Lunar Flagpole Challenge

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I. Abstract

The Lunar Flagpole designed by the Grand Valley State University Astro Anchors is a modular and mechanically simple design, allowing for intuitive assembly and compact storage. The flagpole is composed of four main parts: the anchoring system, the telescoping flag pole, and two extension pieces, one of which acts as a handle for driving the anchoring system into the ground. The device has been designed such that no additional tools are necessary for assembly. The device weighs a total of 8.65 pounds, with 4.65 pounds of that coming from the anchoring system. The flag stands right at 8 feet tall once fully assembled and allows a flag to remain unfurled in the absence of wind. The flagpole remains secured in the ground due to an auger and baseplate system, which resists both axial and lateral movement, respectively. Each pole segment is connected via a push-and-twist coupling mechanism. The flag is unfurled using a hanger system, which aids in speedy deployment. The flagpole's functionality was tested in NASA's Neutral Buoyancy Lab (NBL) in Texas, and live communication with the diver occurs via onsite communication systems. At the testing site 40 feet under the pool's surface, the diver was able to successfully deploy the flag within the 10-minute time limit. The testing of the device showcased its intuitive assembly and unique design choices. Improvements to the design that will be considered include improving the ergonomics during the anchoring process, adjusting the coupler design to be easier to connect, and adding more visual markings on the device to indicate when mechanical actions are completed.

II. Introduction

This paper addresses a challenge that NASA faces with its upcoming Artemis program which involves lunar missions. The goal of the Lunar Flag Challenge is to develop a flagpole and anchoring system that can be easily assembled and deployed by a fully suited astronaut on the surface of the moon from a stowed configuration in under 10 minutes. The assembly must be lightweight, dust tolerant, withstand axial and lateral forces, and satisfy imposed dimensional requirements both in deployed and stowed configurations. With the upcoming Artemis missions, NASA plans to send astronauts back to the Moon. Although not a mission-critical component, the U.S. flag holds immense symbolic significance. When American astronauts first set foot on the Moon, they planted the flag to signify this historic achievement. The flags deployed were the height of the astronaut and were secured using a garden-stake-like method. With this challenge, the Astro Anchors design a taller and more robust flagpole that remains easy to deploy.

III. Phase I

A. Brainstorming

The Astro Anchors team began the design process for Phase 1 by reviewing the specifications provided by the NASA Micro-g NExT challenge owners shown in Table 1 located in Appendix A. The team identified key features required for the flagpole design including, an anchoring system, stowable pole sections, and flag mounting. Specifications that constrain the size, and mass of the flagpole as a whole as well as its sections were the focus

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points of the brainstorming phase. As a design was selected to move forward with the ideation, and the following phases focused on the list of specifications was expanded until the team's design met all of the requirements.

B. Ideation and Initial Design

Initially, the team was split into small groups, each tasked with brainstorming ideas for a section of the flagpole rotating every 20 minutes. The groups met together deciding on the idea to move forward with. From these sessions, several stood out and were considered. For the main pole sections three ideas were discussed, a telescoping mechanism, a twist and lock coupling mechanism, and a system that would use tensioned cords similar to tent poles. Ultimately the coupling mechanism was chosen to attach sections of tubing due to its strength and simplicity of design and use. When discussing the anchoring system two ideas were highlighted which include garden stakes and an auger with a baseplate. The auger was selected because of its potential for better performance in lateral and axial stability over the garden stakes.

C. Proposed Design

The proposed design that was created during the first phase of the NASA Micro-g NExT competition was made of four primary features: an anchoring base, the anchor installation process, pole segments with locking couplers, and the flag deployment process.

The base anchoring system comprised a baseplate to provide lateral support, an anchor to provide axial support, and a bearing surface to allow the baseplate to spin freely from the auger. Additionally, spikes were to be welded to the base plate to increase the lateral support of the device while installed on the lunar surface. The design of the anchor was that of an auger to allow for minimal resistance during insertion into the ground, while the taper increases the axial support provided to the device.

Figure 1. Overview of flagpole

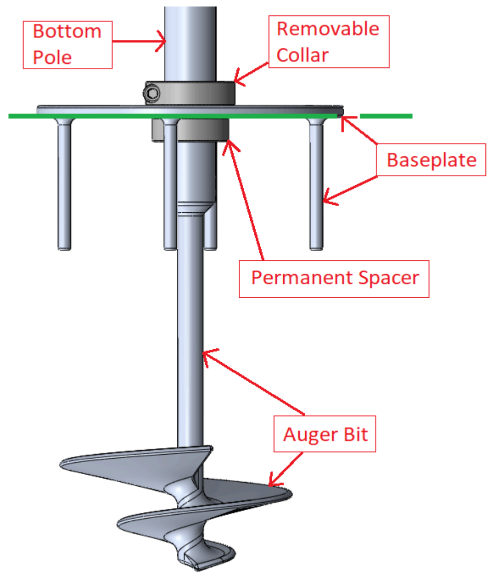

Figure 2. Anchoring system

The anchor was to be installed into the ground using a square torque application point (Figure 4) on the base anchor component in conjunction with a pole segment that has a matching square opening, allowing for easy connection and disconnection during the anchoring process. The installed pole segment was used as a handle to rotate the anchor, driving it into the ground. This pole segment was then removed and reused in the assembly of the flagpole.

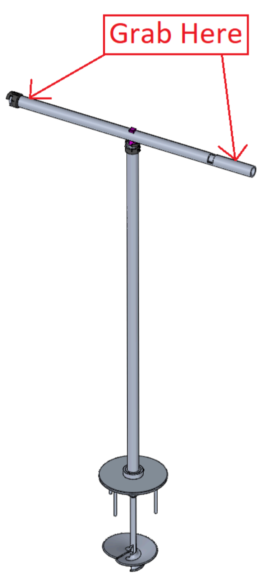

Figure 3. T-shaped handle for auger installation

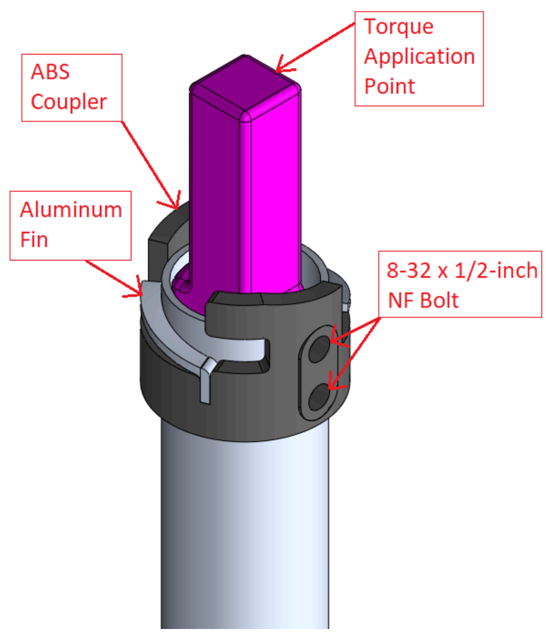

Figure 4. Torque application point sub-assembly

Each pole segment was connected in series using a twist-and-lock coupler design, which made use of spring steel fins to allow for each pole segment to lock into position during installation. The design was comprised of five pole segments in total, one at the base of the device with the aforementioned anchoring device, two 3ft segments with couplers on each end, one 3 ft segment with one coupler rotated at 90 degrees (see Figure X), and finally on 2-ft segment with the square opening for anchor installation. The modular design of the device allows for a minimal footprint while packed (Figure 7) while also minimizing complexity during assembly.

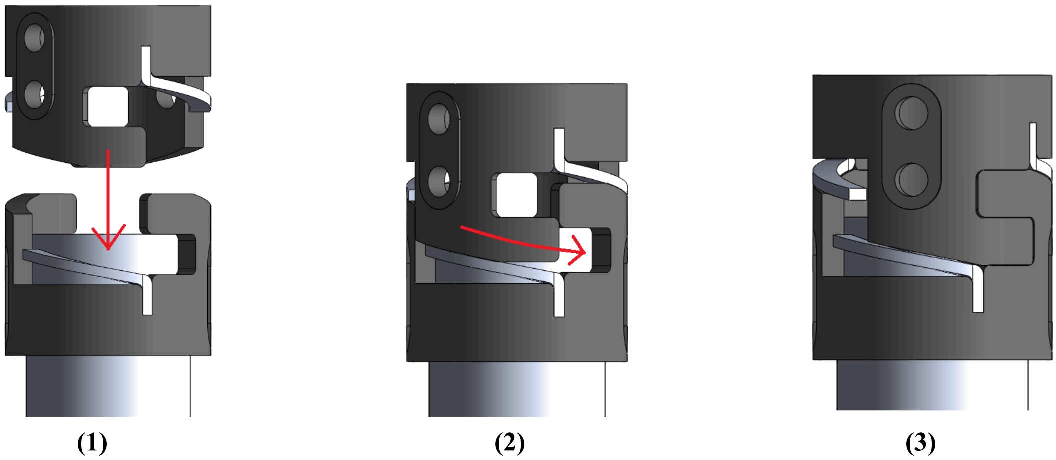

Figure 5. Twist-and-lock coupler design

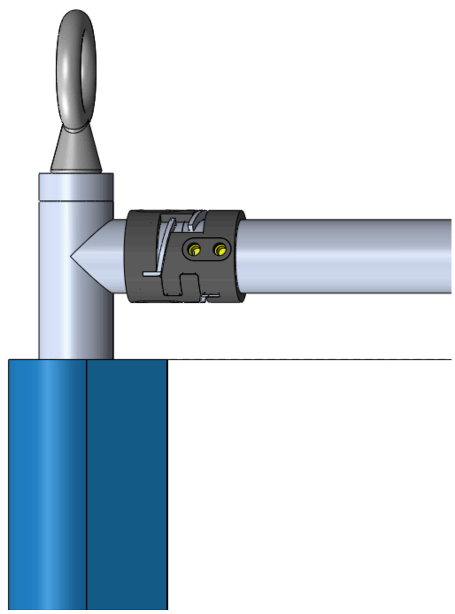

Figure 6. 90-degree pole segment with twist-and-lock coupler

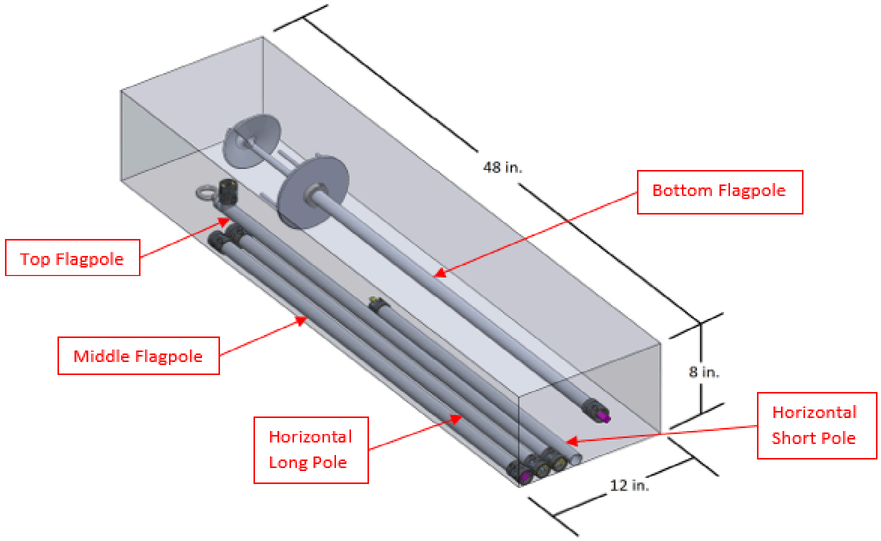

Figure 7. Disassembled flagpole device stowed within required 48” x 12” x 8” container

The flag deployment was accomplished by extending the flag, which was sewn onto the 90-degree pole segment, On the distal end of the flag, a ring is attached, which once the flag is fully extended, sits in a recess on the final pole segment.

IV. Phase II

The initial auger design, shown in Figure xx, was 3D printed and tested early on during this challenge. However, these tests revealed several issues with this auger. First, the auger was difficult to get into the ground. During the test shown in Figure A-2, the auger was only able to be installed around 4 inches into the ground before becoming difficult. This did not work with the overall design of the anchoring system and the force requirements of this challenge. Additionally, this 3D-printed auger was weak; during testing the plastic broke and was unable to be repaired. While the plan previously had been to cast the auger from aluminum in-house, the logistics of this, combined with the cost, led to looking into premade auger options. Shown below in Figure 8 is the first purchased auger.

Figure 8. First tested auger

Initial tests using this auger showed promising results, with pullout resistances ranging from 10 to 20 pounds. To get a better sample of other existing products, another anchor was purchased around the same time. This occurred because, while the initially purchased auger met the requirements, the goal was to create an anchoring system that exceeded all the requirements. For the second auger tested, a completely different design, shown below in Figure 9, was acquired.

Figure 9. Second tested auger

This auger was tested because the surface area seemed as though it might be greater than the first tested anger, which could lead to increased pullout resistance. However, this auger performed similarly in testing, so no formal decision was made as to which auger was the best. Both of these augers were tested in dry play sand, which is what was thought to be the most comparable to the NBL lunar simulant. However, in mid-April, it was learned that using wet play sand was a more accurate representation of the conditions of the NBL, so testing switched to utilizing that. The two premade auger designs met the requirements while using dry sand, but when wet sand was used for testing, it was not as reliable for resistance to axial forces. The old auger designs would both pull out of the ground at anywhere from 5 pounds to 12 pounds of upward force. These results prompted another design iteration of the auger. The goal with the next auger design was to maximize the amount of surface area that would be directly underneath the sand, hence the wide flight design shown in Figure 10. Both the auger shown, as well as a wider auger of similar style were tested and compared. The wider auger was difficult to get into the ground and provided less aid to lateral stability, thus, the smaller auger was chosen. With this auger, the entire bucket of wet sand could be lifted once fully installed, easily passing the 10-pound axial force requirement. To make this auger feasible for use in the design, the long "stem" had to be removed, as shown below in Figure 10.

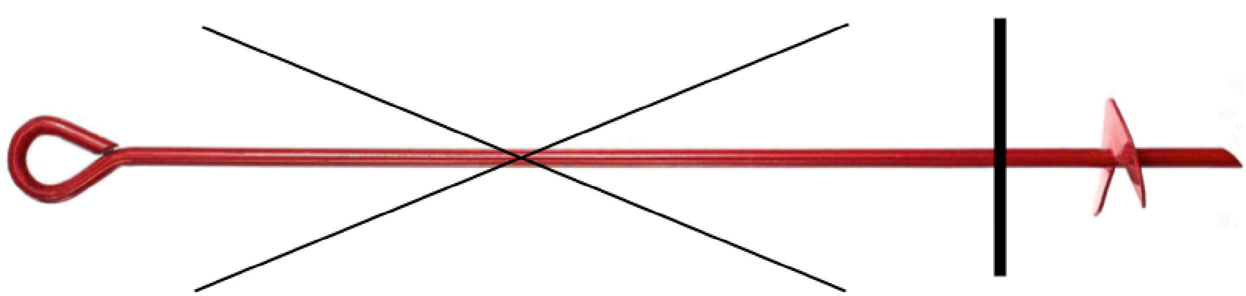

Figure 10. Final auger design

Happening concurrently with auger testing was the prototyping of the coupling mechanism of the device. The prototypes created were 3D printed from ABS and attached to wooden rods to get a rough understanding of what changes may be necessary. One quickly apparent issue was the quality of the 3D print. Since the design for the coupling mechanism required tight tolerances, low-fidelity 3D printing would not be a viable method for creating these couplers. Additionally, the ABS coupler proved to be fragile, as it would consistently snap during testing. To combat these issues, a resin 3D printer was used to improve both the quality and strength of the printed couplers. Additionally, in the initial design, both couplers had the same design and length. However, this caused the connection point to be unstable at the seam. Consequently, one coupler from each pair was extended by 1.5 inches while moving its connecting coupler down by the same amount. This allows for the entire shaft of the coupler to encompass the meeting edge between pole segments, ensuring a tight and stable fit. The first iteration of the elongated coupler connection is shown below in Figure 12.

Figure 11. Resin coupler

Figure 12. Resin couplers connected

These prints worked considerably better due to the increased print quality. This allowed for the couplers to fit together as originally planned, giving way to better testing capabilities. These resin-printed couplers were still fragile, so the decision was made to have them fabricated from aluminum. Another issue with the resin prints was that they were flexible, which allowed for major deflection between pole segments, as shown below in Figure 13. In the original design, a small fin was planned to be used, indicated in Figure 3, to apply a force to lock the couplers together. Once the resin couplers were made, these tabs proved to be problematic in several aspects. First, they were difficult to produce due to their small size. Their thinness, only 1/16 of an inch, meant that they did not apply nearly enough force to reliably lock the coupler together. The method of attaching these fins to the couplers was also unknown at this time.

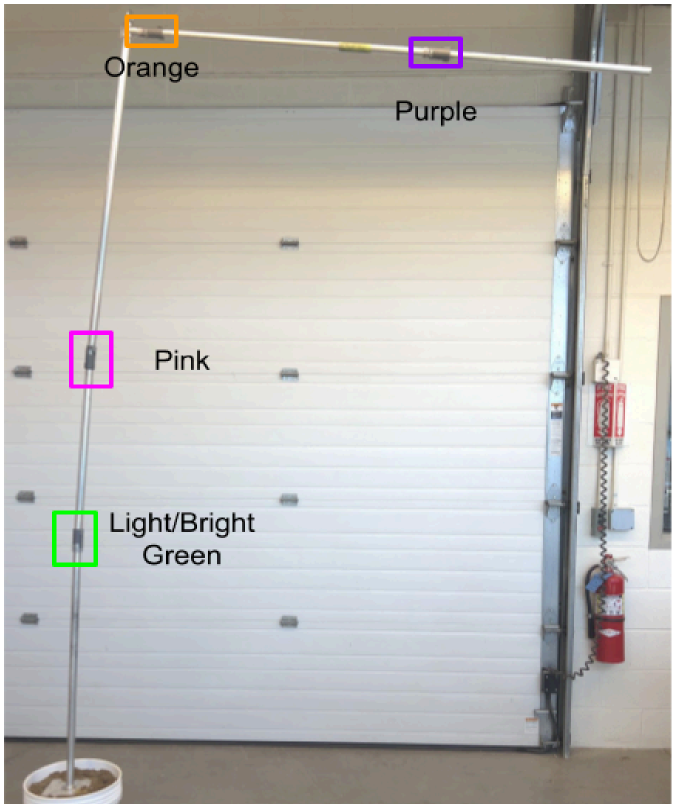

Figure 13. Deflection of pole segments while using resin couplers

These factors culminated in a decision to redesign the couplers to instead be an interference fitting lock rather than the tab lock. The redesigned couplers were a simpler shape than the original, allowing for the final couplers to be made manually from aluminum. The figure below shows the final coupler design, still using the same twist-and-lock coupler design as in our initial design.

Figure 14. Final twist-and-lock couplers

Initially, the goal was for there to be a 0.005-inch interference between the two coupler tabs. In addition to the slight interference between the coupler tabs, the opposite side of the coupler is indented slightly so that the tab can be pushed down to achieve the locking fit. This relatively high interference made the couplers difficult to twist together. It was decided that easier-to-put-together couplers were more important than a super secure fit, so the locking mechanism was toleranced down so that there was less interference. This adjustment was made using a hand-file, so no exact measurements can be given. This simpler redesign, combined with being made from aluminum, means that these couplers are easy to manufacture, decrease deflection greatly between pole segments, and hold up during testing without breaking. In the final flagpole, one of the couplers used was made out of a 3D-printed carbon fiber Onyx filament due to time constraints. This caused significantly more deflection in the corresponding connection, indicated below in Figure 15.

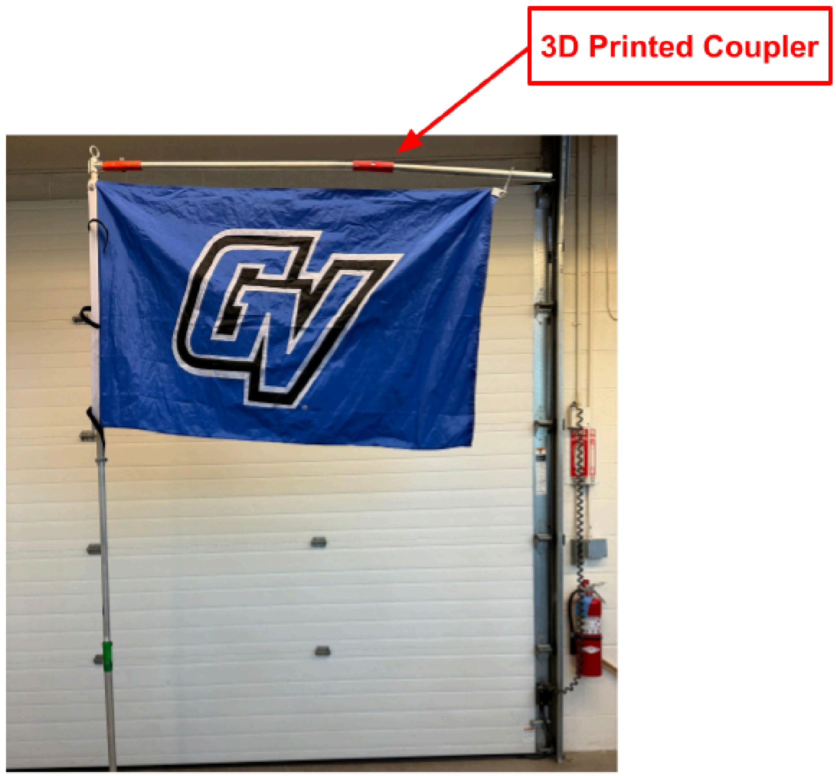

Figure 15. Deflection caused by non-aluminum coupler

Until mid-April, the initial plan of having five distinct pole segments had not changed. During testing, it was apparent that this created several logistics issues with the operations plan assembly of the device. These issues included the possibility of the flag touching the ground as well as the user struggling to build the flagpole at the required height. With this, a substantial redesign of the top pole segment was conceived in which the top 3 feet of height required would be achieved using a telescopic extension.

The extending mechanism was designed with the notion that it had to be mechanically simple and easy to operate. Photos of the final design are shown below.

Figure 16. Telescoping slot

A simple slot was cut into a pole with a 1-inch outer diameter. Surrounding this was another pole with an inner diameter of slightly larger than 1 inch. This tight fit was to limit deflection between the telescoping poles. The outer pole had a small bolt secured to it to ride through the slot. At each end of the slot, a locking feature was cut. The locking feature at the bottom was to ensure that the inner pole did not slide out accidentally during the assembly of the device, it is also designed to stay locked in its natural resting position and unlock with the coupling motion. The top locking feature was to catch the bolt to keep the flag at its required height.

For lateral stability, the original design utilized screws as stabilizing legs that would provide a surface to oppose the displacement of the sand. Testing found that this was not a suitable design for the flagpole to maintain stability. These stabilizing legs are indicated in the figure below.

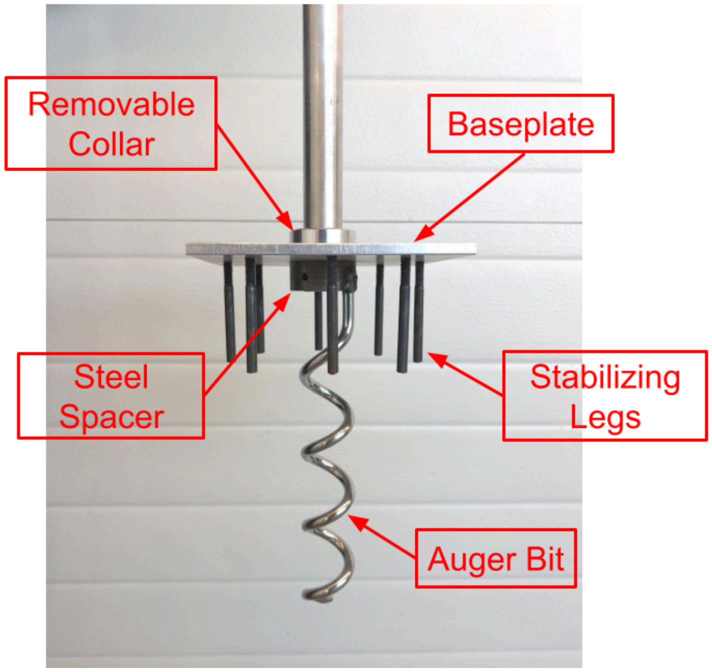

Figure 17. Anchoring system prototype

Still utilizing the baseplate, different fins and plates were tested to achieve the most effective lateral stabilizer. It was found that plates attached to the edges of the baseplate were the best solution to the lateral stability issue. To better test this idea, small steel shovels were purchased to provide a better profile as the anchoring system was installed into the ground over the previous rectangular aluminum plates. These shovels not only added more surface area pushing on the sand, but they were also slightly pointed which allowed them to be driven into the ground with less force. It was found that the steel shovels added too much weight to the overall design. The decision was then made to manufacture the shovels out of aluminum, so they were approximately half the weight of the steel shovels. The aluminum shovels were designed to be larger than the original steel shovels because they would provide more surface area to push back on the sand. The final aluminum shovels are shown in the figure below.

Figure 18. Final anchoring system

A major change made from the original design to the design tested in the pool was how the flag was attached to the flagpole and how it was then unfurled. Originally, the flag was to be connected to the topmost vertical flagpole segment using additional fabric sewn onto it in a tight-fitting loop. Then the top corner of the flag would have a small fabric loop to allow the flag to be stretched across the horizontal pole segments. It was decided that the protocol for utilizing the American flag would be followed (not altering the flag), so the flag attachment was approached differently. The final design for the flag attachment and extension method is shown below in Figures 19 and 20.

Figure 19. Flag attachment onto the top vertical pole

Figure 20. Flag hanger for extension

Using the grommets found on many flags, steel conduit hangers are rigidly attached to the vertical pole segment and the flag without additional manufacturing. Additionally, velcro straps are wrapped around both the vertical pole as well as the flag itself. These velcro straps ensure that the flag remains condensed to the pole during assembly while making it easy to free the user. An aluminum hanger is used to extend across the horizontal pole segments. Created from a sheet of aluminum, a hole was cut out large enough to easily fit over the horizontal pole segments and couplers. The hanger is clamped onto the top right corner of the flag to ensure the flag never slips out during or after deployment.

V. Test Week at the Neutral Buoyancy Lab

In June, the flagpole design was tested at NASA's Neutral Buoyancy Lab (NBL) in Houston, TX, to simulate the lunar environment. Once the device arrived at the NBL test bay, the Grand Valley State University Astro Anchors team verified that the flagpole shipped without damage and was properly functioning. The flagpole was subject to a QSAR quality and safety review to assess the device's safety and approve it for use in the NBL. The flagpole had a few sharp edges on the couplers that needed to be filed. After filing the edges and ensuring no more sharp corners or edges, the flagpole passed the QSAR and was approved for testing in the pool. Before testing, the GVSU Astro Anchors demonstrated an overview of the operations plan to the team of divers responsible for testing the device. The divers appreciated the simplicity of the operations plan and the flagpole design. They liked that the flagpole pieces fit together all the same way, with a push and twist motion, "like LEGOs." Before testing, the team anticipated that the long handle for anchoring the flagpole might be slightly long and would need to be shortened to make the experience easier for the user. It was also anticipated that the couplers on the last flagpole piece would be more fragile due to them being made out of carbon fiber Onyx filament rather than aluminum, due to lack of manufacturing time.

Testing in the NBL pool went according to the operations plan outlined in Appendix B. Communication with the diver to perform the operations plan was carried out via the NBL control room. Team lead Scott Strayer verbally communicated the operations plan to the divers, communicating the proper actions necessary for the diver to correctly install the flagpole and use the device. The testing session overall went according to plan, and the flagpole worked as intended. Several small pauses occurred due to a lack of time to get familiar with the design, such as when the diver was rotating the handle to drive the auger into the ground. It was not made clear to the diver beforehand that the baseplate spun freely from the auger, so there was a pause as that was communicated. Additionally, the diver was instructed to apply pressure to the baseplate to aid in driving the anchoring system further into the ground. This proved effective but slightly awkward as the diver's air cord got slightly caught in the rotating handle. After the anchoring system was installed, no major problems occurred. There was a slight difficulty getting the final piece of the horizontal pole segment installed, but this was due to the material being the carbon fiber composite. Because of this, the coupler flexed during the connection, hindering the speed at which the diver could assemble it.

Overall, the testing was a success. The diver was able to easily anchor the flagpole, connect the flagpole pieces, and extend the flag with minimal difficulty. The flagpole extended to just over 8 ft tall, and the flag was fully extended within the allowed 10 minutes of operation. The flagpole was easily able to withstand a 10lb axial force pulling upwards, with little to no movement from the anchor. Feedback from the divers was equally as important as proving the design functioned as intended. After the testing session, the diver rated their experience with using the flagpole. They said that the frustration level and difficulty for the operations of the flagpole were very low. Overall, the diver commented that the operations of the flagpole were easy and simple. However, important feedback for future design iterations was received as well. The diver commented that the anchoring system took more effort to twist into the ground than other operations of the flagpole, but that it was not overly demanding. They mentioned that the handle for anchoring the flag could benefit from being shorter because the longer length of the handle required the diver to step backward into a slightly bent-over position, which is not ideal for the diver or a future astronaut. This was already an issue the team had anticipated and planned to fix in the future. They also mentioned that extra grips on the handle could improve their hold on the handle and aid in anchoring the flag. The diver also noted that the height of the anchoring system was low to the ground, causing the diver to have to bend over, so the flagpole could be improved by making this section taller. The diver mentioned that the couplers were mostly easy to use but were difficult trying to line up and secure into place sometimes. They said that a new coupler design that involves a ramped or curved slot with a locking mechanism, to ensure the coupler easily slots into place and cannot become undone, would be very beneficial and greatly improve the usability and efficiency of the flagpole design. This was very important feedback that is will be implemented in future design iterations. The team had anticipated that the couplers might need more improvement to be more user-friendly, and this feedback will be crucial for making those necessary improvements. The diver also mentioned that it would be beneficial to have clearer markings for telescoping the flagpole to know when to stop pushing the flag upwards and where to turn to lock the flag in place. Overall, the diver expressed that the device felt very safe and simple to use, and testing the flagpole was a success. The figures below show photos of the testing session.

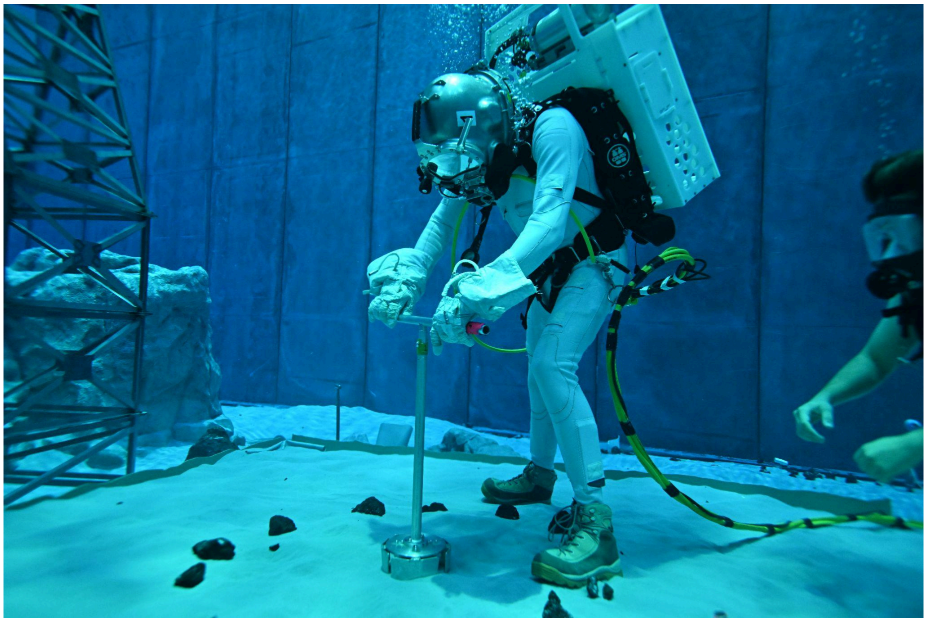

Figure 21. The diver secures the anchoring system at the bottom of the NBL pool

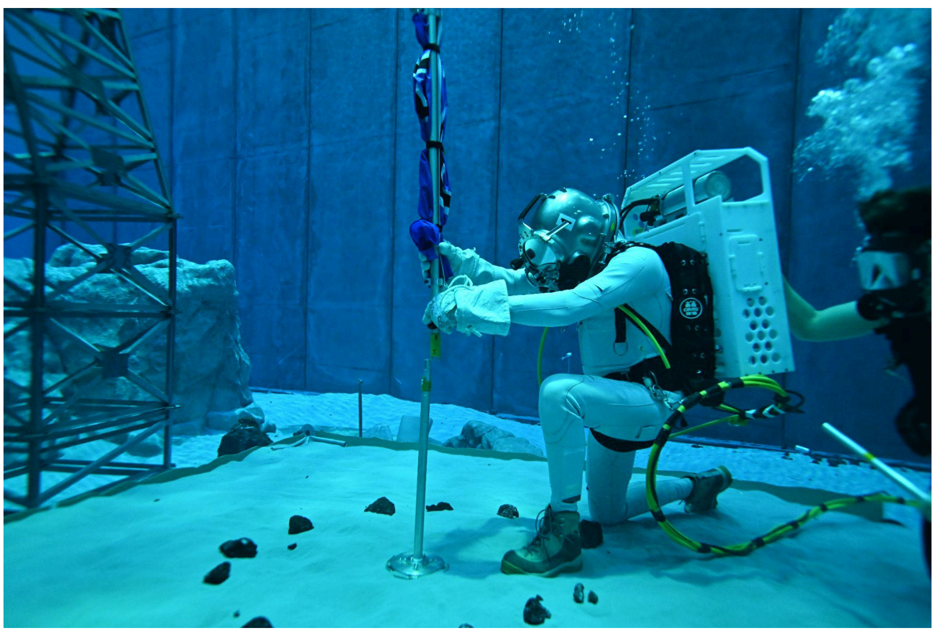

Figure 22. The diver connects two flagpole segments.

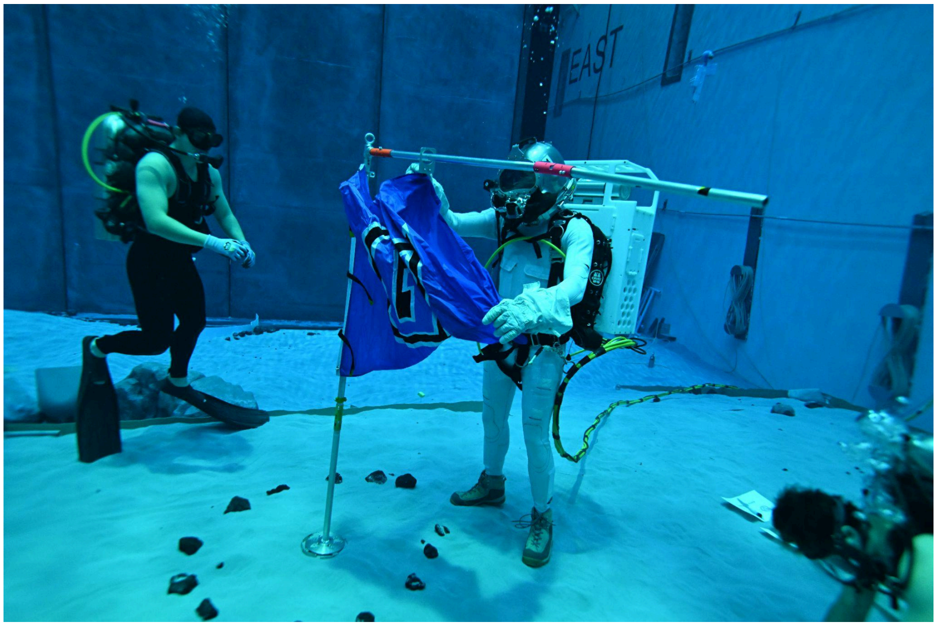

Figure 23. The diver extends the GVSU flag

Figure 24. The diver fully extends the completed flagpole

VI. Beyond Test Week

Based on feedback from the divers and issues that arose during the manufacturing of the flagpole, there would be several changes necessary to make the device better for Lunar deployment. Several overall changes would occur to the lunar flagpole. One such change is to include markings on the device to indicate when actions are completed, such as connecting couplers or extending the telescopic pole. This will allow the user to gain immediate feedback on the assembly action that they are undertaking. Another general change for the device would include streamlining and improving the manufacturing process to have more stable and logical connections and interfaces. This would improve the user's understanding of the flagpole while increasing repairability if a piece were to break.

One of the more time-consuming changes lies in the pole segment lengths. While the device presented was able to be assembled, there was feedback on the ease of several aspects. The handle used to rotate the anchoring system is slightly longer than what would be comfortable. Additionally, the bottom pole segment is at a height at which the diver had to uncomfortably bend over during the auger installation. While these are not large changes, adjusting these lengths would have a cascading effect on the other pole segments' lengths due to the overall size requirements of the pole. These pole length changes would take trial and error to identify the perfect sizes for a wide range of astronauts.

The coupling mechanism would also require changes for higher assembly efficiency. The diver stated that there were several small issues with the current design of the coupling mechanism. First, to aid in the alignment of the coupler tabs, A sloped tab would be implemented to help naturally guide connecting couplers together, as shown in Figure xx. Additionally, the poles themselves would be given some texture, possibly knurling, to allow the user to have a better grip on the poles while actuating the twisting motion with the couplers. The coupler's locking mechanism would also be improved to have them remain easy to twist together while preventing accidental unlocking.

Another change would be to the flag extension system; it was found that the flag hanger did not provide a feedback mechanism that confirmed the flag was fully extended, and because the flag hanger was placed into a slot, it was not securely attached to the horizontal flagpole segment in the presence of microgravity. This issue could be improved by adding a locking slot mechanism, comparable to that on the telescoping pole segment, preventing the flag hanger from floating upwards, as well as providing a stopping point where the astronaut can identify the full extension of the flag.

The T-joint (Figure 3) created for the anchoring system installation was also considered a weak point in the design. The interfacing between the square torque application point and the square cut-out in the horizontal pole section allowed for the handle to slip off of the anchoring system. A deeper cut-out in the handle with tighter tolerancing on the square extrusion would prevent the horizontal segment from slipping off the anchoring system.

Several aspects of the design highlight its capabilities of being usable on the Moon. First, its lightweight and modular design would allow the astronauts great maneuverability during assembly with little strain. Additionally, the standard size poles utilized (1" OD) allow for preexisting holding mechanisms to be used during transportation. One such example includes the cart shown below, used for carrying tools with similar structures.

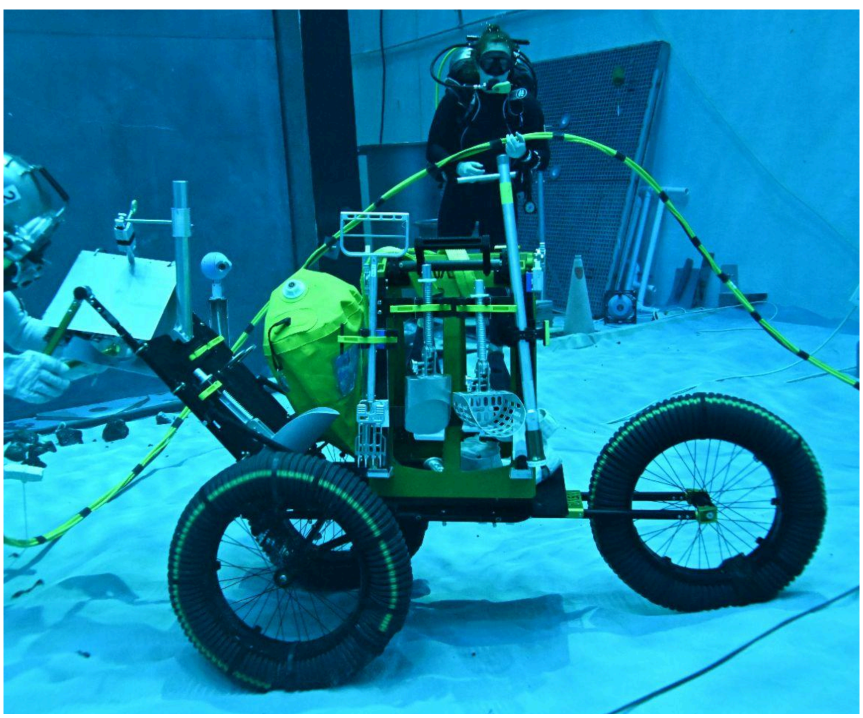

Figure 25. Cart to potentially carry flagpole

VIII. Outreach

In addition to the project work, the team strongly emphasized educational outreach to share their experiences and inspire the next generation of engineers. One of the highlights of the outreach efforts was hosting an engaging booth at the 2024 Roger That! conference held at the Grand Rapids Public Museum. This event provided a unique platform to showcase early prototypes and offer insights into the engineering work behind the Lunar Flagpole Challenge and the Artemis program. Visitors of various ages and professions had the opportunity to see firsthand the complexities involved in the project and the innovative solutions the team developed. This interaction not only increased public awareness of the work but also sparked interest in STEM fields among attendees.

Secondly, the team actively supported Allendale High School's Science Olympiad students. The team met with the students bi-weekly from September to May. The team guided the students in their tower-building and salt concentration sensor projects. This mentorship involved identifying and reviewing problems in the students' projects. It also included sharing problem-solving techniques. By closely working with the students, the team helped them understand the engineering design process used in the flagpole project and how to navigate challenges and troubleshoot issues. The mentorship gave the students practical insights and hands-on experience, enhancing their skills.

The outreach initiative achieved considerable success, as demonstrated by the Outreach Award received for the Micro-g NExT challenge. This accolade highlights the team's efforts to actively engage the community and promote STEM education effectively. It is a testament to the team's dedication and the significant impact of the outreach initiatives. Additionally, the outreach efforts could have incorporated more interactive elements in our presentation for Roger That! By offering participants hands-on opportunities to engage with engineering concepts and tools, we could have further enriched their learning experience, particularly for the younger audience, thereby fostering a deeper interest in STEM. Additionally, expanding our outreach to include a greater number of schools or community groups would have helped broaden our audience reach.

VII. Conclusion

Overall, the Grand Valley State University Astro Anchors flagpole designed for the 2024 Micro-g NExT Lunar Flagpole Challenge was a great success, and the team is excited about the future of this project. Over two semesters, the Astro Anchors brainstormed, prototyped, built, and tested a design for a lunar flagpole that could be easily assembled and deployed by a fully suited astronaut on the surface of the Moon during NASA's upcoming Artemis missions. The flagpole assembly was designed to be lightweight, dust tolerant, stable, and deployable from a stowed configuration to a height of around 8 feet. The team's design consisted of four individual parts: the anchoring system, the telescoping flag pole, and two extension pieces, one of which acted as a handle for driving the anchoring system into the ground. The anchoring system design used a freely rotating auger and a baseplate with shovel attachments to effectively stabilize the flag during and after deployment. The anchoring system was designed to use a handle, which is reutilized in the assembly, to allow the astronaut to drive the auger into the ground. The telescoping flagpole segment holds the stowed flag furled using velcro straps. The flag is later unfurled after two horizontal poles are secured at a 90-degree angle to the main pole, creating an "L" shape. Upon flag unfurlment, the telescoping pole can be extended using its internal slot guiding system to bring the flagpole to its full height of 8 feet. The pole segments are connected using couplers that are actuated by a push-and-twist motion, securely locking flagpole pieces together. Extensive prototyping and testing ensured the flagpole functioned properly and met the challenge and astronaut needs. In June, the flagpole was tested at NASA's Neutral Buoyancy Lab in Houston, TX. Testing was a success and the diver gave helpful feedback to the team, suggesting improvements in the coupler design, pole lengths, and other aspects of the design. To improve the Astro Anchors flagpole design for lunar deployment in the Artemis missions, the team outlined multiple areas of improvement needed, including improved couplers, connections, and pole lengths to ensure the best performance and ease of use for an astronaut on the lunar surface.

Appendix A

Table A-1. 2024 Micro-g NExT Lunar Flagpole Challenge Requirements

1	A structurally stable, easily deployed flag for lunar EVA shall be developed.
2	Mass of the full flag assembly shall not exceed 10 lbs. in 1G Earth gravity.
3	For any mechanisms used: For a linear-actuating mechanism, force required to actuate shall not exceed 20 lbf (89 N). For a rotating mechanism, torque required to actuate shall not exceed 30 in-lb (3.4Nm).
4	All mechanisms used shall be dust tolerant.
5	The flag shall remain deployed vertically and anchored without the use of an operator.
6	The flag shall be deployable from its stowed configuration in 10 minutes or less.
7	When deployed, lunar flag shall remain anchored when pulled upward with a 10 lb. force.
8	When deployed in the ground, lunar flag shall remain anchored when pulled laterally from the top of the flagpole with a 10 lb. force.
9	A 1 in. tether loop shall be included at the top of the flagpole for use in applying axial and side loads during testing.
10	The flag shall have a method of remaining unfurled in the absence of wind.
11	Height of the deployed flag shall be no less than 96 in. and no more than 120 in.
12	Flag size shall be 3 ft. x 5 ft.
13	Flag shall not touch the ground during deployment operations or once deployed.
14	Flag shall be the flag of the institution the student team is from
15	Flag assembly shall be collapsible into an EVA-compatible stowed configuration* that fits within a volume of 48 in. x 12 in. x 8 in.
16	The proposed design shall specify all materials the provided hardware will be made from.
17	All materials used must be on the NBL Approved Materials List**. A waiver may be granted on a case-by-case basis. (No regular PLA allowed. Tough PLA is okay.)
18	Stress analysis and physical testing shall be conducted on the flagpole and anchoring system to ensure the materials and design are properly selected to ensure no structural damage occurs. You are expected to show stress analysis in the proposal. Physical testing may be done later.
19	Factor of safety of at least 1.25 shall be used in stress analysis and physical testing. Specify the factor of safety used in the proposal.

20	The flag, flagpole, and anchoring system shall be usable with EVA-gloved hands (like heavy ski gloves).
21	The flag, flagpole, and anchoring system shall use only manual power.
22	There shall be no holes or openings which would allow/cause entrapment of fingers on the device.
23	There shall be no sharp edges on the device.

Figure A-2. Physical testing of original auger design

Appendix B

1. Grab the pole segment with a single pink coupler (marked as 3) on the end, and a square hole cut into the middle.
    a. After he has picked up the pole with the pink coupler, tell her to orient it so the square cut out towards her other hand.

2. Then pick up anchoring system containing an auger on one end and a green coupler (marked as 1) on the other.

3. Press the tip of the auger into the sand as much as possible.

4. Fit the square cut-out on the small pole segment with the square extrusion on the top of the anchoring system.
    a. Make sure the two pieces are fully fitted together.

5. Position your hands on each end of the horizontal pole.

6. Rotate the handle clockwise, readjusting your hands as needed. Adding downward pressure can be helpful during this step.
    a. Can be applied by foot or pushing down

7. Continue rotating the handle until the top of the baseplate is flush with the ground.

8. Remove the handle from the assembly and set aside.

9. Pick up the pole with the flag attached to it and locate the green coupler (marked as 1) at the bottom of the pole.

10. Align two green couplers and then rest the pole with the flag attached to it on the bottom coupler.

11. Slowly twist the top pole counterclockwise pushing down lightly until it falls into a recess. Visually confirm that the coupler is fully seated in the recess.

12. Then twist the top pole counterclockwise until fully secured. Visually confirm that couplers are fully fitted together.

13. Look at the top of the pole, ensure the flag hanger is located behind the horizontal orange coupler (marked as a 2).

14. Grab the longest remaining pole piece. Connect the orange coupler (marked as a 2) to the horizontal orange coupler on the top of the assembly in the same push and twist motion as before.

15. Grab the remaining pole segment. Connect this to the horizontal pink coupler on the top of the assembly in the same push-and-twist motion as before. Orientate so the hazard-marked slot is facing towards you.

16. Undo the three velcro straps from around the flag. Ensure that the flag is free from the velcro.

17. Take the flag hanger and pull it across the horizontal pole segments and rest it in the slot marked with hazard tape.

18. Go back to the main vertical pole segments.

19. Grab the bottom of the top pole segment and start gently lifting it. Continue lifting until it stops. Then rotate clockwise until the pole stops and allow it to slide down.

20. This concludes the assembly of the flagpole.

Acknowledgments