CLaMP

Camera Locking and Mobile Positioning System

Micro-G NExT Design Challenge 2: EVA Camera Attachment Mechanism

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1 Abstract

Quintessence has performed static analysis, stress testing, and underwater testing to determine the validity of the Camera Locking and Modular Positioning System (CLaMP) as a functional tool in neutrally buoyant environments. The CLaMP is composed of three distinct subsystems, the attachment mechanism that fastens to three distinct surfaces on the International Space Station (ISS), the connecting arms and joints which allow for pitch adjustment, and the camera positioning system which allows for yaw adjustment. This paper describes in detail: the design of the CLaMP, the aforementioned testing and analysis, an operations plan for using the tool in the Neutral Buoyancy Laboratory (NBL) at Johnson Space Center (JSC), the hazards present in the tool and how they are mitigated, and the tasks remaining to complete before the onsite testing for the Micro-Gravity Neutral Buoyancy Experiment Design Teams challenge at JSC from May 22nd to May 25th, 2019.

2 Background

The Camera Locking and Modular Positioning System (CLaMP) was designed for use in Extravehicular Activities (EVAs) on the International Space Station (ISS) to provide a better view of current tasks being completed by astronauts during spacewalks. Per NASA's Micro-Gravity Neutral Experiment Design Teams official challenge documentation, "Extravehicular Activities (EVAs), or spacewalks, on the International Space Station (ISS) are currently viewed through cameras mounted on the astronauts' suits. There is a desire to have another view of the EVA tasks from a separate camera that the astronauts can carry with them and attach to the ISS exterior nearby their worksite. The camera will need to be attached to a stanchion that allows for clocking and adjustability of the camera angle. Since the tasks performed on EVAs are different and take place in a different location each time, the stanchion will need the ability to attach to different interfaces. These interfaces include ISS handrails, the ISS truss segment frame, and the CETA cart square grid" [1].

The task for the first round of the challenge was to design and test a prototype of the tool and to write a technical proposal detailing the function of the design, the process of building it, and planned outreach with regards to the competition. The second round of the challenge involves finalizing the design and manufacturing a proof of concept to be used during a one week test session at Johnson Space Center in Houston, Texas, where their design will be tested by NASA divers in the simulated microgravity environment of NASA's 6.2 million gallon indoor pool (the Neutral Buoyancy Laboratory) where astronauts train for spacewalks. The team with the "best" design at JSC will get the opportunity to present their design at Ames Research Center in Silicon Valley, and possibly even have their design used by astronauts aboard the ISS.

The CLaMP's design draws inspiration from the human body - the attachment mechanism is modeled after a hand, and the camera positioning system is modeled to function as an arm. The positioning system has both pitch and yaw capability. The attachment mechanism is composed of two clamp arms, with appendages and attachment points modeled after fingers. To fasten onto each surface, a crank mechanism similar to that used in bow compasses is used to tighten the clamp arms, closing the hand around the surface. The positioning system is composed of multiple components; the hinges of each distinct piece act as joints, and the point at the end of the arm to which the camera attaches swivels 45° in each direction. This allows optimal camera adjustability for view of EVA tasks. The CLaMP was designed with the intent of ensuring maximal modularity of its constituent components, and a majority of the components are 3D printable. This modularity and ease of manufacturing facilitates flexibility in lengths of the arm pieces and potential for necessary modifications to the design of the clamp arm. This design offers a high degree of customizability, providing a new means of collecting data and providing video of EVA tasks.

3 Hardware Design

3.1 Overview of design and components

The CLaMP weighs $7\frac{1}{3}$ lbs and consists of 65 pieces: 8 set screws, 10 bushings, 11 nuts, 10 screws, 7 knobs, 3 protective covers, 1 key, and 15 working pieces. These working pieces are compartmentalized into three distinct subsystems: the Clamp Mechanism (6 working pieces) holds the CLaMP to the ISS, the Arm Mechanism (5 working pieces) facilitates pitch adjustment, and the Yaw Mechanism (4 working pieces) facilitates yaw adjustment.

ITEM NO.	PART NUMBER	Material	Weight	QTY.
1	Clamp Arm	Nylon 6/10	0.65	2
2	Threaded Cylender	Stainless Steel (ferritic)	0.13	2
3	Threaded Rod	Stainless Steel (ferritic)	0.09	1
4	Clamp Mount	Stainless Steel (ferritic)	1.23	1
5	Arm Attachment	Nylon 6/10	0.46	2
6	Camera Attachment	Nylon 6/10	0.06	1
7	Yaw Mechanism Mount	Nylon 6/10	0.23	1
8	Yaw Mechanism Cover	Nylon 6/10	0.04	1
9	Arm Boom	Nylon 6/10	1.51	1
10	Claw Mount Bushing	Nylon 6/10	0.01	2
11	Mount Retention Bushing	Nylon 6/10	0.01	8
12	Clamp Knob	Nylon 6/10	0.14	1
13	pin	Nylon 6/10	0.01	1
14	block	Nylon 6/10	0.02	1
15	key	Stainless Steel (ferritic)	0.00	1
16	Screw Cover	Nylon 6/10	0.01	1
17	Knob	Nylon 6/10	0.17	5
18	stop	Stainless Steel (ferritic)	0.02	2
19	nut	Stainless Steel (ferritic)	0.01	9
20	Clamp Screw	Stainless Steel (ferritic)	0.06	1
21	Arm Screw	Stainless Steel (ferritic)	0.05	2
22	Arm Clamp Screw	Stainless Steel (ferritic)	0.04	2
23	Mounting Screw	Stainless Steel (ferritic)	0.04	4
24	Yaw Mechanism Nut	Stainless Steel (ferritic)	0.00	2
25	Yaw Mechanism Spacer	Nylon 6/10	0.00	1
26	Yaw Knob	Nylon 6/10	0.06	1
27	Yaw Mechanism Screw	Stainless Steel (ferritic)	0.01	1

Figure 1: Clamp parts

3.2 Evolution of the design

The design of the Clamp Mechanism [see Figure 5] draws inspiration from that of a bow compass [see Figure 2]. A bow compass has oppositely spun threads that are cut into a rod with a sprocket in its center that will always bisect the angle created by the compass legs. By modifying the sprocket to index an attachment point and moving the winding mechanism to the outside for easier access, we created a device that is simple to build and maintain, but also intuitive for the user. In addition, this design always leaving the attachment point in the exact same position regardless of the surface to which the device is attached. The fastening mechanism of the clamp has been slightly modified from that of the original design. A smaller, lighter, and safer scalloped knob replaced the original design of a crank and handle, which was likely to fall, catch, and snag on different objects. This modification minimizes the snagging risk created by the threaded rod mechanism. Originally, each hinge and point of rotation was held by a cam lock. These cam locks were replaced by scalloped knobs to minimize the potential risk of snagging and pinch points. Areas which cracked during stress testing were reinforced with more material.

Figure 2: Bow compass

The second system that the CLaMP uses is the Arm Mechanism [see Figure 11]. This system was modeled upon a microphone boom. This design allows the camera to be placed in a variety of different positions along a single plane by means of a pair of hinges. Hinges allow for complex positioning while maintaining the camera's upright position. The arm attachments 1 and 2 [see Figures 3 and 4] hold the Clamp and Yaw Mechanisms respectively. By implementing the Clamp and Yaw mechanisms independently of one another, the position of the Clamp Mechanism will have little effect on the ability to position the camera correctly. The design of the Arm Mechanism has also been changed since the proposal submission. Originally, the Arm Mechanism had interchangeable booms that would have allowed for its length to be increased and decreased. These interchangeable booms would also have been capable of being rotated for additional means of positioning the camera (though the total number of possible views would remain the same). By eliminating the interchangeable booms, this new design is more structurally sound in that there are fewer points of failure. Having fewer parts also reduces the risk of Foreign Object Debris (FOD) during assembly in the ISS at the NBL. These enhancements to the design are done without a reduction in the number of camera positions possible. The change comes at the cost of slightly increased mass, a negligible tradeoff in comparison to the aforementioned benefits. The cams that were on this part of the CLaMP were also replaced with the scalloped knobs to reduce pinch points throughout the mechanism. An internal clamping piece was also added to replace one of the removed cams as a redundant locking mechanism for each joint in this mechanism. The mounting bolts that hold the mechanisms together have mount retention bushings added to them to prevent a bolt head catching on anything that it may brush against during normal operation. It may not be feasible to use traditional wrenches to dismantle these areas for repositioning of mechanisms, but the bolts have been designed to fit most standard sockets for the correct head size, and can easily be added to the kit without going over weight or size limitations. Wingnuts were not used due to possible snagging hazards.

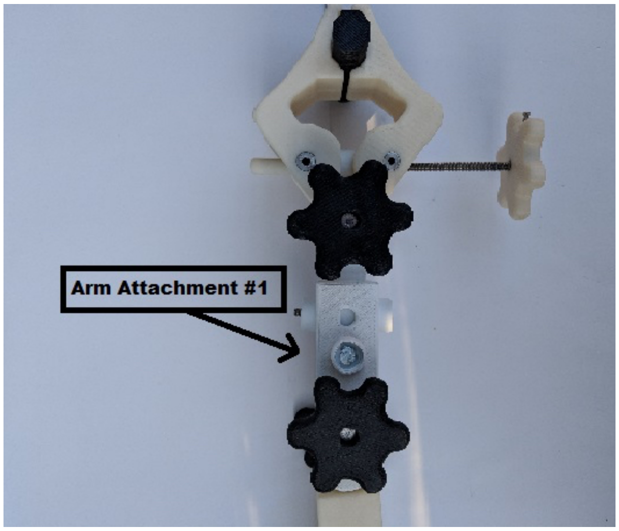

Figure 3: Arm Attachment 1

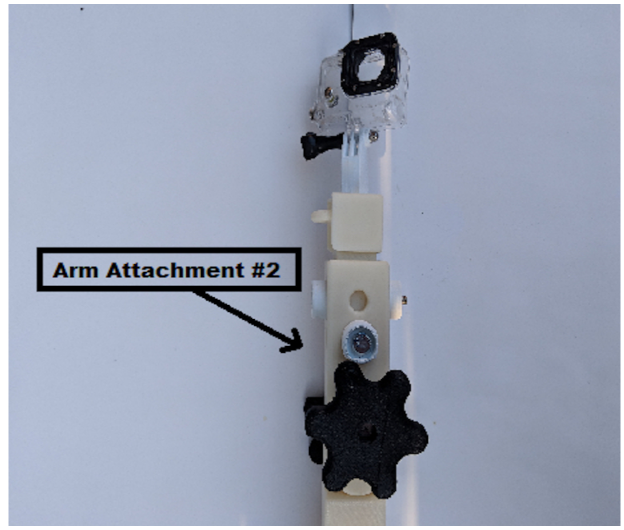

Figure 4: Arm Attachment 2

The final mechanism is the Yaw Mechanism [see Figure 14]. This mechanism operates by rotating along two interlocking sections. A pinch clamp has replaced the original cam lock to secure the mechanism in place and is operated by a similarly shaped scalloped knob. A pin holds the two sections together while a block inside the mechanism keeps the pin stationary. A yaw cover was implemented to cover any pinch points the operator will experience when rotating the mechanism. The original 90° of rotation has been increased to 110°. A ball and socket was considered but not used for the Yaw Mechanism due to their complexity and tendency to wear faster than a traditional hinge. Pinch points could not be completely eliminated and are labeled with red arrows.

3.3 Detailed description of CLaMP subsystems

The CLaMP is separated into three subsystems: the Clamp Mechanism, the Arm Adjustment Mechanism(s), and the Yaw Mechanism.

3.3.1 Clamp Mechanism

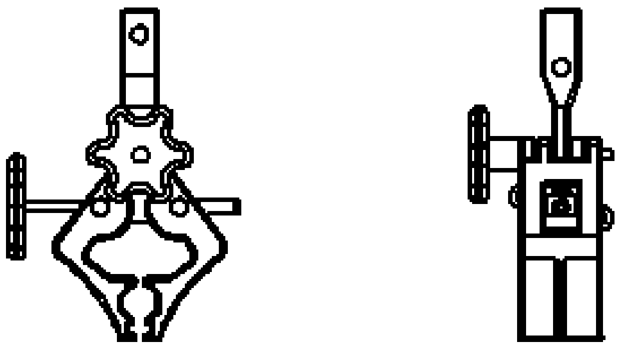

Figure 5: Clamp Mechanism

The Clamp mechanism operates to adhere to each surface. It is composed of two clamp arms, threaded cylinders, a threaded rod, a scalloped knob, a screw cover, clamp mount bushings, and the clamp mount.

The clamp arms open and close by fastening oppositely spun threads on the threaded rod. As the threaded rod is rotated, the threaded cylinders move against the motion of the rod to move the clamp arms towards or away from each other with respect to the rotation of the knob. The threaded rod contains a middle indexing point much like a bow compass to keep the rod in the center with respect to the clamp mount.

Once fully opened, the clamp arms are free to surround any surface filling the 2" gap [see Figure 7]. The knob connected to the threaded rod is then rotated to close the clamp onto each surface. On the clamp arms are attachment points [see Figure 6] tailored to fit the ISS EVA Handrails, CETA Cart Square Grids, and ISS Truss Frame.

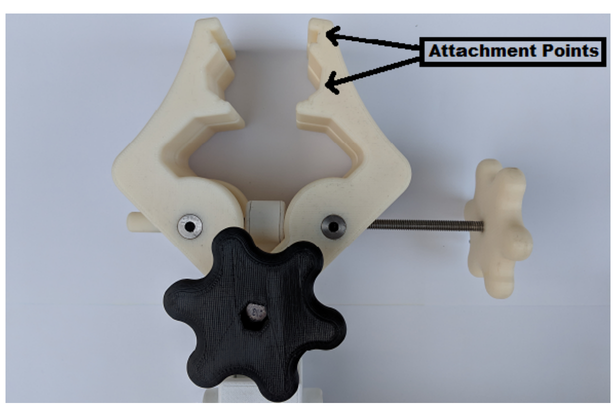

Figure 6: Points of contact with EVA surfaces

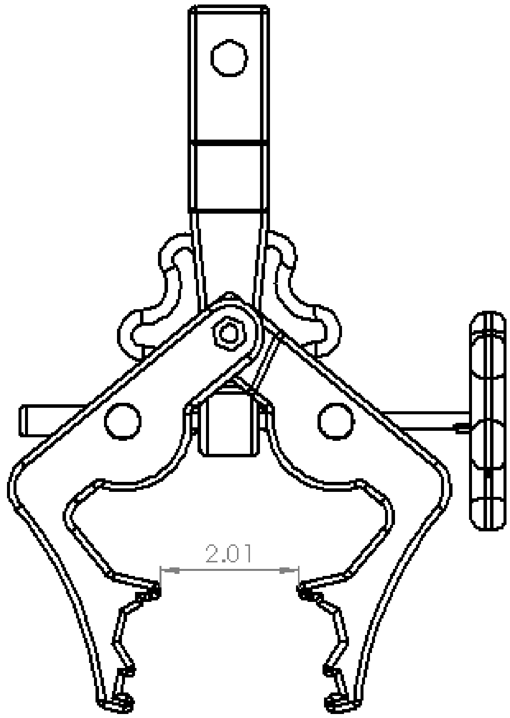

Figure 7: Maximum distance between jaws of CLaMP

The octagonal portion of the clamp attachment points is meant for attachment to the CETA Cart Square Grid [see Figure 8].

The rectangular portion of the clamp attachment points is meant for horizontal attachment to the ISS EVA Handrail. The clamp can also surround the ISS EVA Handrail with the octagonal and rectangular portion as pictured below [see Figure 9].

The attachment points can also fasten to the truss frame [see Figure 10].

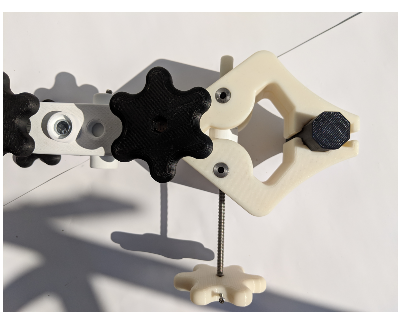

Figure 8: Clamp attached to CETA Cart Square Grid

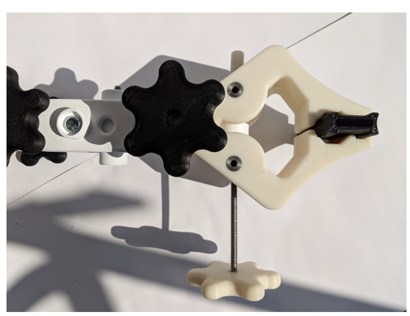

Figure 9: Clamp attached to ISS EVA handrail

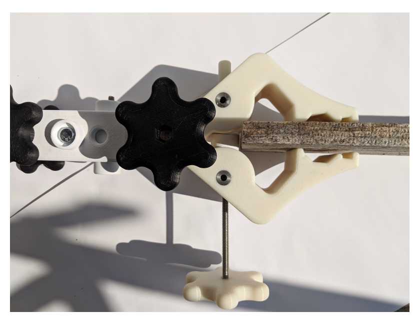

Figure 10: Clamp attached to ISS truss frame

Once secured on the surface, the rotation point knob is turned clockwise to tighten the clamp arms together for two-fault tolerance across all surfaces that the clamp arms attach to [see Figures 12 and 13].

3.3.2 Arm Mechanism

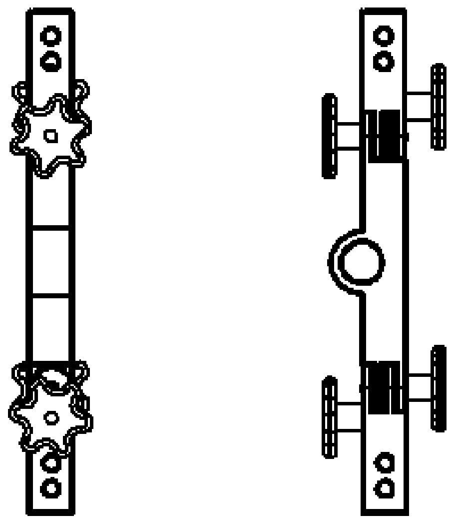

Figure 11: Arm Mechanism

The Arm Adjustment Mechanism allows for and controls the pitch of the camera's viewing angle. It is composed of the arm mid boom, arm attachments 1 & 2, and arm attachment knobs.

Attached to the clamp mount is arm attachment 1, which holds the device's first hinge point. To loosen the knobs on the hinge, rotate them counter-clockwise. Once the knobs are loosened, the arm mid boom is free to move ±90° from a vertical position parallel to arm attachment 1. To lock the arm mid boom in place, rotate the knobs attached to the hinge clockwise. The hinge attached to arm attachment 2 (which is attached to the camera mount) functions identically to arm attachment 1.

To loosen the hinge to modify the configuration of each Arm Adjustment Mechanism pieces, rotate the knobs counter-clockwise. It is suggested that modifications to each hinge be made individually to reduce complications with free-moving hinges and pinch points.

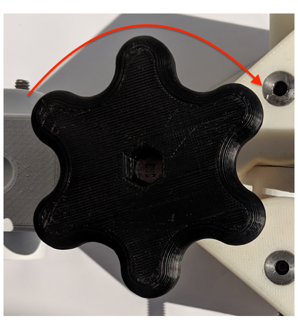

Figure 12: Direction of rotation that tightens all knobs

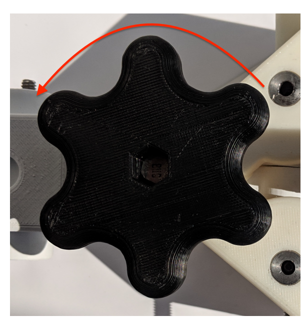

Figure 13: Direction of rotation that loosens all knobs

3.3.3 Yaw Mechanism

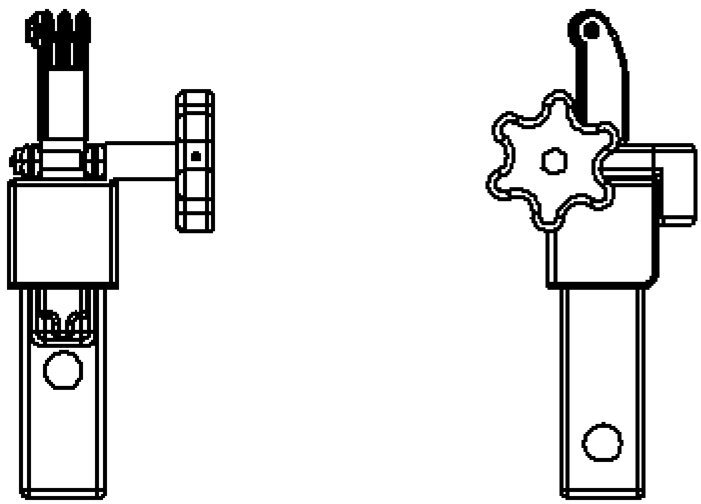

Figure 14: Yaw Mechanism

The Yaw Mechanism allows for and controls the yaw of the camera's viewing angle. It is composed of the camera attachment, yaw mount, yaw cover, pin, and block.

The Yaw Mechanism was initially implemented with a cam locking system, and is now implemented with a knob locking system. The swivel is capable of rotating $\pm 55^{\circ}$ from the neutral position. The force between the pin and block provides friction for the camera attachment to remain stationary. Turning the knob attached to the yaw mount mechanism locks the swivel point in place by pinching the base of the camera attachment and increasing the frictional force holding it in place.

4 Analysis and Testing

4.1 Structural analysis

Analysis was done in order to quantify the forces on the clamp. The clamp experiences the highest stress of all components of the design, and it interfaces directly with the ISS cross sections. For this reason, the compressive force that the clamp applies to the ISS cross sections has been analyzed. The forces on the clamp are modeled using a free body diagram [see Figure 22].

4.1.1 Compressive force analysis

The applied force by the clamp on the ISS cross sections was measured using a scale [see Figure 15]. Only one of the four pads on the scale was pressed to ensure that the only force measured was that from the CLaMP. The knob was turned in $\frac{1}{4}$ turn increments and the resulting force was measured at each step [see Figures 16-20]. The measured forces were then averaged and the average compressive force applied by the clamp per $\frac{1}{4}$ turn was found. It was found that approximately $17.5lbs$ of force are applied per $\frac{1}{4}$ turn of the knob. Figure 21 displays this force data.

Figure 15: Structural Analysis Experimental Setup

Following the compressive force testing which determined the force at the end of the each clamp half (force C), the forces at the vertical screw (force B) and at the hinge (force A) were also found.


Figure 16: 0 turn

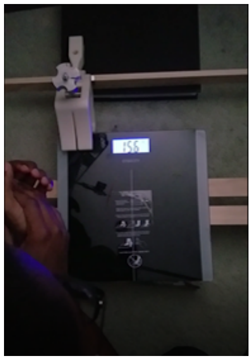
Figure 17: $\frac{1}{4}$ turn

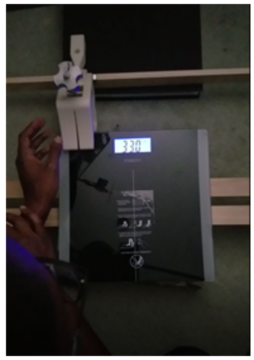
Figure 18: $\frac{1}{2}$ turn


Figure 19: $\frac{3}{4}$ turn

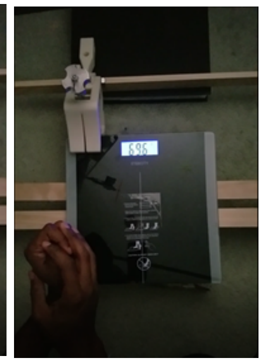
Figure 20: 1 turn

Trial 1			Trial 2	
Turn	Force (Ibf)		Turn	Force (Ibf)
0.25	16.8		0.25	16.2
0.5	33.4		0.5	33.6
0.75	50.4		0.75	50.4
1	68		1	68.6
Trial 3			Trial 4	
Turn	Force (Ibf)		Turn	Force (Ibf)
0.25	17		0.25	15.8
0.5	34.8		0.5	33.8
0.75	51.4		0.75	50
1	69.6		1	68
Trial 5				
Turn	Force (Ibf)			
0.25	15.6			
0.5	34.8			
0.75	51.6			
1	69.6			
Turn	Average Force (lbf)	Change in Average Force (lbf)		Change in Average Force per ¼ Turn (lbf)
0.25	16.3			17.5
0.5	34.1	17.8		
0.75	50.1	16		
1	68.8	18.7		

Figure 21: Compressive Force Data

4.1.2 Sum of forces analysis

Using the free body diagram [see Figure 22] and taking the sum of moments about point A, where the force at A is applied, the force at B is found. Figure 23 summarizes the results of the force analysis.

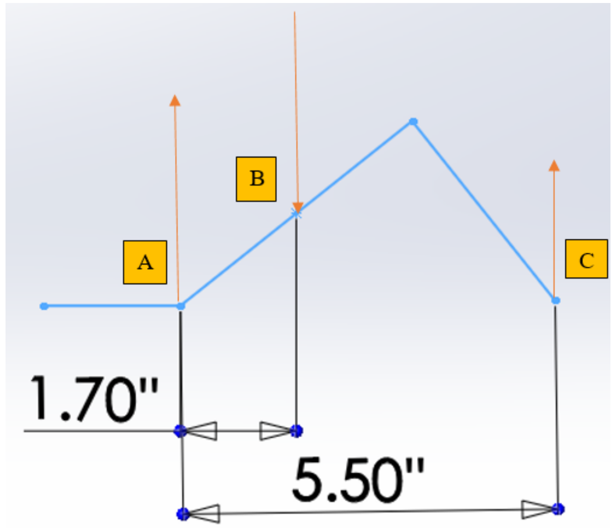

Figure 22: Free Body Diagram of Clamp half

Let $D_1 = 1.70in$ be the horizontal distance between point A and point B.
Let $D_2 = 5.50in$ be the horizontal distance between point A and point C.

$$\sum M_A = 0$$

$$-F_B D_1 + F_C D_2 = 0$$

Since F_C was measured and D_1 and D_2 are known, F_B can be computed directly.

$$F_B = \frac{F_C D_2}{D_1}$$

To find F_A, the sum of forces in the vertical direction (y) is found.

$$\sum F_y = 0 \implies F_A + F_C - F_B = 0 \implies F_A = F_B - F_C$$

Turn	A (lbf)	B (lbf)	C (lbf)
0.25	36.5	52.8	16.3
0.5	76.9	111	34.1
0.75	112.9	163	50.1
1	154.2	223	68.8

Figure 23: Applied forces on each clamp half

4.1.3 Finite element analysis

Finite element analysis was performed using the maximum force data at 1 turn. In submersive testing, it was found that 1 turn is the maximum amount of turns before discomfort. This data was used to determine maximum stress. The analysis is done on the clamp half to find any stress concentrations [see Figure 24]. The units of measurement are ksi.

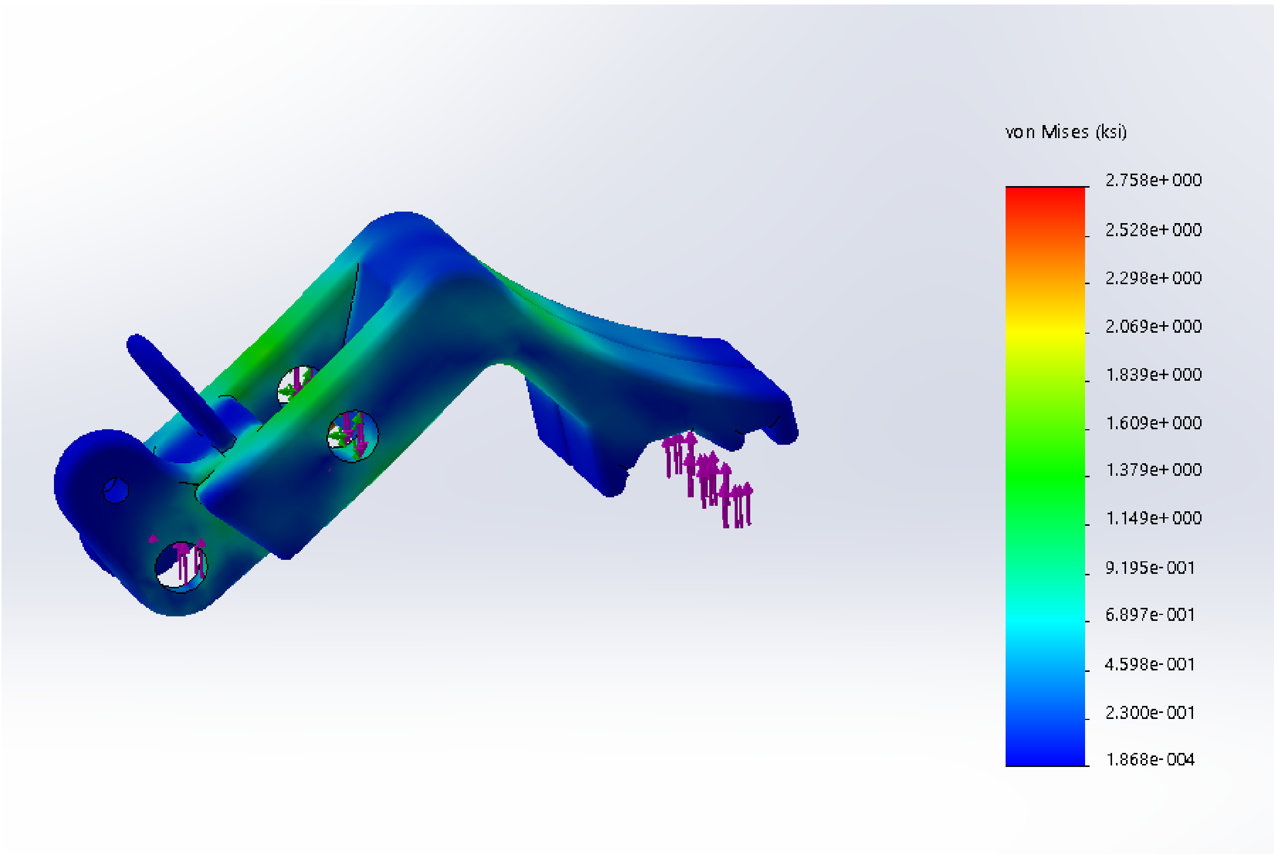

Figure 24: Finite Element Analysis of Clamp half

Following repeated testing, a crack developed in the clamp mechanism [see Figure 25]. The crack developed after repeated loading to 1 full turn and represents fatigue of the material which this FEA (Finite Element Analysis) did not take into account. This crack developed at the weakest point of the design according to the FEA, which validates that the FEA model was done accurately. Further testing and design iteration is needed to ensure cracks do not form under maximum loading conditions. Maximum loading conditions are not expected to be reached per the operations plan, however, in the event that the knob is twisted to 1 full turn, it's expected to stay structurally sound.

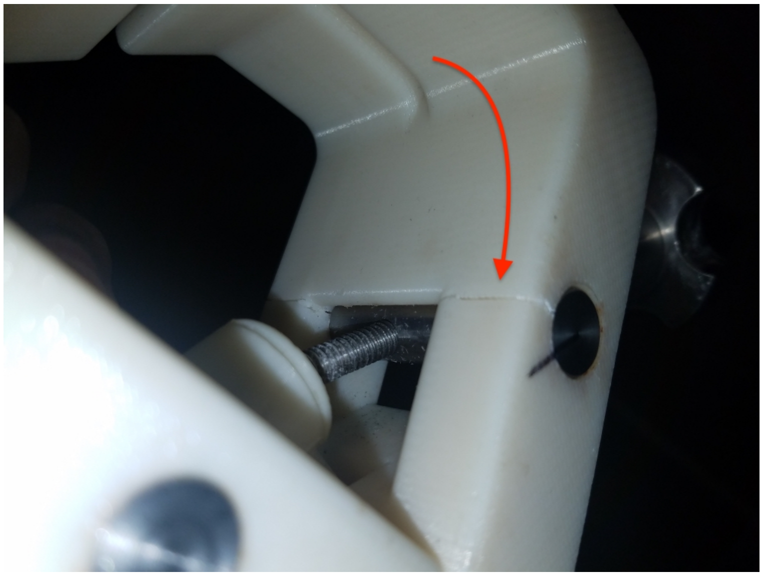

Figure 25: Cracked Clamp

4.2 Submersion Tests

Following the stress analysis, submersion tests were conducted at the Fullerton College pool. It was found that the clamp successfully grapples to the ISS Handrail and CETA Cart when under water at $\frac{1}{4}$ turn [see Figures 26-28]. In addition, it was found that the knob can only be rotated 1 turn before turning becomes uncomfortable to the user with gloves on. Rusting on the screw developed 20 minutes after the CLaMP was taken out of the water. Resultantly, a second iteration of the knob was machined with steel and tested again with no rust development following submersion.

Figure 26: Underwater testing of CLaMP attaching to ISS handrail

Figure 27: Clamp attached to ISS handrail

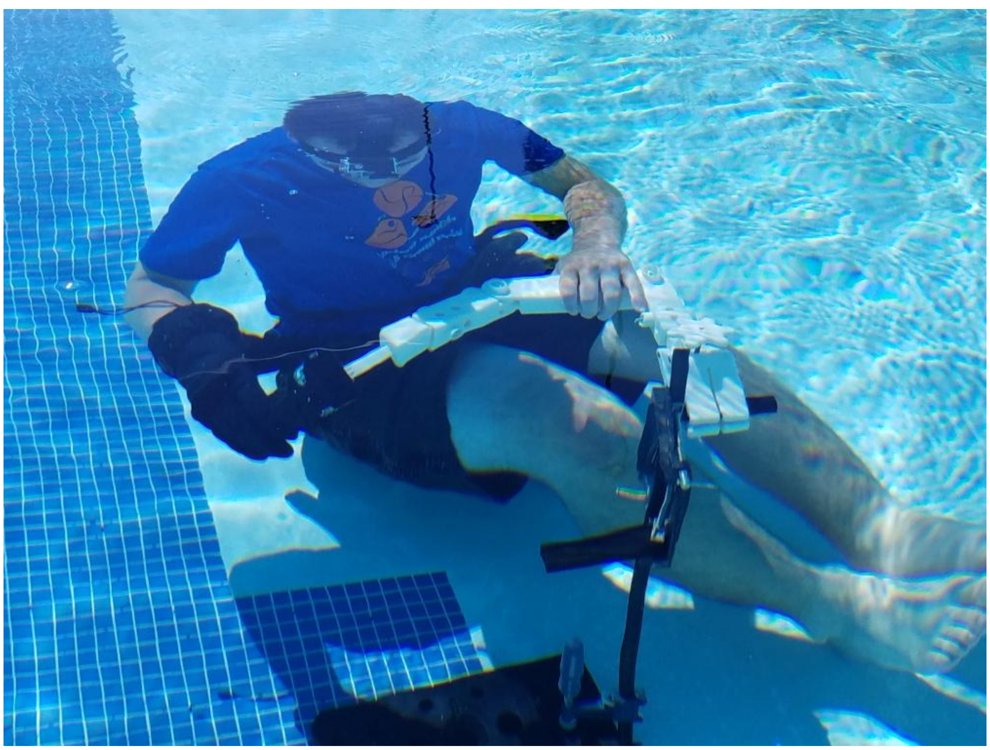

Figure 28: Underwater testing of CLaMP attached to CETA Cart octagonal surface

5 References

References

[1] NASA Education Projects *Micro-G Challenge Document v2, 2019* 2018.