Space Suit Attachment Quick Release System
Final Design Review (FDR) Report

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Statement of Disclaimer

Abstract

NASA plans to make it back to the Moon by 2024 with their Artemis Program, and stay there for a longer period of time to conduct research which will support the future of space exploration. While on the lunar surface, astronauts need to maximize their efficiency by carrying tools on their Exploration Extravehicular Mobility Unit (xEMU), and to accommodate this need, the Extravehicular Activity (EVA) Tools Team is pursuing a utility belt concept. The objective of this project is to develop a system capable of interfacing between the utility belt and any given tool, while also accommodating numerous restrictions and obstacles present on the lunar surface. The design proposed in the Final Design Review Report is a two-piece system made of the tool probe and belt receptacle. The tool probe is made of a wire frame flexure which locks the system in place when docked. The receptacle half is a simple two rung sleeve. This document outlines the final design concept, including the preliminary design process, initial background research, preliminary design concept, design requirements, project timeline, design justification, final design manufacturing procedure, and design verification.

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1.0 Introduction

Between the years of 1963 and 1972, Apollo missions 7 through 17 journeyed into space with the objective of learning more about the moon. Since the return of Apollo 17, no further space missions have traveled beyond Earth's low orbit, much less stepped foot on the moon (Williams, David). In 2017, National Aeronautics and Space Administration (NASA) announced a new program named Artemis with the objective of landing the first woman and the next man on the moon by 2024. Artemis will consist of multiple missions, each of which will contribute to a system of sustainable elements on and around the moon. This lunar infrastructure will allow for robots and astronauts to explore and conduct the research necessary for space exploration to progress past the moon (Dunbar, Brian).

On the first Artemis mission, astronauts will perform spacewalks on the lunar surface, also called Extravehicular Activities (EVAs). These EVAs will include end-to-end sampling operations as well as exploration of the lunar surface. Astronauts wearing their Exploration Extravehicular Mobility Units (xEMUs), or space suits, will need access to a range of specialty tools which need to be managed by a second astronaut. Efficiency while on the lunar surface could be greatly improved with a tool support and quick-release system which would also eliminate the need for the assistance of a second astronaut on certain tasks. The EVA Tools Team at NASA is currently pursuing a concept for carrying tools on a utility belt; however, they are still unsure of the most effective way to attach and release tools efficiently (Micro-g NExT).

Our team entered a competition provided by Micro-g Neutral Buoyancy Experiment Design Teams (Micro-g NeXT), which aims to get undergraduate students involved in current space exploration challenges. Based on competition guidelines, the objective of our project is to design and prototype two components which will interface between any given EVA Tool and the astronaut's utility belt. The design must conform to numerous specifications including size and weight limitations, material requirements, and load capacity.

Two of the most significant obstacles which our group had to overcome included the need for our system to be lunar dust tolerant while also maintaining simplicity and ease of use for the mobility restrained astronaut. These considerations played a significant role in the ideation and idea selection phases, and yielded our proposed design shown in Figure 1.

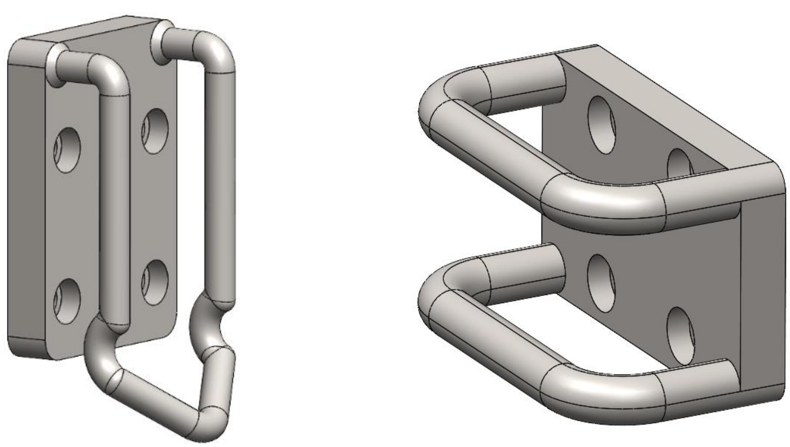


Figure 1. Isometric Views of Proposed CAD Model

Our team includes Andres Elzaurdia (lead), Michael Roth, Elyse Gillis-Smith, and Cole Stanton, all of whom are mechanical engineering undergraduates at California Polytechnic State University in San Luis Obispo.

This document serves to summarize project progress thus far and outline future project plans. Included below are the sections and their purpose summarized.

- The introduction describes the history and brief description of the problem, as well as a summary of the Final Design Review (FDR) report and its contents.
- The background section of the FDR contains detailed information regarding the Micro-g Next competition guidelines, related products research that had input on our design development, and technical research which further directed ideation concepts.
- The objectives section serves to define the problem in detail. It includes a problem statement, project boundary diagram, customer needs/wants table, quality function deployment (QFD), and project specifications descriptions and table.
- The concept design section serves as a descriptive outline of the process we took to go from the design challenge to a preliminary design concept and prototype. It documents our ideation process, matrices used to enlarge and narrow our design concepts, alternative design concepts, and our final design choice.
- The final design section describes our current final design selection and discussions of the structural prototype, meeting requirements, safety, and cost analysis.
- The manufacturing plan section describes the procedure we followed throughout our manufacturing process. It includes how we will acquire our materials, how we will manufacture, how we will assemble.
- The design verification section confirms that our verification prototype meets all of our design specifications.
- The project management section describes the team's current status in the design process as well as what tasks are next and how they will be completed. It also contains a table of Milestones and their respective dates.
- The conclusion and recommendations section summarizes the project, reiterates key points from the document, and discusses steps for moving forward with our design if we had more time or funding.

2.0 Background

Throughout the process of conducting our preliminary background research we were able to condense all the information into three main categories: competition research, related product research, and technical research. Competition research involved thoroughly covering guidelines provided by Micro-g NExT to define design limitations. Related product research covered existing products which could be adapted to solve our problem. Finally, technical research included any information on space travel, space suits, and most importantly lunar dust.

2.1 Competition Research

Our project scope was defined by the assumptions and requirements of the Micro-g NExT project description and information sessions ("Micro-g NExT 2021 Design Challenges"). We must assume for testing that the subject will be weighed out to lunar gravity, which is approximately $1/6^{th}$ of Earth's gravity, and walk on the bottom of the Neutral Buoyancy Laboratory. During testing, NASA will also provide the

EVA tool and Utility belt to attach to test our design. The figure below displays how our two pieces should be designed to fit together with the NASA equipment provided.

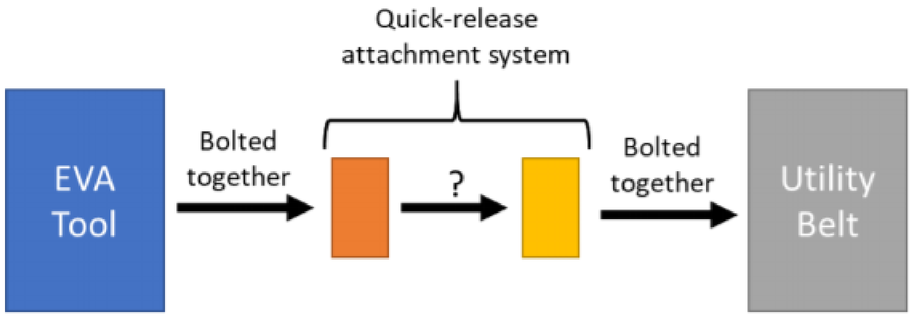


Figure 2. Overview of system and interface interactions (Micro-g NExT)

Micro-g has predetermined project requirements that the design must follow ("Micro-g NExT 2021 Design Challenges"). The mechanism must be able to support at least 15 pounds of weight in Earth's gravity. The mechanism must be operable out of the astronaut's line of sight and operable with one hand. It must be able to be fully functional after being cycled in and out of lunar dust 10 times. The astronaut should be able to release the two pieces with minimal force, but it must be able to stay in place while walking and bending. The mechanism must be operated with only manual power. The mechanism must be smaller than a 4" x 4" x 3" space but must be operable while wearing EVA gloves which can be simulated with heavy ski gloves. The total weight must be under 2 pounds. And there should be no holes or openings that could trap and pinch fingers. The mechanism must be made from either from Aluminum 6061, Aluminum 7075, any series of Stainless Steel, or Teflon. Our mechanism must not have any sharp edges, and we must minimize and label pinch points and anything that would tear or snag on space suits. Both sides of our part must be attached to the EVA tool and to the Utility belt with the 4-hole bolt pattern shown in Figure 3.

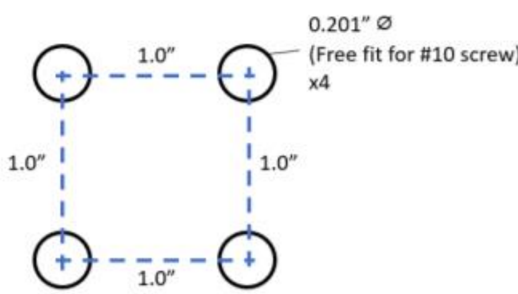


Figure 3. Interface details - bolt pattern requirement ("Micro-g NExT 2021 Design Challenges")

2.2 Related Product Research

The related products research was done in order to gauge what currently exists on the market that may already serve our purpose, and if not perfectly, what concepts we can mirror in our design. Much of the research was performed on Amazon and Google, seeking quick release products or dust tolerant mechanisms. There were no hits for dust resistant quick release products, so brainstorming was required to think of gadgets which are quick release and exposed to dust.

Figure 4. P-7 keychain pocket clip ("P-7 Suspension Clip")

The first product that stood out was a clip designed to hold keys on the edge of the user's pocket or waistband ("P-7 Suspension Clip"). One aspect of this clip that was intriguing was that it **only requires an upward motion to remove the clip** and no finger use. Another component was that its **simplicity makes it dust resistant since there are no tight mechanical fits to obstruct**. One downside is that there is no lock securing the clip so if the tool were to be bumped upward, it may come off, a clear weak point.

The second clip that met a couple design requirements was a bike shoe clip, also referred to as clipless pedals. There are two main types of clipless pedals, road bike and mountain bike ("How to Choose"). This clip was studied further because of three main qualities: It only requires **general movements to enter and exit** since it is on the user's feet, **it is exposed to dust on the tread of a shoe** which gets used to walk on all terrains, and it is a **two-component design similar to how we envision our product**. The mountain bike clips are also exposed to mud and other more extreme terrain. Some downsides to the design are the several pinch points which can cause issues with the space suit fabric, and potentially exceeding load requirements for removal since the shoes are extremely stiff while the space suit fabric is not.

Figure 5. Clipless bike pedals diagram ("How to Choose Bike Pedals")

The third product which captured our attention was a previous Cal Poly SLO senior project which designed a quick release snowboard attachment to allow the user to remove the board for arial maneuvers as well as for safety during a crash, similar to skis (Crossen et al. 9). Several things about this project were attractive. First, their research methods are helpful, for example weighing different movements in a morph matrix for release and re-entry into the binding (Crossen et al. 18-19). This project also referred us to other products that we had not thought about such as the bike clips. **The design's chosen movements for exit are twisting the toe inwards and re-entry is done by stomping on the attachment. This is also the clipless pedals' methods for entry and exit.** However, this project's final CAM follower design has many similar downfalls to the bike clips such as pinch points and mounting load requirements.

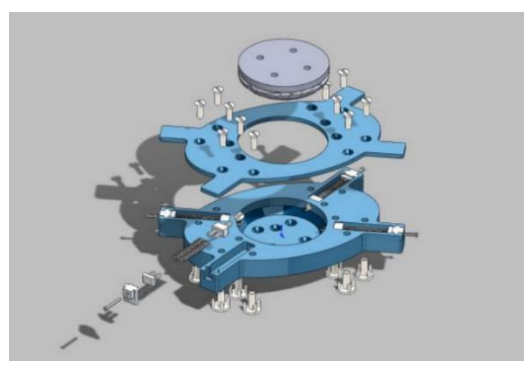


Figure 6. Quick release snowboard binding final design exploded view (Crossen, Rex, et al.)

The fourth clip which proved to be useful for our research was the Modified Mini-Workstation Tool Stowage Caddy (MMWS) which is currently used in space for tethering tools to spacesuits (Carey, Bjorn). It works by clipping to a tool and when the tool is drawn, a tether extends from a box at the base and the clip remains attached to the tool (Hutchinson, Lee). This clip does not meet several requirements such as size, dust resistance, and security methods but it does prove to clarify the capability of space suit mobility. From looking at the photo next the space suit, they appear relatively small, about 4" x 1” x 0.5”, but for ease of use for the astronaut, **they have a circular pad to make finding the release mechanism location easier. It also shows that NASA may prefer to have an actuated release mechanism such as a lever or button rather than a passive release such as a twist or pull.**

Figure 7. MMWS attached to a spacesuit (Hutchinson, Lee)

The last clip on the market that attracted attention was the long line clip used in all types of diving sports. This clip is used by divers to attach lines to important objects such as buoys and spearguns. It operated by pinching the long edges with one hand which extends the hook out of the clip, then the rope loop is hooked, and the clip is released (“Rob Allen How To”). This clip’s **one-handed capability and dust tolerance** meets two design requirements. However, important issues arise when considering security, materials (rope), and line of sight of the astronaut. Mainly this clip was included due to its unique fastening method.

Figure 8. Long line clip (“Rob Allen Long Line Clip”)

The Related Patent Table, documented as Table 1, summarizes the different patents that we used to help our understanding of the problem. Researching patents helped us both define our problem and open our eyes to possible solutions that we had previously not thought of. For each patent we saw similarities to the challenges we faced. We were initially drawn to the bike clip design because the clip would have to function despite any debris accumulated on the ground. Additionally, the bike clip required different movements to secure and release which we also thought was an interesting idea. The tradesman’s tool belt reminded us of the importance of simplicity and ease of access in our design. Other aspects of designs shown below also inspired ideas that we ideated upon after our background research.

Table 1. Related Patent Table

Patent Name	Patent Number	Key Characteristics
Helmet with a chin strap buckle system	US9125446B2	• Quickly attaches and removes chin strap • Can withstand impacts • Simple to use
Retention holster	EP2307845B1	• Pressure locking system • Secures with pressure and friction
Tradesman's tool belt	US5511703A	• Holds all necessary tools • Provides core support • Tools secured with friction
One-handed backpack harness	US6349921A	• Pressure plate secures back • Operable with one hand
Bicycle pedal that fit a multiplicity of shoe cleats	US6877399B1	• Clips in with no hands or vision

While researching dust tolerant mechanisms, a document written by the International Agency Working Group (a collaboration between numerous space agencies) was found which detailed numerous strategies and attempts at minimizing the effects of lunar dust. Some of the passive strategies discussed in the article included the use of an adhesive coating, a dust filtration system, or the use of fabric to attract or repel dust. The most applicable strategy which we believed was simple enough to be considered for our design was the fender design used on lunar roving vehicles. The fender provided a shield on all sides of the rover wheels, leaving only the bottom open and exposed to the dust. While this design still allowed dust to enter the wheel well, it prevented most of the possible dust exposure and minimized design features which could promote dust entrapment (Working Group Membership). The effectiveness of the fender's simple design proved to be an important consideration for our team.

2.3 Technical Research

As stated above, technical research includes information on space travel, space suits and lunar dust. We have found valuable information in the form of transcripts and interviews from previous moon missions, research reports, and scientific articles. Early in our research for this project it became clear to us that the lunar dust would be the greatest unknown and therefore the greatest challenge of designing this space suit attachment.

2.4 Lunar Dust Research

On all prior missions to the moon lunar dust has created problems for astronauts. Lunar dust particles have a net negative charge which makes them attracted to everything that is brought on the mission from earth. This includes tools the astronauts use, the space suits, and the Lunar vehicle itself. This dust is formed when micrometeorites collide with the lunar surface (Stubbs, Timothy). These collisions are frequent and the lack of atmosphere on the moon allows the remnants from micrometeorite collisions to remain extremely sharp, as shown in Figure 9 ("Don't Breathe the Moondust").

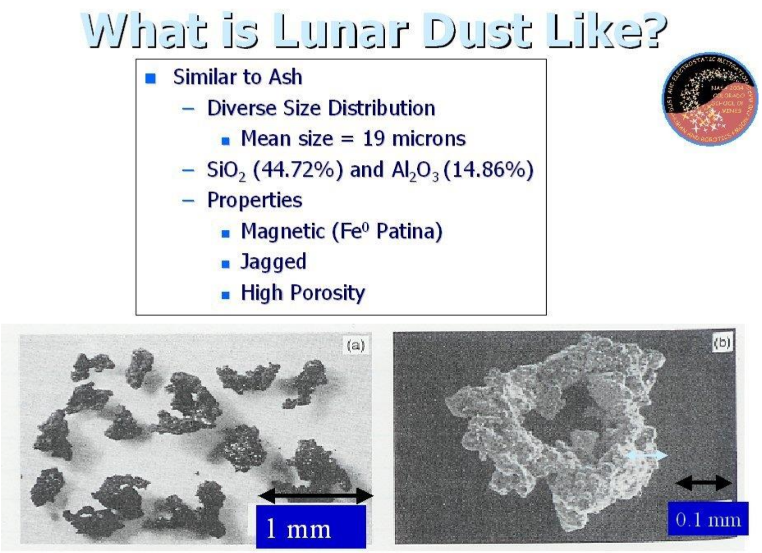


Figure 9. NASA's lunar dust information sheet ("Don't Breathe Moon Dust")

2.5 Impact of Lunar Dust on Astronauts

Astronauts partake in extensive training before they get to the moon but there are many situations during the moon walk that arise on the fly and cannot be simulated. On the moon an astronaut's time is extremely valuable and they try to waste as little time as possible dealing with lunar dust. As mentioned above, lunar dust's negative charge causes it to stick to almost everything it has contact with. This causes the astronauts to take time and address the dust with by brushing off and wiping down equipment when they could be taking samples or doing other tasks (Gaier, James). The picture below shows Gene Cernan after an Apollo 17 moonwalk covered in lunar dust. Fortunately, contact with lunar dust has yet to pose any serious threat to the astronauts upon return to Earth (Mckay, et al.).

Figure 10. Gene Cernan covered in lunar dust (Don't Breathe Moon Dust)

In addition to the primary impacts the dust has on astronauts, the dust combined with other factors also provide problems for astronauts' balance. For example, the difference in gravity between the moon and the earth, the soft surface of the lunar dust and the abundance of rocks of all sizes makes astronauts prone to falls (Moiseev, N., et al.). These falls cost the astronauts time and can also damage valuable equipment and samples.

2.6 Impact of Lunar Dust on Equipment

Dust is extremely effective at quickly and completely coating all surfaces it encounters. It has also covered cords that astronauts later tripped on. It also destroyed a contrast chart that was dropped in it by one of the astronauts (Lunar Surface Journal). This dust coating has caused problems for lunar equipment such as the clogging of mechanisms, seal failures, abrasion and reducing the effectiveness of thermal control surfaces (Gaier, James). NASA has experimented with multiple different solutions to remove dust from thermal control surfaces including vibration, use of a brush and a compressible fluid jet. The most effective method was the brush, which ended up 'flying' or going to the moon, but it was still not supremely effective cleaning the thermal control surfaces.

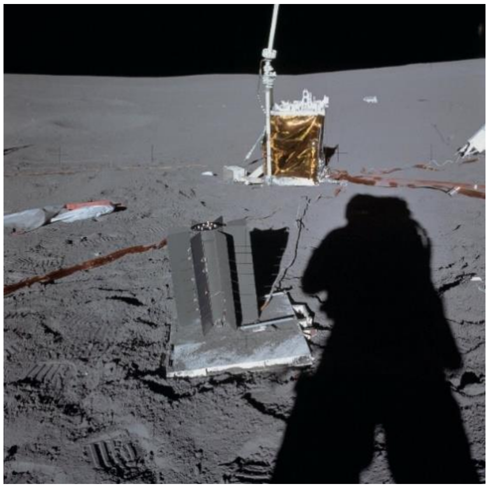


Figure 11. Rover covered in lunar dust (Apollo Lunar Surface Journal)

2.7 Temperature Range

Another influence on our design is going to be the temperature fluctuations that our system may experience. This is particularly impactful considering the design of the flexure and how material properties change with temperature. The Artemis Program plans to land near the South Pole of the moon, and in the most extreme case, explore the Permanently Shadowed Regions (PSR) for a goal of 2 hours (Coan, Dave). In these PSRs, according to Ochoa et al., the temperatures can reach as low as -387 °F. If our system is going to be exposed to these temperatures for nearly two hours, it is likely that the parts would reach near steady state of a very low temperature. This will affect the metal's brittleness, strength, toughness, and elasticity. Brittleness and strength affect astronaut safety, as an exposed, sharp broken wire is a threat to the xEMU. Toughness is determinant of life of the system, and elasticity is critical for the flexure's successful operation. The effects of the extreme temperatures on the final material choice must be further investigated to ensure comprehensive design success.

3.0 Objectives

NASA astronauts moonwalking for several consecutive hours will require a physical system to both secure and quickly release tools from their utility belt. The attachment must be lunar dust tolerant, operable with large gloves, usable without looking down at the mechanism, and able to fit the utility belt size constraints. Our team has entered a competition to design the most effective solution to this problem while still adhering to the competition guidelines.

Figure 12 shows our project's boundary diagram, which outlines the scope of our project as shown by the dotted line. Our space suit quick-release system should be made up of two parts and will interface between an astronaut's utility belt and any given EVA tool. To attach our parts to either the tool or the utility belt, they should both incorporate a specified 4-hole pattern fitting #10 screws.

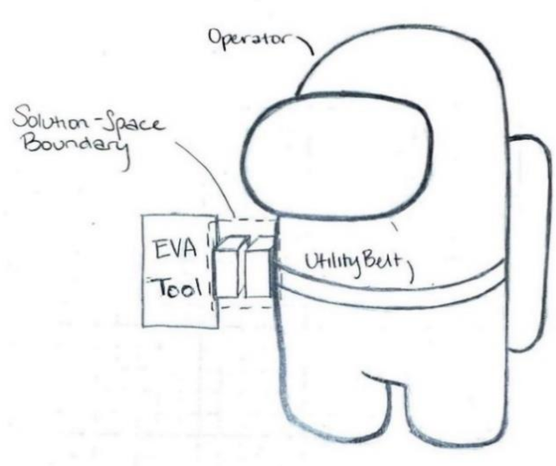


Figure 12. Space suit quick-release project Boundary Diagram

3.1 Customer Needs/Wants

Table 2 below shows a list of needs and wants which will be crucial to the success of our project in the Micro-g NExT competition. Upon submission of our project proposal on 10/30/20, if any of the needs are not met, our project might not have been considered. We intend to focus on the wants shown below as a guide for improving our design. While excluding a want from our proposal will not eliminate our team from the competition, considering them thoroughly throughout the design process and including them in our design will improve our chances of success.

Table 2. List of customer needs and wants based on Micro-g NExT project description

Customer Needs	Customer Wants
Support 15 lbs.	Minimize Volume
Operable outside of line of sight	Minimize Weight
Operable with one hand	Minimize force for release
Resistant to lunar dust simulant	Minimize pinch points
Specified 4-hole bolt pattern	Astronaut ease of use
Fit within 4" x 4" x 3"	Maximize tool stability
Use only manual power	
Operable with EVA gloved hands	
Weigh under 2 lbs.	
Made using specified materials	
No sharp edges	

3.2 Quality Function Deployment

We used Quality Function Deployment (QFD) process to determine what parameters will be most essential for our design. Requirements we used to determine these include quick release, lightweight, dust tolerant, and load capacity. We analyzed the how each of these requirements are important to the astronauts, NASA Micro-g NExT competition, and the manufacturer. Tests and specifications were described to test the various requirements, such as measuring the weight, a vertical load test, and timed operation test. Requirements and tests were associated with strong, moderate, weak, or no relationships, and all tests were given positive, negative, or no correlations to other tests. We also examined how some current products meet these requirements, such as bike pedal clips, the current NASA Tool Caddies, and gun holders. The results of this Quality Function Deployment, or House of Quality, can be found in Appendix A. From this document, we were able to construct Table 3, which tabulates our project specifications, the risk, and the compliance of our design.

3.3 Project Specifications

Shown below in Table 3 are the project specifications which will allow our team to quantifiably assess the performance of our design in the future. Each specification describes a provided project guideline as well as how we intend to test whether we met said guideline. Most of the specifications can be divided into two categories, the first being geometry and the second being operation. Geometric specifications such as weight, volume, or pinch points should be easy to assess using common measurement methods. Operation specifications, such as single handed, blind, and ski glove operation, will likely be manually tested and timed by all our team members. Testing our final product using the specifications will allow us to determine the quality of our design solution.

Table 3. List of project specifications

#	Specification	Requirement	Tolerance	Risk	Compliance
1	Total Weight	2 lbs.	Max	H	I
2	Total Volume	4” x 4” x 3”	Max	H	I
3	Release Force	5 lbf < F < 10 lbf	N/A	H	T
4	Secure Force	10 lbf < F	Max	M	T
5	Load Capacity	15 lbs.	Min	H	T, A
6	Bolt Pattern	4-Hole	N/A	H	I
7	Single Handed Operation	Locate and release tool with one hand	N/A	H	T
8	Ski Glove Operation	Operate while wearing ski glove, 4 seconds	Max	H	T
9	Blind Operation	Tool location blindfolded, 4 seconds	Max	M	T
10	Timed Operation	4 seconds	Max	M	T
11	Material Evaluation	Alum 6061/7075, SS, Teflon	N/A	M	I, A
12	Moon Dust Cycles	10 cycles, Still Functions	N/A	H	T, A, I
13	Jostling	Tool does not release while being jostled.	N/A	M	A, T
14	Pinch Points	No greater than 4 & low force	Max	H	T, I
15	Sharp Edges	Radius for edges, r ≥ 0.02”	Min	M	T, I
16	Finger Entrapment	Fingers cannot get irremovably trapped	N/A	M	I

Specifications Explanations:

1. Micro-g NExT specified that the two mating parts must not weigh more than 2 lbs.
2. Micro-g NExT specified that the total volume occupied by the quick release system should be no more than 4” x 4” x 3”.
3. Micro-g NExT specified that the system should minimize the release force for the astronaut while having enough force to stay in place while walking and bending. This resulted in a minimum release force of 5 lbf for stability and a maximum release force of 10 lbf for comfort.
4. Micro-g NExT specified that the system should also be able to secure with minimum force. This resulted in a maximum securing force of 10 lbf, similar to the release force.
5. Micro-g NExT specified that the quick release should be able to support a tool of 15 lbf in earth’s gravity.
6. Micro-g NExT specified that both halves of the quick-release system must conform to a specified 15/16-inch square bolt pattern.
7. Micro-g NExT specified that the system should be operable with just one hand.
8. Micro-g NExT specified that our system should be usable with large, gloved hands similar to in the xEMU.
9. Micro-g NExT specified that the quick-release system should be operable out of the astronaut’s line of sight.
10. Micro-g NExT specified that we should attempt to minimize the time required to operate the quick release system. We determined that we should specify a max operation time of four seconds.
11. Micro-g NExT specified that our system should be made from aluminum 6061, aluminum 7075, stainless steel, or Teflon.
12. Micro-g NExT specified that our quick release system should be able to operate despite the presence of lunar dust.
13. Micro-g NExT specified that the system must be able to support the tool in the case of jostling or bouncing as frequently done on the lunar surface.
14. Micro-g NeXT specified that we must minimize the number of pinch points. A pinch point refers to a part of the system in which an astronaut could pinch a part of their suit throughout the use of the system.
15. Micro-g NExT specified that there must be no sharp edges on our system, which we intend to comply with through our manufacturing process and test to ensure the safety of a user.
16. Micro-g NExT specified that the system should not allow for entrapment of the diver or astronaut’s fingers in a hole or cutout. This was determined to be safe if the holes are larger than 1”.

4.0 Concept Design

Our concept design process began with a Functional Decomposition to analyze the individual functions and subfunctions of our design challenge. From these functions, we utilized ideation processes for our concept development. With these ideas generated, we individually sketched our top ideas for each function. In a team meeting, we created a morphological matrix using the best ideas after discussion and demonstration, and then used this matrix to generate concepts. We voted on these concepts to decide which to prototype and model with CAD, and then put them into a weighted decision matrix to determine the final design. Using this general design shape, more prototypes and CAD models were made until a final prototype design was selected. The final design for the Micro-g NExT proposal was modeled in CAD and is displayed in Figure 13.

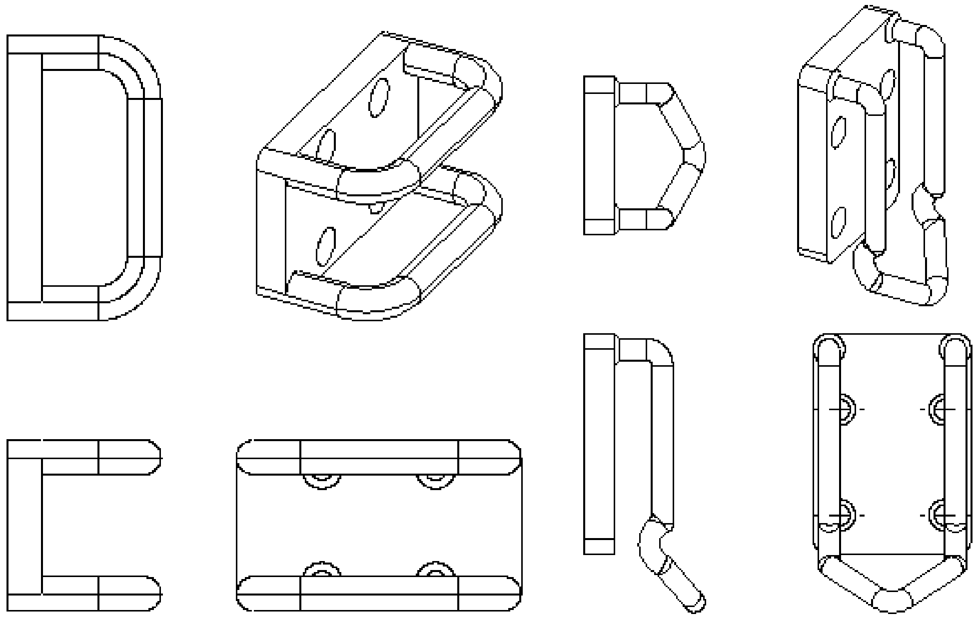


Figure 13. Proposed Prototype CAD Drawing

4.1 Functional Decomposition and Ideation

The design development began with the diverging phase during which the team's objective was to generate as many unique ideas as possible. The first technique used through this phase were functional decomposition method along with several other ideation approaches.

The first step required to begin ideation was a functional decomposition which can be seen in Figure 14. Functional decomposition allowed our team to simplify our problem into the most basic functions and subfunctions, which would ultimately help us with idea generation. Our problem was broken down into five functions: securing the tool, releasing the tool, functioning in the presence of lunar dust, and securing to the tool and the belt.

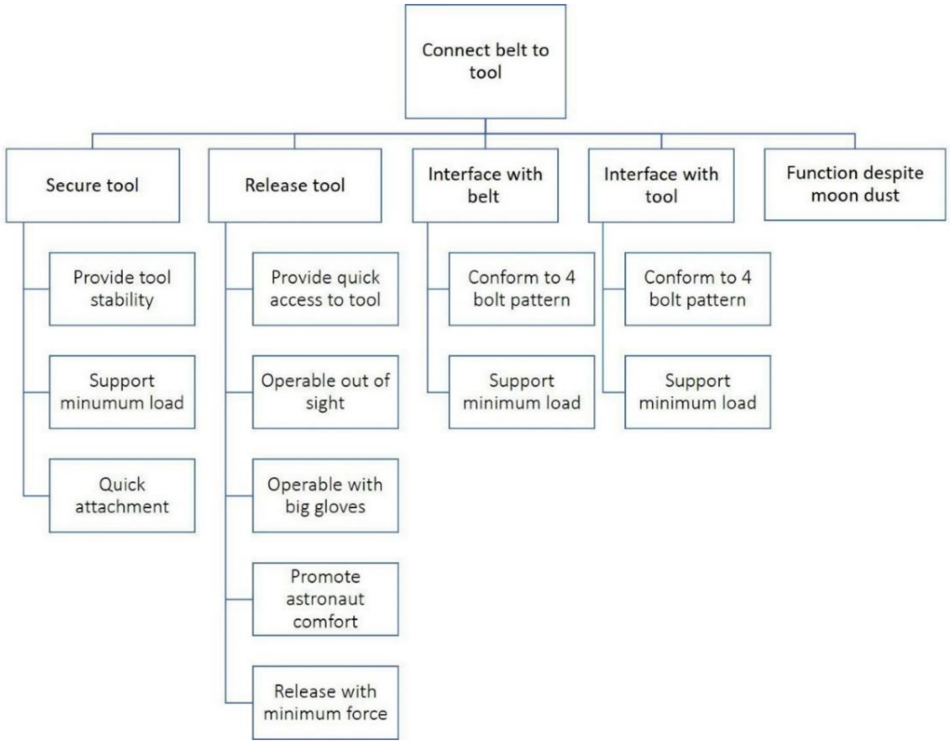


Figure 14. Functional Decomposition of our space suit tool belt interface

The next step of our process was ideation which was performed on the three most critical functions outlined through our functional decomposition. These functions included securing the tool, releasing the tool, and functioning in the presence of lunar dust. Securing the tool to the belt was left out of the ideation process because a 4-bolt hole pattern had already been designated by Micro-g NeXT. Our ideation process involved Braindumps, Brainstorms, and Brainwrites which helped our team generate as many ideas as possible for each function, regardless of feasibility.

Our Braindump sessions consisted of dedicating certain amounts of time ranging from 10 to 25 minutes to individually ideating on the specific functions. This is designed to allow the team to put down on paper initial ideas and concepts we had been subconsciously thinking of. The Brainstorm was a team session lasting about 20 minutes, in which we were able to build off each other's ideas in a fluid and unstructured way. Brainwrites involved multiple ten-minute sessions in which each team member generated ideas individually and then passed those ideas on so that other team members could build off them.

For securing and releasing the tool, one Braindump and one Brainwrite were performed. A Brainstorm and then Braindump were done for the lunar dust function. All these sketches and concept descriptions were documented in our Team Project Notebook and are displayed in Appendix B.

Due to our condensed time frame and size of scope, we had an expedited ideation process. Instead of using a Pugh matrix to refine each function's set of ideas, we each individually selected three ideas that we believed to be the most functional and promising concepts. This left us with twelve ideas (3 ideas x 4 people) for each function (36 concepts in total) to consider. These sketches and idea concepts are displayed in Appendix B. From these top twelve ideas, many of them overlapped. Thus, the team discussed each function and refined the top twelve into four concepts for each function to be put into the morphological matrix.

4.2 Morphological Matrix

The next step in our design process was to input the results of our ideation process into a morphological matrix. The morph matrix, which can be seen in Appendix D, combines the ideas of the separate functions to create preliminary system designs. From the morph matrix, we had sixteen system level designs. We then narrowed down those sixteen to four designs to be put into the weighted decision matrix by using a voting system. Each team member chose the top four designs they believed were most viable solutions, which were then assigned one point and summed. The four system level designs at the end with the most points were selected to advance into the weighted decision matrix. A fifth idea which was a team member's interpretation of one of the four designs was added to the weighted decision matrix.

4.3 Initial Prototypes and CAD Models

After reaching the top four designs, initial prototypes and CAD models were made to analyze the viability of each solution. This analysis allowed for deeper understanding of the designs to increase the accuracy and insight in the weighted decision matrix ratings. Two team members each created two prototypes between meeting days, while the other two team members worked on developing the Micro-g NExT proposal. Images of the top four designs prototypes can be seen in Figure 15, and additional prototypes can be found in Appendix E.

Idea 1: **Idea 2:** **Idea 3:** **Idea 4:**

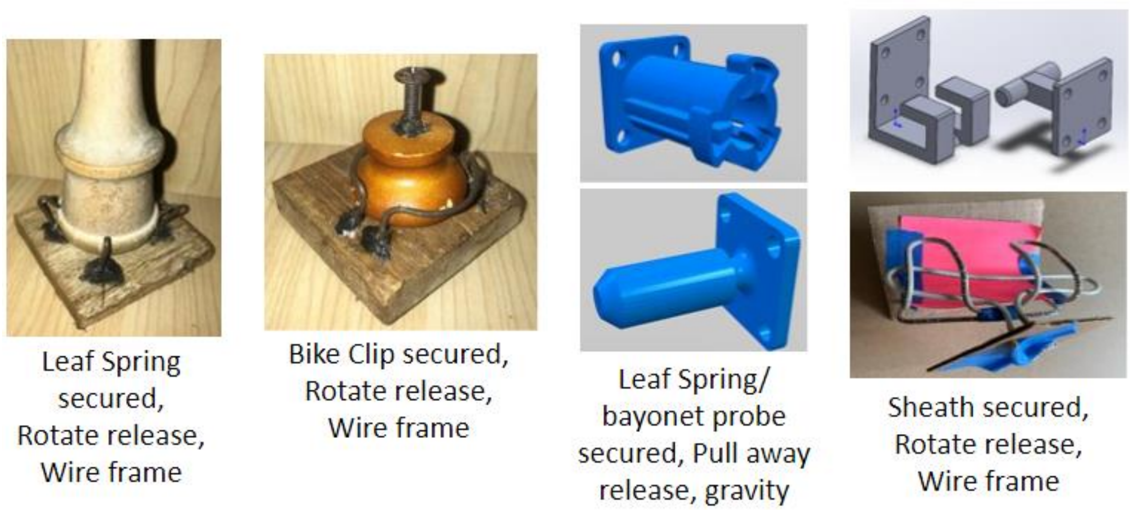


Figure 15. Most Promising Alternative Design Concepts for Weighted Decision Matrix

4.4 Weighted Decision Matrix

The final step in our idea selection process involved the use of a Weighted Decision Matrix, which can be seen in Figure 16. The matrix shows the top five ideas that our ideation process yielded and rates them on a 1-10 scale for each specification that we detailed in our QFD. Each design is graded on its ability to perform each of the specifications.

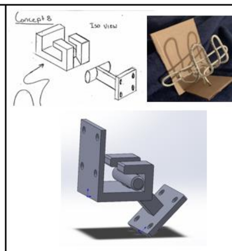
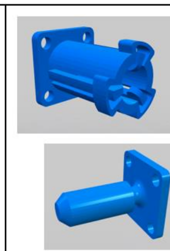
						
Specification	**Weight**	**Idea 1**	**Idea 2**	**Idea 3**	**Idea 4**	**Idea 5**
Lightweight	0.08	5	3.5	6	7	3
Quick release	0.08	7	7	5	6	7
Stable	0.07	6	7	5	3	7
Dust Tolerant	0.10	10	10	10	10	9
Load Capacity	0.10	6	7	7	6	7
Easy to Use	0.09	6	8	8	9	8
Mounting Pattern	0.12	10	10	10	10	10
Size	0.10	7	7	5	7	6
Comfort	0.07	6	6	7	6	5
Safety	0.09	2.5	7	8	8	8
Ease of Fabrication	0.10	3	6	7	8	4.5
Totals:	1.00	6.365	7.3	7.26	7.5	6.93

Figure 16. Weighted Decision Matrix displaying specifications scoring for each prototype idea

All ideas scored relatively close but after filling in the weighted decision matrix it became clear that Idea 5, shown in Figure 17, would yield the most effective final design. This design was the highest ranked in our weighted decision matrix because it did at least moderately well in all the specifications. The other designs may have been higher ranked in certain areas, but they also had serious deficiencies that Idea 5 did not have.

Figure 17. Initial Prototype for Idea Five

Idea 1 was promising because it did not have any joints, crevices, or moving parts that would be perfect places for lunar dust to get stuck in to obstruct the attachment. But this design is also very hazardous due to the sharp points of the leaf spring flexures. This could easily tear into a space suit and compromise a mission.

Idea 2 was a strong candidate due to its lunar dust resiliency, as well as being very easy to use. Our doubts for this idea included concerns with the possibility of finger entrapment, pinch points, and accidental release of the tool because it was so easy to release.

Idea 3 was one of our strongest design concepts in terms of load capacity, but this also means it would be one of the heaviest designs with the most about of metal housing. We also had worries with the ability to fabricate and the possibility of finger entrapment.

Idea 4 was one of the simplest to find and secure blindly, but due to these strengths, the tool was much less stable. This design also had a strong possibility of finger entrapment.

4.5 Selected Concept

The final step in formalizing our concept design involved building a CAD model and physical prototype which would help us to display and explain our design. After eliminating four of five concepts using the weighted decision matrix, we were left with the conceptual materials shown in Figure 18. In this design, the receptacle would be bolted to the belt of the space suit, and the probe attachment piece would be bolted to the tool piece.

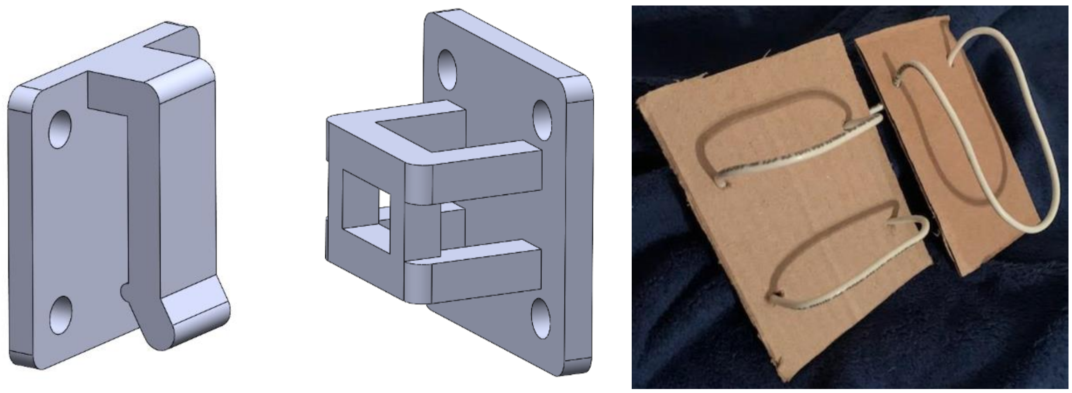


Figure 18. Preliminary Models and Prototypes

Using the existing SOLIDWORKS CAD model and concept prototype, we discussed design features which we wanted to see added to or removed from the final CAD model. The first significant change to the concept models related to the scale. We determined that the receptacle rails should be made wider, and the probe flexure latch be made thinner which would leave clearance allowing the probe part to have some freedom of motion in the lateral direction. The second significant addition made to the existing models was a latching system. We determined that the probe tool part should be designed to flex open slightly to fit over the rails of the belt receptacle part, thus preventing the two parts from separating without an applied force. This change required careful consideration of dimensions on both parts, and the inclusion of a latch on the probe part. The third significant change involved an adjustment to the probe tool part. We determined that the end of the part should simplify location of the receptacle belt part by using both an outwards flange and bringing the end of the part to a rounded point, similar to a probe. The final design adjustment involved a combination of both the CAD model and the concept prototype shown in Figure 18, which was the inclusion of a wire frame design in the final CAD Model. All these design considerations can be seen in Figure 19, showing the 3D printed model of our final design.

Figure 19. Probe and Receptacle 3D Printed Parts

The proposed design concept is a two-part frame system composed of a probe connector attached to the EVA tool and a receptacle attached to the Utility Belt. The components are meshed by simply holding the tool as it would be used and sliding the connector into the receptacle where it will latch twice, first over the top wire, and second over bottom wire, where it is ultimately secured. This means the astronaut never needs to interact with the system, only the tool which they are operating. Tool removal involves simply lifting the tool out of its latched position. The wire frame design of both components and simple locking mechanism prevents the possibility of malfunction due to lunar dust.

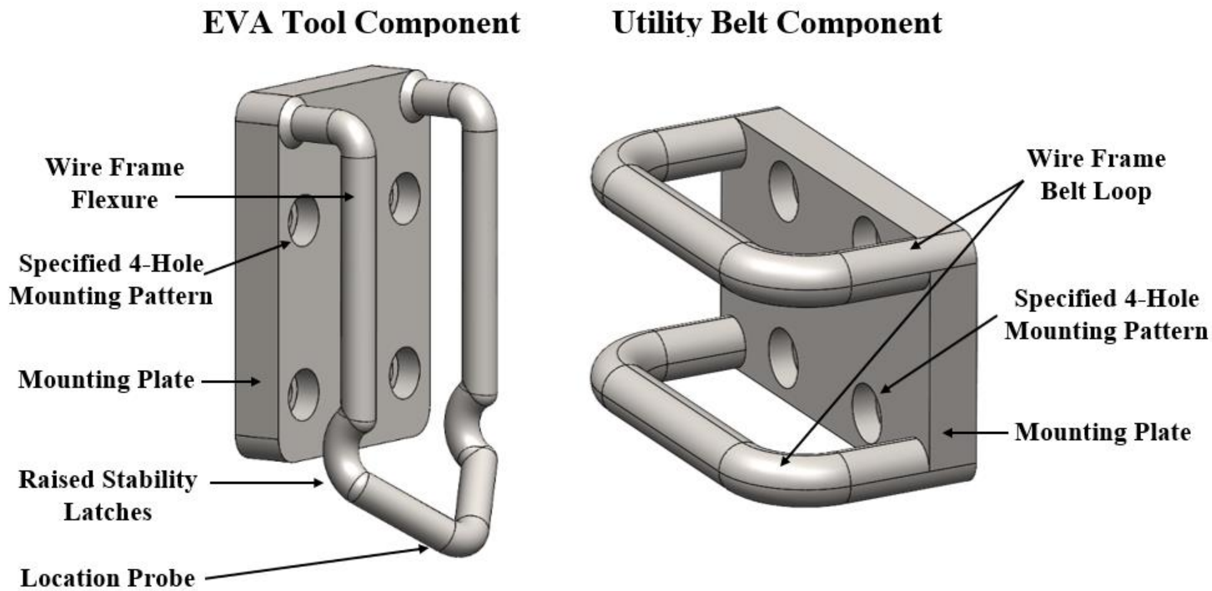


Figure 20. Isometric View of CAD Models with Key Elements Labeled

The EVA tool component of the quick-release system functions to both support and lock the tool into place, as shown in Figure 20. The support component of the design creates stability along the horizontal plane, preventing the tool from being pulled away from the astronaut's waist. The locking component incorporates a spring-loaded flexure which latches onto the receptacle and prevents vertical displacement from the toolbelt during Lunar Surface EVA movement (NASA Video). At the tip of the flexure, the frame narrows to an outward point to increase the area across which the astronaut can locate the receptacle, in turn making securing the part with limited dexterity and no vision easier. Furthermore, the geometry of the angled flange aptly angles the normal force to make opening the flexure and securing the tool effortless. Lastly, operation of the flexure over the first securing wire will release any larger particles that may have been stuck to the part such that when it secures over the second wire, malfunction due to dust is much less likely.

The utility belt component is a simple receptacle made of two horizontal wires, as shown in Figure 20. The wires have intentionally been formed in a square-U shape to provide an easily located slot for the probe connector to mate with. A clearance of one inch was designed into the slots on this part to allow tool to have some freedom of motion in the lateral direction. The wire frame-like design prevents the inclusion of small crevices or interior corners which could cause dust buildup. The design also accounts for astronaut safety by leaving no sharp edges and minimizing risk of finger entrapment.

4.6 Manufacturing Considerations

For our materials consideration, we had to look at materials that would survive the harsh environment of lunar dust and that would function as a spring in our design. We discovered that aluminum does not survive well in the dust environment on the moon, and the sharp particles easily damage aluminum structures ("Apollo Lunar Surface Journal"). However, we were suggested in our Proposal Feedback to reconsider aluminum due to manufacturability and weight considerations. As a result, we have considered using anodized aluminum, commonly used by NASA, as a substitute for stainless steel on the receptacle component to decrease the weight while retaining abrasion resistance. There are several forms of anodization, but according to Luna, Type III anodization "is an extremely hard, abrasion resistant, porous oxide" which appears to suit our purposes best.

The materials that were ordered for the structural and verification prototypes were Aluminum 7075 and 6061 and Stainless Steels 303 and 316. There are various reasons these materials were ordered, from limited stock on Grainger to ductility and weldability. Originally, the plan was to used additive manufacturing for our part due to its intricate geometry; however, due to funds and timeline constrains our plan shifted towards manufacturing the system in house. Cal Poly has a student workshop where we were able to manufacture these parts. The Manufacturing Plan was a culmination of consultation with Cal Poly IME professors, shop techs, and research to produce all the prototypes and final systems by team members Elyse Gillis-Smith and Cole Stanton.

5.0 Final Design

This section of the report will discuss in detail the final design of the quick release system. This section will also discuss design functionality, specifications, safety, maintenance, verification prototypes, and any remaining design concerns. Shown in Figure 21 are CAD models of both individual components as well as an isometric assembly view.

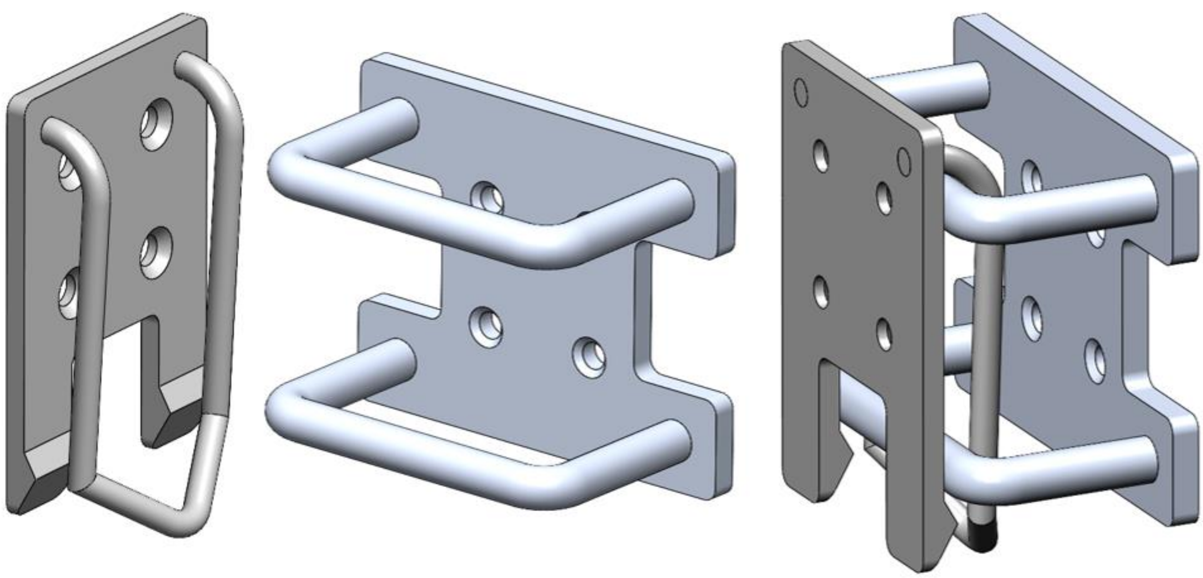


Figure 21. Tool Component, Belt Component, System Assembly

5.1 Design Function

Our quick release system intended for use on the lunar surface is made up of two parts, each designed according to the provided NASA specifications. The first of the two parts is the utility belt component, shown in Figure 22. Design features included in the belt component are a flat mounting plate and the wire frame rungs. The objective of the flat mounting plate was to provide a stable connection with the utility belt, assuming the utility belt will also feature a flat mounting surface. The two wire rungs are crucial to the attachment and release of the tool component. The top rung carries the weight of the tool while the bottom rung allows the tool component to latch and prevent undesired release. Once both rungs have been engaged by the tool component, they also restrain much of the tool's movement.

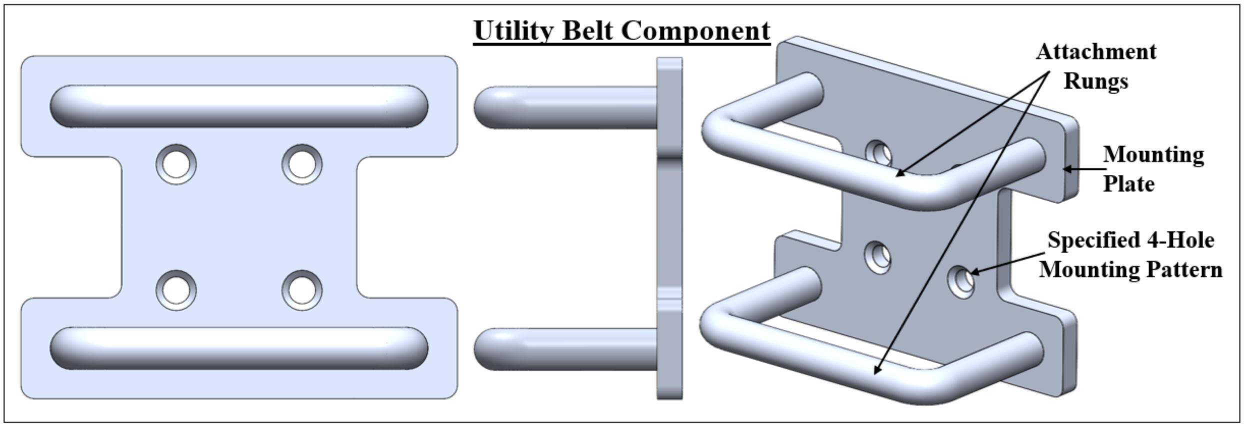


Figure 22. Front View, Side View, and Labeled Isometric View of Belt Component

The second part of the quick release system is the EVA tool component, shown in Figure 23. The major features of the part include the mounting plate, location probe, stability latches, and flexure. The plate serves the same purpose as in the belt part, providing a surface for rigid connection with the EVA tool. Additionally, the opposite side of the plate provides a surface along which the belt rungs can slide seamlessly during attachment. The location probe on this part reduces the likelihood of error when trying to locate the belt component. By ending the flexure in an outward angled point, it increases the area across which the two components will have make a proper connection. Once the tool has been attached to the belt, the latches in combination with the flexure will prevent the tool from releasing without an applied vertical force from the astronaut.

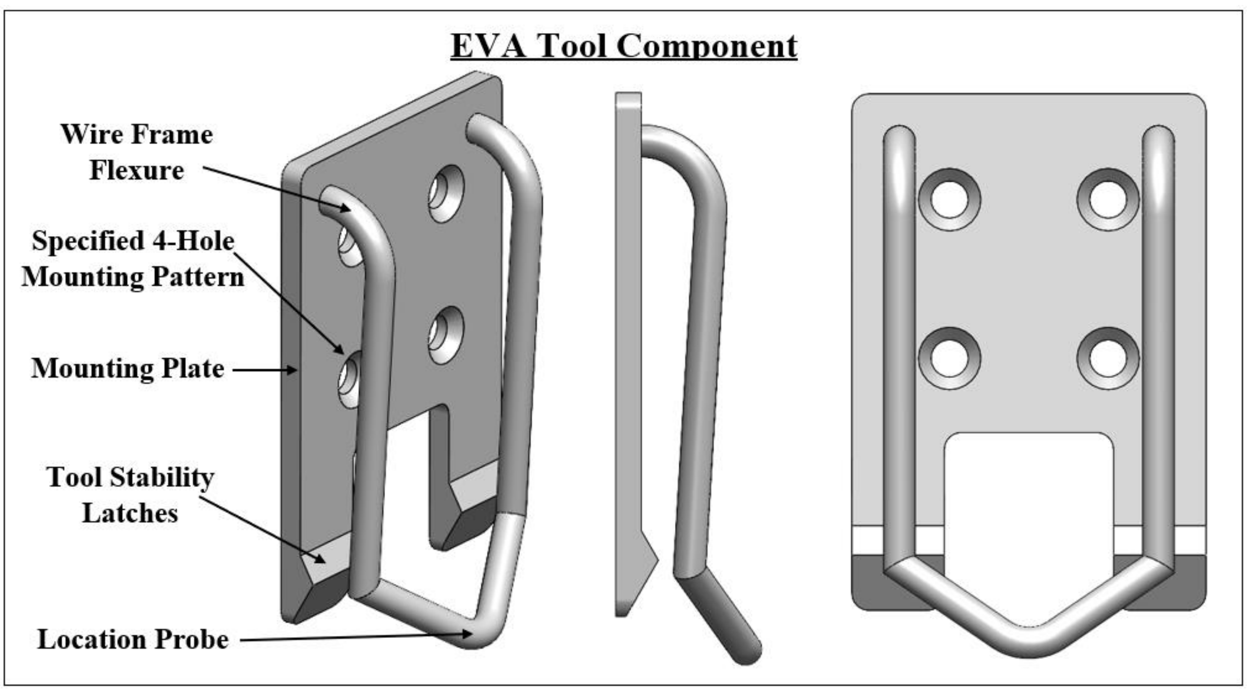


Figure 23. Labeled Isometric View, Side View, and Front View of Tool Component

Once both the tool and belt halves of the system have been mounted, they should easily connect and disconnect from each other with minimal force. As is shown in Figure 24, the flexure on the tool component slides over the two rungs of the belt component and hangs the weight of the tool on the top rung. To accomplish this, the astronaut must use the pointed location probe on the tool to engage the opening in the top rung of the belt part. Once location of the top rung has been achieved, the slanted flexure and tool base plate will guide the part until pressure is induced on the latches from contacting the top rung. At this point, the astronaut must apply minimal force to the tool to stretch the flexure over the top rung, and then again over the bottom rung. The tool has now been securely attached and the astronaut can release their grip on the tool without any concern of it falling. The feedback from the flexure snapping over the second rung should indicate to the astronaut when the tool has been properly secured. To release the astronaut should simply grab the tool and apply minimal lifting force, at which point the tool component flexure will bend over both belt component rungs and the EVA tool will be quickly released from the utility belt.

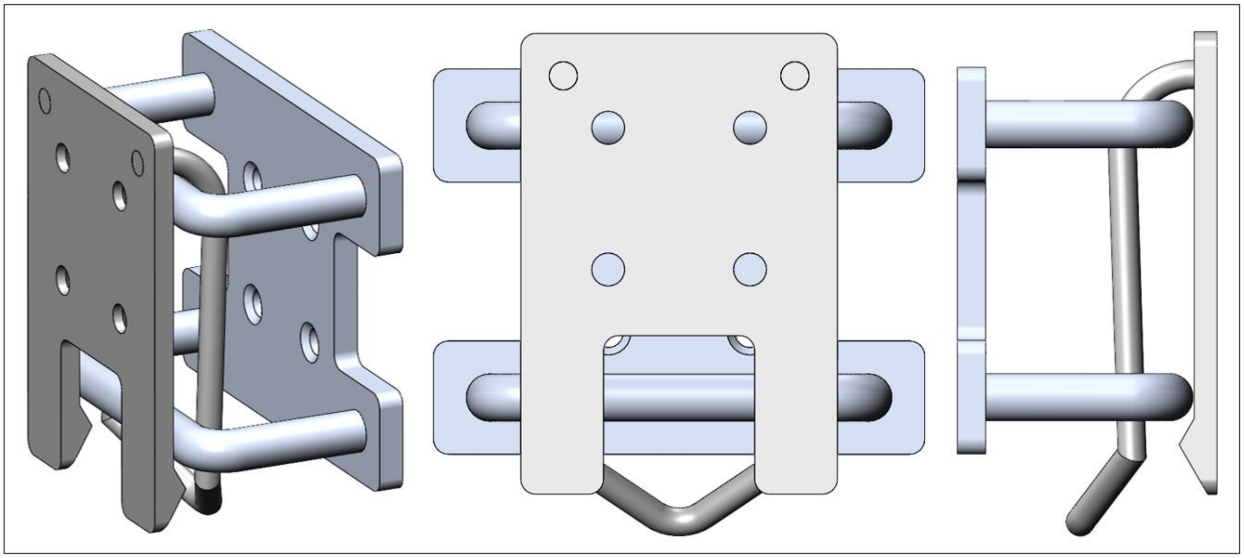


***Figure* 24.** Isometric, Front, and Side Views of Quick Release Assembly

5.2 Design Requirement Conformity

Table 4 shows the design justifications for each of the requirements provided in the Micro-g competition guidelines. These requirements played a significant role in our design process and shaped the final design, which we believe will allow our system to be successful when tested in the Neutral Buoyancy Lab. After performing extensive analysis, prototyping, and testing, our system effectively met each of the requirements and specifications posed by NASA. A more detailed description of how each specification was met can be seen in the Design Verification section.

Table 4. Design justification for provided NASA requirements

Reference Number	Requirement	Meeting Requirement
1	Attachment able to support 15 lbs. in Earth's gravity	FEA and physical load tests
2	Operable outside line of sight	Manufactured prototypes and final design tested without sight
3	Operable with one hand	Manufactured prototypes and final design tested with single handed use
4	Able to function despite interference from lunar dust	Design concept principles and lunar dust simulant testing with aluminum 6061 prototype
5	Installation and separation should require minimal force, but enough force to stay walking and bending	Tests with manufactured prototypes, final design, and analysis indicate comfortable yet functional force to join and separate parts
6	Device shall use only manual power	Design uses only manual power
7	Device shall fit within a volume of 4" x 4" x 3"	Design dimensions are 3.25" x 3.29" x 1.65"
8	Device shall have a compliant 4-hole bolt pattern	Both parts conform to 15/16" square hole pattern
9	Device must be operable with EVA gloved hands	Design concepts and prototypes have been tested with ski gloves
10	Total weight of all parts should be under 2 lbf	Total weight of fabricated prototypes is 0.30 lbf
11	No holes or openings which would allow for finger entrapment	Manufactured prototypes tested while wearing ski gloves didn't yield any finger entrapment. Holes of potential entrapment are too small and inaccessible
12	Parts should be made from only specified materials	Manufacturing includes use of Aluminum 6061 for all components
13	Parts should not include any sharp edges	Post-processing of manufactured prototype was thoroughly sanded to remove all sharp edges
14	Pinch points should be minimized and labeled	Pinch points are inaccessible to gloved hands, of low force, labelled, and informed to NASA

5.3 Design Safety

Safety was a significant consideration throughout our design process, ultimately resulting in a very astronaut friendly solution. Some of the provided NASA specifications relating to safety included minimizing pinch points, eliminating any sharp edges, and excluding any geometry that would allow finger entrapment. All these specifications are reflected in numerous features of our final design as we considered astronaut safety to be of utmost importance.

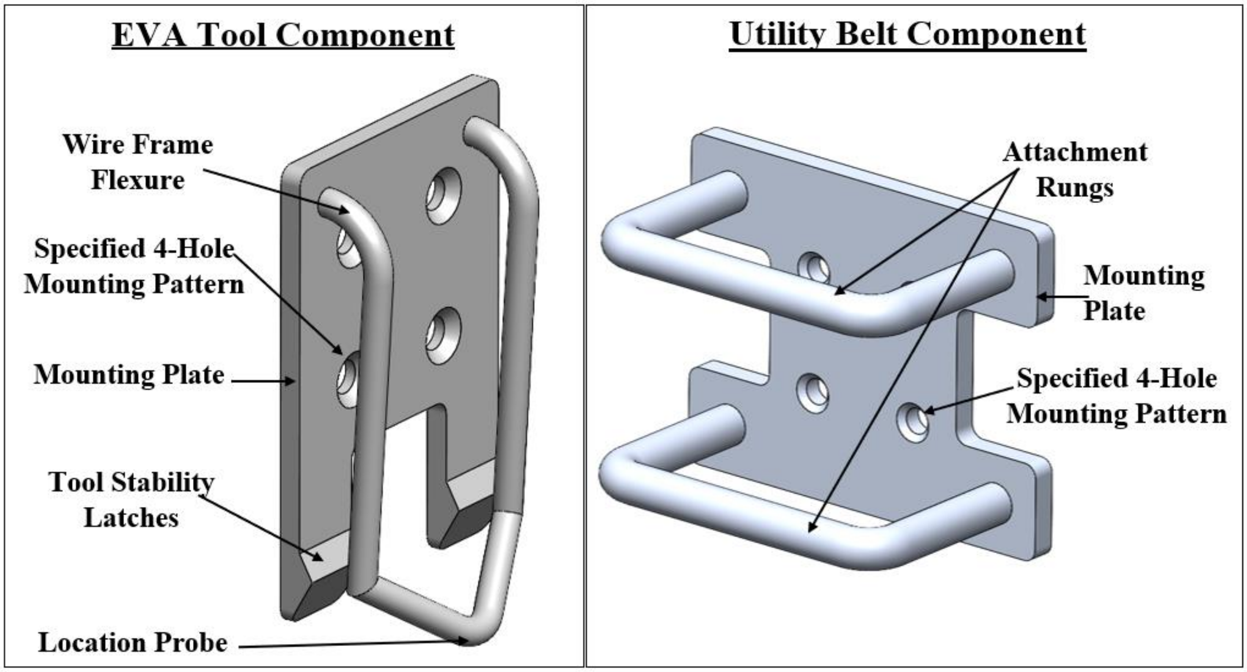


Figure 25. Labeled Isometric Views of Both Components

To meet the requirements of minimizing pinch points as well as excluding geometry that would allow for finger entrapment, we designed our parts to be very inaccessible to large, gloved hands. All geometries within each of the parts were designed to be small enough such that they would not allow the fitment of rigid gloves. On the utility belt component, the length of the interior of the rung is only 0.8 inches, just enough to allow the location probe to pass through. On the EVA tool component, the gap between the flexure and mounting plate is 0.45 inches, preventing any access to gloved fingers. Preliminary tests have been done using 3D printed parts and ski gloves, but further testing will be discussed in the Design Verification section of this report.

As can be seen in Figure 25, our final design features no sharp edges. This NASA specification had a large impact on our design decisions after completing ideation and was one of the main motivations for choosing to use mainly rounded, wire-like features. The base plates on both the EVA tool component and utility belt component have the only potentially hazardous edges at ninety degrees in the model but through post-processing, we ensured that all edges on both parts are properly sanded down and deburred to eliminate any risk to the astronaut.

Another hazard we plan to address is the risk of a ruptured wire in the case of an impact. This hazard is going to be mitigated through FEA using a calculated impact load as well as selection and use of a ductile material. This hazard is a larger concern for final use on the lunar surface since ductility will be impacted by the cold temperature, however it is still certainly essential to consider for diver safety at the NBL.

Based on both the simple design of our part as well as its intended use, we do not expect for maintenance or repair to be applicable. The only assembly required by our design is the attachment of the parts to their respective halves of the system using the included 4-hole mounting pattern. Initial finite element analysis conducted on both parts suggests that we should not expect failure to occur. Additionally, if any damage is caused to either of the parts due to rough usage, we assume that NASA will replace the part rather than risk failure after repair.

5.4 Structural Prototype

Our team has completed most of the fabrication for the structural prototype, shown in Figure 26. Unlike previous 3D printed prototypes made from PLA, the objective of this prototype is to test the effects of loading and manufacturing methods.

Figure 26. Structural Prototype, Tool Left and Belt Right

As specified by Micro-g NExT in the competition guidelines, there are two loading requirements which our system needs to meet. The first requirement is that the system be able to support 15 lbf applied by the EVA tool. By mounting the parts of our structural prototype to a compression tester we were able to apply the appropriate load and assess the affects it has on the parts. The second requirement is that the astronaut should be able to detach the tool from the belt with no more than 4lbs of force. Since the material properties of the structural prototype were representative of the final prototype, we were able to test the amount of force required to stretch the flexure over the rungs of the belt component. During testing, we had the opportunity to iterate on the stability latch dimensions, allowing us to increase or decrease the release force, as necessary.

Through the fabrication of the structural prototype, we have gained valuable information on the limitations of certain techniques and materials. When bending aluminum rod to reflect the shape of the flexure on the tool component, we ran into issues with the rod snapping. To mitigate this problem, we began heating the aluminum rod with a propane torch, which allowed us to bend it to smaller angles without snapping. Through further work on the structural prototype, we should gain insight into the limitations of our manufacturing method, which will ultimately help us finalize our manufacturing plan.

Appendix J, Table J-1 shows the cost of the materials purchased for the structural prototype using the Cal Poly ProCard. The table also shows raw materials ordered from Grainger using funds provided by NASA. These materials included aluminum plate, aluminum rod, stainless steel rod, stainless steel U-bolts and other components used in the fabrication of the structural prototype. Also shown are estimates of the cost to direct metal laser sintering (DMLS) or metal 3D print in aluminum. Quotes from multiple companies have varied drastically, which explains the large range in price.

6.0 Manufacturing

The quick release system is a small and intricate design which has unique manufacturing considerations, even more so with the competition aspect. An important distinction for our project is that there is going to be several verification prototypes which we manufacture in house to use for the DVP tests, as well as a Final Prototype which will be sent to NASA for final testing. Section 6.1 describes how the materials were procured, and Section 6.2 lists all the manufacturing processes that were used to build our verification and final prototypes. Sections 6.3 through 6.7 discuss the manufacturing of the Verification Prototypes and final prototype sent to the NBL. Section 6.9 discusses the challenges and lessons that were learned from all our verification prototypes and offers recommendations for other post-manufacturing processes that we are unable to accomplish due to budget limitations. Section 6.10 discusses an alternative manufacturing method of 3D printing that was considered for our design. Only four different raw materials are needed to build our Verification Prototype, but we will be using both drilling and welding techniques to construct our pieces. The aluminum rungs of the belt and tool halves will be bent and welded to the aluminum plates.

6.1 Material Procurement

Since our component is made with raw materials, these can be purchased from any raw material metal manufacturer. The materials needed include aluminum 6061 plates for both base plates and the components that interface in our clip attachment. All our materials will be purchased from Grainger. We welded the raw materials together, so we used welding rod acquired through the Cal Poly Hangar. To ensure a smooth final surface on our aluminum rods, copper scrap coverings are used during the metal bending process and were given to us by the Cal Poly Hangar.

6.2 Manufacturing Processes

- Propane torch metal heating and bending
- Sawing
- Milling
- Drilling
- Tig Welding
- Belt Sanding
- Waterjet
- Sand blasting

6.3 Belt Receptacle Base Plate

The belt receptacle base plate was originally cut out of ¼" Aluminum 6061 on a vertical band saw, drilled using a drill press, milled for the cutouts, countersunk using the larger bit on a drill press, and then finally sanded to remove sharp edges. We found this process to be very time intensive due to the many different processes required. We also found it was not accurate or clean enough. As a result, our final prototype base plates were cut using the Cal Poly waterjet located in Mustang 60. The manufacturing steps are as follows.

Step 1: Converted part face to .dxf file.

Step 2: Patterned part face within surface area of available stock

Step 3: Ran waterjet to base plate, including weld holes and mounting holes

Figure 27. Tool base plate in the process of being waterjet cut.

Step 4: Countersunk mounting holes using countersink bit.

6.4 Belt Receptacle Wire Frame

This section describes the manufacturing of the wire frame of the belt half of our system. This piece will be made from the 6061-aluminum 5/16" diameter, 12" long rod.

Step 1: Cut in half to two pieces of 6" length with flat ends of the rod using a saw.

Step 2: Clamped the rod in a vice with 6" exposed to the side

Step 3: With a propane torch, heated the location of bend for around a minute or until the flame changed from blue to orange, as shown in the image below.

Figure 28. Heating of flexure rod for bending to demonstrate color change of flame.

Step 4: Wearing welding gloves and using the vice grips and a copper covering, clamped about an inch away from where the bend location will be.

Step 5: Loosened the vise enough to move the aluminum piece to where the edge of the vise was used to bend the metal rod.

Step 6: Slowly torqued the wire such that it bends towards the 90 degrees intended. If the wire became noticeably harder to bend, stopped and repeated steps 3 and 4 until at the desired 90 degrees.

Step 7: Repeated steps 2-4 to create two 90-degree bends in each rung.

Step 8: After bend process had been completed, sand blasted rails to remove deeper marks in the rungs from bend process.

Step 9: Used sandpaper, a metal brush, and Scotch Brite to smoothen the rungs where the tool probe component rubs against.

6.5 Belt Receptacle Assembly

This section describes the assembly of the belt half of our system using the belt receptacle base plate and belt receptacle wire frame. The images in Appendix K demonstrate how this part should be assembled.

Step 1: Placed the rungs in the through holes, of the front of the base plate.

Step 2: Used a clamp to secure the pieces in place and ensured the rungs are the correct spacing away from the base plate.

Step 3: Used gas tungsten arc welding or tungsten inert gas (TIG) welding, welded the back of the base plate and rungs to tack the rungs in place.

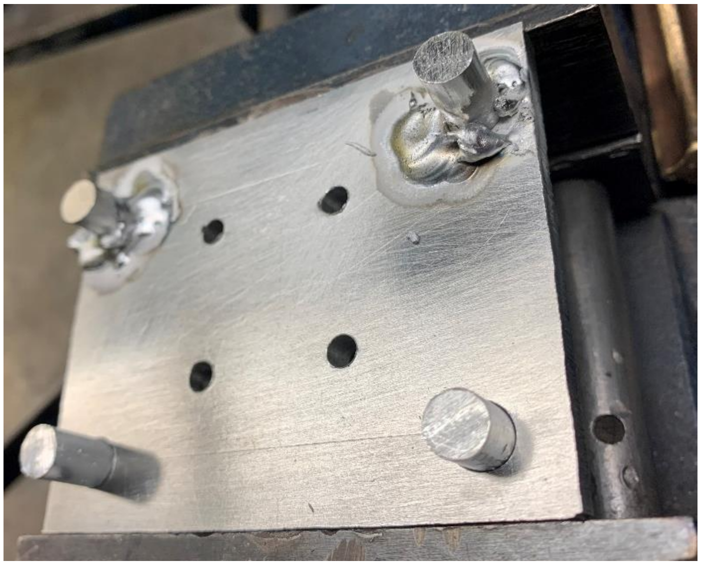


Figure 29. Belt component with two of the four welds on the back completed.

Step 4: Flipped the part over and welded around each rung on the front of the plate.

Step 5: Grinded down the excess rod material on the back of the base plate.

Step 6: Rewelded the back of the base plate to ensure total fusion of the rungs and the base plate.

Step 7: Grinded down excess material so back of base plate is flat. If rod outline was still seen, repeated weld and grind process until full fusion had been achieved.

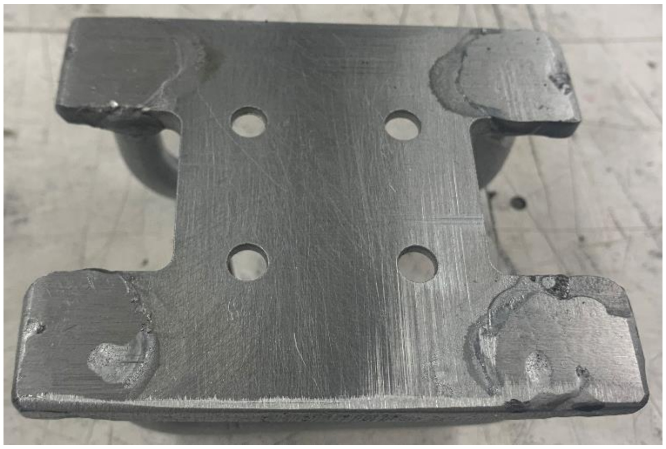


Figure 30. Back of base plate after welding and grinding process.

Step 8: Final filing, sanding, and polishing with Scotch Brite on all surfaces to ensure flush back surface, smooth rails, and no sharp edges.

6.6 Tool Probe Base Plate

The tool component base plate was originally cut out of ¼” Aluminum 6061 on a vertical band saw, drilled using a drill press, faced down using a mill, countersunk on a drill press, and then finally sanded to remove sharp edges. Similar to the belt base plate, we decided to use the waterjet at the Cal Poly Mustang 60 Shop to save time and have better quality parts.

Step 1: Converted part face to .dxf file

Step 2: Patterned part face within surface area of available stock

Step 3: Ran waterjet to base plate, including weld holes and mounting holes

Step 4: Clamped base plate into mill with length of part oriented on the Y-axis and part face normal oriented on the Z-axis. Used parallels to allow the part face to sit above the vise by at least 0.1”.

Step 5: Using a 0.5” endmill while the mill is running, touched off with the face of the part, moved the endmill away from the part, and proceeded to raise the Z-axis 0.1”.

Step 6: Passed across the part along the X-axis, engaging only half of the endmill with the part.

Step 7: Repeated step 6, advancing the endmill along the Y-axis down the length of the part until it reached the start of the latch.

Step 8: Removed part from vise and brush away material, then re-clamped the part in the same orientation but using the 30-degree angled parallel.

Figure 31. Mill set up for milling angled surfaces of tool base plate.

Step 9: Faced off the angled surface facing the top of the part first, taking multiple passes until the corner of the endmill meets the corner of the machined face.

Step 10: Removed part from vise and brush away material, then flipped the part 180-degrees about the Z-axis and re-clamped, again using the 30-degree parallel.

Step 11: Took passes across the bottom edge of the part, repeating until the edge of the face meets the existing angled face.

Step 12: Used deburring tool to clean machined edges of the part

Step 13: Countersunk mounting holes using countersink bit

6.7 Tool Probe Flexure

This section describes the manufacturing of the flexure of the tool half of our system. This piece will be made from Aluminum 3/16" diameter rod, ours was manufactured with a 12" length of rod.

Step 1: Clamped the rod in a vice with 8" exposed to the side.

Step 2: With a propane torch, heated the location of the rightmost bend of the probe for around a minute or until the flame changed from blue to orange.

Step 3: Wearing welding gloves and using the vice grips and a copper covering, clamped about an inch away from where the bend location will be.

Step 5: Loosened the vise enough to move the aluminum piece to where the edge of the vise was used to bend the metal rod.

Step 6: Slowly torqued the wire such that the angle is 126 degrees. If the wire became noticeably harder to bend, repeated steps 3 and 4 until the desired angle has been reached.

Figure 32. Bending of the flexure probe tip

Step 7: Repeated Steps 2 – 7 for the center bend, then the left most bend, while keeping the remaining straight excess in the clamp for easier bending.

Figure 33. Resulting probe bend after steps 2-7

6.8 Tool Probe Assembly Plan

This section describes the assembly of the tool half of our system using the tool probe base plate and tool probe flexure. The images in Appendix K demonstrate how this part should be assembled.

Step 1: Inserted the flexure into the 0.2” ø flexure holes.

Step 2: Used two spare 5/16” rungs, placed them as spacers so that the probe would have the correct spacing, as demonstrated in the image below. Used a clamp to secure the pieces in place.

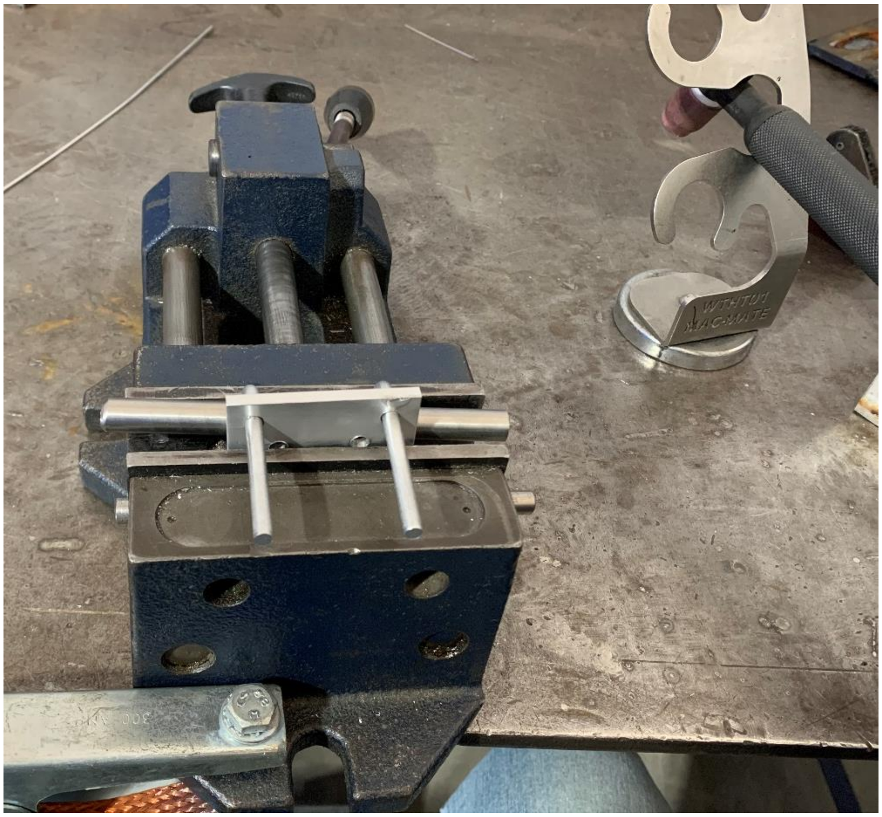


Figure 34. Weld setup of tool component before welding has been completed

Step 3: Used gas tungsten arc welding or tungsten inert gas (TIG) welding, welded the back of the base plate and rungs to ensure that the part will be flush.

Step 4: Ground down excess rod material.

6.9 Challenges and Recommendations

One of the biggest challenges was learning how to tig weld aluminum with very small wire structures on thicker plates. No one in our team had more experience than the one class we all had been required to take, so Elyse was placed in charge of welding. It took her about a week before she was able to get puddles and beads, but after hours of practice in the machine shops and the advice of the shop techs, she was able to produce structurally sound and strong welds for our prototypes.

As we began bending our rod, we discovered that having the stability latches incorporated into the wire frame would be nearly impossible to manufacture with the tools available to us at the Cal Poly Machine Shops, so this resulted in a design change of moving those latches to the base plate of the tool probe component.

Due to the softer surface finish of the aluminum rods, we are recommending that NASA should anodize the rungs before use on the moon. But because the tool is still functional, our part will still be functional for testing in the NBL.

6.10 Alternative Manufacturing Method

After our initial design was approved by NASA, we believed that we would manufacture our parts using additive manufacturing, specifically Direct Metal Laser Sintering (DMLS). One major benefit to this process is that it would fabricate our complex geometry with the most precise dimensions. This method would reduce any inaccuracies caused by human error in our current design process. It would also reduce the amount of time to fabricate parts compared to our existing method. For example, if a dimension needed to be changed the designer would just need to alter the CAD model and send it to the shop tech and it would be done in less than a week. Another advantage of DMLS is that it would allow designers to deviate from standardized dimensions of rod and plate stock. This would allow the designer to hone the design to optimize release force and part weight. Ultimately, we did not proceed with this method because it was too expensive, the lowest quotes that we received were around $600 for both parts. However, we recommend that NASA explore this method further because it will help create a more optimal design and likely will reduce the total weight of the parts being shipped into space. We also recommend that if NASA were to use this method that they perform all the same tests that we did to ensure the functionality, safety and longevity of the parts created using DMLS.

7.0 Design Verification

The system design must be thoroughly tested and inspected to ensure that the final prototype to be sent to the NBL will meet all of the requirements. A unique consideration for our project testing is that the final prototype must be send to NASA without having been damaged by any tests. As a result, our project is going to have two more prototypes, a Verification Prototype manufactured by us in the Cal Poly Machine Shops used for the Design Verification Plan tests, as well as a Final Prototype to be sent to NASA. This is to allow for extensive testing without concern of breaking the final prototype which will be sent to the NBL. Furthermore, this allows for destructive testing to obtain load capacity until yield and ultimate failure data.

A specifications table, Table 3, was created to ensure successful achievement of the requirements. The specifications which require tests are going to be tested according to our Design Verification Plan (DVP) which can be seen in Appendix L. Table 5 below steps through each specification and the corresponding test or inspection required to prove success. Descriptions of each DVP test are beneath Table 5.

Table 5. Specifications and corresponding verification and success criteria

Specification #	Specification	Test/Inspection	Success Criteria
1	Total Weight	Weight the system using a scale and compare to SOLIDWORKS weight.	< 2lbf
2	Total Volume	Measure dimensions of secured system with a caliper.	< 4"x4"x3"
3	Releasing Force	DVP Test 1	5 lbf < RF<10 lbf
4	Securing Force	DVP Test 2	SF<10 lbf
5	Load Capacity	DVP Test 3	No decrease in release force
6	Bolt Pattern	Measure distances between holes and hole diameters.	Dimensions match Figure 3
7	Single Handed Operation	DVP Test 4, 5, & 8	All tests were successfully performed with one hand operating system
8	Ski Glove Operation	DVP Test 8	< 4 seconds
9	Blind Operation	DVP Test 5	< 4 seconds
10	Timed Operation	DVP Test 4	< 4 seconds
11	Material Evaluation	Ensure materials used in Verification Prototype and Final Prototype are approved	Only Aluminum 6061/7075, SS, or Teflon
12	Moon Dust Cycles	DVP Test 6	0% failed securing
13	Jostling	DVP Test 10	Tool does not release when jostled
14	Pinch Points	DVP Test 7	No glove pinches during use
15	Sharp Edges	Measure all fillets and chamfers	Fillets R > 0.025" Corners $\theta \geq 135°$
16	Finger Entrapment	DVP Test 9	Holes > 1", No entrapments during use

7.1 Specifications Verified by Inspection

Specifications for the total weight (Spec 1), total volume (Spec 2), the bolt hole pattern (Spec 6), material evaluation (Spec 11), and sharp edges (Spec 15) were all verified by inspection rather than testing. Please see Table 5 to see specific inspections for these specifications.

7.2 Specification 3 – Releasing Force

Overview

This specification addresses half of requirement 5, specification 3, that states the system will separate with minimal force for the astronaut but have enough release force to stay in place while walking and bending.

The test capturing the release force involves measuring the maximum release force for a given flexure displacement. The detailed procedure can be seen in Appendix M. This test was performed with two of our verification prototypes made out of Aluminum 6061, our final prototype material selection. The minimum acceptable force was determined by a simple Newton's 2^{nd} law calculation assuming a tool mass and acceleration, and the maximum force was determined by testing our system ourselves and comparing the difficulty to holding weights.

Results

The results can be seen below in Figure 35, where the maximum and minimum acceptable forces are delimited with red lines. There are two sets of data from the two prototypes that have been tested.

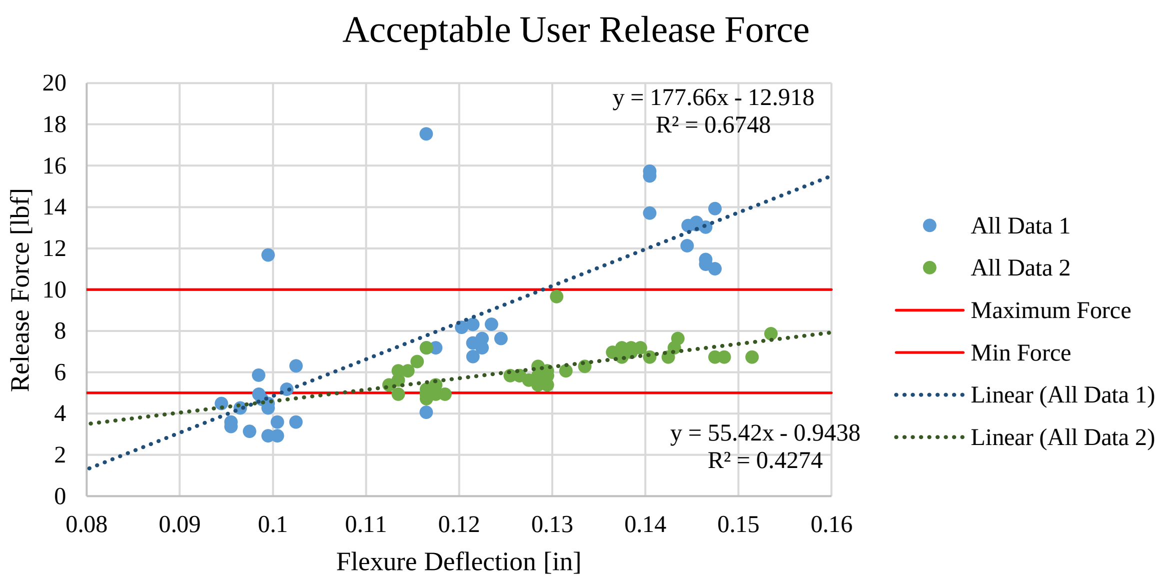


***Figure* 35.** Release force data for two prototypes with minimum and maximum acceptable force lines

Conclusions

The data in blue was used to size the flexure deflection for our second prototype. We chose a deflection of 0.1 inches to create the prototype tested with data in green. From data set 2, we upped the deflection to 0.13 inches since we noticed a flatter trend for the release force compared to data set 1. The 0.13 inch deflection was used in the manufacturing of our final prototype to send to NASA since for both data sets it falls within the acceptable range. The final system's release force was ~7.1 lbf, right in the middle of our desired range.

7.3 Specification 4 – Securing Force

Overview

The secure force, specification 4, ensures that the astronaut can comfortably secure the system with minimal force, the second half of requirement 5.

This test was similar to that of the releasing force, just inverted, where the force gauge is used to push the system into the secured position. A detailed description of the test procedure can be seen in Appendix M. The purpose of this test was to prove that for a given flexure displacement, the securing force is less than or equal to that of the releasing force. This is so that if our releasing force is in the acceptable range, we are sure that the securing force is as well.

Results

The results of comparison between secure and release force can be seen in Figure 36 below.

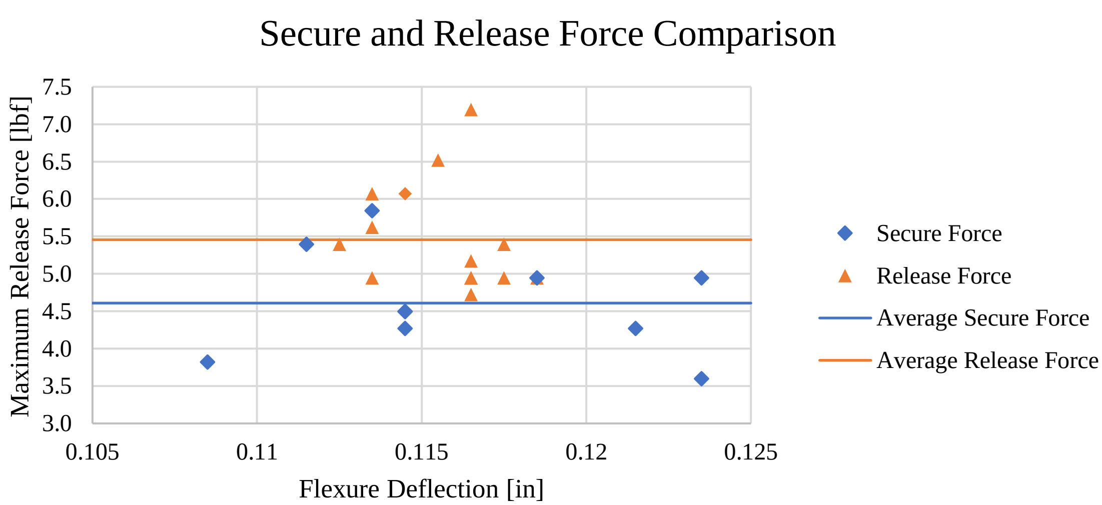


Figure 36. Release to secure force comparison

Conclusions

As demonstrated by the plot above, for a given flexure deflection, on average the securing force was less than that of the releasing force. This ensures that if our releasing force is less than 10 lbf, what we deemed comfortable for the astronaut, so will our securing force, thus meeting the specification.

7.4 Specification 5 – Load Capacity

Overview

The purpose of the Load Capacity Specification was to verify that the system would operate the same before and after loading. We were concerned that the wire frame flexure of the tool component was susceptible to yielding while it was loaded. This would ultimately lead to an inability of the part to secure properly and remain secured when the astronaut was doing activities while his or her tool was stowed. To verify that our part maintained its design security we compared release forces before and after loading. If the release force did not decrease that meant that our part was secured while supporting the required load and ultimately that the wire frame was not yielding. A detailed procedure for this test can be found in Appendix M.

Results

We tested the release force of the part in 5-pound loading increments from 0 to 15 pounds. Figure 37 shows that the release force does not significantly change up to and including the maximum load given to us by NASA of 15 pounds.

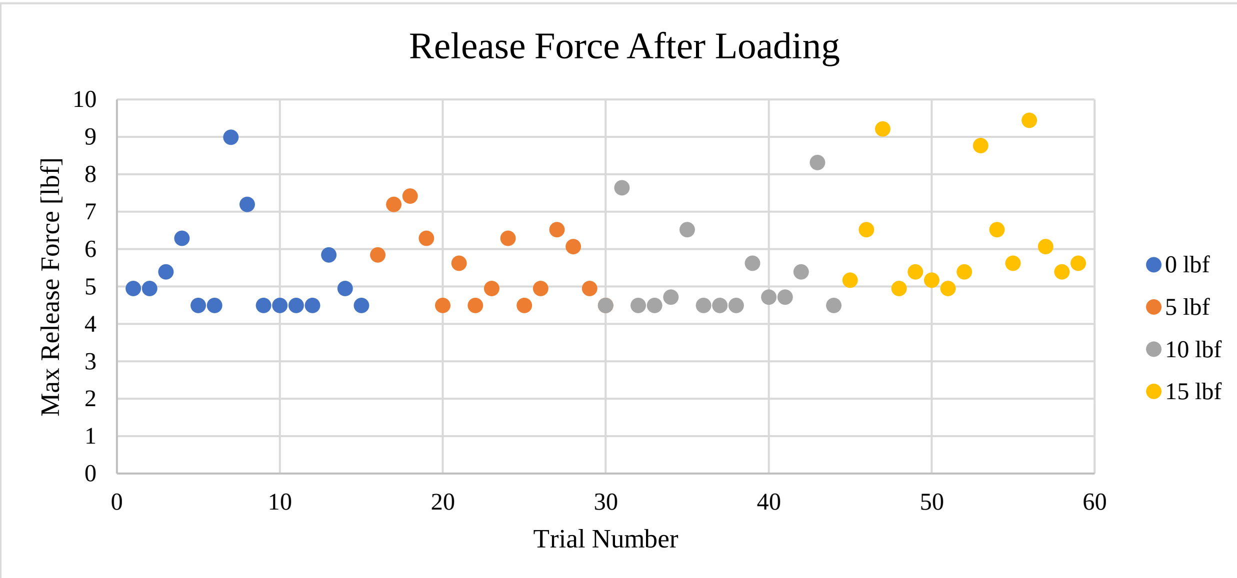


Figure 37. Release force after incremental loading versus trial number

Conclusions

The Finite Element Analysis performed using our SOLIDWORKS model in Appendix L also shows that our part does not yield when this maximum load is applied. Because of the manufacturing methods of our part, we wanted to run this test to ensure that the bending of the wires and the welding did not impact our design's ability to perform under our required loads. This verifies our initial hypothesis that the part will not yield under the maximum force.

7.6 Specification 7 – Single Handed Operation

Overview

DVP Tests 4, 5, and 8 were all performed with the simulated astronaut using only one hand. As a result, the results of all those tests apply to specification 7.

Results

The test results for DVP test 4, 5, and 8, all indicate that the astronaut will be able to secure the system in under 4 seconds using only one hand.

Conclusion

As a result, we deemed that our diver and astronaut can successfully secure the system in under our 4 second requirements with only one hand.

7.7 Specification 8 – Gloved Operation

Overview

DVP Test 8 informs us of how easy securing the system will be for the astronaut wearing thick xEMU gloves. In this test the user is only wearing thick ski gloves, not a blindfold. The user attempted to secure the system 10 times. The amount of time until successful securing was recorded for each attempt. This test gave us data on the time required to secure the system while wearing gloves.

Results

The test results for DVP test 8 show that the user on average secured the system in 2.1 seconds, well below our required 4 seconds.

Conclusion

As a result, we deemed that our diver and astronaut can successfully secure the system in under our 4 second requirement wearing thick gloves such as those of the xEMU.

7.8 Specification 9 – Blind Operation

Overview

DVP Test 5 informs us of how easy securing the system will be for the astronaut with limited vision. In this test the user is only wearing a blindfold, not gloves. The user attempted to secure the system 10 times. The amount of time until successful securing was recorded for each attempt. This test gave us data on the time required to secure the system while wearing a blindfold.

Results

The test results for DVP test 5 indicate that after a period of practice of around 7 cycles, what we called the learning curve, the user then consistently secures the system in under 3 seconds.

Conclusion

As a result, we deemed that our diver and astronaut can successfully secure the system in under our 4 second requirements out of the line of sight.

7.9 Specification 10 – Timed Operation

Overview

DVP Test 4 is the most comprehensive of the ergonomics tests above. It combines all of the difficulties the astronaut will see such as thick gloves, limited vision, and one handedness. It serves to inform us of the amount of time the diver or astronaut would take to secure the system in the complete space setting. In this test the user is wearing both a blindfold and gloves and uses only one hand. The user attempted to secure the system 10 times. The amount of time until successful securing is recorded for each attempt. This test gave us the most realistic data on the time required to secure the system while on the moon.

Results

The simulated astronaut secured the system 20 times. The average time to secure the system came out to 2.23 seconds.

Conclusion

This test demonstrated that with all of the obstacles the astronaut is facing, they should still be able to secure the tool in under 4 seconds with our system, meeting all of the ergonomics requirements.

7.10 Specification 12 – Moon Dust Cycles

Overview

The purpose of our Moon Dust Cycles test (DVP Test 6) was to verify that our system would function in the presence of lunar dust simulant which in this case was sand. We created a worst-case scenario by performing the test in the air with wet parts that were each dunked into a bag of sand. This caused the sand to stick to the parts significantly more than if the parts were either dry during the sand coating and the test or completely submerged in water for the test. The design did function as intended and did, to some extent did self-clean as it was being secured and released. Overall, the sand did not stop the tool component from being secured once but while coated with sand it was more difficult to secure and release the tool.

Conclusions

The tool and the belt components were still capable of securing despite the presence of our lunar dust simulant. The presence of sand as the tool component was being secured caused abrasion on the plate of the tool component and the wire frame on both parts. We recommend anodizing the part to increase the ability of the surface to resist abrasion.

7.11 Specification 13 – Jostling

Overview

This specification is meant to ensure that the tool will not unintentionally release when the user is performing other tasks or moving around. Like the gloved and blind operation tests this test is a functional test meant to verify our initial hypothesis of our design. The design was secured to a user’s waist and the user proceeded to hop around and bend over.

Conclusions

The design remained secured regardless of the action taken by the user. This demonstrates our inherently stable design and shows that users in the NBL and on the moon should feel comfortable that it will remain secured while they are not using it.

7.12 Specification 14 – Pinch Points

Overview

One of our NASA goals was to reduce the designs pinch points. Below is a picture labeling the pinch points.

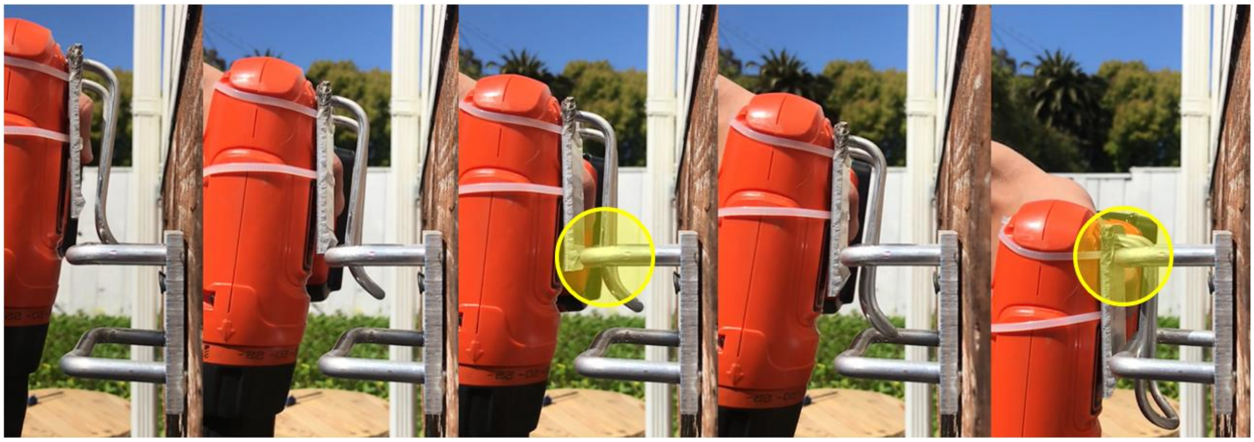


Figure 38. Pinch point locations in the securing process

Conclusions

Our design has a few pinch points, but they are effectively mitigated to be as safe as possible. The left most pinch point hazard is of low risk because it is nearly inaccessible to the gloved hand, the pinching force is very low, and the pinch point is marked with yellow sharpie. The right pinch point caused by the user completely securing the system and is of low risk because the pinching force is controlled by the user and also very difficult to access since the user isn't interacting with our system. As a result, we deemed our design safe from pinch point hazards. However, we are still notifying NASA of the pinch point locations to educate the diver.

7.13 Specification 16 – Finger Entrapment

Overview

Another requirement by NASA was that the system cannot entrap the astronaut's fingers during operation such that it cannot be removed. This resulted in a specification of making holes > 1" so that the astronaut's finger can easily be removed.

Conclusions

The belt half of our system has spaces that are only larger than 1" and with rounded rungs which ensures that any finger than can enter can easily exit without catching on anything. The majority of the openings on the tool half are also larger than 1", other than the flexure distance from the base plate. This shouldn't be a hazard because the clearance is ~0.4", too small to fit a gloved finger, and also made out of the rounded rod. The cutout that produces the "legs" of the tool half is 1" exactly which also works as a safety feature so that if the gloved finger is inserted it will simply protrude through that hole rather than get trapped. All of this logic was also tested with our system using thick ski gloves and both halves of our system. In this test we attempted to purposefully entrap our fingers in the separate components and assembled system and it was not possible. As a result, we have deemed our system to be safe from finger entrapment.

8.0 Project Management

Throughout this project, our team followed a modified Stanford d.school design process. The Stanford design process consists of 5 phases performed chronologically, Empathize, Define, Ideate, Prototype, and Test. In Fall quarter we completed the Empathize and Define phases and began the first Ideate phase. In Winter and Spring Quarters our team performed multiple iterations of the Ideate, Prototype and Test phases.

Fall Quarter (9/14/2020 – 12/4/2020)

The Empathize and Define phases were completed in Fall Quarter of 2021. Throughout these phases we performed extensive research to understand and define our problem. After problem definition, we performed a functional decomposition to begin our first Ideation phase. That led to our concept selection and ultimately the submission of our Proposal to NASA and Preliminary Design Review to Cal Poly.

Winter Quarter (1/4/2021 – 3/19/2021)

Early in Winter Quarter we finished the first Ideation phase with detailed design improvements as a result of analysis and further ideating. This led into our first round of prototyping in which we used additive manufacturing to test the user experience with our design. We then went back to the ideation phase, incorporating all of the improvements. The same process was followed with the structural prototype in which we used aluminum 7075 to create a better proof of concept. At this point we completed our Critical Design Review for Cal Poly. For the rest of Winter Quarter, we manufactured more Aluminum 6061 prototypes and prepared for the Design Verification Plan.

Spring Quarter (3/29/2021 – 6/11/2021)

In Spring Quarter, we began our most extensive rounds of prototyping and testing. During this time, we split into two main teams, a manufacturing team made up of Elyse Gillis-Smith and Cole Stanton, and a testing team made up of Michael Roth and Andres Elzaurdia. This allowed each group to specialize in their respective duties. We proceeded to fabricate and test many aluminum 6061 prototypes during which we simultaneously improved the manufacturing process and incorporated the testing feedback into our final design. We then used this final design and manufacturing process to produce our final prototype which we sent to NASA on 5/24/21. This was the conclusion of our design process and beginning of our final design justification in the Test Readiness Review for NASA and Final Design Review for Cal Poly. The dates of the milestone submissions are seen below in Table 6.

Table 6. Milestones and corresponding due dates

Milestone	Due Date
Scope of Work	10/13/2020
NASA Proposal	10/30/2020
Preliminary Design Review	11/12/2020
Critical Design Review	2/12/2020
Final Design Review	6/4/2020

There are still a few upcoming activities and deliverables which will not have been concluded by the submission of the FDR. First of which is the Test Readiness Review (TRR) on Wed 6/9 to NASA engineers to ensure our design is safe for testing in the NBL. The next item is the NBL testing itself during which our system will be fastened to a diver and tested in a lunar EVA simulation. After that, the Final Report and Outreach Report are due on 7/8 which concludes our Senior Project and NASA Micro-g NExT Design Challenge.

9.0 Conclusion and Recommendations

The purpose of this document is to clearly detail our initial design direction, justify its feasibility, show its improvements, and prove our timeline and design's preparedness for success. We feel very confident that the research that we have done has allowed us to accurately diagnose the problem, which is the first step in finding a solution. We generated many ideas using different concepts to secure and release the tool. We combined the best aspects of our initial designs and incorporated the wire frame, leaf springs and sheath concepts into our preliminary design. Finally, we performed analysis, prototyping, and testing to improve our design and further justify our requirement completion. The Quick Release System that we have designed utilizes gravity, the material properties of aluminum, and geometry to keep it from being clogged with lunar dust.

Our manufacturing experience inspired numerous improvements to our design which both improved the parts' manufacturability and functionality. Through the testing of numerous prototypes, we were able to verify that our design met all of the Micro-g requirements and determine the most effective manufacturing methods. After many days of manufacturing and testing we were able to produce a final product which we were proud to ship to NASA on May 25th. Through clear team communication, creativity, and intelligent engineering practices, we designed and built a quick-release system which we believe is an intuitive and effective solution to the needs of astronauts on the lunar surface.

In the coming weeks, our team will be participating in testing events organized by Micro-g which culminate in the testing of our final prototype in the Neutral Buoyancy Lab on June 15th. We will work closely with a skilled diver to assess the viability of our design and highlight any possible improvements that could be made. On July 8th we will officially complete our project with the submission of our final report and outreach report to Micro-g.

In our final report we plan to discuss the results of our testing experience and make recommendations to Micro-g for the improvement of our design. We expect for some of our recommendations to surface based on our testing at the NBL, but there are also a few recommendations we already identified regarding our design and how it could be improved. Our resources didn't allow for testing with parts made via additive manufacturing, but we would recommend looking into it further as it would greatly reduce the time and difficulty of manufacturing our parts. We would also recommend doing further research into the material choice. We chose aluminum to reduce the overall weight of our part and for manufacturing purposes, but the spring properties and behavior at varying temperatures of stainless steel may be more desirable for the final design if it were to go to the lunar surface. With the aluminum prototype we also recommend anodization to increase surface hardness and reduce abrasive wear as observed in the lunar dust simulant test. Based on diver feedback from the NBL testing we will also give final recommendations for the desired release force of the final system. This release force would be modulated by simply increasing or decreasing the deflection of the flexure.

References

"Apollo Lunar Surface Journal." *NASA*, NASA, www.hq.nasa.gov/alsj/main.html. Accessed 10 October 2020.

Carey, Bjorn. "Space Tools: Off the Shelf, Onto the Shuttle." *Space.com*, Space, 13 July 2005, www.space.com/1308-space-tools-shelf-shuttle.html. Accessed 10 October 2020.

Coan, Dave. *Exploration EVA System Concept of Operations Summary for Artemis Phase 1 Lunar Surface Mission*. February 2020, https://www.nasa.gov/sites/default/files/atoms/files/topic_1-_eva_lunar_surface_concept_of_operations.pdf. PowerPoint Presentation.

Crossen, Rex, et al. Edited by Joseph Mello, Cal Poly Senior Project, 2012, pp. 9–32, *Design of a Releasable Snowboard Binding*.

Dam, Rikke F., et al. "Learn How to Use the Best Ideation Methods: Brainstorming, Braindumping, Brainwriting, and Brainwalking." *Interaction Design Foundation.*UX Design, August 2020, https://www.interaction-design.org/literature/article/learn-how-to-use-the-best-ideation-methods-brainstorming-braindumping-brainwriting-and-brainwalking. Accessed 10 October 2020.

"Don't Breathe the Moondust." *NASA Science*, 22 Apr. 2005, https://science.nasa.gov/science-news/science-at-nasa/2005/22apr_dontinhale. Accessed 10 October 2020.

Dunbar, Brian. "Artemis." *NASA*, NASA, www.nasa.gov/specials/artemis/. Accessed 10 October 2020.

Gaier, James. "The Effects of Lunar Dust on EVA Systems During the Apollo Missions." NASA/TM—2005-213610/REV1. *NASA Glenn Research Center*, Apr. 2007.

"How to Choose Bike Pedals." *REI Co-Op*, www.rei.com/learn/expert-advice/bike-pedals.html. Accessed 10 October 2020.

Hutchinson, Lee. "Swimming with Spacemen: Training for Spacewalks at NASA's Giant Pool." *Ars Technica*, 4 Mar. 2013, arstechnica.com/science/2013/03/swimming-with-spacemen/2/. Accessed 10 October 2020.

Luna, Sarah. "Process Specification for the Anodizing of Aluminum Alloys." NASA, June 2020.

Mckay, D.s., et al. "Physicochemical Properties of Respirable-Size Lunar Dust." *Acta Astronautica*, vol. 107, 2015. Accessed 10 October 2020.

"Micro-g NExT." *NASA JSC Micro-g NExT*, https://microgravityuniversity.jsc.nasa.gov/about-micro-g-next.cfm. Accessed 10 October 2020.

"Micro-g NExT 2021 Design Challenges." *NASA JSC Micro-g NExT*. 1 Oct. 2020, https://microgravityuniversity.jsc.nasa.gov/docs/micro-g/2021%20Micro-g%20NExT%20Challenge%20Descriptions%20v5.pdf. Accessed 10 October 2020.

Moiseev, N., et al. "Space Suit Foot and Ankle Mobility in Walking on Uneven Terrain." *SAE Technical Paper Series*, 1999. Accessed 10 October 2020.

Ochoa, Dustin A., et al. "Lunar EVA Thermal Environment Challenges." *SAE Transactions*, vol. 115, 2006, pp. 492–505. *JSTOR*, www.jstor.org/stable/44657705. Accessed 17 Nov. 2020.

"P-7 Suspension Clip." *TEC Accessories*, www.tecaccessories.com/products/p-7-suspension-clip. Accessed 10 October 2020.

"Rob Allen How To : Long Line Clip." Performance by Rob Allen, *YouTube*, Rob Allen Spearfishing, 31 Oct. 2014, www.youtube.com/watch?v=ijEpdv8AIvo&ab_channel=RobAllenSpearfishing. Accessed 10 October 2020.

"Rob Allen Long Line Clip." *Rob Allen*, 30 July 2020, roballendiving.com/product/longline-clip-w-swivel/. Accessed 10 October 2020.

Swift, Paul, "Bicycle Pedal That Can Fit a Multiplicity of Shoe Cleats", 10/10/2001. Accessed 10 October 2020.

Stubbs, Timothy J., et al. "A Dynamic Fountain Model for Lunar Dust." *Science Direct*, Pergamon, 1 June 2005, www.sciencedirect.com/science/article/abs/pii/S0273117705004989. Accessed 10 October 2020.

Thurston, Jim. "JT Frog Quick Draw Concealed Holster," EP2307845B1, 2009. Accessed 10 October 2020.

Wayne R. Ryerson, "Tradesman's tool belt", US5511703A, 1996. Accessed 10 October 2020.

Wegener, James D. *Helmet with a Chin Strap Buckle System*. 2015. Accessed 10 October 2020.

Williams, David R. "The Apollo Program (1963 - 1972)." *NASA*, NASA, 2013, nssdc.gsfc.nasa.gov/planetary/lunar/apollo.html. Accessed 10 October 2020.

Working Group Membership. *Dust Mitigation Gap Assessment Report*. 9 Feb. 2016, www.globalspaceexploration.org/wordpress/docs/Dust%20Mitigation%20Gap%20Assessment%20Report.pdf

Appendix A: House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

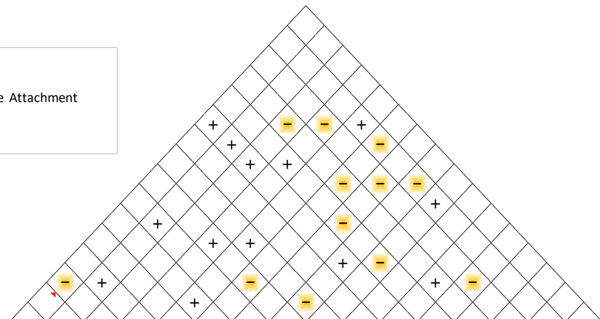
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F55 Space Suit Quick Release Attachment

Revision Date: 10/7/20



WHO: Customers | HOW: Engineering Specifications (Tests) | NOW: Curr. Products

Row #	Weight Chart	Relative Weight	Lunar Surface Astronaut	NASA Micro-g	Builder		Maximum Relationship	WHAT: Customer Requirements (Needs/Wants)	Total weight	Single hand operation testing	Vertical load test	Ski glove operation testing	Pinch Points	No sharp edges	Blind operation testing	CP shop feasibility survey	Moon Dust Exposure Cycles	4-hole specified pattern	Material Evalution	Timed attach and release test	Finite element analysis: failure	Walking and Bending test	No Holes and Openings		Bike pedal clips	Ski boot attachment system	NASA MMWS Tool Caddy	Cable Cuff ziptie system	Gun holster	Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
								Direction of Improvement	▼	▼	◇	▼	▼	◇	▼	▲	◇	◇	◇	▼	◇	◇	◇							
1		8%	8	8	2		9	Lightweight	●										▽		○				3	2	1	4	3	1
2		8%	8	7	2		9	Quick release		○					○					●					5	5	4	3	3	2
3		7%	5	6	3		9	Stable	▽		○											●			2	2	4	2	4	3
4		10%	10	6	4		9	Dust Tolerant									●						●		0	0	0	4	3	4
5		10%	6	8	6		9	Load Capacity			●								●		●				3	4	5	4	4	5
6		9%	8	7	4		9	Easy to Use		●		●			●					●					5	4	4	2	3	6
7		12%	6	10	8		9	Mounting Pattern								●		●							4	4	5	4	5	7
8		10%	5	7	8		9	Size	●																5	5	5	4	2	8
9		8%	9	6	2		9	Comfort		○		○			○							●			2	2	4	2	3	9
10		9%	9	8	2		9	Safety					●	●								▽	●		0	0	4	3	4	10
11		10%	2	7	10		9	Possible to Fabricate								●			▽		▽		○		5	5	4	5	4	11
12		0%																												12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

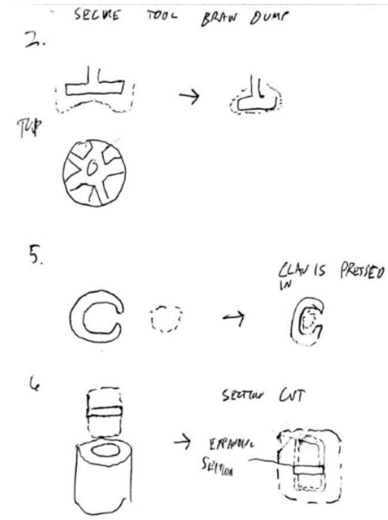
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	2 lb	Possible/Impossible	25 lb	5 seoncds	As few as possible	0	Possible/Impossible	Possile/Impossible	10 cycles	Yes/No	Aluminum 6061, Aluminum 7075, Stainless Steel (any series), or Teflon	5 seconds	Possible/Impossible	Possible/Impossible	0	
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
	Technical Importance Rating	173	127.8	108.9	104.6	77.29	77.29	127.8	201.2	85.5	108.2	107.5	151	123.8	138.3	193.8	0
	Relative Weight	9%	7%	6%	5%	4%	4%	7%	11%	4%	6%	6%	8%	6%	7%	10%	0%
Curr. Products	Bike pedal clips	5	5	4	3	1	2	4	5	0	3	3	4	3	4	0	
	Ski boot attachment system	5	5	4	3	1	2	4	5	0	3	3	4	3	3	0	
	NASA MMWS Tool Caddy	5	3	5	4	3	4	4	5	0	5	5	5	4	5	3	
	Cable Cuff ziptie system	5	4	4	4	3	3	3	5	2	5	2	3	2	4	3	
	Gun holster	4	5	3	4	4	4	4	5	2	4	2	4	4	4	3	
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: Concept Development Process

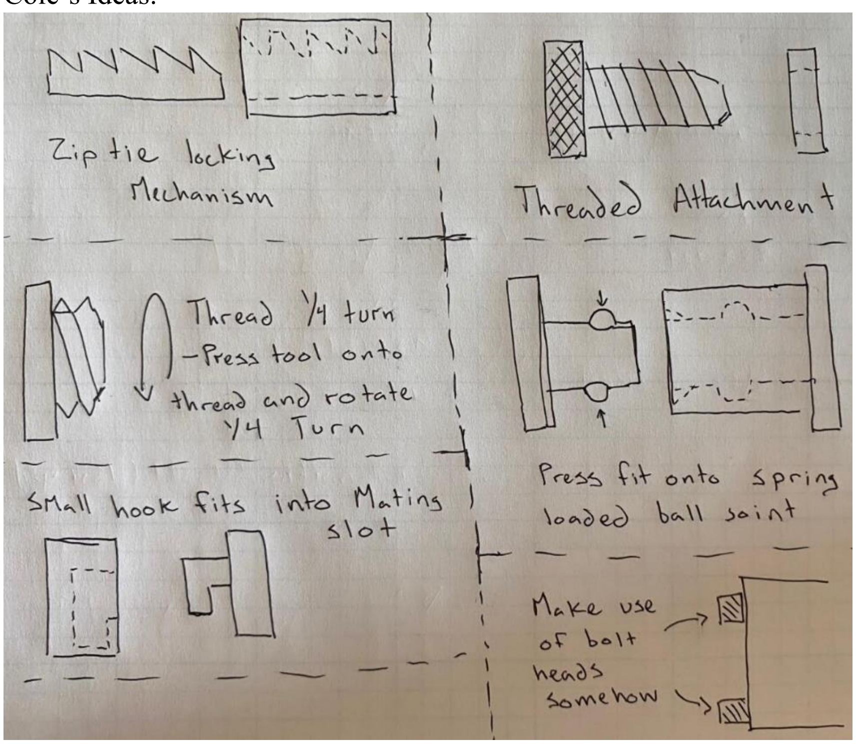
Secure Tool Function- Braindump

Michael's Ideas:

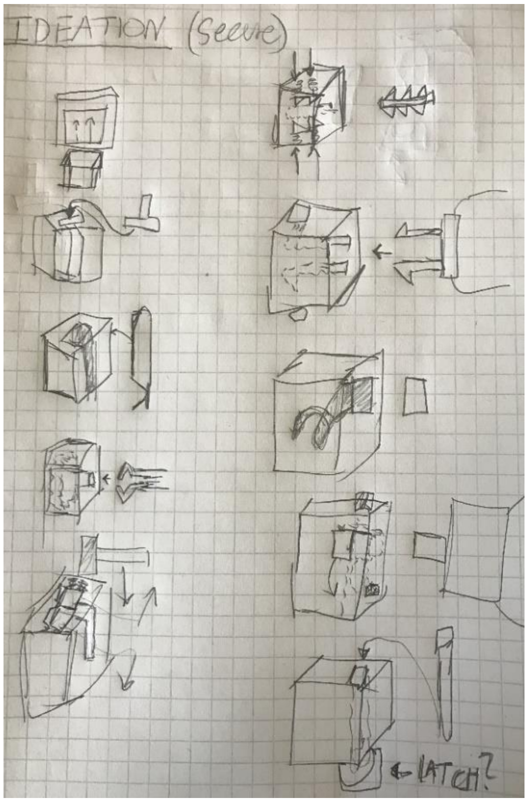
1. Press fit with an expanding ball (think pin for weights)
2. Mechanism that secures as it is pressed into place (something with fins)
3. Pressure plate locking (like holster patent)
4. Conical insert (wide at top and narrow at bottom)
5. Claw securing mechanism
6. Fit and expanding mechanism held in place by friction activated by button
7. Carabiner
8. Circular press fit (think football helmet strap)
9. Lego type connection
10. Slide in sheath (like TI-84 Calculator)
11. Press fit like a sharpie cap

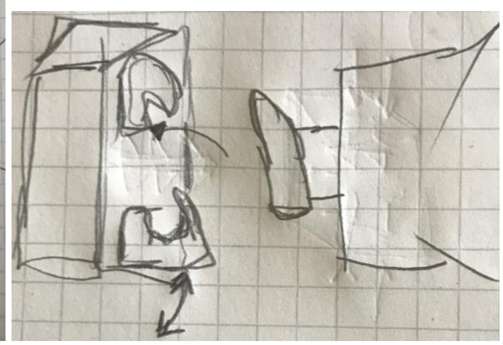


Cole's Ideas:

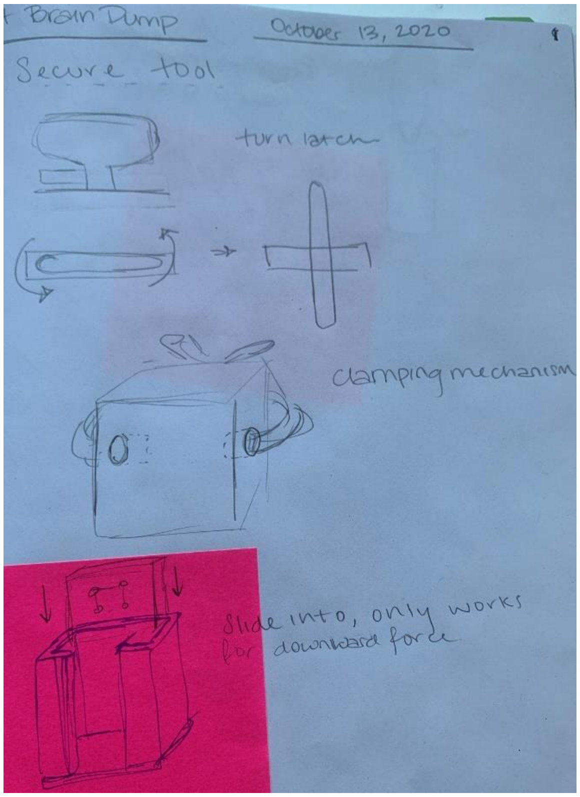


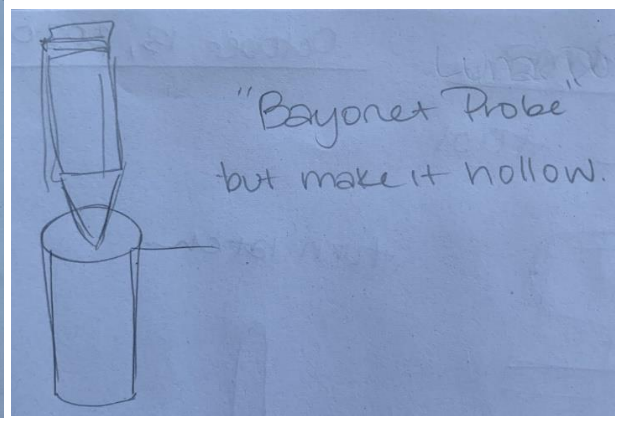
Andres' Ideas:





Elyse's Ideas:

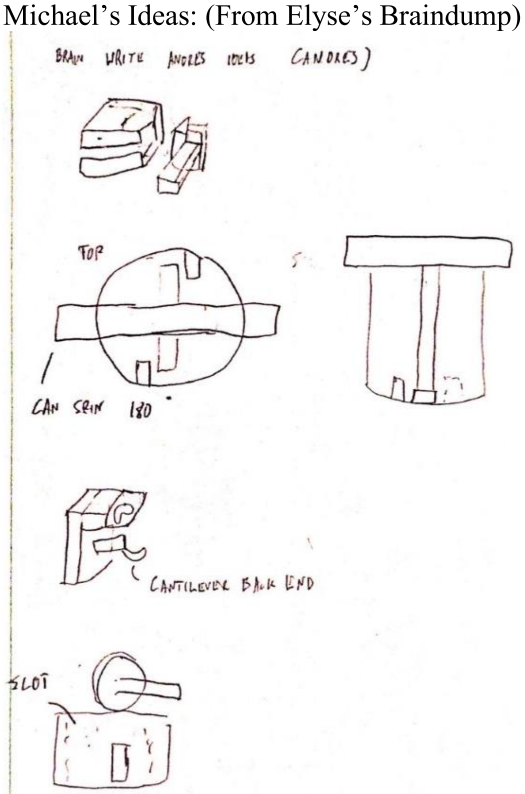


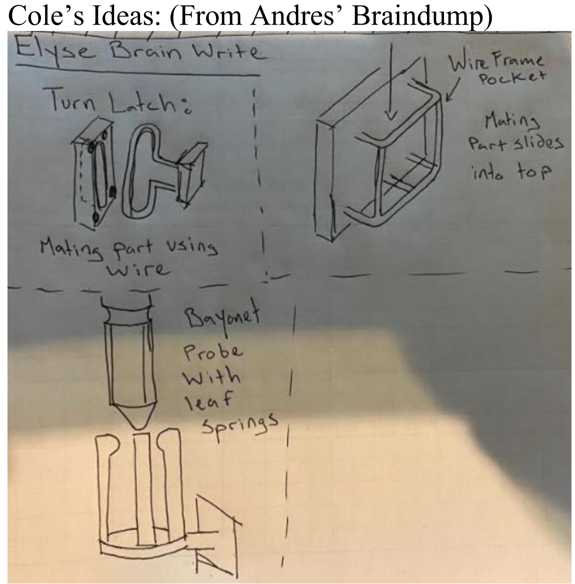


Secure Tool Function- Brainwrite

Michael's Ideas: (From Elyse's Braindump)

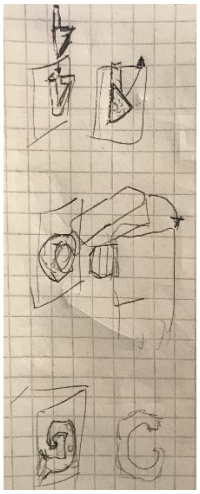
Cole's Ideas: (From Andres' Braindump)

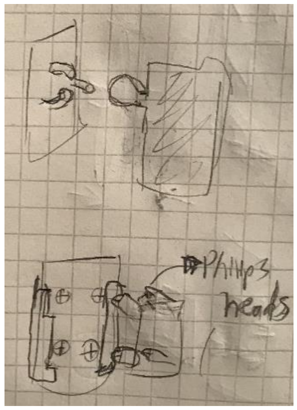


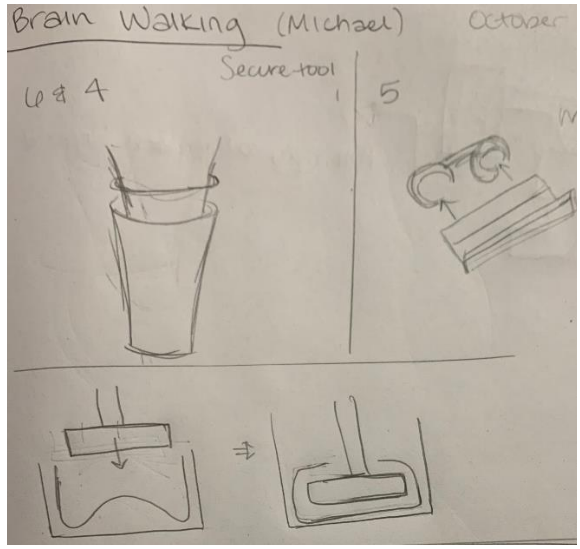


Andres' Ideas: (From Cole's Braindump)

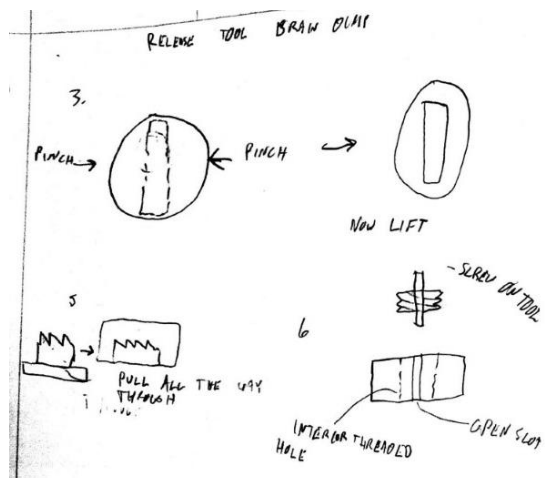
Elyse's Ideas: (From Michael's Braindump)







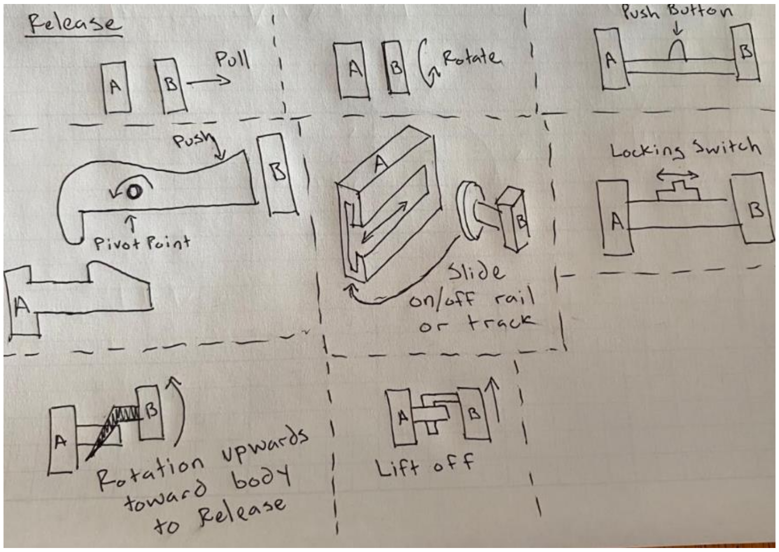
Release Tool Function- Braindump



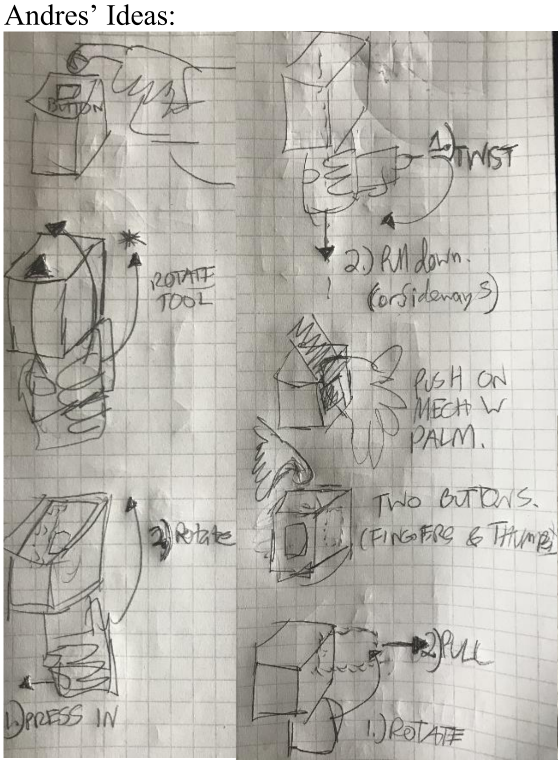
Michael's Ideas:

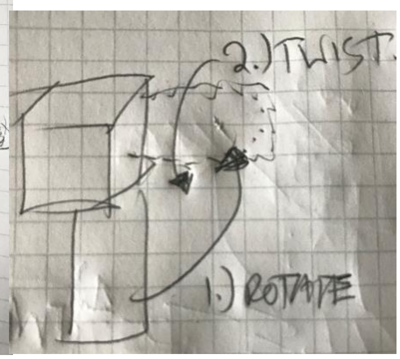
1. Button that activates release mechanism
2. Release via rotation out of press fit
3. Pinch and lift to release
4. Brute force release out of a press fit
5. Pull through ziptie release
6. Rotate all the way through threaded release
7. Pull up like an airplane seatbelt

Cole's Ideas:

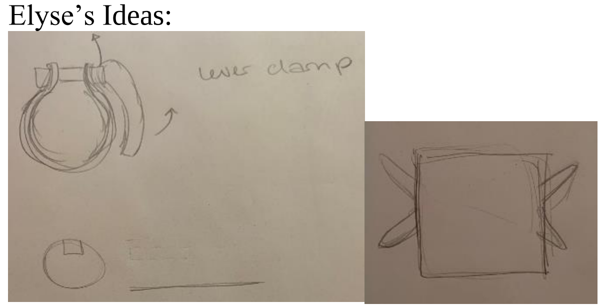


Andres' Ideas:



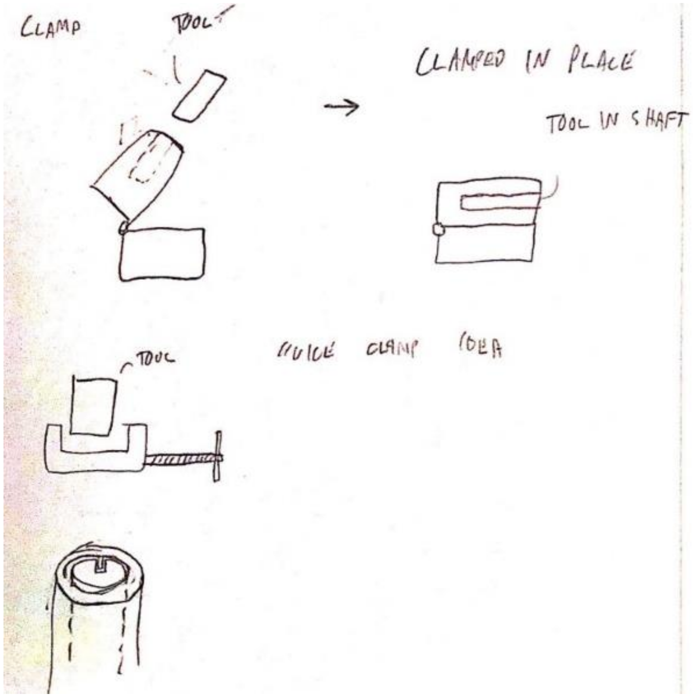


Elyse's Ideas:

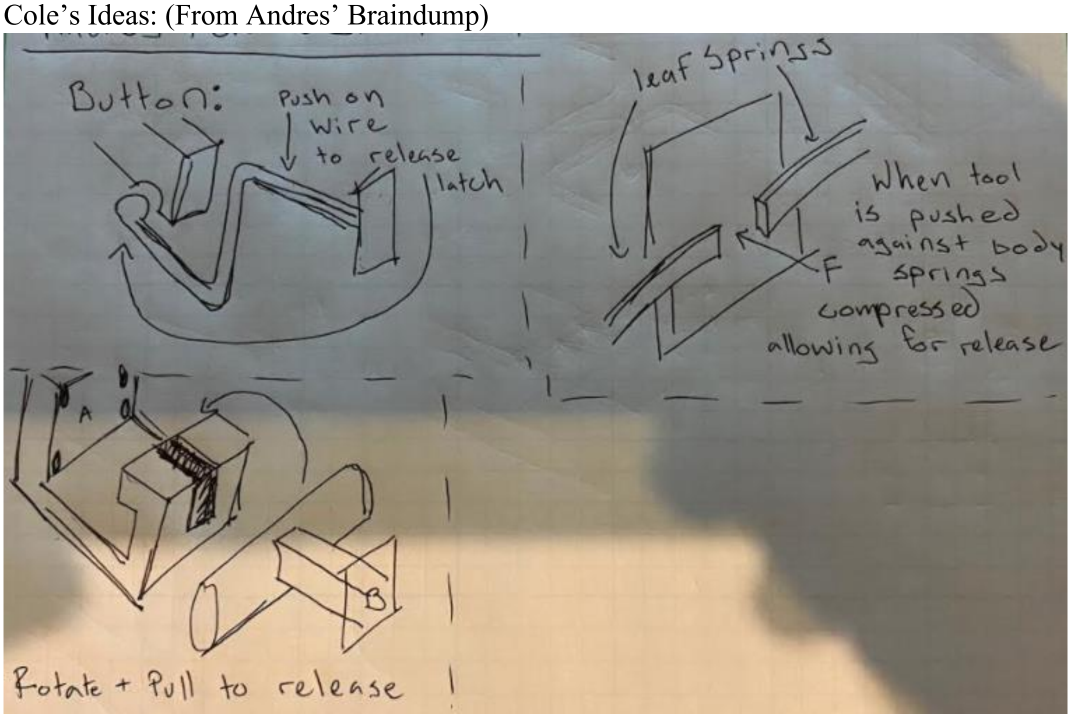


Release Tool Function- Brainwrite

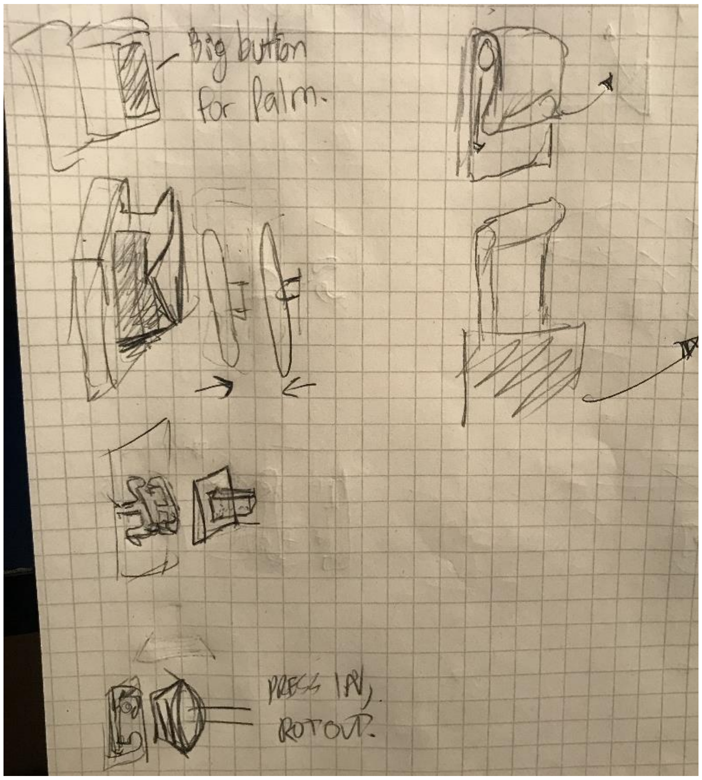
Michael's Ideas: (From Elyse's Braindump)



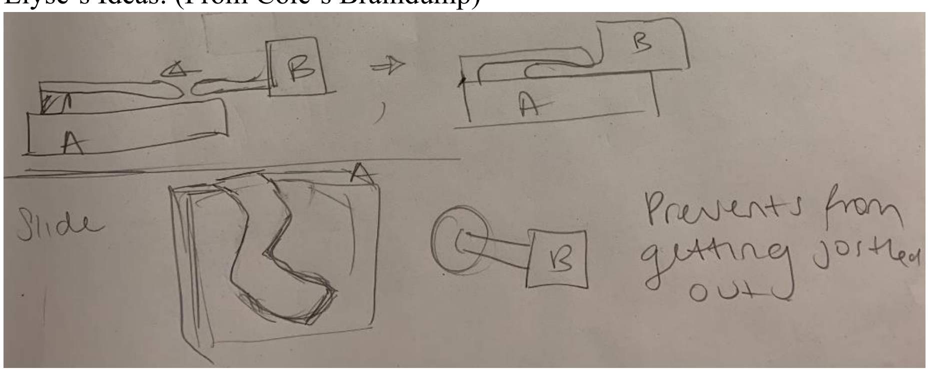
Cole’s Ideas: (From Andres’ Braindump)

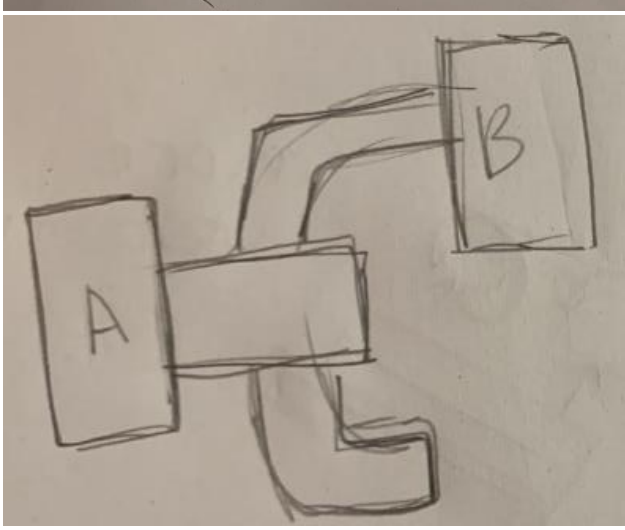


Andres’ Ideas: (From Micahel’s Braindump)



Elyse’s Ideas: (From Cole’s Braindump)

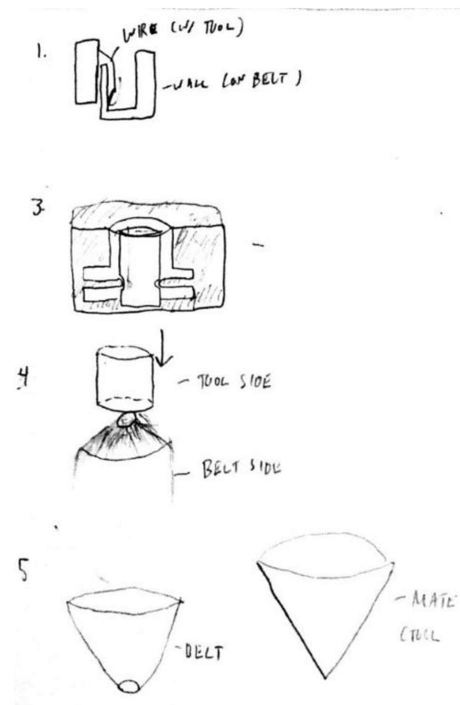




Lunar Dust Function- Brainstorm

-could use magnetic wire brush or just wire brush
-could use to cover a hole or cut in the parts
-bristles cover the opening of a hole, inserting a part clears it of lunar dust on entrance and exit
-like a golf club cleaner
-aluminum brush exists
-would lunar dust cause damage to an aluminum part compared to a SS part?
-by using SS we would definitely be increasing weight
-Pockets where dust can get swept in and be pushed out of the way
-cavities in parts should have horizontal through holes to allow for dust to enter and also leave
-use some kind of knocking procedure to remove majority of small particles
-button actuates brush which knocks dust off of parts
-what is the effect of dust on mechanical fits?
-magnets selectively placed to attract dust
-bike clip style connection
-clip in knocks or brushes dust off
-also include brushes
-pinch points

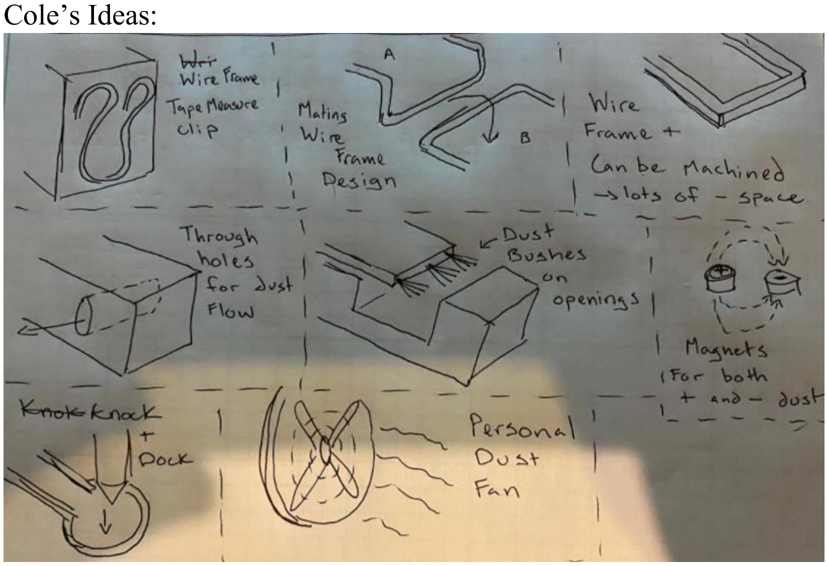
Lunar Dust Function- Braindump



Michael's Ideas:

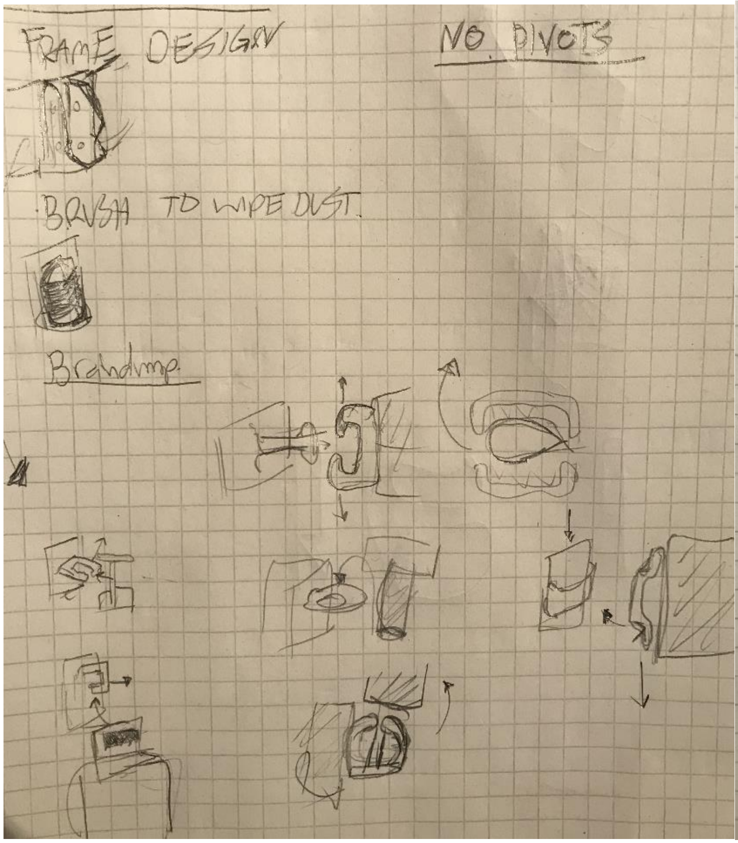
1. Wire clip mating to a metal wall
2. Shaft and hole design w/ hollow bottom
3. Shaft and hole cantilever spring and grooves design
4. Slanted Circular brush cleaning mechanism (maybe to threaded hole or tighter fit)
5. Slanted conical hollow entry (like those spinning quarter games museums have)
6. General idea: hole at bottom so gravity takes the dust down
7. Self clearing bike shoe design

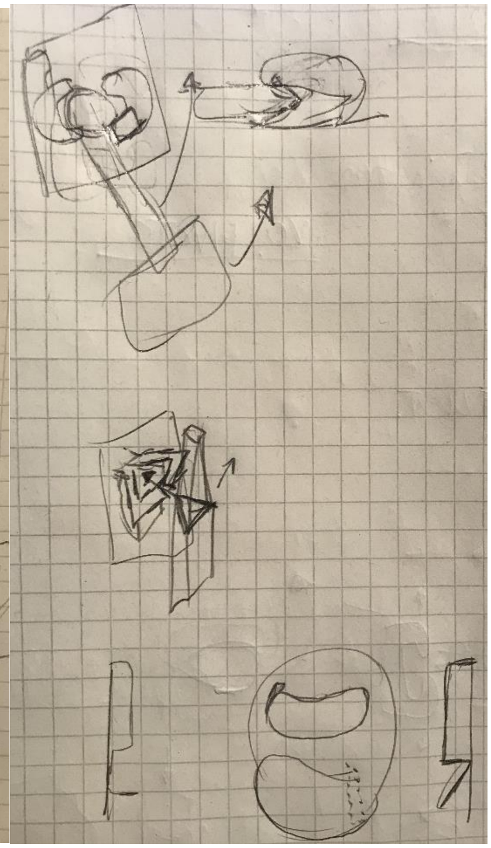
Cole's Ideas:



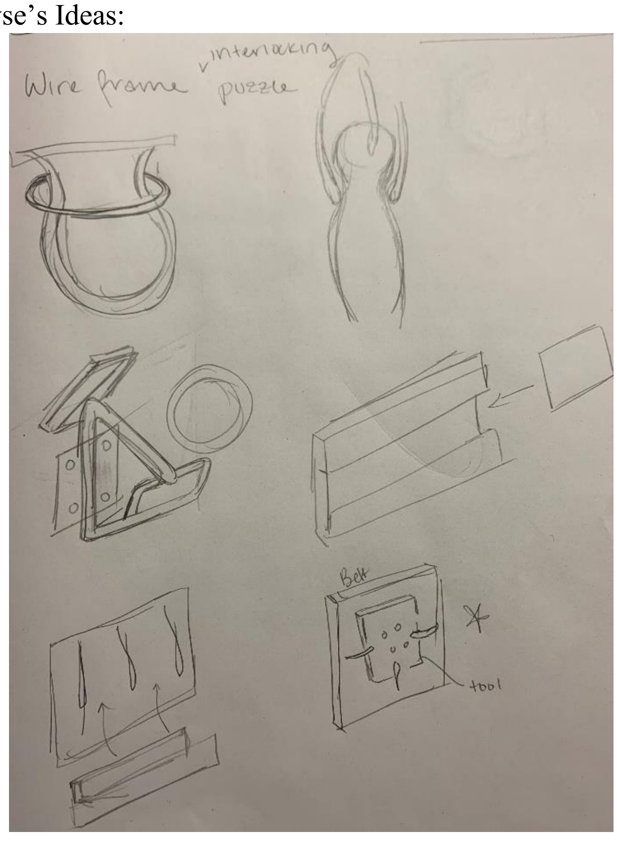
Andres' Ideas:

A)





Elyse's Ideas:



A)

Appendix C: Idea Generation to Morph Matrix

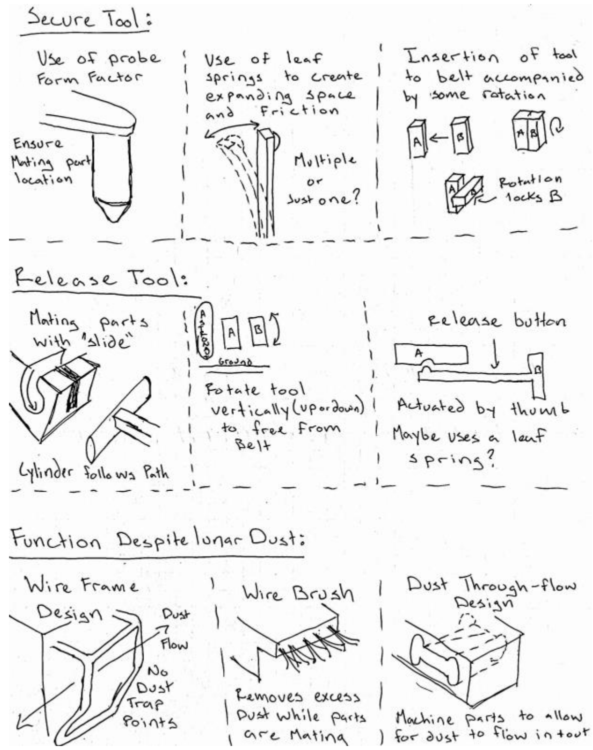
Michael's Ideas:

Secure:
Press onto spring loaded ball (Cole)
Bike shoe insert into slot and press down to secure (Andres)
Double claw design from secure brain write

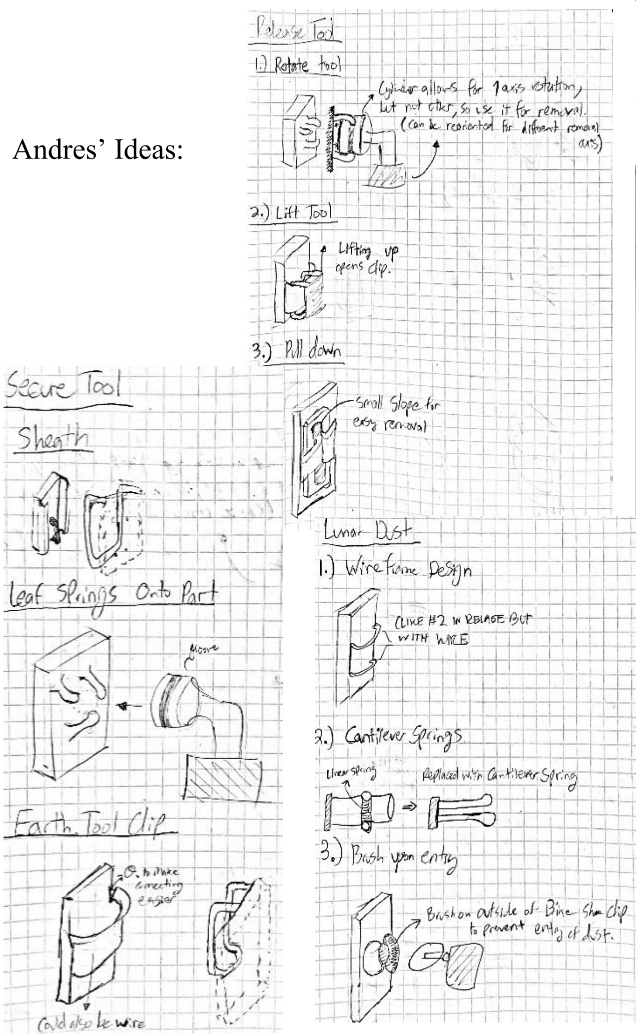
Release:
Cole original lift off design
Release with friction created by cantilever (like tape measure clip)
Rotate out from bike clip design

Lunar:
Grooved shaft and cantilever design
3 clip cantilever design (Elyse)
Self cleaning bike clip (Andres)

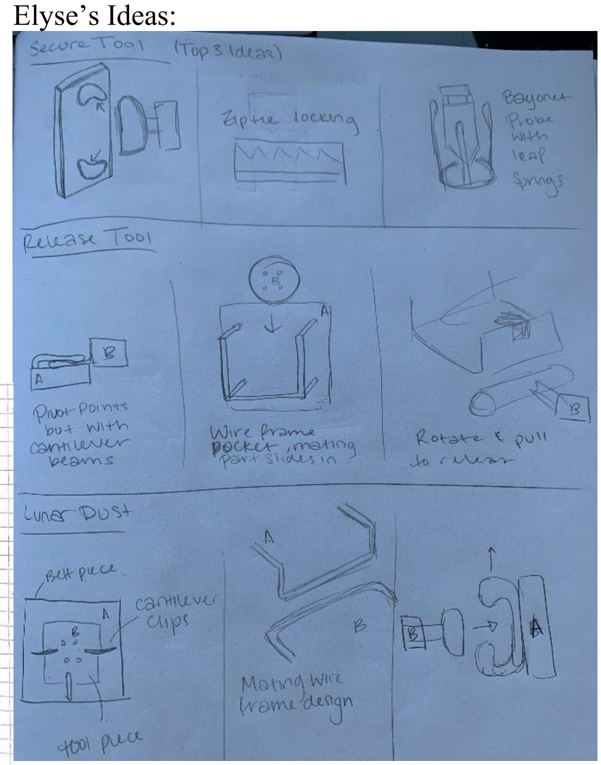
Cole's Ideas:



Andres' Ideas:



Elyse's Ideas:



Appendix D: Morphological Matrix

Required Functions	Idea 1	Idea 2	Idea 3	Idea 4
Secure Tool	Sheath	Bayonet Probe	Leaf Springs	Bike clip design
Release Tool	Lift up	Pull away from body	Rotate	Press Button
Function Despite Lunar Dust	Wire Frame Design	Knocking off dust	Brushes	Gravity

Morphological Matrix Concept Generation

Concept 1		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Sheath	Lift Up	Wire Frame Design

Concept 2		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Lift up	Gravity

Concept 3		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Lift Up	Brushes

Concept 4		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Pull away from body	Gravity

Concept 5		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Rotate	Wire Frame Design

Concept 6		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bike Clip Design	Rotate	Brushes

Concept 7		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Press Button	Brushes

Concept 8		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bike Clip	Rotate	Wire Frame Design

Concept 9		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Sheath	Rotate	Wire Frame Design

Concept 10		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Press Button	Brushes

Concept 11		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Lift up	Wire Frame Design

Concept 12		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Lift up	Wire Frame Design

Concept 13		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Lift up	Gravity

Concept 14		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bike Clip	Rotate	Gravity

Concept 15		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Rotate	Gravity

Concept 16		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf springs	Press Button	Wire frame design

Morphological Matrix Concept Selection

Concept 1		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Pull away from body	Gravity

Concept 2		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf springs	Press Button	Wire frame design

Concept 3		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bike Clip Design	Rotate	Brushes

Concept 4		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Lift up	Gravity

Concept 5		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Sheath	Lift Up	Wire Frame Design

Concept 6		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Rotate	Wire Frame Design

Concept 7		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bike Clip	Rotate	Wire Frame Design

Concept 8		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Sheath	Rotate	Wire Frame Design

Concept 9		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Bayonet Probe	Lift up	Wire Frame Design

Concept 10		
Secure Tool	**Release Tool**	**Function Despite Lunar Dust**
Leaf Springs	Lift up	Wire Frame Design

Morphological Matrix Concept Selection: Voting

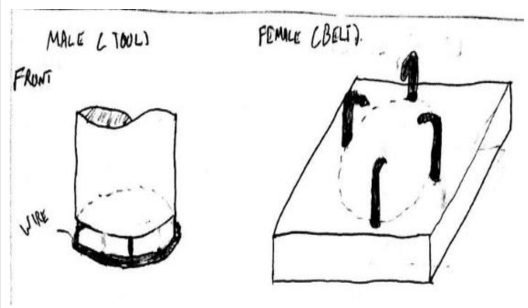
	1	2	3	4	5	6	7	8	9	10
Elyse						1		1	1	1
Andres					1	1	1	1		
Michael			1	1	1		1			
Cole	1						1	1		1
Sums:	1	0	1	1	2	2	3	3	1	2

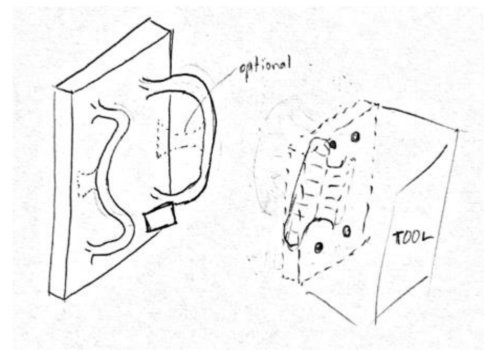
	5	6	7	8
Elyse	X			
Andres			X	
Michael		X		
Cole				X

Appendix E: Initial Prototypes and CAD Models

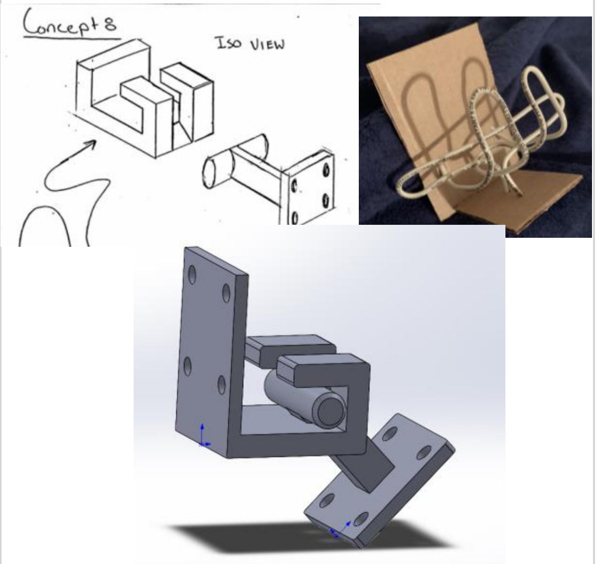
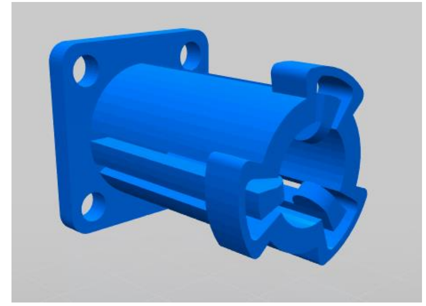
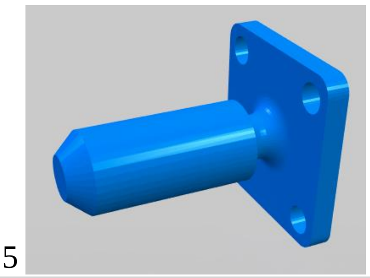



Appendix F: Weighted Decision Matrix





SCAQRS		Idea 1	Idea 2
Specification	**Weight**		
Lightweight	0.08	5	3.5
Quick release	0.08	7	7
Stable	0.07	6	7
Dust Tolerant	0.10	10	10
Load Capacity	0.10	6	7
Easy to Use	0.09	6	8
Mounting Pattern	0.12	10	10
Size	0.10	7	7
Comfort	0.07	6	6
Safety	0.09	2.5	7
Ease of Fabrication	0.10	3	6
Totals:	1.00	6.365	7.3

 Idea 3	Idea 4 	Idea 5  
6	7	3
5	6	7
5	3	7
10	10	9
7	6	7
8	9	8
10	10	10
5	7	6
7	6	5
8	8	8
7	8	4.5
7.26	7.5	6.93

Appendix G: Design Hazard Checklist

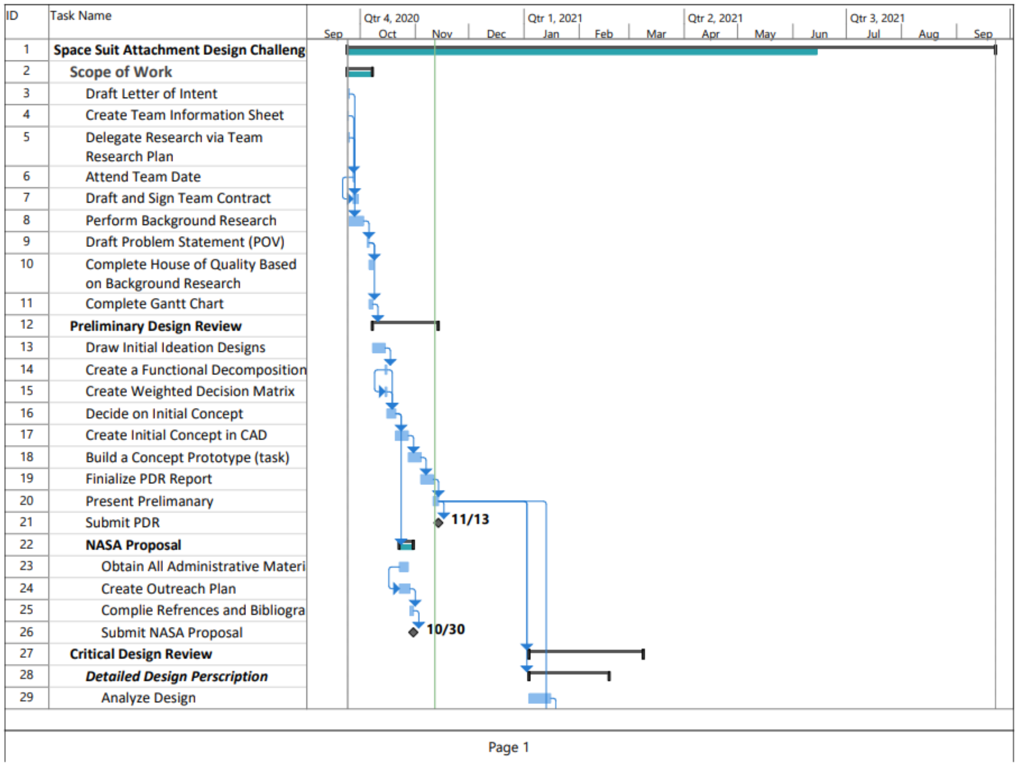
Y	N	
	●	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	●	2. Can any part of the design undergo high accelerations/decelerations?
	●	3. Will the system have any large moving masses or large forces?
	●	4. Will the system produce a projectile?
	●	5. Would it be possible for the system to fall under gravity creating injury?
	●	6. Will a user be exposed to overhanging weights as part of the design?
	●	7. Will the system have any sharp edges?
	●	8. Will any part of the electrical systems not be grounded?
	●	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	●	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	●	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	●	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	●	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	●	14. Can the system generate high levels of noise?
●		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	●	16. Is it possible for the system to be used in an unsafe manner?
●		17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

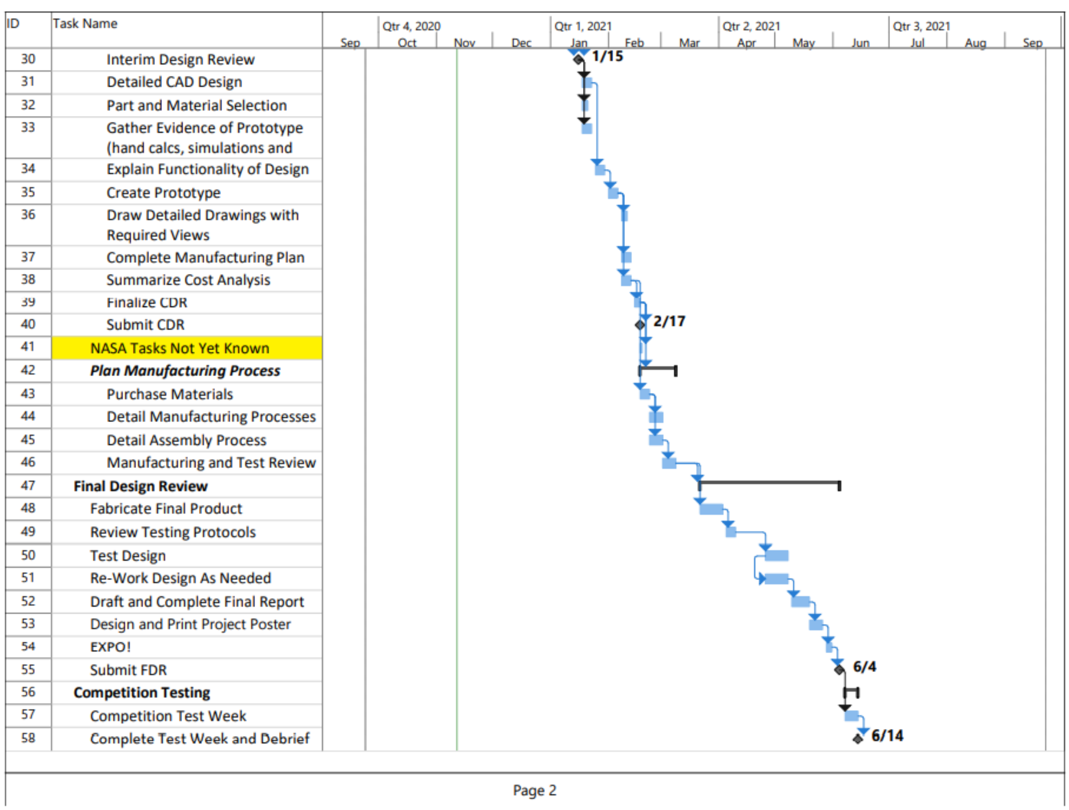
For any “Y” responses, on the reverse side add:

1. a complete description of the hazard,
2. the corrective action(s) you plan to take to protect the user, and
3. a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Pinch points	Label pinch points on final design and thoroughly explain to astronauts in training. However, not needing to handle the mechanism makes them less hazardous.	3/04/2021	
Extreme conditions	Make the mechanism of materials incapable of off gassing like S.S. or Al.	11/6/2020	
Finger entrapment	Perform thorough inspection and testing with gloves to ensure fingers cannot get entrapped in the system	1/15/2020	

Appendix H: Gantt Chart





Appendix I: Finite Element Analysis Results

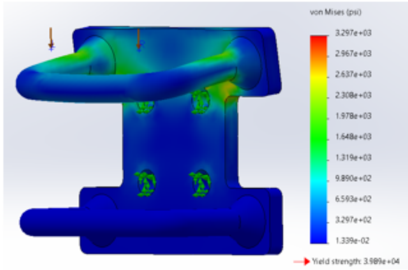
Load Capacity

Load Capacity Requirement:

- The system must be able to support 15 lbf

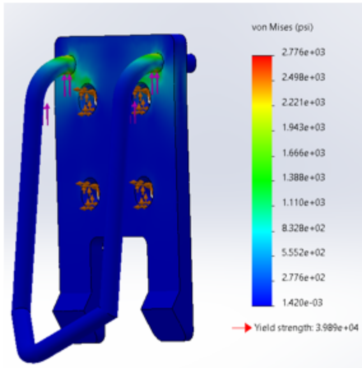
Verification:

- Physical load testing with 20 lbf
- Finite Element Analysis



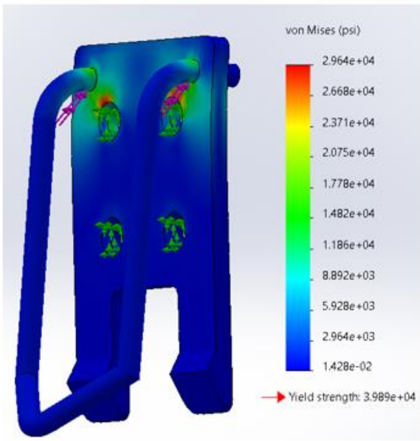
Component	Yield Strength [ksi]	Max Stress [ksi]	Safety Factor
Belt	39.89	3.30	12.1
Tool	39.89	2.78	14.3

Table 1: FEA Results Summary



Impact from Above Finite Element Analysis
Tool Component

Component	Scenario	Ultimate Strength [ksi]	Max Stress [ksi]	Safety Factor
Tool	Top Impact	45.0	29.6	1.52

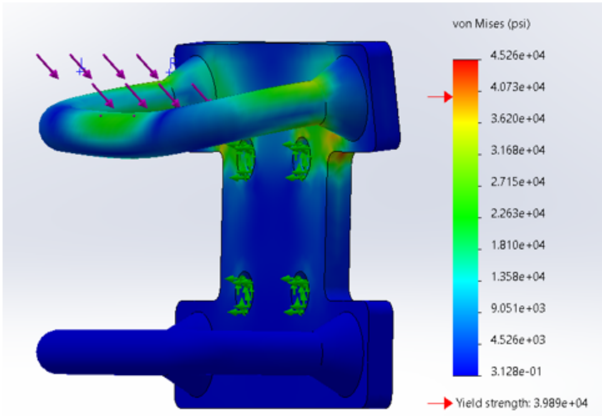


Impact from Above Finite Element Analysis
Belt Component

Component	Scenario	Ultimate Strength [ksi]	Max Stress [ksi]	Safety Factor
Belt	Top Impact	45.0	45.3	0.99

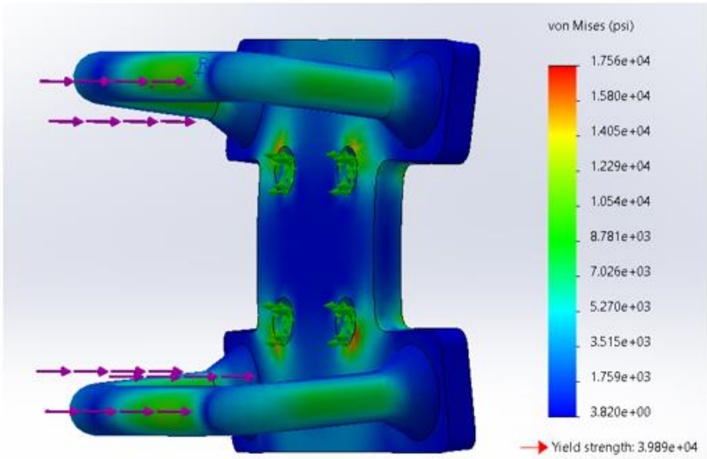
Further Justification

- Due to direction of load, higher stress is on bottom of rung and therefore in compression, so failure mode is crumpling rather than cracking and rupturing which is safety concern
- Conservativism in calculations that led to applied load of 330 lbf



Impact from Front Finite Element Analysis
Belt Component

Component	Scenario	Ultimate Strength [ksi]	Max Stress [ksi]	Safety Factor
Belt	Front Impact	45.0	17.6	2.56



Appendix J: Current Budget

Table J-1 Complete List of Purchases Made

Date purchased	Vendor	Description of items purchased	Part #	Quantity	Unit Cost	Transaction amount
01/20/21	McMaster-Carr	Aluminum 7075 6”x6”x0.25” plate stock	8885K891	1	$21.79	$21.79
01/20/21	McMaster-Carr	Tight-Tolerance High-Strength 7075 Aluminum Rod 3/16" Diameter	9063K25	1	$23.75	$23.75
01/20/21	McMaster-Carr	3x W 2” Ht. 2 5/8” Th. Lg. 1 ½” 304 Stainless Steel Square U-Bolts	3060T71	3	$8.15	$24.45
01/20/21	McMaster-Carr	Multipurpose 304 Stainless Steel Rods 3/16”x2’	89535K84	1	$3.56	$3.56
02/11/21	Grainger	Stainless Steel Rod 3/8" Dia x 6ft L	3GTD4	1	$10.55	$10.55
02/11/21	Grainger	Rod, SS, 303, 5/16 In Dia x 6 Ft L	2EXC9	1	$5.87	$5.87
02/11/21	Grainger	Rod Stock, SS, 1 ft. L, 3/16 in. dia.	48KU24	10	$1.84	$18.40
02/11/21	Grainger	Rod, SS, 303, 1/8 In Dia x 6 Ft L	2EXC7	1	$4.16	$4.16
02/11/21	Grainger	Rod, SS, 303, 1/4 In Dia x 6 Ft L	2EXC8	1	$3.67	$3.67
02/11/21	Grainger	#10-24 Machine Screw, Flat, SS, 1/2"	2AB61	1	$7.45	$7.45
02/11/21	Grainger	U-Bolt, Square Bend, 304 Stainless Steel, 3/8"-16, 1 1/2 in Thread Length	5YY64	6	$12.00	$72.00
02/11/21	Grainger	3/8"-16 Jam Nut, Plain Finish, 316 Stainless Steel, Right Hand, ASME B18.2.2, PK25	41VL68	1	$4.31	$4.31
02/11/21	Grainger	Fender Washer, 0.065 in Thickness, PK 50	22UF01	1	$1.26	1.26
02/11/21	Grainger	General Purpose 6061 Aluminum Rod Stock, 1/8 in Dia. X 1 ft L, Mill Finish	48KU32	6	$0.88	$5.28
02/11/21	Grainger	General Purpose 6061 Aluminum Rod Stock, 3/16 in Dia. X 1 ft L, Mill Finish	48KU18	12	$1.05	$12.60
02/11/21	Grainger	General Purpose 6061 Aluminum Rod Stock, 5/16 in Dia. X 1 ft L, Mill Finish	48KU20	12	$1.86	$22.32
02/11/21	Grainger	#10-24 Flat SS screw 3/4"	2AB65	1	$11.55	$11.55
02/11/21	Grainger	3/16" Aluminum plate 12x12 6061	3DTC4	1	$49.47	$49.47
02/11/21	Grainger	1/4" Aluminum Plate 12x12 6061	2HGN8	1	$42.08	$42.08
03/31/21	McMaster-Carr	Multpurpose 304 Stainless Steel Sheet 6" x 12", 1/4" Thick	8983K221	1	$36.47	$36.47
03/31/21	Home Depot	Bessey 4 in. Capacity Square Jawed Ratcheting Hand Clamp with 3 in. Throat Depth	Unknown	2	$7.47	$14.94
03/31/21	Home Depot	Grip-Rite #8 x 5-1/2 in. Electro-Galvanized Steel Tile Nails (5 lb.-Pack)	512EGTL5	1	$10.95	$10.95
03/31/21	Home Depot	1 in. x 4 in. x 12 ft. Standard Fir Board	418532	1	$5.77	$5.77
05/14/21	Ace Hardware	Misc. Hardware fir	Misc	1	$14.77	$14.77
					Total expenses:	$427.42

Table J-2 Summary of Initial and Remaining Funding

Current Cal Poly Budget:	$500.00
Expenses From Cal Poly ProCard:	$156.45
Remaining Cal Poly Funds	$343.55
Current NASA Stipend:	$400.00
NASA Expenses:	$270.97
Remaining Funds:	$129.03

Appendix K: Manufacturing Drawing Package

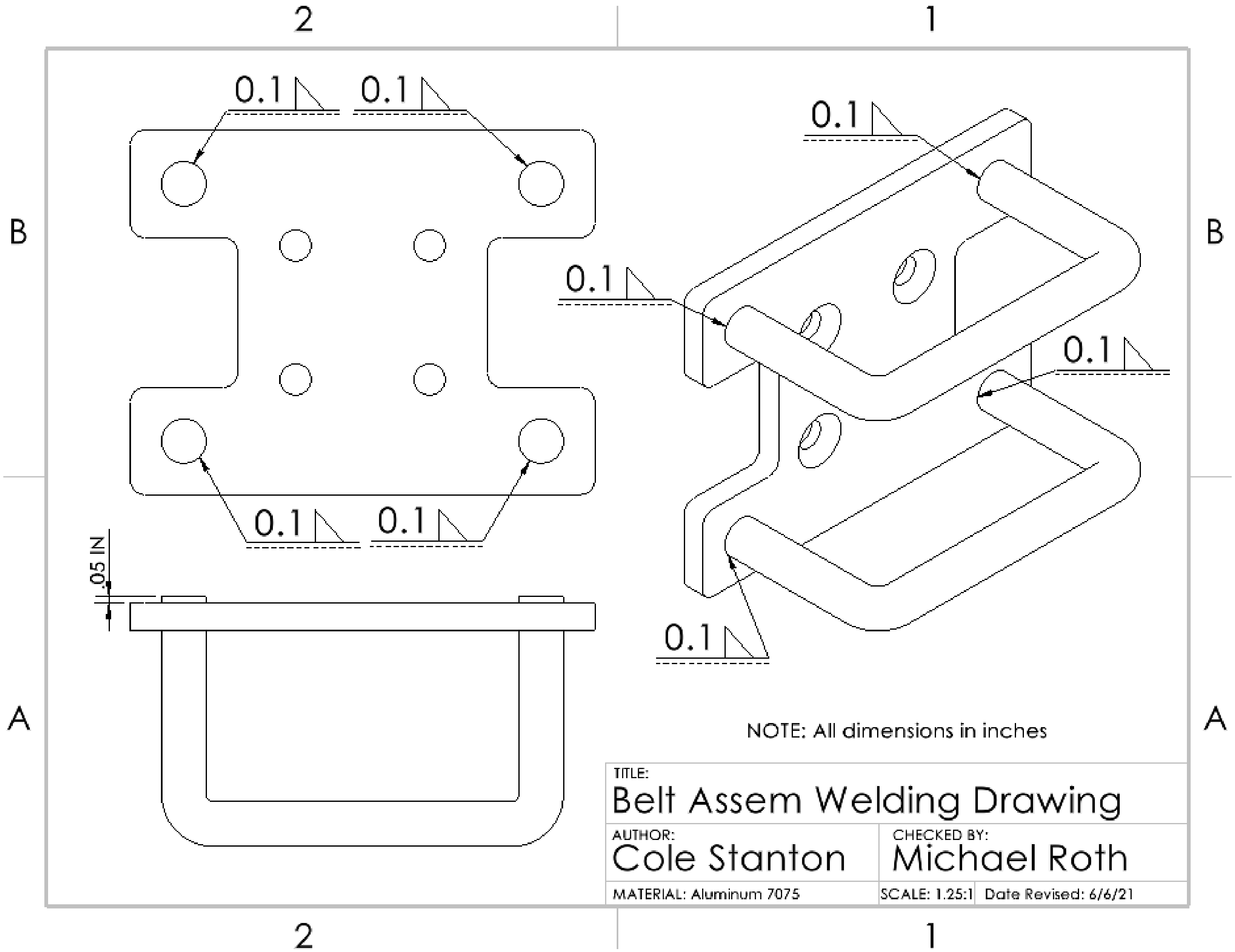
Indented Bill of Materials:

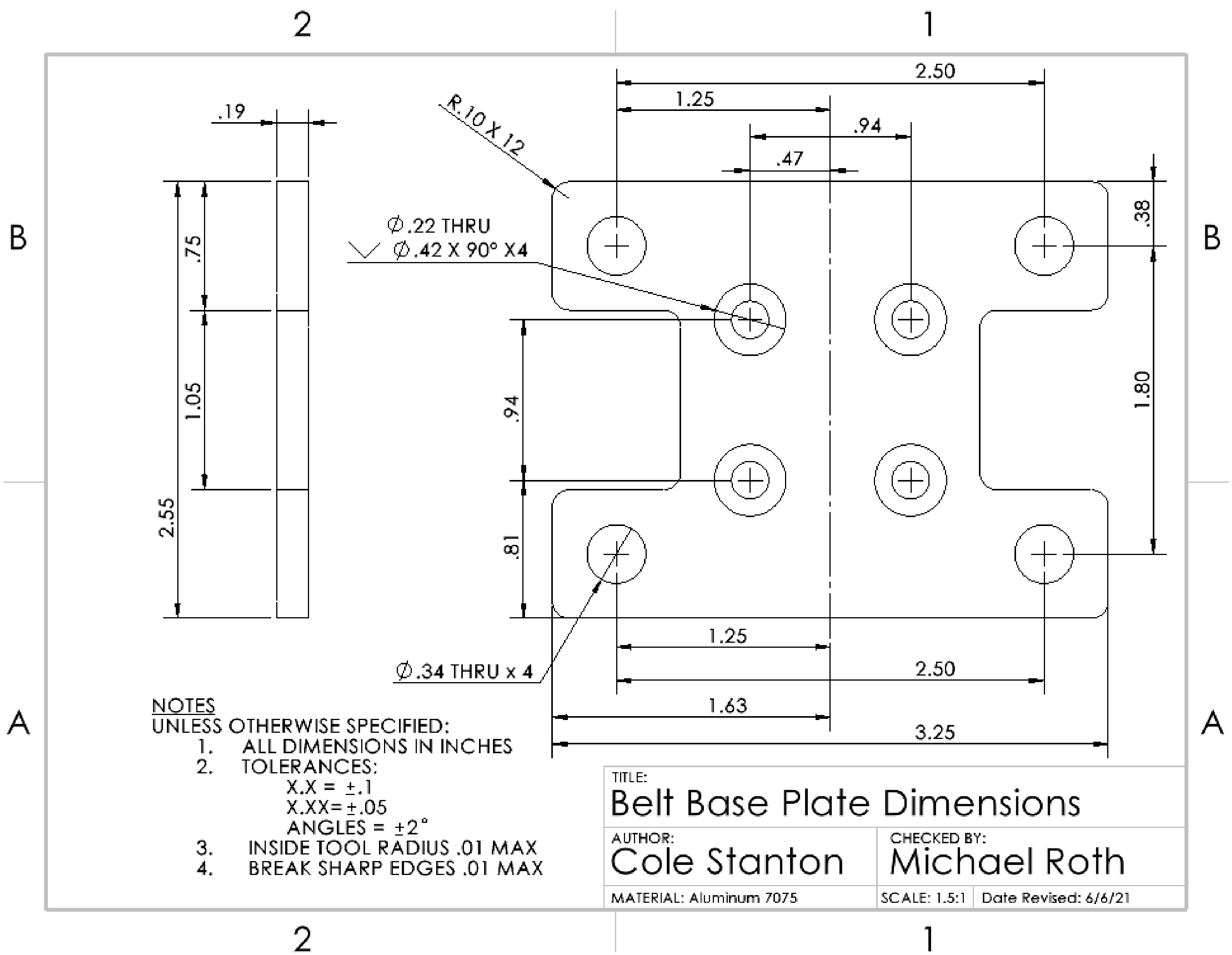
Space Suit Tool Belt Clip Interface

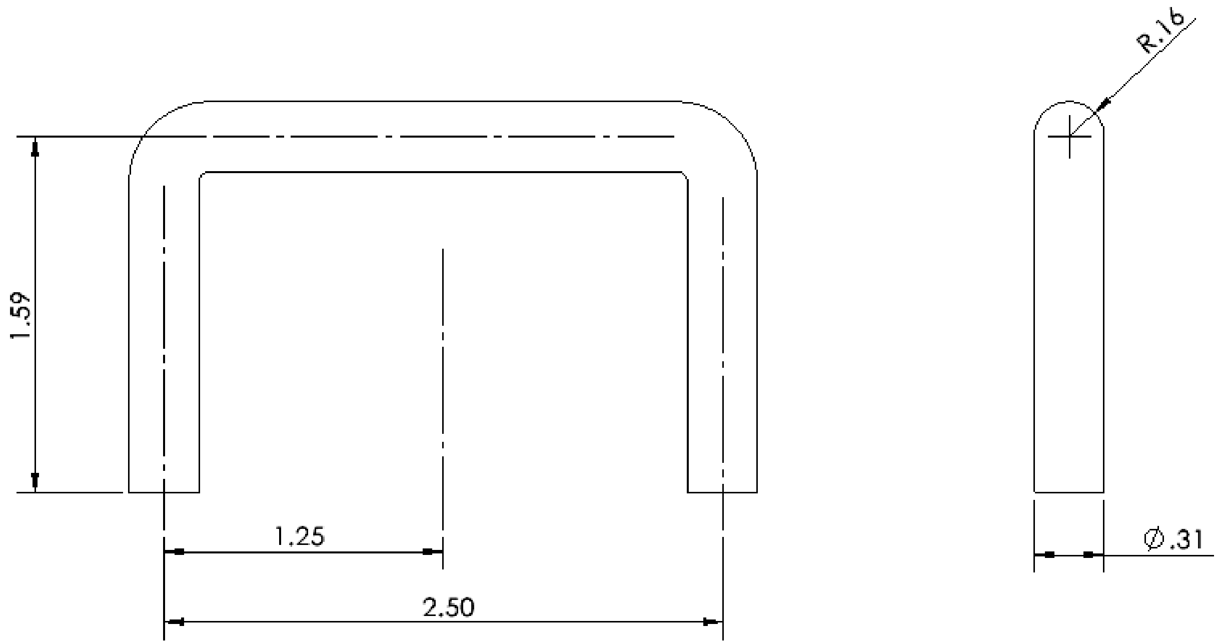
Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name	Qty	Mat'l Cost	Production Cost	Total Cost	Part Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4						
0	100000	Final Assy					------	
1	110000	Probe Tool Half					------	
2	111000	Base plate	1	$5.50	$ -	$ 5.50	McMaster	Mill and drill, item 8885K891
2	112000	Probe 7075 Aluminum Rod	1	$1.00	$ -	$ 1.00	McMaster	bend and weld, item 9063K25
1	120000	Belt Receptacle						
2	121000	Base plate	1	$5.50	$ -	$ 5.50	McMaster	Mill and drill, item 8885K891
2	122000	Probe 7075 Aluminum Rod	1	$1.00	$ -	$ 1.00	McMaster	bend and weld, item 9063K25
	Total Parts		**4**			**$ 13.00**		

Dimensioned Part Drawings:




2
1
B
A
.19
.75
1.05
2.55
R.10 X 12
Ø.22 THRU
Ø.42 X 90° X4
2.50
1.25
.94
.47
.38
1.80
.94
.81
Ø.34 THRU x 4
1.25
2.50
1.63
3.25
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.X = ±.1
X.XX= ±.05
ANGLES = ±2°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
TITLE:
Belt Base Plate Dimensions
AUTHOR:
Cole Stanton
CHECKED BY:
Michael Roth
MATERIAL: Aluminum 7075
SCALE: 1.5:1
Date Revised: 6/6/21



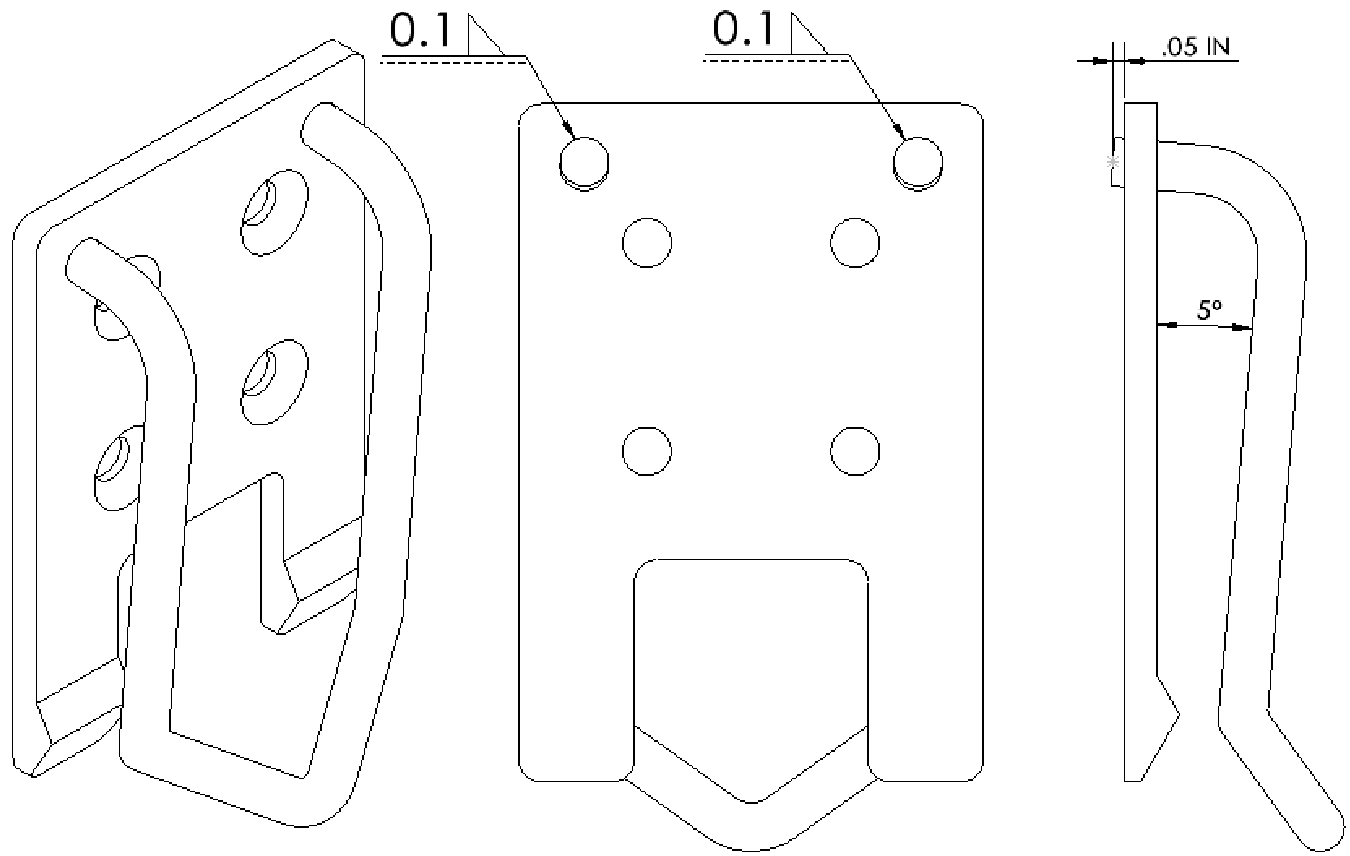
NOTES

- Quantity = 2

UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.X = ±.1
   X.XX= ±.05
   ANGLES = ±2°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX

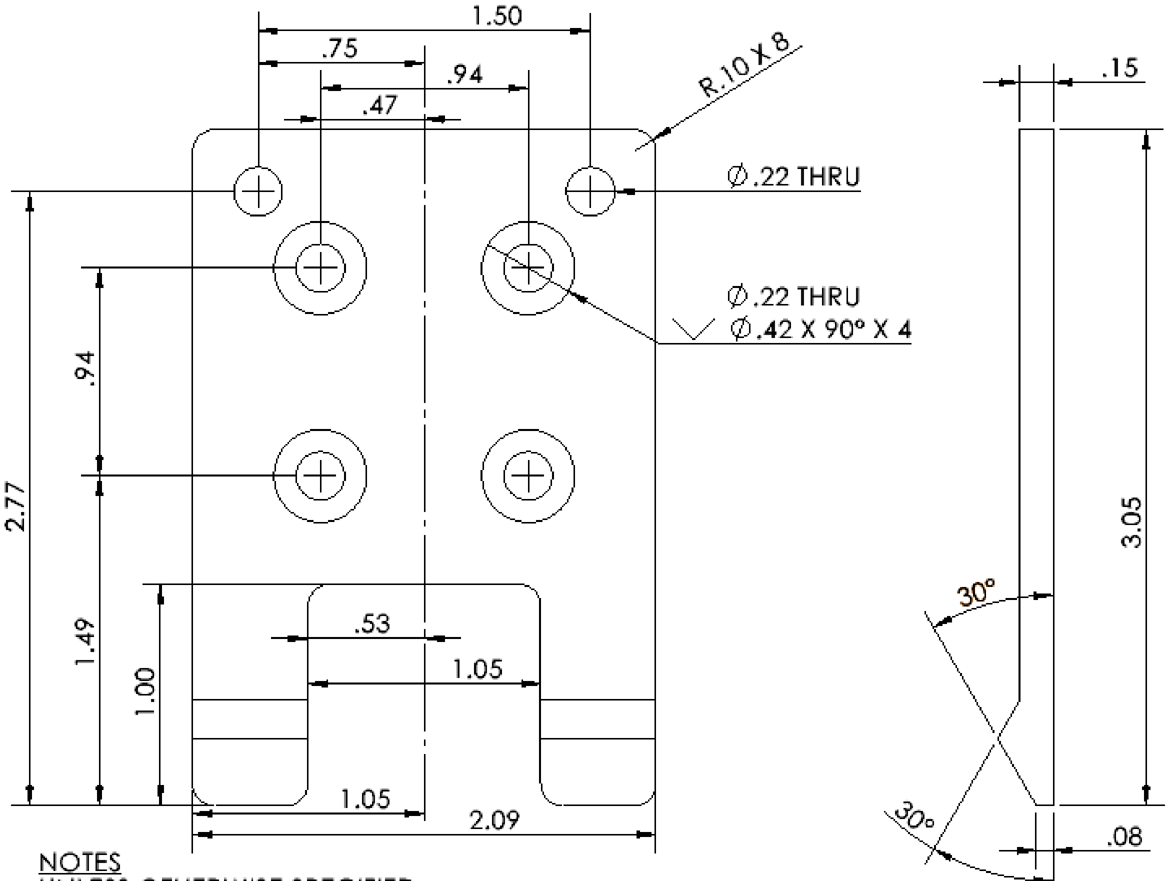
TITLE: Belt Rung Dimensions		
AUTHOR: Cole Stanton	CHECKED BY: Michael Roth	
MATERIAL: Aluminum 7075	SCALE: 1.5:1	Date Revised: 2/18/21



NOTE: All dimensions in inches

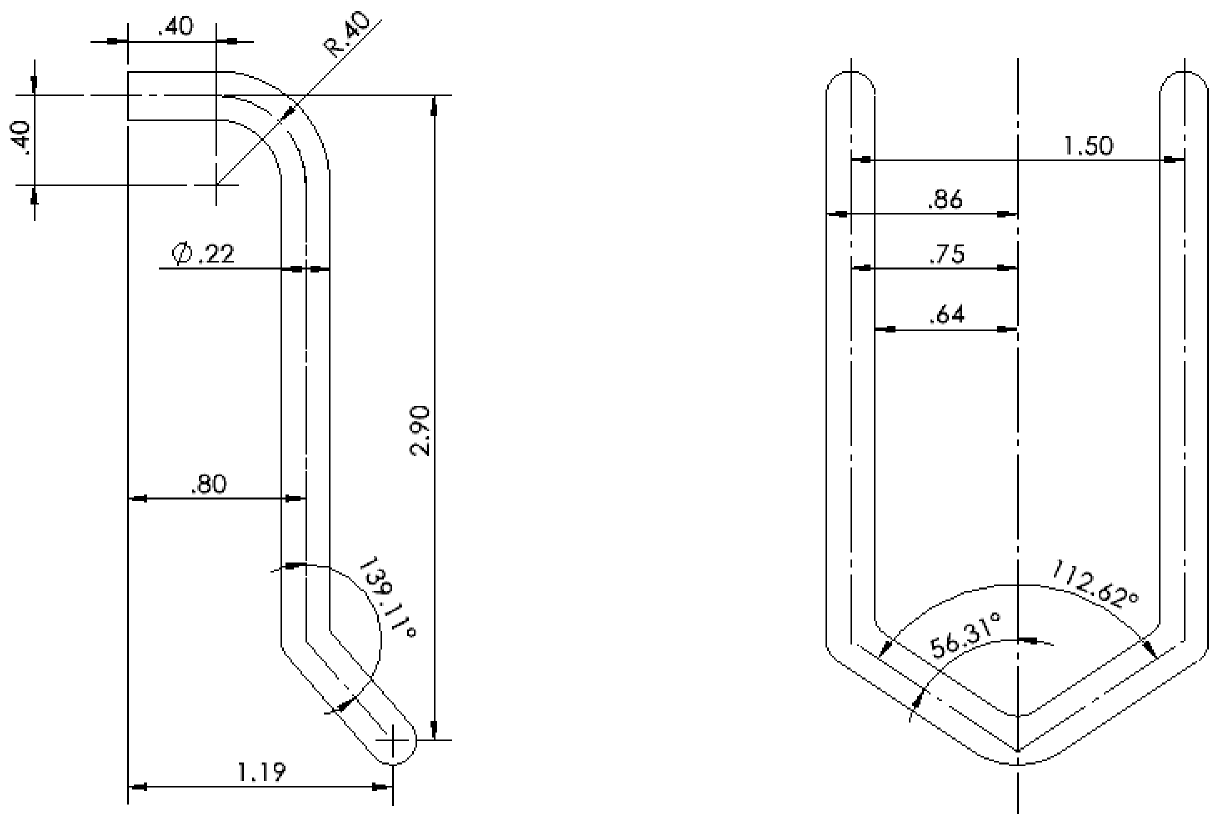
TITLE:
Tool Assem Welding Drawing

AUTHOR: Cole Stanton	CHECKED BY: Michael Roth	
MATERIAL: Aluminum 7075	SCALE: 1.5:1	Date Revised: 6/6/21



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.X = ±.1
   X.XX= ±.05
   ANGLES = ±2°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX

TITLE: Tool Base Plate Dimensions	
AUTHOR: Cole Stanton	CHECKED BY: Michael Roth
MATERIAL: Aluminum 7075	SCALE: 1.5:1 Date Revised: 6/6/21



NOTES
- Overall length of wire = 8 IN

UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.X = ±.1
   X.XX= ±.05
   ANGLES = ±2°

TITLE: Tool Wire Frame Dimensions		
AUTHOR: Cole Stanton	CHECKED BY: Michael Roth	
MATERIAL: Aluminum 7075	SCALE: 1.5:1	Date Revised: 2/16/21

Appendix L: Design Verification Plan & Report

DVP&R - Design Verification Plan (& Report)											
Project:	F55 - LUNAR EVA TOOL SPACE SUIT QUICK RELEASE SYSTEM		**Sponsor:**	Gotthard Janson, Dr. Schuser						**Edit Date:**	5/18/2021
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
SPEC TABLE TESTS											
1	3 (Release Force)	Secure belt half to solid surface and tool half to spring scale. Secure system manually. Set up camera to observe spring scale. Slowly increase **upward** force until system **releases** from receptacle. Also have user release by hand with gloves on to note difficulty relative to human strength.	Maximum force required to release tool.	5 lbf< F < 10 lbf	Force gauge	Both system components, spring scale, stable camera setup, ski gloves, welding gloves	Michael & Andres	4/1/2021	(Prelim 2/28/2021) Final 4/15/21	Preliminarily complete. Results in "Preliminary Testing Results" spreadsheet. Final Results in Securing User Load Spredsheet.	Found that maximum force in release process is dependent on velocity. There is a linear relationship between release force and the deflection the wire flame flexure must undergo.
2	4 (Secure Force)	Secure belt half to solid surface and tool half to spring scale. Set up camera to observe spring scale. Slowly increase **downward** force until system **secures** on receptacle rungs. Perform test multiple times for data. Also have user secure by hand with glove on to note difficulty relative to human strength.	Maximum force required to release tool.	5 lbf< F < 10 lbf	Force gauge	Both system components, spring scale, stable camera setup, ski gloves, welding gloves	Michael & Andres	4/1/2021	4/15/2021	Preliminarily complete. Results in "Preliminary Testing Results" spreadsheet. Final Results in Securing User Load Spredsheet.	Assumed to be less than or equal to release force due to gravity and symmetry.
3	5 (Load Capacity)	First measure the release force of the design before any loading has occurred. Then load the tool component, while secured to the belt component, with 5 pounds and let it sit for 60 seconds. Then measure the release force again. Repeat these steps with loads of 10 and 15 pounds.	Maximum force required to release tool.	Release force should not decrease after any loading.	Force gauge	Both system components, fixture	Michael & Andres	4/8/2021	4/27/2021	Results in Release Force After Loading Data spreadsheet in OneDrive.	No decrease in release force as a result of loading.
4	10 (Timed Operation)	Fasten belt half to a belt on user's waist and fasten tool half to drill. blindfold user **and** cover user's hands with ski glove covered by welding glove and have them attempt to secure tool several times. For each attempt, measure amount of time until successful secure. Also note attempt numbers. Move belt half location and try again.	Time of each attempt until sucessful securing.	4 seconds	None.	Both system components, belt, drill, ski glove, welding glove, blindfold, timer	Michael & Andres	4/6/2021	(Prelim 2/28/2021)	Preliminarily complete. Results in "Preliminary Testing Results" spreadsheet.	Rounded probe versus pointed probe made no difference in securing time.
5	9 (Blind Operation)	Fasten belt half to a belt on user's waist and fasten tool half to drill. Blindfold user and have them attempt to secure tool several times. Time each attempt at a given belt half location. Note amount of failed and succesful locations per attempt. Move belt half location and try again.	Time of each attempt until sucessful securing. & Successful locations as a percentage of total attempts	4 seconds	None.	Both system components, belt, drill, blindfold	Michael & Andres	4/6/2021	(Prelim 2/28/2021)	Preliminarily complete. Results in "Preliminary Testing Results" spreadsheet.	Time to secure system quickly reduces with practice.

DVP&R - Design Verification Plan (& Report)

Project: F55 - LUNAR EVA TOOL SPACE SUIT QUICK RELEASE SYSTEM | **Sponsor:** Gotthard Janson, Dr. Schuser | **Edit Date:** 5/18/2021

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
6	12 (Moon Dust Cycles)	Submerge separate tool and belt halves into lunar dust simulant (crushed limestone). Pull out and cycle securing and releasing. On each cycle test security by turning system upside down and seeing if system remains secured. Perform 10 times and then resubmerge and try again. Lastly, document wear on aluminum by dust.	% of failed securings caused by lunar dust per submersion (10 cycles).	0%	None.	Both system components, lunar dust simulant	Michael & Andres	4/8/2021	4/22/2021	Results in Dust Tolerance Data spreadsheet in OneDrive.	Thick sand doesn't impede securing of the system as a result of clogging. However, riction on surfaces does increase. Mention surface hardness in final report and do dust testing last in NBL.
7	14 (Pinch Points)	Secure belt half to solid surface and tool half to drill. Glove user's hand with ski glove. Have user clumsily secure system and remain absolutely still after securing. Have observers note number of pinched locations of glove.	Number of pinched glove locations per cycle.	0	None.	Both system components, ski gloves, welding gloves, observers	Michael & Andres	4/6/2021	4/22/2021	Results are in video form and observer deductions.	Very very difficult to get glove stuck under flexure and wire. Even once done, doesn't damage the flove if forcibly removed due to low force.
8	8 (Gloved Operation)	Fasten belt half to a belt on user's waist and fasten tool half to drill. Cover user's hands with ski glove covered by welding glove and have them attempt to secure tool several times. Time each attempt at a given belt half location. Note amount of failed and succesful locations per attempt. Move belt half location and try again.	Time of each attempt until sucessful securing. & Successful locations as a percentage of total attempts	4 seconds	None.	Both system components, belt, drill, ski glove, welding glove	Michael & Andres	4/6/2021	(Prelim 2/28/2021)	Preliminarily complete. Results in "Preliminary Testing Results" spreadsheet.	Gloves appear to not be large boundary in securing system. This was expected since our system doesn't require any pecise motor functions.
9	16 (Entrapment)	Secure the belt half to a solid surface. With the belt hald, tool half, and secured system, attempt to entrap fingers in any way shape or form.	Number of times glove gets irremovably stuck.	0	None.	Both system components, ski gloves, welding gloves, observers	Michael & Andres	4/28/2021	4/22/2021	Results are in video form and observer deductions.	System must be completely intentionally misused to get finger in system. Furthermore, glove and finger were not damaged on removal.
10	13 (Jostling)	Fast belt half to belt on user and tool half to drill. Secure system. Have user: 1) Jump up and down softly, normally, then vigorously, each 10 times. 2) Bend over as if performing inspection of something on ground. Stand back up. x 10 Note number of time system separates.	Number of times system separates	Release force > 5 lbf. Functional testing with system and fastened drill shows no unintentional release	None.	Both system components, belt, drill, blindfold	Michael & Andres	4/1/2021	4/18/2021 4/15/21	Results in Securing User Load Spredsheet. Also performed functional tests for the Concept Video	Intertial analysis alongside release force tests show it can support large accelerations. Also functionally tested in concept video to show versatility.

Appendix M: Test Procedures

Test Procedure – F55 Space Suit Attachment

Test Name: Release System User Loads

Purpose: The purpose of this test is to analyze the amount of force required release the system for varying flexure diameters at a given stability latch size.

Scope: This test will function to analyze the amount of force necessary to release the system. It will encompass varying the flexure diameters while keeping the flexure displacement constant.

Equipment:

- Force gauge
- Belt component
- Tool component
- Vertical surface capable of mounting belt component
- Screws
- Drill
- Force gauge
- 3D Printed connector between force gauge and tool component

Hazards:

- If the tool clip system becomes released from the mounts, the system could become a projectile by the forces used in the test. Although the loads used will be most likely <15 lbs, this still can pose a hazard for test operators.

PPE Requirements:

- Safety goggles

Facility:

Test can be performed on any flat surface in a controlled space.

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1. Mount belt half to the vertical surface perpendicular to the ground with screws and drill
2. Attach force gauge and the connector to the tool half
3. Secure the tool and belt components to each other
4. Set the force gauge to measure max force
5. Pull the tool half at a reasonable velocity over both rungs, simulating a user release
6. Record max force seen by force gauge
7. Measure flexure distance again to ensure no yielding has occurred
8. Repeat steps 3-7 10 times

Results: Pass Criteria, Fail Criteria, Number of samples to test

Pass Criteria: Securing force should be less than 15 lbf.

The results of this test will be documented in the table below, and we will have multiple versions of this table for the variations of flexure displacement. This test will be repeated 10 times for each flexure diameter.

Test Date(s): 4/10/21

Test Results:

Constants	Flexure displacement =		
Test #	**Flexure Diameter [in]**	**Maxiumim Securing Force [N]**	**Notes**

Performed By:

Michael Roth

Test Procedure – F55 Space Suit Attachment

Test Name: Maximum Load Test

Purpose: The purpose of this test is to analyze the amount of force the device can withstand without breaking.

Scope: This test will function to analyze the amount of force the system can support without deforming or breaking. It will place more weight than required by the NASA requirements so that there is a factor of safety for the load the part can hold.

Equipment:

- Force gauge
- Belt half
- Tool half
- Mounting fixture for belt component
- Weights to attach to tool half
- Fishing line
- Zip-ties
- Carabiner

Hazards:

- If the tool clip system becomes released from the mounts, the system could become a projectile by the forces used in the test. Although the loads used will be most likely <15 lbs, this still can pose a hazard for test operators.
- If the tool clip system deforms or breaks during the tests, the system could drop and crush anything below where the test is occurring. Do not test high above a surface and use cushioning to avoid damaging the parts further.

PPE Requirements:

- Safety goggles

Facility:

Test can be performed on any flat surface in a controlled space.

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

9. Mount belt half to vertical surface with weights/bolts
10. Attach force gauge to top of tool half
11. Secure the tool and belt components to each other
12. Set the force gauge to measure max force
13. Place increasing weights until 15 pounds is reached or the system beings to deform.
14. Record max force the system was able to withstand.
15. Using force gauge, measure how much force is needed to release the system to determine if deformation has affected system performance
16. Measure flexure distance again to ensure no yielding has occurred if 15 lbs was reached

Results: Pass Criteria, Fail Criteria, Number of samples to test

Pass Criteria: System does not deform

The results of this test will be documented in the table below, and we will have multiple versions of this table for the variations of flexure displacement. This test will be repeated 10 times for each flexure diameter.

Test Date(s): 4/20/21

Test Results:

Test #	Part Number	Maximum Load [lbs]	Flexure Displacement [in]	Release force after test [N]	Notes

Performed By:

Andres Elzuardia, Michael Roth, Elyse Gillis-Smith, Cole Stanton

Test Procedure – F55 Space Suit Attachment

Test Name: System Dust Tolerance Test

Purpose: Prove that our system performance will not be obstructed in the presence of lunar dust.

Scope: This test will ensure that our system, after submersion in lunar dust, will not fail to secure or release. The lunar dust in this case will be bunker sand as recommended in the Focus Session.

Equipment:

- Verification Prototypes of our system
- Bunker sand
- Force gauge
- Box to hold sand and submerge system in
- Bucket of water to submerge system in

Hazards:

- Users' fingers may be pinched by flexure if handling system carelessly

PPE Requirements:

- Safety Glasses to prevent sand in eyes

Facility:

Anywhere outdoors where the sand can be used.

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

17. Place sand in open top box with area large enough to submerge system in dust.
18. With the system halves separate, submerge the components in the bucket of water
19. Pull the system halves out and then submerge and roll in the sand such that they are coated
20. Pull the parts out of the sand without shaking to remove sand.
21. Attempt to secure the system.
22. Once attempt is complete, fix belt half to surface.
23. Attach force gauge to top of tool half.
24. Pull on force gauge at reasonable releasing speed to release the system completely.
25. Record the maximum release force.

Results:

Pass Criteria: Release force is greater than calculated maximum inertial force due to jostling and less than the max force we deem comfortable for an astronaut to release.

Number of samples to test: For each verification prototype, perform test 10 times per sand coating.

Test Date(s): 4/22/2021
Performed By: Andres Elzaurdia, Michael Roth
Test Results:

Test #	Flexure Diameter [in]	Flexure Displacement [in]	Maximum Release Force [N]

Test Procedure – F55 Space Suit Attachment

Test Name: Timed Operation Test

Purpose: To test the ability of a blinded and gloved astronaut to secure the tool to the belt and release the tool from the belt.

Scope: This test will determine the overall ability of our design to function while an astronaut or other user to secure and release their tool while blindfolded and wearing gloves.

Equipment:

- 3D printed belt component
- Belt
- 3D printed tool component with pointed locator probe
- 3D printed tool component with rounded locator probe
- Any tool (in this case a drill was used)
- Blindfold
- Stopwatch
- Large ski gloves

Hazards:

- 3D printed parts could rupture and become sharp, if a part is broken handle it with care while disposing of it.

PPE Requirements:

- n/a

Facility:

Any flat location that is safe to stand without vision.

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1. Thread the belt component through a belt so it can be attached to the tester's waist. The thinner the belt the better.
2. Attach tool component with a pointed locator probe to a tool of choice and in an orientation that makes it easily accessible while resting on the tester's waist.
3. Tester should now put on the large ski gloves and blindfold in that order.
4. Take the tool and bend over as if to perform some EVA task on the ground. The data recorder will say "Go" at which point the tester will stand up and secure the tool. The tester will time and record this action.
5. Repeat Step 4, 10 times
6. Remove the tool component with a pointed locator and attach the tool component with a rounded locator probe.
7. Repeat Step 4 and 5 with this new setup and record the results.
8. Record testers observations of the experiment qualitatively.

Results: Pass Criteria, Fail Criteria, Number of samples to test

Pass: If the astronaut is able to locate the belt component and correctly secure the tool component with out and missing the belt component in under 4 seconds the test 95% of the time.

Test Date(s): 2/27/2021

Test Results:

Test #	Notes	Timed Operation [S]
1	Secured top but not bottom flexure	2.08
2	1 miss	4.76
3	near miss	1.86
4		2.04
5		3.38
6	1 miss	2.12
7	1 miss	3.3
8		1.88
9		1.8
10		1.77

Performed By: Andres Elzuardia and Michael Roth

Appendix N: User Manual

Space Suit Attachment Quick Release System User Manual

May 13, 2021

Team:
Space Suit Squad (F55)

Compiled By:
Andres Elzaurdia
Elyse Gillis-Smith
Michael Roth
Cole Stanton

spacesuitF55@gmail.com

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
Spring 2021

Prepared For:
NASA
Micro-g NExT Challenge

This user's manual includes instruction for assembly of the part, best practices for appropriate use, and warnings about potential safety hazards.

Assembly

This section describes how to successfully assemble the quick release system so that it is ready for testing.

Belt Half

The belt half assembly mounts to the xEMU Utility Belt. Below are step by step instructions for how to mount the belt half to the Utility Belt.

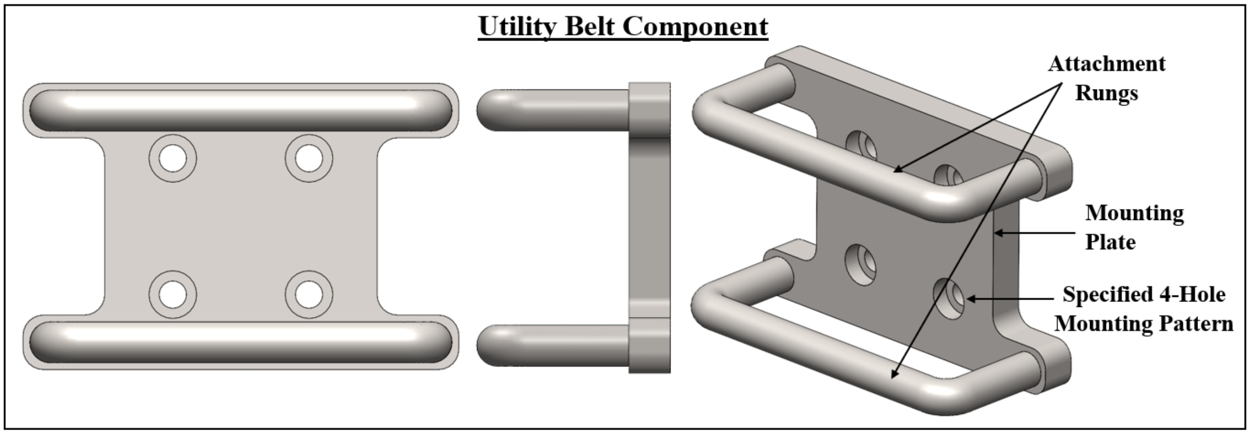


Figure 1. Utility Belt component assembly diagrams

1. Align Belt Half mounting holes with the Utility Belt mounting holes.
2. Insert #10 bolts through both the Belt Half and the Utility Belt mounting holes. There should be roughly a ¼" protruding out of the back of the Utility Belt.
3. Hand-tighten the nut to the bolt.
4. Perform steps 1-3 for all 4 bolts.
5. Using a screwdriver to hold the bolt in place, use a wrench to tighten the bolt to a snug fit on the Utility Belt.
6. Perform step 5 for all 4 bolts.

Tool Half

The tool half assembly mounts to the astronaut or diver's tool using the same four bolt pattern mentioned above. Below are step by step instructions for how to mount the tool half to the Utility Belt.

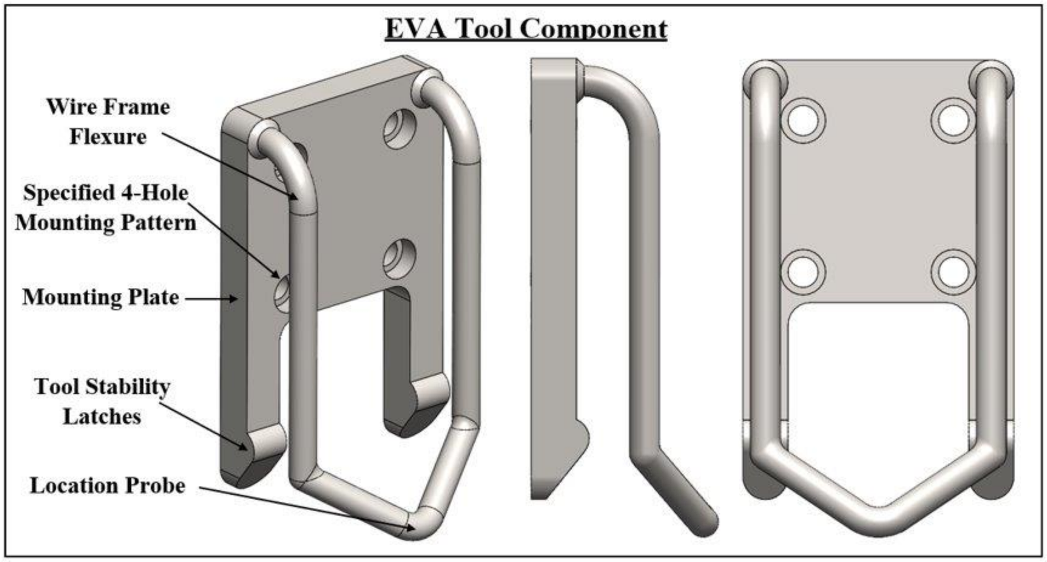


Figure 2. EVA Tool component assembly diagrams

1. Align tool half mounting holes with the Utility Belt mounting holes.
2. Insert #10 bolts through both the tool half and the Utility Belt mounting holes. There should be roughly a ¼" protruding out of the back of the Utility Belt.
3. Hand-tighten the nut to the bolt.
4. Perform steps 1-3 for all 4 bolts.
5. Using a screwdriver to hold the bolt in place, use a wrench to tighten the bolt to a snug fit on the tool.
6. Perform step 5 for all 4 bolts.

Appropriate Use

This section describes generally how our system operates and includes a step-by-step procedure for securing and releasing the system.

Figure 3: Securing tool process demonstrated in a series of images.

Steps to Release and Secure the Tool:

1. Beginning with the system secured, the user must locate the tool and firmly grasp it.
2. Pull the tool straight up, releasing the tool and the tool component from the belt and the belt component.
3. Perform task that requires tool.
4. Locate the tool using the locator probe as shown on the left of the Figure 3.
5. Push the tool directly downwards so that the wire frame flexure passes over both rungs of the utility belt to secure the tool.

Tips for Users:

- Practice securing and releasing the tool numerous times before the mission or test. The more you use it, the faster you use it.
- During use only interact with the tool, <u>NOT the tool or belt components.</u>
- Tool component is capable of slight lateral motion when secured, it will move around slightly when jostled. Be aware of this so it will not impact your balance.

Safety

This section describes the safety hazards and precautions that must be taken with our design. Thorough hazard mitigation and testing was performed with our system to ensure the safety of the diver and the astronaut, but it is still prudent to educate them on the risks present.

1. Pinch Points

An essential function of our design is the stability latch and flexure deflection over the belt half rungs. This action creates a temporary pinch point in the process of securing of our system.

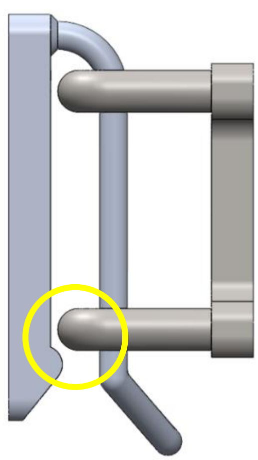


Figure 4: Location of the pinch point of the system when it is assembled.

When the stability latch and the flexure undergo interference with the Belt Half rung, the flexure acts as a spring, creating a pinch point. This pinch point hazard was effectively mitigated in two ways. First is that it is very difficult to access by the user since the user should only interact with the tool, proven in a test where we intentionally tried to pinch our gloves. Second is that the spring only exerts a very small force. When we performed the pinch points test and pinched our ski glove, we forcefully removed it and there was no damage to the ski glove.

Although this hazard is mitigated as best as possible, the pinch points will still be labeled with a yellow highlight as seen in Figure 5 below.

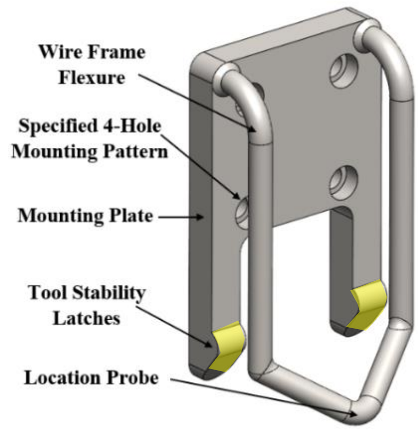


Figure 5: EVA Tool component diagram showing the highlighted pinch point location.

2. Finger Entrapment

Finger entrapment by the diver or astronaut's gloved fingers is a safety hazard that was considered throughout the design process. One method of mitigation was that the diver or astronaut don't have to interact with either half of the system, only the tool, preventing proximity of gloves to holes. Another was to use rounded components such as the flexure and rungs which prevent ensnaring the suit. Lastly, the orifices of the system were sized such that wherever possible, they are either larger than a 1" gloved finger or small enough to make insertion impossible.

For the belt half of the system, there are no holes smaller than 1". Furthermore, the rungs are rounded so that if somehow two fingers entered the receptacle, they can be easily removed without concern of damage to the space suit.

For the tool half of the system, the space between the flexure and the base plate had to be less than one inch in order for the latching mechanism to work. This distance can be seen in Figure 6 below.

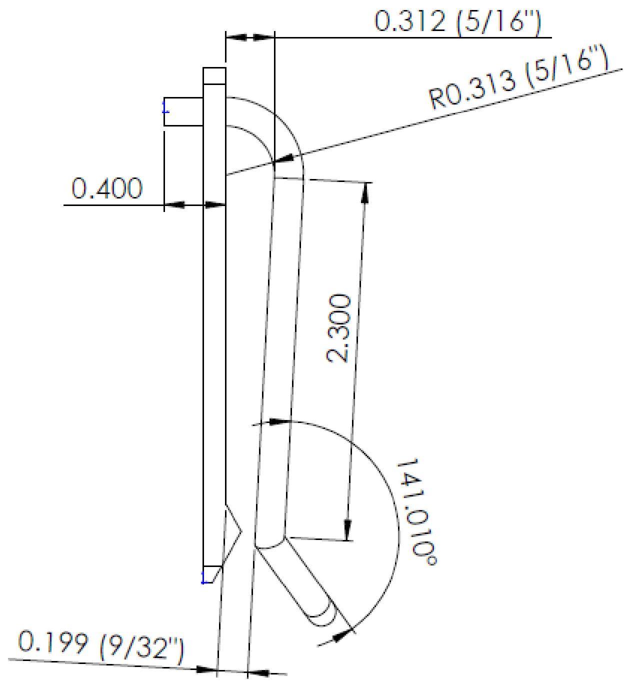


Figure 6: Tool half side view showing flexure dimensions

As a result, the diver should be aware of the small spaces between the tool half plate and flexure, shown by the 5/16” and 9/32” dimensions in parenthesis. These dimensions should be too small for the gloved finger to enter in the first place, but safety is only improved with their education.

One hole however is in a reasonable range for finger entry. This hole can be seen in Figure 7 below.

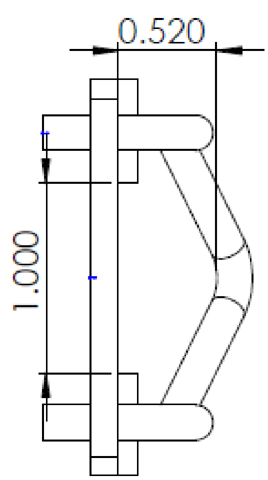


Figure 7: Tool half top view showing flexure hole that may be able to fit a finger

This orifice shown in Figure 7 is a hole which should be known by the diver. Although all edges will be filleted and sanded to be a curve and the flexure is round, if sufficient force is applied into that hole, it may open the flexure which could then compress and trap the finger. However, the compression force would be very low, and the system would have to be severely misused for this to occur.

Appendix O: Risk Assessment

designsafe Report

Application:	Space Suit Attachment Quick Release System	Analyst Name(s):	Andres Elzaurdia, Michael Roth, Elyse Gillis-Smith, Cole Stanton
Description:		Company:	Cal Poly
Product Identifier:		Facility Location:	San Luis Obispo
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	Testing Team Common tasks	mechanical : cutting / severing	Minor Unlikely	Negligible		Minor		
1-2-1	Testing Team normal operation	mechanical : pinch point	Minor Unlikely	Negligible		Minor		
1-3	Testing Team basic trouble shooting / problem solving	<None>						
1-4-1	Testing Team load / unload materials	mechanical : crushing	Serious Unlikely	Medium	Comply with compression machine safety requirements such as not turning on system while anyone is loading system.	Serious		
1-4-2	Testing Team load / unload materials	mechanical : cutting / severing	Moderate Unlikely	Low		Moderate		
1-4-3	Testing Team load / unload materials	mechanical : break up during operation	Minor Very Likely	Medium	Wear safety glasses and handle ruptured system with care.	Minor		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-5-1	Testing Team misuse - (add description)	mechanical : drawing-in / trapping / entanglement	Minor Likely	Low		Minor		
1-5-2	Testing Team misuse - (add description)	mechanical : pinch point	Minor Unlikely	Negligible		Minor		
2-1-1	Manufacturing Team Common Tasks	mechanical : crushing	Moderate Likely	Medium		Moderate		
2-1-2	Manufacturing Team Common Tasks	mechanical : cutting / severing	Serious Unlikely	Medium		Serious		
2-1-3	Manufacturing Team Common Tasks	mechanical : drawing-in / trapping / entanglement	Serious Unlikely	Medium		Serious		
2-1-4	Manufacturing Team Common Tasks	mechanical : pinch point	Moderate Unlikely	Low		Moderate		
2-1-5	Manufacturing Team Common Tasks	electrical / electronic : lack of grounding (earthing or neutral)	Moderate Likely	Medium		Moderate		
2-1-6	Manufacturing Team Common Tasks	electrical / electronic : shorts / arcing / sparking	Serious Unlikely	Medium		Serious		
2-1-7	Manufacturing Team Common Tasks	ergonomics / human factors : excessive force / exertion	Moderate Likely	Medium		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-8	Manufacturing Team Common Tasks	fire and explosions : hot surfaces	Serious Likely	High		Serious		
2-1-9	Manufacturing Team Common Tasks	fire and explosions : flammable gas	Serious Remote	Low		Serious		
3-1-1	passer by / non-user work next to / near machinery	ergonomics / human factors : excessive force / exertion	Moderate Unlikely	Low		Moderate		
4-1-1	NBL Diver Common Tasks	mechanical : cutting / severing	Serious Unlikely	Medium	Break all sharp edges with deburr or fillet using deburring tool and sandpaper.	Serious		
4-1-2	NBL Diver Common Tasks	mechanical : drawing-in / trapping / entanglement	Moderate Unlikely	Low		Moderate		
4-1-3	NBL Diver Common Tasks	mechanical : pinch point	Moderate Unlikely	Low		Moderate		
4-1-4	NBL Diver Common Tasks	mechanical : break up during operation	Serious Unlikely	Medium	Perform impact FEA as well as impact testing to ensure no rupture.	Serious		
4-1-5	NBL Diver Common Tasks	ergonomics / human factors : excessive force / exertion	Moderate Likely	Medium	Peform analysis on release force as well as testing with future prototypes to verify model and securing and releasing loads are comfortable.	Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
5-1-1	Astronaut Common Tasks	mechanical : cutting / severing	Catastrophic Remote	Low		Catastrophic		
5-1-2	Astronaut Common Tasks	mechanical : drawing-in / trapping / entanglement	Serious Remote	Low		Serious		
5-1-3	Astronaut Common Tasks	mechanical : pinch point	Catastrophic Remote	Low		Catastrophic		
5-1-4	Astronaut Common Tasks	mechanical : break up during operation	Catastrophic Unlikely	Medium	Perform impact FEA considering lunar temperature as well as impact testing to ensure no rupture.	Catastrophic		
5-1-5	Astronaut Common Tasks	ergonomics / human factors : excessive force / exertion	Moderate Remote	Negligible		Moderate		
5-1-6	Astronaut Common Tasks	ergonomics / human factors : posture	Moderate Unlikely	Low		Moderate		
5-1-7	Astronaut Common Tasks	ergonomics / human factors : repetition	Moderate Likely	Medium	Place system at prudent place on utility belt and peform analysis on release force as well as testing with future prototypes to verify model and securing and releasing loads are comfortable.	Moderate		