Micro-g NExT 2023 CoRVUS Final Report

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I. Abstract

Space exploration has widened the horizon for what is possible for aviation and aeronautics. Operational complexities have created many problems for astronauts when completing menial tasks in space. One of these issues is the uncertainty and exhaustion in applying zip ties quickly and efficiently throughout the spacecraft. Finding a tool that can quickly apply zip ties while also accommodating the difficulties of space such as gloved hands would benefit operations in reducing the time spent on EVAs by each astronaut. The zip tie installer tool CoRVUS was purpose built with these considerations in mind. The tool provides an ergonomic, reliable, compact, and easy to use solution to the aforementioned problems, capable of deploying up to 10 zip ties per clip. After testing at the Neutral Buoyancy Lab, the tools potential was shown, installing 4 zip ties in the allotted 7 minutes of testing time, with the potential to install more given more time. The testing also allowed the team to identify several flaws in the initial design, most significantly which was the need for more consistency in chambering the next zip tie. This problem could be easily eliminated through further development and the tool could be of great benefit to astronauts on EVA's as a crucial time saving tool where every second saved counts.

II. Nomenclature

NBL - Neutral Buoyancy Laboratory
JSC - Johnson Space Center
OSU - Oklahoma State University
DML - Design and Manufacturing Labs at Oklahoma State University
CoRVUS – Constricting Radius Variable Unpowered System
EVA - Extra-Vehicular Activity

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III. Introduction

This is the report for Oklahoma State University's team CoRVUS for the 2023 Micro-g NExT zip-tie installer challenge. This report will discuss the tool's design, operations, and safety. Additionally, this report will cover testing at the Neutral Buoyancy Laboratory in Houston, Texas, its results, future improvements and plans regarding the tool. Team CoRVUS initially designed this EVA tool to accomplish the parameters laid out by the challenge in October 2022. By the following June, the team had modified, built, and protype many versions of the tool to undergo testing in the NBL. This document covers only the final designs and results of the modifications, for what was physically tested for the challenge in June of 2023.

IV. Design Overview

The goal for the design of CoRVUS was to create a system that could attach zip ties while being used during EVA missions. A crucial factor for the team was to reduce the complications of many moving parts so that the tool would be simple to manufacture while being easy to use and repair if needed. The most obvious and typical design was utilizing a claw to push the zip tie tail into the head during the initial design phase. With a rotating arm to push the tail into the zip tie head that can be easily repeated multiple times. Without the use of electrical mechanisms, the design relied on the manually pushed arm that rotated around an axis. Without many other similar tools existing in the market the team were able to create the CoRVUS tool, over many variations and designs a successful prototype had been produced.

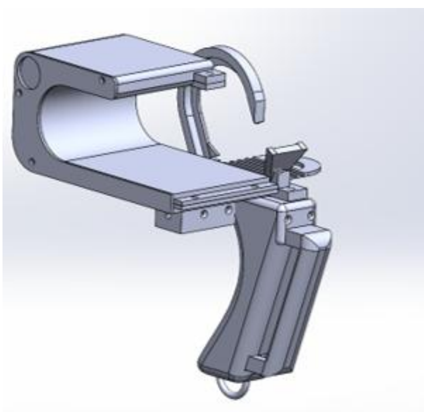

Figure 1. Full Tool Cad,

Figure 2. Diver Operating Tool

Figure 3. Final Prototype of Tool

The photos above show the finality of the design. There is a box on the top of the device with a protruding lever on the side. This box acts as a magazine with a slider inside that holds the zip ties in place. The large lever on the side is rotated towards the front of the device to push the zip tie into tail into the head. *Figure 2* above shows a diver operating the tool. The guide in the front acts as a visual indicator while the claw can be rotated to close around the object being zip tied. The tool is held with a handle at the bottom that also contains the trigger that is used to squeeze the tail during the tightening process. Further details for all these components can be seen below with a blown-out model of the CoRVUS tool.

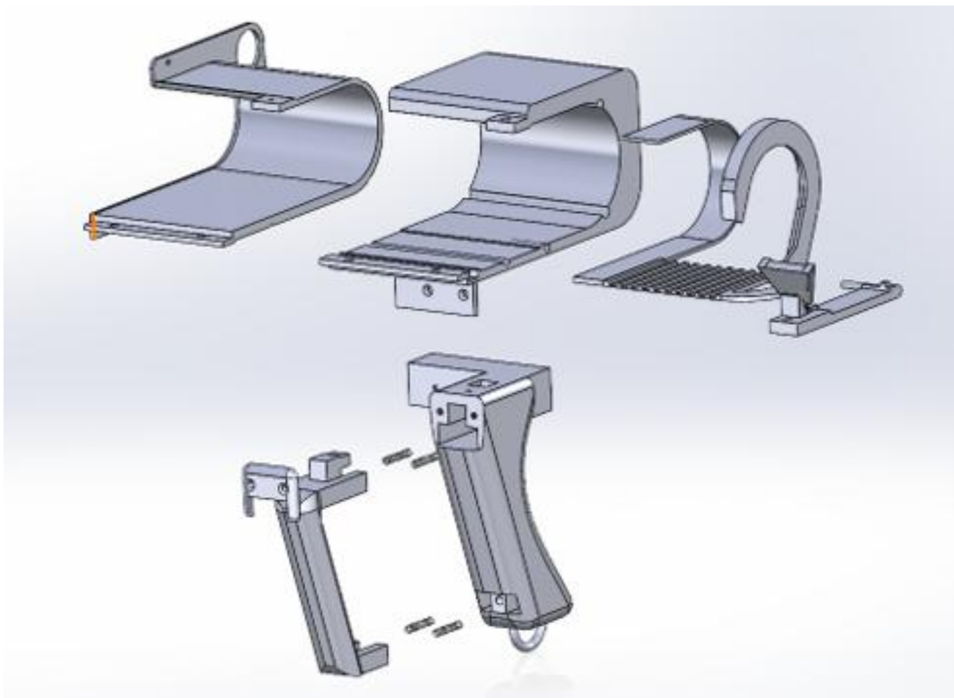

Figure 4. Exploded View of CoRVUS

The exploded view in Figure 4 shows the internals of CoRVUS. It was created entirely from ABS plastic with 3D Printers. Eight parts were printed that were connected using screws. Other additions were the axle on the guide for the zip tie tail, this allowed the claw arm mechanism to rotate freely to move the zip tie tail to the guide and ultimately the head of the zip tie. There is a handle on the bottom of the tool, that simply allows the user to have greater stability on the tool and comfortably squeeze the trigger to hold the zip tie tail while tightening. The magazine has a slider that sits inside with cutouts that hold the base of the zip tie to hold them in place while in the magazine. The slider has a small cut out to allow the user to pull it out to reload the tool after deploying a zip tie.

CoRVUS also needed to be able to maintain a tight grasp on the zip tie tail while being reloaded without the astronaut having to actively pull out the zip tie; to accomplish this, a piece of grip tape/sandpaper was attached to the magazine slider. The original design was to use the zip tie behind it to push the zip tie forward, however the zip ties were causing them to overlap and jam. The redesigned sliding mechanism has the astronaut pull the grip tape/sandpaper. Through testing the team found that this update has fewer issues with jamming without and a reduction in ergonomics when compared with the proposed design.

V. Operations Overview

A. Usage Instructions

C.o.R.V.U.S. is a tool composed of four key mechanical and static parts that allow for operation of the tool. The magazine and handle are static parts, where the trigger and clamping mechanism, with an optional sandpaper pull strip, are mechanical parts that are operated. C.o.R.V.U.S. is very simple to use to install zip-ties around various objects.

Handling the Tool

The first step in the operation of C.o.R.V.U.S. is to properly hold the tool. The operator's palm should be resting on the back of the handle, labeled A, with their thumb on the side of the handle labeled B, as shown in Figure 2. Their fingers should be wrapped around the trigger, where the trigger is facing the object to be zip-tied.

Loading the First Zip Tie

The user must ensure the first zip tie to install is properly aligned with the indented square area for the head of the zip tie. The tail of the zip tie must also be fully removed from the internal of the magazine. If the tail is not visible, the operator may gently pull the sandpaper strip to guide the tail out of the magazine. If the zip tie is properly loaded, the head will be fitted in the indented area, and the tail will be visible and concentric with the clamp.

Clamp Operation

Position the curved area of the tool around the object the operator is to zip tie. Once the tool is in the desired position, push the clamp, labeled D, around the object towards the head of the zip tie. This will guide the tail of the zip tie through the head.

Trigger Operation

The tail of the zip tie should be inserted through the head of the tie at this point. The user may return the clamp to its original position. The operator should then squeeze the trigger with their hand until it is completely flush with the handle.

Tightening the Zip-Tie

The trigger should still be compressed by the operator. While compressing the trigger, pull down and away from the object being zip tied. Ideally, this will tighten the zip tie around the object. Once the tie is tightened, release the trigger and operation for installation of a single zip-tie is complete.

Reloading for Next Installation

Pull the magazine tray one notch to load the next zip tie into place where the previous zip tie was before installation. If the tail of the zip tie is not fully visible and aligned with the c-shaped clamp, gently pull the sandpaper strip until the tail becomes visible.

B. Compliance Matrix

	Criteria	Tool Solution	Requirements Met?
1	The device shall be able to install and tighten a zip tie around an object ranging from 0.5" to 2" in diameter/width.	The C-shape area of the tool is large enough to fit around various objects.	Yes

2	The device shall be able to hold and dispense 10 zip ties.	A magazine was designed large enough to hold and dispense 10 ties.	Yes
3	Teams must supply their own zip ties. For testing, please supply minimum 10, maximum 20.	The proper sized zip-ties were brought.	Yes
4	The device shall be able to pack within a 10” x 10” x 3” volume.	The design was optimized to fit these dimensions by modifying our 3D model, however, the individual parts were unable to fit together to meet this requirement. The tool’s dimensions are 9.4”x5.9”x10.3”	No
5	The total weight of all parts shall be less than 4 lbs.	3D printed with lightweight material with <50% infill	Yes
6	The device shall use only manual power.	Only manually powered components were included.	Yes
7	The device should be capable of one-handed operation, but two-handed operation is acceptable.	A hand must remain on the handle the entire time to keep the tool steady, and one other hand must move the clamping mechanism. It is possible to move the clamping mechanism without touching once pressure is applied from the object being zip-tied.	Sometimes (it is much easier with two handed operation)
8	The device shall be ambidextrous.	There are no major obstructions for operation when using either hand. Improvements could be made to improve left-handed operation.	Yes (Although it is not as comfortable for left-handed operators)
9	The device and any removable components shall have a tether point 1” in diameter.	All removable parts have a tether hole at least 1-in in diameter. When fully assembled there is also a tether loop for the device itself that does not impede usability.	Yes
10	The proposed design shall specify all materials the provided hardware will be made from. The device shall be built for an underwater testing environment at the NBL and must be made from NBL Approved Materials. A waiver may be granted on a case-by-case basis. *	The tool was made up of 3D printed parts from ABS plastic. There were small screws used to secure some parts.	Yes
11	The device shall be operable with EVA gloved hands (like heavy ski gloves)	The handle and trigger were designed large enough to be operated with the EVA gloves.	Yes
12	There shall be no holes or openings which would allow or cause entrapment of fingers on the zip tie installer.	There were no small holes in the design to cause entrapments.	Yes
13	There shall be no sharp edges on the device. Functional sharp edges are acceptable but should be labeled and only exposed during operation	The edges had fillets in their design, therefore reducing the sharpness. Any small sharper edges were sanded down.	Yes
14	Pinch points should be minimized and labeled.	Operations and testing procedures keep fingers away from zip tie loop and divers are informed of all pinch point locations.	Yes
15	Tools shall be designed with drain holes or geometry to allow the free flow of air and water as required to support	All areas with cavities that could hold water have included drain holes to allow the water to easily leave the cavities.	Yes

	submersion and removal to and from the NBL pool		

Table 1. Compliance Matrix

C. Parts and Assembly

After many sets of prototypes, the final C.o.R.V.U.S. tool was finalized to consist of eight parts, with springs, screws, nuts, and bolts to support the components. The trigger is connected to the handle with the trigger holder and screws. The trigger clamps the tail of the zip tie so it can be tightened with a motion performed by the operator. Above the trigger and handle is the magazine and clamping components. Inside the magazine is a slider that assists in holding the zip ties in place within the magazine. This helps to eliminate overlap of the tails. The clamping mechanism both secures the zip tie in the loaded position and is operated to guide the tail of the zip tie into the head. Finally, the sandpaper pull strip acts as friction to pull out the tail of the zip tie in order to become fully loaded.

Aside from the springs, screws, and bolts, every part was 3D printed with ABS plastic. The sandpaper pull strip was added upon arrival at the NBL. By cutting a strip of sandpaper that was brought from OSU, the team found a last-minute solution to inconsistent reloading of the zip ties. ABS was decided to be used because of its durability and safety properties required for testing in the NBL. Overall, the use of ABS plastic was an appropriate choice, because there were no issues with fracturing or cracking with extensive use of the tool. The noncorrosive springs held up during operation. The sandpaper pull strip could have been improved considering it was a last-minute addition. It was hard to install into the tool, yet once secured in place, it resolved our problem.

Bill of Materials

Item No	Part	Description	Qty.
1	Handle	Section connected to the trigger to hold the tool	1
2	Trigger	The trigger can be compressed and returned to its initial position with two springs. The purpose of the trigger is to pull the tail through the head of the zip tie	1
3	Trigger Holder	Secures the trigger in place	1
4	Magazine	Compartment to hold the loaded zip ties	1
5	Magazine Back Plate	Plate to enclose the back of the magazine, and has an anchor point. It slides inside the outer part of the magazine and is secured with screws.	1
6	C-Shaped Clamping Mechanism	Acts as a guide for the loaded zip tie tail to be pushed through the head of the zip tie. It is one of the manually operated parts.	1
7	Magazine Slider	Tray that has notches for the zip tie tails to be held in place with. Can be pulled out as the zip ties are installed one by one	1
8	Sandpaper strip	Can be pulled to provide friction to pull out a zip tie tail if not loaded properly	1
9	Non-Corrosive Springs	Used to restore the trigger back to its original position	4
10	#4 Size Screws	Used to assemble the detachable parts	7
11	Bolts	Used to assemble the detachable parts	3

12	Nuts	Used to secure the bolts	3

Table 2. Bill of Materials

VI. Safety

A. Hazard Analysis Purpose

This analysis described the hazards in operating CoRVUS tool which could lead to personal injury, equipment failure, or experimental failure and provided measures to reduce these risks. The analysis considered the potential consequences of each hazard and the likelihood of occurrence to prevent and mitigate potential hazards from happening during the testing procedures.

B. Hazard Analysis Matrix

To evaluate hazards, the following hazard analysis table was implemented. By cross-referring the severity of a risk to the likelihood it will occur, the team effectively planned for potential malfunctions in the testing of the CoRVUS tool.

See Appendix B for information on these matrices

C. Hazards Evaluated

Pinch Points:

Pinch points inhibit the tool's operation and can lead to personal injury and equipment damage. When a pinch point also contains sharp edges, cuts can occur on the user leading to personal injury. Additionally, when caught in a pinch point, the operator may try to free themselves and damage the equipment involved. As such, pinch points will be eliminated as much as possible during the manufacturing phase by rounding any corners and covering all mechanical components. Any pinch points that cannot be eliminated will be labeled so the operator will be attentive during operation.

Sharp Edges:

Sharp edges create a threat to the user, as direct contact can result in harm to the diver and damage to equipment. 3d printing can create sharp edges after printing. All 3D printed parts had any possible sharp edge sanded down. Any edges that could not be sanded down were marked with red tape and the divers were informed of all possible sharp edges.

Finger Entrapment:

Finger entrapment occurs when a diver's finger or glove gets caught in a small gap, such as a pinch point. This can slow down the efficiency of the mission while the diver has to spend time to themself. The design was made to minimize the number of locations where finger entrapping could occur. All locations where finger entrapment could occur were marked with red tape and the diver was made aware of these locations.

Plastic Fracturing:

3D printing creates parts that are not as strong as the more traditional form of fabrication. Plastic Fracturing can cause debris to spread throughout the NBL and create new sharp edges. To avoid this the structures are designed to be strong enough to withstand the stress they are put under. The plastic we chose was ABS, it is far more durable than PLA and ensures we did not have any fracturing.

Unplanned Potential Energy Release:

If a spring releases all its potential energy at once, it can launch parts off at high velocities that damage the tool and injure the divers. To counteract this, we chose the springs to only have the amount of force required for their operations. Co.R.V.U.S was also designed to ensure that in the case of a malfunction the spring would not be able to dislodge any pieces.

<u>Loading failure:</u>
If Co.R.V.U.S fails to load a new zip tie it could affect the efficiency of testing. To counteract this, we added a de-jamming panel on the right side of the tool that can be removed to deal with any loading failures. The tool was also tested to ensure loading was reliable.

VII. Testing

A. Stillwater, OK

Prior to being shipped to Houston, CoRVUS was extensively tested. These tests were primarily ‘dry’ tests to determine changes to dimensions, as well as to determine any weak points in the design. Examples include the iterative design changes made to the C-shaped clamp, the follower, and the feeding device for the zip tie tail. After making the necessary design and dimension changes for the device to operate while ‘dry’, we moved on to ‘wet’ testing. When in water we observed that the handle had some difficulty clamping onto the zip tie tail but overall performed similarly then it did during dry tests. We concluded that this was because of abrasion on the handle due to continuous use, so we opted to replace the handle with a newly printed one.

B. Houston, TX

Our team arrived at the NBL on June 5th, and we were notified that we were able to make any final changes to our design if it passed a safety inspection before being demonstrated to the diver the following day. We had noticed that the zip ties would occasionally get stuck in the magazine when being pulled out with the tray, causing the zip ties to stack on each other. We were able to mitigate this issue by attaching a piece of waterproof sandpaper to the top of the magazine, allowing the operator to pull on the sandpaper, causing the zip ties to be manually pulled out. We were able to ‘wet’ test this design change in our hotel swimming pool. CoRVUS was tested at the NBL on the morning of June 6th. Prior to this, the tool passed a safety inspection, then a team member walked the diver through the tool’s operation that morning. The diver easily understood the tool’s operation as it was very intuitive and had labels to identify various parts and directions. Once the testing session began, a team member read off a predetermined script as shown below. It consisted of a beginning where the diver was reminded of the various parts of the tool, how to hold it, and how to operate it. After giving the diver instructions on how to operate the tool, the diver was able to use it to tie four zip ties, including twice without any assistance or instructions. However, none of them were able to be fully tightened. This was due to the handle losing its gripping ability due to abrasion and the head of the zip tie would get stuck on the tail feeder.

NBL Diver Script:

This is the script that team CoRVUS prepared prior to testing, to efficiently teach the mechanics of the tool and complete the necessary testing in the limited time provided. This script provides a general outline of what the team planned to attempt during testing, but it is not the full transcript of the back and forth between the team and the diver. As expected, there were some portions of the test that did not go as planned, so alternative instructions had to be given, such as the zip tie escaping the feeder and having to be moved back into place. The team was able to finish the entirety of the testing procedure during the testing allotment.
Chance: Hi I’m Chance Wagner with team Corvus from Oklahoma State University and we will be walking you

through the operation of the Corvus tool. First, I’ll be reviewing the labeled parts of the tool. You will grab the tool with your palm on the back of the handle labeled **A,** with your thumb resting on the side of the handle labeled **B,** and your fingers wrapped around the yellow part of the trigger. The clip is labeled **C**, and the clamp is labeled with the letter **D.** Lastly there is a pull strip on the top of the tool with an arrow pointing towards it.

Diver: Ok I have picked up the tool

Chance: Ensure that a zip tie is loaded by looking to see if there is a zip tie.

Diver: Ok I see a zip tie loaded

Chance: Great, locate an object to be zip tied with the smallest diameter. Ensure the zip tie tail is in line with the zip tie head

--- if the tail is not aligned with the head pull on the magazine slide to ensure the head is aligned with the head. Position the tool so the object is just above the clip labeled C.

Diver: Ok the zip tie is centered in the tool

Chance: Position the tool so object is directly above the clip labeled **C.**

Once in position push the clamp labeled **D** forwards to close the zip tie.

Squeeze the trigger until it is completely flush with the handle, and keep the trigger firmly compressed while pulling down and away from yourself to tighten the zip tie. Release the trigger and pull away once tightened

Chance: To reload the next zip tie pull the **C** labeled clip until the next zip tie head is in the chamber. Then pull the pull strip in the direction of the arrow very gently until one zip tie tail is in line with the zip tie head

Chance: Now find another object to be zip tied

Chance: Now notice the small triangle part, that is the catch designed to enable one handed operation. Position the tool around the object and push the object against the catch to close the clamp around the pipe. If the clamp does not close all the way use your left hand to push to fully close the clamp. Ensure the clamp is fully closed, pushing the tail as far through the head as possible.

Diver: The tail has been feed through the head of the zip tie

Chance: Squeeze and continue compressing the trigger, then pull down and away to tighten as in the previous step.

Diver: Ok the zip tie is fully tightened.

Chance: Let go of the trigger and keep pulling away until the tail is out of the handle.

Diver: Ok the zip tie has been fully removed

Chance: Once again to reload pull the **C** clip until the next zip tie head is chambered. Next pull the pull strip until one more zip tie tail is visible.

Chance: If you're comfortable with it we'd like you to zip tie an object and reload without any instruction to test the ease of use

VIII. Results

A. Brief Overview

Testing of the CoRVUS tool in the Neutral Buoyancy Laboratory was an overall success for the team and helped to reveal some adjustments to ensure a better working tool. During testing, the CoRVUS tool performed very well attaching four zip ties with the allotted time and this was due to the very simple nature of the design. The diver was easily able to use the tool after two attempts and gave us important feedback during testing to adjust and better improve the tool. Testing helped to illustrate an issue with the loading mechanism of the tool that made it hard to load zip ties when in use but could be easily fixed with intervention of the diver as well as issues with tightening the zip tie around objects. With the overall success of the tool and with some minor adjustments to the loading systems to not rely on user intervention and a more reliable tightening mechanism, the next version of the CoRVUS device is guaranteed to be a more efficient and successful EVA tool.

B. Discussion of Tests

Testing began with our operator introducing themselves to the diver and guiding them on hand placement on the tool as well as the locations of different parts of the tool important for testing. The first test consisted of the operator guiding the diver on the steps to load the tool and secure the hook mechanism around a horizontal bar. The first attempt took some time as the diver got comfortable with the tool and adjusted the orientation of the tool to ensure the hook fully enclosed the horizontal bar. In the first attempt the diver had to use two strips of sandpaper that were added to the loading mechanism of the tool to ensure that the zip tie fully left the magazine and was fully loaded before use. In the second attempt the diver was told to use the tool on a vertical pole and was given little instruction. After the first attempt the device showed issues with fully tightening the zip tie once attached to the object, but the diver was able to reliability attach a zip tie to each object. The next two attempts the diver was able to quickly apply zip ties without instructions and answered some premade questions about the tool and its usage during the end of the testing time.

C. Testing Results Table

Operation	Status?	Mitigations
Loading the tool	Partial Success	Two straps were added to aid in loading the tool after use, but some intervention of the diver was needed to fully load the tools in some of other attempts.
Wrapping around objects	Success	Positioning of the tool had some issues in closed spaces
Zip tie tail entering tip tie head	Partial Success	Diver needed to use two hands to fully close the loop
Horizontal Bar Attached	Success	None
Vertical Bar Attached	Success	None
Wire Attachment	Success	none
Enclosed object attachment	Failed	Was not attempted due to the shape of our tool not fitting within the enclose space
Tightening Zip Ties	Partial Success	Zip ties were attached to each object, but issues arise with tightening

Table 3. Testing Results Table

D. Results Reflection

Of all the tools presented during the testing period the CoRVUS tool was notable due to how simplistic the design was when compared to other tools. Many other tools had used ratch style methods to tighten zip ties and folding pieces to stay within the size restrictions. This led to many tools having very long and complicated operational steps during testing where the CoRVUS tool excelled with a simple and fast step leading to the tool performing the best when it came to securing zip ties in the given time. An important aspect when creating the tool was for it to be easy to use for the divers during testing which came true during testing. After two guided attempts the diver was able to use the tool with no assistance and with little issue during testing. Testing in the NBL lead to some observations such as the tool floating while in use, but this issue would not be present during actual use. Overall testing shows with some adjustments made to the loading and tightening mechanism the next CoRVUS tool iteration will be perfect for actual space use with its simple and efficient design.

E. Testing Expectations and Surprises

Going into testing, some issues were expected from previous experiences using the tool and some suprises came during testing, but overall CoRVUS tool performed well in the NBL. The main source of unease before testing were issues with loading zip ties during use as that had been an issue in past protypes. Another small issue was the guide not working fulling causing the tail to miss the head of the zip tie. Once testing started and the diver was guided through the process of using the tool, it was very apparent that the diver fully understood how to use the tool and had no need for guidance from the operators. During testing, loading was an issue at the beginning of the first attempt but with the addition of two sandpaper straps on the tool, it allowed for easier loading for the diver. An unexpected occurrence during the testing was issues with tightening the zip tie once it was fully secured around an object. Later inspection led to the conclusion that the tightening section of the tool needed to be replaced after rigorous use to maintain tightening ability of the tool. There were some issues with alignment of the tool during testing, but the diver was able to mitigate the issues by adjusting the hook shape when securing the tool around an object. A big surprise during testing was that the diver was able to secure zip ties around four objects during the allotted time and gave feedback while using the tool about the ergonomics of the tool and some small changes that could be made.

IX. Future Improvements and Changes, Conclusion

A. Brief Overview

Testing of CoRVUS in the NBL provided essential feedback on problem areas that could be improved for diver usage, as well as elements that worked better than expected in the hands of the diver. The fundamental design of the tool worked as intended wonderfully and was able to install four zip ties in the testing time, however a great deal of diver intervention was required to fix several malfunctions mid test. Improvements would center around improving consistency and mitigating malfunctions when in operation, providing a more seamless experience for the user.

B. Discussion of Improvements

1. Sandpaper Pull Strip

The latest addition to CoRVUS occurred less than 24 hours before testing. While experimenting with chambering subsequent zip ties, it was discovered that a small strip of sandpaper inside the top section of the magazine could drastically help improve the success rate of chambering another zip tie. The tails would always have more trouble coming out of the magazine, and by pulling this strip it would help guide each tail out to be in alignment with the rest of the zip tie. This strip can be seen in action in the figure below as the diver grabs on to it to guide a zip tie tail out.

Figure 5. Sandpaper Strip

The first iteration was made of standard sandpaper, but later that night the team purchased some wet sanding paper which would be better suited to underwater testing. Although the wet sandpaper could endure testing, it was torn slightly after testing, and any further use would likely cause it to tear. Improvements to this feature would revolve around improving material selection. There seems to be a plethora of waterproof sandpaper options available online which could hold up far better than the sandpaper bought last minute at a hardware store. Additionally, rubber, or any other material with sufficiently high friction would also be capable of pulling the tails and rubber would have the added benefit of better durability than paper.

2. Handle/Trigger

Although 4 zip ties were deployed in testing, none of them were fully sinched around the object. The tail would always slip out of the clamping mechanism before the zip tie would tighten all the way. In testing the trigger seemed more than capable of clamping a tail enough to fully hold it, but when a diver who has never operated the tool before, who is in a bulky suit, with limited visibility uses the trigger, they aren't able to make sure the tail is fully pushed through the head. All they have to go off is it seems like it's more or less pushed through. This is an oversight that an improved design of the trigger could compensate for. The first improvement would be to shrink the space between the zip tie head, and the trigger section that grabs onto the tail. Currently there is about half an inch of extra space above the trigger that with improved designs could be eliminated, allowing an extra half inch of the zip tie tail to be grabbed onto for a more secure grasp. The second improvement of the trigger would be covering the part that clamps the zip tie in grip tape to increase the friction holding the zip tie in when clamped. Alternatively, this could be accomplished by having one or several small spikes that would press into the zip tie tail when compressed, which would ultimately have a similar effect of holding the zip tie tail more forcefully.

3. Storage Dimensions

Upon measuring the dimensions of the final tool, it was discovered the tool measures 9.4x10.3x5.9 inches which lies outside the required 10x10x3 inch dimensions. The 10.3 inches could easily be shrunk to fit to 10 inches by slightly decreasing height of the trigger. The 5.9 inches would be a little more difficult to shrink to 3 inches and for orientation purposes is the dimension running parallel to where an object to be zip tied would be inserted. The best place to begin trying to shrink this size would be to reduce the width of the spacers in the clip separating zip ties. The spacers on the clip can be seen in the figure below. The width of the follower at the end of the clip could also be reduced, however a stronger material than ABS may need to be used in this case since the follower does need to withstand a decent amount of pulling force. Lastly the tab on the end of the clip could be vastly shrunk and would shave off several inches. Once these changes to shrink the clip size occur, the width of the magazine could be shrunk accordingly, and the tool would then hopefully fit within the needed dimensions.

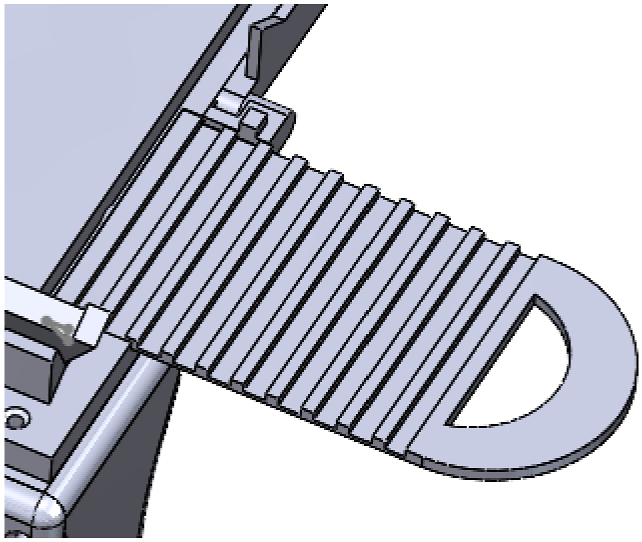

Figure 6. Clip Spacers

4. Minor Improvements

The only minor improvement noticeably needed is an increased structural integrity of certain parts. Although luckily nothing broke during testing, there were several parts throughout the year that snapped during testing, and even a part broke off the day before testing that had to be super glued back on. Small changes like thickening or re-dimensioning certain parts could increase their survivability and durability. Printing these problem parts on the carbon fiber nylon printers our school has available could also greatly increase their material strength.

C. Conclusion

CoRVUS performed at and above the team's expectations for a simulated real-world scenario. Testing gave team members many new and inventive ideas that could be implemented if work on this project were to continue. Seeing a former astronaut diver use this tool with all the limitations, but also experience they brought to the table truly gave an idea of how this tool might work in the hands of astronauts in space. Seeing where the tool struggled was as valuable as seeing it succeed. After testing everyone on the team all had new and inventive ideas on how to solve these problems and this newfound drive to keep improving and reiterating each and every fault. Not only testing but interacting and collaborating with other teams served as sources of inspiration for improving the tool. Other teams would describe their tool and it would give a completely new perspective on the problem somebody else might have been struggling with all semester and gave new, alternate ideas to explore. Testing, and the entire NBL trip was an incredible experience which provided so much feedback and new ideas for the tool. The team's only regret is they don't have even more time to implement these changes into CoRVUS to see how much better of a tool it can become.

X. Appendices

A. Social Media and PR Link

https://www.facebook.com/ZerogeePete/
https://www.instagram.com/microg_teamcorvus/

B. Hazard Tables

Appendix Table 1. Consequences Table

Consequence Class	Description
I	**Catastrophic** A condition that may cause death or permanently disabling injury, facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission; schedule slippage causing launch window to be missed; cost overrun greater than 50% of planned cost.
II	**Critical** A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, or flight hardware; schedule slippage causing launch date to be missed; cost overrun between 15% and not exceeding 50% of planned cost.
III	**Moderate** A condition that may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or flight hardware; internal schedule slip that does not impact launch date; cost overrun between 2% and not exceeding 15% of planned cost.
IV	**Negligible** A condition that could cause the need for minor first-aid treatment but would not adversely affect personal safety or health; damage to facilities, equipment, or flight hardware more than normal wear and tear level; internal schedule slip that does not impact internal development milestones; cost overrun less than 2% of planned cost.

Appendix Table 2. Probability Table

Hazard	Cause	Effect	Consequence	Likelihood	RAC	Controls
Pinch Points	System Design	Personal Injury, Equipment Damage	III	C	4	Safety Regulations, Rounded Corners, Training, Protective Coverings
Sharp Edges	System Design	Personal Injury	III	D	5	Safety Regulations, Rounded Corners, Protective Covering
Entrapping Fingers	Operation Error	Personal Injury	III	C	4	Safety Regulations, Training, Protective Covering
Plastic Fracturing	System failure	Personal Injury, Equipment Damage	III	C	4	Safety Regulations, Training

Toxic ABS Fumes	Manufacturing	Personal Injury	II	D	4	Safety Regulations
Unplanned Potential Energy Released	System Failure	Personal Injury, Equipment Damage	IV	D	5	Safety Regulations, Protective Covering
Locking Failure	System Failure	Equipment damage	IV	C	4	Safety Regulation, Training

Letter	Description
A	**Likely** to occur (e.g., probability > 0.1).
B	**Probably** will occur (e.g., 0.1 ≥ probability > 0.01).
C	**May** occur (e.g., 0.01 ≥ probability > 0.001).
D	**Unlikely** to occur (e.g., 0.001 ≥ probability > 0.000001).
E	**Improbable** (e.g., 0.000001 ≥ probability).

Appendix Table 3. Risk Matrix

Consequence Class	Likelihood Estimate				
	A	B	C	D	E
I	1	1	2	3	4
II	1	2	3	4	5
III	2	3	4	5	6
IV	3	4	5	6	7

XI. Acknowledgements

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