Tholos™ – EVA Sample Location Calibration Device

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Presented by

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Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.
Abstract

To support NASA’s upcoming Artemis missions, an extravehicular activity (EVA) photometric calibration scale was developed to replace the Apollo-era Gnomon device. The Gnomon was a gimbaled stadia rod mounted on a tripod which provided color and reflectivity photo calibration, vertical orientation, and solar shadow direction, to include in photos of lunar geologic samples and features. With over 50 years of innovation since the first Gnomon deployment on Apollo 11, this redesign of the photometric calibration scale will support NASA’s missions in the modern day. The Tholos™, named after the ancient Greek repository of standardized measures, consists of a quadrupedal design with low center-of-mass, ensuring high stability at steep angles. The design contains a telescoping extendable stadia rod at its center. The stadia rod slides out of the protective sheath to provide color, greyscale, and linear measurement calibration targets. An attached reflective 360° prism provides accurate polar line of sight position information when used with a ground-based transit theodolite with electronic distance measurement. The Tholos™ can be operated, deployed, and retrieved while standing and can be stored within the provided 2” x 4” x 15” volume when collapsed. The deployment and retrieval of the Tholos™ is compatible with the limited dexterity of an EVA suit. The design uses flight-like materials that were selected for optimal mass, stiffness, fracture criteria, resistance to lunar dust abrasion, and ease of manufacture. Additionally, the Tholos™ unit’s materials can be modified for Neutral Buoyancy Lab (NBL) testing. As such, the design satisfies all requirements imposed by the Micro-g NExT competition in an effective manner. Final testing showed that the design was operable with EVA gloves and fit all necessary NASA criteria.
Introduction

Our senior project involved the participation in the National Aeronautics & Space Administration’s (NASA) Micro-g Neutral Buoyancy Experiment Design Teams (Micro-g NExT) student design challenge. This program involves yearly challenges posed to undergraduates across the country in the realm of space travel and exploration.

Because of NASA’s plans to send humans back to the moon, it is necessary that outdated tooling from the Apollo missions be redesigned. Our team’s prompt was to reimagine the Apollo-era *Gnomon*, a device used during the lunar geologic sampling process. To be more specific, the purpose of the device was to act as a photometric calibration device in lunar surface photography. Due to the moon’s lack of an atmosphere, there is very little light scattering on the lunar surface. For this reason, objects situated on the lunar surface have much higher levels of contrast than objects on Earth. When an astronaut takes a picture of a sample, they must thusly include an object with known colors and light levels in order to correct the differences via white- and color-balance methods. The Apollo-era *Gnomon* used a vertical stadia rod mounted on a tripod as a linear scale (for size comparison). Then, a color chart was located on one of the tripod’s legs, with reflectivity information on the vertical stadia rod. Feedback from astronauts who used the *Gnomon* illuminated the fact that the device was difficult to operate in the bulky suits worn during lunar Extravehicular Activities (EVAs). Furthermore, the presence of the lunar dust posed an issue with color and reflectivity scales becoming obscured by aerated particulate. As there is very little atmosphere on the moon, there are almost no erosive processes on the surface. For this reason, the dust that covers the surface, called the regolith, is composed of very sharp particles which can cause surface damage to the calibration reference material. It is the *Gnomon* that we set out to redesign-
something that would conform to the ergonomic needs of the astronaut while also protecting sensitive color scales from the lunar regolith. Our final design can be seen in *Figure 0*.

This document includes four primary components: the Scope of Work (SOW), the Preliminary Design Review (PDR), the Critical Design Review (CDR), and the Final Design Review (FDR). Each of these sections was created as a separate document and compiled into this final report. The SOW details the background research and communication of the main problem at hand. The PDR outlines the direction we decided to take our design while also providing supporting evidence for why we thought that direction was valid. The CDR details the final design we came up with and demonstrates to the sponsor that it fulfills all design criteria. The FDR discusses the results of final testing and any ultimate design changes made since CDR.
Tholos™ – EVA Sample Location Calibration Device
Scope of Work (SOW)

December 8, 2021

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1. Introduction

NASA’s Micro-g NExT challenge is an annual competition open to undergraduate students across the country. Each year, NASA selects a number of pertinent challenges in the field of space exploration and technology for students to tackle. Teams that are selected to participate may travel to the Neutral Buoyancy Laboratory (NBL) in Houston to test their designs in simulated microgravity. In this way, participants play a direct role in the development of new designs and technologies for use by NASA engineers. This year’s projects include a lunar sample collection system, a lunar surface anchoring system, and a photometric calibrator for use on the lunar surface.

Our team is composed of four 4th-year mechanical engineering students at California Polytechnical State University, San Luis Obispo (also known as Cal Poly). James is from Bend, Oregon and enjoys studying geology and exploring the outdoors in his free time. Kat is concentrating in Energy Resources and enjoys swimming and spending quality time with her roommates. Julia is concentrating in Energy Resources, and in her free time enjoys reading graphic novels, taking walks, and making drawings. Ben is studying to receive a minor in German, and in his free time, enjoys reading science fiction novels, learning foreign languages, and playing Dungeons & Dragons with his friends. We have decided to pursue the calibration photo scale challenge. For the Apollo missions, astronauts used a device known as the “Gnomon” to calibrate sample photographs from the lunar surface. With this project, we have set out to address the issues of the Gnomon and come up with a sleek, innovative solution to the design problems at hand.

The ‘Background’ section of this document details the preliminary research we performed, including patent research, NASA’s requirements, and the technical challenges at hand. The ‘Project scope’ section of this document details the functional decomposition and ideation portions of our process. The following section, labelled ‘Objectives’, defines the problem statement and includes the required engineering specifications.

2. Background

Previous lunar missions used the Apollo era Gnomon for photo calibration. The gnomon consisted of a self-leveling stadia rod with color and reflectivity targets. A tripod allowed for the device to be placed on a variety of surfaces. The gimbling mechanism did not consist of ridged parts, but rather ball chain like material that ‘hung’ the stadia rod. With over 50 years of innovation since the first lunar landing, our project seeks to redesign the gnomon into the twenty-first century.

2.1 Customer Research

Customer research was done by collecting information about NASA, the Micro-g NExT Competition, and information regarding the usage of the Gnomon and work being done in the lunar environment. To better understand the conditions of the lunar environment and how tools such as the Gnomon were used, information was gathered from NASA Mission Technical Debriefings and preliminary science reports from missions. A summary of customer research is described below.

2.1.1 Sponsor & Company Information

For the Micro-g NExT Competition, NASA is our sponsor. This competition allows for undergraduate students to innovate new designs for tools that assist with upcoming space missions. In addition to designing new tools, opportunities are given to chosen teams to test the design at the
Neutral Buoyancy Laboratory located at the NASA Johnson Space Center. The Neutral Buoyancy Laboratory simulates a micro-gravity environment, which in turn reflects how the design will function in space. The current Micro-g NExT challenge is centered around developing designs to be utilized on lunar extravehicular activities that take place during the upcoming Artemis missions [1].

2.1.2 Technical Debriefings
Technical Debriefings given by NASA astronauts after finishing the mission and returning to earth were analyzed. These technical debriefings discuss feedback, experiences, and other observations with regards to equipment, environment, and other factors. The provided information includes insights on human factors regarding their spaceflight experience, along with their own experiences and observations when using tools like the gnomon for lunar rock studies. Because the information provided in technical debriefings overlaps with customer data, it will be discussed in the section below.

2.1.3 Customer Data
Customer data was found through preliminary science reports from missions. Although these preliminary science reports contained information regarding the gnomon only, it also highlighted different concerns and functions of the original gnomon that might be important to incorporate within our design. The Apollo 15 preliminary science report provided details on how the gnomon was not only used to study geological photometry, and how photometric data was collected using photographs of geological samples with the Gnomon in the image (see Figure 7). Additionally, the report also uncovered issues with using the gnomon due to lunar dust:

“Minor operational problems were caused by thin layers of dust on the camera lenses and dials, gnomon color chart, navigation maps, and LCRU mirror. As on previous missions, the adhering dust was brushed off easily. However, the dust was so prevalent that, during part of the mission, the astronauts reported that, to set the lens, dust had to be wiped from the camera settings every time they took a picture.” [2]

In addition to these preliminary science reports, NASA has provided information regarding the concepts for geologic exploration and conducting geologic studies. Key elements necessary for geologic exploration included mobility, strength, manipulation, and ability to perform fine-scale tasks [3]. These key elements were reflective of the requirements established by the NASA Micro-g NExT Competition, and they were kept in mind while developing our Tholos™ Design.
2.2 Existing Products & Solutions

The Apollo-era Gnomon consists of a tripod with a gimbaled stadia rod in the center. The gimballed mechanism allows the stadia rod to remain vertical under all normal leg configurations, ensuring the shadow cast by the rod has a consistent angle. The size of this shadow could then be used to determine the relative orientation to the sun of the lunar geologic sample in the photograph. The vertical stadia rod had spaced reflectivity bands which would be used to calibrate varying lighting conditions. The leg or the stadia rod, depending on the model, would contain color reference markers to be used for color correction for photos. A number of issues were reported with the Gnomon during its use on the moon. First, the location of the color reference data created a proclivity for the color swatches to become obscured by dust. Next, the device was not easy to store or deploy when using the bulky gloves of an EVA suit. Lastly, the device was not always stable on the different terrains encountered by astronauts. While the Gnomon is naturally the most similar product of which we are aware, several products exist on the market with aspects we found insightful during our ideation process. After researching multiple patents, they were placed into different categories depending on the information they provided. These three categories included patents that provided information on geographical location, designs to resist to foreign object debris (for our case, lunar dust), and structural designs.

To research these similar patents, different search strategies and key terms were utilized. Searches were done on Google Patents, and search terms varied from general terms to more specific terms depending on what possible patents we could find. For example, one search was done using the terms “NASA gnomon”, and other search terms were tailored to functions that came from our ideation process, such as “Surveying Instrument” or “Road ‘folding’ ‘sign stand’”. Quotations were used around certain key terms to further narrow down relevant patents.

After completing our patent research, we have gathered information that assisted in helping us refine our design with regards to how it will be able to be structurally sound, have location-defining features, and how it can be resilient when dealing with lunar dust and other environmental obstacles. Although these patents provide valuable information with regards to how our functional requirements may be fulfilled, there are still areas that have not been fully addressed by these patents. Nonetheless, we intend for these areas to be addressed through other methods, such as conceptual prototyping, testing, and further design development.

2.2.1 Summary of Patent Research & Categories

For all the patents researched, each patent provided insight on how we could improve the Tholos™’s design in terms of locating, resisting lunar dust, and structure. The High Precision Solar Compass [4] seen in Figure 2 determines its orientation in space using the sun's position...
rather than using a magnetic field. Similarly, we intend on utilizing the method of indirectly using the sun to measure position and direction just as the Gnomon did through shadows. Alternatively, we could consider adding a laser system like in the Surveying Laser [5] in Figure 3. Its method of determining distance uses a laser-system and a series of mirrored survey markers which are placed on the ground. The laser would be fired from the emitter directed back into the receiver so the receiver can use the time delay to determine the distance to the marker. This would allow sample locations to be mapped extremely accurately. Another potential method of determining location would utilize a camera to create a relative coordinate system for taking geological samples across a relatively large area. The Survey Location Localization [6] (Figure 4) uses a camera to determine the distance to different geological survey markers.

To prevent lunar dust from interfering with the inner and outer stadia rods, the Expandable Telescoping Rod [7] (Figure 5) poses unique advantages for use in the lunar environment. The fully contained extension mechanism prevents contact with external environments which could be useful on the Moon to help mitigate the dangers posed by lunar dust.

Since stability of the Tholos™ is a major concern, the Compact Sign & Stand [8] design contains an improved attachment mechanism for the sign to be attached to the frame. As shown in Figure 6, the frame design utilizes four legs to provide structural integrity to the sign so that it may resist tipping on inclined surfaces. This concept provides insight on what configuration would be the most ideal for our design with regards to maintaining stability on inclined surfaces and various terrain. The tetrapod concept was inspired by the stand design of the compact sign.
Table 1: Patent Search related to different Tholos™ Unit Design Functions.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Solar compass photometric positioning system</td>
<td>EP2938963B1</td>
</tr>
<tr>
<td></td>
<td>Surveying laser positioning system</td>
<td>US8629905B2</td>
</tr>
<tr>
<td></td>
<td>Survey Location Localization</td>
<td>JP2006090947A</td>
</tr>
<tr>
<td>Lunar Dust Resistance</td>
<td>Environment-resistant telescoping rod mechanism</td>
<td>US9011499B1</td>
</tr>
<tr>
<td>Structural Design</td>
<td>Compact Sign &amp; Stand</td>
<td>US4548379A</td>
</tr>
<tr>
<td></td>
<td>Portable wind-resistant sign stand with flexible sign</td>
<td>US4516344A</td>
</tr>
</tbody>
</table>

2.3 Technical Challenges

A number of technical challenges will likely present themselves to us during our design process. Many of these challenges may be unique to the lunar environment in which the final device is to be used. As of right now, the technical challenges we are aware of and working to address include the adhesion and abrasion of lunar dust to the Tholos™, the ability for the device to tolerate different terrains and load angles, the minimization of pinch points, and the ability to be stored in a compact manner. These challenges are well-documented and assessed; we do not foresee any difficulties in designing the Tholos™, so long as we keep these challenges in mind.

The presence of lunar dust poses several problems to the proper function of the Tholos™. Firstly, the presence of a thin layer of very fine dust (also known as the lunar “regolith”) requires that all tolerances for sliding components be loose as to prevent this fine dust from becoming lodged in undesirable locations. The potential for this dust to become electrostatically charged also creates the issue of dust adhesion [9]. It is because of this tendency for the dust to adhere to flat surfaces that the color calibration data on the Gnomon became so easily obstructed. Lastly, the abrasive quality of the regolith poses an issue regarding our materials selection. When analyzed on the microscopic level, it becomes apparent that the lunar regolith is, in fact, very sharp and glass-like in nature. This is due to the fact that very few erosive processes exist within the lunar environment. Because the regolith is so sharp, it can very quickly lead to ruined surface finishes and create frictional issues, specifically in moving or sliding parts. For this reason, we will have to devise a method for both keeping regolith out of our sliding mechanisms and preventing the regolith from scratching the exposed surfaces of the Tholos™.

The issue of the Tholos™ tolerating different load angles and terrains without slipping or falling ultimately boils down to a question of static friction. The force of static friction is what allows the Tholos™ (and other devices like it) to remain upright without falling or sliding on a surface. The
static friction, on the microscopic level, is ultimately determined by the interaction between local minima and maxima of the two surfaces in contact [10]. Due to the fact that the lunar regolith will be present, the coefficient of static friction between the Tholos™ feet and the surface upon which they find themselves may not be easily predictable. We must, therefore, consider changing the design of the feet so as to maximize the force of static friction holding the Tholos™ in place.

The remaining challenges of minimizing pinch points and storing the device in a compact way will be tackled during the ideation and design processes. These particular challenges are not unique to lunar environments and can be tackled using our current engineering background.

3. Project Scope
The goal of this project is to create an innovative design for lunar photometric calibration scale which can be used by Artemis astronauts during extra-vehicular activities (EVA). In addition to this, the resulting design must be able to fulfill all the requirements set by the NASA Micro-g NExT Competition so that the device may successfully function and provide the requested information needed during missions. To ensure this, our project scope is defined by all given NASA criteria (see Table 3), and our device will provide the functions assessed in the functional decomposition assessment. The project scope was specified by producing a boundary sketch and performing a functional decomposition study, which are elaborated upon in the sections below.

3.1 Stakeholders & Needs
NASA Micro-g NExT has explicitly specified their needs and competition requirements in their published challenge description.

3.1.1 Customer Needs & Wants
Upon obtaining sufficient information from NASA regarding competition requirements and combining this information with the customer research, a list of needs and wants for the customer was generated below in Table 1. The list of customer needs and wants is split into two categories, where the needs and wants are specified for both the user of the device and the design of the Tholos™ unit.

<table>
<thead>
<tr>
<th>Category</th>
<th>Needs</th>
<th>Wants</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>• No kneeling to operate/set up device</td>
<td>• One handed deployment and retraction</td>
</tr>
<tr>
<td></td>
<td>• Carry with one hand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Deploy device while using EVA suit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Limited setup time</td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>• 2&quot; x 2&quot; alpha-numeric label on device</td>
<td>• Smallest size &amp; weight achievable</td>
</tr>
<tr>
<td></td>
<td>• 1cm x 1cm color reference on device</td>
<td>• Changeable alphanumeric label</td>
</tr>
<tr>
<td></td>
<td>• Max dimensions for device: 2&quot; x 4&quot; x 15&quot;</td>
<td>• Total station (radial coordinates)</td>
</tr>
<tr>
<td></td>
<td>• Max of 20º tilt when on ground</td>
<td>• Calibration markers on bottom half of device</td>
</tr>
<tr>
<td></td>
<td>• Device must be less than 1 lb.</td>
<td>• Photometric Reflectivity scale</td>
</tr>
<tr>
<td></td>
<td>• Device must be resistant to lunar dust</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Boundary Sketch
Figure 7 depicts our boundary sketch, which was used to further understand the scope of our project and our goals. The scope of our design task is what is within the dotted box.

![Figure 7: Boundary Sketch](image)

3.3 Functional Decomposition
The calibration scale’s primary function is to provide photometric calibration through color correction and reflectivity. Other functions are auxiliary to supporting this feature. An identifiable number, holding mechanism, operability, and transportability all support the main goal of the product which is to provide photo calibration. A diagram shown in Figure 8 was created to highlight the basic functions and their respective sub-functions.
4. Objectives
The objective of this project is to design a novel and effective photo calibration device that can be used on upcoming Artemis missions. An additional goal is to be selected to proceed in the NASA design challenge. If selected, we shall be tasked with producing five working models for testing at NASA’s Neutral Buoyancy Laboratory in Houston, Texas.

4.1 Problem Statement
NASA is looking for a sample calibration marker for lunar extra vehicular activities (EVA) to assist in the collection and documentation of geologic samples and features on the upcoming Artemis missions. The calibration marker deployment, retrieval, and transportation must be compatible with the limited mobility and dexterity of astronaut spacesuits.

4.2 Quality Function Deployment (QFD)
The Quality Function Deployment process included breaking down the design of the Tholos™ into a number of different needs and requirements desired by the end user. These requirements were compared to different engineering metrics in order to determine the correlations between them. This system allowed us to determine while technical requirements and customer requirements to prioritize when designing the Tholos™. This process helps us ensure that we meet the requirements of our customer (that being NASA). From this process, we were able to determine the level of urgency of each design requirement. This risk-level is reported in Table 3. Overall, we learned that the wight and dimensions of the Tholos™ dictate compliance in the majority of important categories, so working on optimizing both of these criteria should allow the final design of the Tholos™ to be a great improvement to the Gnomon. While the Quality Function Deployment illustrates the relative weights of different requirements and specifications, the nature
of a NASA design competition necessitates that all of the provided criteria be satisfied. This, however, provides a hierarchal approach to design, as it dictates which design aspect should be prioritized. See Appendix L for Quality Function Deployment diagram.

**4.2.1 Engineering Specifications**
The Table 3 below lists the engineering specifications outline by the Micro-G NExT challenge along with the assessed level of risk and compliance status. Below is a numbered list of specifications, along with elaboration on the assessment method for each specification.

1. **Sample set of identical markers**
   a. **Description:** A set of 5 individual devices shall be constructed.
   b. **Assessment method:** 5 devices will be counted within the set.

2. **Remain independently stable at 20° incline**
   a. **Description:** The device must be stable and still stand on surfaces with slopes ranging up to a 20° incline.
   b. **Assessment method:** Place the device on a 20° and check for stability.

3. **Sample marker deployed and retrieved without kneeling all the way down**
   a. **Description:** The device is requested to be able to be operated without the astronaut kneeling to the ground.
   b. **Assessment method:** Practicing deploying and retrieving the Tholos™ without kneeling. The simulated astronaut should have limited dexterity and be of average height.

4. **Sample marker with unique alphanumeric identification information**
   a. **Description:** Each device shall have a unique alphanumeric identification label or marker that is able to distinguish each individual device from one another.
   b. **Assessment method:** Five unique alphanumeric labels will be created, with one going for each device.

5. **Sample marker labeled with a color reference scale consisting of red, blue, green, black, grey, and white blocks**
   a. **Description:** The device shall have a color reference scale consisting of the described colors in order to provide photometric data.
   b. **Assessment method:** A color reference scale will be provided by NASA to place on the device.

6. **(a) Flight-like materials; (b) NBL approved materials**
   a. **Description:** The device used for flight shall be made of flight-like materials, and the device used for testing at the NBL facility shall be made of pool-safe materials approved by NASA.
   b. **Assessment method:**

7. **Volume of its stowed configuration**
   a. **Description:** The stowed device must fit within a 2”x4”x15” volume.
b. Assessment method: The device will be measured to determine if it satisfies the volumetric constraints, or a 2”x4”x15” box will be created, and the device will be check for size by fitting inside the box.

8. Total weight
   a. Description: The total device weight must not exceed 1 lbf.
   b. Assessment method: A calibrated scale shall be used to measure the total device weight.

9. Operable with EVA gloves
   a. Description: The device must be operable with simulated EVA gloves with minimal dexterity.
   b. Assessment method: Practice operation while wearing thick winter gloves.

10. Only manual power
    a. Description: The device must only use manual power.
    b. Assessment method: It will be ensured that the device only uses manual power.

11. No holes or openings
    a. Description: The device design should have minimal holes or opening which could pose as pinch or entrapment hazards.
    b. Assessment method: While using thick winter gloves, operate the device and look for potential pinch points.

12. No sharp edges
    a. Description: The device should not have sharp edge that could catch or tear other equipment.
    b. Assessment method: Simulated EVA gloves and exterior textiles will be used to determine if there are any sharp edges.

13. Minimize and label pinch points
    a. Description: The device design should have minimal holes or opening which could pose as pinch or entrapment hazards.
    b. Assessment method: While using thick winter gloves, operate the device and look for potential pinch points.
### Table 3. Engineering Specifications

<table>
<thead>
<tr>
<th>Spec No.</th>
<th>Specification Description</th>
<th>Requirement</th>
<th>Tolerance</th>
<th>Level of Risk</th>
<th>Compliance Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample set of identical markers</td>
<td>5 markers</td>
<td>Min.</td>
<td>L</td>
<td>I</td>
</tr>
<tr>
<td>2</td>
<td>Remain independently stable at 20° incline</td>
<td>20°</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
</tr>
<tr>
<td>3</td>
<td>Sample marker deployed and retrieved without kneeling all the way down</td>
<td>-</td>
<td>N/A</td>
<td>L</td>
<td>I</td>
</tr>
<tr>
<td>4</td>
<td>Sample marker with unique alphanumeric identification information.</td>
<td>2” x 2”</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
</tr>
<tr>
<td>5</td>
<td>Sample marker labeled with a color reference scale consisting of red, blue, green, black, grey, and white blocks</td>
<td>1cm x 1cm color block ea.</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
</tr>
<tr>
<td>6</td>
<td>(a) Flight-like materials</td>
<td>-</td>
<td>N/A</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>(b) NBL approved materials</td>
<td>-</td>
<td>N/A</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>Volume of its stowed configuration</td>
<td>2” x 4” x 15”</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
</tr>
<tr>
<td>8</td>
<td>Total weight</td>
<td>1 lb.</td>
<td>Max.</td>
<td>M</td>
<td>A, I</td>
</tr>
<tr>
<td>9</td>
<td>Operable with EVA gloves</td>
<td>-</td>
<td>N/A</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>10</td>
<td>Only manual power</td>
<td>No electrical components</td>
<td>Max.</td>
<td>M</td>
<td>I</td>
</tr>
<tr>
<td>11</td>
<td>No holes or openings</td>
<td>-</td>
<td>N/A</td>
<td>M</td>
<td>A, I, T</td>
</tr>
<tr>
<td>12</td>
<td>No sharp edges</td>
<td>0</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
</tr>
<tr>
<td>13</td>
<td>Minimize and label pinch points</td>
<td>-</td>
<td>N/A</td>
<td>M</td>
<td>A, I</td>
</tr>
</tbody>
</table>

### 5. Project Management

The design process we plan to follow is straightforward in nature. First, we shall perform a set of different brainstorming tasks, including mind mapping, “How might we-?” questions, and brain dumping. Next, we will construct several different ideation models to illustrate key design concepts that emerged during our ideation process. We will construct these models using hot glue guns, foam board, popsicle sticks, and rubber bands. From this point on, we shall select the designs we find the most viable and compare them empirically. After deliberation, we will select the design we believe both best accomplishes the tasks set by NASA. Once a design has been selected, our design proposal document, along with a short pitch video explaining our design, will be submitted to NASA Micro-G NeXT. Upon completing the design proposal and short pitch video, both the Scope of Work and Preliminary Design Review (PDR) documents will be written. This will also transition to our PDR presentation, where feedback is provided regarding our design proposal. Once the PDR feedback has been implemented to our design, we will transition to the detailed design and analysis phase, which includes Failure Modes & Effects Analysis (FMEA), an Interim Design Review (IDR), and finally a Critical Design Review (CDR). Completion of this phase will then lead to manufacturing and testing of the design, which may potentially include the opportunity

---

1 Risk of meeting specification: (H) High, (M) Medium, (L) Low
2 Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test
to test the design at the NBL facility. The end stages of the project will consist of a Final Design Review (FDR) report and presentation, and the design will be shared in detail at the Senior Project Expo.

From this point on, we will focus on writing our design proposal for NASA, performing necessary research and analysis to support our chosen design. We will then record our short pitch video and submit this to Micro-G NeXT prior to submitting our design proposal. Next, we will write and submit the Scope of Work and Preliminary Design Proposal documents. As for right now the next steps we will be taking are to construct a working concept prototype and finish our PDR. The schedule of tasks can be seen in Table 4 below, as well as in the Gantt Chart in Appendix J.

<table>
<thead>
<tr>
<th>Task</th>
<th>Start Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideation</td>
<td>6 October 2021</td>
</tr>
<tr>
<td>Create physical prototypes of design concepts</td>
<td>14 October 2021</td>
</tr>
<tr>
<td>Narrow down design with prototype results</td>
<td>19 October 2021</td>
</tr>
<tr>
<td>Produce final design for proposal</td>
<td>21 October 2021</td>
</tr>
<tr>
<td>STEM Engagement</td>
<td>24 October 2021</td>
</tr>
<tr>
<td>Video Proposal</td>
<td>26 October 2021</td>
</tr>
<tr>
<td>Proposal Deadline</td>
<td>28 October 2021</td>
</tr>
<tr>
<td>Scope of Work (SOW)</td>
<td>28 October 2021</td>
</tr>
<tr>
<td>ME 428 PDR Presentation</td>
<td>14 November 2021</td>
</tr>
<tr>
<td>PDR Final Report</td>
<td>10 November 2021</td>
</tr>
</tbody>
</table>

6. Conclusion
To support NASA’s future Artemis missions and engage the public in science and engineering, NASA is holding a design competition to focus on a variety of aspects relating to their upcoming missions. Our team selected to take part in the photo calibration scale challenge. During the Apollo missions, the Gnomon was used by astronauts to provide qualitative calibration information in photos. With over 50 years of innovation since the Apollo 11 moon landing, our team seeks to design a photo calibration scale to support NASA’s mission in the twenty-first century. We will accomplish this goal through design ideation, computer modelling, and eventual construction of the final design.4

References


Tholos™ – EVA Sample Location Calibration Device
Preliminary Design Review (PDR) Report

January 10, 2022

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1. Introduction
The introduction section of this document provides descriptions for the project objective, scope, and a summary of the report contents below.

NASA’s Micro-g NExT challenge is an annual competition open to undergraduate students across the nation. Each year, NASA selects several pertinent challenges in the field of space exploration and technology for students to tackle. Teams that are selected to participate may travel to the Neutral Buoyancy Laboratory (NBL) in Houston to test their designs in simulated microgravity. In this way, participants play a direct role in the development of new designs and technologies for use by NASA engineers. This year’s projects include a lunar sample collection system, a lunar surface anchoring system, and a photometric calibrator for use on the lunar surface. Our team has chosen to pursue the calibration photo scale challenge. For the Apollo missions, astronauts used a device known as the “Gnomon” to calibrate sample photographs from the lunar surface. With this challenge, we have set out to address the issues of the Gnomon and come up with a sleek, innovative solution to the design problems at hand. Since the submission of our Scope of Work (SOW), we have chosen a few different specific areas of the design which require attention and fine-tuning in order for us to arrive at our final design.

The aim of this document is to describe the design direction we have selected for this challenge. The following document is broken up into six primary sections, each of which is composed of several subsections. The second section, ‘Concept Development,’ describes the different methods of ideation we employed to arrive at our final design. This section also outlines a number of different design concepts we considered, with images and descriptions of each of them. The next section, the ‘Concept Design,’ highlights the design idea we found to maximize both functionality and manufacturability. This section delves into the function of the final design, including images of our CAD model and our concept prototype. Following this, we describe the rationale behind our design, including the engineering analysis, insight, and analysis of each individual design requirement in the ‘Concept Justification’ section. In the next section, entitled ‘Project Management,’ we discuss the plans for the project moving forward. Lastly, in the ‘Conclusion,’ we summarize the important highlights of this document and the key steps we will take moving forward.

2. Concept Development
Numerous methods for stimulating new ideas were employed during the ideation process. Most prominently, our ideation process featured the use of “How might we-?” brainstorming activities in order to arrive at a large number of different solutions to each given aspect of the final design. Outcomes of these brainstorming activities are listed in Section 2.1. Several unique design ideas were considered during the ideation process, with our studies eventually converging upon the final design of the Tholos™. These alternative designs included tripodal, flexural, hemispheric, and planar designs; our top five design ideas are outlined in Section 2.2.
2.1 Brainstorming & Ideation
To begin our ideation, our group has participated in multiple brainstorming activities and has set specific goals to produce a number of possible designs to start with. The results of our brainstorming activities, which consisted of answering the question of “How might we-?” as mentioned previously, were used to converge on a number of reasonable designs. In addition to these activities, sketches of possible designs were also produced. These sketches are shown in Appendix M.

2.2 Design Idea Prototypes – Top Concepts
As a team, we created multiple prototypes to assess whether certain designs were more feasible than others.

**Design 1: Tri-Stand**
Inspired by roadside retroreflective safety triangles, this prototype investigated a similar concept. The prototype consisted of three legs to support the stand, with one side containing device information such as the color calibration and alpha-numeric label. An image of the prototype can be seen in Figure 1a.

**Design 2: Forensic Tent and Placement Rod**
The prototype shown in Figure 1b was inspired by tent markers used in crime scenes during forensic investigations. This concept consisted of a forensic tent marker with a collapsible rod attached to the top so that the tent may be placed near the sample location with ease. The tent would contain necessary information for color calibration and labelling.

**Design 3: Collapsible Omnidirectional Tube**
This design concept consisted of a collapsible cylinder that would be able to be extended. Figure 2 contains two images of the collapsible omnidirectional tube prototype, in which one is collapsed and the other is extended. Although not pictured, there would be fabric attached to both circular ends—this is intended to be simulated using the tape strip. The tube fabric would contain the color calibration chart going all the way around and other necessary features. Because of the circular shape, the device is omnidirectional, removing the need to be normal to the calibrator’s features while taking a photograph. This would allow multiple photographs to be taken from different angles without the need to readjust the calibration equipment.

![Design 1: Tri-Stand Prototype](image1a.png)
![Design 2: Forensic Tent & Placement Rod Prototype](image1b.png)

![Design 3 - Collapsible Omnidirectional Tube](image2a.png)
![Design 3 - Collapsible Omnidirectional Tube](image2b.png)
Design 4: Hedgehog  
Inspired by Czech “hedgehogs” used in World War II as obstacles for enemy tanks, this design leveraged the concept of being a simple object that could be placed or thrown on ground consisting of any kinds of terrain. This concept is also similar to a jack. Figure 3 pictures the prototyped design. This design would allow for ease of usage, where the astronaut will simply be able to throw the device on the ground. In addition to eliminating any kinds of complex deployment processes, the design would be small enough so that it can easily be carried during missions.

Design 5: Quadrapod Prototype  
Upon considering alternate designs by creating prototypes, the prototype highlighting the quadrapod feature yielded promising results regarding stability and resilience against varying terrain. Pictures of our initial prototype are shown in Figure 4, in which we tested the quadrapod concept on various examples of geological terrain.

2.3 Weighted Decision Matrix & Final Concept Selection  
After creating our initial quadrapod prototype, we narrowed down to three more additional designs that utilized the quadrapod concept. Sketches of these designs are shown in Figure 5 below. With these three final designs, we constructed a decision matrix to identify our final design for the Tholos™ unit. This led us to create our initial prototypes, shown in Figures 9a and 9b in section 3.2. The weighted decision matrix can be found in Appendix N. While the final design we chose may suffer slightly in the areas of ease of deployment and lunar dust resistance, the telescoping rod design excelled in the areas of portability, retrievability, and color-calibration functionality, leading it to be the most effective design we came up with.
3. Concept Design
The following section provides details on our chosen design for the Tholos™ device.

3.1 Description of Tholos™ Design
Our chosen design for this competition consists of a quadrapod with an extendable stadia rod. The four legs are attached to a collar which slides along the outer stadia rod. The legs range in motion from extended (75° f

Figures 7a and 7b illustrate the leg folding mechanism design of the Tholos™ unit. The four legs are attached to a sliding collar that can travel along the outer stadia rod. Each of the four attached legs are designed as to only permit movement from the collapsed position to the extended position. When the legs are extended, they grab onto the outer stadia rod preventing movement. A flange at the bottom of the stadia rod facilitates easy extension of the legs. Since the legs only fold downwards, the risk of unintended closure is removed. An engineering drawing containing a labeled isometric view of the Tholos™ design is provided in Figure 8 below.
Figure 7: (a) Two legs folded down and the collar slid up 2/3 of the stadia rod, (b) Closeup view of collar with legs in extended and retracted positions. Rounded detail of legs is shown. Nylon Brushes located internally between the outer and inner stadia rod.

Figure 8: Tholos™ Design Concept - Isometric Drawing
The inner stadia rod extends from the outer stadia rod to reach approximately 28” in height. Nylon brushes attached to the inside of the outer stadia will help reduce friction and prevent abrasion of the color markers if dust is introduced inside the mechanism. The outer stadia rod will include linear measurement targets at the bottom, close to the sample, and alphanumeric identifiers at the top, allowing for identification even when not extended. The inner stadia rod houses the color, reflectivity, and additional linear measurement calibration targets. When closed, the outer stadia rod protects these calibration markers from damage or dust due to lunar regolith. On the top of the inner stadia rod is a 360° reflective surveying micro prism, which when used in conjunction with a stationary ground-based transit theodolite with electronic distance measurement, commonly called a total station, provides accurate real-time line-of-sight position information. The lightweight prism would provide valuable information about the location of the samples. While not required for operability, an additional optional battery-powered diode on the top would allow for increased tracking performance of the theodolite.

### 3.2 Concept Prototype

The concept prototype, which reflects the current design, is depicted in Figures 10a and 10b. The concept prototype consists of the extendable stadia rod, leg deploying collar, and legs. Additionally, calibration features such as the color calibration chart are also included in this prototype. This prototype was also built to scale for the real model.

### 3.3 Materials

Our chosen materials have been carefully selected so as to remain ductile in the low-temperature environments of the lunar surface near the location of the Artemis missions. Brittle fracture should be avoided, as it could pose a risk to the safety of the astronaut during an EVA. Furthermore, the extreme wear

![Figure 9: Tholos™ Design Concept](image)

![Figure 10: Concept prototype – (a) Collapsed; (b) Extended.](image)
caused by the lunar dust tends to warrant the use of stiff and durable materials. For this reason, we have decided that the best materials to use would be austenitic stainless steels in the AISI 300 series. Because steel is so much denser than aluminum, we will have to take note of the mass of the Tholos™ and adjust each part’s wall thickness accordingly. We plan to use this material family for the extendable stadia rod, quadrapod legs, and other features of the Tholos™ unit, with our current selection being a 302 cold-worked steel due to its stiffness.

Our design uses pool-safe materials which can be tested at the Neutral Buoyancy Laboratory. The only significant alteration to our design will be to use a pool-approved paint or adhesive to demonstrate the chromatic and reflective calibration markers. Using simulated color markers will not negatively affect pool testing, as NASA already uses standard calibration color swatches.

3.4 Manufacturability
This design was carefully developed with manufacturability in mind. The final prototype will be easy to produce with Cal Poly’s machining equipment using standard bar and tube stock. Machining operations will consist of cutting tube stock to desired lengths and utilizing a CNC mill to manufacture finer features, such as the collar. There are several locations where a press fit may be necessary, such as the flange at the bottom of the outer stadia rod. Using commercial and stock parts will be advantageous and less expensive. The nylon brush collar can be turned from a stock nylon tube. Similar manufacturing plans will be used for both flight-like and pool-safe materials. The four legs that attach to the sliding collar may be fastened on with metal dowel pins through the hole and retainers on each side. Moreover, any sharp edges will be broken to the specified radius. Overall, it is intended for fit tolerances to be large as tightly-toleranced parts may pose issues if lunar dust enters areas where the parts interface together.

4. Concept Justification
The chosen design for the Tholos™ was selected only after careful design consideration. The design was guided by the Quality Function Development chart and preliminary calculations ensured criteria satisfaction. Hazards and risks were assessed, and a safety plan was developed.

4.1 Specification Fulfillment
Table 1 below contains the engineering specifications outlined by the Micro-G NExT challenge along with the compliance status of our proposed design for each of the provided competition requirements. The number and description of each requirement is provided, along with the compliance status, level of risk, and additional notes if applicable. To determine the level of risk for each requirement, our team filled out a Quality Functional Development (QFD) chart, which can be found in our Scope of Work. The resulting weight of each requirement was assigned with a high, medium, or negligible risk level.
<table>
<thead>
<tr>
<th>No.</th>
<th>Specification Description</th>
<th>Requirement</th>
<th>Tolerance</th>
<th>Level of Risk</th>
<th>Compliance Status</th>
<th>Design Feature for Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample set of identical markers</td>
<td>5 markers</td>
<td>Min.</td>
<td>L</td>
<td>I</td>
<td>5 devices will be constructed to complete the set.</td>
</tr>
<tr>
<td>2</td>
<td>Remain independently stable at 20° incline</td>
<td>20°</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
<td>See section 4.2.</td>
</tr>
<tr>
<td>3</td>
<td>Sample marker deployed and retrieved without kneeling all the way down</td>
<td>-</td>
<td>n/a</td>
<td>L</td>
<td>I</td>
<td>The Tholos™ will stand over 30 inches tall when deployed; its retrievability will be tested during the manufacturing process.</td>
</tr>
<tr>
<td>4</td>
<td>Sample marker with unique alphanumeric identification information.</td>
<td>2” x 2”</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
<td>The Tholos™ will include a unique identifying system on the outer stadia rod.</td>
</tr>
<tr>
<td>5</td>
<td>Sample marker labeled with a color reference scale consisting of red, blue, green, black, grey, and white blocks</td>
<td>1cm x 1cm color block ea.</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
<td>The Tholos™ will include chromatic and reflectivity calibration markers along the inner stadia rod.</td>
</tr>
<tr>
<td>6</td>
<td>(a) Flight-like materials</td>
<td>-</td>
<td>n/a</td>
<td>M</td>
<td>A</td>
<td>Materials selection shall vary between the flight-ready design and the NBL testing design.</td>
</tr>
<tr>
<td></td>
<td>(b) NBL approved materials</td>
<td>-</td>
<td>n/a</td>
<td>M</td>
<td>A</td>
<td>Materials selection shall vary between the flight-ready design and the NBL testing design.</td>
</tr>
<tr>
<td>7</td>
<td>Volume of its stowed configuration</td>
<td>2” x 4” x 15”</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
<td>The Tholos™ is collapsible to be within these dimensions.</td>
</tr>
<tr>
<td>8</td>
<td>Total weight</td>
<td>1 lb.</td>
<td>Max.</td>
<td>M</td>
<td>A, I</td>
<td>Lightweight materials and minimalistic design will be used to minimize weight. (see section 3.2)</td>
</tr>
<tr>
<td>9</td>
<td>Operable with EVA gloves</td>
<td>-</td>
<td>Min.</td>
<td>M</td>
<td>T</td>
<td>The opening mechanism can be operated with limited dexterity.</td>
</tr>
<tr>
<td>10</td>
<td>Only manual power</td>
<td>0 electrical components</td>
<td>Max.</td>
<td>M</td>
<td>I</td>
<td>Only manual mechanisms are used to operate the Tholos™. An optional localizing diode would improve theodolite tracking.</td>
</tr>
<tr>
<td>11</td>
<td>No holes or openings allowing/causing entrapment of fingers</td>
<td>-</td>
<td>Max.</td>
<td>M</td>
<td>A, I, T</td>
<td>The design has removed holes and openings where fingers will be located to operate the device.</td>
</tr>
<tr>
<td>12</td>
<td>No sharp edges</td>
<td>0</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
<td>All sharp edges are broken and rounded as necessary.</td>
</tr>
<tr>
<td>13</td>
<td>Minimize and label pinch points</td>
<td>-</td>
<td>Min.</td>
<td>M</td>
<td>A, I</td>
<td>External pinch points are eliminated from the design.</td>
</tr>
</tbody>
</table>

4.2 Preliminary Calculations

One of the primary requirements for the design was to ensure that the Tholos™ unit would be able to not tip over while being placed on terrain inclines up to 20°. To ensure that our design was robust enough to sustain the worst-case scenario, preliminary calculations were done to show where the center of mass for the Tholos™ would have to be in order under a 20° slope. From our

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1 Risk of meeting specification: (H) High, (M) Medium, (L) Low
2 Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test
preliminary calculations, the center of mass for the Tholos™ would only need to be located on the lower 81% of the stadia rod (or 83% of entire device). This is a very achievable target which we will have no problem surpassing. Full results and work for our preliminary calculation are shown in Appendix D.

4.3 Design Hazards, Risks, & Safety Plans
In spaceborne environments, the well-being of astronauts must be treated as an utmost priority. During an EVA, a safety hazard posed by a piece of equipment could be the difference between a successful mission and a tragedy. As such, safety considerations have played a key role in our design process.

4.3.1 Design Hazards & Risks
A number of viable design ideas were eliminated based on the safety risks posed. This includes avoiding design elements such as springs, flexed parts, and suspended masses which, in the event of failure, could pose significant risk to the user. Additionally, pinch points posed a significant barrier in our design process; were a pinch point to puncture an astronaut’s EVA suit, catastrophic depressurization may occur, severely endangering the astronaut’s life. To add to this, we considered using the force imparted by lunar gravity as the method of stowing the legs of the Tholos™, but determined it posed too large a risk of pinching the astronaut’s EVA suits. It is for this reason that the current stowing mechanism was selected over a potentially more elaborate design. Furthermore, we decided to minimize the use of potential energy storage in our design so as to normalize and streamline the behavior of the Tholos™. An additional risk would be of impalement on the Tholos™ if the astronaut were to trip. This hazard can be minimized by ensuring the ends of the legs and top of the prism are blunt. This can be done easily by adding brightly colored rubber tips to the ends so the user is not only aware of the sharp ends, but is also protected from them. Specifics on each of the different design hazards present, as well as our plans to tackle them, can be found in Appendix O.

4.3.2 Safety Plans
Our design achieves a desired level of safety of use by first fulfilling the requirement of being able to be successfully operated without requiring the user to bend down to their knees. By minimizing the amount of motion the astronaut has to undergo in order to deploy and store the Tholos™, we also minimize the number of possibly dangerous steps they must undergo to use the device effectively. Moreover, design features that may result in finger entrapment and pinch points have been reduced. The outer retention ring blocks the fingers of the EVA suit’s gloves from coming into direct contact with the hinge joints on the legs. This design decision makes sure the primary pinch points are minimized and kept out of access of the end user. Additionally, all machined edges will be broken and subsequently verified to avoid tearing or snagging when handling.

4.4 Design Challenges & Unknowns
A primary unknown associated with this project is the addition of the prism. While the original design directive did not desire global location methods, our team feels that adding this feature would greatly improve the overall functionality of the device. For the design competition, NASA was primarily looking for a method to display its color calibration targets; however, by adding a prism, the device is now also capable of precise position tracking. This would greatly help in data acquisition and comprehension of the lunar surface. While this project is only focused on intrinsic features of the Tholos™ (in this case, the prism), a complementary ground-based transit theodolite would also need to be designed. This would be mounted in a central area such as on the exterior
of the Lunar Module or on a separate tripod. Since the physics and engineering of surveying measurement is already extensively researched, this project only focuses on the addition of the retroreflective prism, not the engineering behind light reflection for measurement purposes. If NASA desires to use this method, they will need to develop an adequate theodolite system.

Other unknowns are abundant. One large one is the method with which lunar dust will be prevented from entering the sliding mechanism between the inner (Part number 4, Figure 9) and outer (Part number 1) stadia rods. We are currently considering applying a dust-resistant coating to the inner stadia rod in order to prevent the static adhesion of abrasive regolith particles, though this is subject to change. Another unknown is the extent to which the Tholos™ could be misused—we hadn’t given this aspect of the design much consideration until recently, and we are as of yet unsure as to what further dangers the Tholos™ could pose to its end users (apart from those already listed in this document). Another big question is how the Tholos™ is going to be disposed of after its use. Being a self-supporting structure, this could be used to hold permanent scientific experiments left on the moon, or other cultural projects. Examples of previous uses applicable to adaptation for the Tholos™ are the many retroreflectors and the Moon Museum.

5. Project Management
This section discusses plans for ensuring design feasibility and implementation through project management. For a detailed overview of important project milestones and future actions, refer to the Gantt Chart in Appendix J.

5.1 Planned Analysis
The following section details the empirical, numerical, and computer-simulated testing our final design shall undergo.

5.1.1 Initial Testing
The initial testing of our design shall include terrain testing and pool testing; before manufacturing the finished project, we will test a concept model on a number of different surfaces and at different angles. Although this will have to be conducted in Earth’s gravity, further testing in a swimming pool and later at the NASA Neutral Buoyancy Laboratory will help us determine the viability of the design in low-gravity environments. See section 5.1.2 below for more information on this process.

Numerical testing shall include static analysis of the final Tholos™ design which ensures a net-zero moment at an angle of 20 degrees. Computer-aided simulation and finite element analysis may also be utilized to determine different factors of safety for the device; however, due to the low-load environments in which the Tholos™ shall be deployed, load cases likely will not significantly change the design.

5.1.2 Operation Procedures
A central requirement of NASA’s Micro-g NeXT program is that we, as designers, detail the procedures we would like to follow during the “testing” phase of the tournament at the Neutral Buoyancy Laboratory. Within these procedures, we aim to test three different critical features of our design. The first test is to assess the weight and size of the Tholos™, which also determines the size compliance of each unit. The second test will investigate the design’s operational accessibility, mechanical function, and structural stability. Lastly, the third test will investigate the Tholos™’s resistance to an abrasive environment to study its function in simulated lunar dust.
Test 1: Weight and Size Test
1. The Tholos™ is measured using a calibrated electronic balance to ensure its weight is under 1 pound.
2. The dimensions of the stowed Tholos™ are measured to ensure they fit within the 2” x 4” x 15” maximum stowed dimensions.

Test 2: EVA Ease-of-Use, Mechanism Function, and Structural Stability Test
1. The astronaut, wearing gloves to simulate those of the EVA suit, dives to the bottom of the testing pool to mimic the low-gravity environment of the moon.
2. The astronaut begins testing the ease of deployment of the Tholos™
   a. The astronaut deploys the four legs of the device by grasping the collar and pushing down
   b. The astronaut then extends the stadia rod at the center of the Tholos, preparing it for deployment.
3. Without bending down or kneeling, the astronaut places the Tholos™ on one of several different surfaces at the bottom of the testing pool designed to replicate the varied terrain of the lunar surface. The angle these surfaces form with the level ground may range up to 20° in magnitude.
4. The astronaut takes a photograph of a geological sample with the Tholos™ in frame, ensuring the color scale and alphanumeric label are present.
   a. The photograph taken will be inspected to ensure that it captures the proper photometric information needed.
5. The astronaut retrieves the Tholos™ without kneeling or bending over by gripping it by the stadia rod.
6. The Tholos™ is stowed by:
   a. Retracting the telescoping stadia rod.
   b. Folding the device’s legs and sliding the collar up into the storage configuration.
7. Steps 4 through 6 are repeated ad libitum using several plausible configurations of orientation, angle, and surface roughness.
8. Steps a. and b. for deployment (2) and stowage (6) may be performed in either order.

Test 3: Abrasion Test
1. The astronaut procures a suitable analog for lunar dust.
2. The astronaut surrounds the Tholos™ with a reasonable ground and aerial concentration of lunar dust.
3. The Tholos™ is repeatedly deployed and stowed as per the instructions outlined in steps 4 through 6 of Test 1. This is performed to test the effects of repeated exposure to abrasive dust and may be repeated up to 20 times to ensure sustained function of key systems.

5.2 Planned Purchases & Final Design Construction
Because of the limited budget of the senior project, it is crucial that we take engineering economics into account when planning the manufacture and construction of our final design. Our team has been given a starting budget of $1000 provided by the Cal Poly Mechanical Engineering Department, which was allocated for senior project funds. It is important to note that this starting budget is considered as “state funds” and, thus, cannot be used for travel or lodging to the state of
Texas. Additional fundraising and procurement of funds will take place accordingly. Table 2 provides a conservative estimate of expected expenditure associated with the proposed design.

Our plans for constructing and manufacturing each of the five required Tholos™ units involves purchasing both stock materials and COTS\(^3\) parts, along with utilizing Cal Poly’s machine shops to shape parts that require machining operations.

<table>
<thead>
<tr>
<th>Table 2. Expected Expenditures for Development of Calibration Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category</strong></td>
</tr>
<tr>
<td>Materials &amp; Supplies</td>
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<tr>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Travel</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td><strong>Total</strong> (excluding Texas trip expenditures)</td>
</tr>
</tbody>
</table>

6. Conclusion
This section contains a report summary and a section outlining next steps. The report summary provides an overview of the key points for this document, whereas the section outlining next steps will highlight the upcoming action items and milestones that must be completed in order to proceed with the project.

6.1 Report Summary
To support the upcoming Artemis missions, NASA is holding design competitions for various EVA components. For our project, we were tasked to design a photometric calibration scale. Five design prototypes were developed, and a weighted decision matrix was used to narrow down the options. The design selected consists of a low angled quadrupod with an extendable stadia rod. The design was analyzed for materials, manufacturability, and specification compliance. Preliminary calculations were performed, and risks and hazards were assessed. Planned analysis and initial testing were laid out and operational procedures were written.

6.2 Next Steps
Next steps will be creating a more thorough prototype that shows all aspects of the design to scale. This would provide a model that could be tested in a variety of environments to ensure stability, deployment, storage, and use are all consistent with the required criteria. This would also allow for further design refinement including improving the leg storage locking and nylon brush configuration. After narrowing down a final design, the best manufacturing process will need to

---

3 Commercial Off The Shelf.
be determined for each part. Parts such as the stadia rods and legs will be purchased as stock sizes and the collar and prism mounting assembly will need to be machined and/or turned. The identification numbers and colorimetric target stimulants will also need to be ordered.

References


Tholos™ – EVA Sample Location Calibration Device
Critical Design Review (CDR) Report

February 28, 2022

Presented by

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Kat Gipson
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California Polytechnic State University
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1. Introduction

NASA’s Micro-g NExT challenge is an annual competition open to undergraduate students across the nation. Each year, NASA selects several pertinent challenges in the field of space exploration and technology for students to tackle. Our team has been selected to travel to the Neutral Buoyancy Laboratory (NBL) in Houston to test their designs in simulated microgravity. In this way, participants play a direct role in the development of new designs and technologies for use by NASA engineers. This year’s projects include a lunar sample collection system, a lunar surface anchoring system, and a photometric calibrator for use on the lunar surface. Our team has chosen to pursue the calibration photo scale challenge. For the Apollo missions, astronauts used a device known as the “Gnomon” to calibrate sample photographs from the lunar surface. With this challenge, we have set out to address the issues of the Gnomon and come up with a sleek, innovative solution to the design problems at hand.

Since our preliminary design review (PDR), we have solidified a multitude of the questionable aspects of our design. First off, the internal “brushes” between the two stadia rods have been changed so simply act as spacers. These will help stabilize the two concentric stadia rods and increase the static friction holding them in place. By making this change, we can help ensure that the Tholos™ will not deploy unexpectedly. Another very important change we made was the addition of a keyway slot on the external face of the outer stadia rod. By including a mating extrusion on the collar, we can ensure that the collar, and with it, the legs, do not rotate about the stadia rod. This type of motion would pose a danger to the end user by allowing legs to “helicopter” around. Next, we decided to add brightly colored rubber tips to the ends of the legs. These tips, also called “feet”, will help the Tholos™ both grip the surfaces it is placed on and stand out from the backdrop in photographs. Furthermore, we have determined how to secure the legs during transport and pre-deployment. Rubber holsters have been secured to the outer stadia rod to hold the legs in the closed position until they are ready to be deployed. Finally, we devised a more reliable locking method to keep the Tholos™ in its deployed state during use. Two quarter-turn locking mechanisms (similar to those found in hiking poles) have been inserted into the outer stadia rod to provide a method of securing the Tholos™ in the deployed position without solely relying on static friction.

The aim of this document is to describe the design direction we have selected for this challenge. The following document is broken up into six primary sections, each of which is composed of several subsections. The second section, ‘System Design,’ explains the details of the design and the manner in which the Tholos™ functions. This section also outlines the cost breakdown of the Tholos™. The next section, titled ‘Design Justification’ includes the analyses and preliminary tests we have performed to assess the fitness of our design. This section serves to justify our choices regarding the design of the Tholos™. The fourth section, titled ‘Manufacturing Plan,’ highlights the methods in which we plan to construct each Tholos™ unit’s individual parts and subassemblies. The following section, ‘Design Verification Plan,’ outlines the tests we will perform to determine how viable our verification prototype is. Lastly, the ‘Conclusion’ section of this document summarizes the results of our analysis herein and includes key steps going forward.
2. System Design
This section provides a description of our overall final design, and is aided with details of our final design’s functionality. Both the overall design and the design’s subsystems will be described in the following sections.

2.1 Design Overview
The design of the Tholos™ was carefully crafted to meet the needs of the Micro-g NExT challenge. Conditions, such as the extreme environment in which the Tholos™ needs to operate, were given special attention. Safety was found to be of the utmost importance when dealing with extra vehicular operations.

2.1.1 Subsystems
The Tholos™ is composed of three main subsystems: the outer stadia rod, inner stadia rod, and legs. A design overview and function explanation for each respective subsystem can be found in Figure 1 below.

![EXTENDED CONFIGURATION](image)

*Figure 1: The Tholos™ is composed on multiple parts including the outer stadia rod (1), collar (2), legs (3), inner stadia rod (4), flange (5), brushes (6), and prism (7).*

Outer Stadia Rod
The outer stadia rod contains the inner stadia rod and has the collar slide along the outside. The outer stadia rod also displays the alpha-numeric labels. The alpha-numeric labels will be 2” tall and will wrap around the stadia rod. The alpha-numeric code will be printed multiple times around the length of the label and an additional binary bar strip will provide an additional confirmation of marker ID if necessary. Examples of these labels are shown in Figure 2 and Figure 4. The alpha-numeric labels were chosen to be located on the outside stadia rod so the individual device could be identified even while in the stowed position. This allows the devices to be easily kept track of and so the same Tholos™ can be identified and used. The outer stadia rod will also feature a keyway slot along the length of it which will constrain the collar, preventing the legs from spinning around.

The flange will be attached using a press fit onto the bottom of the outer stadia rod and will assist with spreading the legs during deployment. The flange will also be manufactured out of a type of plastic to reduce weight.

**Inner Stadia Rod**

The inner stadia rod slides inside the outer stadia rod and contains the color calibration targets. By having the inner stadia rod collapse inside the outer stadia rod, the inner stadia rod is protected from lunar regolith and dust from handling and accidental dropping. The inner stadia rod will contain the required red, green, blue, black, grey, and white color markers on the color calibration target. An example of the color calibration target can be seen in Figure 2. The markers will be applied vertically, around the stadia rod and will be 1cm tall. This will provide an additional linear calibration system. Plastic brushes will be located between the inner and outer stadia rod to accommodate the material gap, reduce friction, and minimize wear from lunar regolith. Color markers will be protected by a thin, translucent coating to avoid being scratched by stray dust.

The 360˚ prism fits on top of the inner stadia rod with an additional device which is press fit into the inner stadia rod and has a hole for a ¼ threaded screw. The prism will be fastened onto this device so that it may be attached to the inner stadia rod. The prism will be used in conjunction with a ground-based transit theodolite to provide polar position information. The specific design of the prism is outside the scope of this study as extensive research and entire industries are devoted to surveying prism design.

**Legs**

The legs are built from ¼ inch hollow aluminum square tubing and are the length of the stadia rods. The hollow design was chosen to reduce weight while maintaining strength. The ends of the tubes have a 15˚ cut with a fillet which will allow the legs to move from the stowed position (0˚) to the extended position (75˚), as seen in Figure 3. A hole for the connection to the collar will be concentric with the fillet which has a radius half the width of the square tubing. The ends of the legs will feature plastic type tips which will decrease the puncture risk. Additionally, the legs will

---

**Figure 2:** Each color target will be 1cm tall and will wrap around the inner stadia rod.
be applied with high visibility material so as to contrast from the grey environment of the moon and NBL. This is once again done to increase the safety of the device by reducing the probability of inadvertently hitting the legs. One of the legs will also feature a linear scale bar, which will allow for a scale to be included for up close photos of samples. An example of this scale is shown in Figure 4. Note the scale shown is rotated 90°. The height of the major bars will be 1cm and the width of the minor bars will be 0.5cm. The height of the minor bars is 1mm and are offset to align with the major bar behind.

The collar slides along the outer stadia rod and connects the four legs. The collar allows the legs to move from the collapsed and extended position, and the assembly slides along the outer stadia rod. A screw in the collar fits into the keyway on the stadia rod to prevent the legs and collar from spinning. The top of the collar is flat and provides a safe place for the astronaut to push the legs down. A model of the collar is shown in Figure 5. The leg mechanism was designed to minimize and eliminate pinch points. To minimize weight, the collar will be fabricated out of plastic.

For detailed part drawings, see Appendix A. The indented bill of materials for the design can be found in Appendix B.

### 2.2 Summary Cost Breakdown

Below is a summary of the costs associated with each subsystem for the verification prototype. This summary excludes manufacturing costs, and only is associated with material costs since we will not be outsourcing any manufacturing. A more detailed breakdown is provided in the Project Budget, which is found in Appendix C. The Project Budget shows all completed and planned purchases of each item. Additionally, the indented bill of materials, located in Appendix B, lists the costs of each part along with the chosen vendor and other part information.

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Stadia Rod</td>
<td>$28.18</td>
</tr>
<tr>
<td>Inner Stadia Rod</td>
<td>$22.48</td>
</tr>
<tr>
<td>Legs</td>
<td>$23.76</td>
</tr>
<tr>
<td>Cost of 1 Tholos™ Unit</td>
<td>$74.41</td>
</tr>
</tbody>
</table>

### 3. Design Justification
The following sections describe the specifications that need to be fulfilled, and how the design will fulfill said specifications. Additionally, the safety and repairability of the design are discussed, as well as any remaining concerns.

### 3.1 Design Specification Fulfillment

NASA has provided design specifications as part of the Micro-g NExT challenge [1]. The engineering specifications table below was used to assess the provided specifications and complementary design choices. This allowed for a focused design approach to specifically craft the design to meet the product requirements.

#### Table 2: Engineering Specifications

<table>
<thead>
<tr>
<th>No.</th>
<th>Specification Description</th>
<th>Requirement</th>
<th>Tolerance</th>
<th>Level of Risk</th>
<th>Compliance Status</th>
<th>Design Feature for Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample set of identical markers</td>
<td>5 markers</td>
<td>Min.</td>
<td>L</td>
<td>I</td>
<td>5 devices will be constructed to complete the set.</td>
</tr>
<tr>
<td>2</td>
<td>Remain independently stable at 20° incline</td>
<td>20°</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
<td>See section 4.2.</td>
</tr>
<tr>
<td>3</td>
<td>Sample marker deployed and retrieved without kneeling all the way down</td>
<td>-</td>
<td>n/a</td>
<td>L</td>
<td>I</td>
<td>The Tholos™ will stand over 30 inches tall when deployed; its retrievability will be tested during the manufacturing process.</td>
</tr>
<tr>
<td>4</td>
<td>Sample marker with unique alphanumeric identification information.</td>
<td>2” x 2”</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
<td>The Tholos™ will include a unique identifying system on the outer stadia rod.</td>
</tr>
<tr>
<td>5</td>
<td>Sample marker labeled with a color reference scale consisting of red, blue, green, black, grey, and white blocks</td>
<td>1cm x 1cm color block ea.</td>
<td>Min.</td>
<td>L</td>
<td>I, S</td>
<td>The Tholos™ will include chromatic and reflectivity calibration markers along the inner stadia rod.</td>
</tr>
<tr>
<td>6</td>
<td>(a) Flight-like materials</td>
<td>-</td>
<td>n/a</td>
<td>M</td>
<td>A</td>
<td>Materials selection shall vary between the flight-ready design and the NBL testing design.</td>
</tr>
<tr>
<td></td>
<td>(b) NBL approved materials</td>
<td>-</td>
<td>n/a</td>
<td>M</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Volume of its stowed configuration</td>
<td>2” x 4” x 15”</td>
<td>Max.</td>
<td>M</td>
<td>A, I</td>
<td>The Tholos™ is collapsible to be within these dimensions.</td>
</tr>
<tr>
<td>8</td>
<td>Total weight</td>
<td>1 lb.</td>
<td>Max.</td>
<td>M</td>
<td>A, I</td>
<td>Lightweight materials and minimalist design will be used to minimize weight. (see section 3.2)</td>
</tr>
<tr>
<td>9</td>
<td>Operable with EVA gloves</td>
<td>-</td>
<td>Min.</td>
<td>M</td>
<td>T</td>
<td>The opening mechanism can be operated with limited dexterity.</td>
</tr>
<tr>
<td>10</td>
<td>Only manual power</td>
<td>0 electrical components</td>
<td>Max.</td>
<td>M</td>
<td>I</td>
<td>Only manual mechanisms are used to operate the Tholos™. An optional localizing diode would improve theodolite tracking.</td>
</tr>
<tr>
<td>11</td>
<td>No holes or openings allowing/causing entrapment of fingers</td>
<td>-</td>
<td>Max.</td>
<td>M</td>
<td>A, I, T</td>
<td>The design has removed holes and openings where fingers will be located to operate the device.</td>
</tr>
<tr>
<td>12</td>
<td>No sharp edges</td>
<td>0</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
<td>All sharp edges are broken and rounded as necessary.</td>
</tr>
<tr>
<td>13</td>
<td>Minimize and label pinch points</td>
<td>-</td>
<td>Min.</td>
<td>M</td>
<td>A, I</td>
<td>External pinch points are eliminated from the design.</td>
</tr>
</tbody>
</table>

#### 3.1.1 Calculations & Analyses

1 Risk of meeting specification: (H) High, (M) Medium, (L) Low
2 Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test
Calculations were done to identify the maximum tilt angle for the device when placed on terrain, as well as buckling analysis for the legs of the Tholos™. The calculations for the maximum tilt angle are shown in Appendix D, and the calculations for the buckling analysis are shown on Appendix E. The buckling calculations were done with an Excel spreadsheet that calculates the required parameters for buckling analysis. From the buckling analysis, the resonant frequency of the legs was also calculated, which is a useful metric when considering the vibrational loads that the Tholos™ device may experience when being launched into space. Key takeaways of our analysis include the fact that the legs, even with the hollow design, should be able to withstand significant axial loads without buckling. The factor of safety calculation for the legs buckling assumes the astronaut and their suit have a collective mass of 115 kg and that they strike a single Tholos™ leg at 4 meters per second. With these parameters, the factor of safety of the legs buckling is 2.5.

3.1.2 Prototype Tests
We are still in the process of building our prototype. All the parts are manufactured, they just need to be assembled and then we can begin testing the prototype. From what we have accomplished so far, we learned that the inner stadia rod will be shorter in length than the outer stadia rod since part of the flange is located within the outer rod.

3.2 Safety, Maintenance, & Repair
The design was analyzed for potential safety risks and failure modes by performing a Failure Mode & Effect Analysis (FMEA) report, shown in Appendix H, and a design hazard checklist, shown in Appendix I. Due to the extreme and mission critical nature of space, safety was carefully considered in all of the design decisions. Pinch points were minimized, and the legs were designed to only fold down and out to prevent the legs from inadvertently hitting an astronaut. Protective tips and high visibility material were also added to the legs for safety. A keyway was also added to the outer stadia rod to constrain the legs as to only move up and down, preventing the legs from spinning.

3.3 Remaining Concerns
A remaining concern would be that of the leg locking mechanism. With our structural prototype, it became evident that close consideration of the leg and collar manufacturing and tolerances would be of utmost importance. Therefore, we would like to continue to investigate the leg locking mechanism and confirm it will perform as expected.

4. Manufacturing Plan
The information covered in this section includes how the verification prototype will be manufactured. Details on the procurement of necessary parts and materials, the manufacturing operations involved, and the assembly process will be discussed.

4.1 Procurement
To construct the verification prototype, all parts listed on the indented bill of materials (see Appendix B) must be purchased. The indented bill of materials includes the name of the part of interest, the name of the vendor, cost, and a link leading to the product page online. If a part does not list a price, then there is no need for it to be purchased. However, it is important to note that some of these parts have no cost listed for them because they are identified as modified or built parts. Some items such as fasteners for the Theodolite holder have no vendor specified, as they are common items that may be purchased at any hardware store that holds these fasteners. Procurement purchases for the specified materials can be made through our sponsor, NASA. The stipend
awarded to the team for submitting milestone deliverables on time will not be sent to the school directly, but instead will be used by NASA to cover a variety of costs. These costs can include purchasing costs for materials, along with shipping and/or lodging expenses. Additionally, purchases that have already been made by individual team members are able to be reimbursed.

4.2 Verification Prototype Manufacturing Steps & Assembly
A detailed manufacturing plan, shown in Appendix F, was produced and reviewed by a shop technician from the Cal Poly Machine Shops in order to construct our verification prototype. The manufacturing plan outlines the different manufacturing steps required and identifies the tools and machines to be used for manufacturing. Assembly steps are also provided at the end of the manufacturing plan. All of the steps sequenced for manufacturing and assembly below are included in the Project Gantt Chart, which can be found in Appendix J.

4.2.1 Manufacturing Steps
Below lists the sequences for all manufacturing operations that must be done in order to produce the verification prototype. It is important to note that we are currently still in the process of deciding what procedure to take for the leg securing mechanism; once information regarding the material can be verified with NASA, the manufacturing plan will be updated.

**Outer Stadia Rod**

**Outer Stadia Body**

**Circular Saw**
1) Cut ¾” ID hollow aluminum bar stock to a length of 15”.

**Manual Mill**
2) Machine 0.13” x 15” rectangular slot into outer surface of bar.
3) Deburr cut edge of aluminum to remove burrs from cutting.

**Brush Collar**

**Manual or CNC Machining**
1) Have shop tech write G-code for brush collar from SolidWorks file.
2) Machine two brush collars per Tholos™ unit.

**Leg Securing Mechanism**
***NOTE: confirm with NASA which rubbers/plastics are acceptable

1) OPTIONS:
   a. Rubber/Plastic Injection molding
      i. Ask IME instructor about the process.
      ii. At home kit (3D print structure to use as mold template).
   b. Modifications:
      i. Buy rubber/plastic ring with slight interference with outer stadia.
      ii. Buy snap-in pen holders and cut four pieces to length of ring.
      iii. Adhere holders to ring.

**Leg Flange**

**CNC Mill**
1) Cut 2” plastic solid bar stock to length of .35”.
2) Use lathe to turn part
3) Machine 1 flange per Tholos™ unit in CNC.
**Alpha-Numeric Label**

**UGS [outsource]**

1) Send PDF file containing alpha-numeric code design to be printed as a vinyl sticker to Cal Poly UGS.
2) Identify alpha-numeric code for each Tholos™ model.
3) Use graphics software to create each label and print the labels on a printable, waterproof, vinyl-based adhesive sticker sheet.
4) Once printed, use an x-acto knife and a straight edge to cut each alpha-numeric label to size.

**Inner Stadia Rod**

**Inner Stadia Body**

**Circular Saw**

1) Cut ¾” OD aluminum hollow tube stock to 15”.
2) Deburr cut edge of aluminum to remove burrs from cutting.

**Theodolite Holder**

**Drill**

1) Obtain procured cap and drill a ¼” hole in the middle using a #7 size drill bit (referred tap chart).
2) Select a ¼”-20 size tap and insert the tap into the drilled hole to create threads.

**Color Calibrator**

**UGS [outsource]**

1) Send PDF file containing color calibrator design to be printed as a vinyl sticker
2) Use graphics software to create a color calibrator design and print the design on a printable waterproof adhesive.
3) Once printed, use an x-acto knife and a straight edge to cut the color calibrator label to size.

**Legs**

**Sliding Collar**

**Chop Saw**

1) Cut 2” diameter plastic solid bar stock to a length of 2”.
2) Use Manual Mill to machine final part.

**Device Legs**

**Chop Saw**

1) Cut four pieces of ¼” square aluminum tubing to 18” in length.
2) Demarcate end fillets and hole locations using a magic marker.
3) Use water jet to create fillets and chamfers.
4) Locate and pre “drill” holes.

Drill Press

5) Drill 5/64” holes at hole locations.

Deburring Tool

6) Deburr all cut edges and holes.

4.2.2 Assembly Steps
A sequence of assembly steps is listed below.

Top Assembly

Brush Collar

Press Fit
1) Press fit one brush collar to each end (internally) of the outer stadia.

Leg Securing Mechanism

Press Fit
1) Manually fit over end of outer stadia leaving 0.35” for the flange.

Leg Flange

Press Fit
1) Press fit flange on end of outer stadia at the same end as locking mechanism.

Alpha numeric label

Adhesion
1) Apply the cut alpha-numeric labels onto the appropriate area of each Tholos™ device (one label per device).

Color Calibration Label

Adhesion
1) Apply the cut color-calibrator label adhesive onto the appropriate area of the Tholos™ device (one label per device).

Theodolite Holder

Threading
1) Attach theodolite prism by screwing on theodolite onto threaded hole of cap.
2) Attach theodolite holder onto the top of the inner stadia rod.

Bottom Assembly

Feet (ends of leg)

Press Fit & Adhesion
1) Purchase ¼” rubber caps.
2) Place a drop of pool-safe epoxy within each rubber cylinder.
3) Press rubber feet onto the end of each leg.
Final Assembly

**Stadia Rod Assembly**
1) Insert inner stadia rod assembly into outer stadia rod assembly.

**Leg Assembly**
1) Place each leg in the sliding collar such that the holes in the legs align with the pinholes in the collar.
2) Attach each leg to the sliding collar with 2mm diameter pins. Secure each side of the pin with a retaining ring so that the pin does not slide out.

5. Design Verification Plan

There are a number of tests we plan on performing to determine the viability of our Verification Prototype. This step is crucial to the success of our project; we need to know that the Tholos™ will be able to function properly when we bring it to Houston. For this reason, it is imperative that we test the Tholos™ in San Luis Obispo. We will test each of the criteria detailed in Appendix G to ensure that all standards set by NASA are met. A description of each of the following specifications included in the design verification plan is listed in the table below.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The device needs to withstand a 20-degree slope</td>
<td>Place Tholos™ on a 20-degree slope when extended and verify the device remains upright. Increase slope and note when the device falls over.</td>
</tr>
<tr>
<td>2</td>
<td>The device needs to fit within a 2&quot;x4&quot;x15&quot; volume</td>
<td>Measure the Tholos™ with calipers and/or ruler and ensure the device fits within required volume.</td>
</tr>
<tr>
<td>3</td>
<td>1 lb. max weight</td>
<td>Weigh the Tholos™ on a scale.</td>
</tr>
<tr>
<td>4</td>
<td>Alpha numeric label size</td>
<td>The alpha numeric label is 2&quot; x 2&quot;.</td>
</tr>
<tr>
<td>5</td>
<td>Reference scale size</td>
<td>Each reference color should be at least 1cm x 1cm.</td>
</tr>
<tr>
<td>6</td>
<td>Reference scale colors</td>
<td>The reference scale should include red, blue, green, black, grey, and white colors.</td>
</tr>
<tr>
<td>7</td>
<td>Sample set includes 5 devices</td>
<td>The sample marker set must include 5 markers.</td>
</tr>
<tr>
<td>8</td>
<td>EVA Operability: Handling</td>
<td>The device is operable with EVA gloves.</td>
</tr>
<tr>
<td>9</td>
<td>EVA Operability: Deployment</td>
<td>The device can be deployed and retrieved without kneeling.</td>
</tr>
<tr>
<td>10</td>
<td>Manual Power</td>
<td>The sample marker uses manual power only.</td>
</tr>
<tr>
<td>11</td>
<td>User safety</td>
<td>The device minimizes pinch points, entrapment points, and sharp edges. Pinch points are labeled.</td>
</tr>
</tbody>
</table>

Lastly, specifications 1, 4, 5, and 13 will be verified through visual inspection. Our final test will be a load test on the cross section of leg to determine whether each Tholos™ unit will be able to tolerate the loads and stresses involved with its use cases (and potential misuse cases). Ideally, the Tholos™ should yield without breaking in a brittle manner, hopefully preventing the lunar astronaut’s EVA suit from being punctured. We will perform a load test and complete uncertainty propagation for a final, real factor of safety.

5.1 Maintenance & Repair

The lifespan of one Tholos™ unit is, in actuality, not very long. Because the Artemis III mission is only going to take between 1 and 2 weeks, each Tholos™ unit only must last that long. The Tholos™ must, however, be resilient due to the harsh conditions of the lunar surface. For this
reason, we’ve attempted to find a middle ground between structural integrity and overall costs. When the astronauts leave the lunar surface, the Tholos™ units they have deployed will be left behind. Because NASA intends to instruct the astronauts to discard the Tholos™ units after the mission, neither maintenance nor repair is of concern. If a Tholos™ is to break during use, it should simply be discarded and replaced to save both the astronauts’ time and energy.

6. Conclusions
This section contains a report summary and a section outlining the next steps. The report summary provides an overview of the key points for this document, whereas the section outlining next steps will highlight the upcoming action items and milestones that must be completed in order to proceed with the project.

To support the upcoming Artemis missions, NASA is holding design competitions for various EVA components. Upon doing preliminary design analyses and further refining the design, a structural prototype was used to further refine the design and test for specification fulfillments. This led to specifying the materials and manufacturing steps for a verification prototype, which will be used to verify that the design is able to fully meet the required specifications. Preliminary calculations for the maximum tilt angle and leg buckling were performed, and risks and hazards were re-assessed and included in an updated Design Hazard Checklist. Planned analysis and initial testing were laid out and operational procedures were written.

The next steps will be creating a verification prototype that represents the full-scale Tholos™ device with all of its intended functions. This model will be tested with procedures mentioned in the Design Verification Plan, in which the model will be tested to ensure that it fully fulfills the engineering specifications described in the Micro-g NExT requirements. Once the design verification plan has been completed, results from the conducted tests will be used to determine any necessary modifications and improvements to the design. These modifications will lead to the final design of the Tholos™ device. Once the final design is solidified, parts for manufacturing will be procured and a set of 5 devices will be manufactured. Once the set is complete, it will be sent to the Natural Buoyancy Lab for testing.

References
Tholos™ – EVA Sample Location Calibration Device
Final Design Review (FDR) Report

June 5, 2022

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1. Design Updates

A few changes were made to the final design since our presentation of the CDR. These changes are outlined in the sections below.

1.1 VELCRO® Strap

In order to secure the legs in place when the Tholos™ is stowed, we added a VELCRO® strap. This strap secures the legs by wrapping around the legs and outer stadia rod, holding them in place. The VELCRO® strap has a bright red canvas handle at the end so as to be easily manipulated by astronauts wearing EVA gloves. The VELCRO® selected has a relatively smooth hook side to ensure that it would not snag or attach itself to other articles of clothing or materials. The strap was attached to one of the legs through the use of a washer and a rivet. As seen in Figure 1, the strap is thick and sturdy for ease-of-use while wearing gloves.

![Figure 1: The black VELCRO® with red handle attached to a leg with a rivet.](image)

1.2 Stadia Rod & Leg Shortening

In order to better conform our design to the strict volume and weight requirements imposed by the competition, we decided to decrease the length of some of our components. Specifically, the inner stadia rod was shortened to 11.5 inches in length, while the legs and outer stadia rod were each shortened to 12 inches in length. We found that these proportions served to allow the Tholos™ to still fulfill the other functionality requirements, such as withstanding a 20-degree slope, while also getting each unit into the desired size range. This new component can be seen in more detail in Figure 2.
1.3 Reflective Tape

In order to increase the safety of the legs, yellow reflective 3M tape was adhered to the end of each of the four legs. This helps to improve contrast during pool testing and allows for increased spatial awareness. Figure 3 highlights this yellow reflective tape on the “feet” of each leg.

1.4 Outer Stadia Rod Inner Diameter

The second shipment of material received from Metals Depot had a different inner diameter (ID) for the outer stadia rod. The second shipment had a larger ID which was better for the design. While it was concerning that the two shipments of materials received were not the same, the second shipment size benefited the design. We were able to make the thickness of the outer rod thinner and the brushes thicker which reduced the weight of overall unit. Minor adjustments were made to the dimensions of the brushes to account for the change.

1.5 Prism Analogue

Since commercially available 360 mini prisms cost several hundred dollars, a prism analogue substitute was manufactured for the device. The analogue was turned from Delrin® and contained...
a hole which attaches to the ¼-20 screw inserted in the inner stadia cap. The analogue prisms can be seen in Figure 4 without the reflective surface. Red reflective 3M tape was originally affixed to the prism to represent the optical surface with the color red being chosen as that is the color of commercially available prisms. However, engineers at the NBL expressed that red is used in the pool to signify hazardous no touch zones. While it would be permissible to keep the red color if we inform divers it is safe to touch, we procured white reflective tape to be swapped with the red tape when we arrive in Texas. This will help to minimize confusion during testing.

![Prism analogue shown without reflective tape around the center section.](image)

2. Manufacturing

The manufacturing of the Tholos™ devices involved the use of a number of different machine-tools, including lathes, manual mills, grinding wheels, drill presses, and band saws. The manufacturing process is described in the following section of this report.

2.1 Part Procurement

The verification prototype used a number of materials and parts that needed to be procured, either from online or local vendors. The majority of this stock material came from either McMaster-Carr or MetalsDepot. Funding for these materials was acquired via the M.E. department. See Appendix C. for a more detailed cost breakdown.

2.2 Outsourcing

To make our verification prototype, no outsourcing was needed. The well-equipped machine shops at Cal Poly have allowed us to fabricate each physical part in-house. These include the color calibration labels and the alpha-numeric labels, as we are utilizing Cal Poly’s on-campus printers to produce them.
2.3 Verification Prototype Manufacturing

The verification prototype consisted of components that were machined using campus resources. Alongside these processes, our team has gained a considerable amount of knowledge regarding manufacturing and machining operations. Each section below outlines the manufacturing steps for each component within a subassembly of the Tholos™. Alongside these descriptions, images are included when applicable.

2.3.1 Manufacturing Steps

In general, five units were to be constructed to fulfill NASA’s requirement of having a set of 5 devices. The manufacturing steps described below are not described in order; some manufacturing was done in parallel with other operations to save time (i.e., one team member worked on manufacturing one part meanwhile another team member was manufacturing another part on another machine). Sections of our updated manufacturing plan will be included into their respective sections below. The material safety data sheets (MSDS) for Acetal Copolymer, Al 6061, Carbon Steel, and Delrin are attached in Appendices P-S.

OUTER STADIA ROD

1) Cut ¾” ID hollow aluminum bar stock to a length of 12”.

2) Face the ends of the part to size

3) With standard vice, machine 0.044” width and .050” depth rectangular slot into outer surface of bar. The length of the slot to determined by the collar screw location to ensure the top or bottom of the collar is always flush with the top and bottom of the rod.

4) With rotary vice, continue rectangular slot on each end making an ‘L’ shape going in the clockwise direction for 45°.

5) Deburr cut edge of aluminum to remove burrs from cutting.

OUTER STADIA BODY

Circular Saw

Lathe

Mill

BRUSHES

Lathe

LEG SECURING MECHANISM

1) Cut VELCRO® strips to size with scissors

2) Attach cut VELCRO® to one leg with adhesive or rivet
**FLANGE**

**Lathe**

1) Face the Delrin® rod  
2) Turn down the part to specified diameter  
3) Use compound slide to create angled flange  
4) Using the tailstock, drill the center of the flange for water escapement  
5) Taper the insertion end for easy assembly  
6) Part the piece

**ALPHA-NUMERIC LABEL**

**Printer**

1) Identify alpha-numeric code for each Tholos™ model.  
2) Use graphics software to create each label and print the labels on a printable, waterproof, vinyl-based adhesive sticker sheet.  

**X-acto Knife**

3) Once printed, use an x-acto knife and a straight edge to cut each alpha-numeric label to size.

**INNER STADIA ROD**

**INNER STADIA BODY**

**Circular Saw**

1) Cut ¾” OD aluminum hollow tube stock to 15”.

**Lathe**

2) Turn down the outer diameter to size

**Deburring Tool**

3) Deburr cut edge of aluminum to remove burrs from cutting.

**THEODOLITE HOLDER**

**Lathe**

1) Use a lathe to face the part.  
2) Turn down the diameter to 0.75”  
3) Turn down the inset portion diameter to 0.620”  
4) Using the tailstock, drill the ¼” mounting hole.  
5) Insert a 7/16” end mill into the tailstock to remove the inside material  
6) Taper the inset for easy insertion  
7) Part the piece using a lathe parting tool

**COLOR CALIBRATOR**

**Printer**

1) Use graphics software to create a color calibrator design and print the design on a printable waterproof adhesive.  

**X-acto Knife**

2) Once printed, use an X-acto knife and a straight edge to cut the color calibrator label to size.
SLIDING COLLAR

**Lathe**
1) Face the Delrin® rod
2) Turn down the outer diameter
3) Drill and bore the inner diameter
4) Part the piece

**Mill**
5) Use a ¼” end mill to cut the slots and inside corners to the part

**Mill (another)**
6) Use a rotary vice to hold the part and position the holes.
7) Use a drill bit to drill the holes, rotating the rotary vice 90° each time

DEVICE LEGS

**Chop Saw**
1) Cut four pieces of ¼” square aluminum tubing to 18” in length.
2) Demarcate end fillets and hole locations using a permanent marker and calipers to score.

**Sander**
3) Sand the legs to a 15° angle

**Drill Press**
4) Use a hole placement jig to drill 7/64” holes at specified locations.

**Deburring Tool**
5) Deburr all cut edges and holes

**Test**
6) Test the legs for fit within the collar slot

2.3.2 Outer Stadia Rod Subassembly

The outer stadia rod subassembly consists of the outer stadia rod itself, the flange, and the collar-leg locking mechanism. The manufacturing for each of these features are described below.

**Outer Stadia Rod Manufacturing**

The outer stadia rod was manufactured using procured 1” diameter aluminum tube stock. The stock was cut to size on an abrasive circular saw (*Figure 5 (a)*), and the edges were deburred. Once the outer stadia rods were placed in the lathe chuck, each end was faced off to ensure that all burs from the abrasive saw were removed. The setup of the lathe was similar to what is pictured in *Figure 6 (a)*, which was also used for the inner stadia rod. To create the “keyway” slot, the outer stadia rod was secured on a mill. An endmill cut out the length of the slot as seen in *Figure 5 (b)*. The part was then transitioned into a rotary vice to cut the “legs” with the endmill.
Figure 5. Left: Inner & outer stadia rods after being cut to length with abrasive saw; Right: Slot being milled on outer stadia rod

**Flange Manufacturing**

The flange was manufactured using procured 2” diameter Delrin® rod stock. The flange was primarily a lathing operation, in which a lathe was used to turn down the flange. The compound slide was used to produce an angled cut as shown in *Figure 6*. A slight taper on the extrusion on top of the flange allows for it to be pressed into the outer stadia rod and fit snugly. A water escapement hole should be drilled in the center for pool testing. The setup and procedures used to cut the Delrin® stock on the lathe are shown in *Figure 6*.

Figure 6. Left: setup used to lathe 2” Delrin® stock; Middle: lathe turning down Delrin® stock to desired size; Right: manufactured flange.

**Collar-Leg Locking Mechanism Manufacturing**

The locking mechanism for the legs was a complex manufacturing process, which required accuracy and precision to ensure effective locking of the legs. A rotary vice was used in conjunction with the manual mill to allow us to drill holes coincident to the collars surface and tangent to the outer stadia rod’s surface. This process can be seen in *Figure 7* below.
2.3.3 Inner Stadia Rod Subassembly

The inner stadia rod subassembly consists of the inner stadia rod, the inner stadia rod cap, and the theodolite analogue. The manufacturing processes for these parts are discussed below.

**Inner Stadia Rod Manufacturing**

The outer stadia rod was manufactured using procured 1” diameter aluminum tube stock. First, the stock was cut to size on a lathe, and the edges were deburred. Each inner stadia rod was then turned down to the diameter specified on the part drawing for the inner stadia rod. Because the available tube stock options did not have an optimal diameter size for our design, we purchased stock with a slightly larger outer diameter to ensure there is enough material to turn the outer diameter of the inner stadia rod to the correct size. An image of the lathe setup and the lathe in action with the inner stadia rod are shown in Figure 8.
Inner Stadia Rod Cap (Theodolite Holder) Manufacturing

The inner stadia rod cap was made out of Delrin® rod stock of a different diameter. It is important to note that although the Delrin® used for the flange, collar, and analogue prism (black Delrin®) is not different from the Delrin® used for the inner stadia rod cap (white Delrin®)—the only difference is the color. The inner stadia rod cap was primarily a lathe operation, in which the white Delrin® stock was turned down to the proper size and the geometry shown was made with different cutting tools. The inner stadia rod cap was turned down to a diameter such that it would fit snugly into the inner stadia rod at the top. A hole goes through the cap; this hole serves the purpose of mounting the 360° prism with a standard ¼” connection. An image of the manufactured inner stadia rod cap is shown in Figure 9.
Theodolite Analogue Manufacturing

Additionally, the theodolite analogue was also manufactured on the lathe. It was turned from black Delrin® to the specifications outlined in the manufacturing drawings.

2.3.4 Leg Subassembly

The leg subassembly consists of the legs themselves, as well as the collar they attach to. The sections below describe the manufacturing performed for each component.

**Leg Manufacturing**

The legs were manufactured out of square aluminum tube stock. To cut each leg to size, a hacksaw was used. Once the ends of the legs were deburred, the legs were taken to the metal grinding wheel shown in Figure 11. Through using a protractor to mark how to angle the legs to achieve a 15° cut, the legs were ground to reflect this angle. Afterwards, the legs were ground slightly more to round out the edges near the cut so that they may move as intended while assembled to the collar. To make the pin holes in each leg, a centerpunch and scribe were used to carefully locate and drill the hole with a drill press and a #29 drill bit. An additional hole was drilled on one of the legs halfway down for the VELCRO® rivet attachment. An image of the legs once rounded is included below; the leg in this picture is prepared to be drilled through.
Collar Milling

The collar was manufactured out of the same Delrin® used for the flange. First, the Delrin® was faced on a lathe and turned down to size. The inner diameter was drilled and bored. Figure 13 shows the collar after its lathe procedure. After parted, the piece was transitioned to the mill. The slots on the top and inner corners were cut with an end mill. The part was then transferred to a rotary vice for hole placement. After a hole was drilled, the part could be rotated 90° into the next position. The setup and process for the collars is similar to what is shown in Figure 14, where Delrin® was being turned on the lathe for the flange. Once the lathe operations were complete, the collar was set into the manual mill as shown in Figure 12. Lastly, the collar is placed in a rotary vice, which is used to drill the pin holes. To maintain both setups, two manual mills were required: one with a regular vice, and one with a rotary vice.

Figure 12. Left: Setup with regular vice; Right: Collar during mill operation.

Figure 13. Collars after lathe procedure.
2.4 Challenges & Lessons Learned

The development of the verification prototype has brought some challenges to light, which in turn has allowed us to learn valuable lessons regarding our design. First, the fact that the design is to be submerged underwater during testing, which differs from the final product’s actual implementation, means that we need to consider the effects of buoyancy. Without this consideration, there could be issues with the Tholos™ retaining water; for this reason, we added a narrow hole into the bottom of the flange to allow for drainage. Next, we realized that the most crucial dimensions are those which dictate the placement of the holes within the collar subassembly and the angles of the legs. If these holes are out of tolerance, the design can easily fail to hold itself up. In order to fix this problem, we designed a small jig assembly for use during manufacturing in order to ensure an even and consistent drilling operation. We were able to mark a 15° angle on each leg, but since they were ground down by hand (Figure 15), the tolerance of each leg was too great. If the future, water jetting the legs would keep the dimensions within tolerance and provide better support to the stadia rods. Lastly, it is important to note the areas of highest wear in the system. As the leg flanges slide directly against a material of similar hardness (i.e., the outer stadia rod), they tend to wear and deform over time. While this does not affect the efficacy of the Tholos™ in the short term, it is something we need to include in our final report to NASA.
3. Design Verification

The Tholos™ was designed as part of the Micro-g NExT challenge and as such needed to conform to a set of qualitative and quantitative requirements specified in Table 1. The design verification included testing the device to ensure compliance with the provided criterion. Results of our design verification can be seen in Table 2.

<table>
<thead>
<tr>
<th>No</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The sample marker set includes five sample markers.</td>
</tr>
<tr>
<td>2</td>
<td>Each sample marker is placed on the lunar surface and a boulder up to a 20° incline and remain independently stable.</td>
</tr>
<tr>
<td>3</td>
<td>Each sample marker is deployed and retrieved without the crew member kneeling all the way down to their knee.</td>
</tr>
<tr>
<td>4</td>
<td>Each sample marker includes a 2” x 2” label with unique alphanumeric identification information (ex. A1, 01-A, 1A).</td>
</tr>
<tr>
<td>5</td>
<td>Each sample marker includes a label with a color reference scale consisting of red, blue, green, black, grey, and white blocks at least 1 cm x 1 cm each. Note: no specific RGB color codes are required.</td>
</tr>
<tr>
<td>6a</td>
<td>The proposed sample marker design uses flight-like materials and adhere to all requirements.</td>
</tr>
<tr>
<td>6b</td>
<td>The sample markers built for NBL testing is made for an underwater testing environment and made from NBL approved materials. A waiver may be granted on a case-by-case basis.</td>
</tr>
<tr>
<td>7</td>
<td>Each sample marker fits within a volume of 2” x 4” x 15” in its stowed configuration.</td>
</tr>
<tr>
<td>8</td>
<td>The total weight of each sample marker is less than 1 lb.</td>
</tr>
<tr>
<td>9</td>
<td>Each sample marker is operable with EVA gloved hands (like heavy ski gloves).</td>
</tr>
<tr>
<td>10</td>
<td>Each sample marker uses only manual power.</td>
</tr>
<tr>
<td>11</td>
<td>No holes or openings allowing/causing entrapment of fingers on the sample markers.</td>
</tr>
<tr>
<td>12</td>
<td>No sharp edges on the sample markers.</td>
</tr>
<tr>
<td>13</td>
<td>Minimize and label pinch points.</td>
</tr>
</tbody>
</table>
### 3.1 Testing Results

**Table 2: Design Verification Test Results**

<table>
<thead>
<tr>
<th>No</th>
<th>Requirement</th>
<th>Result</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The sample marker set includes five sample markers.</td>
<td>5 sample markers produced</td>
<td>PASS</td>
</tr>
<tr>
<td>2</td>
<td>Each sample marker is placed on the lunar surface and a boulder up to a 20° incline and remain independently stable.</td>
<td>The device can withstand +20° slope</td>
<td>PASS</td>
</tr>
<tr>
<td>3</td>
<td>Each sample marker is deployed and retrieved without the crew member kneeling all the way down to their knee.</td>
<td>The device can be deployed and retrieved without kneeling</td>
<td>PASS</td>
</tr>
<tr>
<td>4</td>
<td>Each sample marker includes a 2” x 2” label with unique alphanumeric identification information (ex. A1, 01-A, 1A).</td>
<td>Each device contains a 2” x 2” unique alphanumeric label</td>
<td>PASS</td>
</tr>
<tr>
<td>5</td>
<td>Each sample marker includes a label with a color reference scale consisting of red, blue, green, black, grey, and white blocks at least 1 cm x 1 cm each. Note: no specific RGB color codes are required.</td>
<td>Each device includes red, blue, green, black, grey, and white color targets greater than 1 cm x 1 cm</td>
<td>PASS</td>
</tr>
<tr>
<td>6a</td>
<td>The proposed sample marker design uses flight-like materials and adhere to all requirements.</td>
<td>The device uses flight-like materials</td>
<td>PASS</td>
</tr>
<tr>
<td>6b</td>
<td>The sample markers built for NBL testing is made for an underwater testing environment and made from NBL approved materials. A waiver may be granted on a case-by-case basis.</td>
<td>The device built for NBL testing uses approved materials</td>
<td>PASS</td>
</tr>
<tr>
<td>7</td>
<td>Each sample marker fits within a volume of 2” x 4” x 15” in its stowed configuration.</td>
<td>Each device can fit within 2” x 2” x 15”</td>
<td>PASS</td>
</tr>
<tr>
<td>8</td>
<td>The total weight of each sample marker is less than 1 lb.</td>
<td>The device weighs 0.928 lbs</td>
<td>PASS</td>
</tr>
<tr>
<td>9</td>
<td>Each sample marker is operable with EVA gloved hands (like heavy ski gloves).</td>
<td>The device can be operated with thick ski type gloves</td>
<td>PASS</td>
</tr>
<tr>
<td>10</td>
<td>Each sample marker uses only manual power.</td>
<td>The device uses only manual power</td>
<td>PASS</td>
</tr>
<tr>
<td>11</td>
<td>No holes or openings allowing/causing entrapment of fingers on the sample markers.</td>
<td>No holes or openings allowing/entrapment</td>
<td>PASS</td>
</tr>
<tr>
<td>12</td>
<td>No sharp edges on the sample markers.</td>
<td>Sharp edges have been minimized</td>
<td>PASS</td>
</tr>
<tr>
<td>13</td>
<td>Minimize and label pinch points.</td>
<td>Pinch points have been minimized</td>
<td>PASS</td>
</tr>
</tbody>
</table>
3.2 Numerical Data Collection

The Tholos™ was measured on a calibrated mass balance from the chemistry department. The scale was applied, then the Tholos™ was placed on it to record the mass. The mass of the Tholos™ was measured to be 421 g or 0.928 lb, pictured in Figure 16, passed the requirement. The uncertainty for the mass is ±0.004 lb. The Tholos™ was also placed on a slope which was measured to be 33° ± 2° and the Tholos™ did not tip over, passing the test. The vinyl labels were also measured to check compliance and they all passed the test. As the requirements predominantly called for maximum or minimum values, statistical analysis was not very critical to the results.

3.3 Missing Tests & Specifications Not Met

All of the verification tests were completed, and the specifications were satisfied. Further testing will be completed at NBL (Neutral Buoyancy Lab) on June 9th, 2022. This includes testing the Tholos™ with real astronaut gloves and on simulated moon surface conditions.

3.4 Challenges & Lessons Learned

A lesson learned is to either design parts requiring less precision, or machine parts with greater precision. Both the stadia brush locking mechanism and the leg collar mechanism presented some
issues as they would not fully operate as intended with some of the available machining processes. Same for the angles in the legs, a more precise angle would provide more stability to the stadia rods. While improved manufacturing techniques would eliminate any issues, further development could have been taken to create a more robust design.

4. Discussion & Recommendations

The design passed all measured requirements set forth by the Micro-g NExT competition. However, additional work can be done to further refine the design and improve its performance. A more precise leg and collar manufacturing method involving CNC equipment would reduce variability stemming from our craftsmanship. This would increase the consistency of the legs and improve the quality of the final product.

In the event the Tholos™ is to be produced in high volume, we believe the manufacturing process should be as streamlined and automated as possible. There were certainly a number of quirks with the manufacturing process we underwent; this could certainly be improved upon with the help of individuals more knowledgeable in the field of manufacturing engineering. This could involve improving the order and efficiency of manufacturing steps on the lathes and mills to cut down on shop time. Additionally, other manufacturing processes such as CNC may be used to increase the accuracy of the parts. The main issues stemmed from the collar-leg interface and the stadia rod-brush interface. For the collar-leg interface, the leg-locking and angle-defining mechanism can have improved consistency if the leg fillet and angle as well as the collar hole placement were more accurate. For the stadia-brush interface, the angle and diameters of the brushes can be further refined to fit on the stadia rods. One of the issues encountered with manufacturing was the fact that the inner stadia rods did not all have the same outer diameter. This necessitated that each individual brush be custom sized to the complementary inner stadia rod.

Overall, the design of the Tholos can be used as a device for Artemis astronauts to judge lunar geologic samples. The safe operation and transport of the device is outlined in the User Manual in Appendix K. While the Tholos may not see use on the moon, we hope that NASA is able to gain insight into the design process for the Photometric Calibration system.

5. Conclusions

This section contains a report summary and a section outlining the next steps. The report summary provides an overview of the key points for this document, whereas the section outlining next steps will highlight the upcoming action items and milestones that must be completed in order to proceed with the project.

To support the upcoming Artemis missions, NASA is holding design competitions for various EVA components. Over the past year, our team has ideated, designed, prototyped, tested, and manufactured a device for the challenge. Named Tholos™ after the ancient Greek repository of weights and measures, the device is designed to satisfy and exceed all requirements set forth by the NASA Micro-g NExT challenge.
The Tholos was designed to meet and exceed the requirements set for by the Micro-g NExT challenge. Novel additional features added to the device included the 360° prism and close up linear calibration target. The 360°-degree prism will be used in conjunction with a transit theodolite with electronic distance measurement to provide accurate polar coordinate positions of the device with respect to a central datum. This will help the astronauts and scientists on the ground better keep track of the markers when they are deployed. Additionally, the position information will aid in data collection of geologic samples. The close-up linear calibration target located on each of the four legs provides a reference for close up photos. This provides a reference scale for small geologic samples and creates an extra layer of functionality to the device. Both of these additions were not required as part of the Micro-g NExT challenge. NASA engineers expressed their interest in these additional features.

After designing, the Tholos was manufactured in the Cal Poly machine shops. Various tools including mills, lathes, sanders, and more were used to craft each device. While the devices consist of predominantly aluminum and Delrin® for NBL testing, material selection can differ to best meet the environmental requirements of the lunar surface. Over the course of prototyping and manufacturing, many insights were gained for how to improve and refine the design; these ideas were either implemented or noted for future development.

In the next upcoming week (June 6th-9th 2022), the Tholos™ will be tested at the Neutral Buoyancy Laboratory at the Johnson Space Center in Houston Texas in simulated microgravity. The deployment, retrieval, and operation will be tested by trained divers and will allow for both us and NASA to assess our design. The results of which testing will aid in NASA’ development of the device to be used on the upcoming Artemis missions while also providing us useful data in the final revisions of our design.

References

Appendices

- Appendix A: Drawing & Spec Package
- Appendix B: iBOM
- Appendix C: Project Budget
- Appendix D: Slope Calculations
- Appendix E: Buckling Calculations
- Appendix F: Manufacturing plan
- Appendix G: DVP&R
- Appendix H: FMEA
- Appendix I: Design Hazard Checklist
- Appendix J: Gantt Chart
- Appendix K: User Manual
- Appendix L: QFD House of Quality Table
- Appendix M: Ideation Sketches
- Appendix N: Weighted Decision Matrix
- Appendix O: PDR Design Hazard Checklist
- Appendix P: MSDS Acetal Copolymer
- Appendix Q: MSDS Al 6061
- Appendix R: MSDS Carbon Steel
- Appendix S: MSDS Delrin
### Retracted Configuration

Note: The legs retract by folding downwards and the collar slides up along the outer stadia rod.

### Extended Configuration

![Diagram of the extended configuration of THOLOS](image)

### Parts List

<table>
<thead>
<tr>
<th>Item NO.</th>
<th>Part Number</th>
<th>Part Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>112000</td>
<td>OUTER STADIA</td>
<td>STAINLESS STEEL TUBE WITH LINEAR MEASUREMENT REFERENCE ON BOTTOM AND ALPHANUMERIC IDENTIFIER AT TOP</td>
</tr>
<tr>
<td>2</td>
<td>122000</td>
<td>COLLAR</td>
<td>PLASTIC COLLAR WHICH SLIDES ALONG THE OUTER STADIA ROD AND ATTACHES THE FOUR LEGS</td>
</tr>
<tr>
<td>3</td>
<td>121000</td>
<td>LEG</td>
<td>STAINLESS STEEL LEGS</td>
</tr>
<tr>
<td>4</td>
<td>111000</td>
<td>INNER STADIA</td>
<td>STAINLESS STEEL TUBE WITH CHROMATIC, REFLECTIVITY, AND ADDITIONAL LINEAR MEASUREMENT TARGETS</td>
</tr>
<tr>
<td>5</td>
<td>112100</td>
<td>FLANGE</td>
<td>FLANGE WHICH SPREADS LEGS, PRESS FIT ONTO OUTER STADIA ROD</td>
</tr>
<tr>
<td>6</td>
<td>112200</td>
<td>BRUSH</td>
<td>NYLON BRUSH WHICH REDUCES FRICTION BETWEEN STADIA RODS</td>
</tr>
<tr>
<td>7</td>
<td>111300</td>
<td>INNER STADIA CAP</td>
<td>CAP WITH HOLE TO MOUNT 360 PRISM PRESS FIT INTO INNER STADIA ROD</td>
</tr>
</tbody>
</table>

---

Cal Poly Mechanical Engineering
THOLOS

CP Team: F55  Micro-g NEXT  Title: THOLOS ISOMETRIC  Drwn. By: JAMES VERHEYDEN
Dwg. #: 003  Nxt Asb: Date: 02/10/2022  Scale: 1:4  Chkd. By: GiPSON, RIOS, TRUST

SOLIDWORKS Educational Product. For Instructional Use Only.
PART NAME
1 OUTER STADIA
2 COLLAR
3 LEG
4 INNER STADIA
5 FLANGE
6 BRUSH
7 PRISM MOUNT
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ± .01
   X.XXX = ± .005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: ALUMINIUM
6. INNER STADIA ROD VOLUME = 2.098 IN^3
Notes: COLOR TARGET
1. PART NUMBER : 111100
2. ALL DIMENSIONS ARE IN CM
3. MATERIAL IS VINYL
4. ALL COLOR BLOCKS ARE OF EQUAL SPACING
5. RED: #c2272d
   BLUE: #2e3192
   GREEN: #059245
   BLACK: #000000
   GRAY: #646464
   WHITE: # ffffff
Notes ALPHA NUMERIC LABEL
1. PART NUMBER : 112200
2. ALL DIMENSIONS ARE IN CM
3. MATERIAL IS VINYL
4. ALL COLOR BARS ARE OF EQUAL SPACING
5. BLACK: #000000

THE FOUR BARS AT THE BOTTOM CAN BE PRINTED IN EITHER WHITE OR BLACK AND DISPLAY THE SAMPLE NUMBER IN 4-BIT BINARY FORM.
Notes LEG LINEAR SCALE
1. PART NUMBER : 121700
2. ALL DIMENSIONS ARE IN MM UNLESS NOTED
3. MATERIAL IS VINYL
4. ALL COLOR BARS ARE OF EQUAL SPACING
5. BLACK: #000000
Mini prism specifications for Tholos

Dims in mm

\( \frac{3}{4}-20 \) fine external threads on bottom
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: HDPE
6. CAP VOLUME = .105 IN^3
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: ALUMINIUM
6. OUTER STADIA ROD VOLUME = 4.891 in^3
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: HDPE
6. FLANGE VOLUME = .488 in^3
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: RUBBER
6. BRUSH VOLUME = .046 IN^3
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.X = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: ALUMINIUM
6. LEG VOLUME = .700 IN^3

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.X = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: ALUMINIUM
6. LEG VOLUME = .700 IN^3

Cal Poly Mechanical Engineering
THOLO
PART #: 121000
Title: LEG
Drwn. By: K. GIPSON, J. VERHEYDEN
Chkd. By: TEAM
Lab: ME 429-05
CDR
Nxt Asb: Date: 2/10/2022 Scale: 2:1
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. INSIDE TOOL RADIUS .03 MAX.
4. BREAK SHARP EDGES .03 MAX.
5. MATERIAL: HDPE
6. COLLAR VOLUME = .955 IN^3

Cal Poly Mechanical Engineering
THOLOS
Lab: ME 429-05  CDR
PART #: 122000  Title: SLIDING COLLAR
Nxt Asb:  Date: 2/10/2022  Scale: 2:1
Drwn. By: K. GIPSON, J. VERHEYDEN
Chkd. By: TEAM
### Appendix B IBOM

**Tholos**  
Indented Bill of Material (IBOM)

<table>
<thead>
<tr>
<th>Assy Level</th>
<th>Part Number</th>
<th>Descriptive Part Name</th>
<th>Qty</th>
<th>Part Cost</th>
<th>Source</th>
<th>URL</th>
<th>More Info</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>100000</td>
<td>Final Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>110000</td>
<td>Top Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11100</td>
<td>Inner Stadia Rod</td>
<td>1</td>
<td>$15.75</td>
<td>Metals Depot</td>
<td>Inner Stadia Rod Tube Stock</td>
<td>Part number: 73134065</td>
</tr>
<tr>
<td>3</td>
<td>111100</td>
<td>Color Targets</td>
<td>1</td>
<td>$1.20</td>
<td>Amazon</td>
<td>Printable Matte Vinyl</td>
<td>Analogue. Printable vinyl decal, also waterproof + tear resistant</td>
</tr>
<tr>
<td>3</td>
<td>111200</td>
<td>Theodolite Prism Analogue</td>
<td>1</td>
<td>$1.88</td>
<td>Amazon</td>
<td>Acetal Copolymer</td>
<td>Analogue. Manufactured from black acetal copolymer</td>
</tr>
<tr>
<td>4</td>
<td>111210</td>
<td>Red reflective tape</td>
<td>1</td>
<td>$1.00</td>
<td>Tractor Supply Co.</td>
<td>Red Reflective Tape Strips</td>
<td>COTS part</td>
</tr>
<tr>
<td>4</td>
<td>111220</td>
<td>1/4 x 1&quot; Machine Screw</td>
<td>1</td>
<td>$1.00</td>
<td>Home Depot</td>
<td>-</td>
<td>COTS part</td>
</tr>
<tr>
<td>3</td>
<td>111300</td>
<td>Inner Stadia Cap</td>
<td>1</td>
<td>$2.03</td>
<td>Amazon</td>
<td>White Delrin (1/2 OD x 12&quot;)</td>
<td>3/8 threaded hole. Manufactured from white delrin</td>
</tr>
<tr>
<td>3</td>
<td>111400</td>
<td>Brush Collar (Spacers)</td>
<td>1</td>
<td>$2.03</td>
<td>Amazon</td>
<td>White Delrin (1/2 OD x 12&quot;)</td>
<td>Manufactured from white delrin</td>
</tr>
<tr>
<td>2</td>
<td>112000</td>
<td>Outer Stadia Rod</td>
<td>1</td>
<td>$10.80</td>
<td>Metals Depot</td>
<td>Outer Stadia Rod Stock</td>
<td>Part number: 7336</td>
</tr>
<tr>
<td>3</td>
<td>112100</td>
<td>Bottom Flange</td>
<td>1</td>
<td>$1.88</td>
<td>Amazon</td>
<td>Acetal Copolymer</td>
<td>Manufactured from black acetal copolymer</td>
</tr>
<tr>
<td>3</td>
<td>112200</td>
<td>Alphanumeric Label</td>
<td>1</td>
<td>$1.20</td>
<td>Amazon</td>
<td>Printable Matte Vinyl</td>
<td>Printable vinyl decal, also waterproof + tear resistant</td>
</tr>
<tr>
<td>1</td>
<td>120000</td>
<td>Bottom Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>121000</td>
<td>Legs</td>
<td>4</td>
<td>$10.81</td>
<td>McMaster-Carr</td>
<td>Al Rectangular Tubes</td>
<td>will need to be cut to size</td>
</tr>
<tr>
<td>3</td>
<td>121100</td>
<td>#6 flat washer</td>
<td>1</td>
<td>$1.00</td>
<td>Home Depot</td>
<td>-</td>
<td>COTS part</td>
</tr>
<tr>
<td>3</td>
<td>121200</td>
<td>Pins</td>
<td>4</td>
<td>$1.25</td>
<td>Cal Poly Shops</td>
<td>-</td>
<td>3/32 aluminum welding wire cut to size to secure legs</td>
</tr>
<tr>
<td>3</td>
<td>121300</td>
<td>1/8&quot; Rivets, White Aluminum</td>
<td>1</td>
<td>$1.25</td>
<td>Home Depot</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>121400</td>
<td>3/4&quot; x 12ft Velcro</td>
<td>1</td>
<td>$0.11</td>
<td>Home Depot</td>
<td>-</td>
<td>8&quot; of velcro cut for each unit</td>
</tr>
<tr>
<td>3</td>
<td>121500</td>
<td>Red Canvas Fabric</td>
<td>1</td>
<td>$0.11</td>
<td>Upholstery Store</td>
<td>-</td>
<td>Red canvas was glued onto velcro handle for high visibility</td>
</tr>
<tr>
<td>3</td>
<td>121600</td>
<td>Yellow reflective tape</td>
<td>1</td>
<td>$0.90</td>
<td>Home Depot</td>
<td>-</td>
<td>Yellow reflective tape was added for high visibility</td>
</tr>
<tr>
<td>3</td>
<td>121700</td>
<td>Leg Linear Scale</td>
<td>4</td>
<td>$0.15</td>
<td>Amazon</td>
<td>Printable Matte Vinyl</td>
<td>Printable vinyl decal, also waterproof + tear resistant</td>
</tr>
<tr>
<td>2</td>
<td>122000</td>
<td>Collar</td>
<td>1</td>
<td>$1.88</td>
<td>Amazon</td>
<td>Acetal Copolymer</td>
<td>Manufactured from black acetal copolymer</td>
</tr>
<tr>
<td>2</td>
<td>122100</td>
<td>#8 x 1/2&quot; Machine Screw</td>
<td>1</td>
<td>$5.34</td>
<td>Home Depot</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

| Total Parts | 29 | $60.33 |

Note: parts colored in red are COTS parts. All other parts have been manufactured in house from stock/materials bought online, unless otherwise specified. Costs are listed for one unit; this means that the costs listed are the cost for the total item divided by 5 to yield the cost for one unit.
## Appendix C. Project Costs

### Materials & Manufacturing Costs

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Item</th>
<th>iBOM PN¹</th>
<th>Qty.²</th>
<th>Units purchased³</th>
<th>Total Cost</th>
<th>Vendor</th>
<th>Vendor IN⁴</th>
<th>Link</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Inner Stadia Rod</td>
<td>Inner Stadia Rod Body</td>
<td>111000</td>
<td>1</td>
<td>1</td>
<td>$15.75</td>
<td>Metals Depot</td>
<td>T3R34065</td>
<td>Inner Stadia Rod Tube Stock</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Color Targets</td>
<td>111100</td>
<td>1</td>
<td>1</td>
<td>$0.80</td>
<td>UGS</td>
<td>-</td>
<td>UGS- Cal Poly Graphics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Theodolite Prism Analogue</td>
<td>111200</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>Innovation Sandbox</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Theodolite Screw Hardware</td>
<td>111300</td>
<td>1</td>
<td>1</td>
<td>$3.00</td>
<td>McMaster-Carr</td>
<td>TBD</td>
<td>TBD</td>
<td>3D printed. Analogue</td>
</tr>
<tr>
<td></td>
<td>Hiking Pole Twist-Lock</td>
<td>111400</td>
<td>1</td>
<td>1</td>
<td>$7.63</td>
<td>eBay</td>
<td>-</td>
<td>Hiking Pole Internal Locks</td>
<td>may need multiple sources due to limited inventory</td>
</tr>
<tr>
<td>Outer Stadia Rod</td>
<td>Outer Stadia Rod Body</td>
<td>112000</td>
<td>1</td>
<td>1</td>
<td>$10.80</td>
<td>Metals Depot</td>
<td>T334</td>
<td>Outer Stadia Rod Stock</td>
<td>Modification to tubing</td>
</tr>
<tr>
<td></td>
<td>Bottom Flange</td>
<td>112100</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>Innovation Sandbox</td>
<td>-</td>
<td>CAD will be provided to Innovation Sandbox for it to be 3D printed.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brush Collar</td>
<td>112200</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>Innovation Sandbox</td>
<td>-</td>
<td>CAD will be provided to Innovation Sandbox for it to be 3D printed.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adhesive</td>
<td>112210</td>
<td>1</td>
<td>1</td>
<td>$0.49</td>
<td>Amazon</td>
<td>B000BRQ0TW</td>
<td>Waterproof Metal Epoxy</td>
<td>ballpark value; need approval of adhesive type first</td>
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<tr>
<td></td>
<td>Alphanumeric Label</td>
<td>112300</td>
<td>1</td>
<td>1</td>
<td>$1.20</td>
<td>Amazon</td>
<td>B082ZDZ894</td>
<td>Printable Matte Vinyl</td>
<td>Printable vinyl decal, also waterproof + tear resistant</td>
</tr>
<tr>
<td></td>
<td>Snap-in Leg Holder</td>
<td>112400</td>
<td>4</td>
<td>1</td>
<td>$9.99</td>
<td>Amazon</td>
<td>B07F2KSDB</td>
<td>Rubber Pen Pal</td>
<td>not the exact ones we will purchase</td>
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<tr>
<td>Device Legs</td>
<td>Legs</td>
<td>121000</td>
<td>4</td>
<td>4</td>
<td>$10.81</td>
<td>McMaster-Carr</td>
<td>6546K46</td>
<td>Al Rectangular Tubes</td>
<td>will need to be cut to size</td>
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<tr>
<td></td>
<td>Pins</td>
<td>121100</td>
<td>4</td>
<td>1</td>
<td>$2.85</td>
<td>McMaster-Carr</td>
<td>5429N119</td>
<td>Tapered Pins</td>
<td>comes in pack of 10</td>
</tr>
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<td></td>
<td>Rubber Feet</td>
<td>121200</td>
<td>4</td>
<td>1</td>
<td>$1.76</td>
<td>Amazon</td>
<td>B07RBBDQT4</td>
<td>Rubber Caps</td>
<td>hopefully can stretch into square shape</td>
</tr>
<tr>
<td></td>
<td>Brightly Colored Decals</td>
<td>121300</td>
<td>1</td>
<td>1</td>
<td>$3.00</td>
<td>Amazon</td>
<td>B082ZDZ894</td>
<td>Printable Matte Vinyl</td>
<td>Printable vinyl decal, also waterproof + tear resistant</td>
</tr>
<tr>
<td></td>
<td>Collar</td>
<td>122000</td>
<td>1</td>
<td>1</td>
<td>$5.32</td>
<td>Metals Depot</td>
<td>R32</td>
<td>2&quot; Aluminum Bar Stock</td>
<td>-</td>
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<tr>
<td></td>
<td>Total Parts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost of 10 Tholos Units</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>$744.15</td>
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### Additional Budget Areas

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Qty.</th>
<th>Cost per unit</th>
<th>Cost</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel &amp; Shipping</td>
<td>Air Travel</td>
<td>4</td>
<td>$475.00</td>
<td>$1900.00</td>
<td>SBP to IAH, Ground Transportation</td>
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<tr>
<td></td>
<td>Prototype Shipping</td>
<td>1</td>
<td>$28.00</td>
<td>$28.00</td>
<td>UPS Ground, San Luis Obispo to Houston (Package Estimate: 5lb, 15”x15”x8”)</td>
</tr>
<tr>
<td></td>
<td>Hotel Cost</td>
<td>4</td>
<td>$100.00</td>
<td>$400.00</td>
<td></td>
</tr>
</tbody>
</table>

1. Part Number.
2. Quantity of parts needed in Tholos design.
3. A unit of an item would be a package if multiple items come together. For example, ordering a pack of 5 items would consist of ordering one unit (in this case, one pack).
4. Item Number.
Appendix D. Tholos Tilt Calculations

THOLOS TILT CALCULATIONS

At what location \( x \) does the center of mass need to be to ensure the Tholos can withstand the required 20° slope?

Each leg slopes 15° down, however, the axis of rotation has a different profile view which must be first calculated.

\[
\begin{align*}
  h &= 19\sin(15°) = 3.623'' \\
  w &= 19\cos(15°) = 13.523'' \\
  \theta &= 45° \\
  h' &= w\cos(45°) \\
  h' &= 13.523\cos(45°) = 9.562''
\end{align*}
\]

\[
\begin{align*}
  x + h &= \frac{h'}{\tan\theta} \\
  x &= \frac{h'}{\tan\theta} - h \\
  x &= \frac{9.562''}{\tan(45°)} - 3.623'' \\
  x &= 22.649''
\end{align*}
\]

\[
\frac{22.649''}{28''} = 81\% \text{ up the stadia rod}
\]

The above calculations found that the center of mass must be 22.649'' (81%) up the stadia rod in order to withstand a 20° slope. This value is more than reasonable and the Tholos has little risk of not surpassing this specification.
## Appendix E

### Preliminary Tholos Leg Design Parameters

<table>
<thead>
<tr>
<th>1/4&quot;</th>
<th>1/4&quot;</th>
<th>18&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.00635 m</td>
<td>bar height</td>
</tr>
<tr>
<td>H</td>
<td>0.00635 m</td>
<td>bar width</td>
</tr>
<tr>
<td>L</td>
<td>0.4572 m</td>
<td>bar length</td>
</tr>
</tbody>
</table>

| 2/10/2022 |

Elastic modulus:
- $E = 68.9$ GPa

Compressive yield strength:
- $\sigma_y = 386$ MPa

Material density:
- $\rho = 2700$ kg/m$^3$

Effective length factor:
- $K = 0.5$

T 6061 Aluminum:
- $t = 0.0015875$ m

### Extruded Bar Parameters

<table>
<thead>
<tr>
<th>Solid Bar</th>
<th>Hollow Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>$A_{\text{cross-sectional area}} = 1.76411 \times 10^{-05}$ m$^2$</td>
</tr>
<tr>
<td>$I_{yy}$</td>
<td>$I_{yy_{\text{cross-sectional area}}} = 5.55729 \times 10^{-10}$ m$^4$</td>
</tr>
<tr>
<td>$r$</td>
<td>$r_{\text{radius of gyration}} = 0.0056126$ m</td>
</tr>
<tr>
<td>$m_B$</td>
<td>$m_B_{\text{mass of each bar}} = 0.022$ kg</td>
</tr>
<tr>
<td>$q$</td>
<td>$q_{\text{distributed mass (mass per unit length)}} = 0.047630953$ kg/m</td>
</tr>
<tr>
<td>$\sigma_{\text{crit}}$</td>
<td>$\sigma_{\text{crit}}_{\text{critical stress}} = 102481153.4$ Pa</td>
</tr>
<tr>
<td>$L/r$</td>
<td>$L/r_{\text{slenderness ratio}} = 81.46$</td>
</tr>
<tr>
<td>$R_{\text{trans}}$</td>
<td>$R_{\text{trans}}_{\text{buckling transition slenderness ratio}} = 118.72$</td>
</tr>
<tr>
<td>$P_{\text{cr},\text{Jo}}$</td>
<td>$P_{\text{cr},\text{Jo}}_{\text{critical load using Johnson/Intermediate method}} = 9839.5$ N</td>
</tr>
<tr>
<td>$P_{\text{cr in lbf}}$</td>
<td>$P_{\text{cr in lbf}}_{\text{critical load in pounds-force}} = 2212.0$ lbf</td>
</tr>
</tbody>
</table>

### Buckling Analysis

<table>
<thead>
<tr>
<th>Solid Bar</th>
<th>Hollow Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_c$</td>
<td>$k_{c,\text{equivalent spring stiffness of each bar}} = 1757.8$ N/m</td>
</tr>
<tr>
<td>$\omega_c$</td>
<td>$\omega_{c,\text{natural frequency of each bar in rad/s}} = 29.91$ Hz</td>
</tr>
<tr>
<td>$f_c$</td>
<td>$f_{c,\text{natural frequency of each bar in Hz}} = 119.65$ Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Axial Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_a$</td>
</tr>
<tr>
<td>$\omega_a$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed-Fixed Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_f$</td>
</tr>
<tr>
<td>$\omega_f$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compound Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{\text{total}}$</td>
</tr>
<tr>
<td>$\omega_{\text{total}}$</td>
</tr>
<tr>
<td>$f_{\text{total}}$</td>
</tr>
</tbody>
</table>
## Appendix F. Manufacturing Plan

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Purchase (P)</th>
<th>Modify (M)</th>
<th>Build (B)</th>
<th>Raw Materials Needed to make/modify the part (only M &amp; B)</th>
<th>Where/how procured?</th>
<th>Equipment and Operations anticipate using to make the component</th>
<th>Key limitations of this operation places on any parts made from it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Stadia Rod</td>
<td>Leg Flange</td>
<td>B</td>
<td></td>
<td></td>
<td>Aluminum bar stock</td>
<td>Metals Depot</td>
<td>CNC mills will be used to machine the leg flange.</td>
<td>Mill time must be scheduled in advance</td>
</tr>
<tr>
<td></td>
<td>Brush Collar</td>
<td>B</td>
<td></td>
<td></td>
<td>COTS collar or aluminum tube stock for brush collar body</td>
<td>ME procurement</td>
<td>Printer will be used to print label on adhesive. X-acto knife and straight edge used to cut label to size.</td>
<td>Appropriate printer must be located/found to print adhesive label</td>
</tr>
<tr>
<td></td>
<td>Alpha Numeric Label</td>
<td>B</td>
<td></td>
<td></td>
<td>Vinyl Decal</td>
<td>UGS</td>
<td>3D-printed part to be used to create silicone mold, rubber used to cast final part</td>
<td>Techs should be consulted for the feasibility of this process</td>
</tr>
<tr>
<td></td>
<td>Leg Securing Mechanism</td>
<td>B</td>
<td></td>
<td></td>
<td>Rubber, silicone (for injection molding)</td>
<td>ME procurement</td>
<td>Tube cut to length with chop saw or bandsaw, will require deburring.</td>
<td>Availability of the chop saw or bandsaw in the shop</td>
</tr>
<tr>
<td></td>
<td>Outer Stadia Rod Body</td>
<td>P, M</td>
<td></td>
<td></td>
<td>Aluminum Tube Stock</td>
<td>Metals Depot</td>
<td>Insertion into appropriate locations</td>
<td>Keeping the locks in place</td>
</tr>
<tr>
<td></td>
<td>Theodolite Holder</td>
<td>B</td>
<td></td>
<td></td>
<td>Threaded Fastener, Cap</td>
<td>eBay</td>
<td>Tapped hole created on cap with drill and tap with appropriate thread size.</td>
<td>Availability of drill and taps in the shop</td>
</tr>
<tr>
<td></td>
<td>Color Calibrator</td>
<td>B</td>
<td></td>
<td></td>
<td>Vinyl Decal</td>
<td>UGS</td>
<td>Insertion into appropriate locations</td>
<td>Keeping the locks in place</td>
</tr>
<tr>
<td></td>
<td>Inner Stadia Rod Body</td>
<td>P, M</td>
<td></td>
<td></td>
<td>Aluminum Tube Stock</td>
<td>Metals Depot</td>
<td>Tube cut to length with chop saw or bandsaw, will require deburring.</td>
<td>Availability of the chop saw or bandsaw in the shop</td>
</tr>
<tr>
<td></td>
<td>Legs</td>
<td>B</td>
<td></td>
<td></td>
<td>Aluminum square tube stock</td>
<td>McMaster</td>
<td>Composite curing equipment, or laser cutter to laser cut composite sheet to desired shape</td>
<td>Laser cutter time must be scheduled in advance; Shop Tech may be consulted to lay up/cure composites</td>
</tr>
<tr>
<td></td>
<td>Sliding Collar</td>
<td>B</td>
<td></td>
<td></td>
<td>Aluminum Bar/solid tube stock or COTS collar</td>
<td>Metals Depot</td>
<td>CNC Mill, g-code programmed from a CAD model of the final part</td>
<td>Mill time must be scheduled in advance</td>
</tr>
<tr>
<td></td>
<td>Pins</td>
<td>P</td>
<td></td>
<td></td>
<td>N/A</td>
<td>McMaster</td>
<td>Presses for press-fitting the pins in place</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Rubber Feet</td>
<td>P</td>
<td></td>
<td></td>
<td>COTS rubber feet</td>
<td>Amazon</td>
<td>N/A</td>
<td>Must fit snugly on the ends of legs, for use in NBL</td>
</tr>
</tbody>
</table>
## TEST PLAN

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
<th>Measurements</th>
<th>Acceptance Criteria</th>
<th>Required Facilities/Equipment</th>
<th>Parts Needed</th>
<th>Responsibility</th>
<th>TIMING</th>
<th>Notes on Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The device needs to withstand a 20 degree slope</td>
<td>Place tholos on a 20 degree slope when extended and verify the device remains upright. Increase slope and note when the device falls over.</td>
<td>Slope (deg)</td>
<td>20 degrees</td>
<td>Flat board, inclinometer/protractor</td>
<td>Flat board, inclinometer/protractor</td>
<td>Team</td>
<td>3/12/2022</td>
<td>5/1/2022</td>
</tr>
<tr>
<td>2</td>
<td>The device needs to fit within a 2”x4”x15” volume</td>
<td>Measure the tholos with calipers and/or ruler and ensure the device fits within required volume</td>
<td>Inches</td>
<td>Fits within 2”x4”x15”</td>
<td>Caliper</td>
<td>Caliper</td>
<td>Team</td>
<td>2/20/2022</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>3</td>
<td>1 lb max weight</td>
<td>Weight the tholos on a scale.</td>
<td>weight, lb</td>
<td>1 lb max</td>
<td>Scale</td>
<td>Scale</td>
<td>Team</td>
<td>2/20/2022</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>4</td>
<td>Alpha numeric label size</td>
<td>The alpha numeric label is 2”x2”</td>
<td>inches</td>
<td>2”x2”</td>
<td>Ruler</td>
<td>Ruler</td>
<td>Team</td>
<td>2/20/2022</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>5</td>
<td>Reference scale size</td>
<td>Each reference color should be at least 1cmx1cm</td>
<td>cm</td>
<td>1cmx1cm</td>
<td>Ruler</td>
<td>Ruler</td>
<td>Team</td>
<td>2/20/2022</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>6</td>
<td>Reference scale colors</td>
<td>The reference scale should include red, blue, green, black, grey, white colors.</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Visual inspection</td>
<td>Visual inspection</td>
<td>Team</td>
<td>2/20/2022</td>
<td>3/12/2022</td>
</tr>
</tbody>
</table>
## DVP&R - Design Verification Plan (& Report)

### TEST PLAN

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
<th>Measurements</th>
<th>Acceptance Criteria</th>
<th>Required Facilities/Equipment</th>
<th>Parts Needed</th>
<th>Responsibility</th>
<th>TIMING</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Sample set includes 5 devices</td>
<td>The sample marker set must include 5 markers</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Visual inspection</td>
<td>Visual inspection</td>
<td>Team</td>
<td>2/20/2022</td>
</tr>
<tr>
<td>8</td>
<td>EVA Operability: Handling</td>
<td>The device is operable with EVA gloves</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Ski type gloves</td>
<td>Ski type gloves</td>
<td>Team</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>9</td>
<td>EVA Operability: Deployment</td>
<td>The device can be deployed and retrieved without kneeling</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Ski gloves, body of water (preferably a swimming pool)</td>
<td>Ski gloves, body of water (preferably a swimming pool)</td>
<td>Team</td>
<td>3/12/2022</td>
</tr>
<tr>
<td>10</td>
<td>Manual Power</td>
<td>The sample uses manual power only</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Visual inspection</td>
<td>Visual inspection</td>
<td>Team</td>
<td>2/20/2022</td>
</tr>
<tr>
<td>11</td>
<td>User safety</td>
<td>The device minimizes pinch points, entrapment points, and sharp edges. Pinch points are labeled.</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Ski gloves, body of water (preferably a swimming pool)</td>
<td>Ski gloves, body of water (preferably a swimming pool)</td>
<td>Team</td>
<td>2/20/2022</td>
</tr>
</tbody>
</table>
### Design Failure Mode and Effect Analysis

<table>
<thead>
<tr>
<th>System / Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effects of the Failure Mode</th>
<th>Severity</th>
<th>Potential Causes of the Failure Mode</th>
<th>Current Preventative Activities</th>
<th>Current Detection Activities</th>
<th>Detection Priority</th>
<th>Recommended Action(s)</th>
<th>Responsibility &amp; Target Completion Date</th>
<th>Actions Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner rod / Color targets</td>
<td>Color targets are scratched</td>
<td>Reduced color visibility</td>
<td>4</td>
<td>Brushes are too stiff</td>
<td>Test abrasiveness of bristles</td>
<td>1) Test dropping on ground 2) Test cleaning ability of bristles</td>
<td>2</td>
<td>Test opening</td>
<td>16</td>
<td>Find brush bristles that are less stiff</td>
</tr>
<tr>
<td>Inner rod / Theodolite</td>
<td>Prism breaks away from holder on inner rod</td>
<td>Failure to use location system</td>
<td>9</td>
<td>Device is dropped/hit</td>
<td>Ensure connection is strong</td>
<td>1) Ensure prism is not obstructed 2) Add dust cover</td>
<td>2</td>
<td>Drop test</td>
<td>36</td>
<td>Modify prism mount design to better secure prism</td>
</tr>
<tr>
<td>Outer rod / Brush collar</td>
<td>Does not contact inner rod</td>
<td>1) The stadia rod does not stay up</td>
<td>6</td>
<td>1) Brush collar diameter is too small 2) Brush bristles are too short</td>
<td>Ensure brush collar is properly sized</td>
<td>Make bristles stiff and dense enough</td>
<td>2</td>
<td>Test opening</td>
<td>36</td>
<td>1) Re-size brush collar diameter 2) Find longer brush bristles</td>
</tr>
<tr>
<td>Outer rod / Locking mechanism</td>
<td>Failure to lock in legs</td>
<td>The legs can swing out; failure to be stored</td>
<td>5</td>
<td>Holds become too loose</td>
<td>Pick durable material</td>
<td></td>
<td>3</td>
<td>Test closing</td>
<td>30</td>
<td>Select different material that prevents/minimizes leg locking system wear</td>
</tr>
<tr>
<td>Outer rod / Flange</td>
<td>Does not constrain outer rod</td>
<td>Unintentional sliding occurs</td>
<td>3</td>
<td>Flange is too small</td>
<td>Make flange larger</td>
<td></td>
<td>2</td>
<td>Test opening</td>
<td>6</td>
<td>Re-size flange on design</td>
</tr>
<tr>
<td>Leg system / Legs</td>
<td>Failure to deploy</td>
<td>The device cannot be placed on ground/used</td>
<td>6</td>
<td>Leg mechanism breaks</td>
<td>Ensure sturdy leg mechanism</td>
<td></td>
<td>1</td>
<td>Test opening</td>
<td>6</td>
<td>Modify design to improve structural strength and reduce stresses</td>
</tr>
<tr>
<td></td>
<td>Failure to stow</td>
<td>The device cannot be transported</td>
<td>6</td>
<td>Leg mechanism breaks</td>
<td>Allow for larger tolerances</td>
<td></td>
<td>1</td>
<td>Test closing</td>
<td>6</td>
<td>Re-size with larger tolerances</td>
</tr>
<tr>
<td></td>
<td>Buckling under system weight</td>
<td>The device cannot stand up</td>
<td>6</td>
<td>Leg mechanism breaks</td>
<td>Ensure part strengths are acceptable</td>
<td></td>
<td>1</td>
<td>Test opening</td>
<td>12</td>
<td>1) Modify design to improve structural strength and reduce stresses 2) Select new material to provide more strength</td>
</tr>
<tr>
<td></td>
<td>Device falls over</td>
<td>The device cannot stand up</td>
<td>6</td>
<td>Legs are not sturdy</td>
<td>Ensure sturdy locking mechanism</td>
<td></td>
<td>6</td>
<td>Test opening</td>
<td>36</td>
<td>1) Modify design to improve sturdiness and reduce stresses 2) Select new material to improve sturdiness</td>
</tr>
<tr>
<td>Leg system / sliding collar</td>
<td>Failure to slide</td>
<td>The device cannot stand up</td>
<td>6</td>
<td>Dust caught between mobile surfaces</td>
<td>Allow for larger tolerances</td>
<td></td>
<td>4</td>
<td>Test in dust bath</td>
<td>24</td>
<td>Re-size with larger tolerances</td>
</tr>
<tr>
<td></td>
<td>Shock fracture</td>
<td>The device cannot stand up</td>
<td>6</td>
<td>Drops/bumps</td>
<td>Ensure sturdy design</td>
<td></td>
<td>3</td>
<td>Drop test</td>
<td>72</td>
<td>Modify design to improve structural strength and reduce stresses</td>
</tr>
</tbody>
</table>
## Appendix I.
### CDR Design Hazard Checklist

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

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.
<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>The folding mechanism of the legs could feasibly create pinch points if an astronaut’s finger is caught between the main stadia rod and the leg.</td>
<td>The collar to which the Tholos’ legs are attached acts as a barrier between the folding mechanism and the astronaut’s fingers. Because of this, the primary pinch points will be internal and inaccessible to the end user in the final design of the Tholos. The final design will explain that the collar also acts as a ‘finger guard’. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
<tr>
<td>Naturally, each piece of stock will have sharp edges which may pose a threat to the end user.</td>
<td>In the final product, we will ensure all sharp edges are broken by either a fillet or a chamfer. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
<tr>
<td>Given the environment on the moon, both extremely low temperatures and the presence of abrasive lunar dust pose serious threats to the functionality of the Tholos.</td>
<td>Since this is one of the primary issues present in the design of the location calibrator, the Tholos has already been designed with these hazards in mind. We will, however, have to test the sliding mechanism to make sure it is not severely impeded by the presence of the abrasive lunar dust. This shall be accomplished at the Neutral Buoyancy Laboratory.</td>
<td>June 5, 2022</td>
<td></td>
</tr>
<tr>
<td>If used improperly, the Tholos may cause bodily damage to the end user by damaging EVA suits.</td>
<td>We will include an instructional manual for proper use and operation of the Tholos; this will be included in the final submission to Micro-g NeXT. Additionally, sharp edges (such as those on the ends of the legs of the Tholos) will be capped with brightly colored rubber caps. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
</tbody>
</table>
## F55 EVA Marker

#### Problem Definition

#### Competition Proposal

#### Concept Generation & Selection

#### Detailed Design & Analysis

#### Manufacturing
- **Verification Prototype Manufacturing**
  - Purchase Materials
  - Collect scrap metal for practice machining

#### Manufacture Verification Prototype
- **Outer Stadia Rod Subsystem**
  - Outer Stadia Rod Body
  - Brush Collar
  - Leg Securing Mechanism
  - Leg Flange
  - Alphanumeric label

- **Inner Stadia Rod Subsystem**
  - Inner Stadia Rod Body
  - Theodolite Holder
  - Color Calibration Label

#### Legs Subsystem
- Sliding Collar
- Device Legs

#### Assembly
- Top Assembly
- Bottom Assembly
- Final Assembly

#### Manufacturing & Test Review
- Verification Prototype Sign-Off
- Manufacturing & Test Update

#### Testing
- Senior Exam
- Final Manufacturing (5 units)

### Experimental Design
- **Experimental Design Planning Form**
- Write Preliminary Experiment Test Procedure

### Design Verification
- **Design Verification Plan & Report (DVPR)**

#### Design Verification Plan
- Test #1 - Slope check
- Test #2 - Volume Dimensions Check
- Test #3 - Weight Check
- Test #4 - Alphanumeric Label Size Check
- Test #5 - Reference Scale Size Check
- Test #6 - Reference Scale Color Check
- Test #7 - 5 Devices in set
- Test #8 - EVA Operability: Handling
- Test #9 - EVA Operability: Deployment

### Appendix J
Appendix L. QFD House of Quality Table

<table>
<thead>
<tr>
<th>HOW MUCH: Target Values</th>
<th>1 Pound Max</th>
<th>2&quot; x 4&quot; x 15&quot; Max</th>
<th>Scale is visible in photo</th>
<th>Scale is visible less than 20 days</th>
<th>Setup time is less than 5 minutes</th>
<th>Devices is used without welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Relationship</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Technical Importance Rating</td>
<td>310</td>
<td>408.8</td>
<td>149.7</td>
<td>253.8</td>
<td>182.3</td>
<td>341.2</td>
</tr>
<tr>
<td>Relative Weight</td>
<td>23%</td>
<td>25%</td>
<td>9%</td>
<td>15%</td>
<td>11%</td>
<td>21%</td>
</tr>
<tr>
<td>Past product - Apollo Gnomon</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column #</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
- Prism
- Collapsible antenna
- Forensic scene flag
- Carabiner
- Retractable string (safe measure)
- Scale
- Stake
- Magnet
- Traffic cone
- Colors
- Roomba to collect rocks
- Inflatable scale
- Saucer cone
- QR codes
SKETCH #1, 2 ON OVERLAP
CREATE → CONCEPT SKETCHES

SKETCH #3
TO HOLD DEVICE ON SIDE OF LEG/HIP

LOOP
VELCRO
SEW

SKETCH #4
PUSH HERE
TWIST OPEN AND CLOSE BY PUSH OF BUTTON

HOLD HERE

SKETCH #5
PRESS DOWN TO RELEASE SUPPORT LEGS

INCORPORATE RETRACTABLE PEN AS A WAY TO OPEN/CLOSE
SKETCH #6

TILT FORWARD OR BACK

PADS FOR END OF SUPPORT LEGS TO ACCOUNT FOR UNEVEN SURFACE

SKETCH #7

COLLAPSIBLE RINGS

COLLAPSIBLE TRAFFIC CONE

SKETCH #8

DROPPED

COMPARTMENT

FORCE SENSITIVE

GUIDE COVER?

POPS UP

FOLDS DOWN
## Appendix N Weighted Decision Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Idea 1 Score</th>
<th>Total</th>
<th>Idea 2 Score</th>
<th>Total</th>
<th>Idea 3 Score</th>
<th>Total</th>
<th>Idea 4 Score</th>
<th>Total</th>
<th>Idea 5 Score</th>
<th>Total</th>
<th>Idea 6 Score</th>
<th>Total</th>
<th>TOTAL Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carry &amp; Operate with one hand</td>
<td>0.1</td>
<td>2</td>
<td>0.2</td>
<td>3</td>
<td>0.3</td>
<td>5</td>
<td>0.4</td>
<td>5</td>
<td>0.5</td>
<td>3</td>
<td>0.3</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>Deployable while in EVA suit</td>
<td>0.1</td>
<td>4</td>
<td>0.4</td>
<td>2</td>
<td>0.2</td>
<td>5</td>
<td>0.5</td>
<td>4</td>
<td>0.4</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>3</td>
</tr>
<tr>
<td>Minimal setup time</td>
<td>0.05</td>
<td>5</td>
<td>0.25</td>
<td>5</td>
<td>0.25</td>
<td>5</td>
<td>0.25</td>
<td>5</td>
<td>0.25</td>
<td>5</td>
<td>0.25</td>
<td>5</td>
<td>0.25</td>
<td>3</td>
</tr>
<tr>
<td>No kneeling</td>
<td>0.1</td>
<td>4</td>
<td>0.4</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>3</td>
<td>0.3</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>4</td>
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<tr>
<td>Less than 1 lb</td>
<td>0.1</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>2&quot;x4&quot;x15&quot; (Folded Max dims)</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>0.5</td>
<td>2</td>
<td>0.2</td>
<td>5</td>
<td>0.5</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>Alpha-numeric label &amp; calibration reference</td>
<td>0.06</td>
<td>5</td>
<td>0.3</td>
<td>1</td>
<td>0.06</td>
<td>3</td>
<td>0.18</td>
<td>5</td>
<td>0.3</td>
<td>4</td>
<td>0.24</td>
<td>1</td>
<td>0.06</td>
<td>5</td>
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<tr>
<td>Space compatible materials</td>
<td>0.12</td>
<td>5</td>
<td>0.6</td>
<td>5</td>
<td>0.6</td>
<td>5</td>
<td>0.6</td>
<td>2</td>
<td>0.24</td>
<td>5</td>
<td>0.6</td>
<td>5</td>
<td>0.6</td>
<td>5</td>
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<tr>
<td>Pool safe materials</td>
<td>0.06</td>
<td>5</td>
<td>0.3</td>
<td>5</td>
<td>0.3</td>
<td>2</td>
<td>0.12</td>
<td>5</td>
<td>0.3</td>
<td>5</td>
<td>0.3</td>
<td>5</td>
<td>0.3</td>
<td>5</td>
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<tr>
<td>Measure sample size from Photo</td>
<td>0.09</td>
<td>5</td>
<td>0.45</td>
<td>1</td>
<td>0.09</td>
<td>1</td>
<td>0.09</td>
<td>4</td>
<td>0.36</td>
<td>4</td>
<td>0.36</td>
<td>1</td>
<td>0.09</td>
<td>5</td>
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<tr>
<td>No tipping at 20° max</td>
<td>0.11</td>
<td>5</td>
<td>0.55</td>
<td>3</td>
<td>0.33</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0.44</td>
<td>4</td>
<td>0.44</td>
<td>4</td>
<td>0.44</td>
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<tr>
<td>Lunar Dust resistance</td>
<td>0.001</td>
<td>5</td>
<td>0.05</td>
<td>4</td>
<td>0.04</td>
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<td>0.04</td>
<td>4</td>
<td>0.04</td>
<td>5</td>
<td>0.05</td>
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<tr>
<td>TOTAL</td>
<td>1.0</td>
<td>4.1</td>
<td>3.67</td>
<td>3.49</td>
<td>4.13</td>
<td>4.03</td>
<td>4.29</td>
<td>4.7</td>
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<td>Y/N</td>
<td>Question</td>
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</tr>
<tr>
<td>✗</td>
<td>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?</td>
<td></td>
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<tr>
<td>✗</td>
<td>2. Can any part of the design undergo high accelerations/decelerations?</td>
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<tr>
<td>✗</td>
<td>3. Will the system have any large moving masses or large forces?</td>
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<tr>
<td>✗</td>
<td>4. Will the system produce a projectile?</td>
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<tr>
<td>✗</td>
<td>5. Would it be possible for the system to fall under gravity creating injury?</td>
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<tr>
<td>✗</td>
<td>6. Will a user be exposed to overhanging weights as part of the design?</td>
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<tr>
<td>✗</td>
<td>7. Will the system have any sharp edges?</td>
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</tr>
<tr>
<td>✗</td>
<td>8. Will any part of the electrical systems not be grounded?</td>
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</tr>
<tr>
<td>✗</td>
<td>9. Will there be any large batteries or electrical voltage in the system above 40 V?</td>
<td></td>
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</tr>
<tr>
<td>✗</td>
<td>10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
<td></td>
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</tr>
<tr>
<td>✗</td>
<td>11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?</td>
<td></td>
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</tr>
<tr>
<td>✗</td>
<td>12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>✗</td>
<td>13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>✗</td>
<td>14. Can the system generate high levels of noise?</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>✗</td>
<td>15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?</td>
<td></td>
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</tr>
<tr>
<td>✗</td>
<td>16. Is it possible for the system to be used in an unsafe manner?</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>✗</td>
<td>17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>The folding mechanism of the legs could feasibly create pinch points if an astronaut’s finger is caught between the main stadia rod and the leg.</td>
<td>The collar to which the Tholos' legs are attached acts as a barrier between the folding mechanism and the astronaut’s fingers. Because of this, the primary pinch points will be internal and inaccessible to the end user in the final design of the Tholos. The final design will explain that the collar also acts as a ‘finger guard’. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
<tr>
<td>Naturally, each piece of stock will have sharp edges which may pose a threat to the end user.</td>
<td>In the final product, we will ensure all sharp edges are broken by either a fillet or a chamfer. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
<tr>
<td>Given the environment on the moon, both extremely low temperatures and the presence of abrasive lunar dust pose serious threats to the functionality of the Tholos.</td>
<td>Since this is one of the primary issues present in the design of the location calibrator, the Tholos has already been designed with these hazards in mind. We will, however, have to test the sliding mechanism to make sure it is not severely impeded by the presence of the abrasive lunar dust. This shall be accomplished at the Neutral Buoyancy Laboratory.</td>
<td>June 5, 2022</td>
<td></td>
</tr>
<tr>
<td>If used improperly, the Tholos may cause bodily damage to the end user by damaging EVA suits.</td>
<td>It should be very clear in our final design submission that the device must be used in the intended manner; this will be included in the final submission to Micro-g NeXT. This will be detailed in the Micro-g NeXT PDR and included in the final product deliverables.</td>
<td>January 26, 2022</td>
<td></td>
</tr>
</tbody>
</table>
Section 1: Identification

Product Identifier: Acetron GP POM-C Black

Manufacturer:
Quadrant EPP USA, Inc.
2120 Fairmont Ave.
Reading, PA 19605
(610) 320-6600

In case of an emergency, please call Chemtrec 1-800-424-9300.

Recommended Use: Engineering thermoplastic stock shape

Section 2: Hazard Identification

GHS – Classifications

Classification: None

Signal Word: None

Pictograms and Symbols: None

Hazard Statements: None

Precautionary Statements: None

Section 3: Composition/Information on Ingredients

This is a polymeric material. All constituents are encapsulated within the polymer system and therefore present no likelihood of exposure under normal conditions of processing and handling.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS No.</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyoxyethylene Copolymer</td>
<td>24969-26-4</td>
<td>&gt;99</td>
</tr>
<tr>
<td>Carbon black</td>
<td>1333-86-4</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>50-00-0</td>
<td>Trace level contaminant</td>
</tr>
</tbody>
</table>
Section 4: First-Aid Measures

**Eyes:** Flush with plenty of water for at least 15 minutes. Seek medical attention if irritation continues.

**Skin:** No health risks concerning skin contact at room temperature. Wash with soap and water. If molten material comes in contact with the skin, cool under running water. Do not attempt to remove the molten material from the skin. Get medical attention immediately.

**Inhalation:** If fumes from overheating are inhaled, remove to fresh air. Seek medical attention if respiratory symptoms occur or breathing becomes difficult.

**Ingestion:** Rinse the victim’s mouth with plenty of water. Do not induce vomiting. Seek medical attention.

**Notes to physician:**
This product is essentially inert and nontoxic. However, if it is overheated or burns, gases such as carbon monoxide and formaldehyde may be released. Those exposed to off-gases may need to have their arterial blood gases and carboxyhemoglobin levels checked. If the carboxyhemoglobin levels are normal and the exposure occurred in an enclosed space, asphyxia (carbon dioxide replacing oxygen) is a possibility. Formaldehyde is a respiratory irritant gas. If patients may have inhaled high concentrations of irritating fumes they should be monitored for delayed onset pulmonary edema.

Section 5: Fire-Fighting Measures

Fire-fighters should protect themselves from decomposition and combustion products by using a full-face self-contained breathing apparatus and impervious protective clothing. Keep personnel removed and upwind of fire. Extinguish fires with water, foam, carbon dioxide or dry chemical media.

Burns with invisible flame.

Hazardous gases/vapors produced in fire are: carbon oxides and formaldehyde.

Dust is flammable and explosive when finely divided and suspended in air.

Section 6: Accidental Release Measures

If a spill occurs, stop the leak at the source and sweep up for disposal. Do not flush to sewers or waterways.

Section 7: Handling and Storage

**Precautions for Safe Handling**
Personal hygiene such as washing the hands and face immediately after working with this material and before eating is recommended.

Dust may form explosive mixtures with air. Avoid dust formation and control ignition sources. Polyolefin dust particles suspended in air are combustible and may be explosive. Keep away from heat, sparks, flame, and other ignition sources. Prevent dust accumulations and dust clouds. Employ ground, bonding, venting, and explosive relief provisions in accordance with
accepted engineering practices and NFPA provisions in any process capable of generating dust and/or static electricity. Explosion hazards apply only to dusts, not granular forms of this product.

The handling of powder in both loading and unloading operations, as well as fabrication, may cause dust to be formed and necessary precautions for personal protection should be used. As with all finely divided materials precautions should be taken to avoid inhalation and eye contact.

If in dust form, transfer from storage with a minimum amount of dusting. Ground all transfer, blending, and dust collecting equipment to prevent static sparks in accordance with NFPA 70 “National Electric Code.” Review and comply with all relevant NFPA provisions, including but not limited to NFPA 484 and NFPA 654 related to combustible dust hazards. Remove all ignition sources from material handling, transfer, and processing areas where dust may be present. Local exhaust ventilation should be provided in work area.

Precautions for Safe Storage
Store in a sprinkler protected warehouse. Since products are organic they will burn with a hot flame if ignited. Avoid contact with ignition sources such as open flames. Keep a fire extinguisher near if welding is done in the area of organic products. If a heat source is present, keep the area well ventilated.

Section 8: Exposure Controls/Personal Protection

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>ACGIH TLV</th>
<th>OSHA PEL</th>
<th>NIOSH REL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>10 mg/m³</td>
<td>15 mg/m³ – Total</td>
<td>Not Determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 mg/m³ – Respirable</td>
<td></td>
</tr>
<tr>
<td>Carbon black</td>
<td>3.5 mg/m³</td>
<td>3.5 mg/m³</td>
<td>3.5 mg/m³</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.3 ppm (Ceiling)</td>
<td>0.75 ppm (TWA)</td>
<td>0.016 ppm (TWA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 ppm (STEL)</td>
<td>0.1 ppm (Ceiling)</td>
</tr>
</tbody>
</table>

Engineering Measures:
Provide local exhaust ventilation to keep airborne particulate concentrations below the OELs.

Personal Protective Equipment: Eyes/Face
Safety glasses with side shields.

Personal Protective Equipment: Skin
When handling molten material, protective clothing such as long sleeves or laboratory coat should be worn. Use heat-resistant gloves, boots and face protection.

Personal Protective Equipment: Respiratory
If levels are above published OELs, then a NIOSH approved respirator.

Good industrial hygiene practice should be followed which includes preventing eye contact, minimizing skin contact and minimizing inhalation of dust, vapors or mist.
**Section 9: Physical and Chemical Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance and Odor</td>
<td>Solid in rod, plate, tube or strip form with essentially no odor</td>
</tr>
<tr>
<td>Odor Threshold</td>
<td>No Information Available</td>
</tr>
<tr>
<td>Specific Gravity (Relative Density)</td>
<td>1.38 – 1.42</td>
</tr>
<tr>
<td>Solubility in Water</td>
<td>Insoluble</td>
</tr>
<tr>
<td>VOC Content (%)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>pH</td>
<td>No data available</td>
</tr>
<tr>
<td>Melting Point/Freezing Point</td>
<td>320°-342°F</td>
</tr>
<tr>
<td>Vapor Pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>Vapor Density</td>
<td>No data available</td>
</tr>
<tr>
<td>Evaporation Rate</td>
<td>No data available</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>No data available</td>
</tr>
<tr>
<td>Flammability</td>
<td>Combustible</td>
</tr>
<tr>
<td>Flash Point</td>
<td>608°F (ASTM-D-1929)</td>
</tr>
<tr>
<td>Explosion Data</td>
<td>LEL – No data available</td>
</tr>
<tr>
<td>Auto ignition Point</td>
<td>UEL – No data available</td>
</tr>
<tr>
<td>Partition Coefficient: n-octanol/water</td>
<td>No data available</td>
</tr>
<tr>
<td>Decomposition Temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>Viscosity</td>
<td>446° F</td>
</tr>
<tr>
<td></td>
<td>No data available</td>
</tr>
</tbody>
</table>

**Section 10: Stability and Reactivity**

**Reactivity:**
None known

**Chemical Stability:**
Material is stable under normal industrial conditions and is not susceptible to hazardous polymerization.

**Conditions to Avoid:**
Flame. Do not allow mixing of this material with PVC, other halogen containing materials, and partially and/or fully crosslinkable thermoplastic elastomers. Do not heat above 460° F (238° C). Avoid prolonged heating at or above the recommended temperature.

**Incompatibility:**
PVC, strong acids, oxidizing agents.

**Hazardous Decomposition Products:**
At temperatures above 460°F/238° C, heavy fuming of formaldehyde will occur.
Section 11: Toxicological Information

Acetal Polymer
There are no known effects from exposure to the Acetron polymer itself. If overheated, the polymer releases formaldehyde which may cause skin, eye, and respiratory irritation and allergic reactions.

Signs and Symptoms of Overexposure: Eye irritation signs and symptoms may include a burning sensation, redness, swelling, and/or blurred vision. Skin irritation signs and symptoms may include a burning sensation, redness and swelling. Respiratory irritation signs and symptoms may include a temporary burning sensation of the nose and throat, coughing, and/or difficulty breathing.

Aggravated Medical: None.

Acute Effects: Non-toxic.
Skin Corrosion/Irritation: Not irritating to the skin.
Serious Eye Damage/Irritation: Particulates can be mechanically irritating to the eyes.
Ingestion: None.
Inhalation: Inhalation of particulates may produce respiratory tract irritation.
Respiratory or Skin Sensitization: Not expected to be a sensitizer.

Chronic Effects:

Germ Cell Mutagenicity: Not expected to be a germ cell mutagen.
Carcinogenicity: Not classifiable as carcinogen to humans (group 3 IARC).
Reproductive Toxicity: There aren’t known reproductive toxicity effects.
STOT-single Exposure: At dust form, may cause respiratory irritation with cough and sneezing.
STOT –multiple Exposure: There aren’t known repeated exposure effects.
Aspiration Hazard: No data available. Not expected to be an aspiration hazard.
Other: Formaldehyde, which is degradation product, is listed as a potential cancer hazard by OSHA, a known human carcinogen by The International Agency for Research on Cancer (IARC, Group 1), and a substance which can reasonably be anticipated to be a carcinogen by The National Toxicology Program (NTP). Formaldehyde should not pose a risk if exposures are kept below the OELs.

Primary Route of Entry: Inhalation of particulates.

Section 12: Ecological Information

Ecotoxicity: There aren’t known ecological toxicity values.

Persistence and degradability: It’s expected high persistence and slow degradability.

Bioaccumulative Potential: It’s expected moderate to high bioaccumulative potential.
Mobility in Soil:
No data available

Other Adverse Effects:
No data available

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Toxicity to Algae</th>
<th>Toxicity to Fish</th>
<th>Microtox</th>
<th>Daphnia Magna (Water Flea)</th>
</tr>
</thead>
</table>

Section 13: Disposal Considerations
Dispose of in accordance with federal, state and local regulations.

Section 14: Transportation Information
US Department of Transportation Classification (49CFR)
Not classified as hazardous for transport.

Section 15: Regulatory Information
SARA Section 302 & 304:
No chemicals

SARA Section 313:
The following component is subject to reporting levels established by SARA Title III, Section 313:
- None

TSCA:
All components of this product are either listed or are exempt on the TSCA inventory.

Section 16: Other Information

Label Information

Product Identifier: Acetron GP POM-C Black

Manufacturer:
Quadrant EPP USA, Inc.
2120 Fairmont Ave.
Reading, PA 19605
(610) 320-6600

In case of an emergency, please call Chemtrec 1-800-424-9300.
**Classification:** None

**Signal Word:** None

**Pictograms and Symbols:** None

**Hazard Statements:** None

**Precautionary Statements:** None

<table>
<thead>
<tr>
<th>Revision Date</th>
<th>Reason for Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1, 2015</td>
<td>SDS format</td>
</tr>
</tbody>
</table>

The information set forth herein has been gathered from standard reference materials and/or supplier test data and is, to the best knowledge and belief of Quadrant EPP, accurate and reliable. Such information is offered solely for your consideration, investigation and verification, and it is not suggested or guaranteed that the hazard precautions or procedures mentioned are the only ones that exist. Quadrant EPP makes no warranties, expressed or implied, with respect to the use of such information or the use of the specific material identified herein in combination with any other material or process, and assumes no responsibility therefor.
Material Name: Aluminum Extrusion Metal, 6061 Series Alloys

*** 1. Product Name and Company Identification ***

<table>
<thead>
<tr>
<th>MATERIAL NAME</th>
<th>Aluminum Extrusion Metal, 6061 Series Alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT NAME</td>
<td>00001E</td>
</tr>
<tr>
<td>MANUFACTURER INFORMATION</td>
<td>Sierra Aluminum, a Division of Samuel, Son &amp; Co. (USA) Inc.</td>
</tr>
<tr>
<td></td>
<td>2345 Fleetwood Drive</td>
</tr>
<tr>
<td></td>
<td>Jurupa Valley, California</td>
</tr>
<tr>
<td></td>
<td>Phone: (951) 781-7800</td>
</tr>
<tr>
<td></td>
<td>Fax: (951) 787-6576</td>
</tr>
<tr>
<td>APPEARANCE AND ODOR</td>
<td>Grey to silver solid; odorless</td>
</tr>
<tr>
<td>USES</td>
<td>Primary Metal</td>
</tr>
</tbody>
</table>

*** 2. Hazardous Identification ***

General Hazard Statement: Under the definition of the OSHA Hazard Communication Standard (29 CFR 1910.1200), solid metallic products are classified as “articles” and do not contain hazardous materials in solid form. Any articles manufactured from these solid products would be generally classified as non-hazardous. However, these products contain hazardous elements that can be emitted under certain processing conditions such as burning, melting, cutting, sawing, brazing, grinding, machining, milling, and welding. There is no fire or explosion hazard presented in the solid state. Small chips, fines, and dust may ignite readily, though. The following classification information is for the hazardous elements which may be released during processing.

GHS Classification:
- Flammable Solid- Category 1
- Eye Damage/Irritation- Category 2B
- Respiratory Sensitizer- Category 1
- Skin Sensitizer- Category 1
- Germ Cell Mutagenicity- Category 2
- Carcinogenicity- Category 1B
- Specific Target Organ Toxicity (Repeated Exposure)- Category 1
- Hazardous to the Aquatic Environment –Acute Hazard- Category 1
- Hazardous to the Aquatic Environment- Chronic Hazard- Category 2

GHS Label Elements:

- Symbols

Signal Word
- Danger

Hazard Statements
- Flammable solid.
- Causes eye irritation.
- May cause allergy or asthma symptoms or breathing difficulties if inhaled.
- May cause and allergic skin reaction.
- Suspected of causing genetic defects.
- May cause cancer.
- If prolonged or repeated exposure exits, it can cause damage to respiratory system.
- Very toxic to the aquatic life. Toxic to the aquatic life with long lasting effects.
**Precautionary Statements:**

**Prevention**
- Keep away from heat/sparks/open flames/hot surfaces. No smoking.
- Use explosion proof electrical/ventilating/lighting equipment.
- Wear protective gloves/protective clothing/eye protection/face protection.
- Do not breathe dust/fume.
- In case of inadequate ventilation wear respiratory protection.
- Contaminated work clothing should not be allowed out of the workplace.
- Obtain special instructions before use.
- Do not handle until all safety precautions have been read and understood.
- Wash thoroughly after handling.
- Do not eat, drink or smoke when using this product.
- Avoid release to the environment.

**Response**
- In case of fire: Use Class D agent to extinguish.
- IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do.
- Continue rinsing. If eye irritation persists get medical advice/attention.
- IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing. If experiencing respiratory symptoms: Call a poison center/doctor.
- IF ON SKIN: Wash with plenty of soap and water. If skin irritation or rash occurs: Get medical advice/attention. Wash contaminated clothing before reuse.
- If exposed or concerned: Get medical advice/attention. Get medical advice/attention if you feel unwell. Collect spillage.

**Storage**
- Store locked up

**Disposal**
- Dispose of contents/containers with local/region/national/international regulations

### ***3. Composition/ Information on Ingredients***

<table>
<thead>
<tr>
<th>CASE #</th>
<th>NAME</th>
<th>CONC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7429-90-5</td>
<td>Aluminum</td>
<td>Remainder</td>
</tr>
<tr>
<td>7440-47-3</td>
<td>Chromium</td>
<td>0.04-0.35%</td>
</tr>
<tr>
<td>7440-50-8</td>
<td>Copper</td>
<td>0.15-0.40%</td>
</tr>
<tr>
<td>7439-89-6</td>
<td>Iron</td>
<td>0.20-0.70%</td>
</tr>
<tr>
<td>7439-95-4</td>
<td>Magnesium</td>
<td>0.80-1.20%</td>
</tr>
<tr>
<td>7439-96-5</td>
<td>Manganese</td>
<td>0.05-0.15%</td>
</tr>
<tr>
<td>7440-21-3</td>
<td>Silicon</td>
<td>0.40-0.80%</td>
</tr>
<tr>
<td>7440-32-6</td>
<td>Titanium</td>
<td>0.05-0.15%</td>
</tr>
<tr>
<td>7440-66-6</td>
<td>Zinc</td>
<td>0.05-0.25%</td>
</tr>
</tbody>
</table>

*For more detailed chemical composition, refer to the certificate of analysis.*
### 4. First aid Measures

**First Aid: Inhalation**  
In case of discomfort, remove to a ventilated area. If discomfort persists, consult a physician.

**First Aid: Skin**  
In case of burns with hot metal, rinse with plenty of cold water. If burn is severe, consult a physician.

**First Aid: Eyes**  
Flush eyes thoroughly with water, taking care to rinse under eyelids. If irritation persists, continue flushing for 15 minutes, rinsing from time to time under eyelids. If discomfort continues, consult a physician.

**First Aid: Ingestion**  
Not applicable.

### 5. Fire Extinguisher Measures

**General Fire Hazards**  
Not applicable. This product does not present fire or explosion hazards. Small chips, fines and dust from processing may be ignitable.

**Extinguishing Media**  
Not a fire hazard unless in particle form. Suspensions of aluminum dust in air may pose a severe explosion hazard. A potential for explosion exists for a mixture of fine and coarse particles if at least 15% to 20% of the material is finer than 44 microns (325 mesh). Buffing and polishing generate finer material than grinding, sawing and cutting. In case of aluminum fires, use a **Class D Dry Powder Extinguisher** (Lith-X). Do not use water or halogenated extinguishing media.

**Hazardous Combustion Products**  
Not applicable. In the event of fire and/or explosion, do not breathe fumes.

**Fire Fighting Equipment/Instructions**  
Wear self-contained breathing apparatus, MSHA/NIOSH (approved or equivalent) and full protective gear.

### 6. Accidental Release Measures

**Recovery and Neutralization**  
Recycle if possible. Avoid dust formation.

**Methods for Clean Up**  
If molten, contain flow using dry sand or salt flux as a dam. Preheat or specially coat all tools and containers that come in contact with molten metal. Must be rust free. Allow spill to cool before remelting as scrap.

**Emergency Measures**  
Keep away from spill/leak.

**Personal Protective Equipment (PPE)**  
Wear appropriate protective equipment and respiratory equipment for the situation.

**Environmental Precautions**  
Prevent further leakage or spillage. Prevent from entering the drains. Do not flush into surface water or sanitary water system.

**Prevention of Secondary Hazards**  
None
*** 7. Handling and Storage ***

Handling Precaution  
Because of the risk of explosion, aluminum ingots and metal scrap should be thoroughly dried prior to remelting. Use standard techniques to check metal temperature before handling. Hot aluminum does not present any warning color change. Exercise great caution, since the metal may be hot. For more information on the handling and storage of aluminum, consult the following documents published by The Aluminum Association, 900 19th St., N.W., Washington, D.C., 20006:

- Guidelines for handling molten aluminum
- Recommendation for storage and handling of aluminum powders and paste.
- Guidelines for handling Aluminum fines generated during various aluminum fabrications operations.

Storage Conditions  
Keep containers closed and dry.

*** 8. Exposure Control/ Personal Protection ***

Special ventilation should be used to convey finely divided metallic dust generated by grinding, sawing etc., in order to eliminate explosion hazards. Maintain dust concentration in ventilation ducts below the lower explosive limit of 40 g/mg (0.04 oz/ft³). See “National Fire Protection Association Codes”: Code 65 “Processing and Finishing of Aluminum”, Code 651, “Standard for the manufacture of Aluminum and magnesium powder” and Code 77 “Static electricity”. Use an approved respirator designed for the hazard, where concentrations exceed exposure limits. The use of both primary and secondary protective equipment is necessary when handling molten metal. Refer to “Aluminum Association” guidelines.

Engineering Controls  
Use adequate ventilation to meet exposure limits listed in this section.

Eye Protection  
When cutting, wear approved safety glasses and/or goggles to prevent foreign particles from projecting into the eye.

Skin Protection  
Wear appropriate gloves to avoid direct skin contact.

Exposure Limits

<table>
<thead>
<tr>
<th></th>
<th>ACGIH (TLV)</th>
<th>OSHA (PEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TWA</td>
<td>STEL</td>
</tr>
<tr>
<td>Aluminum (total dust)</td>
<td>10 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>(fume, powder, respirable dust)</td>
<td>5 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>Silicon (total dust)</td>
<td>10 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>(Respirable dust)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Iron Oxide (fume, dust)</td>
<td>5 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>Copper (fume)</td>
<td>0.2 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>(dust)</td>
<td>1.0 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>Magnesium, Oxide (fumes)</td>
<td>10 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>Manganese (as Mn and compounds)</td>
<td>0.2 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>Zinc (oxide fume)</td>
<td>5 mg/m³</td>
<td>10 mg/m³</td>
</tr>
<tr>
<td>(total dust)</td>
<td>10 mg/m³</td>
<td>None</td>
</tr>
<tr>
<td>(respirable dust)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Chromium (metal)</td>
<td>0.5 mg/m³</td>
<td>None</td>
</tr>
</tbody>
</table>
### 9. Physical and Chemical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>N/A</td>
</tr>
<tr>
<td>Boiling point</td>
<td>N/A</td>
</tr>
<tr>
<td>Melting point</td>
<td>482-660°C</td>
</tr>
<tr>
<td>Vapor Pressure</td>
<td>N/A</td>
</tr>
<tr>
<td>Vapor Density (Air=1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Evaporation Rate</td>
<td>N/A</td>
</tr>
<tr>
<td>Relative Density (water=1)</td>
<td>2.5-2.9</td>
</tr>
<tr>
<td>Water solubility</td>
<td>N/A</td>
</tr>
<tr>
<td>Odor threshold</td>
<td>N/A</td>
</tr>
<tr>
<td>Flashpoint</td>
<td>N/A</td>
</tr>
<tr>
<td>Auto ignition temperature</td>
<td>N/A</td>
</tr>
<tr>
<td>Lower flammability limit</td>
<td>N/A</td>
</tr>
<tr>
<td>Higher flammability limit</td>
<td>N/A</td>
</tr>
<tr>
<td>Explosive properties</td>
<td>N/A</td>
</tr>
<tr>
<td>NFPA Fire Code</td>
<td>0</td>
</tr>
<tr>
<td>Partition Coefficient</td>
<td>N/A</td>
</tr>
<tr>
<td>(N-Octa Nol/water)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### 10. Chemical Stability and Reactivity Information

- **Stable (yes/no)**: Yes
- **Conditions and Materials to Avoid**: Molten aluminum may explode on contact with water. In the form of particles, it may explode when mixed with halogenated acids, halogenated solvents, bromates, iodated or ammonium nitrate. Aluminum particles on contact with copper, lead, or iron oxides can react vigorously with release of heat if there is a source of ignition or intense heat.
- **Hazardous Decomposition Products**: In the form of particles, aluminum reacts with water, strong basic solutions, strong acidic solutions, halogenated acids (eg. Hydrofluoric acid) producing flammable hydrogen gas.

### 11. Toxicological Information

#### ROUTES OF EXPOSURE:
- **Inhalation**: Yes
- **Ingestion**: No
- **Eye Contact**: No
- **Skin Contact**: No
- **Skin Absorption**: No

#### ACUTE TOXICITY:
- **Iron (7439-89-6)**: Oral LD50 Rat 984 mg/kg
- **Magnesium (7439-95-4)**: Oral LD50 Rat 230 mg/kg
- **Manganese (7439-96-5)**: Oral LD50 Rat 9g/kg
- **Silicon (740-21-3)**: Oral LD50 Rat 3160 mg/kg
Material Name: Aluminum Extrusion Metal, 6061 Series Alloys Safety Data Sheet

ACUTE EFFECTS:
Inhalation  Solid aluminum does not present an inhalation hazard. Aluminum and silicon dusts generated during use are considered nuisance particulates.

Skin Contact  Skin contact with hot metal can cause burns.

Eye Contact  Aluminum dust can irritate the eyes (mechanical abrasion).

Ingestion  May be harmful if swallowed.

CHRONIC EFFECTS:
Medical conditions aggravated by exposure to the product: Not applicable

Carcinogenicity/Mutagenicity/Reproductive Toxicity:
Certain alloys of this series may contain chromium. Chromium and its compounds are listed in the current annual report on carcinogens, Prepared by the "National Toxicology Program" (NTP). Does not contain any other carcinogen or potential carcinogen (IARC, NTP, OSHA). (IARC=International Agency for Research on Cancer; NTP=National Toxicology Program ; OSHA=Occupational Safety and Health Administration).

Carcinogenicity: May cause cancer

Component Carcinogenicity

Aluminum (7429-90-5)
  ACGIH: A4 - Not Classifiable as a Human Carcinogen

Chromium (7440-47-3)
  ACGIH: A4 - Not Classifiable as a Human Carcinogen
  IARC: Monograph 49 [1990] (listed under Chromium and Chromium compounds);
  Supplement 7 [1987] (Group 3 (not classifiable))

Mutagenicity: Suspected of causing genetic defects

Reproductive Toxicity: May cause damage to the respiratory system organs through prolonged or repeated exposure. Repeated contact may cause allergic reactions. Avoid repeated exposure. Prolonged exposure may cause chronic effects. Repeated or prolonged skin contact may cause skin irritation and/or dermatitis and sensitization of susceptible persons. May cause adverse effects on the bone marrow and blood-forming system. May cause adverse liver effects.

Supplementary Information:
Aluminum fumes generated during welding or melting present low health risks. Welding or plasma arc cutting of aluminum alloys can generate ozone, nitric oxides and ultraviolet radiation. Ozone over exposure may result in mucous membrane irritation or pulmonary discomfort. UV radiation can cause skin erythema and welders flash. High concentrations of freshly-formed fumes of copper, magnesium, manganese or zinc oxides can produce symptoms of metal fume fever. High concentrations of copper dust can cause irritation of the upper respiratory tract. High concentrations of manganese dust can affect the central nervous system (apathy, drowsiness, weakness and other symptoms resembling to Parkinson's Disease).
12. Ecological Information

Ecotoxicity: Very toxic to aquatic organisms. May cause long-term adverse effects in the aquatic environment. Aluminum and its alloys under solid form, such as ingots or manufactured items, do not present any hazard for environment because metals are not biologically available. Aluminum can be recycled.

Component Analysis

Copper (7440-50-8)

<table>
<thead>
<tr>
<th>Test &amp; Species</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 Hr LC50 Pimephales promelas</td>
<td>0.0068 - 0.0156 mg/L</td>
</tr>
<tr>
<td>96 Hr LC50 Pimephales promelas</td>
<td>&lt;0.3 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Oncorhynchus mykiss</td>
<td>0.052 mg/L [flow-through]</td>
</tr>
<tr>
<td>96 Hr LC50 Lepomis macrochirus</td>
<td>1.25 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>0.3 mg/L [semi-static]</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>0.8 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Poecilia reticulate</td>
<td>0.112 mg/L [flow-through]</td>
</tr>
<tr>
<td>72 Hr EC50 Pseudokirchneriella subcapitata</td>
<td>0.0426 - 0.0535 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr EC50 Pseudokirchneriella subcapitata</td>
<td>0.031 - 0.054 mg/L [static]</td>
</tr>
<tr>
<td>48 Hr EC50 Daphnia Magna</td>
<td>0.03 mg/L [static]</td>
</tr>
</tbody>
</table>

Iron (7439-89-6)

<table>
<thead>
<tr>
<th>Test &amp; Species</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 Hr LC50 Morone saxatilis</td>
<td>13.6 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>0.56 mg/L [semi-static]</td>
</tr>
</tbody>
</table>

Zinc (7440-66-6)

<table>
<thead>
<tr>
<th>Test &amp; Species</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 Hr LC50 Pimephales promelas</td>
<td>2.16 - 3.05 mg/L [flow-through]</td>
</tr>
<tr>
<td>96 Hr LC50 Pimephales promelas</td>
<td>0.211 - 0.269 mg/L [semi-static]</td>
</tr>
<tr>
<td>96 Hr LC50 Pimephales promelas</td>
<td>2.66 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>30 mg/L</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>0.45 mg/L [semi-static]</td>
</tr>
<tr>
<td>96 Hr LC50 Cyprinus carpio</td>
<td>7.8 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Lepomis macrochirus</td>
<td>3.5 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr LC50 Oncorhynchus mykiss</td>
<td>0.24 mg/L [flow-through]</td>
</tr>
<tr>
<td>96 Hr LC50 Oncorhynchus mykiss</td>
<td>0.59 mg/L [semi-static]</td>
</tr>
<tr>
<td>96 Hr LC50 Oncorhynchus mykiss</td>
<td>0.41 mg/L [static]</td>
</tr>
<tr>
<td>96 Hr EC50 Pseudokirchneriella subcapitata</td>
<td>0.11 - 0.271 mg/L [static]</td>
</tr>
<tr>
<td>72 Hr EC50 Pseudokirchneriella subcapitata</td>
<td>0.09 - 0.125 mg/L [static]</td>
</tr>
<tr>
<td>48 Hr EC50 Daphnia magna</td>
<td>0.139 - 0.908 mg/L [Static]</td>
</tr>
</tbody>
</table>

Degradability: Metal powders may cause ecological damage through silting or sedimentation effect in water depriving organisms of habitat and mobility, and/or fouling of gills, lungs and skin thus limiting oxygen uptake.

Bioaccumulation: Metal powders in water or soil may form metal oxides or other metal compounds that could become bioavailable and harm aquatic or terrestrial organisms.

Mobility in soil: Metal powder would be relatively immobile in soils but some metal compounds may be transported with ground water.
Material Name: Aluminum Extrusion Metal, 6061 Series Alloys Safety Data Sheet

*** 13. Disposal Considerations ***
Recycle – Aluminum in the form of particles may be reactive. Its hazardous characteristics, including fire and explosion, should be determined prior too disposal. Dispose of waste in accordance with federal, state, or local regulations.

*** 14. Transport Information ***

*** 15. Regulatory Information ***
WHMIS Classification (Canada) D2 Material causing other toxic effects
European Union Classification Not classified
Warning Symbol None
Warning Word None
Risk Phrases None
Safety Phrases None

U.S. Federal Regulations
Section 313 Supplier Notification
This product contains the following toxic chemical(s) subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act of 1986 (Title 111 of SARA) and of 40 CFR 372. (This information must be included in all MSDSs that are copied and distributed for this material).
CERCLA Hazardous Substances: Chromium, Copper, Zinc.
TSCA: All components of this product are listed in the TSCA inventory.

A. Component Analysis
Aluminum (7429-90-5)
SARA 313: 1.0 % de minimis concentration (dust or fume only)

Chromium (7440-47-3)
CERCLA: 5000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm); 2270 kg final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm)

Copper (7440-50-8)
SARA 313: 1.0 % de minimis concentration
CERCLA: 5000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm); 2270 kg final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm)

Manganese (7439-96-5)
SARA 313: 1.0% de minimis concentration

Zinc (7440-66-6)
SARA 313: 1.0 % de minimis concentration (dust or fume only)
Material Name: Aluminum Extrusion Metal, 6061 Series Alloys Safety Data Sheet

CERCLA: 454 kg final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm); 1000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is >100 μm)

B. Component Marine Pollutants
   Copper (7440-50-8)
   0-6.9 DOT regulated severe marine pollutant (powder)

State Regulations
The following appear on one or more of the state hazardous substance lists

A. Component analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS#</th>
<th>CA</th>
<th>MA</th>
<th>MN</th>
<th>NJ</th>
<th>PA</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>7429-90-5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chromium</td>
<td>7440-47-3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Copper</td>
<td>7440-50-8</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Iron</td>
<td>7439-89-6</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Magnesium</td>
<td>7439-95-4</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Manganese</td>
<td>7439-96-5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Silicon</td>
<td>7440-21-3</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Titanium</td>
<td>7440-36-6</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Zinc</td>
<td>7440-66-6</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

WARNING! This product contains a chemical known to the state of California to cause cancer and reproductive/developmental effects.

The following components are identified under the Canadian Hazardous Products Act Ingredients Disclosure Lists

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS#</th>
<th>Minimum Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>7429-90-5</td>
<td>1%</td>
</tr>
<tr>
<td>Chromium</td>
<td>7440-47-3</td>
<td>0.1%</td>
</tr>
<tr>
<td>Copper</td>
<td>7440-50-8</td>
<td>1%</td>
</tr>
<tr>
<td>Manganese</td>
<td>7439-96-5</td>
<td>1%</td>
</tr>
</tbody>
</table>

Additional Regulatory Information

Component Analysis - Inventory

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS #</th>
<th>TSCA</th>
<th>CAN</th>
<th>EEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>7429-90-5</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Chromium</td>
<td>7440-47-3</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Copper</td>
<td>7440-50-8</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Iron</td>
<td>7439-89-6</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Magnesium</td>
<td>7439-95-4</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Manganese</td>
<td>7439-96-5</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Silicon</td>
<td>7440-21-3</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Titanium</td>
<td>7440-32-6</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
<tr>
<td>Zinc</td>
<td>7440-66-6</td>
<td>Yes</td>
<td>DSL</td>
<td>EINECS</td>
</tr>
</tbody>
</table>
California Proposition 65: Hexavalent Chromium (if present) is known in the State of California to cause cancer. This product contains trace amounts of lead (Pb) (<0.1%). Any process resulting exposure to more than 0.5 mg/m3 of metal dust per day may result in a daily dose of lead of over 0.5 ug/day, the dose above which the "California Safe Drinking Water and Toxic Enforcement Act" of 1986 requires notification. Refer to the appropriate regulation notification wording guidelines. The dose is considered dangerous for health according to current toxicology studies.

### Abbreviations

Hazard Ratings: NFPA=N/A, HMIS=N/A

Although the information in this MSDS was obtained from sources, which we believe to be reliable, it cannot be guaranteed. In addition, this information may be used in a manner beyond our knowledge or control. The information is therefore provided for advice purposes only, without any representation or warranty expressed or implied.*

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Fax: (951) 787-6576
E-mail: naro.kuch@samuel.com & Rafael.mendoza@samuel.com

DATE OF REVISION: September 15, 2020
REASON FOR REVISION: Update Company Information
Appendix R. MSDS Carbon Steel

Carbon Steel - Leaded Grades

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 04/23/2015 Version: 1.0

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Product form : Mixture
Blooms, billets, hot rolled bars, cold finished bars

Product name : Carbon Steel - Leaded Grades

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture : Automotive & Machine Components
Multiple Industrial Uses

1.3. Details of the supplier of the safety data sheet

Republic Steel
2633 Eighth Street NE
Canton, Ohio 44704
Fax 330-438-5423
Phone 330-438-5466
http://www.republicsteel.com/

1.4. Emergency telephone number

Emergency number : 24 hr. Emergency Contact : Republic Steel
U.S.A. 330.438.5466
International +1.330.438.5466

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification (GHS-US)
Acute Tox. 4 (Oral) H302
Skin Sens. 1 H317
Carc. 2 H351
STOT RE 1 H372

Full text of H-phrases: see section 16

2.2. Label elements

GHS-US labeling
Hazard pictograms (GHS-US)

Signal word (GHS-US) : Danger
Hazard statements (GHS-US) : H302 - Harmful if swallowed
H317 - May cause an allergic skin reaction
H351 - Suspected of causing cancer
H372 - Causes damage to organs through prolonged or repeated exposure

Precautionary statements (GHS-US) : P260 - Do not breathe dust/fume
P264 - Wash hands and other exposed areas thoroughly after handling
P270 - Do not eat, drink or smoke when using this product
P272 - Contaminated work clothing must not be allowed out of the workplace
P280 - Wear protective gloves/protective clothing/eye protection/face protection
P301 + P312 - If swallowed: Call a poison center/doctor if you feel unwell
P302 + P352 - If on skin: Wash with plenty of water
P308 + P313 - If exposed or concerned: Get medical advice/attention
P333+P313 - If skin irritation or rash occurs: Get medical advice/attention
P362+P364 - Take off contaminated clothing and wash it before reuse

2.3. Other hazards

Steel products in the solid state present no fire or explosion hazard; however, the particulates generated may present a dust explosion hazard. Steel products in the natural state do not present an inhalation, ingestion or contact hazard. However, operations such as burning, welding, sawing, brazing, and grinding may result in exposures.
CARBON STEEL - Leaded Grades
Safety Data Sheet
due to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

2.4. Unknown acute toxicity (GHS US)

None of the ingredients are of unknown toxicity.

SECTION 3: Composition/information on ingredients

3.1. Substance

Not applicable – this product is a mixture.

3.2. Mixture

<table>
<thead>
<tr>
<th>Name</th>
<th>Product identifier</th>
<th>%</th>
<th>Classification (GHS-US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>(CAS No) 7439-89-6</td>
<td>97 - 99</td>
<td>Acute Tox. 4 (Oral), H302</td>
</tr>
<tr>
<td>Copper</td>
<td>(CAS No) 7440-50-8</td>
<td>&lt;0.01 - 1</td>
<td>Not classified</td>
</tr>
<tr>
<td>Lead</td>
<td>(CAS No) 7439-92-1</td>
<td>0.15-0.35</td>
<td>Carc. 1B, H350</td>
</tr>
<tr>
<td>Manganese</td>
<td>(CAS No) 7439-96-5</td>
<td>0.20-1.65</td>
<td>Not classified</td>
</tr>
</tbody>
</table>

Full text of H-phrases: see section 16

SECTION 4: First aid measures

4.1. Description of first aid measures

First-aid measures general: Never give anything by mouth to an unconscious person. If you feel unwell, seek medical advice (show the label where possible). Suspected of causing cancer.

First-aid measures after inhalation: Allow victim to breathe fresh air. Allow the victim to rest.

First-aid measures after skin contact: Remove affected clothing and wash all exposed skin area with mild soap and water, followed by warm water rinse. Wash with plenty of soap and water. If skin irritation or rash occurs: Get medical advice/attention. Wash contaminated clothing before reuse.

First-aid measures after eye contact: Rinse immediately with plenty of water. Obtain medical attention if pain, blinking or redness persist.

First-aid measures after ingestion: Rinse mouth. Do NOT induce vomiting. Obtain emergency medical attention. Call a POISON CENTER or doctor/physician if you feel unwell.

4.2. Most important symptoms and effects, both acute and delayed

Symptoms/injuries: Causes damage to organs through prolonged or repeated exposure.

Symptoms/injuries after inhalation: May cause an allergic skin reaction.

Symptoms/injuries after ingestion: Swallowing a small quantity of this material will result in serious health hazard.

4.3. Indication of any immediate medical attention and special treatment needed

No additional information available

SECTION 5: Firefighting measures

5.1. Extinguishing media


Unsuitable extinguishing media: Do not use a heavy water stream.

5.2. Special hazards arising from the substance or mixture

Fire hazard: Steel products in the solid state present no fire or explosion hazard; however, the particulates generated may present a dust explosion hazard.

5.3. Advice for firefighters

Firefighting instructions: Exercise caution when fighting any chemical fire. Prevent fire-fighting water from entering environment.

Protection during firefighting: Do not enter fire area without proper protective equipment, including respiratory protection.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

6.1.1. For non-emergency personnel

Emergency procedures: Evacuate unnecessary personnel.

6.1.2. For emergency responders

Protective equipment: Equip cleanup crew with proper protection.

Emergency procedures: Ventilate area.

6.2. Environmental precautions

Prevent entry to sewers and public waters. Notify authorities if liquid enters sewers or public waters.
6.3. Methods and material for containment and cleaning up
Methods for cleaning up: On land, sweep or shovel into suitable containers. Minimize generation of dust. Store away from other materials.

6.4. Reference to other sections
See Heading 8. Exposure controls and personal protection.

SECTION 7: Handling and storage

7.1. Precautions for safe handling
Precautions for safe handling: Wash hands and other exposed areas with mild soap and water before eating, drinking or smoking and when leaving work. Provide good ventilation in process area to prevent formation of vapor. Do not breathe dust/fume.

Hygiene measures: Do not eat, drink or smoke when using this product. Wash hands and other exposed areas thoroughly after handling. Contaminated work clothing should not be allowed out of the workplace. Wash contaminated clothing before reuse.

7.2. Conditions for safe storage, including any incompatibilities
Storage conditions: Store in a cool, well ventilated place.

Incompatible products: Strong bases. Strong acids.

Incompatible materials: Sources of ignition. Direct sunlight.

7.3. Specific end use(s)
Appropriate protective equipment should be worn when burning or welding this product. Gloves should be considered when handling material to prevent cuts and skin irritation. Approved eye protection is recommended for operations involving burning, grinding, brazing, welding, or machining.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

<table>
<thead>
<tr>
<th>CARBON STEEL</th>
<th>ACGIH</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>OSHA</td>
<td>Not applicable</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Iron (7439-89-6)</th>
<th>ACGIH</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>OSHA</td>
<td>Not applicable</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Copper (7440-50-8)</th>
<th>ACGIH</th>
<th>ACGIH TWA (mg/m³)</th>
<th>0.2 mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td></td>
<td>OSHA PEL (TWA) (mg/m³)</td>
<td>1 mg/m³</td>
</tr>
<tr>
<td>OSHA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead (7439-92-1)</th>
<th>ACGIH</th>
<th>ACGIH TWA (mg/m³)</th>
<th>0.05 mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td></td>
<td>OSHA PEL (TWA) (mg/m³)</td>
<td>50 µg/m³</td>
</tr>
<tr>
<td>OSHA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manganese (7439-96-5)</th>
<th>ACGIH</th>
<th>ACGIH TWA (mg/m³)</th>
<th>0.1 mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACGIH</td>
<td></td>
<td>OSHA PEL (Ceiling) (mg/m³)</td>
<td>5 mg/m³</td>
</tr>
<tr>
<td>OSHA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.2. Exposure controls

Personal protective equipment: Avoid all unnecessary exposure.

Hand protection: Wear protective gloves.

Eye protection: Chemical goggles or safety glasses.

Respiratory protection: If processing of this product generates particulates, local and general ventilation may be necessary to control employee exposures to within applicable limits. If the exposure limits indicated are exceeded, NIOSH approved respirators for protection against dust and/or fume should be worn in accordance with 29 CFR 1910.134.

Other information: Do not eat, drink or smoke during use.
SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical state</td>
<td>Solid</td>
</tr>
<tr>
<td>Appearance</td>
<td>Steel-grey, lustrous metal.</td>
</tr>
<tr>
<td>Color</td>
<td>Steel-grey</td>
</tr>
<tr>
<td>Odor</td>
<td>Characteristic</td>
</tr>
<tr>
<td>Odor threshold</td>
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</tr>
<tr>
<td>pH</td>
<td>No data available</td>
</tr>
<tr>
<td>Melting point</td>
<td>1316 - 1538 °C</td>
</tr>
<tr>
<td>Freezing point</td>
<td>No data available</td>
</tr>
<tr>
<td>Boiling point</td>
<td>No data available</td>
</tr>
<tr>
<td>Flash point</td>
<td>No data available</td>
</tr>
<tr>
<td>Relative evaporation rate (butyl acetate=1)</td>
<td>No data available</td>
</tr>
<tr>
<td>Flammability (solid, gas)</td>
<td>No data available</td>
</tr>
<tr>
<td>Explosion limits</td>
<td>No data available</td>
</tr>
<tr>
<td>Explosive properties</td>
<td>No data available</td>
</tr>
<tr>
<td>Oxidizing properties</td>
<td>No data available</td>
</tr>
<tr>
<td>Vapor pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>Relative density</td>
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</tr>
<tr>
<td>Relative vapor density at 20 °C</td>
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</tr>
<tr>
<td>Solubility</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Log Pow</td>
<td>No data available</td>
</tr>
<tr>
<td>Log Kow</td>
<td>No data available</td>
</tr>
<tr>
<td>Auto-ignition temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>Decomposition temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>Viscosity</td>
<td>No data available</td>
</tr>
<tr>
<td>Viscosity, kinematic</td>
<td>No data available</td>
</tr>
<tr>
<td>Viscosity, dynamic</td>
<td>No data available</td>
</tr>
</tbody>
</table>

9.2. Other information

No additional information available.

SECTION 10: Stability and reactivity

10.1. Reactivity

No additional information available.

10.2. Chemical stability

No additional information available.

10.3. Possibility of hazardous reactions

No additional information available.

10.4. Conditions to avoid

None

10.5. Incompatible materials

Strong acids. Strong bases.

10.6. Hazardous decomposition products


SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity: Oral: Harmful if swallowed.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Route</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBON STEEL - Leaded Grades</td>
<td>ATE US (oral)</td>
<td>993.939 mg/kg body weight</td>
</tr>
<tr>
<td>Iron (7439-89-6)</td>
<td>LD50 oral rat</td>
<td>984 mg/kg</td>
</tr>
</tbody>
</table>
CARBON STEEL - Leaded Grades
Safety Data Sheet
according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Iron (7439-89-6)
ATE US (oral) 984.000 mg/kg body weight

Skin corrosion/irritation: Not classified
Serious eye damage/irritation: Not classified
Respiratory or skin sensitization: May cause an allergic skin reaction.
Germ cell mutagenicity: Not classified
Carcinogenicity: Suspected of causing cancer.

Lead (7439-92-1)
IARC group 2A - Probably carcinogenic to humans
National Toxicology Program (NTP) Status 3 - Reasonably anticipated to be Human Carcinogen
In OSHA Hazard Communication Carcinogen list Yes

Reproductive toxicity: Not classified
Specific target organ toxicity (single exposure): Not classified
Specific target organ toxicity (repeated exposure): Causes damage to organs through prolonged or repeated exposure.
Aspiration hazard: Not classified

Potential Adverse human health effects and symptoms
Symptoms/injuries after inhalation: May cause an allergic skin reaction.
Symptoms/injuries after ingestion: Swallowing a small quantity of this material will result in serious health hazard.

SECTION 12: Ecological information

12.1. Toxicity

Copper (7440-50-8)
LC50 fish 1 0.0068 - 0.0156 mg/l (Exposure time: 96 h - Species: Pimephales promelas)
EC50 Daphnia 1 0.03 mg/l (Exposure time: 48 h - Species: Daphnia magna [Static])
EC50 other aquatic organisms 1 0.0426 - 0.0535 mg/l (Exposure time: 72 h - Species: Pseudokirchneriella subcapitata [static])
LC50 fish 2 < 0.3 mg/l (Exposure time: 96 h - Species: Pimephales promelas [static])
EC50 other aquatic organisms 2 0.031 - 0.054 mg/l (Exposure time: 96 h - Species: Pseudokirchneriella subcapitata [static])

Lead (7439-92-1)
LC50 fish 1 0.44 mg/l (Exposure time: 96 h - Species: Cyprinus carpio [semi-static])
EC50 Daphnia 1 600 µg/l (Exposure time: 48 h - Species: water flea)
LC50 fish 2 1.17 mg/l (Exposure time: 96 h - Species: Oncorhynchus mykiss [flow-through])

12.2. Persistence and degradability

CARBON STEEL - Leaded Grades
Persistence and degradability Not established.

12.3. Bioaccumulative potential

CARBON STEEL - Leaded Grades
Bioaccumulative potential Not established.

12.4. Mobility in soil

No additional information available

12.5. Other adverse effects

Other information: Avoid release to the environment.
SECTION 13: Disposal considerations

13.1. Waste treatment methods

Waste disposal recommendations: Dispose in a safe manner in accordance with local, state and federal regulations.

Ecology - waste materials: Avoid release to the environment.

SECTION 14: Transport information

Department of Transportation (DOT)
In accordance with DOT

ADR
No additional information available

Transport by sea
No additional information available

Air transport
No additional information available

SECTION 15: Regulatory information

15.1. US Federal regulations

Iron (7439-89-6)
Listed on the United States TSCA (Toxic Substances Control Act) inventory

Copper (7440-50-8)
Listed on the United States TSCA (Toxic Substances Control Act) inventory
Listed on United States SARA Section 313
SARA Section 313 - Emission Reporting 1.0% deminimis

Lead (7439-92-1)
Listed on the United States TSCA (Toxic Substances Control Act) inventory
Listed on United States SARA Section 313
SARA Section 313 - Emission Reporting No deminimis

Manganese (7439-96-5)
Listed on the United States TSCA (Toxic Substances Control Act) inventory
Listed on United States SARA Section 313
SARA Section 313 - Emission Reporting 1.0% deminimis

15.2. International regulations

CANADA

CARBON STEEL
WHMIS Classification Class D Division 2 Subdivision B - Toxic material causing other toxic effects

Iron (7439-89-6)
Listed on the Canadian DSL (Domestic Substances List)

WHMIS Classification Uncontrolled product according to WHMIS classification criteria

Copper (7440-50-8)
Listed on the Canadian DSL (Domestic Substances List)

WHMIS Classification Uncontrolled product according to WHMIS classification criteria

Lead (7439-92-1)
Listed on the Canadian DSL (Domestic Substances List)

WHMIS Classification Class D Division 2 Subdivision A - Very toxic material causing other toxic effects

Manganese (7439-96-5)
Listed on the Canadian DSL (Domestic Substances List)

WHMIS Classification Class D Division 2 Subdivision A - Very toxic material causing other toxic effects

EU-Regulations

Iron (7439-89-6)
Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

Copper (7440-50-8)
Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)
CARBON STEEL - Leaded Grades
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**Lead (7439-92-1)**
- Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

**Manganese (7439-96-5)**
- Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)

**Classification according to Regulation (EC) No. 1272/2008 [CLP]**
No additional information available

**Classification according to Directive 67/548/EEC [DSD] or 1999/45/EC [DPD]**
No additional information available

**National regulations**

**Iron (7439-89-6)**
- Listed on the AICS (Australian Inventory of Chemical Substances)
- Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China)
- Listed on the Korean ECL (Existing Chemicals List)
- Listed on NZIoC (New Zealand Inventory of Chemicals)
- Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances)

**Copper (7440-50-8)**
- Listed on the AICS (Australian Inventory of Chemical Substances)
- Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China)
- Listed on the Korean ECL (Existing Chemicals List)
- Listed on NZIoC (New Zealand Inventory of Chemicals)
- Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances)
- Listed on the Canadian IDL (Ingredient Disclosure List)

**Lead (7439-92-1)**
- Listed on the AICS (Australian Inventory of Chemical Substances)
- Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China)
- Listed on the Japanese ENCS (Existing & New Chemical Substances) inventory
- Listed on the Korean ECL (Existing Chemicals List)
- Listed on NZIoC (New Zealand Inventory of Chemicals)
- Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances)
- Pollutant Release and Transfer Register Law (PRTR Law)
- Listed on the Canadian IDL (Ingredient Disclosure List)

**Manganese (7439-96-5)**
- Listed on the AICS (Australian Inventory of Chemical Substances)
- Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China)
- Listed on the Korean ECL (Existing Chemicals List)
- Listed on NZIoC (New Zealand Inventory of Chemicals)
- Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances)
- Pollutant Release and Transfer Register Law (PRTR Law)
- Listed on the Canadian IDL (Ingredient Disclosure List)

**15.3. US State regulations**

**Lead (7439-92-1)**

<table>
<thead>
<tr>
<th>U.S. - California - Proposition 65 - Carcinogens List</th>
<th>U.S. - California - Proposition 65 - Developmental Toxicity</th>
<th>U.S. - California - Proposition 65 - Reproductive Toxicity - Female</th>
<th>U.S. - California - Proposition 65 - Reproductive Toxicity - Male</th>
<th>No significance risk level (NSRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>15 µg/day</td>
</tr>
</tbody>
</table>

**SECTION 16: Other information**

Other information: Steel products may be coated with petroleum oils to meet customer specifications. Information relative to specific coatings may be obtained from Republic Steel. Republic’s steel products undergo close scrutiny in the steel manufacturing process to ensure they are free of any radioactive contamination. First, our purchasing specifications prohibit any foreign, radioactive articles and if any are detected at our truck/rail gate detectors, they are returned to the scrap supplier in accord with DOT requirements.
CARBON STEEL - Leaded Grades
Safety Data Sheet
according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

<table>
<thead>
<tr>
<th>Full text of H-phrases:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Tox. 4 (Oral)</td>
<td>Acute toxicity (oral) Category 4</td>
</tr>
<tr>
<td>Carc. 1B</td>
<td>Carcinogenicity Category 1B</td>
</tr>
<tr>
<td>Carc. 2</td>
<td>Carcinogenicity Category 2</td>
</tr>
<tr>
<td>Skin Sens. 1</td>
<td>Skin sensitization Category 1</td>
</tr>
<tr>
<td>STOT RE 1</td>
<td>Specific target organ toxicity (repeated exposure) Category 1</td>
</tr>
<tr>
<td>H302</td>
<td>Harmful if swallowed</td>
</tr>
<tr>
<td>H317</td>
<td>May cause an allergic skin reaction</td>
</tr>
<tr>
<td>H350</td>
<td>May cause cancer</td>
</tr>
<tr>
<td>H351</td>
<td>Suspected of causing cancer</td>
</tr>
<tr>
<td>H372</td>
<td>Causes damage to organs through prolonged or repeated exposure</td>
</tr>
</tbody>
</table>

SDS US (GHS HazCom 2012)

The information in this SDS was obtained from sources we believe are reliable. However, the information is provided without any representation or warranty, express or implied, regarding the accuracy or correctness. The conditions or methods of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use, or disposal of the product.
Appendix S. MSDS Delrin

SAFETY DATA SHEET

Section 1: Identification

Product Identifier: Delrin Products

Manufacturer:
Quadrant EPP USA, Inc.
2120 Fairmont Ave.
Reading, PA 19605
(610) 320-6600

In case of an emergency, please call Chemtrec 1-800-424-9300.

Recommended Use: Engineering thermoplastic stock shape

Section 2: Hazard Identification

GHS – Classifications

Classification: None

Signal Word: None

Pictograms and Symbols: None

Hazard Statements: None

Precautionary Statements: None

Section 3: Composition/Information on Ingredients

This is a polymeric material. All constituents are encapsulated within the polymer system and therefore present no likelihood of exposure under normal conditions of processing and handling.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS No.</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyoxymethylene Copolymer</td>
<td>24969-26-4</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Stabilizers</td>
<td></td>
<td>0-3</td>
</tr>
<tr>
<td>Carbon black</td>
<td>1333-86-4</td>
<td>0-3</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>50-00-0</td>
<td>Trace level contaminant</td>
</tr>
</tbody>
</table>
Section 4: First-Aid Measures

**Eyes:** Flush with plenty of water for at least 15 minutes. Seek medical attention if irritation continues.

**Skin:** No health risks concerning skin contact at room temperature. Wash with soap and water. If molten material comes in contact with the skin, cool under running water. Do not attempt to remove the molten material from the skin. Get medical attention immediately.

**Inhalation:** If fumes from overheating are inhaled, remove to fresh air. Seek medical attention if respiratory symptoms occur or breathing becomes difficult.

**Ingestion:** Rinse the victim’s mouth with plenty of water. Do not induce vomiting. Seek medical attention.

**Notes to physician:**
This product is essentially inert and nontoxic. However, if it is overheated or burns, gases such as carbon monoxide and formaldehyde may be released. Those exposed to off-gases may need to have their arterial blood gases and carboxyhemoglobin levels checked. If the carboxyhemoglobin levels are normal and the exposure occurred in an enclosed space, asphyxia (carbon dioxide replacing oxygen) is a possibility. Formaldehyde is a respiratory irritant gas. If patients may have inhaled high concentrations of irritating fumes they should be monitored for delayed onset pulmonary edema.

Section 5: Fire-Fighting Measures

Fire-fighters should protect themselves from decomposition and combustion products by using a full-face self-contained breathing apparatus and impervious protective clothing. Keep personnel removed and upwind of fire. Extinguish fires with water, foam, carbon dioxide or dry chemical media.

Burns with invisible flame.

Hazardous gases/vapors produced in fire are: carbon oxides and formaldehyde.

Dust is flammable and explosive when finely divided and suspended in air.

Section 6: Accidental Release Measures

If a spill occurs, stop the leak at the source and sweep up for disposal. Do not flush to sewers or waterways.

Section 7: Handling and Storage

**Precautions for Safe Handling**
Personal hygiene such as washing the hands and face immediately after working with this material and before eating is recommended.

Dust may form explosive mixtures with air. Avoid dust formation and control ignition sources. Polyolefin dust particles suspended in air are combustible and may be explosive. Keep away from heat, sparks, flame, and other ignition sources. Prevent dust accumulations and dust
clouds. Employ ground, bonding, venting, and explosive relief provisions in accordance with accepted engineering practices and NFPA provisions in any process capable of generating dust and/or static electricity. Explosion hazards apply only to dusts, not granular forms of this product.

The handling of powder in both loading and unloading operations, as well as fabrication, may cause dust to be formed and necessary precautions for personal protection should be used. As with all finely divided materials precautions should be taken to avoid inhalation and eye contact.

If in dust form, transfer from storage with a minimum amount of dusting. Ground all transfer, blending, and dust collecting equipment to prevent static sparks in accordance with NFPA 70 “National Electric Code.” Review and comply with all relevant NFPA provisions, including but not limited to NFPA 484 and NFPA 654 related to combustible dust hazards. Remove all ignition sources from material handling, transfer, and processing areas where dust may be present. Local exhaust ventilation should be provided in work area.

**Precautions for Safe Storage**
Store in a sprinkler protected warehouse. Since products are organic they will burn with a hot flame if ignited. Avoid contact with ignition sources such as open flames. Keep a fire extinguisher near if welding is done in the area of organic products. If a heat source is present, keep the area well ventilated.

### Section 8: Exposure Controls/Personal Protection

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>ACGIH TLV</th>
<th>OSHA PEL</th>
<th>NIOSH REL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>10 mg/m³</td>
<td>15 mg/m³ – Total 5 mg/m³ – Respirable</td>
<td>Not Determined</td>
</tr>
<tr>
<td>Carbon black</td>
<td>3.5 mg/m³</td>
<td>3.5 mg/m³</td>
<td>3.5 mg/m³</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.3 ppm (Ceiling)</td>
<td>0.75 ppm (TWA) 2.0 ppm (STEL)</td>
<td>0.016 ppm (TWA) 0.1 ppm (Ceiling)</td>
</tr>
</tbody>
</table>

**Engineering Measures:**
Provide local exhaust ventilation to keep airborne particulate concentrations below the OELs.

**Personal Protective Equipment: Eyes/Face**
Safety glasses with side shields.

**Personal Protective Equipment: Skin**
When handling molten material, protective clothing such as long sleeves or laboratory coat should be worn. Use heat-resistant gloves, boots and face protection.

**Personal Protective Equipment: Respiratory**
If levels are above published OELs, then a NIOSH approved respirator.

Good industrial hygiene practice should be followed which includes preventing eye contact, minimizing skin contact and minimizing inhalation of dust, vapors or mist.
Section 9: Physical and Chemical Properties

Appearance and Odor
Solid in rod, plate, tube or strip form with essentially no odor

Odor Threshold
No Information Available

Specific Gravity (Relative Density)
1.39 – 1.44

Solubility in Water
Insoluble

VOC Content (%)
<1

pH
No data available

Melting Point/Freezing Point
342°-363°F

Vapor Pressure
No data available

Vapor Density
No data available

Evaporation Rate
No data available

Boiling Point
No data available

Flammability
Combustible

Flash Point
608°F (ASTM-D-1929)

Explosion Data
LEL – No data available
UEL – No data available

Auto ignition Point
No data available

Partition Coefficient: n-octanol/water
No data available

Decomposition Temperature
446° F

Viscosity
No data available

Section 10: Stability and Reactivity

Reactivity:
None known

Chemical Stability:
Material is stable under normal industrial conditions and is not susceptible to hazardous polymerization.

Conditions to Avoid:
Flame. Do not allow mixing of this material with PVC, other halogen containing materials, and partially and/or fully crosslinkable thermoplastic elastomers. Do not heat above 460° F (238° C). Avoid prolonged heating at or above the recommended temperature.

Incompatibility:
PVC, strong acids, oxidizing agents.

Hazardous Decomposition Products:
At temperatures above 460°F/238° C, heavy fuming of formaldehyde may occur.

Section 11: Toxicological Information

Acetal Polymer
There are no known effects from exposure to the Acetron polymer itself. If overheated, the polymer releases formaldehyde which may cause skin, eye, and respiratory irritation and allergic reactions.
**Signs and Symptoms of Overexposure:** Eye irritation signs and symptoms may include a burning sensation, redness, swelling, and/or blurred vision. Skin irritation signs and symptoms may include a burning sensation, redness and swelling. Respiratory irritation signs and symptoms may include a temporary burning sensation of the nose and throat, coughing, and/or difficulty breathing.

**Aggravated Medical:** None.

**Acute Effects:** Non-toxic.

**Skin Corrosion/Irritation:** Not irritating to the skin.

**Serious Eye Damage/Irritation:** Particulates can be mechanically irritating to the eyes.

**Ingestion:** None.

**Inhalation:** Inhalation of particulates may produce respiratory tract irritation.

**Respiratory or Skin Sensitization:** Not expected to be a sensitizer.

**Chronic Effects:**

**Germ Cell Mutagenicity:** Not expected to be a germ cell mutagen.

**Carcinogenicity:** Not classifiable as carcinogen to humans (group 3 IARC).

**Reproductive Toxicity:** There aren’t known reproductive toxicity effects.

**STOT-single Exposure:** At dust form, may cause respiratory irritation with cough and sneezing.

**STOT –multiple Exposure:** There aren’t known repeated exposure effects.

**Aspiration Hazard:** No data available. Not expected to be an aspiration hazard.

**Other:** Formaldehyde, which is degradation product, is listed as a potential cancer hazard by OSHA, a known human carcinogen by The International Agency for Research on Cancer (IARC, Group 1), and a substance which can reasonably be anticipated to be a carcinogen by The National Toxicology Program (NTP). Formaldehyde should not pose a risk if exposures are kept below the OELs.

**Primary Route of Entry:** Inhalation of particulates.

**Section 12: Ecological Information**

**Ecotoxicity:**
There aren’t known ecological toxicity values.

**Persistence and degradability:**
It’s expected high persistence and slow degradability.

**Bioaccumulative Potential:**
It’s expected moderate to high bioaccumulative potential.

**Mobility in Soil:**
No data available

**Other Adverse Effects:**
No data available

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Toxicity to Algae</th>
<th>Toxicity to Fish</th>
<th>Microtox</th>
<th>Daphnia Magna (Water Flea)</th>
</tr>
</thead>
</table>


Section 13: Disposal Considerations

Dispose of in accordance with federal, state and local regulations.

Section 14: Transportation Information

US Department of Transportation Classification (49CFR)

Not classified as hazardous for transport.

Section 15: Regulatory Information

SARA Section 302 & 304:
No chemicals

SARA Section 313:
The following component is subject to reporting levels established by SARA Title III, Section 313:
- None

TSCA:
All components of this product are either listed or are exempt on the TSCA inventory.

Section 16: Other Information

Label Information

Product Identifier: Delrin Products

Manufacturer:
Quadrant EPP USA, Inc.
2120 Fairmont Ave.
Reading, PA 19605
(610) 320-6600

In case of an emergency, please call Chemtrec 1-800-424-9300.

Classification: None

Signal Word: None

Pictograms and Symbols: None

Hazard Statements: None

Precautionary Statements: None

<table>
<thead>
<tr>
<th>Revision Date</th>
<th>Reason for Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1, 2015</td>
<td>SDS format</td>
</tr>
</tbody>
</table>
The information set forth herein has been gathered from standard reference materials and/or supplier test data and is, to the best knowledge and belief of Quadrant EPP, accurate and reliable. Such information is offered solely for your consideration, investigation and verification, and it is not suggested or guaranteed that the hazard precautions or procedures mentioned are the only ones that exist. Quadrant EPP makes no warranties, expressed or implied, with respect to the use of such information or the use of the specific material identified herein in combination with any other material or process, and assumes no responsibility therefor.