BYU Mars Rover Final Report Draft

April 19, 2017

Project Sponsor: Department of Mechanical Engineering

Capstone Team 30: BYU Mars Rover

By signing below, we approve the submission of this report, and agree that it accurately represents the work the team has accomplished.

Westley Barragan	Date
Angus Cameron	Date
Michael Farrell	Date
Jacob Greenwood	Date
Taylor Greenwood	Date
Benjamin Hilton	Date
Brian Jackson	Date
Garrett Jones	Date
Richard Livingston	Date
Steven Markham	Date
Jameson Marriott	Date
Jordan Oldroyd	Date
Peter Schleede	Date
Drew Warren	Date
Taylor Welker	Date
Mary Wilson	Date
Marc Killpack, Team Coach	Date
Carl Sorensen, Capstone Instructor	Date
David Allred, Project Sponsor	Date

Ira A. Fulton College of Engineering and Technology
Brigham Young University

Executive Summary

Background

Each year for the past decade, BYU has competed in the Mars Society's University Rover Challenge (URC). The challenge is to design and build the next generation of Mars rovers that will one day work alongside humans in the field on Mars, as simulated in Hanksville, Utah. In previous years, BYU has placed as high as second place. The current BYU Mars Rover team has built on the success of past teams and plans to place first in this world-renowned competition in June 2017. We based our market requirements and critical success measures for this project on the four required during the competition: science cache, extreme retrieval and delivery, equipment servicing, and autonomous traversal. The science cache requires sample collection, on-rover and in-lab tests, and a presentation on possible signs of life (based on the sample-tests) to the judges. Extreme retrieval and delivery requires the rover to drive up to 1 km from a base station—including some out-of-line-of-sight portions—and to navigate rough terrain while delivering tools to mock astronauts. Equipment servicing tests the dexterity of the rover's robotic arm in completing tasks such as turning knobs, flipping switches, pouring fluid from a gas can, and pulling a wagon. Finally, autonomous traversal—a new task for this year—asks the rover to autonomously navigate between two GPS way-points marked by tennis balls and to send a message notifying the base station when it has arrived at the destination.

Project Objective

The project objective is to design and develop a working rover by January 1, 2017, and a world-class rover costing $15,000 or less by April 1, 2017, in order to place first in the URC competition and in the top three for the next three years.

Project Description

The rover is a mobile unmanned vehicle designed to explore the surface of Mars and assist astronauts in their tasks. Our system is divided into several subsystems, including chassis, robotic arm, electrical, science, navigation, and communication. Our rover is almost ready for the competition but has not finished the system refinement stage.

Market Response

We have already passed the first milestone of market acceptance by passing through the critical design review (CDR) stage of the competition. For this stage we wrote a four page document detailing our progress and plan for success, coupled with a five minute video that featured our working subsystems. After reviewing our submission, the URC accepted our design and invited us to come to Hanksville, Utah, to participate in the rest of the competition on June 1–3, 2017.

Short Contents

Full Contents

1 Introduction

The challenge of the BYU Mars Rover program is to design and build a robotic rover that will complete all competition tasks in the 2017 University Rover Challenge (URC) in Hanksville, Utah. The Mars Society designs this competition to evaluate the effectiveness of rovers in assisting scientists in research and aiding astronauts in their routine tasks. Beyond this, the rover must adhere to a strict set of monetary and performance constraints. The URC rules, included in appendix B, define the market requirements for the rover and we have summarized them in appendix E.1.

The project objective is to design and develop a working rover by January 1, 2017, and a world-class rover costing $15,000 or less by April 1, 2017, in order to place first in the URC competition and in the top three for the next three years. The three primary goals for the current year are 1) to improve last year's rover design in order to better complete all competition tasks, 2) provide better transferability for future teams, and 3) build a second rover.

After careful evaluation of last year's performance in the competition (eleventh place), the current team identied key areas of improvement to ensure success (see section 4.1). The team sponsor, Dr. Allred in the BYU Physics Department, requested that we build a second, fully functioning rover. This allowed us to always have a working rover for tests and practice and as backup for the competition. We divided the project into six individual subsystems that allowed the team to focus on improving specific components of the design. We individually assigned each of these components a stage in the product development process since some of them only needed refinement instead of a complete redesign. The team set a goal to complete the entire rover by April 1, 2017, to allow time for any contingencies and for making the design completely transferable.

2 Design Requirements

We based our design-decisions on the Mars Society URC rules (appendix B), making the Mars Society our primary market. Specifically, we based our market requirements and desirability goals on the URC rules, videos of the 2016 competition, feedback from last year's Mars Rover team coach (Dr. Homer), and feedback from members of the 2016 team as described in appendix A of the project contract (appendix A). We also included a more detailed description of how we reached our design requirements in section 3 of our project contract (appendix A). We included the market requirements, performance measures, ideal values, and target values for the project in a requirements matrix in appendix E.1 and defined them in detail in appendices E.2 and E.3. The project requirements matrix is also divided into subsystem requirements matrices which are also in appendix E.1. We will discuss our performance in relation to our design requirements in section 4.

2.1 Project Scope

We did not take our new rover through all the stages of development, and table 1 summarizes the planned starting and end stage for each subsystem. (We have described these subsystems in more detail in section 3.) As shown in the table, the team anticipates finishing each stage at the system refinement stage, but not all subsystems have reached that stage yet. It was our goal to reach system refinement for each subsystem by the end of the semester, so we are behind schedule. Section 6.1 details the team's plan to have these subsystems ready by the competition in early June.

Table 1: Stages of development for each subsystem

Subsystem	Starting	Current	Final*
Chassis	System Refinement	System Refinement	System Refinement
Robotic Arm	Subsystem Engineering	System Refinement	System Refinement
Electrical	Concept Development	System Refinement	System Refinement
Science	Concept Development	Subsystem Engineering	System Refinement
Navigation	Concept Development	Subsystem Engineering	System Refinement
Communication	System Refinement	System Refinement	System Refinement

* Final stage to be completed by May 2017

2.2 Competition Tasks

The competition itself is sectioned into four tasks plus a design review, each of which we have summarized below. A complete description of the tasks is in section 3 of the URC rules (appendix B). Each task below is worth 100 points (out of 500 total) and has a time limit within which to complete it for full points.

Critical Design Review

The critical design review (CDR) happens before the teams arrive at the competition site and determines which teams get to participate. It consists of a five page report detailing the team's progress in preparing for the competition and also has a video-component. We have included our report in appendix F, and we posted the video on YouTube at youtu.be/tF4-JAdvwBE. The URC judges notified us on March 20, 2017, that we passed this round and would continue on to participate in Hanksville. This notification constituted our first real market acceptance.

Science Cache

The purpose of this task is to analyze the soil in the competition area (which the Mars Society chose based on its earth-based-approximation to Mars) for signs of life by taking samples and performing tests on those samples. Basic analysis of the samples happens onboard the rover, and the rover will retrieve at least one sample for the team to analyze in a lab environment. This task ends with a presentation on the team's findings.

Extreme Retrieval and Delivery

This task consists of transporting tools over diverse terrain ranging from mild to extreme difficulty. The degree of dificulty will increase progressively in distance from the base station and roughness of the terrain. The rover must complete easier stages to progress to more difficult ones.

Equipment Servicing

The equipment servicing task tests the dexterity of the robotic arm on the rover. The rover will need to perform functions such as attach a carabiner to a wagon, pull the wagon, pour fluid out of a gas can, flip switches, and turn valves.

Autonomous Traversal

This task requires the rover to navigate between two points without any input from the team. This task will consist of three legs denoted by a start and end "gate," marked by a tennis ball on a post. The URC will give the team the approximate GPS locations of each gate, and the rover must autonomously navigate from the start gate to the end gate over moderate terrain. The rover must also correctly self-report success in order to move on to the next leg.

3 Product Description

The BYU Mars Rover is a six-wheeled rover powered by lithium polymer batteries and controlled remotely from a ground station (see figure 1). Depending on the task, we can equip the rover with either a six-degree-of-freedom robotic arm for dexterous manipulation of tools or a science module for soil sample collection and analysis. The rover consists of six primary subsystems, described below. We have included the complete design package in appendix I and have documented all models and tests in appendix G. This year we re-created the entire design package for the rover, even for parts that we did not alter, in order to leave a more uniform, standardized, and transferable design for future teams. In addition to the design package, the team has maintained a wiki on Github. In this wiki we have documented design decisions, outlined overall system architecture, and explained rover setup and operating instructions. This will allow future teams to quickly understand our design, thus allowing them to focus on improving the design and make more progress before the URC each year.

We attempted to keep as much of last year's design as possible, focusing on improving areas in which last year's rover performed poorly. We also used last year's rover to help mitigate the risk of making a new design by keeping it intact and making our new design as compatible with the old rover as possible. This allowed us to have almost continuous access to a working rover for testing, and also gave us a backup option in case something didn't work with our new design.

3.1 Chassis

The rover uses a six-wheel, modified rocker-bogie suspension with pneumatic tires. The structural frame is built from welded, square aluminum tubing. The wheel motors are geared DC motors capable of delivering $23.4\,\mathrm{N \cdot m}$ of torque per motor. Appendix I.2 contains the full drawings of the chassis.

3.2 Robotic Arm

The robotic arm is a six-degree-of-freedom serial-link manipulator and is mounted onto the rear of the rover. The arm is built from lightweight carbon fiber tubes and aluminum mounting hardware, and is actuated using two $890\,\mathrm{N}$ linear actuators, a $22.6\,\mathrm{N \cdot m}$ gear DC

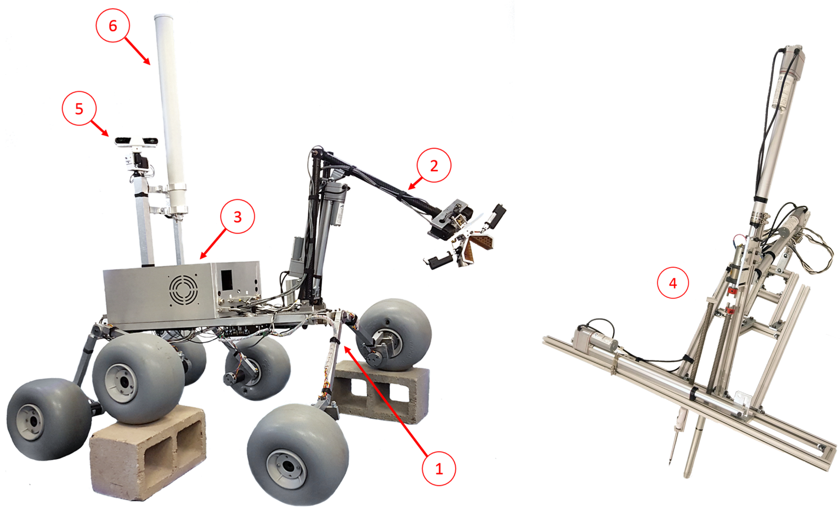

Figure 1: Subsystems of the rover (shown with arm attached and science module not to scale)

1. Chassis
2. Robotic Arm
3. Electrical
4. Science
5. Navigation
6. Communication

motor and two $6\,\mathrm{N}\cdot\mathrm{m}$ dynamixel servo motors connected to a differential drive gearbox. The gripper is a honeycomb silicon claw encased in aluminum and powered by two $80\,\mathrm{N}$ linear actuators. The arm is controlled using a game controller and can be moved in joint or cartesian space. We included all of the documentation for the arm in appendix I.3.

3.3 Electrical

The electrical system on the rover, encased in an aluminum electronics box, is powered by six lithium-polymer, $5\,\mathrm{A}\cdot\mathrm{h}$ batteries. On-board computation is performed primarily by a TX-1 Jetson computer which communicates via UART with a PsoC microcontroller. Most of the circuitry runs through custom-designed PCBs and are connected using secure wiring connections. Appendix I.4 contains the complete documentation for the electrical system.

3.4 Science

The science subsystem allows the collection and analysis of geological soil samples. The module can collect three uncontaminated soil samples and temperature and humidity data from the collection sites. It can also take high-definition photographs of the soil and wide-angle panoramas of the landscape. Appendix I.5 contains the complete drawings for the science module.

3.5 Navigation

The navigation subsystem includes the hardware and software necessary to accurately locate the rover and autonomously navigate between given GPS waypoints. The system uses an IMU and a GPS module with an extended Kalman filter to estimate the 3D location and orientation of the rover, and it uses an RPLidar to detect obstacles. The autonomous navigation of the rover can be intuitively controlled via a custom-designed GUI. We have included all the documentation for the navigation system in appendix I.6.

3.6 Communication

The communication system allows for wireless communication between the rover and the base station at distances up to 1.75 km. The system uses a pair of Rocket M2 receivers and a Ubiquity omnidirectional antenna that we have measured transmitting a 4 Mbps WiFi signal at 1.75 km. The communication system also includes the base system consisting of a laptop and a Gigabyte BRIX and the necessary hardware to connect to the 120° directional base station antenna. We included complete documentation for the communication system in appendix I.7.

4 Performance Testing and Validation

This part of the report details the goals that we set for our rover design and how well we achieved those goals. We will first discuss our key success measures (desirability goals) and then cover all of our performance measures and the tests that we did to validate our performance.

4.1 Desirability Goals

We established a list of primary goals that best represented the improvements the rover needed in order to perform well in the competition (our market). We based these goals on feedback from last year's coach and team, and the new competition requirements for 2017. We have listed these key success measures in table 2 along with the level of performance we achieved for each measure. Also in the table, we included the appendix references to the tests that lead up to the measurement given in that row. The team contract in appendix A has a complete list of what performance values correspond to what "level" of success.

Table 2: Desirability goals: Level achieved and relevant appendices

Measure	Level Achieved	Measured Performance	Relevant Tests and Models
Max Incline	Excellent	Rover can withstand 45° incline	G.1, G.9, G.32, G.33
Weight	Good	Rover frame and drive train weigh 29.6 kg	G.28, G.29
End Effector Accuracy	Excellent	End effector is measured to be accurate within 8 mm	G.10, G.13, G.16, G.41, G.43, G.46

Continued on next page

Measure	Level Achieved	Measured Performance	Relevant Tests and Models
Arm Strength	Excellent	Arm can lift 5 kgat 0.5 m from its base	G.8, G.26, G.42
Component Replaceability	Excellent	Electrical component can be replaced within 5 min	
Temporary Electrical Connections	Excellent	$< 5\%$ non-latching connections	G.50, G.53
Run Time	Excellent	Rover is predicted to run at full capacity for 78 min	G.49
Communication	Excellent	Base station and rover can communicate wirelessly 1.75 km out of line-of-sight	G.15, G.23, G.24, G.25, G.58, G.61
Reliability	$<$ Fair	Rover system starts up 30 % of the time	G.49, G.51, G.53
General Vision	Excellent	A three-camera system that that starts 100 % of the time, publishing at 15 fps	G.17, G.18, G.56
Navigation	Fair	Non-autonomous, manual navigation to within 3 m	G.2, G.11, G.21, G.30, G.31, G.34, G.35, G.48, G.54, G.59, G.62, G.63
Sample Collection	Excellent	Collect an uncontaminated 5 g sample of soil from 15.25 cm underground	G.36, G.37, G.38, G.39, G.40

4.2 Performance Measures

In addition to the key success measures that we identified above, we also defined many performance measures to objectively evaluate our design. These measures turned the market requirements that we identified into quantifiable targets. The methods we used to create these measures are in the team contract in appendix A. Figure 2 below shows graphically how well we achieved each of our performance measures in comparison to the upper and lower targets that we set. We scaled the values according to their upper and lower acceptable limits to make them easier to compare to each other. The blue circles show our achievement and the yellow squares represent our targets; vertical lines show our upper and lower limits and light-gray lines connect the targets to the achieved values.

Our ability to transmit video well over our goal of 1 km exemplifies our achievement. We changed our antenna design to one capable of multiple-in multiple-out (MIMO) transmission that simultaneously improved our transmission rates at long distances and reduced the size and weight of our on-board communication system. Appendix E.1 contains the rest of our requirements with all their corresponding achieved and predicted values. Section G contains all of the procedures used to determine those values.

Not all of our performance values represent success, such as our current start-up reliability. This number is exceptionally low right now because we have been testing many things for the first time and are early into the system integration and refinement stage. However, we feel that we will significantly improve these areas in the coming weeks before the URC as we focus on testing and system integration. Section 6.1 details our plans for our remaining time. Additionally, not all of our achieved values that are outside of their limits indicate a poor design. For example, while the max rover speed is faster than we originally wanted, we do not feel that it travels too fast and we can easily implement software limits on the rover's speed if further testing demonstrates that it needs to slow down.

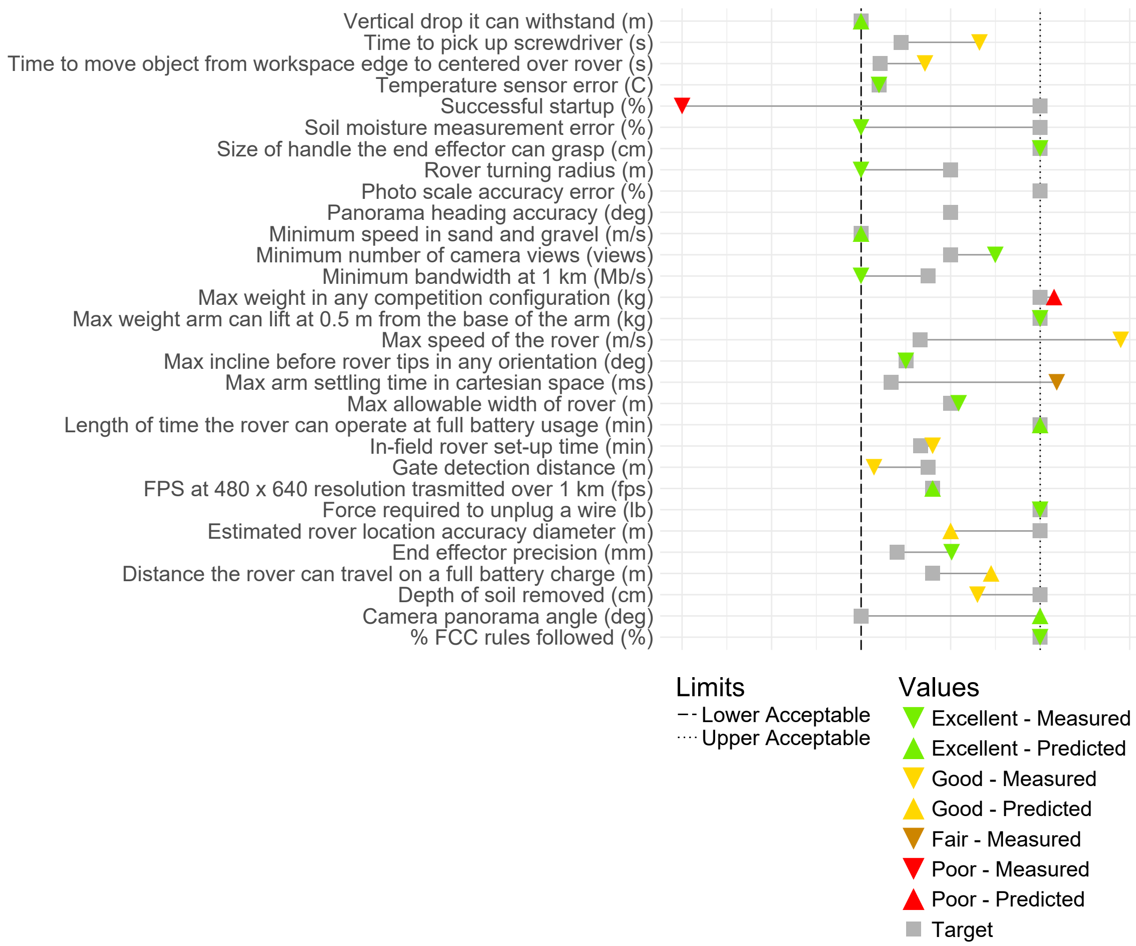

Figure 2: Achieved and predicted performance

4.3 Validation Testing

Our best market validation has been our acceptance by the URC. The URC selected us and 35 other teams out of a record 82 teams that applied from 13 countries. We submitted a CDR package to the URC that included a written report (section F) and a video (youtu.be/tF4-JAdvwBE). The URC accepted our design by chosing our team to move on to the next stage of the competition in June, 2017. Ultimately the URC judges will assess our design at the competition which will be our final market test.

4.4 Summary

We have achieved 75 % of our desirability goals at the "excellent" level and all but one at "fair" or better. We have also measured or strongly predicted 70 % of our performance goals within our upper and lower acceptable limits. While not perfect, we think that the rover will compete well in June. Section 6.1 goes into detail about our plans for success.

5 Predicted Competition Performance

This section will detail our predicted performance in each of the competition tasks. For a complete list of our tests and models along with their corresponding goals, see appendix C. Since the Mars Society does not provide a grading rubric prior to the competition in an effort to help increase the utility and universality of the designs, we can only qualitatively evaluate our predicted competition performance.

The URC does release the weight penalty being overweight in any competition task: for each 1 kg of the rover's mass over 50 kg, a 5 % penalty will be applied to the scored points. Our current prediction puts our heaviest configuration (with the science module attached) at 53 kg, which would cost us 15 % on the science tasks. Reducing this weight will be a primary focus in the coming weeks before the competition, as detailed in section 6.1.

5.1 Science Cache

Our rover can take sufficient soil samples and measurements to earn full points in this task. Additionally, we have assembled a team of student geologists with extensive expertise in the geology of the competition region to help us present on our findings so that we can score high on that portion of the task.

5.2 Extreme Retrieval and Delivery

We have demonstrated that we can control and receive feedback from the rover at over 1.75 km. Because this task requires us to drive up to 1 km from a command station, our communication achievement will help us drive farther with less video latency than last year's design could.

This task does still present a challenge for us. While our rover is performing well in nearly all of our goals associated with this task, it is currently struggling to climb steep inclines due to the wheel motors stalling. We have yet to determine the cause of this problem, but we believe that it is related to configuration or software settings since we have motors with similar specs to last year and a larger power source.

5.3 Equipment Servicing

A strong and precise robotic arm is key to performing well in this task. Our robotic arm is currently undergoing extensive testing and is lighter, stronger, and more precise than last year's design. Linear actuators provide the actuation for the shoulder and elbow joints and give the arm high strength and smooth, accurate control. The arm has successfully lifted 7 kg when the maximum required by the competition is 7 kg. A newly designed wrist uses differential gearing to double the torque output and increase the maneuverability of the end effector. We have measured the end effector accuracy at 8 mm, which will help it perform dexterous movements such as pouring gasoline and turning knobs. All of the motors and actuators in the arm have built-in feedback, allowing the user to intuitively control the position of the end effector through forward and inverse kinematics in multiple frames of reference.

5.4 Autonomous Traversal

Our autonomous features are not yet working, so according to our team contract, we only have "fair" performance for our desirability goal. We can only manually drive the rover, however, we have successfully tested local terrain mapping for dynamic obstacle recognition and optimal path planning. Also, we have successfully simulated the behavior-based waypoint navigation controller.

In conclusion, we have some uncertainty left in our URC performance. However, we feel that most of our problems at this point are refinement issues rather than basic design issues.

6 Next Steps

This section explains our plan for the coming weeks before the URC in addition to our suggestions to future teams. Of course, we will have better suggestions for next years team after we have attended the URC and received market validation from the judges' feedback.

6.1 Plan to Prepare for Competition

We plan to efficiently use the remaining weeks of our project by focusing mainly on weight reduction, navigation, electrical, and testing.

Weight

In any given configuration, the rover must weigh less than 50 kg in order to compete without a penalty. As of right now, we need to remove almost 4 kg from the rover to meet this requirement when configured with the science module and 2 kg when configured with the robotic arm. We have discussed several options to reduce weight and have a few promising possibilities. We can switch our rover computer to a unit that is lighter, smaller, and still has the computing power that we need. While this change of weight for the computer is small, the size reduction is much more significant. The replacement onboard computer is almost half the size which means that we could make the electrical box significantly smaller. With these changes, we believe we can reduce the weight of just the box from 2.5 kg to 1.5 kg, and an additional 0.5 kg by replacing components such as the computer and a bulky voltage converter.

We can also remove one of the linear actuators on the science module and still accomplish the requirements for the science cache, which will remove an additional 1.6 kg. This leaves an additional 1.0 kg to remove for the science task and 0.5 kg to remove with the arm equipped. We should be able to accomplish this by using only the sensors needed for each task. If we cannot meet the weight requirements with this option, we can remove the two middle wheels from the rover for the science and equipment servicing tasks of the competition. These two tasks use our heaviest configurations and the terrain in these two tasks is relatively easy to navigate. For the autonomous task we can remove the robotic arm and science module. Extreme retrieval and delivery requires all six wheels and the robotic arm, so we may choose to take the 5 % penalty for the additional 1 kg. With these plans in place, we will meet the competition weight requirement for most tasks.

Navigation

Our navigation team, comprised of 7 individuals, is currently developing software for the autonomous task. We have developed the software to the point that it can perform the minimum necessary sub tasks. We have successfully performed local terrain mapping, obstacle recognition, gate detection, waypoint selection in a GUI, automatic waypoint generation, a behavior-based go-to-goal controller, and state estimation. In the weeks remaining we will integrate each of these functions and incrementally test, as we add functionality, at least twice a week from May 1-13 before we travel to Hanksville for our mock competition. While we still have goals to complete in order to make navigation more desirable, we are confident in our ability to perform well based upon our current tests and models.

Electrical and Reliability

While our electrical system provides all the necessary power requirements to the subsystems of the rover, we need to make some changes to enable easier debugging and minor problem fixing that we have encountered over the past couple weeks. The rover has experienced some surges in its electrical system that have caused problems. We have identified the problem by consulting experts in the electrical engineering department and plan to fix the surges by optically isolating our 12 V and 24 V systems; this should fix any existing current problems. We also have plans to improve our cable management and to make our PCBs more secure. This will make debugging easier and minimize the risk of wires shorting due to unwanted contact.

Our motors do not seem to provide the torque specified by their manufacturer. We have discussed the issue and believe that either a incorrect setting or insufficient power supply causes the issue. We will have at least two people assigned to identifying and resolving this issue in the next two weeks. If we cannot resolve the problem, we can replace those motors with the motors from last year's design. Based on feedback from last year's team, we know that those motors would work.

Testing

We will prioritize testing over the next few weeks. Testing up to this point has invaluably helped us identify problems and practice necessary skills for the competition. We plan to make another trip to Hanksville on May 13 in order perform a mock competition. This will give us a clear picture of how prepared we are for the URC. In addition to this major test, we will run a full-system test at least twice a week for every week until the competition. We have included a copy of a Gantt chart showing our schedule in appendix D.

6.2 Suggestions for Future Years

This project can have a large scope, but, like us, next year's team won't have time to do everything that they want to do. For example, we re-built the entire rover so that we could always have a working rover. The previous team had also recommended a refresh because the previous rover had seen a lot of use. We recommend that next year's team avoid hardware as much as possible and instead focus on iterative improvements to the rover, using both rovers to their advantage.

We strongly recommend that next year's team document early and often. We struggled to document as much as we wanted to, and while we have generated hundreds of pages of documentation, we would document even more if we did it over again.

This year we took on several volunteers who helped us as part of their ME 497R course, and who will be in Capstone next year. We did this with the hope that it would help transfer our design to next year's team. Volunteers who have already worked on the rover can then become Capstone members of the team next year, and would already have a working knowledge of the competition and our rover design. These volunteers have contributed in a very meaningful and productive way. We strongly recommend that next year's team also bring on volunteers who can work on the rover for a year or two before Capstone. In this way the team can develop members over several years, thus providing a more transferable design for future teams.

We included a complete list of our recommendations in appendix H.

7 Conclusion

We have improved our rover and progressed towards our goal of placing first in this year's URC. We have documented a lot of our work, including methods, designs, and tests, so that next year's team will have a head-start towards building a competitive rover for the 2018 competition. Extensive testing has demonstrated good to excellent performance in almost all of our critical success measures, which shows that we will perform well this year. We have addressed our critical areas of concern, and we have a plan to overcome these challenges in the remaining weeks in order to meet our goal of winning the 2017 URC.

A Team Contract

BYU Mars Rover Project Contract

Version 1.2
March 7, 2017

Project Sponsor: Department of Mechanical Engineering

Capstone Team 30: BYU Mars Rover

Ira A. Fulton College of Engineering and Technology
Brigham Young University

Revision History

Rev.	Date	Description
1.0	11/01/16	First draft submitted to capstone instructors
1.1	11/7/16	Requirements matrix and desirability goals revised based on capstone instructor feedback
1.2	3/7/17	Final changes made to realistically reflect our goals and changes to team structure and budget

Contents

By signing below, we approve this project contract.

Westley Barragan	3/8/17 Date
Angus Cameron	3/8/17 Date
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Steven Markham	3/8/17 Date
Jameson Marriott	3/8/17 Date
Jordan Oldroyd	2017-03-08 Date
Peter Schleede	3-8-17 Date
Drew Warren	3/8/17 Date
Taylor Welker	3/8/17 Date
Mary Wilson	3/8/17 Date
Marc Killpack, Team Coach	3/9/17 Date
Carl Sorensen, Capstone Instructor	Date
David Allred, Project Sponsor	3/8/17 Date

1 Introduction

The BYU Mars Rover Team is sponsored by the BYU Mechanical Engineering Department for the purpose of promoting BYU engineering in an inter-university environment and providing a learning experience for the team within the context of the capstone program. The team will develop a rover, building on the work of past years' teams. At the end of the school year, the team will take the rover to the University Rover Competition (URC) in Hanksville, Utah, to compete against other universities.

2 Project Objective Statement

Design and develop a working rover by January 1, 2017, and a world-class rover costing $15,000 or less by April 1, 2017, in order to place first in the URC competition and place in the top three for the next three years.

3 Market Identification

The team members themselves are in some ways both designers and market representatives because they will be the end users of the rover and will be the ones attempting to win the URC challenge with it. However, most of the team have never been to the competition previously and so they don't make the best market representatives. The Mars Society, who runs the URC, is also part of the market for the rover because it sets the rules and is looking for improved rovers each year. Additionally, the Mars Society has expressed interest in purchasing our rover for their own use, making them literally in the market for the rover. Ultimately the vision of the Mars Society and our sponsor, Dr. Allred, is that the technology developed on the rover will be used by astronauts on Mars, making organizations like NASA a potential market. Finally, there are many earth-bound missions that would benefit from parts of our design, such as its ability to traverse rough terrain and manipulate switches and valves, but these are less direct markets. The rules that the URC publishes are the main source of market requirements, but they are intentionally left vague in some areas, making additional sources of market requirements important. To improve the likelihood that the rover will satisfy the market, individuals outside of the team with experience in previous competitions and/or robotic systems have been and will be brought in to evaluate the product and specific design artifacts. These representatives will include previous team members who have attended the competition along with school faculty who attended with them. In addition, professors and others with experience in related fields will also be invited to review the team's work.

4 Contact Information

Name and Title	Email	Phone Number
Jameson Marriott *Team Leader* Mechanical Team	jameson.marriott@gmail.com	253-304-9872

Name and Title	Email	Phone Number
Angus Cameron *Team Leader* Electrical Team	angusc_17@yahoo.com	219-204-1300
Mary Wilson *Mechanical Team Leader* Mechanical Team	wmarye2@gmail.com	385-224-6919
Jacob Greenwood Navigation/Mechanical Team	jacobgwood@gmail.com	801-433-8218
Jordan Oldroyd Mechanical Team	jordanoldroyd@gmail.com	801-856-2935
Brian Jackson *Documentation Representative* Navigation Team	bjack205@gmail.com	512-809-5246
Michael Farrell Testing/Navigation Team	michaeldavidfarrell@gmail.com	949-521-8329
Westley Barragan Navigation Team	dwestley.1992@gmail.com	480-309-3411
Peter Schleede *Navigtion Team Lead* Navigation Team	pschleede@gmail.com	585-520-3492
Benjamin Hilton Testing Team	ben.hilton@att.net	817-992-2194
Drew Warren Mechanical Team	drewbwarren@gmail.com	214-405-0071
Taylor Welker Electrical Team	taylormaxwelker@gmail.com	801-885-4223
Taylor Greenwood *Electrical Team Lead* Electrical Team	taylorgwood@gmail.com	801-448-8016
Garrett Jones Electrical Team	garrettjones.co@gmail.com	801-592-7762
Steven Markham *Science Team Leader* Science Team	stevenmark.mbl@gmail.com	801-358-4251
Richard Livingston Science Team	richard_livingston@ymail.com	909-541-6339
Marc Killpack *Team Coach*	marc_killpack@byu.edu	404-895-3243
David Allred *Team Sponsor*	allred@byu.edu	801-400-8277

5 Requirements Matrix

Figure 1: Requirements Matrix

Product: URC Mars Rover

Subsystem: Basic Requirements

Revision Date: 03/6/2017

#	Performance Measures	Units
1	In-field rover set-up time	minutes
2	Length of time the rover can operate at full battery usage	minutes
3	Distance the rover can travel on a full battery charge	meters
4	Force required to unplug a wire	lb
5	Max speed of the rover	m/s
6	Estimated rover location accuracy (diameter)	m
7	End effector precision	mm
8	Time to pick up screwdriver	sec
9	Time to move an object from the edge of the workspace to centered over rover	sec
10	Minimum number of camera views	Views
11	Max arm settling time in cartesian space	ms
12	Camera panorama angle	deg
13	Panorama heading accuracy	deg
14	Photo scale accuracy error	%
15	Soil moisture measurement error	%
16	Depth of soil removed	cm
17	Temperature sensor error	C
18	Max weight arm can lift at 0.5 m from the base of the arm	kg
19	% Successful startup	%
20	Size of handle the end effector can grasp	cm (dia)
21	FPS at 480 x 640 resolution trasmitted over 1km	FPS
22	Max allowable width of rover	m
23	Max incline before rover tips in any orientation	degrees
24	Vertical drop it can withstand	m
25	Minimum speed in sand and gravel	m/s
26	Rover turning radius	m
27	Max weight in any competition configuration	kg
28	Minimum bandwidth at 1 km	Mb/s
29	Gate detection distance	m
30	% FCC rules followed	%

#	Market Requirements	Importance (optional)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Rover can be set up and switched between tasks quickly	2	●																													
2	Rover batteries last the entire competition task	3		●	●																											
3	Rover electrical components and wiring are robust	4				●																										
4	Rover completes tasks within given times	4					●		●			●	●							●			●									
5	Rover tows wagon with carabiner	3										●								●		●										
6	Rover reports its location	4						●																								
7	Rover manipulates tools	4							●	●	●	●	●							●		●	●									
8	Rover arm unscrews/screws cylinder	3							●			●	●							●		●										
9	Rover takes photos	4												●	●	●																
10	Rover measures soil moisture	4															●															
11	Rover digs for soil sample	3										●	●					●		●			●									
12	Rover measures sub-soil temperature	3										●							●													
13	Rover starts up reliably	4																			●											
14	Rover collects soil sample	4							●									●		●												
15	Rover flips open a cap	3							●			●	●							●			●									
16	Rover pushes a button	4							●			●	●							●			●									
17	Rover pours fuel	3									●	●	●							●		●	●									
18	Rover transmits video	4										●											●									
19	Rover fits between posts	3																						●								
20	Rover travels over competition terrain	4																							●	●	●	●				
21	Rover meets competition weight requirements	5																											●			
22	Transmits data required distance	5																												●		
23	Rover navigates autonomously	4																													●	
24	Rover complies with FCC regulations	5																														●
	Importance (optional)																															

#	Ideal Values: Lower Acceptable Limit	Ideal Values: Ideal	Ideal Values: Upper Acceptable Limit	Real Values: Target	Real Values: Predicted	Real Values: Measured
1	-	2	15	5	-	-
2	75	90	-	90	78	-
3	1000	1500	-	1200	1370	-
4	0.5	2	-	2	-	-
5	1	3	-	1.66	3.5	-
6	5	1	-	5	2.5	-
7	50	35	20	10	-	-
8	90	30	-	20	-	-
9	2	5	30	5	-	-
10	2	4	-	4	-	5
11	3000	1000		500	-	-
12	270	360	-	270	360	-
13	-	1	10	5	-	-
14	-	1	10	10	-	-
15	-	2	20	20	-	-
16	5	10	-	10	-	-
17	-	0	10	1	-	-
18	3	4	5	7	-	-
19	95	100	-	100	100	-
20	2.5	5	-	5	-	-
21	5	30	-	15	15	-
22	-	1	2	1	-	-
23	30	45	-	45	-	60
24	0.5	1	-	0.5	0.5	-
25	1	1.66	-	1	1	-
26	-	0	0.5	0.25	-	-
27	-	40	50	50	-	-
28	4	20	-	10	15	-
29	4	20	-	10	-	-
30	100	-	-	100	-	100

3

6 Project Approval Matrix

Since the team is building upon the efforts of previous teams, different aspects of the rover design are in distinct stages of the product development process. The first table (table 1) describes the overall progress of the entire project. Concept development will include everything except the new arm and the science tasks, which will follow the schedule in table 3. To keep the team on schedule, the subsystem engineering phase has been split into two stages: completion of the first stage will result in a working rover than can perform minimal tasks such as driving, arm manipulation, and basic vision; completion of the second stage will result in a rover design with all of the features detailed during the concept development stage. Tables 2, 3, and 4 break down the progress of each of the ten sub-projects, including the budget, approval schedule, and high-level artifacts required. The team defines completion of the subsystem engineering phase to be the completion of a functional design, and completion of system refinement to be the addition of features/capabilities that will improve competition performance.

	General Project	
Product Development Stage	Approval Date	Design Artifacts
Concept Development	11/11/2016	Defined interfaces and sub-project concepts
Subsystem Engineering - Stage 1	3/1/2017	Working Rover
Subsystem Engineering - Stage 2	4/03/2017	Competition Rover
System Refinement	4/17/2017	Passes all Tests
Final Reporting	4/19/2017	All reporting complete

Table 1: Approval matrix for the entire project

Budget

	Concept Development	Subsystem Engineering	System Refinement	Final Reporting
Base / Suspension	X	X	$3000	$10
Current Arm	X	$100	$400	$10
New Arm	$100	$1800	$100	$10
Wiring / PCBs	$600	$200	$100	$10
Communications	X	X	$1000	$10
Onboard Electronics	X	$1200	$300	$10

Continued on next page

Continuation of Budget

	Concept Development	Subsystem Engineering	System Refinement	Final Reporting
3D Vision	X	$500	$100	$10
General Vision	$150	$600	$100	$10
Navigation	$100	$300	$200	$10
Science Tests	$0	$800	$200	$10
Final Competition Preparation	$0	$0	$2950	$0
TOTAL	$950	$5500	$8450	$100

Table 2: Budget for each sub-project by stage of product development

Schedule

	Concept Development	Subsystem Engineering	System Refinement	Final Reporting
Base / Suspension	X	X	03/01/17	04/19/17
Current Arm	X	11/11/16	01/27/17	04/19/17
New Arm	12/08/16	03/03/17	03/24/17	04/19/17
Wiring / PCBs	11/04/16	01/09/17	03/01/17	04/19/17
Communications	X	X	12/08/16	04/19/17
Onboard Electronics	X	12/08/16	03/01/17	04/19/17
3D Vision	X	12/08/16	03/01/17	04/19/17
General Vision	10/28/16	11/30/16	03/01/17	04/19/17
Navigation	11/04/16	02/03/17	04/03/17	04/19/17
Science Tests	11/30/16	02/03/17	04/03/17	04/19/17

Table 3: Approval schedule for each sub-project

Design Artifacts

	Concept Development	Subsystem Engineering	System Refinement	Final Reporting
Base/Suspension	X	X	New frame and wheels, tested and working	Full documentation
Current Arm	X	Control arm with controller; original wrist	Can complete all competition tests; new wrist	Full documentation
New Arm	Finalized Design	Control arm with controller	Can complete all competition tasks	Full documentation
Wiring/PCBs	Interfaces and connector types defined	Accurate wiring schematic made into interchangeable components	Electronics made into PCBs	Full documentation
Communications	X	X	Complete all tests for competition specs	Full documentation
Onboard Electronics	X	All components working and communicating	Pass all tests	Full documentation
3D Vision	X	Video and point cloud transmitting and displaying on base	Obstacle avoidance data for autonomous control	Full documentation
General Vision	Camera choice and method	Cameras transmitting to base station, and controlled by controller	Optimize number of cameras and their locations	Full documentation
Navigation	Design, function, and integration decided	Receiving and displaying GPS location	Autonomous control of rover	Full documentation

Continued on next page

Continuation of Design Artifacts

	Concept Development	Subsystem Engineering	System Refinement	Final Reporting
Science	Hardware and tests selected	Hardware built	Can complete all tests and analysis	Full documentation

Table 4: High-level artifacts required for each approval by sub-project

7 Documentation

In order to facilitate the success of future teams, we have implemented measures to ensure proper documentation of the project. Proper documentation will allow future teams to understand reasoning behind design decisions, see hardware options we researched, and obtain a greater knowledge of how the system works. We believe this will save future teams a lot of time and effort, which will then allow them to focus on fine-tuning the subsystems that already work. We believe this is the key to future success of the BYU Mars Rover team.

We will carry out the majority of the documentation on the wiki associated with the team's github repository. Each sub-team will have their own page on the wiki where they will document their system. The sub-team pages will be divided up by topic to allow for easy searching of material. All transferable design documents will be stored on a set folder on the BYU CAEDM network that will transfer from year-to-year.

Each sub-team will be held responsible for updating the wiki on a weekly basis. The type of information that we will document, includes, but is not limited to: research done on different system options, reasoning behind design decisions, hardware purchased, and system integration. Each subteam will be responsible for reporting any documentation generated during the previous week during the weekly team meeting, and a group of approvers will then review and approve each piece of documentation that will be included in the final report and design package. Upon approval, each document will be assigned a static document number and a revision, and any changes to the document will need to be resubmitted for approval and assigned a new revision. A spreadsheet of all approved documentation will be kept.

8 Desirability Goals

Key Success Measures

Measure	Excellent Performance	Good Performance	Fair Performance	Stretch Goal
Max Incline	Rover can withstand 45 deg. incline	Rover can withstand 30 deg. incline	Rover can withstand 20 deg. incline	
Weight	Rover frame and drive train weigh less than 28kg	Rover frame and drive train weigh less than 30kg	Rover frame and drive train weigh less than 35kg	Rover frame and drive train weigh less than 25kg
End Effector Accuracy	End effector is accurate within 20mm	End effector is accurate within 35mm	End effector is accurate within 50mm	
Arm Strength	Arm can lift 5kg at 0.5m from its base	Arm can lift 4kg at 0.5m from its base	Arm can lift 3kg at 0.5m from its base	
Component Replaceability	Electrical component can be replaced within 5 min	Electrical component can be replaced within 10 min	Electrical component can be replaced within 15 min	
Temporary Electrical Connections	Fewer than 5% non-latching connections	Fewer than 10% non-latching connections	Fewer than 20% non-latching connections	
Run Time	Rover can run at full capacity for 75 min	Rover can run at full capacity for 60 min	Rover can run at full capacity for 45 min	
Communication	Base station and rover can communicate wirelessly over 1km out of line of sight	Base station and rover can communicate wirelessly over 1km in line of sight	Base station and rover can communicate wirelessly over 0.75km in line of sight	
Reliability	Rover system starts up every time and runs continuously without software errors for 75 min	Rover systems starts up 95% of the time and runs continuously for 60 min	Rover system starts up 85% of the time and runs continuously for 45 min	

Continued on next page

Continuation of Key Success Measures

Measure	Excellent Performance	Good Performance	Fair Performance	Stretch Goal
General Vision	A three-camera system that that starts 100% of the time, publishing at 15 fps	A three-camera system that that starts 95% of the time, publishing at 10 fps	A three-camera system that that starts 95% of the time, publishing at 5 fps	
Navigation	Ability to autonomously navigate from point A to point B over moderate terrain within 3m	Ability to autonomously navigate from point A to point B over easy terrain within 15m	Non-autonomous, manual navigation to within 3m	
Sample Collection	Collect an un-contaminated 5g sample of soil from 10cm underground	Collect a 5g soil sample from 5cm underground	Collect 2.5g, contaminated soil sample	Collect and store multiple samples

Table 5: Desirability goals

9 Change Management Procedure

When a party desires to change any part of the contract except for the measured and predicted performance in the requirements matrix, this must be done by unanimous decision of all who signed the contract. The party which desires the change will submit a form outlining what changes are proposed, why these changes should be made, the date, and the names of persons requesting the change. This form will be placed in an appendix to the contract. The new contract is approved when new signatures are obtained on the new contract.

Appendices

A Justification of Requirements

To establish the market and engineering requirements, the team performed a series of research activities. The team watched selected videos of last year's rover competing in Hanksville, Utah, to get a feel for the current state of the rover. Last year's coach, Dr. Homer, met with the team to share his thoughts about the lessons learned and what he feels the current team needs to work on this year to be successful. Additionally, several of last year's team members shared with the whole current team what they did last year, how well they thought it worked, and what they would like to see improved; then the current team broke into subgroups and the applicable team member from last year shared in more detail about that subgroup's particular work. Finally, the team read through the URC rules to learn about the competition updates and what the basic requirements would be. These activities were sorted and combined into a list of market requirements and then related to engineering requirements.

B 2017 University Rover Challenge Rules

University Rover Challenge 2017 – Requirements and Guidelines
Any issues not covered by these published rule sets will be addressed on a case-by-case basis by the University Rover Challenge (URC) Director. Please consult the Questions and Answers (Q&A) portion of the URC web site (http://urc.marssociety.org) for updates. All matters addressed in the Q&A are applicable to the requirements and guidelines.

1. Competition Overview

1.a. The 2017 University Rover Challenge will be held June 1 – 3, 2017 at the Mars Society's Mars Desert Research Station (MDRS) near Hanksville, Utah.

1.b. The rover shall be a stand-alone, off-the-grid, mobile platform. Tethered power and communications are not allowed, except as noted in Section 2.c of the rules.

1.b.i. A single connected platform must leave the designated start gate and return to this location (except when otherwise indicated). In the open field, the primary platform may deploy any number of smaller sub-platforms, so long as the combined master/slave sub-platforms meet all additional requirements published.

1.b.ii. Due to increased FAA (United States Federal Aviation Authority) restrictions, no airborne vehicles will be allowed at URC2017.

1.c. Teams will operate their rovers from designated command and control stations. These stations will be metal trailer units (such as the back of a small moving truck provided by URC) or structures at the Mars Desert Research Station. Visibility of the course by the operators in the control station will be blocked. Basic power (120V, 60Hz), tables, and chairs will be provided. All of the competition events will be held in full daylight.

1.d. There is no restriction on the number of team members or operators allowed. All operators must remain in the designated operators' area. Nobody may follow alongside the rover for the purpose of providing feedback to the operators. Members of the judging team, media, and non-operator team members may follow a rover at the judges' discretion. Team members following the rover may participate as runners in accordance with Section 2.f, or activate an emergency kill switch (in the event of an emergency), but may not otherwise participate in that task.

1.e. The MDRS field site is located in the desert of southern Utah. As such, the site will have a full spectrum of sloped terrain from flat to vertical. Teams should be prepared for any ground conditions that would appear at MDRS. The GPS standard shall be the WGS 84 datum. Coordinates will be provided in latitude/longitude format (degrees/minutes). The rover shall also be capable of withstanding such an environment in the early summer, including airborne dust and temperatures that can easily reach 100°F. Rovers shall be able to withstand light rain but will not be expected to compete in heavy rain or thunderstorms.

1.f. There should be radio communication line-of-sight from the command station to the rover for the Science Cache and Equipment Servicing Tasks. For the other tasks, line of sight communication is not guaranteed for more than 50% of the courses. Rovers are not expected to travel more than 1 km at most from the command station.

1.g. URC does not regulate teams' test activities, especially those on public land, before, during, or after the competition, but please be cognizant that URC does not have the appropriate permits for off-road activities on Bureau of Land Management (BLM) controlled lands, and only has permission to use the two State Trust Land areas outlined (in the blue boxes) on the MDRS BLM map: http://urc.marssociety.org/files/CowDungRdMap.pdf. All land managed by the Bureau of

Land Management (BLM) may NOT be used during URC. Please ask URC staff if you are uncertain where these boundaries are. Teams are also required not to scout or test on any of the URC courses once the judges begin setup the day before the competition begins, with the exception of the Extreme Retrieval and Delivery Task as described in section 3.c.

1.h. Registration, Milestone Reviews and Down-Selections

Prospective teams will undergo a review and down-selection process, meaning that only teams who pass each milestone will be invited to compete in the field. Specific details for each deadline (including deliverable format, submission requirements, and judges' expectations) will be posted to the URC web site (http://urc.marssociety.org). Judges may respond to teams with follow-up questions or requests for clarification at any of these milestones.

1.h.i. Declaration of Intent to Compete

Teams are required to register and declare their intent to compete no later than Friday, December 2, 2016. No significant deliverables are required for this deadline, aside from team details requested via the URC web site.

1.h.ii. Team Proposal

Teams are required to submit a Team Proposal no later than Friday, January 20, 2017. The Team Proposal is expected to focus on the team structure, resources, and project plan. Technical details regarding the rover are encouraged, but not required. Judges will be assessing each team's overall level of readiness to undertake the URC competition. Teams will be assessed on their own merits, not against other teams. Team Proposals may be submitted as early as December 2, 2016, and will be reviewed by judges on a rolling basis.

1.h.iii. Critical Design Review

Teams are required to submit a Critical Design Review (CDR) Package no later than Friday, March 3, 2017. The CDR Package will focus on the overall system design, science plan, and progress to-date of the final system. The CDR Package will consist of both written and video components. The CDR is a competitive milestone and packages will be judged against other teams' submissions by the judges. Only teams who pass the CDR milestone will be invited to compete in the field.

1.i. Teams shall be required to track all finances as related to this project, and submit a final expense record no later than May 22, 2017 (if necessary, teams may submit an updated record – hard or soft copy – on the first day of the URC event – June 1, 2017). Teams shall be penalized 10% of total points per day if they are late in submitting the expense report, and will be disqualified for not submitting their expense report by the end of the URC event (June 3, 2017).

1.i.i. The maximum allowable cash budget to be spent on the project is **$15,000 US**, which shall include money spent on parts and components for the rover, rover modules, rover power sources, rover communications equipment, and base station communications equipment (only that equipment used to communicate with the rover). The budget limit shall not apply to command and control equipment not included above (i.e. base station computers and monitors), tools, travel expenses, or volunteer labor. Volunteer labor applies to any work done helping out with menial labor and should not make a significant contribution to the rover.

1.i.ii. Corporate sponsorship is encouraged. Teams may acquire donations of equipment and services. However, such donations will count towards the cash budget, except for specific exemptions granted by the URC Director for donations made available to all URC teams.

1.i.iii. Teams may be required to submit receipts as proof of budget upon request (donations must be documented by the donor). For donated equipment or services teams may use the cheapest rate commercially available for the same equipment or service.

1.i.iv. If used equipment is purchased commercially the as-bought price may be used. If used equipment is donated to the team and no used market exists for a component then the cost of a new component must be used. Depreciation rules may then be applied if desired according to rule 1.i.v.

1.i.v. If a team uses any parts and/or components purchased in previous years and/or leveraged from previous rovers or projects they have the option of using either the as-bought prices or may apply depreciation rules to 50% of their re-used components. If teams apply depreciation rules they must determine the current prices of all components. The idea is that teams not close to the maximum limit do not need to spend a lot of time here looking up current prices. However teams close to the maximum budget and re-using a lot of components may gain some benefit from depreciation rules if they are willing to go to the effort of finding current prices for everything, some of which like computers may be cheaper but others like raw materials and machining labor may have increased. For information regarding depreciation, teams may consult the U.S. Internal Revenue Service's website.

1.i.vi. Non-US teams have an allowable budget equivalent to $15,000 US based on the most advantageous documented currency conversion rate between August 1, 2016 and June 1, 2017.

1.j. The competition is open to both graduate and undergraduate students. Teams are permitted to include secondary school (high school) students, and students from multiple universities may compete on the same team. A single university may field multiple rovers and multiple teams, however there may be no overlap between team members and leaders, budget, donated equipment, or purchased equipment.

1.k. Teams are encouraged to work with advisors. However, advisors are expected to limit their involvement to academic level advising only. It is incumbent upon the student team leaders to ensure that their respective teams uphold the integrity of this competition. Nontechnical team management duties, including tracking finances, fall within the duties of the students.

2. Rover Guidelines

2.a. Rovers shall utilize power and propulsion systems that are applicable to operations on Mars. Air-breathing systems (such as internal combustion engines and certain fuel cells) are permissible, but must be implemented as fixed-supply systems. No power or propulsion system may ingest ambient air for the purpose of combustion or other chemical reaction that yields energy. Teams implementing such systems are required to understand and follow all applicable safety regulations at their university. Teams are required to document their adherence with these safety regulations during the design phase, and submit this documentation to the URC Director prior to implementation. The URC Director further reserves the right to ban any system deemed unsafe from competition.

2.b. The maximum allowable mass of the rover when deployed for any competition task is 50 kg. The total mass of all fielded rover parts for all events is 70 kg. For example, a modular rover may have a robotic arm and a sensor that are never on the rover at the same time. The combinations of rover plus arm and rover plus sensor must each be under 50 kg, but the total rover plus arm plus sensor must be less than 70 kg. The weight limits do not include command station equipment or any spares or tools used to prepare or maintain the rover. There are no minimum or maximum dimensions for the rover, but the Extreme Retrieval and Delivery Task provides operational constraints that may affect design.

2.b.i. For each event in which the rover is overweight, the team shall be assessed a penalty of

5% of the points scored, per kilogram over 50.

2.b.ii. Rovers over 70 kg in any given configuration must be cleared with the URC Director by email prior to April 28, 2017 to be eligible to compete.

2.b.iii. If a gas-consuming engine is used, the rover shall weigh-in with all tanks full.

2.c. The rover is only required to be autonomous for the Autonomous Navigation Task. In the other tasks autonomy is not required, although some level of autonomy may be beneficial, such as the ability to backtrack to the last good communications location. Besides the Autonomous Navigation Task, the rover shall be operated remotely by a team which will not be able to view the rover on the site or the site itself directly, and line-of-sight communications are not guaranteed for all of the tasks. The rover may be commanded by the team using a wireless link, with information needed for guiding the rover acquired by the rover's own on-board systems and transmitted to the team wirelessly. There shall be no time delay in communications, as the URC is based on the assumption that the rovers in question are telerobots, being operated by astronauts on or orbiting Mars. Refer to rule 2.f regarding the impacts of a loss of communications. **Teams may use tethered communications instead of wireless, but will be penalized 50% of the points earned during that task**. When operating in tethered mode, teams cannot progress beyond the first stage of any staged task.

2.d. Wireless communication methods used by teams shall adhere to all applicable FCC (United States Federal Communications Commission) standards and regulations. The 900 MHz and 2.4 GHz are further regulated in their use at URC as described in section 2.e. Other bands are not further regulated, but we strongly suggest teams use Dynamic Frequency Selection, Frequency Hopping, or at least be able to manually change channels on other bands such as the 5.8GHz band. Teams may utilize multiple bands at the same. Teams must submit details regarding any wireless communication devices being implemented and operator licenses (when applicable) to the URC Director no later than April 28, 2017. Team members are permitted to obtain and utilize any relevant licenses, but must document the license, applicable regulations, and devices as part of the communications documentation deadline. Teams must notify the URC Director immediately of any changes after this date. Teams may be required to power down communications equipment at the event sites while not competing, so as not to interfere with other teams.

2.d.i. Internet is not available in the field or at MDRS, but is available at nearby hotels in Hanksville.

2.d.ii. Both omnidirectional and directional antennae are allowed, but communications equipment must not rely on the team's ability to watch and track the rover first hand. If a team wishes to steer a directional antenna they may:

- Steer it manually from inside the control station with no visual feedback on position.
- Use a mechanized antenna mounted outside that is controlled via an electronic signal from the command station or operates autonomously.
- Place someone outside to manually turn the antenna to point at the rover. Since they can see the rover they are not allowed to communicate with operators inside the control station. This option comes at a 20% penalty per event used.

For any of the above options, signal strength, relayed GPS, or other strategies may be used to give feedback on antenna direction. Teams may not mount a camera on top of the antenna for visual feedback, but a camera may be deployed by the rover in the field.

2.d.iii. Antenna height is limited to 3m, and shall adhere to all applicable regulations. Any antennae must be documented as part of the communications documentation submitted by April 28, 2017. Antenna bases must be located within 5 meters of the team's command station, and any ropes or wires used for stability purposes only may be anchored within 10 meters of the command station. The exception to this is the use of structures at the MDRS where allowable antennae locations will be given by the judge and may be located up to 20m away from the Hab to avoid underground pipe and cables, and other structures which may block radio signals. **All teams should bring at least 25m of antenna cable** to deal with this scenario.

2.d.iv. Lighter-than-air devices are not allowed for communications at URC.

2.e. Teams must notify the organizers of the communications standards they will be using, including frequency bands and channels, by April 28, 2017. The **URC restrictions on the 900 MHz and 2.4GHz bands are as follows:**

2.e.i. 900 MHz frequency band (902-928 MHz): Teams shall not use frequency bandwidths greater than 8 MHz. **Teams must also be able to operate exclusively within each of the following three sub-bands: "900-Low" (902-910 MHz), "900-Mid" (911-919 MHz), and "900-High" (920-928 MHz). The competition schedule will notify teams which sub-band may be used for each task, and teams must be able to shift to another sub-band as required.** There is no limit on the number of 900 MHz channels a team uses, so long as they are all within the designated sub-band.

2.e.ii. **2.4 GHz frequency band (2.400-2.4835 GHz): Teams shall use center frequencies that correspond to channels 1-11 of the IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard for 2.4 GHz.** Teams shall not use frequency bandwidths greater than 22 MHz. **The competition schedule will notify teams which channels may be used for each task, and teams must be able to shift to other channels as required. Teams shall be limited to using no more than three channels in the 2.4 GHz band.**

2.e.iii. Teams may use spread spectrum or narrowband (fixed channel allocation) within the sub-band limits as they fit.

2.e.iv. There will be spectrum monitoring on-site to ensure that teams are not interfering with channels outside those allotted. Teams should anticipate being within signal range of other teams operating on different 900 MHz sub-bands and different 2.4GHz channels and be able to operate their rover under these conditions. Teams must also be able to deconflict communications as specified above (the URC Director will mediate as necessary). Beyond this requirement a 0.5 km minimum separation between competition areas will be guaranteed, which will include large terrain barriers, and event scheduling will avoid communication interference to the greatest extent possible.

2.e.v. Teams are allowed to operate in bands outside of 900 MHz and 2.4 GHz, but should implement spread spectrum, automatic channel switching, frequency hopping, or other interference-tolerant protocols. **In the event of interference outside of 900 MHz and 2.4 GHz, teams will not be granted additional time or special considerations.**

2.f. If a rover suffers a critical problem during a task that requires direct team intervention (including a loss of communication that requires the team to move the rover to reestablish communications), that intervention shall be subject to the following:

2.f.i. **A request for an intervention can only come from the team members operating the rover, not any team members spectating in the field.** They may designate any number of team members who may go to repair or retrieve the rover (hereafter referred to as “runners”). Spectating team members may be asked to act as runners, and also rover operators may leave the command station and become runners.

2.f.ii. **If a spectating team member intervenes with the rover without request from the operators, it counts as an emergency stop.** This is allowed such as to rescue the rover to prevent a fall or a fire. The current task will be considered terminated although the rover may compete in other subsequent tasks.

2.f.iii. If a team member leaves the command station to become a runner they will not be permitted to return to the command station to participate in operating the rover, or analysis of any data, after this point for the current task. Runners will still be permitted to retrieve or repair the rover in future interventions.

2.f.iv. Runners may fix the rover in the field without moving it, return the rover to the command station, or return the rover to the start of that obstacle/task as defined by the judge in the field. However the judge may require the rover to be moved for the safety of the team members or preservation of the course.

2.f.v. If the rover is returned to the command station runners and spectators shall not communicate any details about the task site to the team members operating the rover (judges will monitor conversation), however all team members are permitted to take part in the diagnostic and repair process.

2.f.vi. Spectating team members may carry tools and the command station may radio out to them to request an intervention.

2.f.vii. Teams will be penalized 20% of the total points in that task for every intervention. The task clock will continue to run during an intervention. Multiple intervention penalties in a single task are additive: e.g. two interventions would result in a score of 60% of points earned, not 0.8 x 0.8 = 64%.

2.g. All rover shall have a "kill switch" that is readily visible and accessible on the exterior of the rover. This switch shall immediately stop the rover's movement in the case of emergency. Teams are encouraged to configure their rover such that the kill switch immediately ceases power draw from batteries in the event of a dangerous exothermal runaway event.

3. Competition Tasks

3.a. The rover shall be judged in the four competition tasks outlined below in 3.b to 3.ee. and also on the Critical Design Review.

3.a.i. For the four competition events, the rover is not required to be in the same configuration so modular pieces can be swapped between tasks. Teams will all compete in the Equipment Servicing and Autonomous Traversal Tasks back-to-back, in that order, with 10 minutes of allowed repair time between the two tasks. On days that teams compete in the Science Cache and Extreme Retrieval and Delivery Tasks, teams will only compete in one Task. The rover will otherwise be accessible throughout the competition and modifications can be made at any point.

3.a.ii. Each event and the CDR shall be worth 100 points, for a total of 500 points. Penalties for overweight rovers, interventions, and other penalties are additive: e.g. penalties of 10% and 20% would result in a score of 70% of the points earned, not 0.9x0.8 = 72%. Tasks are scored independently and it is not possible to score less than zero on a task.

3.a.iii. From the time teams are given access to their command station, they shall be able to set up all necessary systems, including all communications systems, and be ready to compete in no more than 15 minutes. Teams shall be able to fully disassemble all equipment in no more than 10 minutes at the end of the event, and may be asked to switch off radio equipment immediately.

3.b. Science Cache Task:

The goal is to collect samples at sites selected in the field, perform basic science evaluation of these samples with onboard instrumentation, and store at least one sample in a cache for further scientific analysis. A single or multiple sites can be sampled. Sites shall be analyzed for their likelihood to support microbial life using the geological context such as evidence of water flow, minerals present and soil structure.

3.b.i. Teams shall submit a written science plan by May 12, 2017, which will be factored into the judges' evaluation for the Science Cache Task. Specifications for the plan will posted to the URC website. The plan should include:

- Basic knowledge about Mars (for example: geology, regolith chemistry, pH, chemical composition, why the surface is red), current operating missions and their instrumentation.
- What the team has done to improve their knowledge for the science task (articles read, experiments performed, experts consulted).
- What instruments and methods the team has chosen for the rover and lab testing, and why.

3.b.ii. Teams will be given a field briefing by judges to discuss the tasks at the science site. Through the information relayed by the rover, teams shall then select sites of potential geological and biological interest within a 0.5 km radius of the command station.

3.b.iii. Teams shall document each site investigated by:

- A wide-angle panorama showing the full context of the site and immediate surrounding area. The panorama must indicate cardinal directions, and have some indication of scale.
- A close up, well focused, high-resolution picture with some indication of scale (scale can be indicated post-capture) at the sampling site.
- Teams will be required to take a stratigraphic profile using the on-board cameras to determine evidence of water.
- GPS coordinates of each site, to include elevation and accuracy range. Thorough documentation is especially crucial for the sample that is returned onboard the rover.

3.b.iv. Based upon investigation of the selected sites, teams shall then collect and return a sub-surface sample, to be stored and sealed in a cache container onboard the rover, from a depth of 5 cm or deeper. Sample(s) must be at least 5 g and may consist of a single rock, loose soil, or anything in between. Sample(s) may return the full depth including the topsoil but teams must be able to distinguish the soil depth for any sample. The portion of the sample from below 5 cm will be used to determine the sample mass.

3.b.v. **Onboard equipment at a minimum should test the soil moisture (relative humidity), subsurface temperature (at least 10 cm below the surface), and use an additional science capability of the team's choice**. Additional sensors, subsystems, and test procedures are left to the discretion of the teams to meet the science-driven objectives of this task.

3.b.vi. Any chemicals used onboard, including water and any reaction products, must follow a no-spill policy of being contained on the rover and not spilt on the ground. Use of hazardous chemicals must be pre-approved prior to competition by submitting a plan of transportation, usage, safety precautions, and accident plan. Teams should consider that URC takes place in a remote desert location with very limited water supplies and no quick access to emergency medical care.

3.b.vii. Teams will be given between 20 and 30 minutes to collect data and the sample with the rover. Teams may investigate as many sites as time allows.

3.b.viii. After return of the rover to the command station, teams shall remove the cached sample from the rover, while minimizing any possibility of contamination. Teams will have the opportunity to use these samples for subsequent laboratory analysis at a later time in the competition.

3.b.ix. At a later time the cache will be returned to the teams and they will be given 15-30 minutes for analysis and preparation of data for a 10 minute discussion with the judges. A discussion with the judges is allowed even if the team was unsuccessful in obtaining samples with their rover. The discussion should include:

- The stratigraphic profile and evidence of water in the profile.
- Results of on-rover and laboratory tests performed.
- Method used to ensure sample was collected at least 5 cm below the surface and stored without contamination.
- Reasoning for sample site selection and documentation of each site.
- Meaning of data collected with respect to geology of the site (past and present) and implications of the site being suitable for life.
- Scientific knowledge of Mars astrobiology.

3.b.x. The score for this task will be based on the following components:

- Thoroughness of the investigation of sites (panoramas, site selection, stratigraphic profile)
- Quality and applicability of the onboard and laboratory analysis (moisture, temperature, rover capability of choice, laboratory analysis)
- Quality of the sample returned (weight, depth, possible contamination)
- Scientific knowledge of Mars astrobiology.

3.c. Extreme Retrieval and Delivery Task:

This will be a staged task in which rovers shall be required to retrieve and deliver objects in the field, and deliver assistance to astronauts, all while traversing a wide variety of terrain. Teams will be given a fixed amount of time for each stage. Each stage will include multiple objectives as described below, and teams must complete each component of a stage as defined below within the allotted time in order to proceed to the next stage. Failure to complete a stage will result in the end of the task. Teams may walk the course ahead of time when other teams are not actively competing.

3.c.i. Terrain may include soft sandy areas, rough stony areas, rock and boulder fields, vertical drops potentially in excess of 0.5 m, and steep slopes in excess of 45°. There is no limit placed on the slopes or size of drops or boulders that may be encountered. Terrain may include routes indicated by visual markers. Terrain will range from very easy and close to the starting line, to exceedingly difficult obstacles at greater distances also involving navigation challenges. Portions of this course, particularly in later stages, will be intentionally placed beyond direct line-of-sight of the control station antenna.

3.c.ii. Rovers will be required to complete a set of objectives not more than 1 km from the start gate. In some areas a set path may be defined. All paths will be at least 2 m wide. Teams will be given approximate GPS coordinates of the object retrieval and delivery locations and any required waypoints. Teams will be scored for each object they successfully retrieve and deliver. Points will be awarded for partial completion, and will be deducted for failure to stay within marked routes.

3.c.iii. Objects to be retrieved in the field will consist of small lightweight hand tools (e.g. screwdriver, hammer, wrench), supply containers (e.g. toolbox, gasoline can), or rocks up to 5 kg in mass. All items will have graspable features (such as a handle) no greater than 5 cm in diameter. The maximum dimensions shall be no larger than 40 cm x 40 cm x 40 cm, but teams should expect a variety of sizes and weights. Rovers may pick up multiple items at a time, but are not required to do so.

3.c.iv. Objects shall be retrieved from and delivered to designated locations, which may include markers or astronauts identifiable by simulated space suits. Approximate GPS coordinates will be provided for each retrieval/delivery location, although accuracy may vary, particularly for astronauts. In certain cases, specific instructions will be provided for each object in advance; in other cases, the object to be delivered will be indicated at the delivery location (e.g. on a small sign held by the astronaut). A 1 m delivery radius from the designated marker will be awarded the maximum score. A 5 m delivery radius from the designated marker will be the minimum threshold required for successful completion of a stage.

3.c.v. Certain objectives of this task will require field science proficiency in order to complete. This can include picking a specified type of rock from an assortment for the retrieval/delivery.

3.c.vi. Teams must successfully complete each objective of a stage in order to advance to the next stage. Any time remaining at the completion of a stage is added to the allotted time of the subsequent stage, which begins immediately. Successful completion of each objective is defined as successful retrieval of all required objects, successful placement of the correct object within 5m of the correct location, and scoring at least 60% of the available points for each route-based objective.

3.c.vii. It is anticipated that there will be a total of two stages in this task, however judges may revise this number for the final schedule. Total time on course will be no greater than 75 minutes.

3.d. Equipment Servicing Task:

Rovers shall be required to perform several dexterous operations on a mock-up equipment system. The rover shall have to travel up to 0.25 km across relatively flat terrain (minimal slope) to reach the equipment. The equipment servicing task will involve performing maintenance on a generator and will include the following sub-tasks:

- Connect a carabiner to a wagon containing a fuel can and use it to tow the wagon to the generator. The wagon will have an attachment point at least 1” in diameter and no more than 0.25” thick, to which the carabiner can be connected. Teams should provide the tow rope and carabiner. The carabiner may be of custom design but must be removable by the rover. The tow rope must be flexible, not a rigid arm for full points to be awarded.
- Flip open a cap on the fuel tank. It will be a press-to-fit cap with a large tab to grip, and hinged on one side.
- Pour the fuel (ethanol simulated by dyed water or simulated magnesium powder) into the tank. Tank opening will be no higher than 0.5m from the ground. Filled fuel can will weigh less than 3 kg. The fuel can will have a handle not more than 5cm in diameter and at least 10cm in length. Other details will not be provided in advance.
- Unscrew a regulator from a simulated empty O2 tank and screw onto a “full” tank. Attaching screw fitting will be a DIN style collar approximately 1” in diameter attached to a hose and may include pressure gauges limiting the ability to grasp from the end.
- Start generator by pushing a button or flipping a switch
- Verify operation by reading a message on a LCD display

3.d.i. Teams will receive points for every sub-task completed successfully, but will be partially penalized for subtasks completed out of order. Sub-task point weights will be consistent with the level of difficulty. Teams will have between 20 and 45 min to complete the task.

3.e. Autonomous Traversal Task:

Rovers shall be required to autonomously traverse between gates in this staged task across moderately difficult terrain. Teams will be given a fixed amount of time for a given stage, and may conduct any activities during this time, including conducting teleoperated excursions (such as previewing routes). Each stage will have one or more legs as described below, and teams must complete each leg of a stage within the allotted time in order to proceed to the next stage. Failure to complete a stage will result in the end of the task.

3.e.i. Teams will begin on this task 10 minutes after the completion of the Equipment Servicing Task, operating from the same control station on an adjacent course.

3.e.ii. A leg is defined as the rover autonomously traversing between a start gate and a finish gate. Gates shall be provided as GPS coordinates, and marked with small visual identifiers not typically observable from a long distance. Each visual marker will include a standard tennis ball elevated 10 – 50 cm off the ground. The finish gate of one leg may be used as the start gate of a subsequent leg.

3.e.iii. To complete a leg, teams must start with their rover within 2 m of the designated start gate (arriving at this gate via teleoperation is permitted). Before proceeding, teams must formally announce to judges that they are entering autonomous mode. In autonomous mode team members may monitor video and telemetry information sent from the rover, but may not transmit any commands that would be considered teleoperation.

3.e.iv. At any time operators may abort autonomous operation and revert to teleoperation, but the time will continue to run and teams shall be required to resume that leg in autonomous mode from the start gate. Interventions that require the physical intervention of runners are still penalized as in rule 2.f.

3.e.v. The rover shall autonomously navigate from the start gate to the finish gate. The rover's on-board systems are required to decide when it has reached the finish gate, and transmit a message back to operators that is displayed for judges to observe. Scores for each leg will be based on proximity to the final gate when the rover perceives that it has completed the leg. A 3 m radius from the gate will be considered successful.

3.e.vi. Teams may resume teleoperation mode between legs and conduct any operations prior to attempting the subsequent leg but competition time will not stop.

3.e.vii. Teams must successfully complete each leg of a stage in order to advance to the next stage. Any time remaining at the completion of a stage is added to the allotted time of the subsequent stage, which begins immediately.

3.e.viii. It is anticipated that there will be a total of three stages in this task at increasing levels of difficulty, however judges may revise this number for the final schedule. Total time on course will be no greater than 75 minutes, and the cumulative distance of all legs shall be no greater than 1000 m.

C Document Database

Table 3 contains the key to the document numbers and table 4 has all of the documents generated by the 2016-2017 Mars Rover team.

Table 3: document prefix key

Document Prefix	Description
MRT	Mars Rover Template
MRD	Mars Rover Document
MRD-TR	Testing Report
MRD-MR	Model Report
MRD-DE	Design Document
MRP	Mars Rover Part (for drawings)
MRP-CHA	Chassis
MRP-SCI	Science
MRP-ARM	Arm
MRP-ELE	Electronics
MRP-COM	Communications

Table 4: Document database

Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-DE-0001 R1	Wheel Tread Determination	4/6/2017	Brian Jackson	Max Incline	Max incline before rover tips in any orientation	G.1
MRD-DE-0002 R1	Navigation Subsystem Description	4/17/2017	Brian Jackson	Navigation		G.2
MRD-DE-0003 R1	PSOC Pin Layout 2017	4/17/2017	Brian Jackson			G.3
MRD-DE-0004 R1	Forearm Twist Feedback	4/19/2017	Brian Jackson	Arm Strength	Max weight arm can lift at 0.5 m from the base of the arm	G.4
MRD-DE-0006 R1	Communications Overview	4/18/2017	Jameson Marriott			G.5
MRD-DE-0007 R1	Software Design	4/19/2017	Jameson Marriott			G.6
MRD-DE-0008 R1	Drive Motors and Controllers	4/19/2017	Brian Jackson			G.7
MRD-MR-0001 R1	Arm Torque Model	12/15/2016	Brian Jackson	Arm Strength	Max weight arm can lift at 0.5 m from the base of the arm	G.8
MRD-MR-0002 R1	Gear Model	12/15/2016	Brian Jackson	Max Incline	Max incline before rover tips in any orientation	G.9
MRD-MR-0003 R1	Simulated Arm Control	12/15/2016	Brian Jackson	End Effector Accuracy	End effector precision	G.10
MRD-MR-0005 R1	Husky Waypoint Simulation	4/18/2017	Jameson Marriott	Navigation		G.11

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-MR-0006 R1	Robot Arm Arm	4/19/2017	Brian Jackson	End Effector Accuracy		G.12
MRD-MR-0007 R1	Arm angles calculation	4/17/2017	Brian Jackson	End Effector Accuracy	Time to pick up screwdriver	G.13
MRD-MR-0008 R1	Camera Panorama Angle Model	4/18/2017	Jameson Marriott		Camera panorama angle	G.14
MRD-TR-0001 R1	Antenna Interference	12/15/2016	Brian Jackson	Communication	Minimum bandwidth at 1 km	G.15
MRD-TR-0002 R1	Arm Accuracy and Precision	12/15/2016	Brian Jackson	End Effector Accuracy	End effector precision	G.16
MRD-TR-0003 R1	Camera Connection Test	12/15/2016	Brian Jackson	General Vision	Minimum number of camera views	G.17
MRD-TR-0004 R1	Camera on TX1	12/15/2016	Brian Jackson	General Vision	Minimum number of camera views	G.18
MRD-TR-0005 R1	GPS Accuracy Testq	12/15/2016	Brian Jackson		Estimated rover location accuracy (diameter)	G.19
MRD-TR-0006 R1	New Arm Control Code Test	12/15/2016	Brian Jackson			G.20
MRD-TR-0007 R1	Point Cloud Test	12/15/2016	Brian Jackson	Navigation		G.21
MRD-TR-0008 R1	Potentionmeter Accuracy Test	12/15/2016	Brian Jackson		End effector precision	G.22
MRD-TR-0009 R1	Ubiquiti Antenna Test	12/15/2016	Brian Jackson	Communication	Minimum bandwidth at 1 km	G.23
MRD-TR-0010 R1	Ubiquiti Omnidirectional Campus Test	1/30/2017	Brian Jackson	Communication	Minimum bandwidth at 1 km	G.24

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-TR-0011 R1	Ubiquiti Omnidirectional 1km Test	2/7/2017	Brian Jackson	Communication	Minimum bandwidth at 1 km	G.25
MRD-TR-0012 R1	Wrist Max Load Test	4/6/2017	Jameson Marriott	Arm Strength	Max weight arm can lift at 0.5 m from the base of the arm	G.26
MRD-TR-0013 R1	Setup Time	4/18/2017	Jameson Marriott		In-field rover set-up time	G.27
MRD-TR-0016 R1	Base and Drivetrain Weight	4/6/2017	Brian Jackson	Weight	Max weight in any competition configuration	G.28
MRD-TR-0017 R1	Chassis Weight Test	4/19/2017	Jameson Marriott	Weight	Max weight in any competition configuration	G.29
MRD-TR-0018 R1	Camera View Test	4/17/2017	Brian Jackson	Navigation	Minimum number of camera views	G.30
MRD-TR-0019 R1	IMU Test	4/17/2017	Brian Jackson	Navigation	Panorama heading accuracy	G.31
MRD-TR-0020 R1	45 Deg. Incline Test	4/6/2017	Brian Jackson	Max Incline	Max incline before rover tips in any orientation	G.32
MRD-TR-0020 R2	45 Deg. Incline Test	4/13/2017	Jameson Marriott	Max Incline	Max incline before rover tips in any orientation	G.33
MRD-TR-0023 R1	Gate Detection Distance (Outdoors)	4/6/2017	Brian Jackson	Navigation	Gate detection distance	G.34
MRD-TR-0024 R1	Gate Detection Distance (Indoors)	4/6/2017	Brian Jackson	Navigation	Gate detection distance	G.35

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-TR-0025 R1	Depth of Soil Removed	4/17/2017	Jameson Marriott	Sample Collection	Depth of soil removed	G.36
MRD-TR-0028 R1	Sample Collection	4/17/2017	Jameson Marriott	Sample Collection	Depth of soil removed	G.37
MRD-TR-0029 R1	Science Module Setup Time	4/17/2017	Jameson Marriott	Sample Collection	In-field rover set-up time	G.38
MRD-TR-0030 R1	Soil Moisture Sensor Accuracy	4/17/2017	Jameson Marriott	Sample Collection	Soil moisture measurement error	G.39
MRD-TR-0031 R1	Temperature Probe Accuracy Test	4/17/2017	Jameson Marriott	Sample Collection	Temperature sensor error	G.40
MRD-TR-0032 R1	Arm Settling Time	4/18/2017	Brian Jackson	End Effector Accuracy	Max arm settling time in cartesian space	G.41
MRD-TR-0033 R1	Arm Strength Test	4/17/2017	Brian Jackson	Arm Strength	Max weight arm can lift at 0.5 m from the base of the arm	G.42
MRD-TR-0034 R1	End Effector Accuracy Test	4/19/2017	Brian Jackson	End Effector Accuracy	End effector precision	G.43
MRD-TR-0035 R1	Size of Objects Hand Can Grasp	4/17/2017	Brian Jackson		Size of handle the end effector can grasp	G.44
MRD-TR-0036 R1	Delivering Object to Center of Rover Test	4/19/2017	Angus Cameron	End Effector Accuracy	Time to move an object from the edge of the workspace to centered over rover	G.45
MRD-TR-0037 R1	Picking Up Objects Test	4/19/2017	Brian Jackson	End Effector Accuracy	Time to pick up screwdriver	G.46
MRD-TR-0038 R1	3/25 Test	4/17/2017	Brian Jackson		Max speed of the rover	G.47
MRD-TR-0040 R1	RPLidar Test	4/17/2017	Brian Jackson	Navigation		G.48

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-TR-0042 R1	Run Time	4/15/2017	Jameson Marriott	Run Time	Length of time the rover can operate at full battery usage	G.49
MRD-TR-0044 R1	Temporary Electrical Connections	4/17/2017	Brian Jackson	Temp. Elec. Connections		G.50
MRD-TR-0046 R1	System Reliability	4/17/2017	Brian Jackson	Reliability		G.51
MRD-TR-0048 R1	Rover Turning Radius	4/17/2017	Jameson Marriott		Rover turning radius	G.52
MRD-TR-0049 R1	Force to unplug a wire	4/17/2017	Brian Jackson	Reliability	Force required to unplug a wire	G.53
MRD-TR-0050 R1	USB Cam Outdoor Gate Detection	4/17/2017	Brian Jackson	Navigation	Gate detection distance	G.54
MRD-TR-0052 R1	Maximum Width of the Rover	4/15/2017	Jameson Marriott		Max allowable width of rover	G.55
MRD-TR-0053 R1	Jetson Camera Test	4/17/2017	Brian Jackson	General Vision		G.56
MRD-TR-0056 R1	Percent FCC Rules Followed	4/19/2017	Brian Jackson		Percent FCC rules followed	G.57
MRD-TR-0058 R1	Antenna 1.6 km Test	4/17/2017	Jameson Marriott	Communication	Minimum bandwidth at 1 km	G.58
MRD-TR-0059 R1	Run ZED with multiple cameras and camera gimbal	4/17/2017	Brian Jackson	Navigation		G.59
MRD-TR-0061 R1	Rock Canyon Test 2: New Base/Motors and Comms	4/17/2017	Brian Jackson			G.60
MRD-TR-0062 R1	Rock Canyon Test 1: Wireless Drive and Cameras	4/17/2017	Brian Jackson	Communication		G.61

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRD-TR-0063 R1	4/15 Marigold Quad Test	4/18/2017	Jameson Marriott	Navigation	Minimum bandwidth at 1 km	G.62
MRD-TR-0064 R1	HSV Values for World and Tennis Ball	4/18/2017	Jameson Marriott	Navigation	Gate detection distance	G.63
MRP-ARM-0001 R1	Middle Bracer	4/17/2017	Brian Jackson			I.3
MRP-ARM-0002 R1	Elbow Bracer	4/17/2017	Brian Jackson			I.3
MRP-ARM-0003 R1	AttachBracketInsideModified	4/17/2017	Brian Jackson			I.3
MRP-ARM-0004 R1	Wrist Mounting Bracket	4/19/2017	Brian Jackson			I.3
MRP-ARM-0005 R1	Base Plate	4/17/2017	Brian Jackson			I.3
MRP-ARM-0006 R1	Bottom Plate	4/19/2017	Brian Jackson			I.3
MRP-ARM-0007 R1	Bottom Plate 2	4/17/2017	Brian Jackson			I.3
MRP-ARM-0008 R1	Shaft Support	4/17/2017	Brian Jackson			I.3
MRP-ARM-0009 R1	Wrist Coupler	4/17/2017	Brian Jackson			I.3
MRP-ARM-0010 R1	Shaft Motor Joint	4/17/2017	Brian Jackson			I.3
MRP-ARM-0100 R1	Turret Assembly	4/19/2017	Brian Jackson			I.3
MRP-ARM-0200 R1	Offset Assembly	4/18/2017	Brian Jackson			I.3
MRP-ARM-0300 R1	Wrist Assembly	4/18/2017	Brian Jackson			I.3
MRP-ARM-0400 R1	Main Block Assembly	4/19/2017	Brian Jackson			I.3
MRP-ARM-0500 R1	Arm Assembly	4/19/2017	Brian Jackson			I.3
MRP-ARM-0600 R1	Arm Assembly Combined	4/19/2017	Brian Jackson			I.3
MRP-ARM-0700 R1	Hand Assembly	4/19/2017	Brian Jackson			I.3
MRP-ARM-0800 R1	Forearm Assembly	4/19/2017	Brian Jackson			I.3
MRP-ARM-0900 R1	Total Arm	4/19/2017	Brian Jackson			I.3

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Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRP-CHA-0001 R1	Base Back Beam	4/17/2017	Brian Jackson			I.2
MRP-CHA-0002 R1	Base Center Beam	4/17/2017	Brian Jackson			I.2
MRP-CHA-0003 R1	Base Front Beam	4/17/2017	Brian Jackson			I.2
MRP-CHA-0004 R1	Base Angled Beam	4/17/2017	Brian Jackson			I.2
MRP-CHA-0005 R1	Front Angle Bracket	4/17/2017	Brian Jackson			I.2
MRP-CHA-0006 R1	Front Arm	4/17/2017	Brian Jackson			I.2
MRP-CHA-0009 R1	Rear Angle Bracket	4/19/2017	Brian Jackson			I.2
MRP-CHA-0010 R1	Rear Arm Long	4/17/2017	Brian Jackson			I.2
MRP-CHA-0011 R1	Rear Arm Short	4/17/2017	Brian Jackson			I.2
MRP-CHA-0017 R1	Wheel Adapter Plate	4/17/2017	Brian Jackson			I.2
MRP-CHA-0018 R1	Motor Mounting Bracket	4/17/2017	Brian Jackson			I.2
MRP-CHA-0019 R1	Front Suspension Bearing	4/17/2017	Brian Jackson			I.2
MRP-CHA-0020 R1	Rear Suspension Bearing	4/17/2017	Brian Jackson			I.2
MRP-CHA-0021 R1	Front Axle	4/17/2017	Brian Jackson			I.2
MRP-CHA-0022 R1	Rear Angle Bracket	4/17/2017	Brian Jackson			I.2
MRP-CHA-0023 R1	U Bracket	4/17/2017	Brian Jackson			I.2
MRP-CHA-0024 R1	Square Side Bracket 1.15	4/19/2017	Brian Jackson			I.2
MRP-CHA-0025 R1	Square Side Brakcet 1	4/17/2017	Brian Jackson			I.2
MRP-CHA-0026 R1	Square Middle Support	4/17/2017	Brian Jackson			I.2
MRP-CHA-0027 R1	Front Bearing Housing	4/17/2017	Brian Jackson			I.2

Continued on next page

Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRP-CHA-0028 R1	Rear Bearing Housing	4/17/2017	Brian Jackson			I.2
MRP-CHA-0030 R1	Front Arm Weld	4/17/2017	Brian Jackson			I.2
MRP-CHA-0100 R1	Frame	4/17/2017	Brian Jackson			I.2
MRP-CHA-0200 R1	Front Arm Assembly	4/17/2017	Brian Jackson			I.2
MRP-CHA-0300 R1	Rear Arm Assembly	4/17/2017	Brian Jackson			I.2
MRP-CHA-0400 R1	Bracket Assembly	4/17/2017	Brian Jackson			I.2
MRP-CHA-0401 R1	Bracket Assembly with Antenna	4/17/2017	Brian Jackson			I.2
MRP-CHA-0500 R1	Front Bearing Assembly	4/19/2017	Brian Jackson			I.2
MRP-CHA-0600 R1	Rear Bearing Assembly	4/19/2017	Brian Jackson			I.2
MRP-CHA-0700 R1	Wheel and Motor Assembly	4/19/2017	Brian Jackson			I.2
MRP-CHA-0800 R1	Rear Arm and Wheel Assembly	4/19/2017	Brian Jackson			I.2
MRP-CHA-0900 R1	Chassis	4/18/2017	Brian Jackson			I.2
MRP-CHA-1000 R1	Rover with Arm	4/19/2017	Brian Jackson			I.2
MRP-ELE-0001 R1	Tx; Rx wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0002 R1	5V Signal wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0007 R1	Battery Connection wire	4/19/2017	Jameson Marriott			I.4
MRP-ELE-0008 R1	Parallel Battery Connector	4/19/2017	Jameson Marriott			I.4
MRP-ELE-0009 R1	Dynamixel 3-pin wire	4/19/2017	Jameson Marriott			I.4
MRP-ELE-0010 R1	Voltage Board wire	4/19/2017	Jameson Marriott			I.4

Continued on next page

Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRP-ELE-0012 R1	MotA/B wires	4/19/2017	Brian Jackson			I.4
MRP-ELE-0013 R1	Chute Enable wire	4/19/2017	Brian Jackson			I.4
MRP-ELE-0015 R1	Pololu 12V wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0016 R1	Jetson 12V power	4/19/2017	Brian Jackson			I.4
MRP-ELE-0017 R1	USB Hub 12V power	4/19/2017	Brian Jackson			I.4
MRP-ELE-0018 R1	Relay Power Fuse Box wire	4/19/2017	Brian Jackson			I.4
MRP-ELE-0019 R1	Relay Enable wire	4/19/2017	Brian Jackson			I.4
MRP-ELE-0020 R1	Kill Switch 12V wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0021 R1	Drive Wheel wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0022 R1	5V Power wires	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0023 R1	12V Power wire	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0024 R1	24V Power wire	4/19/2017	Brian Jackson			I.4
MRP-ELE-0025 R1	Relay Power wire	4/19/2017	Jameson Marriott			I.4
MRP-ELE-0201 R1	12V PCBA	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0202 R1	5V PCBA	4/17/2017	Jameson Marriott			I.4
MRP-ELE-0203 R1	Pololu PCBA; small	4/19/2017	Brian Jackson			I.4
MRP-ELE-0204 R1	Pololu PCBA; large	4/19/2017	Brian Jackson			I.4
MRP-ELE-0205 R1	Drive Wheel PCBA; small	4/19/2017	Brian Jackson			I.4
MRP-ELE-0206 R1	Drive Wheel PCBA; large	4/19/2017	Brian Jackson			I.4
MRP-ELE-0207 R2	Gimbal and GPS PCBA	4/19/2017	Brian Jackson			I.4

Continued on next page

Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRP-ELE-0208 R1	Wrist and Hand PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0209 R2	Lidar PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0210 R1	Chutes PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0211 R1	Turret PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0212 R1	PSoC PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0215 R1	Forearm PCBA	4/19/2017	Brian Jackson			I.4
MRP-ELE-0301 R1	12V PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0302 R1	5V PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0303 R1	D-sub Combo Box Connector; small	4/19/2017	Brian Jackson			I.4
MRP-ELE-0304 R1	D-sub Combo Box Connector; large	4/19/2017	Brian Jackson			I.4
MRP-ELE-0305 R1	D-sub Box Connector; small	4/19/2017	Brian Jackson			I.4
MRP-ELE-0306 R1	D-sub Box Connector; large	4/19/2017	Brian Jackson			I.4
MRP-ELE-0307 R1	Dynamixel PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0308 R1	Turret PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0309 R1	Chutes Box Connector	4/19/2017	Brian Jackson			I.4
MRP-ELE-0310 R1	PSoC PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0311 R1	Forearm Encoder PCB	4/19/2017	Brian Jackson			I.4
MRP-ELE-0500 R1	Electrical Box	4/19/2017	Brian Jackson			I.4
MRP-ELE-0500 R2	Rover Schematic	4/19/2017	Brian Jackson			I.4
MRP-SCI-0001 R1	Base Plate	4/19/2017	Brian Jackson			I.5

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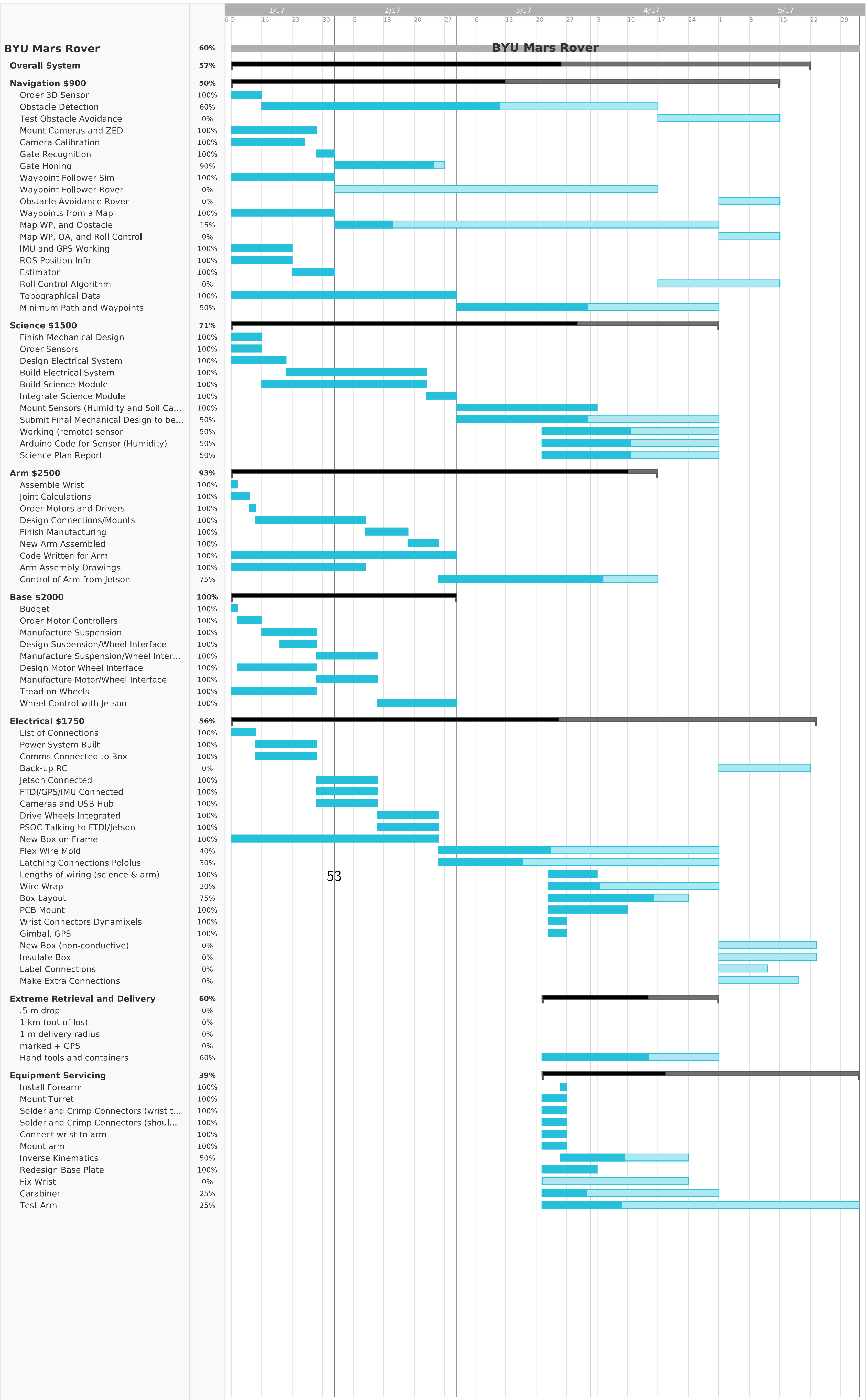
Document Number	Title	Approval Date	Approver	Desirability Goal	Performance Measure	Section
MRP-SCI-0002 R1	Rocker Arm	4/19/2017	Brian Jackson			I.5
MRP-SCI-0003 R1	Tool Holder	4/18/2017	Brian Jackson			I.5
MRP-SCI-0004 R1	Rocker Base Back Mount	4/19/2017	Brian Jackson			I.5
MRP-SCI-0005 R1	Rocker Base Front Mount	4/19/2017	Brian Jackson			I.5
MRP-SCI-0006 R1	Drill Alignment	4/19/2017	Brian Jackson			I.5
MRP-SCI-0007 R1	Rocker Base Spacer	4/19/2017	Brian Jackson			I.5
MRP-SCI-0008 R1	Plate Connector	4/19/2017	Brian Jackson			I.5
MRP-SCI-0009 R1	Motor Brace	4/19/2017	Brian Jackson			I.5
MRP-SCI-0013 R1	Temperature Sensor Bottom	4/19/2017	Brian Jackson			I.5
MRP-SCI-0014 R1	Temperature Sensor Top	4/18/2017	Brian Jackson			I.5
MRP-SCI-0015 R1	Drill Bearing	4/19/2017	Brian Jackson			I.5
MRP-SCI-0016 R1	Dirt Holder Flap	4/18/2017	Brian Jackson			I.5
MRP-SCI-0017 R1	Humidity Holder	4/19/2017	Brian Jackson			I.5
MRP-SCI-0018 R1	Humidity Rod	4/18/2017	Brian Jackson			I.5
MRP-SCI-0019 R1	Auger	4/18/2017	Brian Jackson			I.5
MRP-SCI-0020 R1	Auger Adapter	4/18/2017	Brian Jackson			I.5
MRP-SCI-0021 R1	Dirt Holder Rod	4/19/2017	Brian Jackson			I.5
MRP-SCI-0022 R1	Auger Rod	4/19/2017	Brian Jackson			I.5

D Schedule

We have included a copy of our team schedule in this section.


1/17
2/17
3/17
4/17
5/17
6 9 16 23 30 6 13 20 27 6 13 20 27 3 10 17 24 1 8 15 22 29
BYU Mars Rover 60%
BYU Mars Rover
Overall System 57%
Navigation $900 50%
Order 3D Sensor 100%
Obstacle Detection 60%
Test Obstacle Avoidance 0%
Mount Cameras and ZED 100%
Camera Calibration 100%
Gate Recognition 100%
Gate Honing 90%
Waypoint Follower Sim 100%
Waypoint Follower Rover 0%
Obstacle Avoidance Rover 0%
Waypoints from a Map 100%
Map WP, and Obstacle 15%
Map WP, OA, and Roll Control 0%
IMU and GPS Working 100%
ROS Position Info 100%
Estimator 100%
Roll Control Algorithm 0%
Topographical Data 100%
Minimum Path and Waypoints 50%
Science $1500 71%
Finish Mechanical Design 100%
Order Sensors 100%
Design Electrical System 100%
Build Electrical System 100%
Build Science Module 100%
Integrate Science Module 100%
Mount Sensors (Humidity and Soil Ca... 100%
Submit Final Mechanical Design to be... 50%
Working (remote) sensor 50%
Arduino Code for Sensor (Humidity) 50%
Science Plan Report 50%
Arm $2500 93%
Assemble Wrist 100%
Joint Calculations 100%
Order Motors and Drivers 100%
Design Connections/Mounts 100%
Finish Manufacturing 100%
New Arm Assembled 100%
Code Written for Arm 100%
Arm Assembly Drawings 100%
Control of Arm from Jetson 75%
Base $2000 100%
Budget 100%
Order Motor Controllers 100%
Manufacture Suspension 100%
Design Suspension/Wheel Interface 100%
Manufacture Suspension/Wheel Inter... 100%
Design Motor Wheel Interface 100%
Manufacture Motor/Wheel Interface 100%
Tread on Wheels 100%
Wheel Control with Jetson 100%
Electrical $1750 56%
List of Connections 100%
Power System Built 100%
Comms Connected to Box 100%
Back-up RC 0%
Jetson Connected 100%
FTDI/GPS/IMU Connected 100%
Cameras and USB Hub 100%
Drive Wheels Integrated 100%
PSOC Talking to FTDI/Jetson 100%
New Box on Frame 100%
Flex Wire Mold 40%
Latching Connections Pololus 30%
Lengths of wiring (science & arm) 100%
Wire Wrap 30%
Box Layout 75%
PCB Mount 100%
Wrist Connectors Dynamixels 100%
Gimbal, GPS 100%
New Box (non-conductive) 0%
Insulate Box 0%
Label Connections 0%
Make Extra Connections 0%
Extreme Retrieval and Delivery 60%
.5 m drop 0%
1 km (out of los) 0%
1 m delivery radius 0%
marked + GPS 0%
Hand tools and containers 60%
Equipment Servicing 39%
Install Forearm 100%
Mount Turret 100%
Solder and Crimp Connectors (wrist t... 100%
Solder and Crimp Connectors (shoul... 100%
Connect wrist to arm 100%
Mount arm 100%
Inverse Kinematics 50%
Redesign Base Plate 100%
Fix Wrist 0%
Carabiner 25%
Test Arm 25%

E Requirements

E.1 Requirement Matrices

Product: URC Mars Rover

Subsystem: Basic Requirements

Revision Date: 03/6/2017

Market Requirements

#	Market Requirements	Importance (optional)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Rover can be set up and switched between tasks quickly	2	●																													
2	Rover batteries last the entire competition task	3		●	●																											
3	Rover electrical components and wiring are robust	4				●																										
4	Rover completes tasks within given times	4					●		●			●	●							●			●									
5	Rover tows wagon with carabiner	3										●								●		●										
6	Rover reports its location	4						●																								
7	Rover manipulates tools	4							●	●	●	●	●							●		●	●									
8	Rover arm unscrews/screws cylinder	3							●			●	●							●		●										
9	Rover takes photos	4												●	●	●																
10	Rover measures soil moisture	4															●															
11	Rover digs for soil sample	3										●	●					●		●			●									
12	Rover measures sub-soil temperature	3										●							●													
13	Rover starts up reliably	4																			●											
14	Rover collects soil sample	4							●									●		●												
15	Rover flips open a cap	3							●			●	●							●			●									
16	Rover pushes a button	4							●			●	●							●			●									
17	Rover pours fuel	3									●	●	●							●		●	●									
18	Rover transmits video	4										●											●									
19	Rover withstands natural elements of competition	0																														
20	Rover can be quickly turned off for emergencies.	0																														
19	Rover fits between posts	3																						●								
20	Rover travels over competition terrain	4																							●	●	●	●				
21	Rover meets competition weight requirements	5																											●			
22	Transmits data required distance	5																												●		
23	Rover navigates autonomously	4																													●	
24	Rover complies with FCC regulations	5																														●
	Importance (optional)																															

Performance Measures

#	Performance Measures	Units	Ideal Values: Lower Acceptable Limit	Ideal Values: Ideal	Ideal Values: Upper Acceptable Limit	Real Values: Target	Real Values: Predicted	Real Values: Measured
1	In-field rover set-up time	minutes	-	2	15	5	-	6
2	Length of time the rover can operate at full battery usage	minutes	75	90	-	90	90	-
3	Distance the rover can travel on a full battery charge	meters	1000	1500	-	1200	1363	-
4	Force required to unplug a wire	lb	0.5	2	-	2	-	2
5	Max speed of the rover	m/s	1	3	-	1.66	3.5	3.9
6	Estimated rover location accuracy (diameter)	m	5	1	-	5	2.5	-
7	End effector precision	mm	50	35	20	10	-	25.3
8	Time to pick up screwdriver	sec	90	30	-	20	-	59.5
9	Time to move object from workspace edge to centered over rover (s)	sec	2	5	30	5	-	12
10	Minimum number of camera views	Views	2	4	-	4	-	5
11	Max arm settling time in cartesian space	ms	3000	1000		500	-	3280
12	Camera panorama angle	deg	270	360	-	270	360	-
13	Panorama heading accuracy	deg	-	1	10	5	-	-
14	Photo scale accuracy error	%	-	1	10	10	-	-
15	Soil moisture measurement error	%	-	2	20	20	0	0
16	Depth of soil removed	cm	5	10	-	10	-	8.25
17	Temperature sensor error	C	-	0	10	1	-	1
18	Max weight arm can lift at 0.5 m from the base of the arm	kg	3	4	5	7	-	7
19	% Successful startup	%	95	100	-	100	100	31
20	Size of handle the end effector can grasp	cm (dia)	2.5	5	-	5	-	5.5
21	FPS at 480 x 640 resolution trasmitted over 1km	FPS	5	30	-	15	15	-
22	Max allowable width of rover	m	-	1	2	1	-	1.09
23	Max incline before rover tips in any orientation	degrees	30	45	-	45	-	45
24	Vertical drop it can withstand	m	0.5	1	-	0.5	0.5	-
25	Minimum speed in sand and gravel	m/s	1	1.66	-	1	1	-
26	Rover turning radius	m	-	0	0.5	0.25	-	0
27	Max weight in any competition configuration	kg	-	40	50	50	53.9	-
28	Minimum bandwidth at 1 km	Mb/s	4	20	-	10	15	4
29	Gate detection distance	m	4	20	-	10	-	5.15
30	% FCC rules followed	%	100	-	-	100	-	100

E.2 Market Requirements

1. Rover can be set up and switched between tasks quickly

   This market requirement is very important because some competition tasks occur on the same day. The market has specifically identified this as a requirement, as stated in rule 3.a.iii: "[Teams] shall be able to set up all necessary systems... and be ready to compete in no more than 15 min." This market requirement applies to rules 3.a.i and 3.a.iii.

2. Rover batteries last the entire competition task

   Rule 1.b states "Tethered power and communications are not allowed." Since we are powering the rover through batteries, the batteries must last the entire competition task.

3. Rover electrical components and wiring are robust

   One of the major problems encountered last year was that the electrical components and wiring were not very reliable. For example, during the terrain traversal task, one of the wheel motors became unplugged. This caused the rover to fall off the cliff and compromise the rover's communication and electrical system. Robust wiring and components will help ensure that the rover performs as designed.

4. Rover completes tasks within given times

   The market has stated that failure to complete a task within the given time will result in the end of the task and will not allow them to proceed to the next stage. Desirable rovers must be able to complete all tasks within the given times, as stated in the competition rules. This market requirement applies to rules 3.c, 3.c.vi, and 3.e.

5. Rover tows wagon with carabiner

   For the equipment servicing task, the market has specifically stated that rovers must "connect a carabiner to a wagon containing a fuel can and use it to tow the wagon". This is rule 3.d.

6. Rover reports its location

   Several tasks require the rover to respond to and report GPS coordinates. This market requirement applies to rules 3.b.iii, 3.c.ii, 3.c.iv, 3.c.vi, 3.e.ii, and 3.e.v.

7. Rover manipulates tools

   For the Extreme Retrieval and Delivery Task, rovers should retrieve objects consisting of "small, lightweight hand tools" (rule 3.c.iii). Rovers should also be able to perform maintenance on a generator (rule 3.d).

8. Rover arm unscrews/screws cylinder

   The market has specifically stated that rovers must "unscrew a regulator from a simulated empty O2 tank and screw onto a full tank. This is rule 3.d.

9. Rover takes photos

   One of the rules for the Science Cache Task is that the rover should take a wide-angle panorama, and a close-up, well-focused, high-resolution picture. This is rule 3.b.iii.

10. Rover measures soil moisture

    Rule 3.b.v states that "onboard equipment at a minimum should test the soil moisture (relative humidity)". This is rule 3.b.v.

11. Rover digs for soil sample

    The samples that the rover retrieves should be from a depth of 5cm or deeper. Failure to prove that the sample comes from that depth results in a penalty. See rules 3.b.iv and 3.b.v.

12. Rover measures sub-soil temperature

    Another measurement that the market has requested that the rover measure is the subsurface temperature at least 10 cm below the surface. This is rule 3.b.v.

13. Rover starts up reliably

    The time requirement for each task begins when the URC official states and does not wait for teams to make sure their rover is fully operational. Last year the team had to spend a trial run troubleshooting and repairing their rover because it did not start reliably. Failure to achieve this market requirement will decrease the probability that the rover will perform the task in the required amount of time. This market requirement applies to rules 3.c, 3.c.vi, and 3.e.

14. Rover collects soil sample

    Similar to requirement 11, the market states that "teams shall then collect and return a subsurface sample, to be stored and sealed in a cache container onboard the rover" (rule 3.b.iv). The team will then need to use the sample to perform various experiments.

15. Rover flips open a cap

    For the Equipment Servicing Task, the rules state that rovers must "Flip open a cap on the fuel tank. It will be a press-to-fit cap with a large tab to grip, and hinged on one side." This is rule 3.d.

16. Rover pushes a button

    Again from the Equipment Servicing Task (rule 3.d), rovers must "Start generator by pushing a button or flipping a switch".

17. Rover pours fuel

    Another sub-task from the Equipment Servicing Task is that rovers must pour simulated fuel from a fuel can into a tank. This is found in rule 3.d.

18. Rover transmits video

    Although most tasks do not specifically require video to meet the specified rules, our benchmark research has shown that in the past, all of the top teams have had transmitted video from the rover to the base station. Rule 3.d refers to image transmission, stating that persons at the base station must "Verify operation by reading a message on a LCD display". We plan on using video to fulfill this requirement.

19. Rover withstands natural elements of competition

    The competition is held in southern Utah during the month of June. The URC rules state that "The rover shall also be capable of withstanding such an environment in the early summer, including airborne dust and temperatures that can easily reach 100° F. Rovers shall be able to withstand light rain but will not be expected to compete in heavy rain or thunderstorms." (rule 1.e).

20. Rover can be quickly turned off for emergencies.

    In order to prevent injuries to persons or property, the market has determined that all rovers must have a "kill switch" that is readily visible and accessible on the exterior of the rover. This should completely cut all power from batteries in the event of a dangerous exothermal runaway event. This is rule 2.g.

21. Rover fits between posts

    As part of the Autonomous Traversal Task, rovers need to travel between gates, or posts. These gates are checkpoints that determine the start and finish of each leg of the task. Failure to fit between the posts will result in an incomplete leg and will result in the end of the task. See rule 3.e.

22. Rover travels over competition terrain

    Both the Extreme Retrieval and Delivery Task and the Autonomous Traversal Task require that rovers travel over the terrain of the competition. We were not more specific in what type of terrain because the rules state that there is no limit placed on the terrain that rovers may encounter. See rules 3.e, 3.c, and 3.c.i.

23. Rover meets competition weight requirements

    In order to compete at the competition, the rover may not exceed the maximum allowable mass of 50 during any competition task. The rover also must have a total mass of all fielded rover parts for all events and tasks less than 70 kg. Failure to meet this requirement will result in a penalty. See rule 2.b.

24. Transmits data required distance

    Communication between the rover and base station is key for all tasks. Benchmarking data has shown that rovers that lose data transmission perform poorly in that task and in the competition. Two specific examples that deal with this requirement are rules 3.e.v and 3.d.

25. Rover navigates autonomously

    A new task in this year's competition is the Autonomous Traversal Task. "Rovers shall be required to autonomously traverse between gates in this staged task across moderately difficult terrain" (rule 3.e).

26. Rover complies with FCC regulations

    In order to compete in the competition, rovers and teams just adhere to all applicable FCC regulations. Failure to do so will disqualify the rover from competing in the competition. See rule 2.d.

E.3 Performance Measures, Ideal Values, and Target Values

The following section describes the performance measures that we used to determine the desirability of our product followed by a description of the ideal value we would want in a perfect world and then a description of the target value that we tried to achieve.

1. In-field rover set-up time

   a) This measure applies to requirement 1. We will measure this value by performing several tests on how long it takes to switch necessary equipment between the Equipment Servicing Task and Autonomous Traversal Task. These tasks will be the only tasks performed on the same day and will happen 10 minutes apart.

   b) The upper acceptable limit is 15 minutes because any time more than the 10 preparation minutes will be added to the task time (although this time should be limited). The ideal value is 2 minutes, ensuring that we will be able to start the tasks as soon as possible. There is no lower limit because there is no penalty for starting immediately.

   c) Our target value is 5 minutes. We feel that this is a good goal because it ensures that we will be able to set up the rover faster than required, but not too fast that we have to make unwarranted design changes to the rover.

2. Length of time the rover can operate at full battery usage

   a) This measure applies to requirement 2. We will measure this by running mock competition tasks for up to 3 hours (the maximum length of last year's tests), and record the rover's performance and battery levels. Based on the length and intensity of these tests, we will be able to accurately estimate the length of time the rover can be powered.

   b) The maximum time that any task can be is 75 minutes, thus our lower limit was set as this duration. We did not choose an upper limit because having the rover run longer is always better.

   c) Our target value for battery duration is 90 minutes, providing a 15-minute buffer between the running time and the maximum competition time. This buffer will help us in case some testing needs to happen in the 10-minute set-up stage before competition tasks.

3. Distance the rover can travel on a full battery charge

   a) This measure applies to requirement 2. We will measure this by driving the rover with varying intensities during tests (as described above), and measure the length of time and distance traveled during the tests. The results of these tests should confirm that our models are correct and that the rover can travel enough distance to finish each competition task.

   b) The maximum distance of the Autonomous terrain task (driving only) is estimated at 1km. Because the competition rules do not enumerate a specific distance value, and because our terrain traversal will not necessarily follow the shortest path, we decided to set our lower limit at 1000 m and ideal value of 1500 m. No upper acceptable limit was placed because farther travel on battery life is desired.

c) Our target value was set to 1200 m to give a 20% buffer between the nominal distance in the competition and actual distance traveled.

4. Force required to unplug a wire

   a) This measure applies to requirement 3. We will measure this by testing various electrical connections on the rover with a vibration electrodynamic shaker. We will also use locking and latching connections on the connections to prevent wiring shortages (as happened during last years competition). In these measures, removing a connection means unintentionally breaking a connection.

   b) Because troubleshooting and component replacement can disrupt nearby wiring, and because of the likely vibration present during the competition tasks, we decided on a lower limit of 0.5 lb force to remove a connector. No upper limit was placed (stronger connections are better). The ideal value was placed at 2 lb force to provide substantial strength to protect connections from being bumped out of place during the competition

   c) The target value was placed at 2 lb force for the same reasons as noted above for the ideal value.

5. Max speed of the rover

   a) This measure applies to requirement 4. We will measure this by running the rover at its maximum speed and computing the distance traveled and time required to travel that distance. Several tests will be performed and the average velocity will be computed.

   b) The maximum time of the Autonomous terrain task (driving only) is 75 minutes and the distance is estimated at 1km. This computes to 0.22m/s. However, we won't be able to continuously run in a straight line through the course as we stop to avoid obstacles. Therefore, with a factor of safety of 4, we have set our lower limit to be 1m/s. Our ideal limit of 3m/s applies a factor of safety of 3 to the value set for our lower limit. This gives us plenty of time to complete the course. While we don't want to be rushed for time, there is a certain limit to the speed at which the rover operates with ease. Because of this, we have avoided setting an upper acceptable limit for the speed of the rover.

   c) Our target value of 1.66m/s for the speed of the rover is based on the capabilities of our motors.

6. GPS location accuracy (diameter)

   a) This measure applies to requirement 6. We will measure this by testing the GPS at various locations, plugging the data it gives us into Google Maps, then computing the error. This error will be averaged over the locations tested.

   b) According to the rules, getting within 3 meters of a target is counted as success, so we have made 2.5 meters our lower acceptable limit. We have made 1 meter as our ideal value. An upper value is not necessary.

   c) In order to be considered successful, we must finish within 2.5 meters of our target. Thus, this is our target value.

7. End effector precision

a) This measure applies to requirements 4, 7, 8, 14, 15, and 16. We will measure this by commanding the arm to go certain commanded distances then compare the actual distances traveled compared to those that were commanded. The errors from these tests will then be averaged to find the average precision of the end effector.

b) Rule 3.c.iii states that all objects will have graspable features at least 5cm in diameter. We chose 50mm as our upper acceptable limit to match this value. There is no disadvantages to having a perfectly precise end effector, so there is no lower limit. Ideally the arm would be accurate to 5mm, which would almost guarantee that the arm would be close enough to grasp any object without correction.

c) We talked to two experts in robotic arm design and they recommended that we have a goal of an accuracy of 10mm. This is close enough to have minimal human correction, but is also a reasonable goal that we feel that we can hit with our time and resources.

8. Time to pick up screwdriver

   a) This measure applies to requirement 7 . We will measure this by placing a screwdriver 5m in front of the rover at 10 separate latitudes, then time how long it takes for the user to successfully drive over and lift the screwdriver off the ground using the rover's arm. We will then average the times.

   b) The lower acceptable limit is 90 seconds because that is the time it took last year's team to perform this task in the competition and we are starting with their design. There is no upper limit because there is no penalty for quickly picking up the objects. Ideally we would take 20 seconds to perform this task.

   c) Our target value is 20 seconds and we feel that this is fast enough to do well in the competition but not so fast that it is an extremely difficult goal to achieve given our time and resources constraints.

9. Time to move an object from the edge of the workspace to centered over rover

   a) This measure applies to requirements 7 and 17. We will measure this by placing a screwdriver 5m in front of the rover at various latitudes, then time how long it takes for the user to successfully driver over and lift the screwdriver off the ground using the rover's arm. We will then average the times.

   b) The lower acceptable limit is 2 seconds because we want to go fast, but not so fast that we run the risk of flinging the object or damaging the arm. The upper limit of 10 seconds should be easily reachable, especially once Inverse Kinematics is in place and the computer can control the joint angle motions autonomously. We do not see a reason that it would take greater than 10 seconds with Inverse Kinematics in place. Our ideal value is 5 seconds. We feel that this is quick enough to not waste time on competition tasks, but slow enough as to not damage the arm or drop the object.

   c) The target value is our ideal value for the reasons stated above.

10. Minimum number of camera views

a) This measure applies to requirements 4, 5, 7, 8, 11, 12, 15, 16, 17, and 18. We will measure this by simply counting the number of camera views that the rover can transmit over the connection via ROS.

b) There is no upper limit to the number of camera views because more vision is not inherently bad. We based the ideal value of 6 camera views off of the number of camera views last year's team had recommended for good vision. The lower limit of 4 camera views is the minimum because it would show us the four cardinal directions relative to the rover (front, back, left, right).

c) Our target value is 6 camera views because we feel that it is both achievable and beneficial.

11. Max arm settling time in cartesian space

a) This measure applies to requirements 4, 7, 8, 11, 15, 16, and 17. We will measure this by timing how long it takes for the arm to settle for a variety of tests then average this time.

b) After controlling last year's robotic arm we observed that the slow settling time made it very difficult to accurately position the arm. Though we did not measure the settling time of last year's arm, we observed that it was significantly slower than 1 second. The ideal value for settling time is as fast as possible, therefore we used 100 ms, a value that some of the best robots achieve. For a lower acceptable limit we declared 1000 ms, a value that would allow for decent visual control of the arm.

c) After our experience with the old arm and other robots, we consulted with Dr. Killpack and determined that a 500 ms settling time would be a good compromise between development cost of the robotic arm and controllability. It should allow us to control and position the arm well based on visual feedback.

12. Camera panorama angle

a) This measure applies to requirement 9. We will measure this by measuring the angle of the panorama transmitted from the rover to the base station via ROS.

b) The lower acceptable panorama angle is 160 degrees because that is the angle that a human eye can see. This is generally seen as the benchmark minimum for what constitutes a panorama. We would ideally like to be able to take a 360 degree picture.

c) A 360 degree picture would be ideal because that would give us a full understanding of the surroundings of where we take our soil sample.

13. Panorama heading accuracy

a) This measure applies to requirement 9. We will measure this by comparing the directions printed on the panorama with the actual directions measured by an electronic compass. We will then be able to compute the difference in degrees.

b) Our upper acceptable limit would be a 10 degree error because we should be able to keep our error down to a single order of magnitude. A 10 degree error would give us a very limited understanding of where the rover and soil samples are. We would like to minimize error, so 1 degree would be our ideal goal.

c) A 1 degree heading error would be ideal because knowing our orientation to this degree would give us a very good understanding of our location and the locations of features around us.

14. Photo scale accuracy error

    a) This measure applies to requirement 9. We will measure this by comparing the measurement presented through photos or videos sent by the rover to the actual measurements then compute the percent error.

    b) Our upper acceptable limit would be a 10% error because we should be able to keep our error down to a single order of magnitude. A 10 degree error would give us a poor understanding of distances and location. We would like to minimize error, so 1% would be our ideal goal.

    c) A 1% heading error would be ideal because this would give us a very accurate understanding of the relative position and distance of objects.

15. Soil moisture measurement error

    a) This measure applies to requirement 10. We will measure this by comparing the measurement presented through photos or videos sent by the rover to the actual measurements then compute the percent error.

    b) Our upper acceptable limit would be a 20% error because we should be able to keep our error down to a single order of magnitude. This is especially important because soil humidity may teach us about the presence of water or the evidence of life on Mars. We would like to minimize error to instrument precision, so 2% would be our ideal goal.

    c) An error of 2% would give us a very good idea of the humidity of the soil and would give us consistent, reliable data for our soil tests

16. Depth of soil removed

    a) This measure applies to requirements 11 and 14. We will measure this by testing how deep the rover can dig (up to 15 cm) in varying types of soils.

    b) The lower acceptable limit that we can collect soil is 5 cm because of the requirements given to us by the Mars Society. Our ideal soil collection depth would be 10 cm because we have to measure soil temperature at 10cm anyway.

    c) Our ideal soil collection depth would be 10 cm because we have to measure soil temperature at a depth of 10 cm.

17. Temperature sensor error

    a) This measure applies to requirements 12. We will measure this by comparing the temperature measurement transmitted by the rover to a calibrated thermocouple placed in the same soil then compute the percent error.

    b) The upper acceptable limit of soil temperature error is 1 degree Celsius because a full degree Celsius error would give us a very inaccurate idea of the conditions of our soil. We would like to be within 0.1 degrees Celsius because that is the size of increments in typical thermometers.

c) We would like to have an error within 0.1 degrees Celsius because that is the smallest resolution most conventional thermometers have.

18. Max weight arm can lift at 0.5 m from the base of the arm

    a) This measure applies to requirements 4, 5, 7, 8, 11, 14, 15, 16, and 17. We will measure this by testing how much the arm can lift (up to 7 kg) if the weight is placed 0.5 m from the base of the arm. The arm must lift the weight at least 30 cm off the ground in order to be a successful attempt.
    b) There is no upper limit because we do not feel that it would be bad to have an infinitely strong arm. The lower limit is 5 kg because that is the max weight of any object that the rover will be required to lift in the competition. The ideal value is 7 kg. This will ensure that we will be able to easily lift any object and move with the arm.
    c) The target value is also 7 kg. We feel that it is very important to have an arm that is slightly more powerful than required by the competition.

19. % Successful startup

    a) This measure applies to requirement 13. We will measure this by computing what percent of the systems (vision, navigation, etc.) start up when we boot up the rover. We will average these percentages over various tests to get a total percent successful startup.
    b) The ideal value for successful startup is 100% because we want it to start up every time it is powered on. We will accept a lower limit of 95%, and can feel comfortable entering the competition with those odds. Due to the nature of the measure, there is no need for an upper limit (the more successful startups, the better).
    c) We want to achieve 100% startup because if our rover does not reliably start up during the competition, we risk not being able to compete.

20. Size of handle the end effector can grasp

    a) This measure applies to requirement 5, 7, 8, and 17. We will measure this by testing the end effector on different diameter handles and verifying that it retains grasp even if the load is up to 7 kg.
    b) The rules state that we will be grabbing "lightweight hand tools (e.g. screwdriver, hammer, wrench), supply containers (e.g. toolbox, gasoline can), or rocks" and that "all items will have graspable features (such as a handle) no greater than 5 cm in diameter" (rule 3.c.iii.). Because of this our lower limit is 2.5 cm because most item such as screwdrivers and gas cans often are only 2.5 cm in diameter. The ideal target is 5 cm because there will be no items larger than that. There is no upper limit.
    c) The target value is 5 cm based off the max size of objects they will give us (rule 3.c.iii).

21. FPS at 480 x 640 resolution trasmitted over 1km

    a) This measure applies to requirements 4, 7, 11, 15, 16, 17, and 18. We will measure this by simply measuring the frames per second transmitted at the specified distance and resolution.

b) No upper limit exists because it's never bad to have more continuous vision. The lower is 5 because below that it gets very difficult to control. Ideal is 30 because that is a very smooth, easy to use video.

c) We chose 15 fps to be our target value because it is a frame rate that can be easily viewed. In addition, it will help keep the bandwidth low for communications purposes.

22. Max allowable width of rover

    a) This measure applies to requirement 22. We will measure this by simply measuring the maximum width of the rover.

    b) Our upper limit of 2 m was designated because of the requirement that the rover fit between two poles separated by 2 m. We gave ourselves a factor of safety of 2 and set our ideal limit to be 1 m. We did not set a lower acceptable limit for the width of the rover as there is no minimum size required by the URC rules.

    c) Our target values of 1 m. is based on our measurements of the previous rover and our ideal limit.

23. Max incline before rover tips in any orientation

    a) This measure applies to requirement 23. We will measure this by driving the rover on different incline angles up to 60 degrees and finding at which angle the rover starts to tip.

    b) Our lower and ideal acceptable limits of 30 and 45 degrees respectively were determined based on the URC requiring the rover to traverse inclines of at least 45 degrees. We did not define an upper acceptable limit as we would like the rover to be stable in any orientation.

    c) Our target value of 45 degrees was based on both the URC rules and the current performance of the rover.

24. Height it can clear

    a) This measure applies to requirement 24. We will measure this by simply measuring the minimum clearance beneath the rover (not including the wheels and wheel motors) and the performance of last year's team.

    b) Based on the URC rule requiring the rover to experience drops potentially in excess of 0.5 m and climb over objects, we set our lower acceptable limit to be 0.25 m with a ideal value of 0.5 m. We didn't set an upper limit as we would like to theoretically clear any height.

    c) Our target height of 0.5m that the rover can clear was determined based on both the URC rules and the current capabilities of the rover.

25. Diameter obejects the rover can traverse

    a) This measure applies to requirement 25. We will measure this by driving the rover over different diameter of objects and finding which ones it fails to successfully traverse.

b) Based on the URC rule requiring the rover to experience drops potentially in excess of 0.5 m and climb over boulders, we set our lower acceptable limit to be 0.25 m with a ideal value of 0.5 m. We didn't set an upper limit as we would like to theoretically clear any object that the rover comes across.

c) Our target diameter of 0.5m that the rover can clear was determined based on both the URC rules and the current capabilities of the rover.

26. Minimum speed in sand and gravel

    a) This measure applies to requirement 26. We will measure this by running the rover through sand and gravel and computing the distance traveled and time required to travel that distance. Several tests will be performed and the average velocity will be computed.

    b) The maximum time of the Autonomous terrain task (driving only) is 75 minutes and the distance is estimated at 1km. This computes to 0.22m/s. The capabilities of our motors allow the rover to run at 1.66 m/s. We set our lower limit to be 1 m/s with the assumption that the rover would run slower when driving in sand and gravel. However, ideally our rover would traverse these portions of the course with ease and, therefore, set our ideal value to be 1.66m/s. We didn't set an upper limit as running the rover too fast results in lower performance as it becomes more difficult to operate.

    c) Our target value of 1.66m/s for the speed of the rover is based on the capabilities of our motors.

27. Rover turning radius

    a) This measure applies to requirement 27. We will measure this by having the rover make turns in different soil and inclines and measure the maximum turning radius for all the tests.

    b) Our Ideal value for our turning radius would be 0 m. Ideally we would like the rover to be able to turn on the spot. We set our upper acceptable limit to be 0.5 m to allow for the rover to navigate through the terrain without having to go too far off path.

    c) Our target value of 0.25 m is based on current capabilities of the rover.

28. Max weight in any competition configuration

    a) This measure applies to requirement 28. We will measure this by simply weighing the rover in each configuration (for each competition task).

    b) URC rules dictate that the rover weigh less than 50kgs and we have set our upper acceptable limit as such. To give ourselves some breathing room, we set our ideal limit to be 40kgs.

    c) We set our target value for the overall weight of the rover to be 50kgs based on the current measurements and projected weight of the rover.

29. Minimum bandwidth at 1 km

a) This measure applies to requirement 22. We will measure this by transmitting data over a 1 km distance with and without obstacles similar to those in the competition, and finding the minimum bandwidth achieved through these tests.

b) Testing from the camera has shown that 4 Mb/s will be sufficient to run at least the Zed camera and 2 others, plus the ROS commands; hence, the minimum value.

c) The target value is 10 Mb/s, which will give us sufficient throughput to run all of the cameras. The ideal value is 20 Mb/s, because there is Zed point cloud data that we would like to work with, and we need some extra bandwidth for that. However, the Zed point cloud data has not been integrated with the communications system yet.

30. Gate detection distance

    a) This measure applies to requirement 23. We will measure gate detection distance by driving the rover up to a "gate" (tennis balls on a pole) and recording how far the rover was when it recognized the gate. We will repeat this test several times in different environments and take the average.

    b) Ideally, we would recognize the gates from the moment they come into view of the rover. For this reason, we have determined an ideal value as 20m. The Lower acceptable limit is 4 m because we expect our GPS to get us within this distance from the gates.

    c) The target distance for gate detection is 10 m because this would provide us the time and distance to navigate more directly to the gate.

31. % FCC rules followed

    a) This measure applies to requirement 24. We will measure this by simply computing what percentage of the FCC rules (as cited in the URC competition requirements) we are following for competition setup.

    b) The only limit is the lower limit, which is 100%. Any other limit is unacceptable because we will only be able to compete in the competition if we achieve this value.

    c) Our target value is 100% for the same reasons stated in part b.

F University Rover Challenge Critical Design Review

URC Critical Design Review

March 3, 2017

MARS
ROVER

Contact Info:

Angus Cameron - Team Lead
angus.cameron@byu.net

Dr. Marc Killpack - Team Coach
marc_killpack@byu.edu

Dr. David Allred - Team Sponsor
allred@physics.byu.edu

Introduction

In early September 2016, we, the BYU Mars Rover team, organized ourselves as such to continue a nine-year tradition of participating in the University Rover Competition (URC). This year, our team represents students from a diverse set of majors including electrical, mechanical, and manufacturing engineering as well as biology and geology. We follow a product development process of transforming a design from basic requirements into a refined and marketable product, as outlined by a senior-level capstone course. We have already completed concept development and some subsystem engineering, with special focus on utilizing the successful aspects of past BYU rovers. We have transitioned much of the design to the system refinement stage and are fixing weaknesses and enhancing the rover's capabilities to meet this year's rigorous requirements.

Core Rover System

The current rover system consists of communications equipment at a base station as well as a mobile rover vehicle. We describe the core subsystems within these two units below.

Robotic Arm and Science Module

We have created a new robotic arm (figure 1) and science module (figure 2) that we can quickly interchange for rapid replacement and easier troubleshooting. Both systems share many of the same connections: their feedback and control come from the same onboard Jetson TX1 computer and a Cypress Programmable System-on-chip (PSoC) microcontroller. The robotic arm has six degrees of freedom (DOF): four come from the bending and rotation at the shoulder and elbow joints, and the other two come from differential gearing in the arm's wrist. We made the arm linkages from carbon fiber tubes, and we switched from motors to linear actuators for some of the joints. These changes decrease the weight on the arm, which in turn decreases the required torque to lift and manipulate objects. All of the actuators on the arm have built-in feedback, allowing us to utilize inverse kinematics models to improve the arm's motion and accuracy. The hand attachment on the arm consists of two clamshell, aluminum-polyurethane, compliant gripper claws operated by linear actuators. The science module consists of a sliding tool mount (that holds an auger and several sensors simultaneously), elevation control, drill motor, and power transmission system to plunge tools into the soil. The module will first excavate a hole using the auger, and then a linear actuator will move the tool mount to sequentially position each sensor over the excavated area one at a time. Thus, without moving the rover, we can plunge several sensors into a single hole.

Controls and Communications

An onboard Jetson TX1 computer controls the rover with software that we have built on the Robot Operating System (ROS) framework. This computer receives commands from the base station over Wi-Fi using a Ubiquity Rocket M2 wireless bridge. The Jetson sends commands to a PSoC microcontroller, which actuates the various motors and reports positional feedback from the arm and data from the science sensors. The Jetson also recieves GPS, accelerometer, and 2D and 3D visual data (through onboard cameras and lidar sensors) and sends it back to the base station in real time. We can currently control

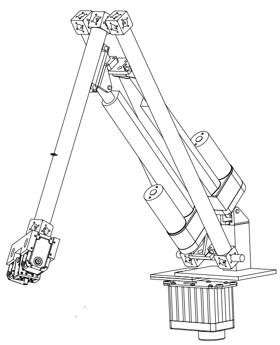


Figure 1: Robotic arm

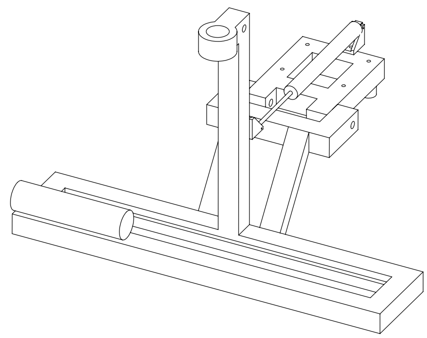


Figure 2: Science module

the rover with an Xbox controller, but ROS also enables inverse kinematics and autonomous functionality.

Chassis, Suspension, and Drive

We took the rover chassis, suspension and wheel design directly from last year's rover because these subsystems have performed well for the past two years. The chassis is a strong, lightweight frame made from aluminum tubing that houses connections for an electronics box, a robotic arm, suspension arms, and an antenna tower. The rover rides on a modified rocker-bogie suspension, which allows all six of its wheels to maintain contact with the ground on uneven terrain. Anaheim motors drive the six polyurethane balloon wheels with rubber cords attached for traction.

Approach to Tasks

Extreme Retrieval and Delivery Task

This task can be broken down into the following system requirements:

- Unknown terrain of unknown gradient that is visually accessible
- Communication up to 1 km and out of line-of-sight
- Object grasping and transport
- GPS navigation
- Field science proficiency

The rover has multiple camera views that provide good visibility for the operator, and its rocker-bogie chassis allows it to traverse difficult terrain. The hand includes a compliant polymer for a tight grip. When combined with strong linear actuators, it can lift the competition items and place them into chutes for transport over terrain. We have designed the communication system for long distance functionality, allowing us to use GPS and IMU information at the base station. The base station team will also feature a geologist for rock identification.

Equipment Servicing Task

This task largely measures the arm dexterity and control. To address it, we have developed inverse kinematic control code for the arm, allowing the operator effortless and precise control. In addition, the six DOF mechanical arm can move within a large sphere in front and to the sides of the rover without moving the base. It can manipulate switches, screws, caps, carabiners, and buttons.

Autonomous Traversal Task

This task requires the rover to autonomously travel and detect gates. We have designed our navigation system to allow layers of autonomous control. At a basic level, the rover will follow waypoints that define a path from start to finish: it will use GPS and IMU data to estimate its position as it follows the path. The next level of control will allow it to navigate around obstacles that it cannot drive over and servo towards the gate based on camera data. At the final level of control, a geography volunteer is helping design a path planner based on topographical data that will allow us to avoid cliffs, steep gradients, or other trouble points. It will also plan a fast, efficient path.

Project State

Status

As of March 3, 2017, we have assembled the rover prototype and are actively testing it. The rover can drive, provide navigational feedback (GPS and IMU), and manipulate the arm and the science module using ROS over Wi-Fi. We are currently developing and building a new arm this year, but we have kept last year's arm as a backup if we have problems with the new arm. We can collect digital video feedback over Wi-Fi. The navigation team has developed software so that the rover can perform a simple waypoint navigation and obstacle detection as well as simple gate honing. We will develop the rest of the autonomous features by April 3. The electrical box is a prototype, and we will complete the final design within two weeks. We have prototyped the science module and will construct the final design within two weeks. Our tests indicate that the rover is on schedule to meet URC competition requirements and will be competitive.

Completion Schedule

We still need to refine several items to complete the rover system. We have completed the electrical schematic, but we still need to solder many electronic connections. As mentioned in the previous section, we will complete this in two weeks. We need to mount additional cameras and test them for long range communication over the next month. We also need to finish and test the new arm, which we estimate will take three weeks because we have already finished manufacturing. Additionally, we need to test and complete the science module's tool holder. We will complete this module in two weeks and then test it. We intend to completely integrate the rover with full functionality by April 3. From that time to the competition at the beginning of June, we will test all systems and train for the competition tasks on a regular basis, and will refine the design as necessary.

Approach to Testing and Training

Our design strategy is to test early and often. We set early deadlines for various design iterations to allow ample time for refinement and testing. We first tested subsystems individually to ensure that they worked as expected before incorporating them into the integrated system. We outline this test strategy below.

Communications Testing

The communications system was the first system that was completed and ready for testing. The system from last year's team performed sufficiently well, but the team reported occasional latency issues. To overcome these issues, we designed a communications system that provides higher throughput in adverse environments. Once built, we began field testing the communication equipment in November 2016. From these tests, we have confirmed that the communications system will perform the required competition tasks.

Science Module Testing

We have tested the science module sensors and the platform on the rover chassis. We have also taken soil samples from Hanksville in order to verify our testing procedures. We will test the entire integrated system over the next couple of weeks.

Navigation Testing

In order to excel in the autonomy portion of the competition, we must improve the rover navigation from past years. We have tested the code by performing a simulation of point-to-point behavior using a Gazebo simulation of the Husky robot. Since the Husky is a four-wheel drive differential, we assume that the dynamics are comparable. We have also tested the GPS and IMU, and both work correctly. We are in the process of developing gate honing and obstacle detection, which we will test on the full rover by the beginning of April.

Integrated System Testing

We will continue to integrate more systems of the rover as they are finished and test them on a weekly basis. We will also travel to Hanksville on March 25 for a mock competition. At that point, we will have all of the systems integrated, and we will test to make sure that we can complete all of the competition tasks. If we run into any problems at our mock competition, we will still have two months to address any hardware difficulties and refine our software.

Funds Available

The BYU Mechanical Engineering department is sponsoring this year's team with a $15,000 budget with an additional travel budget. Currently, the team has spent about $12,072 on expenses, including prototyping, development, materials, and some replacement components. We will use the remaining rover budget of $2,928 to test, repair, modify, and refine the systems between now and the competition. We will have the rover competition-ready by the end of May with this budget. The rover also uses various materials and components from past years, which we will account for when we report the overall budget to satisfy the URC $15,000 budget limit requirement.

Science Plan

Our goal is to utilize visual observation in addition to on-rover and in-lab experiments to search for evidence of a past or current environment that could support life.

The mechanical design consists of a dedicated science module for performing all on-rover tests and sample collection, and we have described this design above. We will have the capability to perform four onboard tests and collect two soil samples.

Onboard Tests

First, temperature is a vital factor for microbial growth, affecting aspects of cell physiology such as membrane fluidity and DNA stability. Extreme temperature ranges indicate the soil may not be suitable for life (although there are notable exceptions[1]). As well, by comparing atmospheric and soil temperatures, we can identify whether daily temperature oscillations are moderated by the soil in a manner conducive to life or liquid water. Second, soil moisture is a direct indication of currently present liquid water. Soil moisture sensors measure volumetric water content. Liquid water is considered a prominent contributor to the development of life and thus is critical to identify. Third, electrical conductivity (EC) is a measure of how well the soil conducts electricity based on the effect of soluble ions and salts on an induced electrical current. EC monitors the quantity of nutrients, salts, and impurities in soil. If soil is too saline, most microbes will have difficulty growing. Additionally, highly saline deposits are often associated with shallow expanses of evaporating liquid water. Fourth, visual surveillance is perhaps the most important onboard capability. We have equipped the rover with a high-resolution camera capable of HD panoramic and macro shots. Visual analysis will allow us to review macro and micro geologic structures preserved in the area. Observations such as preserved river channels, soft sediment deformations, smectitic textures, and pyroclastic tuff are direct evidence of liquid water. Images sent back by the rover are vital in determining a sample site.

In-lab Tests

In-lab tests confirm the readings we receive from the rover, as well as obtain additional information not available from rover tests. First, magnetic susceptibility measurements reflect the magnetic properties of a sample. Minerals associated with high MS readings, such as hematite, have been linked with the presence of liquid water and wide-scale oxidation[2]. Second, x-ray fluorescence (XRF) paired with nitrate test strips, a photometer, and a hydrochloric acid test, can identify the presence of carbon (C), hydrogen (H), and oxygen (O), nitrogen (N), and phosphorous (P)[3]. This is significant because C, H, O, N, and P are the five four most common elements in living organisms. Third, measuring PH reflects the concentration of H+ ions in the sample and indicates its geologic history and hospitality to life.

[1] Buford, Price P., Microbial life in martian ice: A biotic origin of methane on Mars?: Planetary and Space Science, v. 58, i. 10, p. 1199-1206, 2010

[2] Rochette, P., Gattacceca, J., Mathe, P.E., Menvielle, M., Magnetism, Iron Minerals, and Life on Mars: Astrobiology, v. 6, n. 3, p. 423-436, 2006

[3] Toulmin, P., Baird, A.K., Clark, B.C., Keil, K., Rose, H.J., Inorganic Chemical Investigation by X-Ray Fluorescence Analysis: The Viking Mars Lander: Icarus, v. 20, p. 153-178, 1973

G Test and Methodology Reports

This appendix includes all of the design, test, and model reports generated by the team. Design reports (MRD-DE-####) describe the de

G.1 MRD-DE-0001 R1: Wheel Tread Determination

MRD-DE-0001 R1

Wheel Test Determination

Date	Subsystem	Related Desirability Goal	Pass/Fail
2017-04-05	Chassis	Incline (not withstanding, but climbing)	

Names of persons conducting test

Jameson Marriott	Isaiah Young		

Purpose

The purpose of this exercise was to determine what wheel tread ideas to pursue and prototype.

Method

Isaiah Young (volunteer) and Jameson Marriott brainstormed ideas for wheel treads and ranked them in five categories: traction, price, manufacturability, durability, weight. We weighted each on a scale of 1-5 as 4, 2, 2, 3, 5 respectively. We have included the matrix in the appendix of this report.

Results

The ideas that ranked the highest were chicken wire treads, expanded metal treads, and fasteners.

Conclusion

We threw out the expanded metal idea because the chicken wire was a very similar idea and so much easier to prototype. We later thought of the idea to tie v-belts onto the chicken wire, but we haven't had a chance to try it yet. We also decided to prototype a polypropylene webbing tread idea because it was so easy. As of this writing, we haven't fully evaluated the design yet.

Attachments

Concept	Traction	4	Price	2	Manufacturability	2	Durability	3	Weight	5	Total	Percent
Chicken Wire	2	8	5	10	4	8	4	12	5	25	63	1
Expanded Metal	3	12	4	8	5	10	5	15	3	15	60	0.9523809524
Fasteners	3	12	4	8	5	10	2	6	3	15	51	0.8095238095
V-belt stretched circles	3	12	3	6	2	4	4	12	3	15	49	0.7777777778
V-belt circumferance	2	8	2	4	3	6	5	15	3	15	48	0.7619047619
PP webbing	1	4	5	10	3	6	1	3	5	25	48	0.7619047619
Knit trimmer line	1	4	5	10	0	0	2	6	5	25	45	0.7142857143
Glue on tread	1	4	2	4	2	4	4	12	4	20	44	0.6984126984
V-belt across	4	16	1	2	1	2	4	12	2	10	42	0.6666666667
Bungee cords	3	12	1	2	5	10	3	9	1	5	38	0.6031746032
Rubber webbing	1	4	2	4	3	6	1	3	2	10	27	0.4285714286

G.2 MRD-DE-0002 R1: Navigation Subsystem Description

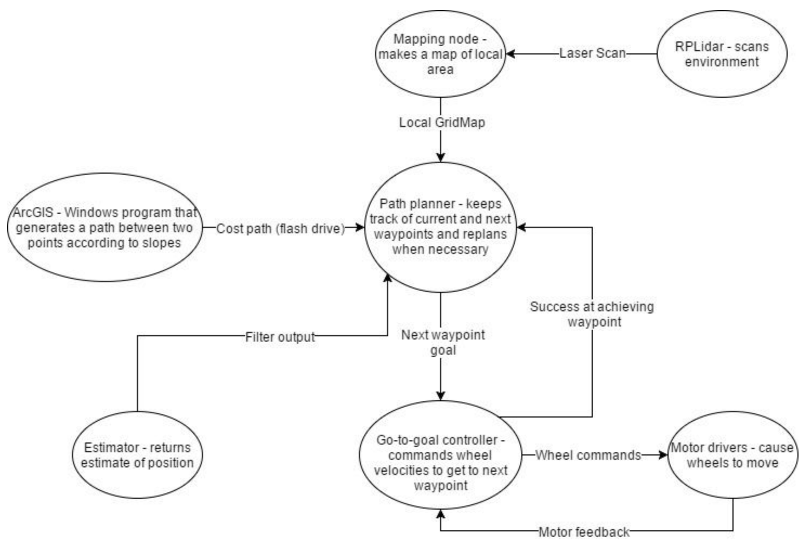
MRD-DE-0002 R1

Navigation Subsystem Description

Date	Subsystem	Related Performance Measure	
4/11/17	Navigation		

Names of Person Creating Model

Peter Schleede			



This description is meant to accompany the above flowchart. The draw.io diagram can be found in Navigation Team -> Pictures.

System Description

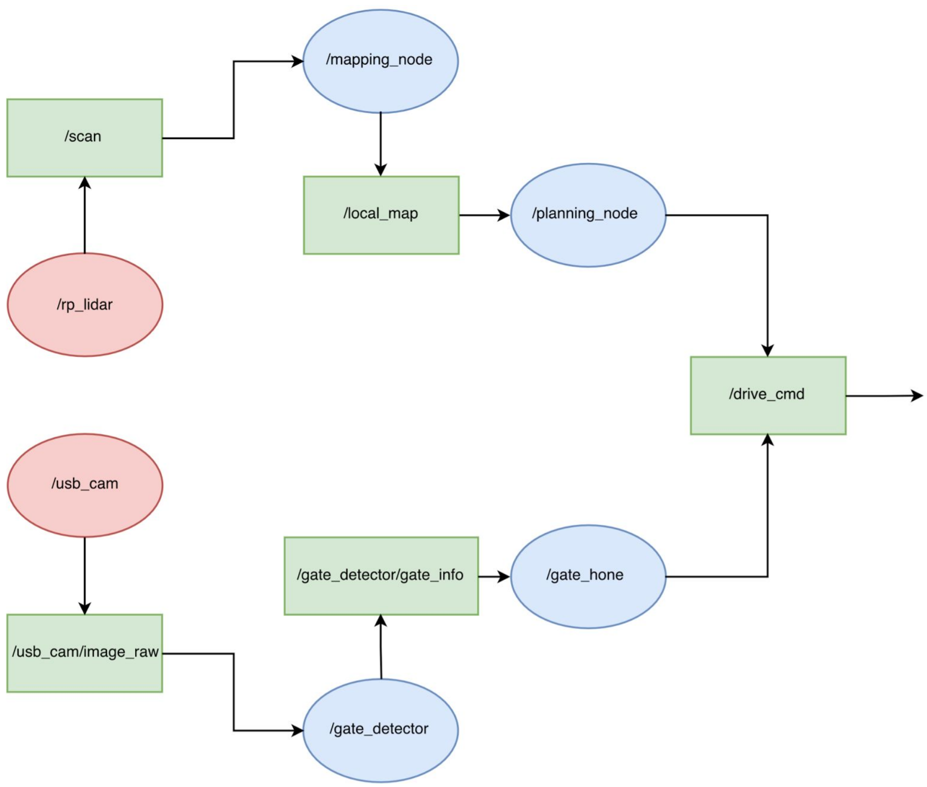
A computer at the competition should be running Windows with ArcGIS installed. ArcGIS is a program geographers use for creating multi-layer maps of areas. One of our volunteers has created such a map with one layer being slopes at a 10x10 meter resolution. Someone running that computer will input the start and end GPS points given to us by the competition officials. ArcGIS will output a path that avoids dangerous slopes (defined as above 25 degrees for now) as a JSON file. We should just stick this on a flash drive and load it into the base station where something will parse it quickly and publish the path it gives us in NED[i].

When that path has been received by the path planner, it will publish the first waypoint for the go-to-goal controller, which is a simple PID controller that commands wheel velocities. This controller will publish commands to the motor drivers which will return feedback.

While the rover is driving towards its next waypoint, the estimator (an Extended Kalman Filter) will estimate its position and publish this for the planner. In this case, the planner acts as the path manager to determine when the rover has achieved each waypoint and publishes the next waypoint for the controller. It uses the half-plane method described in Small Unmanned Aircraft (McLain and Beard).

Also while driving, the RPLidar is scanning its environment. These laser scans feed into the mapping node. This node uses the GridMap package developed by ETH Zurich. It inputs the elevation of points and moves the map as the rover moves. This map is published to the path planner. The planner continuously iterates through it. Whenever it encounters a point elevated above some threshold we define, it raises all points within a radius of that point to some impassable height. This is saved into a temporary GridMap so we don't alter the actual map of the area. The radius must be more than half the width of the rover. This is so that spaces between two objects that are too small for the rover are closed up on the temporary map. The planner checks along the line from the rover to the grid point closest to the next waypoint to see if it is clear. If not, the temporary map is fed into an A* path planning algorithm to find a safe path for the rover. That path is smoothed and the rover then follows it until it able to resume traveling along the global waypoint path.

When the rover is close to the final gate and detects a tennis ball, the gate honing controller takes over. This is not listed on the diagram because it means an end to the above control. It seeks to move the tennis ball to the center of the camera frame by using a PID controller to command the wheels. When it does, it commands both wheels forward until the rover is within a certain distance of the goal. If the rover never sees the ball, it will stop based on its estimate of its position, which should put it within 2.5 meters of the goal.


/mapping_node
/scan
/local_map
/planning_node
/rp_lidar
/drive_cmd
/usb_cam
/gate_detector/gate_info
/gate_hone
/usb_cam/image_raw
/gate_detector

G.3 MRD-DE-0003 R1: PSOC Pin Layout

			PSoC5LP Microcontroller Pin Configuration 2017					MRD-DE-0003-R1
	Chutes		P0_1		P12_7/UART TX		Drafted by:	
	drive wheels		P0_0		P12_6/UART RX		Tayor Welker	
	Arm		P3_6		P12_1/I2C SDA		2016-2017	
	Science (arduino)		P3_5		P12_0/I2C SCL			
	Video (All video removed)		P3_4		P12_5			
	Jetson Communication		P3_0	This part of the PSoC is unused	GND		*An external capacitor	
	Possibly removing		GND		VBUS		is connected to this pin	

Resistor attached?	Category	2017 use				2017 Use	Category	Resistor Attached?
			GND		VDDIO			
			P3_0		GND			
			P3_1		P1_7			
			P3_2		P1_6			
100 ohm		Rx_Science	P3_3		P1_5	Rx_Forearm/Drill		100 ohm
100 ohm		Tx_Science	P3_4		P1_4	Tx_Forearm/Drill		100 ohm
			P3_5		P1_3	Rx_PlateShift		100 ohm
			P3_6		P1_2	Tx_PlateShift		100 ohm
some resistor			P3_7		P1_1/SWDCLK			
		chute1a	P15_0		P1_0/SWDIO			
		chute1b	P15_1		P12_0/I2C SCL	Rx_Elbow/Plunge		100 ohm
		chute2a	XTAL_OUT*/P15_2		P12_1/I2C SDA	Tx_Elbow/Plunge		100 ohm
		chute2b	XTAL_IN*/P15_3		P12_2	Rx_Shoulder/Elevator		100 ohm
100 ohm		hand_en	CMOD*/P15_4		P12_3	Tx_Shoulder/Elevator		100 ohm
100 ohm		leftwheel direction	P15_5		P12_4	Rx_Turret		100 ohm
some resistor		chute_en	P0_0		P12_5	Tx_Turret		100 ohm
100 ohm		leftwheel speed	P0_1		P12_6/UART RX	Rx_Comp		100 ohm
		chute3a	SAR1*/P0_2		P12_7/UART TX	Tx_Comp		100 ohm
		chute3b	EXT REF0*/P0_3		P2_7	hand_b		100 ohm
		chute4a	SAR0*/P0_4		P2_6	hand_a		100 ohm
		chute4b	P0_5		P2_5	rightWheels		100 ohm
			P0_6		P2_4	rightWheels dir		100 ohm
			P0_7		P2_3			
			RESET		P2_2/SW1			
			GND		P2_1/LED1	LED0		
			VDD		P2_0			

G.4 MRD-DE-0004 R1: Forearm Twist Feedback

MRD-DE-0004 R1

Forearm Twist Feedback

Date	Subsystem	Related Desirability Goal	
3/24/2017	Arm	Lift 7 kg	

Names of Person Creating Model			
Drew Warren	Jacob Greenwood		

Purpose

The motor that was chosen for the forearm twist has an integrated encoder on it, but the Pololu motor drivers require an analog signal for feedback. This pcb design takes the encoder signal, analyzes it in an Arduino nano, and outputs an analog signal that the Pololu can read.

Explanation

The Arduino nano receives the encoder channels on pins 2 and 3. A change interrupt starts every time channel A changes and it counts how many times the encoders change. It then maps that number to a value between 0 and 255 to write it to a PWM on pin 6. The PWM signal is then run through a simple RC low pass filter to smooth it out to a more analog type of signal. That is the signal that the Pololu receives. There are a few other things to note on the pcb. The six pin connector goes straight to the motor's six wires. The pinout for the motor can be found at this link:

https://www.pololu.com/product/1576

The screw terminal connector is the power and ground for the motor - 12V on the outside pin, ground on the inside. These two connect to the motor output on the Pololu board. The 3 pin connector goes like this from outside to inside - 5V, signal, GND. These correspond to the feedback pins on the Pololu board. The 5V line is used to power both the encoder on the motor and the Arduino nano.

Conclusion

This sub-system has been built and tested and works as well as other motors run on the Pololu controllers.

Attachments

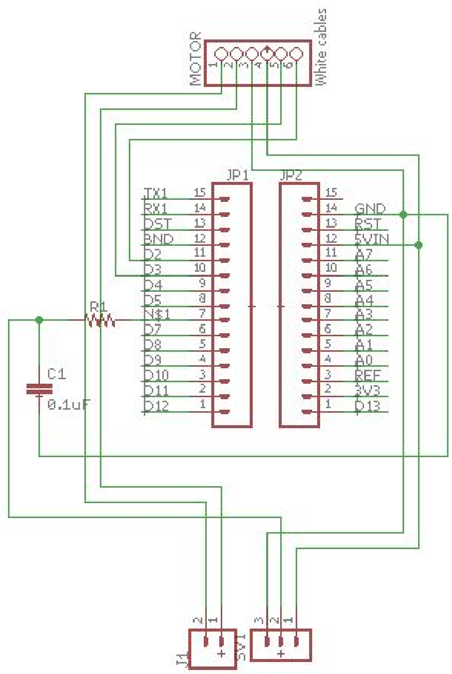
Source Code

```
/* read a rotary encoder with interrupts
   Encoder hooked up with common to GROUND,
   encoder0PinA to pin 2, encoder0PinB to pin 4 (or pin 3 see below)
   it doesn't matter which encoder pin you use for A or B

   uses Arduino pull-ups on A & B channel outputs
   turning on the pull-ups saves having to hook up resistors
   to the A & B channel outputs

*/

#define encoder0PinA  2
#define encoder0PinB  3
#define analog_pin 6
int counts = 99*24;

volatile unsigned int encoder0Pos = 0;

void setup() {

  TCCR0B = (TCCR0B & 0b11111000) | 0x01;


  pinMode(encoder0PinA, INPUT);
  digitalWrite(encoder0PinA, HIGH);       // turn on pull-up resistor
  pinMode(encoder0PinB, INPUT);
  digitalWrite(encoder0PinB, HIGH);       // turn on pull-up resistor

  attachInterrupt(0, doEncoder_Expanded, CHANGE);  // encoder pin on interrupt 0 - pin 2
  //Serial.begin (250000);
  //Serial.println("start");                // a personal quirk

  pinMode(analog_pin, OUTPUT);
  //int analog_value = 0;
}

void loop(){
```

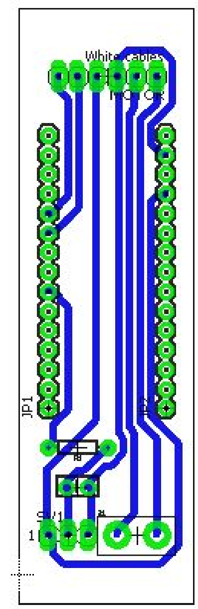
```
// do some stuff here - the joy of interrupts is that they take care of themselves

}

/* See this expanded function to get a better understanding of the
 * meanings of the four possible (pinA, pinB) value pairs:
 */
void doEncoder_Expanded(){
  if (digitalRead(encoder0PinA) == HIGH) {   // found a low-to-high on channel A
    if (digitalRead(encoder0PinB) == LOW) {  // check channel B to see which way
                                             // encoder is turning
      encoder0Pos = encoder0Pos - 1;         // CCW
    }
    else {
      encoder0Pos = encoder0Pos + 1;         // CW
    }
  }
  else                                       // found a high-to-low on channel A
  {
    if (digitalRead(encoder0PinB) == LOW) {   // check channel B to see which way
                                              // encoder is turning
      encoder0Pos = encoder0Pos + 1;          // CW
    }
    else {
      encoder0Pos = encoder0Pos - 1;          // CCW
    }

  }
  //Serial.println (encoder0Pos, DEC);          // debug - remember to comment out
                                              // before final program run
  // you don't want serial slowing down your program if not needed

  int analog_value = map(encoder0Pos, 0, counts, 0, 255);
  analogWrite(analog_pin, analog_value);
}
```

PCB Design

Schematic



Layout



G.5 MRD-DE-0006 R1: Communications Design

MRD-DE-0006 R1

Communications Overview

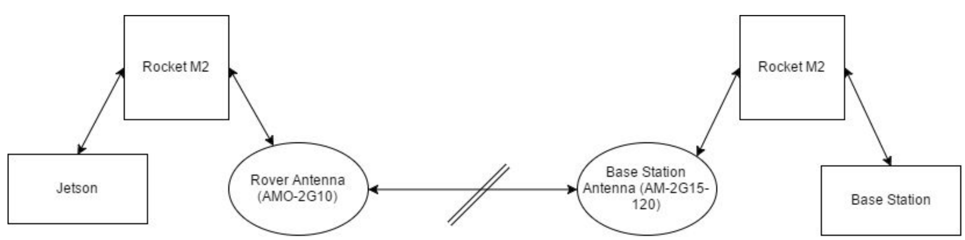
Date	Subsystem	Related Desirability Goal	Pass/Fail
4/18/17	Communications		

Names of persons doing report

Benjamin Hilton			

System Description

The communications system consists of equipment made by Ubiquiti Networks. The antenna on the base station is a Ubiquiti AM-2G15-120 2x2 MIMO Sector Antenna. The rover antenna is the Ubiquiti AMO-2G10. It is an omnidirectional antenna; both operate at 2.4 GHz. The Ubiquiti Rocket M2s are the radios - they connect the antenna to a computer via ethernet. It is possible to put a switch between the Rocket and the Jetson for easier access to that network. It is generally the custom to put a switch (not pictured) between the Rocket M2 and the Base Station.



The rockets must be configured before they can start communicating. To set up an ethernet bridge, both rockets must not be configured to connect with any other rocket. They are very faithful to each other once they have been connected and you need to reset them to factory settings if you are going to change which rocket a rocket connects to. You can reset them by accessing the configurations page, or by using the hard reset button.

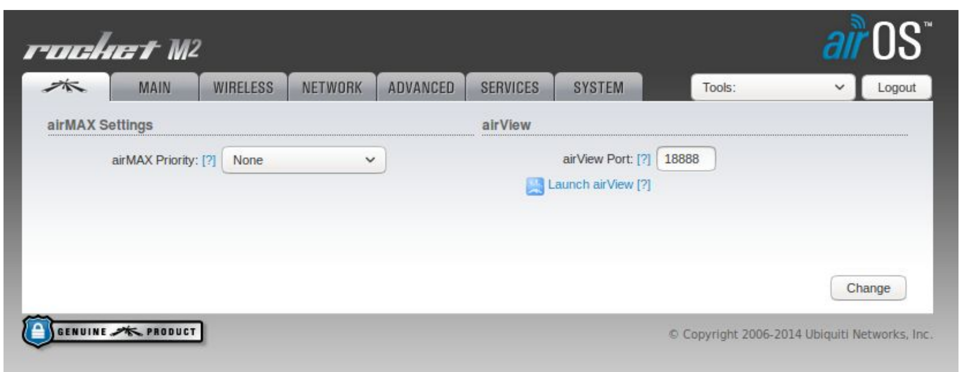
The configurations page can be accessed by opening a web browser and typing in the IP address that is printed on the rocket. If a rocket has been reset, this IP address will change to the default (192.168.1.20). The default password and username to access this page are "ubnt". There is no reason to ever change it. Screenshots of all of these pages are located in this document for both rockets. One rocket is configured as a station and one as an access point so the pages are different.

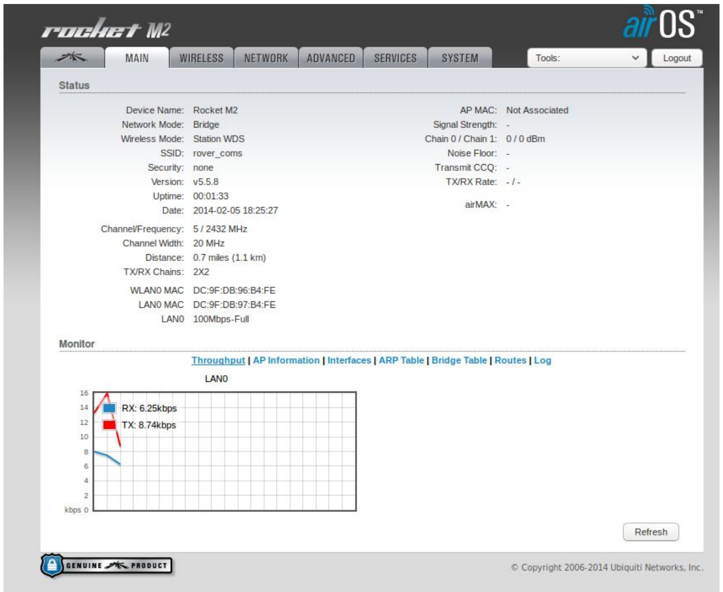
Some useful tools for diagnosing the communications network:
Iperf - a linux tool for testing speeds
Ifconfig - checking what IP address your computer is set to

You will also need to set a static IP address. In ubuntu, this can be done by opening the interfaces file. For example, if emacs is the preferred text editor, type *sudo emacs /etc/network/interfaces* and then edit the file. What you change may depend on your computer and ethernet adapter. Look for help online in doing this.

Some extra tips:
When the antennas are close, turn down the dB on both antennas. If they are both in the shop, they should be turned down to 5-10 dB. When the antennas are both in the shop, you can expect a throughput of between 50 - 90 Mbits/s. Driving the rover, the expected throughput is anywhere between that and 5 Mbit/s. The quality of the connection depends very heavily on the geography. The maximum distance the antennas have been tested at is 1.75 kilometers, for which the throughput was 4 Mbit/s.

Configuration Page (Rover)




rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Status
Device Name: Rocket M2
Network Mode: Bridge
Wireless Mode: Station WDS
SSID: rover_coms
Security: none
Version: v5.5.8
Uptime: 00:01:33
Date: 2014-02-05 18:25:27
Channel/Frequency: 5 / 2432 MHz
Channel Width: 20 MHz
Distance: 0.7 miles (1.1 km)
TX/RX Chains: 2X2
WLAN0 MAC DC:9F:DB:96:B4:FE
LAN0 MAC DC:9F:DB:97:B4:FE
LAN0 100Mbps-Full
AP MAC: Not Associated
Signal Strength: -
Chain 0 / Chain 1: 0 / 0 dBm
Noise Floor: -
Transmit CCQ: -
TX/RX Rate: - / -
airMAX: -
Monitor
Throughput | AP Information | Interfaces | ARP Table | Bridge Table | Routes | Log
LAN0
RX: 6.25kbps
TX: 8.74kbps
kbps
Refresh
GENUINE PRODUCT
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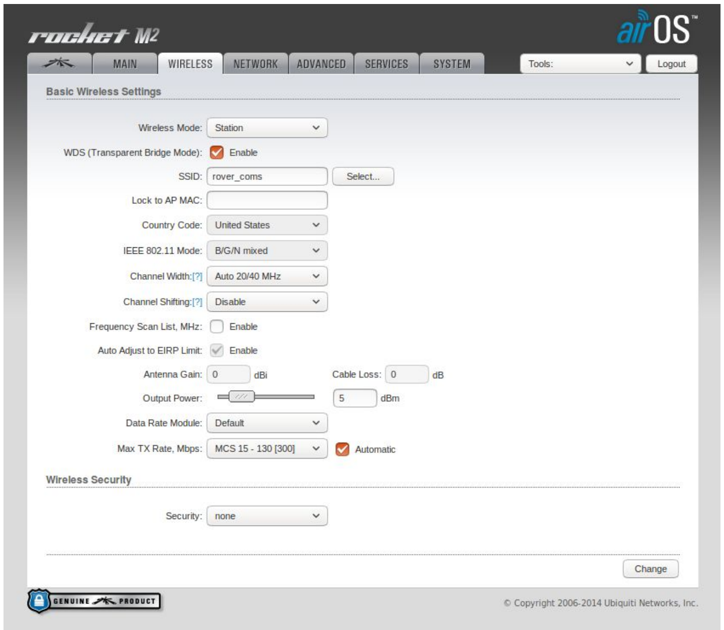
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Basic Wireless Settings
Wireless Mode: Station
WDS (Transparent Bridge Mode): Enable
SSID: rover_coms
Select...
Lock to AP MAC:
Country Code: United States
IEEE 802.11 Mode: B/G/N mixed
Channel Width:[?] Auto 20/40 MHz
Channel Shifting:[?] Disable
Frequency Scan List, MHz: Enable
Auto Adjust to EIRP Limit: Enable
Antenna Gain: 0 dBi
Cable Loss: 0 dB
Output Power: 5 dBm
Data Rate Module: Default
Max TX Rate, Mbps: MCS 15 - 130 [300]
Automatic
Wireless Security
Security: none
Change
GENUINE PRODUCT
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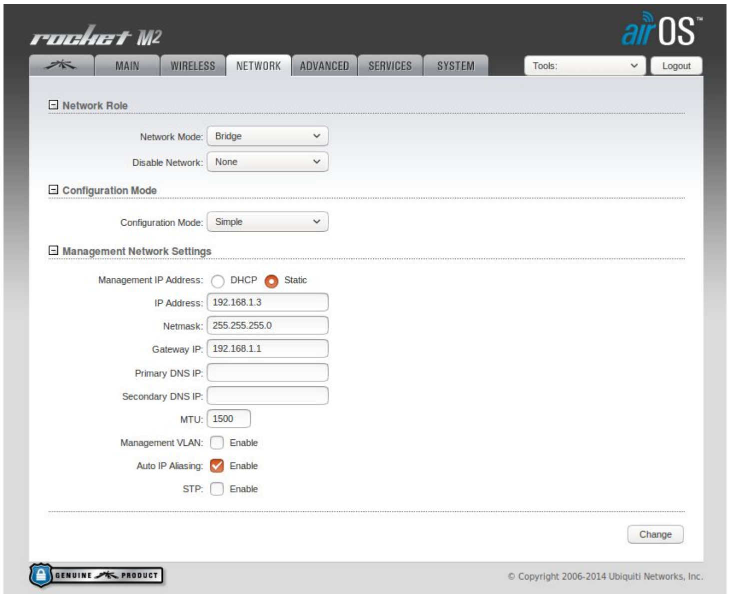
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Network Role
Network Mode: Bridge
Disable Network: None
Configuration Mode
Configuration Mode: Simple
Management Network Settings
Management IP Address: DHCP Static
IP Address: 192.168.1.3
Netmask: 255.255.255.0
Gateway IP: 192.168.1.1
Primary DNS IP:
Secondary DNS IP:
MTU: 1500
Management VLAN: Enable
Auto IP Aliasing: Enable
STP: Enable
Change
GENUINE PRODUCT
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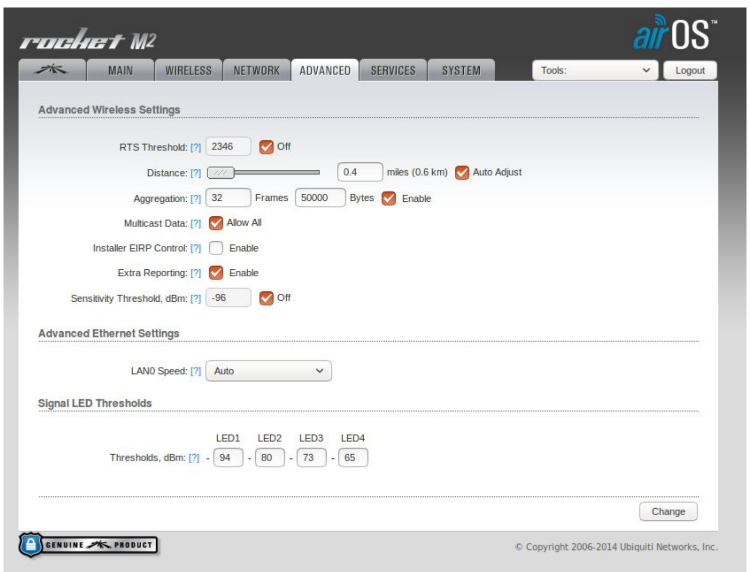
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Advanced Wireless Settings
RTS Threshold: [?] 2346 Off
Distance: [?] 0.4 miles (0.6 km) Auto Adjust
Aggregation: [?] 32 Frames 50000 Bytes Enable
Multicast Data: [?] Allow All
Installer EIRP Control: [?] Enable
Extra Reporting: [?] Enable
Sensitivity Threshold, dBm: [?] -96 Off
Advanced Ethernet Settings
LAN0 Speed: [?] Auto
Signal LED Thresholds
LED1 LED2 LED3 LED4
Thresholds, dBm: [?] - 94 - 80 - 73 - 65
Change
GENUINE PRODUCT
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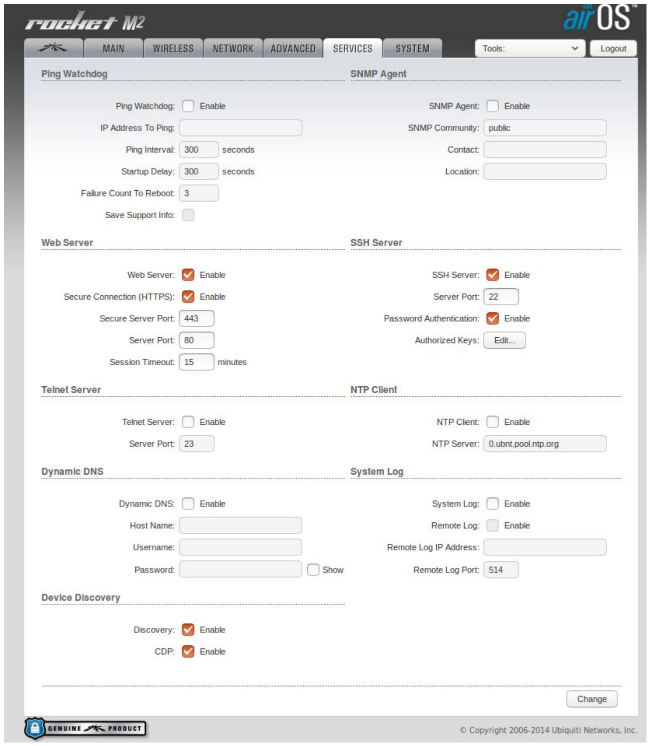
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Ping Watchdog
Ping Watchdog: Enable
IP Address To Ping:
Ping Interval: 300 seconds
Startup Delay: 300 seconds
Failure Count To Reboot: 3
Save Support Info:
SNMP Agent
SNMP Agent: Enable
SNMP Community: public
Contact:
Location:
Web Server
Web Server: Enable
Secure Connection (HTTPS): Enable
Secure Server Port: 443
Server Port: 80
Session Timeout: 15 minutes
SSH Server
SSH Server: Enable
Server Port: 22
Password Authentication: Enable
Authorized Keys: Edit...
Telnet Server
Telnet Server: Enable
Server Port: 23
NTP Client
NTP Client: Enable
NTP Server: 0.ubnt.pool.ntp.org
Dynamic DNS
Dynamic DNS: Enable
Host Name:
Username:
Password: Show
System Log
System Log: Enable
Remote Log: Enable
Remote Log IP Address:
Remote Log Port: 514
Device Discovery
Discovery: Enable
CDP: Enable
Change
GENUINE PRODUCT
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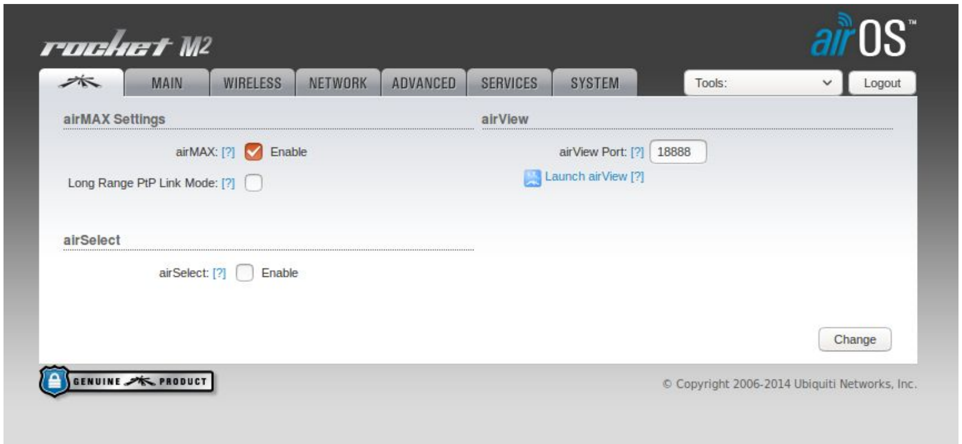
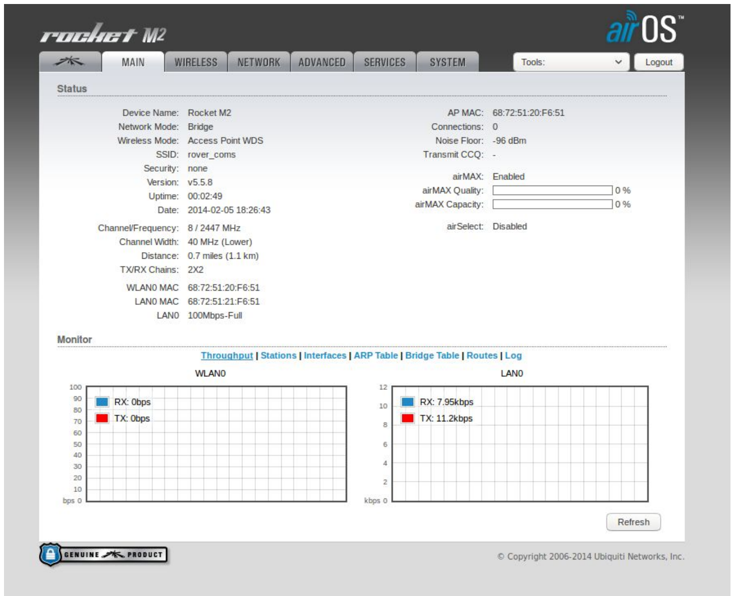
Configuration Page (Base Station)




rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Status
Device Name: Rocket M2
Network Mode: Bridge
Wireless Mode: Access Point WDS
SSID: rover_coms
Security: none
Version: v5.5.8
Uptime: 00:02:49
Date: 2014-02-05 18:26:43
Channel/Frequency: 8 / 2447 MHz
Channel Width: 40 MHz (Lower)
Distance: 0.7 miles (1.1 km)
TX/RX Chains: 2X2
WLAN0 MAC 68:72:51:20:F6:51
LAN0 MAC 68:72:51:21:F6:51
LAN0 100Mbps-Full
AP MAC: 68:72:51:20:F6:51
Connections: 0
Noise Floor: -96 dBm
Transmit CCQ: -
airMAX: Enabled
airMAX Quality: 0 %
airMAX Capacity: 0 %
airSelect: Disabled
Monitor
Throughput | Stations | Interfaces | ARP Table | Bridge Table | Routes | Log
WLAN0
LAN0
RX: 0bps
TX: 0bps
RX: 7.95kbps
TX: 11.2kbps
Refresh
GENUINE PRODUCT
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rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Basic Wireless Settings
Wireless Mode: Access Point
WDS (Transparent Bridge Mode): Enable
SSID: rover_coms
Hide SSID
Country Code: United States
IEEE 802.11 Mode: B/G/N mixed
Channel Width:[?] 40 MHz
Channel Shifting:[?] Disable
Frequency, MHz: Auto
Extension Channel: None
Frequency List, MHz: Enable
Auto Adjust to EIRP Limit: Enable
Antenna Gain: 0 dBi
Cable Loss: 0 dB
Output Power: 5 dBm
Data Rate Module: Default
Max TX Rate, Mbps: MCS 15 - 300
Automatic
Wireless Security
Security: none
RADIUS MAC Authentication: Enable
MAC ACL: Enable
Change
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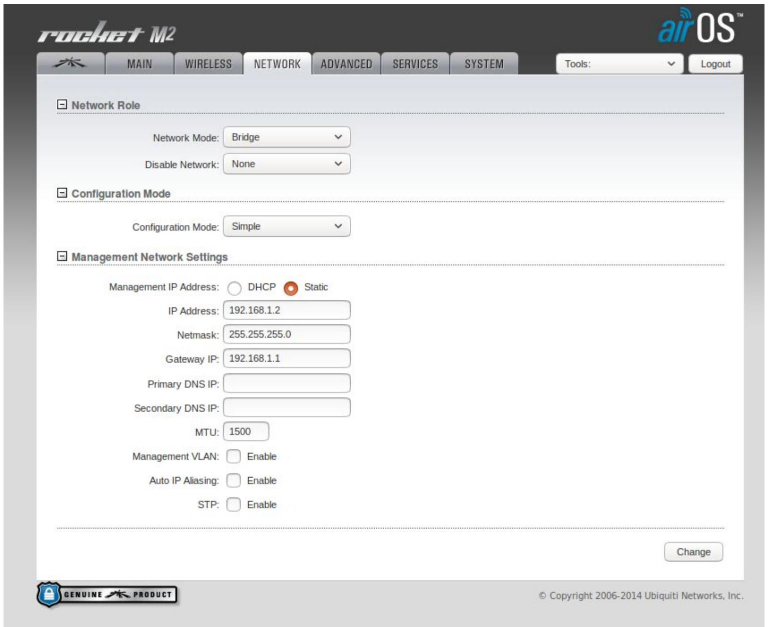
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Network Role
Network Mode: Bridge
Disable Network: None
Configuration Mode
Configuration Mode: Simple
Management Network Settings
Management IP Address: DHCP Static
IP Address: 192.168.1.2
Netmask: 255.255.255.0
Gateway IP: 192.168.1.1
Primary DNS IP:
Secondary DNS IP:
MTU: 1500
Management VLAN: Enable
Auto IP Aliasing: Enable
STP: Enable
Change
GENUINE PRODUCT
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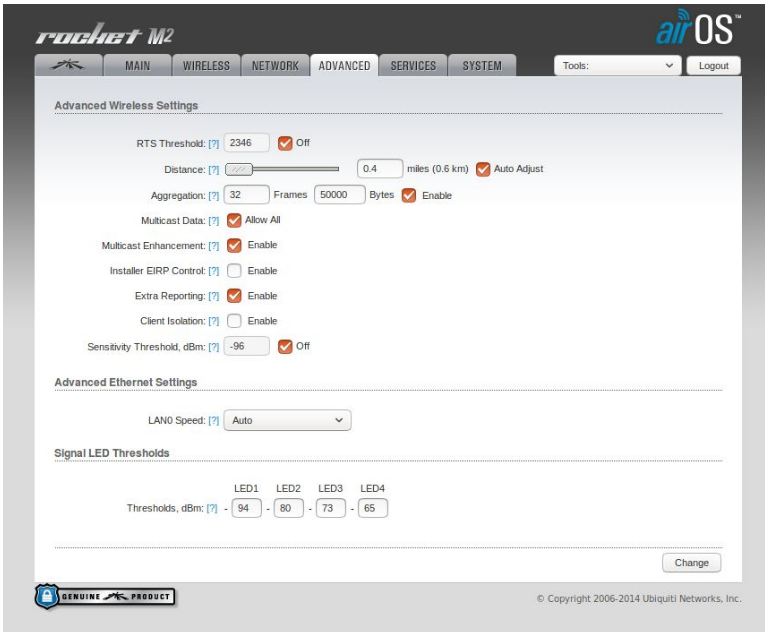
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Advanced Wireless Settings
RTS Threshold: [?] 2346 Off
Distance: [?] 0.4 miles (0.6 km) Auto Adjust
Aggregation: [?] 32 Frames 50000 Bytes Enable
Multicast Data: [?] Allow All
Multicast Enhancement: [?] Enable
Installer EIRP Control: [?] Enable
Extra Reporting: [?] Enable
Client Isolation: [?] Enable
Sensitivity Threshold, dBm: [?] -96 Off
Advanced Ethernet Settings
LAN0 Speed: [?] Auto
Signal LED Thresholds
LED1 LED2 LED3 LED4
Thresholds, dBm: [?] - 94 - 80 - 73 - 65
Change
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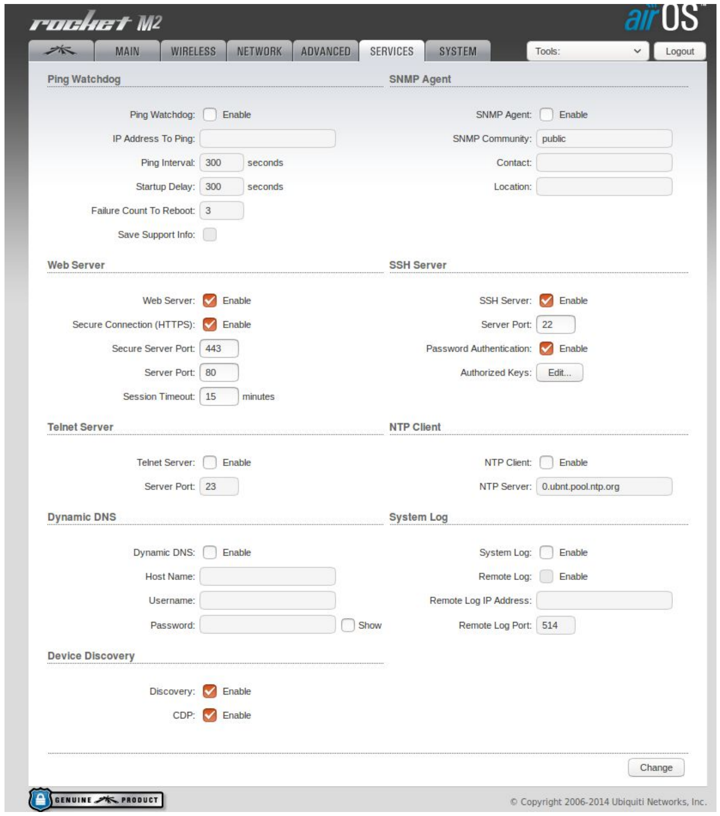
rocket M2
airOS
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Ping Watchdog
Ping Watchdog: Enable
IP Address To Ping:
Ping Interval: 300 seconds
Startup Delay: 300 seconds
Failure Count To Reboot: 3
Save Support Info:
SNMP Agent
SNMP Agent: Enable
SNMP Community: public
Contact:
Location:
Web Server
Web Server: Enable
Secure Connection (HTTPS): Enable
Secure Server Port: 443
Server Port: 80
Session Timeout: 15 minutes
SSH Server
SSH Server: Enable
Server Port: 22
Password Authentication: Enable
Authorized Keys: Edit...
Telnet Server
Telnet Server: Enable
Server Port: 23
NTP Client
NTP Client: Enable
NTP Server: 0.ubnt.pool.ntp.org
Dynamic DNS
Dynamic DNS: Enable
Host Name:
Username:
Password: Show
System Log
System Log: Enable
Remote Log: Enable
Remote Log IP Address:
Remote Log Port: 514
Device Discovery
Discovery: Enable
CDP: Enable
Change
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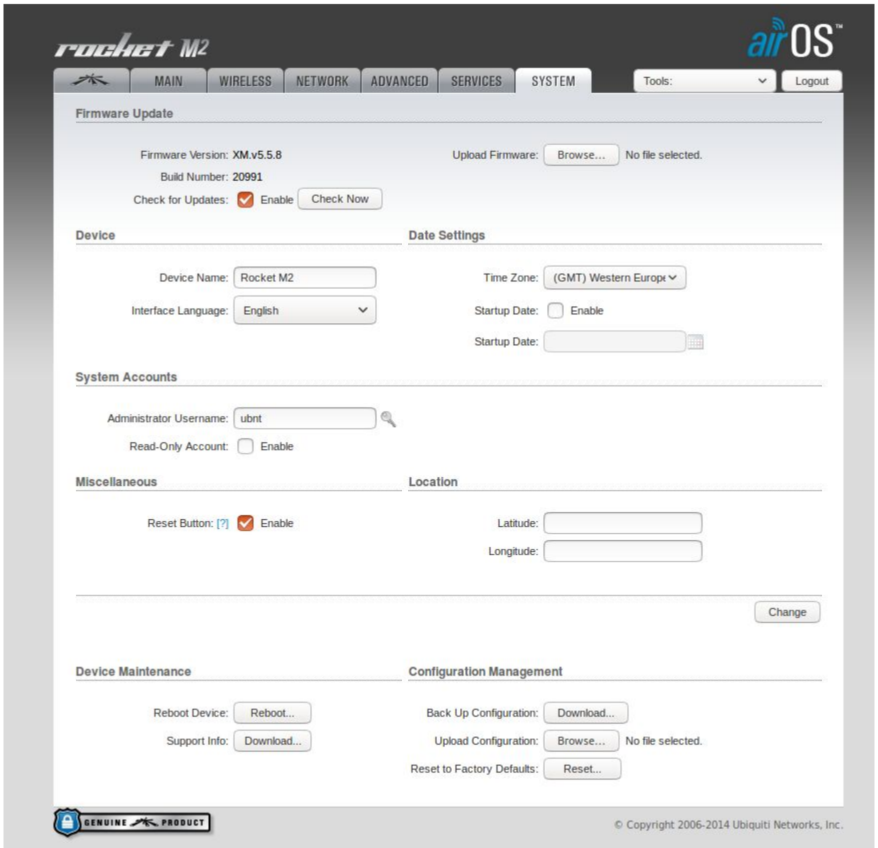
MAIN
WIRELESS
NETWORK
ADVANCED
SERVICES
SYSTEM
Tools:
Logout
Firmware Update
Firmware Version: XM.v5.5.8
Build Number: 20991
Check for Updates: Enable
Check Now
Upload Firmware: Browse... No file selected.
Device
Device Name: Rocket M2
Interface Language: English
Date Settings
Time Zone: (GMT) Western Europe
Startup Date: Enable
Startup Date:
System Accounts
Administrator Username: ubnt
Read-Only Account: Enable
Miscellaneous
Reset Button: [?] Enable
Location
Latitude:
Longitude:
Change
Device Maintenance
Reboot Device: Reboot...
Support Info: Download...
Configuration Management
Back Up Configuration: Download...
Upload Configuration: Browse... No file selected.
Reset to Factory Defaults: Reset...
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G.6 MRD-DE-0007 R1: Software Design

MRD-DE-0007 R1

Software Design

Date	Subsystem	Related Desirability Goal	
4/18/2017	Navigation	Navigation	

Names of Person Creating Model

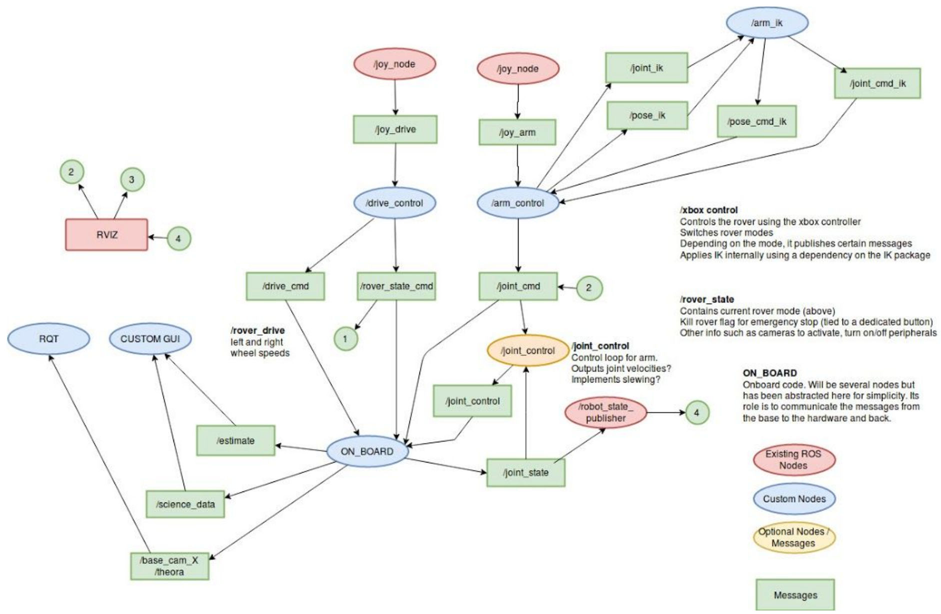
Brian Jackson	Michael Farrell	Westley Barragan	

Purpose

This document gives a high-level overview of the ROS Architecture for both the base station and the rover.

Explanation

The first page is the software network for the ROS nodes running on the base station computers. This has a group of messages that go to the ONBOARD nodes that are detailed on the following page. The onboard diagram has 2 sub-diagrams shown in more detail in the subsequent pages. The last page shows the proposed flow diagram for the behavior-based controller. The appendix contains the file github file structure containing these above nodes. (https://github.com/BYUMarsRover/BYU-Mars-Rover)



Task Procedures

Drive Rover:
Switch into drive mode using controller and use joysticks to control wheels.
Bumper buttons switch speed mode (Slow, Medium, Fast) (Display in GUI?)
HAT controls ZED gimbal
Buttons toggle camera selection
Button to set waypoints

Arm Control (IK):
The joysticks control XYZ position and orientation of the arm.
Triggers open/close hand
Bumper buttons switch speed mode
Buttons toggle camera selection
Buttons for specific tasks? (unscrewing motion, go to chute, etc.)

Arm Joint Command:
Same as Arm Control but joysticks command joint positions directly

Autonomous Mode:
Set waypoints using rover during drive, or set/edit waypoints in GUI.
Set mode to Auto/GUI mode, and enable autonomous mode in GUI.

Emergency Stop:
Press center button on XBOX controller at any time

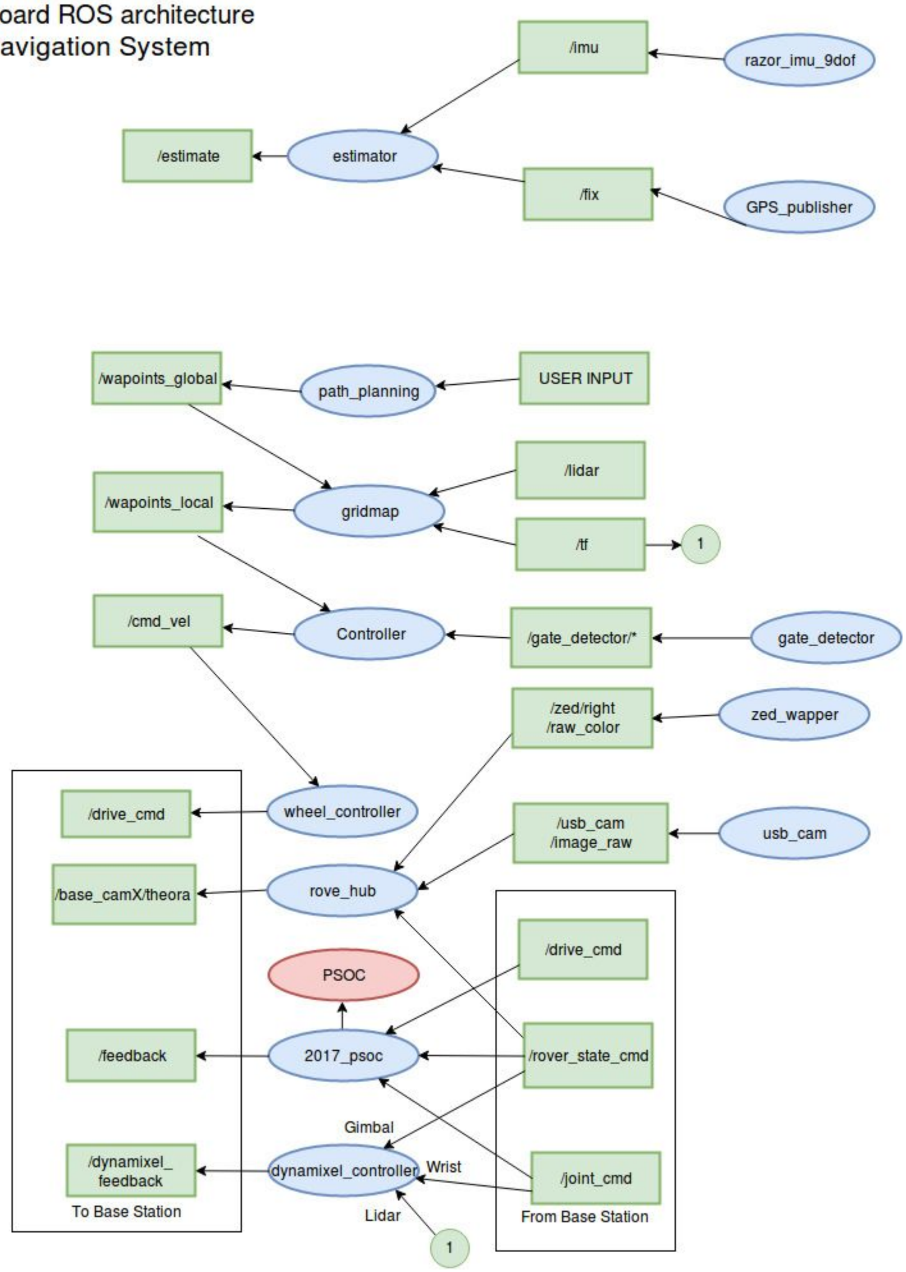
Take Photo:
Button in GUI

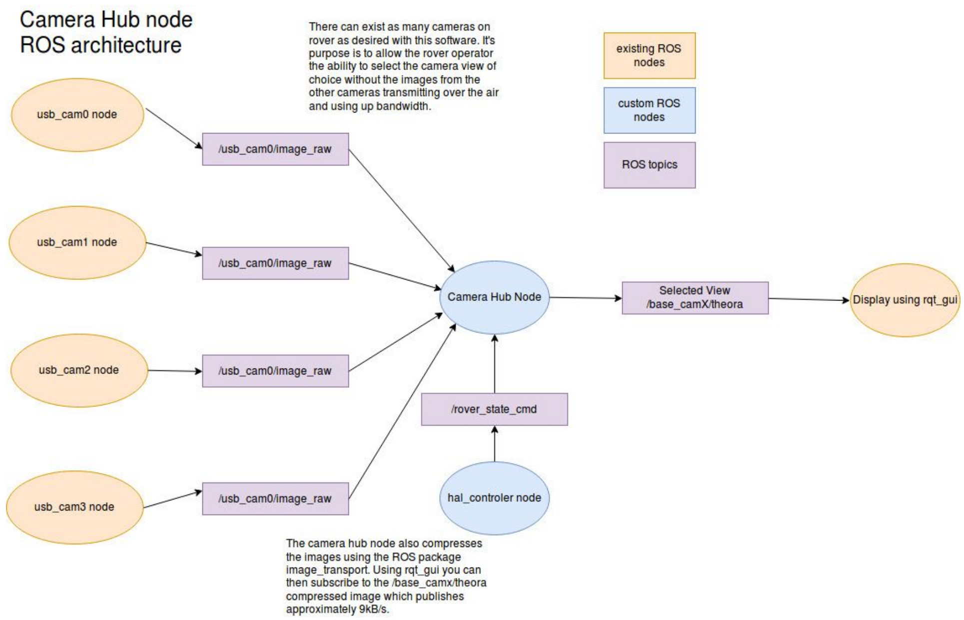
Take Science Readings:
Button/Menu in GUI?

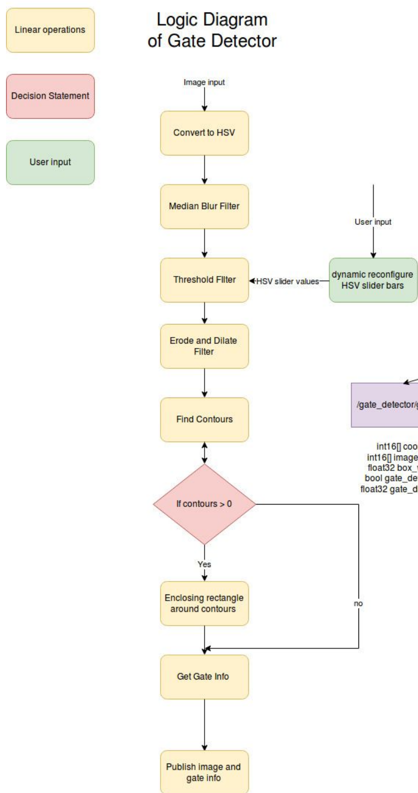
4 Main Modes (specified by /xbox_control to /rover_state)

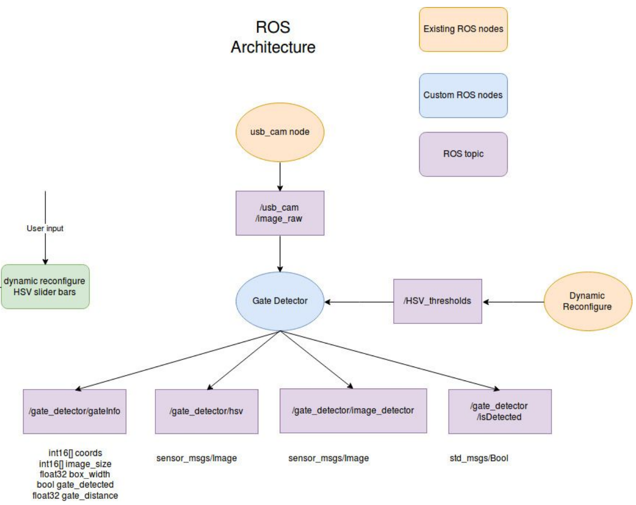
1. Drive: User manually controls the wheels of the rover
2. Arm Control: User manually controls the arm (with IK)
3. Arm Joint Command: User controls joint angles manually
4. Auto/GUI Mode: Control is relinquished to GUI, where the base (and arm?) can be controlled via the interface using waypoints, buttons, etc. Option here for autonomous mode.

Onboard ROS architecture
of Navigation System



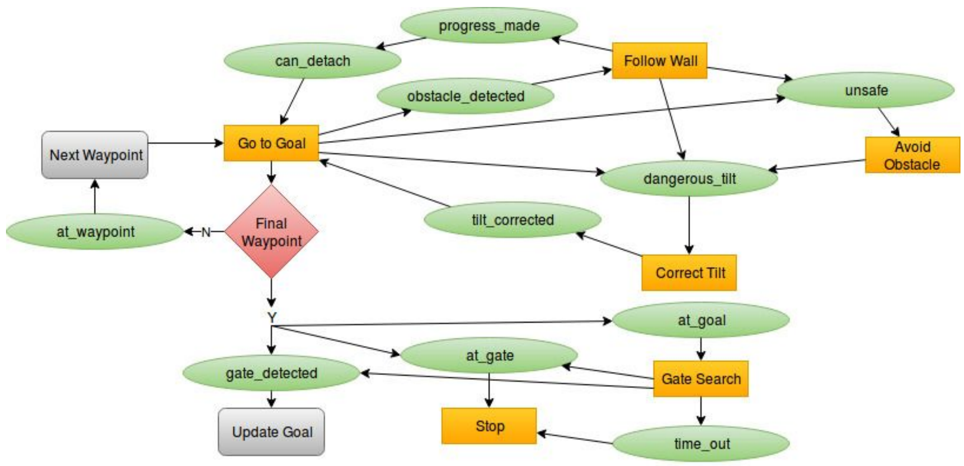

Camera Hub node
ROS architecture
There can exist as many cameras on rover as desired with this software. It's purpose is to allow the rover operator the ability to select the camera view of choice without the images from the other cameras transmitting over the air and using up bandwidth.
existing ROS nodes
custom ROS nodes
ROS topics
usb_cam0 node
usb_cam1 node
usb_cam2 node
usb_cam3 node
/usb_cam0/image_raw
/usb_cam0/image_raw
/usb_cam0/image_raw
/usb_cam0/image_raw
Camera Hub Node
Selected View /base_camX/theora
Display using rqt_gui
/rover_state_cmd
hal_controler node
The camera hub node also compresses the images using the ROS package image_transport. Using rqt_gui you can then subscribe to the /base_camx/theora compressed image which publishes approximately 9kB/s.





Description

This program was designed to assist the Rover in detecting the end gates in the autonomous task of the URC. Since the gates are marked with standard yellow tennis balls, we decided it would be best to use hsv color filtering to detect this unique color out in the desert. In order to get full points, the rover needs to be able to detect the gate within 2 meters of the gate and send a message back to the base station, letting the judges know it indeed has arrived at the marked location. To do this, the gate detector uses user input to select the hsv thresholds that filter out all colors except for the color of the tennis ball, then when contours are present in the filtered image, using opencv API we can enclose a rectangle around said contour, locating the end gate.



States
Go to Goal: Calculate the vector to goal.
Follow Wall: Maintain distance from obstacle and follow it's contour
Avoid Obstacle: Move directly away from closest obstacle. Reduce speed to minimum.
Correct Tilt: back up until stabilized? Or turn to go down the hill
Gate Search: Travel in a circular path around the supposed gate location
Stop: Stop the rover and send target found message back to base station.

Switches
obstacle_detected: distance to obstacle < obstacle distance (5m?)
unsafe: distance to obstacle < 1 m
progress_made: rover is closer to goal than when it started following the wall
can_detach: inner product of vector to obstacle and vector to goal is negative (they're pointing away from each other)
dangerous_tilt: roll angle > 30 degrees?
tilt_corrected: roll angle < 30 degrees?
at_goal: at the presumed location of the goal but the tennis ball isn't in view
at_gate: tennis ball is in view of a camera and determined to be within 2 m
gate_detected: tennis ball is in view of a camera and determined to be more than 2 m away
at_waypoint: rover is within 2 m of waypoint

Actions
Update Goal: Update the location of the goal in the rover frame (override GPS estimate and continually update with vision data)
Next Waypoint: Set the next waypoint in the list as the current goal

Conditionals
Final Waypoint: Is the current goal the last waypoint in the list?

Appendix

G.7 MRD-DE-0008 R1: Wheel Motors and Drivers

MRD-DE-0008 R1

Drive Motors and Controllers

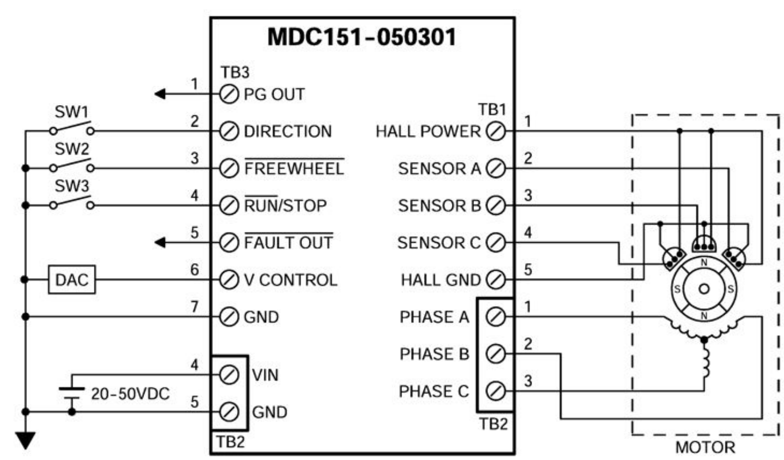
Date	Subsystem	Related Desirability Goal	
4/4/17	Base/Electrical	Drive up incline	Max speed
Names of Person Creating Model			
Drew Warren			

Purpose

For this year the team found new motors for the wheels in an effort to increase power and reduce weight. The goal was to make it so the rover doesn't fall over like last year. The base team (Jameson and Mary) specced the motors and found models that works. The motors they chose are DC brushless motors (from Anaheim Automation, model BLWRPG235S-24V-4000-R18) so that means we needed a specialized motor driver to make them spin. This document is here to explain how to set up the motor controllers and change the settings.

Explanation

We chose to buy the motor drivers that Anaheim recommended because there wasn't time to find others. Other motor drivers would work, and it would be worth trying to find some that are smaller. The model that we have is the MDC151-050301 (NOTE: We learned after that fact that Anaheim has a cheaper, smaller controller with all the same features except the closed loop control, which we have not been using). The user's guide explains all of this information in more depth.The wiring diagram looks like this:



Terminal Blocks

Not all these pins are used. All of TB1 (terminal block 1) and TB2 will be used. The pins on the right side of the diagram all connect to the motor. Reference this table for correct wiring instructions:

Controller	Motor
Hall Power	Red
Sensor A	Blue
Sensor B	Green
Sensor C	White
Hall GND	Black
Phase A	Yellow
Phase B	Red (thick)
Phase C	Black (thick)

The VIN and GND pins are the power source for the motor. These will come directly from our batteries (or fuse box) and they power the controller as well.

Here is a brief description of each pin on TB3:

PG OUT: This pin allows you to measure the rotational speed of the motor shaft. This has not been used because it is not important to our goals.
Direction: This pin selects the direction of the motor. HIGH (5V) is clockwise and LOW (0V) is counter clockwise.
Free Wheel: This pin energizes the motor phases. HIGH activates them, LOW causes the motor to coast to a stop. Essentially, this pin must be HIGH (or floating) if you want the motor to spin.
Run/Stop: This pin has the functionality to stop the motor. LOW allows the motor to run, and HIGH causes it to stop. The stop caused by this pin is a much more rapid deceleration than the Free Wheel pin. This is the recommended pin for adding brake functionality to the drive control of the motor. Currently this is not included in the rover.
Fault Out: This pin notifies when some kind of error has occurred. HIGH means normal operation and LOW means that something bad has happened. Faults include: 1) invalid sensor input code 2) over current and 3) under voltage.

V Control: This pin allows control of the motor speed from an external DC voltage. The range is 0VDC (min) to 5VDC (max). It should be noted that in order to use this, the switch labeled "INT/EXT SPD" must be turned on.
GND: Common ground.

Switches

There are two sets of switches on the controller. One has labels called "O/C LOOP", "CL1", "CL2", and "CL3". These switches are for open or closed loop control. Since the rover does not need such refined control over its speed, it was decided that open loop control would work fine. Leave all these switches in the on position to keep it in open loop control.

The other set of switches has several options.
EXT/INT SPD: Turn this on to allow voltage control of the motor speed. Turning this switch off causes the motor to spin at a constant speed that can be set using the Speed potentiometer.
FLT LATCH: Turns on overcurrent protection.
RAMP 1/RAMP 2: These two switches determine the motors rise time to reach the commanded speed. The options are described in this table:

Rise Time	RAMP 1	RAMP 2
4 sec	Off	Off
2 sec	Off	On
1 sec	On	Off
.5 sec	On	On

120°/60°: This switch changes according to motor model. Since the current motors have 3 hall sensors, keep this switch on to use the 120° setting.

Potentiometers

There are three potentiometers on the controller that change different settings. The Speed dial is used only for changing the constant speed setting when EXT/INT SPD is switched off. The CL ADJ pot is used to tune settings for closed loop control. Both of these features are not being used currently. The last pot is labeled Current Limit, and this can be used to set the max current draw to the motor. Set this as high as is necessary without going over the current protection limits on the fuse box.

Software File Structure and Description (as of April 19, 2017)

github commit ID	2132c8958c5208a4afb4dc07e0f56bb78bd851a7		
Scripts			
startgps	script to reset gps port (should be on startup)		
install_packages.sh	Install package dependencies for all software		
environment/	scripts to setup ubuntu enironment for new computer (copied from the MAGICC lab)		
environment/install_environment	run this to setup environment		
shared_ws	this workspace is to be built and sourced on the rover and at the base station		
Package	**Folder**	**File**	**Description**
rover_msgs	srv	PositionReturn.srv	ros service message for dynamixel initialization
	msg	ArmState.msg	state message for arm (mode, speed, kill, grip)
		Drive.msg	drive command (lw & rw -100 to 100)
		Feedback.msg	message for joint feedback
		Gateinfo.msg	info for gate recognition
		NavState.msg	state message for estimator
		PSOC.msg	Old PSOC message
		PSOC17.msg	New PSOC message containing everything to be written to 2017 PSOC
		RoverState.msg	drive state message (mode, speed, etc)
		Science.msg	commands for science joints
dynamixel_control	src	dynamixel_publisher.py	subscribes to /joint command and executes command to wrist dynamixels
		lib_dynamixel.py	Georgia Tech library
		lib_robotis.py	Georgia Tech library
		servo_config.py	config info for dynamixel servos
onboard_ws	this workspace is to be built and sourced only on the rover (can't build on base b/c of zed stuff)		

Package	Folder	File	Description
base			Contains the base imaging stuff including camer_hub
	include	rover_hub.h	header file for rover_hub
	launch	camera_hub.launch	launches camera_hub of cameras
		camera_hub_withZed.launch	launches camera_hub with the Zed camera
	scripts	camera_base.py	(NOT USED) python version of camera publishers
	src	camera_base.cpp	
gate_detector			Contains the processes to detect the gate while in autonomous mode.
	launch	gate_detector_test.launch	launches usb camera node and the gate detector
	scripts	detector.py	main ROS node to detect gate
		ballHSVgetter.py	allows user to click on image and print out the hsv values of pixel
		gate_detector_calib.py	Not used. Slider bar calibration script
	cfg	Detector.cfg	required for rqt_reconfigure
gate_hone			Contains the processes to hone in on gate. Subscibes to gate_detector
	launch	gate_hone_base.launch	launches rqt_reconfigure, image_view, and gate_detector
		gate_hone_rover.launch	launches gate_detector, gate_honer, and usb_cam
	scipts	controllerPID.py	PID controller for gate honing controller
		param.py	contains the gains and other parameters for the controller
		rosMain.py	ROS nodehandler
hal_control			(This package doesn't really need to be here. I use it sometimes to drive the rover with the xbox controller plugged directly into the rover). The real one is in the rover_ws
	launch	arm_control.launch	launch file to run just arm_control
		controller.launch	launch file from 2016?
		drive.launch	launch file to just drive
		two_controller.launch	launch file for 2 controlers, drive and arm
	src	arm_control.launch	converts xbox to actual arm commands, modes, speed, etc
		drive_control.launch	converts xbox to actual drive commands, modes, speed, etc
hal_launch			Package to group some launch files together
	config	my_ekf.yaml	NOT USED (was used with robot localization package, but coudnt get it to work right)
		my_navsat.yaml	NOT USED
		my_razor.yaml	config file for razor_imu_9dof

	launch	PSOCandEstimator.launch	launches psoc node and estimator
		estimator.launch	launches estimator, gps, imu
		my_ekf.launch	NOT USED
		my_navsat.launch	NOT USED
		navsat_tut.launch	NOT USED
		robot_localization.launch	NOT USED
	src	gps_frame_pub.py	NOT USED
image_common	SUBMODULE		dependency for usb_cam stuff
nav_estimation			estimator (this is the one we use)
	include	nav_estimator.h	NOT USED (estimator header from 2016)
	src	estimate.py	EKF from gps, imu, drive_commands to estimate position and heading
		nav.py	empty
		nav_estimator.cpp	2016 estimator (Gary Ellingson wrote this, but never completed)
		nav_estimation_node.cpp	
psoc			package contains nodes to write commands from ROS to the PSOC
	src	2017_psoc.py	THIS IS THE GOOD ONE. Subscribes to all ROS commands. Writes commands to PSOC at 10 hz.
		2017_psoc_new.py	subscribes to ROS commands and writes to PSOC in callbacks (likely causes lag)
		ArmConversion.py	used to test mapping of joint angles to commands
		science_psoc.py	OLD used for science and not arm
usb_cam	SUBMODULE		used to open USB cams and publish to ROS
zed-ros-wrapper	SUBMODULE		used to run ZED camera and publish in ROS. lots of latency
razor_imu_9dof	SUBMODULE		runs the razor in ROS
GridMap Branch of onboard_ws			contains the work on mapping and planning
global_wp_pub			used to parse the global path JSON file that comes from arcGIS
	msg	FloatList.msg	used to carry the waypoint list as a list of lists
	src	costpath2.json	name the costpath file this for the json parser to work on it
		json_parser.py	node that takes in a json file from arcGIS and republishes it as a list of WPs
grid_map	SUBMODULE		used for local mapping and viewing in rviz

mapping			package for mapping the area around the rover and planning a local path
	config	plan.yaml	config file for rviz when using launch file
	launch	planner.launch	launches the planner node, grid_map_visualization, and rviz
	msg	FloatList.msg	used to carry the waypoint list as a list of lists
	src	map_class.cpp	takes in laser scan and fills in the map. publishes local map
		map_not_class.cpp	NOT USED
		planning_node.cpp	takes in local map, inflates obstacles and optionally plans a path
		pseudo.txt	Old pseudocode from beginning
		simple_demo_node.cpp	NOT USED
rplidar_ros	SUBMODULE		runs the RPlidar in ROS

rover_ws	workspace that is built in base station computer and sends commands to rover over ROS network		
Package	**Folder**	**File**	**Description**
arm_kinematics			Contains the processes for the inverse kinematics of the arm
	launch	IK.launch	Sets up the, motor chain, sample buffer, and initialized IK
	src	ik_node.cpp	contains all functions and processes for IK
base			NOT NEEDED HERE. same as base in onboard_ws
hal_control	launch	DriveandArm.launch	launches 2 xbox and wtih drive and arm controls
		DriveandScience.launch	launches 2 xbox and wtih drive and science controls
		arm_control.launch	launches xbox with arm_control
		controller.launch	2016?
		drive.launch	just one xbox and drive_control
		science_control.launch	just one xbox and science control
		two_controller	old. two controllers, drive and arm
	src	arm_control.py	interprets arm xbox controller, publishes joint command
		drive_control.py	interprets drive xbox controller, pubishes drive commands
		science_control.py	interprets science xbox controller, pubishes science commands

hal_description			old urdf models, replaced by rover_description
	launch	537_example.launch	NOT USED
		display_only_537.launch	NOT USED
		hal_xbox_urd.launch	launch this to move urdf model in rviz
	urdf		urdf model stuff for rover's arm
heartbeat			Provides heartbeat to rover communication (not currently used)
hrl_kdl	SUBMODULE		used for inverse kinematics
image_common	SUBMUDULE		NOT NEEDED. Use sudo apt-get install ros-kinetic-image-common
moveit			NOT USED
navigation			package for wheel controller
	src	wheel_controller.py	sends velocity commands to wheels
robot_localization	SUBMODULE		NOT USED
rover_description			contains urdf and rviz stuff for arm (replaces hal_description)
transforms			broadcasts tf transforms
	src	transforms.py	broadcasts tf transforms
usb_cam	SUBMODULE		

G.8 MRD-MR-0001 R1: Arm Torque Model

MRD-MR-0001 R1

Arm Torque Model

Date	Subsystem	Related Performance Measure	
November 2016	Arm	7,8,9,18,20	

Names of Person Creating Model

Jacob Greenwood	Drew Warren		

Purpose

The purpose of this test is to determine the necessary torque for the joints of the arm.

Explanation

We put the arm parameters (Forces/weights and lengths) in a Matlab code and then computed the required torques of each joint at the max position of the arm (reaching straight out and lifting up). The MATLAB robotics toolbox was used to create a model of the arm and calculate joint torques along common arm configurations.

Conclusion

It showed us that with the past year's design of the wrist, the wrist motors were not strong enough for the competition requirements (lift 5kg), so we needed to redesign the wrist. We were then able to verify that our new design can achieve the required wrist torques without exceeding the motor specifications. We also were able to define the required torques for the rest of the joints to help us define the design for the new arm. This will help ensure that the new arm design meets the desirability goals.

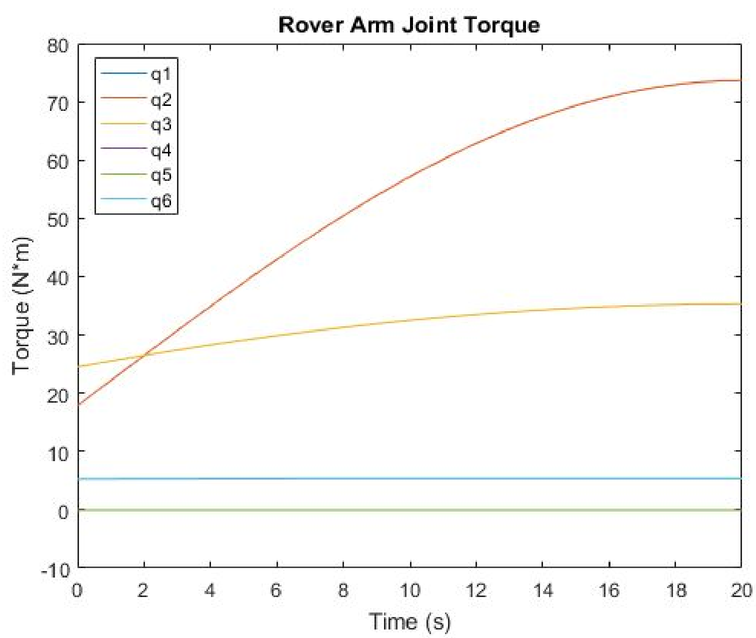
Attachments

Matlab Code:

```
%Link lengths - meters
la = .381; %arm
lfo = .356; %forearm
lp = (.02+.007+.038); %palm (pillow side, pillow top, connecting brackets)
lfi = 0.076; %fingers

%Weight - kg*g
g = 9.81; %m/s^2
%weight of links
wa = .1*2; %arm
wfo = .1; %forearm
%weight of joints
we = 2; %elbow (spin and hinge)
ww = 1; %wrist (connected to link 2)
wp = 1; %palm (not connected to link 2)
wfi = 0.25; %fingers
wload = 5; %max applied load

% DH parameters for the rover arm all the way to the end effector
L(1) = Link('d', 0, 'a', 0, 'alpha', pi/2, 'offset', 0, 'standard');
L(2) = Link('d', 0, 'a', la, 'alpha', 0, 'offset', 0, 'standard');
L(3) = Link('d', 0, 'a', 0, 'alpha', pi/2, 'offset', pi/2, 'standard');
L(4) = Link('d', lfo+lp, 'a', 0, 'alpha', 0, 'offset', 0, 'standard');
L(5) = Link('d', 0, 'a', 0, 'alpha', -pi/2, 'offset', 0, 'standard');
L(6) = Link('d', 0, 'a', lfi, 'alpha', 0, 'offset', -pi/2, 'standard');

% weight of the elbow motors
L(2).m = we + ww;
L(2).r = [0 0 0];

hal = SerialLink(L, 'name', 'Rover Arm');

qz = [0 0 0 0 0 0];
q_resting = [0 100*pi/180 -150*pi/180 0 0 60*pi/180];

hal.plot(q_resting)

% weight of the wrist motors, end effector, and load
hal.payload(wload + wp + ww + wfi,[0 0 0])

hal.gravity = [0 0 9.81];
```

```
time = linspace(0, 20);
q2 = linspace(100, 0);
q3 = linspace(-150, 0);
q6 = linspace(60,0);

for i = 1:length(time)
    q = [0 q2(i) q3(i) 0 0 q6(i)]*pi/180;
    torque(i,:) = hal.gravload(q);
    hal.plot(q)
end

figure
plot(time,torque)
legend('q1','q2','q3','q4','q5','q6')
```

Results:



MRD-MR-0002 R1

Gear Model

Date	Subsystem	Related Performance Measure	
Nov 2016	Base/Chassis	5,24,25,26,28	

Names of Person Creating Model

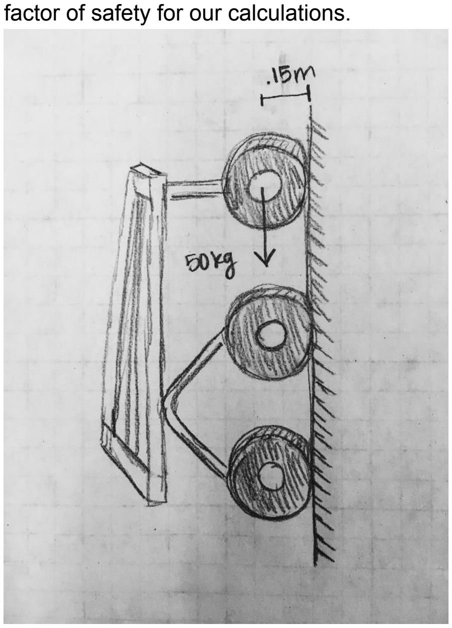
Mary Wilson	Jameson Marriott		

Purpose

This purpose of this model is to determine the necessary torque for the motors of the rover.

Explanation

We modeled the rover as a point load. Basically we estimated it as a mass going straight up a wall with the force evenly distributed between each wheel. This oversimplified model introduced a factor of safety for our calculations.



$$T = M = F\ x\ d,\ where\ F = force,\ d = distance$$

$$= \frac{g \times w \times d}{\#\ of\ wheels},\ where\ g\ =\ gravity,\ w\ =\ weight$$

$$= \frac{(9.8\frac{m}{s^2})(50kg)(.15m)}{6\ wheels}$$

$$T = 12.25\ Nm$$

Conclusion

From this model, we were able to define the required specs for our gear motors:

- 15 Nm

- 120 RPM
- <1.5 kg
- 24 V

G.10 MRD-MR-0003 R1: Simulated Arm Control

MRD-MR-0003 R1

Simulated Arm Control

Date	Subsystem	Related Performance Measure	
11/4/2016	Arm	7	

Names of Person Creating Model

Brian Jackson	Michael Farrell		

Purpose

The purpose of this test was to check on a simulated model if the code for controlling the arm works with both forward and inverse kinematics.

Explanation

A unified robot description file (URDF) was created to store the geometric data for the current robotic arm on the rover, located in the /hal_description package. The URDF can then be used in conjunction with the robot state publisher to visualize the current arm configuration in the ROS visualization package RVIZ. The /hal_control/arm_control node was written to convert joystick commands to the joint angles that will be published to robot state publisher and eventually to the rover. This node is responsible for switching between control modes.

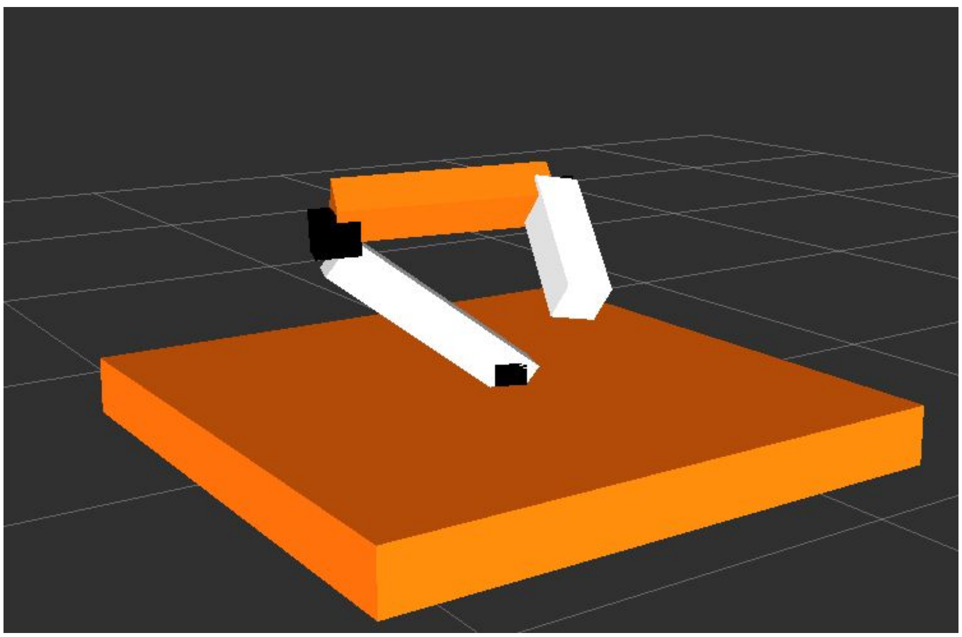
The /hal_control/ik_node was written implementing the trac-ik inverse kinematics and Orocos KDL forward kinematics libraries.

The model can be launched by first plugging in the xbox controller and the launching the hal_description rover_xbox_urdf.launch file. This will bring up the URDF model of the arm in RVIZ and can be controlled via the joystick. To switch between the 3 control modes (joint command, IK with translation in base frame, IK with translation in end effector frame) press the Y button on the controller.

Conclusion

The results of this test showed validated three things: arm can be controlled using Forward Kinematics, arm can be controlled using Inverse Kinematics with translation in the base frame and rotation in the end effector frame, and arm can be controlled using Inverse Kinematics with translation and rotation in the end effector frame.

Attachments




Drive Controller
Kill Button
Bumper: Decrease Speed
Bumper: Increase Speed
U/D: Left Wheel Fwd/Bwd
U/D: ZED Tilt
L/R: ZED Pan
U/D: Right Wheel Fwd/Bwd


Arm Controller: Joint Control
Kill Button
Trigger: Open Gripper
Bumper: Decrease Speed
Trigger: Close Gripper
Bumper: Increase Speed
Change Mode
U/D: Shoulder
L/R: Turret
U/D: Elbow
L/R: Forearm Twist
U/D: Wrist
L.R: Wrist Twist


Arm Controller: IK
Kill Button
Trigger: Open Gripper
Bumper: Decrease Speed
Trigger: Close Gripper
Bumper: Increase Speed
Change Mode
U/D: Y-Axis
L/R: X-Axis
U/D: Rot X (Pitch)
L/R: Rot Y (Yaw)
U/D: Z-Axis
L.R: Rot Z (Roll)

G.11 MRD-MR-0005 R1: Husky Waypoint Simulation

MRD-MR-0005 R1

Husky Waypoint Simulation

Date	Subsystem	Related Desirability Goal	
2/1/2017	Navigation	Navigation	
Names of Person Creating Model			
Brian Jackson			

Purpose

The purpose of the simulation was to test the behavior-based controller to get go-to-goal behavior and waypoint following working in simulation. Having a computer simulation allows for easier testing rather than being dependent on the physical system.

Explanation

Using the Code

First, the Husky Gazebo simulator needs to be installed

```
sudo apt-get install ros-indigo-husky-simulator

export HUSKY_GAZEBO_DESCRIPTION=$(rospack find
husky_gazebo)/urdf/description.gazebo.xacro

sudo apt-get install ros-indigo-husky-desktop
```

To launch Gazebo use the following command:

```
roslaunch husky_gazebo husky_empty_world.launch
```

To launch RVIZ use the following command:

```
roslaunch husky_viz view_robot.launch
```

To test the simulator, launch RQT and load the Robot Steering plugin and use the sliders to control the rotational and linear velocities of the robot.

To test the waypoint simulator, first publish a NavigationData message as /navigation_data. Use RQT to do this quickly and easily. The wp_x field should contain all of the x positions and the wp_y field should contain all of the y positions of the navigation points.

To start the controller, run `rosrun navigation Supervisor.py`. It defaults to using the /odom frame and will run the waypoints in the base frame if a 1 is passed into the command line as an argument.

To tune the gains, modify the kp, kd, and ki variables in the Supervisor.py file (about line 29). The acceptable goal distance can be set in Supervisor.py by changing the goal_distance member variable (about line 32).

Explanation of the Code

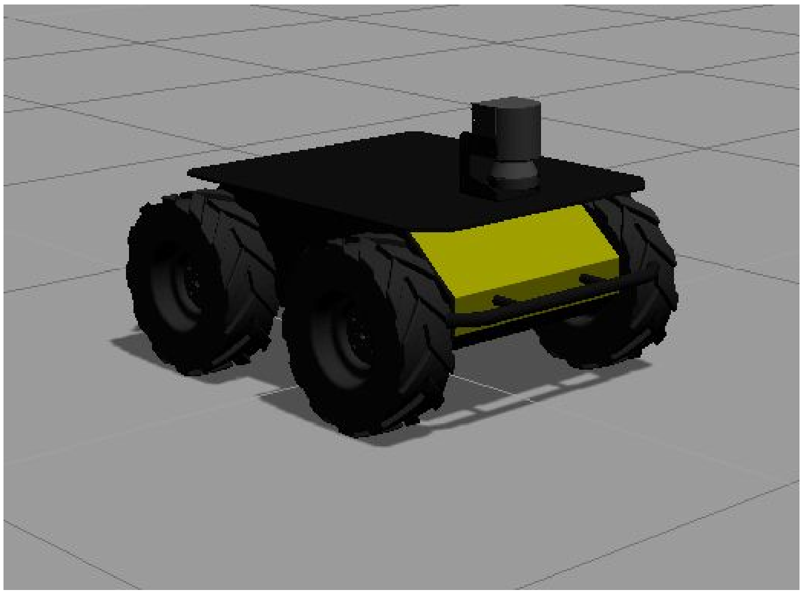
The controller uses behavior-based control, which means it uses a finite state machine with a separate PID controller for each state. In each case, the bearing of the robot is controlled using a PID controller and the velocity is explicitly controlled. The controller takes in the robot odometry, waypoint data, and eventually obstacle data and then returns a linear and angular velocity that will be commanded to the rover. The simulator uses the same interfaces that the real rover will so it a good way to test the code prior to testing it on the actual rover.

Conclusion

The simulation worked well, in that the rover went to the specified waypoints (in either frame) under a variety of initial conditions. This shows that the basic go-to-goal framework is working and is ready to be tested on the physical system.

Attachments

Picture of the Husky robot in simulation



[Video of Simulation](https://drive.google.com/file/d/0B_KGWOr-LxgYSGJoZjNOMmp3R3c/view?usp=sharing)
https://drive.google.com/file/d/0B_KGWOr-LxgYSGJoZjNOMmp3R3c/view?usp=sharing

G.12 MRD-MR-0006 R1: Robot Arm Model

MRD-MR-0006 R1

Robot Arm Model

Date	Subsystem	Related Desirability Goal	
2/15/17	Arm	Arm Strength	

Names of Person Creating Model			
Drew Warren	Jacob Greenwood		

Purpose

This set of models was created to make design decisions about the geometry and configuration of the robot arm.

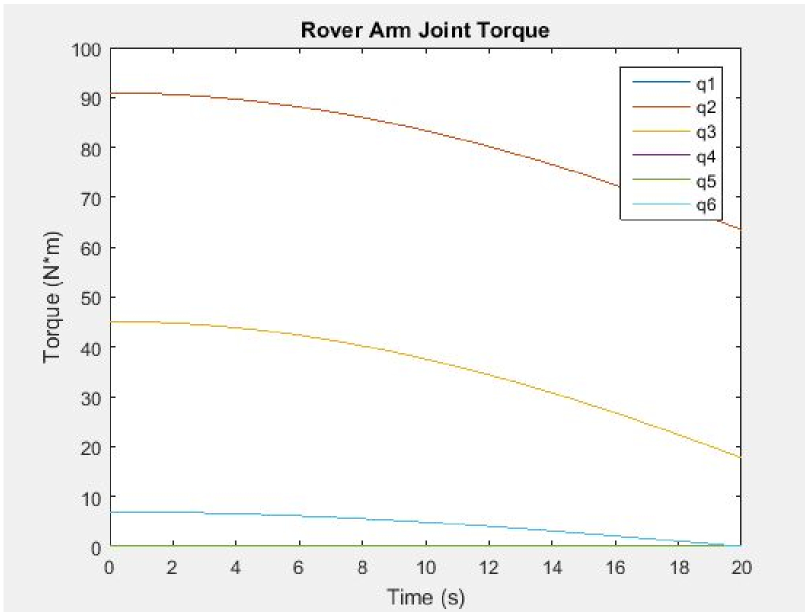
Explanation

Both Jacob and Drew made models of the arm to compare the positions of linear actuators on the links with the torque required to move the arm. Both models also give a workspace approximation of the arm. Jacob used an optimization tool and Drew used the robotics toolbox.

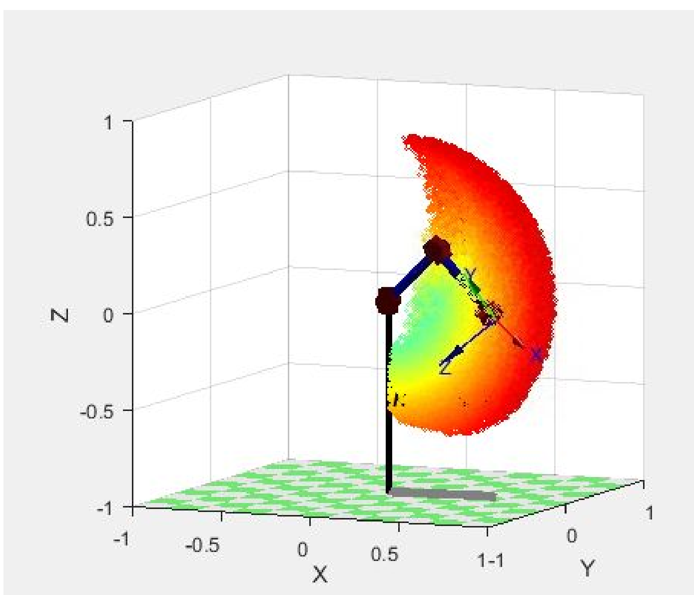
Robotics Toolbox

The first model using the robotics toolbox calculates joint torques due to gravity load (we did not account for the dynamics of the arm because our actuators and motors move slowly enough to ignore them) and then it completes a workspace estimation. The file is called *rover_arm2.m*.

To find joint torques, the model moves the arm from the zero position to a standard grabbing position and calculates the gravity load at each point along the way. The joint torques for each point during that movement are plotted like this:

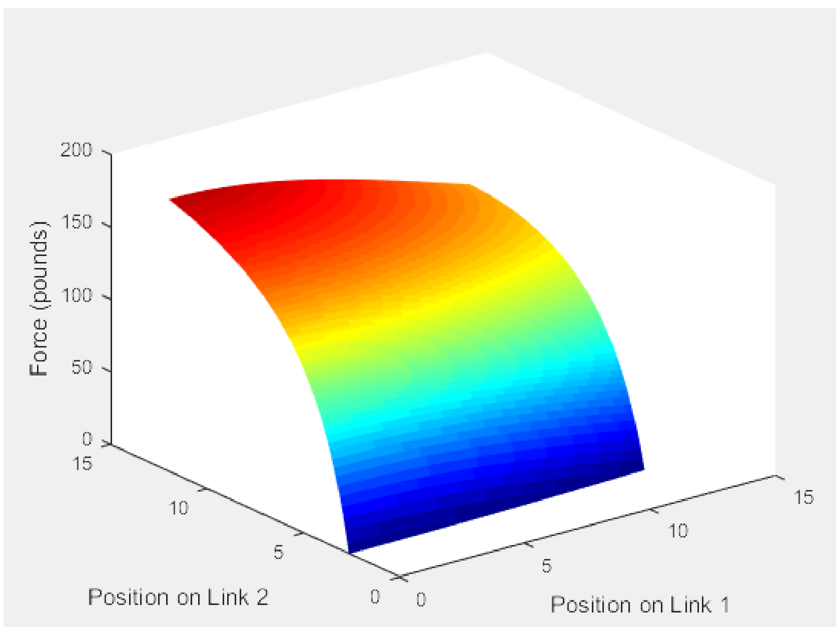


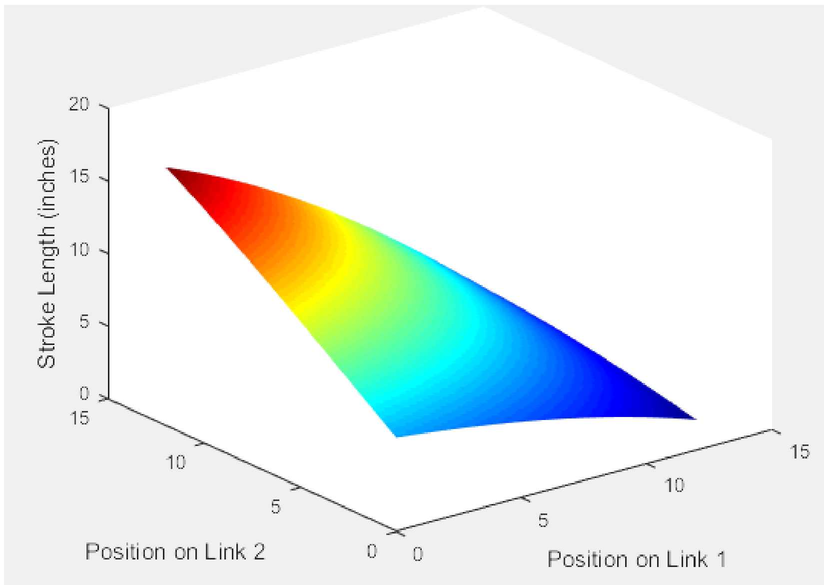
The model then takes the joint limits it is given and performs an approximation of the workspace that looks like this:



In this workspace approximation the multi colored points represent different points in 3D space that the claw can reach, and the color indicates each point's distance relative to the first joint. It should be noted that this plot is easier to visualize by rotating it with the mouse in MATLAB.

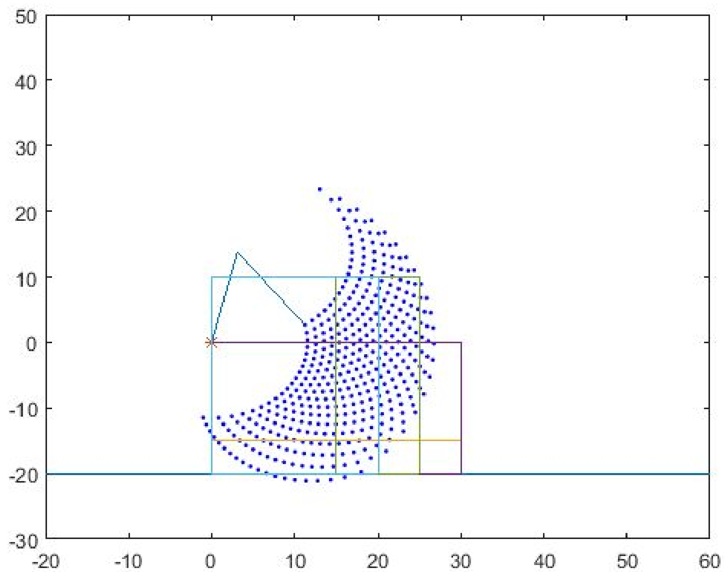
The next two models from the robotics toolbox are named *arm_modeling_shoulder_calculations.m* and *arm_modeling_elbow_calculations.m*. These scripts take the model of the arm and perform sets of calculations on it to learn more about the positioning of the actuators. The first model varies the position of the front and back ends of the linear actuator along the shoulder link and calculates the required force and the stroke length for each position.





Optimization

Jacob made another model of the arm using MATLAB’s optimization tools. This model takes the dimensions and weight approximations of the arm and optimizes the placement of the linear actuators for the best range of motion and max load.



Conclusion

As a result of these analyses, positions for the linear actuators were chosen. The bottom of the shoulder actuator should be behind the joint about 3 inches and above the plate about 5 inches and the top should be about 3 inches down from the elbow joint. The bottom of the elbow actuator should be as close to the shoulder joint as is feasible and the top should be about 5 inches out from the elbow joint.

These results and decisions moved the design of the rover forward. Specifically, this model helped make progress towards the desirability goals of arm strength, precision, and accuracy.

G.13 MRD-MR-0007 R1: Software Design

MRD-MR-0007 R1

Arm Angles Calculation

Date	Subsystem	Related Performance Measure	
4/11/17	Arm	Time to pick up screwdriver	

Names of Person Creating Model

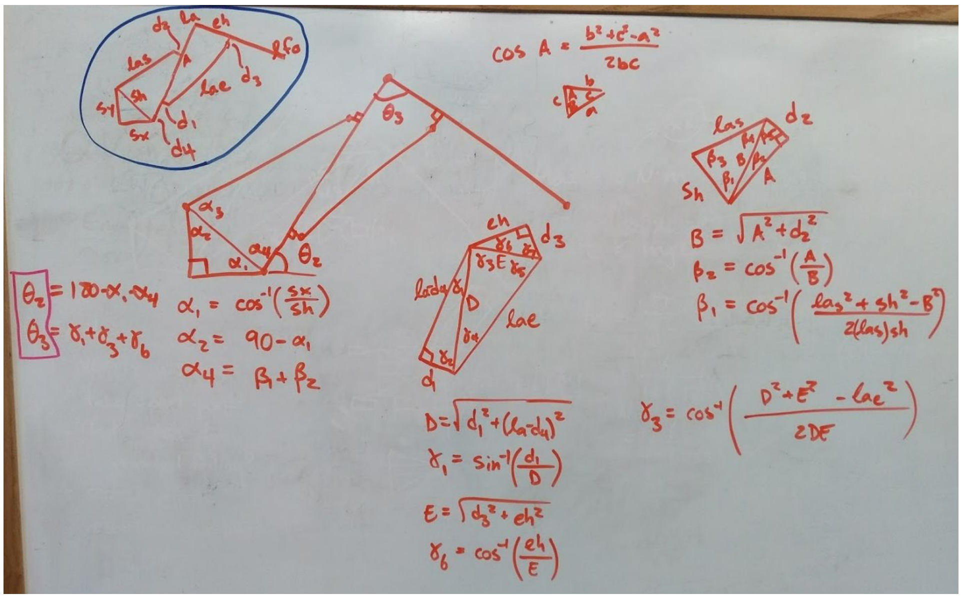
Jacob Greenwood			

Purpose

The purpose of the model was to calculate the arm angles from linear actuator lengths (and vice versa). These angles are important for getting IK (inverse kinematics) to work on the arm. This relates to the "End Effector Accuracy" desirability goal and the "Time to pick up screwdriver" performance measure.

Explanation

The model is two matlab scripts that calculate the arm angles from linear actuator lengths (and vice versa). Since the model is based off geometry, when the arm geometry changes, the values in the model should change. The model was designed to be parametric, and minor geometrical changes (such as the changing of link lengths) will be easy to implement. Below is a picture of the geometry and hand calculations.



The values in the blue circle are the known link lengths. For forward kinematics, we are trying to find theta2 and theta3 (in the red box on the left). For inverse kinematics, we calculate the linear actuator lengths (las, lae) from theta2, theta3, and the rest of the link lengths. The geometry was calculated by breaking it down into many triangles, which are easily solved. Note that sh, sy, and sx refer to the position of the offset; d1, d2, d3, d4, and A refer to the mounting position of the linear actuators on the arms; la is the length of the arm; lae and las are the lengths of the elbow and shoulder linear actuators, respectively.

The matlab scripts are found as attachments to this report. The file “arm_angles_backward.m” calculates the linear actuator lengths given specified angles. The file “arm_angles_forward.m” calculates the angles given specified linear actuator lengths.

Note that the linear actuator lengths come back as a percentage of stroke lengths. This was done so it better interfaces with the Pololu motor drivers. For example, the 6” actuator can stroke from 11.9" to 17.9” (see https://www.firgelliauto.com/products/feedback-rod-actuator), but using the pololu software, we can modify the range. This is often done so that the arm physically cannot go into a position that would injure itself. Let’s say we change the range to 12” to 16”. If we give a 0.5 as a linear actuator stroke percentage for this actuator, it will go to 14”. A value of 0 would go to 12” and a value of 1 would go to 16”. If the limits get reset, you will have to change the minimum and maximum linear actuator lengths in the matlab files.

We do not expect to use Matlab to calculate the angles and implement into IK. I expect that the code will be translated to Python and copied into the IK script.

Attachments

```
function [las_percent,lae_percent] = arm_angles_backward(theta2,theta3)

    %%% arm angles backward

    % This code solves for the linear
    % actuator lengths given the arm
    % angles and other arm geometry

    %--------INPUT ANGLES----------------
    %input angle values
%     theta2 = ;
%     theta3 = ;

    %---------------MATH-----------------
    %linear actuator lengths
    las_min = 13;
    las_max = 16;
    lae_min = 15;
    lae_max = 20;

    %geometric values
    sx = 2.5;
    sy = 3;
    A = 15.375;
    la = 20;
    eh = 3+1/16;
    d1 = 0.5;
    d2 = .75;
    d3 = 2.25;
    d4 = 2;

    %calculated values
    sh = sqrt(sx^2 + sy^2);
    D = sqrt(d1^2 + (la-d4)^2);
    gamma1 = asind(d1/D);
    E = sqrt(d3^2 + eh^2);
    gamma6 = acosd(eh/E);
    B  = sqrt(A^2 + d2^2);
    beta2 = acosd(A/B);
```

```
    alpha1 = acosd(sx/sh);
    alpha4 = 180 - alpha1 - theta2;
    beta1 = alpha4 - beta2;
    gamma3 = theta3 - gamma1 - gamma6;

    lae = (D^2 - 2*cosd(gamma3)*D*E + E^2)^(1/2);
    las = (B^2 - 2*cos(beta1)*B*sh + sh^2)^(1/2);

    %--------OUTPUT LENGTHS----------------
    %output values - linear actuator percentage of range
    las_percent = -(las - las_min)/(las_min - las_max);
    lae_percent = -(lae - lae_min)/(lae_min - lae_max);
end
```

```
function [theta2,theta3] = arm_angles_forward(las_percent,lae_percent)

    %%% arm angles forward

    % This code solves for the arm angles
    % given the linear actuator lengths
    % and other arm geometry

    %--------INPUT LENGTHS----------------
    %linear actuator percentage of range
%     las_percent = ;
%     lae_percent = ;

    %---------------MATH-----------------
    %linear actuator lengths
    las_min = 13;
    las_max = 16;
    las = las_min + las_percent*(las_max-las_min);
    lae_min = 15;
    lae_max = 20;
    lae = lae_min + lae_percent*(lae_max-lae_min);

    %geometric values
    sx = 2.5;
    sy = 3;
    A = 15.375;
    la = 20;
    eh = 3+1/16;
    d1 = 0.5;
    d2 = .75;
    d3 = 2.25;
    d4 = 2;

    %calculated values
    sh = sqrt(sx^2 + sy^2);
    D = sqrt(d1^2 + (la-d4)^2);
    gamma1 = asind(d1/D);
    E = sqrt(d3^2 + eh^2);
    gamma6 = acosd(eh/E);
    B  = sqrt(A^2 + d2^2);
    beta1 = acosd((-las^2 + sh^2 + B^2)/(2*B*sh));
    beta2 = acosd(A/B);
    gamma3 = acosd((D^2 + E^2 - lae^2)/(2*D*E));
```

```
    alpha1 = acosd(sx/sh);
    alpha4 = beta1+beta2;

    %--------OUTPUT ANGLES----------------
    %output values
    theta2 = 180 - alpha1 - alpha4;
    theta3 = gamma1 + gamma3 + gamma6;
end
```

G.14 MRD-MR-0008 R1: Drive Motors and Controllers

MRD-MR-0008 R1

Camera Panorama Angle Model

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/7/17	Science	Camera Panorama Angle	Pass

Names of persons conducting test

Westley Barragan			

Purpose

This test tests the angle which can be seen by the ZED, mounted on a gimbal on the end of the science module.

Method

For this test we will only provide predicted values for the panorama angle. All we need to do is make some simple calculations.
Gimbal rotation angle = 270 degrees
ZED field of view based on specs = 110 degrees

Panorama Field of view = Gimbal rotation angle + ZED field of view based on specs = 380 degrees

Results

Panorama field of view = 380 degrees

Conclusion

Based on these results we can conclude that we have over 360 degrees of panorama view for the science camera. Some things to take into consideration would be the possibility of exchanging the ZED for another camera due to its latency and lack of focus of soil samples at close range. However, the ZED was part of the original design so we'll keep it for the sake of this test.

G.15 MRD-TR-0001 R1: Antenna Interference

MRD-TR-0001 R1

Antenna Interference Test (Directional to Directional)

Date	Subsystem	Related Performance Measure	Pass/Fail
October 2016	Communications	29	Both

Names of persons conducting test

Benjamin Hilton	Angus Cameron		

Purpose

This test was performed to analyze the behavior of the communications system in an environment with a lot of interference. It is difficult to replicate the environment in which the rover will compete, but we suspect that due to multipath, interference will always be a problem. The system differs from last year's because of the point cloud data and the additional cameras that we will be using. Last year's team also reported latency being a problem. Therefore, this test focuses on the part of the desirability goals which states that the rover must be able to communicate out of line-of-sight. Since we have two Ubiquiti base station antennas, we plan to test a link between these two antennas to determine if Ubiquiti or MIMO make a significant difference in communication.

Method

This test was performed twice, the first time for the TP-Link antennas used last year, and the second time for a Ubiquiti AMO-2G15-120 MIMO 2x2 antenna. The test was performed on the BYU campus. A prototype base station and rover were built out of carts. The base station prototype contained the designed communication system for the base station, and the rover prototype contained the designed communication system for the rover, with the antennas (or antenna). The base station prototype remained by the Fletcher building throughout the duration of the test. We then took the rover cart to different distances along the sidewalk towards the west. We tested the connection speed with the base antenna pointed straight ahead and at 45 degrees on both sides. We repeated these measurements at least twice per distance. The throughput was measured across the ethernet bridge using iperf (a linux tool). Images of the prototypes are included as attachments to this document. For information regarding how to setup the communications system, visit the github wiki: https://github.com/BYUMarsRover/BYU-Mars-Rover/wiki/Communications (The Wiki is also included in appendix H).

Results

The results for the TP-Link antennas can be seen in the following table:

Distance (meters)	**45 Degree Rate (Mbps)**	**Straight Rate (Mbps)**	**45 Degree Rate (Mbps)**
50	6.18	22.1	25.5
	0.519	10.2	11.0
130	27.1	41.5	31.2
	12.0	33.9	4.6
230	0.19	0.31	NA
	0.162	12.7	NA
360	NA	NA	NA
	NA	NA	NA

The fields where “NA” is listed is due to the fact that the system could not even connect to start the test.

The results for the Ubiquiti antenna can be seen in the following table:

Distance (meters)	**45 Degree Rate (Mbps)**	**Straight Rate (Mbps)**	**45 Degree Rate (Mbps)**
50	74.9	73.5	72.0
	71.0	65.5	69.4
130	69.1	74.8	73.3

	64.1	71.8	71.7
230	64.9	62.0	59.3
	67.0	69.2	65.8
360	35.4	55.6	33.9
	13.6	18.3	2.93

Conclusion

As can be seen, the speeds were very inconsistent with the first test, while they were much more stable in the second test. This is likely due to the fact that the Ubiquiti antenna is 2x2 MIMO enabled, which allows the antenna to take advantage of multipath. While the environment for the rover will never be surrounded by buildings as in the test, it is a vivid example of how interference can adversely affect the communication. The TP-Link antennas will be replaced by the Ubiquiti antenna. However, even the Ubiquiti antenna begins to drop out at 360 meters. The distance will be tested in another occasion.

Attachments

G.16 MRD-TR-0002 R1: Arm Accuracy and Precision

MRD-TR-0002 R1

Arm Accuracy and Precision

Date	Subsystem	Related Performance Measure	Pass/Fail
11/9/2016	Arm	7	Fail

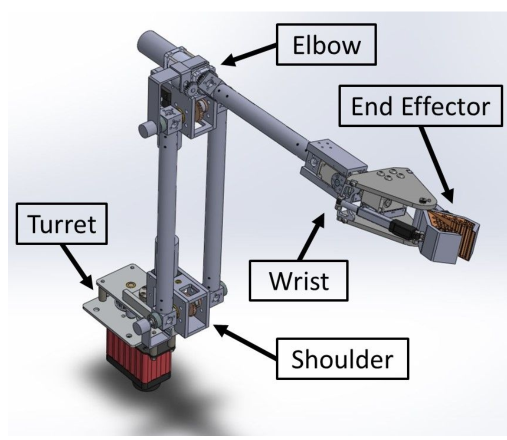
Names of persons conducting test

Jordan Oldroyd	Richard Livingston	Steven Markham	Michael Farrell

Purpose

The purpose of this test is to check the functionality, accuracy, and precision of the joints from the 2015 robot arm. This particular test will only test the elbow joint (pivoting) and the shoulder joint. The rotating elbow joint was unable to be tested due to a disconnected potentiometer, and the turret is not smoothly working with the software. This is related to the end effector accuracy performance value and should be accurate within 50mm but hopefully as accurate as 10 mm.

Method



To test accuracy and precision each joint was mapped out using a protractor. We moved it to a certain location and measured that joint angle compared to a stationary reference. We reset the min and maximum positions of the joints in the Pololu driver software. That minimum and maximum position now represent the range of movement of the joints, and we command the joint to move by sending it a command of 0-4095 (0 being the minimum and 4095 being the max). We then calculated what angles are associated with what values of 0-4095. Each time we used the base station to send a joint command of 0-4095 we could then calculate which angle the arm should go to and also measure the actual angle the arm went to. This tests the accuracy of the joint as we continued to go to a variety of joint angles and compared the target angle versus the actual angle.

To test precision, or repeatability, we chose a few joint angles to repeatedly go to. We would go to these angles and then move away from them to various other joint angles. We then would return to the same target angle and compare the measured angled to the previous measured angle for that specific command. We then calculated the standard deviation of these values. This shows, after random movement, how consistently does the arm move to the point we are commanding it.

Results

The shoulder joint and elbow joint had precision errors that resulted in the end effector being much too inaccurate. Below is a table showing the max degree error experienced as well as the standard deviation. The standard deviation is the standard deviation of the values when we returned to the same spot over and over again and measured how far off we were.

Joint	Max Degree Error	Max Standard Deviation	95% confidence on repeatability
Shoulder	17.4	1.7 deg	4.06 deg
Elbow	15.7	3.7 deg	8.85 deg

This shows that we are not ending up where we expect. Each joint not only doesn't go where our calculations go but do have some deviation when trying to repetitively go to the same location. If the arm was off from the target angles but was consistent in how far off it was then we could perhaps take enough test data to learn the equation for which the arm actually moves, but since there is problems with consistency we can't do that. We have a repeatability of the shoulder joint with 95% confidence at 8.85 deg, and we are at 4.06 deg for the elbow. Here are some calculations using the confidence interval to find out what our end effector range is for repeatability:

a. Current arm: 0.15*(0.381+(0.356+0.1)*2) + 0.0015*2*(0.1) = 194 mm
    i. 0.15 is radians ~= 8.85 degrees. This is the error found for the shoulder and elbow joints with the current arm and feedback system
    ii. 0.381 and 0.356 are the lengths of the arm and forearm, respectively
    iii. 0.1 is the length of the wrist connected to the forearm
    iv. 0.088 degrees ~= 0.0015 radians is the resolution of each dynamixel. This assume that the gearing is perfect which should be close because the gearing is direct :)
    v. 0.1 is the length of the fingers.

This shows that the worse case scenario of the shoulder would result in a 194mm range of repeatability. Notice that this could be different as we take more and more data points to help us understand.

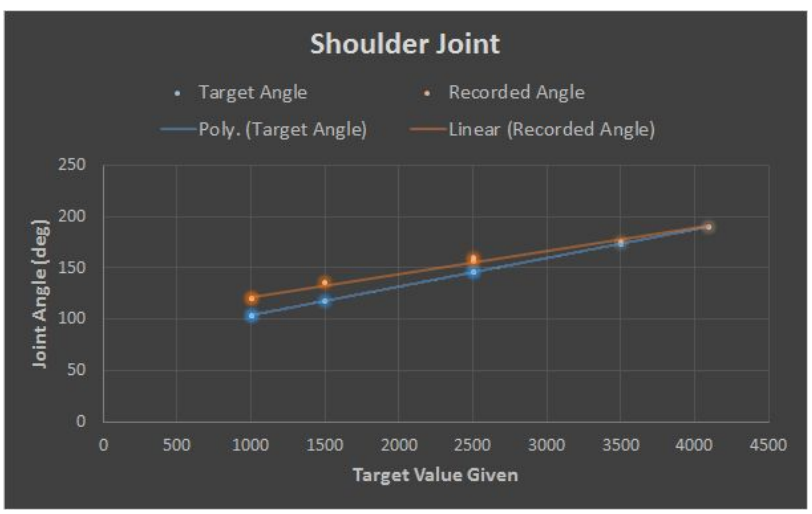
We do have one hypothesis for the angles being further off than we expected. To explain this we will use the example of the shoulder joint. Think of the shoulder joint being straight up as 0 degrees. If we move the arm to a positive angle, the weight of the arm makes the arm fall a little until it rests on the gearing within the shoulder. Since there is a little slop in the gearing, if you then move the arm to a negative angle the weight shifts and falls to the other end of the slop. This introduces a large error in our calculations for the arms target value because we measured the max and min angles from a negative and positive value.

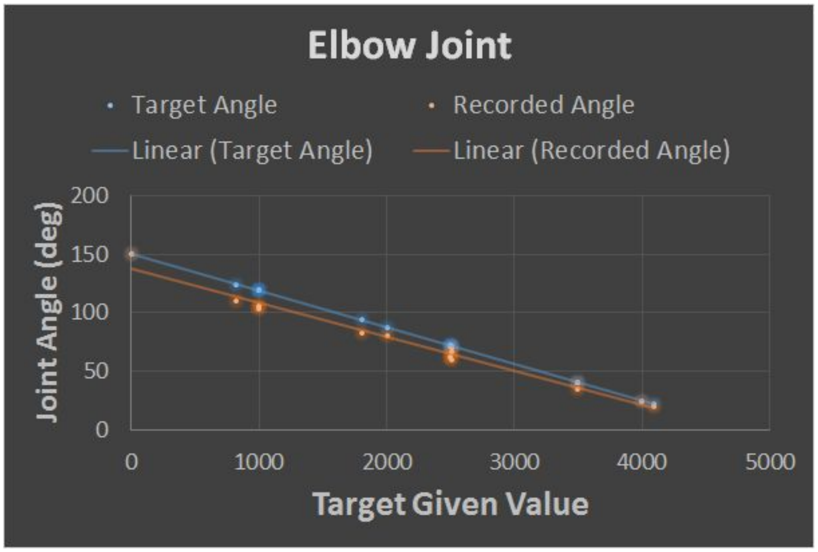
Conclusion

The arm is not as accurate as it needs to be. The test might also need to be altered to help us truly understand where the inaccuracies are coming from, like slop in the gearing or potentiometer connections. We will be running more tests to try and narrow this down.

Attachments

The following plots and charts can be found at the following link:
https://drive.google.com/open?id=0B1hn_sCHVoAeOXZTRms5MG9JT0k





Elbow Joint			
Given Value	Target Angle	Recorded Angle	Degree Error
2507	72	70	1.6
1802	94	83	10.7
822	124	110	14.3
2512	71	60	11.5
4000	25	25	0.0
2507	72	67	4.6
1002	119	105	13.7
0	150	150	0.0
4092	22	20	2.1
2002	87	80	7.4
3500	41	40	0.6
2502	72	62	9.8
1000	119	103	15.7
3500	41	35	5.6
2500	72	62	9.9
1000	119	105	13.7

Shoulder Joint					
Given Value	Target Angle	Recorded Angle	Degree Error	Mod Target	
4092	190	190	0.1	197	6.91648348
2507	146	160	14.2	153	7.20805863
1502	118	135	17.2	125	10.1860806
0	76	75	1.0	83	8
1000	104	120	16.2	111	9.16117217
2500	146	157	11.4	153	4.402930425
3500	173	175	1.6	180	5.435897405
1495	118	135	17.4	125	10.38095239
1005	104	120	16.0	111	9.021978031
2500	146	156	10.4	153	3.402930425
1000	104	120	16.2	111	9.16117217

There is also a presentation for the design review that shares some of this test information: https://docs.google.com/presentation/d/1Fos0AwCLcmy7HJSNdt_eaJP7GxW5xIUNfbJ-Qb-CTaA/edit?usp=sharing

G.17 MRD-TR-0003 R1: Camera Connection

MRD-TR-0003 R1

Camera Connection Test

Date	Subsystem	Related Performance Measure	Pass/Fail
Nov 2016	General Vision	10,14,21,29	Pass

Names of persons conducting test

Westley Barragan	Michael Farrell	Angus Cameron	

Purpose

The purpose of this test is to ensure that the selected cameras work with ROS, and can be transmitted over the designed wireless communication system.

Method

1) Establish a static IP address on the Jetson (refer to github wiki on how to connect machines via the rocket). 2) Establish a ROS master and make sure the base station and Jetson can ping each others' machine names (Refer to wiki.ros.org/ROS/Tutorials/MultipleMachines). They need to be able to ping each others names, not just IP address 3) ssh into Jetson from base computer ("sudo ssh ubuntu"), then run the command "rosrun usb_cam usb_cam_node" 4) Run in base terminal "rosrun image_view image_view image:=/usb_cam/image_raw" to see image 5) Perform same test at different distances to see results

Results

The cameras worked fine across ROS and the ethernet bridge. There was no difference in image quality between the images transmitted across the wireless system and the images on the host computer.

Conclusion

This test does not demonstrate excellent performance since we haven't tested at 1 kilometer, however it shows that we are able to transmit digital images wirelessly with minimum latency at short distances.

G.18 MRD-TR-0004 R1: Camera on TX1

MRD-TR-0004 R1

Camera on TX1

Date	Subsystem	Related Performance Measure	Pass/Fail
Nov 2016	Vision	10,14,21	Fail

Names of persons conducting test

Westley Barragan			

Purpose

The purpose is to test if ROS can manage 5 cameras at once.

Method

Plug in powered usb hub into the Jetson's USB3.0 port
modify usb_cam-test.launch so 5 cameras are turned on when ran
run in terminal:
>>> roslaunch usb_cam usb_cam-test.launch
>>> rostopic list
>>> rosrun image_view image_view image:=/usb_cam/image_raw

run the image view command on all the /usb_cam/image_raw topics. they all should be name something different.

To see fps:
>>> rostopic hz /usb_cam/image_raw

to see bandwidth:
>>> rostopic bq /usb_cam/image_raw

Open and close terminals and keep running system until it breaks to find the percentage of start-up.

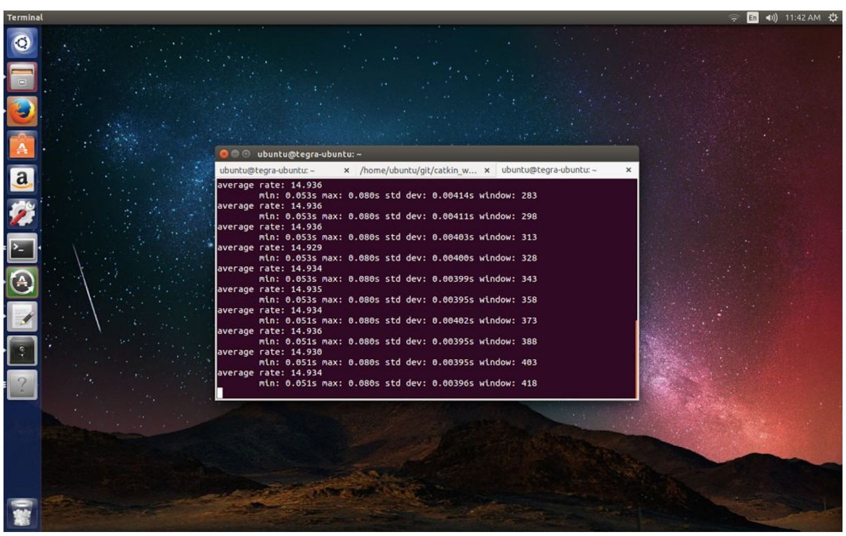
Results

Excellent performance is not quite met. The test was successful 9 out of 10 times, giving us 90% start up reliability. Though this shows some progress in our design, we will need to make some modification to make the system more robust. We will have to find all of the reasons that the camera system wouldn't start and make some safeguards in the software to be able to quickly reboot.

Conclusion

Making reliable launch files in ROS would probable be the best way to fix these kinds of errors.

Attachments



G.19 MRD-TR-0005 R1: GPS Accuracy

MRD-TR-0005 R1

GPS Accuracy Test

Date	Subsystem	Related Performance Measure	Pass/Fail
Dec 2016	Navigation	6	Pass

Names of persons conducting test

Benjamin Hilton			

Purpose

The purpose is to test the absolute accuracy of the GPS. In order to correctly navigate the rover, the accuracy needs to be within a 5 meter diameter, which equals a 2.5 meter radius (lower acceptable limit).

Method

The GPS was connected to the linux system and put on a rolling chair. Several locations were chosen in the area, particularly corners of buildings. The GPS was taken to these locations, and the experimental latitude and longitude were recorded. These values were later entered into google maps, and the distance between the actual location and the reported latitude and longitude was estimated. The values were averaged. For information regarding how to setup the GPS, see the github wiki (which is also included in appendix H): https://github.com/BYUMarsRover/BYU-Mars-Rover/wiki/Communications

Results

The resulting average distance is 2.07 meters.

location	latitude	longitude	Distance (m)
1	40.247858	-111.647628	1.5
2	40.247728	-111.647575	3.0
3	40.247554	-111.647603	4.0

4	40.247390	-111.647620	1.0
5	40.247324	-111.647613	0.5
6	40.247420	-111.647478	1.5
7	40.247830	-111.647521	3.0

Conclusion

The average of the distances is 2.07, which is less than the target value of 2.5 meters. However, there are instances in which the radius is larger than 2.5 meters. There is also a significant amount of uncertainty with Google Maps and the estimations made. In order to further improve the accuracy, the values will be averaged over a small period to get a better value. It is likely as well that during the competition the GPS will have a better signal, because there will be no trees or building to dampen the signal.

G.20 MRD-TR-0006 R1: New Arm Control Code

MRD-TR-0006 R1

New Arm Control Code Test

Date	Subsystem	Related Performance Measure	Pass/Fail
11/4/2016	Arm	7,11	Pass

Names of persons conducting test

Michael Farrell	Brian Jackson		

Purpose

The purpose of this test is to check if the new code for controlling the arm will work on the actual rover.

Method

Launched the ROS launch file "arm_control" in the ROS package “hal_control” on the base station computer. This launch file contains a new arm_control node which allows the operator to switch between different control methods for the arm. A new “PSOC” node to control the PSOC microcontroller was launched on the raspberry pi on the rover. These new nodes use the most recent software architecture and interface definitions.

The code for this test is found on the team github at https://github.com/BYUMarsRover (which is also included in appendix H).

Results

The new code successfully moves all expected joints of the rover’s arm.

Conclusion

This test shows progress because the new control code works and can control the arm. The methods used in the new code are built so that inverse kinematics (IK) will be able to be implemented. With the new code, we have all functionality of the old code as well as the ability to implement IK in the future.

G.21 MRD-TR-0007 R1: Point Cloud

MRD-TR-0007 R1

Point Cloud Test

Date	Subsystem	Related Performance Measure	Pass/Fail
November 2016	Vision	30	Fail

Names of persons conducting test

Westley Barragan	Peter Schleede		

Purpose

The purpose of this test was to check if we can publish 3D point cloud data and view it . We simply wanted to see what it looked like in rviz. We will need to do more testing later to see if this data will be good enough for autonomous terrain traversal.

Method

Use the following steps to conduct this test:

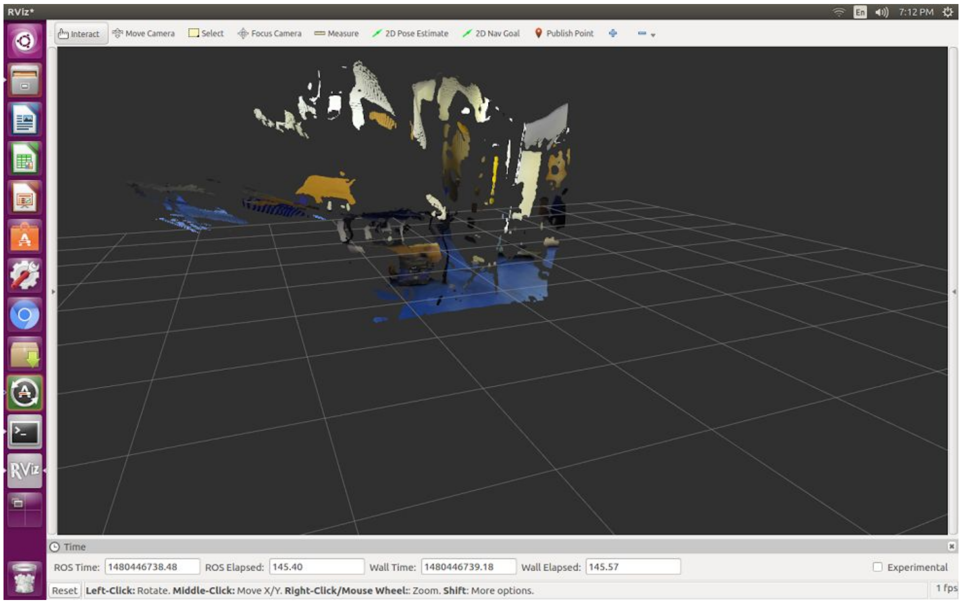
Connect ZED to Jetson.
Run in terminal:
>>> roslaunch zed_wrapper zed.launch
>>> rosrun rviz rviz

In rviz click
add -> pointcould2
click drop down tab "topic" and click on desired topic

From this you can see the point cloud data. The method for checking if this is sufficient is subjective to what you see and if it is suitable for the task.

Results

See the following picture to see the data that was received:



Conclusion

The test shows that point cloud data is being published, however, the resolution and update rate does not seem to be suitable for autonomous operation. This may be due to rviz being run on the jetson, which some online sources say this can cause slow update speeds. We will need to look into some ways to optimize the ZED in ROS. Some things that we could try is recalibrating the cameras, or instead of using the zed_ros_wrapper node we could drive the ZED hardware with another ROS package by calibrate the ZED's 2D cameras separately feeding the stereo camera calibration file into a generic stereo vision ROS package.

G.22 MRD-TR-0008 R1: Potentiometer Accuracy

Potentiometer Accuracy Test

Date	Subsystem	Related Performance Measure	Pass/Fail
11/7/2016	Arm	7	Pass

Names of persons conducting test

Jordan Oldroyd	Richard Livingston		

Purpose

The purpose of this test is to check if the potentiometers attached to the arm at each joint are functioning, and is related to the desirability goal of an accurate end effector. Last years' team was unable to get feedback working, and upon trying to control the arm this year the arm drove itself into the ground when booted up. We suspect the potentiometers are unreliable. This test will not only check if they are working but how reliable they are.

Method

Each joint has a potentiometer with 3 wires. The red wire is Vcc into the POT (5v), the black is ground, and the yellow is the POT signal. Each joint was moved to a position that could easily be returned to (or use a protractor to know exactly which locations). After giving the potentiometer power, the output signal was read from the POT. The joint was then moved to another location that could be repeated with values again read. This was done a third time so that at each joint three positions were taken. Then the joint was moved back to the first position and then cycled through all the positions again. Each time, signal measurements were taken and compared to determine if there were varying results each time the joint was moved to a specific location. This provides a reliability test for the POTs. The POT values were also checked downline where they interface with the Pololus. The values were read to make sure they were the same as at the POT and if the reading was steady.

Results

The potentiometers are reliable. They gave steady readings both at the joint and back at the Pololus. Readings never varied from the POT to the Pololu, so wires are good. When the joint was sitting at a specific location the POT's did not bounce around at all but gave steady values. The repeatability part of the test also showed that the POTs consistently gave the same value for any given location no matter how many times you left the location and returned. Below is a table showing the standard deviation of each POT tested. This deviation may well have been due to human inaccuracy in returning the joint to the exact position.

Potentiometer	Elbow Joint	Elbow Twist	Shoulder Rotation
Standard Deviation	0.013 V	0.002 V	0.022 V

Note that deviation values are also very small compared to the range of the potentiometers voltage. The POT voltage can go anywhere from 0-Vcc volts, so in our case 0-3.3V. So to have a deviation that small means our accuracy is good.

Conclusion

The potentiometers give accurate readings with excellent reliability. This proves that the problem is not with the potentiometer itself. There still may be concerns with potentiometer connections and the slop in the gearing, but the potentiometers are reliable.

G.23 MRD-TR-0009 R1: Ubiquiti Antenna

MRD-TR-0009 R1

Ubiquiti Antenna Test

Date	Subsystem	Related Performance Measure	Pass/Fail
12/5/2016	Communications	29	Fail

Names of persons conducting test

Angus Cameron	Benjamin Hilton		

Purpose

The purpose is to test whether the Ubiquiti omni-directional antenna can communicate with the base station over a distance of 1 kilometer.

Method

This experiment was repeated twice, in two different locations. The base station prototype and the rover prototype were set up a distance of 1 kilometer apart. The first location was on State Street, in South Provo. The second location was on the Industrial Parkway, also in South Provo. The connection was tested between two computers connected to the base station and the rover, respectively.

Results

Although the connection was made through the rockets (lights on the rocket come on when a connection is made) the two computers used were not able to ping each other.

Conclusion

There are several factors that would make the conditions less than ideal; however, the current setup will have to be changed. On possible solution involves raising the base station antenna to a larger height. When the computers were not able to ping each other, raising the antennas up manually has allowed for a ping. Both streets are lined with buildings and powerlines, and are not entirely flat.

G.24 MRD-TR-0010 R1: Ubiquiti Omnidirectional Campus Test

MRD-TR-0010 R1

Ubiquiti Omnidirectional Campus Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
1/27/2017	Testing/Comms		Pass

Names of persons conducting test

Benjamin Hilton	Michael Farrell		

Purpose

In the fall of 2016 we tested the TP-Link Antennas on the BYU Campus. For more information on that test, see the test report. This report compares the TP-Link Antennas to the Omnidirectional Ubiquiti antenna.

Method

The test was performed on the BYU campus. A prototype base station and rover were built out of carts. The base station prototype contained the designed communication system for the base station, and the rover prototype contained the designed communication system for the rover, with the antennas (or antenna). The base station prototype remained by the Fletcher building throughout the duration of the test. We then took the rover cart to different distances along the sidewalk towards the west. We tested the connection speed with the base antenna pointed straight ahead. We repeated these measurements four times per distance. The throughput was measured across the ethernet bridge using iperf (a linux tool). Images of the prototypes are included as attachments to this document. For information regarding how to setup the communications system, visit the github wiki: https://github.com/BYUMarsRover/BYU-Mars-Rover/wiki/Communications (The Wiki is also included in appendix H).

Results

Distance	TP-Link Antenna	Ubiquiti
50 m	16.15	69.35 Mbits/s
130 m	37.7	73.35 Mbits/s
230 m	6.505	44.675 Mbits/s
360 m	NA	45.35 Mbits/s

Conclusion

The omnidirectional antenna works much better than the TP-Link antennas in this type of environment. It is difficult to predict how it will perform in a Mars environment, but it is certain that it is better. We will likely be using this antenna on the rover instead of the TP-Link antennas from last year.

Attachments

None

G.25 MRD-TR-0011 R1: Ubiquiti Omnidirectional 1 km Test

MRD-TR-0011 R1

Ubiquiti Omnidirectional 1km Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
1/31	Comms/Testing		Pass

Names of persons conducting test

Angus Cameron	Benjamin Hilton		

Purpose

The purpose of the test was to determine if the omnidirectional Ubiquiti antenna is capable of communication at 1 km. This test is essentially the same as a previous test (MRD-TR-0009 R1); however, the previous test was not successful. We believed that this is because the base station antenna was not high enough of the ground. For this test, the base station was raised to its full height (3 meters). This test would also determine the appropriate height of the rover antenna.

Method

The locations can be seen in the map on the following page. The road we used is the Industrial Parkway in South Provo and Springville. The base station was set up at the northern location, on the shoulder of the road. We used two laptops to test the speed, using iperf. The base station was powered by the generator. The rover station was powered by a battery. After setting up we tested the speed 11 times. According the google maps, the location is actually approximately 850 meters.

Results

The results are included in the table.

Trial	Speed (Mbit/s)
1	.0732 Mbit/s
2	.8450 Mbit/s
3	.7920 Mbit/s
4	1.660 Mbit/s
5	.2110 Mbit/s
6	.1350 Mbit/s
7	.0823 Mbit/s
8	.1380 Mbit/s

9	.4610 Mbit/s
10	1.390 Mbit/s
11	.1710 Mbit/s

Conclusion

The results vary and are lower than we had hoped, but they are sufficient. We hypothesize that the speeds will be much higher in a different landscape. While the road was free of cars and is mostly straight and flat, there are obstructions. One side of the road is lined with large power lines, which likely cause electrical interference, and the other side is lined with buildings and trees. There is a slight curvature to the road, meaning that the antennas were not entirely in line-of-sight. It is likely that there are other wifi networks competing for the same space. In the competition we will have none of these problems. However, the test did help us understand the importance of having the base station antenna at maximum height. The test worked much better when the base station antenna is at maximum height. We also feel that the majority of the competition will be within distances much shorter than 1 km, and the speeds were sufficient to maintain a connection even with all the interference. It will be the video feed that will suffer.

Attachments

The base station setup

G.26 MRD-TR-0012 R1: Wrist Max Load Test

MRD-TR-0012 R1

Wrist Max Load Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/20/2017	Arm	Arm Strength, 18	Fail

Names of persons conducting test

Brian Jackson			

Purpose

The test was designed to determine if the wrist could lift a 5 kg weight without maxing out the dynamixels.

Method

The wrist was clamped down onto a surface and a string was attached midway across the wrist. 1 kg weights were incrementally strung on the string and the wrist was moved to see if the dynamixels would overload.

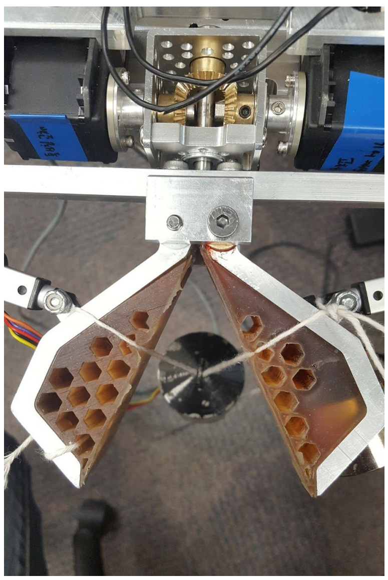
Results

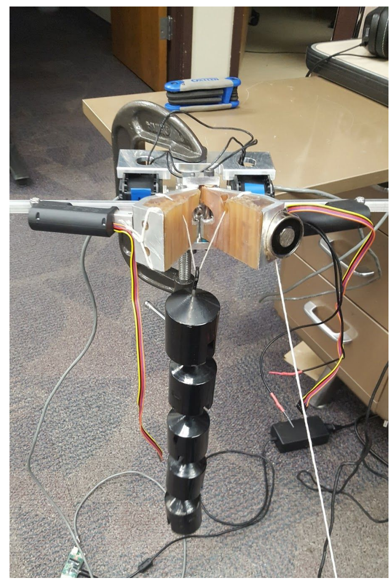
The dynamixels overloaded at 4 kg when the string was placed at the end of the end effector and at 5 kg near the middle of the grip. The wrist is not sufficiently strong to hold 5 kg for an indefinite amount of time. The wrist could hold a 5 kg weight with the load at the middle of the gripper but only for about 30-60 seconds.

Conclusion

The wrist needs to be strengthened. 21.6% more torque can be commanded from the dynamixels by increasing the voltage to 14.8 V instead of 12 V according to the documentation.

Attachments





(The image on the left is shown for visualization purposes only. In the actual test the string was tied on both sides of the gripper.)

G.27 MRD-TR-0013 R1: Setup Time

Setup Time

Date	Subsystem	Related Desirability Goal	Pass/Fail
Multiple		URC Rules: 3.a.iii	

Names of persons conducting test

Brian Jackson	Michael Farrell		

Purpose

This test will quantify the amount of time it takes to set up the base station and the rover and therefore comply with the competition requirements.

Lower Limit: 0 min
Ideal: 2 min
Upper Limit: 15 min

Method

Once the team arrives at the designated testing location, three team members will be designated as the one responsible for the three checkpoints described below. One team member will announce that the time had started and will being a stopwatch timer. Times will be recorded for the following checkpoints:

- Base station computer is running
- Successful communication is established with the rover
- The rover can be remotely teleoperated

The team members responsible for the checkpoint will notify the person with the stopwatch as soon as that task has been completed.

Equipment:

- Rover
- Base station computer
- POE
- Antennae
- Generator (if no power is available)

Results

Test Number	Base Station Running	Communication with Rover	Successful Rover teleoperation
1 (4/8)	6 minutes	7 minutes	7 minutes 30 seconds
2 (4/13)	6 minutes	7 minutes	8 minutes

Conclusion

Based on the results of the two tests, we are confident that we will meet excellent for the setup time requirement. We will continue to become more efficient at setting up as we approach the competition and dedicated time to testing.

G.28 MRD-TR-0016 R1: Base and Drivetrain Weight

MRD-TR-0016 R1

Base and Weight Chassis Report

Date	Subsystem	Related Desirability Goal	
2017-04-04	Base/drivetrain	Weight of base under 30kg, 27	

Names of Person Creating Model

Jameson Marriott			

Purpose

The purpose of this test was to determine what the base weighs and where the weight is in the base system.

Explanation

This test was performed by weighing individual parts, putting them into a spreadsheet, and making a pareto chart.

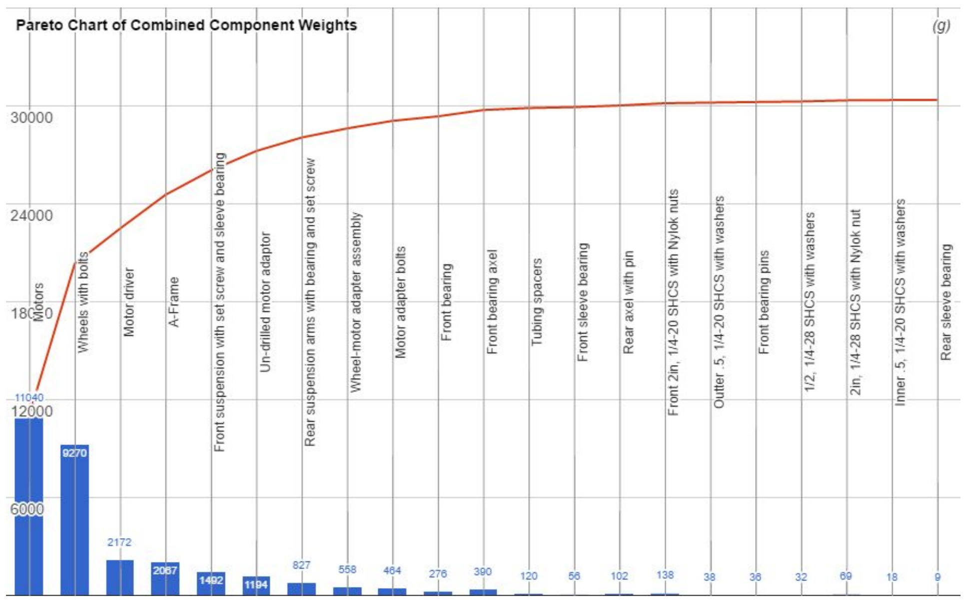
Conclusion

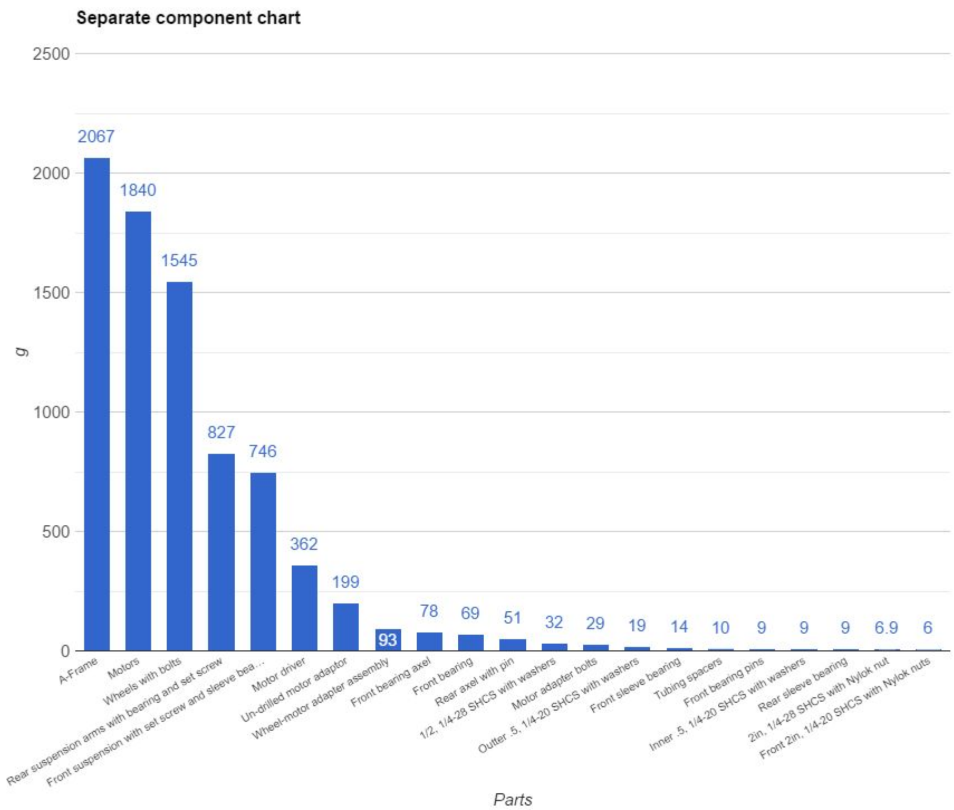
This model is moderately accurate. In accounting for all of the weight of the chassis, I have come within 1 kg of the actual weight when I weigh it as a whole. It is possible that the large scale is the source of our inaccuracy.

The total weight of the base and drivetrain is currently estimated to be 29.1 kg.

I have attached two pareto charts: One of the combined components (i.e. if there are six motors, all six are included as a single weight) and then of separate components (i.e. each motor is included separately, but total weight of the base is not represented, which is why I didn't include a sum-line above the bars).

Attachments




Separate component chart
2500
2000
1500
1000
500
0
g
2067
1840
1545
827
746
362
199
93
78
69
51
32
29
19
14
10
9
9
9
6.9
6
A-Frame
Motors
Wheels with bolts
Rear suspension arms with bearing and set screw
Front suspension with set screw and sleeve bea…
Motor driver
Un-drilled motor adaptor
Wheel-motor adapter assembly
Front bearing axel
Front bearing
Rear axel with pin
1/2, 1/4-28 SHCS with washers
Motor adapter bolts
Outter .5, 1/4-20 SHCS with washers
Front sleeve bearing
Tubing spacers
Front bearing pins
Inner .5, 1/4-20 SHCS with washers
Rear sleeve bearing
2in, 1/4-28 SHCS with Nylok nut
Front 2in, 1/4-20 SHCS with Nylok nuts
Parts

G.29 MRD-TR-0017 R1: Chassis Weight Test

Chassis Weight Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 4, 2017	Chassis	Chassis weight	Fail

Names of persons conducting test

Jameson Marriott	Mary Wilson	Alex Jensen	

Purpose

The purpose of this test is to determine the weight of the base and drivetrain.

Method

Remove all parts from the rover that are not part of the chassis and drivetrain. Basically, keep everything from the a-frame down, including the wheel motor drivers but not the batteries. Place the assembly on a scale and record its weight.

Equipment

Scale that can measure a weight up to ~50 kg

Results

We weighed the chassis with the old motor mounts still attached and it weighed 30.5 kg.
The old motor mounts weighed 1.592 kg and the new mounts weight .662 kg for a total of .93 kg reduced.
30.5 kg - .93 kg = 29.57 kg
Therefore, the weight of the chassis came to 29.6 kg.

Incidentally, we also measured the rover without an arm or science module, and it came to 44.4 kg.

Conclusion

We were really close to hitting our excellent performance goal of 28 kg for the weight of the chassis. We will further reduce weight by using lighter, shorter screws for the new motor mounts.

G.30 MRD-TR-0018 R1: Camera View Test

MRD-TR-0018 R1

Minimum Camera View

Date	Subsystem	Related Desirability Goal	Pass/Fail
4-4-2017	Navigation	Navigation	Pass

Names of persons conducting test

Westley Barragan			

Purpose

This test was to test the minimum number of camera views the rover was capable of transmitting machine to machine over ethernet.

Method

Materials:

- 4 USB cameras
- Rover
- Base Computer
- Ethernet cable
- Ethernet switch

Procedure:

- Set up Rover over to communicate with base station over ethernet.
    - Ethernet cable is connected from jetson to switch and another cable is hooked into the switch to the base station computer..
- Ssh into rover jetson from base station by typing 'sjet'.
- Source shared_ws/devel/setup.bash and then source onboard_ws/devel/setup.bash.
- Run 'roslaunch base camera_hub.launch' to launch the usb_cam node 4 times.
- In the base station machine, run 'rosrun rqt_gui rqt_gui' and add 4 different. image_viewer plugins to the gui.
- From the gui, in the drop down bar, select /usb_camX/image_raw/theora to look at the image.
- Repeat this last step until you have all the onboard cameras running

Results

4 camera camera feeds M2M

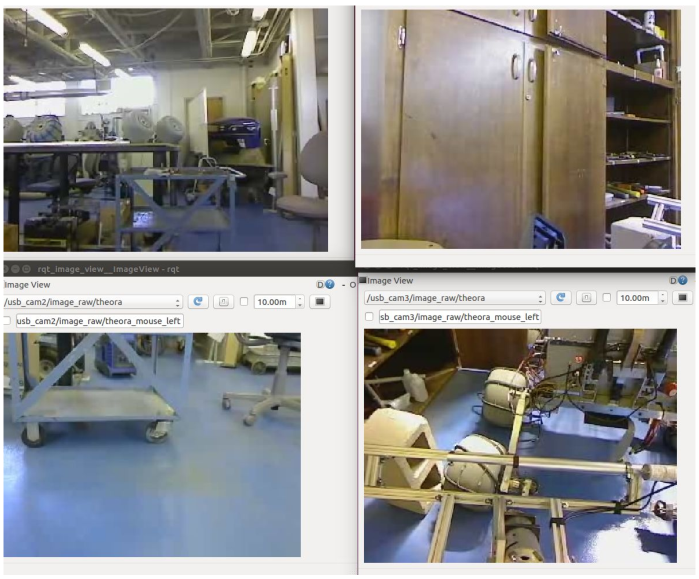


Image bandwidth: ‘rostopic bw /usb_camX/image_raw/theora
Average :7.5KB/s

```
        mean: 0.29KB min: 0.05KB max: 11.99KB window: 100
average: 4.43KB/s
        mean: 0.18KB min: 0.05KB max: 11.97KB window: 100
average: 7.68KB/s
        mean: 0.31KB min: 0.05KB max: 12.03KB window: 100
average: 7.77KB/s
        mean: 0.31KB min: 0.05KB max: 12.03KB window: 100
average: 4.79KB/s
        mean: 0.19KB min: 0.05KB max: 12.03KB window: 100
average: 7.72KB/s
        mean: 0.30KB min: 0.05KB max: 12.03KB window: 100
average: 4.44KB/s
        mean: 0.18KB min: 0.05KB max: 12.01KB window: 100
average: 7.40KB/s
        mean: 0.29KB min: 0.05KB max: 12.03KB window: 100
average: 7.36KB/s
        mean: 0.29KB min: 0.05KB max: 12.03KB window: 100
average: 4.35KB/s
        mean: 0.17KB min: 0.05KB max: 12.03KB window: 100
average: 7.37KB/s
        mean: 0.29KB min: 0.05KB max: 12.03KB window: 100
average: 4.34KB/s
        mean: 0.17KB min: 0.05KB max: 11.99KB window: 100
```

Conclusion

We are now confident that we can subscribe to the images of multiple cameras mounted on the rover over ROS. We can conclude that the rover is capable of transmitting at least 4 machine to machine. However, it would be wise to use the camera toggle function of the drive node and rover_hub node to minimize the data being sent over the air. It would be worth testing how many live camera feeds we can get over wifi and measure the distance of transmission up till the camera feed becomes unusable.

G.31 MRD-TR-0019 R1: IMU Test

MRD-TR-0019 R1

IMU Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
March 2017	Navigation		Pass

Names of persons conducting test

Benjamin Hilton	Michael Farrell	Brian Jackson	

Purpose

The purpose of this test is to determine if the IMU (installed on the rover and running through the estimator) is working correctly.

Method

This test was performed simply by testing the pitch, yaw, and roll of the rover separately by lifting up the rover and turning or tilting it on the desired axis.

Results

The pitch and roll work very accurately. The yaw works reasonably well, but the magnetometer is influenced by outside magnetic sources. So, while the true heading is off, the relative heading is correct (meaning that turning the rover 180 degrees turns the heading by the same amount).

Conclusion

The IMU works well enough. Although the heading is probably the most important of all three axes, for the estimator.

G.32 MRD-TR-0020 R1: 45° Incline Test

45 Degree Incline Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
2017-03-24	Base	23	Fail

Names of persons conducting test

Michael Farrell	Jameson Marriott		

Purpose

The purpose of this test is to determine if the rover can meet with the desirability goal that specifies a 45 degree incline.

Method

1. Find and measure a 45 degree incline
2. Drive the rover on the incline in four directions, facing up, down, left, and right on the incline
3. The rover will pass if it does not tip on this incline. If it does tip, repeat on a smaller incline until it passes and record that value

Results

We attempted to drive the rover up a 39 degree slope and it did not tip, but it also couldn't drive up the slope. The upper wheels spun and the lower wheels stalled. Also, the bolts that go through the wheels and hold both of the hub halves together kept falling out. We did not reduce the slope until we found how much slope it could handle because we learned things that we would like to improve and then we'll test again.

Conclusion

The treads seem to have enough grip (the upper wheels started to dig into the hillside). It is critical that the wheels be fully inflated so that the tires don't spin on their hubs. Also, the chicken-wire treads that we used were not wrapped far enough down the sides so that they came off after trying to go up the hill and drive around in the parking lot at Rock Canyon Park. We'll need to use a lot of loctite on the hub bolts (currently just using nylock nuts).

Improve:

- Treads that don’t come off
- Make sure that there is no slipping between the tires, hubs, and motors.
- Secure all bolts in the wheel-hub-motor assembly.

G.33 MRD-TR-0020 R2: 45° Incline Test

MRD-TR-0020 R2

45 Degree Incline Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
2017-04-13	Base	Rover can withstand 45 deg. incline	PASS

Names of persons conducting test

Michael Farrell	Brian Jackson		

Purpose

The purpose of this test is to determine if the rover can meet with the desirability goal that specifies a 45 degree incline.

Method

1. Find and measure a 45 degree incline
2. Drive the rover on the incline in four directions, facing up, down, left, and right on the incline
3. The rover will pass if it does not tip on this incline. If it does tip, repeat on a smaller incline until it passes and record that value

Equipment

1. Smartphone with level-app to measure incline

Results

The rover successfully did not tip in any direction when placed on a 30-40 degree slope. It drove up diagonally about a 30 degree slope. The rover was then manually oriented into all four orientations (front, back, left, right) and did not tip in any single orientation. Since 45 degree slopes were too difficult to access, we manually tilted the rover until it hit 45 degrees and let it go to see if it tipped. In each case it returned solidly to the original orientation without tipping.

G.34 MRD-TR-0023 R1: Gate Detection Distance (Outdoors)

MRD-TR-0023 R1

Gate Detection Distance (Outdoors)

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/4/2017	Navigation	Navigation	Pass

Names of persons conducting test

Westley Barragan			

Purpose

Measure performance of gate detection software using c270 camera in outdoor lighting.

Method

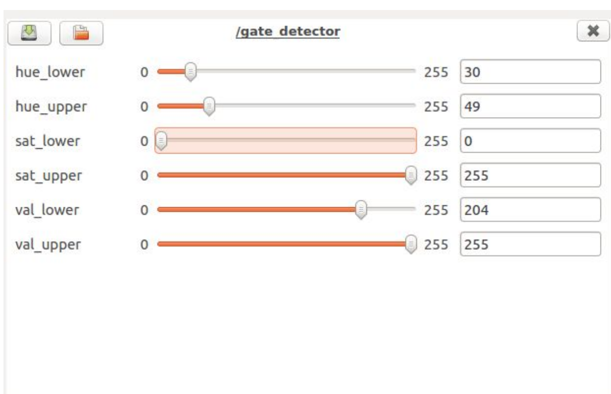
Materials:

- Tennis ball
- C270
- goPro clamp mount
- Chair with wheels
- Laptop w/ ROS, opencv, ubuntu linux, and gate detection node installed
- Antenna mount box

For this setup, I used the GoPro clamp to mount the camera on my laptop as I sat in the chair and manually adjusted the hsv thresholds. Reference test report MRD-TR-0021 R1 for further information on the methodolgy

Results

Camera: c270
Distance: 5.15 meters



In the figures above, you can see what hsv values were required to detect the ball.

Conclusion

Due to the results of the test, we determine that the gate detector has capabilities to detect from a reasonable distance outdoors. However, the test was performed in early morning where full sunlight wasn't a factor. Thus further testing is required. We have plans to go to hanksville this weekend and will perform a similar test on the rover in the actual competition environment.

G.35 MRD-TR-0024 R1: Gate Detection Distance (Indoors)

MRD-TR-0024 R1

Gate Detection Distance (Indoors)

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/3/2017	Navigation	Navigation	Pass

Names of persons conducting test

Westley Barragan			

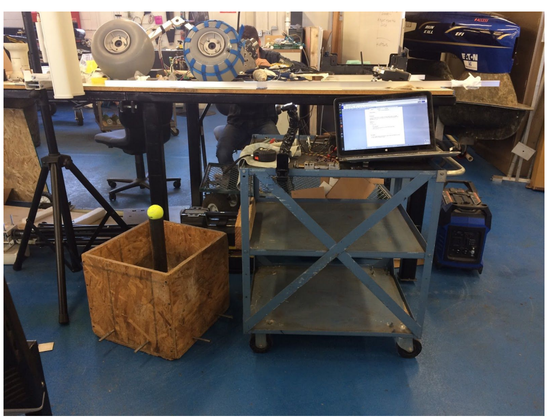
Purpose

In this test we wanted to see the max distance of the gate detector using the c270 Logitec web camera. I chose to do this test because the c270 has the longest focal length and a more clear image then the c500.

Method

Materials:

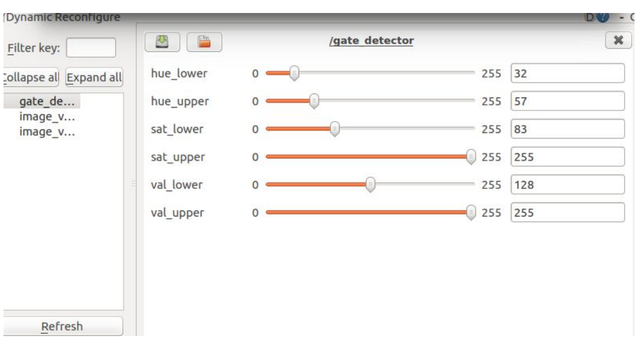
- Tennis ball
- C270
- goPro clamp mount
- Cart with wheels
- Laptop w/ ROS, opencv, ubuntu linux, and gate detection node installed
- Antenna mount box



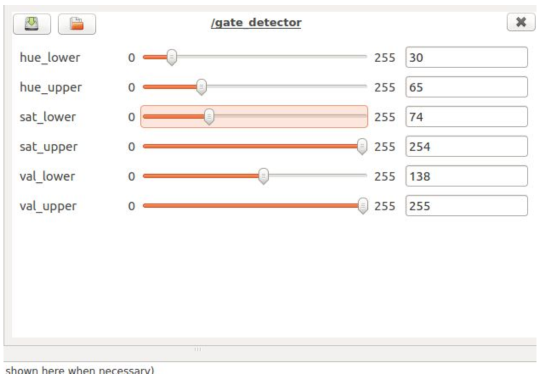
With the setup as shown above, run the gate detection launch file (roslaunch gate_detector gate_detector_test.launch) and point the camera toward the tennis ball. Using the rqt reconfigure gui that pops up when I ran the launch file, tuned my hsv threshold values so the gate detector only sees the tennis ball. Then, I slowly moved the cart further away from the tennis ball until the gate_detector was unable to detect it. I then Reconfigured the hsv thresholds and moved as far as possible from the tennis ball until I reached the max distance without losing detection. With the measuring tape, I then measured from the tennis ball to the casing of the camera in a straight line and recorded my results.

Results

Test 1
5.26 Meters



Test 2
7.31 meters



In test 2, it was necessary to blur the image by shaking the camera in order for there to be any detection. That’s why the image is so blurry; however, there was some detection messages being sent over the ROS network. Here’s the output of ‘rostopic echo /gate_detector/gate_info’:

```
gate_detected: True
gate_distance: 229.182357788
---
coords: [540, 389]
image_size: [480, 640]
box_width: 7.0
gate_detected: True
gate_distance: 305.576477051
---
coords: [540, 389]
image_size: [480, 640]
box_width: 7.0
gate_detected: False
gate_distance: 305.576477051
---
coords: [540, 389]
image_size: [480, 640]
box_width: 8.0
gate_detected: True
gate_distance: 229.182357788
---
coords: [540, 388]
image_size: [480, 640]
box_width: 8.0
```

You see that the gate_detected property displays True.

Conclusion

In this test I was expecting to achieve a distance between 7 and 8 meters so this test passed. Obviously the rover will need to be tested outdoors in sunlight to see if we can achieve the same distance; however, we can conclude that the gate detector has capabilities to detect the from over 7 meters away. The next step in this process would to perform a distance test outdoors and conclude from there what other modifications will be needed to achieve our desirability goals.

G.36 MRD-TR-0025 R1: Depth of Soil Removed

MRD-TR-0025 R1

Depth of Soil Removed

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/8/2017	Science	Sample Collection	Pass

Names of persons conducting test

Steven Markham	Richard Livingston		

Purpose

This test is to determine that the science module can collect a sample weighing at least 5g, from 5 cm below soil surface.

Method

1. Attach Science Module to Rover
2. Drive to an appropriate dig site
3. Actuate module to retrieve a sample
4. Return module to travel state (fully retracted)
5. Return rover to base station
6. Measure depth of soil collected

Results

We went to Hanksville, mounted the science module, placed it in a suitable dig area, and took a sample. The mechanical and electrical systems functioned as expected. We were able to take 8.25 cm. The sample retained its core structure, was free from contaminates, and stayed in the auger due to the soil catch. The weight of the soil collected was 41g. Interesting to note, the sample was quite difficult to remove from the auger. This should be noted and prepared for for the in lab portion.

Conclusion

The Depth and weight of the soil pass. Some modification is being made to increase depth, but only to reach our excellent performance as listed in the contract.

G.37 MRD-TR-0028 R1: Sample Collection

MRD-TR-0028 R1

Sample Collection

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/8/2017	Science	Sample Collection	Pass

Names of persons conducting test

Steven Markham	Richard Livingston		

Purpose

This test is to determine that the science module can collect a sample weighing at least 5g, from 5 cm below soil surface. In addition the sample should be free from contaminates, preserve soil structure, and remain in the auger even after rover movement.

Method

1. Attach Science Module to Rover
2. Drive to an appropriate dig site
3. Actuate module to retrieve a sample
4. Return module to travel state (fully retracted)
5. Return rover to base station
6. Measure depth of soil collected
7. Weigh soil sample
8. Inspect for contaminants

Results

We went to Hanksville, mounted the science module, placed it in a suitable dig area, and took a sample. The mechanical and electrical systems functioned as expected. We were able to take 8.25 cm. The sample retained its core structure, was free from contaminates, and stayed in the auger due to the soil catch. The weight of the soil collected was 41g. Interesting to note, the sample was quite difficult to remove from the auger. This should be noted and prepared for for the in lab portion. In addition to collecting the sample, the module also successfully captured GPS data that was comparable to the same location collected from a cell phone. It also took several photos of the dig site and sample. They will be included below.

Conclusion

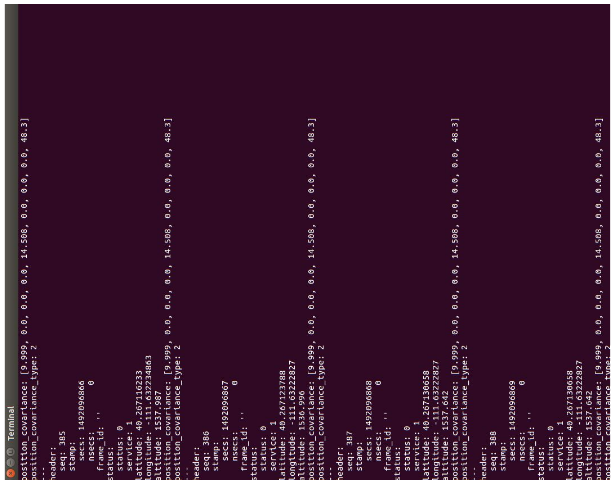
The depth and weight of the soil pass. Some modification is being made to increase depth, but only to reach our excellent performance as listed in the contract.The GPS data was adequate. The pictures that were taken were functional, but we need to work to generate higher quality photos for the actual competition.

Attachments

Image 1: Science Dig site

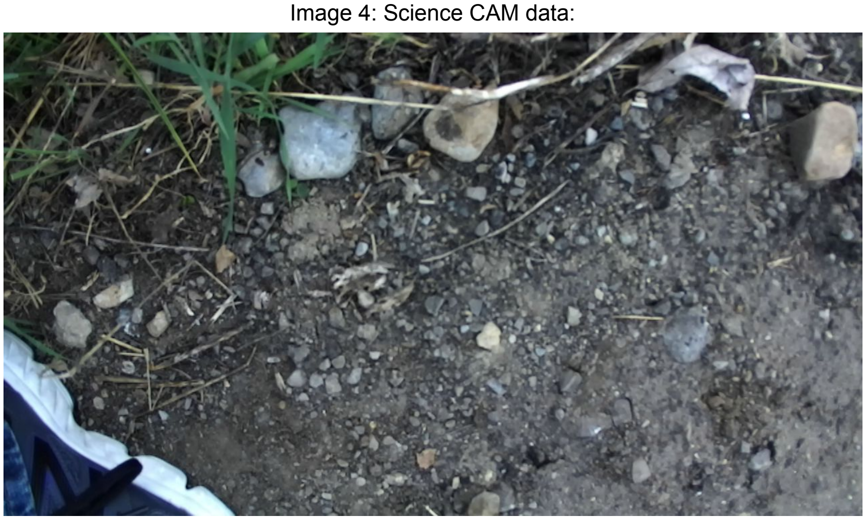
Image 2: Sensor Data

Image 3: GPS Data



```
Terminal
position_covariance: [9.999, 0.0, 0.0, 0.0, 14.508, 0.0, 0.0, 0.0, 48.3]
position_covariance_type: 2
---
header:
  seq: 385
  stamp:
    secs: 1492096866
    nsecs:         0
  frame_id: ''
status:
  status: 0
  service: 1
latitude: 40.267116233
longitude: -111.632234863
altitude: 1537.987
position_covariance: [9.999, 0.0, 0.0, 0.0, 14.508, 0.0, 0.0, 0.0, 48.3]
position_covariance_type: 2
---
header:
  seq: 386
  stamp:
    secs: 1492096867
    nsecs:         0
  frame_id: ''
status:
  status: 0
  service: 1
latitude: 40.267123788
longitude: -111.63222827
altitude: 1536.996
position_covariance: [9.999, 0.0, 0.0, 0.0, 14.508, 0.0, 0.0, 0.0, 48.3]
position_covariance_type: 2
---
header:
  seq: 387
  stamp:
    secs: 1492096868
    nsecs:         0
  frame_id: ''
status:
  status: 0
  service: 1
latitude: 40.267130658
longitude: -111.63222827
altitude: 1537.642
position_covariance: [9.999, 0.0, 0.0, 0.0, 14.508, 0.0, 0.0, 0.0, 48.3]
position_covariance_type: 2
---
header:
  seq: 388
  stamp:
    secs: 1492096869
    nsecs:         0
  frame_id: ''
status:
  status: 0
  service: 1
latitude: 40.267130658
longitude: -111.63222827
altitude: 1537.642
position_covariance: [9.999, 0.0, 0.0, 0.0, 14.508, 0.0, 0.0, 0.0, 48.3]
position_covariance_type: 2
```

Image 4: Science CAM data:



G.38 MRD-TR-0029 R1: Science Module Setup Time

MRD-TR-0029 R1

Science Module Setup Time

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/8/17	Science	In-field Rover setup time	Pass

Names of persons conducting test

Steven Markham	Richard Livingston		

Purpose

Determine how long it takes to attach Science Module.

Method

1. Bolt Science Module to Rover Frame
2. Plug in Drill, Plate, Plunge and Elevator cables as labeled on Rover
3. Connect to each Pololu Driver board via PC and upload settings files
4. Connect to Science Module via ROS
5. Test Functionality of each component

Results

We mounted the module, all cameras, ZED gimbal, and sensors. Flashed Pololus and checked electrical connections. The set up time took us 4:52.

Conclusion

Our goal was less than 5 min. We passed, and are expected to improve with more practice.

G.39 MRD-TR-0030 R1: Soil Moisture Sensor Accuracy

MRD-TR-0030 R1

Soil Moisture Sensor Accuracy

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/28/17	Science	Soil moisture measurement error	Pass

Names of persons conducting test

Steven Markham	Richard Livingston	Bryn Howell	

Purpose

Verify that the soil moisture probe is accurate within 10%, per the in contract performance measure.

Method

1. Calibrate the moisture temperature in code so that in air reads 0%, and placing probe in a cup of water reads 100%
2. Place probe in pre-prepared soil sample
3. Record moisture
4. Perform test on pre prepared soil sample
5. Compare sensor readings to determine if range is met for in air, in water, and in sample

Results

The sensor was calibrated to read 0% in air and 100% in water. This was confirmed by the high accuracy probe. A sample was then brought from outside and measure by both devices. The arduino sensor registered 31% water, which matches the pre prepared soil sample we had.

Conclusion

This sensor is approved for use. An additional test is suggested using a dryer soil sample to check low reading situations.

G.40 MRD-TR-0031 R1: Temperature Probe Accuracy Test

MRD-TR-0031 R1

Temperature Probe Accuracy Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/28/17	Science	Temperature measurement error	Pass

Names of persons conducting test

Steven Markham	Richard Livingston	Bryn Howell	

Purpose

Verify that the temperature probe is accurate within 1 degree C, per the in contract performance measure.

Method

1. Calibrate the sensor temperature as outlined in the instruction manual for the Hanna probe.
2. Measure temperature of a pre-prepared sample of known temperature.

Results

The sensor was calibrated per the instruction manual, then we measured a soil sample of known temperature. The measured temperature of the sample matched the known soil sample temperature within 1 degree.

Conclusion

This sensor is approved for use.

G.41 MRD-TR-0032 R1: Arm Settling Time

MRD-TR-0032 R1

Arm Settling Time

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/18/17	Arm	Max arm settling time	Fail

Names of persons conducting test

Michael Farrell	Brian Jackson	Drew Warren	

Purpose

The time it takes the arm to stop moving will affect both the extreme delivery task as well as the equipment servicing task. The purpose of this test is to quantify the time it takes the arm to stop moving/shaking once it has reached a desired location.

Method

The following steps should be followed for this test:

1. Start with the arm stopped at any given location.
2. Move the arm, controlling several of the joints at once.
3. Once the arm stops receiving commands, start a timer.
4. Once the arm stops moving or shaking, stop the timer.
5. Record the time.
6. Repeat steps 1-5 5 times to get an average settling time of the arm.

Note that the person timing may not know when the arm stops receiving commands by just looking at the arm. This might require the person controlling the arm to coordinate with the timer so that the correct time is started when commands are stopped.

Equipment

1. Accurate timer.

Results

The five settling times recorded were (in seconds): 2.1, 2.5, 2.5, 4.5, and 4.8.
The average settling time was 3.28 seconds. The standard deviation of these tests was 1.27 seconds.

Conclusion

The results of this test show that the arm settling time falls outside of the acceptable limits defined in the requirements matrix (0 - 1000 ms). Some tuning of the PID controllers may help us improve the settling time into the acceptable range.

G.42 MRD-TR-0033 R1: Arm Strength Test

MRD-TR-0033 R1

Arm Strength Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/15/2017	Arm	Strength of the arm	Pass

Names of persons conducting test

Jordan Oldroyd	Brian Jackson		

Purpose

The purpose of this test is the quantify the rover arm's strength. The strength of the rover arm is important in both the extreme delivery task as well as the equipment servicing task.

Method

The following steps should be followed, each time increasing the weight that is being picked up:

1. Move the arm so the hand is near the ground 0.5 meters from the edge of the back of the rover (the side with the arm on it).
2. Place the weights in a bag and hang them from the wrist joint.
3. Move the arm joints so the arm picks up the object until the object is higher than the platform of the rover.
4. Repeat several times to make sure the arm can perform this task repetitively.
5. Repeat steps 1-4 with a heavier weight.

Equipment

1. Objects of known weights that the end effector can grasp (preferably items of 3, 4, 5, 6, and 7 kg).
2. Measuring tape.

Results

The arm was able to pick up 7 kg that was 0.5 m from the rover, lifting the weight from the ground to above the platform of the rover. We conducted the steps above and the shoulder and elbow joints both moved with ease in picking up the weights. The joints moved at regular speeds and didn't seem to struggle at all. Note that this test was just using the shoulder and elbow joints without testing the wrist. The wrist strength will be tested in the next run of this test.

Conclusion

The performance measure for the strength of the arm meets the excellent mark. The arm was successfully able to pick up 7 kg from 0.5 meters from the rover.

G.43 MRD-TR-0034 R1: End Effector Accuracy Test

MRD-TR-0034 R1

End Effector Accuracy Test

Date	Subsystem	Related Desirability Goal	Pass/Fail/
4/18/17	Arm	End Effector Accuracy	Pass

Names of persons conducting test

Michael Farrell	Brian Jackson	Drew Warren	

Purpose

The purpose of this test is to check the accuracy of the arm and the end effector. Inaccuracies or slop in the arm will result in an inability to pick up objects and complete tasks in the equipment servicing portion of the competition.

Method

The steps listed below should be followed in order to test the end effector accuracy. In order to better mimic the competition scenario, the person controlling the arm should be using the camera feed instead of watching the arm in person. If camera feeds are unavailable, the test can be run while watching the arm in person but a note should be made.

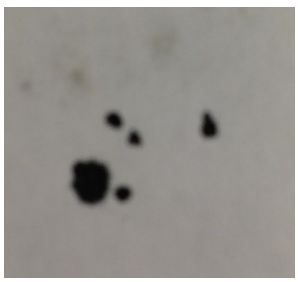
1. Place a marker in the end effector and select a point in 3D space as the test point. Rigidly attach a sheet of paper at that point and make a mark.
2. Move the arm away from that point to a random configuration at least two feet away.
3. Either using cameras or watching the rover in person, the operator moves the end effector to match that point.
4. Measure the distance away from the desired point. Repeat this process a number of times.

Equipment

1. Allen head
2. Sharpie
3. Paper

Results

This test was completed without using cameras. After running for 5 samples, the largest deviation in accuracy was 8mm and the average deviation was 2mm.



Conclusion

The results of this test are 2mm better than the excellent goal. The test should be performed again using only the camera for vision.

G.44 MRD-TR-0035 R1: Size of Objects Hand Can Grasp

MRD-TR-0035 R1

Size of Objects Hand Can Grasp Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/14/2017	Arm	Size of object the hand can grasp	Pass

Names of persons conducting test

Jordan Oldroyd	Brian Jackson		

Purpose

This test is to understand the size of objects that the hand can grasp. This is important in both the extreme delivery task as well as the equipment servicing task.

Method

Perform the following steps, each time increasing the size of the object being grasped:

1. Place the object on the ground in front of the arm in a place where the arm can reach. The orientation of the object can be random.
2. Grasp the object by orientating the arm, forearm, and wrist so that the end effector can effectively pinch the object.
3. Pick up the object off of the ground.
4. Repeat steps 1-3 a couple times with the object in slightly different orientations to make sure the end effector can get the object at different angles.
5. Repeat steps 1-4 with a larger diameter object until the max diameter is found.

Equipment

1. Cylindrical objects with various diameters. Largest needed outer diameter is 5 cm.

Results

The arm's end effector was able to grasp every object we gave it, up to 5.5 cm in diameter. Although this is larger than needed, we decided to test objects that ranged from 2 cm in diameter up to 5.5 cm to see the range of possibilities. The result was the same for each sized object we tested. The end effector was start to grasp the object and the rubber hand would successfully envelop the object. The linear actuators would get louder as they clamped the hand down until they reached a point where they shut off, but each time they had already moved far enough to firmly grasp the objects.

Conclusion

From this test we can safely conclude that the end effector can grasp objects ranging in size with the largest being 5.5 cm in diameter. This is larger that the largest object that will be given us in the competition. This qualifies the rover for the rating of excellent for this desirability goal.

G.45 MRD-TR-0036 R1: Delivering Object to Center of Rover Test

MRD-TR-0036 R1

Delivering Object to Center of Rover Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/18/2017	Arm	Time to move an object over the rover	Fail

Names of persons conducting test

Brian Jackson	Michael Farrell	Drew Warren	

Purpose

The purpose of this test is to verify the rover's ability to accomplish a portion of the extreme delivery task. The arm will have to take objects that it has picked up and drop them in a chute that will be close to the center of the rover. The time it takes to do this will affect the overall time it takes to accomplish this task, so measuring this value is important.

Method

The following steps should be followed for this test:

1. Move the arm to be directly forward from the rover. Extend the shoulder joints so that the end is as far away from the rover as possible.
2. Move the arm from that position until it is holding the object directly over one of the chutes.
   a. Start the timer as soon as the arm begins moving from the initial position
   b. Stop the timer as soon as the arm stops moving
3. Record the time.

Equipment

1. Accurate timer.

Results

The rover arm took 12 seconds to move the hand from a location behind the rover (in front of the arm workspace) to a spot over the chutes.

Conclusion

The time falls outside of the specified upper and lower limits but not by much. Moving the arm faster could decrease accuracy or lead to other problems. Additionally, the chutes are further away than we had originally planned so the extra couple seconds seem reasonable.

Attachments

This should be on a separate page and include any graphs, data, or other information that are too large for the main sections.

G.46 MRD-TR-0037 R1: Picking Up Objects Test

Picking Up Objects Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/18/17	Arm	Time to pick up screwdriver	Pass

Names of persons conducting test

Michael Farrell	Brian Jackson	Drew Warren	

Purpose

The purpose of this test is to test the rover arm's ability to effectively and quickly pick up objects. One of the four main tasks of the competition is the extreme delivery task, which requires the rover to pick up and deliver items. This test helps validate our ability to complete this task.

Method

To get a realistic value of the time it takes to pick up an object, the test must mimic everything as it would be in competition. That means the person controlling the rover and arm must be at the base station, viewing the objects through camera feed instead of being next to the rover.

1. Place a screwdriver somewhere in front of the rover (place in a different position each time, but make sure it is in view of the camera. Place the screwdriver in a place that the arm can reach without having to move the base)
2. Move the arm to its initial position. The arm should be facing straight forward with the both the shoulder and elbow joint fully contracted.
3. Begin moving the arm to pick up the screwdriver. As soon as the arm begins moving, have a team member next to the rover start a timer.
4. Pick up the screwdriver with the end effector.
5. Return the arm to the initial position. As soon as the arm returns to the initial position and stops moving, stop the timer.
6. Record the time.

Equipment

1. Screwdriver
2. Timer (can be a smartphone)

Results

The test was conducted twice, once with a screwdriver and once with a drill. The time to pick up the objects was 80 seconds and 39 seconds respectively.

The average time to pick up an object was measured as 59.5 seconds.

Conclusion

The measured time to pick up an object (59.5 s) falls within the acceptable range of 0 - 90 seconds. The time is still greater than the ideal time of 20 seconds, but with operator practice and the future implementation of inverse kinematics control, we are confident we can achieve 20 seconds.

Attachments

This should be on a separate page and include any graphs, data, or other information that are too large for the main sections.

G.47 MRD-TR-0038 R1: 3/25 Test

MRD-TR-0038 R1

3/25 Rock Canyon Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/25/17	Driving	Max Speed Incline before tipping	Pass Not enough data

Names of persons conducting test

Peter Schleede Mary Wilson Benjamin Hilton	Michael Farrell Garrett Jones	Brian Jackson Angus Cameron	Westley Barragan Jameson Marriott

Purpose

This test was to get values for several of the base desirability goals. It also was a chance to test the chicken-wire tread method.

Method

We first tried to test the rover going up an incline of loose dirt at Rock Canyon park.

After that, we tested the rover's maximum speed was tested by driving a 50 foot distance and hand timing it.

Results

Incline
The rover was able to drive up to a certain point until the back wheels (it was the same forwards or backwards) stalled. The front wheels would continue spinning and digging holes in the dirt. We hit the same angle in both directions. It was measured at 39 degrees at its steepest.

Max Speed
We conducted 3 tests, with times of 4.2, 3.7, and 3.8 seconds. These corresponded to speeds of 3.6, 4.11, and 4.01 m/s, respectively (and an average of 3.9 m/s).

The chicken-wire tread also got taken out by turning, mostly. Since the front and back wheels slip sideways as the rover turns, the wire was pulled off the wheels over time and wrapped around the struts.

Several wheel bolts also came out throughout the test.

Conclusion

We rate this as a pass for max speed (ideal requirement was 3 m/s). Max incline is rated as inconclusive because it didn't tip at 39, which is the wording of the goal, and we didn't test at a steeper slope than that. It does pass the good goal. The chicken-wire in its current configuration is insufficient. The wheel bolts also need a better way to lock them, but probably when we have finalized the motor positions.

G.48 MRD-TR-0040 R1: RPLidar Test

MRD-TR-0040 R1

RPLidar Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4-4-17	Navigation	Autonomous Navigation	Pass

Names of persons conducting test

Peter Schleede	Brian Jackson		

Purpose

This test had several purposes:

1 - test that the RPLidar ran easily and generated a significant amount of points
2 - test the servo code to sweep the RPLidar through a known angle
3 - test that points obtained while scanning and sweeping through an angle if they are real time
4 - test the mapping node and see if it creates a map that represents the terrain

Method

1 - download the RPLidar ros package, compile it, and run view-rplidar.launch
2 - use the dynamixel_control script with the lidar mounted on the dynamixel to see if it properly commands servo positions. Check that the tf transforms are correct by using tf_echo and physical intuition by adding a pseudo point being transformed
3 - watch the points on rviz as the lidar moves and look if the latency is significant. Determine if the latency is due to rviz or the scanner
4 - rosrun mapping map_class. See if the map created has points in expected places relative to the lidar, see if those points are assigned elevation values that make sense, and see if the map holds onto and continues updating points as it runs without moving.

Results

This test was a pass on all 4 accounts. The RPLidar package was easy to use and had quite a few points. The servo control was easy to run and the code could be modified. The transforms were initially not correct but by breaking them down into many small transforms, we got them to work. We noticed latency on the points in rviz as the lidar swept. We think that the latency comes partially from rviz because it is so graphics intensive. Sometimes, the latency was much less. It seemed, while watching the message counter, that sometimes messages would bottle up a bit. Using rostopic hz, we found that the lidar published scans at 2-2.5 Hz. This is less than its 10 Hz rotation rate and limits the frequency of the servo (must be less than or equal to 1 Hz for Nyquist sampling criterion). However, we believe that while running the rover in a slow mode, it will work fine. The mapping node made a gridmap pretty easily. It retained points and updated the map over time. We also tested standing in a range that it could see and having the scanner map our location. It did well. Objects were mapped out to the limits of the map at 2.5 meters behind and about 1 meter to the left of the lidar. We do not have a picture of this because Peter accidentally knocked the vice off the table and the lidar had the top half split from the bottom. We were able to put it back together and it seems to work fine. Rviz was quite slow and clunky displaying the gridmap. We think this is not a result of the gridmap because I had it sending a ROS_INFO message during each callback and it was sending it rapidly. It is probably a graphics things and having two rviz windows open.

Conclusion

While this does not necessarily fulfill any desirability goal, it is an important step on the way to autonomy. Knowing that the lidar can be used for mapping and having started writing a planning node, we can start giving the rover actual autonomous capability. We have tested the planning node to be able to take in the gridmap that is being generated by this and make a second map with inflated obstacles for planning. The next things that need to be done are:

1 - get the go to waypoint controller working on the rover
2 - get planner to check the current line it’s on to find out if the path is safe
3 - get A* algorithm working in planner
4 - modify map class so it does not add any ground (this is based on an average local ground plane)
5 - write a path manager

MRD-TR-0042 R1

Run Time & Distance on Full Battery Charge

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 8, 2017	Electrical	Run Time	Pass!

Names of persons conducting test

Garrett Jones	Taylor Greenwood	Angus Cameron	

Purpose

Run Time:
The purpose of this test is to test how long the rover will last with four batteries running the wheels and two running the electrical system. The goal is be to be able to run the rover for 75 minutes.

Distance on Full Battery Charge:
The purpose of this test is to test how far the rover will travel with four batteries running the wheels and two running the electrical system. The target goal is be to be able to run the rover for 1200 m. Minimum value: 1000 m, Ideal value: 1500 m.

Method

Equipment:

- 6 fully-charged batteries
- Rover
- Cell meter (Lipo Checker)
- Distance measuring wheel

Part 1

1. Plug in six fully-charged batteries into the rover.
2. Make sure cameras and other equipment are running at their competition maximum.
3. Drive continuously for ten minutes.
    a. Make sure the rover is driving in a way that we can measure the distance traveled.

   b. Have a team member walk by the rover, measuring the distance with a distance measuring wheel.
4. Stop the rover.
   a. Check the lipo battery percentage for each battery.
   b. Log the following information: distance traveled and battery percentage.
5. Drive continuously for five minutes.
6. Stop the rover.
   a. Check the lipo battery percentage for each battery.
   b. Log the following information: distance traveled and battery percentage.
7. Repeat steps 4-5 until the battery percentage is 15%.

*NOTE: Do not let batteries get below 15%! This is the minimum that should be reached before they stop working.

<u>Part 2 (this only measures Run Time).</u>

1. Plug in six fully-charged batteries into the rover
2. Make sure cameras and other equipment are running at their competition maximum.
3. Move the arm continuously for ten minutes.
4. Stop the arm and check the lipo battery percentage for each battery.
5. Move the arm continuously for five minutes.
6. Stop the arm and check the lipo battery percentage for each battery.
7. Repeat steps 4-5 until the battery percentage is 15%.

- Graph the results from the tests.
- Determine the maximum run time and distance the rover can travel.

Results

Distance traveled: 300 m
Each Drive Battery Percentages (before): 99%, 96%, 99%, 96%
Each Drive Battery Percentages (after): 82%, 83%, 74%, 75%
Run Time (overall): 1 Hour, 25 minutes
Run Time (drive): 20 minutes
Electronics Battery Percentages (before): 91%, 91%
Electronics Battery Percentages (after): 66%, 66%

Conclusion

Estimated Distance on full Battery Charge (drop to 15%) : 1363 meters
Estimated Run Time (drop to 15%) : 91 minutes
It passes!

G.50 MRD-TR-0044 R1: Temporary Electrical Connections

MDR-TR-0044 R1

Temporary Electrical Connections

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 8, 2017	Electrical	Temporary Electrical Connections	**Pass: Excellent**

Names of persons conducting test

Taylor Greenwood			

Purpose

This test is meant to address the following desirability goal: *Temporary Electrical Connections.* The purpose of this desirability goal is to **reduce (and ultimately eliminate) any connections that could unintentionally come apart** during testing, troubleshooting, the competition, or any other time. Reasoning behind this test stems from problems experienced by last year's team with connections separating while they worked in the box. Also, we struggled with poor connections coming apart while documenting and reverse-engineering their wiring at the start of our time on the team.

The target performance is set at the *excellent performance* measure: "**Fewer than 5% non-latching connections**". In this measure, latching is defined as a connection that could come apart unintentionally (e.g. with only 1 finger, or while adjusting nearby connections). Testing personnel should note this goal's relation to MRD-TR-0049, Performance Measure 5: *Force required to unplug a wire*.

Method

<u>Equipment:</u>

- Paper and pencil
- Calculator

Conducting this test should be very simple.

1. **Take an inventory** of all connections
    a. Count the number and type of each connection
    b. (e.g. 56 latching Molex connectors, 6 USB connectors, 10 screw terminals, etc.).
    c. Most of the connections are located inside the box, with a few located outside the box. Testers can use their discretion when deciding which connectors outside of the box will be taken into account.

2. Determine which connections are non-latching (i.e. non-secure).
    a. Reference Performance Measure 5.
3. **Find the percentage** using the following equation:
    a. ((total # of connections)-(# non-latching))/(total # of connections)

Results

The following type and number of connections was counted on the working rover, April 15, 2017. The force required to remove the connectors was calculated the same day. See MRD-TR-0049.

Latching or secure:

Battery connectors:	12
12V latching connectors:	20
Small molex latching connectors:	39
Ethernet:	2
USB:	6
Screw terminals:	16
Large 2x2 molex latching conn.:	5
Dynamixel connectors:	16
Screws in fuse box:	12
D-sub connectors:	8
Phoenix screw terminal connectors:	18
Relay spade connectors:	4
Lidar connector:	1
Total:	**159**

Non-latching, non-secure:

Small molex non-latching conn.:*	5
Barrel jacks:**	3
Total:	**8**

Percentage = (159)/(159 + 8)
= **95.21%** latching/secure connections.

*(12 oz force to unplug)
**(>16oz force to unplug, but still determined to be non-secure)

Conclusion

This test meets our ‘excellent’ specification of having fewer than 5% latching/non-secure connectors with 4.79%. This shows that the connections on the rover should not break during rover competitions, testing, or troubleshooting.

G.51 MRD-TR-0046 R1: System Reliability

MRD-TR-0046 R1

System Reliability

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 8, 2017	Electrical	System Reliability/Startup	Fail
Names of persons conducting test			
Taylor Welker	I		

Purpose

The purpose to this test is to both determine the number of the Rover initializes without error, and the proportion of times the rover's system crashes compared to the number of times the rover had no issues. We also want to catalog our issues, their symptoms, and the steps we took to fix it.

Method

Upon arriving at Hanksville and Rock Canyon for our testing. One person must log all attempts to start the rover. They must record the time, purpose, and result of startup procedure.

For every system failure, the time should be recorded, the actions that were being performed when the rover died, the relevant symptoms, the procedures for diagnosing the issue, and the conclusion. Also track the number of times the rover had no issues while testing (no shutdowns of any subsystem) in order to measure the ratio and reliability of our rover.

After the tests, we will compare the success and failures on startup and shutdown to obtain percentages for each.

Results

After running the experiments in two testing environments (Hanksville and Rock Canyon), we obtained the following results:

%Successful Startups: 4/7
%Successful Shutdowns: 0/6
%System Reliability: 4/13

The document listed in the Attachments section provides a spreadsheet documenting our tests, the reasons for failures, and the methods taken to fix them.

Conclusion

Our rover does not yet meet the requirements for performing at the competition. To take this rover to the competition in its current state would inevitably lead to system failures early on in each of the tasks.

Fortunately, we still have time to improve this, and we are beginning to address the issues that recur throughout our testing. When it comes to the electrical issues that we had (USB port burning), we are taking greater precautions to isolate the delicate electronics from the motors, providing the correct power requirements for each of our electrical components, and developing an electrical layout within the box that will prevent shorts from occurring. In regards to the communication, we have determined that our antenna is the problem, and are communicating with the manufacturer to determine the source of the errors.

In the end, additional testing will be necessary to prove that our rover is robust enough to handle the competition tasks.

Attachments

System Reliability Test Results

Time	Purpose	Success?	Reason for Failure	Symptoms	Method to fix
Hanksville Tests - April 8, 2017					
Startups					
Time	Purpose	Success?	Reason for Failure	Symptoms	Method to fix
10:36	First Test	Fail	FTDI not connected	The rover did not respond to commands	Connected FTDI
10:40	Init Test	Fail	Wheel motor locked when power in rover is on.	When the power was on, only one motor was locked up. When the power was off, the motor could spin freely	The motor driver for the wheel had its run/stop wire running to the freewheel port instead. The wiring was incorrect. Our temporary fix was to disconnect the motor completely, and let it spin freely without power.
11:58	Post wheel repair test	Success	-	-	-
12:05	Communications retest	Success	-	-	-
12:15	Communications retest	Success	-	-	-
12:22	Communications/science test	Success	-	-	-
Shutdown					
Time	Purpose	Success?	Reason for Failure	Symptoms	Method to fix
12:02	Failed communication	Fail	Rover did not move after rolling a few feet	The rover started rolling on initial communication, but then stopped and didn't reconnect	
12:06	Failed communication	Fail	Rover did not move after rolling a few feet	The rover started rolling on initial communication, but then stopped and didn't reconnect	
12:20	Failed communication	Fail	Rover did not move after rolling a few feet	The roller still has problems running its wheels, but its science module is completely operational.	Tried unplugging the ftdi and plugging it back in (did not work). Decided to begin carrying the rover for the science tests. Decided that the problem is with the code meant to control the wheels
12:30	Failed to switch to ethernet	Fail	Could not communicate after switching ethernet cables	After switching the ethernet cables, no communication with the Rover worked.	Decided that upon switching network cables, it is best to restart the rover.
Rock Canyon Test - April 13, 2017					
Startups					
Time	Purpose	Success?	Reason for Failure	Symptoms	Method to fix
8:47	Initial testing	Success	-	-	-
9:40	Incline test	Fail	No Communication	The Rover was not responding to Base Station Commands	After Unpluggin the FTDI board from the On-Board Computer's USB and plugging it back in, we began communicating properly.
9:43	Incline test	Success	-	-	-
Shutdown					
Time	Purpose	Success	Reason for Failure	Symptoms	Method to fix
9:28	Loss of communication. Generator died	Fail	The generator powering our base station stopped, and so we lost communication with the rover.	The generator sputtered to a stop.	After getting the generator back up, we were able to communicate again.
10:00	USB Hubs started burning	Fail	We believe that the USB hubs were drawing too much current from the single USB port on our On-Board Computer, as they were not being powered externally.	Smoke was rising out of the hub.	In the future, we must make sure to provide the usb hubs their own external power to avoid drawing too much current from the On-Board computer.

G.52 MRD-TR-0048 R1: Rover Turning Radius

MRD-TR-0048 R1

Rover Turning Radius

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/16/17	Base/Chassis	26	Pass

Names of persons conducting test

Michael Farrell			

Purpose

The purpose of this test is to determine the rover's turning radius (performance measure 26).

Method

1. Drive the rover onto Hanksville-like terrain
2. Mark the center of the rover on the ground
3. Turn the left and right wheels in opposite directions (i.e. left wheels forward, right wheels backward) until the rover has turned 90 degrees
4. Measure the distance from the center of the rover to the marking on the ground.

Equipment

- Measuring tape
- Marker (colored rock, tennis ball, etc.)

Results

The test was conducted at Rock Canyon park on dirt that provided similar traction to that found in Hanksville. After spinning the rover 10 times, no deviation was visible from its initial position. The rover tends to walk randomly as it spins. This walk appears random and minimal, leading to an average measurement of 0 meter deviation.

Conclusion

The effective turn radius of the rover is 0 m.

G.53 MRD-TR-0049 R1: Force to Unplug a Wire

MRD-TR-0049 R1

Force to Unplug a Wire

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 15, 2017	Electrical	Reliability, 4	**Pass: Excellent**

Names of persons conducting test

Taylor Greenwood			

Purpose

The purpose of this test is to determine the average, max, and minimum forces the current connectors on the rover can withstand before coming undone.

Lower Limit: 1 lb
Ideal: 2 lb
Upper Limit: 2 lb

Method

1. Attach a hand-held force scale device to one of two linked connectors.*
2. Pull on the device until the latch comes undone or the device reaches its max value.**
3. Repeat and average the results three times on each connector.

*The connection must hold the device onto the connector with a force greater than the force required to unplug the connection being tested.
**The opposing connector will need to be held or positioned so that it resists movement.

Equipment:
- Hand-held force scale

Results

The following data was collected:

Connection:	#	Average force to unplug
• Battery connectors:	12	>32 oz
• 12V latching connectors:	20	latching, >32 oz

Small molex latching connectors:	39	latching, >32 oz
Ethernet:	2	latching, >32 oz
USB:	6	>32 oz
Screw terminals:	16	>32 oz
Large 2x2 molex latching conn.:	5	latching, >32 oz
Dynamixel connectors:	16	latching, >32 oz
Screws in fuse box:	12	screwed in, >32 oz
D-sub connectors:	8	screwed in, >32 oz
Phoenix screw terminal connectors:	18	> 32 oz
Relay spade connectors:	4	>32 oz
Lidar connector:	1	latching, >32 oz
Small molex non-latching conn.:	*5*	*10 oz*
Barrel jacks:	*3*	*16-24 oz*
Total:	**167**	

Conclusion

The above data shows that the average force to unplug a connection is above the ideal value of 32 oz, with the minimum force at 10 oz. With the wide range of connections in the box and the changing wiring, achieving 100% of the connections above the 16 oz limit is near impossible. Instead, we are confident that the majority of the connections (>95%) are secure. As such, the average force (>32 oz) will be the value reported in the performance matrix.

It is important to note the connection between this document and MRD-TR-0044 R1 (which assesses the desirability goal of Temporary Electrical Connections). Only one type of connection on the rover falls below the lower limit (1 lb force), and the total number of temporary connections is below 5%.This remaining 5% will be secured before the competition.

G.54 MRD-TR-0050 R1: USB Cam Outdoor Gate Detection

USB Cam Outdoor Gate Detection

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/25/2017	Navigation	Navigate Autonomously	Fail

Names of persons conducting test

Westley Barragan			

Purpose

The purpose of this test was to see if the usb cameras are capable of detecting a tennis ball in the outdoors in natural sunlight.

Method

1. Place tennis ball on .5m mount outside of Fletcher Building (I used the tall antenna mount)
2. Mount a USB camera (I used the Logitech C500) to a chair and have it plugged into your laptop.
3. Run the gate detector node. I.e command - 'roslaunch gate_detector gate_detecor_test.launch' and then calibrate the detector using rqt_reconfigure. The window should pop up automatically.
4. When the detector is detecting the tennis ball and the tennis ball only, circle the target slowly and try to detect the ball from all angles.

Results

After changing the angle of view by just a few degrees, the built in auto exposure of the web cam would adjust the exposure of the image and therefore change the pixel value of the tennis ball in the frame. I would then have to recalibrate the HSV thresholds or return to my previous position to redetect the tennis ball.

Conclusion

The results show that using webcams with built in auto exposure is a faulty approach for gate detection. Some other approaches for gate detection that we have yet to try are using the ZED cameras 2D images (the ZED might have a setting that keeps it from autoexposing), using the RANSAC algorithm to find spheres in a pointcloud (we are working on obtaining pointcloud data with a laser scanner), or purchasing a robotics camera that is compatible with ROS that has control over the exposure (it would be a dedicated camera for only gate detection).

G.55 MRD-TR-0052 R1: Maximum Width of the Rover

MRD-TR-0052 R1

Max width of rover

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/7/17	Mechanical	Max width of rover	Pass

Names of persons conducting test

Mary Wilson			

Purpose

The purpose of this test is to verify that the rover can pass through gates and compete in all the of the competition task. For this test, we will test the desirability goal of max allowable width of the rover.

Method

This test can be conducted in the MSL. For this test, we will use a tape measure to measure the distance between the outer edge of each left wheel and the outer edge of each right wheel.

Step 1: Measure distance between left and right front wheel
Step 2: Measure distance between left and right middle wheel
Step 3: Measure distance between left and right back wheel
Step 4: Record the max distance

Results

The width of the rover is measured to be 43 in ~ 1.09 m

Conclusion

Since the max width of the rover is 1.09 m, which is less than the required 2 m for the competition, no further refinement is required for this desirability goal.

G.56 MRD-TR-0053 R1: Jetson Camera Test

MRD-TR-0053 R1

Jetson Camera Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
2/3/17	Vision	General Vision	

Names of persons conducting test

Michael Farrell	Westley Barragan		

Purpose

This test was to test 2 different things: the jetson running the rover, and the camera system running on the jetson. The general vision desirability goal is to have 6 camera views available at the base station at 15 fps.

Method

The jetson was placed in the rover, but with hard-wired power. We plugged a monitor into the jetson and ran all of the nodes on the jetson itself. After attaching three cameras onto the rover (with temporary connections), we launched the camera_hub.launch file from the “base” package. This launches the camera publishers. From RQT_imageviewer we could select the different camera views to see.

We also launched the two_controller.launch from the hal_control package and ran the onbaord_psoc node in order to run the rover. Though we did not move the rover a lot because of the hard-wired power, the node appeared to drive the wheels as expected.

Results

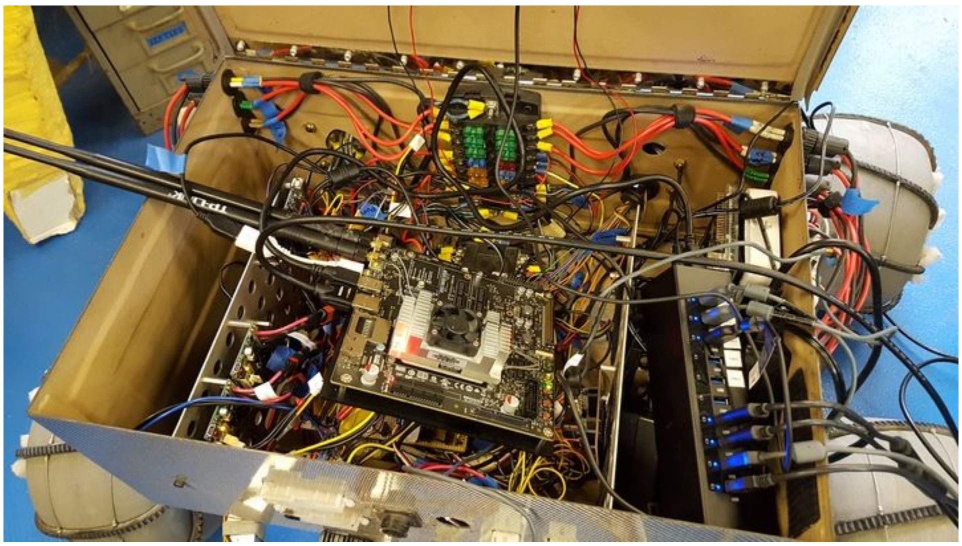
The images seen through RQT_imageviewer were very clear and fluid. The images appeared to be high enough quality to see necessary detail. The psoc node appeared to communicate correctly from the jetson to the psoc to move the wheels of the rover.

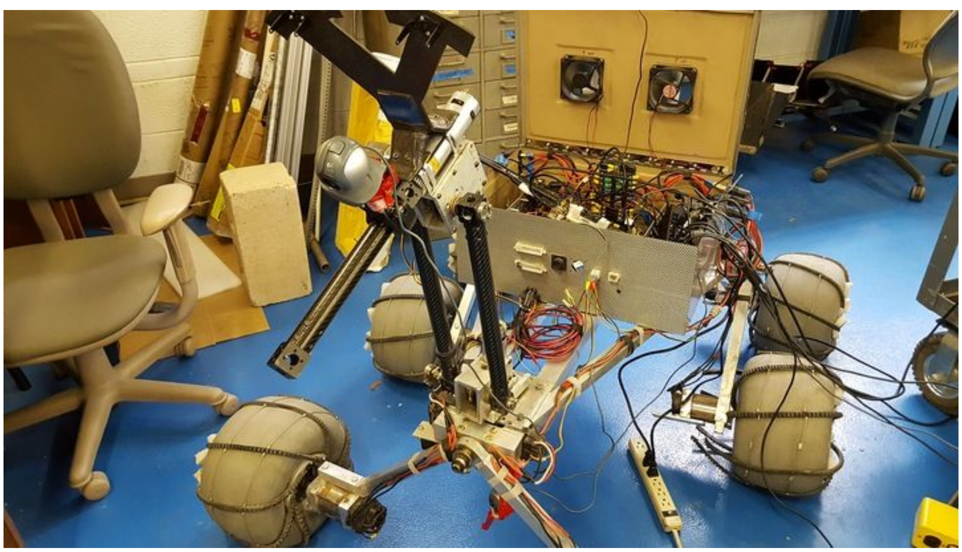
Conclusion

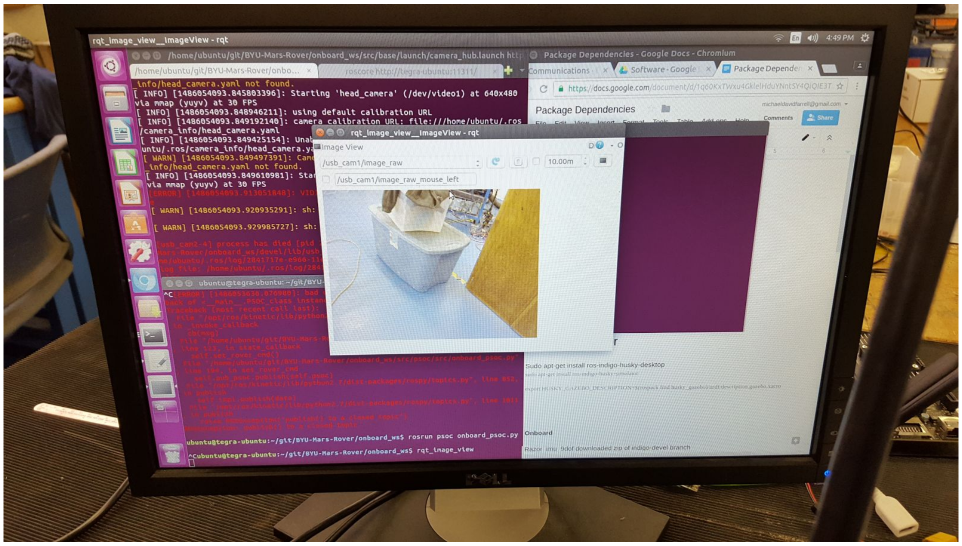
We can conclude that the necessary camera and psoc hardware can be successfully run from the jetson. This test did not include any remote network, so we cannot make any conclusions about the quality of images we will see from the ground station nor the quality of the drive control from the ground station. These network tests will be conducted at a later date.

Attachments

Images from test






rqt_image_view__ImageView - rqt
Package Dependencies - Google Docs - Chromium
Image View
/usb_cam1/image_raw
/usb_cam1/image_raw_mouse_left
Package Dependencies
Sudo apt-get install ros-indigo-husky-desktop
Onboard
DELL

G.57 MRD-TR-0056 R1: Percent FCC Rules Followed

MRD-TR-0056 R1

%FCC Rules Followed

Date	Subsystem	Related Desirability Goal	Pass/Fail
7 April 2017			

Names of persons conducting test

Benjamin Hilton			

Purpose

The purpose of this test is to determine if the rover communications system complies with FCC rules which is specified as a requirement by the competition.

Method

Read the rules of the competition and determine if the rover communications system complies with regulation.

Results

Since the antennas are commercially available, as long as they are set to the right country code they will comply with FCC regulations.

Conclusion

The communications system complies with FCC regulations.

G.58 MRD-TR-0058 R1: Antenna 1.6 km Test

MRD-TR-0058 R1

Antenna 1.75 km Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/15/2017	Communications		Pass

Names of persons conducting test

Benjamin Hilton	Brian Jackson		

Purpose

The purpose of this test is to retest the antenna. We believe that our design is good, but for some reason the communications system is underperforming, and we believe the Rocket to be damaged. The AUVSI team uses a Ubiquiti Picostation for communications and we compared it to our AMO-2G10/Rocket M2 setup. In every location it outperformed our AMO-2G10 antenna and Rocket M2 which led us to believe that one of our Rockets was damaged. For this test we replaced the Rocket on the rover. Assuming that the Rocket is the problem, this test will also validate our claim that the rover and base station can communicate at a distance of greater than 1 kilometer.

Method

For this test, we will station the base station at the parking lot of the Y Trailhead in Provo Utah. It is up on the mountains near BYU. The rover will be stationed in the parking lot between the Clyde Building and the Crabtree Building on BYU Campus. There is a clear path between the two locations. They are at a distance of 1.75 kilometers.

Results

Results were as expected, but an order of magnitude better than they had been with the damaged rocket. We reached speeds up to 4 Mbits/s and averaged about 3 Mbits/s, both of which are sufficient for rover communication and video. We were able to easily SSH into the rover from the base station on the mountain.

We also tested how well the rover could communicate out of line-of-sight. For this test, everything remained constant except the location of the rover. The rover was moved behind a building. We could also communicate, but communication was very spotty. We were able to receive 11 pings in a row before the communication dropped - a few seconds later we would get pings again. However, there are so many sources of interference between the two locations - we expect the communication to be slightly better in environments where there are no buildings and no other RF communication.

Conclusion

This test validates the claims made concerning the communication system. We selected for an “excellent” communications performance that the base station should be able to communicate with the rover at a distance greater than 1 kilometer and out of line-of-sight. This test validates that the rover can communicate out of line-of-sight at distances nearly double what we had hoped for. The communications is also clearly sufficient if there is a clear line-of-sight.

Attachments

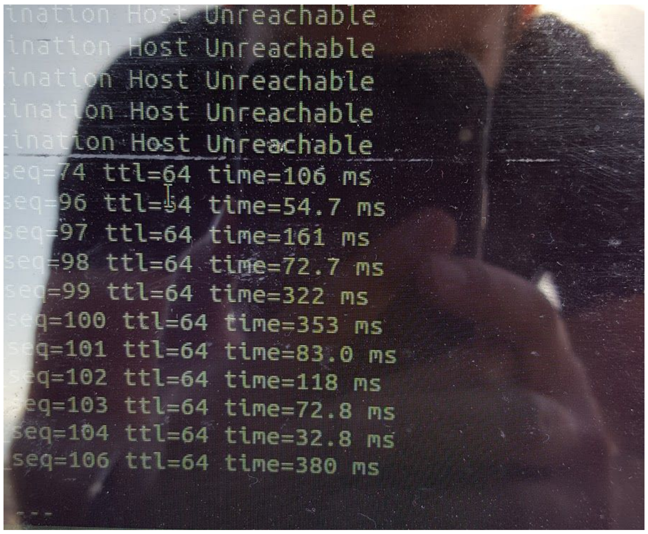


Image showing the pings that we received when the rover was out of line-of-sight at a distance of 1.6 km.

Image showing the setup of the test.

G.59 MRD-TR-0059 R1: Run ZED with Multiple Cameras and Camera Gimbal

Run Zed with multiple cameras and camera gimbal

Date	Subsystem	Related Desirability Goal	Pass/Fail
4-12-2017	Navigation	Navigation/Science	Pass

Names of persons conducting test

Westley Barragan			

Purpose

The purpose of this test was to see how the system reacts when running the ZED camera, multiple webcams through the USB hub, and the camera gimbal. We were having issues with not being able to run the ZED through the USB3.0 hub so I wanted to test different configurations of USB hubs and test if there is a different configuration that would allow us to run multiple cameras with the ZED.

Also, the science team would like to use both USB cameras and ZED simultaneously for the science cache task so this test will be verifying this configuration's performance capabilities.

Method

Materials:
1. ZED
2. Gimbal
3. Base Computer
4. ROVER
5. 3 webcams
6. 4-port USB3.0
7. 10-port USB2.0
8. USB2DYNAMIXEL converter

Process:
1. Turn on Rover, ssh into jetson and source all the `devel/setup.bash` files in all workspaces. See

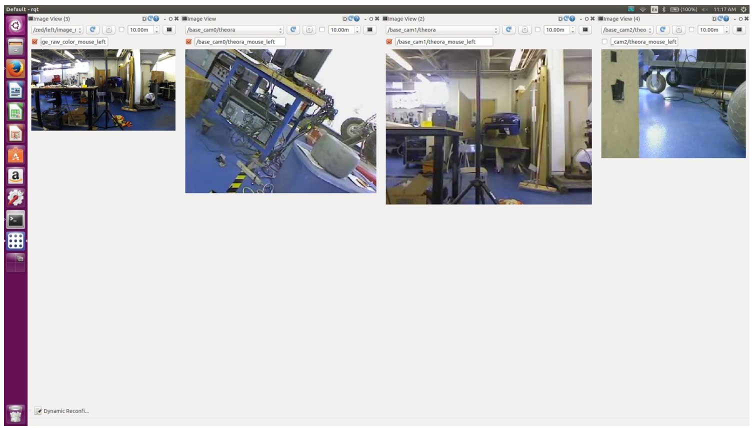
https://github.com/BYUMarsRover/BYU-Mars-Rover/wiki/Running-the-Rover to see how to set up Rover.

2. Connect the ZED to the USB3.0 hub, the cameras and dynamixel converter to the USB2.0 hub. The USB2.0 hub to the USB3.0 hub, and the USB3.0 hub to the Jetson USB3.0 port
3. On the Jetson, run in the terminal `ls /dev/video*` to make sure all your cameras are connected.
4. On the Jetson, run in terminal `ls /dev/ttyUSB*` to make sure all your USB devices are connected. You can unplug the dynamixel converter and rerun the command to see what port the converter is on in case you need to change which port the dynamixel controller points to. (we still need to make dev rules for our devices)
5. On the Jetson, run `roslaunch base camera_hub.launch` to run all the cameras
6. On the Jetson, run `roslaunch zed_wrapper zed.launch` to run the zed and wait for it to initialize
7. On the Jetson, run `rosrun dynamixel_control dynamixel_publisher.py` to run the gimbal
8. On the base computer, run `roslaunch hal_control drive.launch’, to run the drive controller
9. On the Jetson, run `rosrun rqt_gui rqt_gui`, and add image_view plugins and subscribe to the following topics
    a. /zed/lef/image_raw_color
    b. /base_cam0/theora
    c. /base_cam1/theora
    d. /base_cam2/theora

I was then able to cycle through the webcam video feeds by pressing the “A” button on the xbox controller and control the gimbal with the direction pad. I ran this configuration for about 30 minutes without driving, indoors, hardwired to the rover via ethernet.

Results

Rqt_gui subscribing to all desired images:



Left to right: /zed/left/image_raw_color, /base_cam0/theora, /base_cam1/theora, /base_cam2/theora

When the zed was a continuous feed, I was able to successfully toggle through the webcams.

/zed/left/image_raw_color bandwidth:

/zed/left/image_raw_color received frame rate:

```
        mean: 2.76MB min: 2.76MB max: 2.76MB window: 100
average: 3.87MB/s
        mean: 2.76MB min: 2.76MB max: 2.76MB window: 100
average: 3.86MB/s
        mean: 2.76MB min: 2.76MB max: 2.76MB window: 100
```

```
average rate: 1.373
        min: 0.712s max: 0.770s std dev: 0.01065s window: 39
average rate: 1.373
        min: 0.712s max: 0.770s std dev: 0.01051s window: 40
```

/base_cam0/theora bandwidth when publishing:

```
        mean: 0.39KB min: 0.05KB max: 16.62KB window: 100
average: 9.73KB/s
        mean: 0.39KB min: 0.05KB max: 16.62KB window: 100
average: 5.55KB/s
        mean: 0.22KB min: 0.05KB max: 16.60KB window: 100
```

/base_cam0/theora bandwidth when not publishing

```
        mean: 283.79B min: 51.00B max: 11083.00B window: 100
average: 12.10B/s
        mean: 283.79B min: 51.00B max: 11083.00B window: 100
average: 12.09B/s
        mean: 283.79B min: 51.00B max: 11083.00B window: 100
```

/base_cam0/theora frame rate when publishing:

```
average rate: 25.266
        min: 0.000s max: 0.074s std dev: 0.00953s window: 299
average rate: 25.265
        min: 0.000s max: 0.074s std dev: 0.00932s window: 324
```

Conclusion

Based on the results, we can conclude that this is a reliable configuration. However, we still will need to test in a competition environment, transmitting images over wifi and driving over rough terrain to assure that no disconnections or breaks occur. The ZED is still not well-suited for navigation but its images are far superior to the webcams and will be used for the science task capturing images of samples and panorama views. The gimbal feature is very nice and would be worthwhile to design a webcam-to-gimbal interface for general navigation.

G.60 MRD-TR-0061 R1: Rock Canyon Test 2: New Base/Motors, Comms

MRD-TR-0061 R1

Rock Canyon Test #2

Date	Subsystem	Related Desirability Goal	Pass/Fail
3/16/2017	Testing		Pass

Names of persons conducting test

Michael Farrell	Benjamin Hilton	Josh Brinklow	

Purpose

This test was the first time we drove the new rover. We intended to test how well the rover operates as a whole. The rover did not have treads on it yet, and we intended to see how well the rover would drive without treads.

Method

We set up the rover in the parking lot at Rock Canyon Park initially. We drove the rover around, getting a feel for the speed of the rover, how it handles, etc. The rover (according to the operator) drives much smoother than the previous year's rover. The motors are almost silent. The rover can clearly reach higher speeds. We drove the rover up the hiking trail to test the communications systems and the cameras.

Results

The results were not concrete, because we did not collect data. The communications system performed well at an impressive distance, and camera feeds were clear. However, when the antenna was more than a little out of line of sight, the communication dropped to basically nothing. It was also made clear to us that the rover wheels do need treads to operate in rocky environments.

Conclusion

All subsystems on the rover work. The rover drives well. Treads are necessary.

G.61 MRD-TR-0062 R1: Rock Canyon Test 1: Wireless Drive and Cameras

MRD-TR-0062 R1

Rock Canyon Test #1: Wireless Drive and Cameras

Date	Subsystem	Related Desirability Goal	Pass/Fail
2/16/17	Communications/ Vision	General Vision	Fail

Names of persons conducting test

Michael Farrell	Benjamin Hilton	Westley Barragan	Angus Cameron

Purpose

We took the rover to rock canyon to test the general vision desirability goal. The target performance for this test was 15 fps video from the onboard cameras at a resolution of 480x640.

Method

We set up the ubiquiti antenna and base station on a little hill overlooking the parking lot with the idea of driving the rover up the hill and then around the trails with the onboard cameras. To control the rover we were using the “drive” launch file and a single xbox controller. The camera system was launched on the rover and viewing of the cameras was done in rqt_imageviewer. The camera hub and switching with the xbox controller was not yet implemented.

Results

Many problems presented themselves during this first remote test with the rover. The first problem was the wireless connection. Though the ubiquiti rockets appeared to be connected, we could not ping the rover. We decided to push the rover up the hill and start the test with a wired ethernet connection. After connecting the ethernet cable, we were able to drive the rover as expected. We did not test the cameras with the wired connection.

We then tried the ubiquiti network again and were able to wirelessly drive the rover. While driving up the trail, within eyesight, the left middle wheel and motor fell off. We bolted the wheel and motor back on and started up the cameras on the rover. We attempted to drive the rover while looking at the camera feed, but the feed was very spotty. The cameras would stream to the base station and look clear for a few seconds and then they would freeze. While the cameras were running, the drive commands were also very spotty. Sometimes we would move the xbox joy sticks and the rover would not react at all, other times the reaction would be a few seconds delayed.

Conclusion

The ubiquiti wireless network needs to be more extensively tested. We need reliable connection between the ground station and rover. The camera nodes should be tested to ensure that we are not using too much bandwidth. The wheels and motors need to be secured to the frame better (it currently appears that each motor is held to the frame with only two or three threads of the bolts).

G.62 MRD-TR-0063 R1: 4/15 Marigold Quad Test

MRD-TR-0063 R1

4/15 Marigold Quad Test

Date	Subsystem	Related Desirability Goal	Pass/Fail
April 15, 2017	All		**Some pass, some fail**

Names of persons conducting test

Peter Schleede	Brian Jackson	Angus Cameron	Benjamin Hilton

Purpose

This test was a general test of the rover on different surfaces and had the goal of testing the waypoint go-to-goal controller. However, it ended up being more of a survey of the rover's state and driving response.

Method

For this, we took it out to the Marigold Quad and drove it around on both the grass and concrete for a while. That's about it.

Results

This was the first test after Ben talked to Ubiquiti about how to improve the throughput on the antenna. The antenna was very close and acted mostly like just plugging in an Ethernet cable. The communications were still strong driving the rover around, out of line-of-sight north of the Clyde. The USB hub wasn't working so we did not send any images.

As far as the driving, we found that the rover tends to pull to the left while driving. It wasn't entirely repeatable, but happened on most driving trials. This may have been more pronounced on concrete than on grass but, because the grass was farther away, that is hard to tell.

The rover was wholly inadequate on the grass and could rarely turn. In addition, at least one wheel on the rear rockers would come up each time we turned and sometimes even get stuck up until driving more. Overall, the wheels seemed to really struggle with getting enough torque to turn. It was difficult, even on concrete, and often didn't work without already driving. In addition, we could easily stall out wheels with our hands.

Two of the treads eventually ripped off and some others had broken segments of their chicken wire. This probably happened from the concrete and may not be so big of a problem at the competition. In addition, the V-belt seemed to be great at providing initial traction. Wheels never spun in place as they accelerated.

We did not test the controller because the estimator stopped working after a little bit.

Conclusion

This test showed great communications by changing the settings. We rate that as a pass towards a larger-scale test. The estimator clearly failed. The wheels also failed general driving performance. We rate the treads a pass because, even though two were ripped off, we were driving them in adverse conditions and at least one of those was already loose. The V-belt worked very well and we believe that the chicken-wire/V-belt combination will be effective at the competition. However, we should have some pre-built, new treads ready to install after every task.

G.63 MRD-TR-0064 R1: HSV Values for World and Tennis Ball

HSV Values for World and Tennis Ball

Date	Subsystem	Related Desirability Goal	Pass/Fail
4/11/17	Vision and Sensing	Navigation	Pass

Names of persons conducting test

Westley Barragan	Seth Nielsen		

Purpose

In order to better detect a tennis ball, we recorded video outside around campus in both sunlight and shade to get the range of hue, saturation and value number ranges for what is a tennis ball and what is not (the “world”).

Method

We made our own camera rig by placing a long pole on a cart, taping a tennis ball to the end of the pole, and then mounting a usb camera onto a GoPro mount on the cart. This way we could travel to different locations on campus while maintaining the tennis ball’s location in the video frame for easy selection of the pixels that will be recorded as being the tennis ball. Several videos were recorded and the script get_hsv_vid.py was used to select a rectangular area of pixels to be the “tennis ball”. Then, the same video was edited with a black square placed over the tennis ball, and the entire frame was selected to be the pixels that are the “world”. A 3D histogram of the tennis ball vs. the world was made in MATLAB.

Results

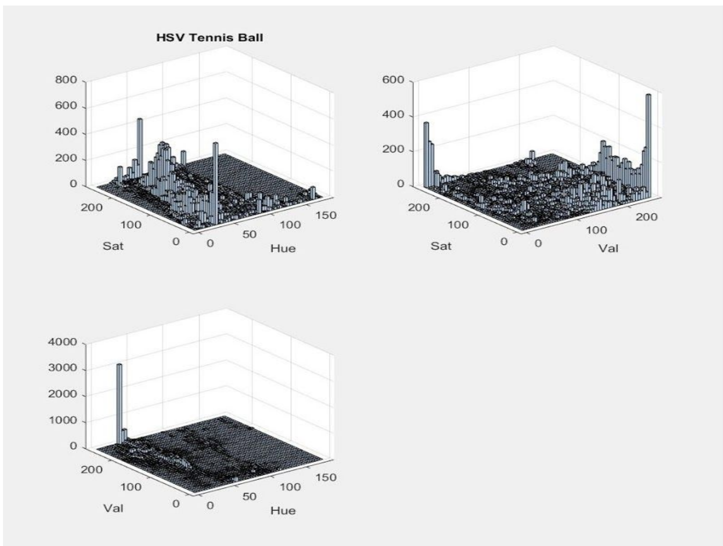
A fairly well-defined band along the Sat-Hue histogram was observed for the tennis ball which was not found in the world histogram (see attachment). The histograms for Hue-Val and Sat-Val did not have easily identifiable differences.

Conclusion

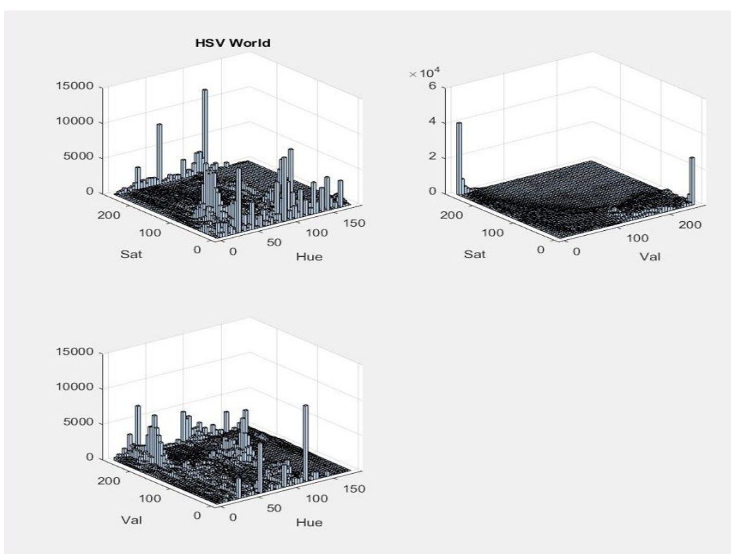
The pixel data received for saturation and hue could potentially be used to separate the tennis ball from the background. The histograms should be made for the other videos recorded as well in order to confirm the observed relationship.

Attachments

Tennis ball:



World:



H Recommendations to Future Teams

These recommendations were compiled by current team members to next year's team. Some focus on specific subsystems, while others are more general. Two were repeated by multiple team members. The first was to document early and consistently throughout the process. The other was to not redesign or re-manufacture the whole rover. Next year's team should remember that these are recommendations. Many are valuable advice that will improve their capstone experience and maximize performance of the rover. Some are speculation and things to be considered, especially when it comes to individual items.

H.1 2016–2017 Advice to Next Year's Team

- Make decisions on sensors quickly. You won't really know how it works until you have it in your hands
- Have several people who are running the rover at least once a week during both semesters
- Dividing up by subtasks is good but those large groups need to be subdivided again because having two people working on week-long tasks works really well
- Check in often so that people don't spend weeks or months struggling with things that someone else can solve for them
- Don't base all sensor decisions off internet research. Ask professors and others that use the equipment to see if it will actually work for our application.
- Use plastics lab to create custom treads to be attached to the wheels.
- Measure twice, cut once
- Make the base smaller to allow more wiggle room for weight
- Get a faster (and better) Lidar. Focus on getting good quality sensors from the beginning.
- Do a structural analysis on the base to determine actually how big each pipe needs to be
- Get the motors further into the wheels to avoid hitting them on rocks
- Get the biggest wheels possible
- Don't try to redo the whole rover
- Make sure the electrical connections are secure and reliable
- Actually do documentation for an hour each week instead of all at the end
- Make decisions earlier so the electrical team has an easier time planning and organizing their system
- Double-check each other's work while developing. A second set of eyes catches mistakes earlier

- Make test stands, or ways to test the arm, science independent of the rover!
- Design even more PCB design to reduce our number of wires
- Possibly try integrating SLAM
- Get stuff running over the antennas in the first semester, keep doing everything wirelessly
- Do everything in your power to impel yourself to have at least a crappy prototype of every subsystem at the end of the first semester
- Make the new arm quickly and focus on what is weak. For instance, if, at the competition, the linear actuators work great, do not in any way change that or brainstorm because it is wasteful of time
- Keep full team meetings short
- Volunteers are more useful second semester when you know what you want them to do
- Figure out how to control power surges and shorts
- Make the system more robust so we fry less components
- Get motors with an integrated drive system (that way we don't need the motor drivers)
- Possibly buy Maxon motors next year. They're expensive, but affordable if we're not buying everything else
- Get the video done early. Make it really good, since it becomes part of your score and it allows you to compete in the competition. It also helps you progress and get things done for the video.
- Plan a mock competition in early March.
- Keep a log of known issues, their priorities, and focus your work to completely resolve them.
- Take the rover out in September and get a feel for where things are and what has to change versus what would be nice to change. (Maybe go do a mock-competition in September)
- Consider using a documentation database (free options available online). 300 pages of documentation gets hard to keep track of.
- When determining desirability goals and performance measures, also create test procedures to go with them. This will help to clarify your goals and give you something to work towards.
- Check for the weight of the entire design early and often. It may be a very rough estimate at first, but needs to be as good as possible (including wiring and fastener estimates).
- Using sharelatex worked great for us to help our report be clean and well-organized. Feel free to use our code as a template.

- We have done our best to document every part of the rover, including parts that we didn't design or change. If you find holes in our documentation, please fix the problems and pass that knowledge on to future teams.

H.2 Repeated Items

- Documentation early (x2)
- Don't redo the whole rover (x3)

I Design Package

I.1 Bill of Materials

Table 5: Arm bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	CF Tube ForeArm	Rock West Composites	46406	18(in)
2	main erector block	Rock West Composites	CE10-MB-01	6(ea)
3	Dynamixel Servo	Robotis	mx-64AR	2(ea)
4	Carbonnect - Main Block with One Adapter	Rock West Composites	CE10-MB-05	7(ea)
5	Shaft Collar	McMaster-Car		5(ea)
6	Main erector cylinder	Rock West Composites	CE10-AD-05	5(ea)
7	CF Tube lower arm	Rock West Composites	46406	28(in)
8	Torxis Servo	GearWurx / Invenscience LC	i00600	1(ea)
9	1.5 in. Aluminum Channel	ServoCity	585440	1(ea)
10	1/4 in. Bore Shaft Mount Bevel Gears - 24 teeth	ServoCity	615398	3(ea)
11	1/4 in. SS D-Shafting	ServoCity	634094	(ea)
12	1/4 in. Bore Side Tapped Pillow Block	ServoCity	535130	1(ea)
13	Feedback Rod Linear Actuators - 12V / 200 lb / 8 in.	Firgelli Automations	FA-PO-240-12-8	1(ea)
14	Feedback Rod Linear Actuators - 12V / 200 lb / 6 in.	Firgelli Automations	FA-PO-240-12-6	1(ea)
15	MB1 Bracket	Firgelli Automations	MB1	3(ea)
16	99:1 Metal Gearmotor 25Dx54L mm HP 12V with 48 CPR Encoder	Pololu Corperation	3219	1(ea)
17	Bearing Small	ServoCity	535198	2(ea)
18	Flanged Sleeve Bearing for 3/8 in. Shaft Diameter	McMaster-Carr	6338K312	10(ea)
19	Clamping Shaft Collar	McMaster-Carr	6157K13	2(ea)
20	Base-Mounted Shaft Support	McMaster-Carr	1865K2	2(ea)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
21	Thrust Bearing for 3/8 in. Shaft	McMaster-Carr	5906K533	2(ea)
22	Carbonnect - Attach Bracket Kit	Rock West Composites	CE10-AB-05	7(ea)
23	1/4 in. to 4mm set screw shaft coupler	ServoCity	625118	2(ea)
24	120mm Lazy Susan Aluminum Bearing	VXB	KIT12876	1(ea)
25	Lightweight Linear Actuator Mounting Bracket	ServoCity	585428	1(ea)
26	Actuator Mount - 90 Dual Side Mount C	ServoCity	585504	2(ea)
27	Actuator Mount - 90 Dual Side Mount E	ServoCity	585596	2(ea)
28	Actuator Mount Tower - Bracket A	ServoCity	585484	1(ea)
29	Actuator Mount - 90 Angle Bracket	ServoCity	585532	2(ea)
30	Middle Bracer - Attachment for actuator to Arm	PLM/ME Shop	MRP-ARM-0001 R1	2(ea)
31	Elbow Bracer - Attachment for Actuarot to Arm	PLM/ME Shop	MRP-ARM-0002 R1	1(ea)
32	AttachBracketInsideModified	PLM/ME Shop	MRP-ARM-0003 R1	1(ea)
33	Wrist Mounting Bracket	PLM/ME Shop	MRP-ARM-0004 R2	1(ea)
34	Base Plate	PLM/ME Shop	MRP-ARM-0005 R1	1(ea)
35	Bottom Plate	PLM/ME Shop	MRP-ARM-0006 R1	1(ea)
36	Bottom Plate 2	PLM/ME Shop	MRP-ARM-0007 R1	1(ea)
37	Shaft Support	PLM/ME Shop	MRP-ARM-0008 R1	2(ea)
38	Wrist Coupler	PLM/ME Shop	MRP-ARM-0009 R1	1(ea)
39	Shaft Motor Joint	PLM/ME Shop	MRP-ARM-0010 R1	2(ea)
40	316 Stainless Steel Washer for M5 Screw Size 5.3 mm ID 10 mm OD	McMaster-Carr	90965A160	8(ea)
41	Hex Drive Rounded Head Screw Black-Oxide Alloy Steel 10-32 Thread Size 1/2 in. Long	McMaster-Carr	91255A265	6(ea)
42	Screw - 6-32 Thread Size 1/4 in. Long	McMaster-Carr	91251A144	28(ea)
43	Hex Nut - 6-32 Thread Size	McMaster-Carr	90760A007	6(ea)
44	Hand Attachment Piece	Custom Made	MRP-ARM-0011	1(ea)

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	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
45	Hand Crossbar	Custom Made	MRP-ARM-0012	1(ea)
46	Finger	Custom Made	MRP-ARM-0013	2(ea)
47	Socket head Cap Screw	McMaster-Carr	91255A146	58(ea)
48	Socket head Cap Screw - Bracer	McMaster-Carr	92949A196	6(ea)
49	SCREW 3/8-16 X 1/2 in	McMaster-Carr	91251A619	6(ea)
50	Screws 8-32 - 5/8 in. Long	McMaster-Carr	90272A196	6(ea)
51	Screw 1/4 in.- 20 - 5/8 in. Long	McMaster-Carr	92220A184	2(ea)
52	Steel Nylon Locknut 8-32	McMaster-Carr	90631A009	4(ea)
53	Shoulder Screw 2-1/4 in. 10-24	McMaster-Carr	91259A104	2(ea)
54	Ultra-Low-Friction Dry-Running Sleeve Bearing	McMaster-Carr	2706T13	4(ea)
55	Black Diamond Neutrino Carabiner	Amazon	BD210230BLUEALL1	1(ea)
56	USB2Dynamixel	Robotis	902-0032-001	1(ea)
57	SMPS2Dynamixel	Robotis	902-0034-000	1(ea)

Table 6: Base station bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Netgear Router	Netgear	GS105NA	1(ea)
2	Antenna and mount	Ubiquity	AM-2G10	1(ea)
3	Ubiquity Rocket M2	Newegg	0ED-0005-00081	1(ea)
4	Gigabyte Brix Ultra Compact PC Intel i5 processor	Amazon	B00FNPCL36	1(ea)
5	Dell Monitor	Amazon	B01LWINT3K	2(ea)
6	Keyboard and Mouse	Amazon	B003NREDC8	1(ea)
7	Ubiquiti POE injector	Amazon	B00NRHNPUA	2(ea)
8	LyxPro Tripod Stand	Amazon	B01BO2RBKE	1(ea)
9	Wired Xbox USB controller	Amazon	B01F9B019Y	2(ea)
10	Cable Matters Shielded Ethernet Cable 50 Ft	Amazon	160012-BLK-50	1(ea)
11	Cable Matters Shielded Ethernet Cable 7 Ft	Amazon	160012-7x5	1(ea)
12	Cable Matters Shielded Ethernet Cable 1 Ft	Amazon	160012-1x5	2(ea)

Table 7: Chassis bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Base Back Beam	Custom Made	MRP-CHA-0001 R1	1(ea)
2	Base Center Beam	Custom Made	MRP-CHA-0002 R1	2(ea)
3	Base Front Beam	Custom Made	MRP-CHA-0003 R1	1(ea)
4	Base Angled Beam	Custom Made	MRP-CHA-0004 R1	2(ea)
5	Front Angle Bracket	Custom Made	MRP-CHA-0005 R1	3(ea)
6	Front Arm	Custom Made	MRP-CHA-0006 R1	6(ea)
7	Rear Axle	Custom Made	MRP-CHA-0007 R1	1(ea)
8	Front Bushing	Custom Made	MRP-CHA-0008 R1	2(ea)
9	Rear Angle Bracket	Custom Made	MRP-CHA-0009 R1	1(ea)
10	Rear Arm Long	Custom Made	MRP-CHA-0010 R1	2(ea)
11	Rear Arm Short	Custom Made	MRP-CHA-0011 R1	2(ea)
12	Rear Bushing	Custom Made	MRP-CHA-0012 R1	1(ea)
13	Stop Pin	Custom Made	MRP-CHA-0013 R1	(ea)
14	Wheel Adapter Plate	Custom Made	MRP-CHA-0017 R1	6(ea)
15	Motor Mounting Bracket	Custom Made	MRP-CHA-0018 R1	6(ea)
16	Front Suspension Bearing	Custom Made	MRP-CHA-0019 R1	2(ea)
17	Rear Suspension Bearing	Custom Made	MRP-CHA-0020 R1	1(ea)
18	Front Axle	Custom Made	MRP-CHA-0021 R1	1(ea)
19	Rear Angle Bracket	Custom Made	MRP-CHA-0022 R1	1(ea)
20	U Bracket	Custom Made	MRP-CHA-0023 R1	1(ea)
21	Square Side Bracket 1.15	Custom Made	MRP-CHA-0024 R1	1(ea)
22	Square Side Brakcet 1	Custom Made	MRP-CHA-0025 R1	1(ea)
23	Square Middle Support	Custom Made	MRP-CHA-0026 R1	2(ea)
24	Front Bearing Housing	Custom Made	MRP-CHA-0027 R1	2(ea)
25	Rear Bearing Housing	Custom Made	MRP-CHA-0028 R1	1(ea)
26	Front Arm Weld	Custom Made	MRP-CHA-0030 R1	2(ea)
27	Brushless Motor with Planetary Gearbox	Anaheim Automations	BLWRPG235S-24V-4000-R18	6(ea)
28	Screw - 5/16 in.-18 - 1-1/2 in. Long Fully Threaded	McMaster-Carr	92240A587	4(ea)
29	18-8 Stainless Steel Hex Nut 5/16 in.-18	McMaster-Carr	91845A030	4(ea)
30	Washer for 5/16 in. Screw Size	McMaster-Carr	90107A030	4(ea)
31	Hex Nut - 1/4 in.-20 Thread Size	McMaster-Carr	91845A029	4(ea)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
32	Wheel Motor Interface	McMaster-Carr	9723T14	6(ea)
33	Wheel Screw - 92198A564	McMaster-Carr	92198A564	24(ea)
34	Wheel nut - 91845A029	McMaster-Carr	91845A029	24(ea)
35	Motor Bracket Screw - 92314A838	McMaster-Carr	92314A838	12(ea)

Table 8: Communications bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Rocket M2	Ubiquiti	RM2 2.4 GHz Rocket 2x2 11n MIMO CPE AirMa	1(ea)
2	Netgear Router	Netgear	GS105NA	1(ea)
3	IMU	Razor	10736	1(ea)
4	GPS	Spark Fun	12751	1(ea)
5	SMAKN 24V converter (step-up)	Amazon	B00VRAQZVK	1(ea)
6	POE injector	iCreatin	6445796	1(ea)
7	Ubiquiti Airmax Omni AMO-2G10	Ubiquiti	AMO-2G10	1(ea)

Table 9: Electrical bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Battery	Turnigy	N5000.3S.35	6(ea)
2	Kill Switch	IDEM	ES-P-230002	1(ea)
3	Fuse box	Blue Sea Systems	5026	1(ea)
4	DC Relay 12V 100A	Ehdis	2C09-12V	1(ea)
5	USB-A Metal panel jack	GT Contact	GT216300-05-Z6	6(ea)
6	Texalium Fiberglass Fabric	Rock West Composites	Rock West - 13014-D	1(ea)
7	Rhino 1411 Epoxy Resin	Plastics and Composites Lab	1411	1000(bulk)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
8	Carbon Fiber Plain Weave Fabric	Plastics and Composites Lab	3K plain dry fabric	2(ea)
9	Loctite E-40HT Hysol - 50 mL	Rock West Composites	1025	2(ea)
10	Carbon Fiber Plain Weave Prepreg	Rock West Composites	14014	4(ea)
11	Piano Hinge	Home Depot	SKU no 594641	20(ea)
12	Tx Rx wire	Custom Made	MRP-ELE-0001 R1	11(ea)
13	5V Signal wire	Custom Made	MRP-ELE-0002 R1	3(ea)
14	Battery Connection wire	Custom Made	MRP-ELE-0007 R1	6(ea)
15	Parallel Battery Connector	Custom Made	MRP-ELE-0008 R1	3(ea)
16	Dynamixel 3-pin wire	Custom Made	MRP-ELE-0009 R1	4(ea)
17	Voltage Board wire	Custom Made	MRP-ELE-0010 R1	2(ea)
18	GPS wires	Custom Made	MRP-ELE-0011 R1	1(ea)
19	MotA-B wires	Custom Made	MRP-ELE-0012 R1	1(ea)
20	Chute Enable wire	Custom Made	MRP-ELE-0013 R1	4(ea)
21	IMU wires	Custom Made	MRP-ELE-0014 R1	1(ea)
22	Pololu 12V wire	Custom Made	MRP-ELE-0015 R1	5(ea)
23	Jetson 12V power	Custom Made	MRP-ELE-0016 R1	1(ea)
24	USB Hub 12V power	Custom Made	MRP-ELE-0017 R1	1(ea)
25	Relay connector	Custom Made	MRP-ELE-0018 R1	1(ea)
26	Relay Enable wire	Custom Made	MRP-ELE-0019 R1	1(ea)
27	Kill Switch 12V wire	Custom Made	MRP-ELE-0020 R1	1(ea)
28	Drive Wheel wire	Custom Made	MRP-ELE-0021 R1	6(ea)
29	5V Power wires	Custom Made	MRP-ELE-0022 R1	2(ea)
30	12V Power wire	Custom Made	MRP-ELE-0023 R1	9(ea)
31	24V Power wire	Custom Made	MRP-ELE-0024 R1	6(ea)
32	DW Single cable	Custom Made	MRP-ELE-0103 R1	2(ea)
33	DW Double cable	Custom Made	MRP-ELE-0104 R1	2(ea)
34	Lin Act cable small	Custom Made	MRP-ELE-0105 R1	1(ea)
35	Lin Act cable large	Custom Made	MRP-ELE-0106 R1	1(ea)
36	Gimbal cable	Custom Made	MRP-ELE-0107 R1	1(ea)
37	Wrist and Hand cable	Custom Made	MRP-ELE-0108 R1	1(ea)
38	Dynamixel Lidar cable	Custom Made	MRP-ELE-0109 R1	1(ea)
39	Turret cable	Custom Made	MRP-ELE-0111 R1	1(ea)
40	GPS cable	Custom Made	MRP-ELE-0112 R1	1(ea)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
41	Chutes cable	Custom Made	MRP-ELE-0113 R1	1(ea)
42	DW Hall Feedback cable	Custom Made	MRP-ELE-0114 R1	1(ea)
43	DW cable	Custom Made	MRP-ELE-0115 R1	1(ea)
44	Cable Mounting hub	Heyco	3458	12(ea)
45	Cable Mounting hub	Heyco	3458	12(ea)

Table 10: Embedded bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Jetson computer	NVidia	TX1 Developer Kit	2(ea)
2	PSoC 5 Microcontroller	PSoC	CY8C5888LTI-LP097	2(ea)
3	FTDI chip	FTDI	FT-MOD-4232HUB	1(ea)
4	USB Hub with 4 ports	Sabrent	HB-UM43	1(ea)
5	Logic Level converter	Adafruit.com	757	3(ea)
6	PSoC 5LP Microcontroller	Cypress	428-3390-ND	1(ea)
7	Pololu Jrk 12v12 USB Motor Controller with Feedback	pololu.com	1393	5(ea)
8	12V PCBA	Custom Made	MRP-ELE-0201 R1	1(ea)
9	5V PCBA	Custom Made	MRP-ELE-0202 R1	1(ea)
10	Gimbal and GPS PCBA	Custom Made	MRP-ELE-0207 R1	1(ea)
11	Wrist and Hand PCBA	Custom Made	MRP-ELE-0208 R1	1(ea)
12	Lidar PCBA	Custom Made	MRP-ELE-0209 R1	1(ea)
13	Chutes PCBA	Custom Made	MRP-ELE-0210 R1	1(ea)
14	Turret PCBA	Custom Made	MRP-ELE-0211 R1	1(ea)
15	PSoC PCBA	Custom Made	MRP-ELE-0212 R1	1(ea)
16	H-bridge PCBA	Custom Made	MRP-ELE-0213 R1	2(ea)
17	FTDI PCBA	Custom Made	MRP-ELE-0214 R1	1(ea)
18	Forearm PCBA	Custom Made	MRP-ELE-0215 R1	1(ea)

Table 11: Science bill of materials

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	Slider Plate	PML / ME Machine Shop	SM0003	1(ea)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
2	Sensor Mounting Brackets	PML / ME Machine Shop	MRP-SCI-0013	3(ea)
3	Spring-Tempered Steel 11.0 in. Long .656 in. OD .062 in. Wire	McMaster Carr	9637K33	5(ea)
4	18-8 Stainless Steel 1/4 in. Diameter 2-1/2 in. Length 2-3/8 in. Usable Length	McMaster Carr	McMaster-Carr	5(ea)
5	Motor Brace	PML / ME Machine Shop	SM0004	1(ea)
6	10 Series Single-Keyed UniBearing Pad (Slider)	80/20 Inc.	6705	6(ea)
7	10 Series 3 Slot Mount - Single Flange Short Standard Linear Bearing	80/20 Inc.	6715	1(ea)
8	DC Motor	Last Year	N/A	1(ea)
9	Rocker Base	PML / ME Machine Shop	SM0001	1(ea)
10	Rocker Arm	PML / ME Machine Shop	SM0002	1(ea)
11	Feedback Rod Linear Actuators - 12V / 200 lb / 8 in.	firgelliauto.com	FA-PO-240-12-8	1(ea)
12	Feedback Rod Linear Actuators - 12V / 200 lb / 12 in.	firgelliauto.com	FA-PO-240-12-12	2(ea)
13	Shaft Coupler 1/2 in. Shaft	McMaster Carr	6408K11	4(ea)
14	Spacer for shaft coupler	McMaster Carr	6408K84	2(ea)
15	Aluminum Rod 1/2 in. Diameter x 6 ft Length	McMaster Carr	8974K28	1(ea)
16	Arduino Uno	EE Shop	Arduino Uno	1(ea)
17	Electrolytic conductivity and temperature sensor	hannainst.com	HI98331	1(ea)
18	Soil Sample Tube Probe	Amazon	120607	2(ea)
19	MB1 Bracket - Bracket	firgelliauto.com	MB1	4(ea)
20	Corner Bracket with 7/8 in. Long Sides (steel)	McMaster Carr	1556A24	20(ea)
21	1/4-20 Thread Size 1/2 in. Long Carriage Bolt (Pack of 100)	McMaster Carr	93548A530	1(ea)
22	Socket Head Screw 1/4-20 1/2 in. Long pack of 100	McMaster Carr	91251A537	1(bulk)

Continued on next page

	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
23	Hex Nut Grade 8 1/4-20 pack of 100	McMaster Carr	90499A029	1(bulk)
24	Flat-Surface Bracket - Zinc-Plated Steel 1-1/2 in. Long	McMaster Carr	1394A23	20(ea)
25	1 in. 80/20 prototyping aluminum bar - 8ft length	McMaster Carr	47065T101	5(ea)
26	Soil Humidity Sensor	BangGood.com	79227	3(ea)
27	Soil Moisture Sensor	Spark Fun	SEN-13322	3(ea)
28	316 Stainless Steel - 1/2 in. Band Width - 2- 1/16 in.- 3 in. Clamp ID Range	McMaster Carr	5011T22	10(ea)
29	305 Stainless Steel Screw 9/16 in. Wide Band 3-5/8 in. to 6-1/2 in. Clamp ID	McMaster Carr	54155K87	10(ea)
30	6061 Aluminum Rectangular Tube 1/8 in. Wall Thickness 1 in. x 1 in. 6ft length	McMaster Carr	6546K21	1(ea)
31	6061 Aluminum Rectangular Tube 1/16 in. Wall Thickness 1 in. x 1 in. 6ft length	McMaster Carr	6546K53	1(ea)
32	Oil-Embedded Sleeve Bearing for 1/2 in. Shaft Diameter 5/8 in. OD 1/2 in. Length	McMaster Carr	6391K212	5(ea)
33	KOOKYE 5PCS Nano V3.0 ATMEGA328P Module CH340G 5V 16M Mini U	Amazon	LYSB019SXND4O-ELECTRNCS	1(ea)

Table 12: Vision bill of materials

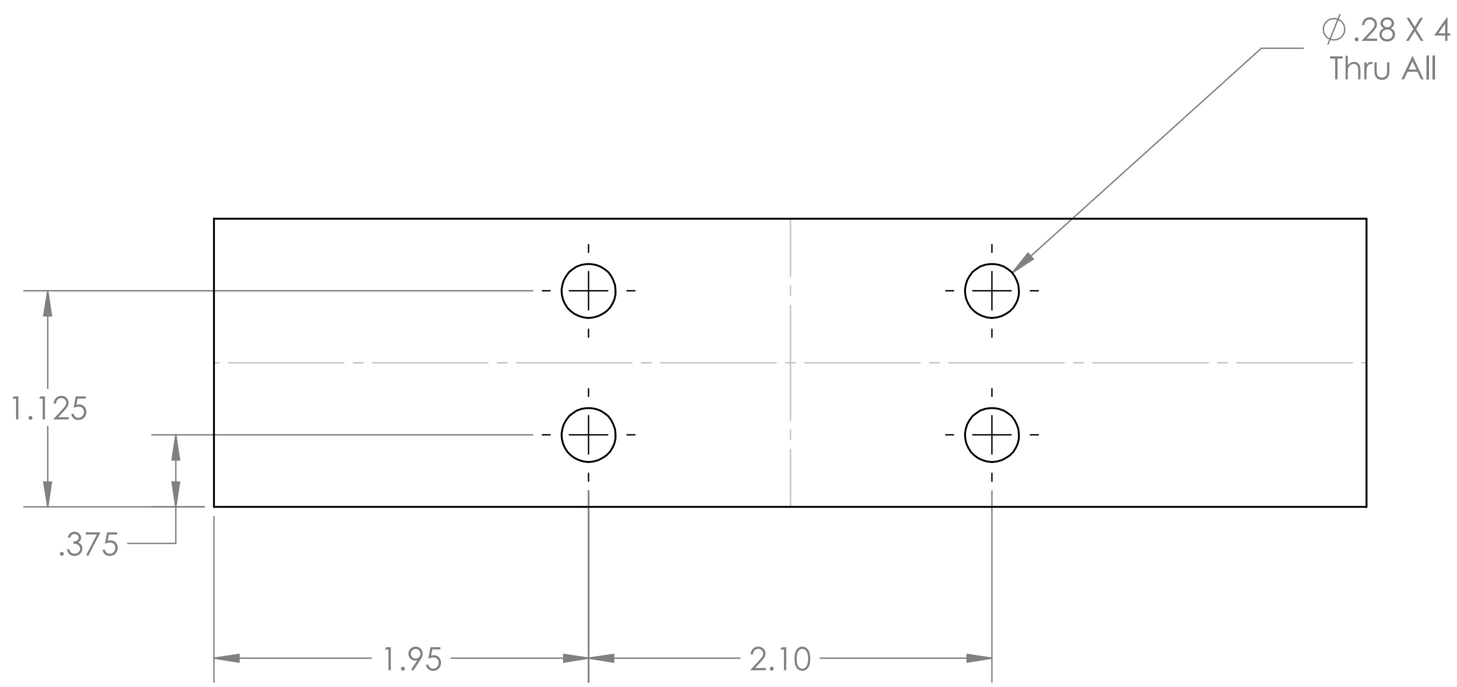
	Description	Supplier / Manufacturer	Part No.	Qty (Unit)
1	ZED	Stereo Labs	4121	1(ea)
2	Logitech C500 webcam	Logitech	C501	1(ea)
3	Logitech C270 webcam	Logitech	C500	2(ea)
4	RPLidar A2	Amazon	B01L1T32PI	1(ea)
5	Anker USB 3.0 SuperSpeed 10-Port Hub	Amazon	AH231	1(ea)

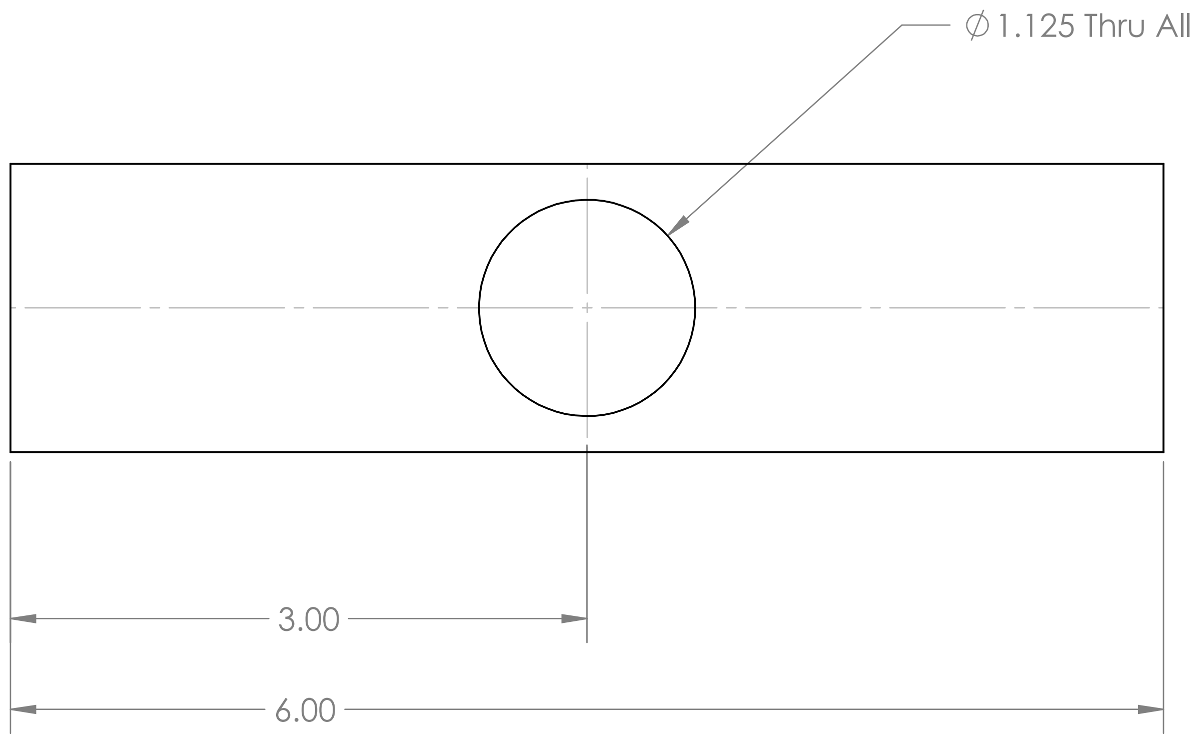
I.2 Chassis Drawings and Documentation

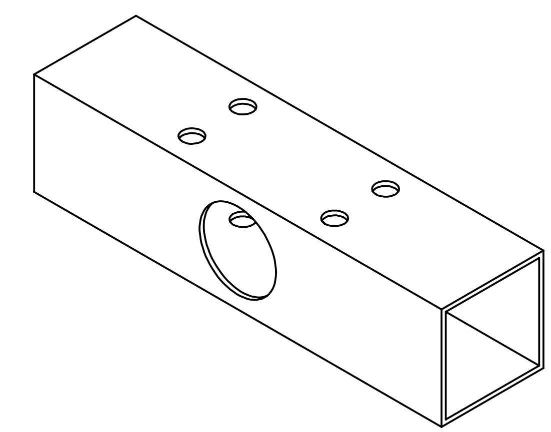
In addition to the drawing package below, MRD-DE-0001 (section G.1) describes the design decision for the current wheel treads, and MRD-DE-0008 gives a detailed description of setting up the wheel motors and motor drivers.

Notes:
1. Metal Depot Part Number: T3112073
2. 1.5" x 1.5" SQAURE TUBE WITH 1/16" THICK WALLS

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	ALEX JENSEN	21 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6063-T52 ALUMINUM

FINISH

BYU
MARS ROVER
2017

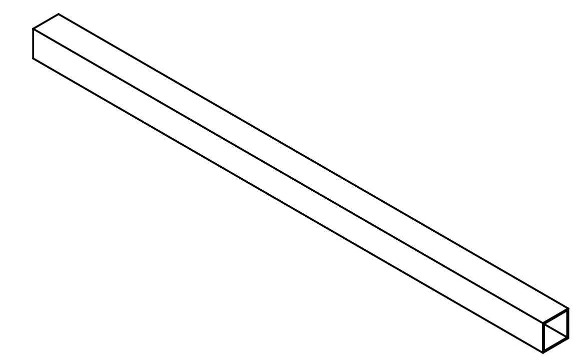
PART #:
MRP-CHA-0001 R1

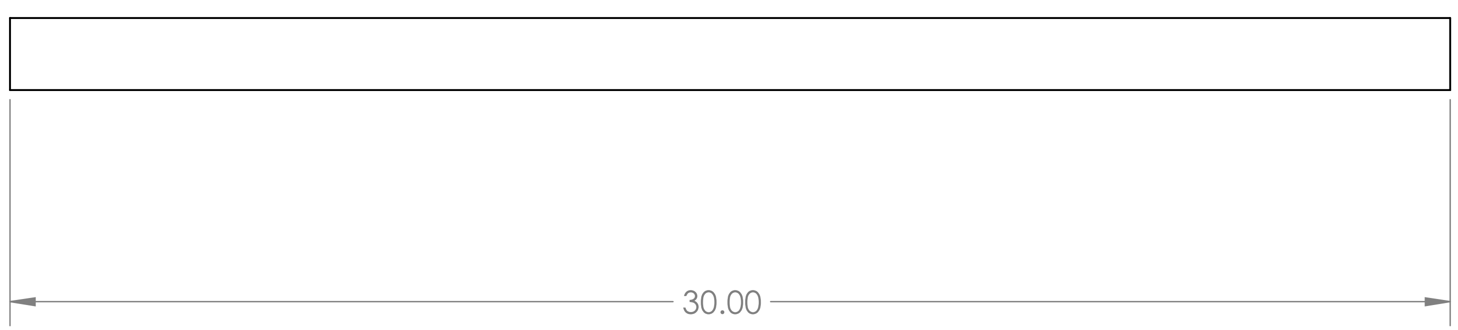
SIZE B | PART NAME: BaseBackBeam | REV 1

SCALE: 1:1 | SHEET 1 OF 1

Notes:
1. 1.5" x 1.5" SQAURE TUBE WITH 1/16" THICK WALLS
2. Metals Depot Stock Number: T311218

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	ALEX JENSEN	21 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52 ALUMINUM

FINISH: 250 µin

BYU
MARS ROVER
2017

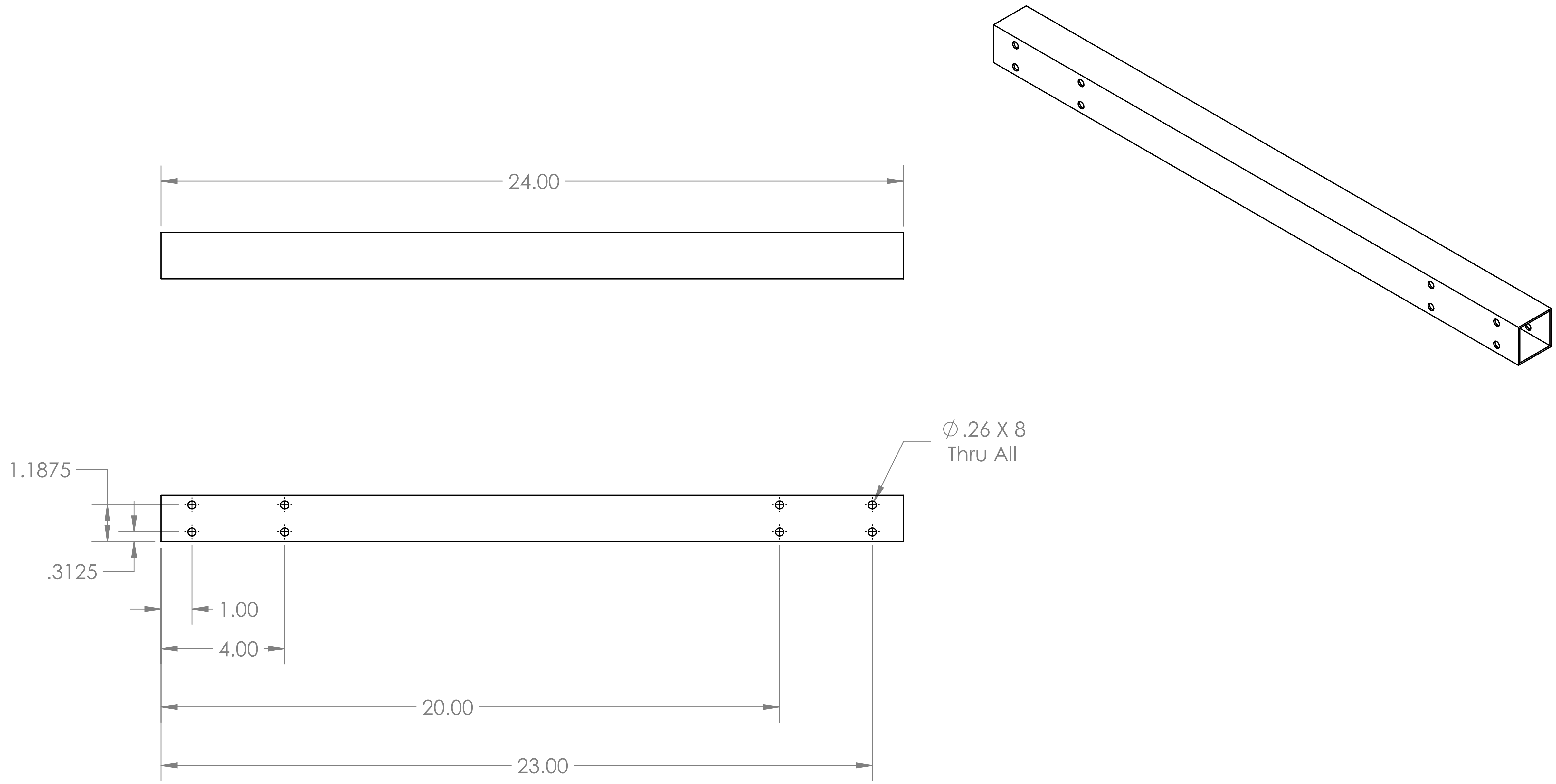
PART #: MRP-CHA-0002 R1

SIZE	PART NAME:	REV
B	BaseCenterBeam	1

SCALE: 1:8 | SHEET 1 OF 1

Notes:
1. Metals Depot Stock Number: T311218
2. 1.5" x 1.5" SQAURE TUBE WITH 1/16" THICK WALLS

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	21 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6063-T52 ALUMINUM

FINISH 250 µin

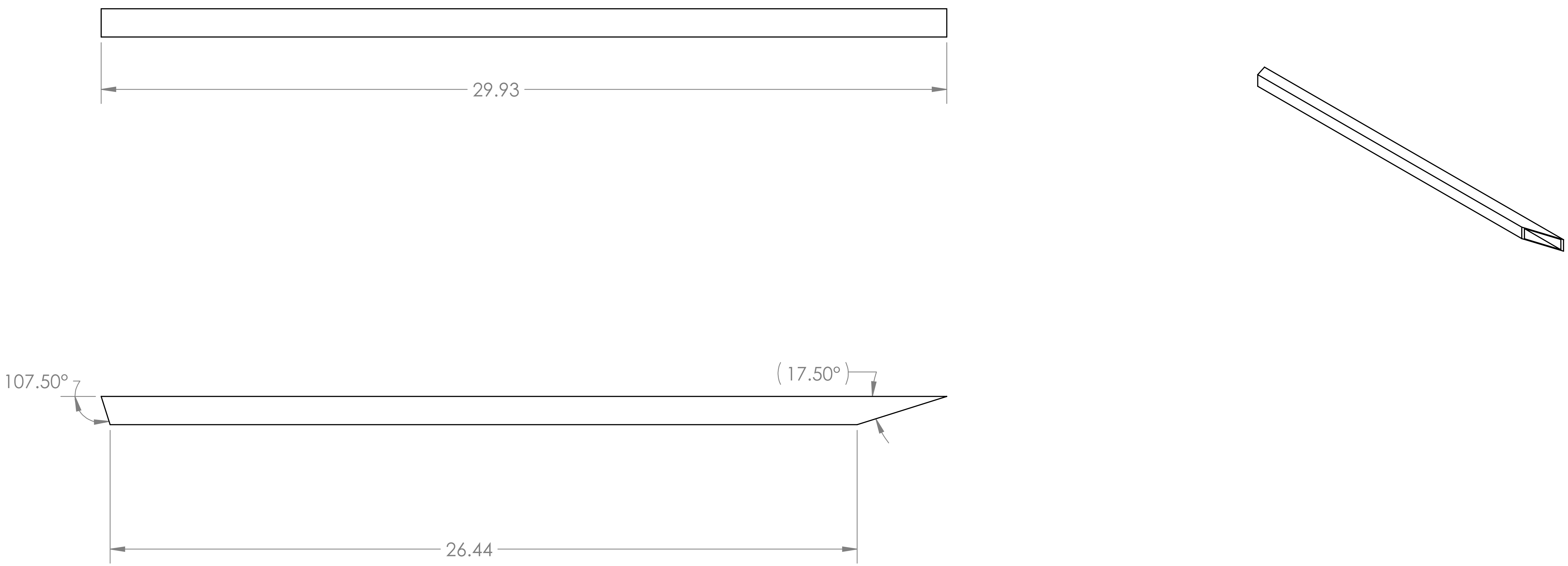
BYU
MARS ROVER
2017

PART #: MRP-CHA-0003 R1

SIZE	PART NAME:	REV
B	BaseFrontBeam	1
SCALE: 1:8		SHEET 1 OF 1

Notes:
1. 1" x 1" SQAURE TUBE WITH 1/16" THICK WALLS
2. Metals Depot Stock Number: T3118

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	21 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6063-T52 ALUMINUM

FINISH

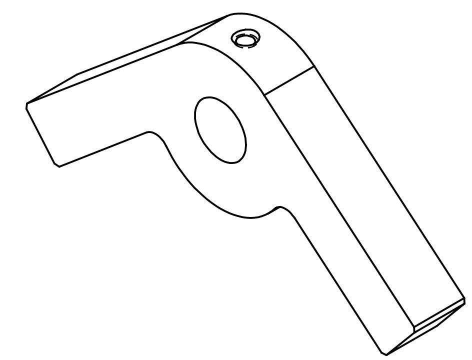
BYU
MARS ROVER
2017

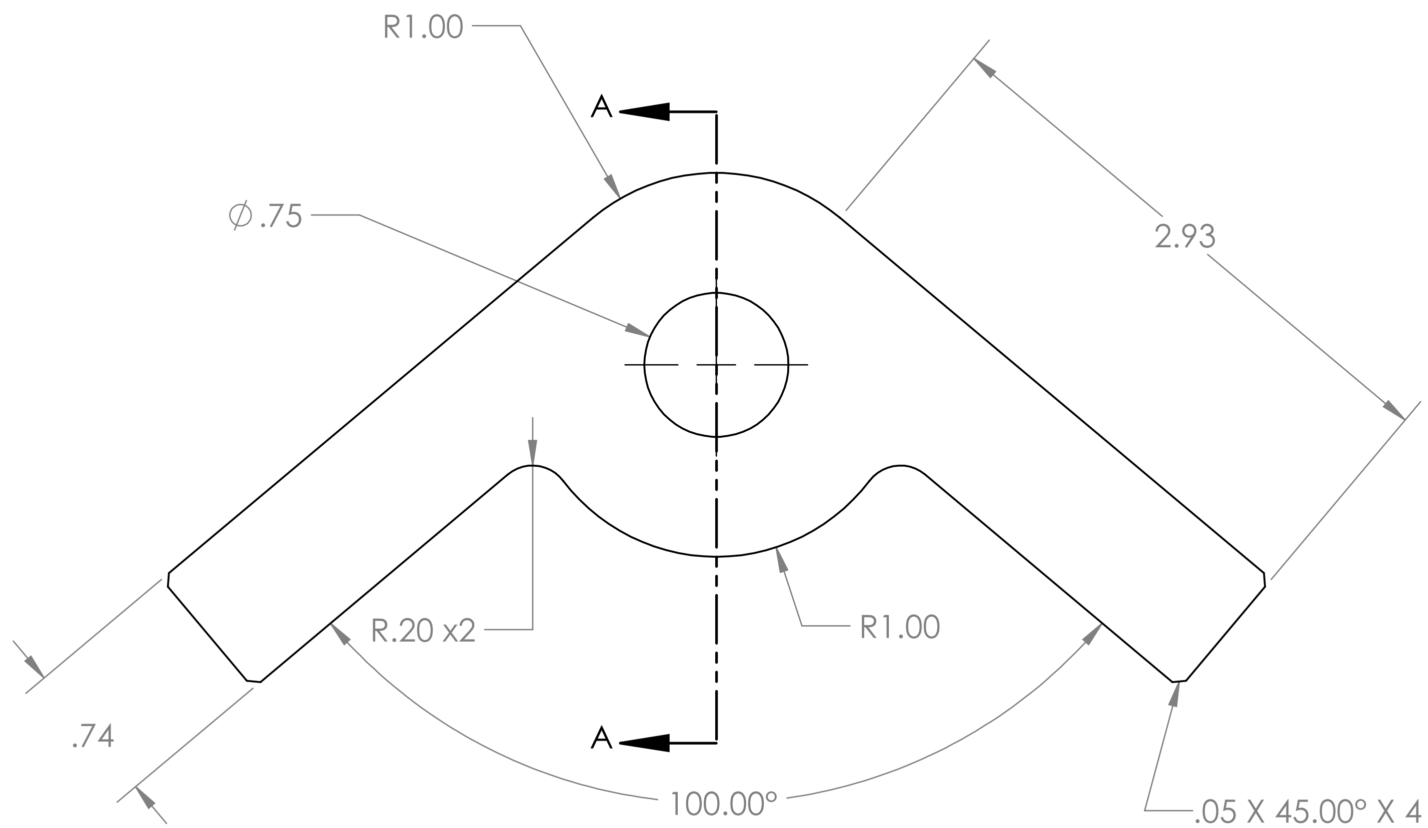
PART #:
MRP-CHA-0004 R1

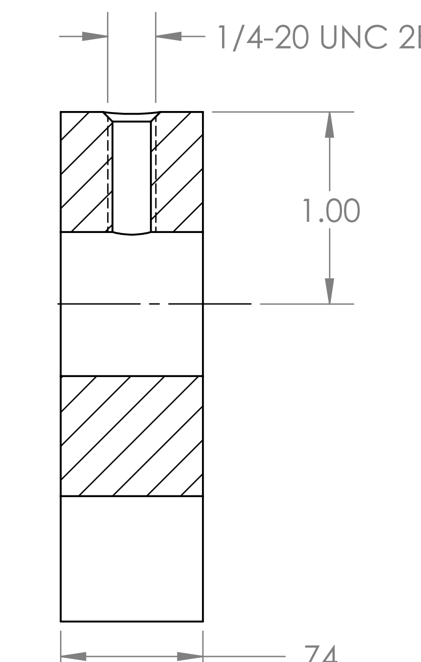
SIZE	PART NAME:	REV
B	BaseAngledBeam	1

SCALE: 1:8 SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





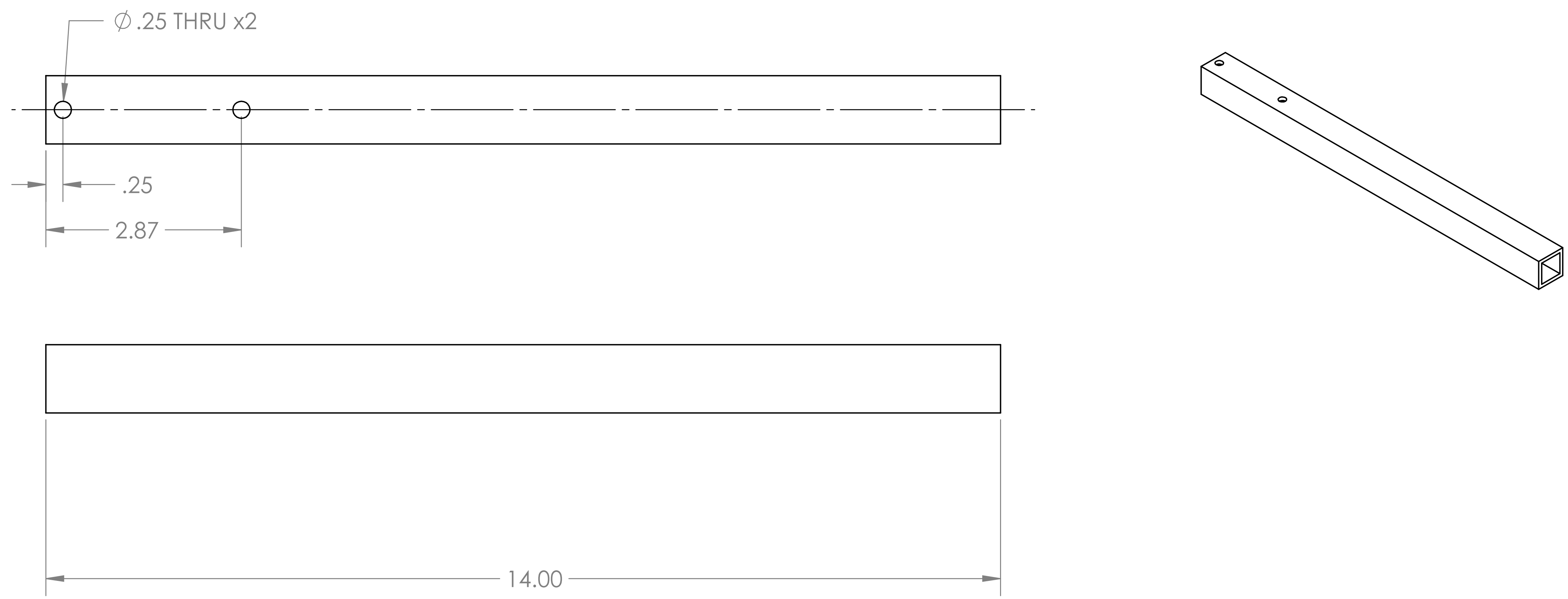


SECTION A-A

	NAME	DATE	BYU MARS ROVER 2017
DRAWN	ALEX JENSEN	21 MAR 2017	
CHECKED	Jameson Marriott	17 April 2017	
ENG APPR.	Brian Jackson	17 April 2017	PART #: MRP-CHA-0005 R1
MFG APPR.			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009 MATERIAL ALUMINUM FINISH 250 µin	SIZE B PART NAME: FrontAngleBracket REV 1
			SCALE: 1:1 SHEET 1 OF 1

Notes:
1. 1" x 1" SQAURE TUBE WITH 1/16" THICK WALLS
2. Metals Depot Stock Number: T3118

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	21 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52 ALUMINUM

FINISH: 250 µin

BYU MARS ROVER 2017

PART #: MRP-CHA-0006 R1

SIZE: B

PART NAME: FrontArm

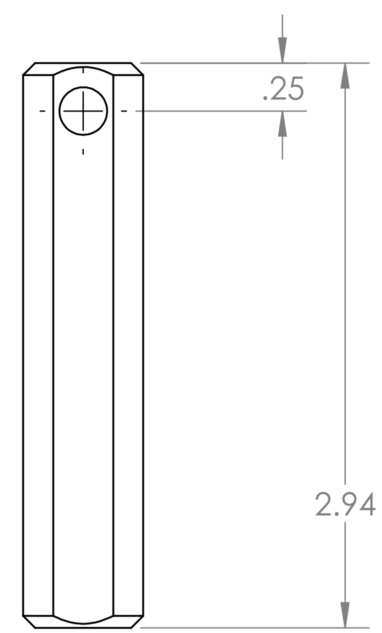
REV: 1

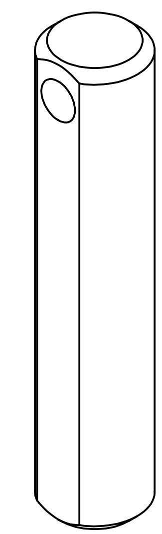
SCALE: 1:4

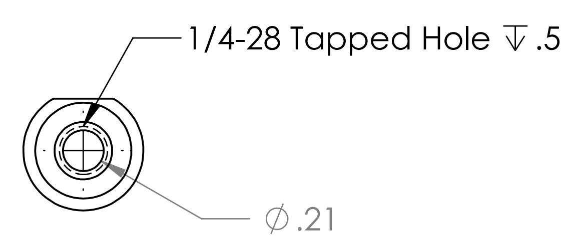
SHEET 1 OF 1

Notes:
1. McMaster Part 8632T160

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	Mary Wilson	19 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 1045 Carbon Steel

FINISH

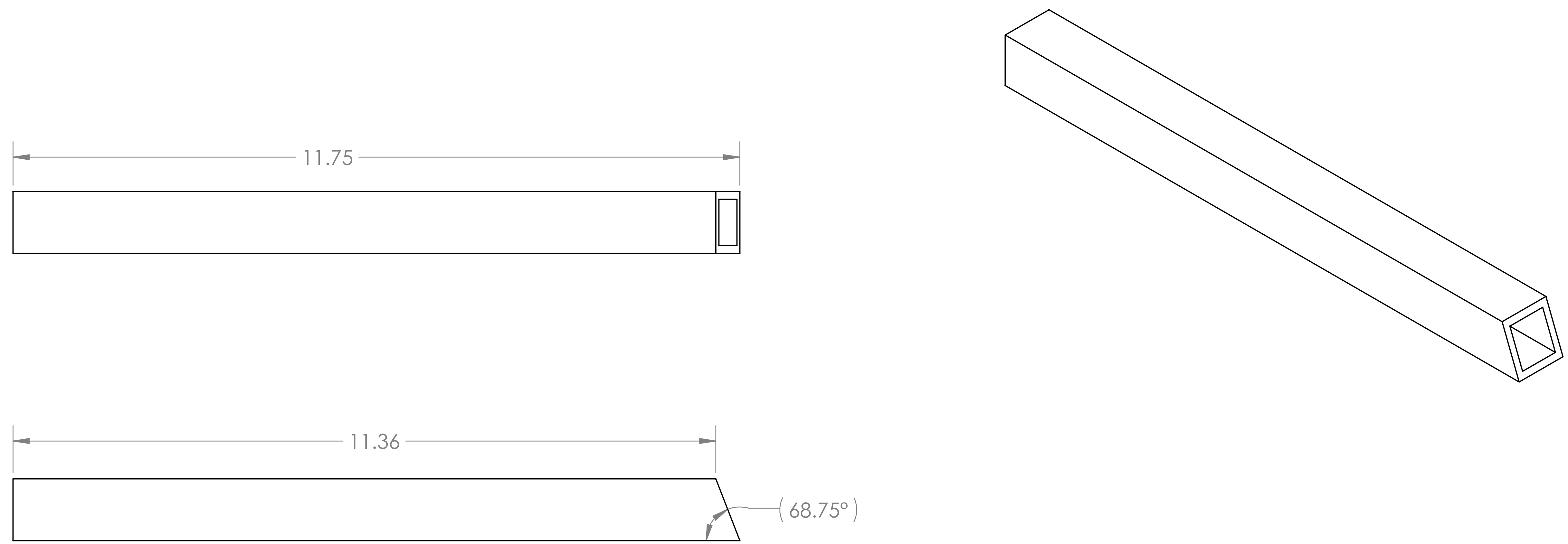
BYU
MARS ROVER
2017

PART #: MRP-CHA-0007 R1

SIZE	PART NAME:	REV
B	Rear Axle	1
SCALE: 1:1		SHEET 1 OF 1

Notes:
1. 1" x 1" SQAURE TUBE WITH 1/8" THICK WALLS
2. Metals Depot Part Number: T3118

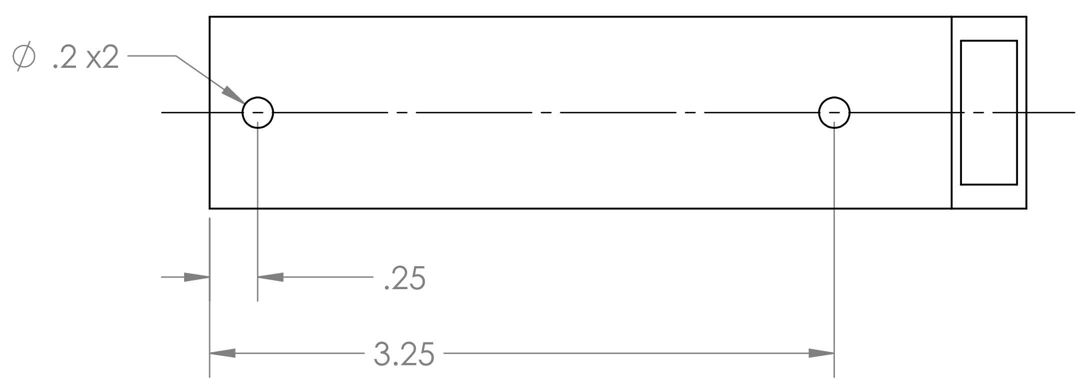
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

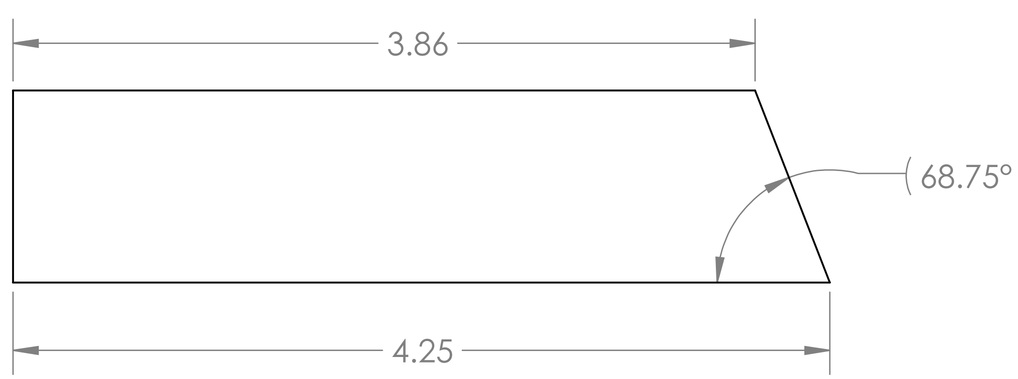


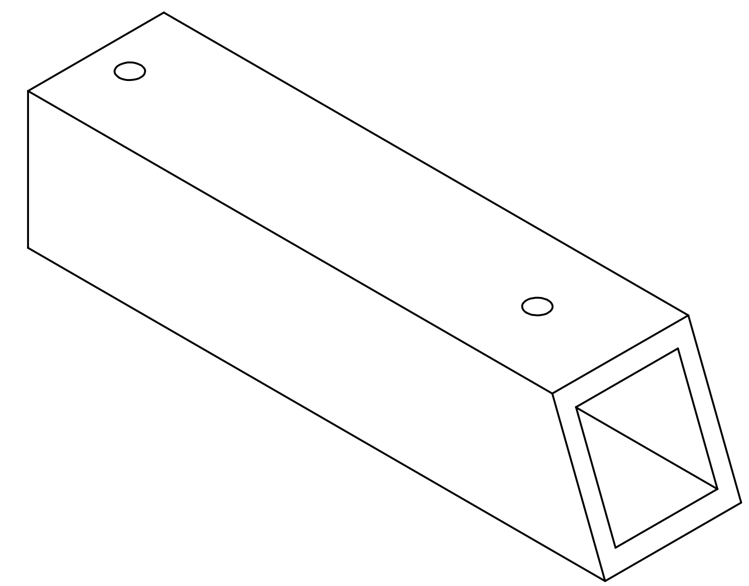
	NAME	DATE	
DRAWN	ALEX JENSEN	23 MAR 2017	BYU MARS ROVER 2017
CHECKED	Jameson Marriott	17 April 2017	
ENG APPR.	Brian Jackson	17 April 2017	
MFG APPR.			PART #: MRP-CHA-0010 R1
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B PART NAME: RearArmLong REV 1
		MATERIAL 6063-T52 ALUMINUM	
		FINISH 250 µin	SCALE: 1:2 SHEET 1 OF 1

Notes:
1. 1" x 1" SQAURE TUBE WITH 1/8" THICK WALLS
2. Metals Depot Part Number: T3118

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	ALEX JENSEN	23 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52 ALUMINUM

FINISH: N/A

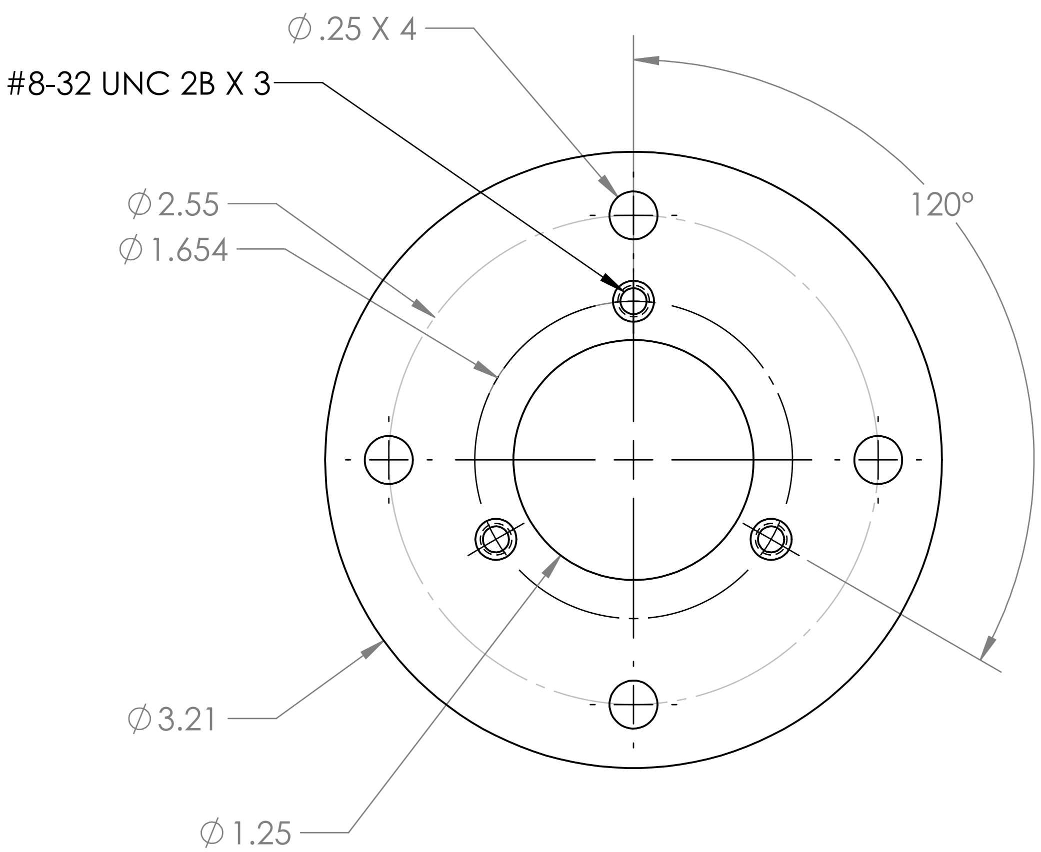
BYU MARS ROVER 2017

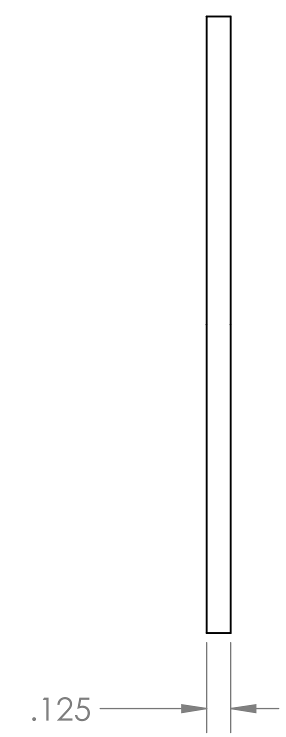
PART #: MRP-CHA-0011 R1

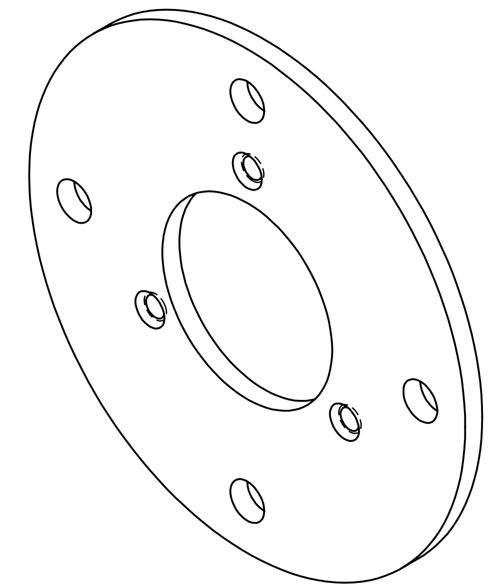
SIZE	PART NAME:	REV
B	RearArmShort	1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	ALEX JENSEN	29 MAR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6061-T6

FINISH N/A

BYU MARS ROVER 2017

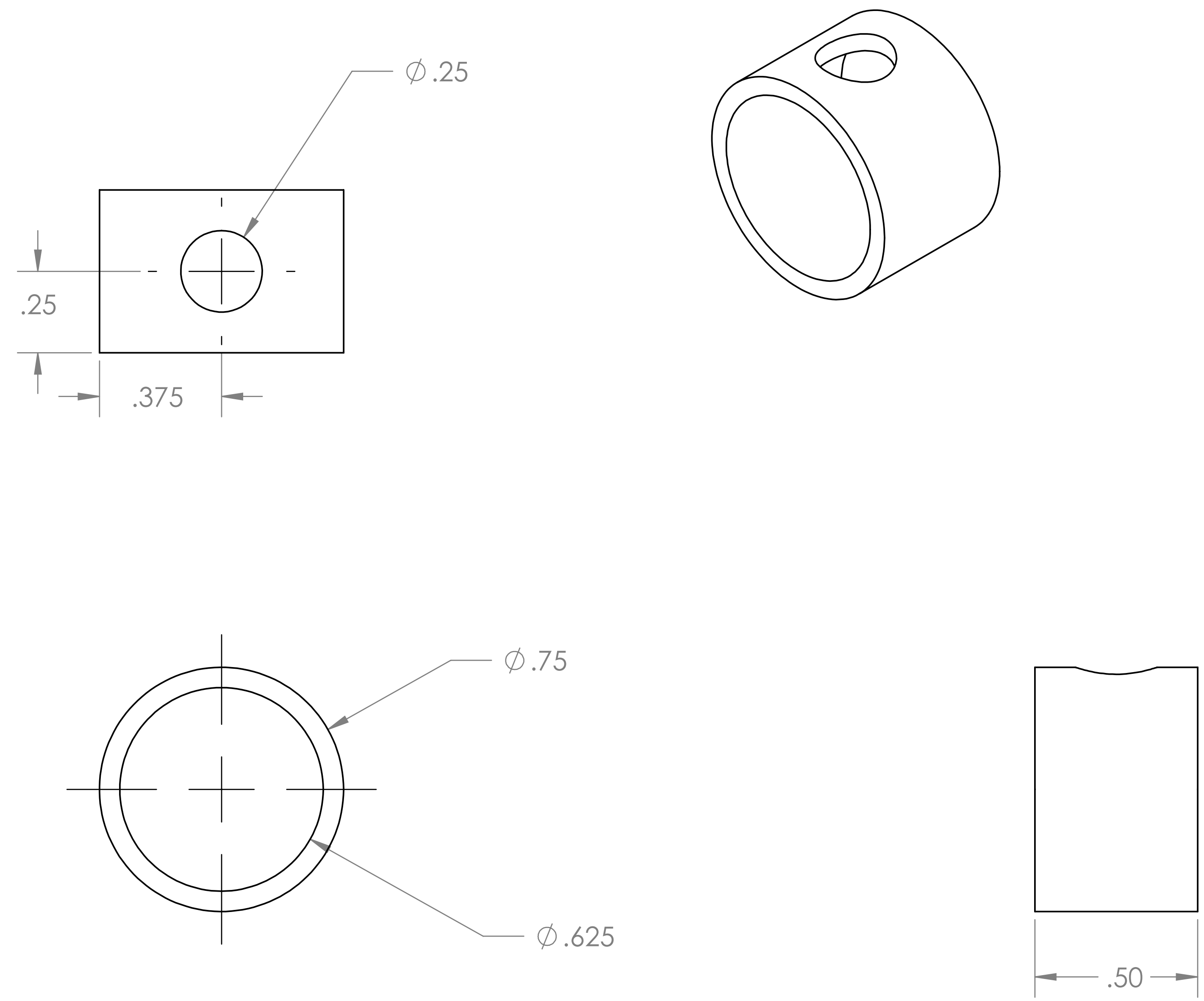
PART #: MRP-CHA-0017 R1

SIZE B | PART NAME: Wheel Adapter Plate | REV 1

SCALE: 1:1 | SHEET 1 OF 1

Notes:
1. Modified from McMaster Carr Part 2868T143

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	17 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0019 R1

SIZE **B**

PART NAME: Front Suspension Bearing

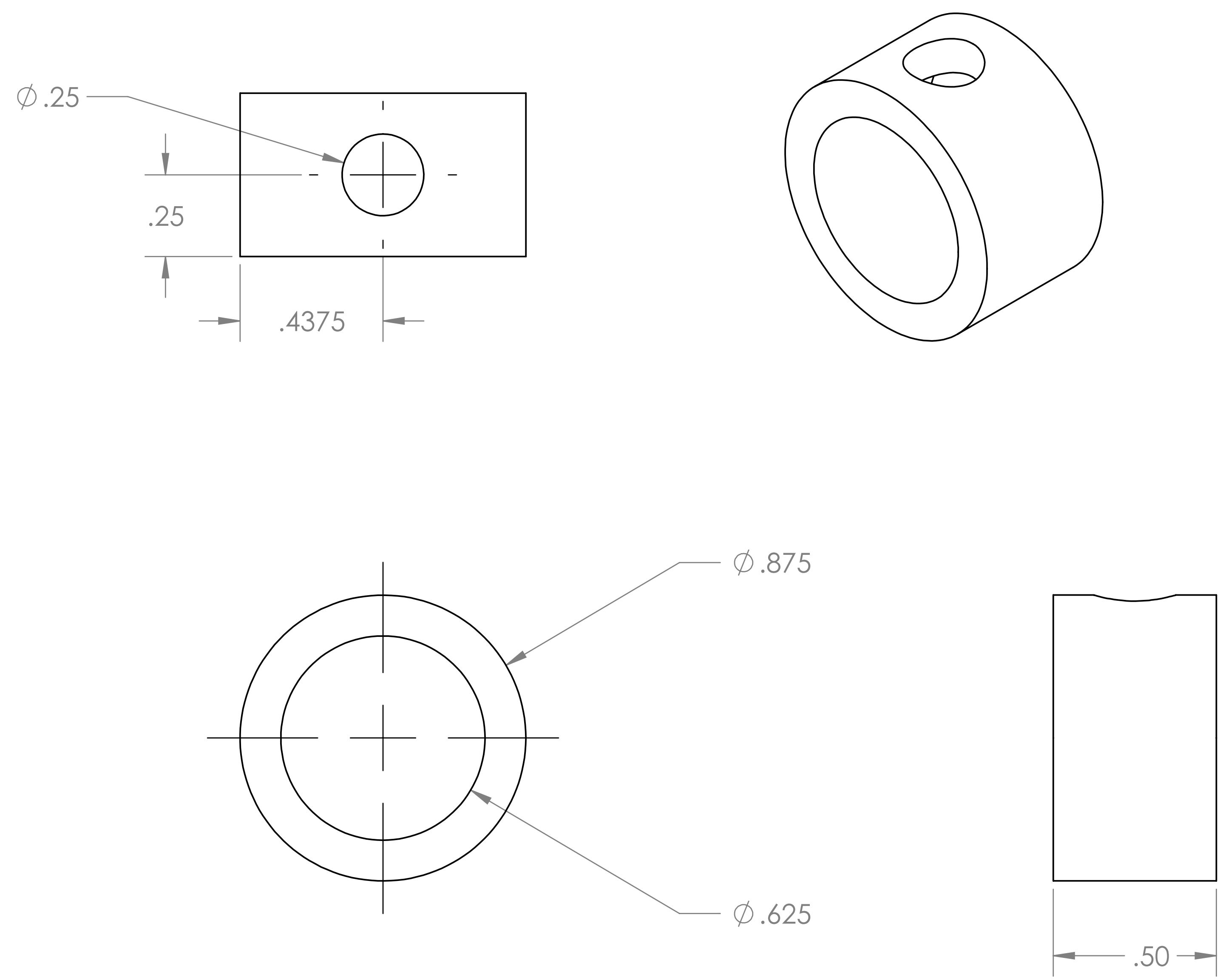
REV 1

SCALE: 2:1

SHEET 1 OF 1

Notes:
1. Modified from the McMaster Carr Part 2868T156

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH
250 µin

BYU
MARS ROVER
2017

PART #:
MRP-CHA-0020 R1

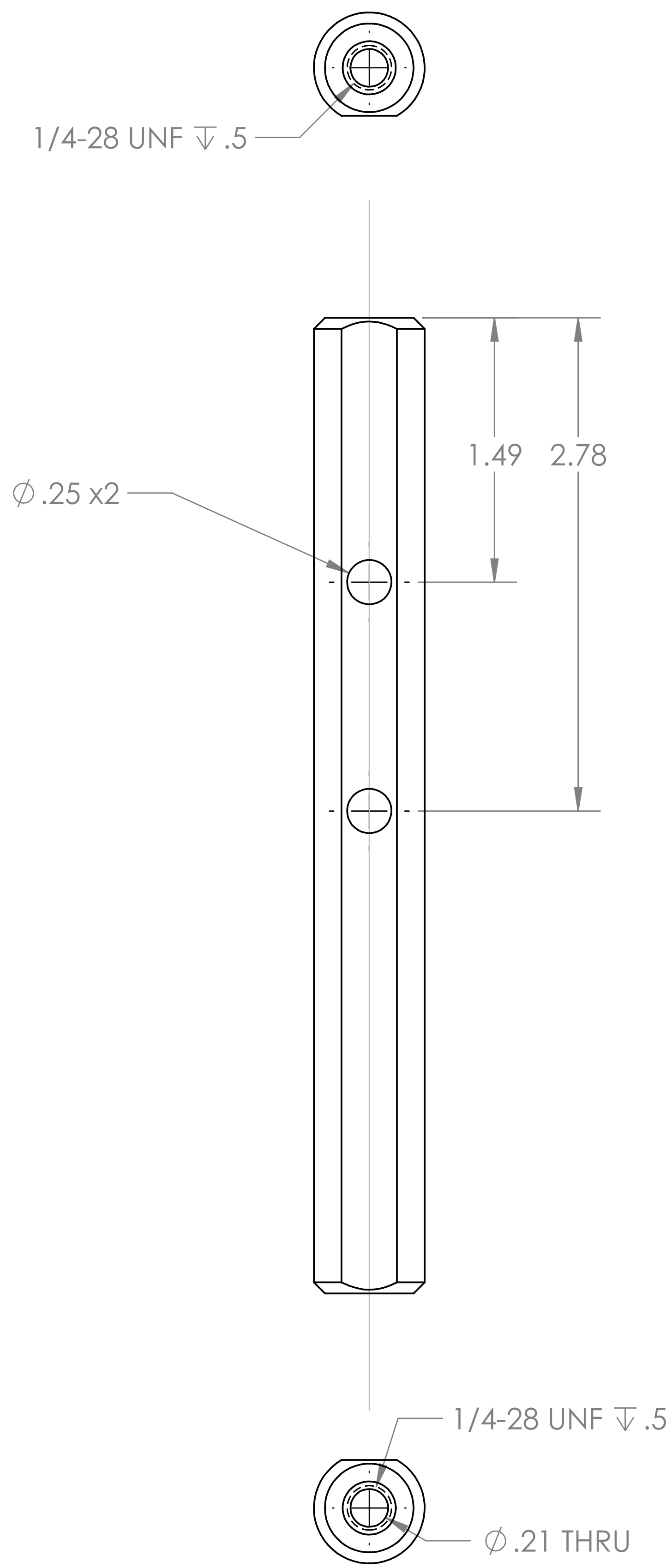
SIZE	PART NAME:	REV
B	RearSuspensionBearing	1

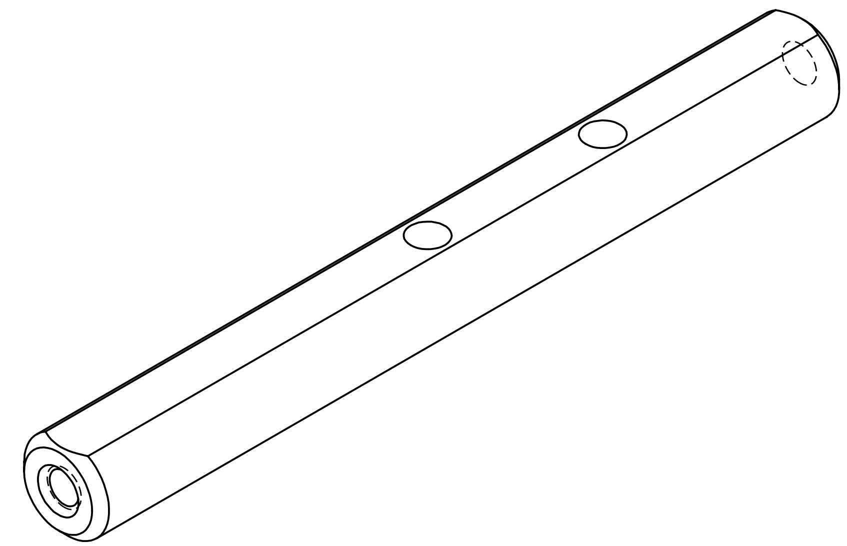
SCALE: 2:1

SHEET 1 OF 1

Notes:
1. McMaster Part 8632T160

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 1045 Carbon Steel

FINISH

BYU MARS ROVER 2017

PART #: MRP-CHA-0021 R1

SIZE: B

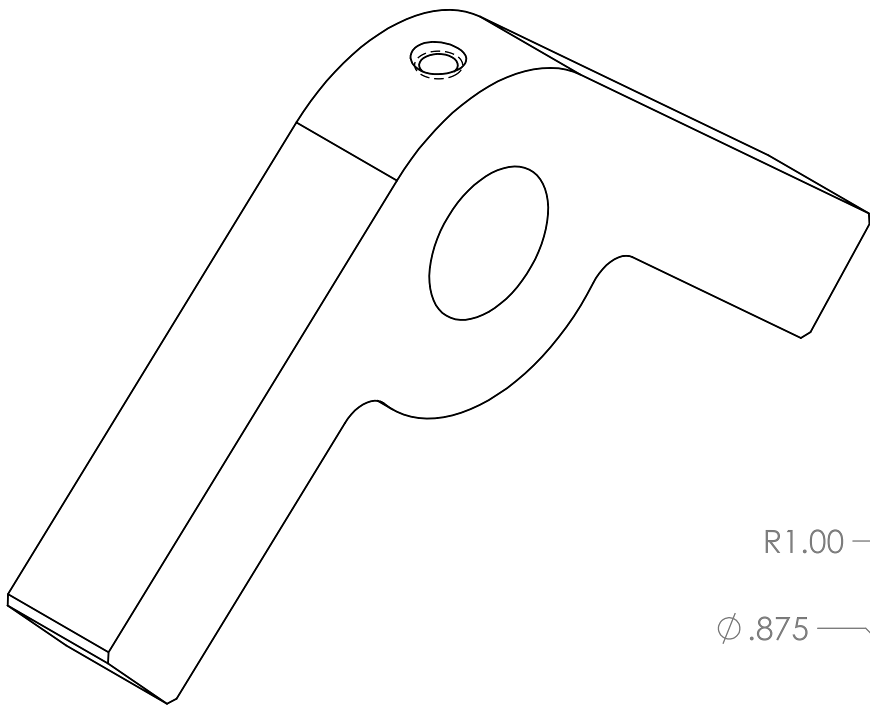
PART NAME: Front Axle

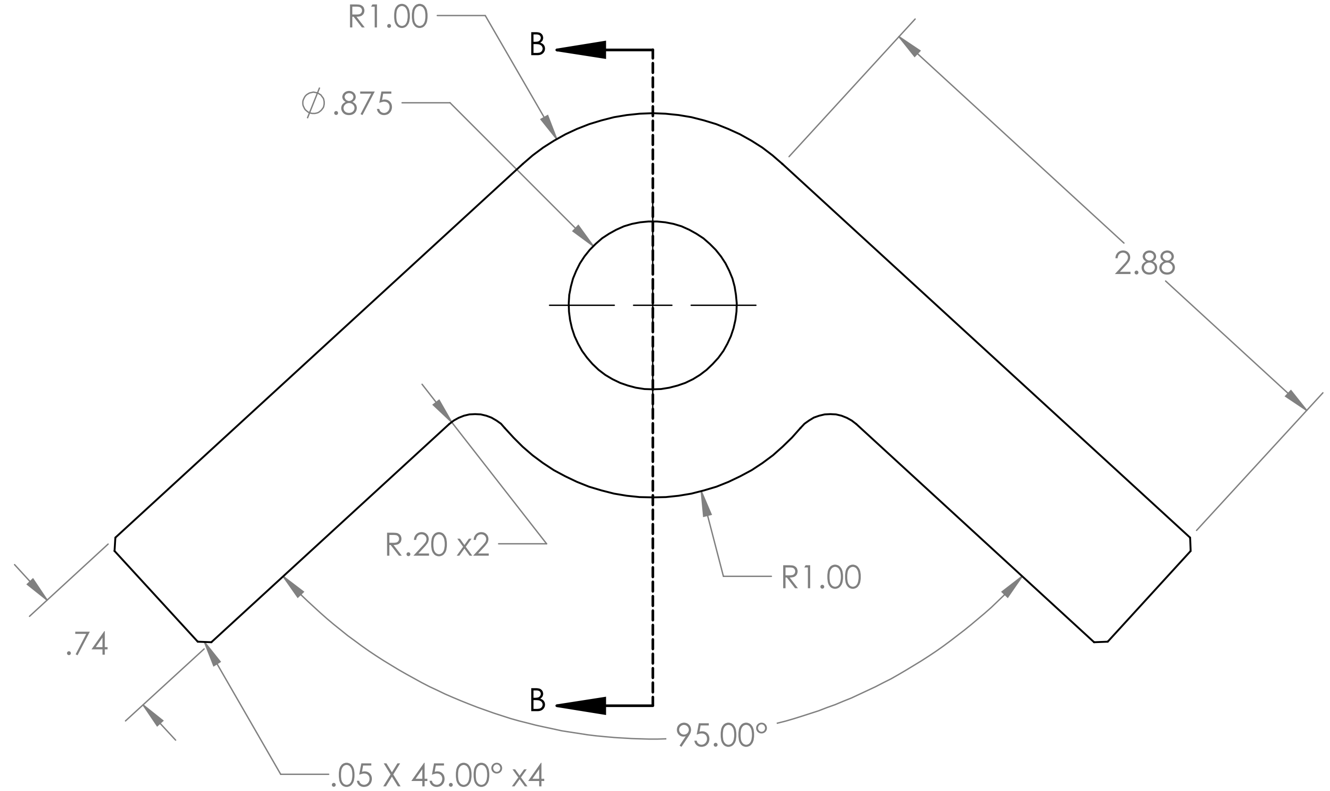
REV

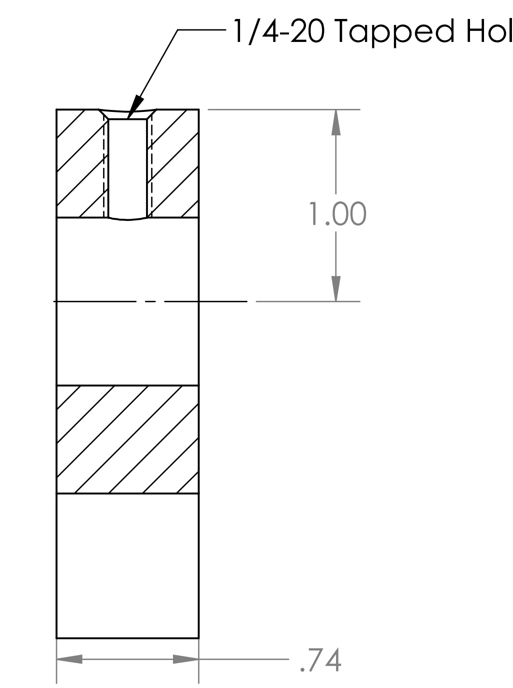
SCALE: 1:2

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







SECTION B-B

	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061-T6

FINISH: 250 µin

BYU
MARS ROVER
2017

PART #: MRP-CHA-0022 R1

SIZE: B

PART NAME: Rear Angle Bracket

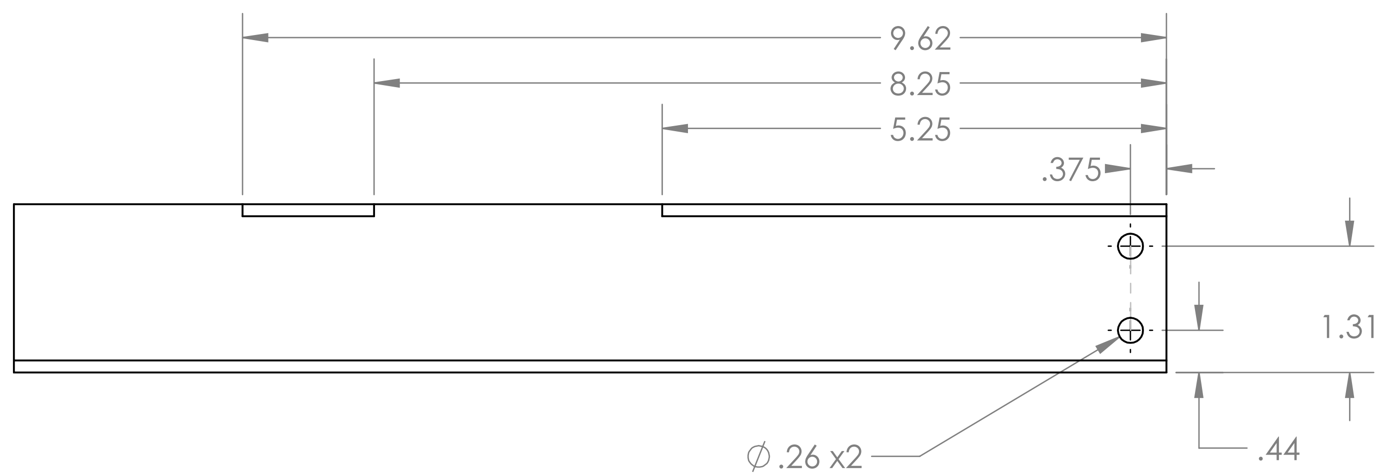
REV: 1

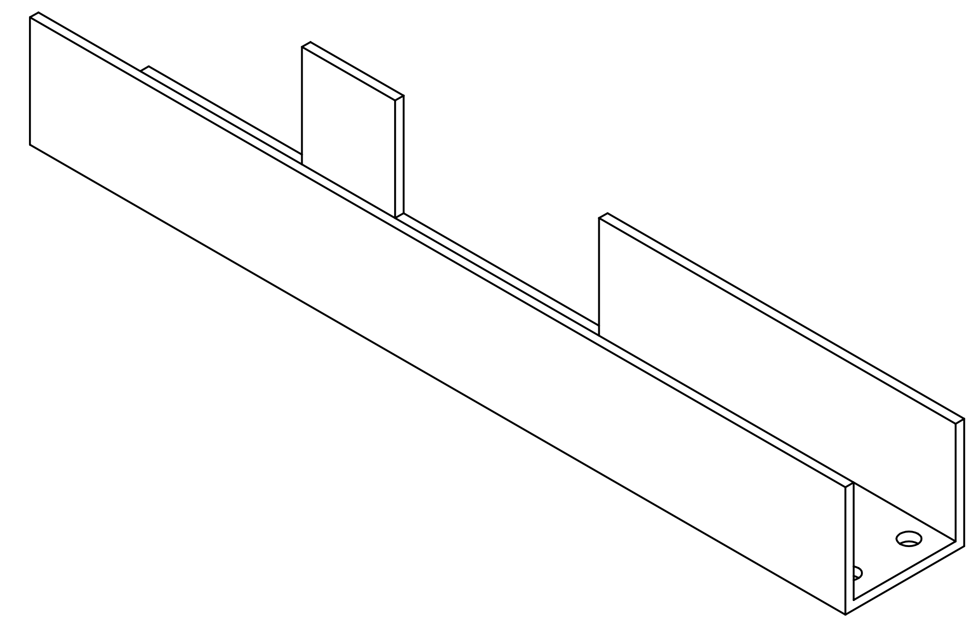
SCALE: 1:1

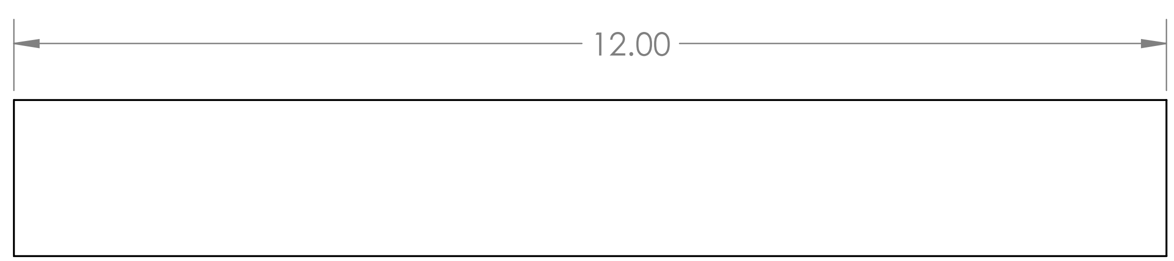
SHEET 1 OF 1

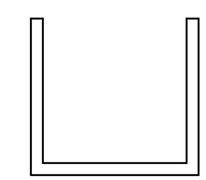
Notes:
1. McMaster Part #6546k6

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED









	NAME	DATE
DRAWN	Mary Wilson	16 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6061 Al

FINISH

BYU
MARS ROVER
2017

PART #:
MRP-CHA-0023 R1

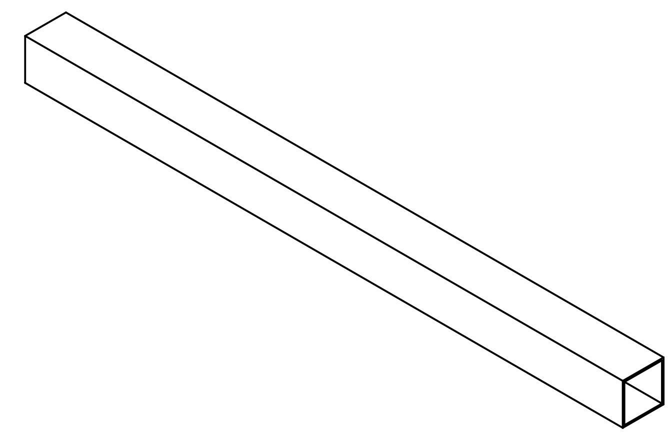
SIZE	PART NAME:	REV
B	u_bracket	1

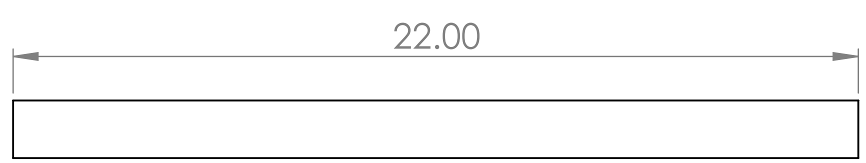
SCALE: 1:2

SHEET 1 OF 1

Notes:
1. 1.5" x 1.5" SQUARE TUBE WITH 1/16" THICK WALLS
2. Metals Depot Stock Number: T31116

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	16 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52

FINISH: 250 μin

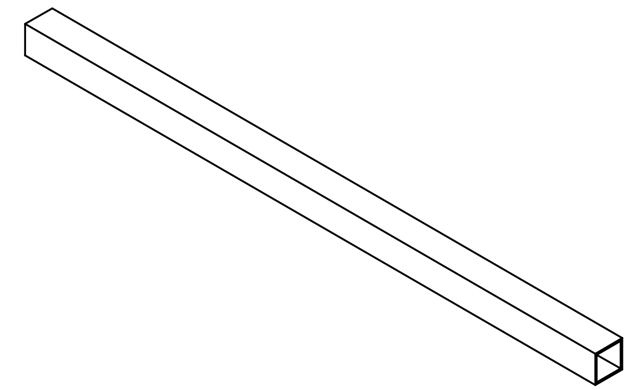
BYU
MARS ROVER
2017

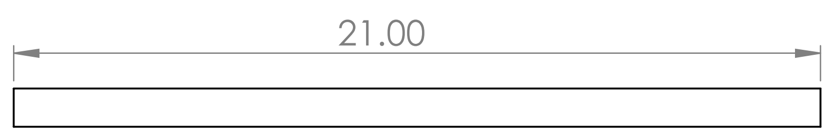
PART #: MRP-CHA-0024 R1

SIZE	PART NAME:	REV
B	Square Side Bracket 1.15	1
SCALE: 1:5		SHEET 1 OF 1

Notes:
1. 1" x 1" SQUARE TUBE WITH 1/16" THICK WALLS
2. Metals Depot Stock Numbers: T31116

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	16 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52

FINISH: 250 µin

BYU MARS ROVER 2017

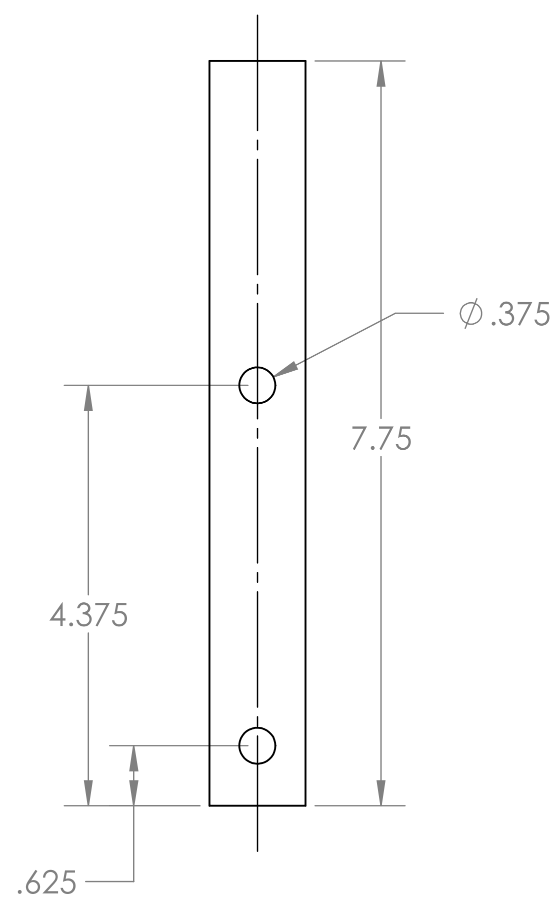
PART #: MRP-CHA-0025 R1

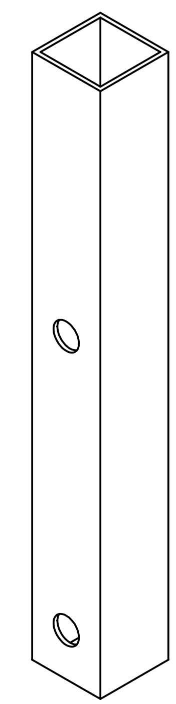
SIZE	PART NAME:	REV
B	Square Side Bracket 1	1

SCALE: 1:5 SHEET 1 OF 1

Notes:
1. 1" x 1" SQUARE TUBING WITH 1/16" WALL THICKNESS
2. Metals Depot Stock Number: T31116

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	16 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52

FINISH: 250 µin

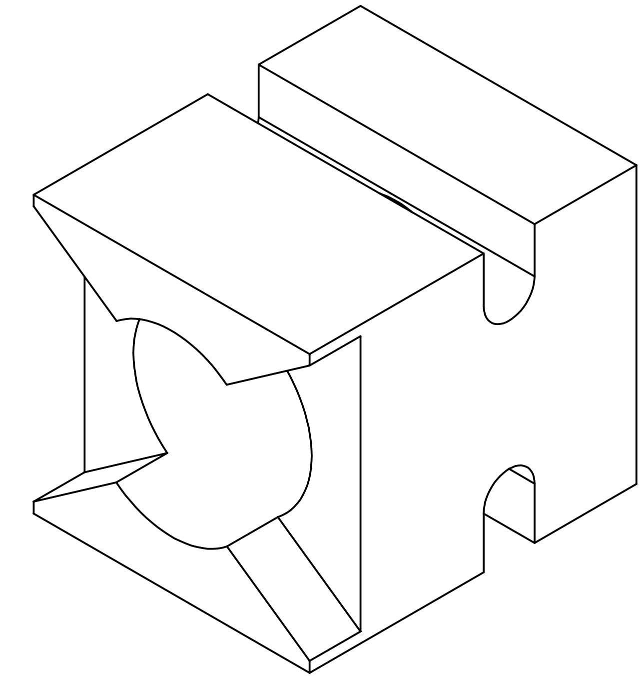
BYU
MARS ROVER
2017

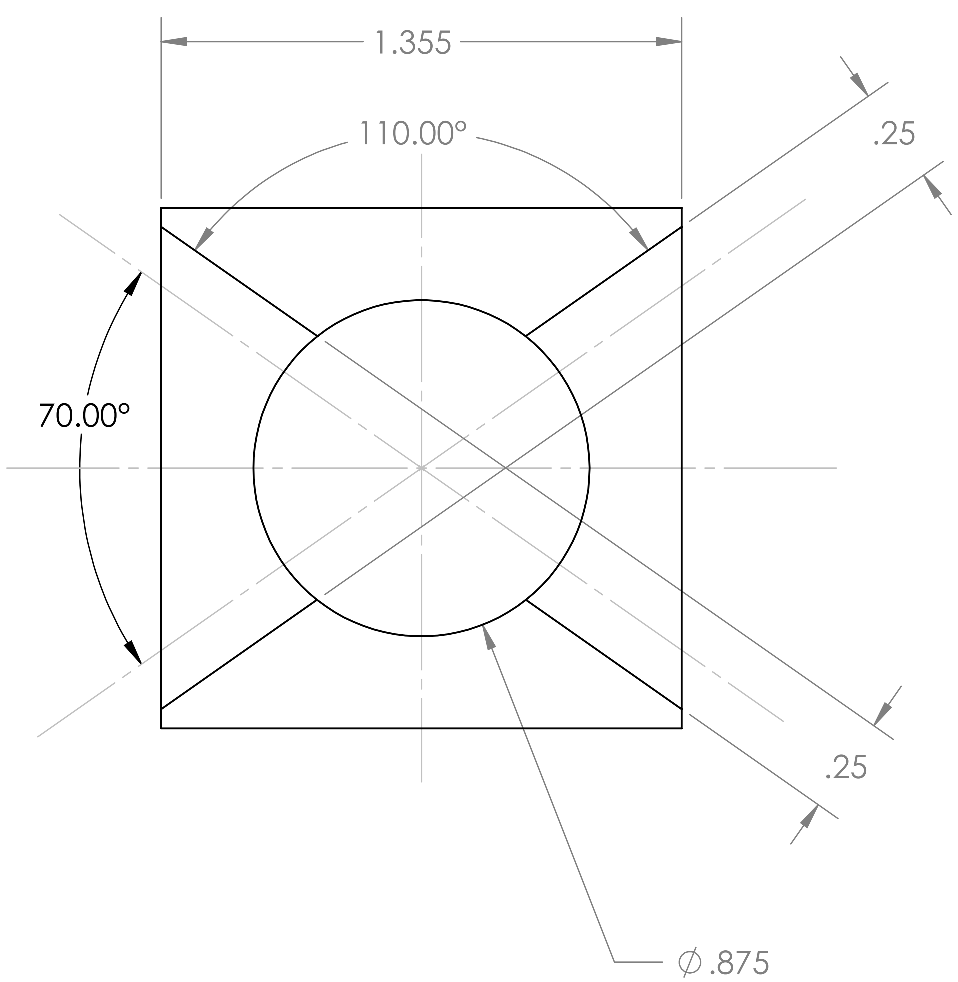
PART #: MRP-CHA-0026 R1

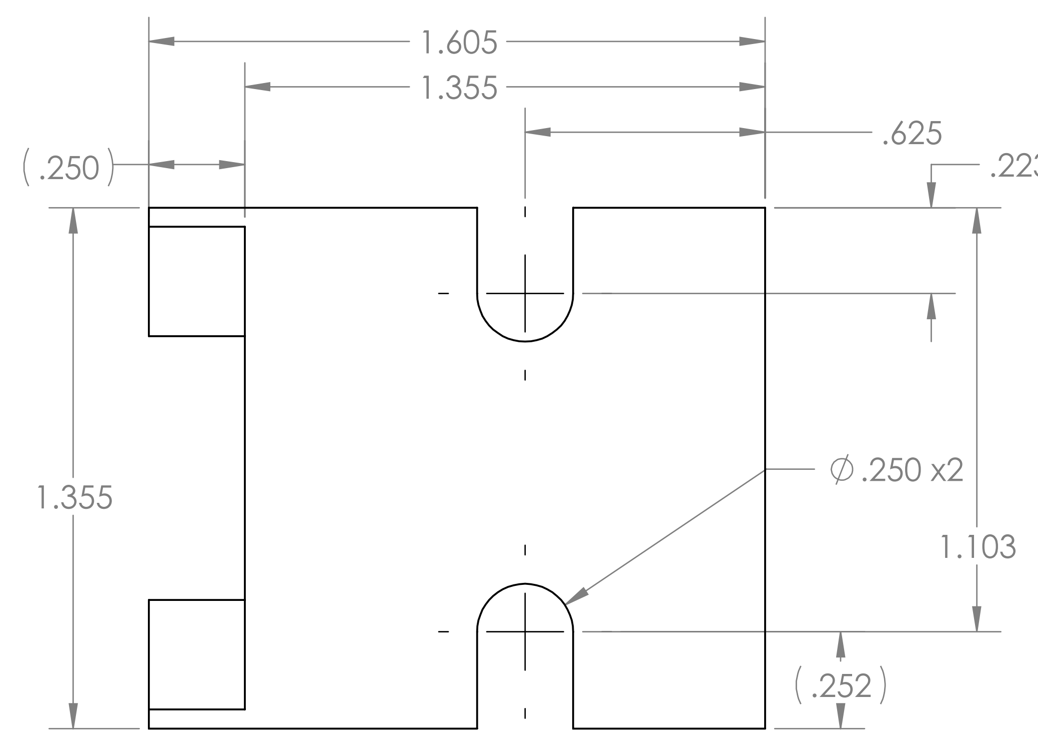
SIZE: B
PART NAME: Square Middle Support
REV: 1

SCALE: 1:2
SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Steel

FINISH: 250 µin

BYU
MARS ROVER
2017

PART #: MRP-CHA-0027 R1

SIZE: B

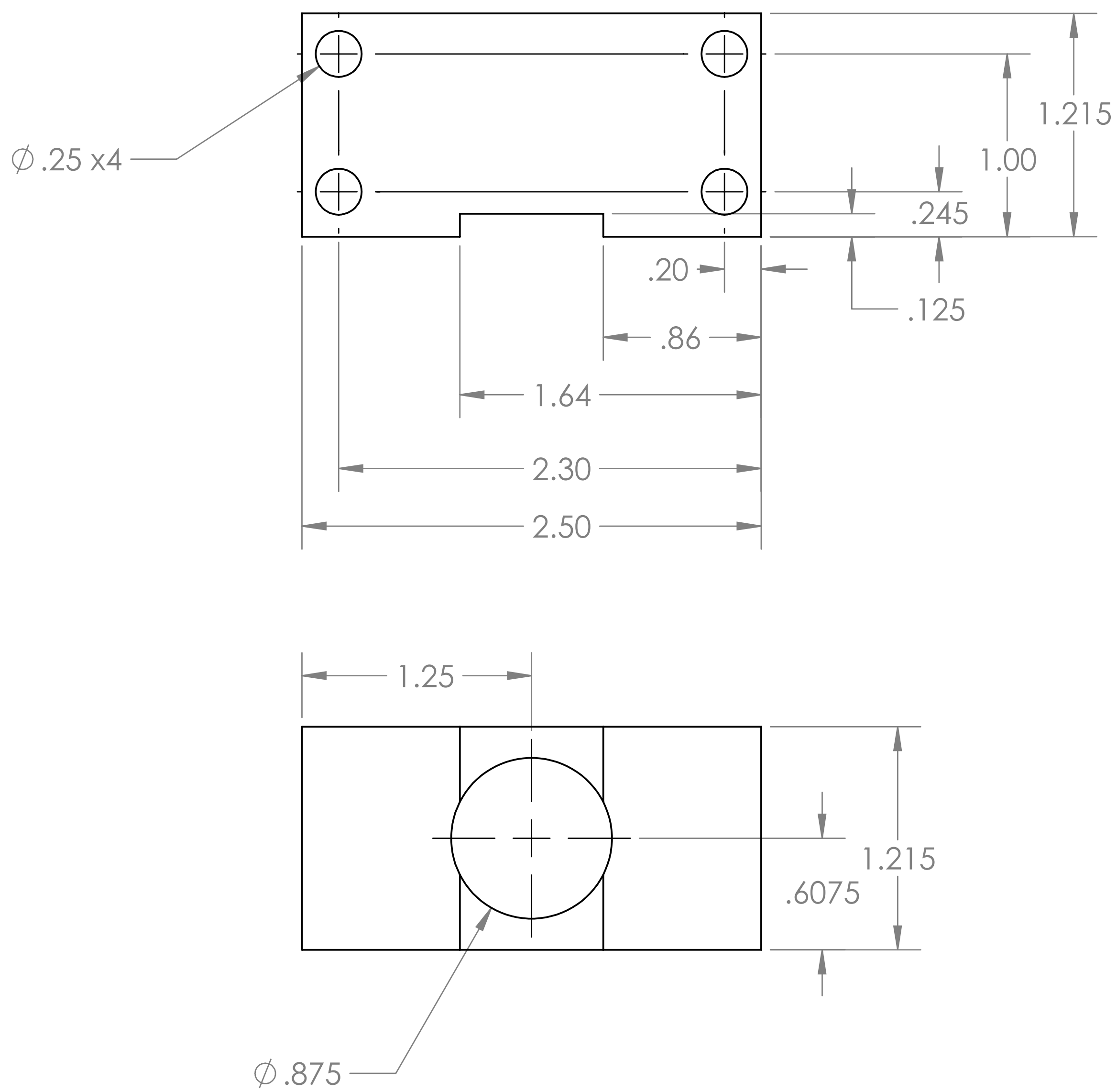
PART NAME: Front Bearing Housing

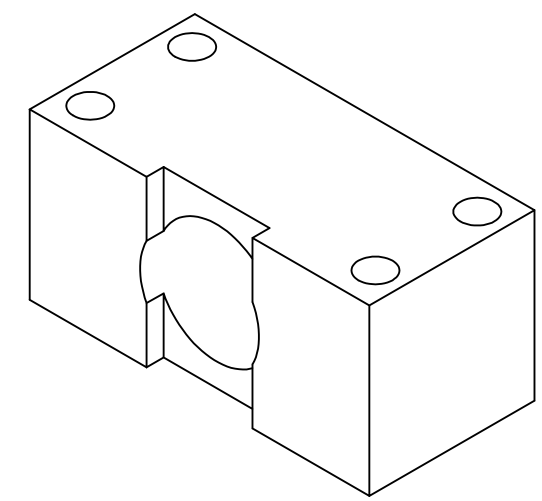
REV: 1

SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	16 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6061-T6

FINISH 250 µin

BYU MARS ROVER 2017

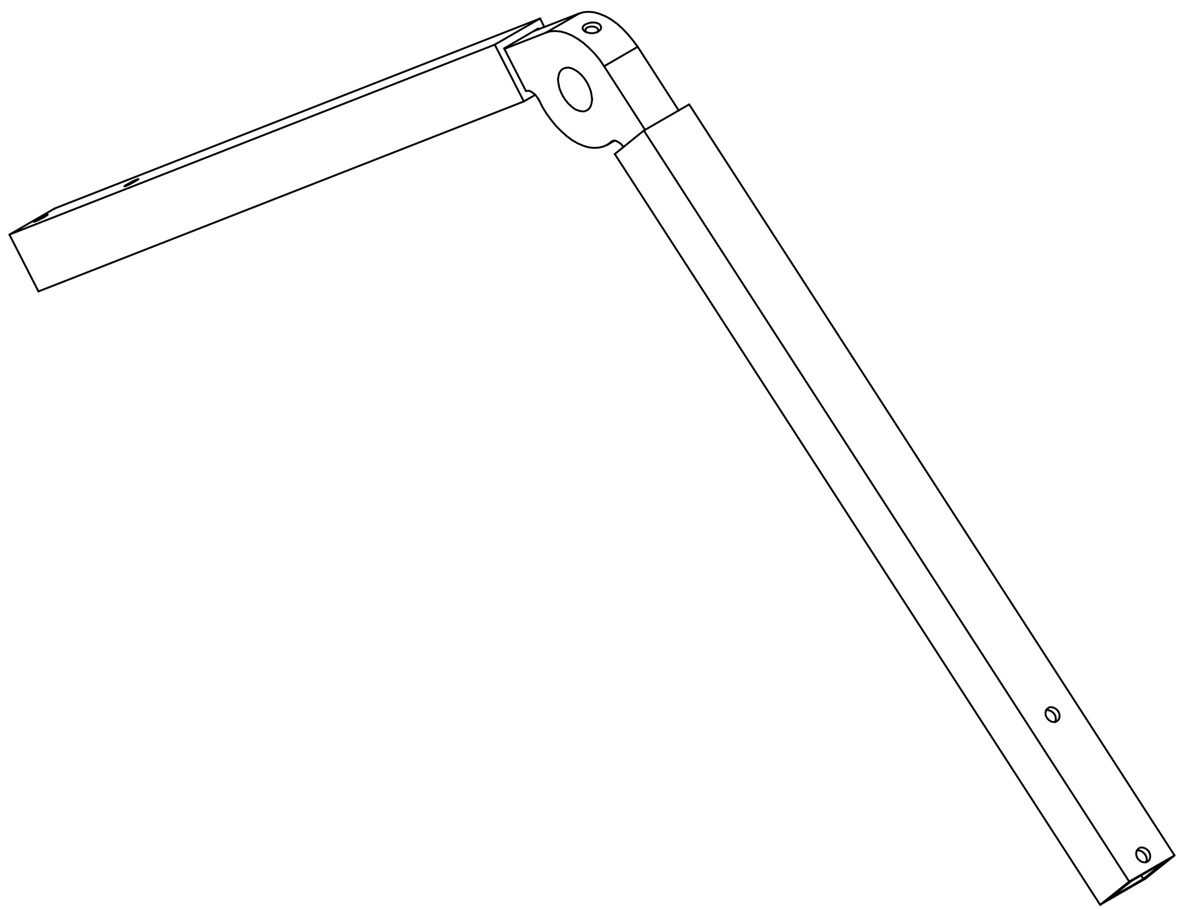
PART #: MRP-CHA-0028 R1

SIZE B | PART NAME: Rear Bearing Housing | REV 1

SCALE: 2:1 | SHEET 1 OF 1

4 3 2 1

B



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REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	ALEX JENSEN	17 APR 2017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRAIN JACKSON	17 APR 2017
MFG APPR.	BRAIN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

MARS ROVER

PART #: MRP-CHA-0030 R1

SIZE B

PART NAME: Front Arm Weld

REV 1

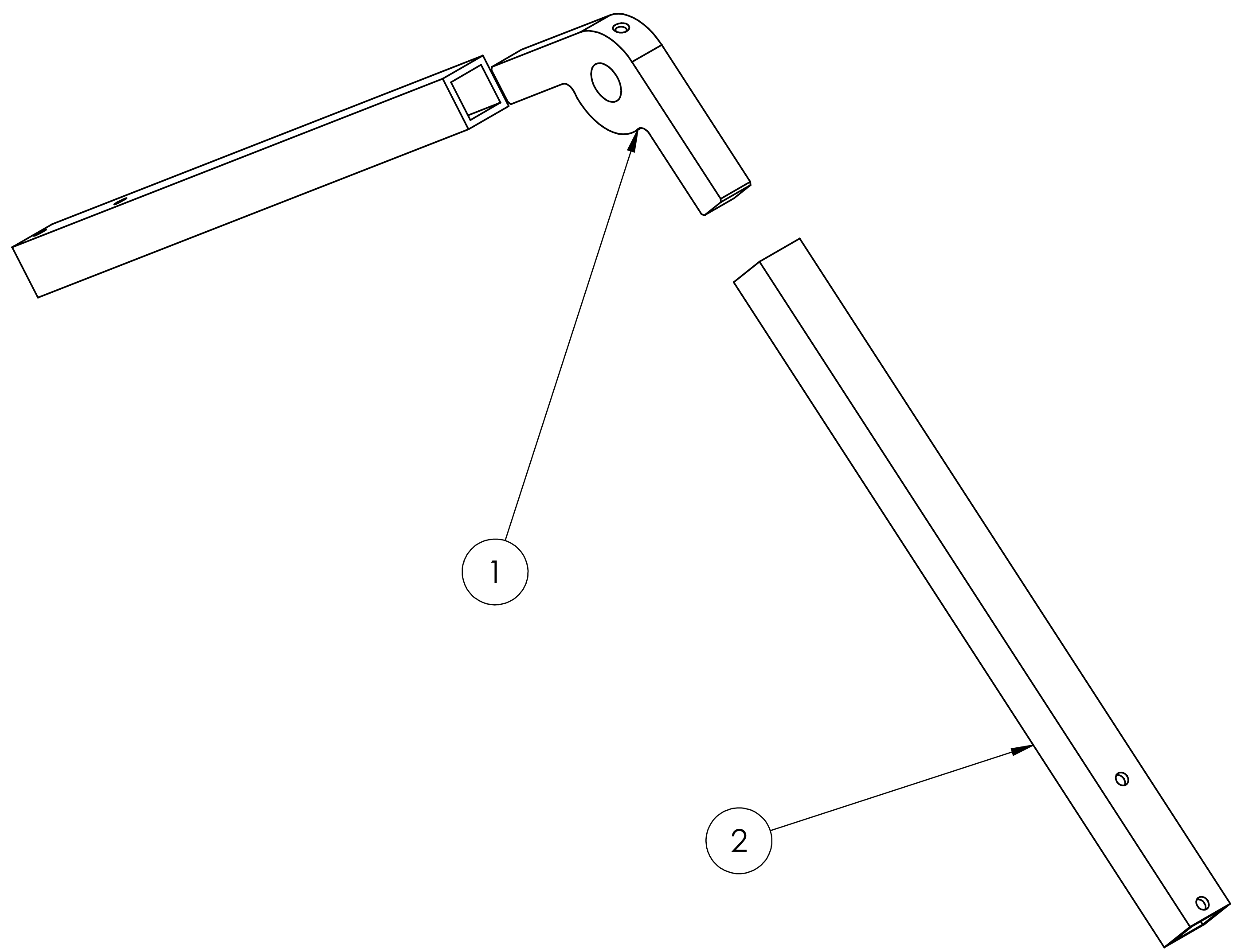
SCALE: 1:3

SHEET 2 OF 2

NOTE:

1. JOINTS ARE WELDED

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	MRP-CHA-0006 R1	FrontArm	2
1	MRP-CHA-0005 R1	FrontAngleBracket	1

	NAME	DATE
DRAWN	ALEX JENSEN	17 APR 2017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRAIN JACKSON	17 APR 2017
MFG APPR.	BRAIN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

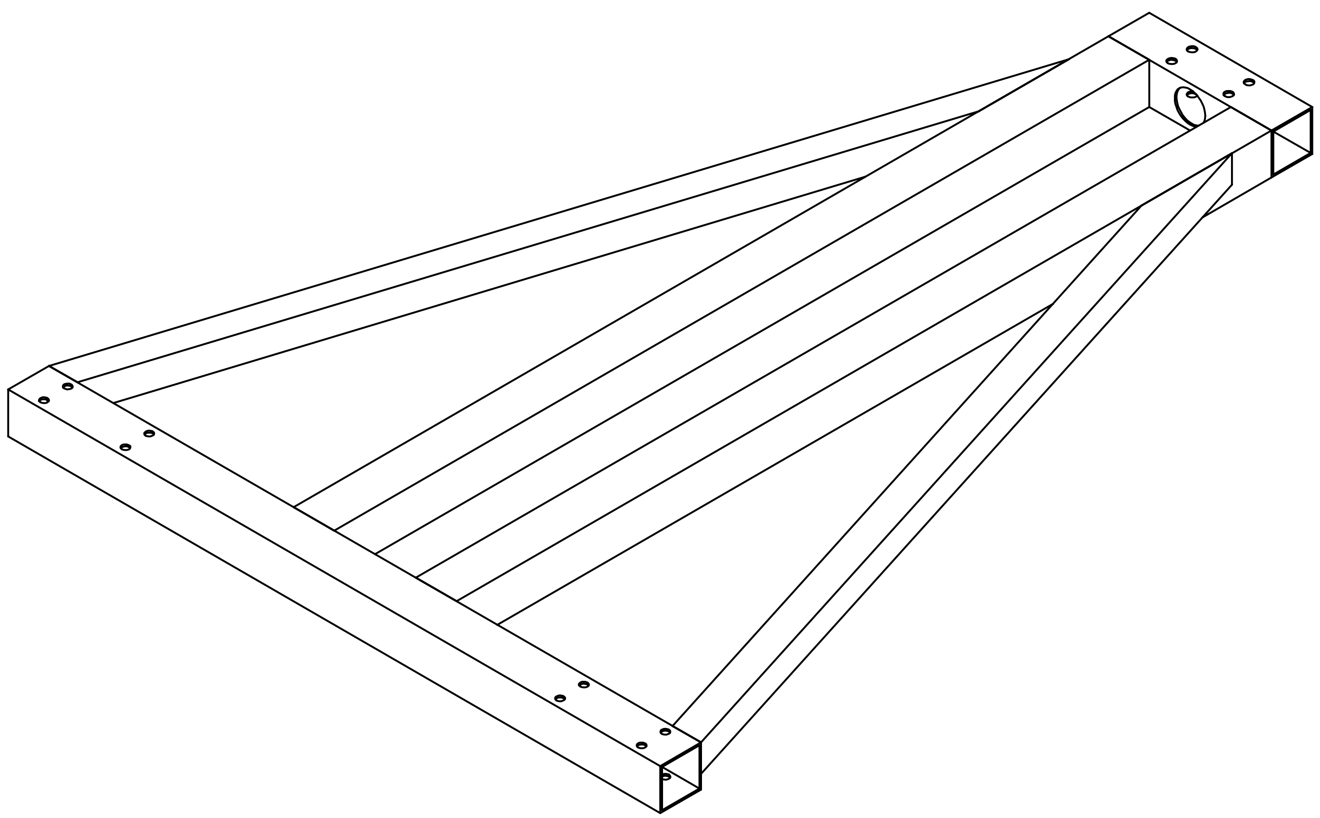
BYU
MARS ROVER
2017

PART #:
MRP-CHA-0030 R1

SIZE B | PART NAME: Front Arm Weld | REV 1

SCALE: 1:3 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	See Sheet1	-	-



	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

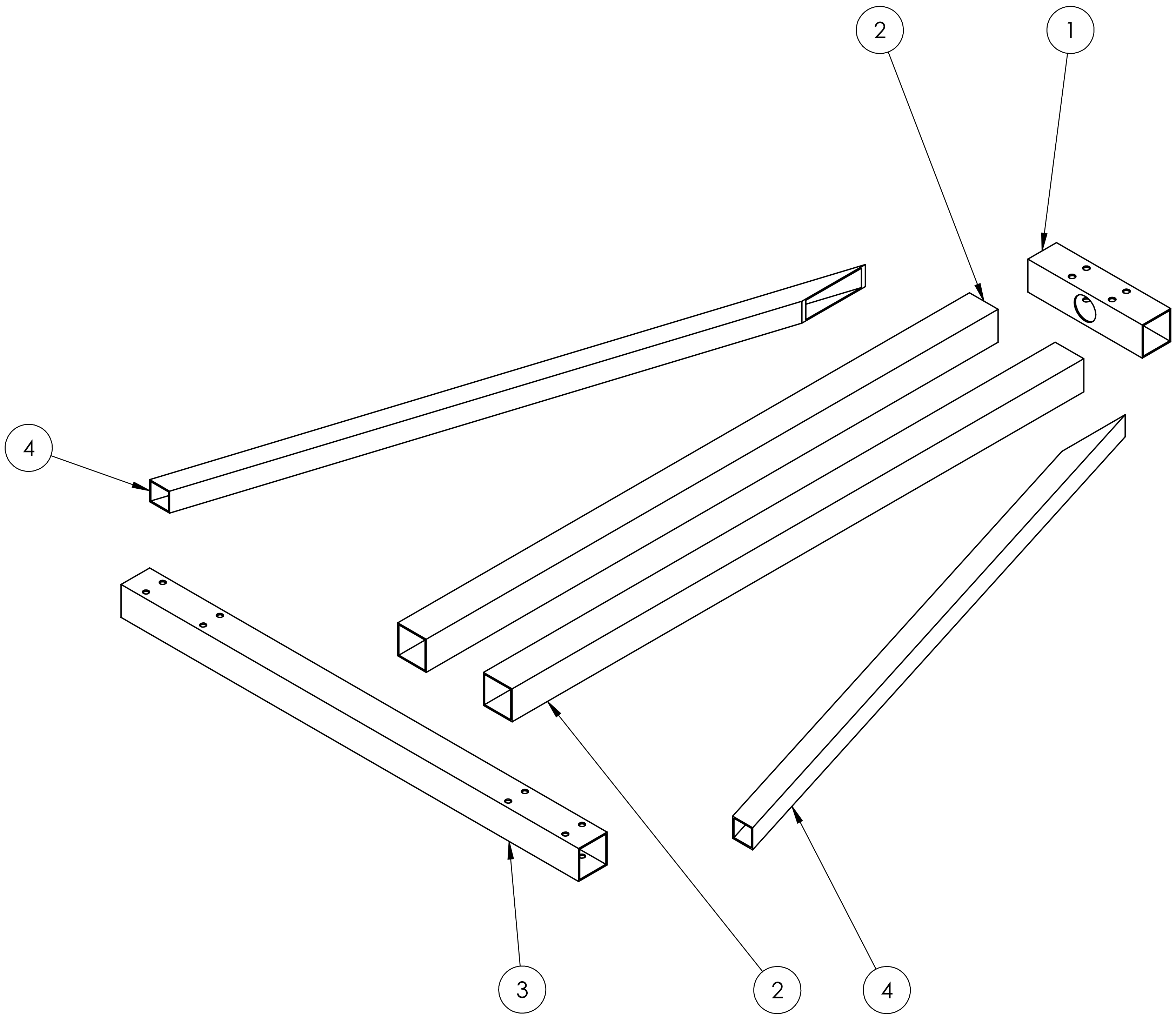
BYU
MARS ROVER
2017

PART #: MRP-CHA-0100 R1

SIZE	PART NAME:	REV
B	Frame	1

SCALE: 1:5

SHEET 2 OF 2



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
4	BaseAngledBeam	MRP-CHA-0004 R1	2
3	BaseFrontBeam	MRP-CHA-0003 R1	1
2	BaseCenterBeam	MRP-CHA-0002 R1	2
1	BaseBackBeam	MRP-CHA-0001 R1	1

	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

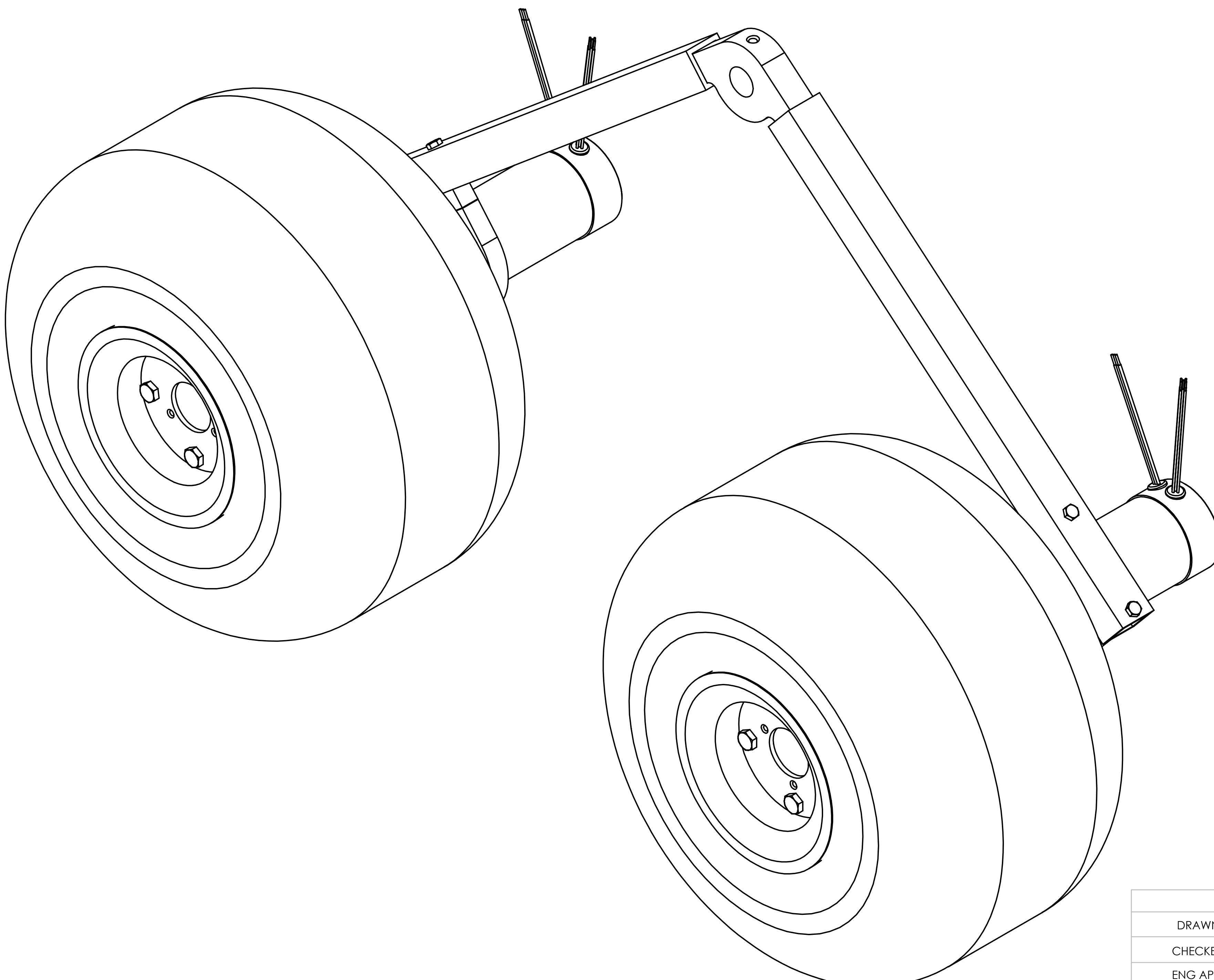
BYU
MARS ROVER
2017

PART #:
MRP-CHA-0100 R1

SIZE **B** | PART NAME: Frame | REV 1

SCALE: 1:5 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRAIN JACKSON	17 APR 2017
MFG APPR.	BRIAN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

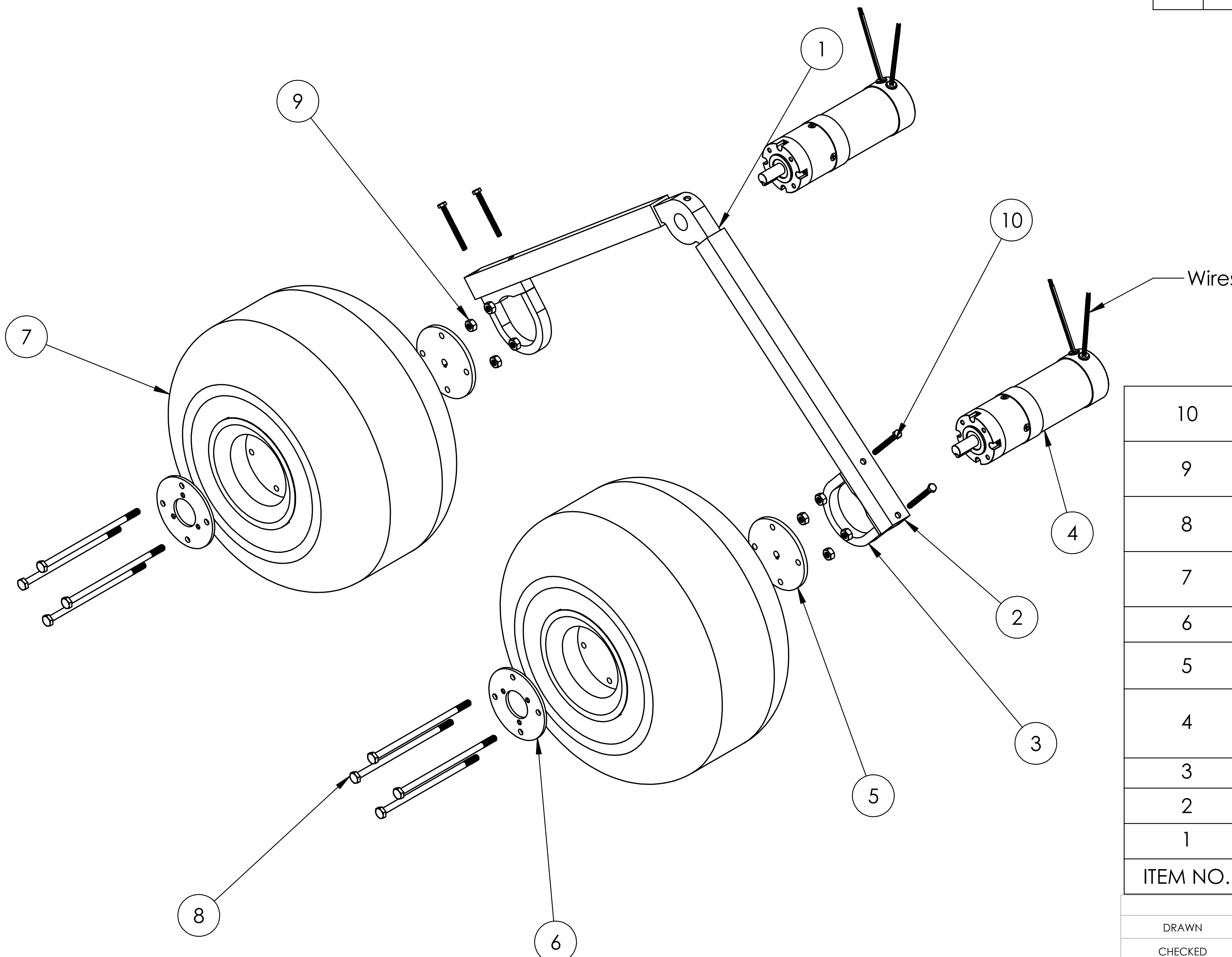
BYU
MARS ROVER
2017

PART #: MRP-CHA-0200 R1

SIZE B | PART NAME: Front Arm Assembly | REV 1

SCALE: 1:3 | SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
10	McMaster Carr # 92314A838	92314A838	4
9	McMaster Carr # 91845A029	91845A029	8
8	McMaster Carr # 92198A564	92198A564	8
7	Wheeleez # WZ1-30UA	Wheel Assembly	2
6	MRP-CHA-0017 R1	Wheel Adapter Plate	2
5	McMaster Carr # 9723T14	Wheel Motor Interface	2
4	Anaheim Automation BLWRPG235S-24V-4000-R18	Brushless Motor with Planetary Gearbox	2
3	MRP-CHA-0018 R1	motor-mounting-bracket	2
2	MRP-CHA-0006 R1	FrontArm	2
1	MRP-CHA-0005 R1	FrontAngleBracket	1

	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRAIN JACKSON	17 APR 2017
MFG APPR.	BRIAN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-CHA-0200 R1

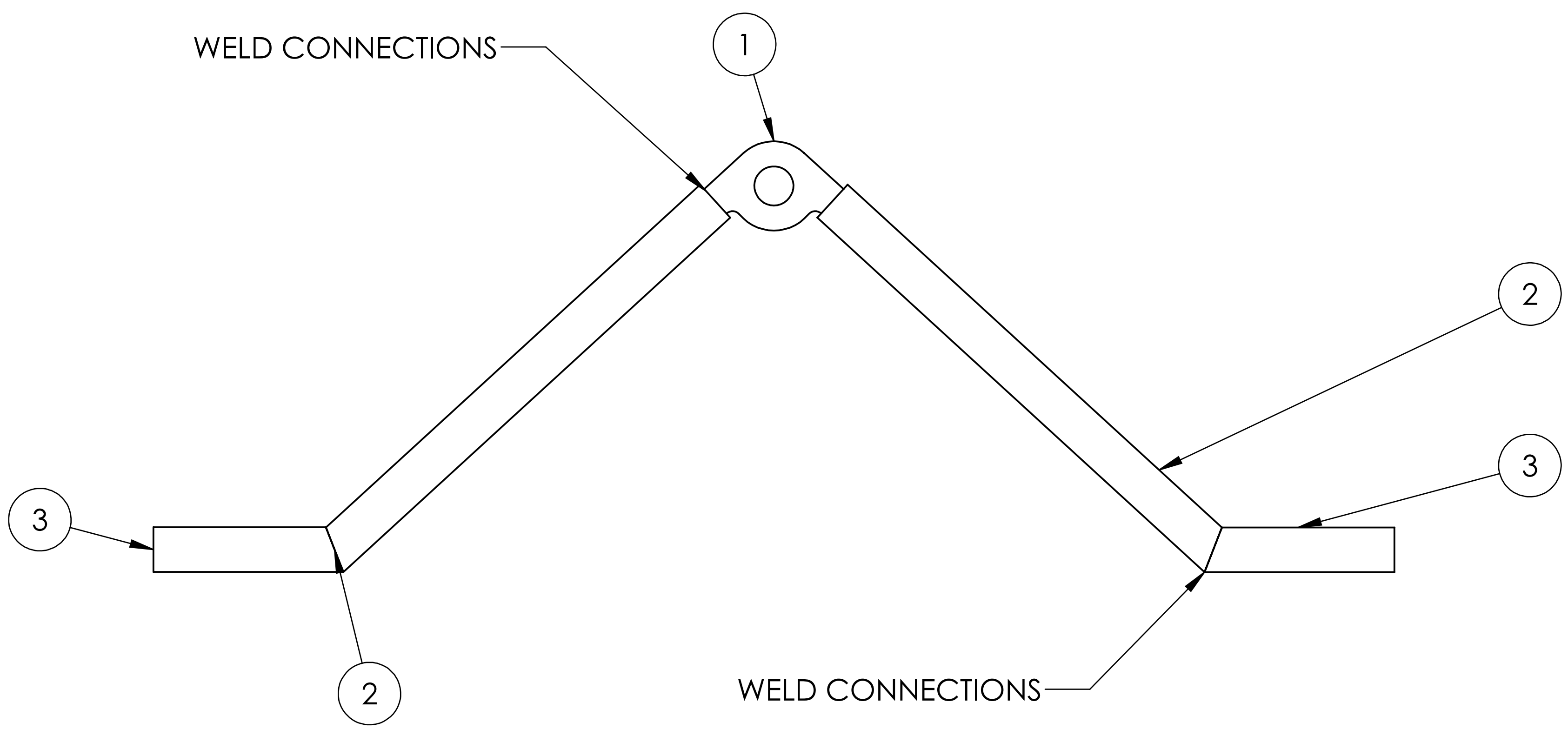
SIZE B

PART NAME: Front Arm Assembly

REV 1

SCALE: 1:5

SHEET 1 OF 2



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

3	RearArmShort	MRP-CHA-0011 R1	2
2	RearArmLong	MRP-CHA-0010 R1	2
1	Rear Angle Bracket	MRP-CHA-0009 R1	1
ITEM NO.	DESCRIPTION	PART NUMBER	QTY.

	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

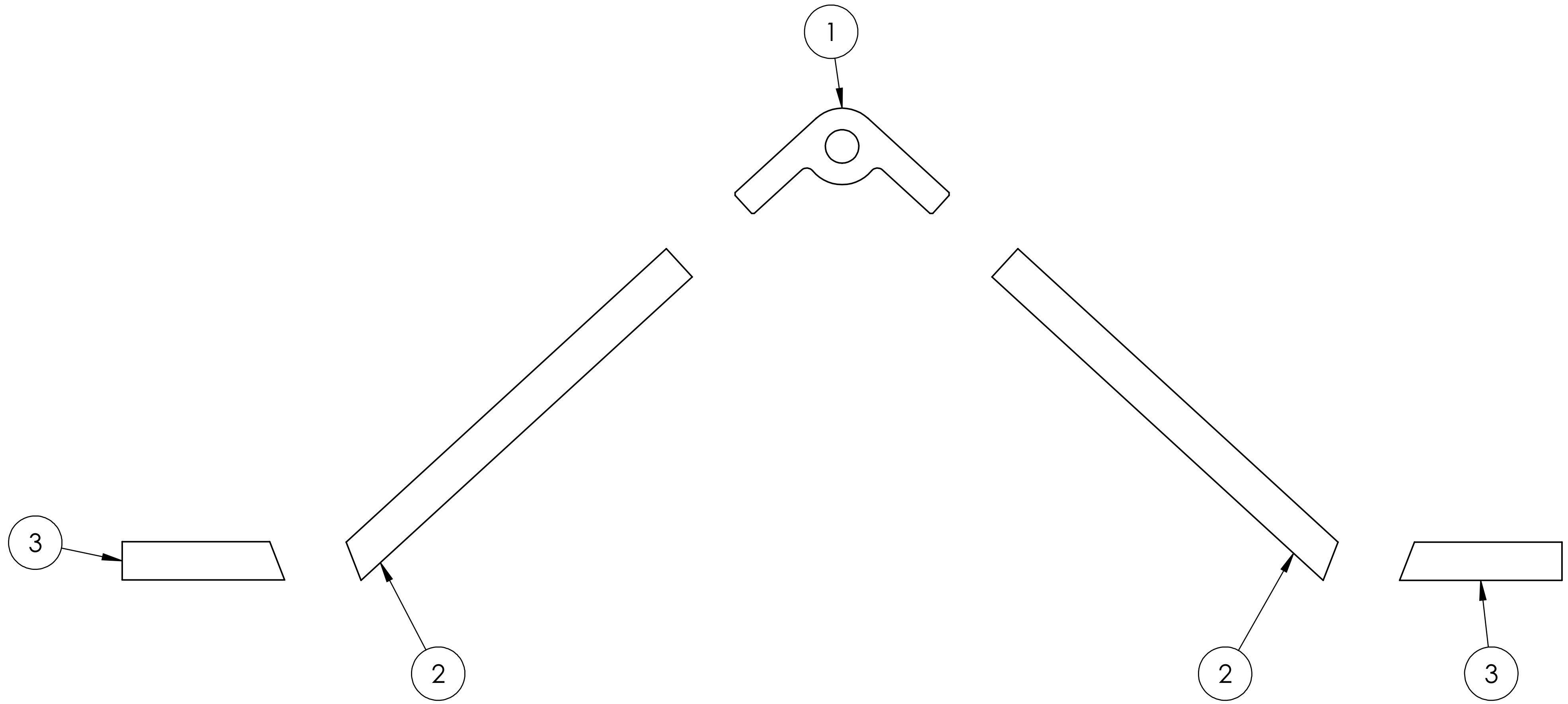
BYU
MARS ROVER
2017

PART #: MRP-CHA-0300 R1

SIZE B | PART NAME: Rear Arm Assembly | REV 1

SCALE: 1:4 | SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



3	RearArmShort	MRP-CHA-0011 R1	2
2	RearArmLong	MRP-CHA-0010 R1	2
1	Rear Angle Bracket	MRP-CHA-0009 R1	1
ITEM NO.	DESCRIPTION	PART NUMBER	QTY.

	NAME	DATE
DRAWN	ALEX JENSEN	8 APR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0300 R1

SIZE B

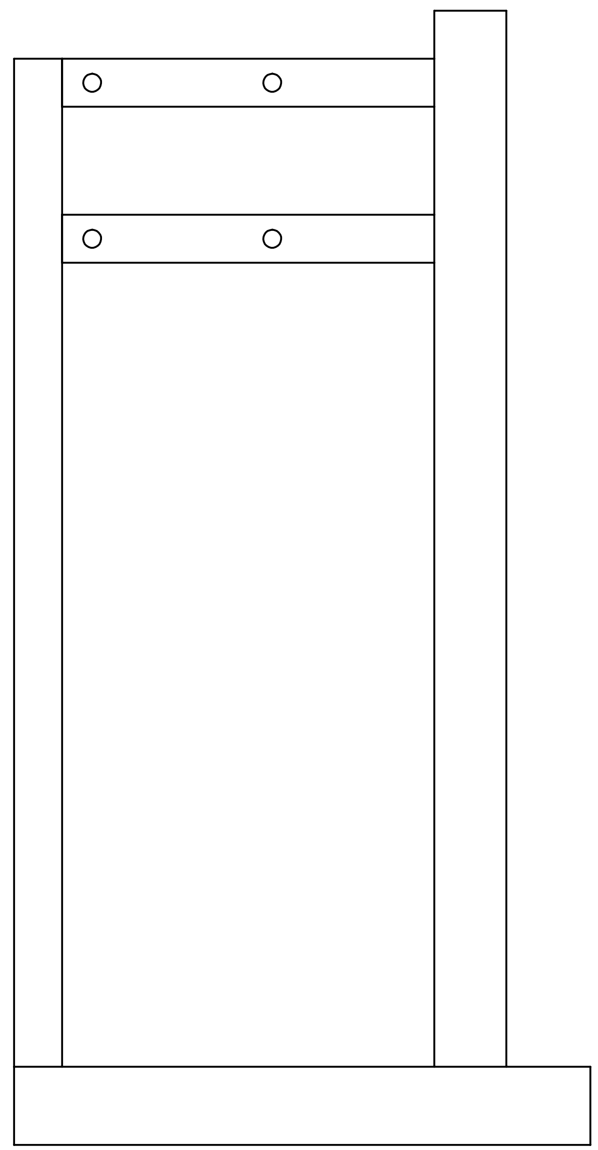
PART NAME: Rear Arm Assembly

REV 1

SCALE: 1:4

SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



WELD ALL CONNECTIONS

	NAME	DATE
DRAWN	Benjamin Hilton	25 February 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

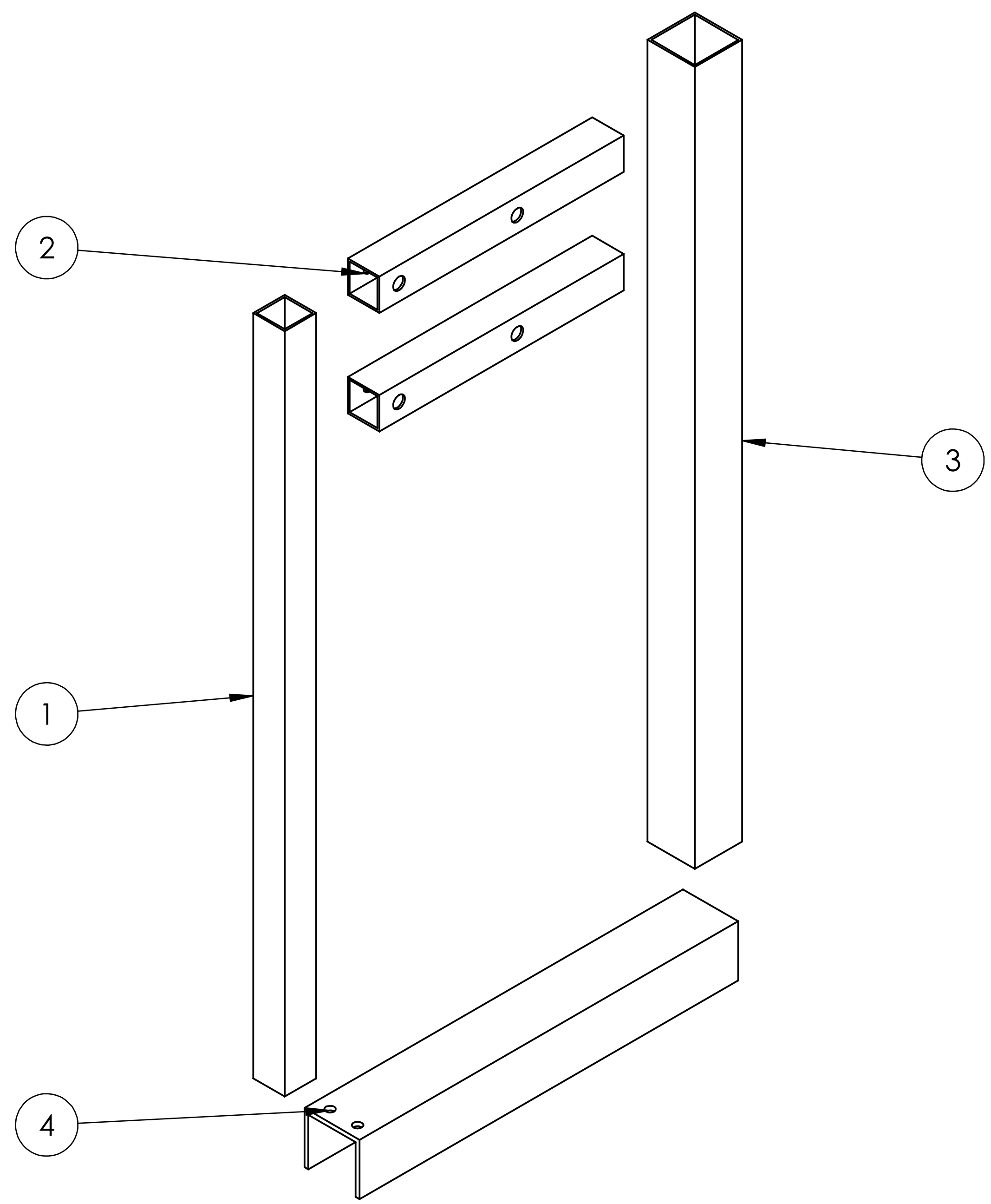
BYU MARS ROVER 2017

PART #: MRP-CHA-0400 R1

SIZE B | PART NAME: bracket assembly | REV 1

SCALE: 1:4 | SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
4	MRP-CHA-0023 R1	U Bracket	1
3	MRP-CHA-0024 R1	Square Side Bracket 1.15	1
2	MRP-CHA-0026 R1	Square Middle Support	2
1	MRP-CHA-0025 R1	Square Side Bracket 1	1

	NAME	DATE
DRAWN	B HILTON	25 FEB 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0400 R1

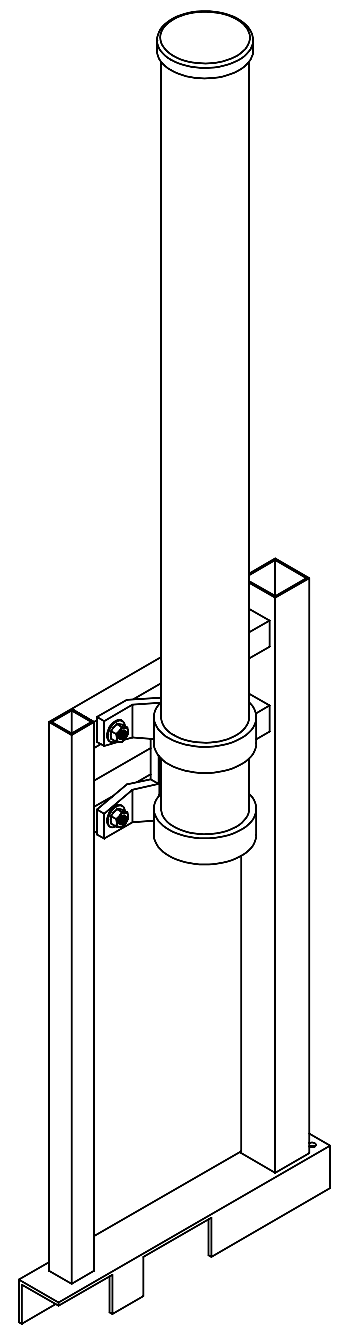
SIZE **B**

PART NAME: bracket assembly

REV 1

SCALE: 1:4

SHEET 1 OF 2



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

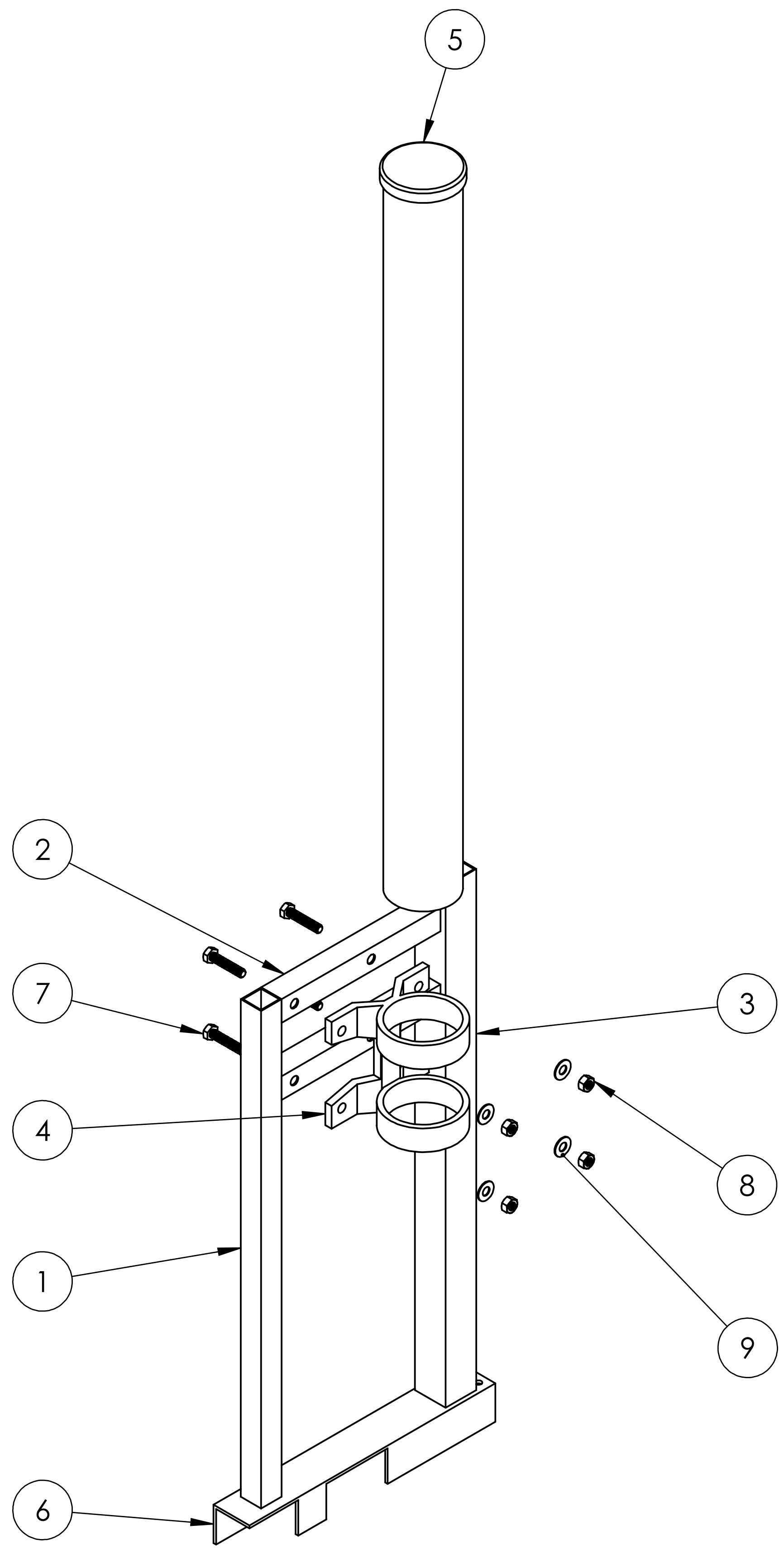
BYU
MARS ROVER
2017

PART #: MRP-ELE-0101 R1

SIZE	PART NAME:	REV
B	Bracket Assembly with Antenna	1

SCALE: 1:6 SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
9	McMaster Carr # 90107A030	316 Stainless Steel Washer for 5/16" Screw Size	4
8	McMaster Carr # 91845A030	18-8 Stainless Steel Hex Nut, 5/16"-18 Thread Size	4
7	McMaster Carr # 92240A587	18-8 Stainless Steel Hex Head Screw, 5/16"-18 Thread Size, 1-1/2" Long, Fully Threaded	4
6	MRP-CHA-0023 R1	U Bracket	1
5	Amazon #AMO-2G10	ubiquiti antenna	1
4	Amazon #AMO-2G10	ubiquiti antenna brace	1
3	MRP-CHA-0024 R1	Square Side Bracket 1.15	1
2	MRP-CHA-0026 R1	Square Middle Support	2
1	MRP-CHA-0025 R1	Square Side Bracket 1	1

	NAME	DATE
DRAWN	ALEX JENSEN	15 APRIL 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0401 R1

SIZE B

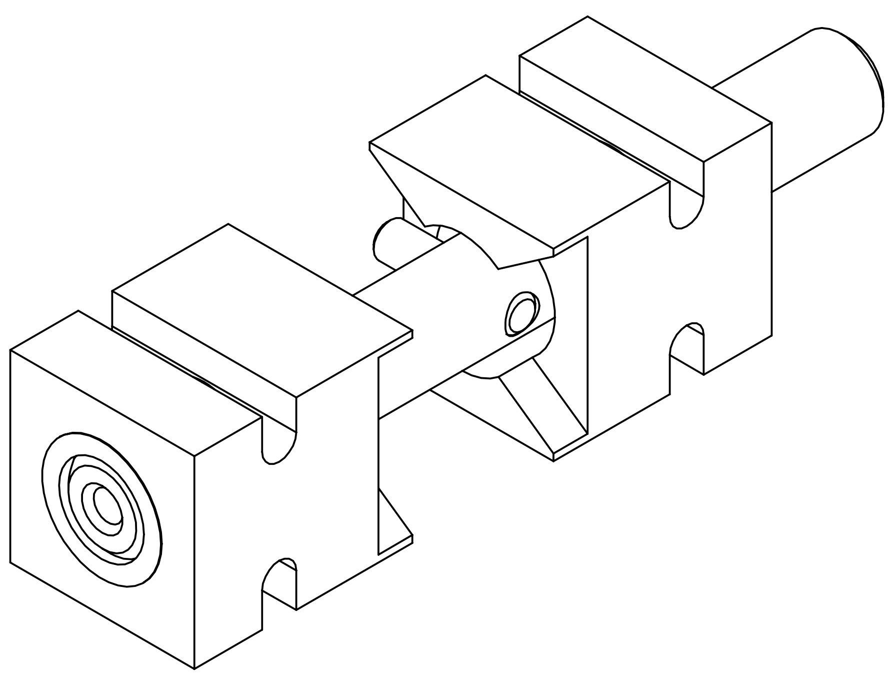
PART NAME: Bracket Assembly with Antenna

REV 1

SCALE: 1:6

SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0500 R1

SIZE: **B**

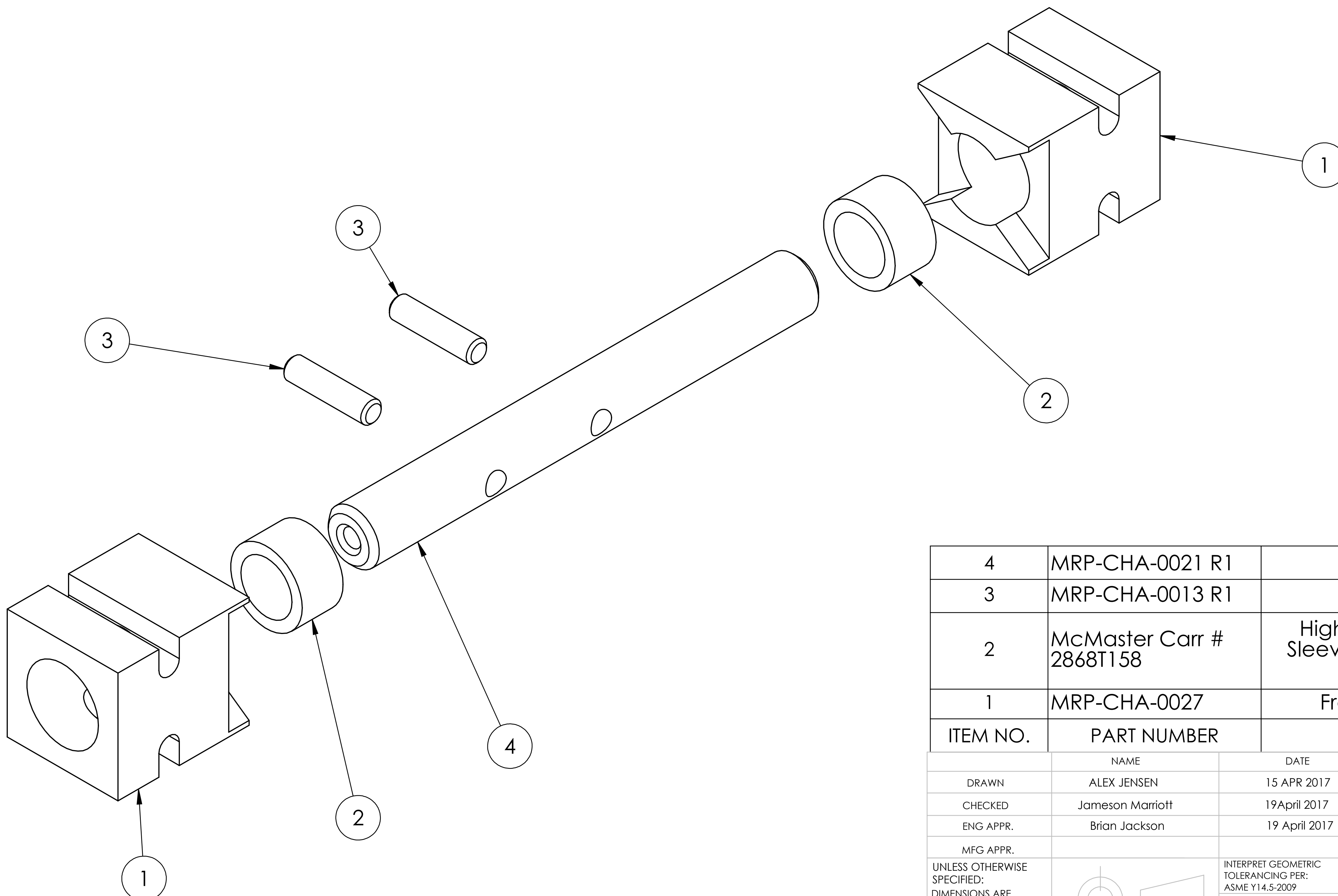
PART NAME: Front Bearing Assembly

REV: 1

SCALE: 1:1

SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



4	MRP-CHA-0021 R1	Front Axle	1
3	MRP-CHA-0013 R1	Stop Pin	2
2	McMaster Carr # 2868T158	High-Load Oil-Embedded Sleeve Bearing for 5/8" Shaft Diameter, 7/8" OD	2
1	MRP-CHA-0027	Front Bearing Housing	2
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0500 R1

SIZE B | PART NAME: Front Bearing Assembly | REV 1

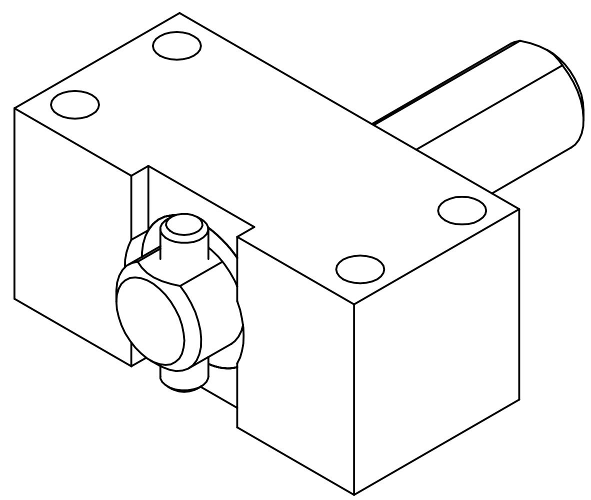
SCALE: 1:1 | SHEET 1 OF 2

4 3 2 1

B B

A A

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0600 R1

SIZE B

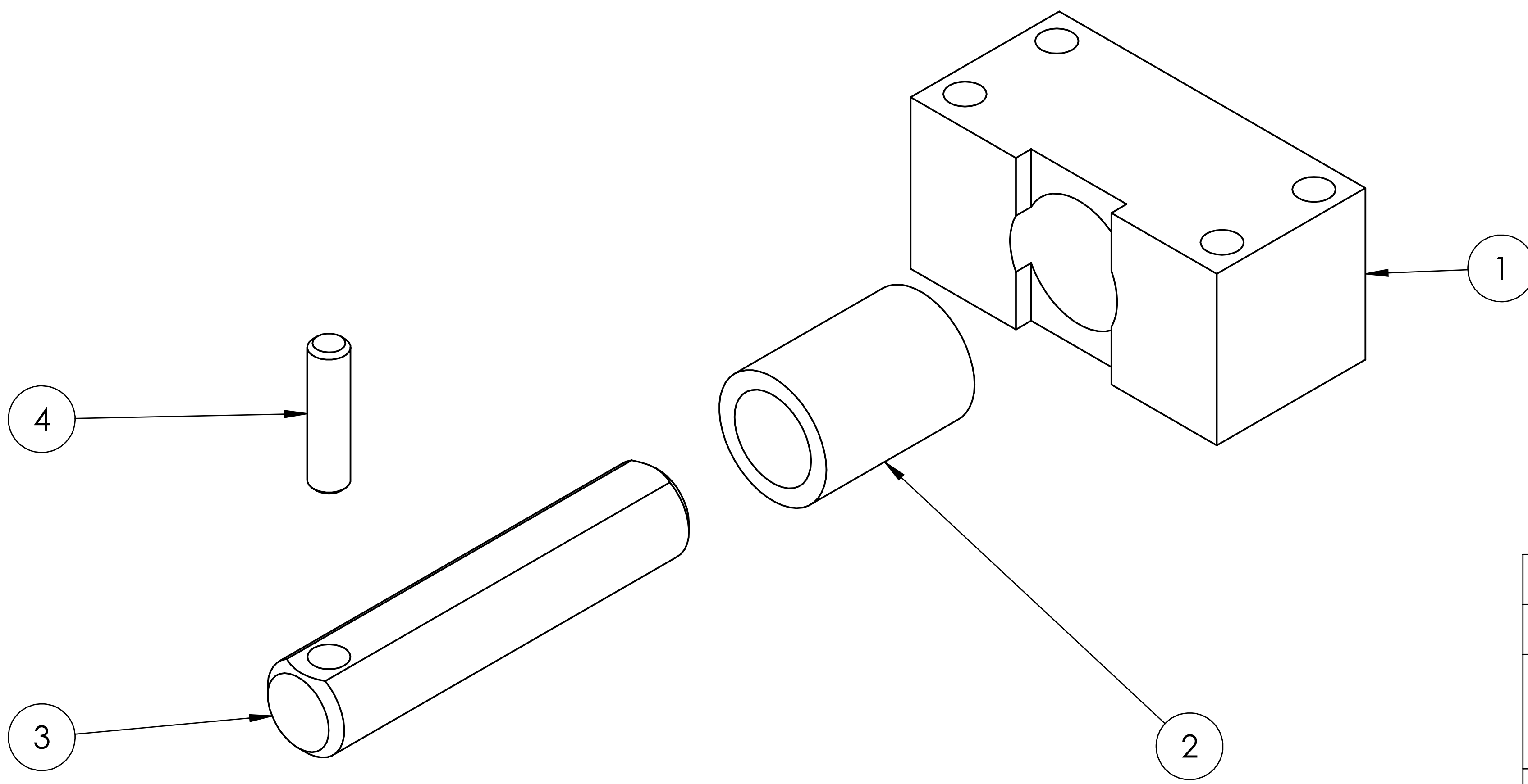
PART NAME: Rear Bearing Assembly

REV 1

SCALE: 1:1

SHEET 2 OF 2

4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
4	MRP-CHA-0013 R1	Stop Pin	1
3	MRP-CHA-0007 R1	Rear Axle	1
2	McMaster Carr # 2868T158	High-Load Oil-Embedded Sleeve Bearing for 5/8" Shaft Diameter, 7/8" OD	1
1	MRP-CHA-0028 R1	Rear Bearing Housing	1

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

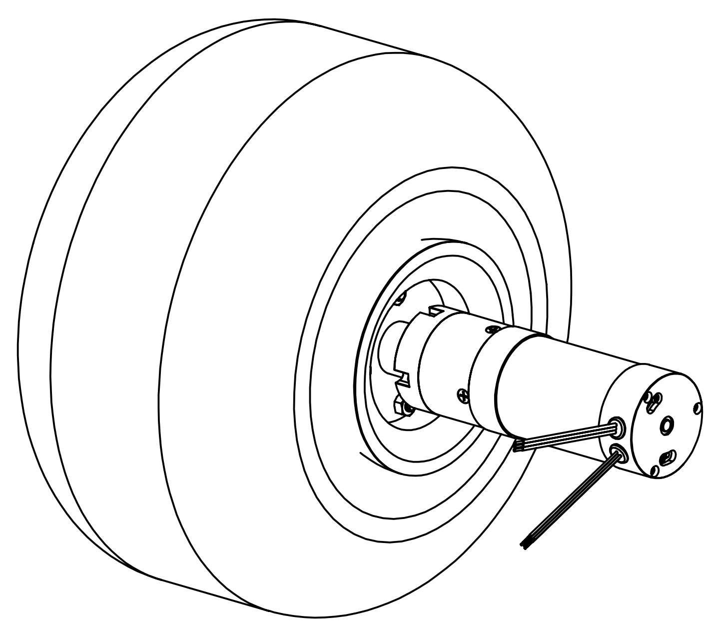
BYU
MARS ROVER
2017

PART #: MRP-CHA-0600 R1

SIZE B | PART NAME: Rear Bearing Assembly | REV 1

SCALE: 1:1 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Brian Jackson	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0700 R1

SIZE B

PART NAME: Wheel and Motor Assembly

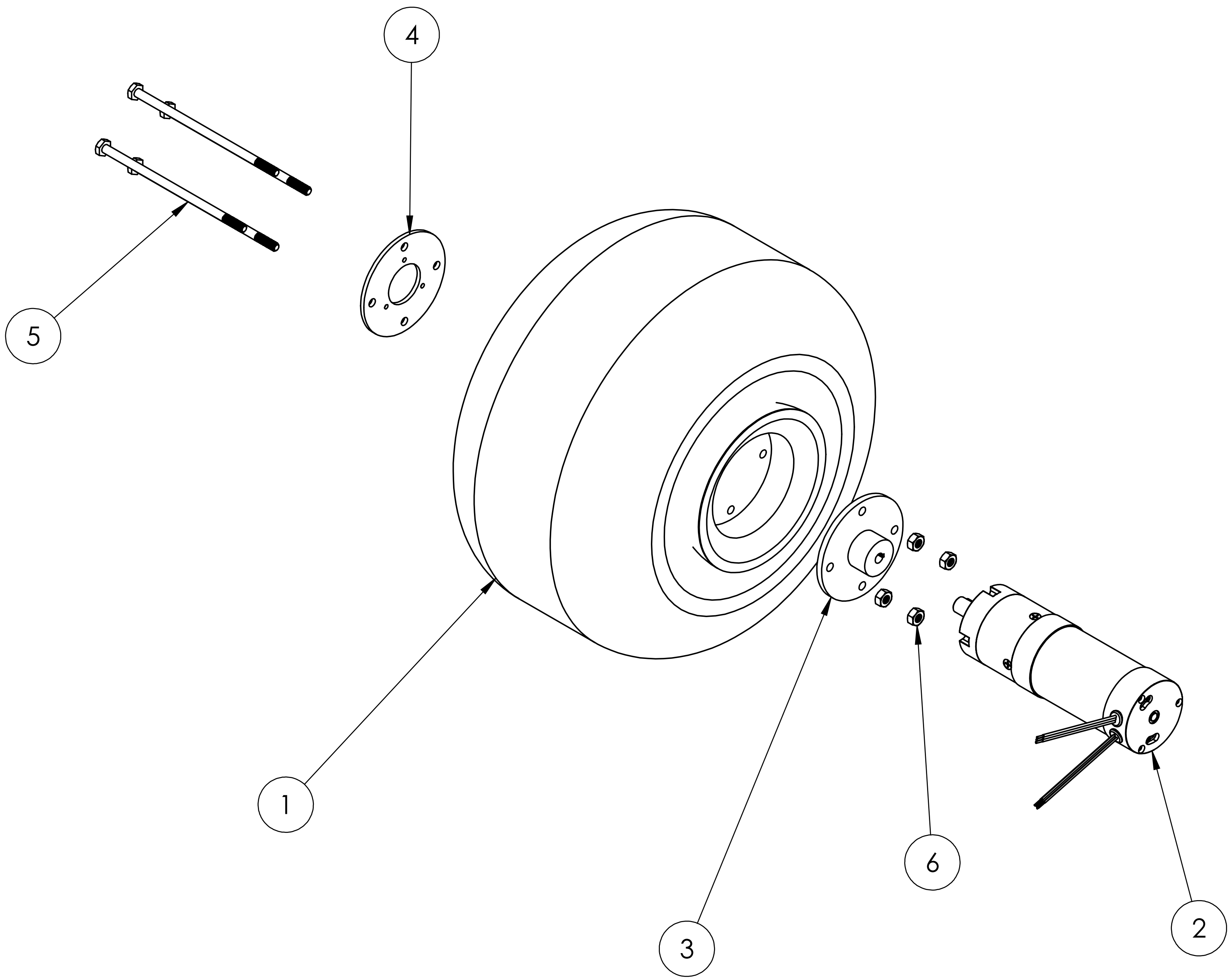
REV 1

SCALE: 1:4

SHEET 2 OF 2

ZONE	REV.	DESCRIPTION	DATE	APPROVED

REVISIONS



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
6	McMaster Carr # 91845A029	91845A02918-8 Stainless Steel Hex Nut, 1/4"-20 Thread Size	4
5	McMaster Carr #92198A564	18-8 Stainless Steel Hex Head Screw, 1/4"-20 Thread Size, 5-1/2" Long, Partially Threaded	4
4	MRP-CHA-0017 R1	Wheel Adapter Plate	1
3	McMaster Carr # 9723T14	Wheel Motor Interface	1
2	Anaheim Automation # BLWRPG235S-24V-4000-R18	Brushless Motor with Planetary Gearbox	1
1	Wheeleez # WZ1-30UA	Wheel Assembly	1

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Brian Jackson	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0700 R1

SIZE: B

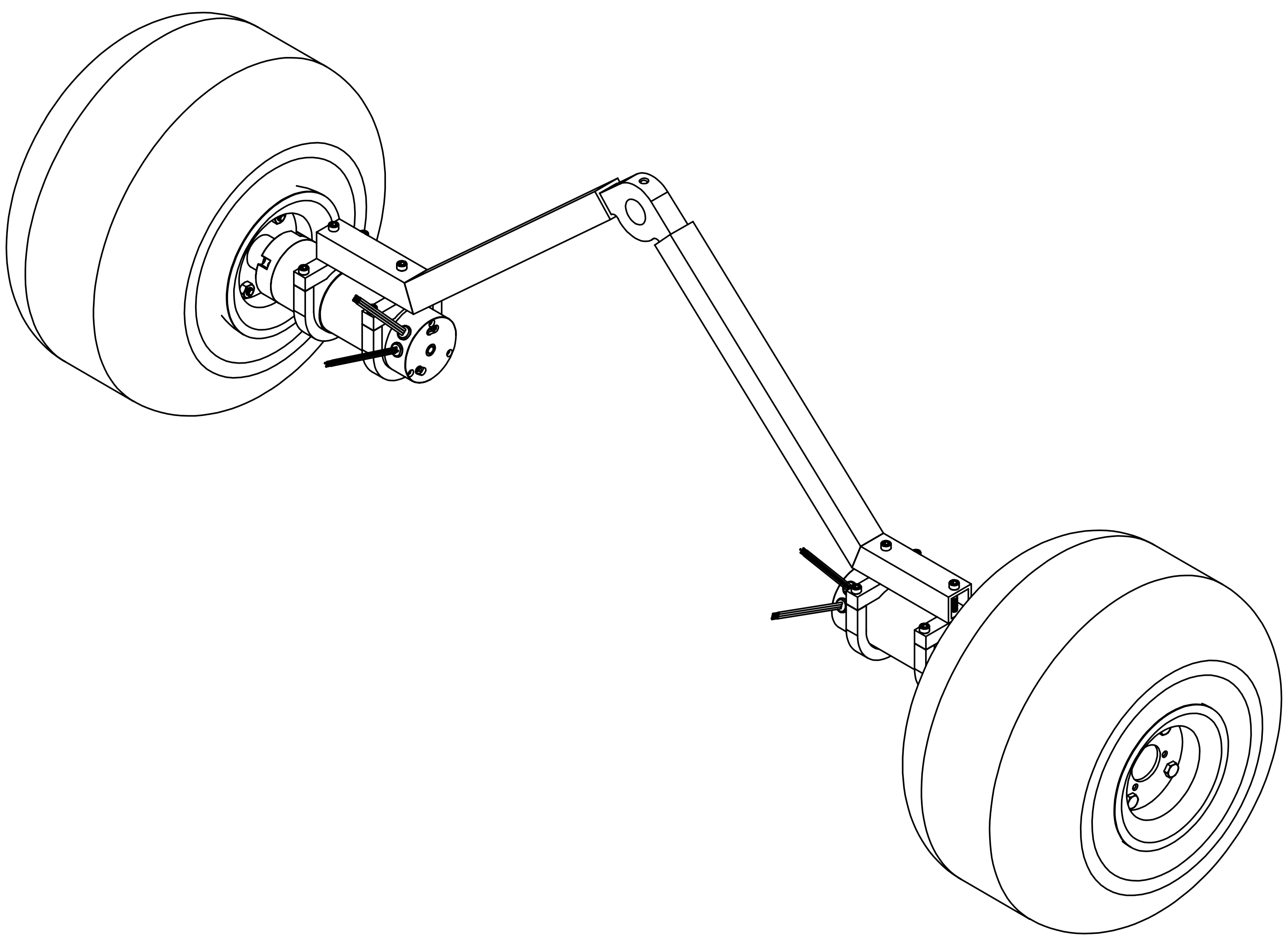
PART NAME: Wheel and Motor Assembly

REV: 1

SCALE: 1:4

SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	17 APR 2017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRIAN JACKSON	17 APR 2017
MFG APPR.	BRIAN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

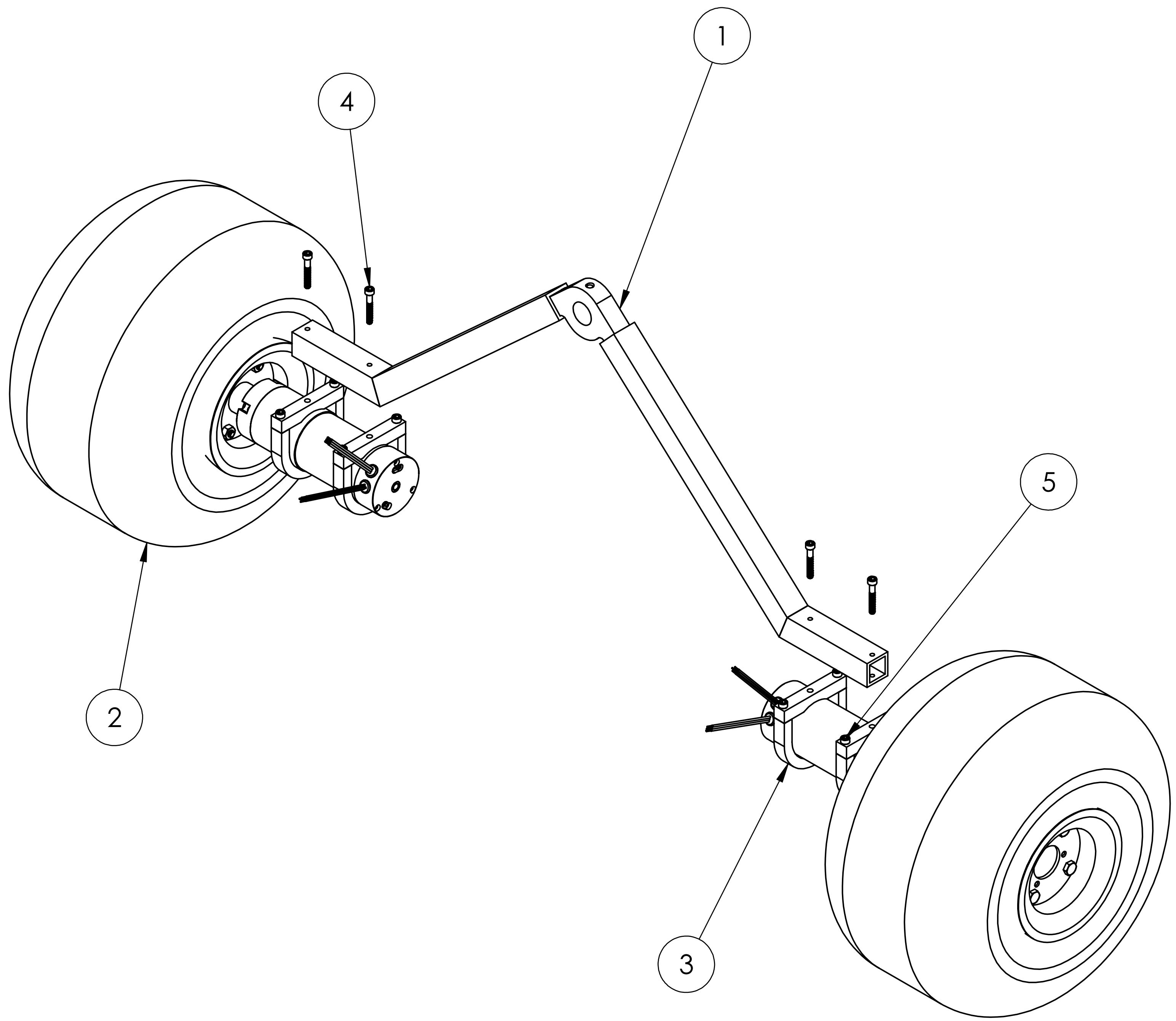
PART #: MRP-CHA-0800 R1

SIZE	PART NAME:	REV
B	Rear Arm and Wheels Assembly	1

SCALE: 1:5

SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	McMaster Carr # 91251A346	Black-Oxide Alloy Steel Socket Head Screw, 10-32 Thread Size, 7/8" Long	8
4	McMaster Carr # 91251A349	Black-Oxide Alloy Steel Socket Head Screw, 10-32 Thread Size, 1-1/4" Long	4
3	MRP-CHA-0018 R1	motor-mounting-bracket	4
2	MRP-CHA-0700 R1	Wheel and Motor Assembly	2
1	MRP-CHA-0300 R1	Rear Arm Assembly	1

	NAME	DATE
DRAWN	ALEX JENSEN	17 APR 017
CHECKED	JAMESON MARRIOT	17 APR 2017
ENG APPR.	BRIAN JACKSON	17 APR 2017
MFG APPR.	BRIAN JACKSON	17 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-0800 R1

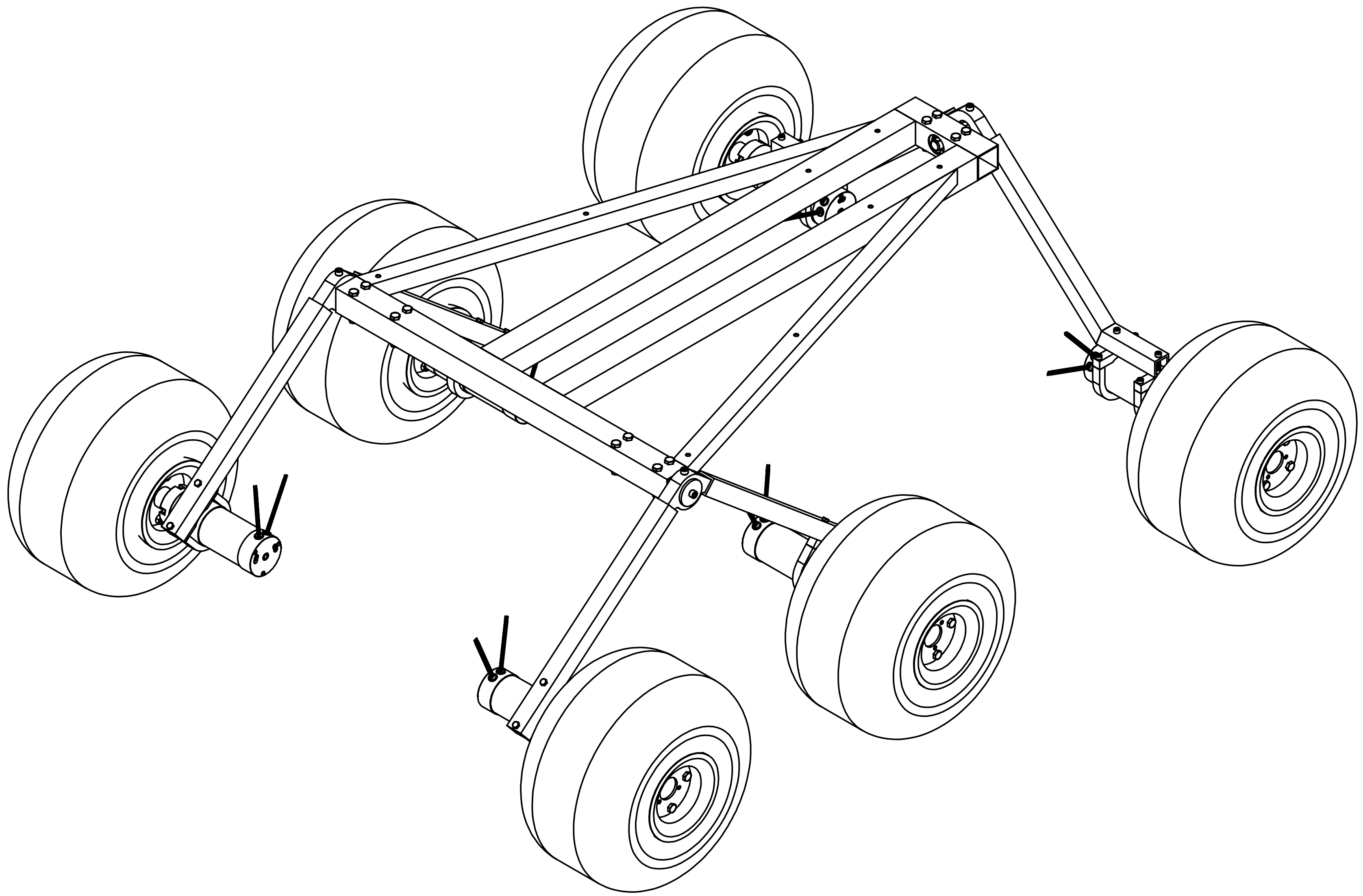
SIZE	PART NAME:	REV
B	Rear Arm and Wheels Assembly	1

SCALE: 1:5

SHEET 1 OF 2

4	3	2	1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRAIN JACKSON	18 APR 2017
MFG APPR.	BRAIN JACKSON	18 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

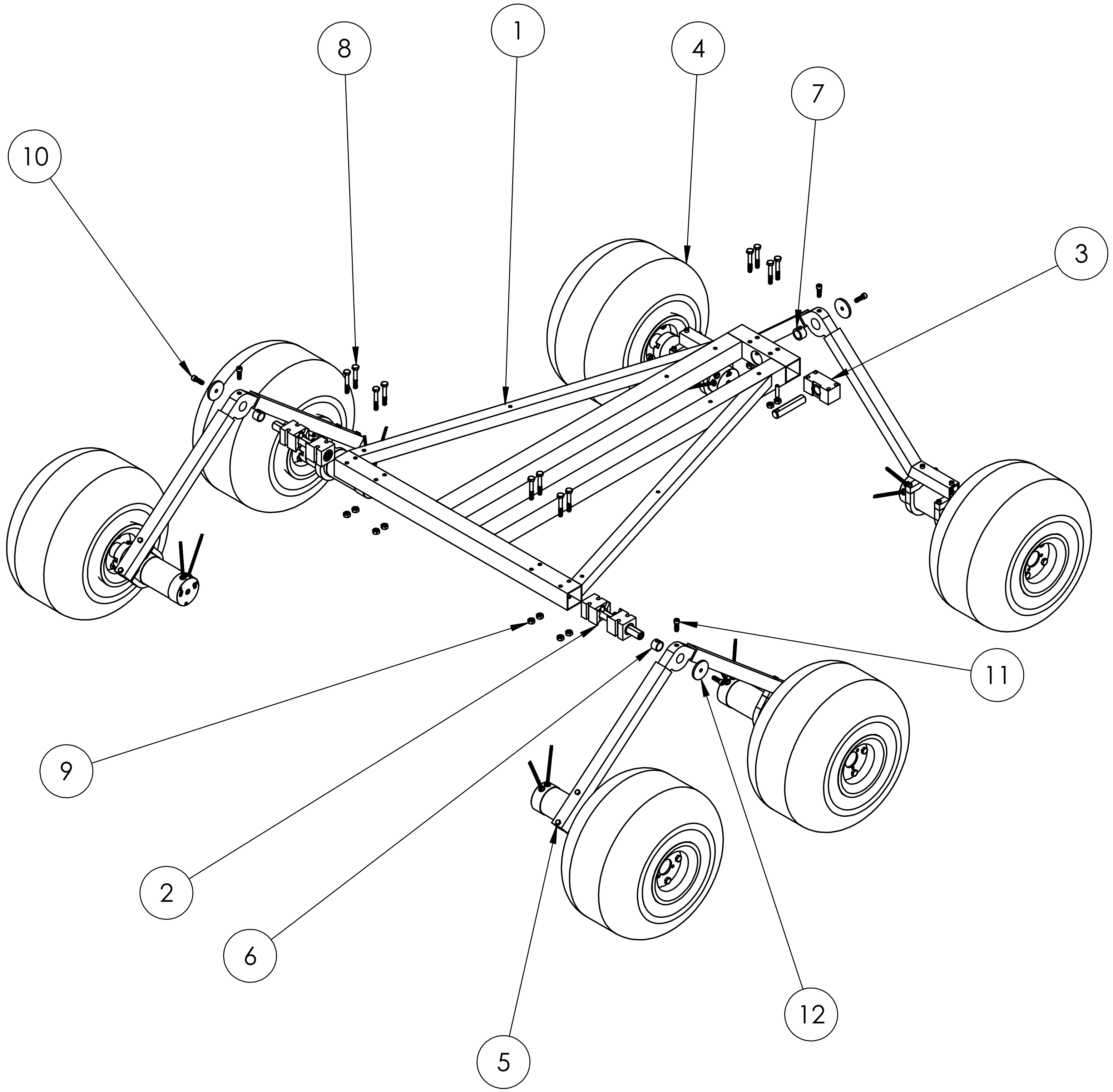
BYU
MARS ROVER
2017

PART #:
MRP-CHA-0900 R1

SIZE	PART NAME:	REV
B	Chassis	1

SCALE: 1:8 | SHEET 2 OF 2

4	3	2	1



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
12	McMaster Carr # 98370A111	18-8 Stainless Steel Washer Oversized, Number 12 Screw Size, 0.25" ID, 1.5" OD	3
11	McMaster Carr # 91251A540	Black-Oxide Alloy Steel Socket Head Screw, 1/4"-20 Thread Size, 3/4" Long	3
10	McMaster Carr # 91251A440	Black-Oxide Alloy Steel Socket Head Screw, 1/4"-28 Thread Size, 3/4" Long	3
9	McMaster Carr #92673A113	18-8 Stainless Steel Hex Nut, 1/4"-20 Thread Size, ASTM F594	12
8	McMaster Carr # 92198A548	18-8 Stainless Steel Hex Head Screw, 1/4"-20 Thread Size, 1-3/4" Long, Partially Threaded	12
7	McMaster Carr # 2868T156	High-Load Oil-Embedded Sleeve Bearing for 5/8" Shaft Diameter, 7/8" OD, 3/4" Long, SAE 863 Bronze	1
6	McMaster Carr # 2868T143	High-Load Oil-Embedded Sleeve Bearing for 5/8" Shaft Diameter, 3/4" OD, 3/4" Long, SAE 863 Bronze	2
5	MRP-CHA-0200 R1	Front Arm Assembly	2
4	MRP-CHA-0800 R1	Rear Arm and Wheels Assembly	1
3	MRP-CHA-0600 R1	Rear Bearing Assembly	1
2	MRP-CHA-0500 R1	Front Bearing Assembly	2
1	MRP-CHA-0100 R1	Frame	1

	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRAIN JACKSON	18 APR 2017
MFG APPR.	BRAIN JACKSON	18 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

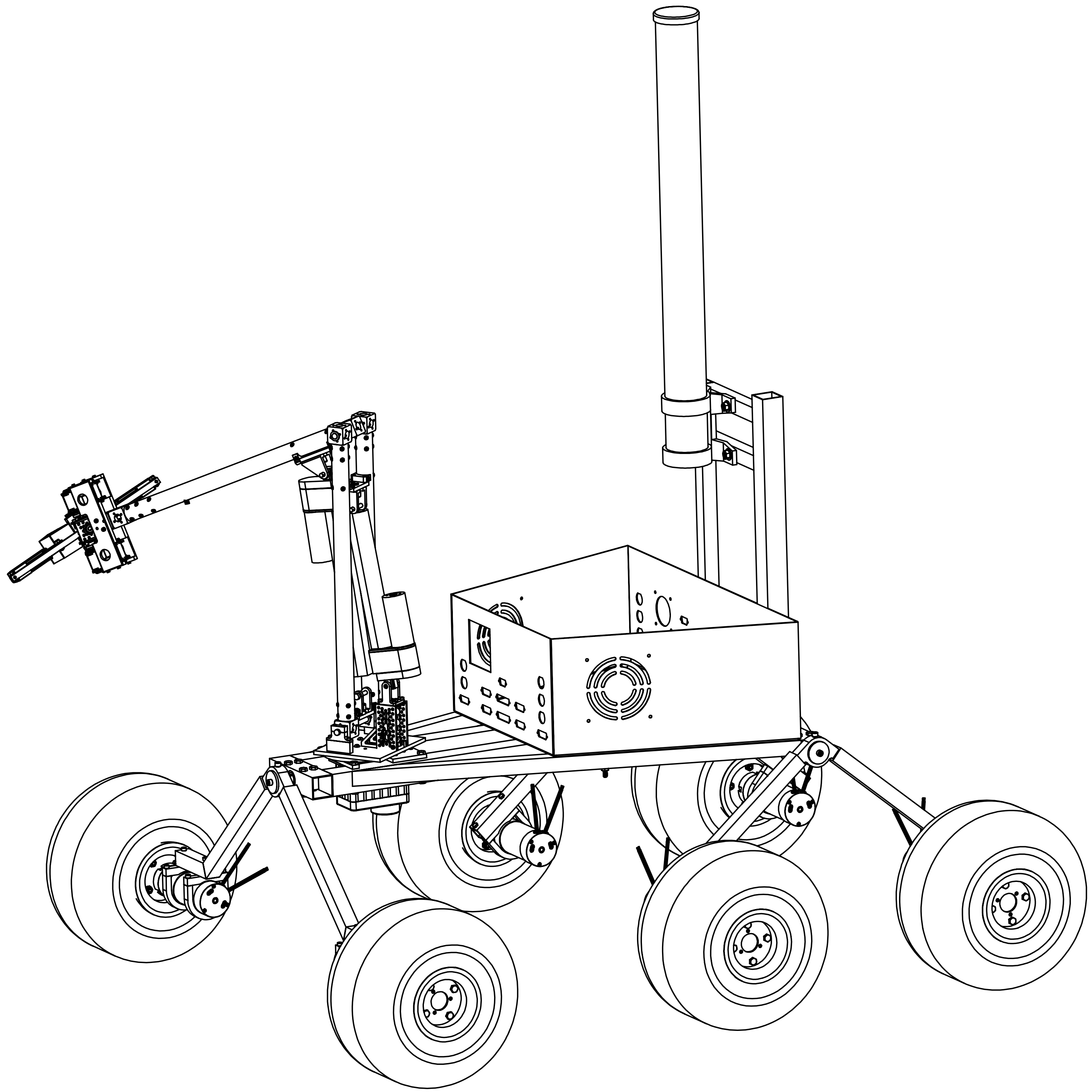
BYU MARS ROVER 2017

PART #: MRP-CHA-0900 R1

SIZE B | PART NAME: Chassis | REV 1

SCALE: 1:10 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRIAN JACKSON	18 APR 2017
MFG APPR.	BRIAN JACKSON	18 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

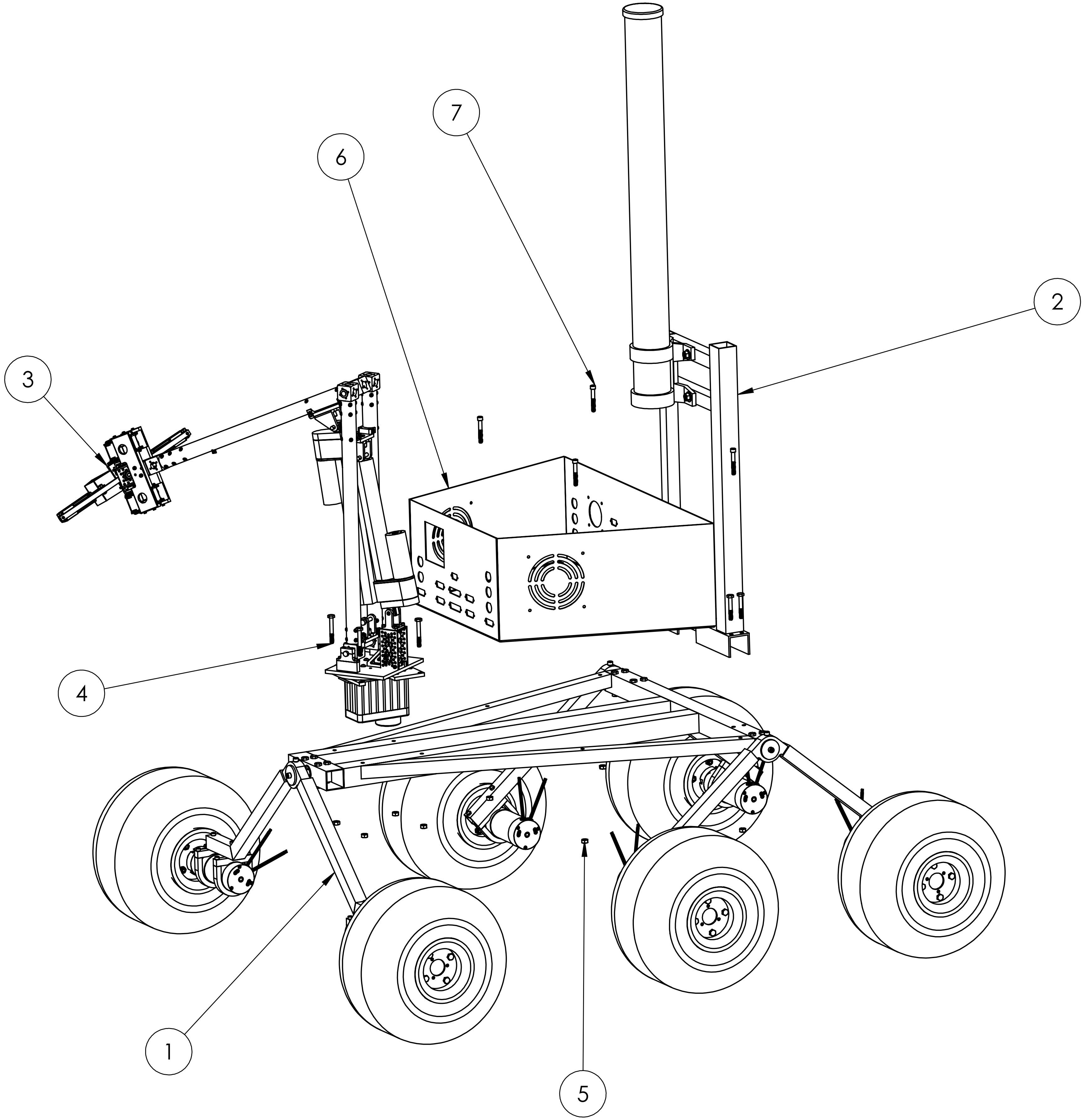
FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-1000 R1

SIZE	PART NAME:	REV
B	Rover with Arm	1

SCALE: 1:9 | SHEET 2 OF 2



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
7	Mcmaster Carr # 91251A548	Black-Oxide Alloy Steel Socket Head Screw 1/4"-20 Thread Size, 1-3/4" Long, Partially Threaded	4
6	MRP-ELE-0500 R1	Trapezoid Box Power	1
5	McMaster Carr # 92673A113	18-8 Stainless Steel Hex Nut, 1/4"-20 Thread Size, ASTM F594	8
4	McMaster Carr # 92198A550	18-8 Stainless Steel Hex Head Screw, 1/4"-20 Thread Size, 2" Long, Partially Threaded	4
3	MRP-ARM-0900 R1	TotalAssembly	1
2	MRP-CHA-0401 R1	bracket assembly with antenna	1
1	MRP-CHA-0900 R1	Chassis	1

	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRIAN JACKSON	18 APR 2017
MFG APPR.	BRIAN JACKSON	18 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-CHA-1000 R1

SIZE: B

PART NAME: Rover with Arm

REV: 1

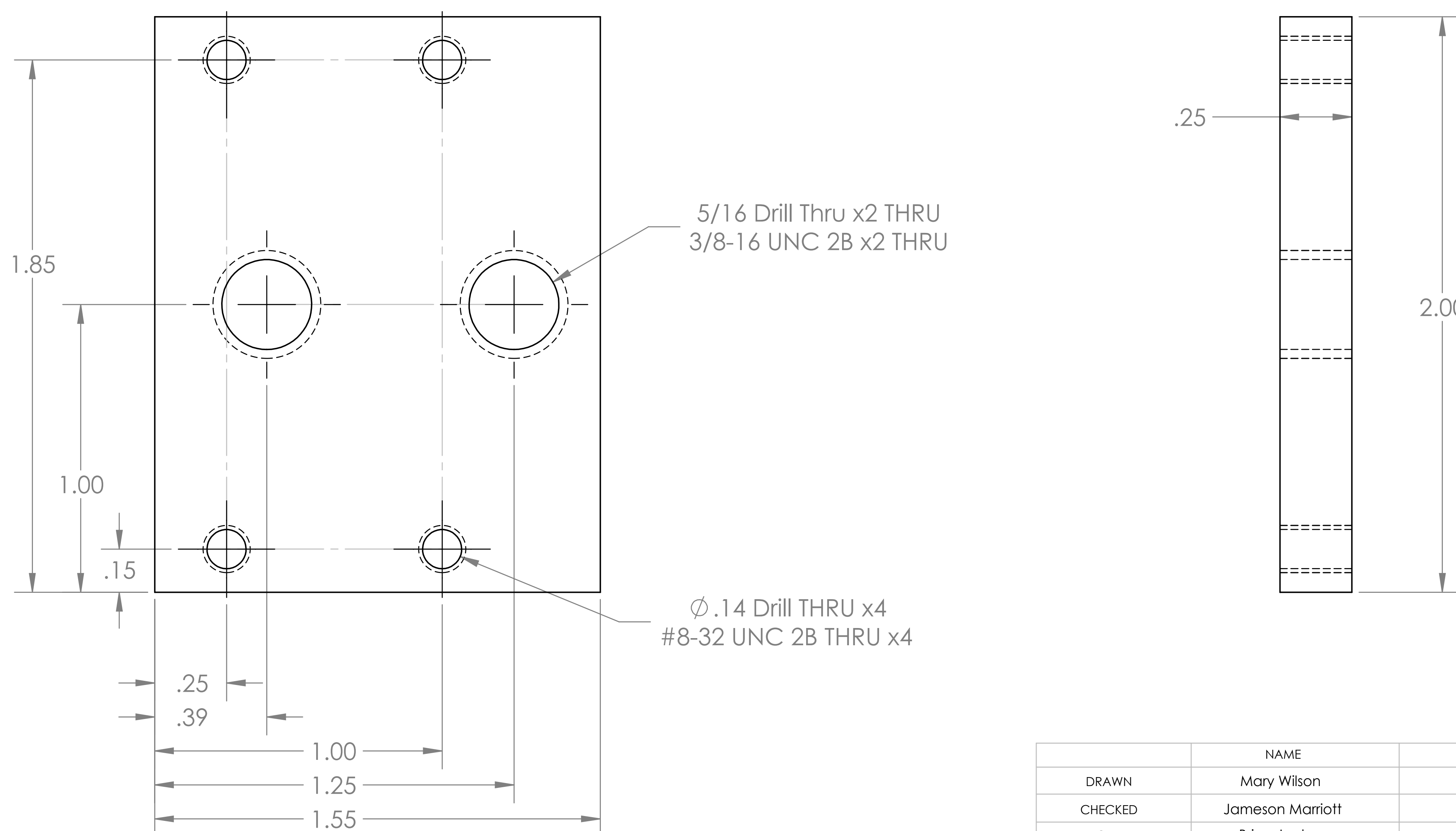
SCALE: 1:9

SHEET 1 OF 2

I.3 Robotic Arm Drawings and Documentation

In addition to the drawing package, MRD-DE-0004 (section G.4) provides a more detailed description of getting feedback from the forearm.

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	14 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Al

FINISH: 250 µin

BYU
MARS ROVER
2017

PART #: MRP-ARM-0001 R1

SIZE: B

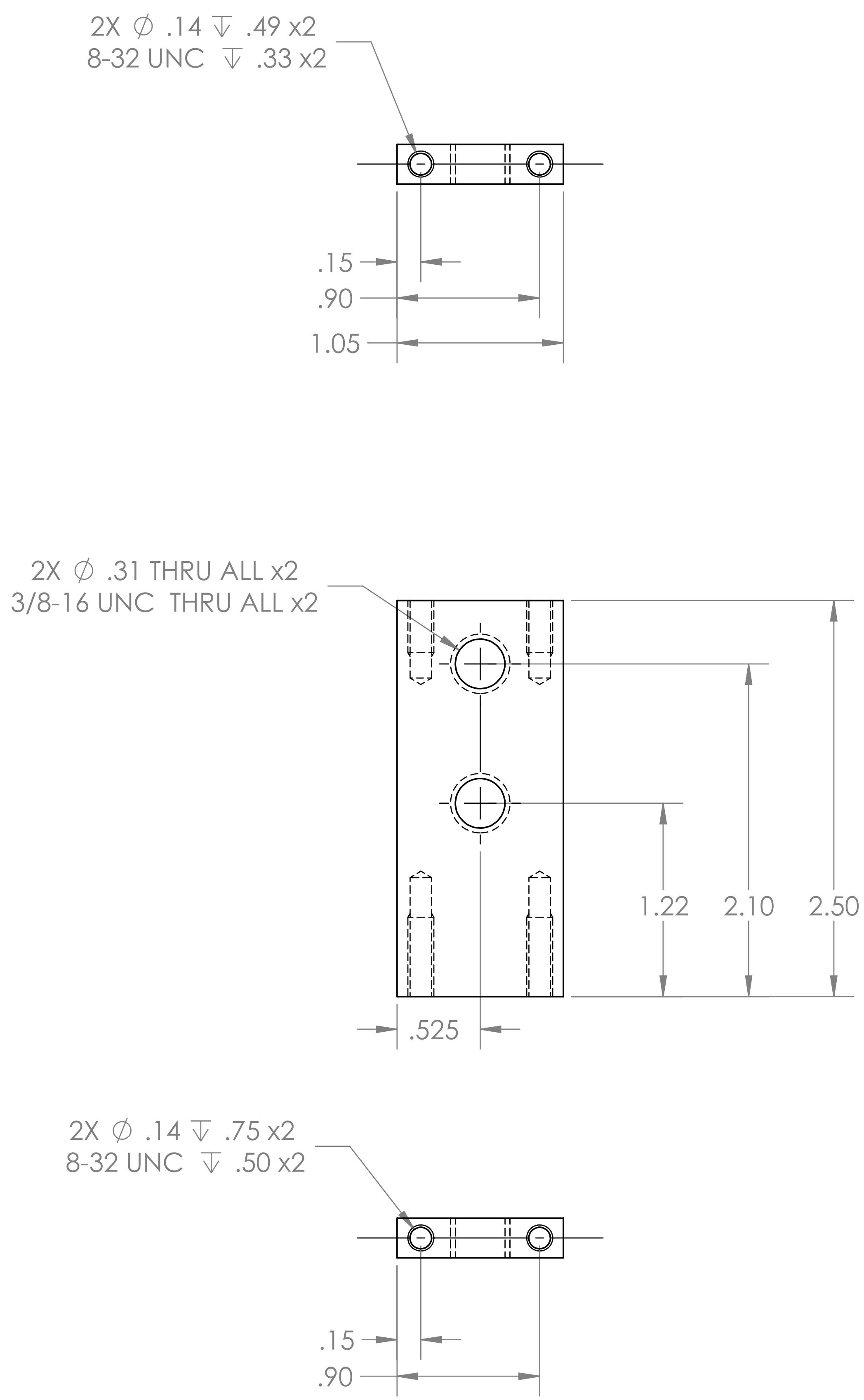
PART NAME: MiddleBracer

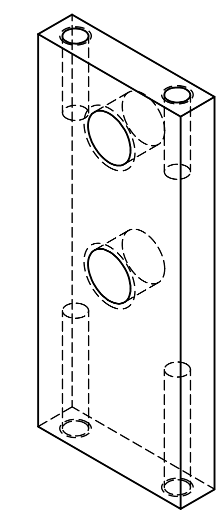
REV: 1

SCALE: 1:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Mary Wilson	14 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Al

FINISH: 250 µin

BYU
MARS ROVER
2017

PART #: MRP-ARM-0002 R1

SIZE: B

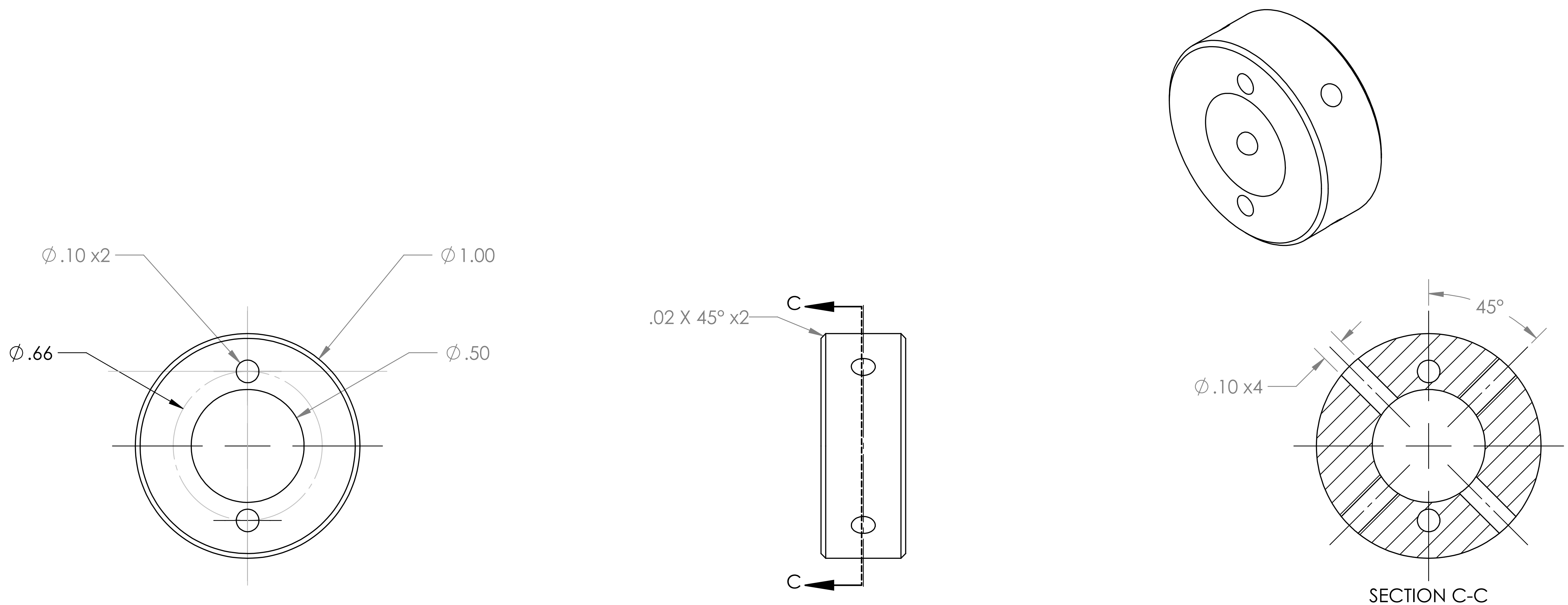
PART NAME: Elbow bracer

REV: 1

SCALE: 1:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Al

FINISH: 250 µin

BYU
MARS ROVER
2017

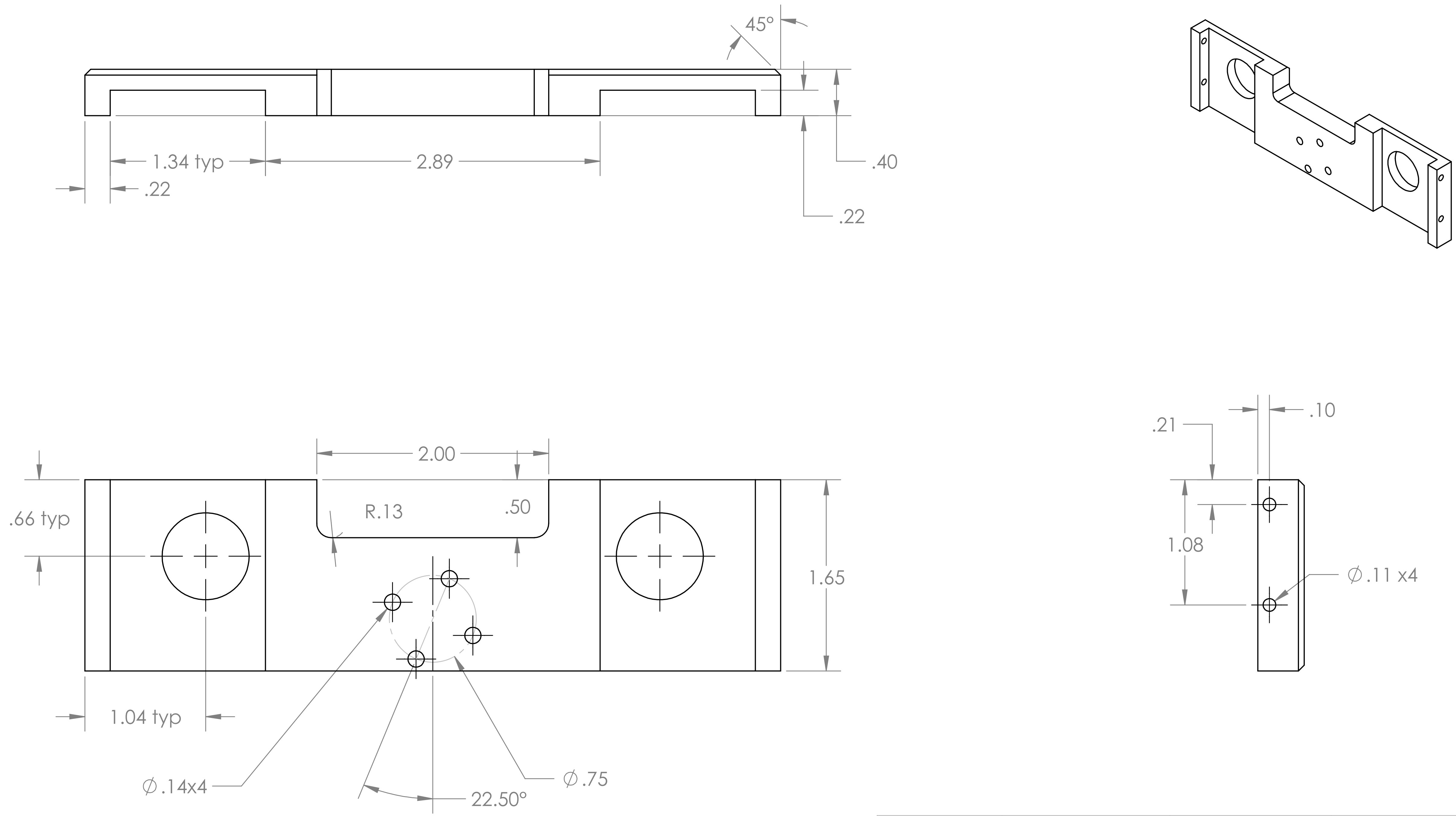
PART #: MRP-ARM-0003 R1

SIZE	PART NAME:	REV
B	AttachBracketInsideModified	1

SCALE: 2:1 SHEET 1 OF 1

4 3 2 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Richard Livingston	12 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Aluminum

FINISH: 250 μin

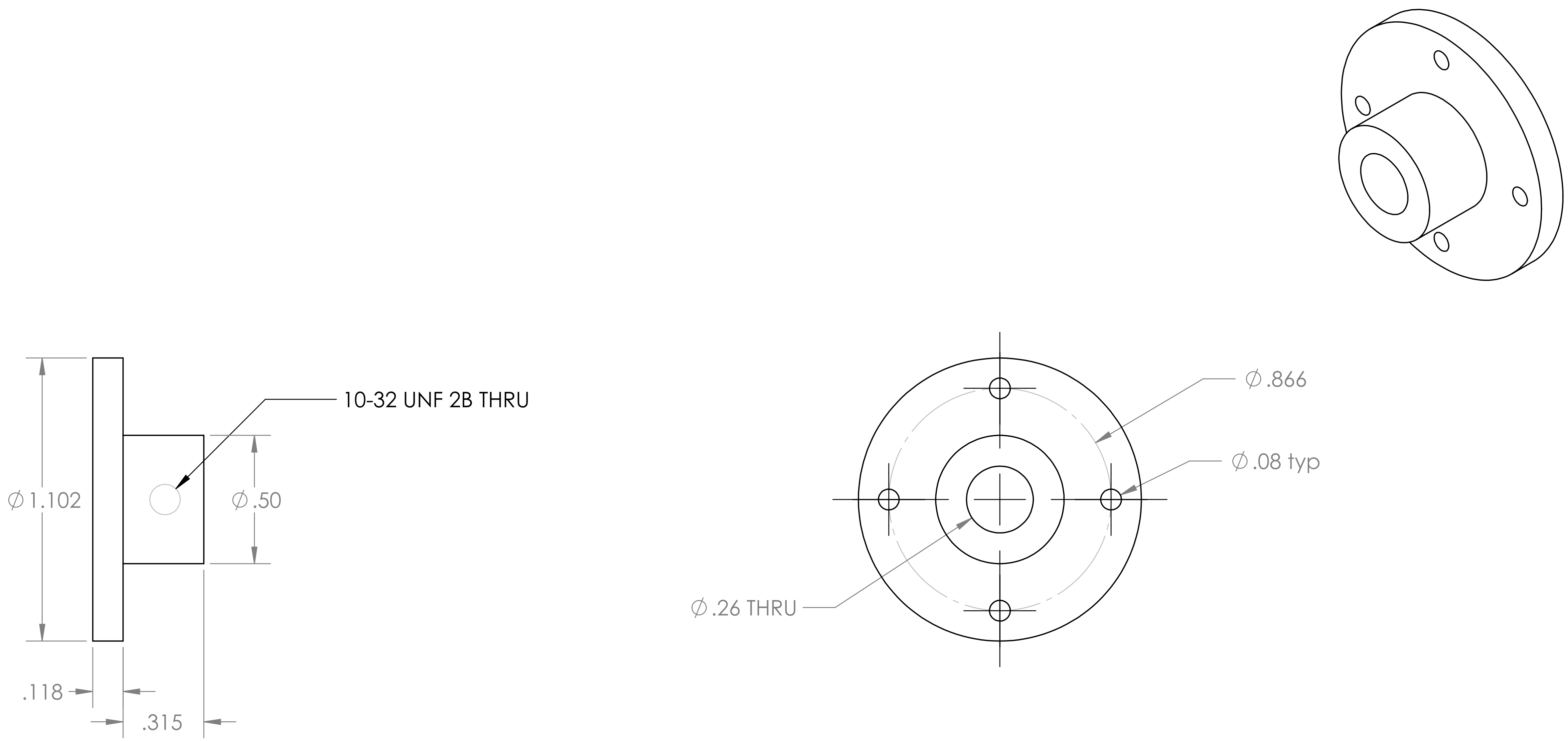
BYU MARS ROVER 2017

PART #: MRP-ARM-0004

SIZE	PART NAME:	REV
B	Wrist Mounting Bracket	1
SCALE: 1:2		SHEET 1 OF 1

4 3 2 1

		REVISIONS		
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Richard Livingston	13 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Al

FINISH: 250 µin

BYU MARS ROVER 2017

PART #: MRP-ARM-0005

SIZE: B

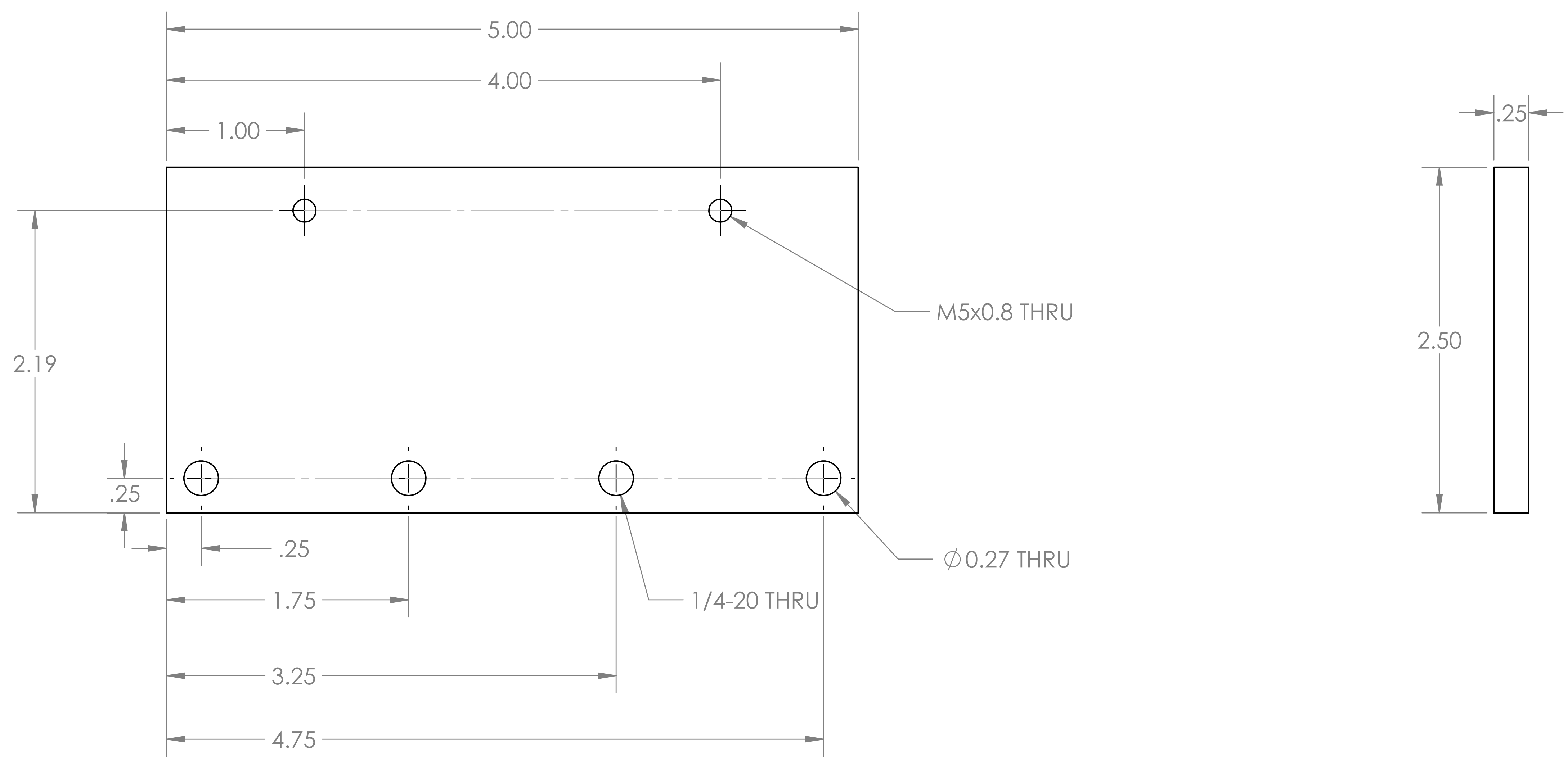
PART NAME: Wrist Motor to Shaft Adapter

REV: 1

SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Jordan Oldroyd	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: Aluminum 6061

FINISH: 250 µin

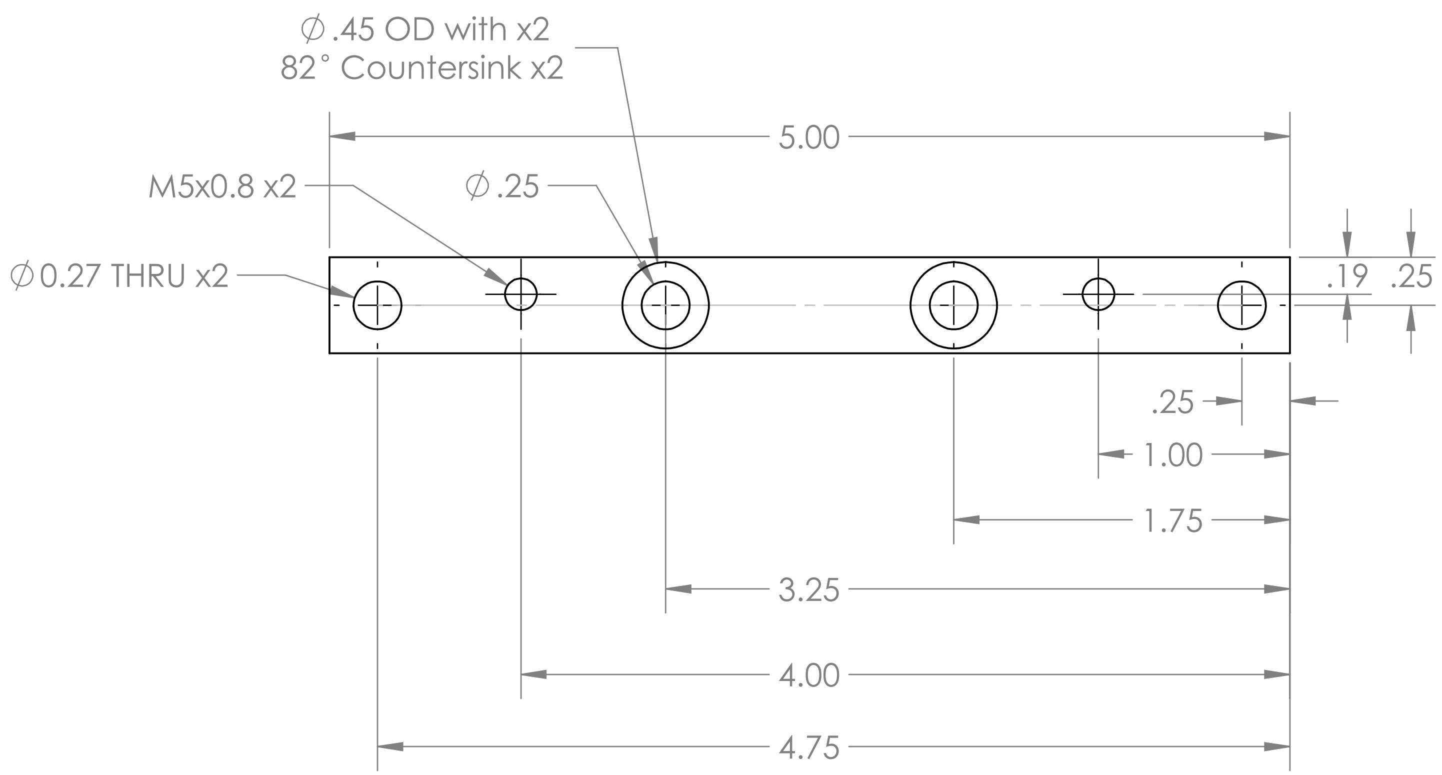
BYU
MARS ROVER
2017

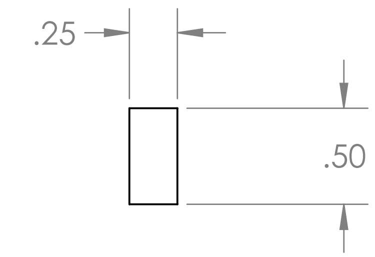
PART #: MRP-ARM-0006

SIZE	PART NAME:	REV
B	Bottom_plate	1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Jordan Oldroyd	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brian Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061-T6

FINISH: 250 µin

BYU
MARS ROVER
2017

PART #: MRP-ARM-0007

SIZE: B | PART NAME: Bottom_plate2 | REV: 1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	Jordan Oldroyd	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061-T6

FINISH: 250 µin

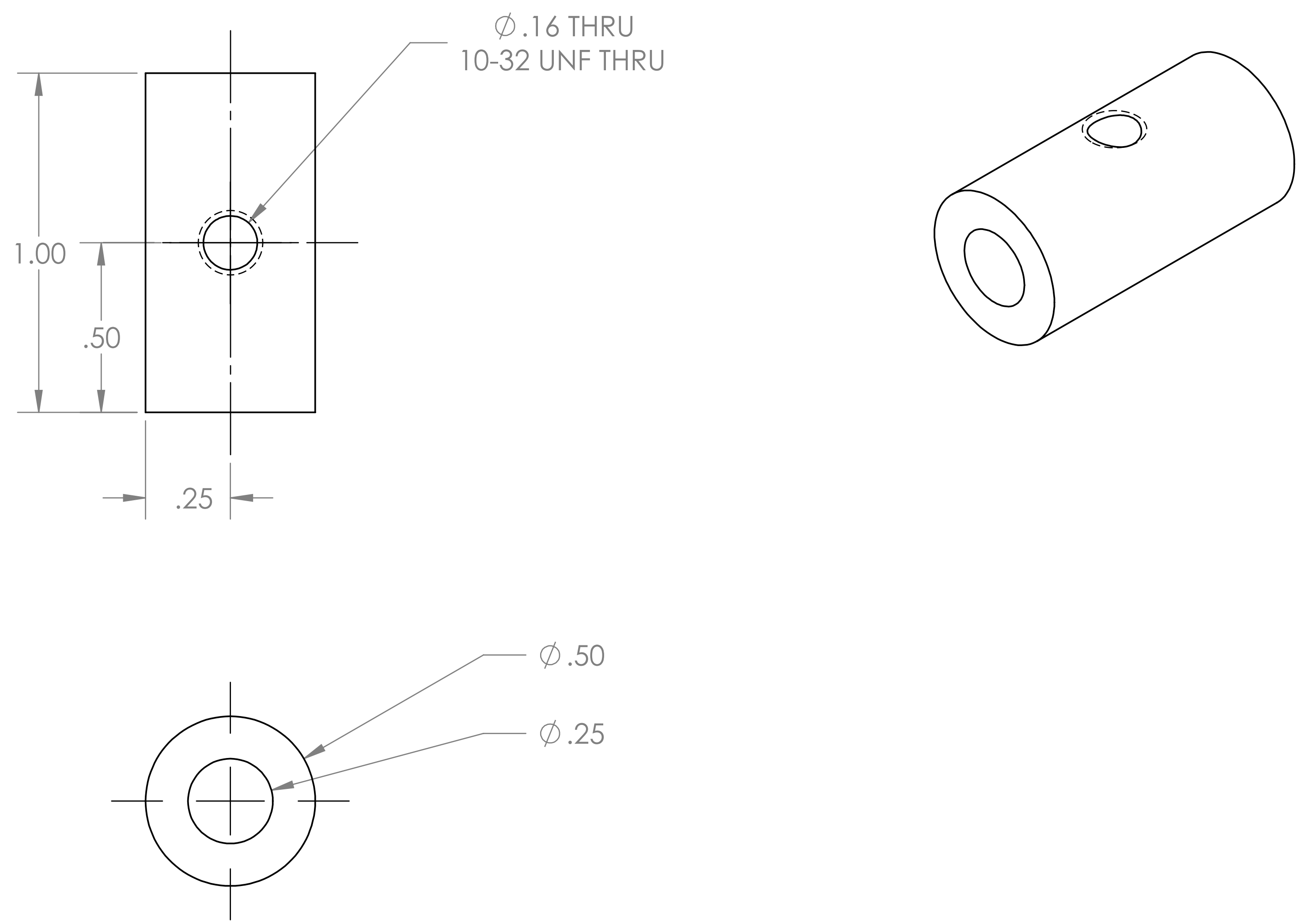
BYU
MARS ROVER
2017

PART #: MRP-ARM-0008

SIZE	PART NAME:	REV
B	Shaft Support	1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	15 April 2017
CHECKED	Jameson Marriott	17 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6061 Al

FINISH 250 µin

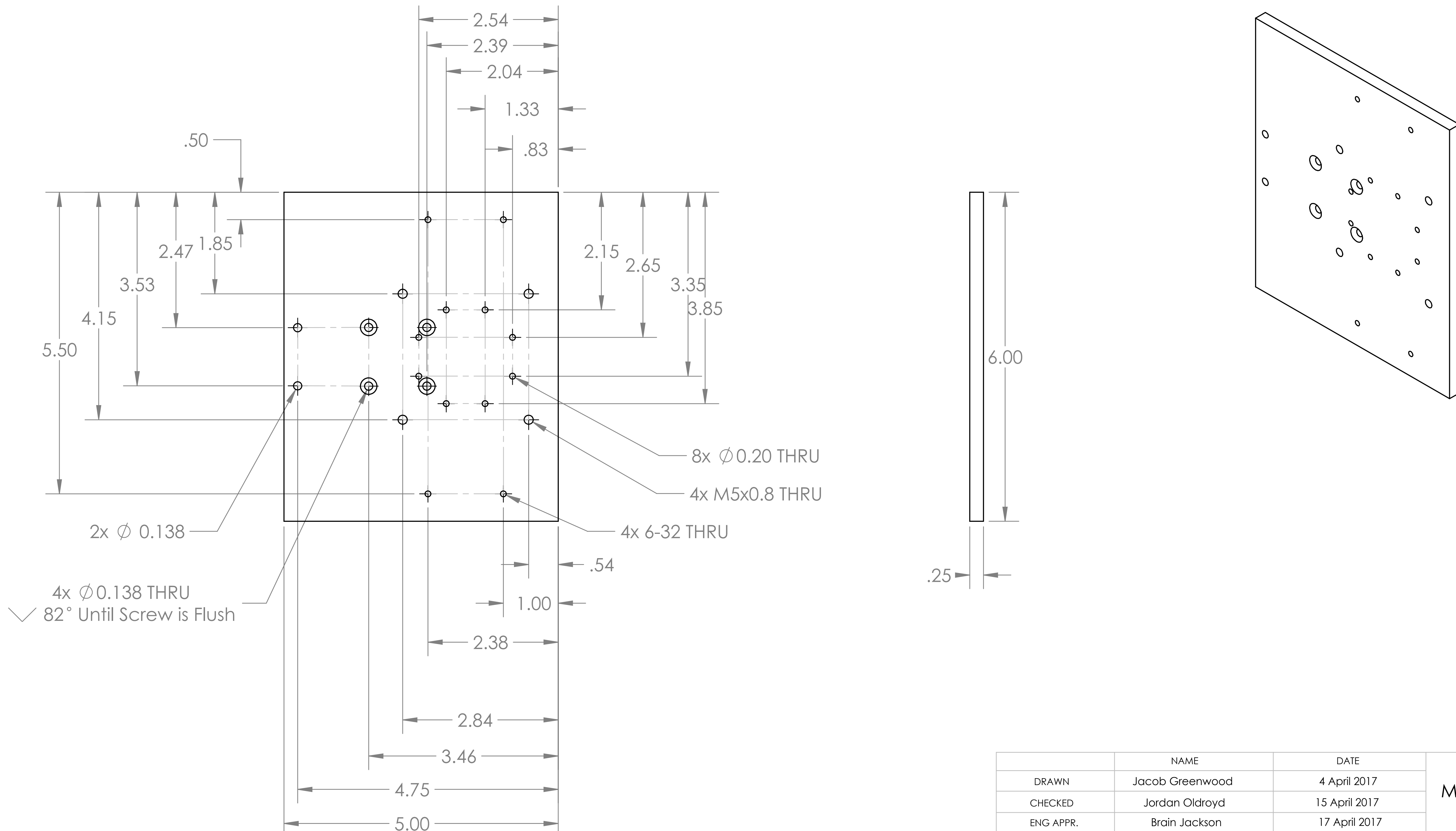
BYU
MARS ROVER
2017

PART #: MRP-ARM-0009 R1

SIZE	PART NAME:	REV
B	WristCoupler	1

SCALE: 2:1 SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Jacob Greenwood	4 April 2017
CHECKED	Jordan Oldroyd	15 April 2017
ENG APPR.	Brain Jackson	17 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
Aluminum 6061

FINISH

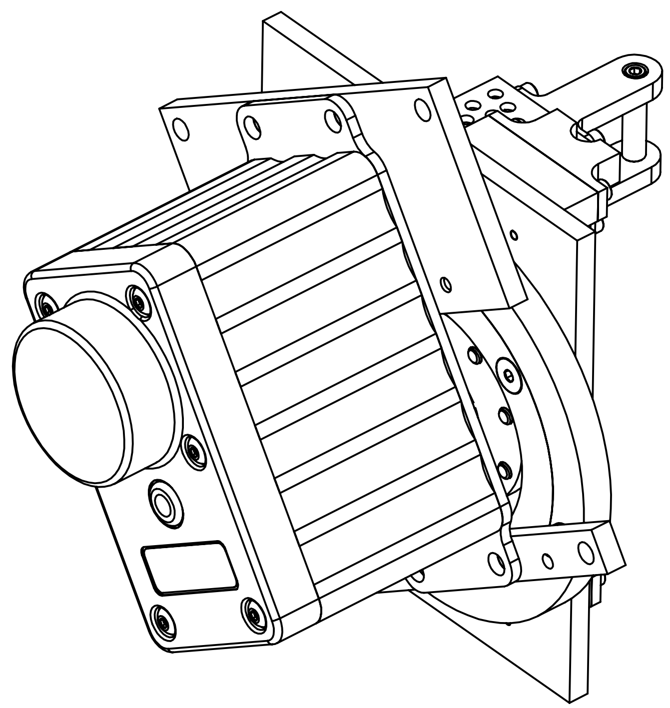
BYU
MARS ROVER
2017

PART #:
MRP-ARM-0010 R1

SIZE	PART NAME:	REV
B	Base	**1**

SCALE: 1:2 SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

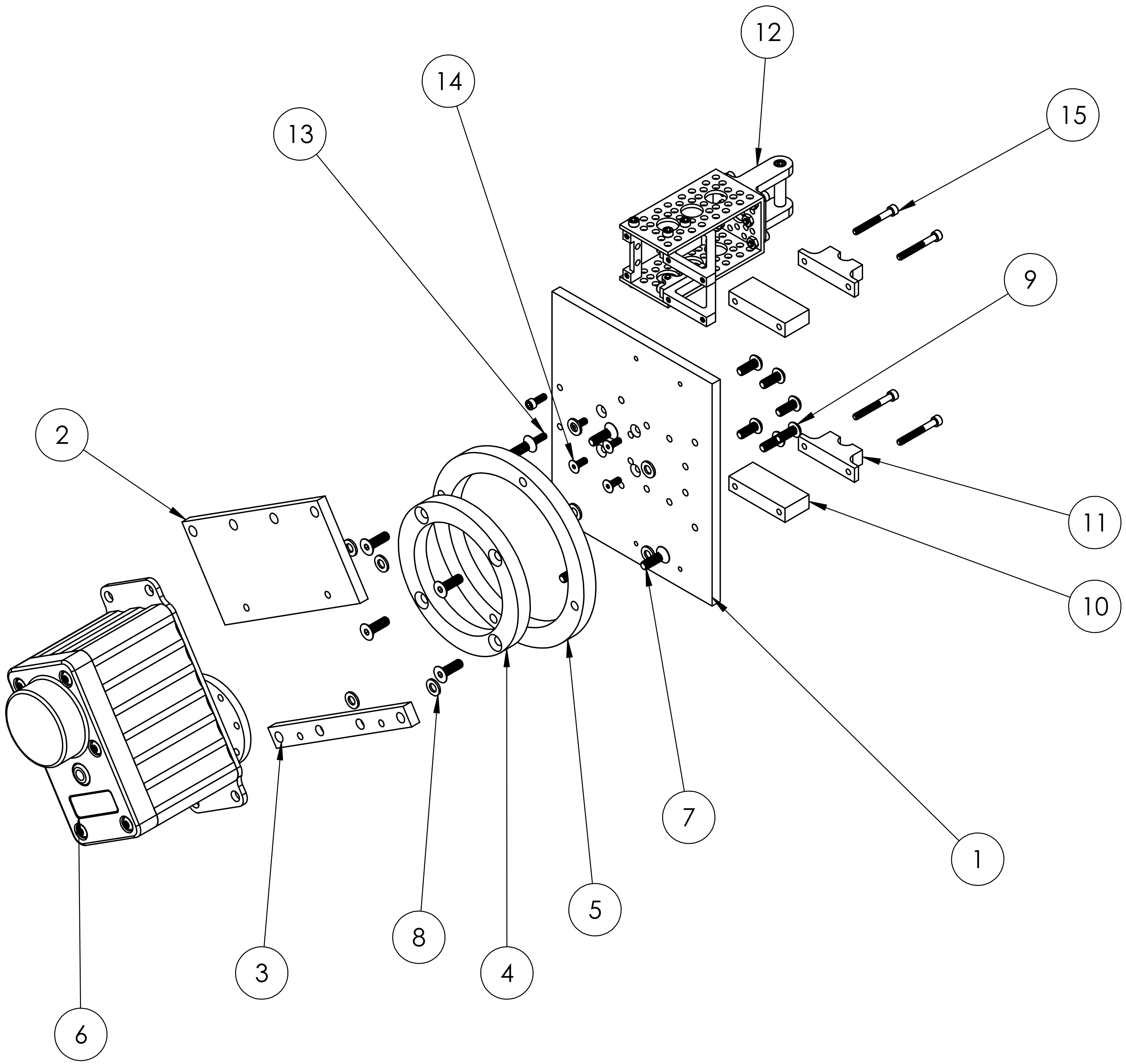
PART #: MRP-ARM-0100 R1

SIZE B | PART NAME: TurretAssembly | REV 1

SCALE: 1:2 | SHEET 2 OF 2

4 3 2 1

B



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
15	McMaster Carr # 92196A154	18-8 Stainless Steel Socket Head Screw, 6-32 Thread Size, 1-1/8" Long	4
14	McMaster Carr # 91263A514	Zinc-Plated Alloy Steel Hex Drive Flat Head Screw, 6-32 Thread Size, 3/8" Long	4
13	McMaster Carr # 91251A144	Black-Oxide Alloy Steel Socket Head Screw, 6-32 Thread Size, 1/4" Long	2
12	MRP-ARM-0200 R1	OffsetAssembly	1
11	MRP-ARM-0008 R1	ShaftSupport1	2
10	MRP-ARM-0008 R1	ShaftSupportBlock	2
9	McMaster Carr # 91255A265	Hex Drive Rounded Head Screw, Black-Oxide Alloy Steel, 10-32 Thread Size, 1/2" Long	6
8	McMaster Carr # 90965A160	316 Stainless Steel Washer for M5 Screw Size, 5.3 mm ID, 10 mm OD	8
7	McMaster Carr # 91294A208	Black-Oxide Alloy Steel Hex Drive Flat Head Screw, M5 x 0.8 mm Thread, 10 mm Long	8
6	Pololu #i00600	TorxisServo	1
5	Amazon #KIT12876	TurntableOutside	1
4	Amazon #KIT12876	TurntableInside	1
3	MRP-ARM-0007 R1	Bottom_plate2	1
2	MRP-ARM-0006 R1	Bottom_plate	1
1	MRP-ARM-0005 R1	Base	1

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
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X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU MARS ROVER 2017

PART #: MRP-ARM-0100 R1

SIZE B | PART NAME: TurretAssembly | REV 1

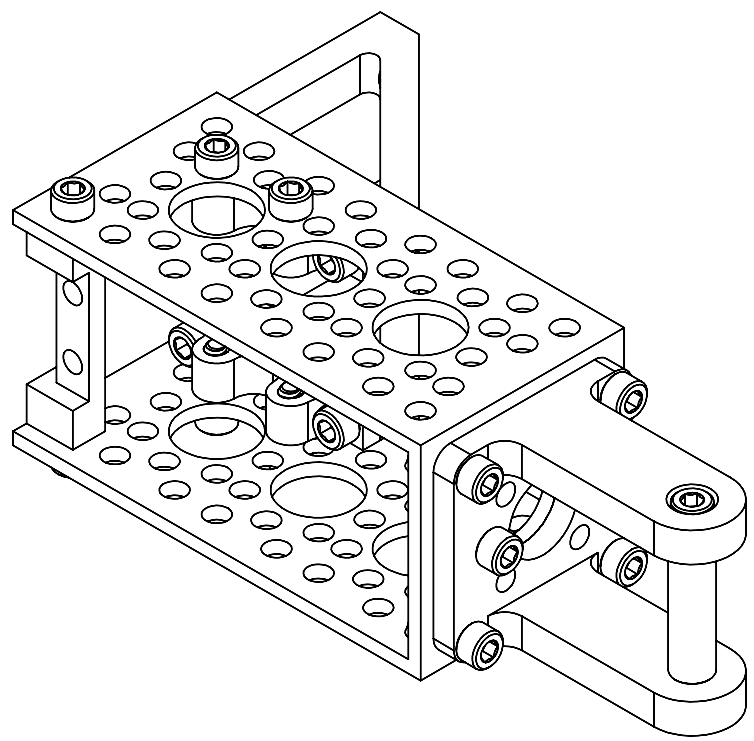
SCALE: 1:3 | SHEET 1 OF 2

A

4 3 2 1

4	3	2	1

B



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REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	18 April 2017
ENG APPR.	Brian Jackson	18 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
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X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ARM-0200 R1

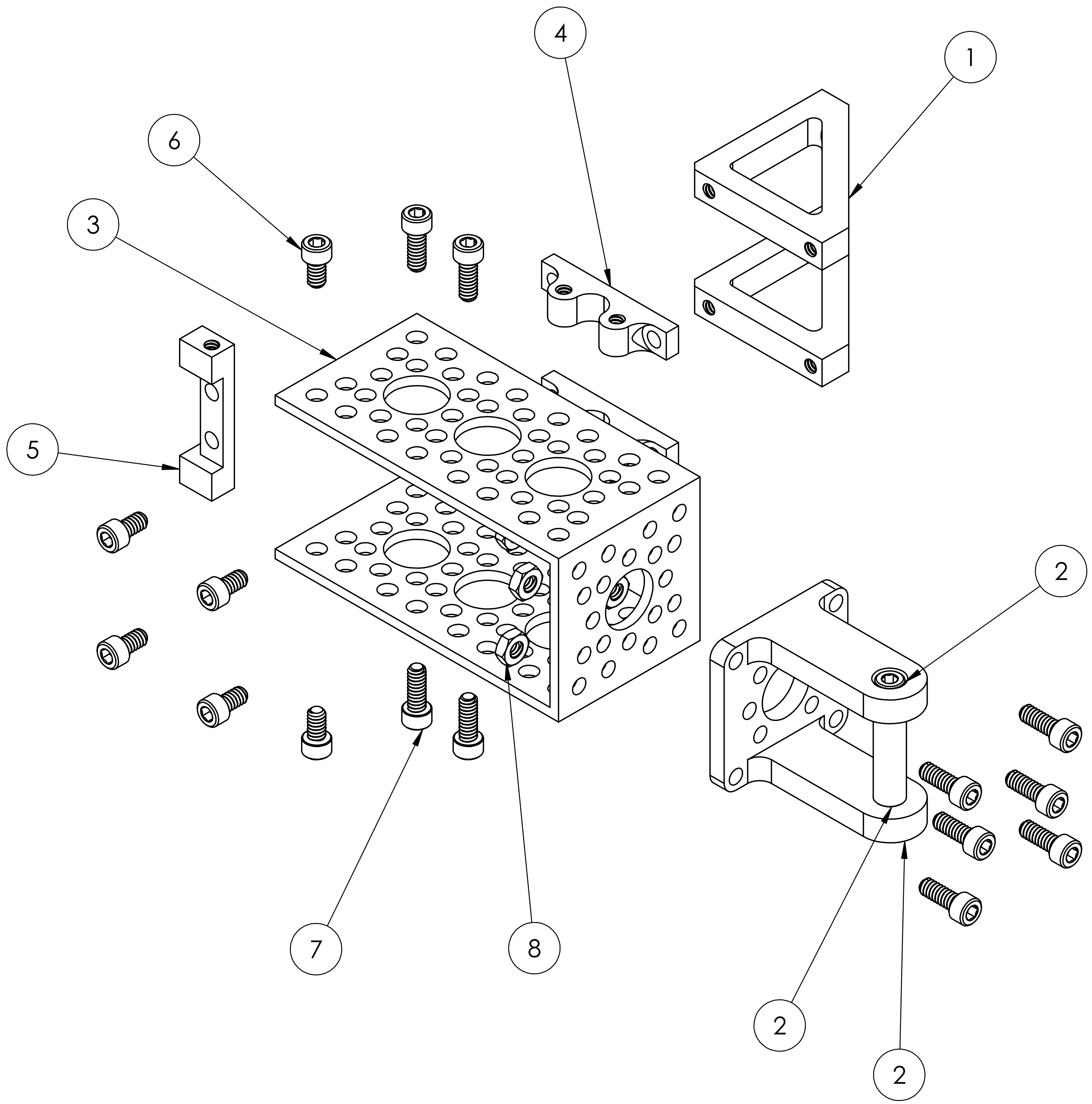
SIZE	PART NAME:	REV
B	OffsetAssembly	1

SCALE: 1:1

SHEET 2 OF 2

4	3	2	1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	McMaster Carr # 90760A007	Zinc-Plated Steel Narrow Hex Nut, 6-32 Thread Size	6
7	McMaster Carr # 91251A144	Black-Oxide Alloy Steel Socket Head Screw, 6-32 Thread Size, 1/4" Long	10
6	McMaster Carr # 91251A144	Black-Oxide Alloy Steel Socket Head Screw, 6-32 Thread Size, 1/4" Long	6
5	ServoCity #585596	BracketE	1
4	ServoCity #585504	BracketC	2
3	ServoCity #585484	PatternBracketA	1
2	ServoCity #585484	LightweightLinearActuatorBracket	1
1	ServoCity # 58553290	90AngleBracket	2

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	18 April 2017
ENG APPR.	Brian Jackson	18 April 2017
MFG APPR.		

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DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009
MATERIAL
FINISH

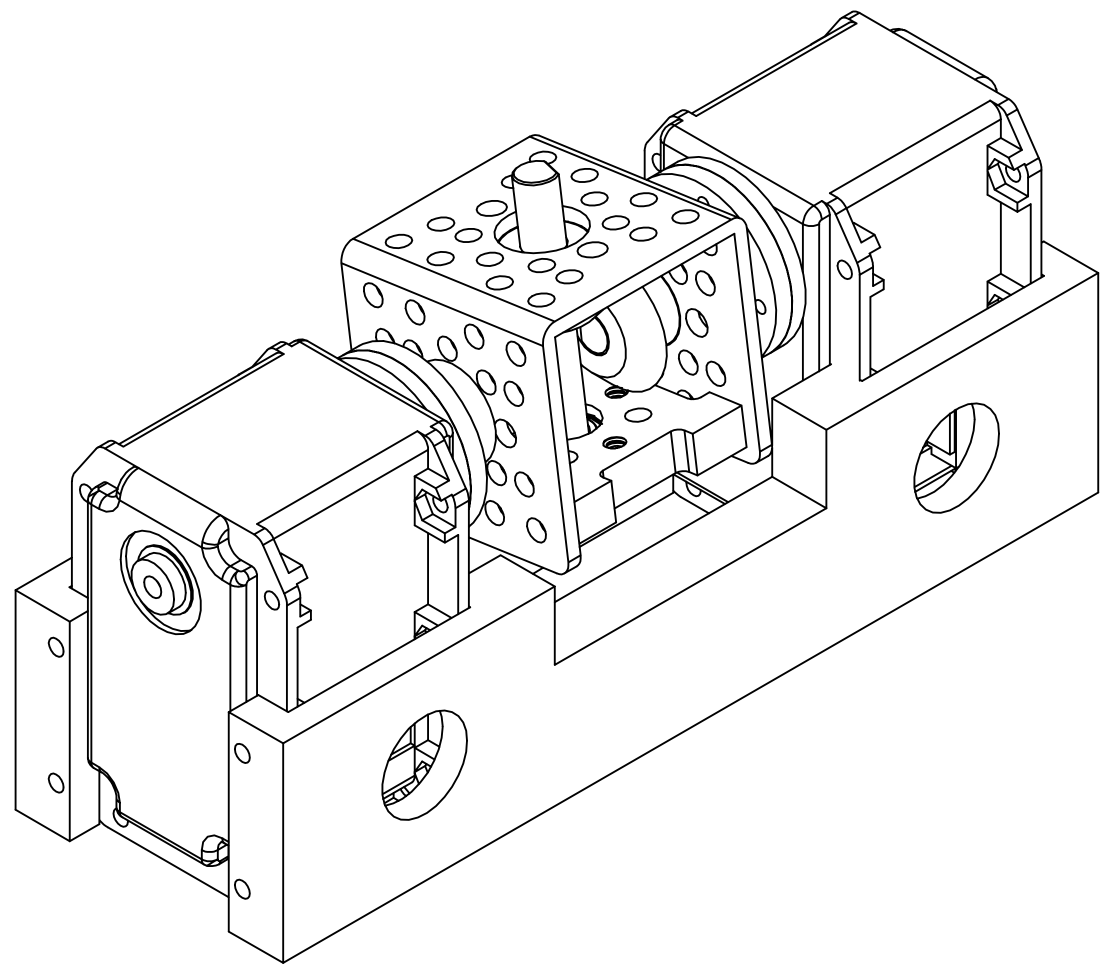
BYU
MARS ROVER
2017

PART #: MRP-ARM-0200 R1

SIZE B | PART NAME: OffsetAssembly | REV 1

SCALE: 1:1 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	See Sheet1	-	-



	NAME	DATE
DRAWN	Mary Wilson	4/16/17
CHECKED	JAMESON MARRIOT	4/16/17
ENG APPR.	BRAIN JACKSON	4/16/17
MFG APPR.	BRAIN JACKSON	4/16/17

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

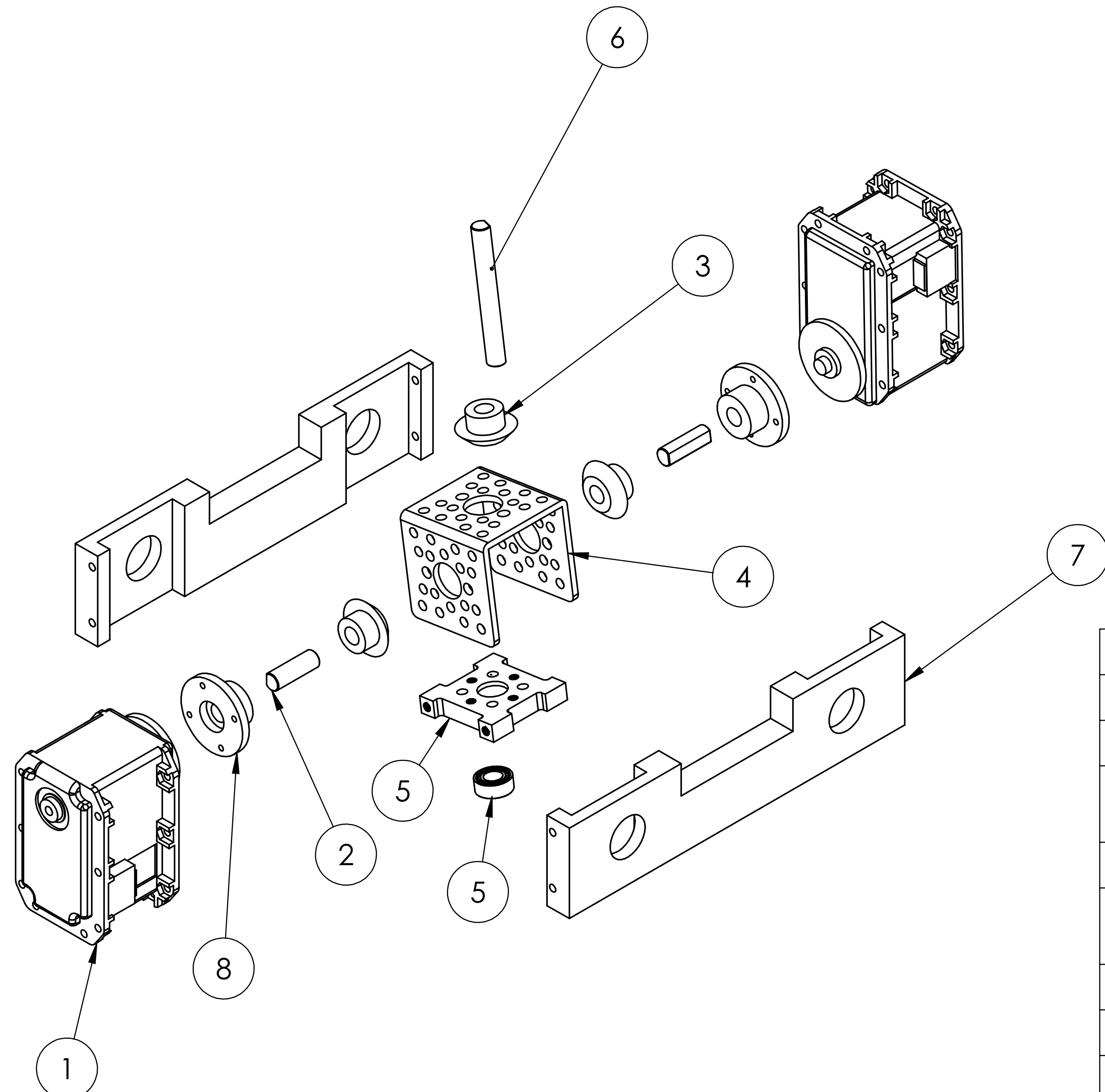
PART #: MRP-ARM-0300

SIZE	PART NAME:	REV
B	Wrist_assembly	1

SCALE: 1:1

SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
8	MRP-ARM-0010 R1	Shaft Motor Joint	2
7	MRP-ARM-0004 R1	Mounting Bracket	2
6	ServoCity #634094	1/4" Stainless Steel D-Shafting	1
5	ServoCity #535130	1/4 in. Bore Side Tapped Pillow Block	1
4	ServoCity #585440	1.50" Aluminum Channel	1
3	ServoCity #615398	1/4 in. Bore Shaft Mount Bevel Gears - 24 teeth	3
2	ServoCity #634094	1/4" Stainless Steel D-Shafting	2
1	Robotis #MX-64T	Dynamixel	2

	NAME	DATE
DRAWN	Mary Wilson	4/16/17
CHECKED	JAMESON MARRIOT	4/16/17
ENG APPR.	BRAIN JACKSON	4/16/17
MFG APPR.	BRAIN JACKSON	4/16/17

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0300

SIZE B

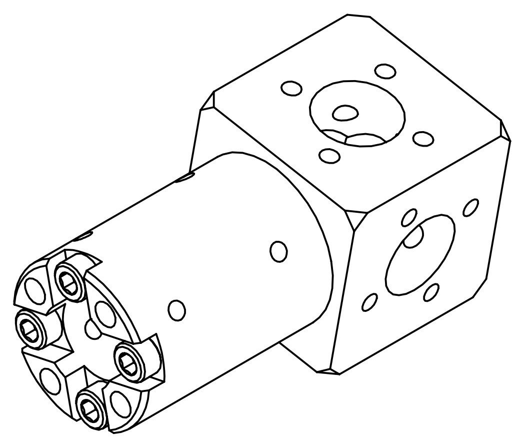
PART NAME: Wrist_assembly

REV 1

SCALE: 1:2

SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	18 April 2017
ENG APPR.	Brian Jackson	18 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

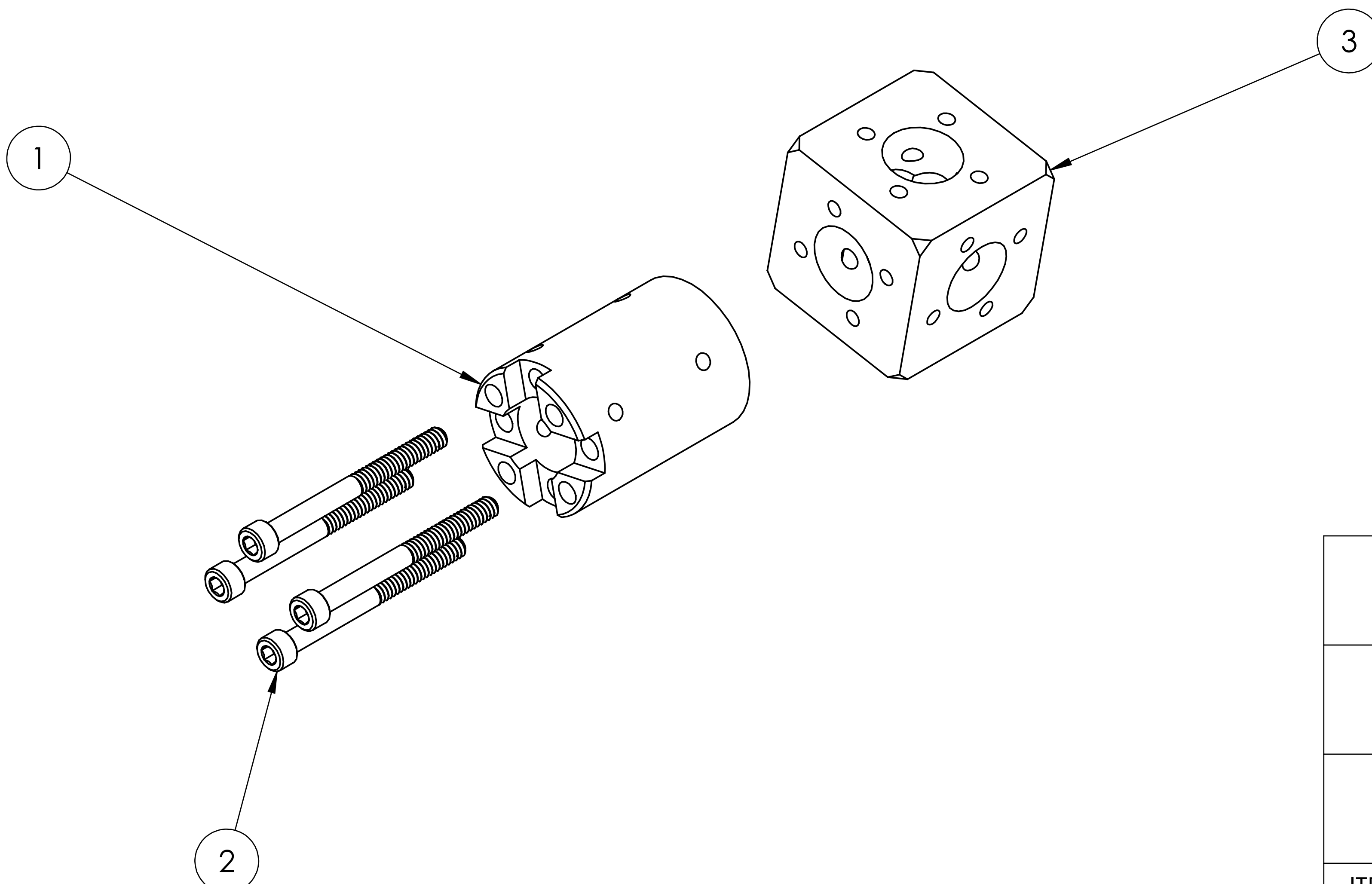
FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0400 R1

SIZE B | PART NAME: MainBlockAssembly | REV 1

SCALE: 1:1 | SHEET 2 OF 2



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
3	Rock West Composites# CE10-MB-01	MainBlock	1
2	McMaster Carr # 91251A157	Black-Oxide Alloy Steel Socket Head Screw, 6-32 Thread Size, 1-1/2" Long	4
1	Rock West Composites # CE10-AD-05	MainBlockAdapter	1

	NAME	DATE
DRAWN	ALEX JENSEN	15 APR 2017
CHECKED	Jameson Marriott	18 April 2017
ENG APPR.	Brian Jackson	18 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

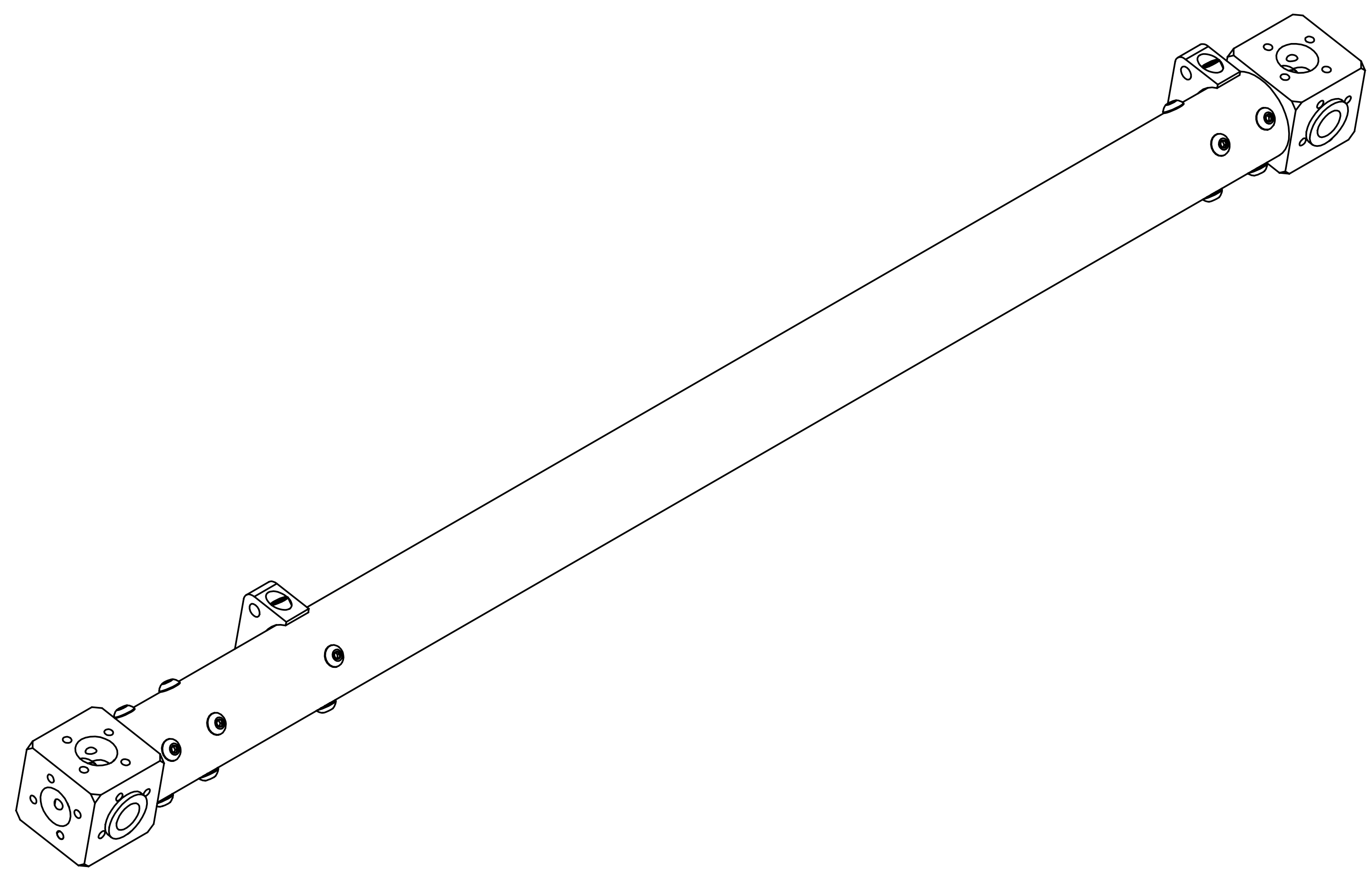
BYU MARS ROVER 2017

PART #: MRP-ARM-0400 R1

SIZE B | PART NAME: MainBlockAssembly | REV 1

SCALE: 1:1 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
-	-	See Sheet1	-	-



	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0500 R1

SIZE B

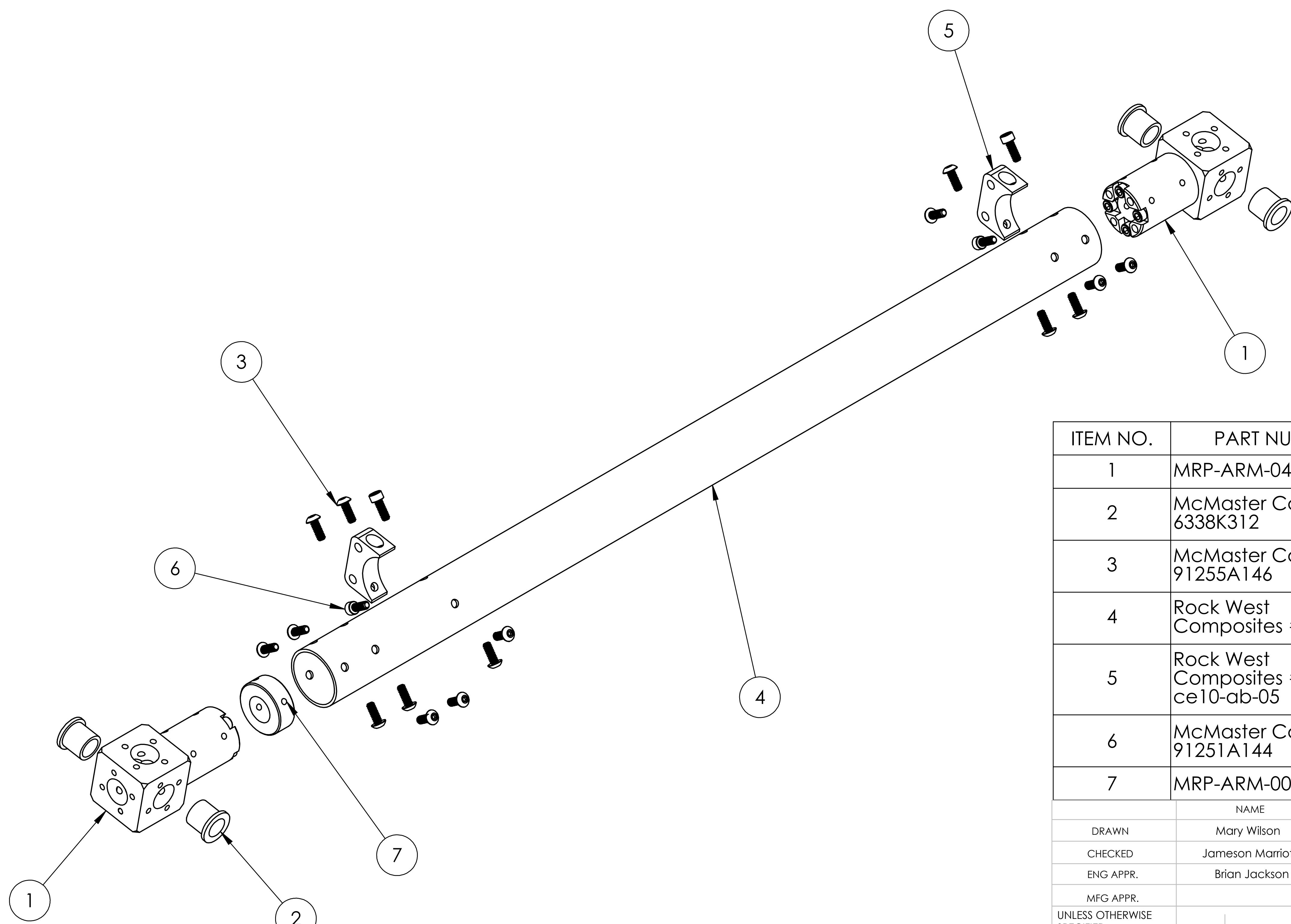
PART NAME: ArmAssembly

REV 1

SCALE: 1:2

SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MRP-ARM-0400 R1	MainBlockAssembly	2
2	McMaster Carr # 6338K312	Bushing (Flange Bearing)	4
3	McMaster Carr # 91255A146	Socket Head Cap Screw	16
4	Rock West Composites #46406	Arm Link	1
5	Rock West Composites # ce10-ab-05	AttachBracketOuside	2
6	McMaster Carr # 91251A144	MCMASTER STEEL SCREW, 6-32 THREAD SIZE, 1/4" LONG	4
7	MRP-ARM-0003 R1	AttachBracketInside	1

	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0500 R1

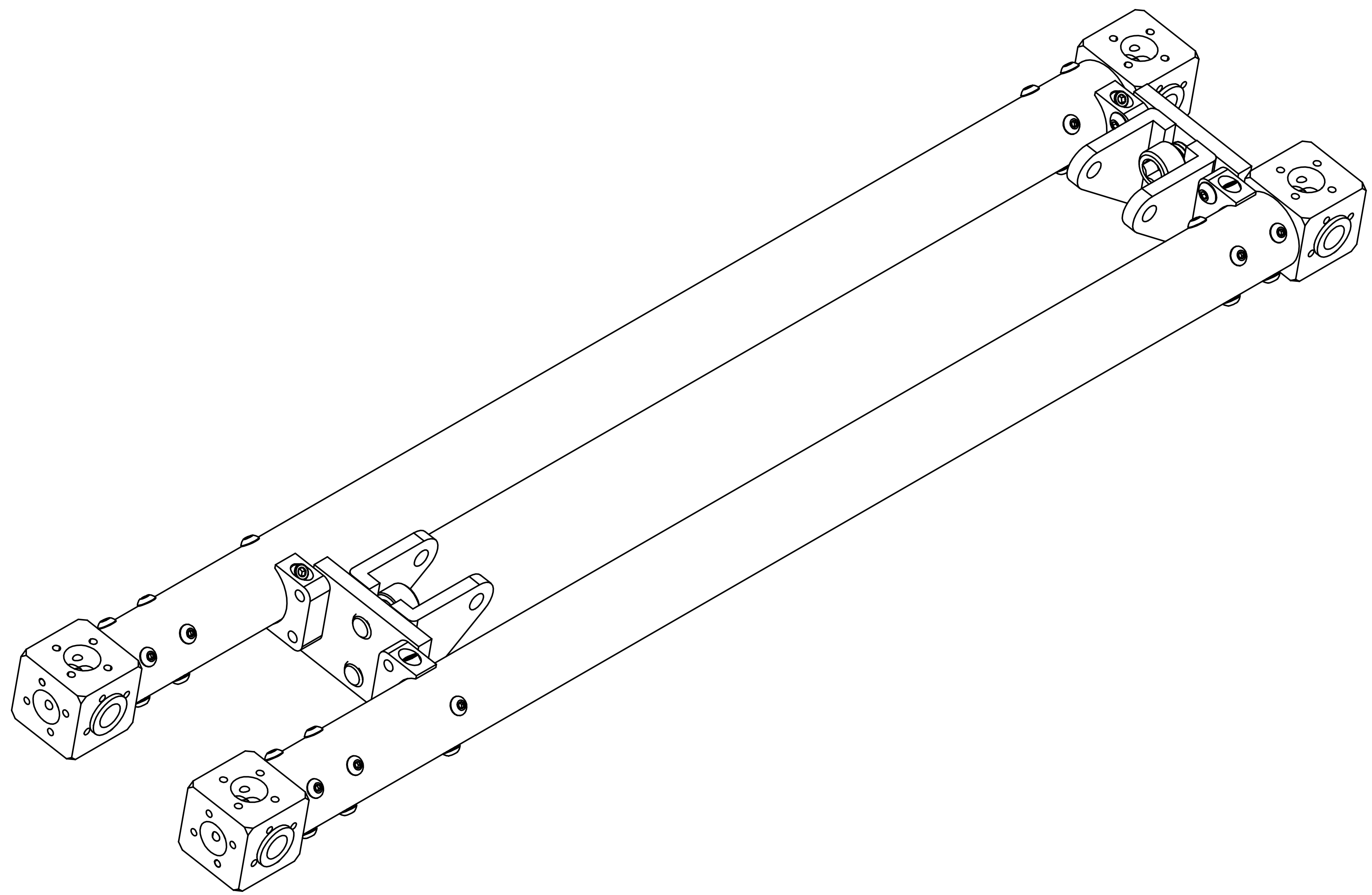
SIZE	PART NAME:	REV
B	ArmAssembly	1

SCALE: 1:2 SHEET 1 OF 2

4	3	2	1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

B



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	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
X.X ± .03
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X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0600 R1

SIZE	PART NAME:	REV
B	ArmAssemblyCombined	1

SCALE: 1:2 SHEET 2 OF 2

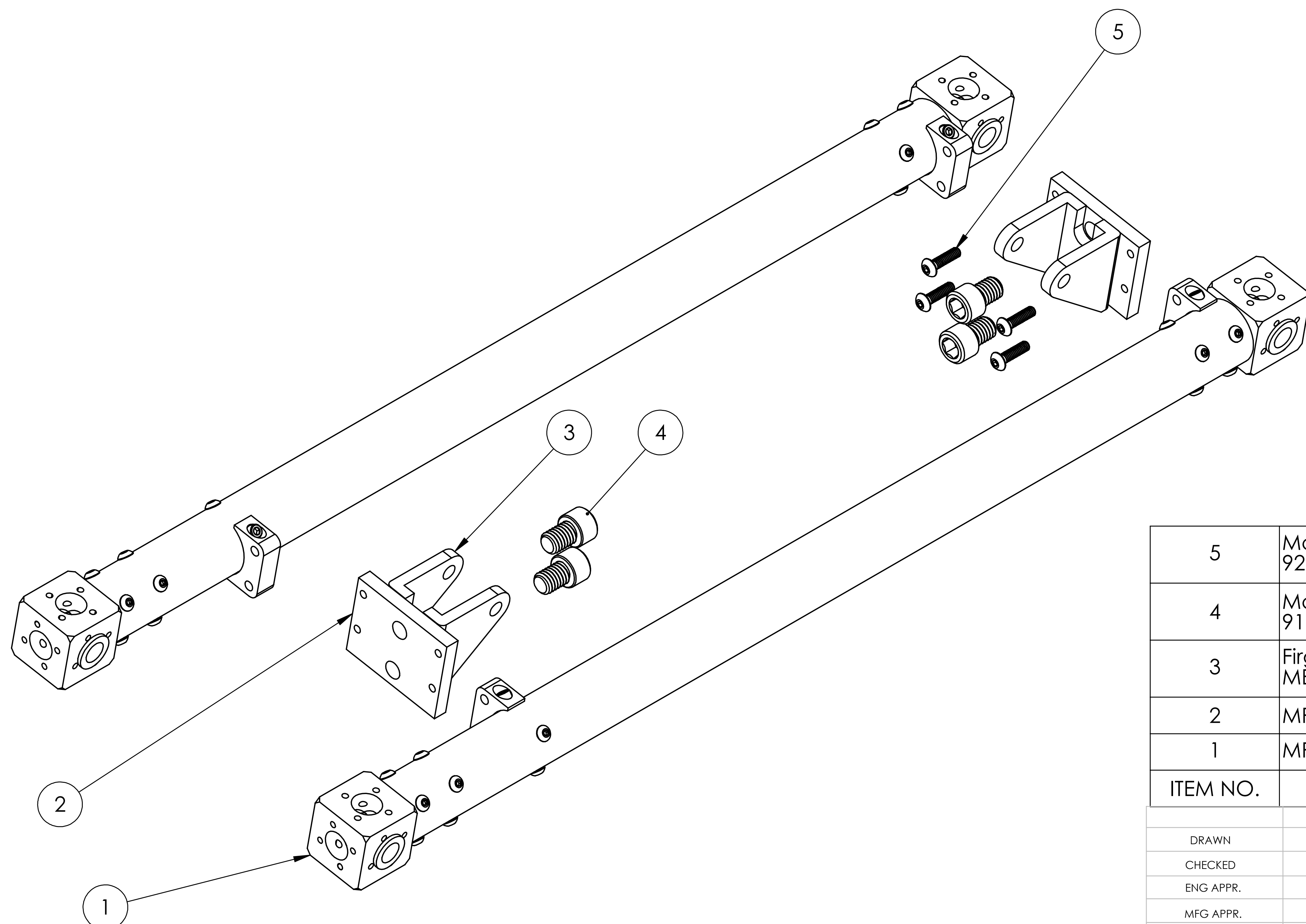
4	3	2	1

4 3 2 1

B

A

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



5	McMaster Carr # 92949A196	Screw Cap Socket Head	4
4	McMaster Carr # 91251A619	SCREW,CAP,SOCKET HD, 3/8-16 X 1/2"	4
3	Firgelli Automation # MB1	MB1 Bracket	2
2	MRP-ARM-0001 R1	Middle Bracer	2
1	MRP-ARM-0500 R1	Arm Assembly	2
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

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X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

MARS ROVER

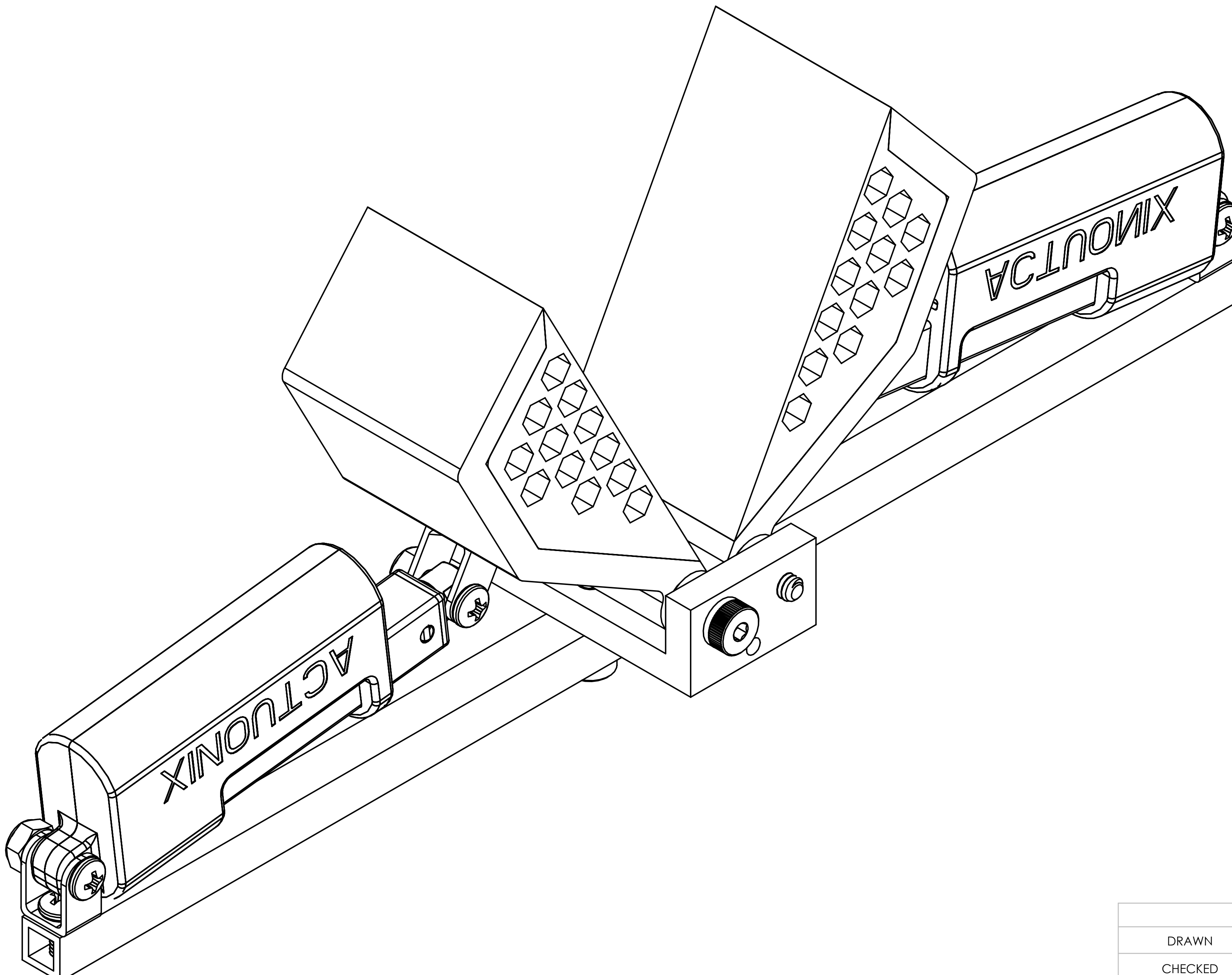
PART #:
MRP-ARM-0600 R1

SIZE B | PART NAME: ArmAssemblyCombined | REV 1

SCALE: 1:2 | SHEET 1 OF 2

1 2 3 4

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRIAN JACKSON	18 APR 2017
MFG APPR.	BRIAN JACKSON	18 APR 2017

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X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

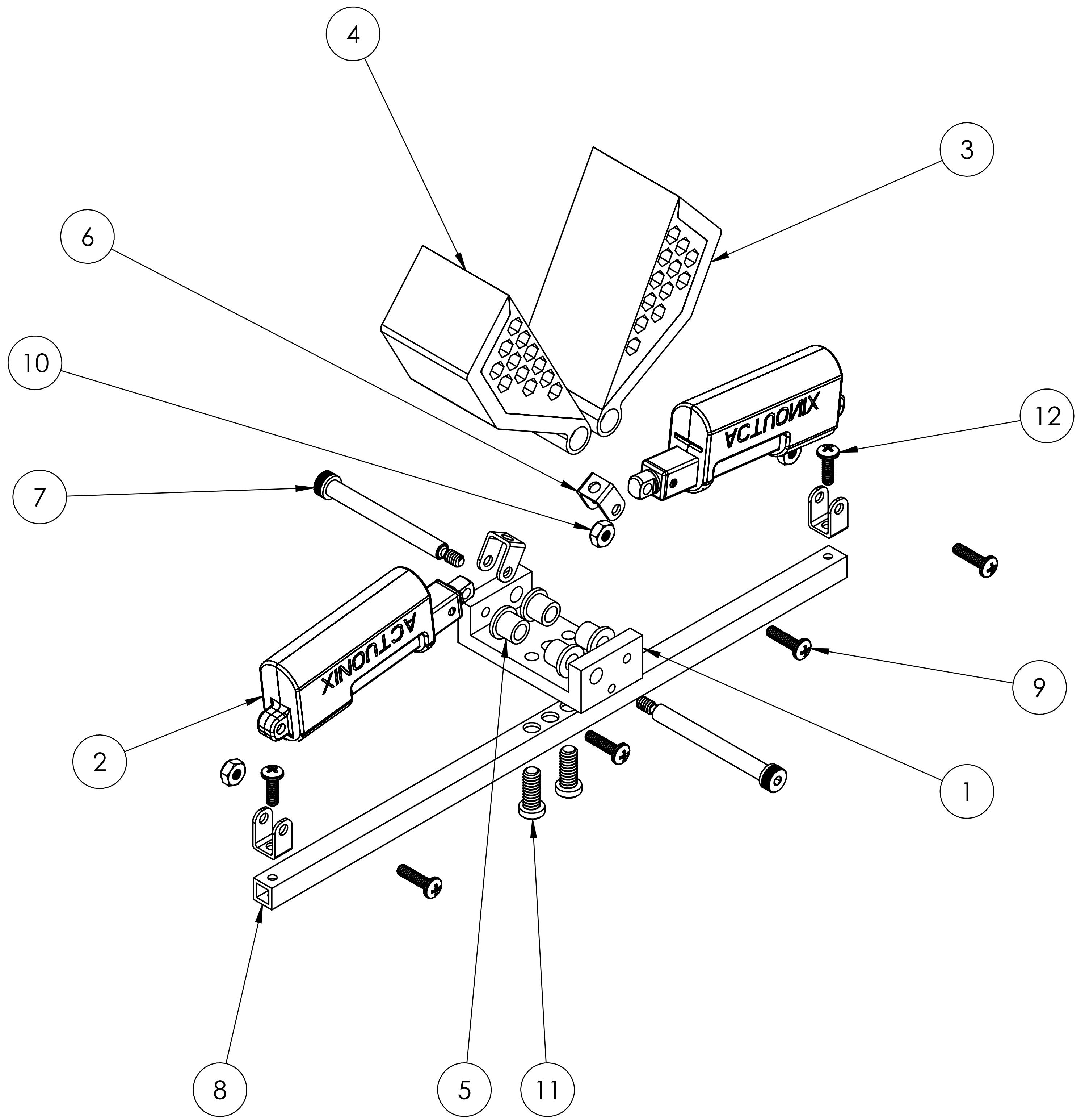
PART #: MRP-ARM-0700 R1

SIZE	PART NAME:	REV
B	HandAssembly	1

SCALE: 1:1

SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
12	McMaster Carr # 90272A196	Steel Phillips Rounded Head Screws, 8-32 Thread Size, 5/8" Long	2
11	McMaster Carr # 92220A184	Alloy Steel Low-Profile Socket Head Screw, Black-Oxide, 1/4"-20 Thread Size, 5/8" Long	2
10	McMaster Carr # 90631A009	Low-Strength Steel Nylon-Insert Locknut, Zinc-Plated, 8-32 Thread Size	4
9	McMaster Carr # 90272A196	Steel Phillips Rounded Head Screws, 8-32 Thread Size, 5/8" Long	4
8	MRP-ARM-0012	HandCrossbar	1
7	McMaster Carr # 91259A104	Alloy Steel Shoulder Screw, 1/4" Diameter x 2-1/4" Long Shoulder, 10-24 Thread Size	2
6	Firgelli Automations # P16-50mm-64:1-12V	HandLinearActuatorBracket	4
5	McMaster Carr #2706T13	Ultra-Low-Friction Dry-Running Sleeve Bearing, Flanged, PTFE, for 1/4" Shaft Diameter, 3/8" Length	4
4	McMaster Carr # 92314A838	Urethane	2
3	MRP-ARM-0013	Finger	2
2	Firgelli Automations # P16-50mm-64:1-12V	HandLinearActuator	2
1	MRP-ARM-0011	HandAttachmentPiece	1

	NAME	DATE
DRAWN	ALEX JENSEN	18 APR 2017
CHECKED	JAMESON MARRIOT	18 APR 2017
ENG APPR.	BRIAN JACKSON	18 APR 2017
MFG APPR.	BRIAN JACKSON	18 APR 2017

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

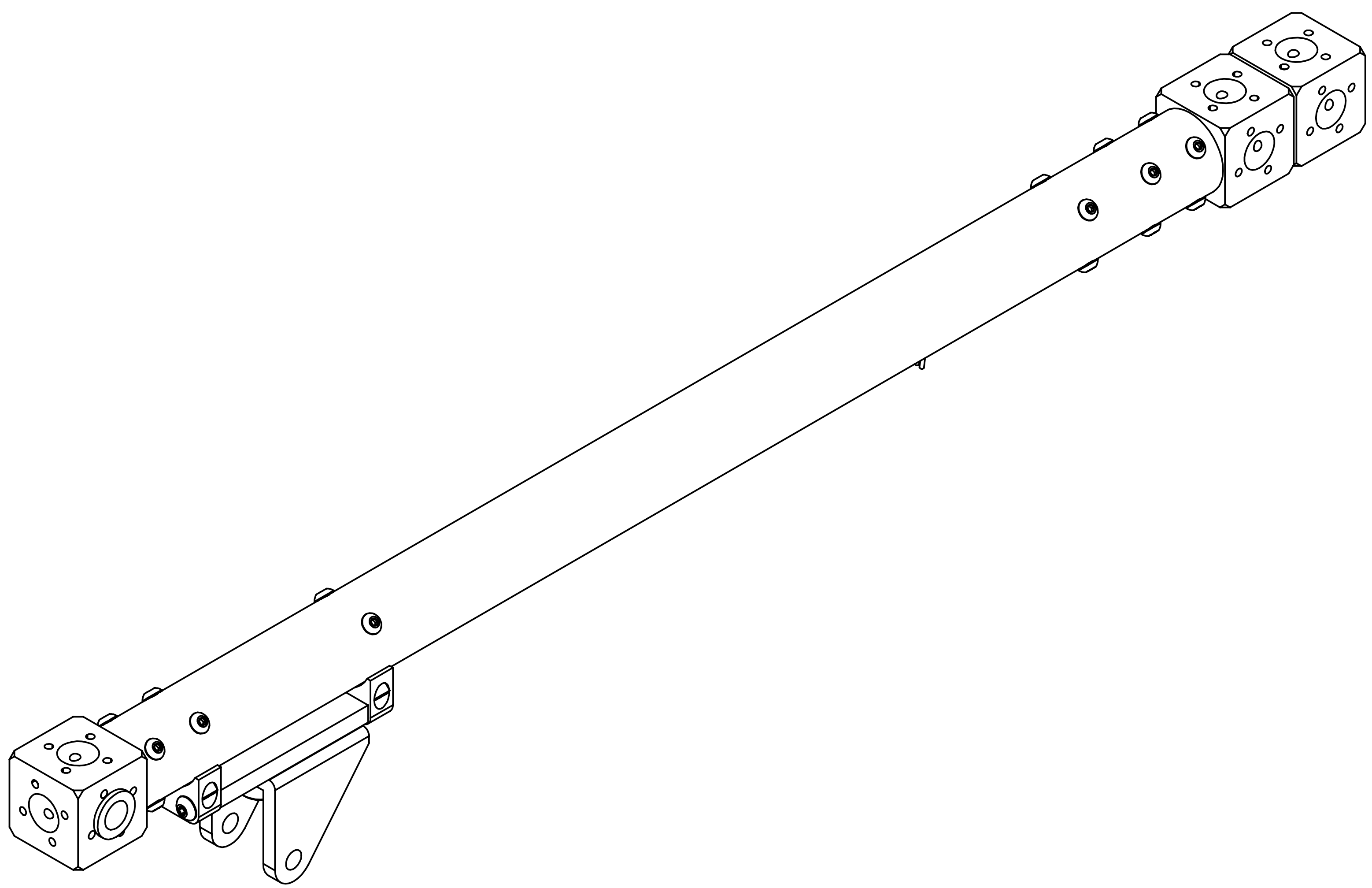
BYU MARS ROVER 2017

PART #: MRP-ARM-0700 R1

SIZE: B | PART NAME: HandAssembly | REV: 1

SCALE: 1:2 | SHEET 1 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0800 R1

SIZE B

PART NAME: ForearmAssembly

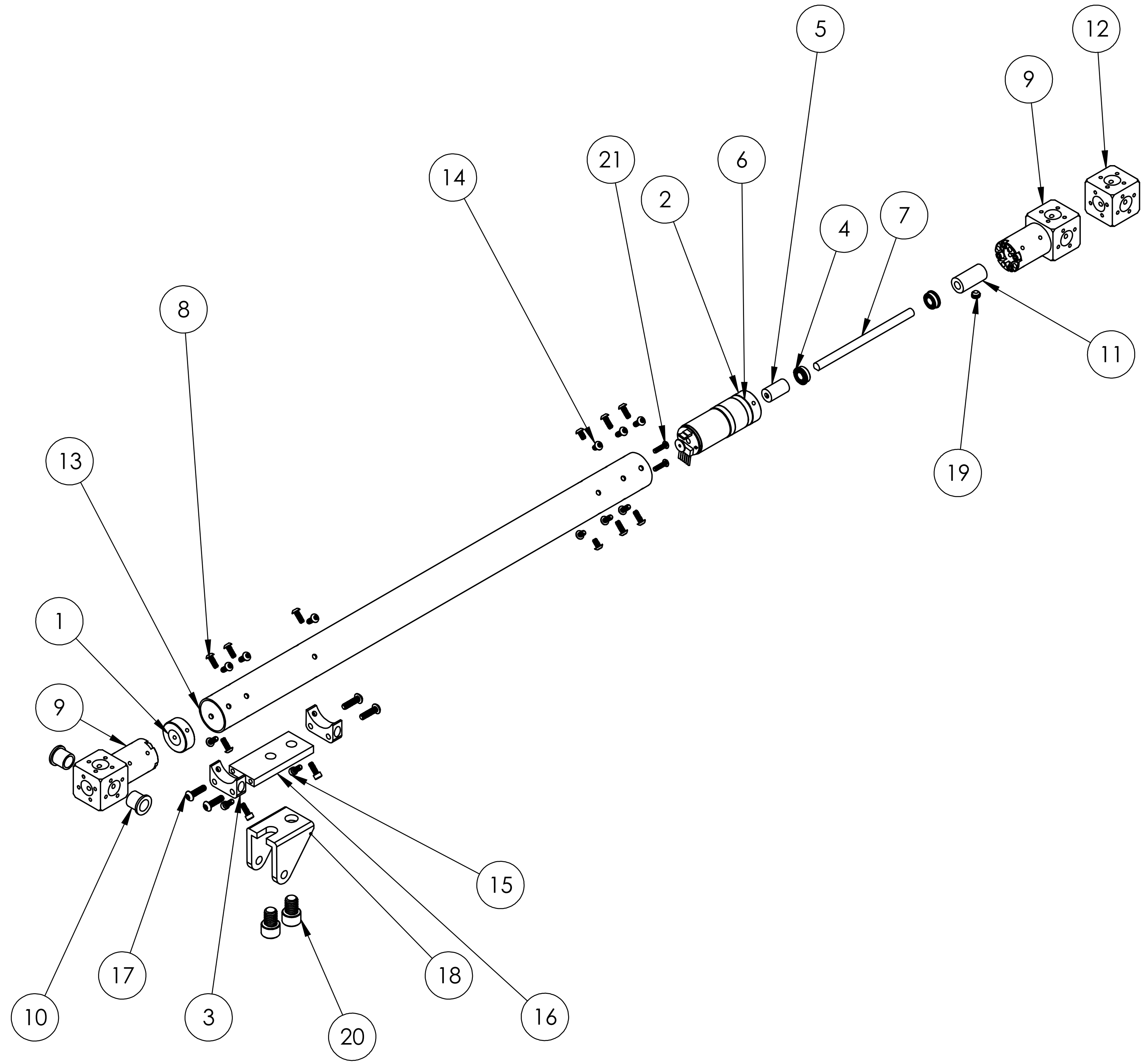
REV 1

SCALE: 1:2

SHEET 2 OF 2

4 3 2 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Rock West Composites # ce10-ab-05	AttachBracketInside	1
2	MRP-ARM-0003 R1	AttachBracketInsideModified	1
3	Rock West Composites # ce10-ab-05	AttachBracketOuside	2
4	Servocity #535198	BearingSmall	2
5	Servocity #625118	ForearmCoupler	1
6	Pololu #3219	ForearmMotor	1
7	Servocity #634094	ForearmShaft	1
8	McMaster Carr # 91255A146	Hex Drive Rounded Head Screw, 6-32 Thread Size, 3/8" Long	16
9	MRP-ARM-0400 R1	MainBlockAssembly	2
10	Mcmaster Carr #6338K312	Bushing (Flange Bearing)	2
11	MRP-ARM-0009 R1	WristCoupler	1
12	Rock West Composites # CE10-MB-05	MainBlock	1
13	Rock West Composites # 46406	ForearmLink	1
14	91255A144	Hex Drive Rounded Head Screw, 6-32 Thread Size, 1/4" Long	4
15	91251A144	Socket Head Screw, 6-32 Thread Size, 1/4" Long	4
16	MRP-ARM-0002 R1	ElbowBracer	1
17	92949A196	18-8 Stainless Steel Hex Drive Rounded Head Screw, 8-32 Thread Size, 5/8" Long	4
18	Firgelli Automations #MB1	MB1Bracket	1
19	McMaster Carr #97705A647	Mil. Spec. 18-8 Stainless Steel Cup-Point Set Screw, 1/4"-28 Thread, 3/16" Long	1
20	McMaster Carr #91251A619	Black-Oxide Alloy Steel Socket Head Screw, 3/8"-16 Thread Size, 1/2" Long	2
21	McMaster Carr #92095A183	18-8 Stainless Steel Hex Drive Rounded Head Screw, M3 x 0.5 mm Thread, 12 mm Long	2

	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

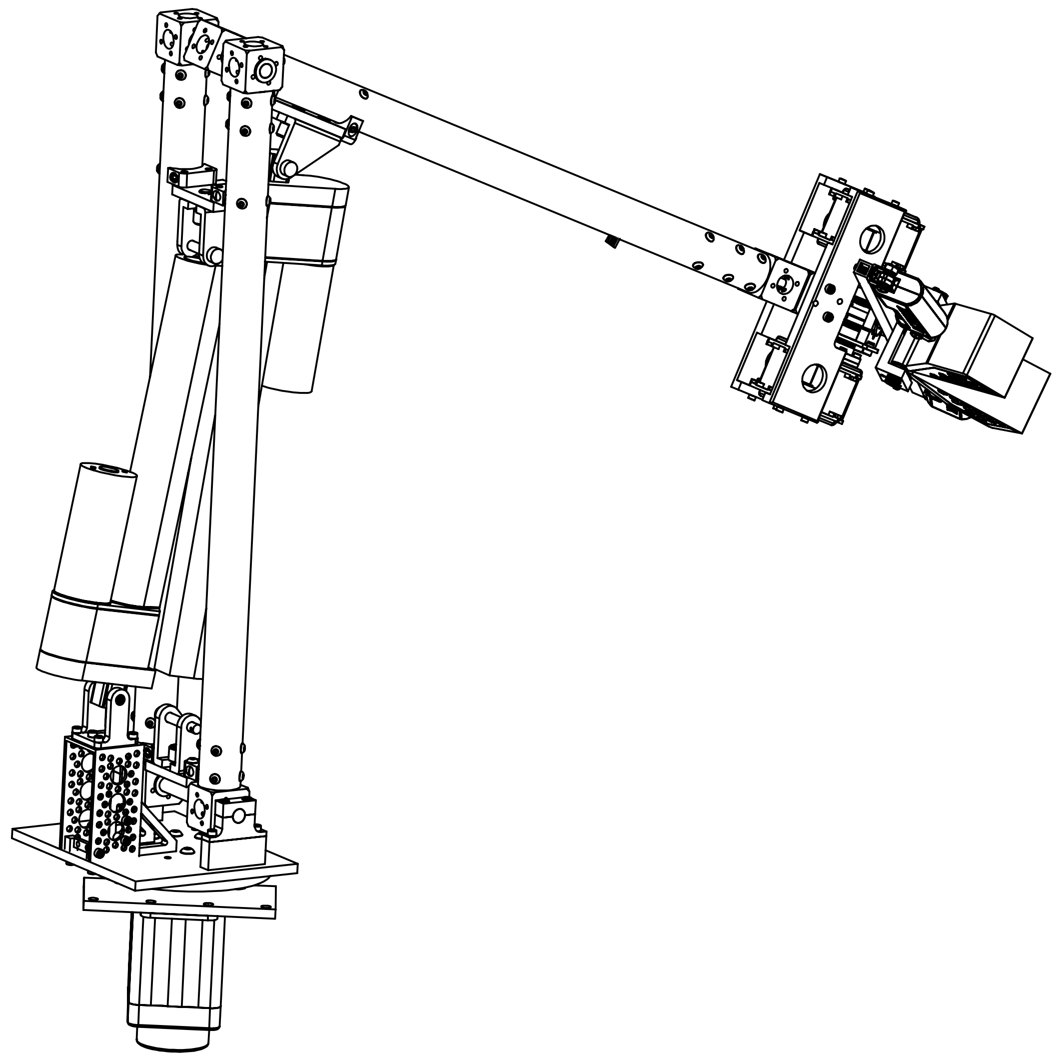
PART #: MRP-ARM-0800 R1

SIZE B | PART NAME: ForearmAssembly | REV 1

SCALE: 1:4 | SHEET 1 OF 2

4 3 2 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

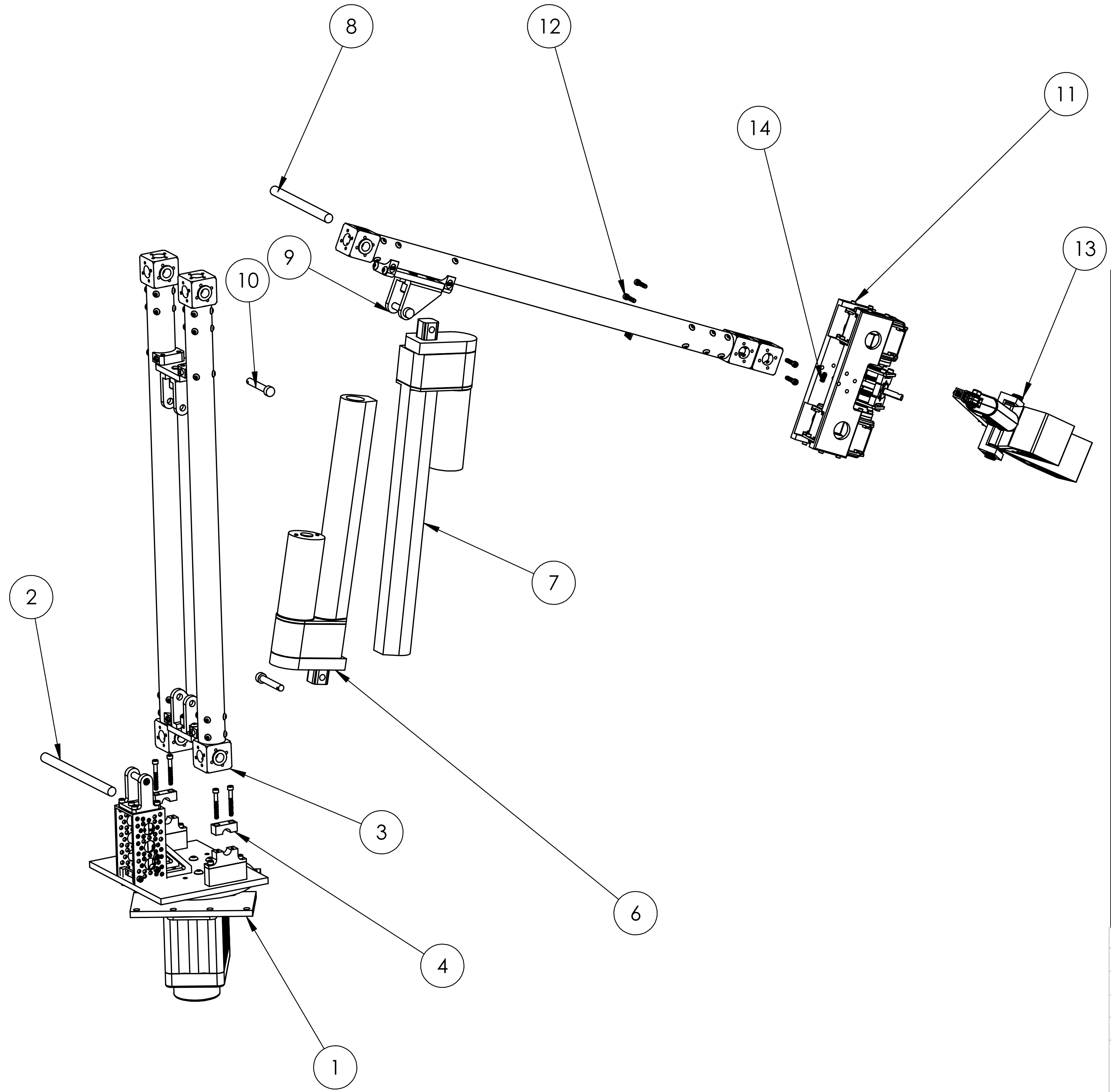
FINISH

BYU
MARS ROVER
2017

PART #: MRP-ARM-0900 R1

SIZE **B** | PART NAME: TotalAssembly | REV 1

SCALE: 1:5 | SHEET 2 OF 2



REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MRP-ARM-0100 R1	TurretAssembly	1
2	Servocity #1346K12	BaseShaft	1
3	MRP-ARM-0600 R1	ArmAssemblyCombined	1
4	MRP-ARM-0008 R1	ShaftSupport2	2
5	McMaster Carr # 92196A154	18-8 Stainless Steel Socket Head Screw, 6-32 Thread Size, 1-1/8" Long	4
6	Firgelli Automations# FA-PO-240-12-06	Actuator6in	1
7	Firgelli Automations # FA-PO-240-12-08	Actuator8in	1
8	Servocity #1346K12	ElbowShaft	1
9	MRP-ARM-0800 R1	ForearmAssembly	1
10	Firgelli Automations # MB1	Pin	3
11	MRP-ARM-0300 R1	Wrist Assembly	1
12	McMaster Carr # 91251A144	Black-Oxide Alloy Steel Socket Head Screw, 6-32 Thread Size, 1/4" Long	4
13	MRP-ARM-0700 R1	HandAssembly	1
14	McMaster Carr # 94105A190	Alloy Steel Flat-Tip Set Screws, Black Oxide, 8-32 Thread, 1/4" Long	1

	NAME	DATE
DRAWN	Mary Wilson	18 April 2017
CHECKED	Jameson Marriott	19 April 2017
ENG APPR.	Brian Jackson	19 April 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ARM-0900 R1

SIZE B | PART NAME: TotalAssembly | REV 1

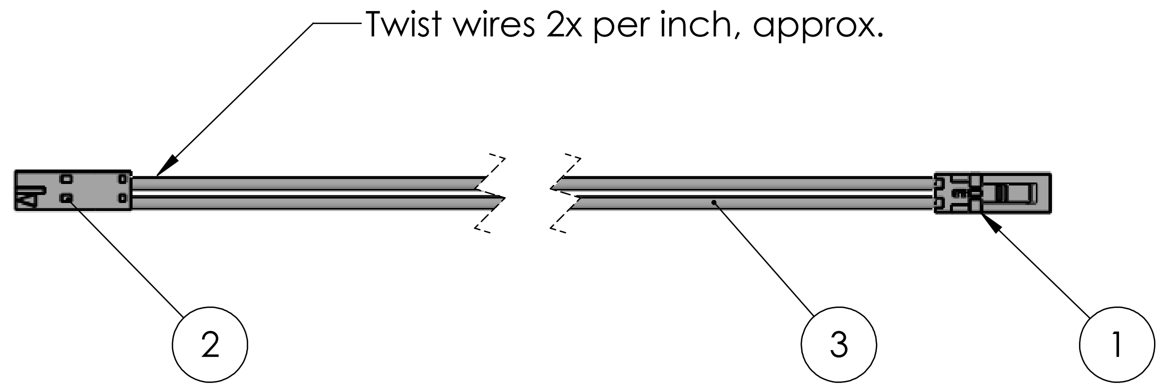
SCALE: 1:5 | SHEET 1 OF 2

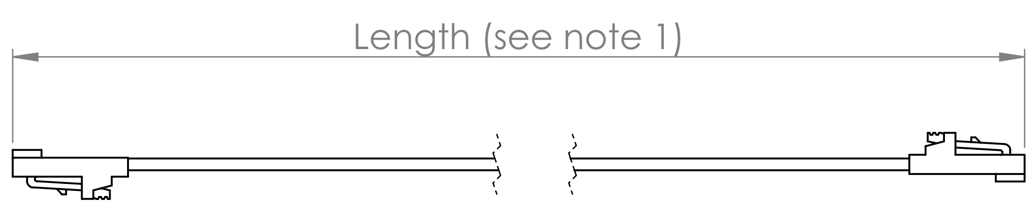
I.4 Electrical Schematics and Documentation

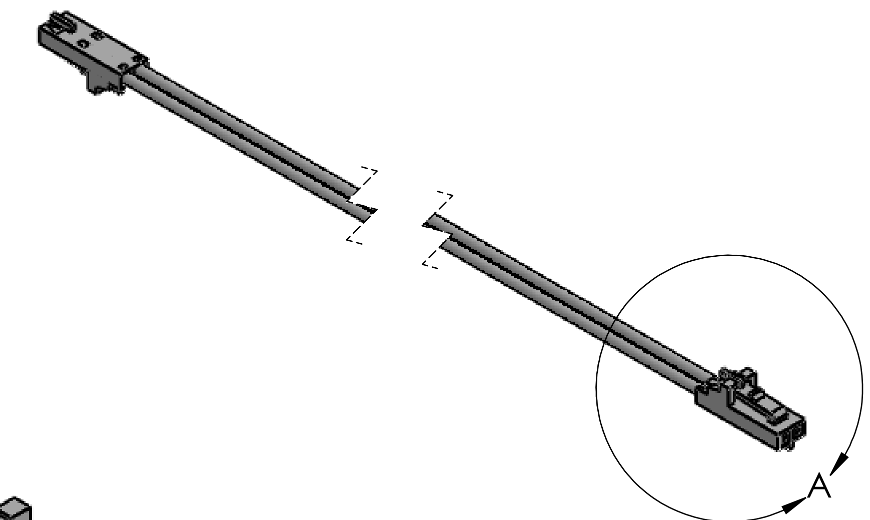
A detailed description of the pin configuration for the PSOC microcontroller is given in MRD-DE-0003 (section G.3).

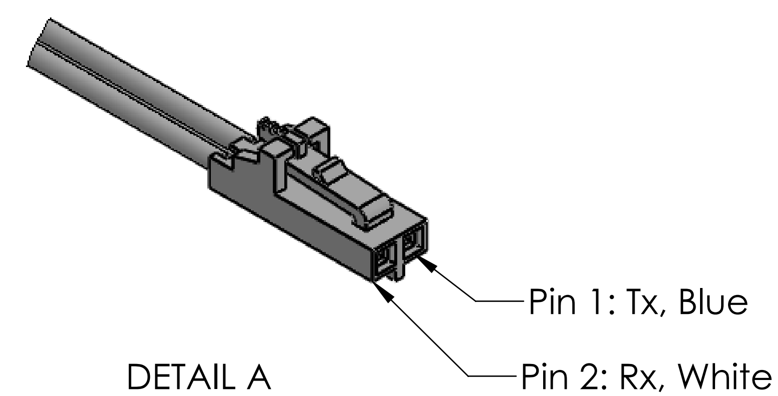
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	1	22 AWG cable, stranded	Any	Any	Pin 1: Tx, Blue Pin 2: Rx, White
2	4	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	2-position rectangular housing	Molex	50-57-9402	

	NAME	DATE
DRAWN	Taylor Greenwood	4/4/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU
MARS ROVER
2017

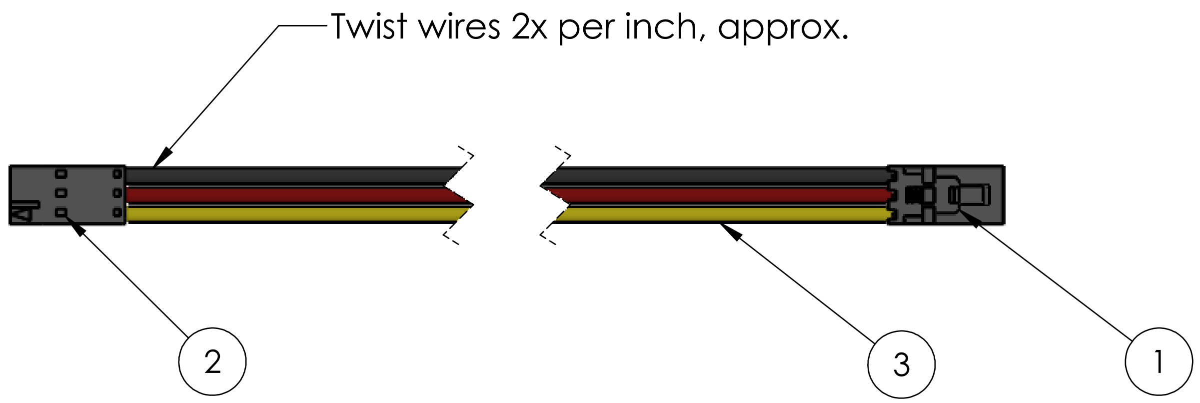
PART #: MRP-ELE-0001 R1

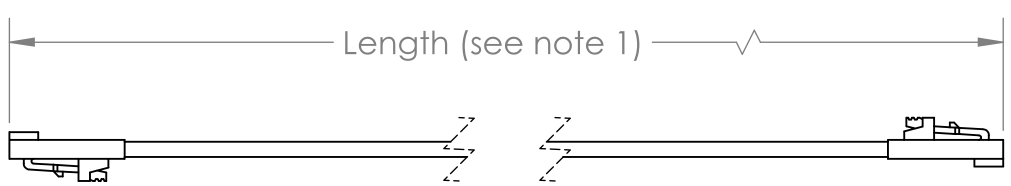
SIZE B | PART NAME: Tx, Rx wire | REV 1

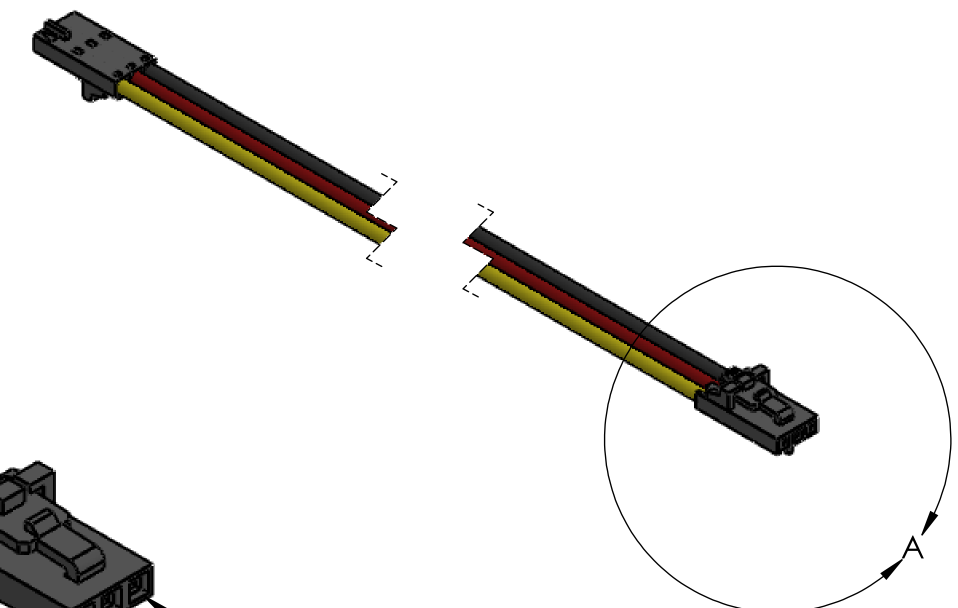
SCALE: 1:1 | SHEET 1 OF 1

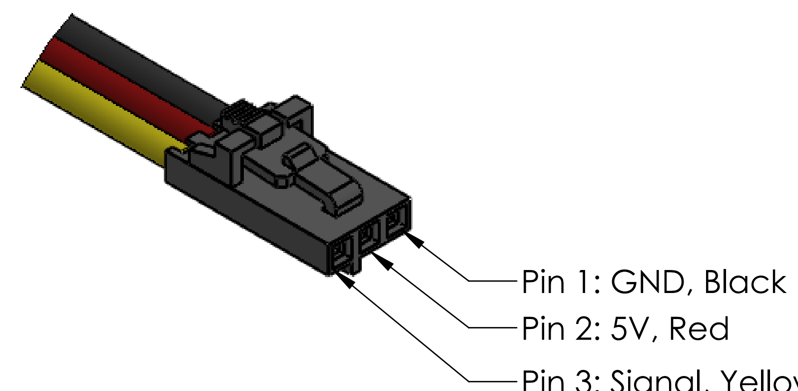
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	1	22 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 5V, Red Pin 3: Signal, Yellow
2	4	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	3-position rectangular housing	Molex	50-57-9403	

	NAME	DATE
DRAWN	Taylor Greenwood	4/4/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU
MARS ROVER
2017

PART #: MRP-ELE-0002 R1

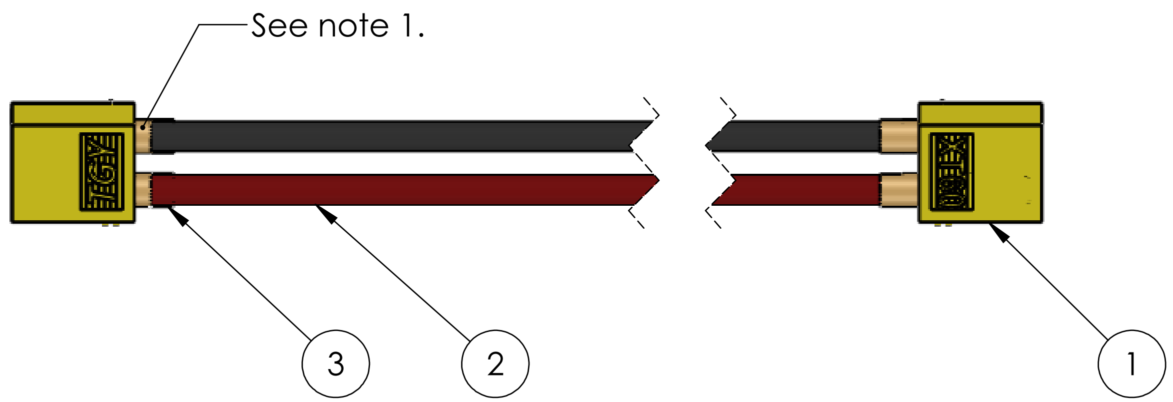
SIZE B | PART NAME: 5V Signal wire | REV R1

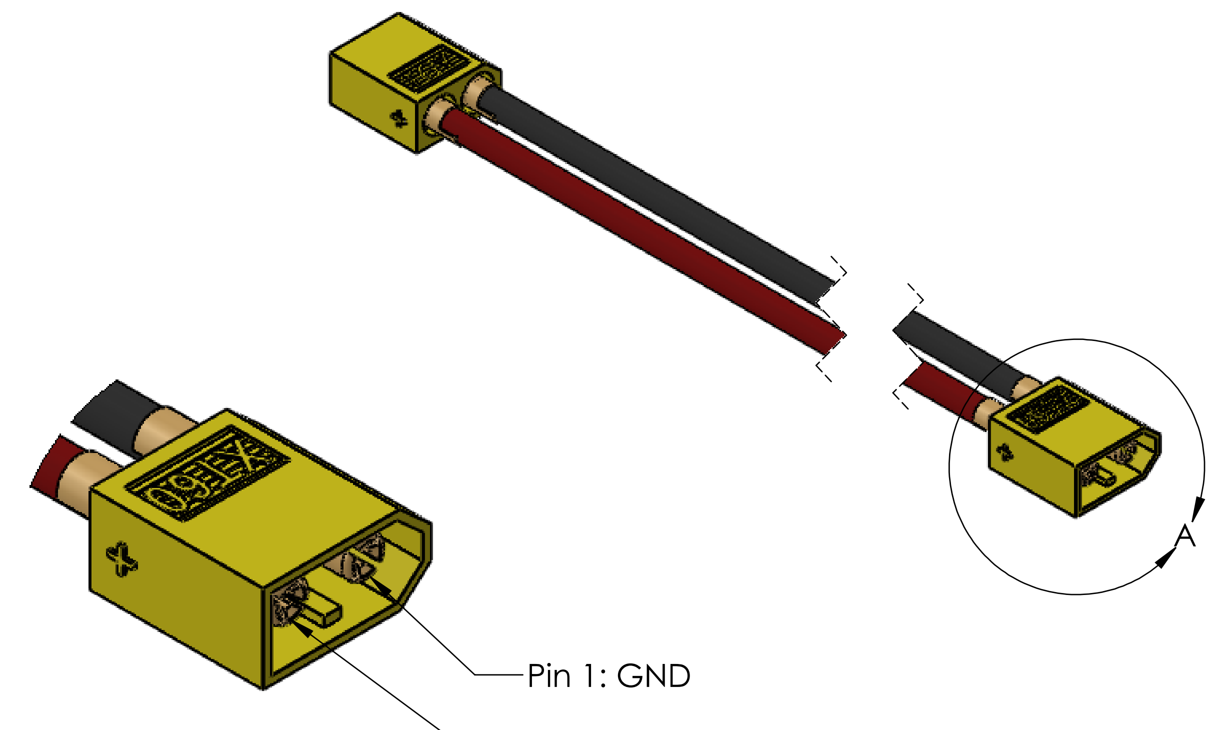
SCALE: 1:1 | SHEET 1 OF 1

ZONE	REV.	DESCRIPTION	DATE	APPROVED

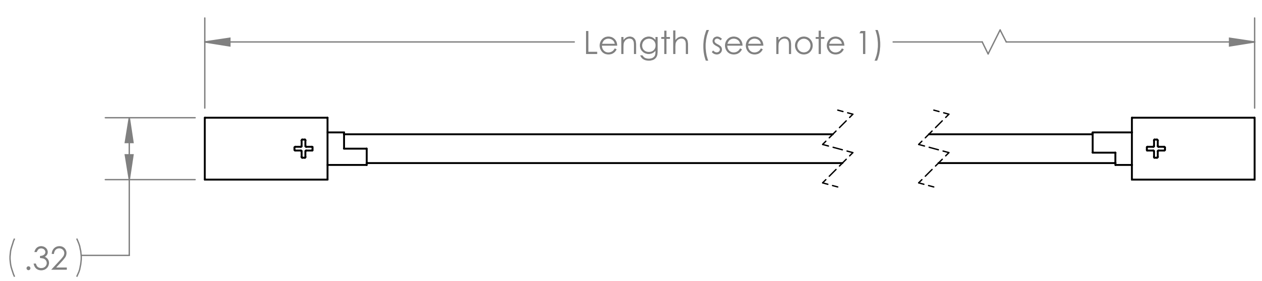
REVISIONS

NOTES:
1. Solder connections and cover with heat shrink.





DETAIL A
SCALE 2 : 1



Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	4	0.25" dia. Heat Shrink, 1" long, approx.	Any	Any	Not shown. See note 1.
2	2	14 AWG wire, stranded	Any	Any	Pin 1: GND Pin 2: VDD
1	2	XT60 2-pin charging connector, male	Any	Any	Any

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ELE-0007 R1

SIZE B

PART NAME: Battery Connection wires

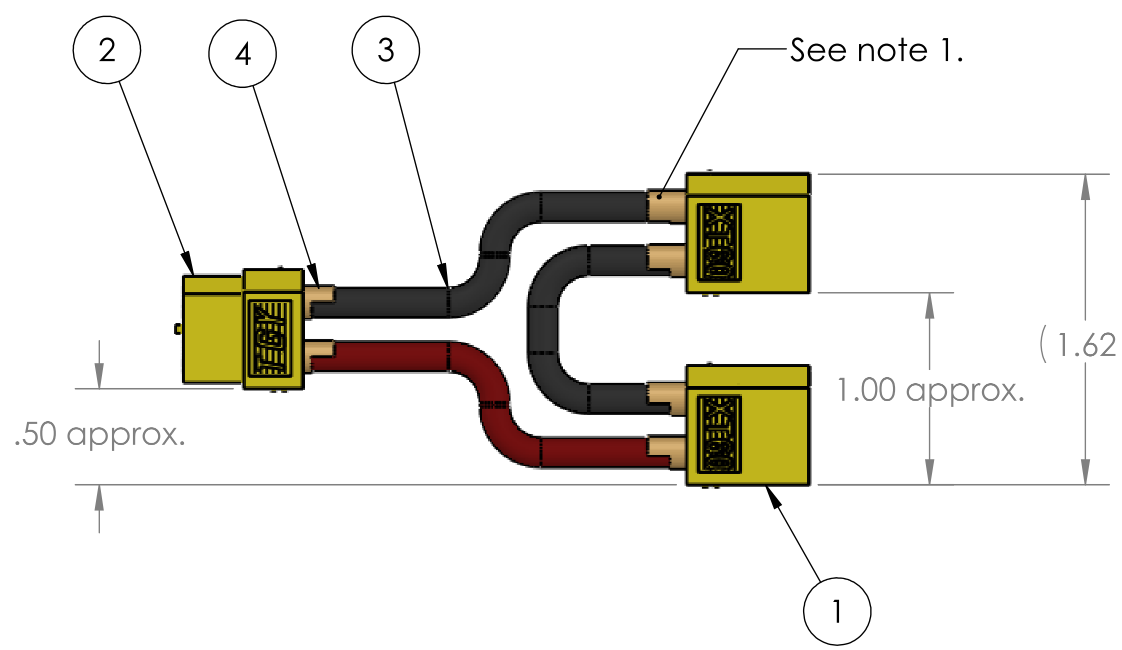
REV R1

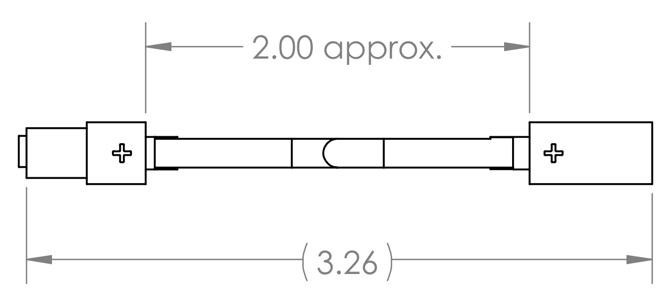
SCALE: 1:1

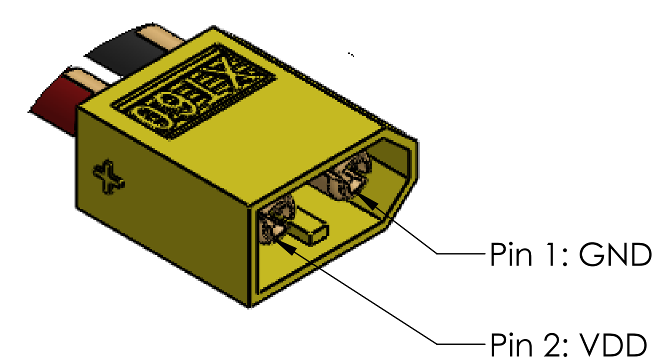
SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

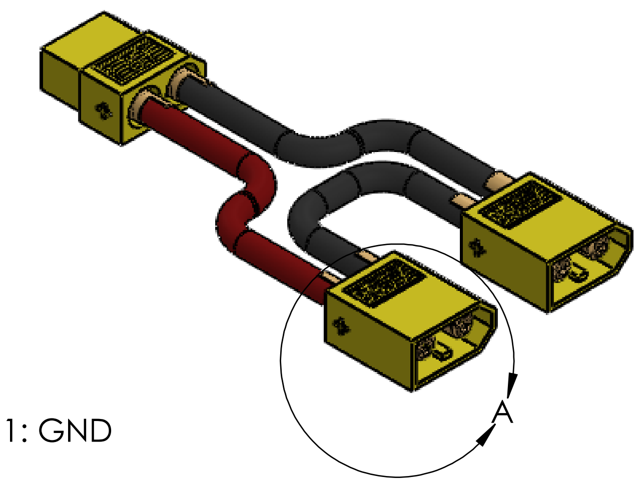
NOTES:
1. Solder connections and cover with heat shrink.







DETAIL A
SCALE 2 : 1



Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	4	0.25" dia. Heat Shrink, 1" long, approx.	Any	Any	Not shown. See note 1.
3	2	14 AWG wire, stranded	Any	Any	Pin 1: GND Pin 2: VDD
2	1	XT60 2-pin charging connector, female	Any	Ansy	
1	2	XT60 2-pin charging connector, male	Any	Any	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #:
MRP-ELE-0008 R1

SIZE
B

PART NAME:
Parallel Battery Connector

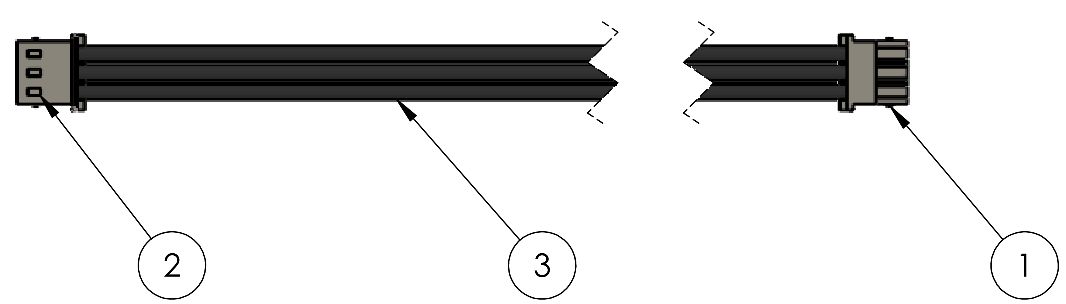
REV
R1

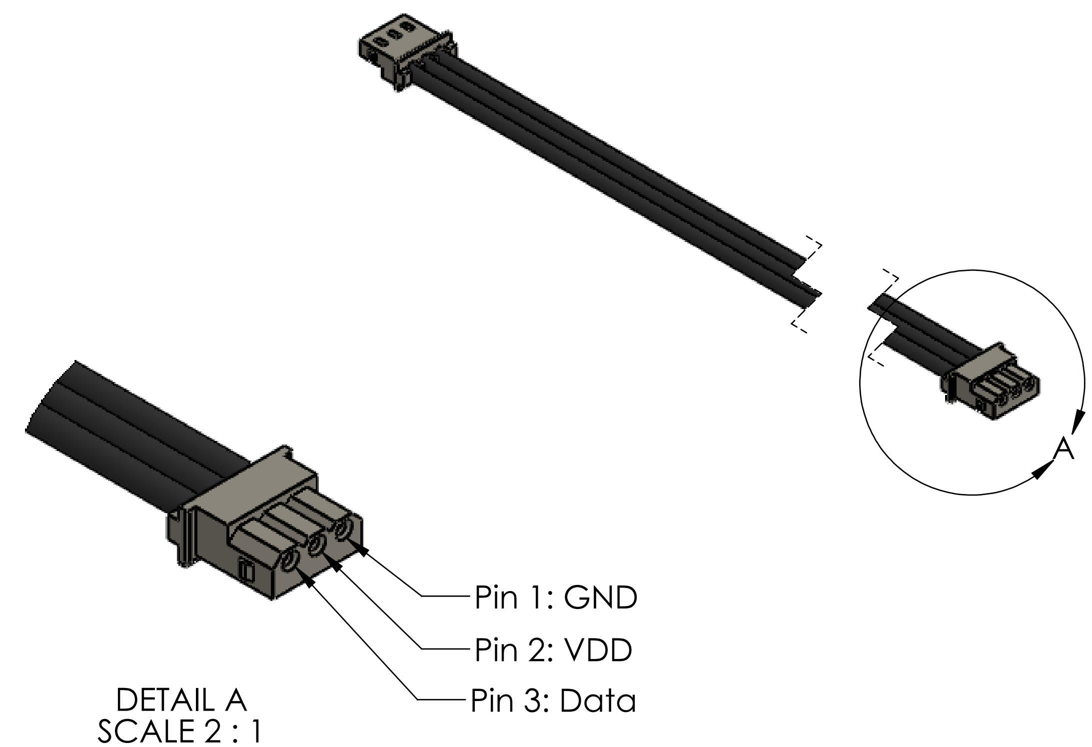
SCALE: 1:1

SHEET 1 OF 1

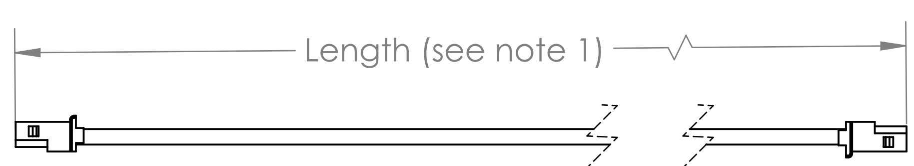
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.





DETAIL A
SCALE 2 : 1



Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	3	22 AWG wire, stranded	Any	Any	Pin 1: GND Pin 2: VDD Pin 3: Data
2	6	Contact Crimp, 22-28 AWG, Tin	Molex	08-70-1039	Not shown. See note 2
1	2	XT60 2-pin charging connector, male	Any	Any	Any

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU
MARS ROVER
2017

PART #: MRP-ELE-0009 R1

SIZE **B**

PART NAME: Dynamixel 3-pin wire

REV R1

SCALE: 1:1

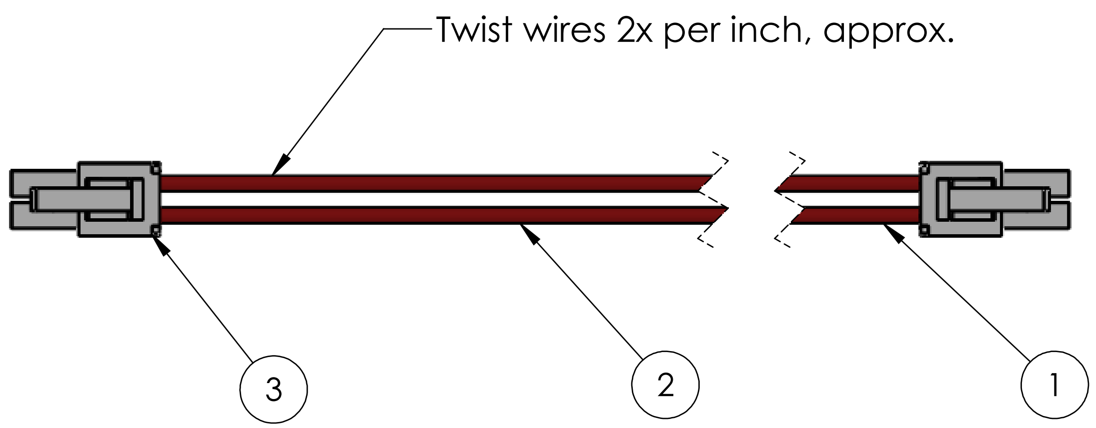
SHEET 1 OF 1

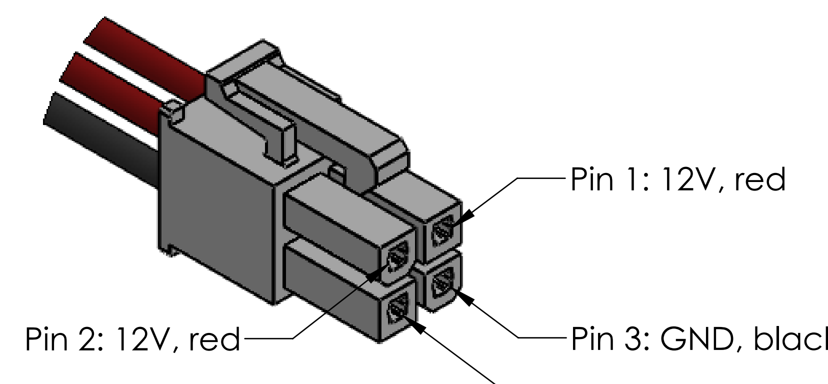
4	3	2	1

REVISIONS

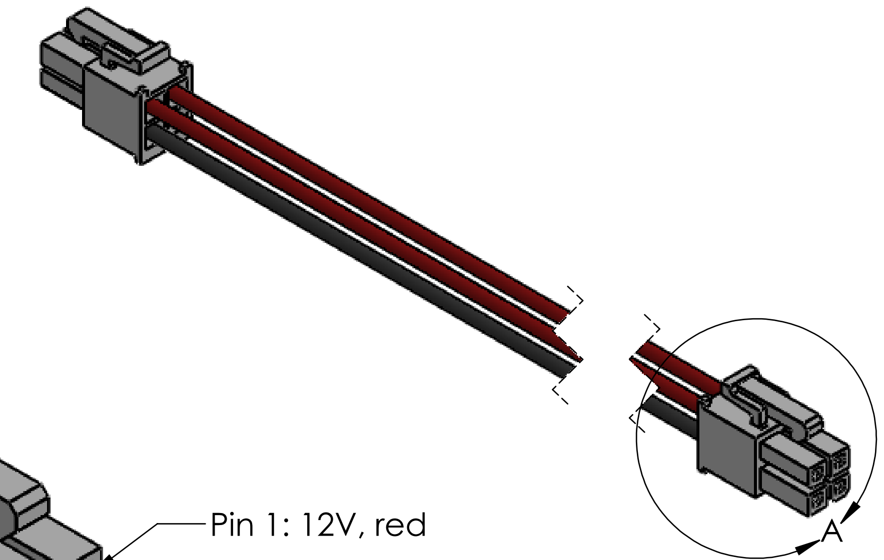
ZONE	REV.	DESCRIPTION	DATE	APPROVED

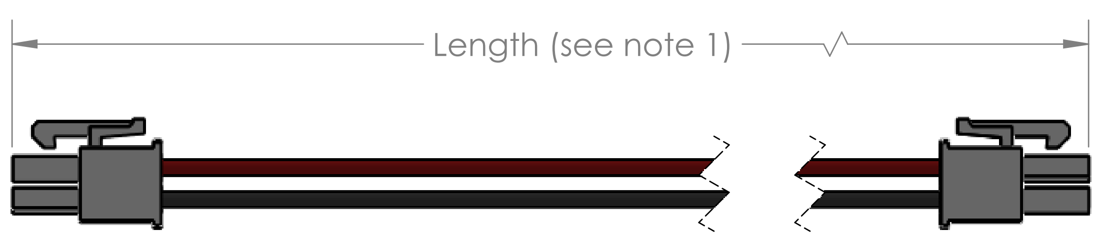
NOTES:
1. Length depends on part number call-out.
(E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.





DETAIL A
SCALE 2 : 1





Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	8	Contact Crimp, 18-24 AWG, Tin	Molex	39-00-0038	Not shown. See note 2
2	4	18 AWG wire, stranded	Any	Any	Pin 1: 12V, red Pin 2: 12V, red Pin 3: GND, black Pin 4: GND, black
1	1	4-position rectangular housing, 2x2	Molex	39-01-2040	

	NAME	DATE
DRAWN	Taylor Greenwood	4/13/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2019
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
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X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

PART #: MRP-ELE-0010 R1

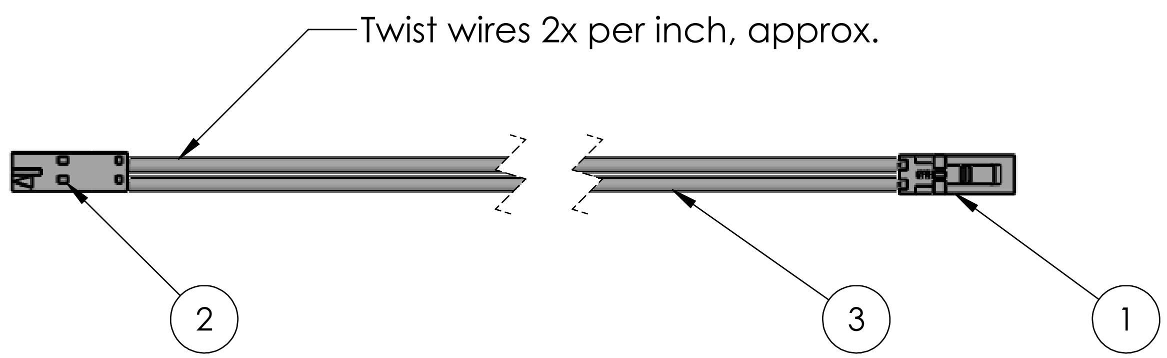
SIZE **B** | PART NAME: Voltage Board wire | REV R1

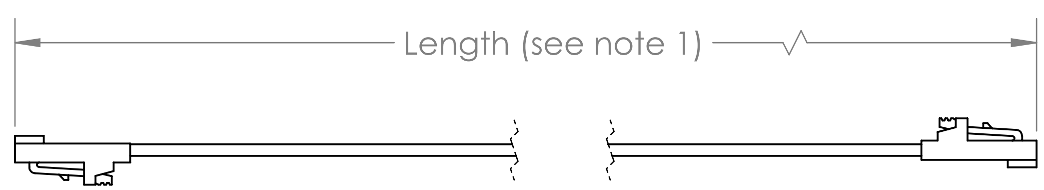
SCALE: 1:1 | SHEET 1 OF 1

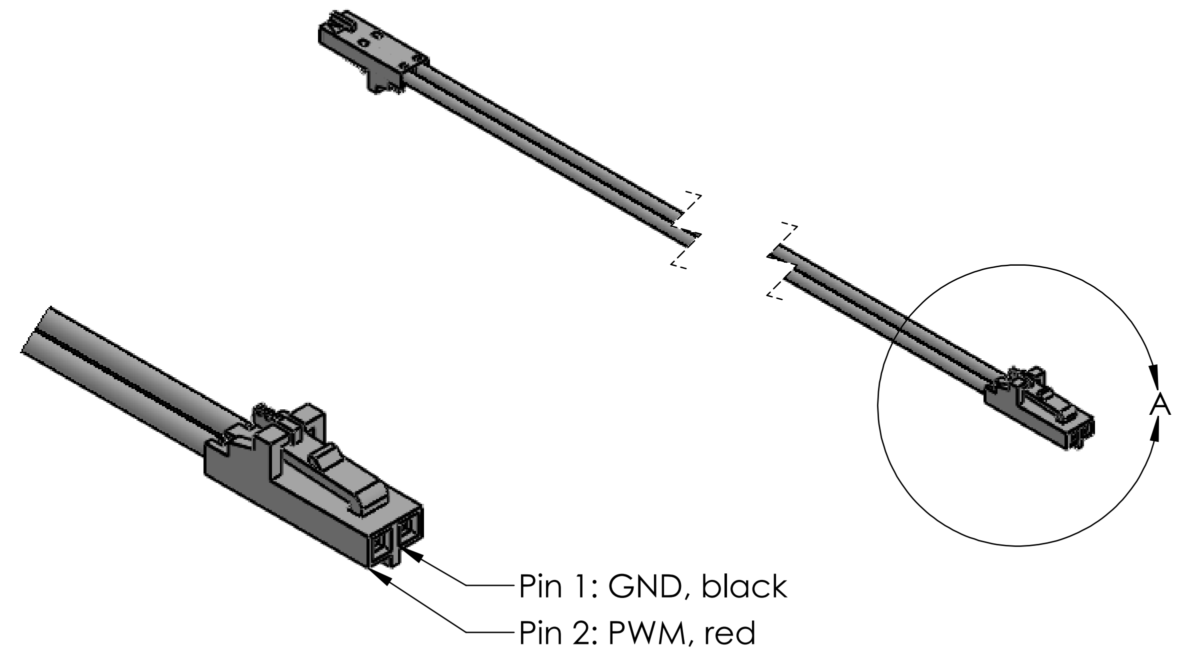
4	3	2	1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.







DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	2	22 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 5V, Red
2	4	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	2-position rectangular housing	Molex	50-57-9402	

	NAME	DATE
DRAWN	Taylor Greenwood	4/10/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU
MARS ROVER
2017

PART #: MPR-ELE-0012 R1

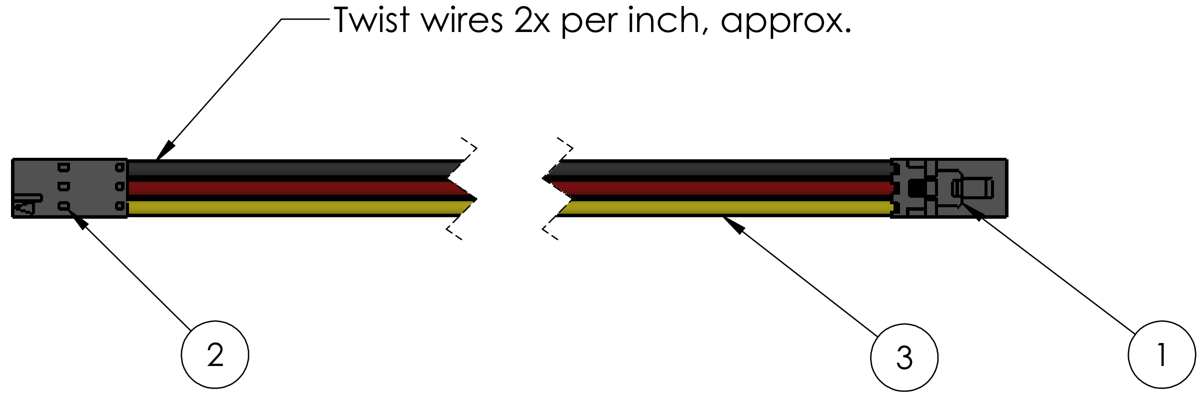
SIZE B | PART NAME: MotA/B wire | REV R1

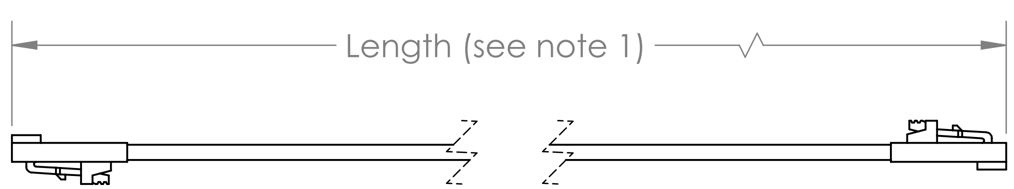
SCALE: 1:1 | SHEET 1 OF 1

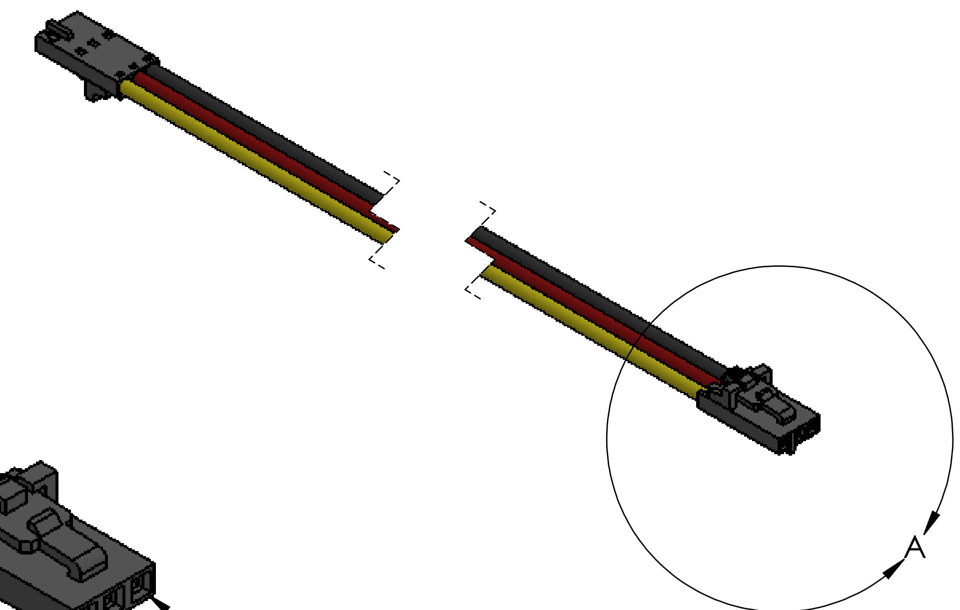
ZONE	REV.	DESCRIPTION	DATE	APPROVED

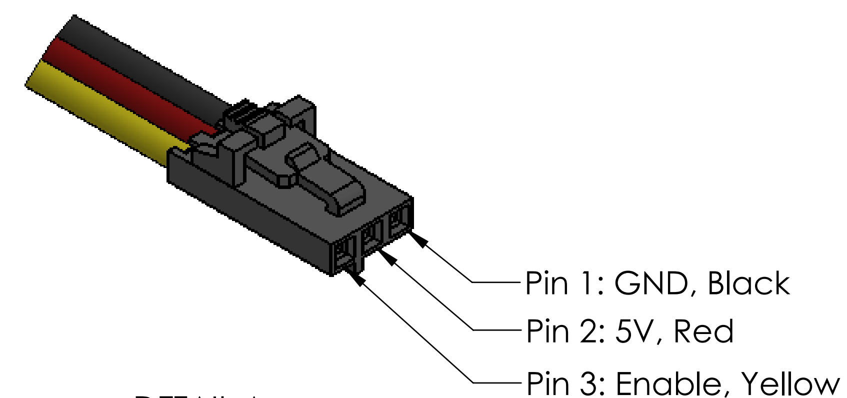
REVISIONS

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	1	22 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 5V, Red Pin 3: Enable, Yellow
2	4	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	3-position rectangular housing	Molex	50-57-9403	

	NAME	DATE
DRAWN	Taylor Greenwood	4/4/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU MARS ROVER 2017

PART #: MRP-ELE-0013 R1

SIZE **B**

PART NAME: Chutes Enable wire

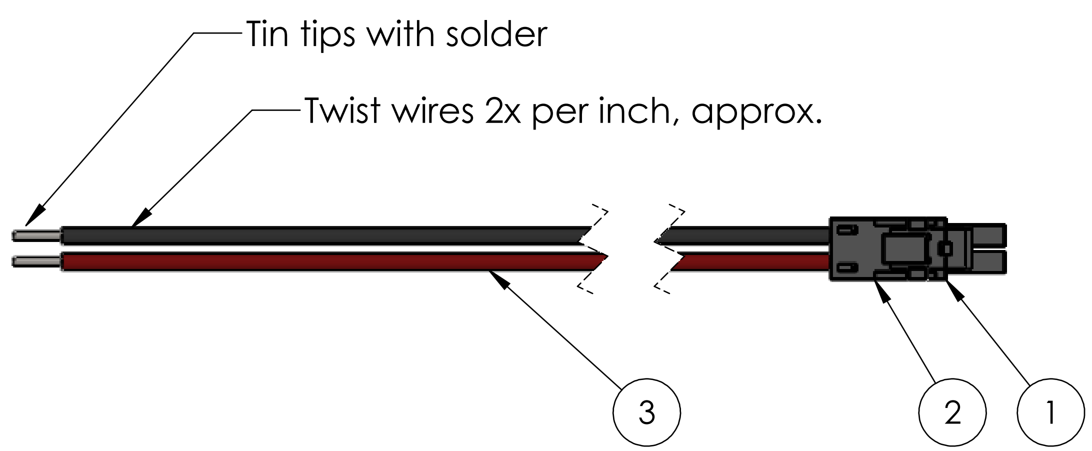
REV R1

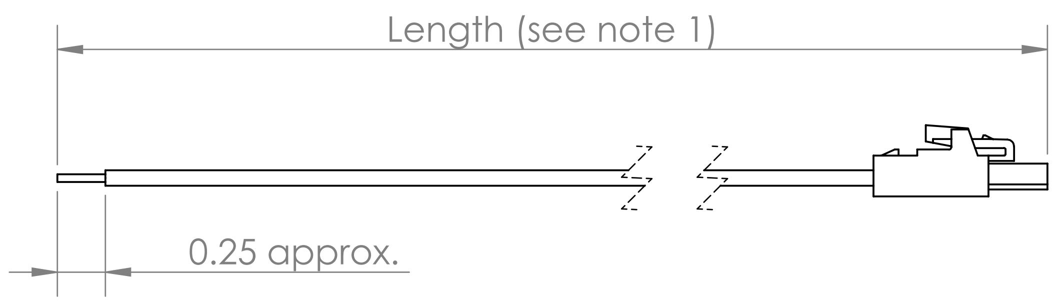
SCALE: 1:1

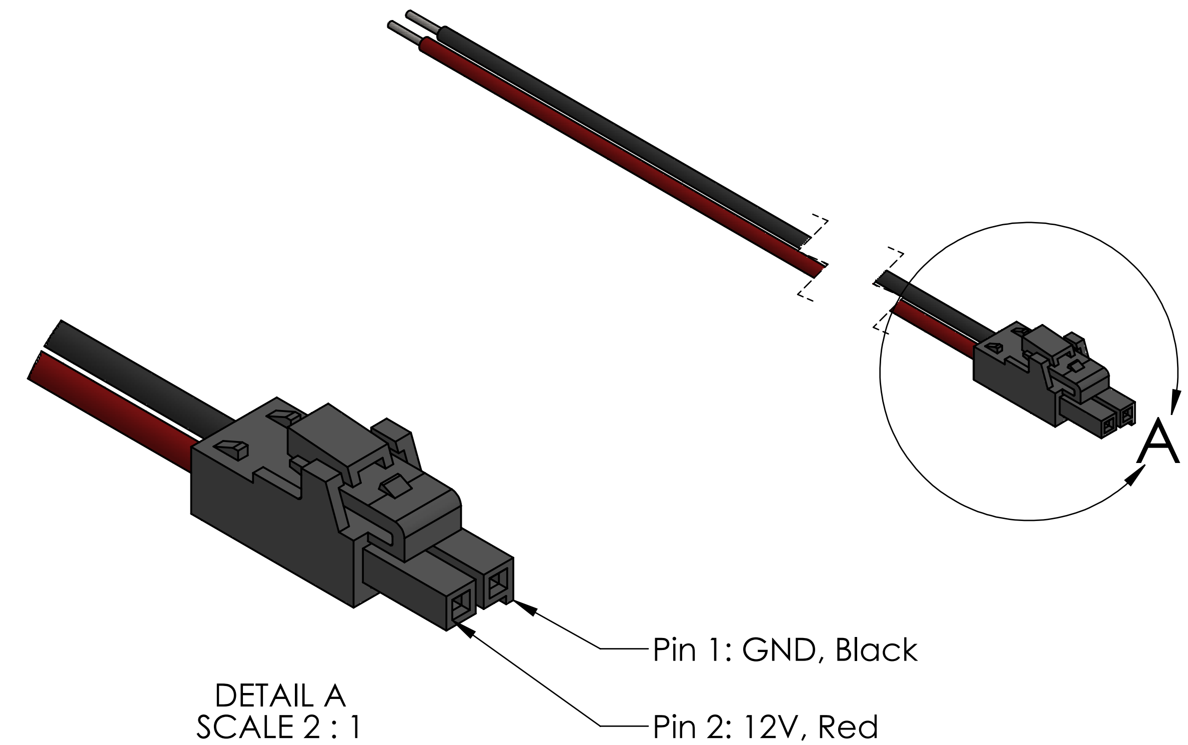
SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.







DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	2	18 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 12V, Red
2	2	Contact Crimp 16-18 AWG Tin	Molex	172253-3023	Crimps not shown. See note 2.
1	1	2-position rectangular housing	Molex	172286-1102	

	NAME	DATE
DRAWN	Taylor Greenwood	4/12/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU MARS ROVER 2017

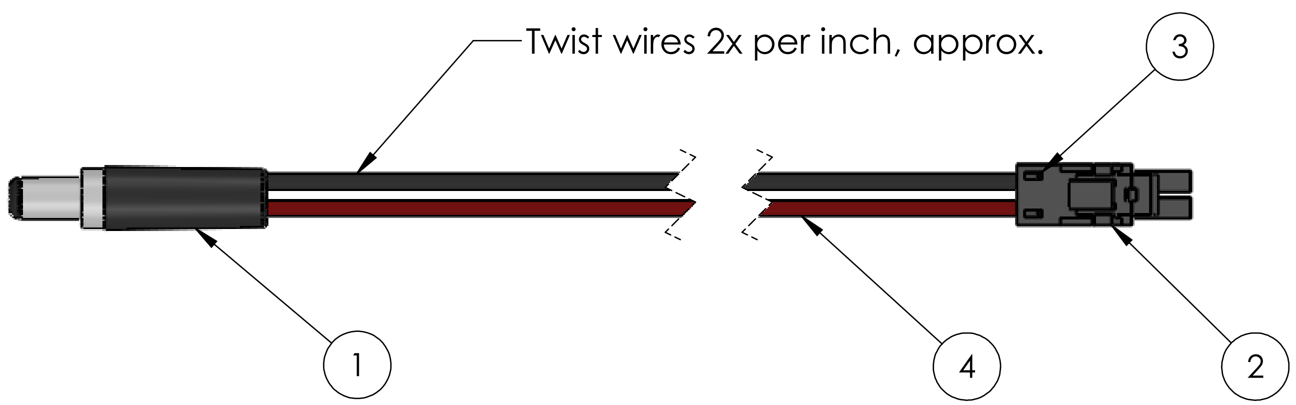
PART #: MRP-ELE-0015 R1

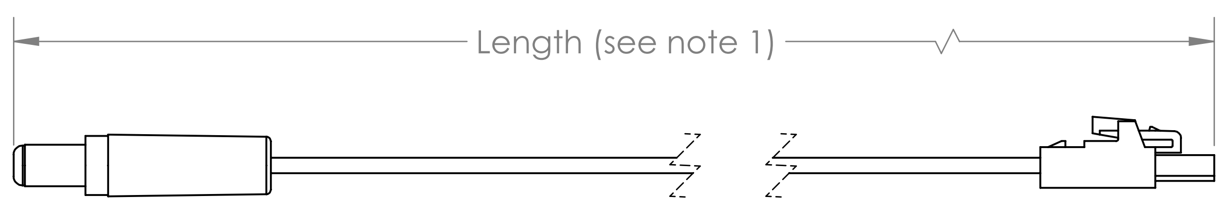
SIZE **B** PART NAME: 12V Pololu wire REV R1

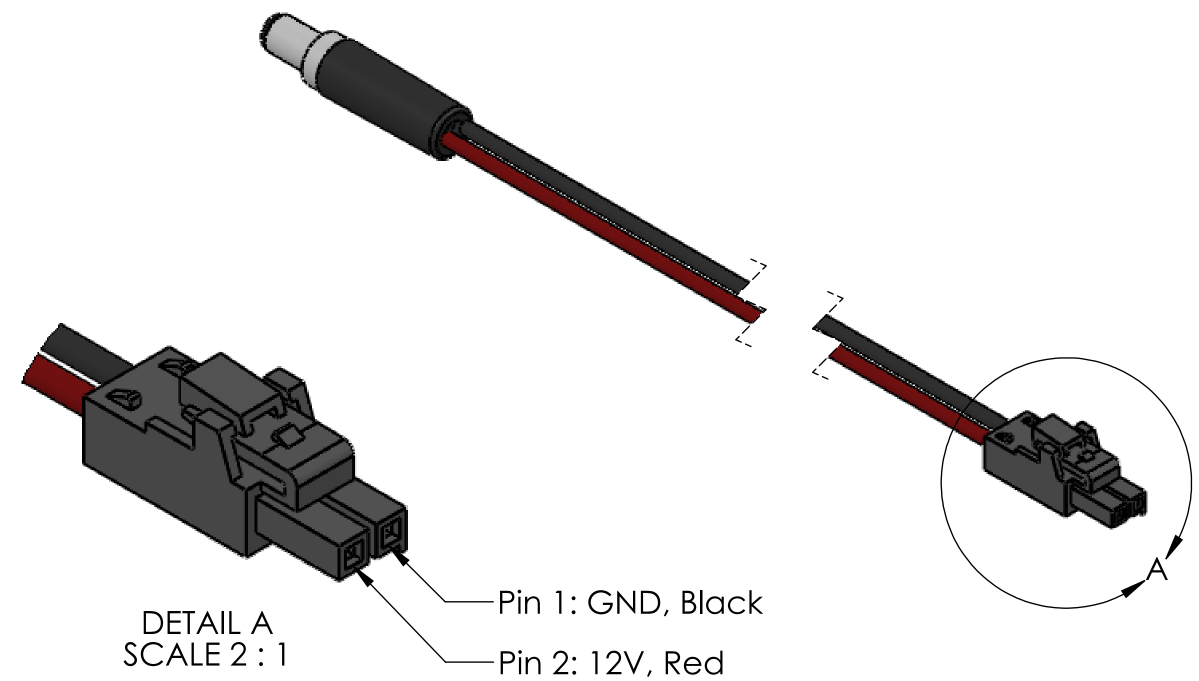
SCALE: 1:1 SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	2	18 AWG wire, stranded	Any	Any	Pin 1: GND Pin 2: 12V
3	2	Contact Crimp 16-18 AWG, Tin	Molex	172253-3023	Crimps not shown. See note 2.
2	1	2-position rectangular housing	Molex	172286-1102	
1	1	Barrel Jack, 2.1 mm diameter	Any	Any	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU MARS ROVER 2017

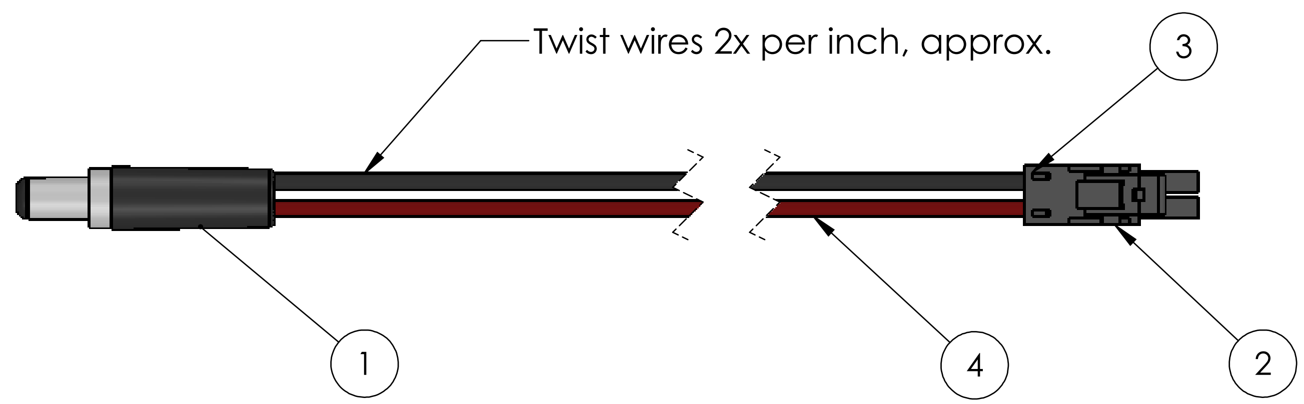
PART #: MRP-ELE-0016 R1

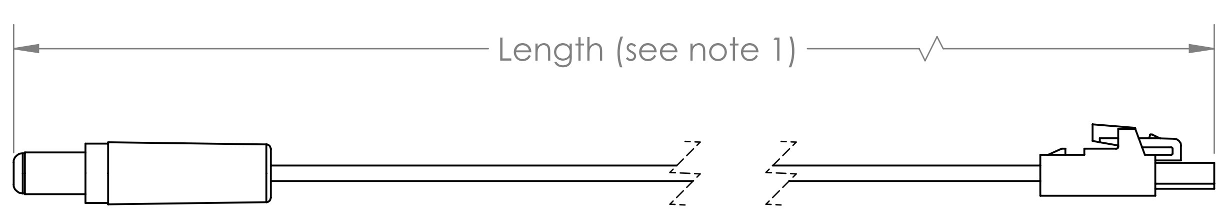
SIZE **B** | PART NAME: Jetson 12V Power | REV R1

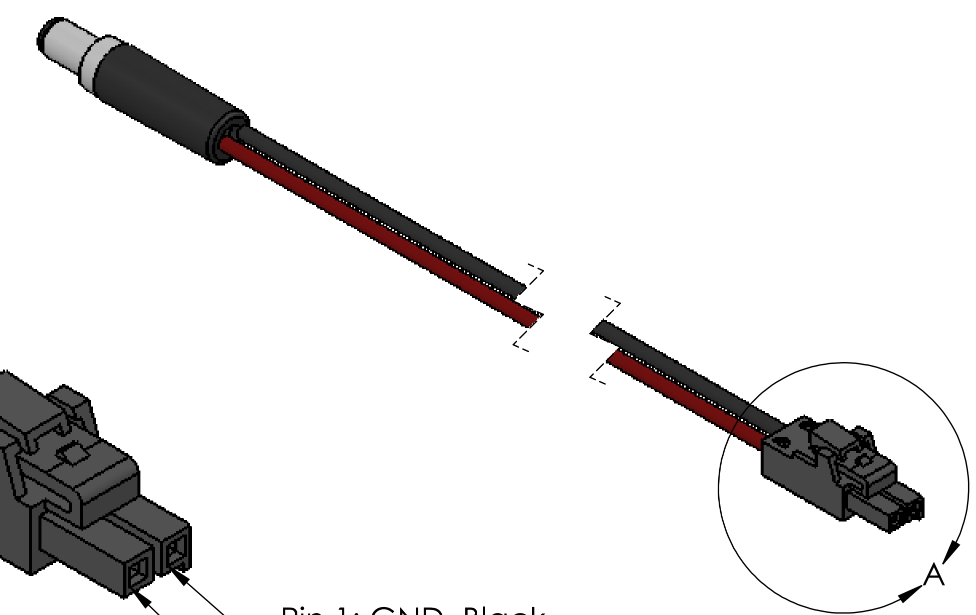
SCALE: 1:1 | SHEET 1 OF 1

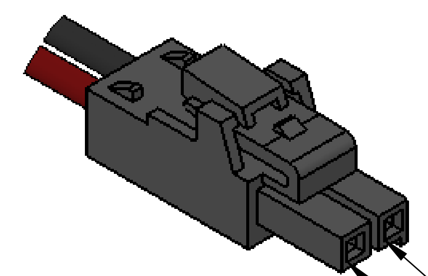
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	2	18 AWG wire, stranded	Any	Any	Pin 1: GND Pin 2: 12V
3	2	Contact Crimp 16-18 AWG, Tin	Molex	172253-3023	Crimps not shown. See note 2.
2	1	2-position rectangular housing	Molex	172286-1102	
1	1	Barrel Jack, 2.1 mm diameter	Any	Any	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

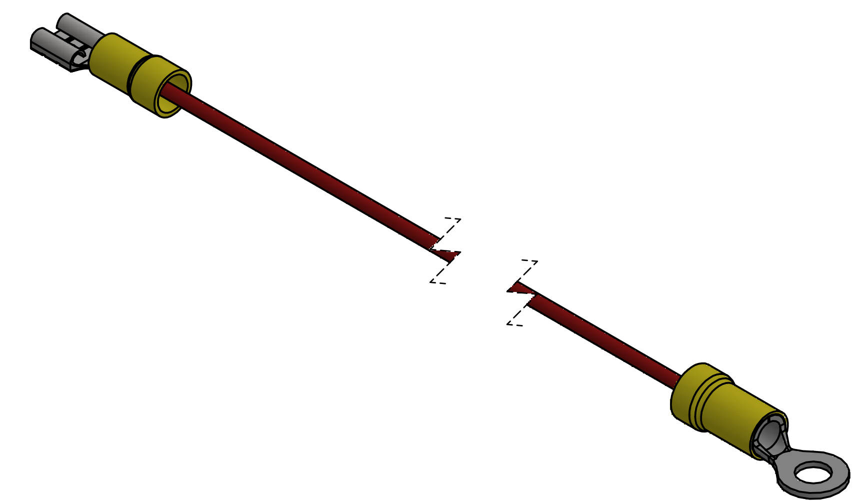
PART #: MRP-ELE-0017 R1

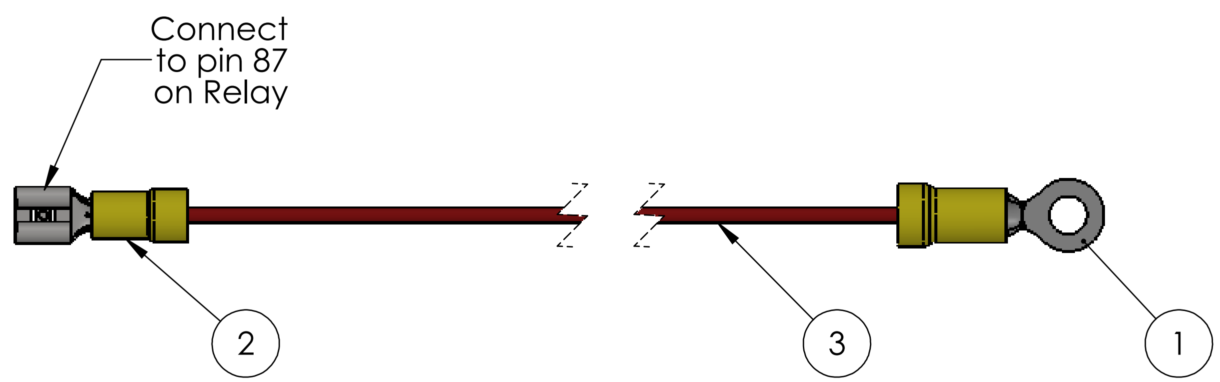
SIZE B | PART NAME: USB Hub 12V Power | REV R1

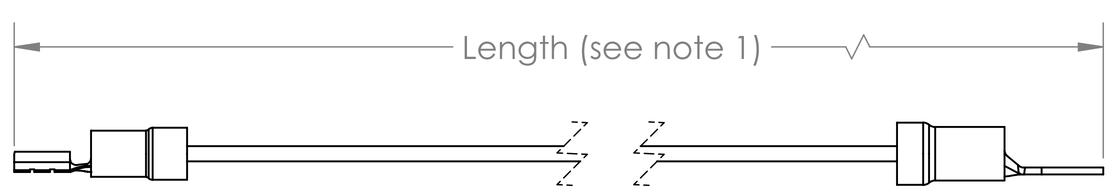
SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	1	18 AWG cable, stranded	Any	Any	24 V
2	1	Spade-style quick-connect solderless connector	Any	Any	Solder on wire
1	1	Ring style quick-connect solderless connector	Any	Any	Solder onto wire

	NAME	DATE
DRAWN	Taylor Greenwood	4/19/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MPR-ELE-0019 R1

SIZE B

PART NAME: Relay Fuse Box Power wire

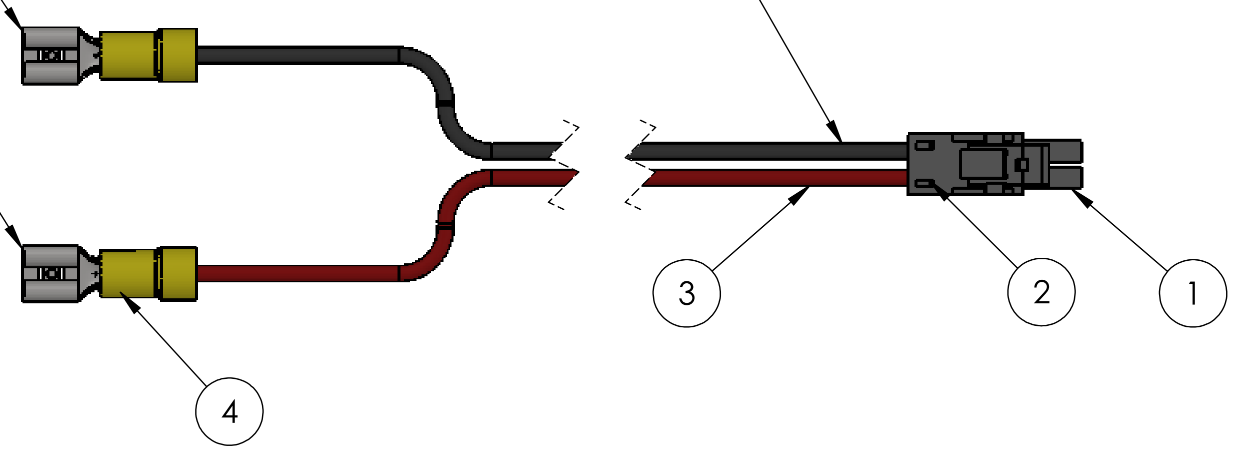
REV R1

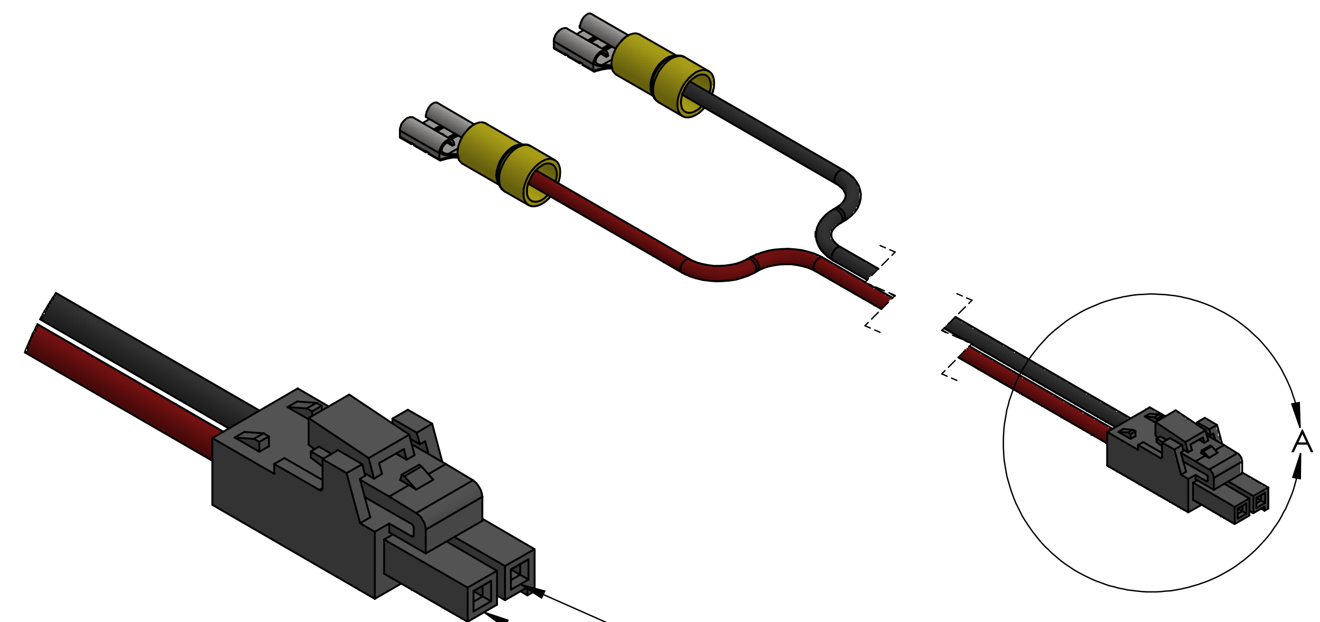
SCALE: 1:1

SHEET 1 OF 1

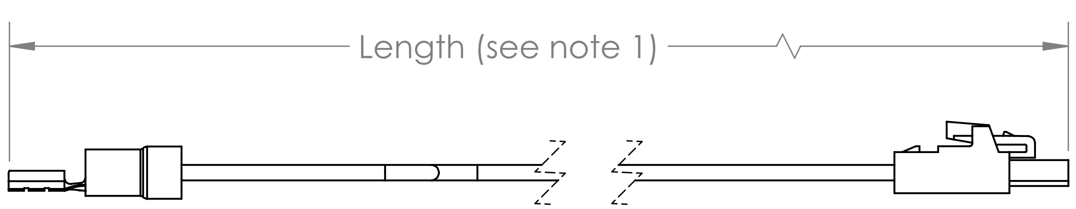
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.





DETAIL A
SCALE 2 : 1



Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	2	Ring style quick-connect solderless connector	Any	Any	Solder onto wires
3	2	18 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 12V, Red
2	4	Contact Crimp 16-18 AWG Tin	Molex	172253-3023	Crimps not shown. See note 2.
1	2	2-position rectangular housing	Molex	172286-1102	

	NAME	DATE
DRAWN	Taylor Greenwood	4/19/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009
MATERIAL
FINISH
N/A

BYU MARS ROVER 2017

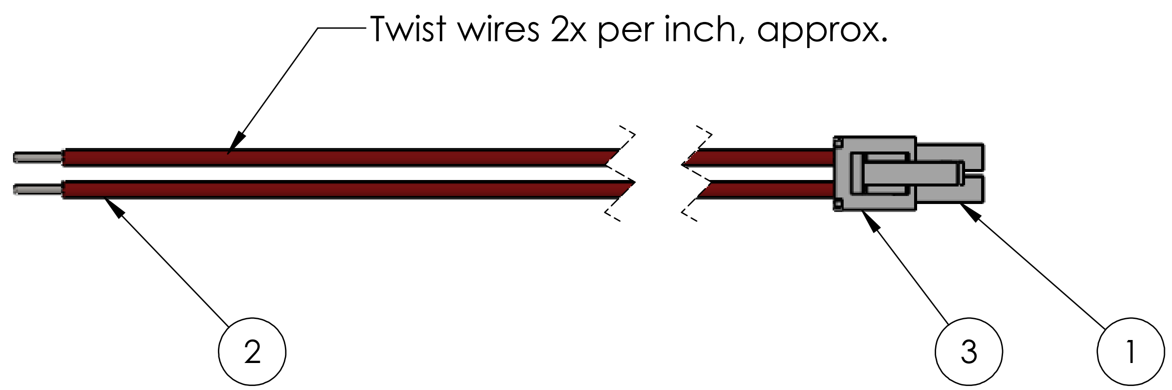
PART #: MPR-ELE-0019 R1

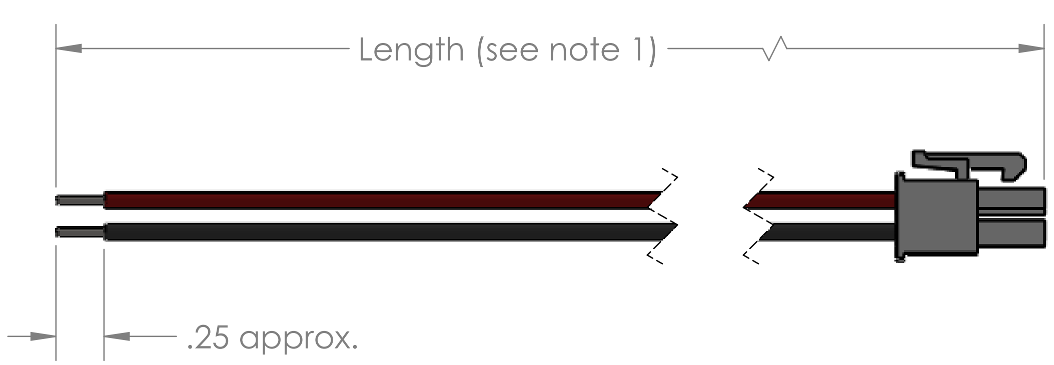
SIZE B | PART NAME: Relay Enable wire | REV R1

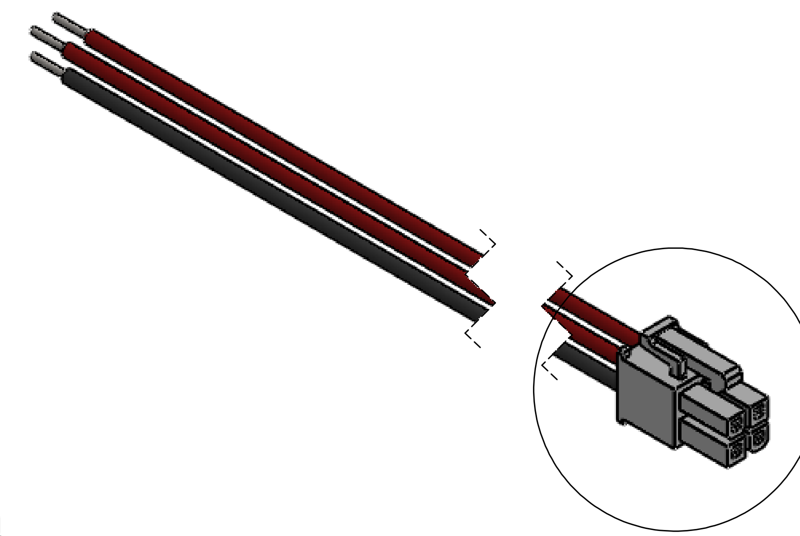
SCALE: 1:1 | SHEET 1 OF 1

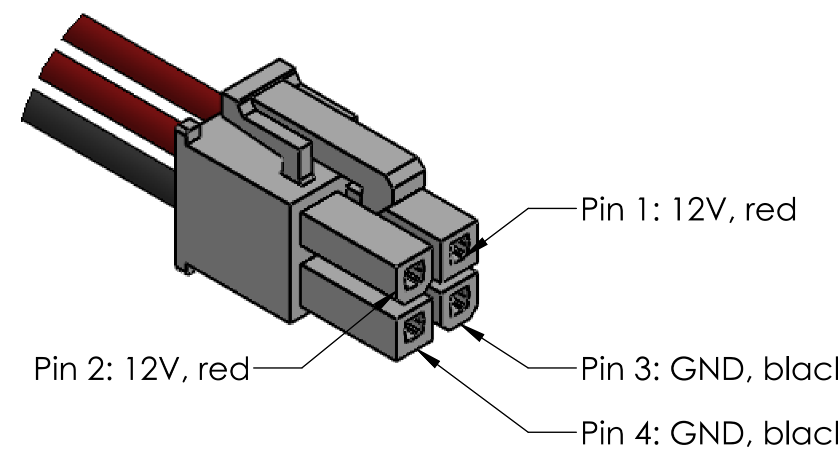
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	4	Contact Crimp, 18-24 AWG, Tin	Molex	39-00-0038	See note 2
2	4	18 AWG wire, stranded	Any	Any	Pin 1: 12V, red Pin 2: 12V, red Pin 3: GND, black Pin 4: GND, black
1	1	4-position rectangular housing, 2x2	Molex	39-01-2040	

	NAME	DATE
DRAWN	Taylor Greenwood	4/13/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

PART #: MRP-ELE-0020 R1

SIZE: B

PART NAME: Kill Switch 12V wire

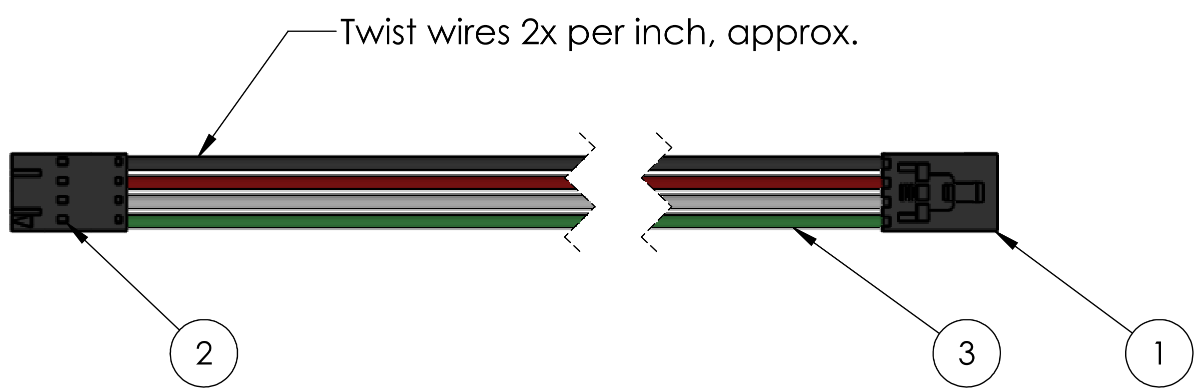
REV: R1

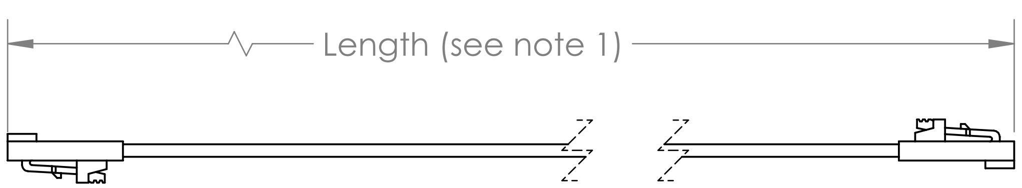
SCALE: 1:1

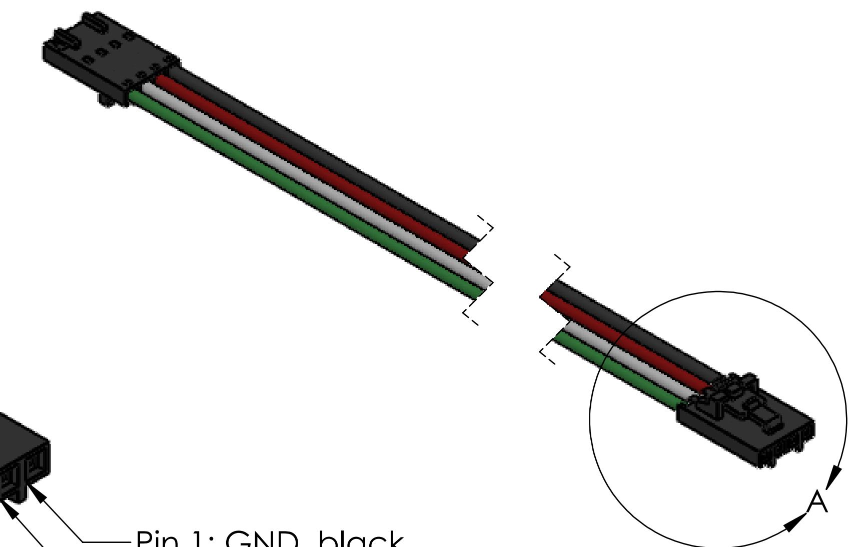
SHEET 1 OF 1

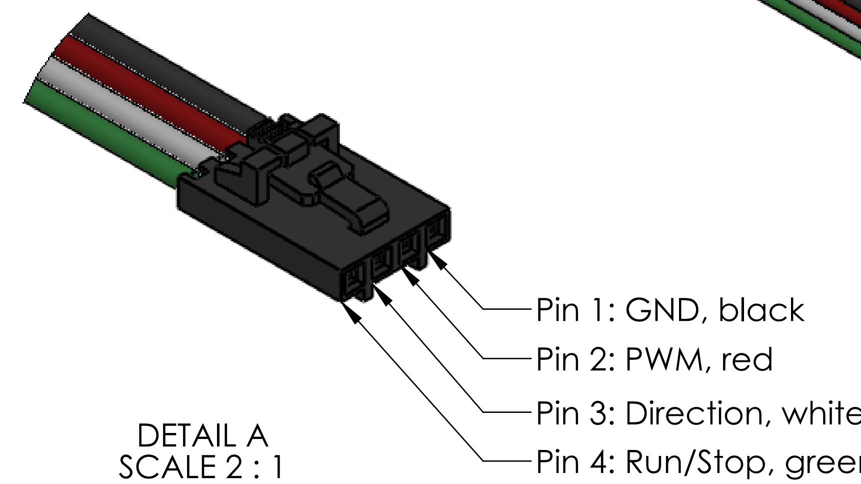
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	4	22 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: PWM, Red Pin 3: Direction, White Pin 4: Run/Stop, Green
2	8	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	4-position rectangular housing	Molex	50-57-9404	

	NAME	DATE
DRAWN	Taylor Greenwood	4/11/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU MARS ROVER 2017

PART #: MRP-ELE-0021 R1

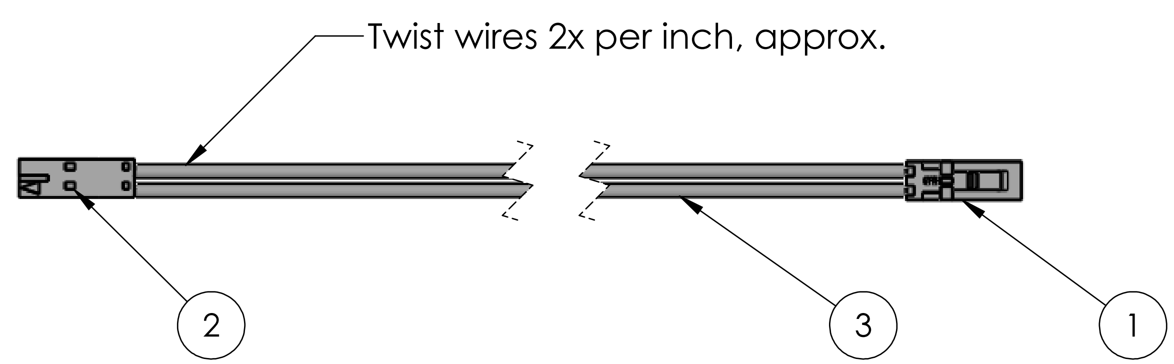
SIZE B | PART NAME: Drive Wheel wires | REV R1

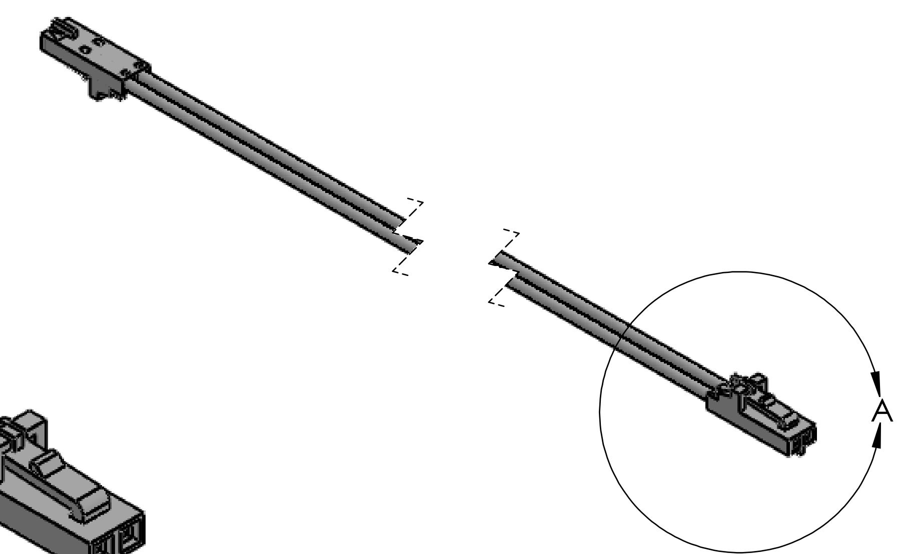
SCALE: 1:1 | SHEET 1 OF 1

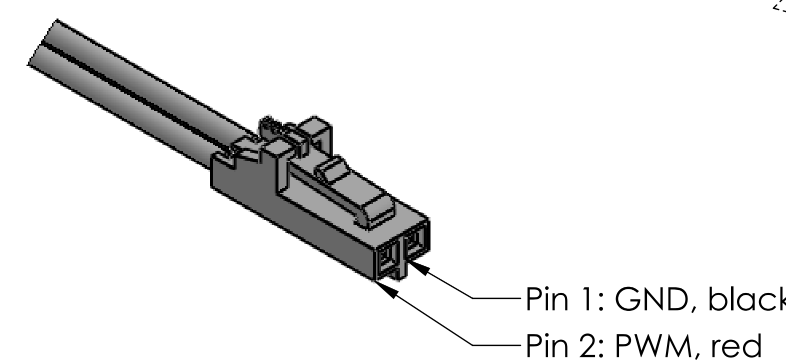
REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED

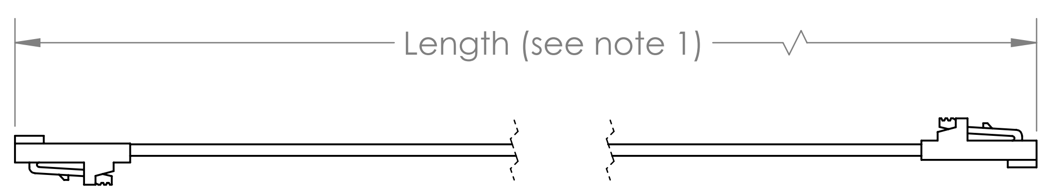
NOTES:
1. Length depends on part number call-out. (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.







DETAIL A
SCALE 2 : 1



Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	2	22 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 5V, Red
2	4	Contact Crimp 24-30 AWG Tin	Molex	16-02-0096	Crimps not shown. See note 2.
1	2	2-position rectangular housing	Molex	50-57-9402	

	NAME	DATE
DRAWN	Taylor Greenwood	4/10/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU MARS ROVER 2017

PART #: MPR-ELE-0022 R1

SIZE B

PART NAME: 5V Power Wire

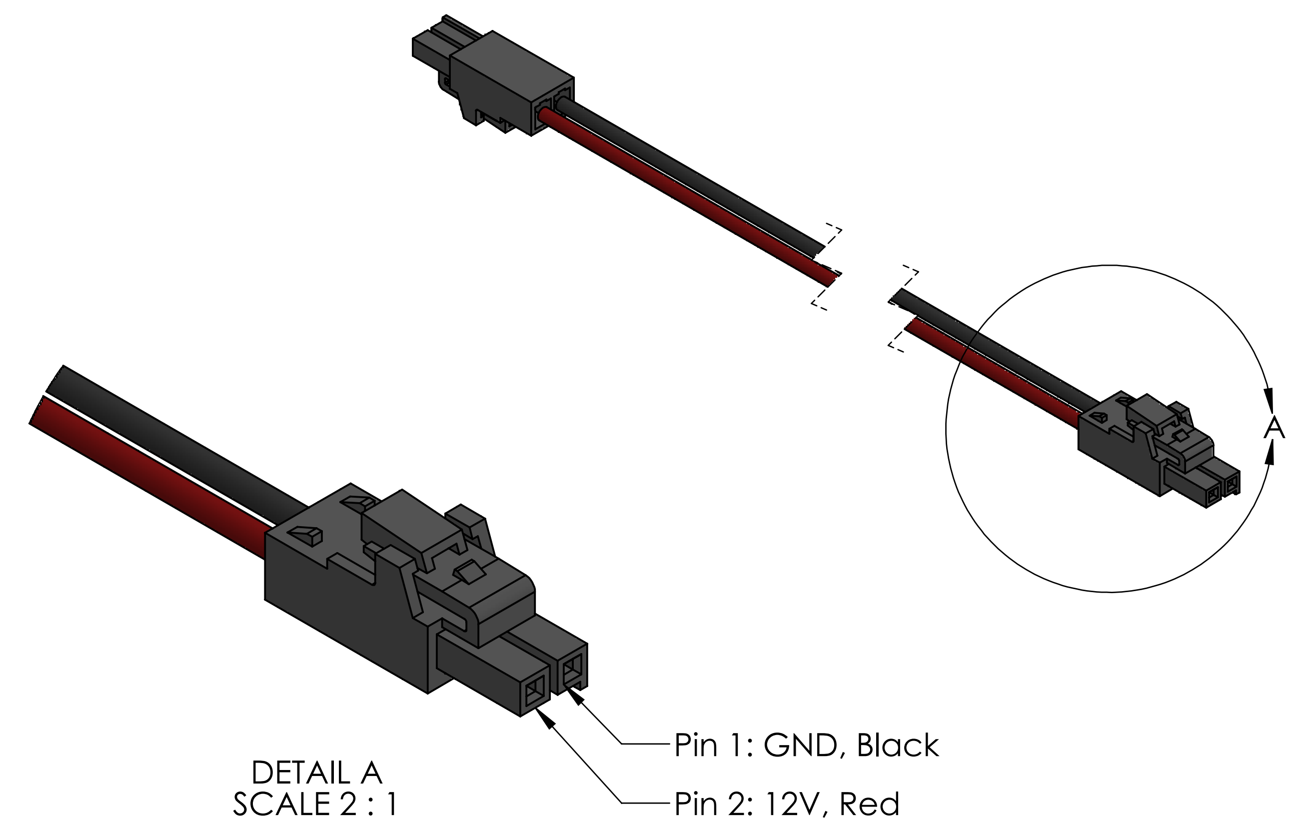
REV R1

SCALE: 1:1

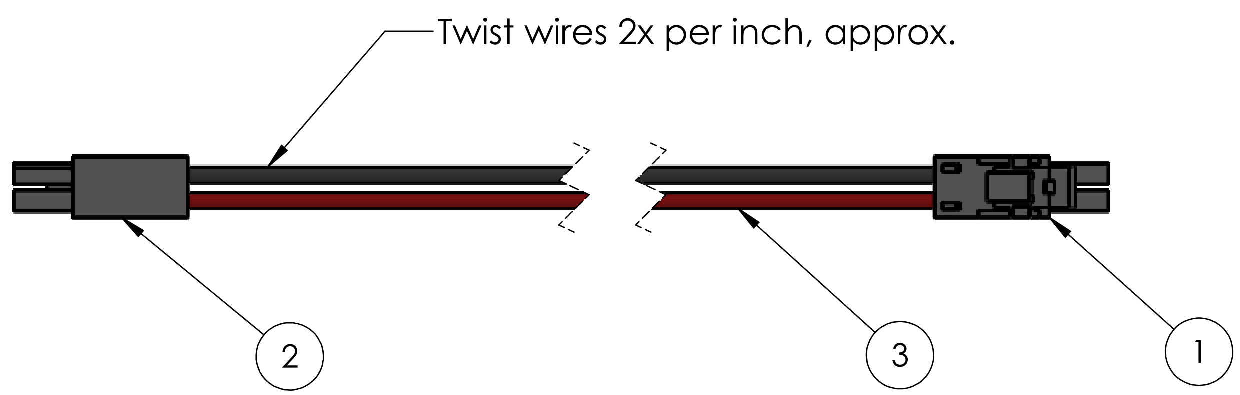
SHEET 1 OF 1

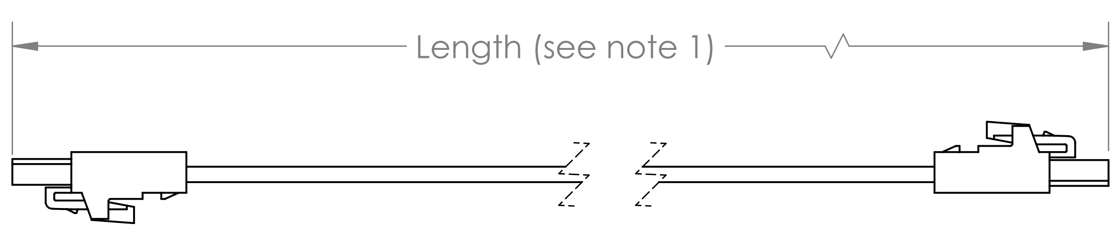
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.



DETAIL A
SCALE 2 : 1





Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	2	18 AWG cable, stranded	Any	Any	Pin 1: GND, Black Pin 2: 12V, Red
2	4	Contact Crimp 16-18 AWG Tin	Molex	172253-3023	Crimps not shown. See note 2.
1	2	2-position rectangular housing	Molex	172286-1102	

	NAME	DATE
DRAWN	Taylor Greenwood	4/11/2017
CHECKED	Jameson Marriott	4/17/2017
ENG APPR.	Jameson Marriott	4/17/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU
MARS ROVER
2017

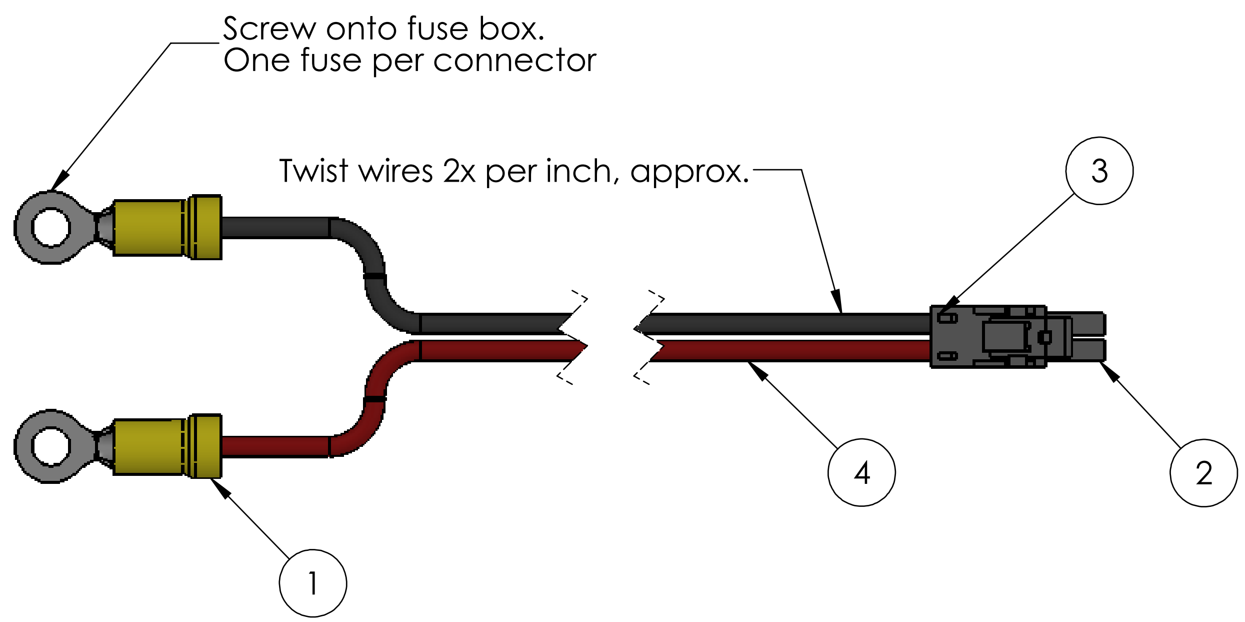
PART #: MPR-ELE-0023 R1

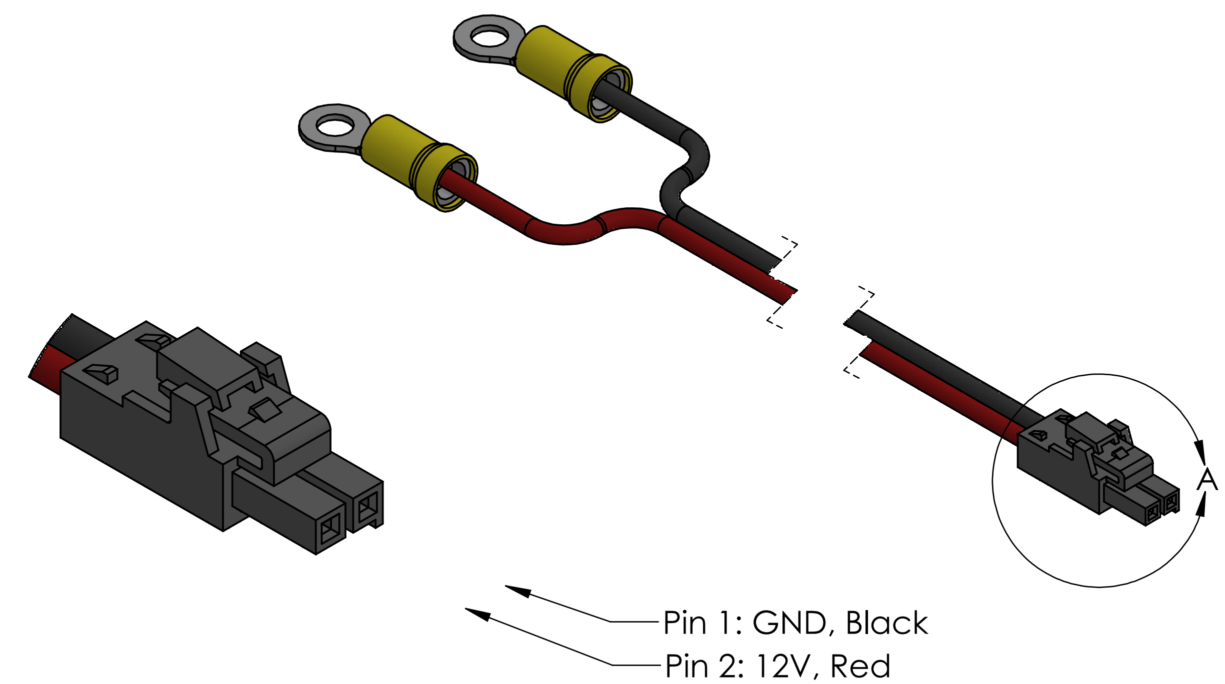
SIZE **B** | PART NAME: 12V Power wire | REV R1

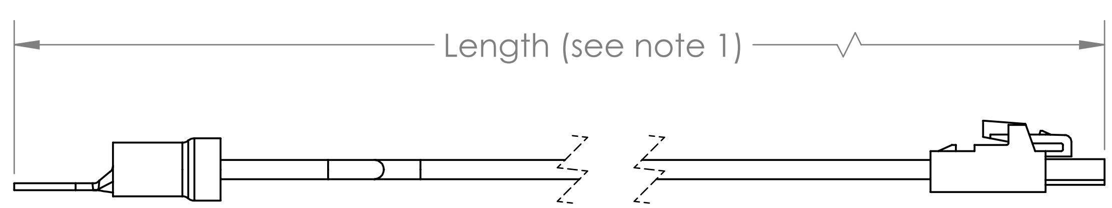
SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Ensure crimps are attached using proper crimping procedures.







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	18 AWG cable, stranded	Any	Any	24 V
3	2	Contact Crimp 16-18 AWG Tin	Molex	172253-3023	Crimps not shown. See note 2.
2	1	2-position rectangular housing	Molex	172286-1102	
1	1	Ring style quick-connect solderless connector	Any	Any	Solder onto wire

	NAME	DATE
DRAWN	Taylor Greenwood	4/19/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH
N/A

BYU
MARS ROVER
2017

PART #:
MPR-ELE-0024 R1

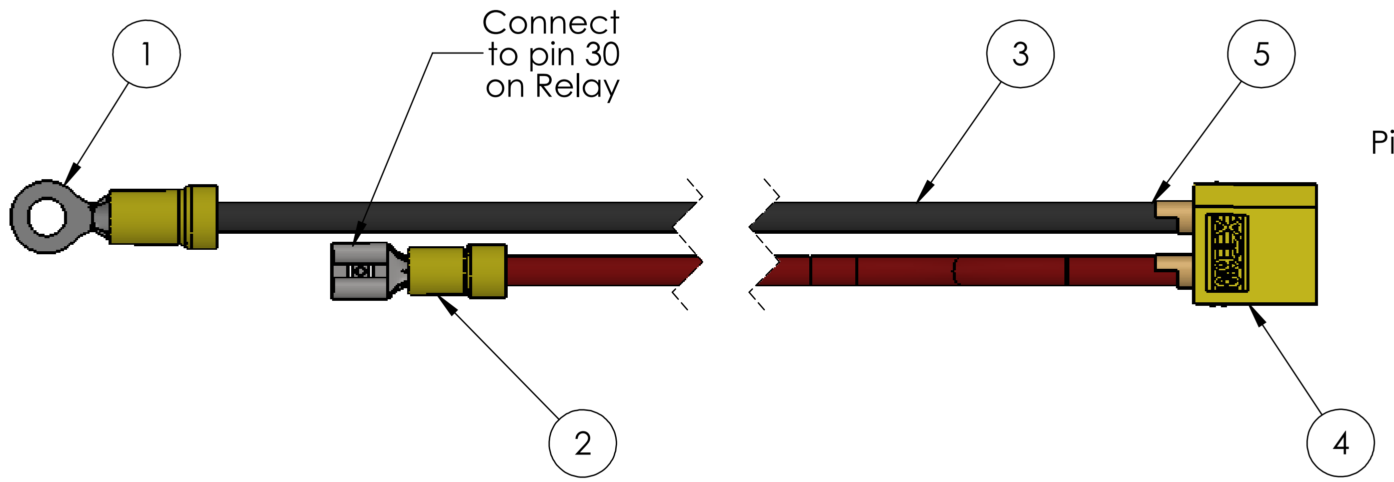
SIZE B | PART NAME: 24V Power wire | REV R1

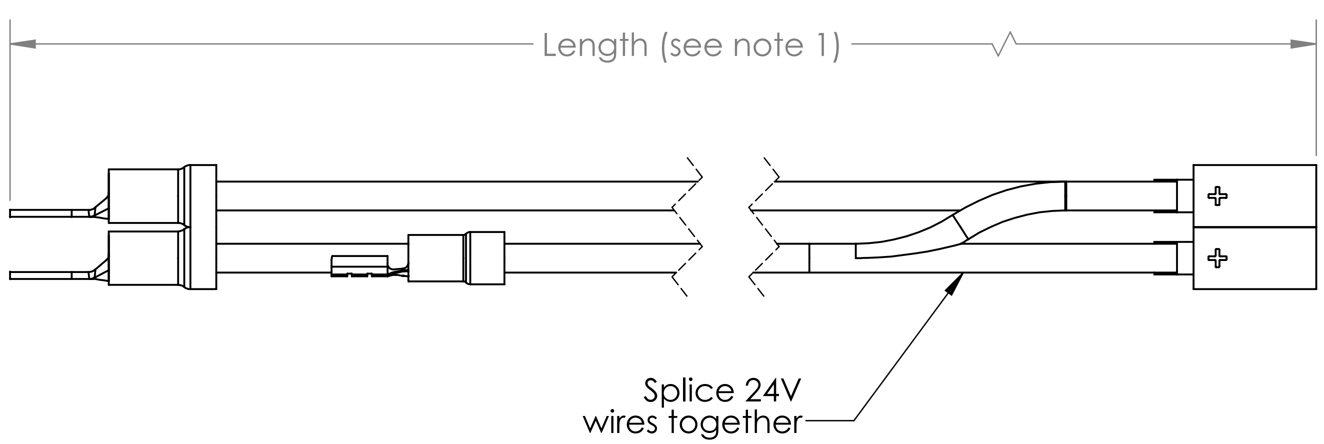
SCALE: 1:1 | SHEET 1 OF 1

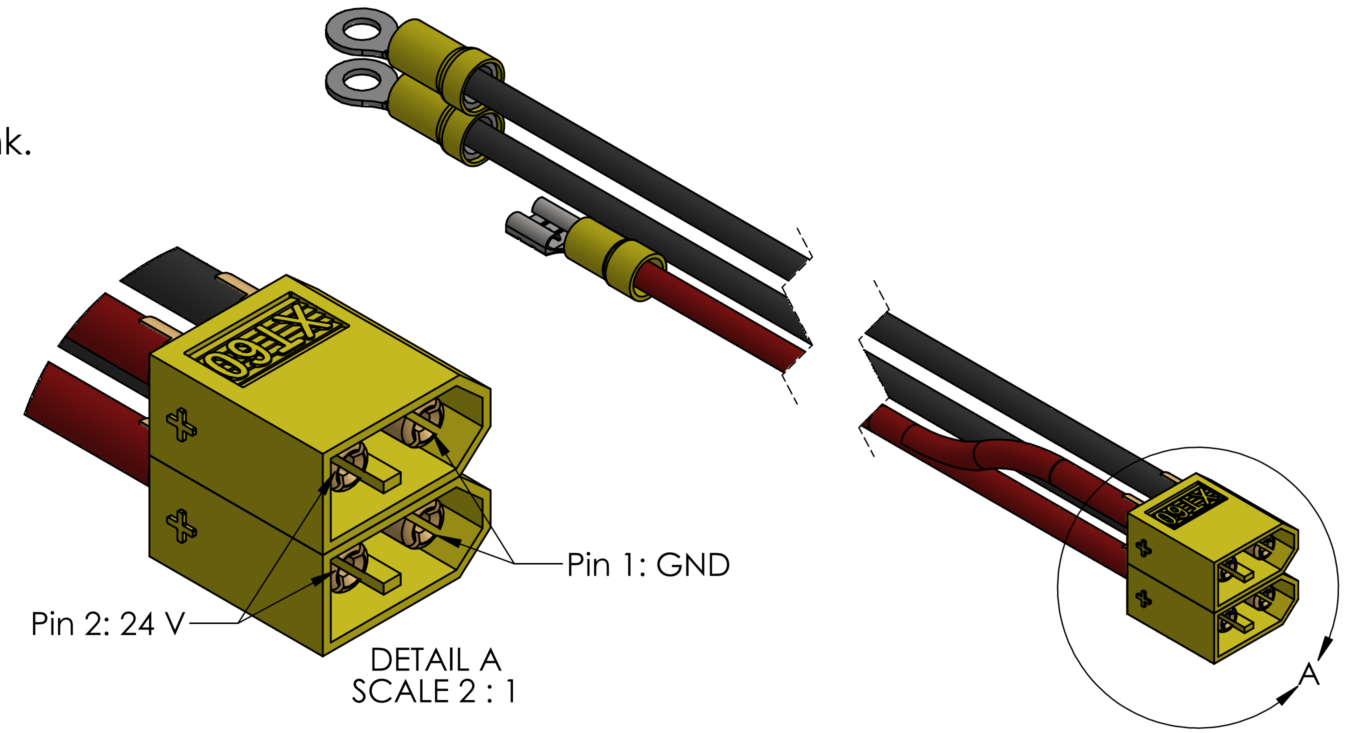
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:

1. Length depends on part number call-out.
   (E.g. MRP-ELE-0001-XX has length XX inches)
2. Solder wires securely into XT60 connector and cover with heat shrink.







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
5	4	Heat shrink, 0.25" diameter, 1" length approx.	Any	Any	Not shown. See note 2
4	2	XT60 Connector, male	Any	Any	
3	1	18 AWG cable, stranded	Any	Any	24 V
2	1	Spade-style quick-connect solderless connector	Any	Any	Solder on wire
1	2	Ring style quick-connect solderless connector	Any	Any	Solder onto wire

	NAME	DATE
DRAWN	Taylor Greenwood	4/19/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

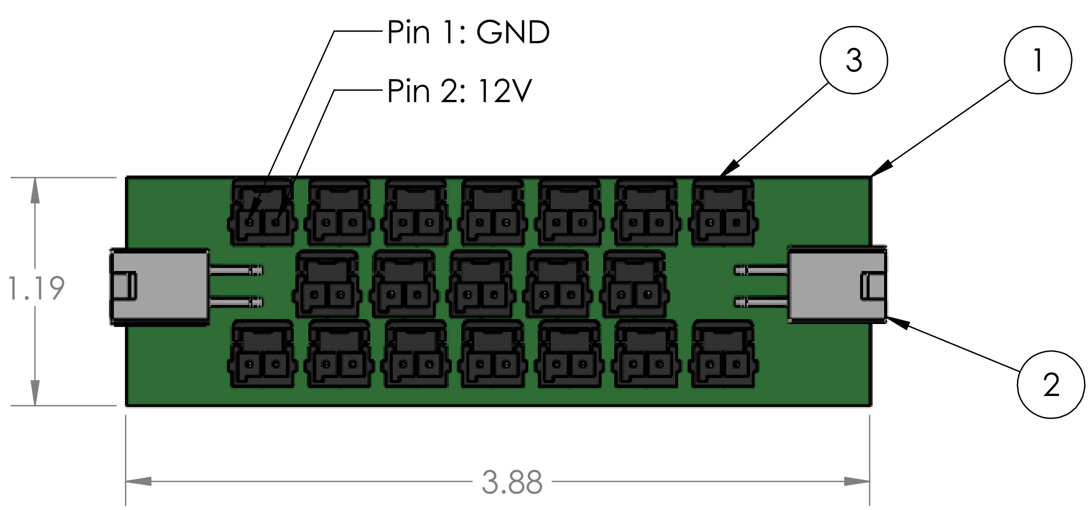
PART #: MPR-ELE-0025 R1

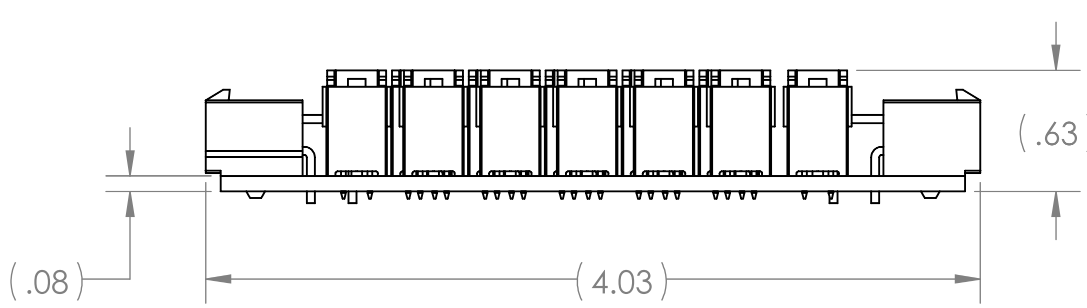
SIZE: B | PART NAME: Relay Power wire | REV: R1

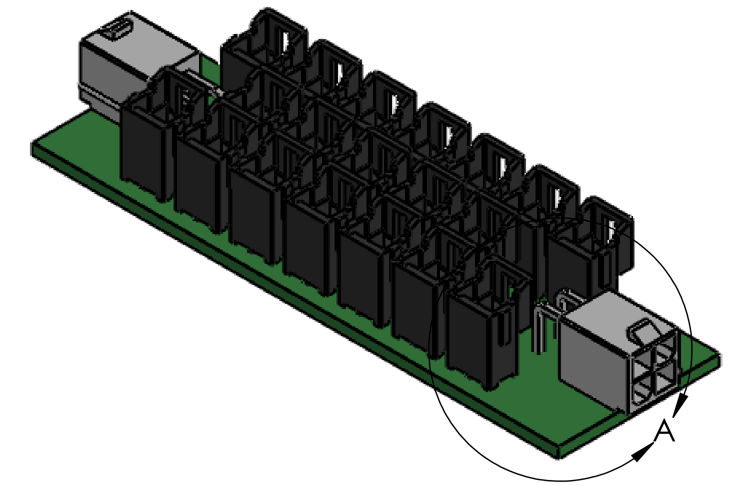
SCALE: 1:1 | SHEET 1 OF 1

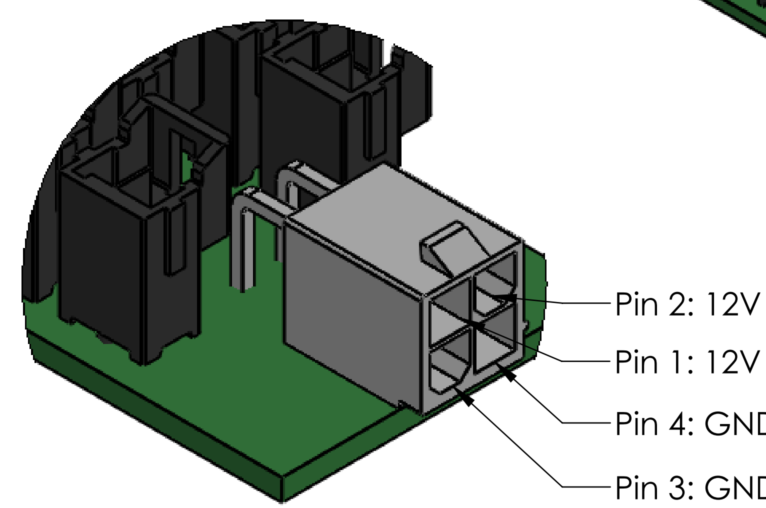
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0301.
3. Attach all components securely with solder, as appropriate.









DETAIL A
SCALE 2 : 1

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	19	Ultra-Fit 2-position Receptacle	Molex	172256-1002	
2	2	Mini-Fit 4-position 2x2 Receptacle, 90°	Molex	003930-1040	Voltage converter has the same receptacles
1	1	12V PCB	Custom	MRP-ELE-0301	See note 2.

	NAME	DATE
DRAWN	Taylor Greenwood	April 15, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU
MARS ROVER
2017

PART #: MRP-ELE-0201 R1

SIZE B | PART NAME: 12V PCBA | REV R1

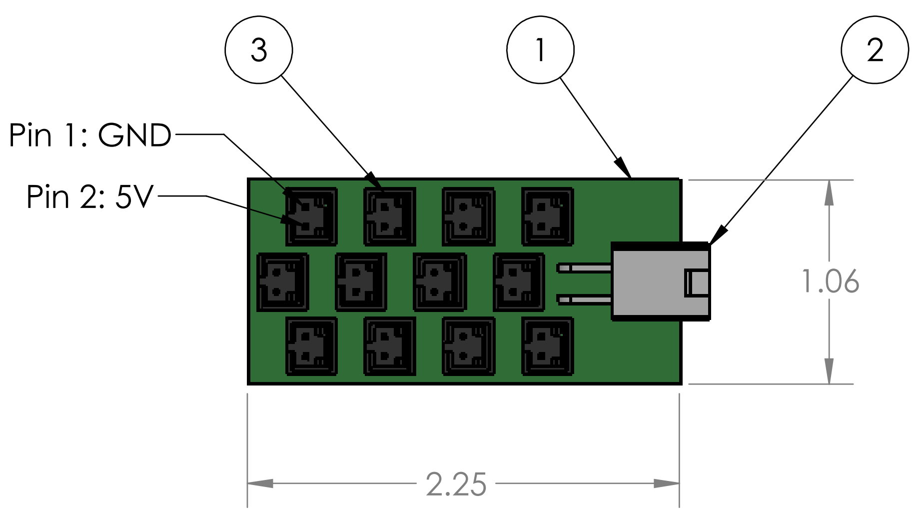
SCALE: 1:1 | SHEET 1 OF 1

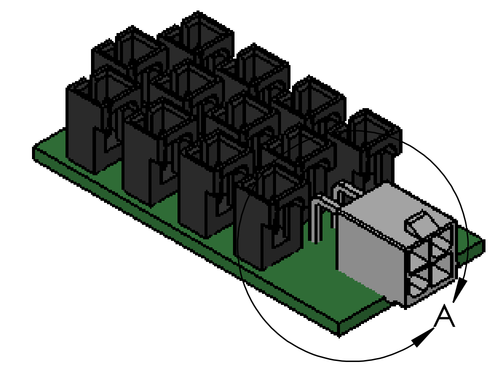
4 3 2 1

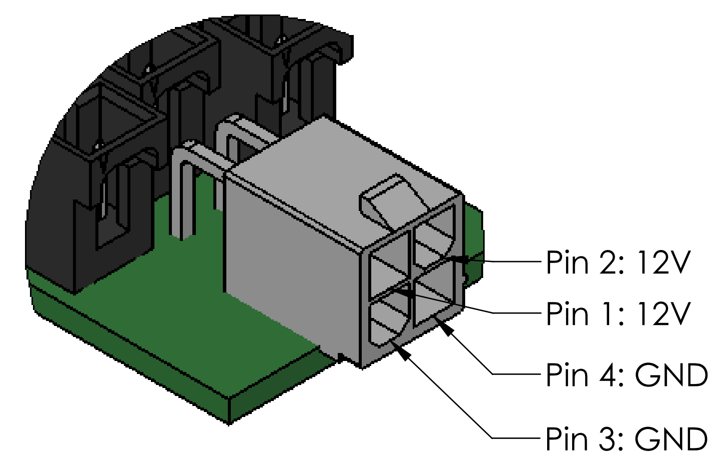
B

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

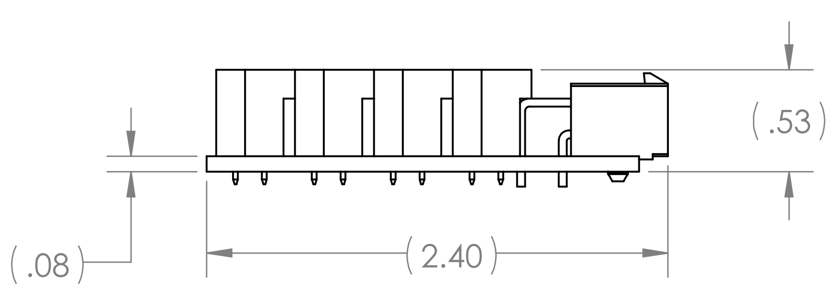
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0302.
3. Attach all components securely with solder, as appropriate.







DETAIL A
SCALE 2 : 1



A

Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	12	2-position latching receptacle	Molex	50-57-9402	
2	2	Mini-Fit 4-position 2x2 Receptacle, 90°	Molex	003930-1040	Voltage converter has the same receptacles
1	1	5V PCB	Custom	MRP-ELE-0302	See note 2.

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

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BYU
MARS ROVER
2017

PART #:
MRP-ELE-0202 R1

SIZE B

PART NAME:
5V PCBA

REV R1

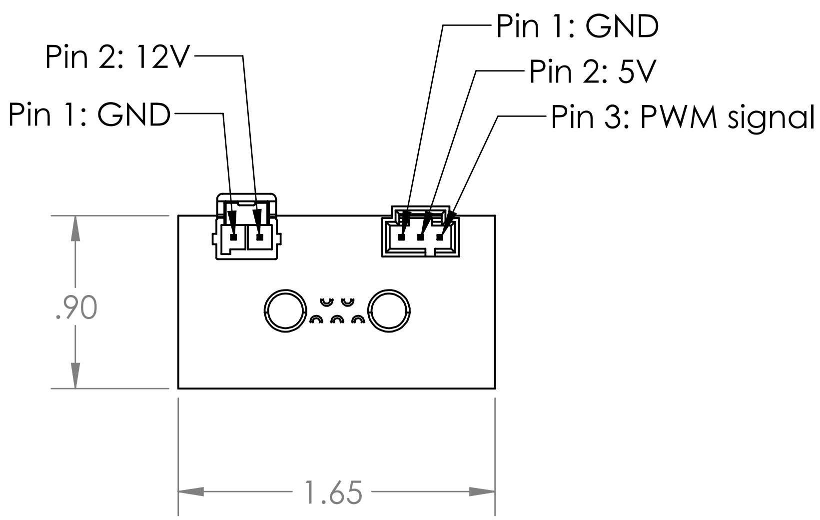
SCALE: 1:1

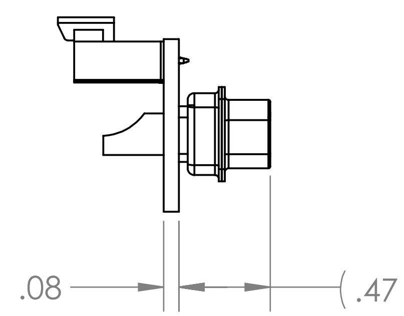
SHEET 1 OF 1

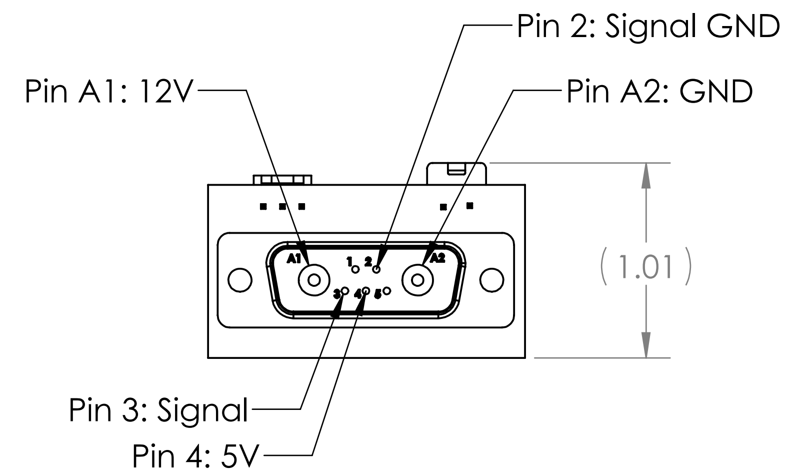
4 3 2 1

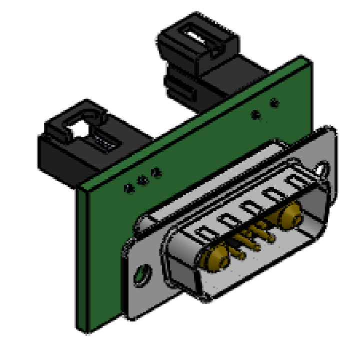
ZONE	REV.	DESCRIPTION	DATE	APPROVED
REVISIONS				

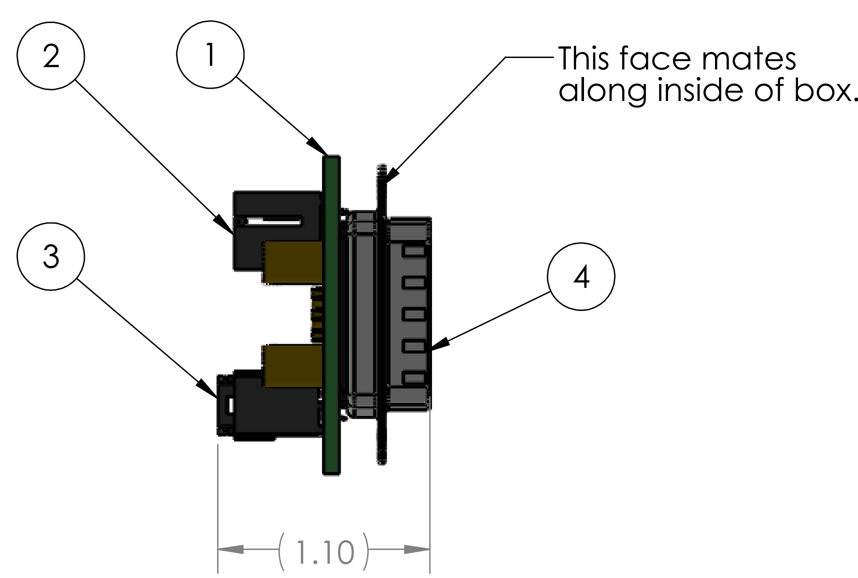
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0303.
3. Attach all components securely with solder, as appropriate.
4. Used for connections with Shoulder/Elevator, and Forearm linear actuators.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub combo connector, male 7 pin	Norcomp. Inc	680M7W2203L201	
3	1	3-pin receptacle,latching	Molex	705430002	
2	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
1	1	D-sub Combo Box Connector, small	Custom	MRP-ELE-0303	See note 2.

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

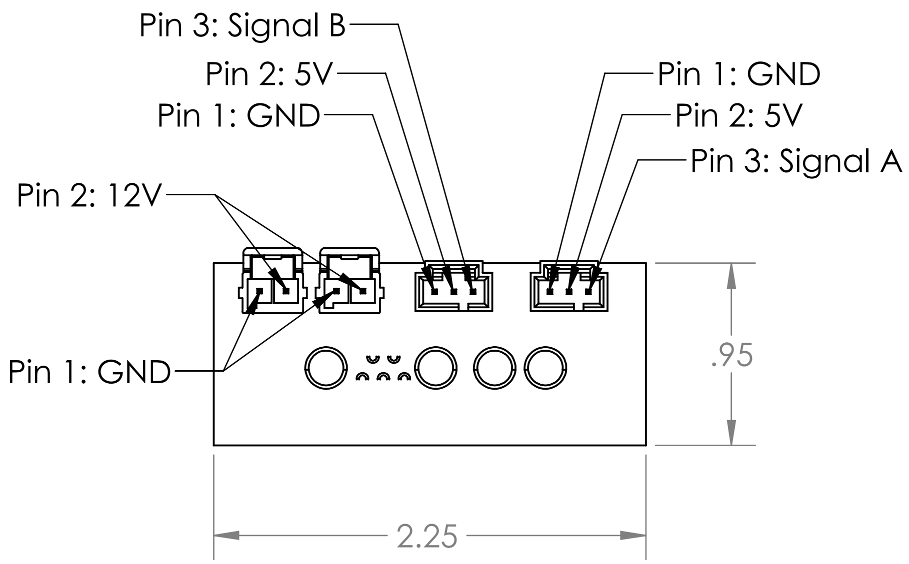
BYU
MARS ROVER
2017

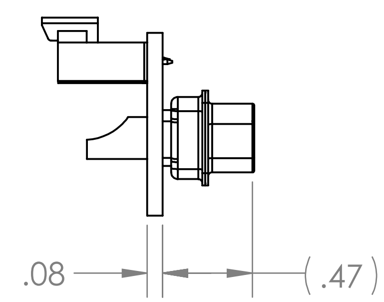
PART #: MRP-ELE-0203 R1

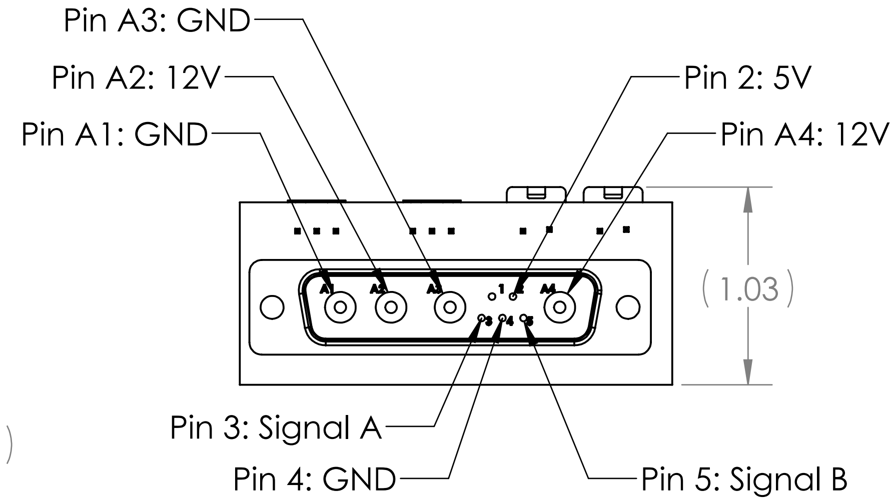
SIZE: B
PART NAME: Pololu PCBA, small
REV: R1

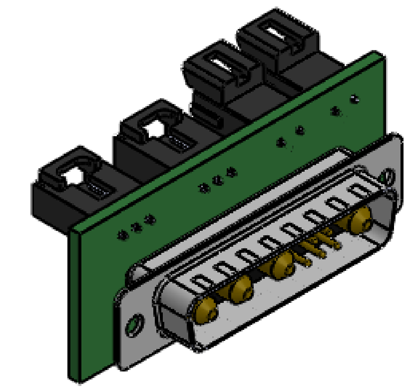
SCALE: 1:1
SHEET 1 OF 1

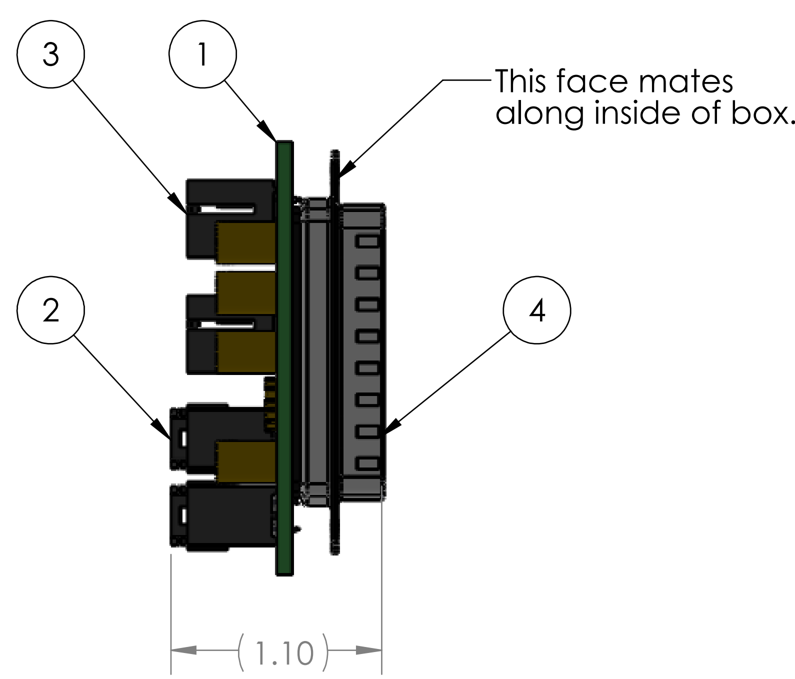
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0304.
3. Attach all components securely with solder, as appropriate.
4. Used for connections with Elbow/Drill Plunge, and Plate shifter linear actuators.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub combo connector, male 9 pin	Norcomp. Inc	680M9W4203L201	
3	2	3-pin receptacle,latching	Molex	705430002	
2	2	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
1	1	D-sub Combo Box Connector, large	Custom	MRP-ELE-0304	See note 2.

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH
N/A

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

PART #: MRP-ELE-0204 R1

SIZE B

PART NAME: Pololu PCBA, large

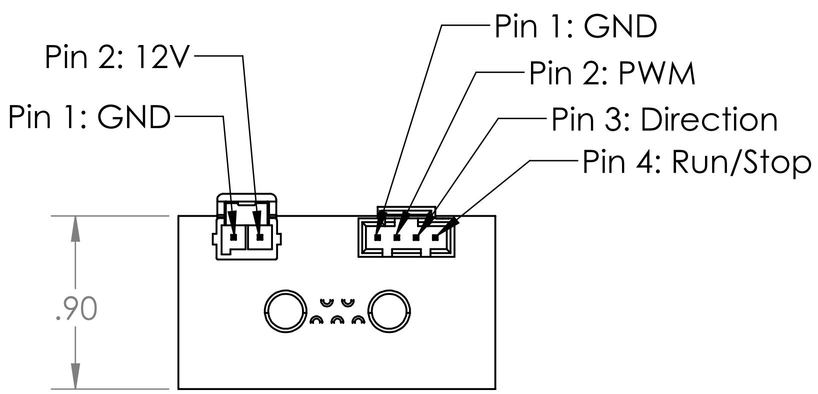
REV R1

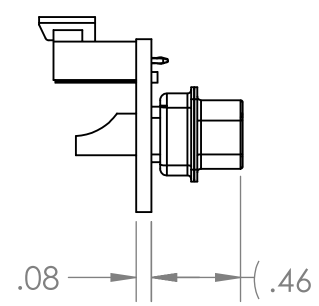
SCALE: 1:1

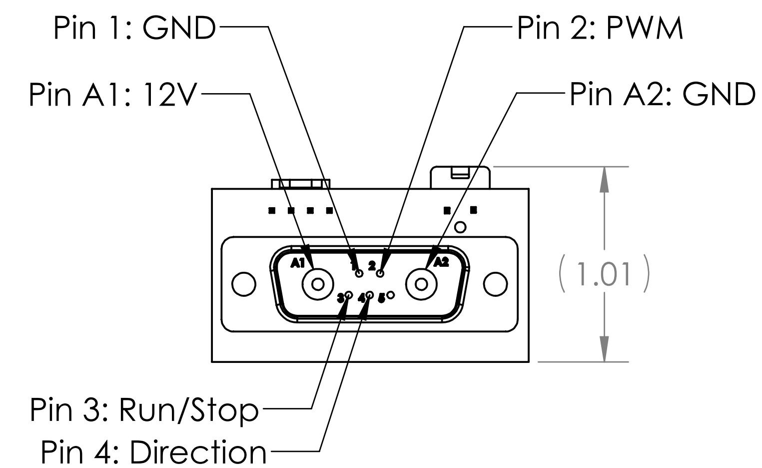
SHEET 1 OF 1

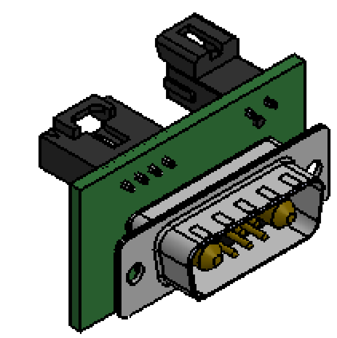
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

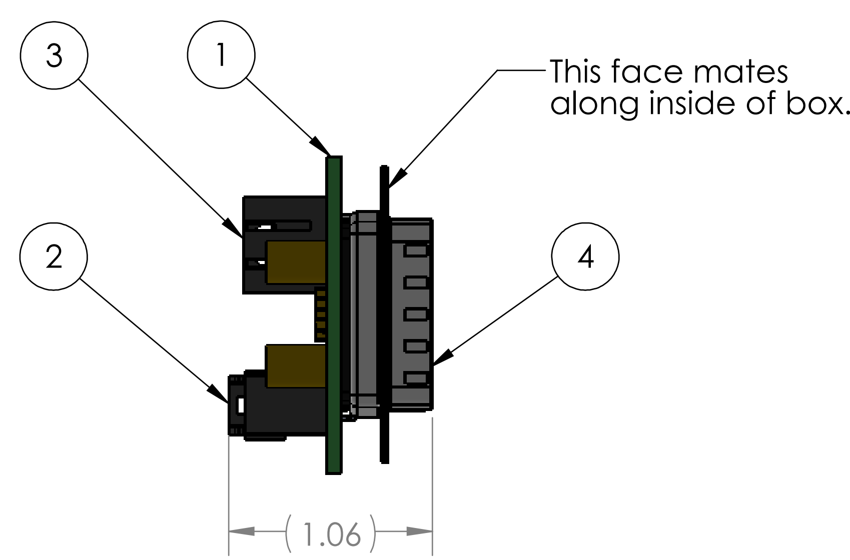
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0303.
3. Attach all components securely with solder, as appropriate.
4. Used for connections with Shoulder/Elevator, and Forearm linear actuators.











4	1	D-sub combo connector, male 7 pin	Norcomp. Inc	680M7W2203L201	
3	1	4-pin receptacle,latching	Molex	705430003	
2	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
1	1	D-sub Combo Box Connector, small	Custom	MRP-ELE-0303	See note 2.
Item	Qty	Description	Manufacturer	Manuf. P/N	Comment

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

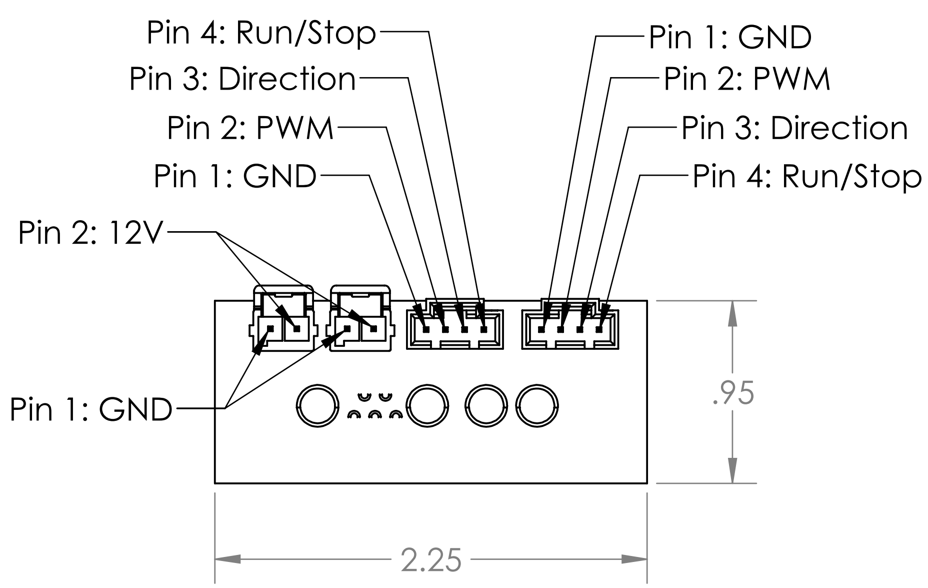
PART #: MRP-ELE-0205 R1

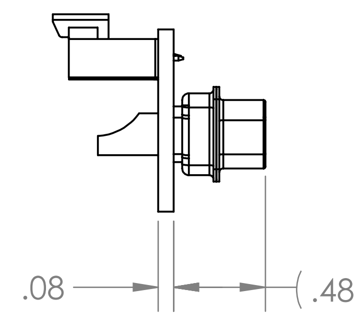
SIZE B | PART NAME: Drive Wheel PCBA, small | REV R1

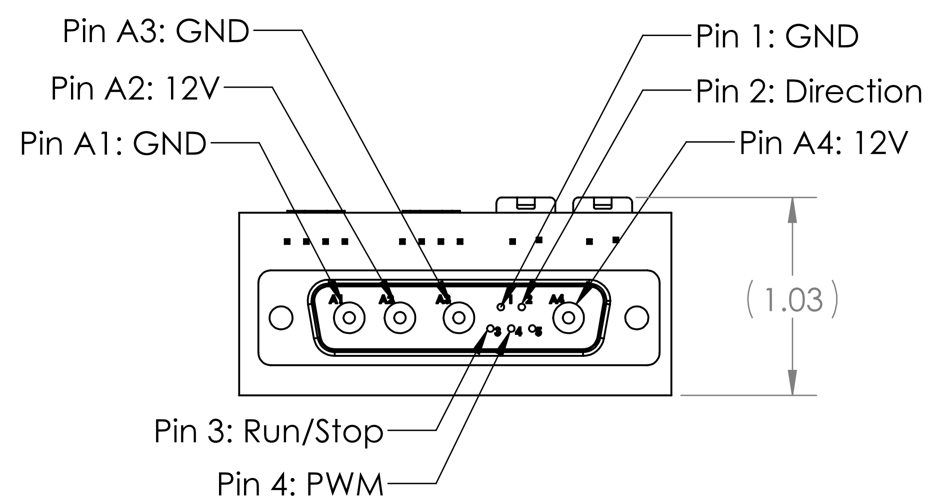
SCALE: 1:1 | SHEET 1 OF 1

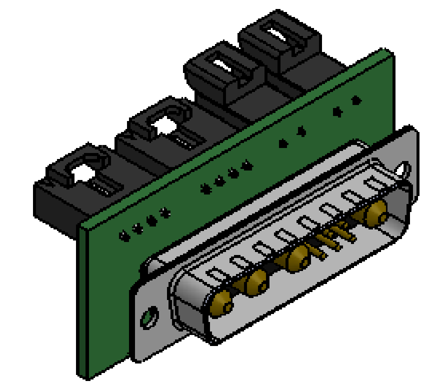
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0304.
3. Attach all components securely with solder, as appropriate.
4. Used for connections with Elbow/Drill Plunge, and Plate shifter linear actuators.

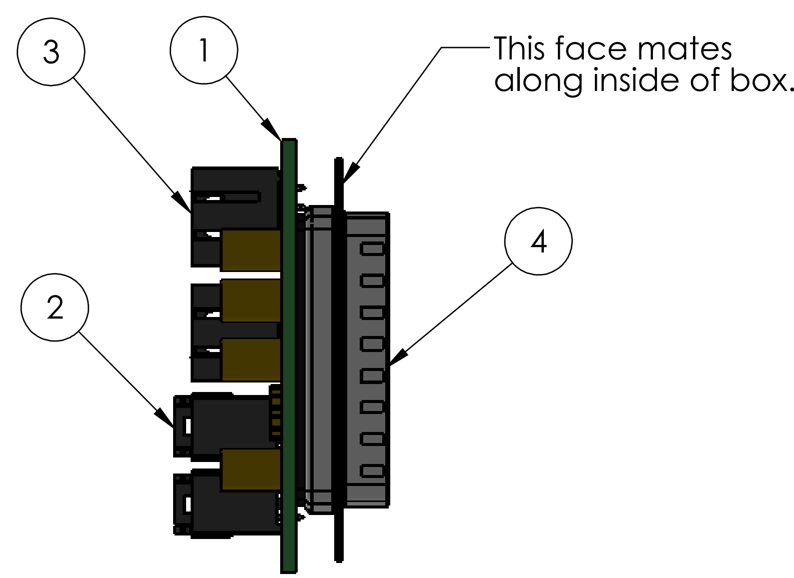
ZONE	REV.	DESCRIPTION	DATE	APPROVED











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub combo connector, male 9 pin	Norcomp. Inc	680M9W4203L201	
3	2	4-pin receptacle,latching	Molex	705430003	
2	2	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
1	1	D-sub Combo Box Connector, large	Custom	MRP-ELE-0304	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ELE-0206 R1

SIZE B

PART NAME: Drive Wheel PCBA, large

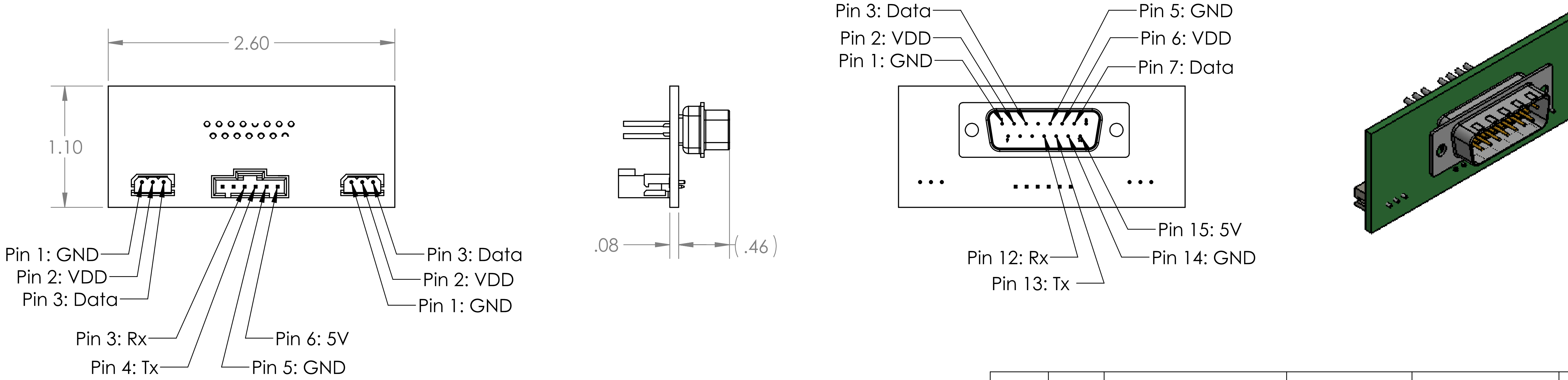
REV R1

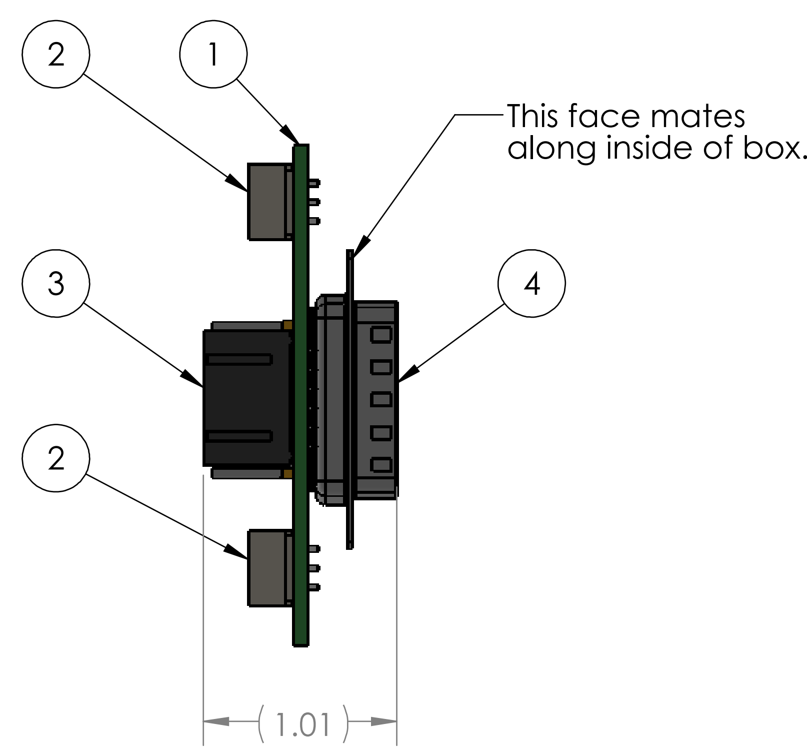
SCALE: 1:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic, and Gerber files as MRP-ELE-0307.
3. Secure all components with solder, as appropriate.





Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub connector, 15-pin	Any	Any	
3	1	6-pin receptacle,latching	Molex	705430005	
2	2	3-position receptacle	Molex	22-03-5035	Same connector as Dynamixels.
1	1	Dynamixel PCB	Custom	MRP-ELE-0307	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

DO NOT SCALE DRAWING

BYU MARS ROVER 2017

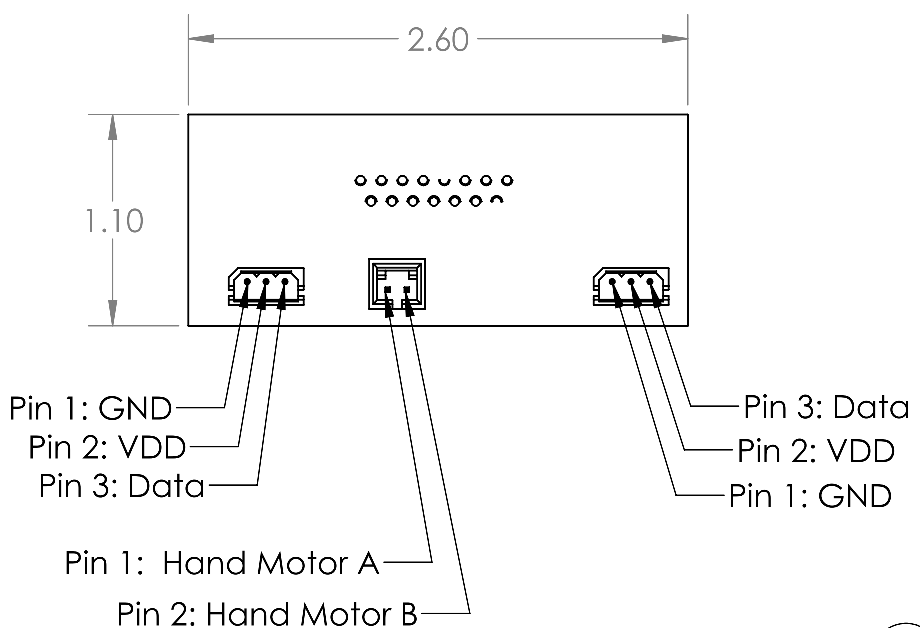
PART #: MRP-ELE-0207 R2

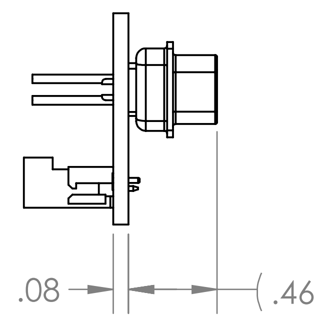
SIZE B | PART NAME: Gimbal & GPS PCBA | REV R2

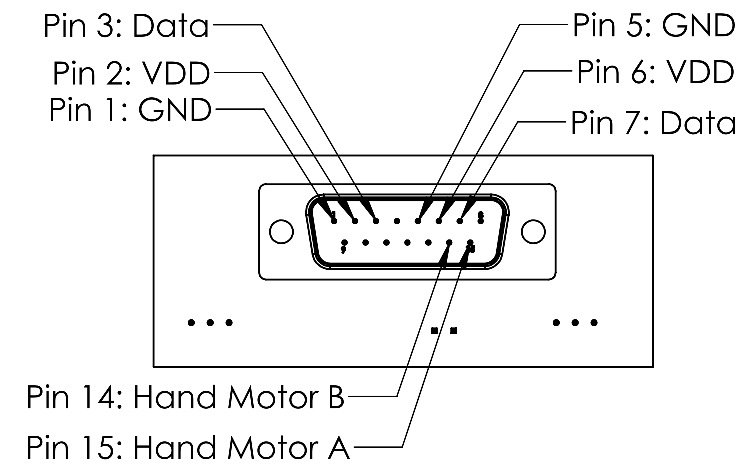
SCALE: 1:1 | SHEET 1 OF 1

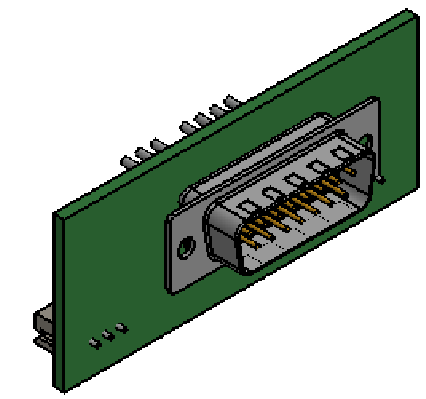
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

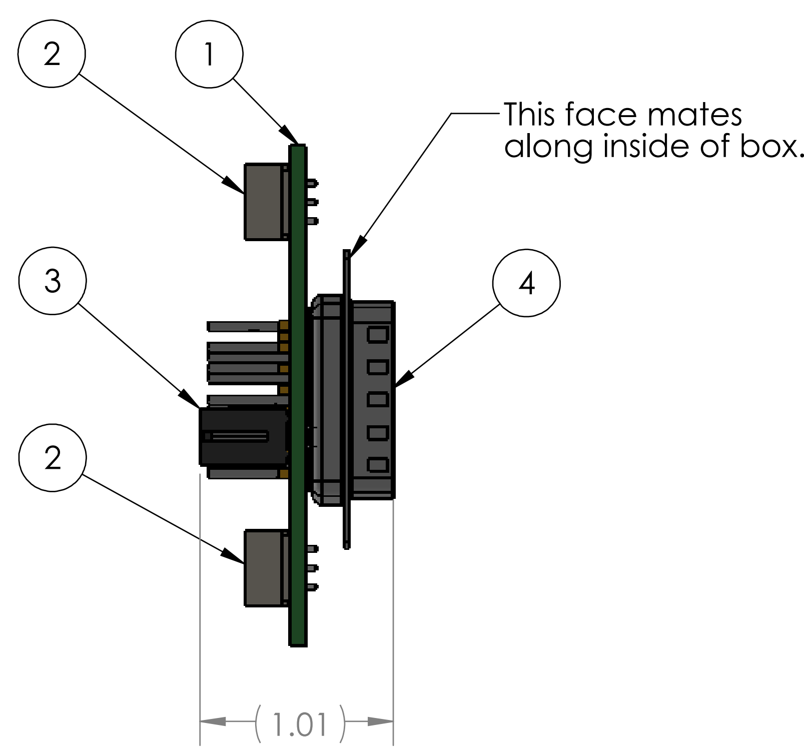
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic, and Gerber files as MRP-ELE-0307.
3. Attach all components securely with solder, as appropriate.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub connector, 15-pin	Any	Any	
3	1	2-pin receptacle,latching	Molex	705430001	
2	1	3-position receptacle	Molex	22-03-5035	Same connector as Dynamixels.
1	1	Dynamixel PCB	Custom	MRP-ELE-0307	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU MARS ROVER 2017

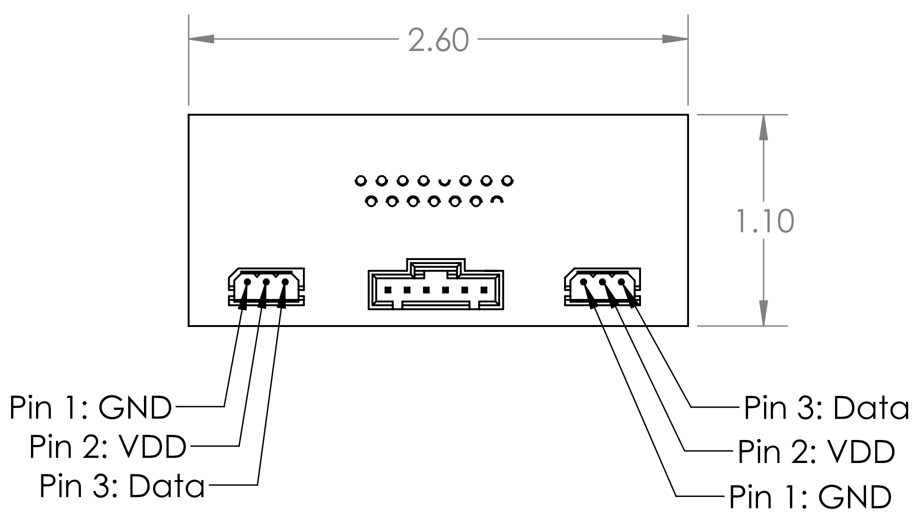
PART #: MRP-ELE-0208 R1

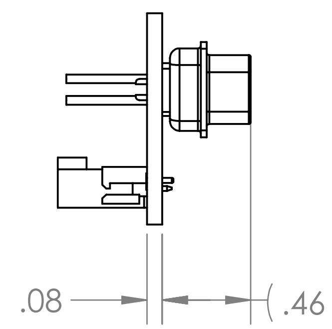
SIZE B | PART NAME: Wrist & Hand PCBA | REV R1

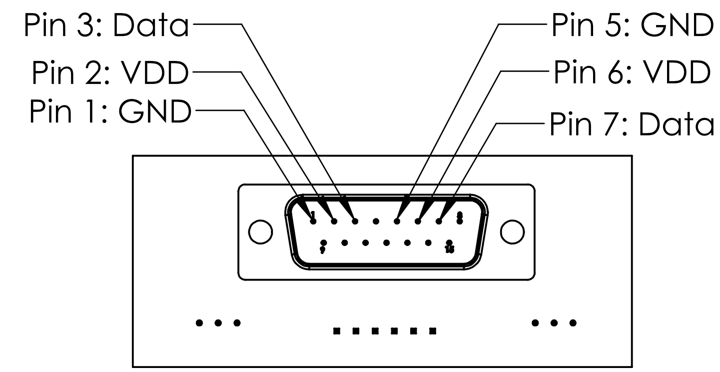
SCALE: 1:1 | SHEET 1 OF 1

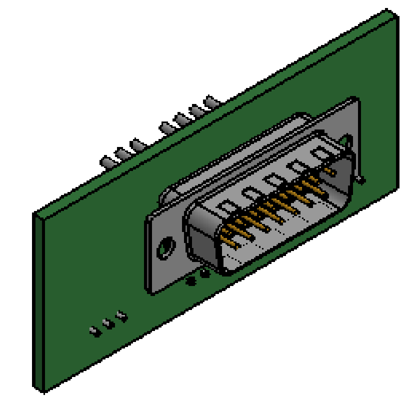
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

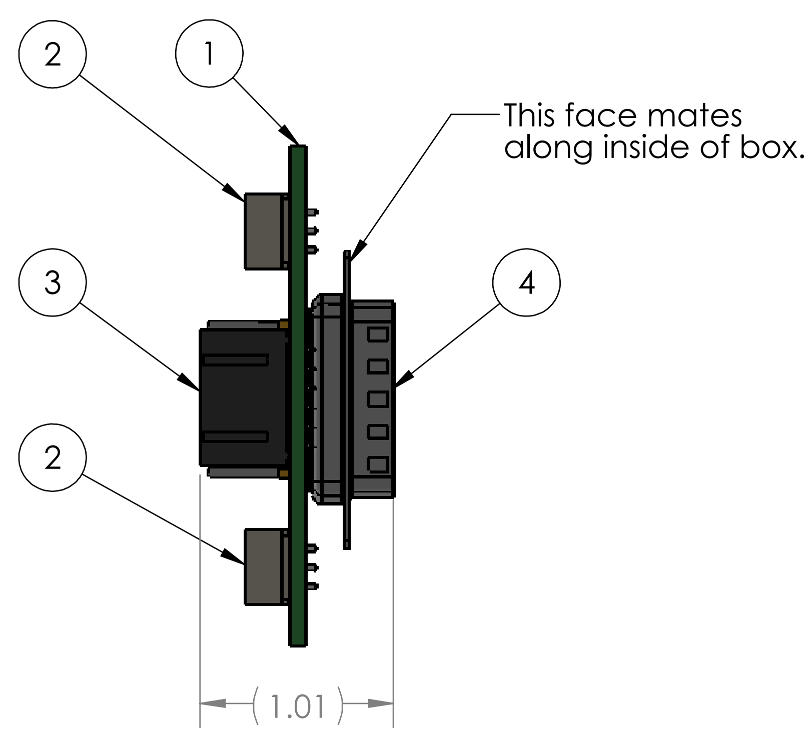
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic, and Gerber files as MRP-ELE-0307.
3. Attach all components securely with solder, as appropriate.
4. Lidar signal comes via USB. Do not use item 3.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub connector, 15-pin	Any	Any	
3	0	6-pin receptacle,latching	Molex	705430005	Not populated. See note 4.
2	2	3-position receptacle	Molex	22-03-5035	Same connector as Dynamixels.
1	1	Dynamixel PCB	Custom	MRP-ELE-0307	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU
MARS ROVER
2017

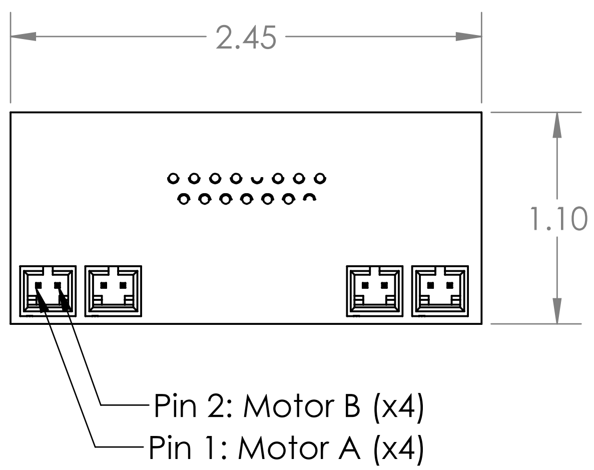
PART #: MRP-ELE-0207 R2

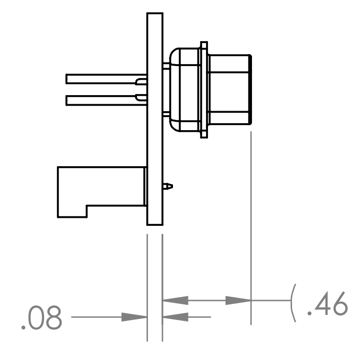
SIZE B | PART NAME: Lidar PCBA | REV R2

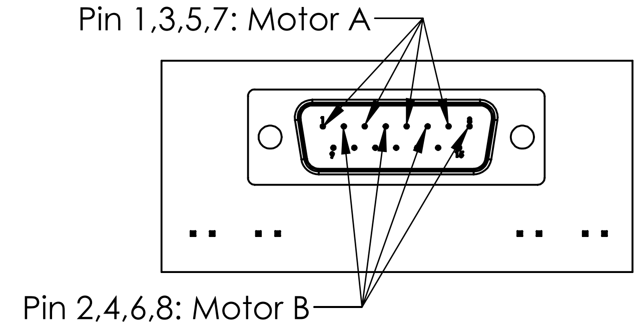
SCALE: 1:1 | SHEET 1 OF 1

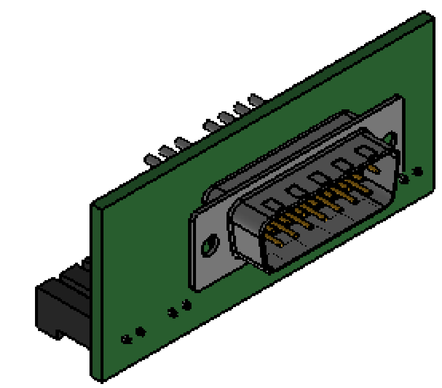
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

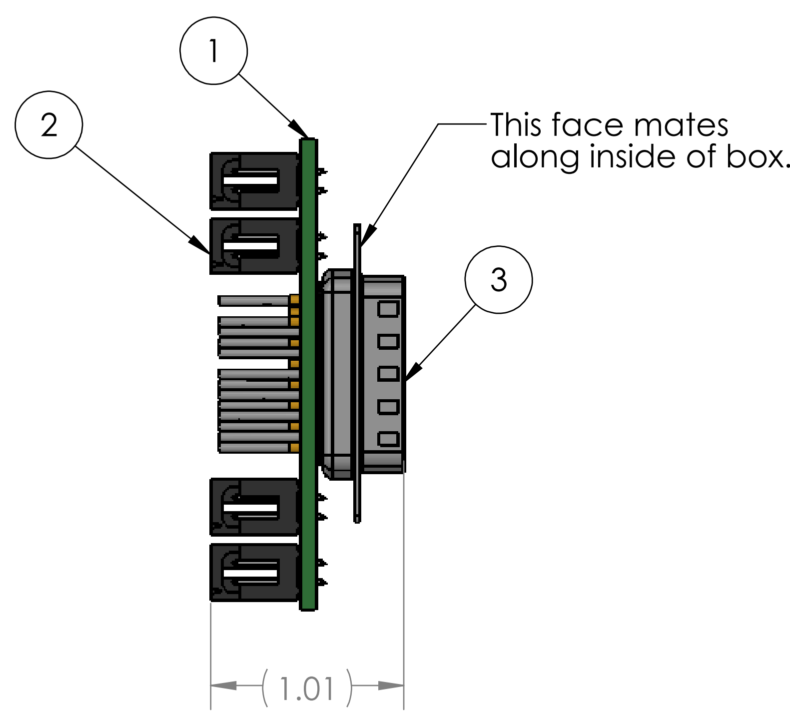
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic, and Gerber files as MRP-ELE-0309.
3. Secure all components with solder, as appropriate.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
3	1	D-sub connector, 15-pin	Any	Any	
2	4	2-pin receptacle,latching	Molex	705430001	
1	1	Chutes Box Connector	Custom	MRP-ELE-0309	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0207 R1

SIZE B

PART NAME: Chutes PCBA

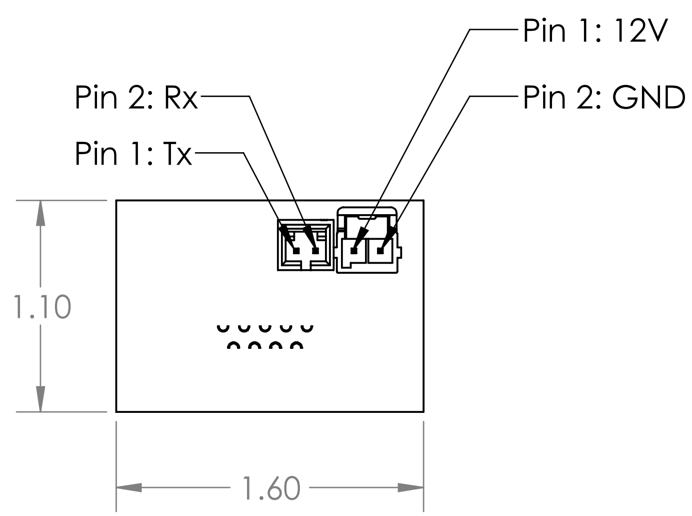
REV R1

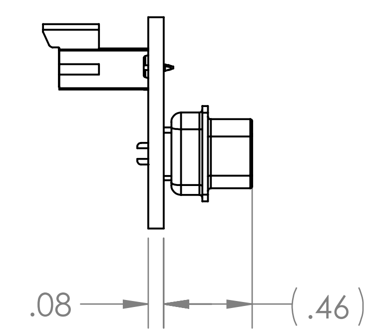
SCALE: 1:1

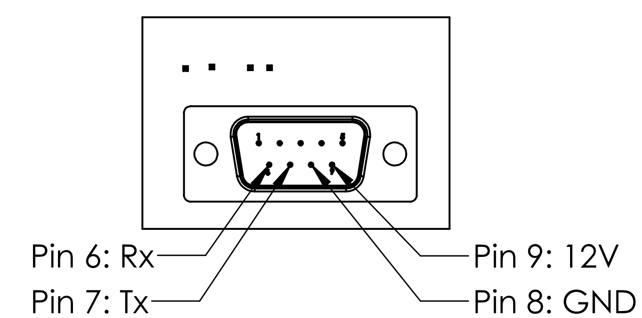
SHEET 1 OF 1

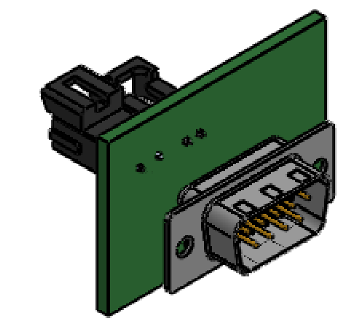
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

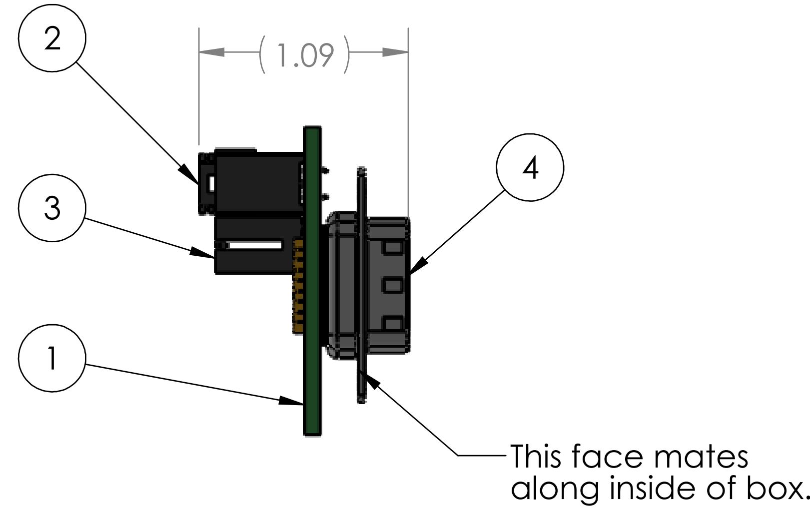
NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0308.
3. Attach all components securely with solder, as appropriate.











Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
4	1	D-sub connector, male 9 pin	Any	Any	
3	1	2-pin receptacle,latching	Molex	705430001	
2	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
1	1	Turret PCB	Custom	MRP-ELE-0308	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH N/A

BYU MARS ROVER 2017

PART #: MRP-ELE-0211 R1

SIZE B

PART NAME: Turret PCBA

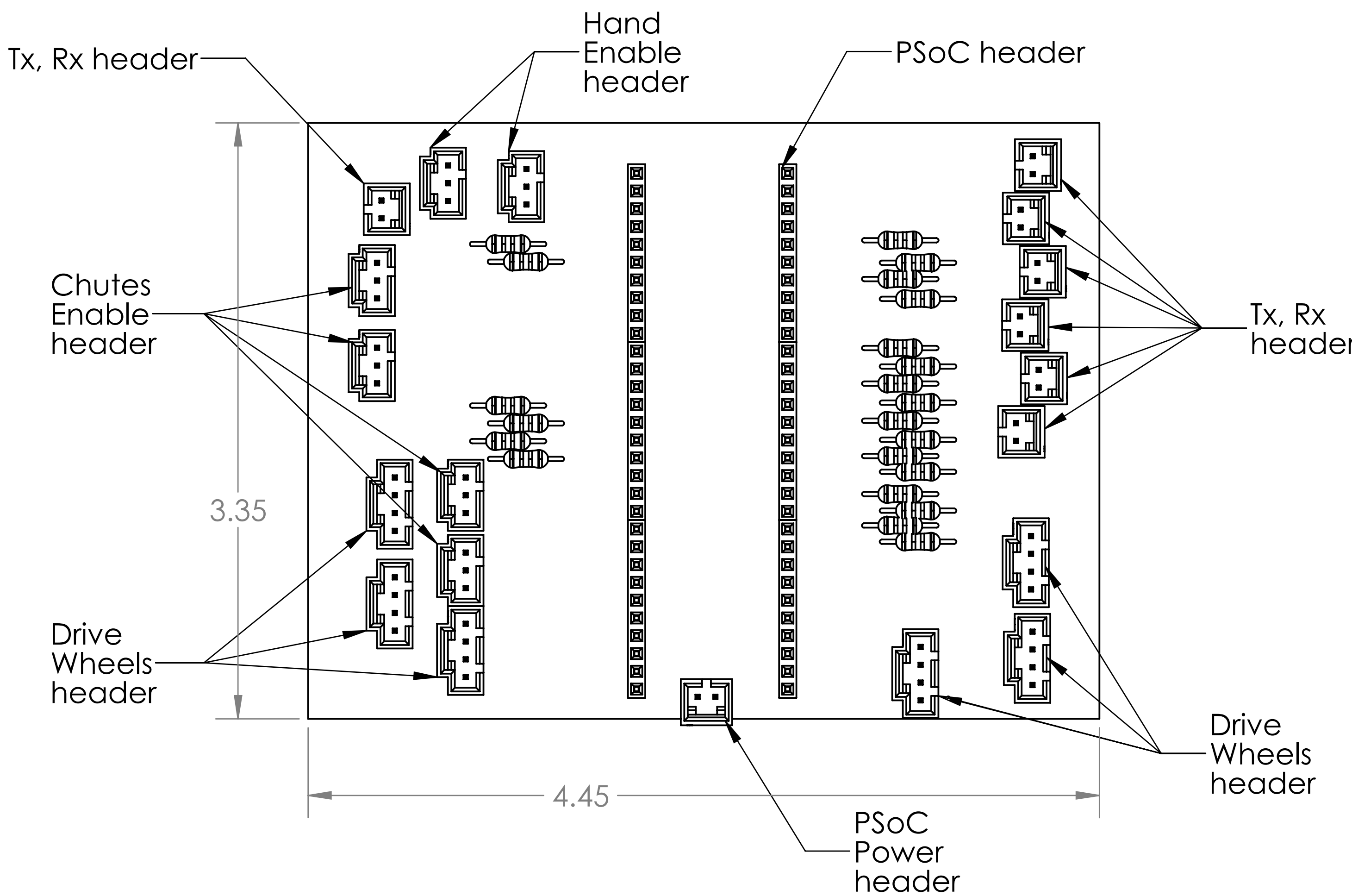
REV R1

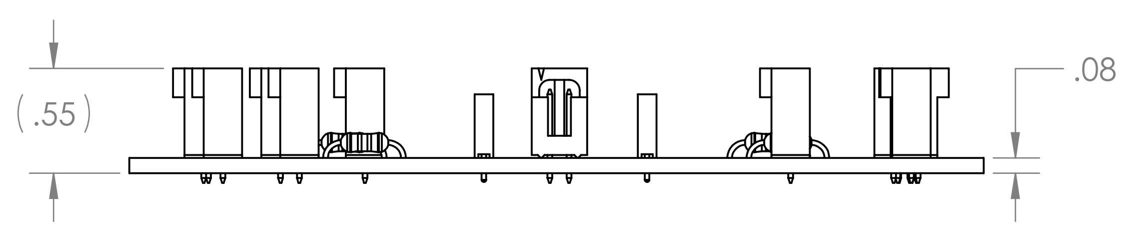
SCALE: 2:1

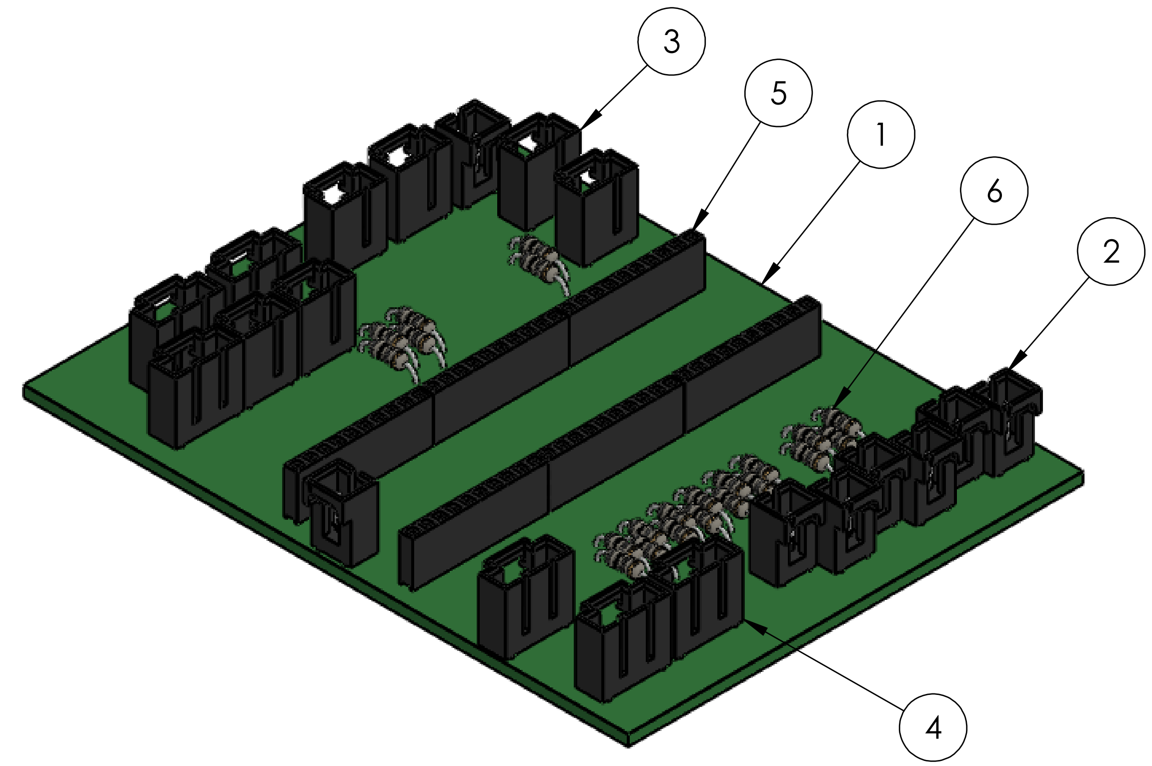
SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. See PCB silkscreen for soldering locations and pin-out details.
2. Reference PCB layout, schematic, and Gerber files as MRP-ELE-0310.
3. Secure all components with solder, as appropriate.
4. See attached sheets for more information.







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
6	22	Resistor, 100 ohms	Any	Any	
5	6	10-pin plain header, 0.1" pitch	Any	Any	PSoC headers
4	6	4-pin receptacle, latching	Molex	705460003	Drive Wheel (6)
3	6	3-pin receptacle,latching	Molex	705430002	Chutes Enable (4), Hand Enable (2)
2	8	2-pin receptacle,latching	Molex	705430001	PSoC Power (1) Tx, Rx (7)
1	1	PSoC PCB	Custom	MRP-ELE-0310	See note 2

	NAME	DATE
DRAWN	Taylor Greenwood	April 18, 2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	04/19/2017
MFG APPR.	Brian Jackson	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

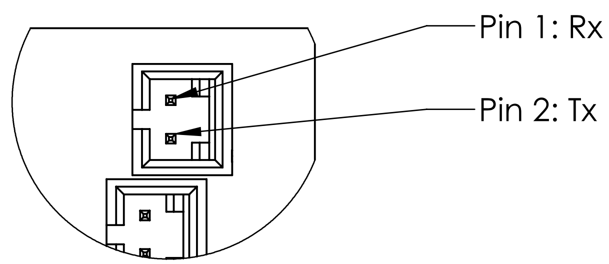
FINISH N/A

BYU MARS ROVER 2017

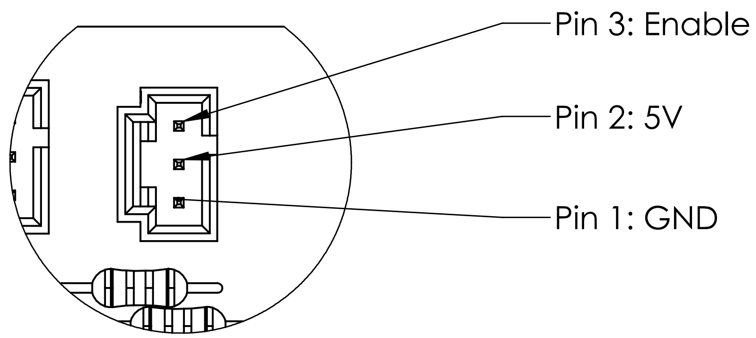
PART #: MRP-ELE-0207 R1

SIZE B | PART NAME: PSoC PCBA | REV R1

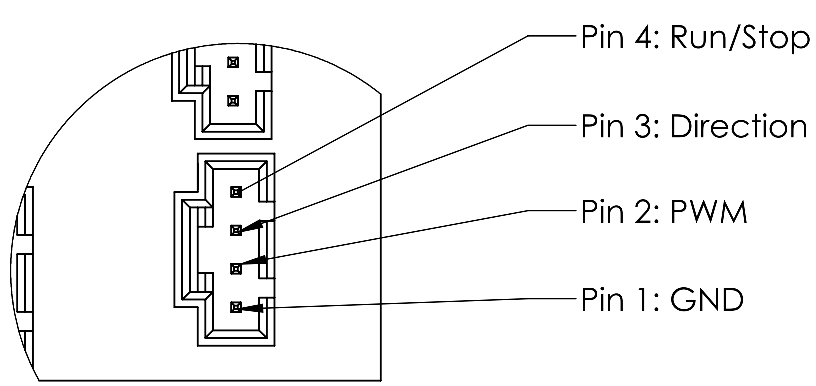
SCALE: 1:1 | SHEET 1 OF 2



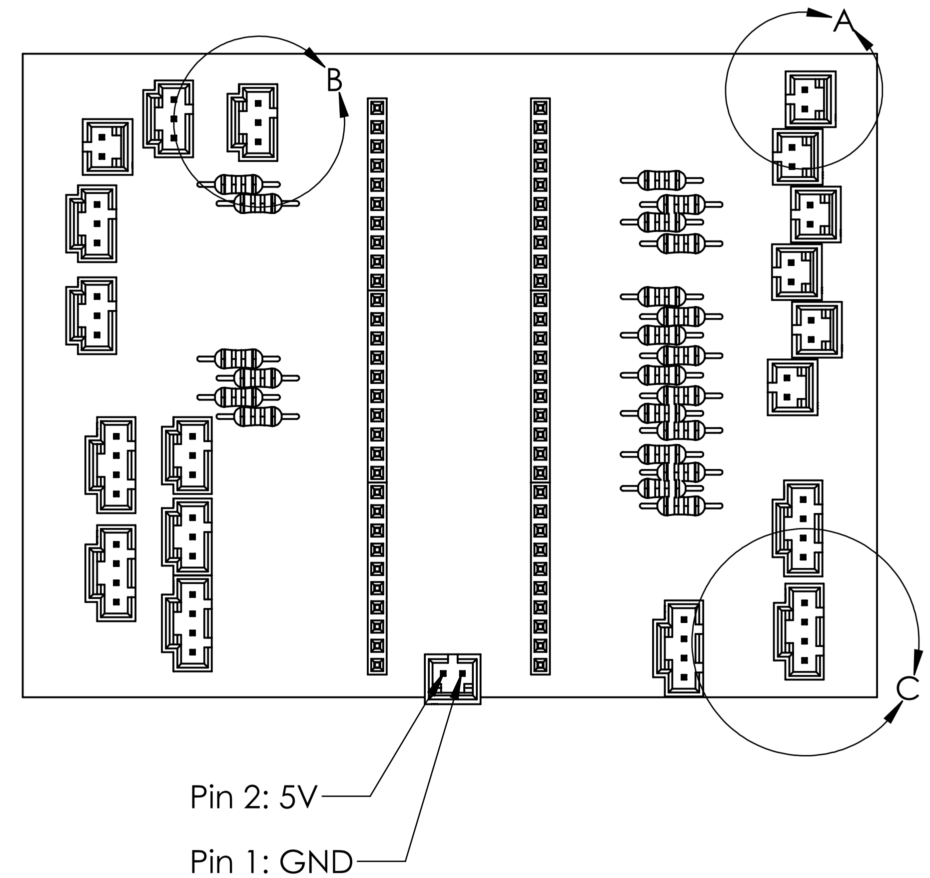
DETAIL A
SCALE 2 : 1
Tx, Rx header



DETAIL B
SCALE 2 : 1
Chute/Hand Enable header



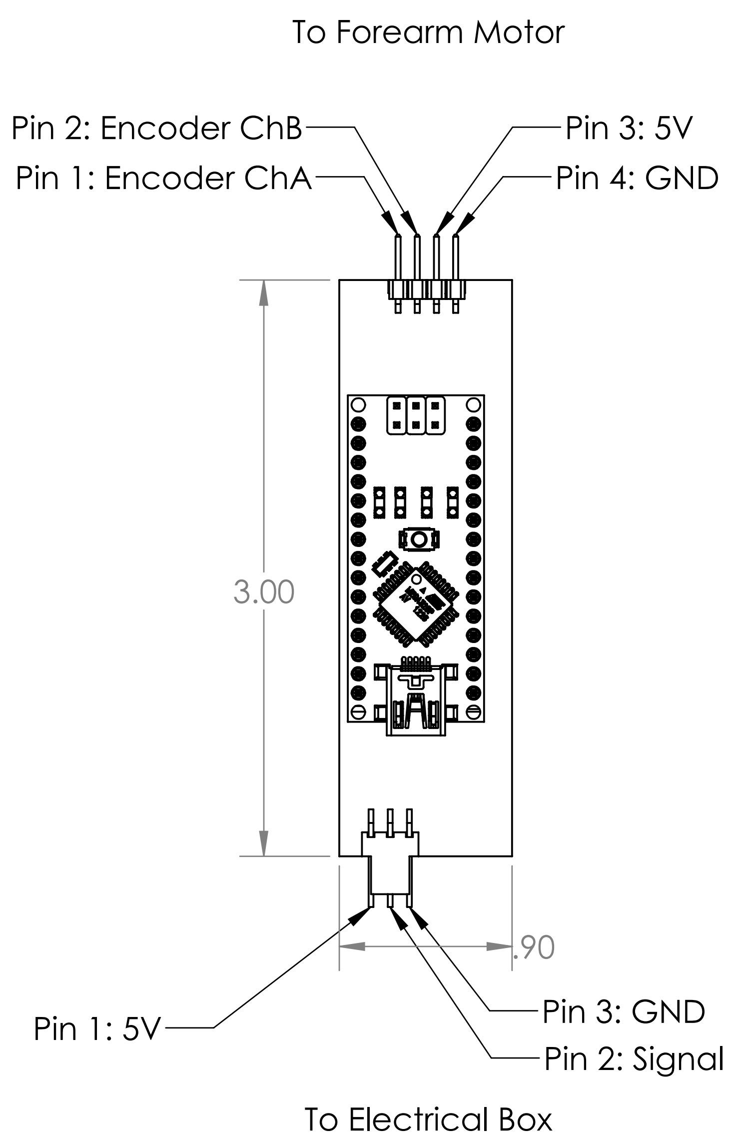
DETAIL C
SCALE 2 : 1
Drive Wheel header

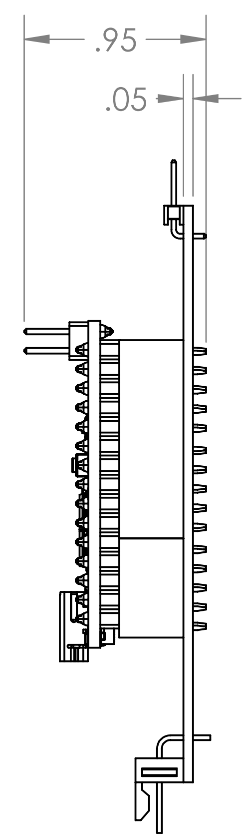


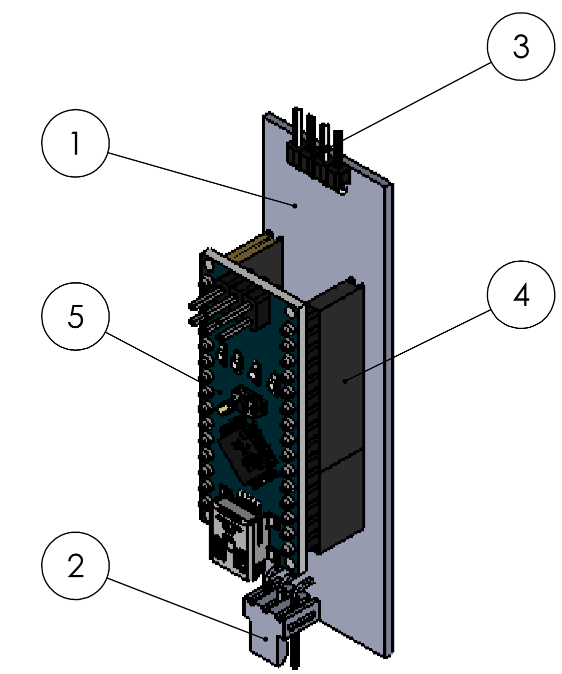
	NAME	DATE	
DRAWN	Taylor Greenwood	04/18/2017	BYU MARS ROVER 2017
CHECKED	Brian Jackson	04/19/2017	
ENG APPR.	Brian Jackson	04/19/2017	
MFG APPR.	Brian Jackson		PART #: MRP-ELE-0207 R1
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B; PART NAME: PSoC PCBA; REV R1
		MATERIAL N/A	
		FINISH N/A	SCALE: 1:1; SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. See PCB silkscreen for soldering locations.
2. Reference PCB layout, schematic and Gerber files as MRP-ELE-0311.
3. Attach all components securely with solder, as appropriate.
4. Used for converting encoder feedback of the forearm motor to an analog signal.
5. Source code for Arduino found in MRD-TR-0019 R1 Forearm Twist Feedback







Item	Qty	Description	Manufacturer	Manuf. P/N	Comment
5	1	Arduino Nano	Arduino	Arduino Nano-Rev3.2	See note 2
4	1	15-pin female header	Molex	DS1022-1x15RD61	
3	1	Right angle, 4-pin male headers	Molex	DS1022-1x4RD61	
2	1	Right Angle, 3-pin male latching headers	Molex	0026605030	
1	1	Forearm Encoder PCB	Custom	MRP-ELE-0311	See note 2.

	NAME	DATE
DRAWN	Drew Warren	April 19, 2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

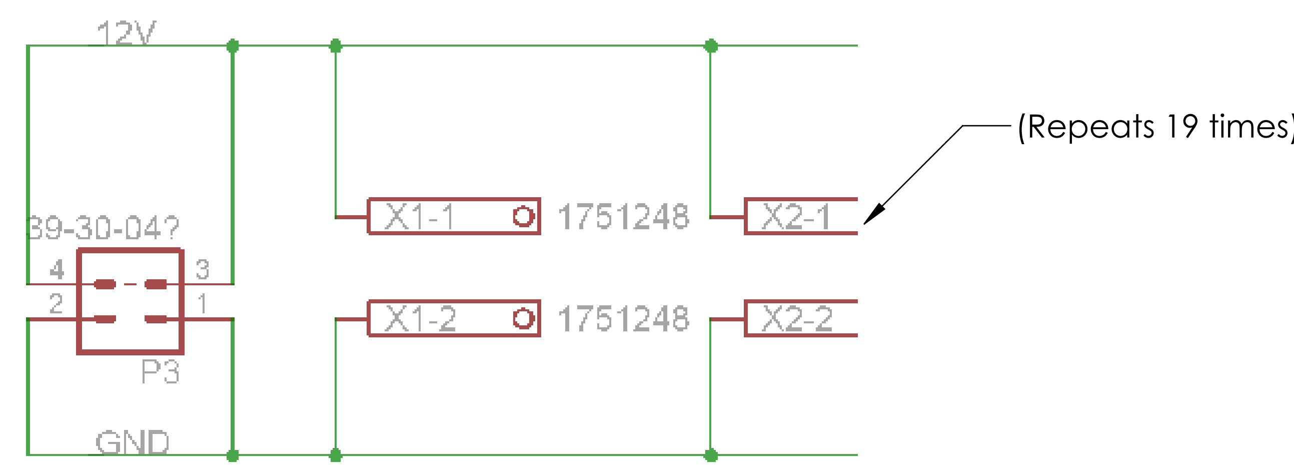
PART #: MRP-ELE-0215 R1

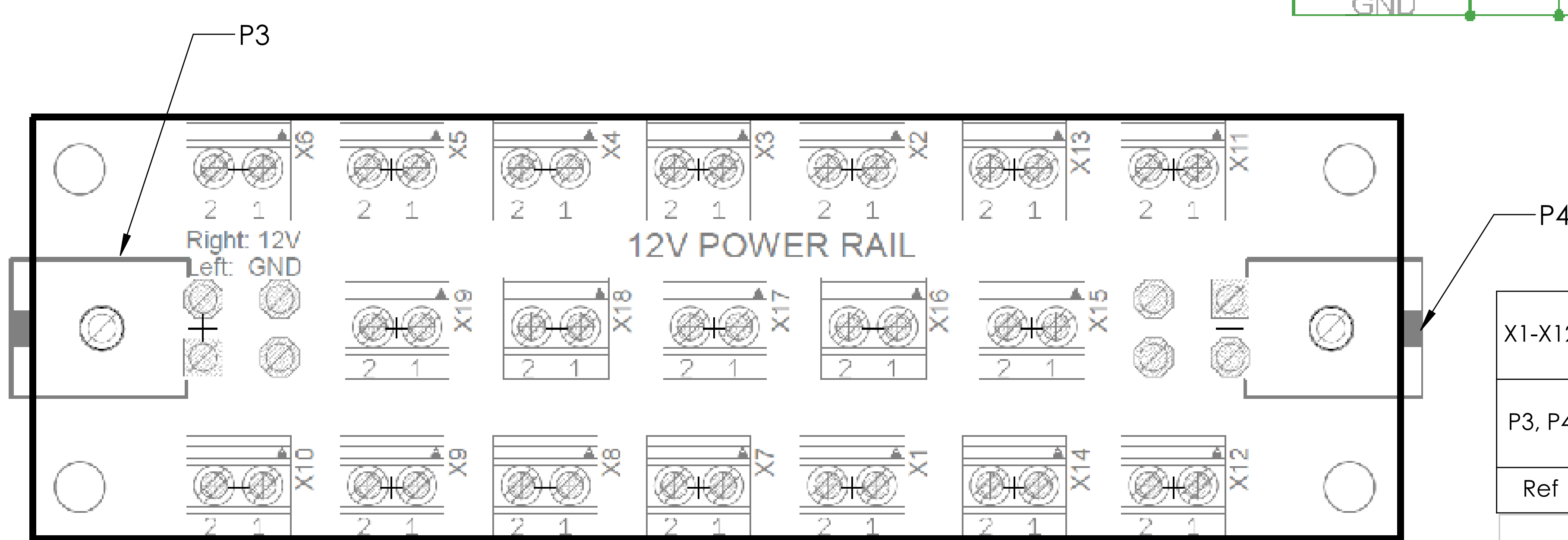
SIZE B | PART NAME: Forearm Encoder PCB | REV R1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





X1-X12	19	Ultra-Fit 2-position Receptacle	Molex	172256-1002	
P3, P4	2	Mini-Fit 4-position 2x2 Receptacle, 90°	Molex	003930-1040	Voltage converter has the same receptacles
Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

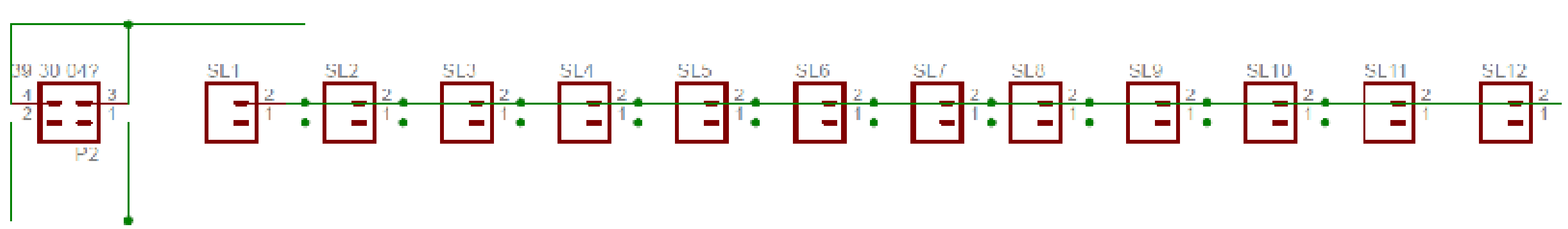
PART #: MRP-ELE-0301 R1

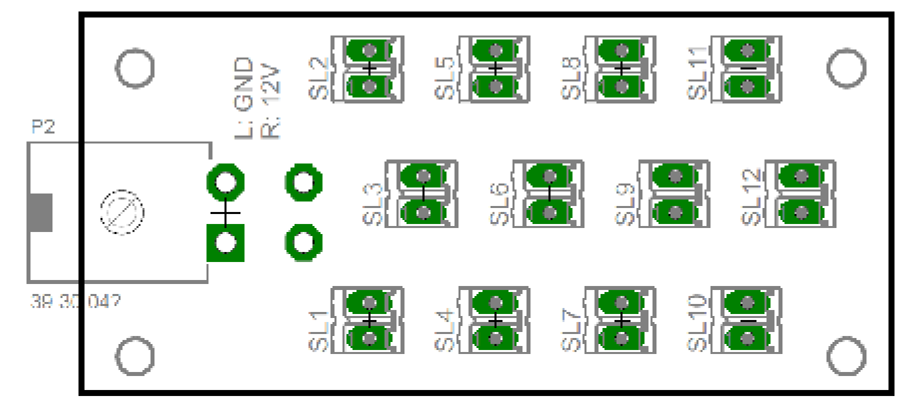
SIZE: B | PART NAME: 12V PCB | REV: R1

SCALE: 2:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref.	Qty	Description	Manufacturer	Manuf. P/N	Comment
SL1-SL12	12	2-position receptacle, male latching	Molex	50-57-9402	
P2	1	Mini-Fit 4-position 2x2 Receptacle, 90°	Molex	003930-1040	Voltage converter has the same receptacles

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	04/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

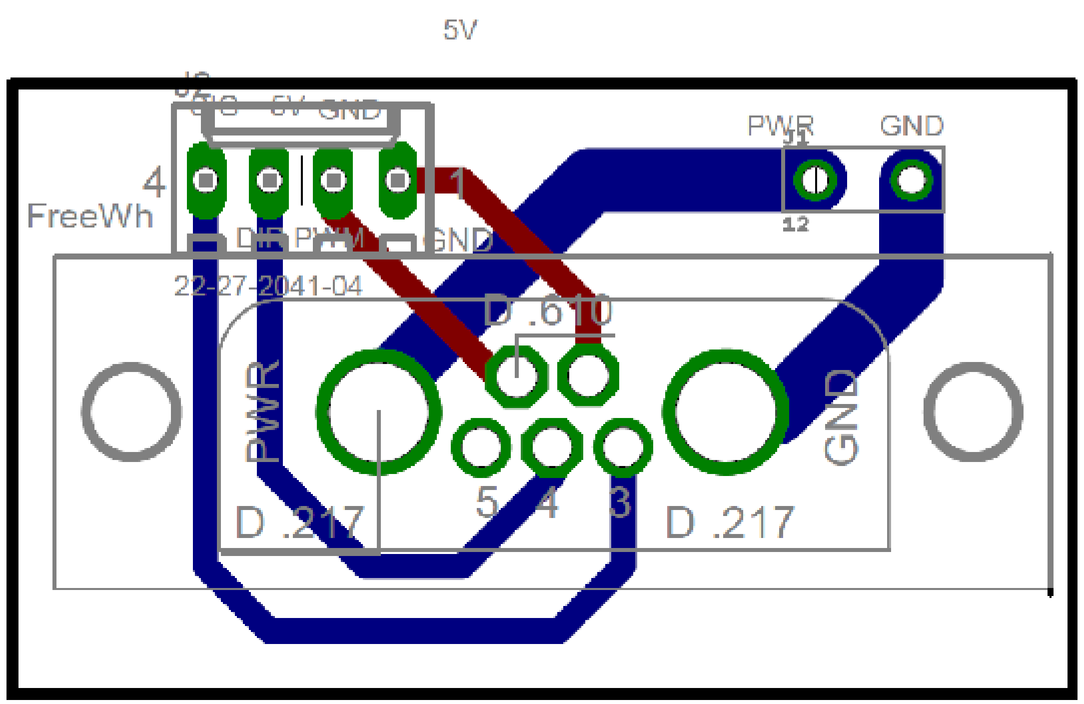
PART #: MRP-ELE-0302 R1

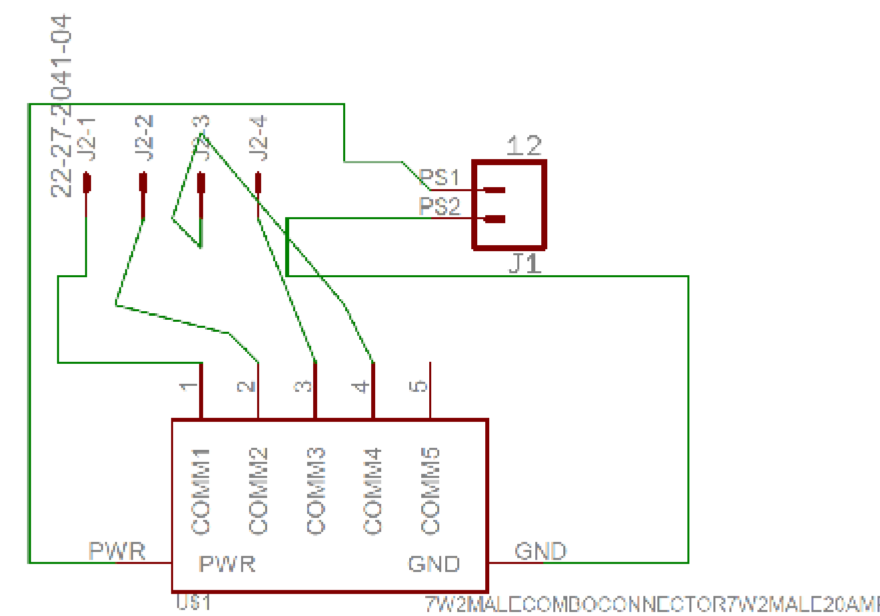
SIZE B | PART NAME: 5V PCB | REV R1

SCALE: 1:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





U$1	1	D-sub combo connector, male 7 pin	Norcomp. Inc	680M7W2203L201	
J2	1	4-pin receptacle,latching	Molex	705430003	
J1	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0303 R1

SIZE B

PART NAME: D-sub Combo Box Connector, small

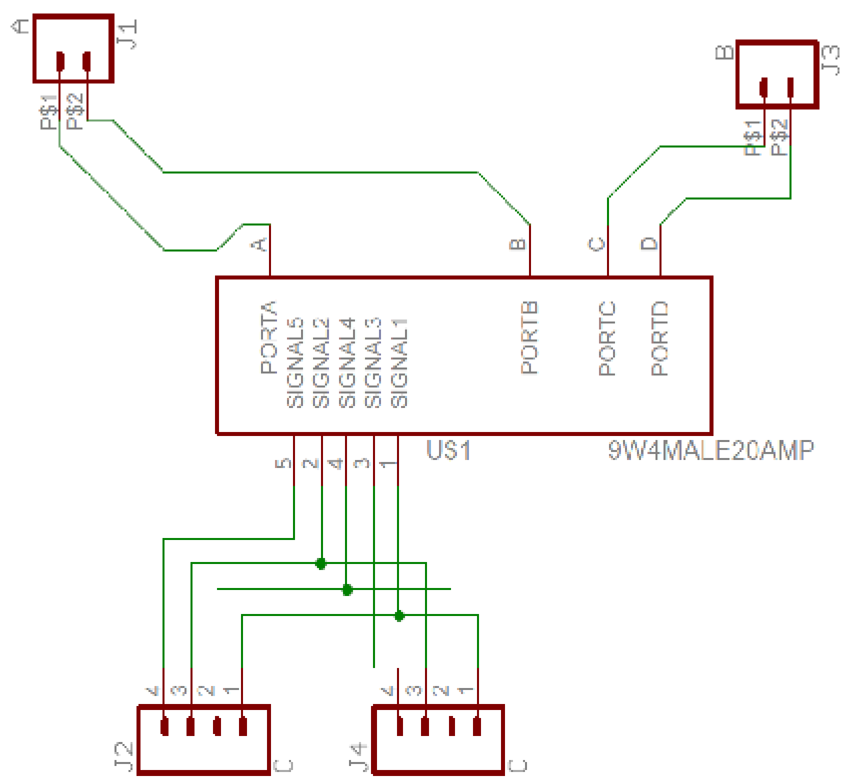
REV R1

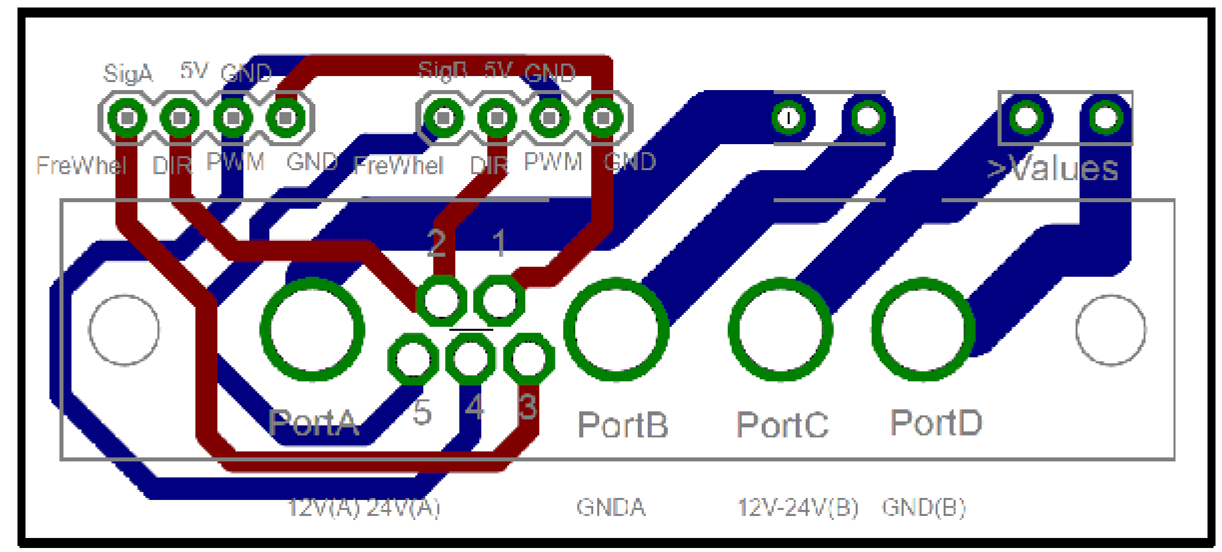
SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref.	Qty	Description	Manufacturer	Manuf. P/N	Comment
U$1	1	D-sub combo connector, male 9 pin	Norcomp. Inc	680M9W4203L201	
J2, J4	2	4-pin receptacle,latching	Molex	705430003	
J1, J3	2	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0304 R1

SIZE B

PART NAME: D-sub Combo Box Connector, large

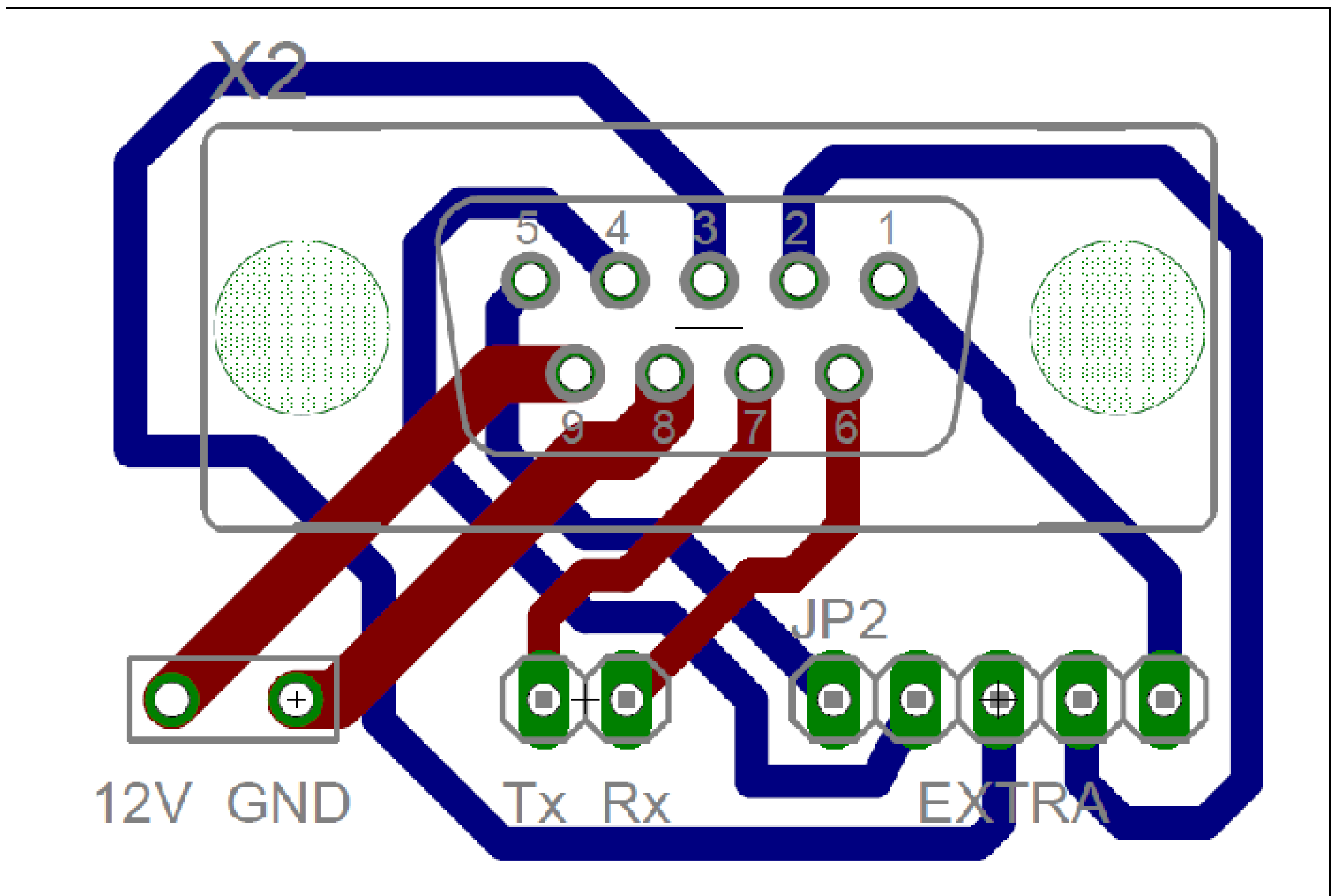
REV R1

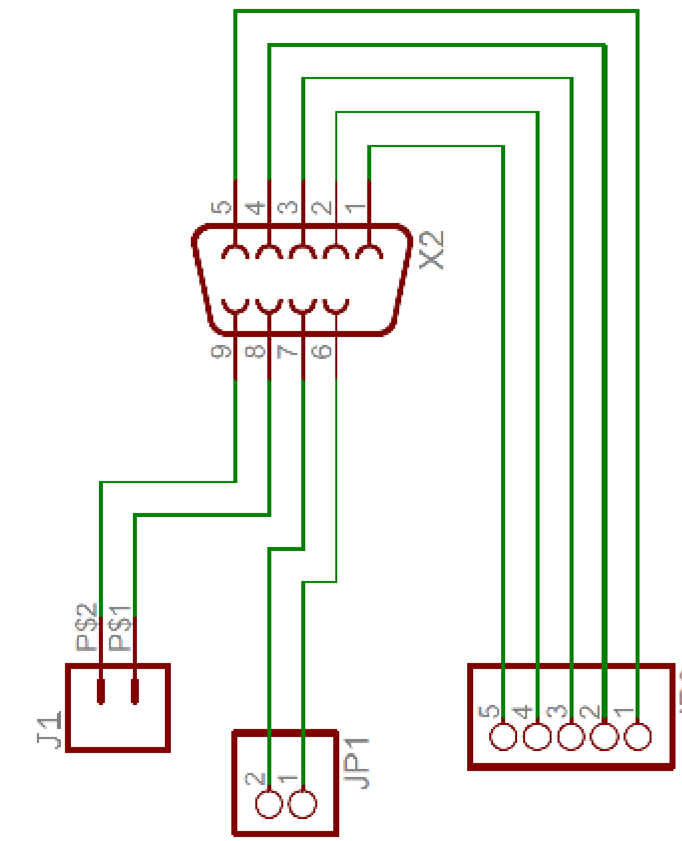
SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





X2	1	D-sub connector, male 9 pin	Any	Any	
JP2	1	5-pin receptacle, latching	Molex	705430004	Extra pins, populate only as needed.
JP1	1	2-pin receptacle,latching	Molex	705430001	
J1	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	
Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0305 R1

SIZE **B**

PART NAME: D-sub Box Connector, small

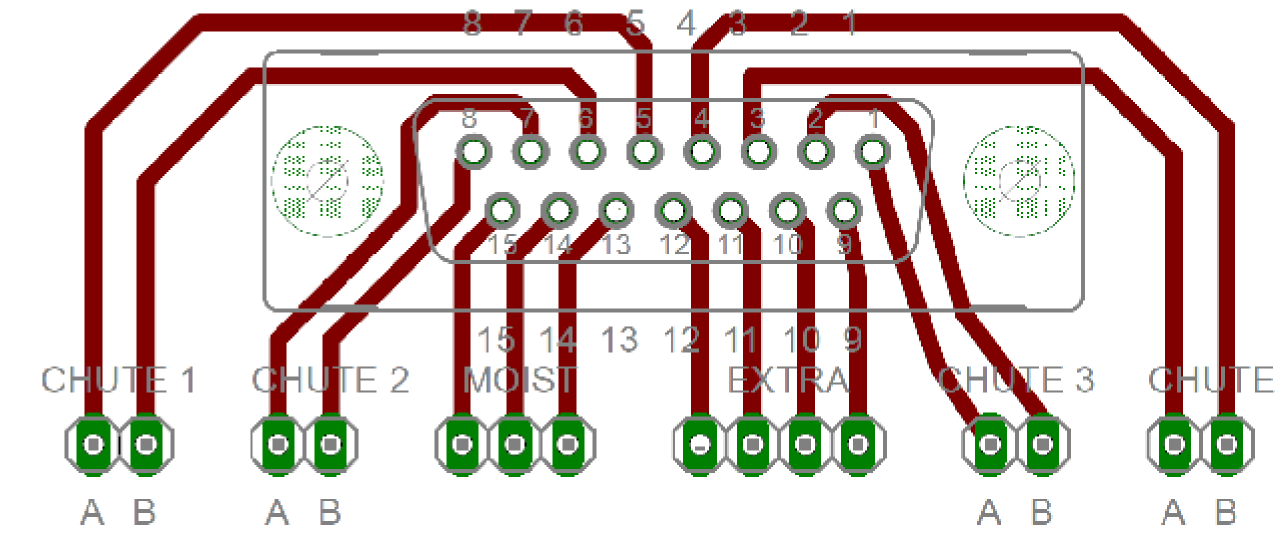
REV R1

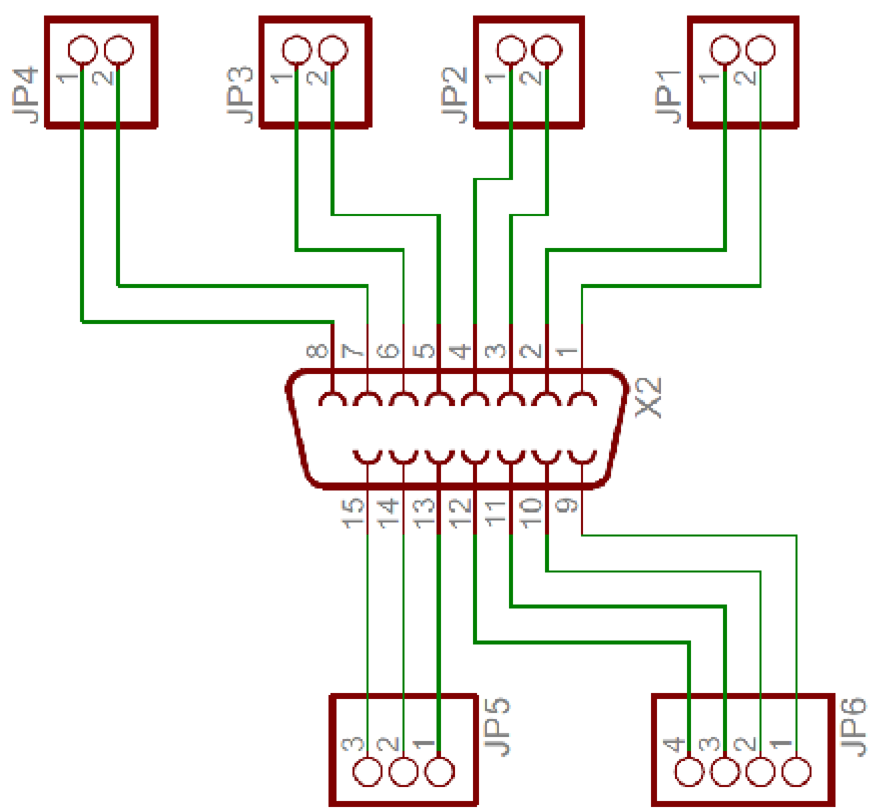
SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment
X2	1	D-sub connector, 15-pin	Any	Any	
JP6	1	4-pin receptacle,latching	Molex	705430003	
JP5	1	3-pin receptacle,latching	Molex	705430002	
JP1-JP4	4	2-position receptacle	Molex	705430001	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0306 R1

SIZE B

PART NAME: D-sub Box Connector, large

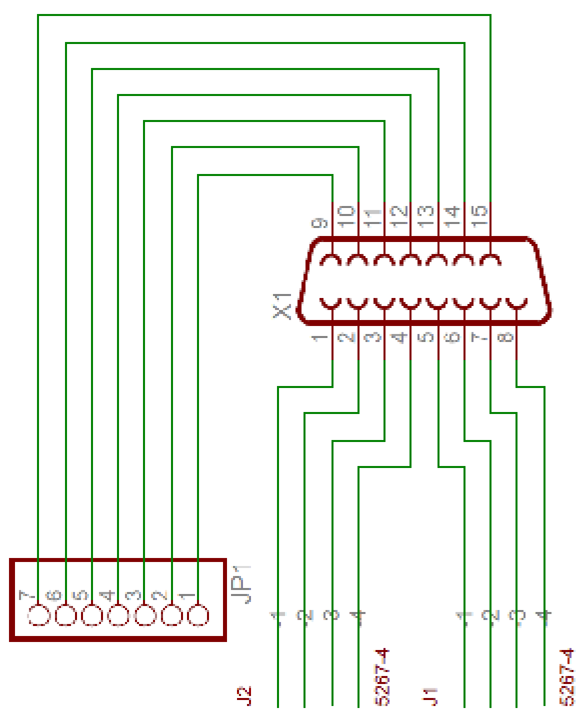
REV R1

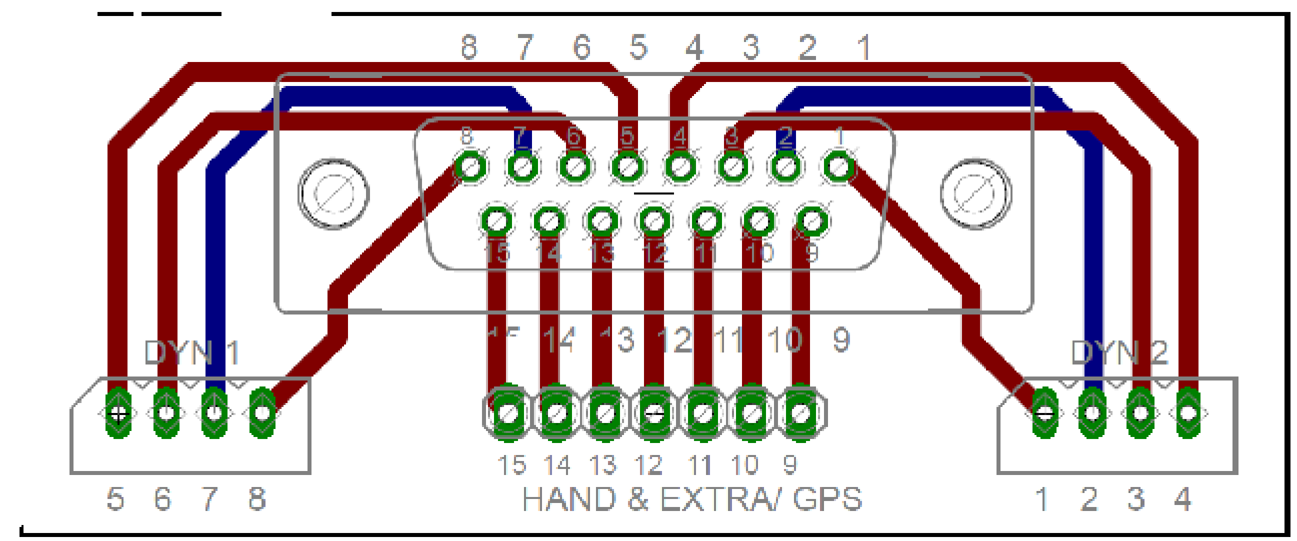
SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment
X1	1	D-sub connector, 15-pin	Any	Any	
JP1	1	6-pin receptacle,latching	Molex	705430005	
J2, J1	1	3-position receptacle	Molex	22-03-5035	Same connector as Dynamixels.

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	04/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

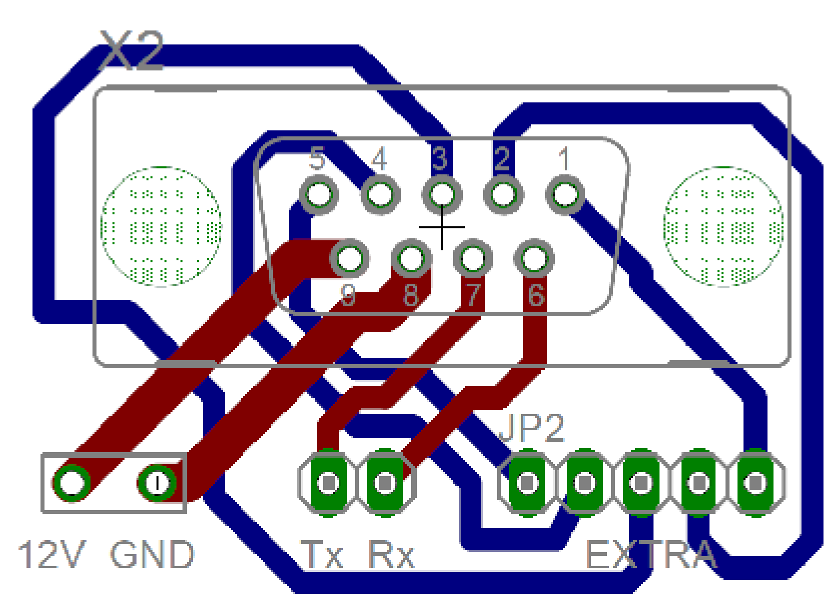
PART #: MRP-ELE-0307 R1

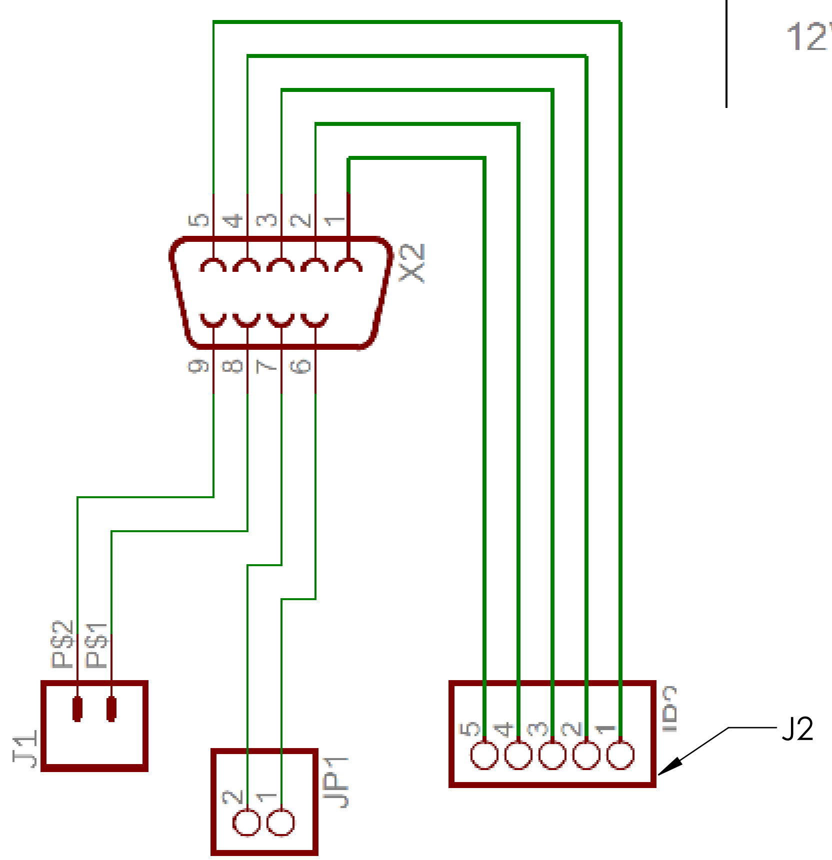
SIZE: B | PART NAME: Dynamixel PCB | REV: R1

SCALE: 2:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref.	Qty	Description	Manufacturer	Manuf. P/N	Comment
X2	1	D-sub connector, male 9 pin	Any	Any	
JP2	1	5-pin receptacle,latching	Molex	705430004	Extra pins, poulated as needed
J1	1	2-pin receptacle,latching	Molex	705430001	
JP1	1	Ultra-fit 2-pin receptacle, latching	Molex	172286-1102	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU MARS ROVER 2017

PART #: MRP-ELE-0308 R1

SIZE **B**

PART NAME: Turret PCB

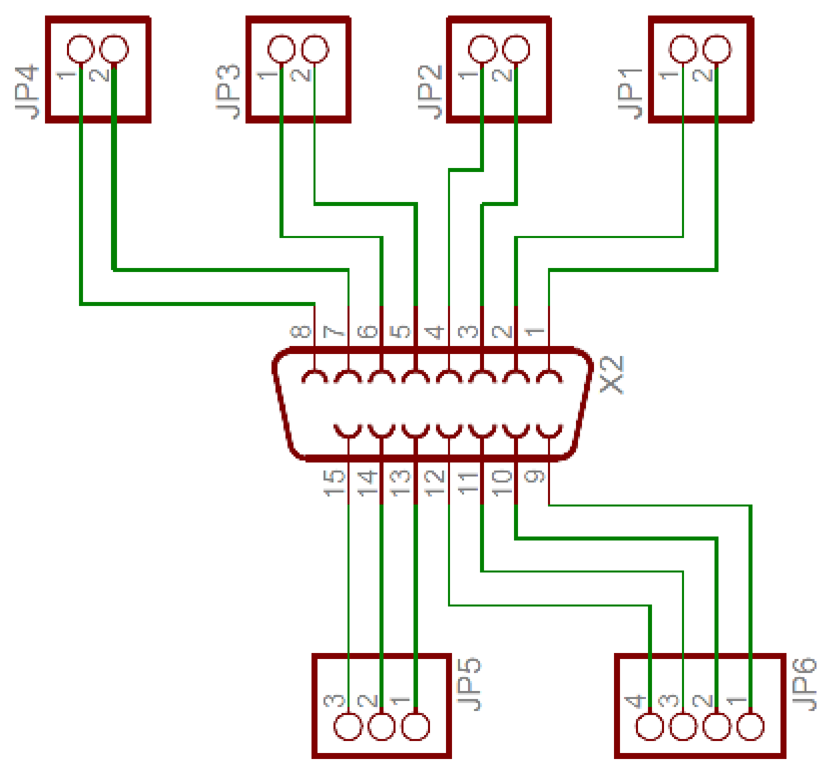
REV R1

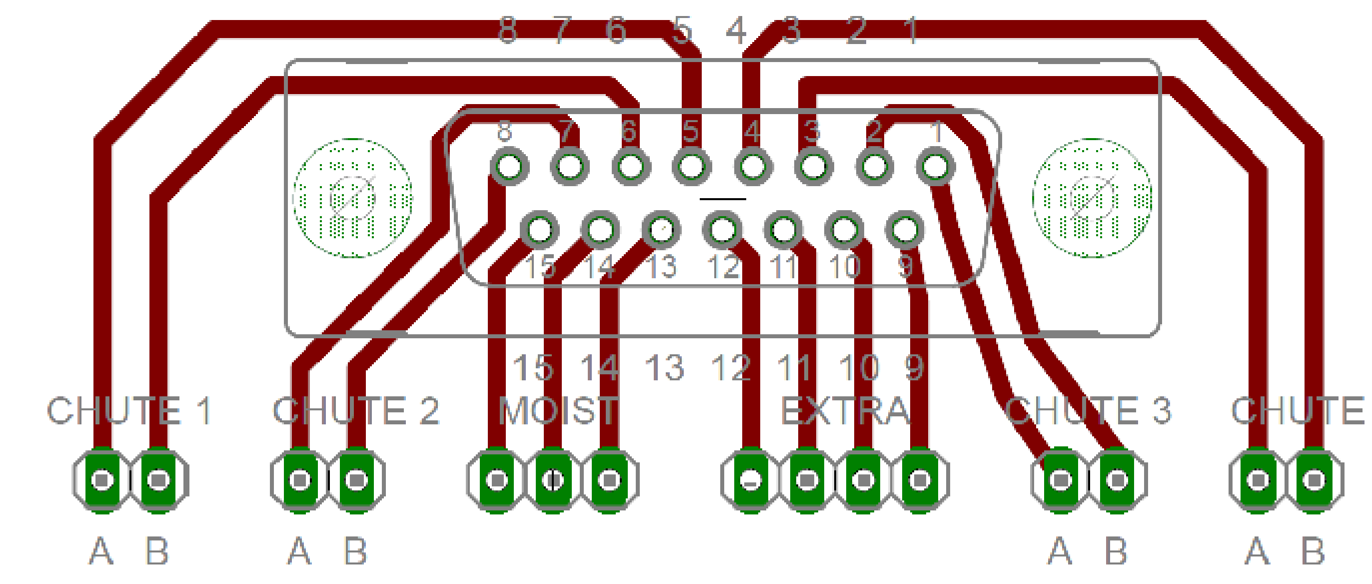
SCALE: 2:1

SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.





Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment
X2	1	D-sub connector, 15-pin	Any	Any	
JP6	1	4-pin receptacle,latching	Molex	705430003	
JP5	1	3-pin receptacle,latching	Molex	705430002	
JP1-JP4	2	2-position receptacle	Molex	705430001	

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU
MARS ROVER
2017

PART #: MRP-ELE-0309 R1

SIZE **B** | PART NAME: Chutes Box Connector | REV R1

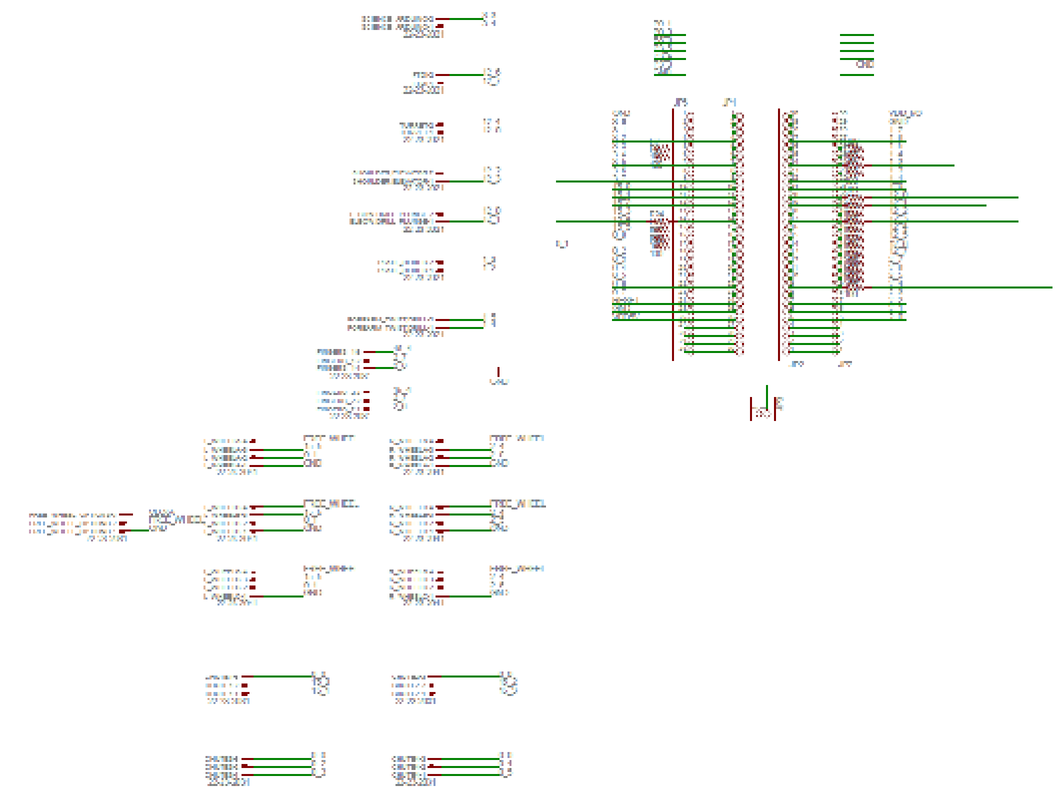
SCALE: 2:1 | SHEET 1 OF 1

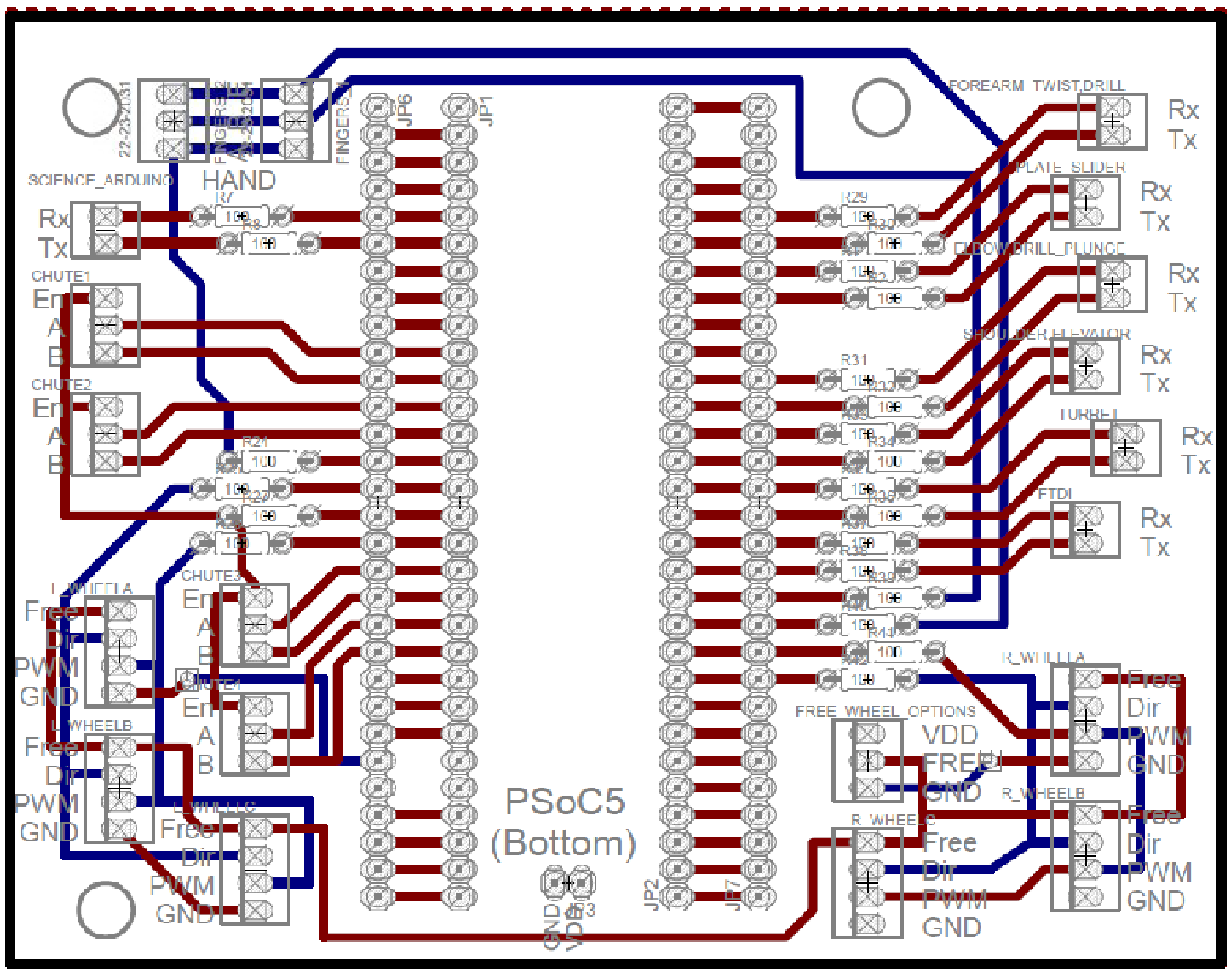
4 3 2 1

B

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.



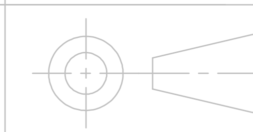


A

Ref.	Qty	Description	Manufacturer	Manuf. P/N	Comment
R1-R22	22	Resistor, 100 ohms	Any	Any	
JP2-JP6	6	10-pin plain header, 0.1" pitch	Any	Any	PSoC headers
See label	6	4-pin receptacle, latching	Molex	705460003	Drive Wheel (6)
See label	6	3-pin receptacle,latching	Molex	705430002	Chutes Enable (6)
See label	8	2-pin receptacle,latching	Molex	705430001	PSoC Power (1) Tx, Rx (7)

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0



DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

BYU
MARS ROVER
2017

PART #: MRP-ELE-0310 R1

SIZE B

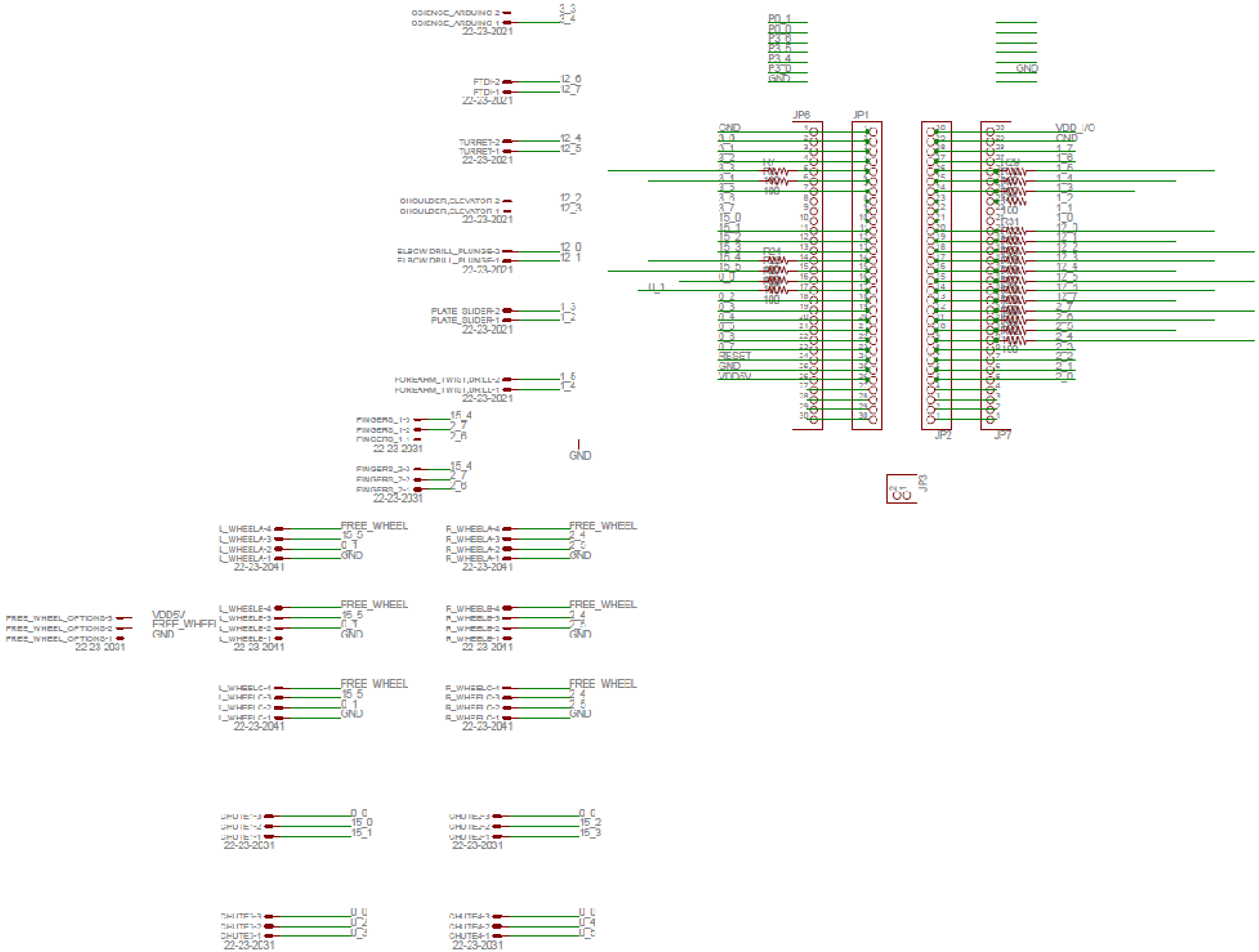
PART NAME: PSoC PCB

REV R1

SCALE: 2:1

SHEET 1 OF 2

4 3 2 1



	NAME	DATE
DRAWN	Taylor Greenwood	4/17/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

BYU
MARS ROVER
2017

PART #:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

SIZE	PART NAME:	REV
B		R1

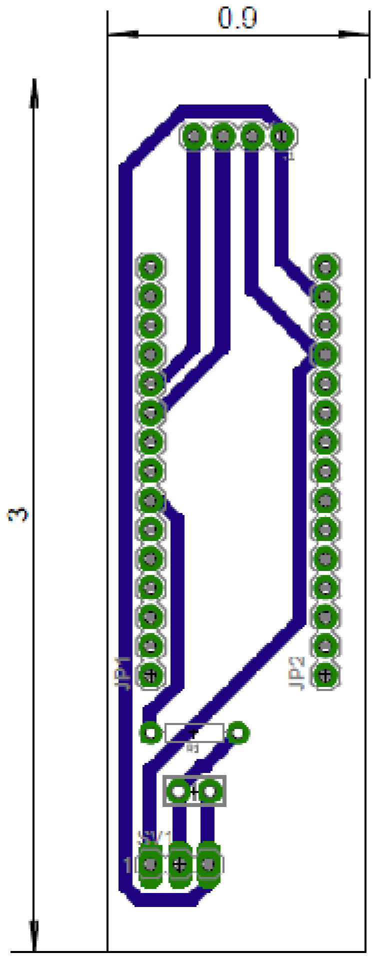
SCALE: 2:1

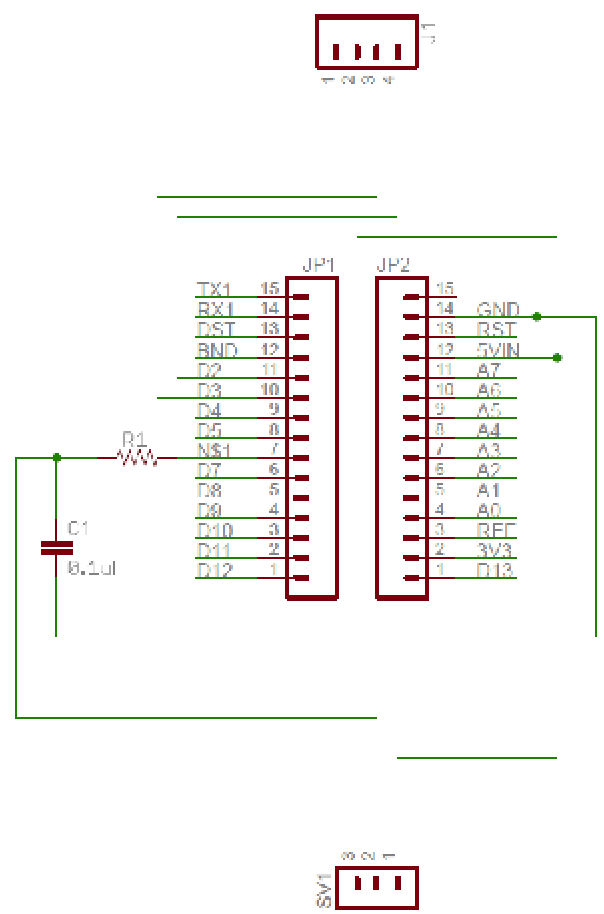
SHEET 2 OF 2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. Schematic and layout provided for reference only.
2. Refer to Eagle and Gerber files located in same folder as this drawing with the same part number.

B





JP1, JP2	1	15-pin female header	Molex	DS1022-1x15RD61	
J1	1	Right angle, 4-pin male headers	Molex	DS1022-1x4RD61	
SV1	1	Right Angle, 3-pin male latching headers	Molex	0026605030	
Ref	Qty	Description	Manufacturer	Manuf. P/N	Comment

A

	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	04/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU MARS ROVER 2017

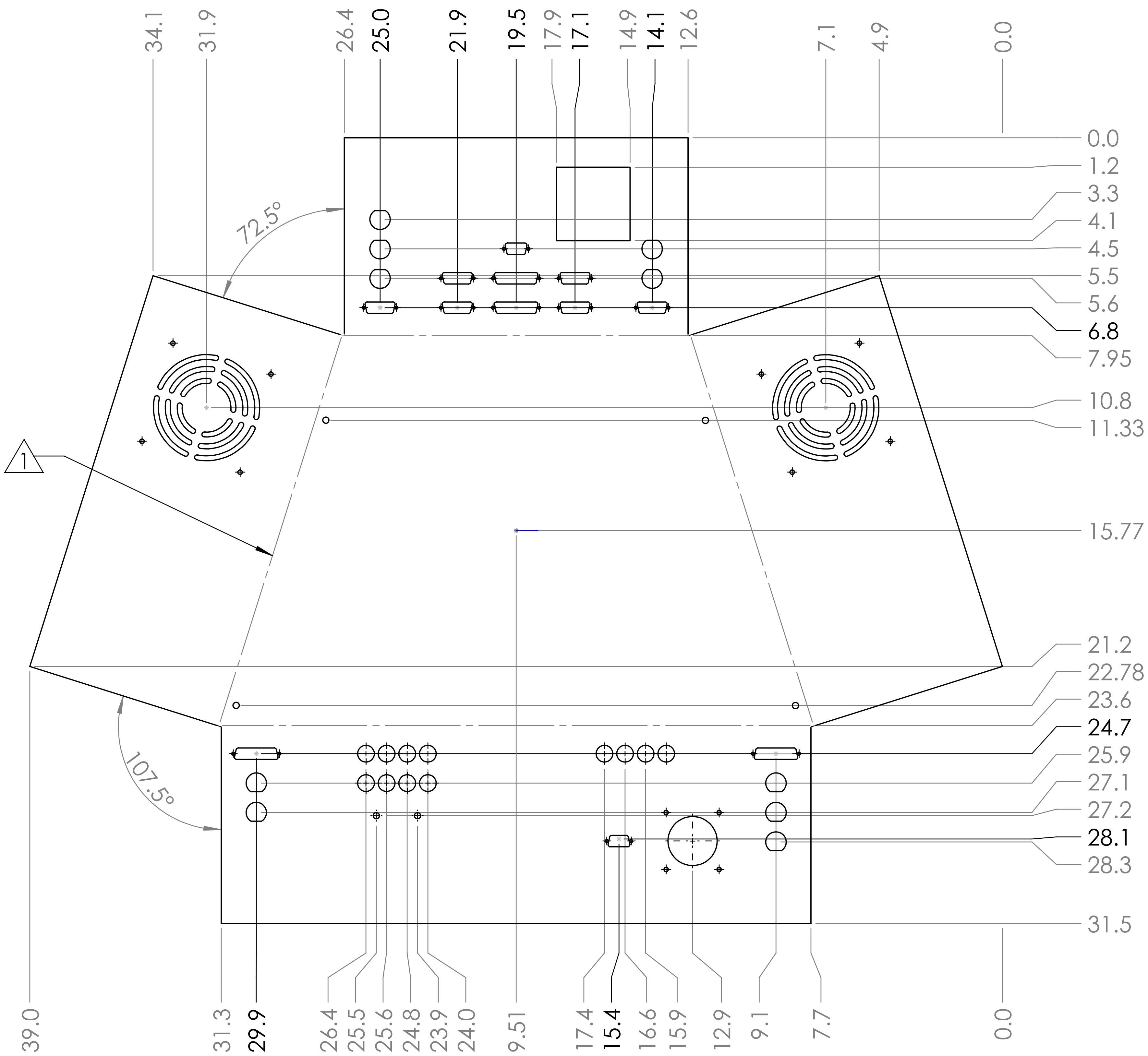
PART #: MRP-ELE-0311 R1

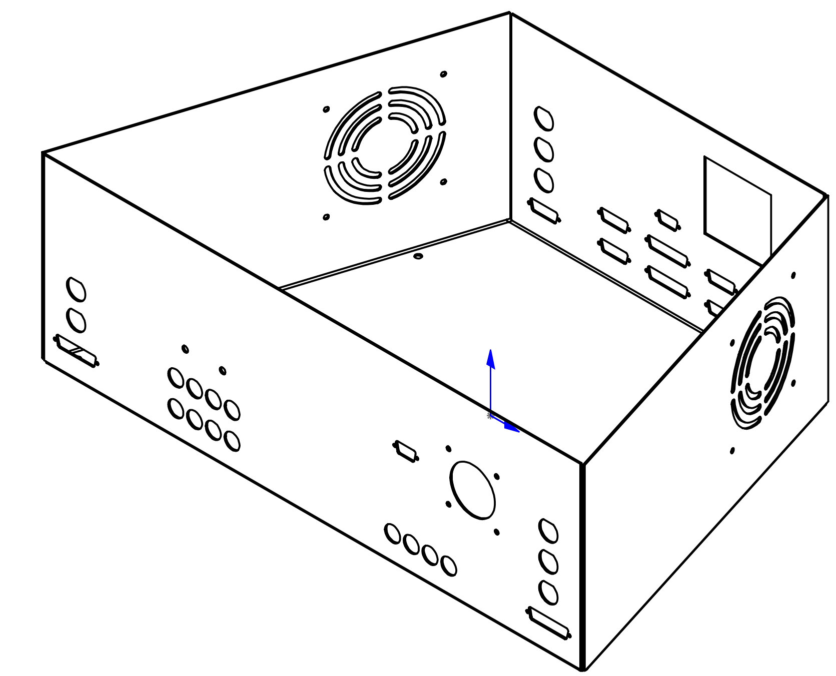
SIZE B | PART NAME: Forearm Encoder PCB | REV R1

SCALE: 2:1 | SHEET 1 OF 1

NOTES:
1. Bend using a radius of .065 in. at the dashed line.
2. Reference the 3D model for ease of manufacturing.

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





Cut-out	Data Sheet
A	Panel_Cutout_D-Sub-Single, 9
B	Panel_Cutout_D-Sub-Single, 15
C	Panel_Cutout_D-Sub-Single, 25
D	Battery_Cordgrip
E	Emergency_Stop
F	GT2_Contact_USB_Port
G	MRP-ELE-0500 SHEET 3

	NAME	DATE
DRAWN	Garrett Jones	4/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: ALUMINUM 5052-H32

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0500 R1

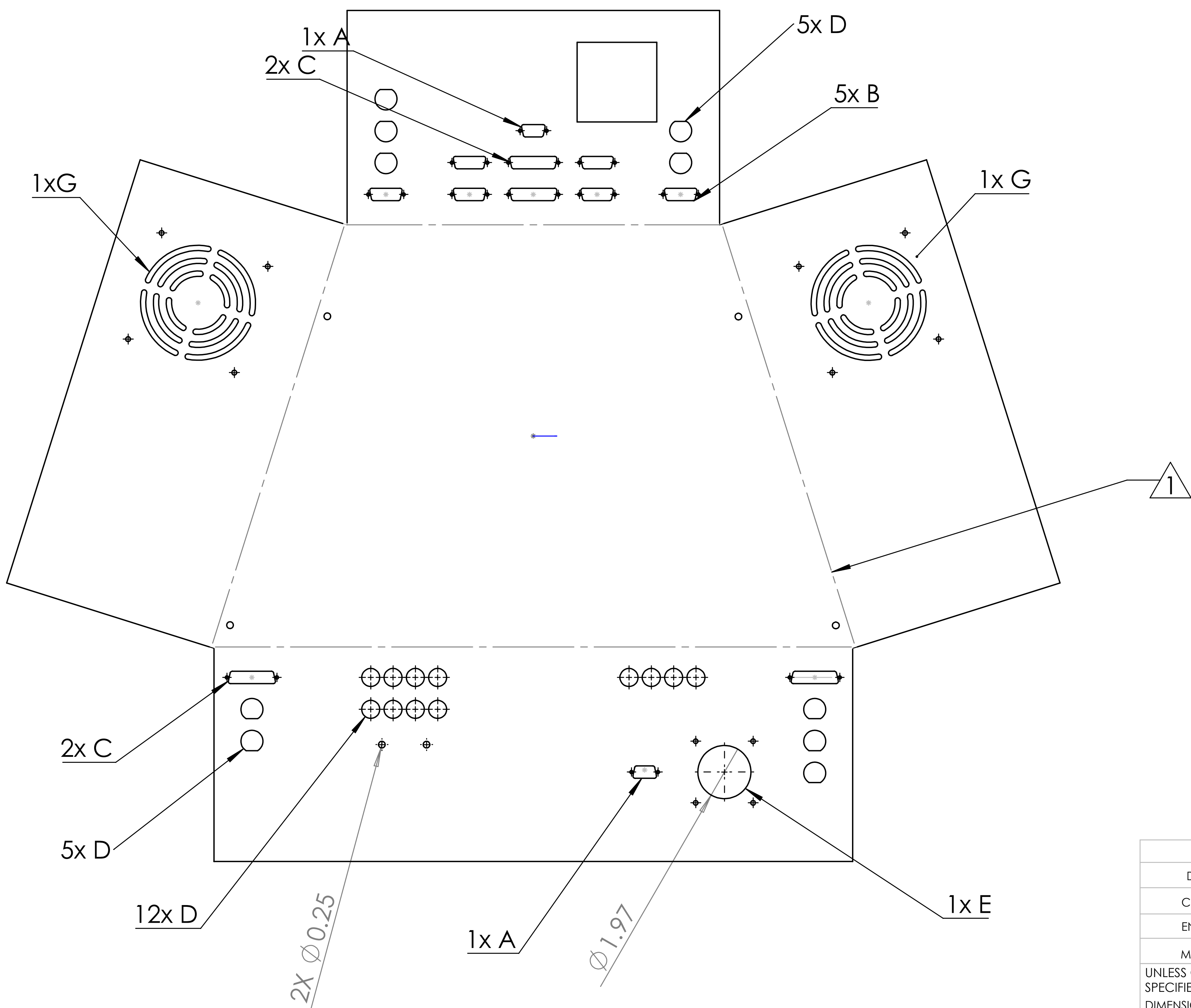
SIZE: B | PART NAME: Electrical Box | REV: R1

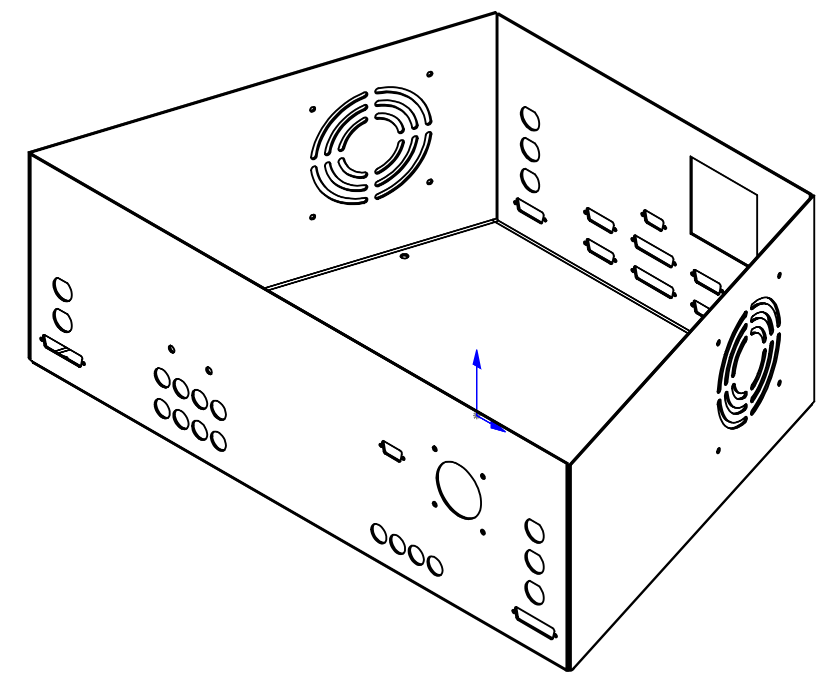
SCALE: 1:5 | SHEET 1 OF 3

4 3 2 1

NOTES:
1. Bend using a radius of .065 in. at the dashed line.
2. Reference the 3D model for ease of manufacturing.

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





Cut-out	Data Sheet
A	Panel_Cutout_D-Sub-Single, 9
B	Panel_Cutout_D-Sub-Single, 15
C	Panel_Cutout_D-Sub-Single, 25
D	Battery_Cordgrip
E	Emergency_Stop
F	GT2_Contact_USB_Port
G	MRP-ELE-0500 SHEET 3

	NAME	DATE
DRAWN	Garrett Jones	4/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL ALUMINUM 5052-H32

FINISH

BYU MARS ROVER 2017

PART #: MRP-ELE-0500 R1

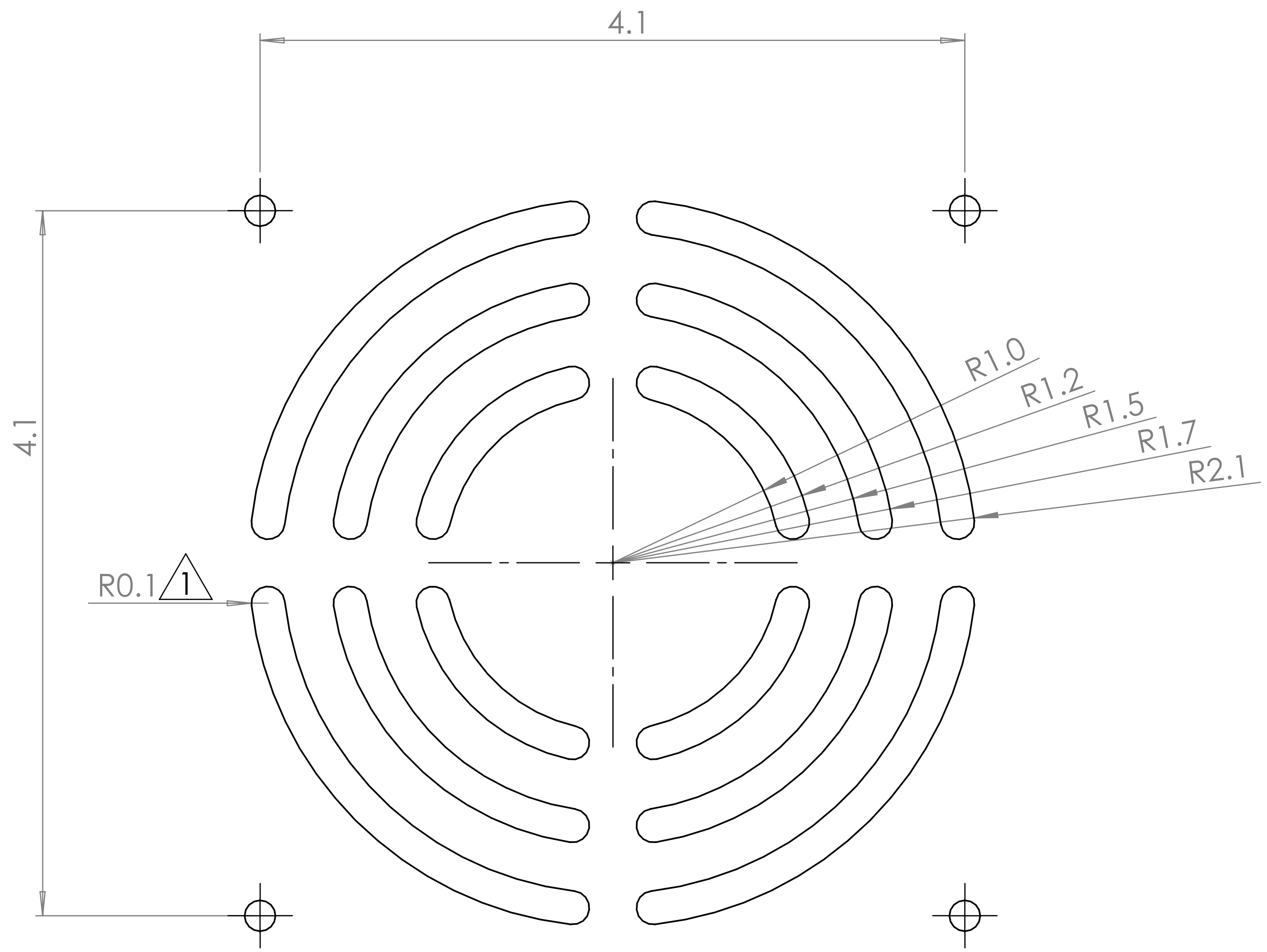
SIZE B | PART NAME: Electrical Box | REV R1

SCALE: 1:5 | SHEET 2 OF 3

4 3 2 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

NOTES:
1. This radius is the same for both ends of every slot.



	NAME	DATE
DRAWN	Garrett Jones	4/19/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL ALUMINUM 5052-H32

FINISH

BYU MARS ROVER 2017

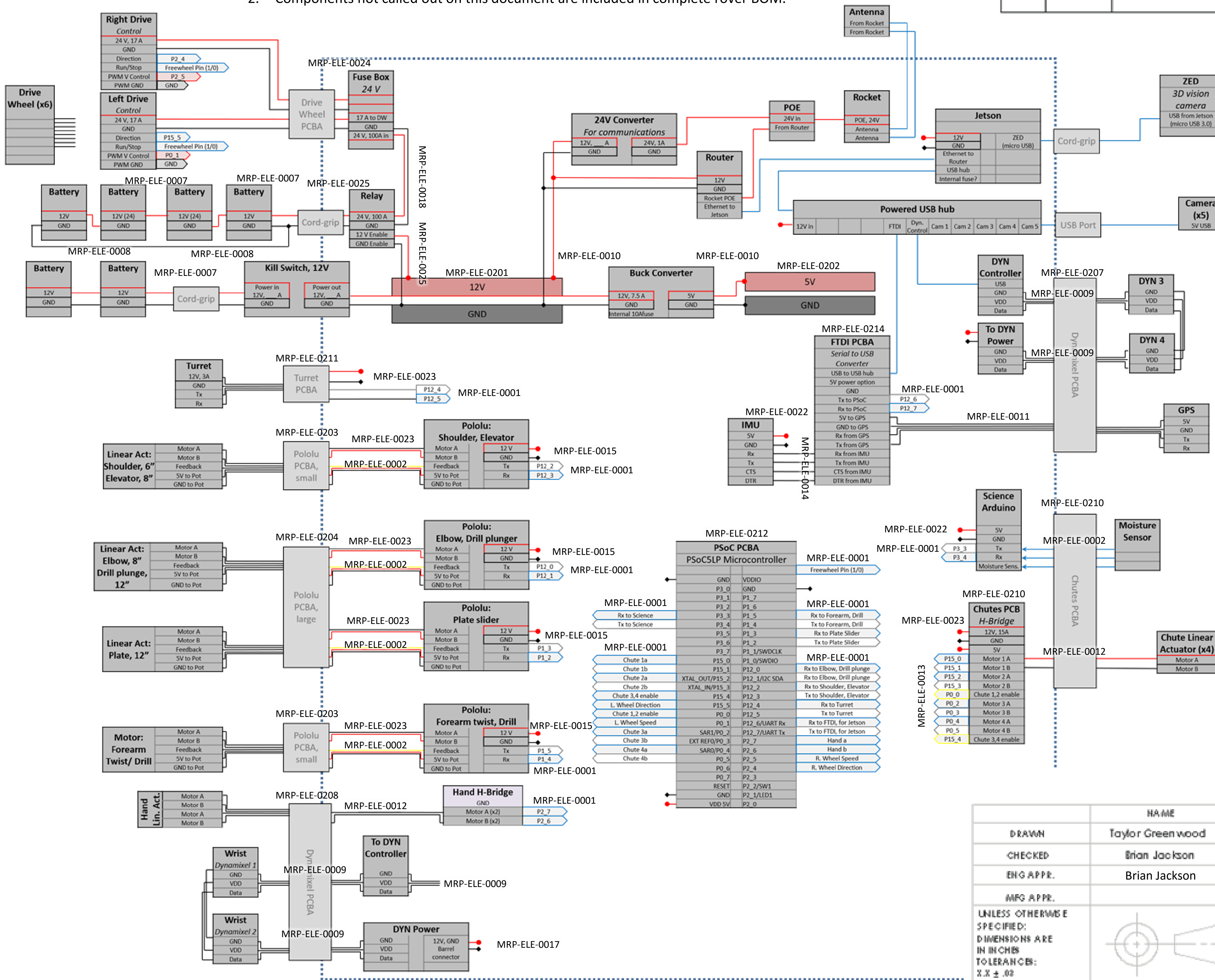
PART #: MRP-ELE-0500 R1

SIZE B | PART NAME: Electrical Box | REV R1

SCALE: 1:5 | SHEET 3 OF 3

NOTES:
1. Dotted line represents wall of box.
2. Components not called out on this document are included in complete rover BOM.

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Taylor Greenwood	04/18/2017
CHECKED	Brian Jackson	4/19/2017
ENG APPR.	Brian Jackson	4/19/2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL

FINISH

DO NOT SCALE DRAWING

BYU MARS ROVER 2017

PART #: MRP-ELE-0600 R1

SIZE: B

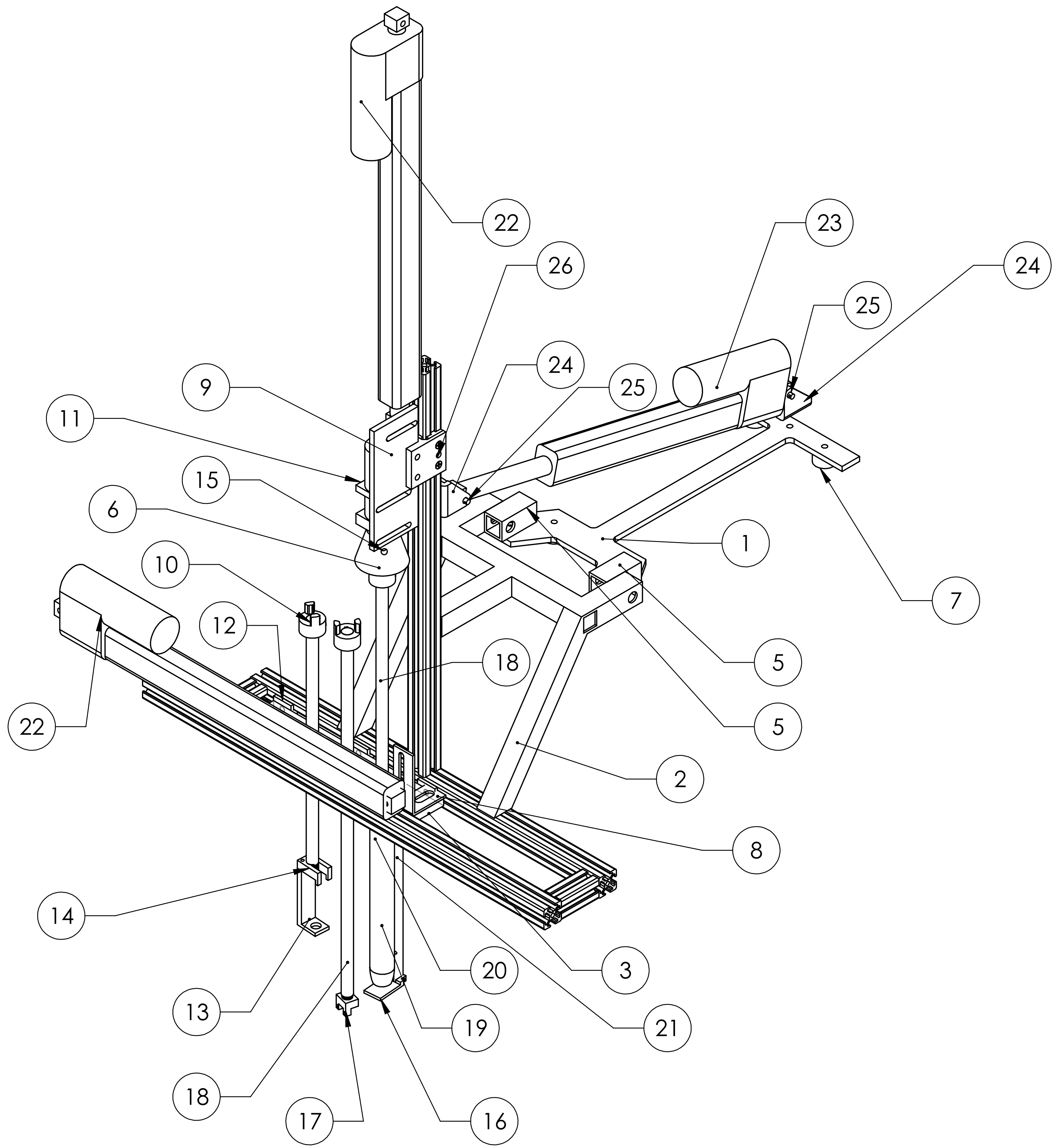
PART NAME: Rover Schematic

REV: R1

SCALE: 1:1

SHEET 1 OF 1

I.5 Science Drawings and Documentation



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MRP-SCI-0001 R1	Base Plate	1
2	MRP-SCI-0002 R1	Rocker Arm	1
4	MRP-SCI-0004 R1	Back Mount	1
5	MRP-SCI-0005 R1	Front Mount	2
6	MRP-SCI-0006 R1	Drill Alignment	1
7	MRP-SCI-0007 R1	Spacer	6
8	MRP-SCI-0008 R1	Plate Connector	1
9	MRP-SCI-0009 R1	Motor Brace	1
10	McMaster Carr #6408K11	Shaft Coupler	3
11	BYU Capstone	12V DC Motor	1
12	80/20 inc #6705	Plate Bearings	6
13	MRP-SCI-0013 R1	Temp Sensor Bottom	1
14	MRP-SCI-0014 R1	Temp Sensor Top	1
15	MRP-SCI-0015 R1	Drill Bearing	1
16	MRP-SCI-0016 R1	Dirt Flap	1
17	MRP-SCI-0017 R1	Humidity Holder	1
18	MRP-SCI-0018 R1	Humidity/Auger Rod	1
19	MRP-SCI-0019 R1	Auger	1
20	MRP-SCI-0020- R1	Auger Adapter	1
21	MRP-SCI-0021 R1	Dirt Rod	1
22	Firgelli #FA-PO-240-12-12	12 in Actuator	2
23	Firgelli #FA-PO-240-12-8	8 in Actuator	1
24	Firgelli #MB1	Actuator Bracket	2
25	Firgelli #MB1	Pin	2
26	80/20 inc #6715	Plunge Slider	1
			1
28	DrillBearing		1

	NAME	DATE
DRAWN	STEVEN MARKHAM	4/18/17
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

BYU MARS ROVER 2017

PART #: MRP-SCI-0000

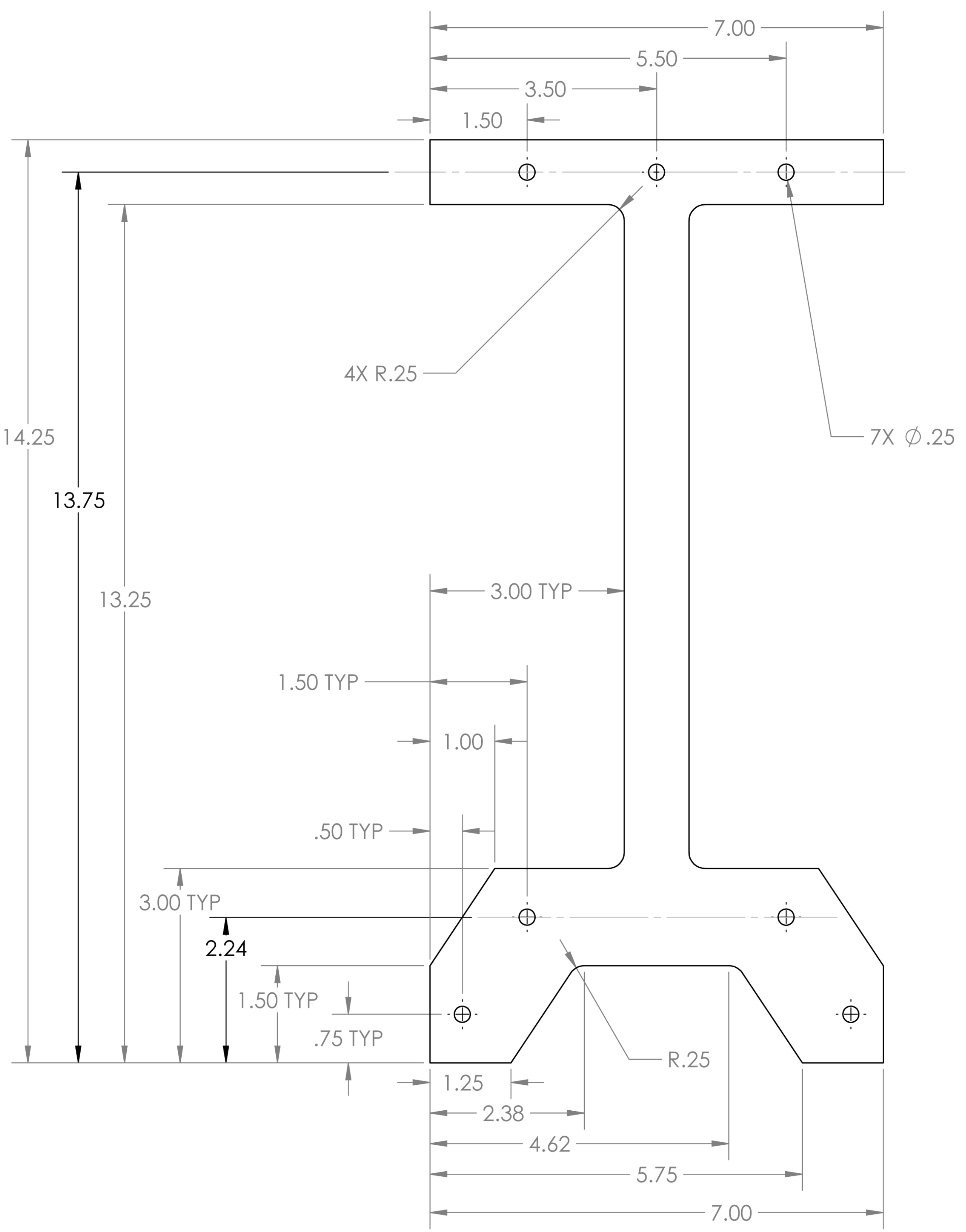
SIZE B

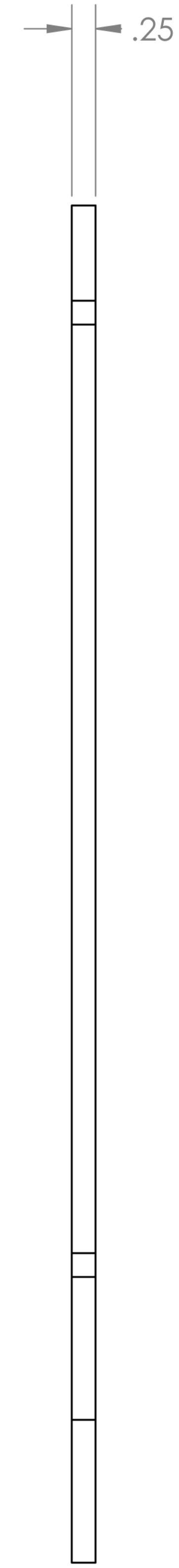
PART NAME: Science Module

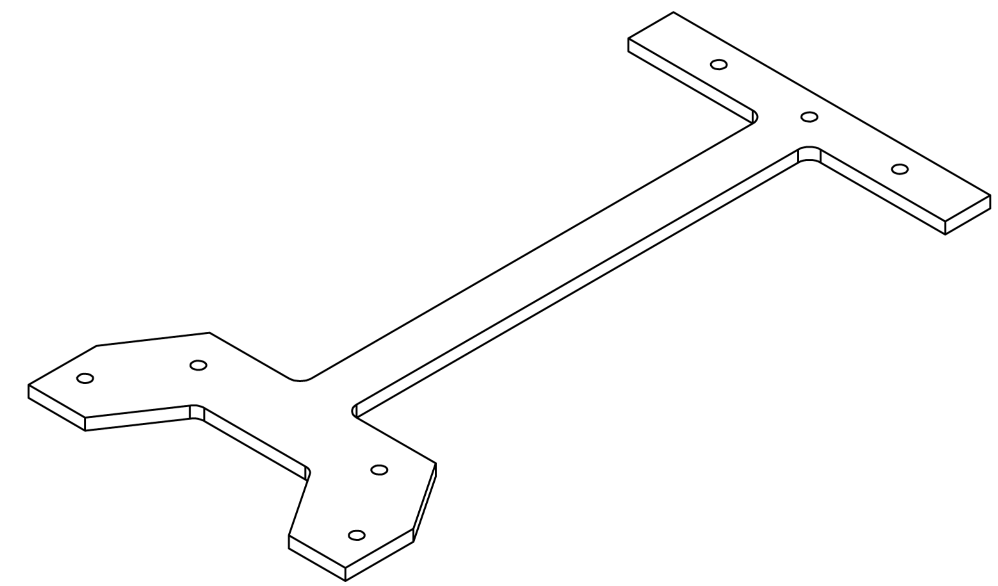
REV 1

SCALE: 1:20

SHEET 1 OF 1

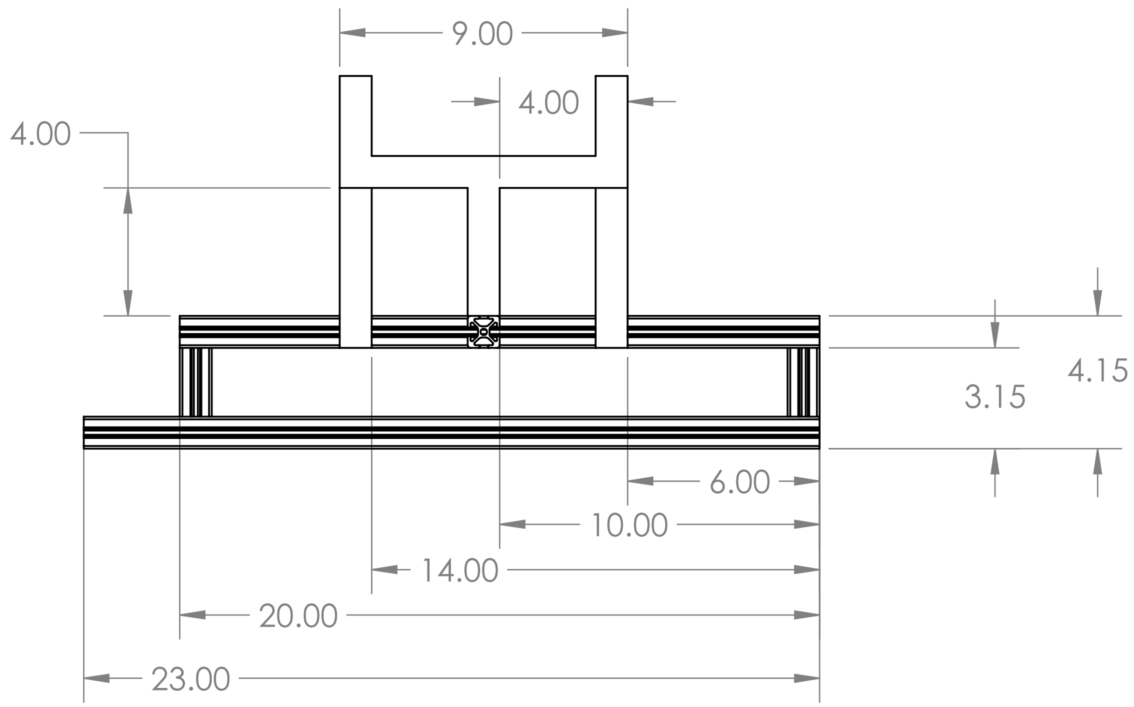


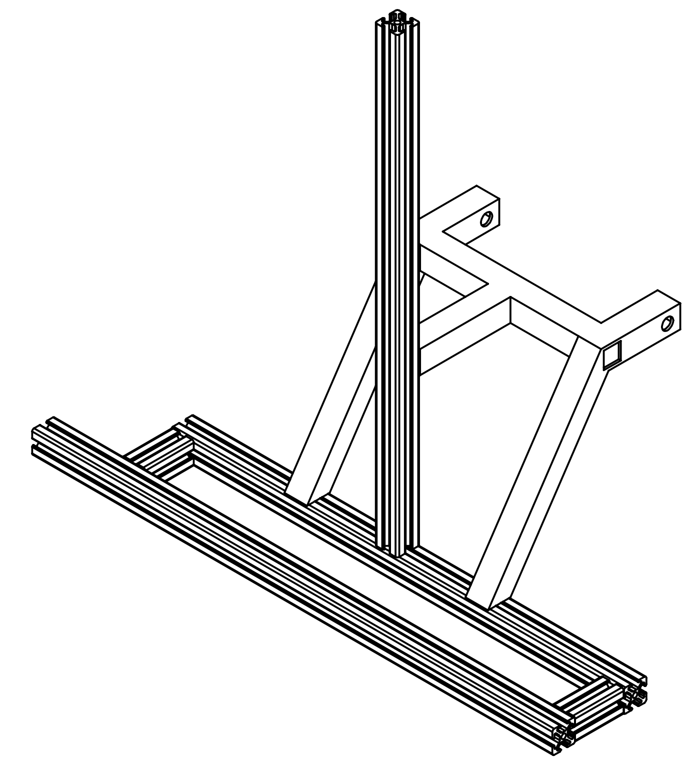


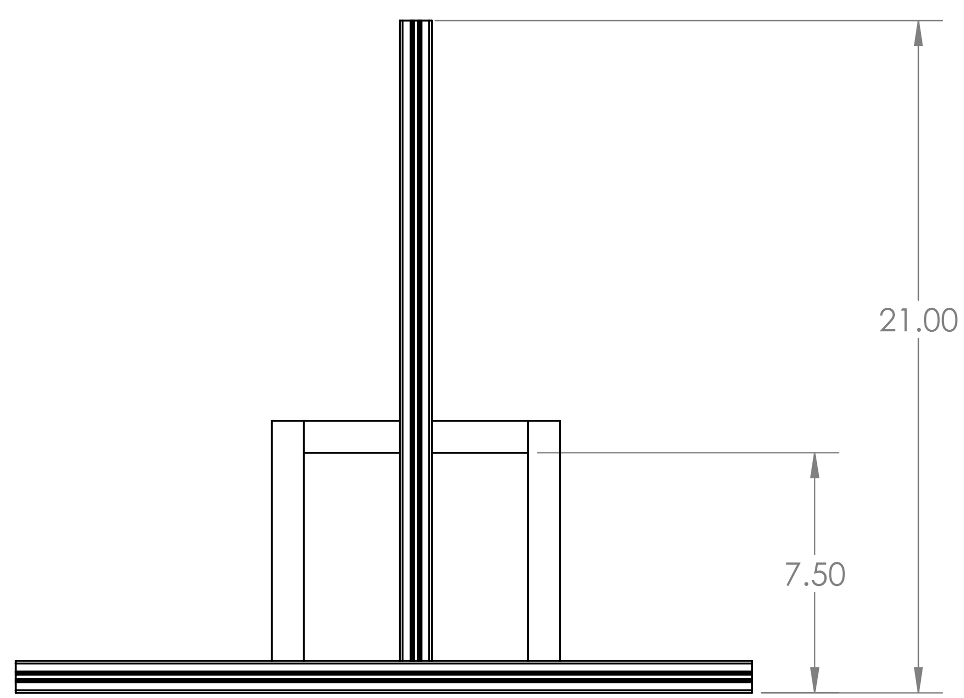


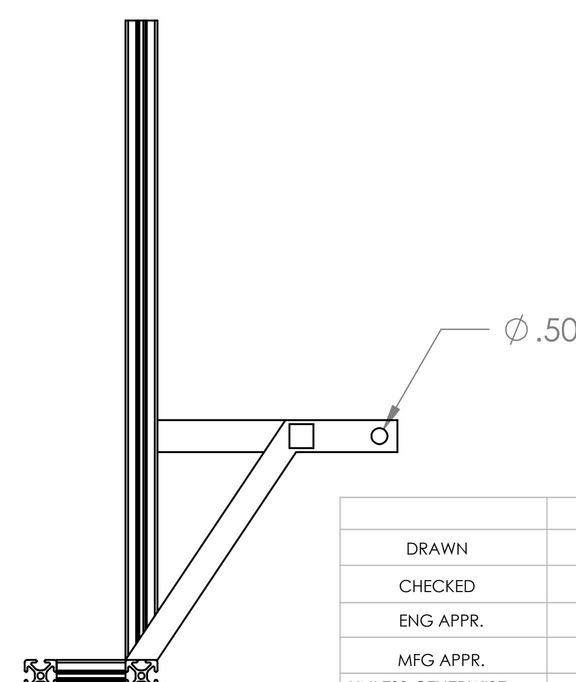
	NAME	DATE	
DRAWN	STEVEN MARKHAM	18 APR 2017	BYU MARS ROVER 2017
CHECKED	BRIAN JACKSON	4/19/17	
ENG APPR.	BRIAN JACKSON	4/19/17	PART #: MRP-SCI-0001 R1
MFG APPR.			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B PART NAME: Base Plate REV 1
		MATERIAL ALUMINUM 6061T6	
		FINISH 250 uin	SCALE: 1:2 SHEET 1 OF 1

NOTE: ALL SHADED MEMBERS ARE MADE FROM 80/20
1"X1" ALUMINIUM BAR STOCK.
THE REMAINING MEMBERS ARE MADE FROM 1"x1" ALUMINIUM
6061T6 BAR STOCK.
THE COMPONENT SHOULD BE WELDED TOGETHER,

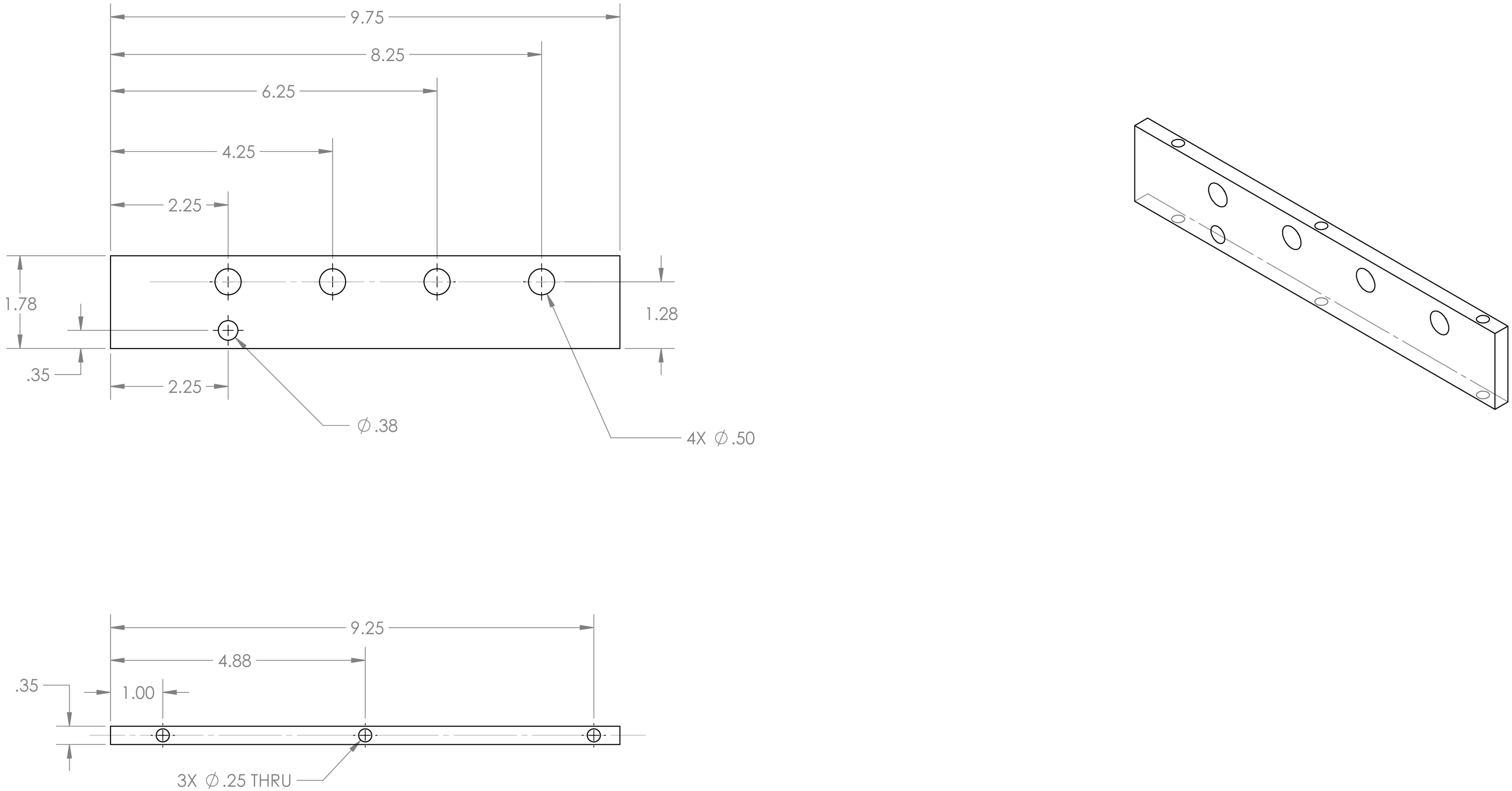






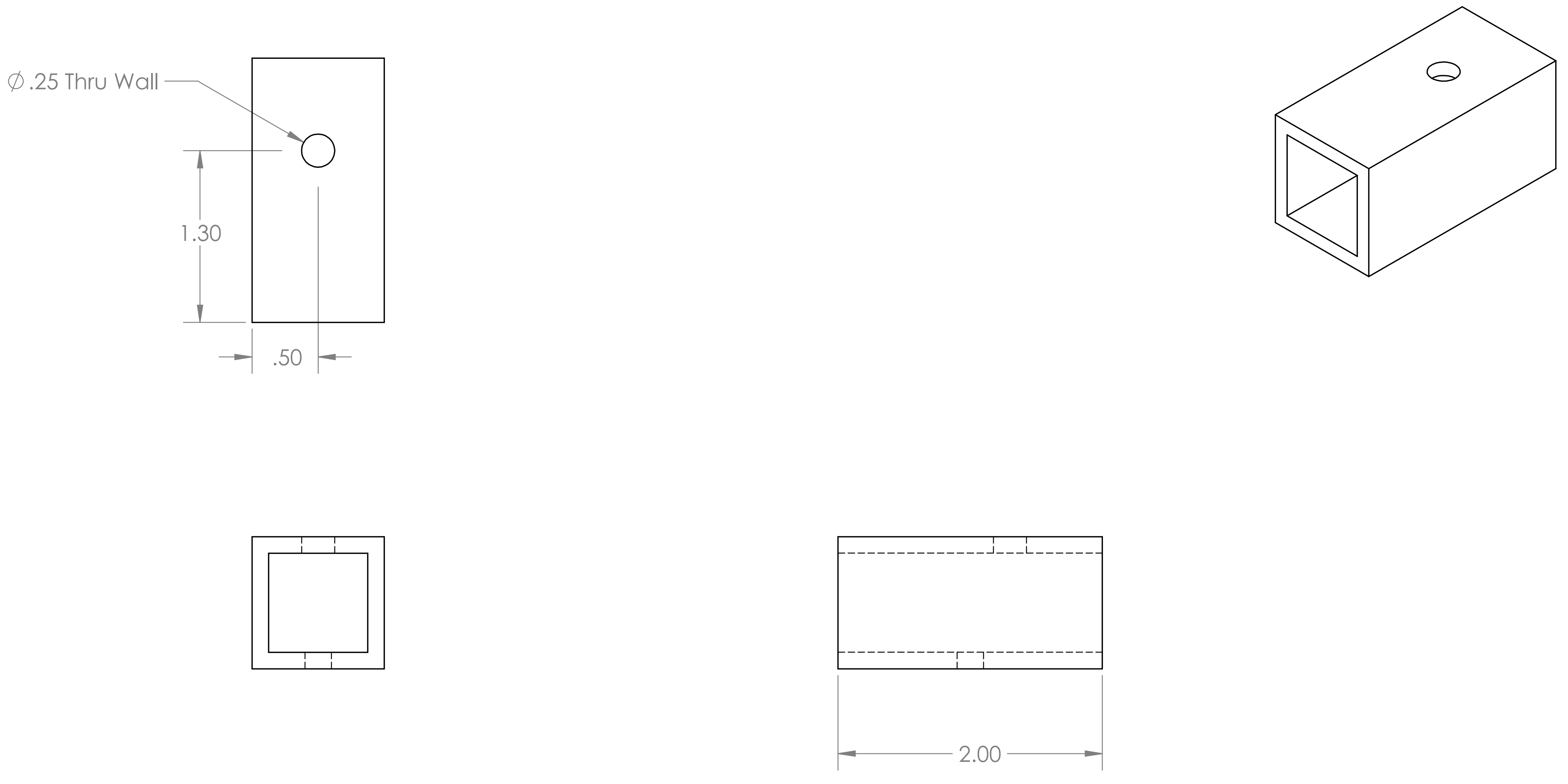


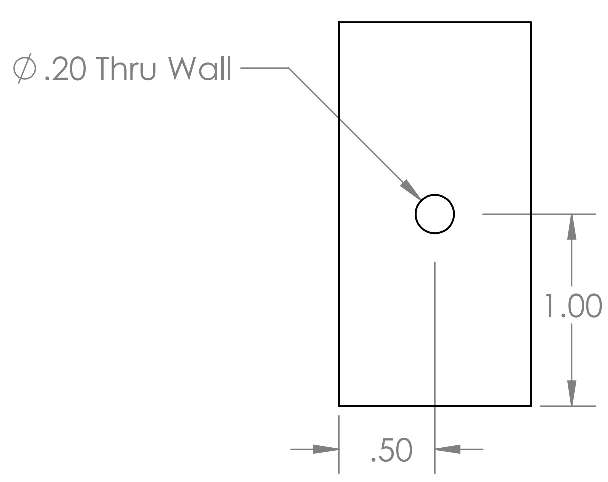
	NAME	DATE	BYU MARS ROVER 2017
DRAWN	STEVEN MARKHAM	18 APR 2017	
CHECKED	BRIAN JACKSON	19 APR 2017	
ENG APPR.	BRIAN JACKSON	19 APR 2017	PART #: MRP-SCI-0002
MFG APPR.			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B
		MATERIAL ALUMINIUM 6061T6	PART NAME: Rocker Arm
		FINISH 250 uIN	REV 1
			SCALE: 1:8
			SHEET 1 OF 1



	NAME	DATE	BYU MARS ROVER 2017
DRAWN	STEVEN MARKHAM	18 APR 2017	
CHECKED	BRIAN JACKSON	4/19/17	
ENG APPR.	BRIAN JACKSON	4/19/17	PART #: MRP-SCI-0003 R1
MFG APPR.			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B — PART NAME: Tool Holder — REV 1
		MATERIAL ALUMINIUM 6061T6	
		FINISH 250 uin	SCALE: 1:2 — SHEET 1 OF 1

Notes:
1. PART IS MADE FROM 6063-T52 ALUMINUM 1"X1" SQUARE TUBE WITH 1/8" THICK WALLS
2. MATERIAL PURCHASED FROM METALS DEPOT
3. PART NUMBER: T3118





	NAME	DATE
DRAWN	ALEX JENSEN	23 MAR 2017
CHECKED	BRIAN JACKSON	19 APR 2017
ENG APPR.	BRIAN JACKSON	19 APR 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6063-T52 ALUMINUM

FINISH: 150 µin

BYU MARS ROVER 2017

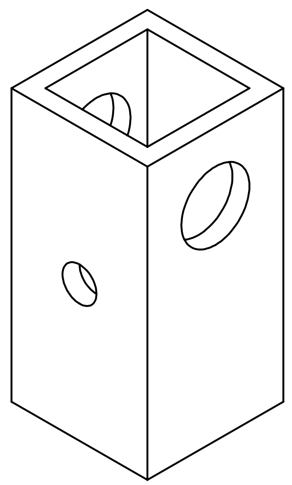
PART #: MRP-SCI-0004 R1

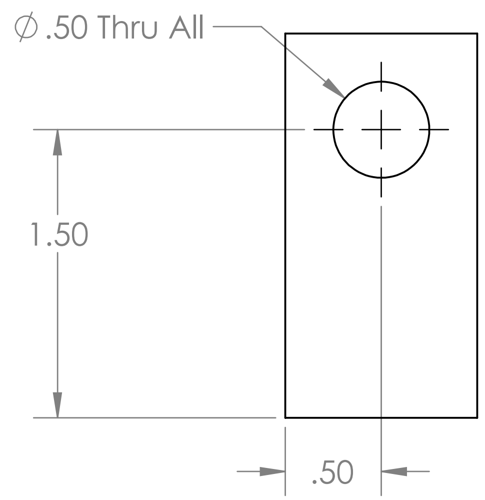
SIZE	PART NAME:	REV
B	RockerBaseBackMount	1

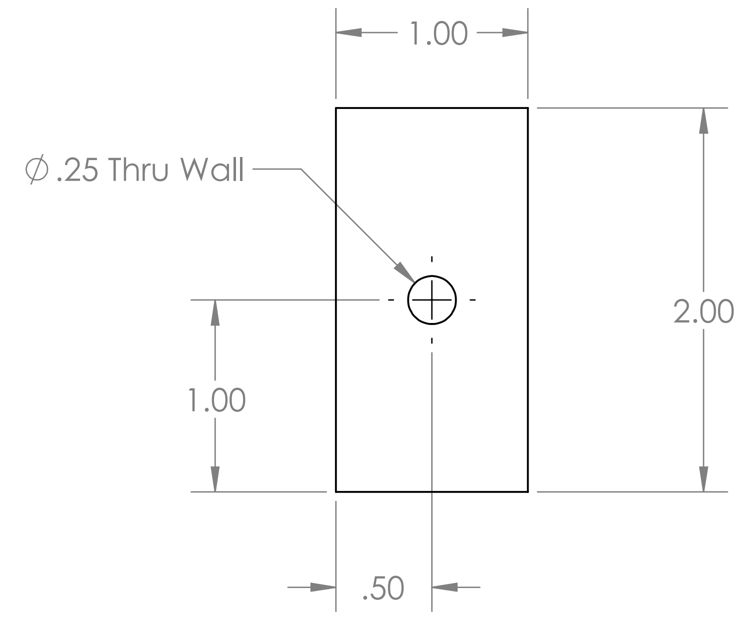
SCALE: 1:1 | SHEET 1 OF 1

NOTES:

1. PART IS MADE FROM 6063-T52 ALUMINUM 1" x 1" SQUARE TUBE WITH 1/8" THICK WALLS
2. MATERIAL PURCHASED FROM METALS DEPOT
3. PART NUMBER: T3118

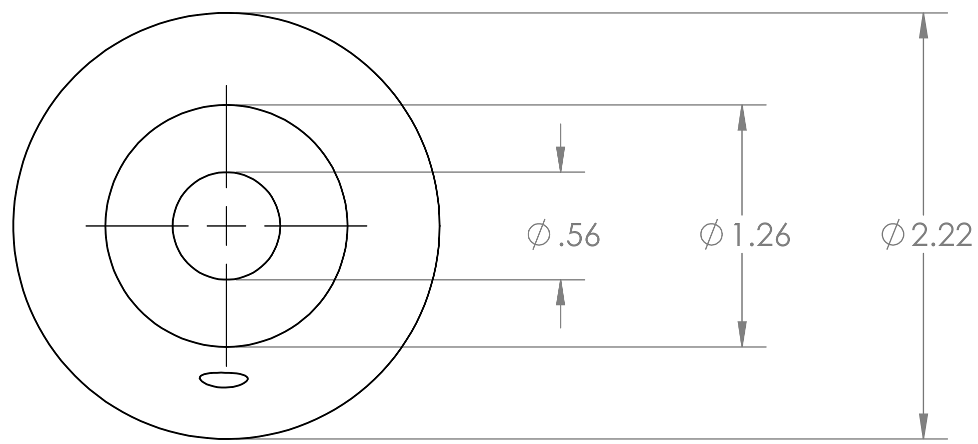


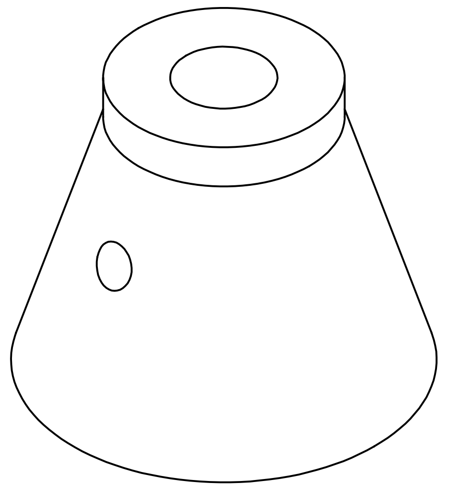


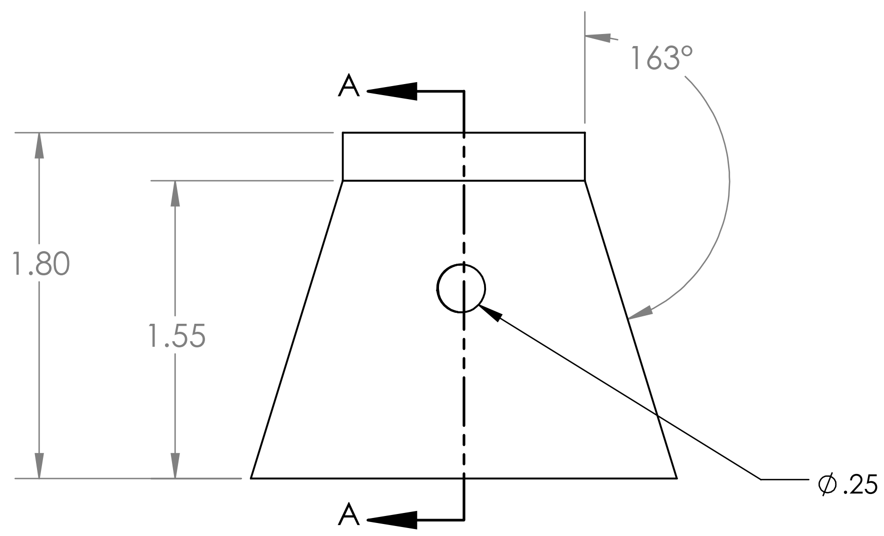


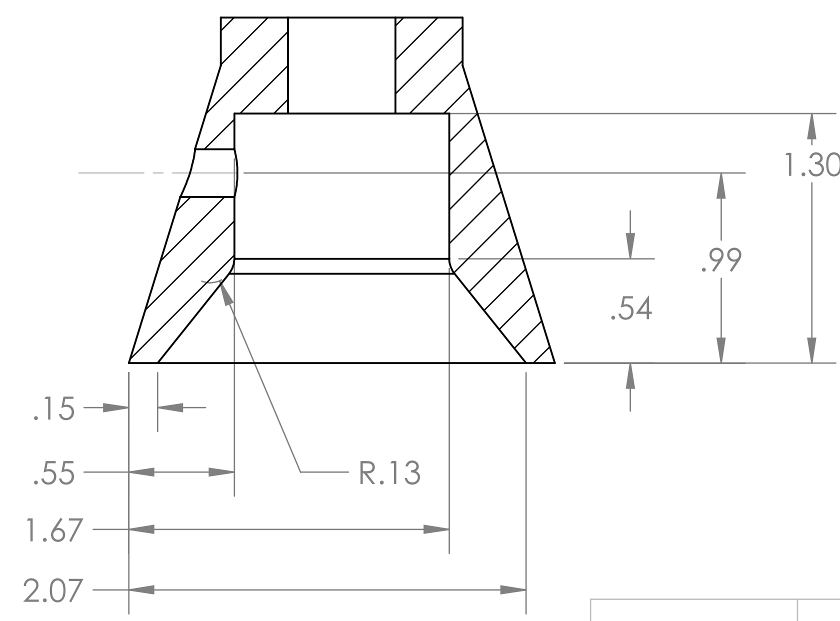
	NAME	DATE	
DRAWN	ALEX JENSEN	23 MAR 2017	BYU MARS ROVER 2017
CHECKED	BRIAN JACKSON	19 APR 2017	
ENG APPR.	BRIAN JACKSON	19 APR 2017	
MFG APPR.			PART #: MRP-SCI-0005 R1
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE: B — PART NAME: RockerBaseFrontMount — REV: 1
		MATERIAL: 6063-T52 ALUMINUM	
		FINISH: 250 µin	SCALE: 1:1 — SHEET 1 OF 1

NOTE: THIS PART SHOULD BE 3D PRINTED









SECTION A-A

	NAME	DATE
DRAWN	Steven Markham	18 APR 2017
CHECKED	Brian Jackson	19 APR 2017
ENG APPR.	Brian Jackson	19 APR 2017
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

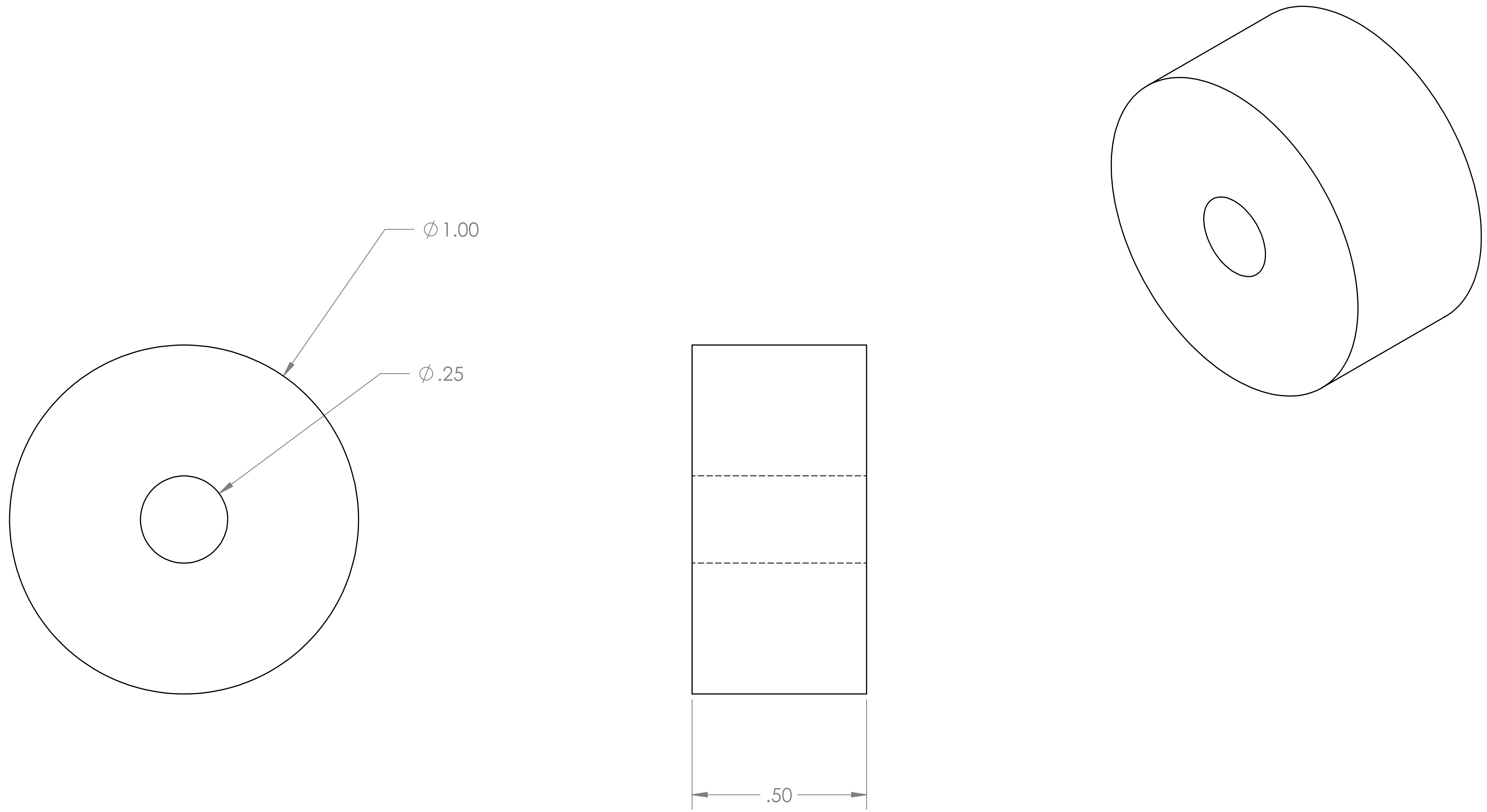
MATERIAL: ABS PLASTIC

FINISH: 250 UIN

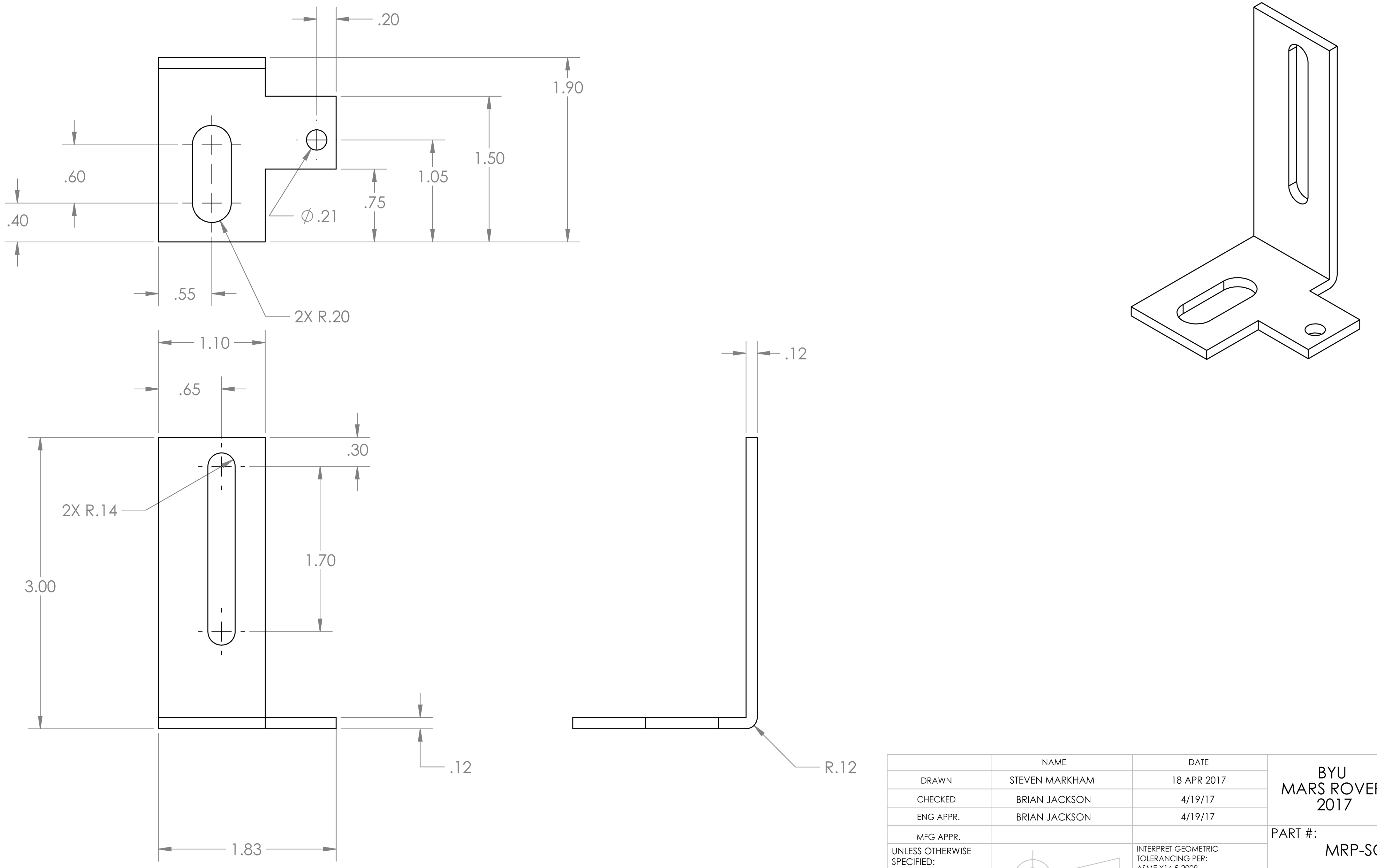
BYU MARS ROVER 2017

PART #: MRP-SCI-0006 R1

SIZE	PART NAME:	REV
B	Drill Alignment	1
SCALE: 1:1		SHEET 1 OF 1



	NAME	DATE	
DRAWN	ALEX JENSEN	23 MAR 2017	BYU MARS ROVER 2017
CHECKED	BRIAN JACKSON	19 APR 2017	
ENG APPR.	BRIAN JACKSON	19 APR 2017	
MFG APPR.			PART #: MRP-SCI-0007 R1
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B PART NAME: RocketBaseSpacer REV 1
		MATERIAL 6061-T6 ALUMINUM	
		FINISH 250 μin	SCALE: 3:1 SHEET 1 OF 1



	NAME	DATE
DRAWN	STEVEN MARKHAM	18 APR 2017
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: ALUMINIUM 6061T6

FINISH: 250 UIN

BYU
MARS ROVER
2017

PART #: MRP-SCI-0008 R1

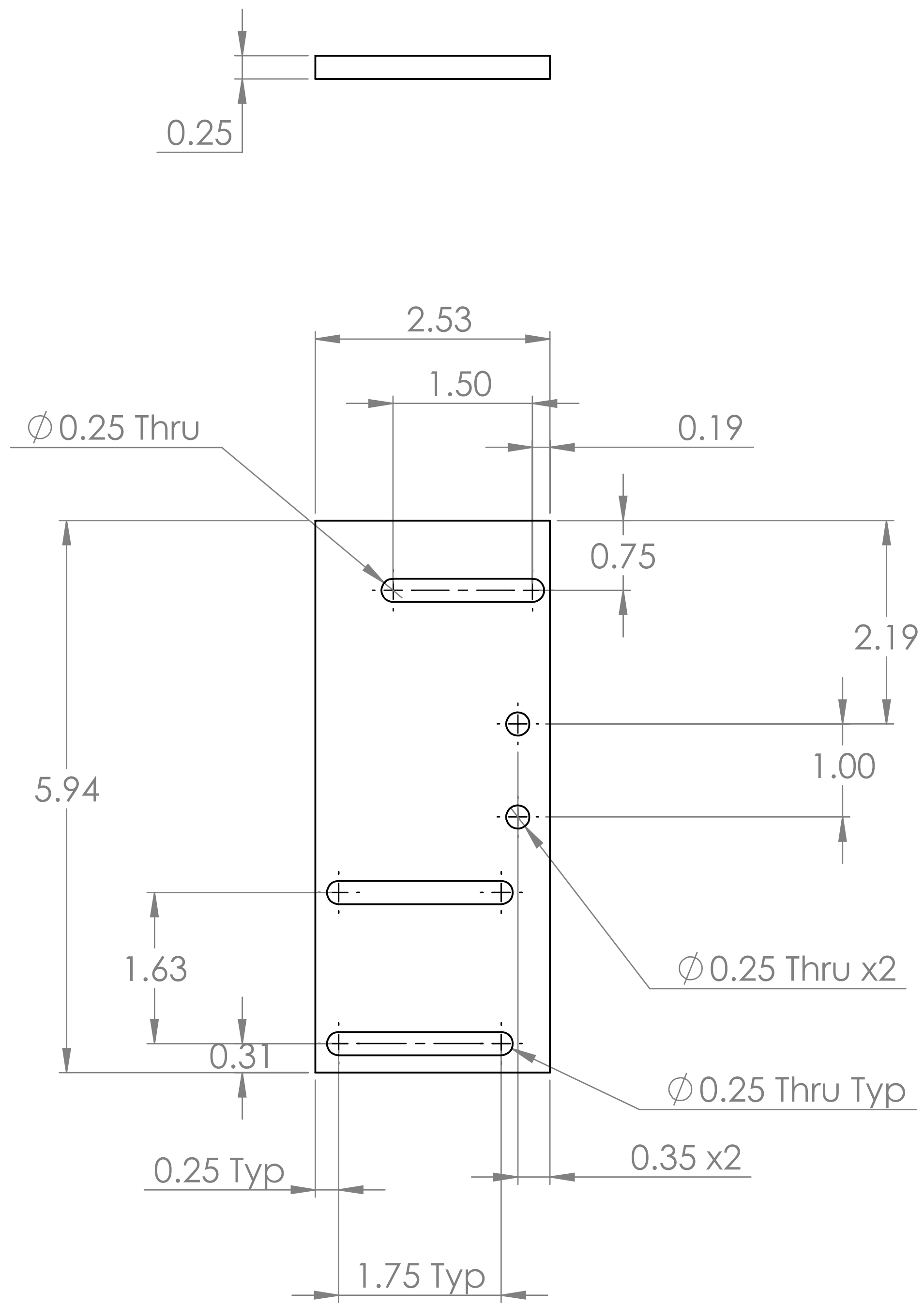
SIZE: **B**

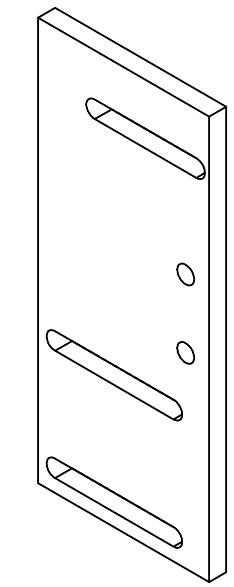
PART NAME: PlateConnector

REV: 1

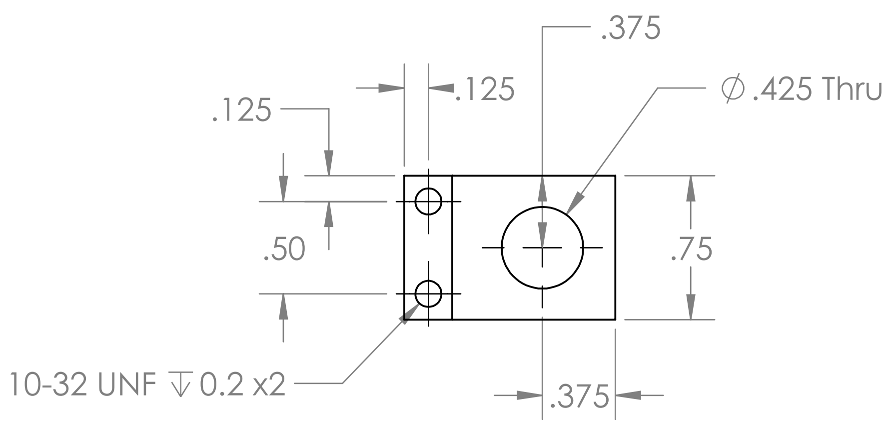
SCALE: 1:1

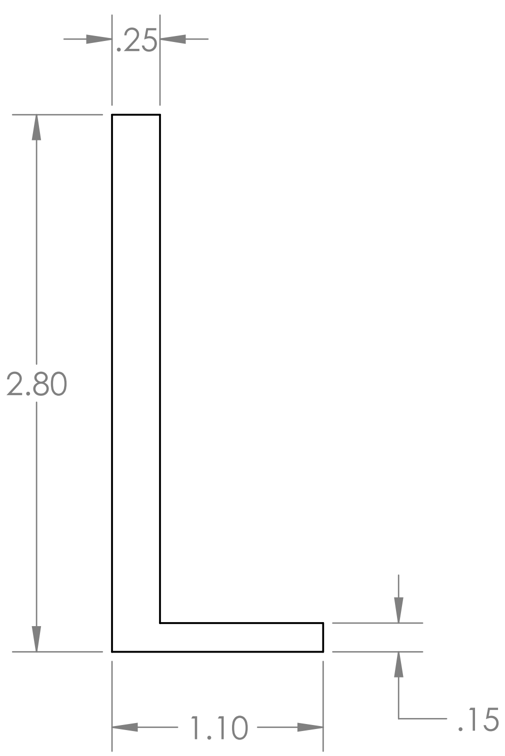
SHEET 1 OF 1

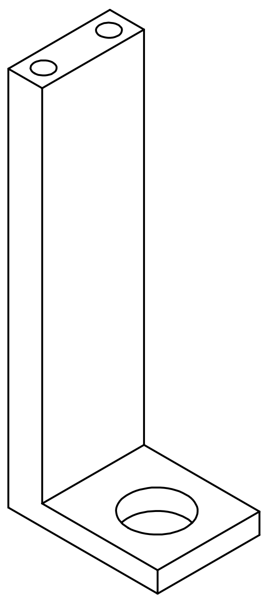




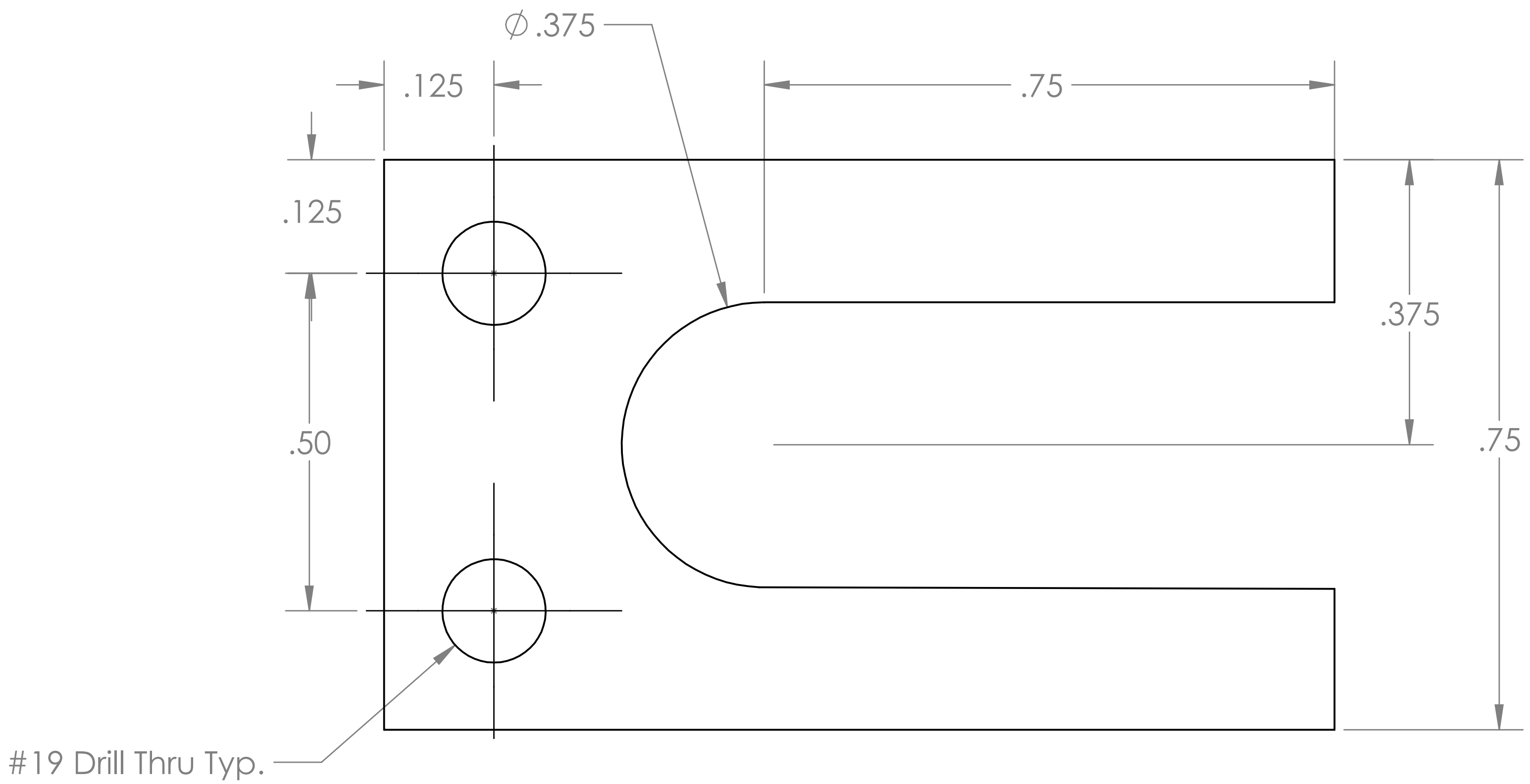
	NAME	DATE	
DRAWN	RICHARD LIVINGSTON	4/18/17	BYU MARS ROVER 2017
CHECKED	BRIAN JACKSON	4/19/17	
ENG APPR.	BRIAN JACKSON	4/19/17	PART #: MRP-SCI-0009
MFG APPR.			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X ± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B PART NAME: Motor Brace REV 1
		MATERIAL 6061-T6 ALUMINUM	
		FINISH 150 µin	SCALE: 1:2 SHEET 1 OF 1

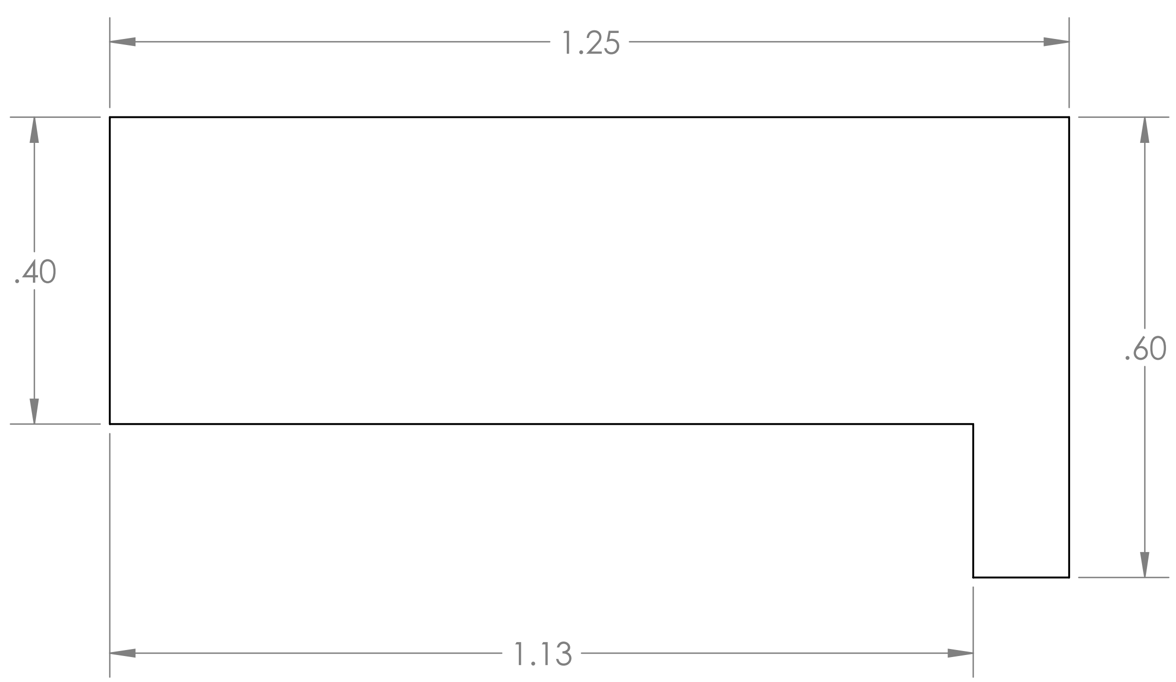


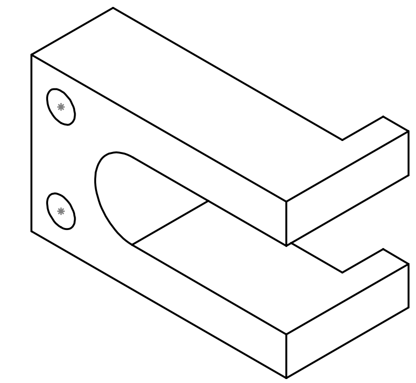




	NAME	DATE	
DRAWN	RICHARD LIVINGSTON	4/13/17	BYU MARS ROVER 2017
CHECKED	BRIAN JACKSON	4/19/17	
ENG APPR.	BRIAN JACKSON	4/19/17	
MFG APPR.			PART #: MRP-SCI-0013
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: X.X ± .03 X.XX ± .01 X.XXX ± .005 ANGULAR X.X± 1.0	DO NOT SCALE DRAWING	INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	SIZE B, PART NAME: temp mount 1, REV 1
		MATERIAL 6061-T6 ALUMINUM	
		FINISH 150 µin	SCALE: 1:1, SHEET 1 OF 1







	NAME	DATE
DRAWN	Richard Livingston	4/13/17
CHECKED	Brian Jackson	4/18/17
ENG APPR.	Brian Jackson	4/18/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Aluminum

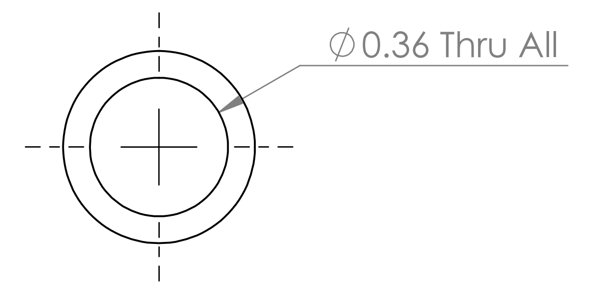
FINISH: 150 µin

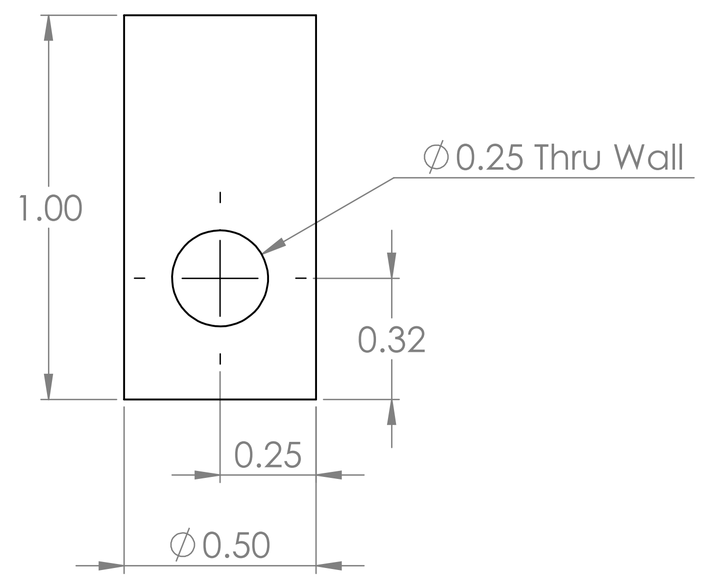
BYU
MARS ROVER
2017

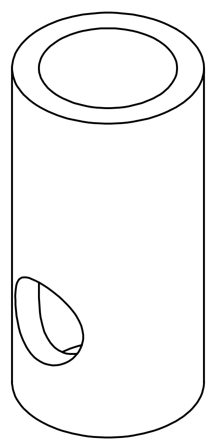
PART #: MRP-SCI-0014

SIZE	PART NAME:	REV
B	Temp sensor top	1

SCALE: 4:1 | SHEET 1 OF 1







	NAME	DATE
DRAWN	RICHARD LIVINGSTON	4/18/17
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6061-T6 ALUMINUM

FINISH 150 μin

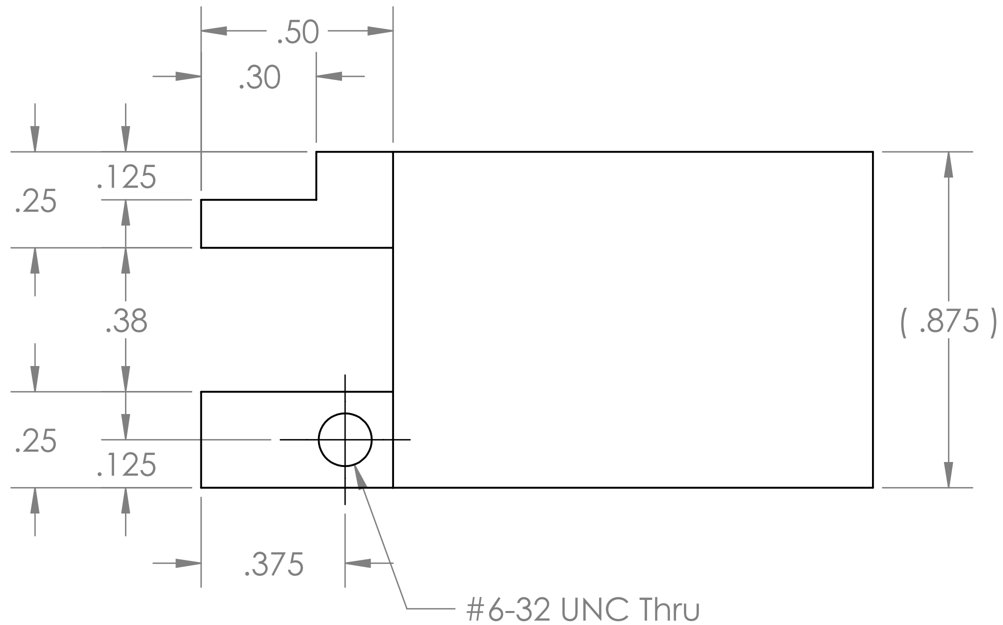
BYU
MARS ROVER
2017

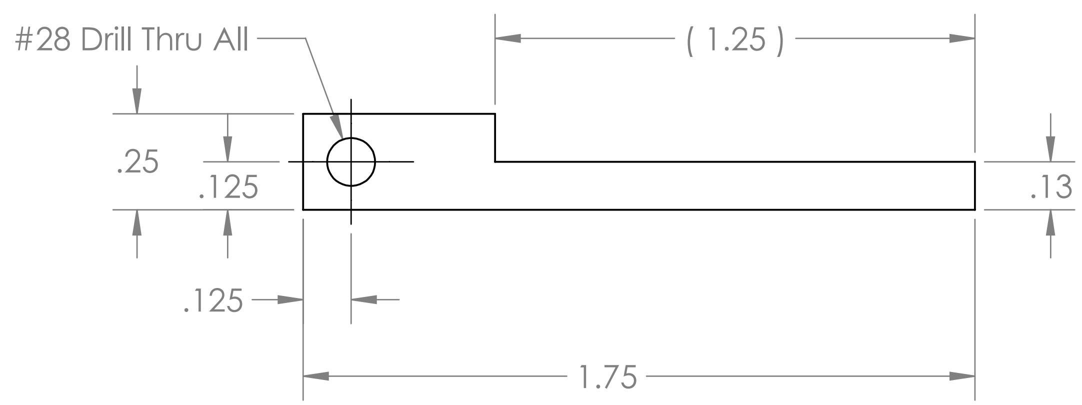
PART #: MRP-SCI-0015

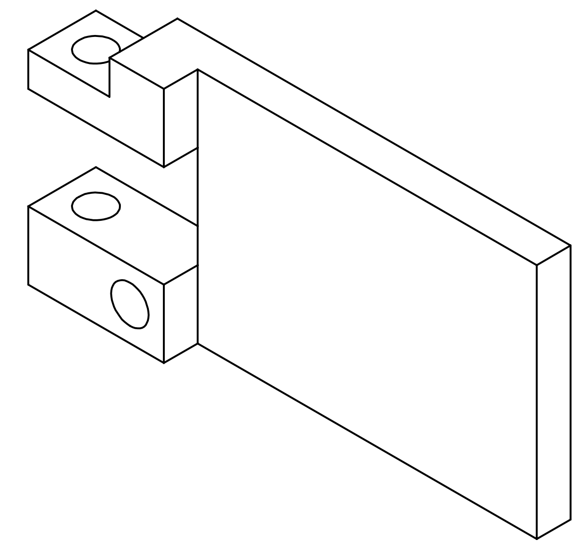
SIZE B | PART NAME: DrillBearing | REV 1

SCALE: 2:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED







	NAME	DATE
DRAWN	Richard	4/14/17
CHECKED	Brian	4/18/17
ENG APPR.	Brian	4/18/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL 6061 Aluminum

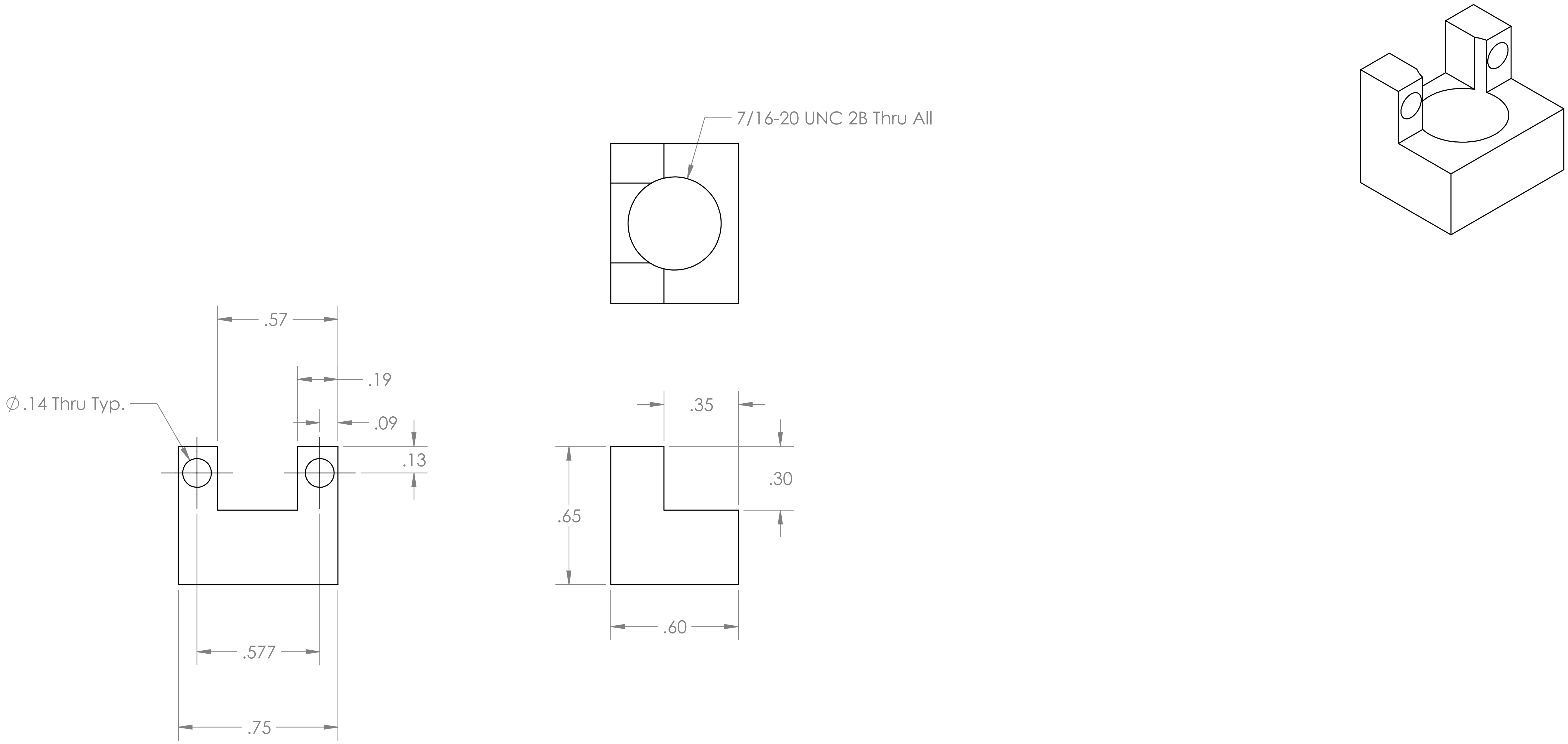
FINISH 500 µin

BYU MARS ROVER 2017

PART #: MRP-SCI-0016

SIZE **B** | PART NAME: Dirt Holder Flap | REV 1

SCALE: 2:1 | SHEET 1 OF 1



	NAME	DATE
DRAWN	RICHARD LIVINGSTON	4/18/17
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6061-T6 ALUMINUM

FINISH
150 μin

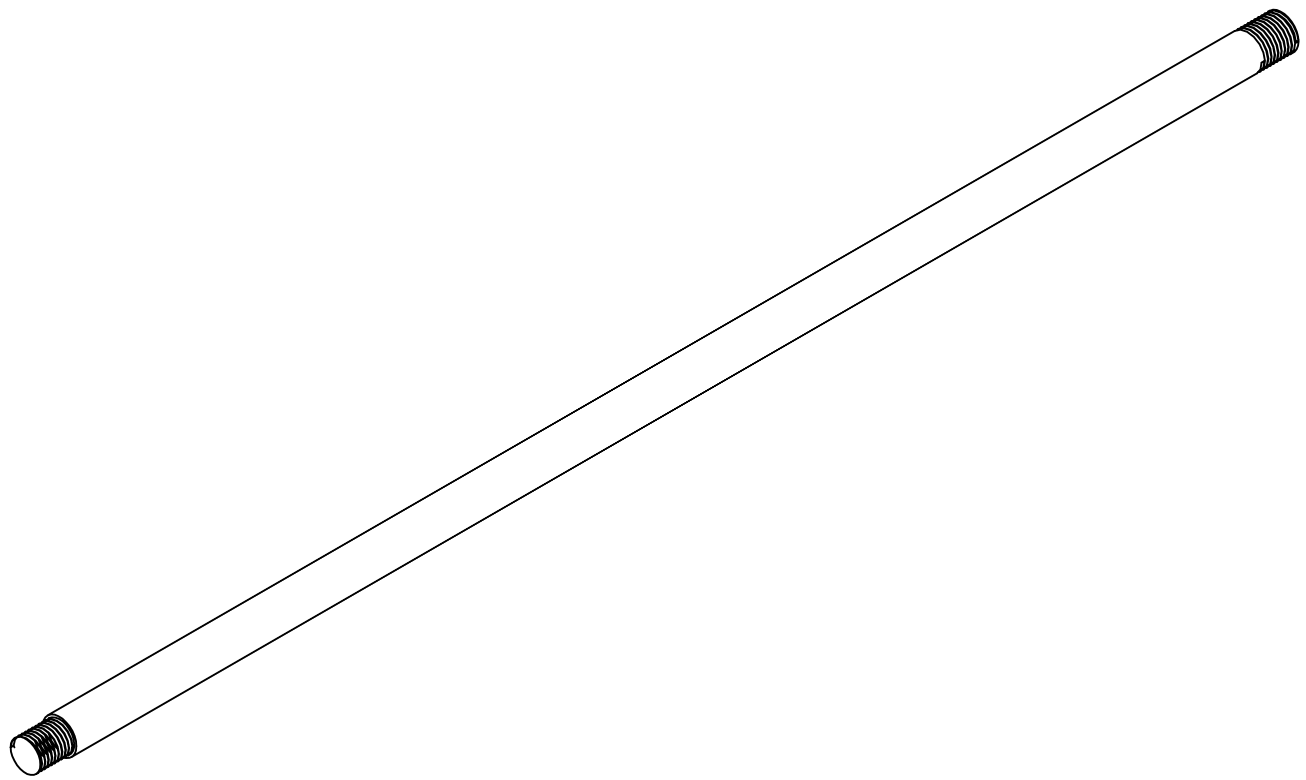
BYU
MARS ROVER
2017

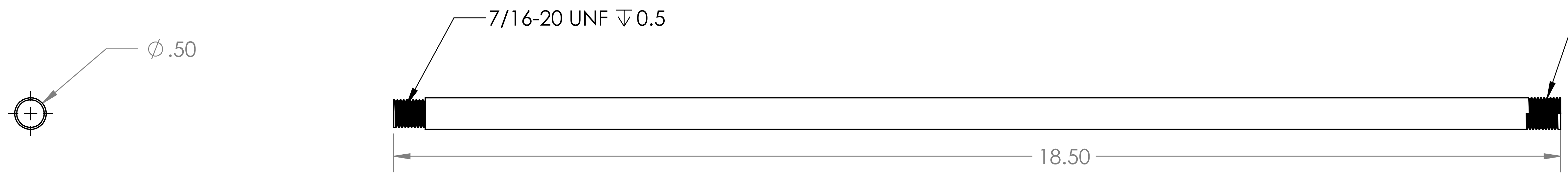
PART #:
MRP-SCI-0017 R1

SIZE B | PART NAME: Humidity Holder | REV 1

SCALE: 2:1 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	Richard	4/15/17
CHECKED	Brian	4/18/17
ENG APPR.	Brian	4/18/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061 Aluminum

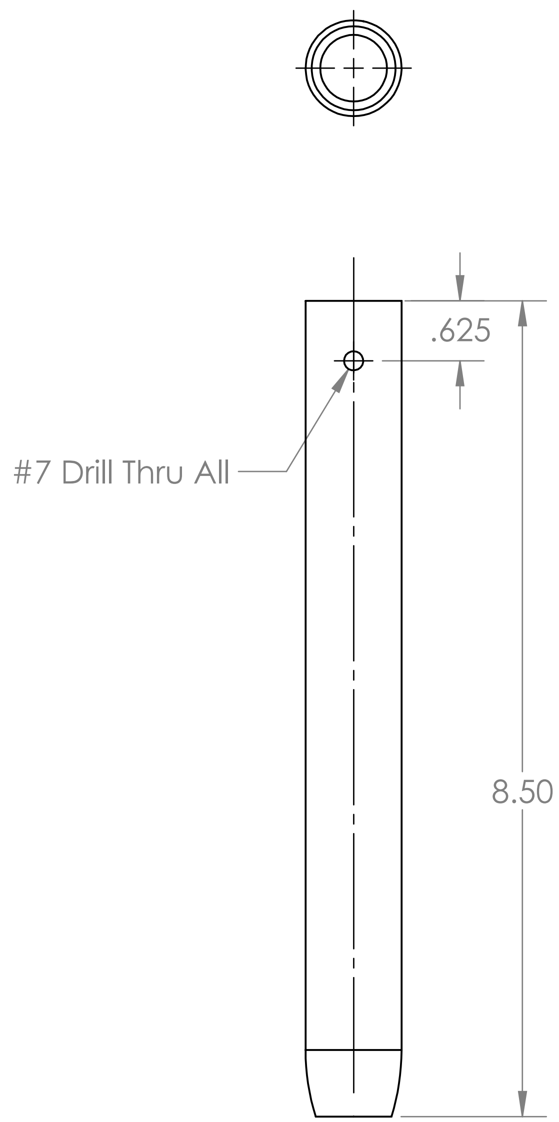
FINISH: 500 μin

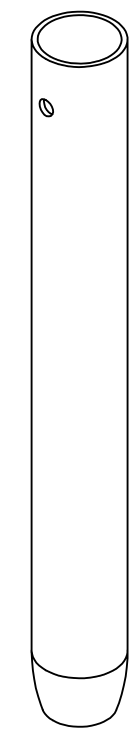
BYU
MARS ROVER
2017

PART #: MRP-SCI-0018

SIZE	PART NAME:	REV
B	Humidity Rod	1
SCALE: 1:3		SHEET 1 OF 1

Notes:
1. Auger purchased on Amazon from Advanced Simplicity as "Soil Sampler Tube Probe"
2. Part Number: B01M7RDBXD
3. Modifications include trimming down the length and drilling a hole in the side.





REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

	NAME	DATE
DRAWN	Richard	4/15/17
CHECKED	Brian	4/18/17
ENG APPR.	Brian	4/18/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL N/A

FINISH N/A

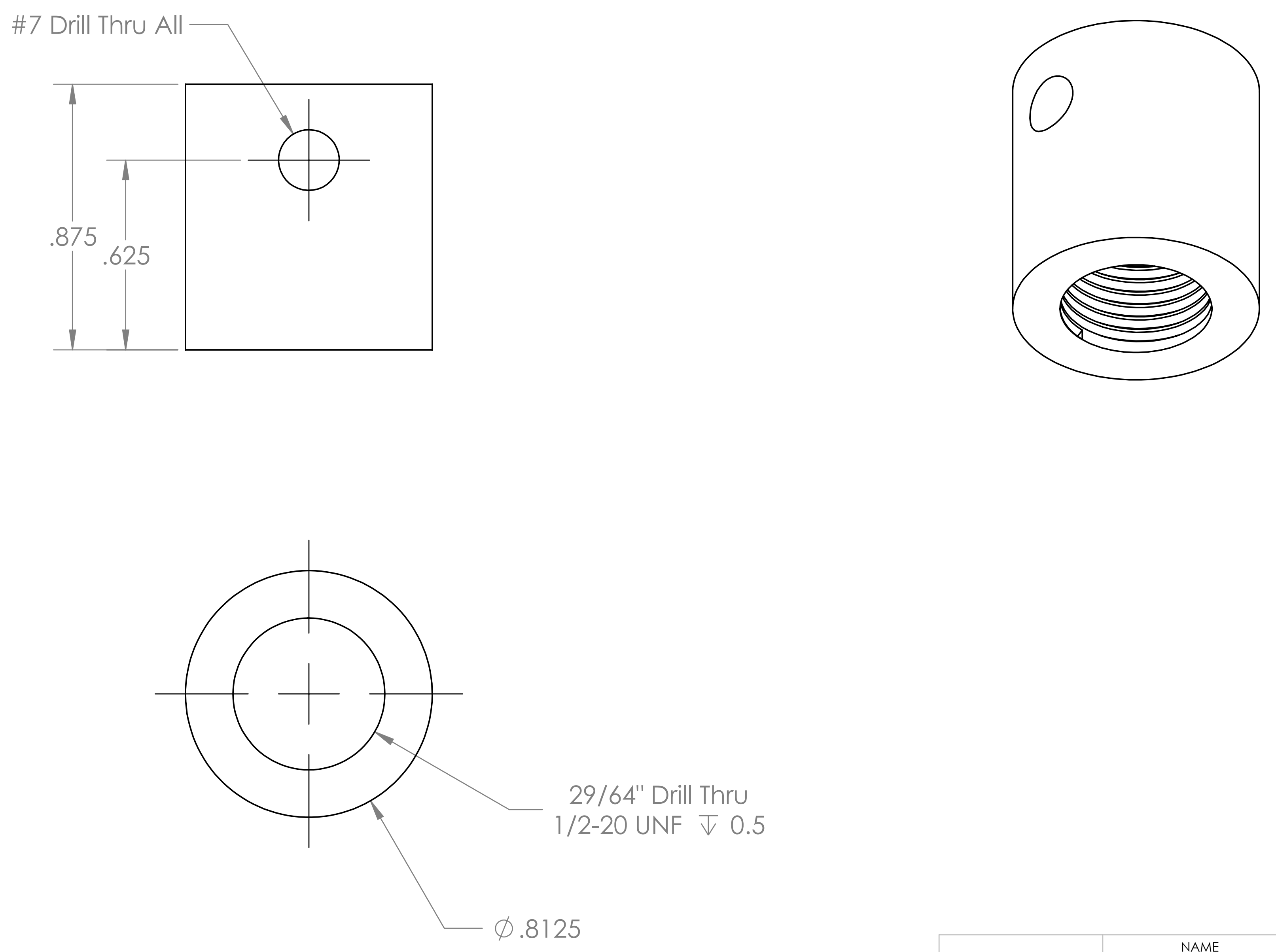
BYU MARS ROVER 2017

PART #: MRP-SCI-0019

SIZE B | PART NAME: Auger | REV 1

SCALE: 1:2 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	Richard	4/15/17
CHECKED	Brian	4/18/17
ENG APPR.	Brian	4/18/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6061 Aluminum

FINISH
150 µin

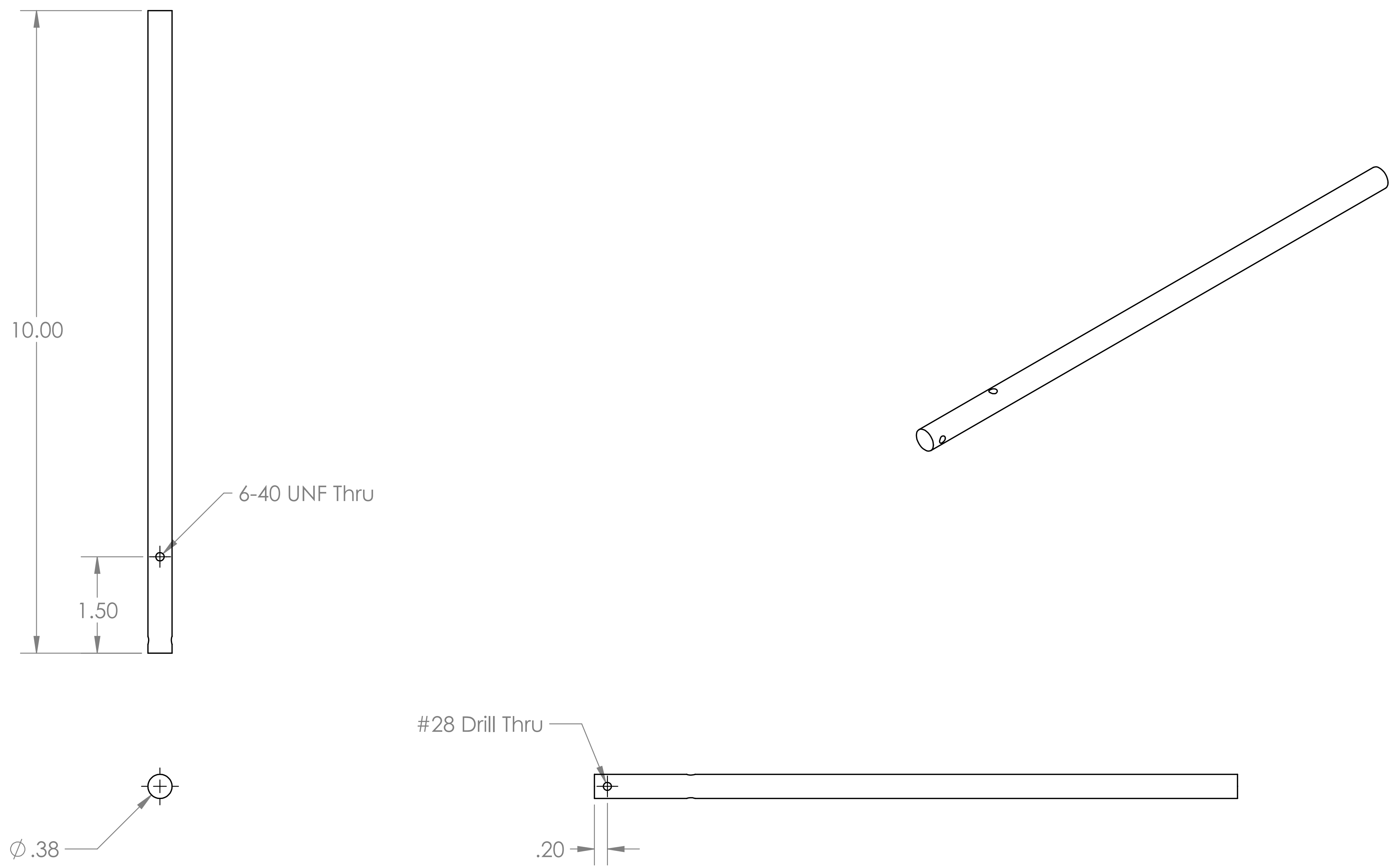
BYU
MARS ROVER
2017

PART #:
MRP-SCI-0020

SIZE	PART NAME:	REV
B	Auger Adapter	1

SCALE: 2:1 SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED



	NAME	DATE
DRAWN	RICHARD LIVINGSTON	4/14/17
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL
6061-T6 Aluminum

FINISH
500 µin

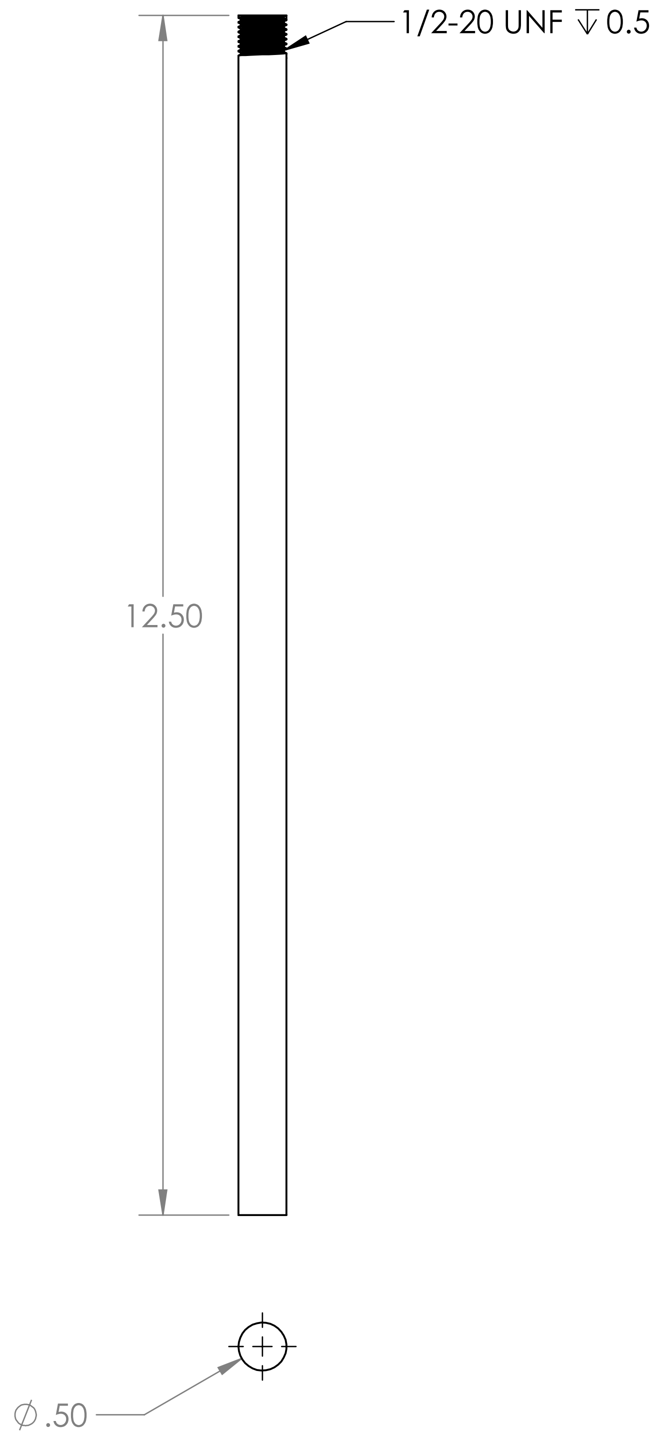
BYU
MARS ROVER
2017

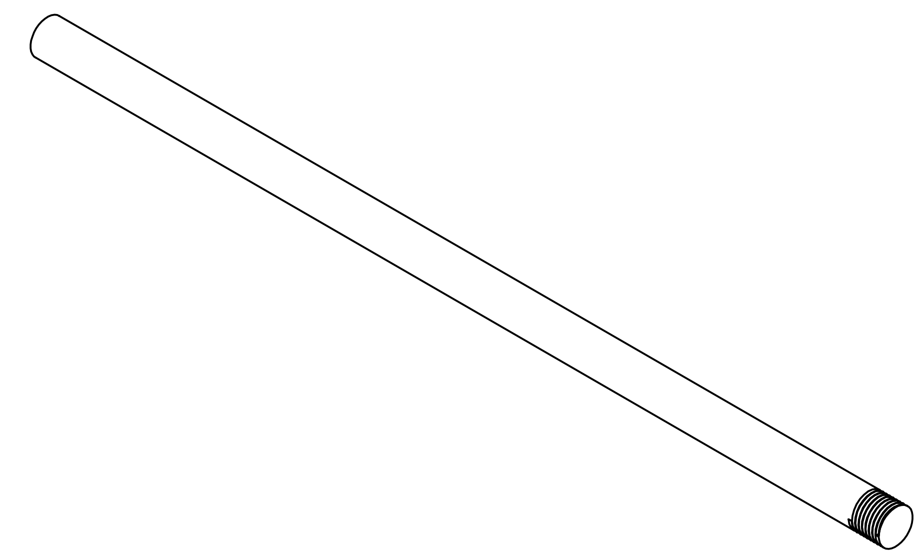
PART #:
MRP-SCI-0021

SIZE B | PART NAME: dirtrod | REV 1

SCALE: 1:0.8 | SHEET 1 OF 1

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED





	NAME	DATE
DRAWN	RICHARD LIVINGSTON	4/15/17
CHECKED	BRIAN JACKSON	4/19/17
ENG APPR.	BRIAN JACKSON	4/19/17
MFG APPR.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
X.X ± .03
X.XX ± .01
X.XXX ± .005
ANGULAR X.X ± 1.0

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009

MATERIAL: 6061-T6 ALUMINUM

FINISH: 250 µin

BYU MARS ROVER 2017

PART #: MRP-SCI-0022

SIZE	PART NAME:	REV
B	Auger Rod	1

SCALE: 1:4 | SHEET 1 OF 1

I.6 Navigation Documentation

Documents MRD-DE-0002 (section G.2) and MRD-DE-0007 (section G.6) provide detailed descriptions of the navigation design as well as the design for the ROS architecture used to control the rover.

I.7 Communication Documentation

The communication system is described in test report MRD-DE-0006 R1 in section G.5.

I.8 Software Documentation

A complete copy of all our code is on the attached optical disk.

ROS Documentation

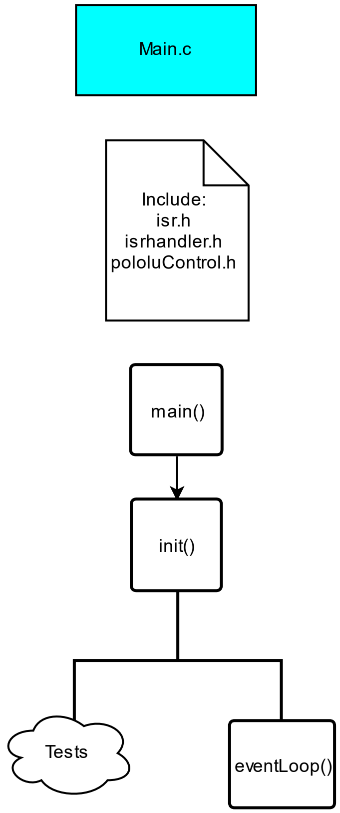
We have included an overview of our ROS code in section G.6 and a complete copy of our code is contained on the attached disk. The most up-to-date version of our code is always at `https://github.com/BYUMarsRover/BYU-Mars-Rover`.

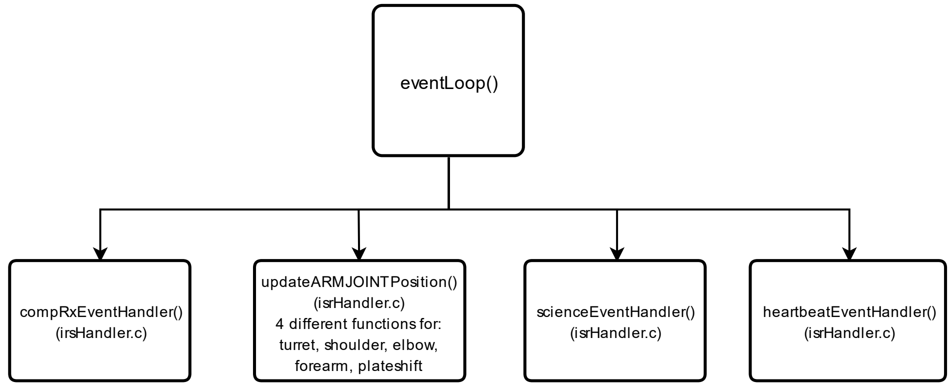
PSoC Code

2017 PSoC Code FlowChart

Drafted by
Taylor Welker
2016-2017

The purpose of this document is to assist in understanding the code that is running on the PSoC. Each file grouping (a source .c file with its corresponding .h file) is described at a high level in order to fascilitate understanding of the overall architecture to the various state machines and functions that govern the wheels, arm/science joints, etc...





The Main.c file is what actually runs on the PSoC It initializes all of the different processes, as well as call "eventLoop()" within a while(1) loop.

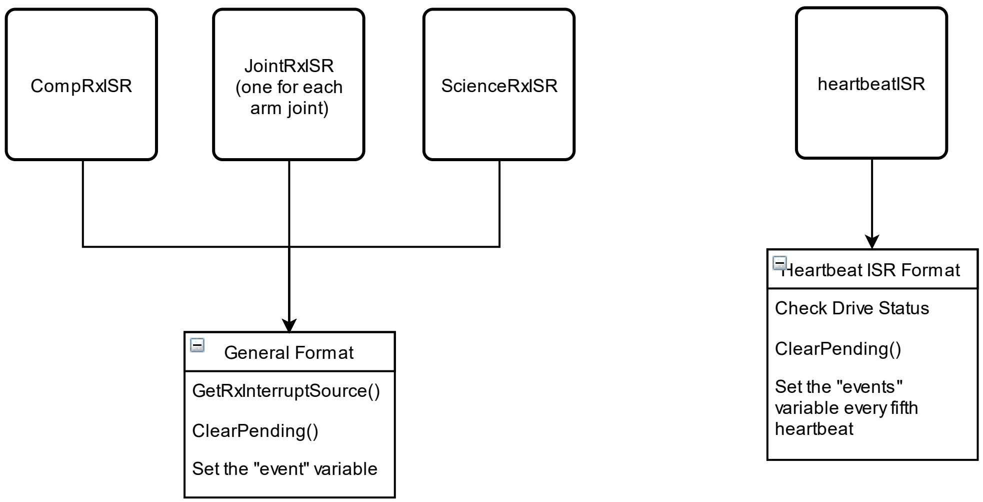
The eventLoop() chooses to do one of 4 types of actions based on the variable "events". "events" is an event group that keeps track of messages that the Jetson will send. (see isr.c for details).

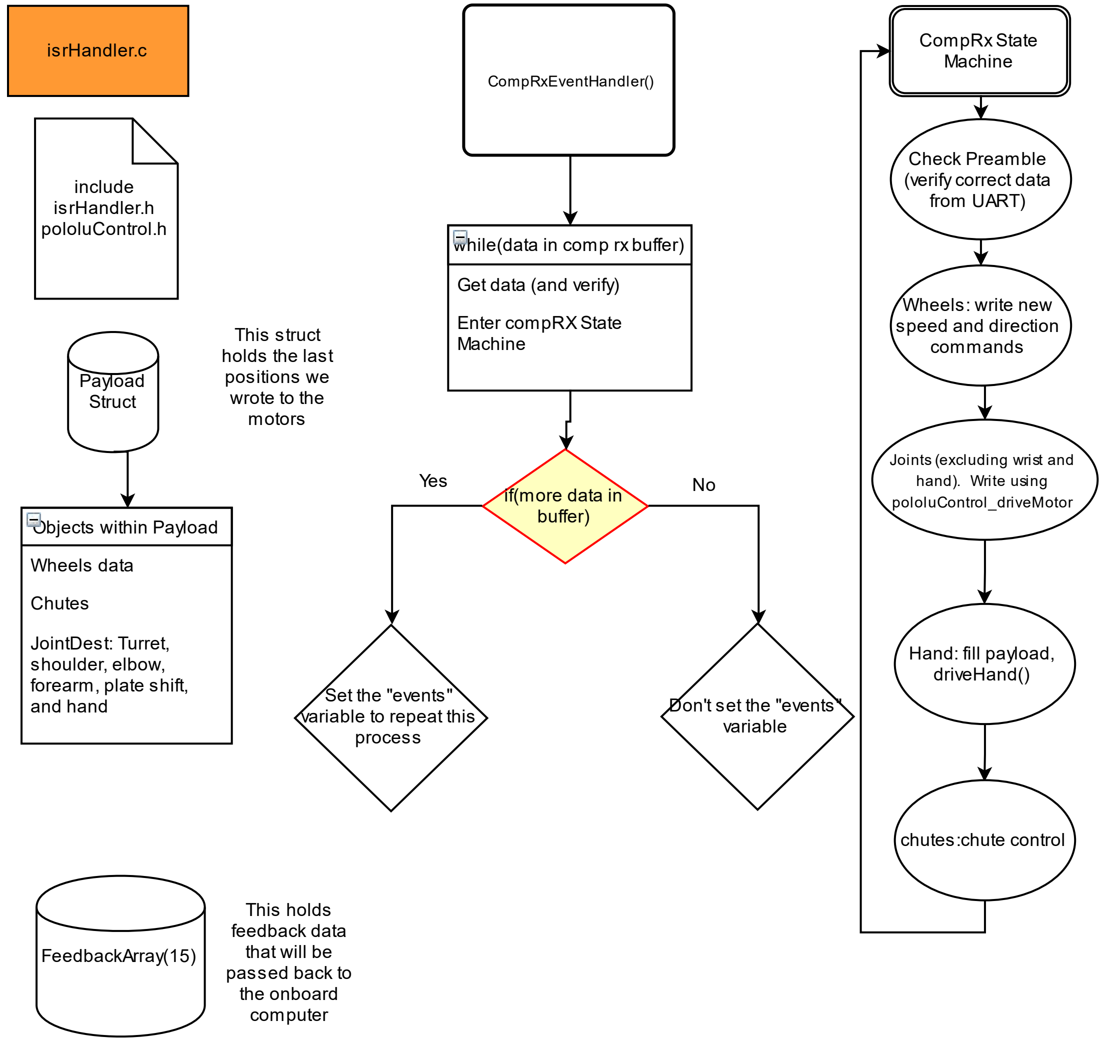
Additionally, this file is configured to perform a variety of tests on the internal systems of the rover. While these tests are useful for testing the conncections between the PSoC and the arm/science and wheel modules, when in competition, these tests are commented out.

isr.c

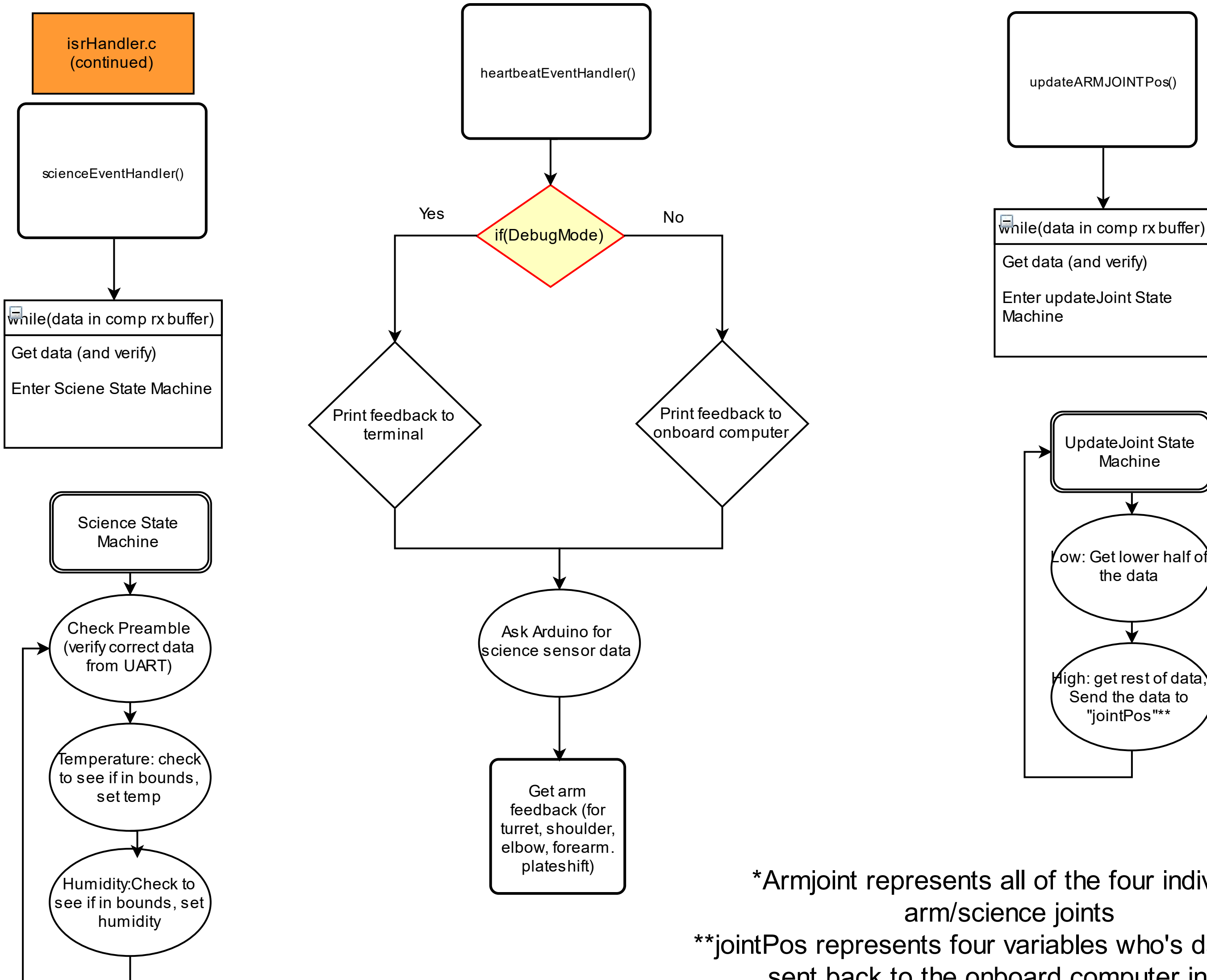
Include:
isr.h
isrhandler.h

Your basic isr file. All it does is find the source of the interrupt, clear the interrupt, and then sets the corresponding bit within the "events" variable. The only real anomaly is the heartbeat isr. In that one, we wait every 5 heartbeat interrupts before setting the event flag.

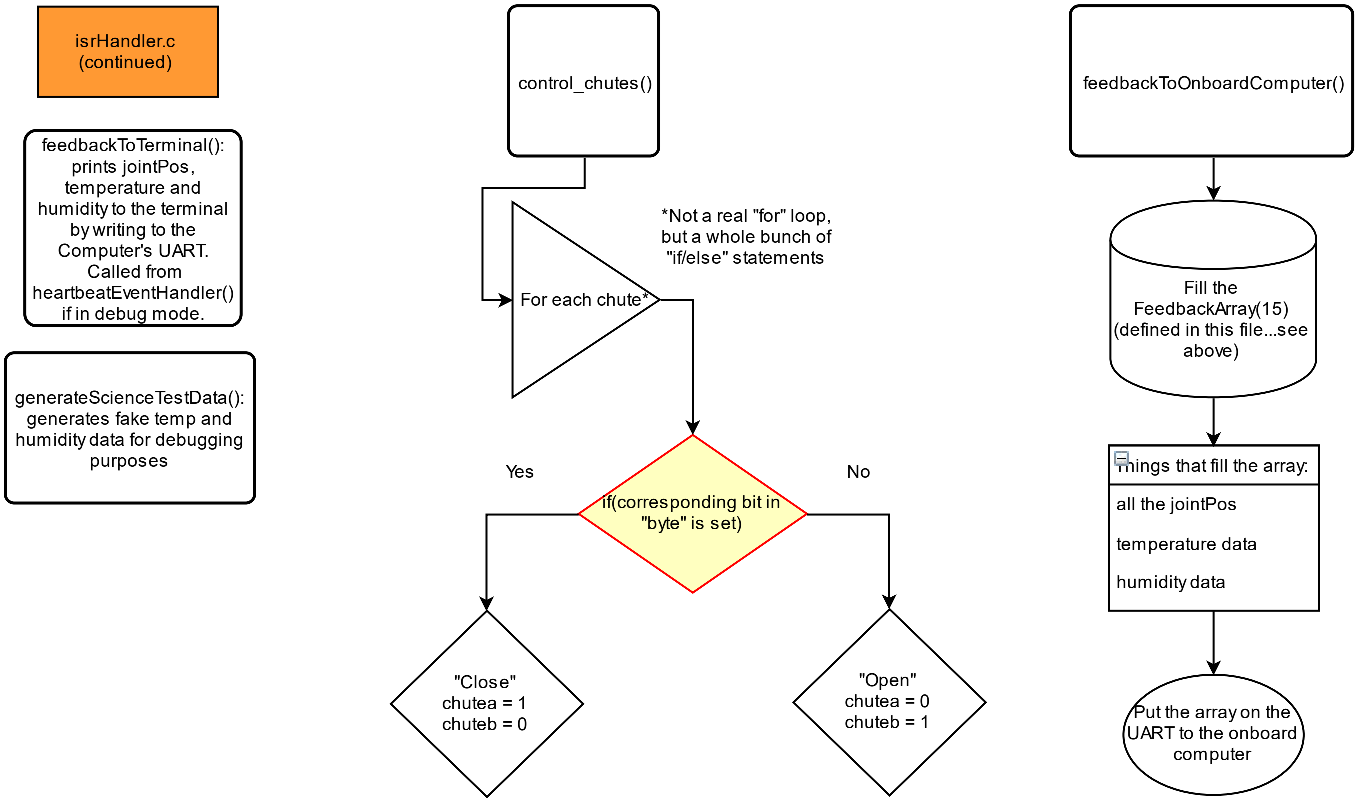


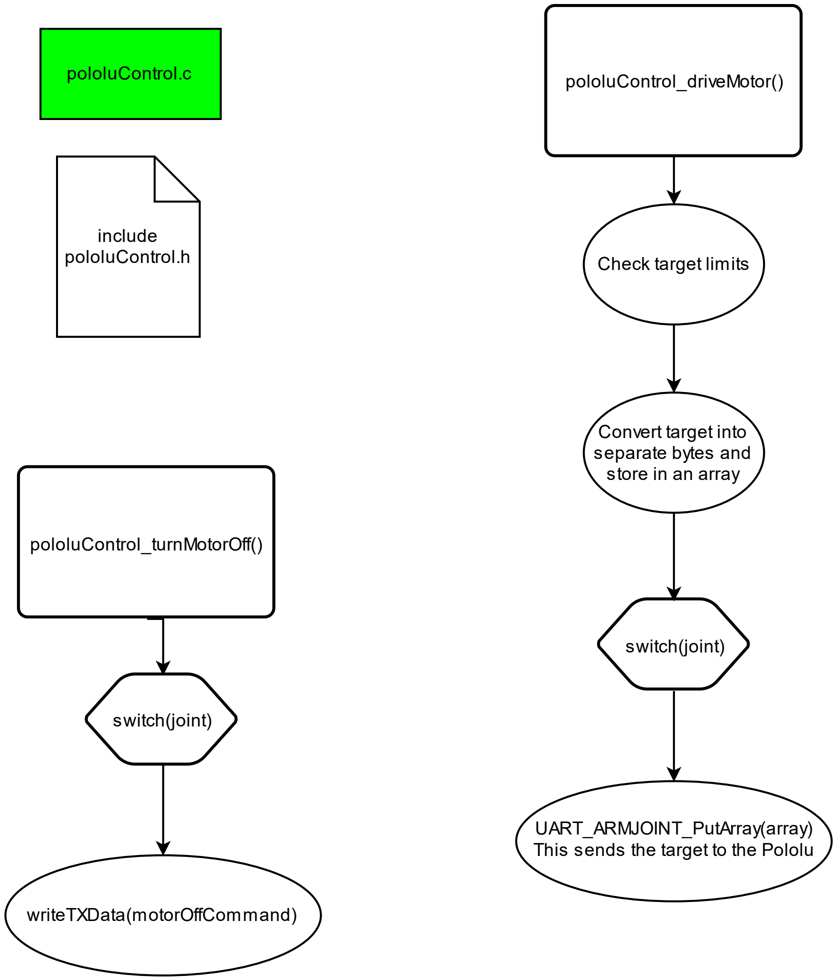


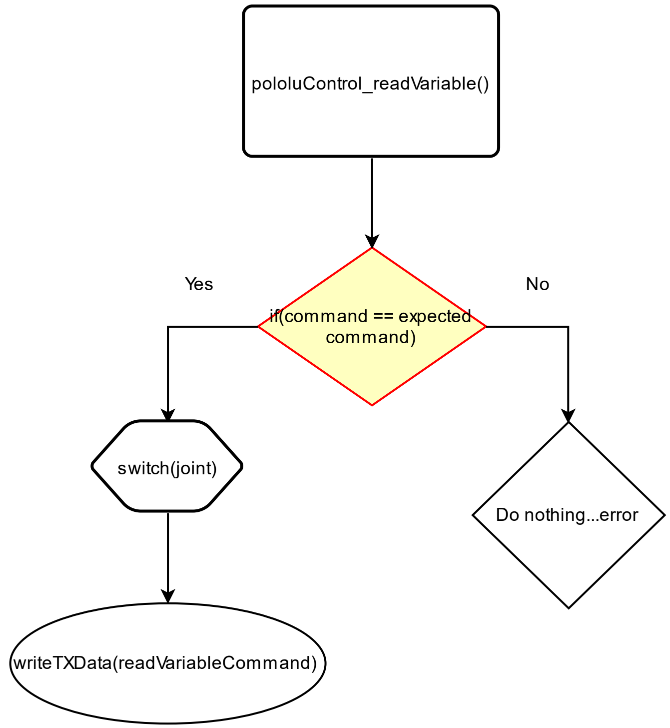
This State Machine model is greatly simplified. In actuality, there are two states for most of the subsections listed here. This is because our UART can only receive one byte at a time, while we need 2 bytes worth of data to run many of these commands. Therefore, the first of the two states gets the first half of the data, and the second completes it, and then sends the data to the proper place.



*Armjoint represents all of the four individual arm/science joints
**jointPos represents four variables who's data will be sent back to the onboard computer in the feedbackToOnboardComputer() function within this file


isrHandler.c (continued)
feedbackToTerminal(): prints jointPos, temperature and humidity to the terminal by writing to the Computer's UART. Called from heartbeatEventHandler() if in debug mode.
generateScienceTestData(): generates fake temp and humidity data for debugging purposes
control_chutes()
For each chute*
*Not a real "for" loop, but a whole bunch of "if/else" statements
if(corresponding bit in "byte" is set)
Yes
No
"Close" chutea = 1 chuteb = 0
"Open" chutea = 0 chuteb = 1
feedbackToOnboardComputer()
Fill the FeedbackArray(15) (defined in this file...see above)
Things that fill the array:
all the jointPos
temperature data
humidity data
Put the array on the UART to the onboard computer





This file is meant to contain the functions that directly interact with the Pololu Motor Drivers. It includes functions to turn the motors off, drive them, and read data from them.