface between the collision mitigation shrouds and top plate of the frame, allowing all four to be mounted in a symmetric, co-planar configuration. Each block mounts to a thruster shroud and the frame top plate with four 6-32 screws each.

4.7.3 Gussets

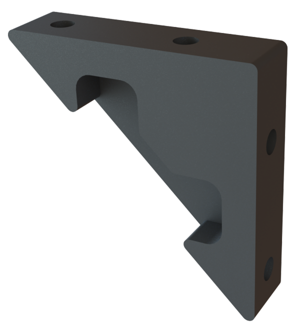
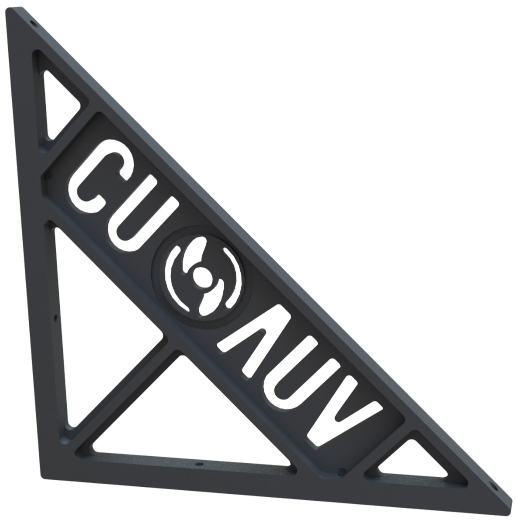


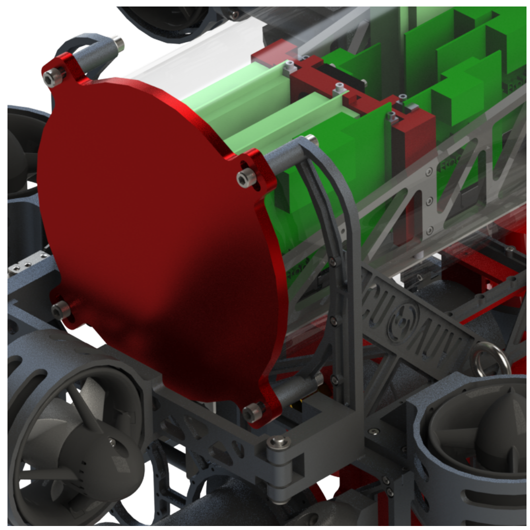
Figure 27: Tiny Little Support Gussets

Since the are so many frame pieces providing mutual rigidity to each other, Odysseus' frame does not require the small triangular gussets seen on most previous frames. However, near the aft end of the vehicle there is a row of extra mounting holes on a relatively unsupported plate, so two small gussets have been included to add rigidity to this plate in the event those holes are required for a high-load application. The gueesets are visible on the frame below the depth thruster in Figure 26b.

4.7.4 Hold Down Blocks



(a) CUAUV Branding

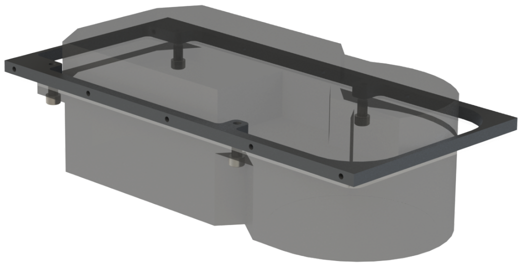


(b) Fore Hold Down Blocks and Support

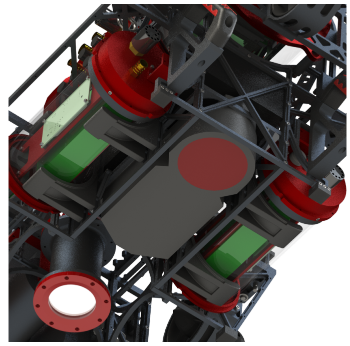
Figure 28: Hold Down Blocks

The hold down blocks to secure the UHPV's hulls when it is sealed take after the ones used on Thor's frame, with cylindrical standoffs from the frame plate to just behind each endap's tabs to minimize the deflection of the tower/hull when the screws are tightened down. The triangular hold down block supports have had the CUAUV logo added to them since it is a manufacturable feature on DATRON machines and because we cannot be outdone by Bumblebee adding their logo to their frame pieces.

4.7.5 DVL Mounting



(a) DVL Mount



(b) Mounted on the Frame

Figure 29: DVL Mounting Assembly

Following the design used on Castor with our new Pathfinder DVL, to avoid interacting with the DVL itself the DVL will be mounted to a separate plate which is then mounted onto the frame. The added plate means that any mishaps during mounting or unmounting the DVL are likely to only damage our part and not the incredibly expensive enclosure. The DVL mount is comprised of an plate which gets screwed into and an acrylic spacer to separate the DVL's enclosure's body from the aluminum bracket.

4.7.6 Feet

Figure 30: Center Port Foot

Also new to Odysseus' frame are small delrin feet. These six little block serve to reduce the contact area of the frame with the ground, and have added benefits of not scratching the wooden tabletops in lab as well as being replaceable with taller feet if more ground clearance is required.

5 Manufacturing

Overall, the manufacturing of Odysseus' frame went much more smoothly than previous vehicles, largely due to the reduction in work from having the plates machined by DATRON (since all holes on the faces of the plates were already added before we received them as opposed to being the largest time sink for the project). Additionally, holes in the ends of the Top Plate did not have to be outsourced (to Brent & Torin) because 24" is the maximum length which can fit on the bed of the taller Bridgeports in Emerson while still fitting under the spindle. The tolerance on some of the holes added this was was not great and they did not interface with the slotted holes on the Fore and/or Aft Plates, but with a bit more care in the fixturing and setup comparable parts should be manufacturable in future years. Additionally, the 3D printed fixtures for drilling the off-angle holes in the handle mounts were surprisingly effective, and the technique should probably be explored in the future as a means of fixturing problematic parts.

Though the manufacturing of the main plate structure of the frame was relatively easy due to our sponsorship from DATRON, the manufacturing of the rest of the frame ended up taking longer than I'd anticipated during the design cycle, though less time than anticipated in Jira estimates. Since the main time sink of previous frames was being removed (in the form of tedious shifts of fixturing and adding terribly toleranced holes on the faces of each plate), I designed the other elements of the frame to be significantly more complex than previous frames were, especially with the mounting for all eight thrusters. I don't necessarily think that it was a mistake to have this added complexity in other areas of the project since they've resulted in a frame which was easy to assemble and has seemed very user-friendly so far, but in the future the added complexity could prove to be an issue since it ended up *increasing* the overall in-house manufacturing time for Odysseus' frame compared to Castor's (29 shifts versus 18). In short, our manufacturing sponsorship from DATRON alleviates a large portion of the *required* manufacturing burden for the frame (as evidenced by the frame for Ajax), but a frame with similar added complexity as with Odysseus' could pose manufacturing challenges if a less experienced machinist were on the project.

6 Modifications

For the most part the frame has not been modified from its original design at the end of the fall semester, with a few minor and largely inconsequential changes:

- The lower Latch Black on the Aft swinging thurster/killswitch mount (originally meant to interface with a ball detent) was removed and replaced with a delrin support since the swinging piece did not fit into the metal block. Since the entire assembly was determined to be rigid enough without it the only purpose of the delrin block is to take the impact of Odysseus reversing into a wall and avoid permanently deforming the entire assembly.
- The delrin pieces on the swinging surge thruster mounts were switched to both being

1/8" and the upper one given a makeover to look more interesting and have rounded corners to stop poking peoples' hands.

- The 3D printed battery pod clips have been iterated a few times to dial in the right grip strength. The initial design was fine for team members with large enough hands to reach around the entire pod to pull it off, but proved difficult for team members with smaller hands. A new implementation with one of the clips being the same version and another having significantly less holding force seems to appropriately address both the need for the pods to be securely mounted to the frame as well as easily removed by any team member.
- The bolts on the hold down blocks have been switched from stainless steel to nylon to avoid marring the UHPV endcaps.
- A few of the tapped #4-40 holes on different plates on the frame were drilled out to clearance in order to facilitate changes in mounting of different projects like manipulators, but this was expected/a known possibility when the extra holes were added to the frame.

7 Current Status

Odysseus' frame has been manufactured and assembled, and at this point is essentially complete as a project. The only outstanding work is cleaning up the trim now that all enclosures can be mounted to it (beyond just the large block of foam above the DVL), as opposed to haphazardly having pieces of foam added as needed over the summer. Given that we now plan to re-use the Odysseus UHPV and racks as-is for 2020, there is a nonzero likelihood that this frame is also reused with them. In that case some degree of updates would probably be required (to interface with new battery pods, for example), but a complete redesign of the frame could probably be avoided if we do not have the manpower for it.

8 Future Improvements

Ever since Thor's frame was over reinforced and bulky (as a reaction to Argo's frame's *issues*), all frames have been similarly over built–*and I do not think that this is necessarily a bad thing.* Since we now mount significantly more external enclosures than during the Gemini era of 4lb frames, our frames are likely to never be critically designed from a stress standpoint just by having mounting for all the enclosures. That being said, attempts to refine weight reduction should be continued whether that is continued use of T-profile members (if the relationship with DATRON continues), more judicious elimination of unneeded frame members and plates, scaling down low load members, or something not even mentioned here.

However, there are two major barriers to future improvement to the frame: freshman projects (given the new recruitment timeline) and the quality of computers available to whoever is designing the frame. Having to project forward for many possible freshman project designs and their corresponding space/mounting requirements cripples the frame designer's ability to work on large areas of the frame in effort to not make too many design decisions for their projects before they have joined the team. Additionally, the change in recruitment timeline has thrown off our upperclassmen design cycle, so there has not been adequate time to iterate on weight reductions and analysis (given that FDRs too place 2.5-4 weeks later than they historically did). Additionally, working on the frame—especially if T-profiles are being applied to the plates—requires a powerful computer to run at any reasonable speed. Given that my computer is generally considered one of the better options for running assemblies on the team and ever it was experiencing $>$ 5min. rebuild times on the weight reduction for certain plates, a new lab desktop is going to be necessary to make improvements from a designer's sanity standpoint.

Finally, one of the most successful elements of the frame's design process in terms of keeping it all together was having identified a multitude of requirements, objectives, and goals from the beginning of the semester (even beyond those listed in Section 2). By identifying all the conflicting desires and deciding which would drive the design versus which would just be passively optimized as the design progressed really smoothed out piecing together the placement and functionality of the vehicle. For example, the hydrophones enclosure was a major driving force in the design after the issues at RoboSub, while the details of mounting the battery pods were left to evolve into whatever worked best for the rest of the design.

Beyond everything I've laid out above, this is an incredibly fulfilling project despite how much it taxes you. As much as everyone will probably continue to complain about working on frame, the amount it teaches you about handling a large design with countless details and requirements to balance means it elevates the CAD skills of anyone working on it.

8.1 What went well

- Defining placement requirements/desires and building the frame to best fit them
- Horizontally pivoting surge thruster wings
- 3D printed battery pods clips (in terms of flexibility in enclosure placement)
- Carving out lots of space with different mounting options for freshman projects (integration of the manipulators in *May* went smoothly since there was a dedicated space large enough for them)
- Freshman project integration assembly (outside of the main Odysseus_OA assembly)
- Accessibility of mounting/unmounting all enclosures
- Angled handle mounting blocks for slightly better ergonomics
- Midcap towards the aft end of the vehicle to better balance buoyancy

- Feet to increase ground plane clearance, reduce scratches to tables, and reduce the risk of placing the vehicle down on SEACON cables
- Sponsorship from DATRON to machine the plates of the frame (both for tolerance and time saved)

8.2 What didn't

- 3D printed battery pods clips (hard to strike balance between usable by *me* versus the team in general, variability between printed iterations of the same .STEP file, etc.)
- Space for SEACON cable management (wrapped in circles and ziptied to the Top Plate)
- Too little reinforcement of the frame where the Midcap attaches to the Top Plate (entire frame deflects when pushing on the UHPV hulls)
- Space for trim foam (space above DVL meant the design came closer than previous years, but the impact of SEACON cables was neglected during buoyancy calcs)
- Adding too many useful but time-consuming components that increased the required manufacturing time despite our sponsorship from DATRON.

Appendices

A Purchased Components

Item	Qty.	Supplier	Part Number
1/4" Clevis Pin, 1.875" Usable Length	2	McMaster	92735A260
1/4" Clevis Pin, 1.375" Usable Length	3	McMaster	92735A250
Ring-Grip Quick-Release Pin 1/4"D, 2"Lg	2	McMaster	98404A960
Tight-Hold Draw Latch with Safety Catch	2	McMaster	1794A550
Plastic Pull Handle, Red	4	McMaster	1950A5
1/4"-20 Eyebolt for Lifting	4	McMaster	3014T450
T200 Thruster	8	Blue Robotics	
Pathfinder DVL	1	Teledyne	

Table 3: Purchased Components

B Bouyancy Calculations

Weight (lbs)	62.69
Volume (in^3)	1543.84
Net Force (lbs)	-6.9110608
Resultant Moment for Pitch (lb-in)	43.047
Resultant Moment for Roll (lb-in)	13.590
Resultant COB for port-starboard	-0.003172406266
Resultant COB for fore-aft	0.05245613827
Resultant COB for up-down	0.06217071628

Table 4: Buoyancy Calculations

Based on the buoyancy calculator spreadsheet and intuition about the weight/volume distribution on Odysseus, the vehicle is going to experience a substantial positive pitching moment (due to the heavier components towards the rear of the vehicle) and will be negatively buoyant. To address this, a large amount of space for trim foam is available on the aft end of the frame, including a large block directly above the DVL and form-fitting pieces around the battery pods. These values will change once freshman projects are finalized, but should capture the overall trend for Odysseus.

C Freshman Project Integration Assembly

A new "feature" of the frame this year was the Freshman Project Integration Assembly. By providing the freshmen with a stripped down version of the main vehicle comprised of relevant frame plates and transparent space allocation boxes, the freshmen were able

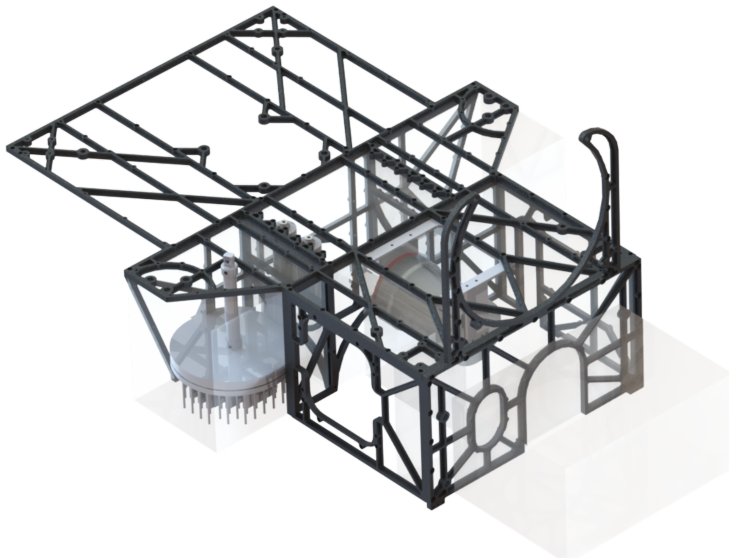


Figure 31: The Freshman Project Integration Assembly

to choose specific positions and design mounting brackets which could coexist with each others' projects despite entering into the equation so late in the design cycle. Once projects had a proven mounting configuration in this assembly they were added into the high-level Odysseus assembly. A freshman integration assembly should at least be considered in future years, especially if a number of their projects will be sharing spaces on the frame as they were on Odysseus.

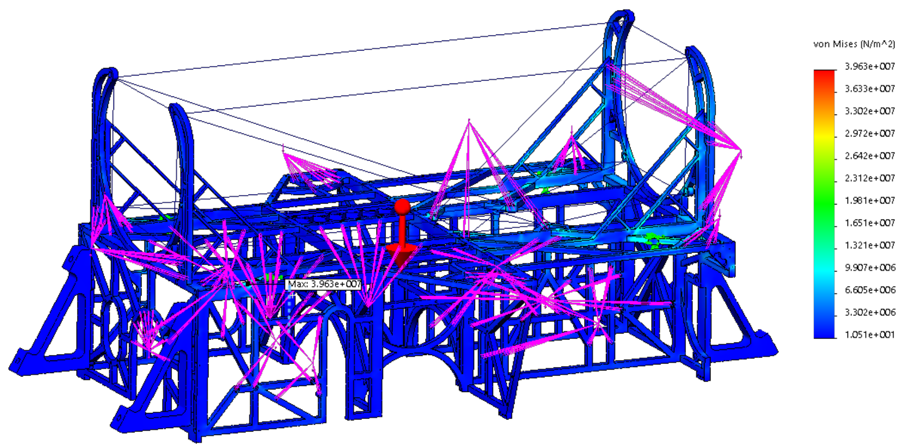
D Finite Element Analysis

Load Case	**Max. Stress (MPa)**	**Max. Deformation (0.001")**	**Factor of Safety**
Crane Lift	39.63	8.08	6.92
Handle Lift	33.04	2.77	8.18
Rapid Deceleration	172.7	28.5	1.56
Killswitch Activation	123.8	22.9	2.18

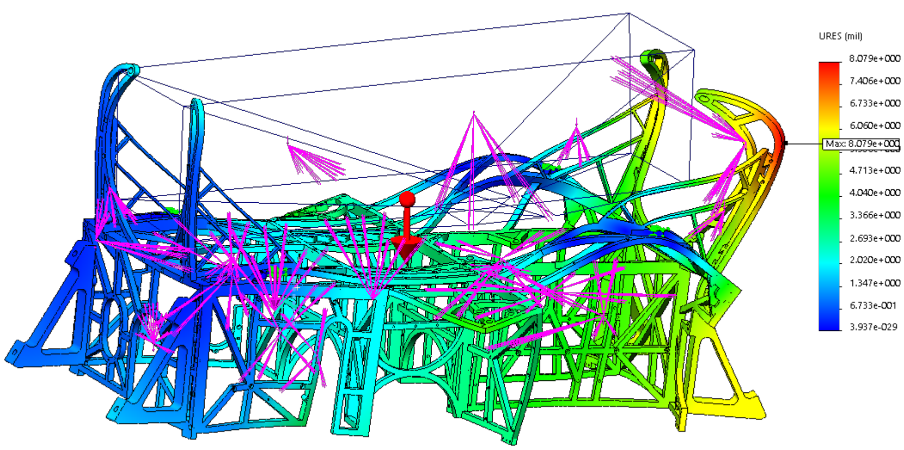
Table 5: FEA Load Cases and Results

A number of different load cases were analyzed using SolidWork's finite element analysis plugin in order to determine whether or not the frame pieces would be structurally sound for operation. Table 5 displays a condensed version of the results of these analyses, while Sections D.1–D.4 provide more detail in terms of what was being analyzed in each simulation.

D.1 Crane Lift



(a) Stress



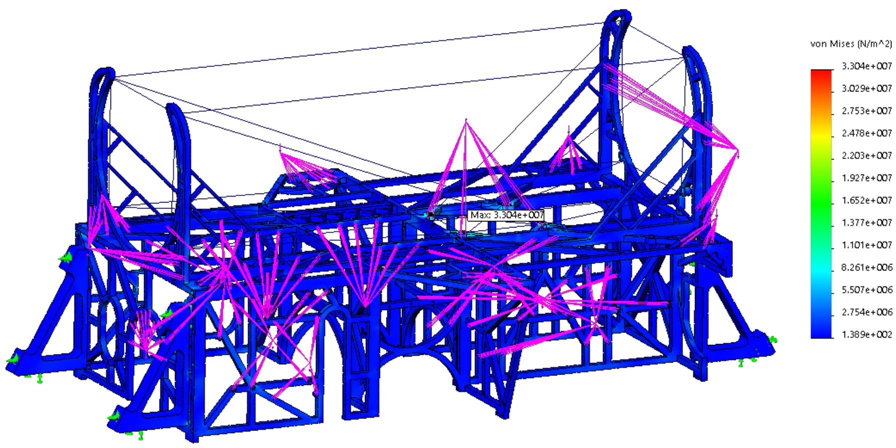
(b) Displacement

Figure 32: Frame loaded as to simulate the crane at TRANSDEC

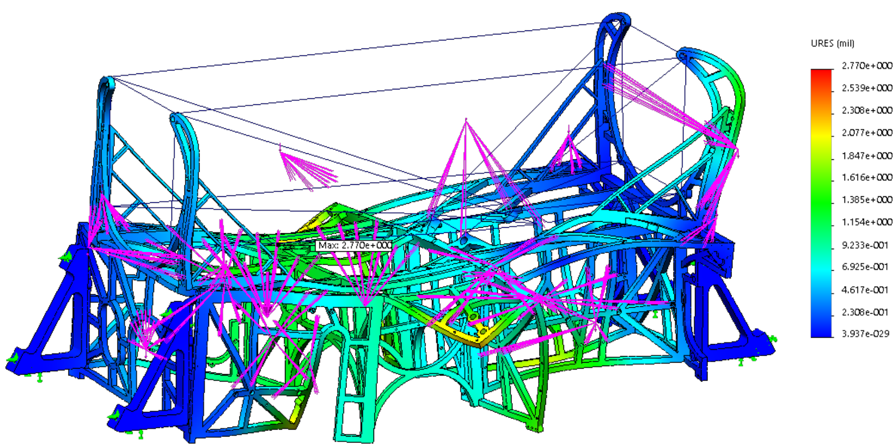
Ever since the extreme deformation experienced by Argo's frame constantly risked unsealing its UHPV on the crane at TRANSDEC, special care has been taken to ensure that this issue does not arise again. The crane lift load case involves applying point loads at the center of mass of each enclosure equal to its weight to all of the enclosure's mounting holes, as well as a gravity load across all the elements of the frame. The eye bolt attachment points are then fixed and analysis run to see how the frame deflects.

In order for the analysis to actually run, the frame had to be simplified greatly with most non-plate components being removed and the plates themselves losing their T-profile weight reduction. Additionally, support between the mounting locations of the UHPV had to be included otherwise the large deflections of the hold down towers would result in the analysis terminating prematurely. Both stresses and deformations are far below values which would cause concern for this analysis.

D.2 Handle Lift



(a) Stress

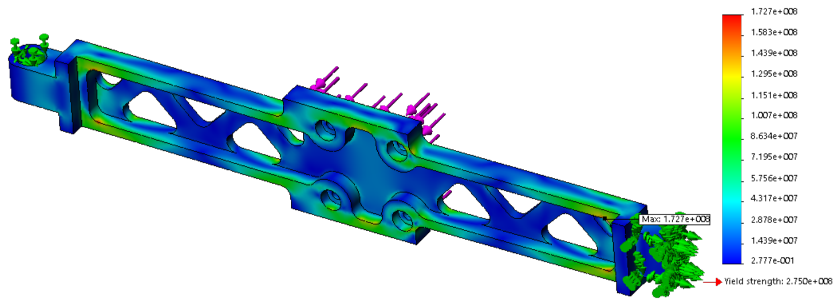


(b) Displacement

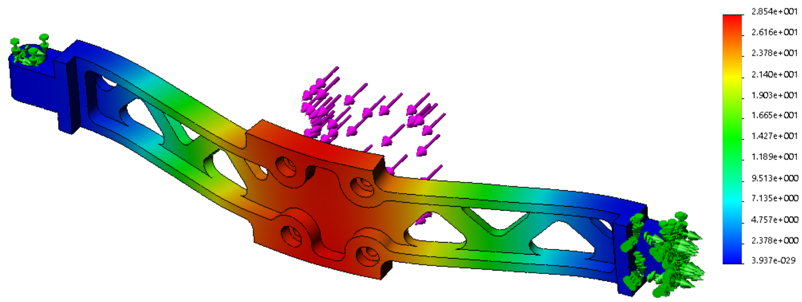
Figure 33: Frame loaded as to simulate being carried by its handles

The handle lift case is functionally identical to the crane lift case described in Section D.1, with the only difference being that the handle mounting holes are fixes instead of the eye bolt holes. Both stresses and deformations are far below values which would cause concern for this analysis.

D.3 Rapid Deceleration



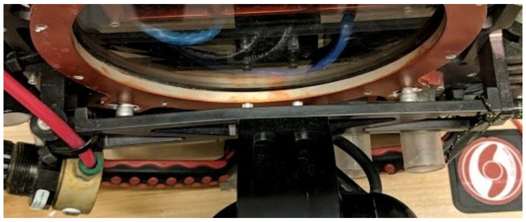
(a) Stress



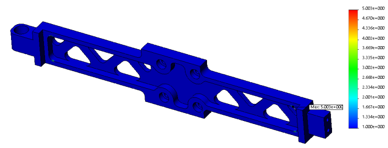
(b) Displacement

Figure 34: Exaggerated load on the Fore Sway Thruster Bar

Since autonomous vehicles have a tendency to rapidly decelerate by crashing into walls, the load case of force applied directly normal to the front of the vehicle to its first contact point should always be explored. Using load cases developed for collision mitigation's analysis during Fall 2017, a 500N load was applied directly to the front of the fore sway thruster's bar in the area which would be in contact with that thruster's shroud. Interestingly, neither the static analysis (Figure 34) nor fatigue analysis (Figure 35b) displays a result anywhere near the damage witnessed on Castor's equivalent component (Figure 35a), even with a relatively exaggerated loading case. Further monitoring of this component's state and refinement of its analysis is likely required for future years.



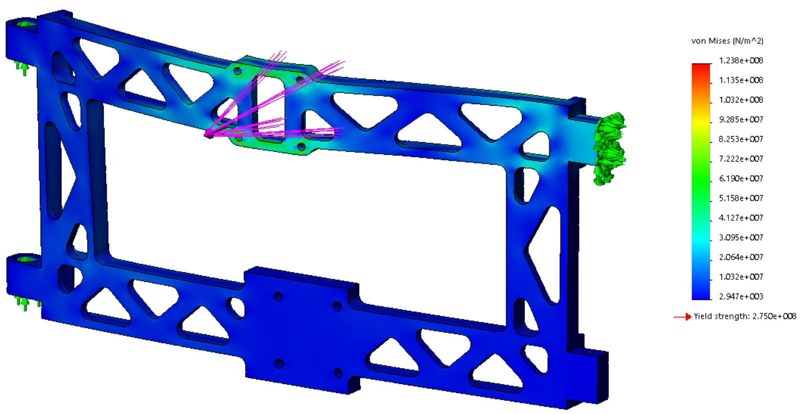
(a) Plastic Deformation on Castor



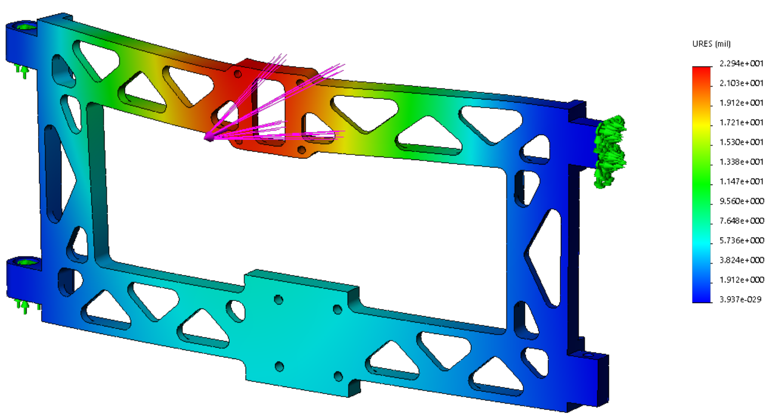
(b) Fatigue Life for Odysseus

Figure 35: Damage to Castor vs. Projected Fatigue Life

D.4 Killswitch Activation



(a) Stress



(b) Displacement

Figure 36: Load to simulate the Killswitch being pulled

The final load case detailed here is an exaggerated 25lbf load on the bar which the killswitch mounts to, representing the load which this component would feel as the vehicle is sent a kill signal and the pulled through the water by a diver at TRANSDEC. There had been some concern related to the moment created by the bar's odd design, but based on the analysis the deformation should still be marginal compared to the overall movement of parts during this load case.