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PERSONAL AUTONOMOUS TOOLBOX PLATFORM

Automation Integration for a Personal Mobile Tool Chest

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ABSTRACT

The Autonomous Toolbox Platform project addresses the challenges of tool accessibility and convenience in personal workspaces, with a particular focus on hobbyists and DIY enthusiasts. This platform is engineered to autonomously navigate the workspace, transporting tools to the user and ensuring they remain equipped for any task, akin to a mobile tool holster with comprehensive capabilities. The development process integrated mechanical, electrical, and software subsystems, culminating in a solution that is not only robust but also remarkably stable, even under overloaded and demanding conditions. Extensive testing validated the platform's exceptional operational stability and its ability to handle substantial loads without compromising performance. The Autonomous Toolbox Platform stands as a testament to the potential of automation in transforming personal workspaces and enhancing user efficiency. The final testing phase demonstrated that the platform performed robustly, navigating the workspace and delivering tools to the user, though minor adjustments to the programming are still needed to optimize sensor sensitivity and motion smoothness.

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1 INTRODUCTION

The pursuit of efficiency and organization in workspace environments is a continual challenge for professionals across various industries. In response to this challenge, the Autonomous Toolbox Platform project was conceived with the objective of revolutionizing tool management and accessibility. This report presents the comprehensive development process of the platform, from conceptualization to final design and testing.

The inception of the Autonomous Toolbox Platform project stems from the dual challenge of constant tool retrieval and occasional tool misplacement within project areas. The project aims to provide a targeted and efficient solution to enhance the user's work environment by leveraging autonomous technology. By focusing on practicality, efficiency, and workspace organization, the project seeks to improve work processes and contribute to the evolving field of autonomous systems.

1.1 Objective

The primary objective of this project is to develop a toolbox that not only stores and organizes tools but also autonomously navigates the workspace to stay within reach of the user. Specifically, the toolbox employs advanced tracking technology to follow the user around the workspace, intelligently positioning itself at convenient locations as various tasks are performed. This ensures that tools are always readily accessible, thereby enhancing efficiency and reducing the time spent searching for tools.

1.2 Deliverables

The key deliverables of the project include a fully functional Autonomous Toolbox Platform equipped with features such as autonomous navigation, manual control, and adaptability to various workspace conditions. Additionally, the project deliverables encompass detailed documentation of the design, fabrication, and testing processes.

These testing processes will include:

- **Functional Testing** (6.1 Manual Manipulation, 6.2 Autonomous Mode)
  - Evaluation of the toolbox's autonomous navigation and manual control features under varied conditions.
- **Load Testing** (6.5 Load Capacity)
  - Verifies the platform's ability to handle specified weights without performance degradation.
- **Stress Testing** (6.4 Operational Stability)
  - Assesses the platform's reliability and stability under extreme conditions.
- **User Interaction Testing** (6.3 Conditional Reactions)
  - Evaluates the platform's user interface and responsiveness to user commands.

1.3 Requirements

The development of the platform was guided by a comprehensive set of enumerated requirements to ensure its effectiveness and usability:

1. **Robust Load Capacity**
   The platform must be able to carry a minimum load of 50 kilograms without a decrease in performance.
2. **Operational Stability**
   Ensure that the platform operates smoothly under typical usage conditions and can sustain minor shocks without malfunctioning.
3. **Reliable User Tracking**
   The platform should consistently follow the user with an accuracy of at least 95%, even in complex environments.
4. **Effective Obstacle Avoidance**
   Ability to detect and navigate around obstacles with a minimum clearance of 10 centimeters.
5. **Energy Efficiency**
   The platform should operate for at least 8 hours on a single charge under normal usage conditions.
6. **Ease of Maintenance**
   Design components should be easily accessible for maintenance and repairs.
7. **User Safety**
   Incorporate safety features to prevent accidents and ensure user safety during operation.

2 BACKGROUND

The concept of autonomous systems has been evolving rapidly, with applications ranging from self-driving vehicles to robotic assistants. One of the key challenges in various project environments, particularly in hobbyist and garage settings, is the constant need for tool retrieval. Additionally, the occasional misplacement of tools can significantly hinder productivity. This often leads to increased fatigue and negatively impacts the overall quality and efficiency of work. This background section explores the historical context, current state of the field, and the motivation behind the development of an autonomous toolbox platform to address these challenges.

2.1 Historical Context

Several projects have been developed with functionalities similar to the proposed autonomous toolbox platform. For instance, the "Follow-Me Cooler" by Hacker Shack [1] (Figure 2) is an autonomous cooler that connects to a smartphone via Bluetooth and uses GPS to navigate. Similarly, the "Bluetooth Based and GPS Based Follow Me Robot" by Ashutosh Gujar and Kalyanee Jadhav [2] leverages sensor technologies for human detection and movement estimation. An example of a consumer product currently on the market is the suitcase with user-following technology, one of the most popular being the Airwheel SR5 (Figure 1). These projects demonstrate the potential of autonomous systems to perform mundane tasks and coexist with humans.

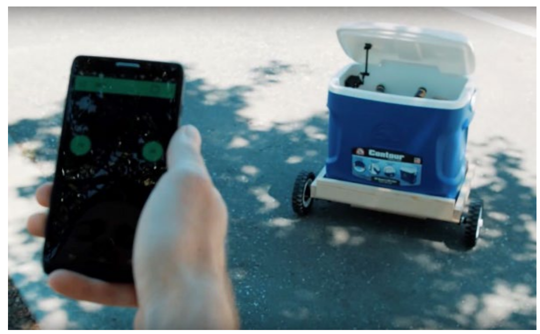

Figure 2: "FollowMe" Cooler by Hacker Shack

Figure 1: Luggage with User-Following Technology

2.2 Current State of the Field

Despite the advancements in autonomous technologies, there has been a gap in integrating such systems into consumer-level or personal-use workshop items. Commercial products like the DOOG Mobile Robot Navigation [3] (Figure 3) and consumer-level drones with follow-me technology have shown the feasibility of target tracking navigation with obstacle avoidance. However, the application of these technologies to enhance the efficiency of personal workshops or small manufacturing facilities remains largely unexplored.

Figure 3: DOOG Mobile Robot Models

2.3 Relevance to Stakeholders

The target audience for the autonomous toolbox platform includes hobbyists, DIY enthusiasts, and professionals working in garages or personal workshops. The project also holds potential for smaller manufacturing businesses, especially those with large floorplans where assembly and workstations are positioned at inconvenient distances. By addressing the challenges of tool retrieval and misplacement, the platform aims to enhance the work environment and improve productivity.

2.4 Standards and Regulations

As autonomous systems continue to integrate into various industries, standards and regulations such as American National Standards Institute (ANSI) and Underwriters Laboratories (UL) Standard 4600 for the evaluation of autonomous products become increasingly relevant. These standards address the safety, reliability, and performance of autonomous systems, ensuring that they can operate safely and as intended without human intervention.

2.5 Preliminary Component Selection

Selecting the appropriate robotics platform for the autonomous toolbox necessitates a meticulous evaluation of diverse options based on project requirements, technical considerations, and budget constraints. The primary alternatives considered encompass the Raspberry Pi with various sensors, Arduino-based platforms, Single-Board Computers (SBCs) with Linux, custom PCB (Printed Circuit Board), robotics development kits, and the Robot Operating System (ROS).

To systematically assess the advantages and disadvantages of different robotics platforms, a table has been generated, Table 1. This table, delineating criteria such as cost, versatility, longevity, strength, and availability, functions as a valuable tool for a comprehensive evaluation.

Criteria	Raspberry Pi	Arduino	SBCs with Linux	Custom PCB	Robotics Kits	ROS
Cost	Affordable	Cost-Effective	More Expensive	Varies	More Expensive	Free
Versatility	High	Limited	High	Ultimate	Limited	High
Longevity	Good	Good	Long	Varies	Good	Good
Strength	Moderate	Limited	High	Varies	Moderate	Varies
Availability	Widely Available	Widely Available	Various Manufacturers	Varies	Various Manufacturers	Open Source

Table 1: System Comparison

Criteria	Integrated Approach (Arduino + Raspberry Pi)
Cost	Cost-Effective
Versatility	High
Longevity	Good
Strength	Limited
Availability	Widely Available

Table 2: System Pros and Cons

Considering factors such as familiarity, cost, simplicity, real-time capabilities, and community support, an Arduino-based platform emerges as the preferred choice for the project. Leveraging existing knowledge and its cost-effectiveness, Arduino provides a suitable foundation for the project, effectively handling all necessary tasks including the vision system and touch-screen interface through compatible shields and modules. This approach ensures progress within the set timeframe and budget while maintaining the flexibility needed as the project advances.

2.5.1 Processor

At the heart of the project, an Arduino-based platform is being considered as the processor. This choice is driven by the platform's familiarity, cost-effectiveness, simplicity, and real-time control capabilities, making it a strong candidate for the foundation of the project. The Arduino platform, if selected, would be integrated with essential sensors and components, focusing primarily on obstacle detection and basic navigation to align with the project's simplified objectives.

Key components being considered for integration into the Arduino platform include ultrasonic sensors and an Inertial Measurement Unit (IMU). The HC-SR04 model of ultrasonic sensors would play a pivotal role in obstacle detection. Furthermore, the IMU is under evaluation to provide critical data on the platform’s orientation and movement, thereby enhancing stability and control. This approach ensures a robust design tailored to navigate complex environments effectively. Additionally, an IMU is being evaluated to provide critical data on the platform's orientation and movement, enhancing stability and control. Wheel encoders are also under consideration to improve the precision of navigation by tracking the platform's movement. For real-time control and precise movement coordination, Arduino-compatible motor controllers are being explored as a crucial component, ensuring responsiveness to user inputs and environmental conditions.

2.5.2 Power and Motion

The selection of motors and the drivetrain is a critical aspect of the project, necessitating a thorough evaluation process to identify the most suitable motor type. Servo motors were ultimately chosen due to their superior torque and speed control, which are essential for dynamic and responsive navigation around obstacles and through varied environments. Unlike stepper motors, servo motors offer feedback control that allows for real-time adjustments to speed and position, enhancing the precision and reliability of the autonomous toolbox. This feedback mechanism is crucial for maintaining optimal performance, even under varying load conditions. Additionally, servo motors are known for their efficiency and robustness, making them ideal for continuous operation on a mobile platform.

To complement the servo motors, Mecanum wheels have been incorporated into the drivetrain. These wheels are uniquely designed to allow omnidirectional movement (Figure 4), meaning the platform can move forward, backward, sideways, and diagonally without turning its body. Each wheel consists of a series of angled rollers around its circumference, which translate the rotational

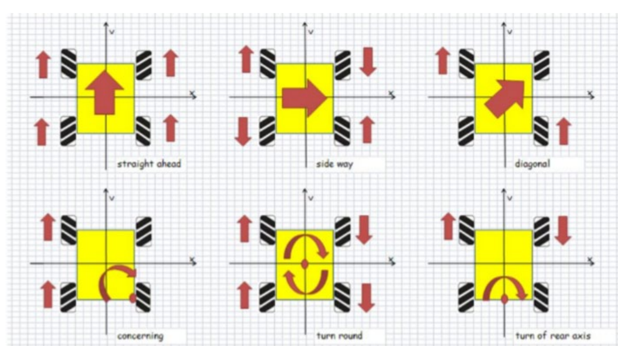

Figure 4: Mecanum Wheel Operation Chart

motion of the wheel into linear motion in multiple directions. This capability is invaluable in tightly packed or cluttered workspaces where traditional turning maneuvers are impractical. The combination of servo motors and Mecanum wheels provides exceptional maneuverability and control, significantly enhancing the toolbox's ability to navigate complex environments.

2.5.3 Battery Packs

The choice of battery technology is a crucial consideration, with Lithium Iron Phosphate (LiFePO4) batteries emerging as a potential optimal solution. These batteries are being selected for their high current output, safety, and stability under heavy loads, meeting the project's power requirements.

2.5.4 Charging System

The charging system for the platform is considering the use of contact-based charging as the primary method, chosen for its reliability and safety. A visual reference of how a contact-based power connection mechanism can be seen in Figure 5. A manual charging option is also being incorporated as a backup, providing a failsafe mechanism in case of issues with the auto-docking system.

The decision to opt for contact-based charging is rooted in its proven safety, efficiency, and reliability, making it well-suited for heavy-load applications. The inclusion of a manual charging backup further enhances the robustness of the charging system, addressing the need for contingencies and ensuring uninterrupted operation.

Figure 5: Contact-Based Charging Setup Example

Charging Method	Safety	Finances	Convenience
Inductive Charging:	Generally safe due to the absence of physical contact, minimizing electrical contact hazards.	Cost-effective, especially when employing standard components and wireless charging technology.	Offers flexibility in docking, eliminating the need for precise alignment.
Contact-Based Charging:	Can be safe with proper insulation and safeguards to prevent accidental electrical contact.	Costs may vary based on connector complexity and the need for safety features.	Requires precise alignment, potentially less convenient for high accuracy docking.
Auto-Plug Charging:	Can be safe with reliable, well-maintained automated mechanisms to prevent accidents.	Implementation may be complex and costly due to additional mechanical components.	Offers convenience by automating the docking and charging process, reducing the need for manual alignment.

Table 3: Charging Method Evaluation

In the pursuit of an optimal charging solution, the emphasis remains on safety considerations, with the selected method aligning seamlessly with the project's design and implementation goals. The integration of contact-based charging, backed by a manual charging option, reflects a careful balance of factors to meet the project's unique needs and available resources. This approach ensures that safety remains a top priority while also providing flexibility and reliability in the charging process.

2.6 Design Alternative and Evaluation

The development of the Autonomous Toolbox Platform involved a meticulous evaluation of various design alternatives, each with its unique set of advantages and challenges. This section outlines the considerations and decisions that shaped the final design.

2.6.1 Original Concept

The inception of the project was marked by the concept of a standalone Automated Guided Vehicle (AGV) platform, designed to support any mobile tool chest. This design aimed to offer unparalleled versatility, allowing for the mounting of diverse equipment such as toolboxes, cabinets, workbenches, and machines with similar footprints.

The advantages of this concept included its adaptability and the minimal limitations it imposed on size and attachment modifications. However, the cons were significant. The anticipated weight of a fully loaded toolbox necessitated robust motors with space-consuming gearboxes. The batteries required to power these motors and ensure a substantial charge life would occupy considerable space. Additionally, mounting the batteries underneath the AGV posed a risk of short-circuiting if the unit ran over protruding objects. This design also suffered from limited ground clearance, hindering its ability to traverse over obstacles and uneven floors.

Furthermore, the integration of motors and batteries into a confined space left inadequate room for the control system. Expanding the overall size to accommodate these components would restrict the user's ability to mount smaller and more basic toolboxes, limiting the platform's versatility.

2.6.2 Toolbox Body

The choice of the toolbox body was a pivotal initial step in the project. The initial consideration was a fully stocked 6-drawer mobile workbench from BoxoUSA (Figure 6). However, budget constraints led to the selection of a more affordable mobile tool chest from Husky, procured from a local Home Depot.

Figure 6: Base-model BoxoUSA 'Loaded' Toolbox

A full-length mobile workbench by Milwaukee was also contemplated but ultimately discarded due to space constraints in the garage designated for the build process.

2.6.3 Suspension

The original suspension concept (Figure 7 and Figure 8) aimed to maximize control arm length to facilitate smoother movements and greater vertical travel. However, this design was abandoned due to concerns about excessive flex and instability. This instability can be visualized in Figure 7 where the shock absorber meets the control arm. The final design adopted independent suspension to ensure that all four wheels maintained traction and remained perpendicular to the ground, essential for the optimal operation of Mecanum wheels.

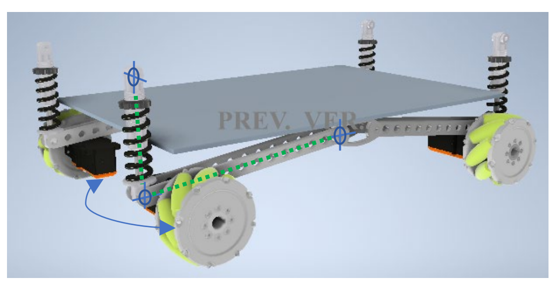

Figure 7: First Suspension Configuration Version (Isometric View)

2.6.4 Drivetrain

The first drivetrain design (Figure 8) involved mounting servo motors directly to the control arms, with the wheels attached to the motors. This configuration was revised when it became evident that the entire weight of the unit would be supported solely by the motor axle shafts, leading to potential structural and operational issues.

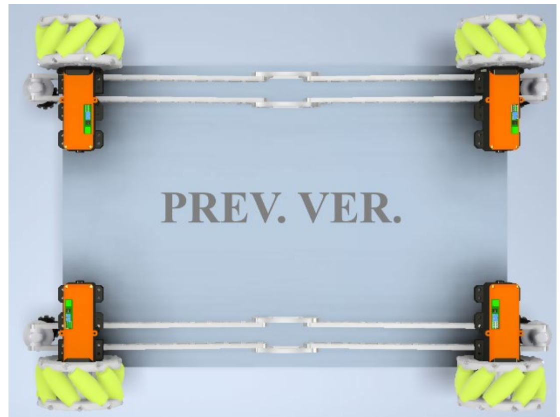

Figure 8: First Drivetrain Configuration Version (Bottom View)

2.6.5 Power and Control

The initial concept for power and control involved programming the toolbox to follow a specially designed device (Figure 9) equipped with a compass module, a three-axis joystick, toggle switches, an ESP8266 NodeMCU module for programming, and a battery. The toolbox was to follow this device when undocked from a charging station mounted on the toolbox. However, this design was ultimately discontinued due to time constraints within the project schedule.

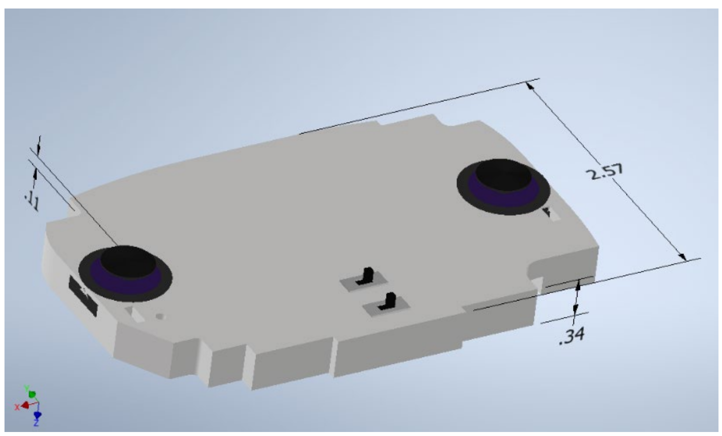

Figure 9: Designated Remote Controller Concept 3D Model PCB Clearance Test

3 FINAL DESIGN

The final design of the Autonomous Toolbox Platform (Figure 10) is the result of an in-depth design rationale and decision-making process, informed by comprehensive research and analysis of existing technologies and user needs. Initially, the project encountered challenges related to ensuring sufficient load capacity and operational stability under diverse conditions. Theoretical evaluations and research into similar technologies guided the selection of components and design features that would best meet these challenges.

Figure 10: Autonomous Toolbox Full Assembly 3D CAD Rendering

The decision to use servo motors combined with Mecanum wheels was based on their known capabilities and benefits, such as superior maneuverability and precision, which are essential for navigating complex environments. The design process involved careful consideration of various motor and wheel configurations, ultimately choosing those that best aligned with the project's goals.

Attention was also paid to the integration of sensors for effective obstacle detection and user tracking. The selection and placement of sensors were strategically planned to optimize functionality and performance, based on industry standards and successful implementations in similar applications.

This entirely conceptual approach allowed the project team to meticulously plan each aspect of the design without the need for physical prototypes or simulations. It was a process characterized by critical thinking and strategic planning, ensuring that every design decision was well-founded and aimed at achieving a robust, efficient, and user-friendly platform. The project thus showcases an innovative approach to solving design challenges purely through theoretical and planning stages.

3.1 Overview of Operation

The Autonomous Toolbox Platform is designed to enhance the efficiency and organization of personal or open workspace environments. At its core, the platform operates autonomously, navigating and maneuvering around the workspace while ensuring the user has convenient access to tools. The integration of manual control options allows for precise positioning and operation when needed. The platform's adaptability and modifiability ensure that it can be tailored to specific user requirements and evolving workspace needs.

3.2 System Breakdown

The final design is a harmonious integration of mechanical, electrical, and software subsystems, each contributing to the platform's functionality and performance.

3.2.1 Mechanical Subsystems

The chassis and suspension form the backbone of the platform, providing structural integrity and stability. The chassis is designed to accommodate the weight of the toolbox and its contents, while the independent suspension system ensures that all wheels maintain contact with the ground, essential for the effective operation of Mecanum wheels. The block diagram below (Figure 11) shows the connections and relationships between the mechanical components and subassemblies.

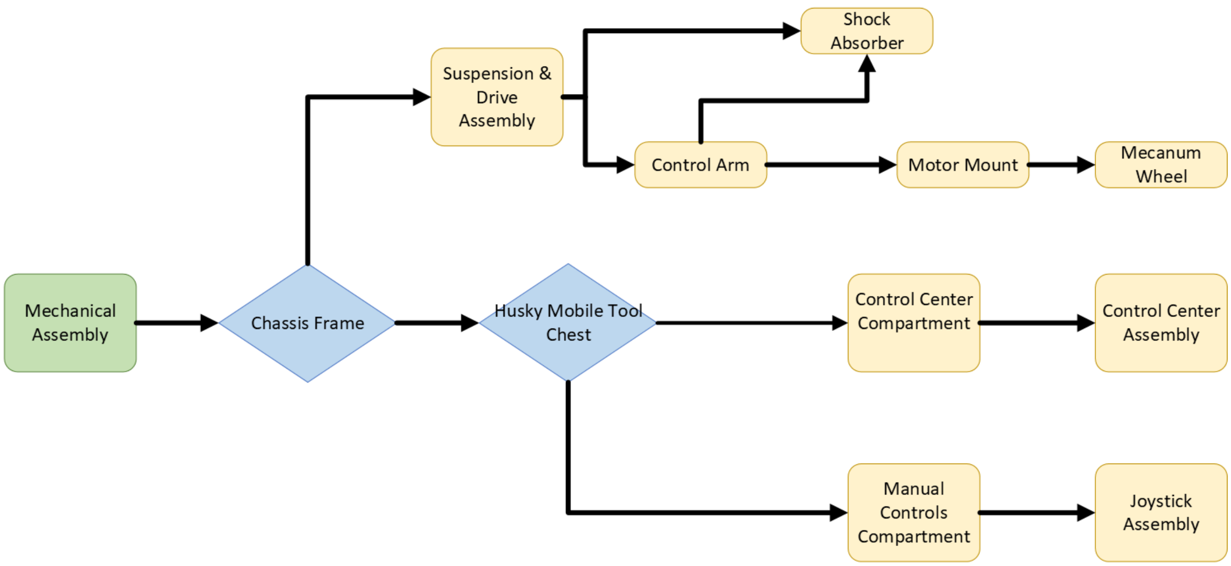

Figure 11: Mechanical Subsystem Breakdown Block Diagram

3.2.1.1 Chassis

The chassis serves as the foundational structure of the Autonomous Toolbox Platform, designed to provide robust support for the toolbox and its contents. Constructed from a quarter-inch thick steel plate, the chassis offers the necessary strength and rigidity to withstand the demands of regular use while remaining easy to weld.

Figure 12 describes, as well as the detailed CAD drawing (APPENDIX E: Chassis), the chassis design incorporates strategic cut-outs aimed at reducing weight without compromising structural integrity. These cut-outs not only contribute to the overall efficiency of the platform but also play a critical role in the chassis' connection with the suspension components. This design consideration ensures a swift and seamless welding process, enhancing the assembly's speed and reliability.

A key feature of the chassis is its custom mounting points, meticulously engineered to accommodate the Husky® brand toolbox. These mounting points align with the toolbox's original caster mounting holes, allowing for seamless and secure integration. This thoughtful design ensures that the toolbox remains firmly in place during operation, providing a stable and organized workspace for the user.

The fabrication of the main vehicle centered around this welded steel chassis, which was precision-crafted using a water jet in the Applied Engineering Center (AEC) at the University of

Southern Indiana. This advanced manufacturing process further underscores the commitment to quality and precision in the development of the Autonomous Toolbox Platform.

In summary, the chassis of the Autonomous Toolbox Platform exemplifies a harmonious blend of strength, efficiency, and thoughtful design, providing a solid foundation for the platform's functionality and durability.

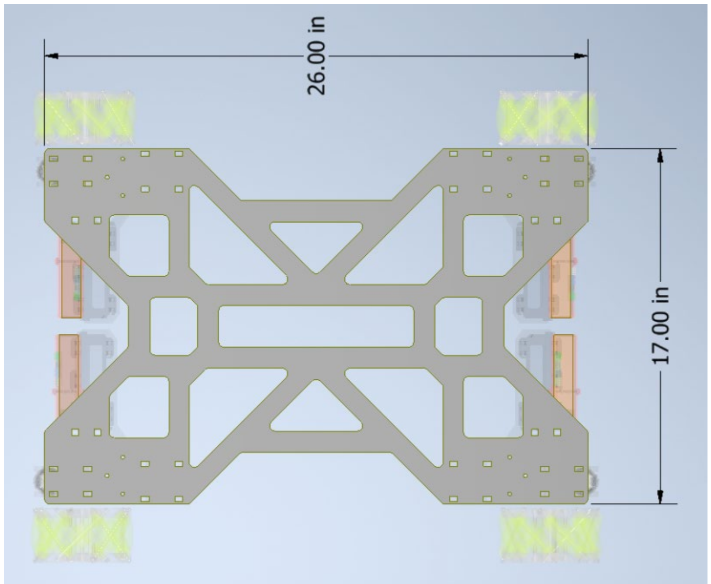

Figure 12: Base Chassis Plate (Bottom View)

3.2.1.2 Suspension & Drive Assembly

The initial suspension concept was designed to maximize control arm length for smoother movement. However, it was abandoned due to concerns about excessive flex and instability under load. In response, the chosen independent suspension system was equipped for its stability and adaptability to uneven surfaces without compromising mobility. As illustrated in Figure 13, this suspension system features short control arms paired with a 100lb shock absorber. Alternative sets, rated at 70 pounds-force (lbf) and 130 lbf, were purchased separately to accommodate varying load conditions provided the springs included with the shock absorbers were too stiff.

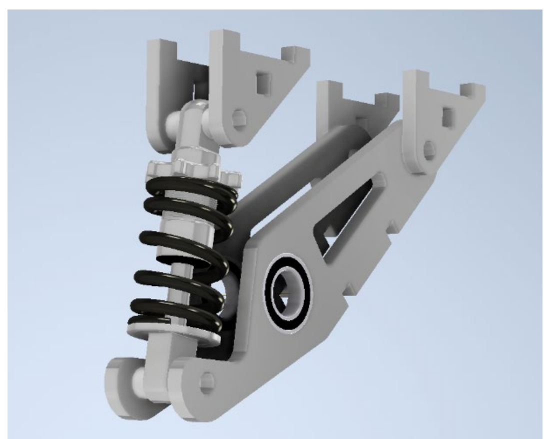

Figure 13: Independent Suspension Section Assembly

The design of the control arms incorporates pressed-in bearings (Figure 16), which support standalone axle shafts. These axle shafts are connected to the motor shafts with flexible spider couplings, as showcased in Figure 18 and Figure 17. This configuration ensures that the motor shafts are relieved from carrying any vertical or horizontal loads, with all loads being supported by bearings and hardened stainless steel axle shafts. The choice of a rear shock absorber for a mountain bike, rated at 300 lbs, further underscores the system's robustness and capacity to handle significant weight and impact.

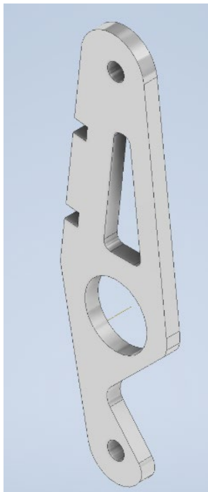

Figure 14: Control Arm 3D CAD Model

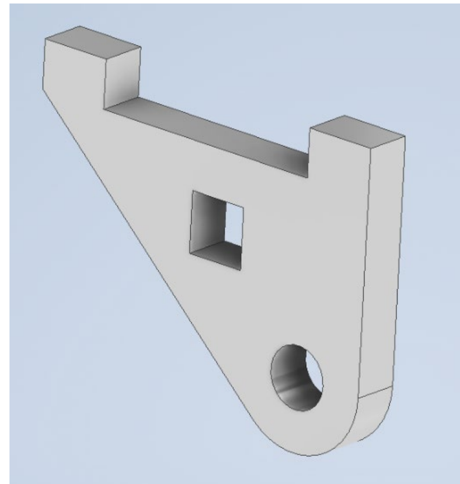

Figure 15: Strut & Control Arm Mount 3D CAD Model

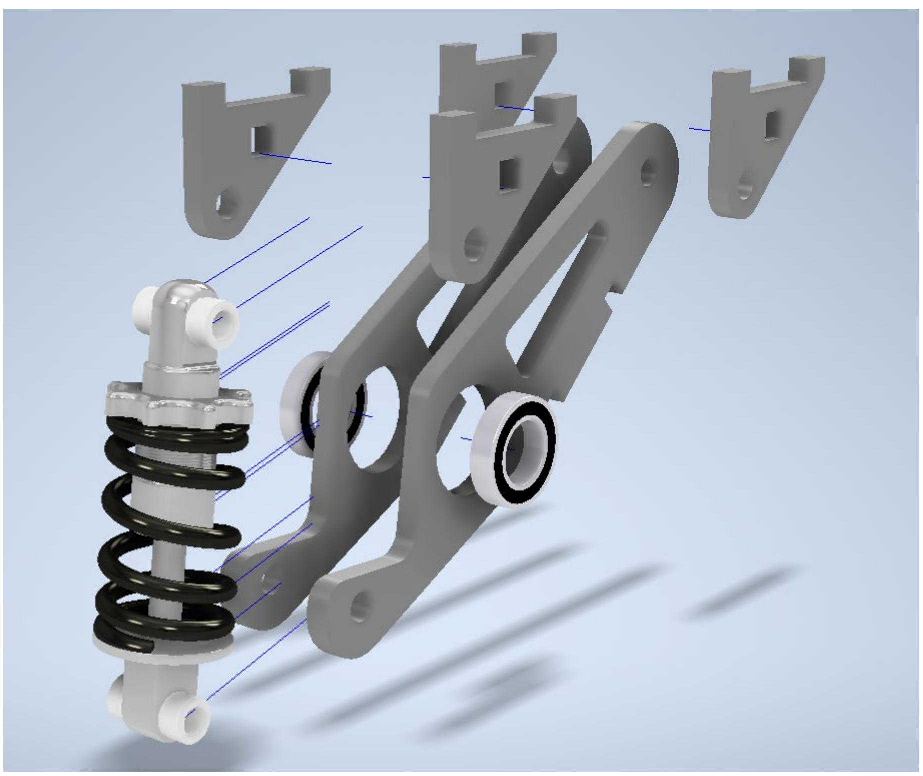

Figure 16: Suspension Assembly (Exploded View)

3.2.1.3 Drive Assembly

The drive assembly of the platform is characterized by the integration of high-torque servo motors and a drivetrain configuration that allows for precise movements and navigation. As depicted in Figure 18 and supported by Figure 17 and the CAD drawing in the Appendix

(APPENDIX E: Drivetrain), the drivetrain is designed to be zero radial-load. Spider couplings play a vital role in absorbing vibration and enabling significant torque transmission.

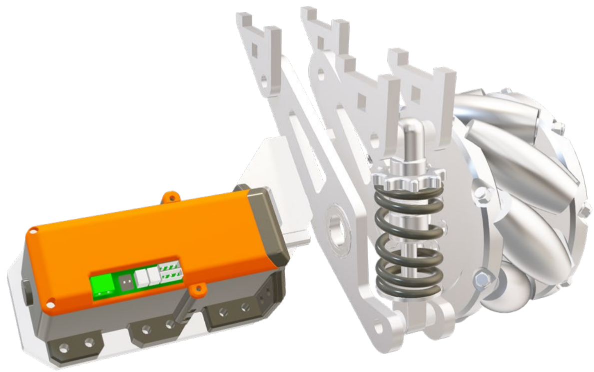

Figure 17: Drive Assembly 3D Visualization

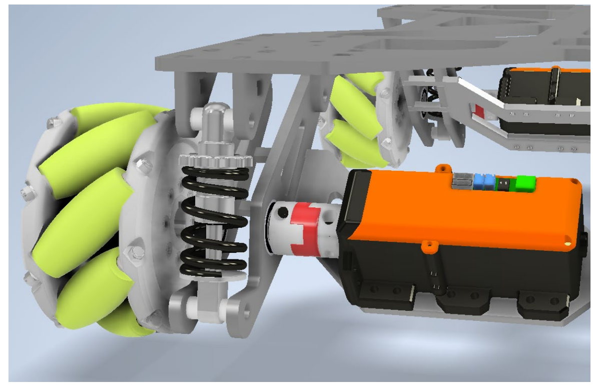

Figure 18: Drive Assembly 3D Rendering (w/ Spider Coupler)

The motors mounted directly to the control arms in the suspension assembly with the brackets shown in Figure 20, boasting a high torque of 32 N-m, are switchable between servo and motor modes and come with built-in drivers. They operate on 24VDC and are equipped with high-quality digital servos for unparalleled control. To complement the motors, industrial-grade Mecanum wheels were selected for their large diameter and industrial strength. As seen in Figure 19 and the detailed drawing in the Appendix (APPENDIX E: Mecanum Wheel), these wheels are constructed from aluminum, with stainless steel hardware and PU rollers. They are capable of supporting the toolbox's maximum recommended load of 650lb, ensuring durability and smooth movement across various surfaces.

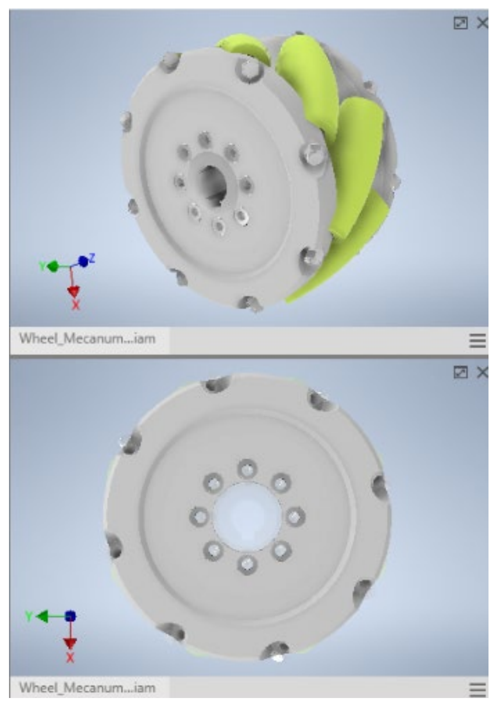

Figure 19: 6 inch Industrial Mecanum Wheels (Multi-View)

In summary, the suspension system and drive assembly of the Autonomous Toolbox Platform are engineered to provide stability, precise control, and durability, ensuring the platform's effective operation in diverse workspace environments.

3.2.1.4 Toolbox Body

The selection of the toolbox body was a pivotal decision in the development of the Autonomous Toolbox Platform, with the Husky brand toolbox (Figure 21) ultimately chosen as the ideal candidate. This choice was informed by a thorough evaluation of various factors, including the size, durability, and compatibility of the toolbox with the chassis. The Husky toolbox was found to offer the perfect balance between providing ample storage space for tools and maintaining a compact form factor that ensures ease of maneuverability. The robust construction of the toolbox further guaranteed its ability to withstand the rigors of daily use and the additional stresses imposed by the integration of mechanical and electrical components. To seamlessly integrate the toolbox with the custom-designed chassis, specific modifications were made to the toolbox body (Figure 22). One of the key modifications involved the incorporation of ultrasonic sensors, essential for the platform's autonomous navigation system. To achieve this, twelve holes were meticulously cut out of the upper sides of the toolbox, allowing the ultrasonic sensors to be mounted flush with the exterior of the toolbox body. This modification not only enhanced the functionality of the platform but also preserved the aesthetic appeal of the toolbox.

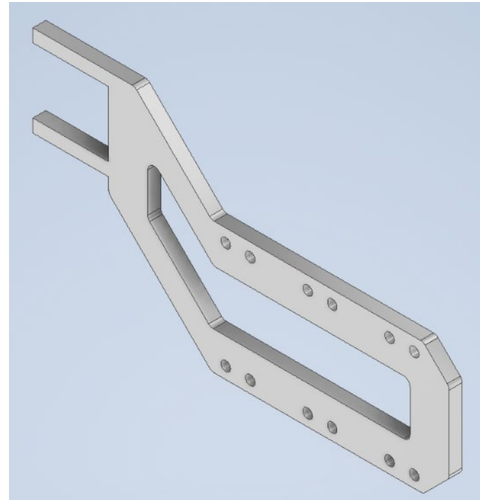

Figure 20: Motor Mount 3D Model

Figure 21: Husky Toolbox Product Image

Figure 22: 5-Drawer Toolbox 3D CAD Model

The placement and orientation of the ultrasonic sensors were carefully considered to ensure comprehensive coverage for obstacle detection. The sensors were strategically positioned around the top of the toolbox, inset from the surfaces to minimize the risk of damage. They were evenly spaced and oriented in a 360-degree pattern, with each sensor angled at an average of 30 degrees from its neighbors (Figure 24). This arrangement was crucial for achieving a wide field of detection and ensuring the platform's ability to navigate safely and effectively.

Furthermore, the ultrasonic sensors were housed in specially designed 3D-printed bezels. These bezels, seen in the Appendix (APPENDIX E: Ultrasonic Sensor 0 Degree Housing & Bezel, APPENDIX E: Ultrasonic Sensor 20 Degree Housing & Bezel, APPENDIX E: Ultrasonic Sensor 35 Degree Inset Housing & Bezel, APPENDIX E: Ultrasonic Sensor 35 Degree Protrude Housing & Bezel) were crafted to inset the sensors and featured a 15-degree chamfer to accommodate the sensors' output angle. This thoughtful design detail ensured optimal performance of the sensors and contributed to the overall functionality of the Autonomous Toolbox Platform.

Figure 23: Wooden Benchtop Accessory for Husky Brand Toolboxes

In summary, the selection and modification of the toolbox body were guided by careful consideration of size, durability, and compatibility with the platform's chassis. The integration of ultrasonic sensors and the attention to their placement and housing exemplify the meticulous engineering that has gone into the development of the platform, ensuring its effectiveness and reliability in various workspace environments.

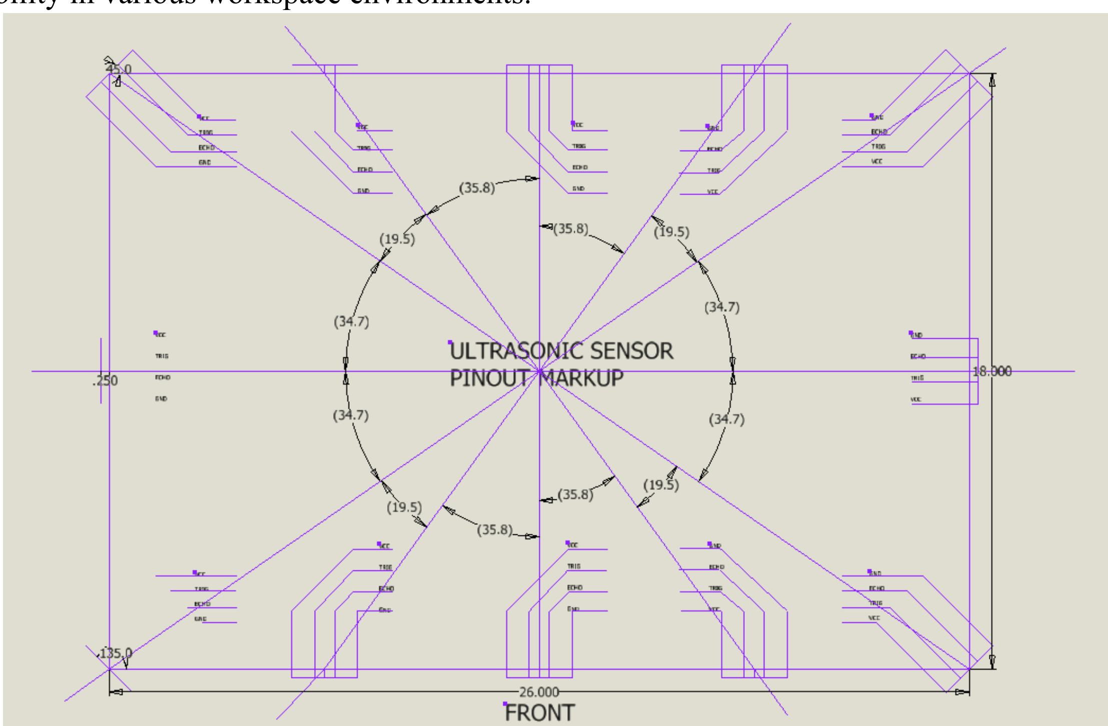

Figure 24: Ultrasonic Sensor Mapping

3.2.1.5 Control Center Compartment

The control center of the Autonomous Toolbox Platform plays a pivotal role in managing the electrical components crucial for the platform's operation. It is strategically located inside the lower drawer of the toolbox, as depicted in Figure 25 and Figure 26. This placement ensures that the control center remains protected while allowing easy access for maintenance and adjustments.

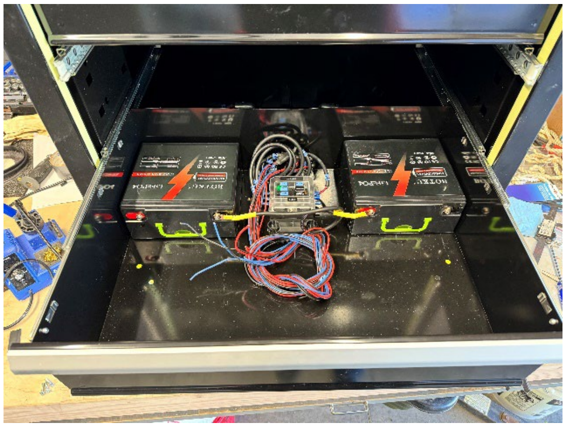

Figure 25: Bottom-Drawer Initial Size and Scale Test

Figure 26: Assembled Control Center Top View

Within the control center, an array of components is housed to facilitate the smooth functioning of the platform. Terminal blocks are a key feature, providing a convenient means for connecting and disconnecting various components, ensuring a streamlined assembly process and ease of troubleshooting. Additionally, a relay module has been included to accommodate future expansions, offering flexibility for incorporating additional features or enhancements.

The power supply system within the control center is meticulously designed for efficiency and reliability. A buck converter is utilized to reduce the primary 24VDC to a stable 5.000VDC, essential for powering the Arduino Mega 2560 rev. 3. This buck converter is notable for its digital, adjustable design, capable of maintaining accurate voltage settings even after power down, as showcased as a detailed drawing in the Appendix (APPENDIX E: Battery Retainer) and

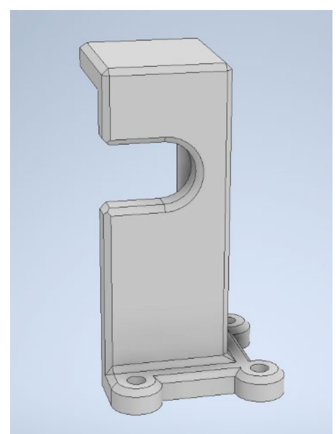

Figure 27: Battery Retainer 3D CAD Model

Each motor within the platform is connected to its own 30 ampere (30 A) fuse on a 6-place fuse block, ensuring primary power protection and safeguarding against electrical faults. The battery system, consisting of 12VDC batteries wired in series to achieve a 24VDC system, is a crucial component of the power supply. The positive terminal of battery 1 is protected by a ZCASE Mega® 100 ampere (100 A) fuse, providing an additional layer of safety. Furthermore, the batteries are secured in each corner with 3D-printed retainers, ensuring stability and minimizing the risk of displacement.

The wiring and cable management within the control center are designed for space efficiency and organization. Wires and cables exit the underside of the drawer and connect to DB25 connectors, facilitating a neat and compact arrangement. To enhance safety and accessibility, the 24V system is shielded with a polycarbonate structure, with all 5V systems and processors mounted atop this protective layer.

In summary, the control center of the Autonomous Toolbox Platform is a meticulously designed hub that houses essential electrical components, ensuring the platform's efficient operation and safety. Its strategic placement and well-organized layout exemplify the careful consideration given to every aspect of the platform's design.

3.2.1.6 Manual Controller

The design of the manual controller is a testament to the thoughtful engineering behind the Autonomous Toolbox Platform. Housed within a 3D-printed enclosure, the manual controller features two joysticks designed for 3-axis operation, enabling pan movements in both the x and y directions, as well as rotation. This design allows for precise control of the platform, ensuring that users can easily maneuver the toolbox to their desired location. The controller's housing is neatly mounted inside the top drawer of the toolbox, providing convenient access while maintaining the sleek aesthetics of the platform. The fabrication process and are showcased in Figure 28Figure 28: Joystick Housing Fabrication & Wiring Progress, while the design details of the joystick assembly in Figure 29 and Figure 30, with the detailed CAD drawing in the Appendix (APPENDIX E: Joystick Control Housing).

Figure 28: Joystick Housing Fabrication & Wiring Progress

Functionality is at the forefront of the manual controller's design. The integration of the joysticks with the platform's user interface allows for intuitive control, ensuring a seamless user experience. Embedded LEDs within the controller unit serve as indicators of the platform's operational state, with four possible states: autonomous mode, manual manipulation mode, program error condition, and emergency-stop button condition. These LEDs provide immediate visual feedback to the user, enhancing the platform's usability.

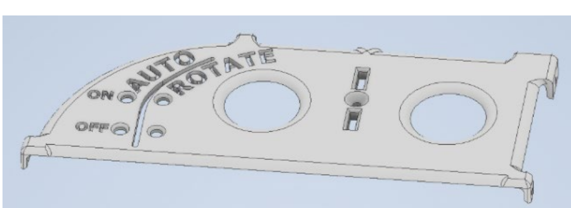

Figure 29: Joystick Module Retaining Face Plate (3D-Printed)

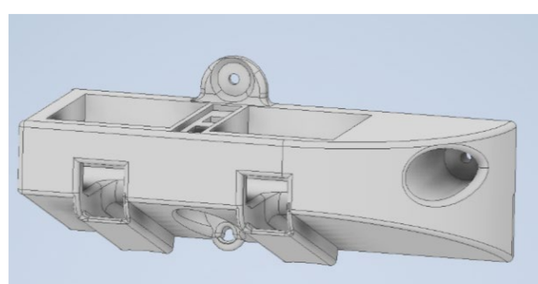

Figure 30: Joystick Module Housing 3D CAD Model (3D-Printed)

Safety features are also integral to the manual controller's design. The emergency stop (estop) button is strategically located on the front of the toolbox, ensuring easy access in case of an emergency. This button is designed to not only shut down the program but also to disconnect the motors' signal wires as a redundant safety feature, ensuring the immediate cessation of all movement. Additionally, the reset button, located outside the top drawer, is wired to the Arduino Mega's reset pin, allowing for easy resetting of the device and reactivation of auto mode.

In summary, the manual controller of the Autonomous Toolbox Platform is a well-designed component that provides precise control, intuitive user interaction, and essential safety features. Its integration within the toolbox and the thoughtful placement of controls contribute to the platform's overall functionality and user-friendliness.

3.2.2 Electrical Subsystems

The electrical architecture encompasses power distribution, motor control, and sensor integration. The platform is powered by a robust battery system, ensuring longevity and reliability. Servo motors, controlled by the electrical subsystem, facilitate precise movements and navigation.

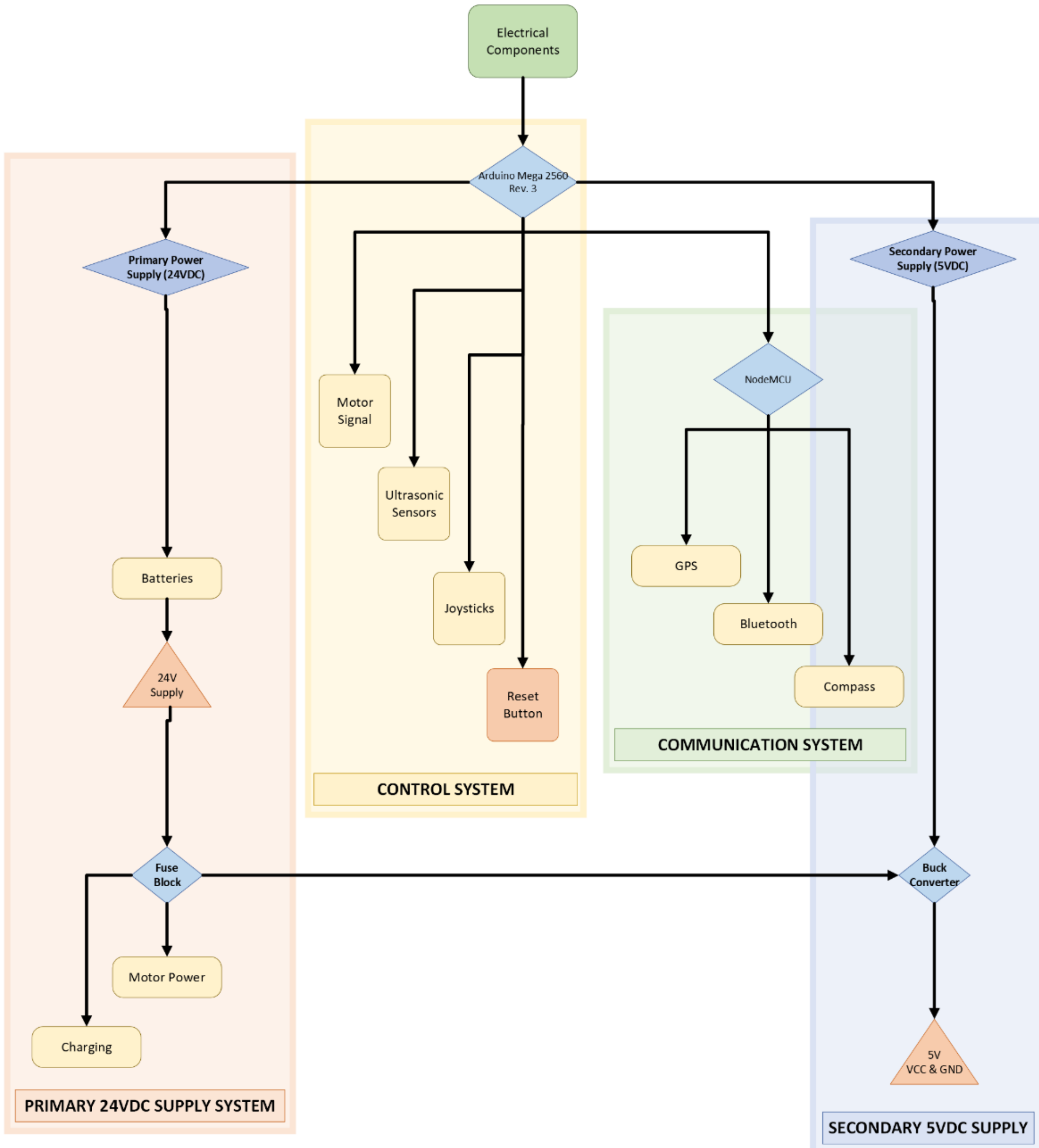

Figure 31: Electrical Subsystem Breakdown Block Diagram

3.2.2.1 Primary Power

The primary power source for the Autonomous Toolbox Platform consists of two 12V LiFePO4 batteries connected in series to obtain a 24VDC output. This voltage level is necessary for powering the motors and is also supplied to a 6-place fuse block, which is grounded to the toolbox along with all other components. The integration of the primary power source into the platform is carefully designed to ensure a reliable and consistent power supply, essential for the platform's uninterrupted operation.

3.2.2.2 Buck Converter

The buck converter plays a crucial role in regulating the voltage from the primary power source to levels suitable for the platform's components. It reduces the primary 24 VDC to a reliable 5 VDC, which is used to power all components. The buck converter is digital, adjustable, and capable of returning to accurate voltage settings after power down, ensuring the platform's components receive a stable power supply.

3.2.2.3 Secondary Power

The need for secondary power sources arises from the software and computing components requiring a 5V power source. The implementation of secondary power sources is achieved by connecting all Arduino components to 5V via terminal blocks, ensuring that the platform's computing elements have a dedicated and stable power supply.

3.2.2.4 Arduino Mega 2560 Rev. 3

The Arduino Mega 2560 Rev. 3 serves as the central processing unit of the platform. It computes distances from each of the 12 ultrasonic sensors simultaneously, determines the device's own location and position, and compares it with the location and position of the user's smartphone. Based on these calculations, it determines the movements required for the platform to navigate effectively. The Arduino is integrated with other components such as ultrasonic sensors, NodeMCU, joysticks, motors, and the reset button, managing all calculations to move the motors in a specific direction.

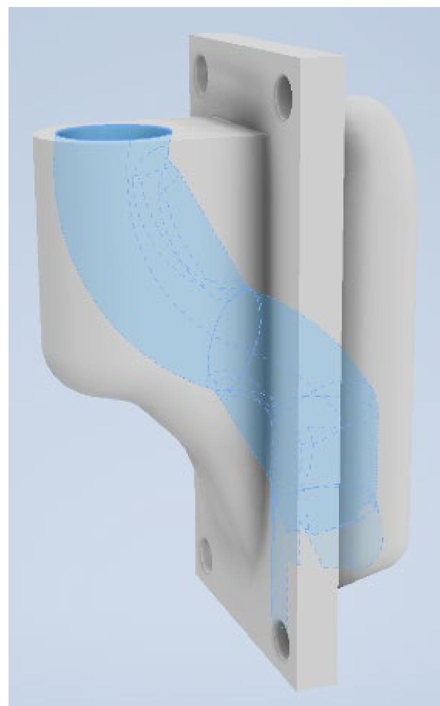

Figure 32: Electrical 180-Degree Pass-Through 3D Model, Cable Path Highlighted

3.2.2.5 Motors

The platform utilizes servo motors with built-in drivers, capable of operating in both "motor" and "servo" modes. These motors feature high hardness steel planetary gear transmission and magnetic encoder feedback for precise control. The motors are powered with the 24V system via the 6-place fuse block, with each motor having its own 30 A fuse. They are controlled by the Arduino via signal wires, ensuring precise and responsive movements.

Figure 33: Motor Specification Sheet from Docyke[8]

3.2.2.6 Ultrasonic Sensors

Ultrasonic sensors play a vital role in obstacle detection and navigation for the platform. They read distances from objects within a 15-degree angle, with all 12 sensors operating simultaneously. This data is essential for calculating obstacle avoidance and maintaining a safe distance from the user. The sensors are positioned around the top of the toolbox, inset from the surfaces to avoid damage, and are spaced evenly in a 360-degree pattern. Each sensor is angled an average of 30 degrees from its neighbors, and they are housed in 3D-printed bezels with a 15-degree chamfer to account for the sensors' output angle, as shown in Figure 24.

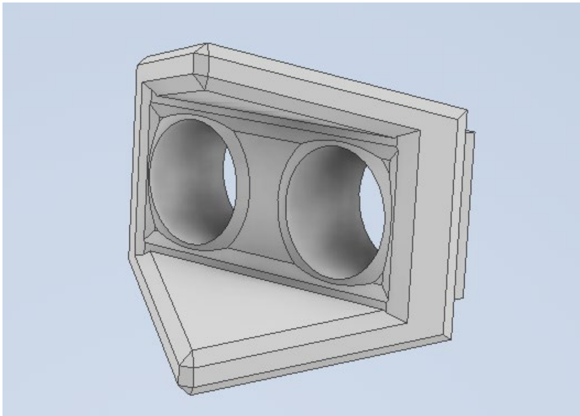

Figure 34: Ultrasonic Sensor Corner Housing

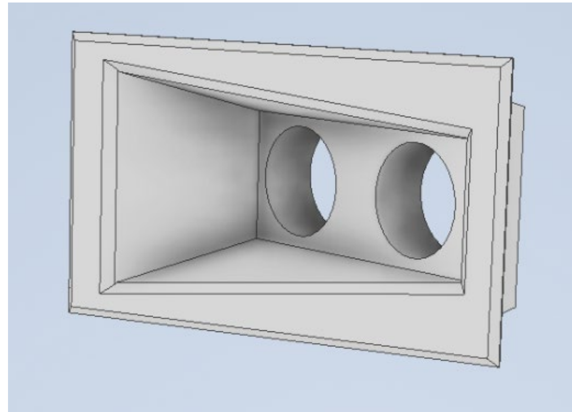

Figure 35: Ultrasonic Sensor 45-degree Housing

3.2.2.7 Joysticks

The manual control of the platform is facilitated by joysticks designed for 3-axis operation, allowing for pan movements in the x and y directions, as well as rotation. This design ensures precise control of the platform, enabling users to maneuver it with ease.

3.2.2.8 Reset button

The reset button is wired to the reset pin on the Arduino and serves to reset the Arduino program. This function is crucial for reactivating auto mode and ensuring the platform can return to autonomous operation after manual control or in the event of a program error.

3.2.2.9 NodeMCU

The NodeMCU has a dual function in the platform: it receives location data from the smartphone and sends it to the Arduino for calculation, and it also obtains its own location data to send to the Arduino. This stand-alone processor is integral to the platform's navigation system and does not reset when the Arduino resets, ensuring continuous operation. Figure 36 below shows a simplified CAD sketch of the communications panel, which houses everything the NodeMCU is in control of.

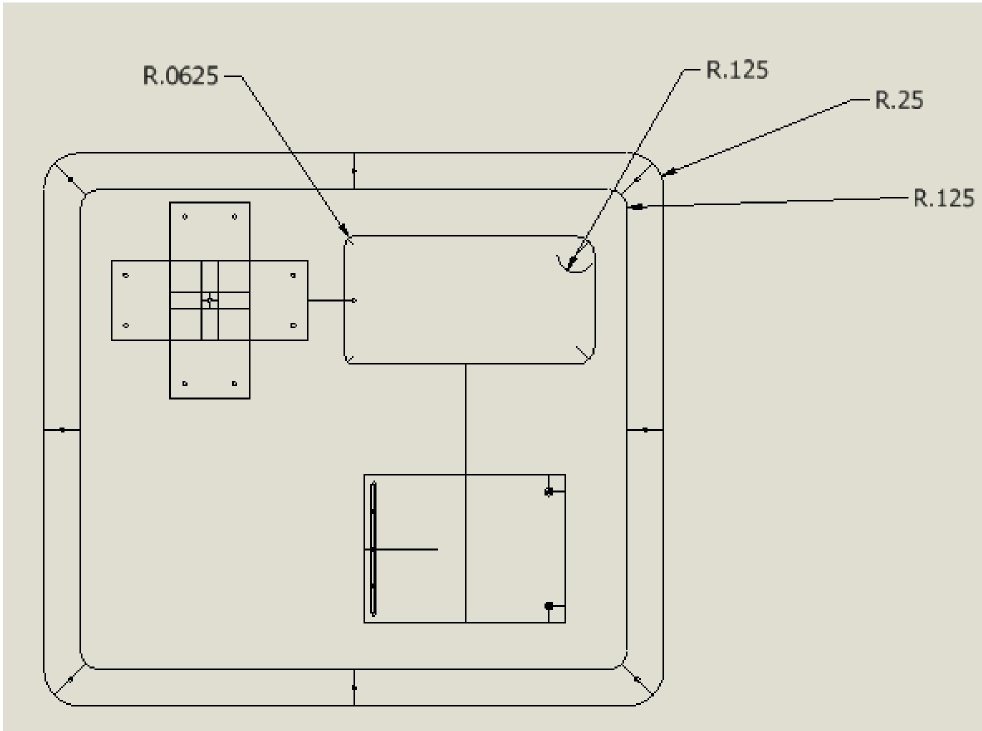

Figure 36: Communication Pannel Layout Map

3.2.2.10 GPS

The GPS module connects to satellites to obtain location data, which is crucial for the platform's navigation and tracking capabilities. The integration of the GPS module with the platform's control system ensures that the platform can accurately determine its position and navigate accordingly.

3.2.2.11 Bluetooth

Bluetooth technology is used in the platform for wireless communication with a smartphone or remote control. It enables smartphone connectivity, allowing users to control the platform remotely and send and receive data seamlessly.

3.2.2.12 Compass

The compass module obtains orientation and directional data, which is essential for the platform's navigation system. This data helps the platform determine its direction of movement and adjust its path accordingly.

3.2.3 Software Subsystems

The software architecture orchestrates the platform's operation, from autonomous navigation to user interaction. Algorithms for obstacle avoidance, path planning, and user tracking are implemented to ensure seamless and intuitive operation.

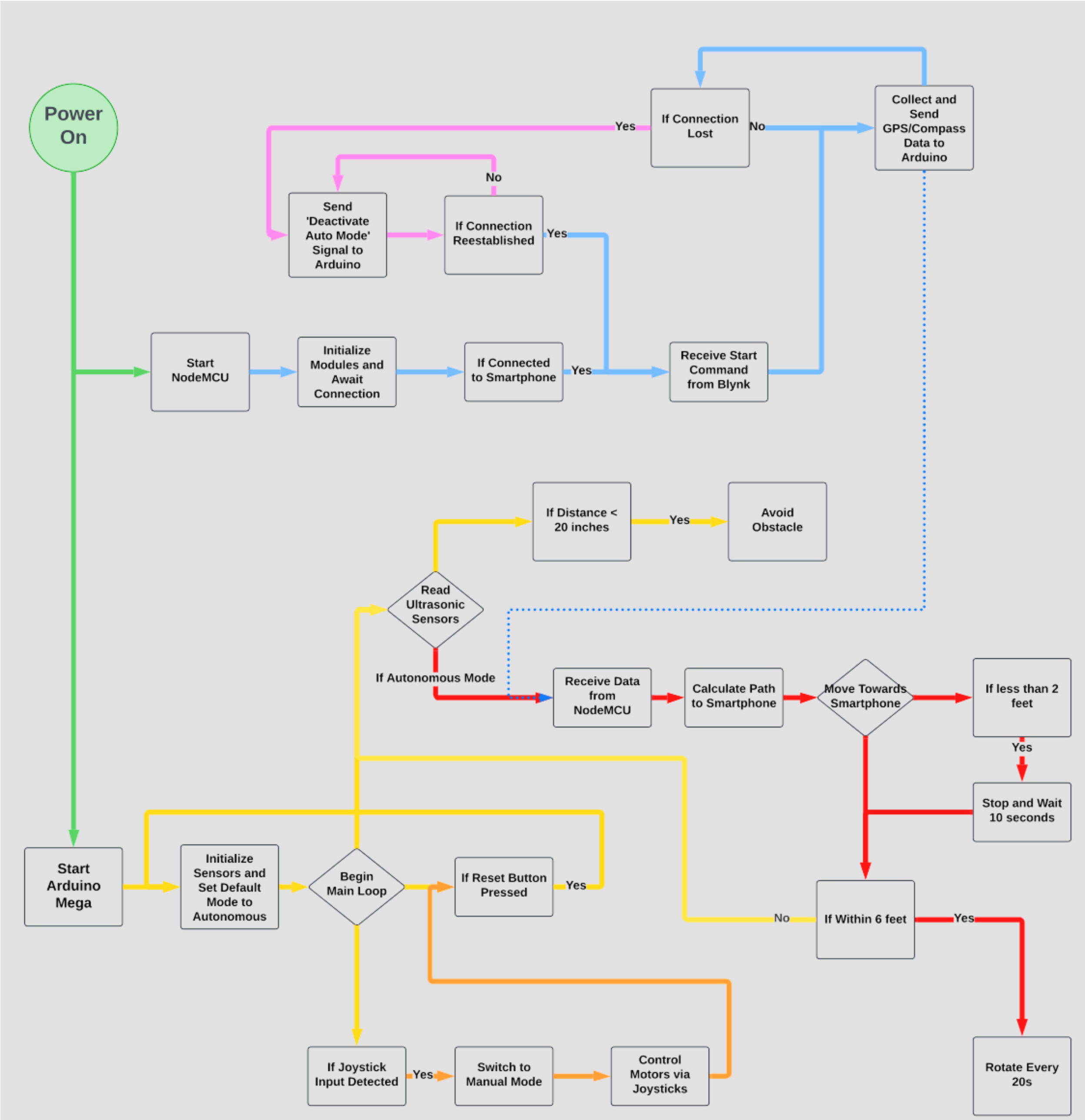

Figure 37:Software and Function Subsystem Breakdown Block Diagram

3.2.3.1 Follow-Me (Yellow)
The Follow-Me feature, shown in Figure 37 as the yellow path, is a cornerstone of the Autonomous Toolbox Platform, enabling it to autonomously navigate and follow the user based on their smartphone's location data. The platform receives and analyzes location data from the smartphone and GPS/compass modules, calculating and executing motor movements to minimize the distance between the toolbox and the user while orienting the toolbox appropriately. The algorithms employed for this feature are designed to calculate the path and speed required to maintain an optimal distance from the user while avoiding obstacles, ensuring smooth and efficient navigation.

3.2.3.2 Manual Control (Orange)
The platform can be manually controlled, shown in Figure 37 as the orange path, using the joysticks, allowing the user to override autonomous navigation and directly control the platform's movements. When the joysticks are activated, Autonomous mode is deactivated, and direct motor control is achieved through joystick input. The software interface translates these joystick inputs into motor commands, ensuring smooth and responsive manual control. The platform returns to Autonomous mode when the reset button is pressed.

3.2.3.3 Obstacle Avoidance (Red)
Obstacle avoidance, shown in Figure 37 as the red path, is a critical function of the platform, ensuring safe navigation by detecting obstacles in its path using data from ultrasonic sensors. If any ultrasonic sensor reads a distance of less than 20 inches, the platform activates its avoidance strategies. These strategies involve dynamically adjusting the platform's path to avoid collisions while maintaining the intended direction of movement. The platform calculates the distance and direction of all other sensors from the smartphone and chooses the path that reduces the distance to the smartphone the most while avoiding obstacles.

3.2.3.4 Location and Position Data (Blue)
The platform utilizes GPS data to determine its location and compass data to ascertain its orientation, shown in Figure 37 as the blue path. The NodeMCU initializes the Bluetooth module, the compass module, and itself, connecting to Wi-Fi and attempting to connect to a smartphone. Once connected, it receives messages from the Blynk app to start collecting data from the compass and GPS module, which the Arduino then analyzes. The location and position data are processed and used in conjunction with the user's smartphone data to enable features like Follow-Me and obstacle avoidance.

3.2.3.5 Connection Failure (Pink)
The platform is equipped to detect a loss of connection with the user's smartphone or other critical communication failures, shown in Figure 37 as the pink path. In the event of a connection failure, the NodeMCU constantly sends a signal to the Arduino to deactivate and disallow Auto mode. Safety measures and protocols are activated, such as halting movement and entering a safe

state. When the connection is reestablished and the Blynk app is active, the NodeMCU stops sending the deactivation signal, allowing the Arduino reset button to reactivate Auto mode.

3.3 Risk Analysis

The development of the Autonomous Toolbox Platform involved a thorough risk analysis to identify potential issues and implement mitigating measures. Key risks and their mitigation strategies are as shown in the matrix below (Table 4).

Risk	Likelihood of Occurrence (L,M,H)	Degree of Impact (L,M,H)	Action on Trigger	Response Plan
Insufficient Servo Strength	M	H	Servos fail under load	Select high-torque servo motors; conduct load tests; consider alternative motor options if needed
Instability on Uneven Surfaces	L	H	Platform tips or loses traction	Implement independent suspension; conduct terrain tests; adjust suspension design as needed
Unreliable User Tracking	M	H	Inaccurate tracking	Integrate multiple sensors; refine tracking algorithms; conduct user tests
Unreliable Object Avoidance	L	H	Collisions occur	Enhance sensor array; improve obstacle detection algorithms; conduct obstacle tests

Table 4: Risk Assessment Matrix

3.3.1 Insufficient Servo Strength

The risk of servo motors being unable to handle the platform's load was addressed by selecting high-torque servo motors and conducting load-bearing tests to ensure their adequacy.

3.3.2 Instability on Uneven Surfaces

To mitigate the risk of instability on uneven surfaces, the platform was designed with an independent suspension system, allowing each wheel to adapt to variations in the terrain, maintaining stability and traction.

3.3.3 Unreliable User Tracking

The potential issue of unreliable user tracking was countered by implementing a robust tracking system that utilizes multiple sensors and algorithms to accurately determine the user's position relative to the platform.

3.3.4 Unreliable Object Avoidance

The risk of the platform failing to avoid obstacles was addressed through the integration of a comprehensive sensor array and the development of advanced obstacle detection and avoidance algorithms.

4 FABRICATION

The fabrication process for the Autonomous Toolbox Platform was meticulously planned and executed, ensuring the structural integrity and functionality of the final product. This section details the fabrication process for the main components of the platform.

4.1 Chassis

The chassis serves as the foundational structure of the Autonomous Toolbox Platform, providing the necessary support and stability for all other components. Fabricated from a quarter-inch steel plate, the chassis was designed to be both robust and lightweight, striking a balance between durability and maneuverability.

The design process involved careful consideration of the platform's requirements, including load capacity, compatibility with the suspension system, and integration with the toolbox body. The steel plate was water jet cut at the Applied Engineering Center (AEC) at the University of Southern Indiana, following a precise cut pattern (Figure 38) to optimize material usage and ensure accuracy in the chassis' dimensions.

Figure 38: Water Jet Monitor Project Path

A custom welding jig made from aluminum extrusion (Figure 39, right) was used to hold the cut pieces in place during the welding process. This jig ensured that the chassis maintained its intended shape and alignment as the pieces were welded together using a 200 ampere (200 A) MIG welder. The welding was performed in a well-ventilated area, with proper safety equipment to protect against sparks and fumes.

Key features of the chassis include cut-outs for weight reduction and mounting points specifically designed for the Husky brand toolbox. These mounting points were positioned to align with the toolbox's original caster mounting holes, allowing for a seamless attachment of the toolbox to the chassis.

The chassis also incorporated design elements to facilitate the integration of the suspension system and motor mounts. The control arms and motor mounts were welded directly to the chassis, ensuring a strong and stable connection. The final assembly of the chassis with the toolbox body was test-fitted to confirm proper alignment and functionality (Figure 40).

Figure 39: Chassis Fabrication, Water Jetting (Left) and Welding Jig Table (Right)

After welding, the chassis underwent a cleaning process to remove any residues or contaminants. A protective coating, such as "gun blue," was applied to prevent rust and corrosion. This coating also provided a finished look to the chassis, enhancing the overall appearance of the platform.

Figure 40: Welded Chassis & Toolbox Body Test Fitting

4.2 Drive Assembly

The motors were mounted to the chassis using custom-fabricated motor mounts, which were designed to integrate seamlessly with the chassis and suspension components. The fabrication process involved welding the motor mounts directly to the control arms, a technique that ensured a sturdy and reliable connection. Once welded, the parts underwent a cleaning process using muriatic acid, followed by a water rinse and neutralization with baking soda (Figure 41). This thorough cleaning was crucial for removing any contaminants and preparing the surfaces for the next step in the fabrication process.

Figure 41: Drive Subassembly Etched with Muriatic Caid, Rinsed

To protect the cleaned parts from oxidation, a "gun blue" solution was applied (seen in the top-most subassembly in Figure 42). This protective layer was essential, especially since painting the parts was not an option due to the potential impact on the suspension components' fit and movement. The final assembly saw the incorporation of 30mm bearings pressed into the control arm sections, which housed a 17mm hardened steel axle. This axle, attached to the wheel, ensured that the weight of the assembly was carried by the axle and wheel, achieving the desired zero radial load on the motor shaft.

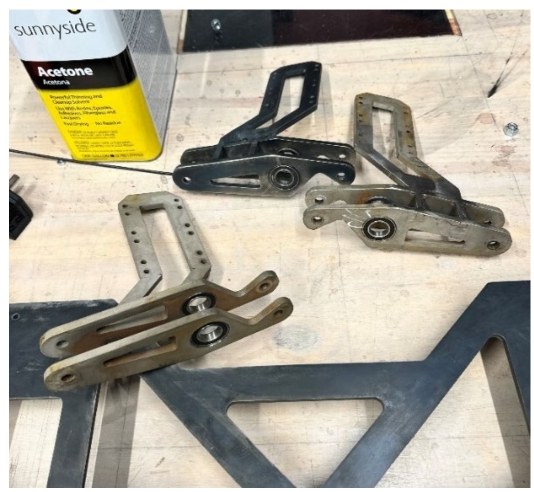

Figure 42: Drive Subassemblies with Bearings Pressed, Difference Between Blued and Non-Blued Parts

The heart of the drive assembly was the high-torque servo motors, each boasting a 32N*m torque capacity and equipped with built-in drivers. These motors, capable of switching between "motor" and "servo" modes, provided the necessary power and control for the platform's movement, as well as options for future modifications.

The drive assembly, a critical component of the Autonomous Toolbox Platform, was engineered with precision to ensure smooth and precise movement. The design focused on achieving a zero radial-load configuration, which was essential for minimizing wear on the motor shafts and ensuring longevity. This was accomplished by employing spider couplings (Figure 43), which not only absorbed vibration but also allowed for significant torque transmission, a key feature given the platform's requirement to carry heavy loads.

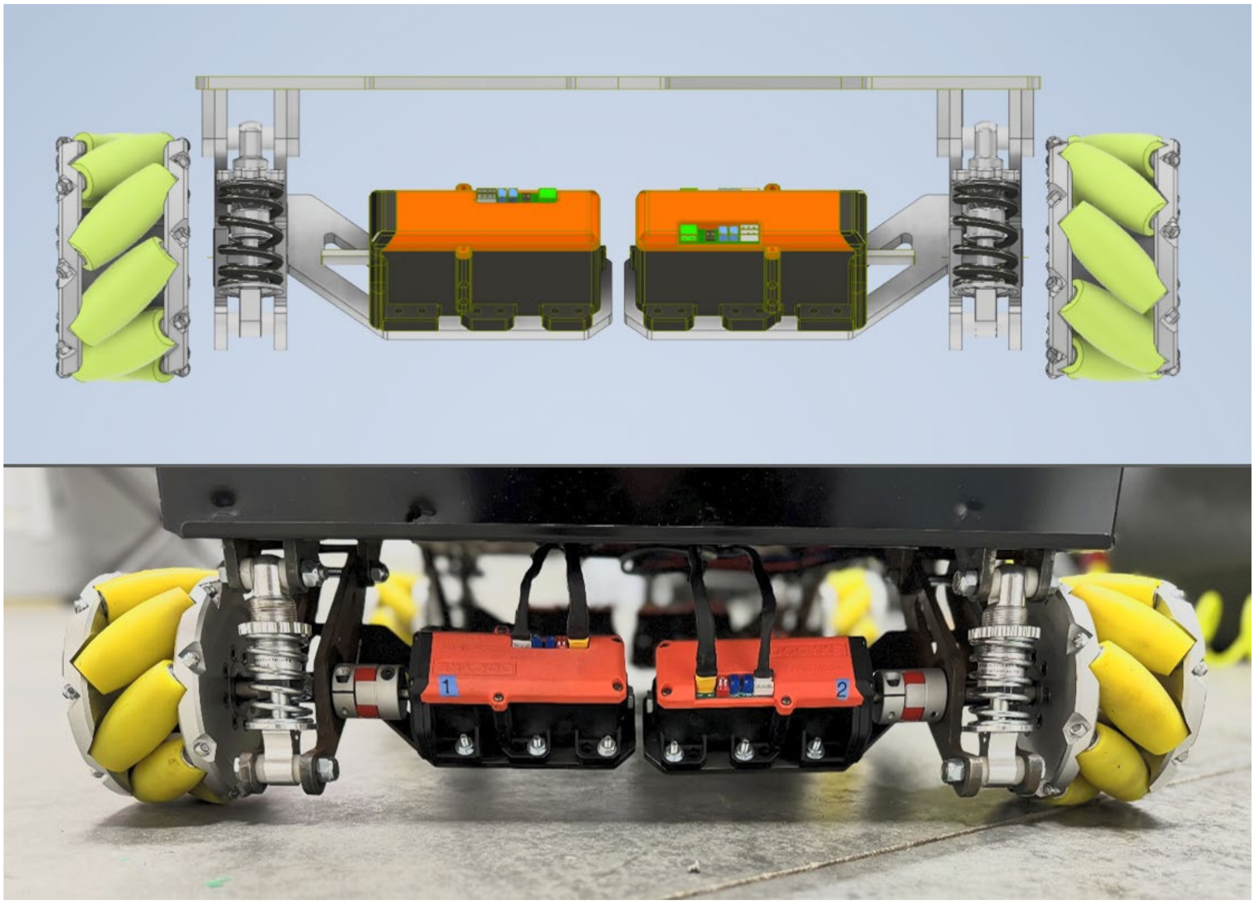

Figure 43: Platform & Drive Full Assembly (Side View)

The assembly process was meticulous, with each component carefully positioned and secured to ensure proper alignment and functionality (Figure 44). The test fitting of the wheels was a crucial step, as it confirmed the correct fit and operation of the drive assembly. This attention to detail during the fabrication process was instrumental in achieving a drive assembly that was both robust and capable of precise movement, as envisioned in the initial design.

4.3 Suspension

The suspension system of the Autonomous Toolbox Platform was designed with a focus on stability and adaptability to various terrains. The independent suspension setup incorporated short control arms and a 100lb shock absorber, ensuring that the platform maintained stability and all wheels remained in contact with the ground, even on uneven surfaces.

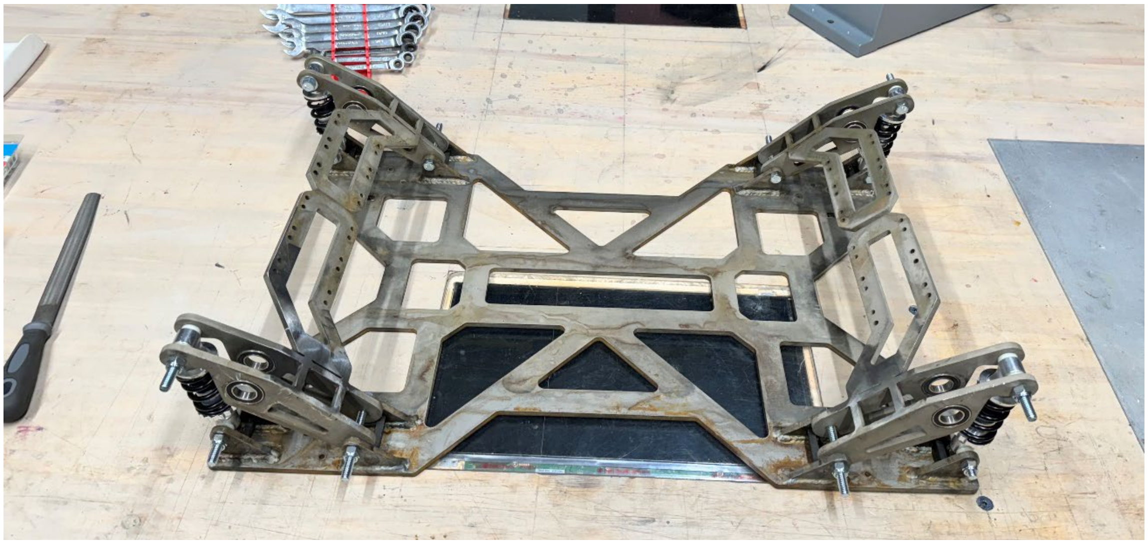

Figure 44: Platform Mechanical Test Assembly

Fabrication of the suspension system began with the careful design and cutting of the control arms from the same quarter-inch steel plate used for the chassis. These control arms were engineered to work in tandem with the shock absorbers, providing the necessary support and flexibility for the platform's movements. The shock absorbers, initially selected with a 100lb rating, were sourced from McMaster-Carr, along with alternative sets rated at 70lb and 130lb to allow for adjustments based on the platform's load and performance requirements.

The control arms featured pressed-in bearings, a design choice that facilitated smooth movement and reliable support for the standalone axle shafts. These axle shafts, made from hardened stainless steel, were a crucial component of the suspension system, ensuring that the weight of the platform was evenly distributed and supported.

The welded chassis, with the suspension and motor mounts roughly fitted, provided a solid foundation for these tests. The testing process included evaluating component fit, spring force, and motion, ensuring that the suspension system met the stringent requirements set for the platform.

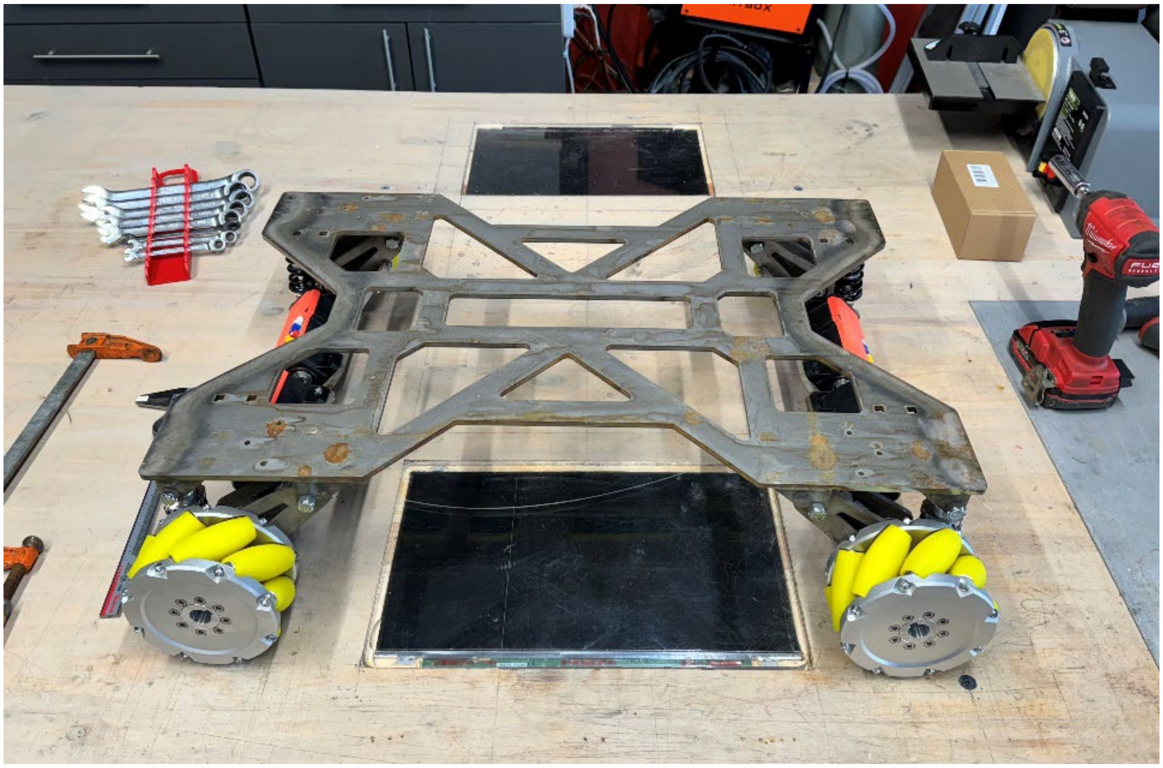

Figure 45: Platform Assembly, Rough Test Fitting

Once the control arms and suspension components were assembled (Figure 44), the system underwent a series of tests to ensure optimal performance. The initial testing with the 100lb shock absorbers (Figure 46) revealed the need for adjustments, leading to the temporary replacement with the 70lb set from McMaster-Carr (). However, it was soon discovered that the lighter springs did not provide sufficient return to the resting position under light load, prompting a return to the original 100lb springs.

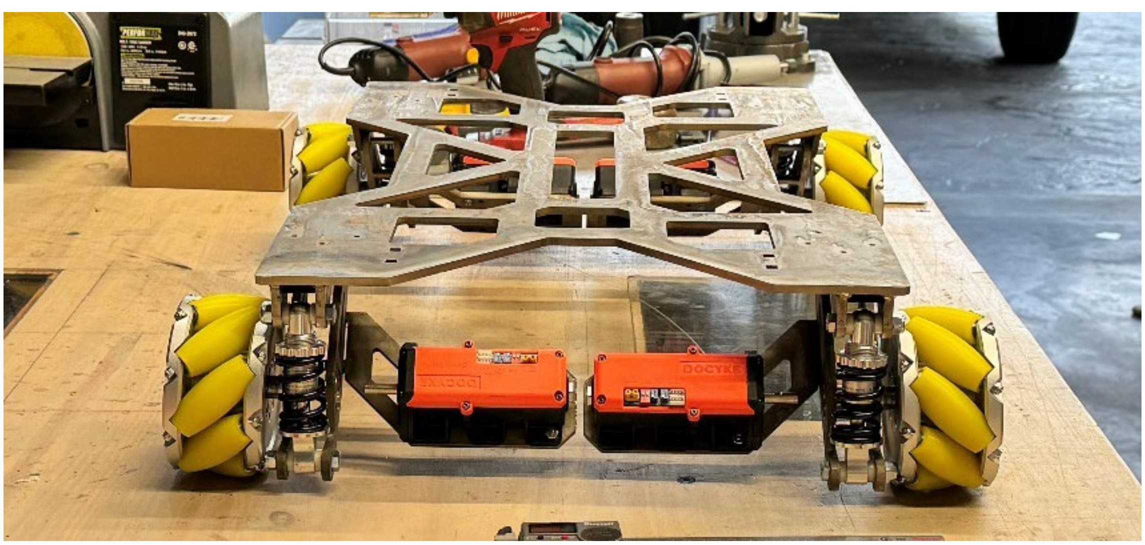

Figure 46: Platform Assembly Rough Fitment and Compression Testin, 100lb Springs

In conclusion, the fabrication of the suspension system was a critical step in the development of the Autonomous Toolbox Platform. It required a combination of careful planning, precise engineering, and rigorous testing to achieve a suspension system that provided stability, adaptability, and reliable support for the platform's various components and functions.

Figure 47:Platform Assembly Rough Fitment and Compression Testin, 70lb Springs

4.4 Feedback Devices

The feedback devices, particularly the ultrasonic sensors, play a pivotal role in the Autonomous Toolbox Platform's ability to navigate and interact with its environment. These sensors are crucial for obstacle detection, distance measurement, and ensuring the platform maintains a safe distance from the user and any potential obstacles.

The platform is equipped with twelve ultrasonic sensors, strategically positioned around the top perimeter of the toolbox. These sensors were carefully inset into the toolbox body to ensure they were flush with the exterior (, minimizing the risk of damage and maintaining the sleek appearance of the platform. The fabrication process for mounting these sensors involved creating precise cutouts in the toolbox sides, a task that required accuracy to ensure a snug fit for the sensors.

Figure 48:Rear Facing Ultrasonic Sensors Shown Mounted Flush and at Varying Angles

The sensors were housed in custom 3D-printed bezels (Figure 49), designed to not only secure the sensors in place but also to provide a protective barrier. These bezels were fabricated using PLA filament on a Creality Ender 3 V2 3D printer, chosen for its reliability and quality of print. The design of the bezels included a 15-degree chamfer, a thoughtful addition that accounted for the sensors' output angle, ensuring optimal performance and reducing the risk of interference.

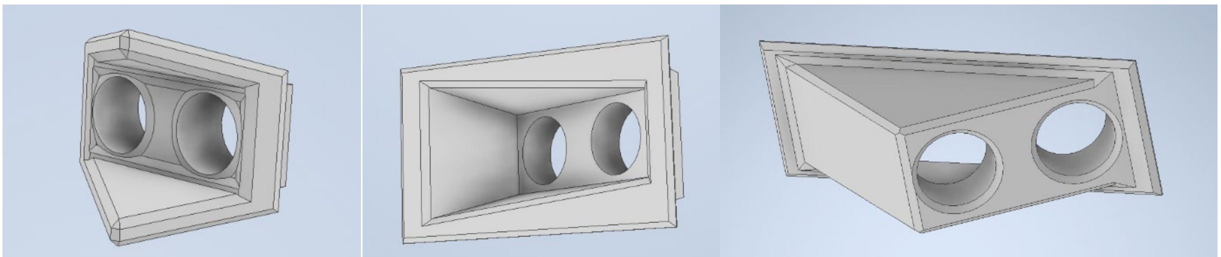

Figure 49: Three of Four Ultrasonic Sensor Housings, 35-degree flush (left), 20-degree flush (center), and 35-degree protruding (right)

Once mounted, the ultrasonic sensors were connected to the platform's control system, allowing them to transmit data on the distances to nearby objects. This information is critical for the platform's obstacle avoidance algorithms and for maintaining a safe following distance from the user.

The integration of these feedback devices into the Autonomous Toolbox Platform was a meticulous process, ensuring that each sensor was correctly positioned, securely mounted, and effectively connected to the platform's control system. The result is a platform that is highly aware of its surroundings, capable of navigating with precision, and equipped to handle the challenges of real-world environments.

4.5 Communications

The communication system of the Autonomous Toolbox Platform is a vital component that enables seamless interaction between the platform, the user's smartphone, and the various onboard sensors and modules. This system is responsible for the exchange of data, commands, and feedback, ensuring the platform operates intelligently and responsively.

At the heart of the platform's communication system is the communication panel (Figure 50), strategically located on top of the toolbox. This panel houses several key communication modules, including the compass module, Bluetooth module, Wi-Fi module (NodeMCU ESP8266), and GPS module. The placement of the panel was carefully chosen to ensure unobstructed signal transmission and reception, a crucial factor for reliable wireless communication.

The fabrication of the communication panel involved a meticulous process. The layout was first designed in 2D CAD and printed in a 1:1 scale to serve as a template. A custom-built sliding router platform was then used to route the panel according to the template, ensuring precision and accuracy in the cutouts for the various modules. The sliding router platform allowed for smooth and controlled movement, resulting in a neatly finished panel.

Figure 50: Communications Panel Fabrication Process

Each communication module on the panel plays a specific role in the platform's operation. The compass module provides orientation data, essential for navigation and maintaining the correct heading. The Bluetooth module enables wireless communication with the user's smartphone, allowing for remote control and data exchange. The Wi-Fi module, part of the NodeMCU ESP8266, offers additional connectivity options and is responsible for handling the communication between the platform and the internet or a local network. Lastly, the GPS module is crucial for determining the platform's precise location, a key factor in the Follow-Me feature.

The integration of these modules into the communication panel was done with attention to detail, ensuring each module was securely mounted and properly connected to the platform's control system. The modules were positioned to optimize signal strength and minimize interference, ensuring reliable and consistent communication.

4.6 Control Center

The control center is the nerve center of the Autonomous Toolbox Platform, housing the electrical components and systems that manage power distribution, signal processing, and overall platform control. This section is strategically located within the lower drawer of the toolbox, ensuring easy access for maintenance and adjustments while protecting the components from external elements.

The lower drawer was chosen as the ideal location for the control center due to its spaciousness and ease of access. This placement allows for efficient organization of the various components, including terminal blocks, relay modules, and the buck converter. The control center is neatly arranged within this drawer, with each component securely mounted to ensure stability and reliability during the platform's operation.

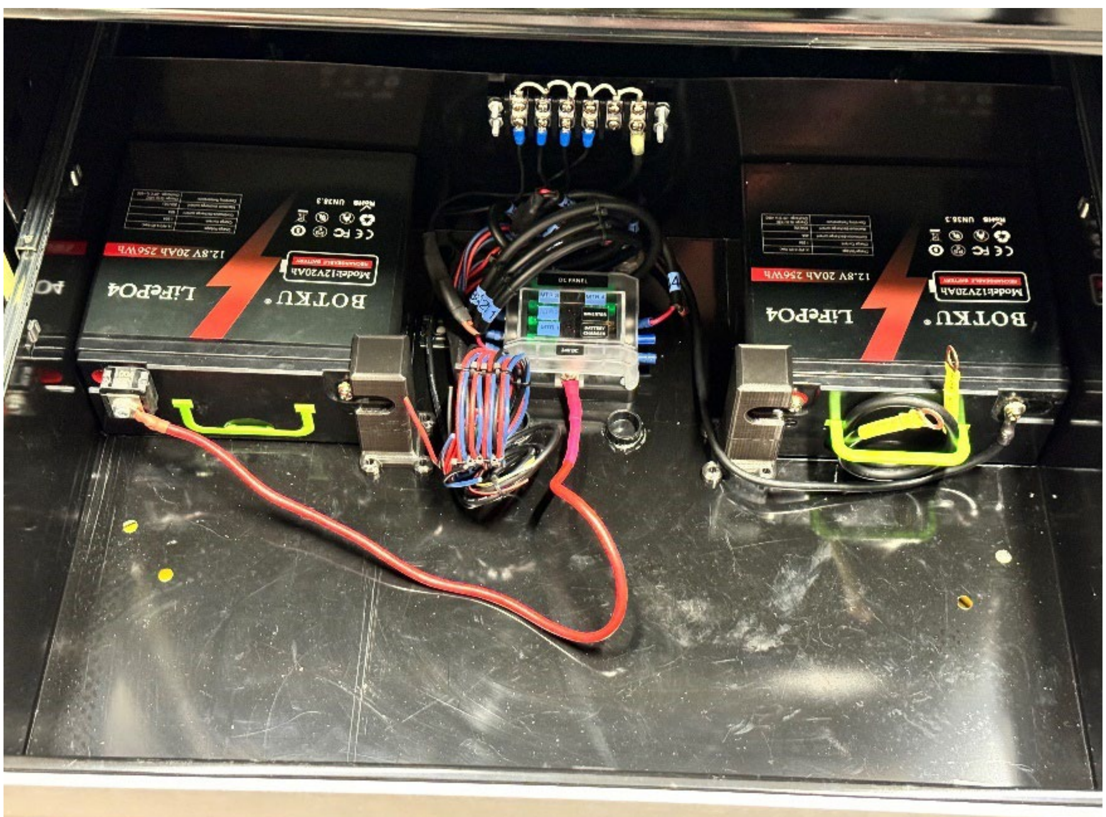

Figure 51: Control Center Battery Arrangement

To facilitate the assembly of the control center, a pulley system was devised to easily lift and position the toolbox onto a workbench (Figure 52). This solution allowed for ergonomic and efficient work during the installation and wiring of the electrical components. The pulley system, a simple yet effective mechanism, consisted of heavy-duty hooks and ropes securely attached to the garage ceiling joists. By weaving a ratchet strap around the frame and attaching the hooks to a system of shackles and pulleys, the platform could be smoothly hoisted onto the workbench, providing clear access to the lower drawer for the assembly of the control center.

Figure 52: Toolbox Assembly Improvised Pulley System

Key components of the control center include:

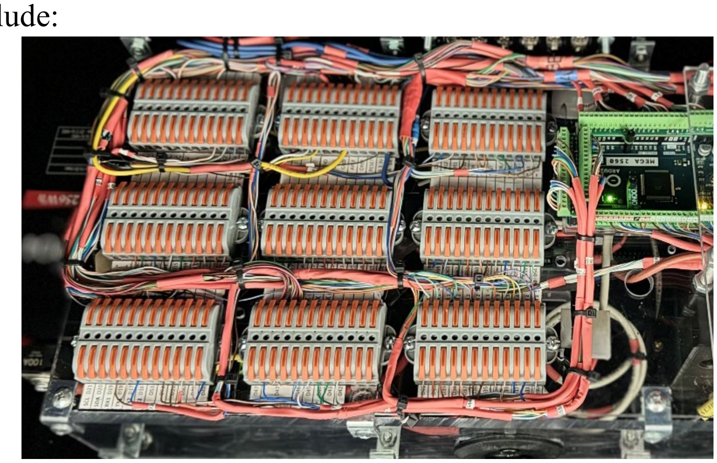

Figure 53: Control Center Terminal Block System

- Terminal Blocks: These are used for the easy and organized connection of the platform's electrical systems. They provide a convenient way to connect and disconnect components, simplifying troubleshooting and maintenance (Figure 53).
- Relay Module: Included for future expansion, the relay module offers flexibility in

controlling additional electrical devices or systems that may be added to the platform.

- Buck Converter: This
- device is crucial for reducing the primary 24VDC from the batteries to a stable 5VDC, which is used to power the Arduino Mega 2560 Rev. 3 and other 5V components. The buck converter is designed to be digital, adjustable, and capable of returning to accurate voltage settings after power down, ensuring reliable operation.

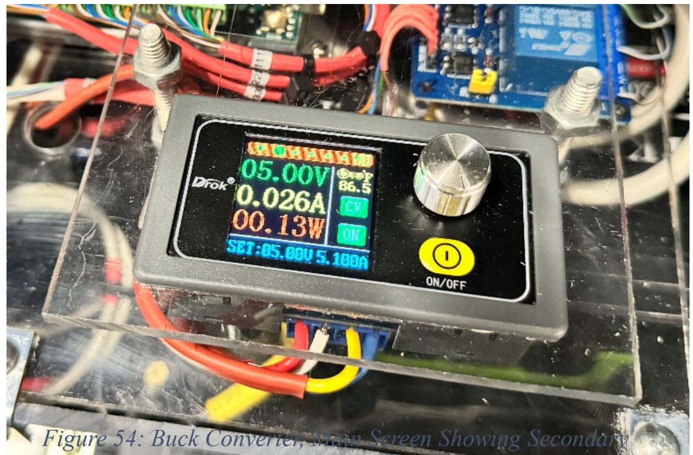

Figure 54: Buck Converter, Main Screen Showing Secondary Voltage

- Fuse Block: A 6-place fuse block is used to distribute power to the motors and other components, with each motor connected to its own 30 A fuse for protection. The batteries, wired in series to achieve a 24VDC system, are also connected to this fuse block, with additional fuses for the buck converter and charging port.

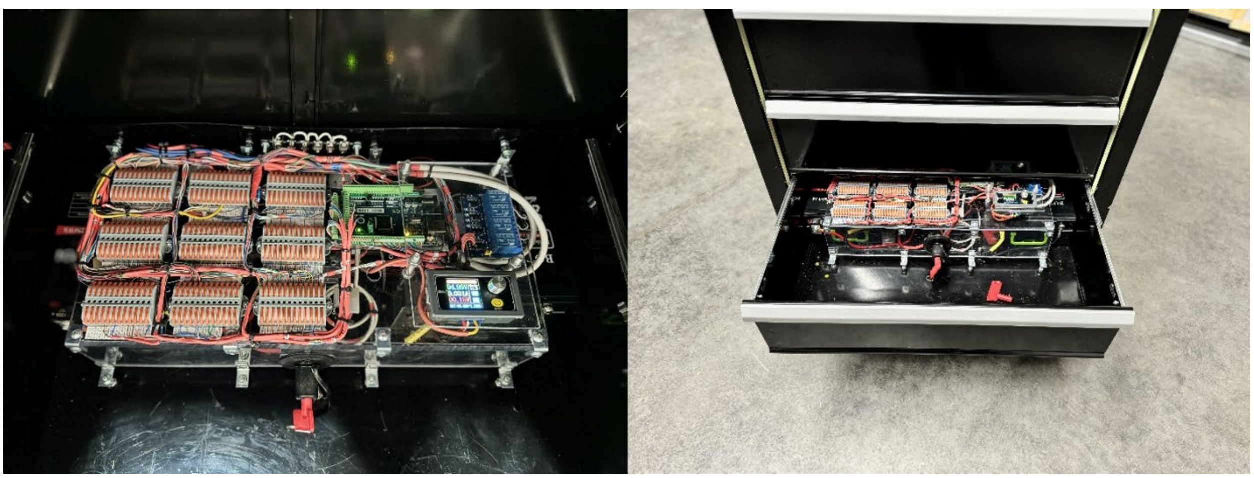
Figure 55: Control Center Final Assembly Arrangement

A notable feature of the control center's wiring is the use of DB25 connectors (Figure 56), which serve as a compact and reliable means of connecting the ultrasonic sensors to the Arduino. These connectors allow for the efficient organization of multiple sensor wires, reducing clutter and simplifying connections. The wires from the ultrasonic sensors are routed through the toolbox and terminate at these DB25 connectors, which are then coupled to the control center, ensuring a secure and tidy setup.

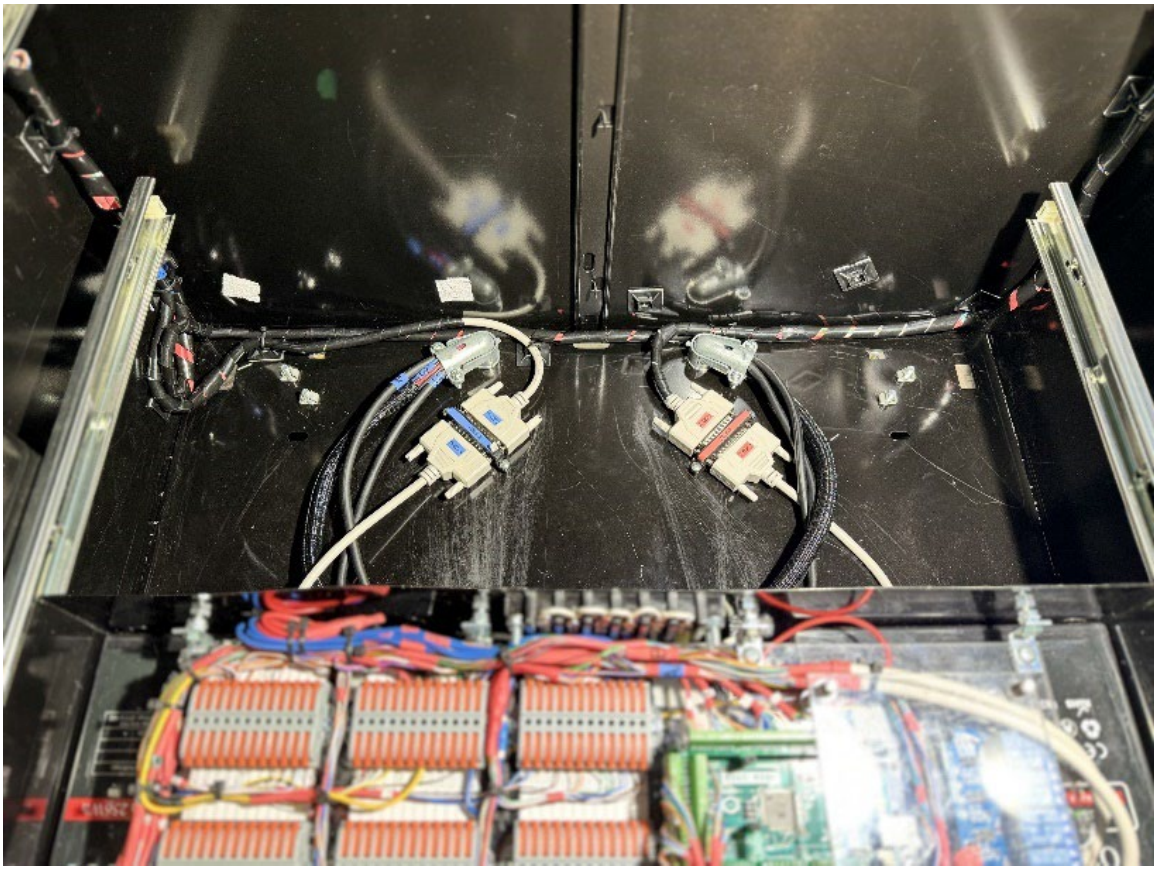

Figure 56: Control Center Connectivity, Two DB25 Connections to Sensors and Communications Panel

4.7 Controller

The manual controller is an essential interface that allows the user to directly control the Autonomous Toolbox Platform, providing an alternative to the autonomous Follow-Me mode. This controller is designed for precision and ease of use, ensuring that the user can maneuver the platform with confidence.

Figure 57: Manual Motor Controller Fabrication and Wiring Progress

The controller is housed in a custom-designed 3D-printed enclosure, which is strategically mounted inside the top drawer of the toolbox for easy access. This placement not only protects the controller when not in use but also ensures that it is readily available when manual control is needed. The housing is designed to accommodate two joysticks, allowing for 3-axis operation: pan in the x-direction, pan in the y-direction, and rotation. This setup provides intuitive control over the platform's movements, allowing the user to navigate the toolbox with precision.

Figure 58: Controller Assembly

The controller's functionality is centered around its two joysticks, which are directly connected to the platform's control system. Input from the joysticks is translated into motor commands, allowing the user to steer the platform in any direction and rotate it as needed. The controller also features an emergency stop (e-stop) button, a critical safety feature that immediately halts the platform's movements in case of an emergency. This e-stop button is designed to not only shut down the program but also to disconnect the motors' signal wires as a redundant safety measure.


Figure 59: E-Stop Button Location

In addition to the e-stop button, the controller includes a reset button (Figure 60), which is wired to the Arduino Mega's reset pin. Pressing this button resets the device, allowing the user to easily switch back to Autonomous mode after manual control. The controller is also equipped with LEDs that indicate the platform's current operating mode, providing visual feedback to the user.

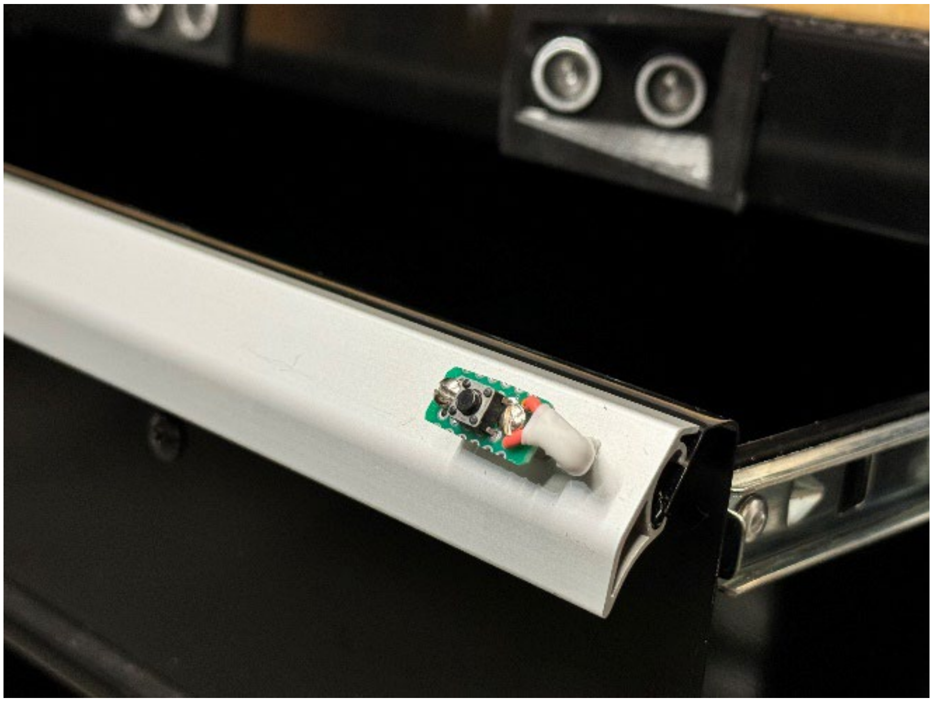

Figure 60: External Arduino Reset Button

The integration of the controller into the platform's control system was a key step in the fabrication process. The joysticks, e-stop button, and reset button were all carefully wired to the Arduino Mega, ensuring that their signals were accurately transmitted and processed. The placement of the controller within the top drawer of the toolbox was also carefully considered, ensuring that it was both accessible and secure.

5 FEATURES AND FUNCTION

The Autonomous Toolbox Platform is designed with a focus on enhancing user experience and productivity in various workspace environments. This section outlines the key features and functionalities of the platform.

5.1 Autonomous

In autonomous mode, the platform follows the user automatically, maintaining a comfortable distance and speed with safe acceleration. The platform is programmed to have a follow buffer, ensuring it does not follow if the user stays within a 5-foot radius. This mode is activated by pressing the reset button after being in manual mode. If the reset button is pressed while in auto mode, the Arduino program simply restarts without affecting the mode.

5.2 Manual Control

Manual control of the platform is facilitated by two joysticks, positioned for one-handed operation when the top drawer is opened. Manual mode is immediately activated upon any input from the joystick modules, temporarily deactivating auto mode. Auto mode can be restored by pressing the reset button, allowing for seamless switching between modes.

5.3 Adaptation and Modifiability

The platform is designed to be adaptable and modifiable to meet the evolving needs of users. Every pin on the Arduino Mega terminates at its own terminal block in the control panel, enabling easy addition of components, convenient troubleshooting, and enhanced safety. This design feature ensures that the platform can be customized and upgraded as required.

6 PROTOTYPE TESTING AND IMPROVEMENT

Before finalizing the design of the Autonomous Toolbox Platform, a series of comprehensive tests were conducted to evaluate its functionality, stability, and load capacity. These tests were designed to rigorously assess the platform's performance under various conditions and to identify any potential areas for improvement. The testing process was crucial in validating the design assumptions and ensuring that the platform could meet the practical demands of real-world use. This section details the methods, challenges, and outcomes of testing the manual manipulation capabilities, autonomous mode functionality, conditional reactions to environmental interactions, operational stability, and load capacity. Each test was aimed at confirming that the platform not only adhered to theoretical design specifications but also excelled in everyday operational scenarios, thereby guaranteeing reliability and user satisfaction.

6.1 Manual Manipulation

During the manual manipulation tests, the platform was controlled using a dual joystick setup to assess its responsiveness and precision. These tests involved navigating through intricate paths and tight spaces, effectively demonstrating the platform's ability to accurately follow user commands under real-world conditions. The results confirmed that the manual control system was both robust and precise, ensuring effective maneuverability in varied scenarios.

6.2 Autonomous Mode

The initial functionality test in autonomous mode showed promising results with successful activation and navigation, indicating the platform's potential for independent operation. However, a critical incident occurred when a maintenance oversight left a 12VDC supply wire connected, leading to a catastrophic failure upon power-up. This severely damaged most components, compromising the autonomous functionality and necessitating a temporary return to manual operation. Recovery efforts included ordering new parts, but full restoration of autonomous mode was not feasible within the project timeline.

6.3 Conditional Reactions

Throughout testing, the platform's interaction with the user and environment was closely monitored. Adjustments were made to refine how the platform reacted to various stimuli, such as navigating around obstacles and responding to user inputs. These conditional reactions were essential for ensuring that the platform could operate intelligently and adaptively in a dynamic environment.

6.4 Operational Stability

Operational stability tests were conducted under various load conditions to assess the platform's robustness. The platform was loaded with a full complement of Milwaukee power tools and additional heavy items, including two landscaping bricks, to simulate an overloaded condition. Despite the significant additional weight, the platform's manual movements were only minimally affected, with an estimated maximum speed reduction of 10%. Further stability tests involved extending each drawer to its full length, and even under these conditions, the platform remained stable without leaning or tipping over. This demonstrated the platform's exceptional stability, even when carrying and maneuvering with heavy loads.


Figure 41: Operational & Load Testing

6.5 Load Capacity

The platform's load capacity was rigorously tested to verify its ability to handle significant weight without compromising performance or stability. It was loaded to its maximum recommended capacity of 650 pounds, including heavy power tools and additional weight to simulate extreme conditions. The tests confirmed that the platform could sustain this weight, maintaining operational efficiency and stability without any significant reduction in speed or mobility.

7 CONCLUSION

The development of the Autonomous Toolbox Platform represents a significant advancement in workspace organization and efficiency. Throughout the design, fabrication, and testing phases, the project has demonstrated a commitment to innovation, user-centric design, and technical excellence.

The final design of the platform successfully integrates mechanical, electrical, and software subsystems to provide a robust and versatile solution for tool management. Key features such as autonomous navigation, manual control, and adaptability ensure that the platform can meet the diverse needs of users in various workspace environments.

The extensive testing and improvement process has validated the platform's operational stability, load capacity, and overall performance. The platform has proven capable of handling a wide range of tools and equipment, maintaining stability even under overloaded conditions, and providing reliable and efficient operation.

As we look to the future, the Autonomous Toolbox Platform has the potential to revolutionize the way tools are managed and accessed in workspaces. The lessons learned and insights gained from this project will undoubtedly inform future developments and enhancements, further advancing the field of workspace automation.

In conclusion, the Autonomous Toolbox Platform stands as a testament to the power of innovative engineering and design. It offers a glimpse into the future of workspace organization, where efficiency, convenience, and adaptability are paramount.

8 SOURCES

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9 APPENDIX

9.1 APPENDIX A: WORK BREAKDOWN STRUCTURE

PAGE 1 of 2

1 Project Design
2 Bill of Materials
  2.1 3D Design - Draft 1
  2.2 Component Delivery Checklist
3 Project Fabrication
  3.1 Base Frame Fabrication
  3.2 Drivetrain Fabrication
  3.3 Electronics Assembly
    3.3.a Motors & Drivers
    3.3.b Power Supply Wiring
    3.3.c Signal Wiring
    3.3.d Control Center
    3.3.e Compartment Layout & Planning
    3.3.f Mechanical Component Fabrication
    3.3.g Electrical Component Assembly
    3.3.h Components
    3.3.i Sensor Layout & Planning
    3.3.j Sensor Wiring & Assembly
    3.3.k Communications Layout & Planning
    3.3.l Communication Wiring & Assembly
    3.3.m Wiring
      3.3.m.i Terminal Block Layout & Planning
      3.3.m.ii Terminal Wiring
      3.3.m.iii Sensors
      3.3.m.iv Motors
      3.3.m.v Communication
      3.3.m.vi Power Supply
4 Testing & Adjustments
  4.1 Primary & Secondary Power Supply
  4.2 Motor Power & Function
  4.3 Sensor & Module Power Indicators
5 Project Programming
  5.1 Motion System Programming
    5.1.a Arduino Setup
    5.1.b Motor Driver Setup
    5.1.c Bluetooth/Wi-Fi Setup
    5.1.d Function Programming
    5.1.e MAIN 1 - Directional Motion

9.1 APPENDIX A: WORK BREAKDOWN STRUCTURE (Continued)

PAGE 2 of 2

- 5.1.f MAIN 2 - User Pairing
- 5.1.g MAIN 3 - User Activation
- 5.1.h MAIN 4 - User Deactivation

6 Extra Components Needed
- 6.1 Itemize and Source New Components
- 6.2 Purchase New Components
- 6.3 Component Delivery Checklist

7 Feature Programming
- 7.1 Primary Features
  - 7.1.a PRIMARY 1 - User Detection and Tracking
  - 7.1.b PRIMARY 2 - User Following
  - 7.1.c PRIMARY 3 - Manual Motion Control
  - 7.1.d Remote Controller
  - 7.1.e Component Arrangement
  - 7.1.f 3D Design
  - 7.1.g 3D Print & Fabrication
  - 7.1.h Arduino Compatibility Connection
  - 7.1.i Arduino Programming

8 Testing
- 8.1 WEEK THIRTEEN
  - 8.1.a Draft Report
  - 8.1.b Draft Presentation
- 8.2 Secondary Features
  - 8.2.a SECONDARY 1 - Obstacle Detection
  - 8.2.b SECONDARY 2 - Obstacle Avoidance
  - 8.2.c SECONDARY 3 - Auto-Docking & Charging
  - 8.2.d Function & Feature Testing

9 HMI Programming
- 9.1 Raspberry Pi Setup
- 9.2 Raspberry Pi Interface Design
- 9.3 Raspberry Pi Compatibility Connection
- 9.4 HMI Mount & Wiring

10 Project Testing
- 10.1 Load & Stress Testing

11 Project Finalizing
- 11.1 Photo & Video Documentation
- 11.2 Final Report
- 11.3 PowerPoint Presentation
- 11.4 Final Presentation Preparation
- 11.5 Final Presentation

9.2 APPENDIX B: PROJECT SCHEDULE

ID	Task Name	Duration	Start	Finish
1	**Project Design**	**11 days**	**Mon 1/15/24**	**Thu 1/25/24**
2	**Bill of Materials**	**5 days**	**Mon 1/15/24**	**Fri 1/19/24**
5	3D Design - Draft 1	5 days	Sat 1/20/24	Wed 1/24/24
6	Component Delivery Checklist	1 day	Thu 1/25/24	Thu 1/25/24
7	**Project Fabrication**	**45 days**	**Fri 1/26/24**	**Sun 3/10/24**
8	Base Frame Fabrication	5 days	Fri 1/26/24	Tue 1/30/24
9	Drivetrain Fabrication	5 days	Wed 1/31/24	Sun 2/4/24
10	**Electronics Assembly**	**32 days**	**Mon 2/5/24**	**Thu 3/7/24**
11	**Motors & Drivers**	**3 days**	**Mon 2/5/24**	**Wed 2/7/24**
12	Power Supply Wiring	2 days	Mon 2/5/24	Tue 2/6/24
13	Signal Wiring	1 day	Wed 2/7/24	Wed 2/7/24
14	**Control Center**	**16 days**	**Thu 2/8/24**	**Fri 2/23/24**
15	Compartment Layout & Planning	2 days	Thu 2/8/24	Fri 2/9/24
16	Machanical Component Fabrication	6 days	Sun 2/11/24	Fri 2/16/24
17	Electrical Component Assembly	6 days	Sun 2/18/24	Fri 2/23/24
18	**Components**	**6 days**	**Sat 2/24/24**	**Thu 2/29/24**
19	Sensor Layout & Planning	1 day	Sat 2/24/24	Sat 2/24/24
20	Sensor Wiring & Assembly	3 days	Sun 2/25/24	Tue 2/27/24
21	Communications Layout & Planning	1 day	Wed 2/28/24	Wed 2/28/24
22	Communication Wiring & Assembly	1 day	Thu 2/29/24	Thu 2/29/24
23	**Wiring**	**7 days**	**Fri 3/1/24**	**Thu 3/7/24**
24	Terminal Block Layout & Planning	3 days	Fri 3/1/24	Sun 3/3/24
25	**Terminal Wiring**	**4 days**	**Mon 3/4/24**	**Thu 3/7/24**
26	Sensors	1 day	Mon 3/4/24	Mon 3/4/24
27	Motors	1 day	Tue 3/5/24	Tue 3/5/24
28	Communication	1 day	Wed 3/6/24	Wed 3/6/24
29	Power Supply	1 day	Thu 3/7/24	Thu 3/7/24
30	**Testing & Adjustments**	**3 days**	**Fri 3/8/24**	**Sun 3/10/24**
31	Primary & Secondary Power Supply	1 day	Fri 3/8/24	Fri 3/8/24
32	Motor Power & Function	1 day	Sat 3/9/24	Sat 3/9/24
33	Sensor & Module Power Indicators	1 day	Sun 3/10/24	Sun 3/10/24
34	**Project Programming**	**53 days**	**Sun 3/10/24**	**Thu 5/2/24**
35	**Motion System Programming**	**1 day**	**Sun 3/10/24**	**Mon 3/11/24**
36	Arduino Setup	0 days	Sun 3/10/24	Sun 3/10/24
37	Motor Driver Setup	1 day	Mon 3/11/24	Mon 3/11/24
38	Bluetooth/Wifi Setup	0 days	Mon 3/11/24	Mon 3/11/24
39	**Function Programming**	**4 days**	**Tue 3/12/24**	**Fri 3/15/24**
40	MAIN 1 - Directional Motion	1 day	Tue 3/12/24	Tue 3/12/24
41	MAIN 2 - User Pairing	1 day	Wed 3/13/24	Wed 3/13/24
42	MAIN 3 - User Activation	1 day	Thu 3/14/24	Thu 3/14/24
43	MAIN 4 - User Dectivation	1 day	Fri 3/15/24	Fri 3/15/24
44	Extra Components Needed	0 days	Fri 3/15/24	Fri 3/15/24
45	Itemize and Source New Components	0 days	Fri 3/15/24	Fri 3/15/24
46	Purchase New Components	0 days	Fri 3/15/24	Fri 3/15/24
47	Component Delivery Checklist	0 days	Fri 3/15/24	Fri 3/15/24
48	**Feature Programming**	**48 days**	**Sat 3/16/24**	**Thu 5/2/24**
49	**Primary Features**	**11 days**	**Sat 3/16/24**	**Tue 3/26/24**
50	PRIMARY 1 - User Detection and Tracking	2 days	Sat 3/16/24	Sun 3/17/24
51	PRIMARY 2 - User Following	2 days	Mon 3/18/24	Tue 3/19/24
52	**PRIMARY 3 - Manual Motion Control**	**7 days**	**Wed 3/20/24**	**Tue 3/26/24**
53	**Remote Controller**	**7 days**	**Wed 3/20/24**	**Tue 3/26/24**
54	Component Arrangement	1 day	Wed 3/20/24	Wed 3/20/24
55	3D Design	1 day	Thu 3/21/24	Thu 3/21/24
56	3D Print & Fabrication	2 days	Fri 3/22/24	Sat 3/23/24
57	Arduino Compatibility Connection	1 day	Sun 3/24/24	Sun 3/24/24
58	Arduino Programming	1 day	Mon 3/25/24	Mon 3/25/24
59	Testing	1 day	Tue 3/26/24	Tue 3/26/24
60	**WEEK THIRTEEN**	**0 days**	**Mon 4/1/24**	**Mon 4/1/24**
61	Draft Report	7 days	Mon 4/1/24	Sun 4/7/24
62	Draft Presentation	1 day	Mon 4/8/24	Mon 4/8/24
63	**Secondary Features**	**13 days**	**Tue 4/9/24**	**Sun 4/21/24**
64	SECONDARY 1 - Obstacle Detection	4 days	Tue 4/9/24	Fri 4/12/24
65	SECONDARY 2 - Obstacle Avoidance	4 days	Sat 4/13/24	Tue 4/16/24
66	SECONDARY 3 - Auto-Docking & Charging	4 days	Wed 4/17/24	Sat 4/20/24
67	Function & Feature Testing	1 day	Sun 4/21/24	Sun 4/21/24
68	**HMI Programming**	**11 days**	**Mon 4/22/24**	**Thu 5/2/24**
69	Raspberry Pi Setup	1 day	Mon 4/22/24	Mon 4/22/24

Project: Senior Project Schedule
Date: Sun 4/7/24

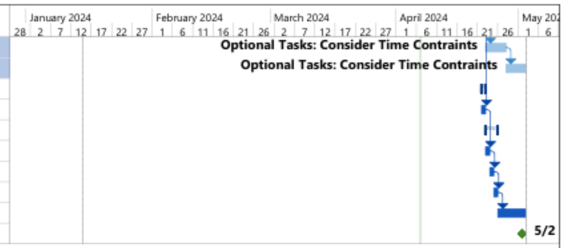
Task		Inactive Task		Manual Summary		Deadline	
Split		Inactive Milestone		Start-only		Progress	
Milestone		Inactive Summary		Finish-only		Manual Progress	
Summary		Manual Task		External Tasks			
Project Summary		Duration-only		External Milestone			

Page 1

Table 5: Detailed Project Schedule (Page 1 of 2)

9.2 APPENDIX B: PROJECT SCHEDULE (Continued)

ID	Task Name	Duration	Start	Finish
70	Raspberry Pi Interface Design	5 days	Tue 4/23/24	Sat 4/27/24
71	HMI Mount & Wiring	5 days	Sun 4/28/24	Thu 5/2/24
72	**Project Testing**	**1 day**	**Mon 4/22/24**	**Mon 4/22/24**
73	Load & Stress Testing	1 day	Mon 4/22/24	Mon 4/22/24
74	**Project Finalizing**	**3 days**	**Tue 4/23/24**	**Thu 4/25/24**
75	Photo & Video Documentation	1 day	Tue 4/23/24	Tue 4/23/24
76	Final Report	1 day	Wed 4/24/24	Wed 4/24/24
77	PowerPoint Presentation	1 day	Thu 4/25/24	Thu 4/25/24
78	Final Presentation Preparation	7 days	Fri 4/26/24	Thu 5/2/24
79	Final Presentation	0 days	Thu 5/2/24	Thu 5/2/24



Project: Senior Project Schedule
Date: Sun 4/7/24

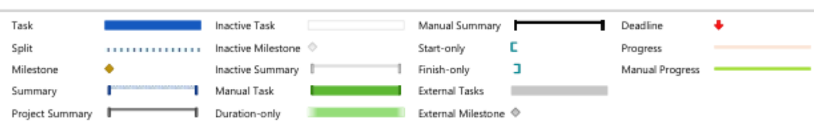


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Table 6: Detailed Project Schedule (Page 2 of 2)

9.3 APPENDIX C: BILL OF MATERIALS

Table 7: Bill of Materials

Autonomous Toolbox — Created by: J A LOCHER — Project: — Date Created: 9/27/2023 11:49 AM — BOM rev: 1

		Component				Main Specifications			Price						
		No.	Part	Description	Qty	Spec. 1	Spec. 2	Spec. 3	Price	Vendor	Link	SELECTED OPTION	TOTAL	Ordered	Delivered
MECHANICAL		1	2796N15	Omni-Directional Wheel - LEFT	2	500 lb cap.	8" dia. X 3.5"	1.875in shaft	$153.00	McMasterCarr	https:/				
		2	2796N16	Omni-Directional Wheel - RIGHT	2	500 lb cap.	8" dia. X 3.5"	1.875in shaft	$153.00	McMasterCarr	https:/				
		3	NM127A	Omni-Directional Wheel - Set	1	440 lb cap.	5" dia.		$487.00	OzRobotics	https:/	X	$ 487.00	X ##	X
		4	B0CBC4C5Y7	Strut/Shock Absorber	4	300 lb cap.	100mm Mounts		$54.91	Amazon	https:/	X	$ 219.64	X ##	X
		5	1180903	Axle Bearings	1	10pcs	17 ID x 30 OD (mm)	30mm OD	$13.90	Amazon	https:/	X	$ 13.90	X 14	X
	OPTIONAL	6	48-22-8520	Milwaukee Mobile Workbench	1	200 lb wt.	37H x 18D x 49W		$798.00	Home Depot	https:/				
		7	GW192CABNTCB	GearWrench Tool Cabinet Set	1	5-Drawer	192-pc tools		$899.00	Home Depot	https:/				
		8	HKST98066BK	Husky Mobile Tool Chest	1	4-Drawer	26W x 18D x 33H	650 lb cap.	$169.00	Home Depot	https:/	X	$ 169.00	X ##	X
		9	57805	Yukon Mobile Tool Chest	1	9-Drawer	46W x 18D x 37H	1200 lb cap.	$349.99	Harbor Freight	https:/				
		10													
ELECTRICAL	BATTERY	11	NM-12V18AH	12V LiFePO4 Battery Pack	3	18Ah	60A discharge		$54.99	Amazon	https:/				
		12	LF4040	12V LiFePO4 Battery Pack	2	24Ah	20A continuous		$89.99	Amazon	https:/				
		13	12V20AH	12V LiFePO4 Battery Pack	2	20Ah - 256Wh	40A Continuous	3in x 7in x 7in	$55.99	Amazon	https:/	X	$ 111.98	X ##	X
		14													
		15													
	CHARGING	16	P3648	36VDC Smart Charger	1	13A	Delta Q		$132.79	Amazon	https:/				
		17	B09CGYLD8Z	24VDC Smart Charger	1	10A	Aligator		$54.55	Amazon	https:/	X	$ 54.55	X 55	X
		18													
		19													
		20													
	AUTOMATION	21	Ao T116D Pro	HMI Touch Screen Display	1	1920x1080 IPS	10P-Touch	11.6"	$162.75	Amazon	https:/				
		22	23HS45-4204S	DC Stepper Motor	4	3 Nm	114mm	36 VDC	$39.99	Amazon	https:/				
		23	DM556T	DC Stepper Motor Driver (2-pack)	2	1.8-5.6A	20-50 VDC		$26.99	Amazon	https:/				
		24	697394023	DC Servo Motor & Driver	4	37 Nm	12-24 VDC	356kg	$99.99	Amazon	https:/	X	$ 399.96	X ##	X
		25	HRC60-62	Motor Shaft Keystock	1	2pcs	6 x 6 x 200 (mm)	HSS Steel	$8.99	Amazon	https:/	X	$ 8.99	X 9	X
				compass											
				buck converter											
				gps											
		26		bluetooth											
TRICAL (secondary)	ARDUINO / RASPI	27	B00E0NSORY	Arduino Relay Module	1	4 Relays	5VDC	STM32	$7.99	Amazon	https:/	X	$ 7.99	X 8	X
				Arduino Mega 2560 Rev. 3											
		28	HD-190-BK-0.1M-XY	HDMI Mini to HDMI Flat Cable	1	Male-to-Male	100mm	FPC	$8.99	Amazon	https:/	X	$ 8.99	X 9	X
		29	HDMIATYPE	HDMI - Female Breakout	1	10pcs	Female A-Type	19-pin	$9.99	Amazon	https:/	X	$ 9.99	X 10	X
		30	J16-811/S11	E-Stop Button	1	16mm	SPDT	1NO - 1NC	$11.99	Amazon	https:/	X	$ 11.99	X 12	X
		31	HC-SR04	Ultra Sonic Sensors	1	10pcs	20mm to 5000mm	3mm tol.	$12.99	Amazon	https:/	X	$ 12.99	X 13	X
		32	TKM32F499	HMI Display	1	4.3 in	TFT	800 x 480	$40.90	Amazon	https:/	X	$ 40.90	X 41	X
		33													

9.4 APPENDIX D: SUBSYSTEM BREAKDOWN

9.4.1 Mechanical Block Diagram

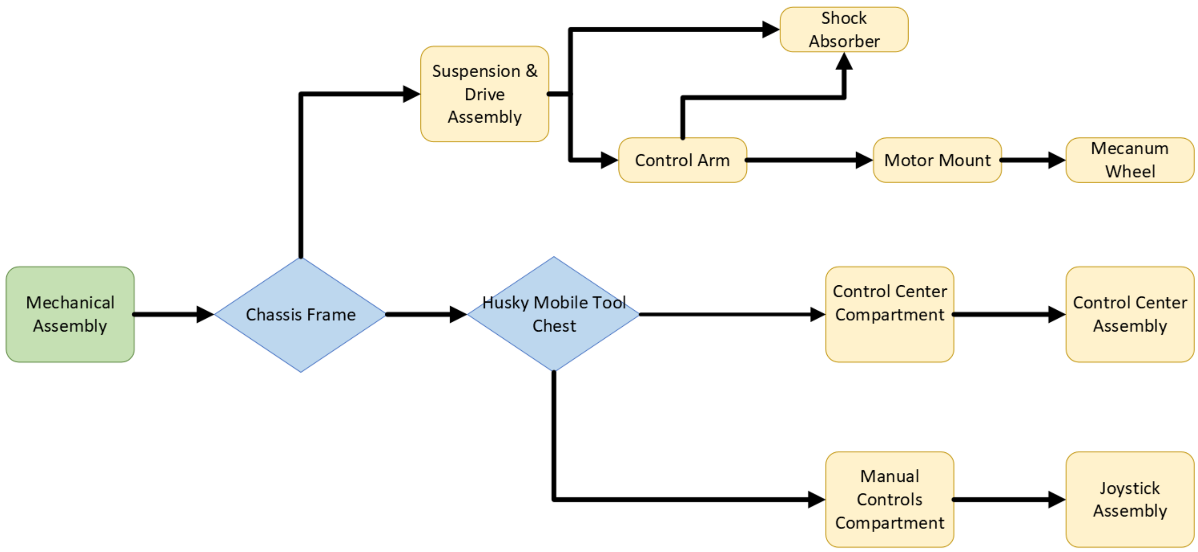


Figure 62: Mechanical Block Diagram

14.4 APPENDIX D: SUBSYSTEM BREAKDOWN (Continued)

9.4.2 Electrical Block Diagram

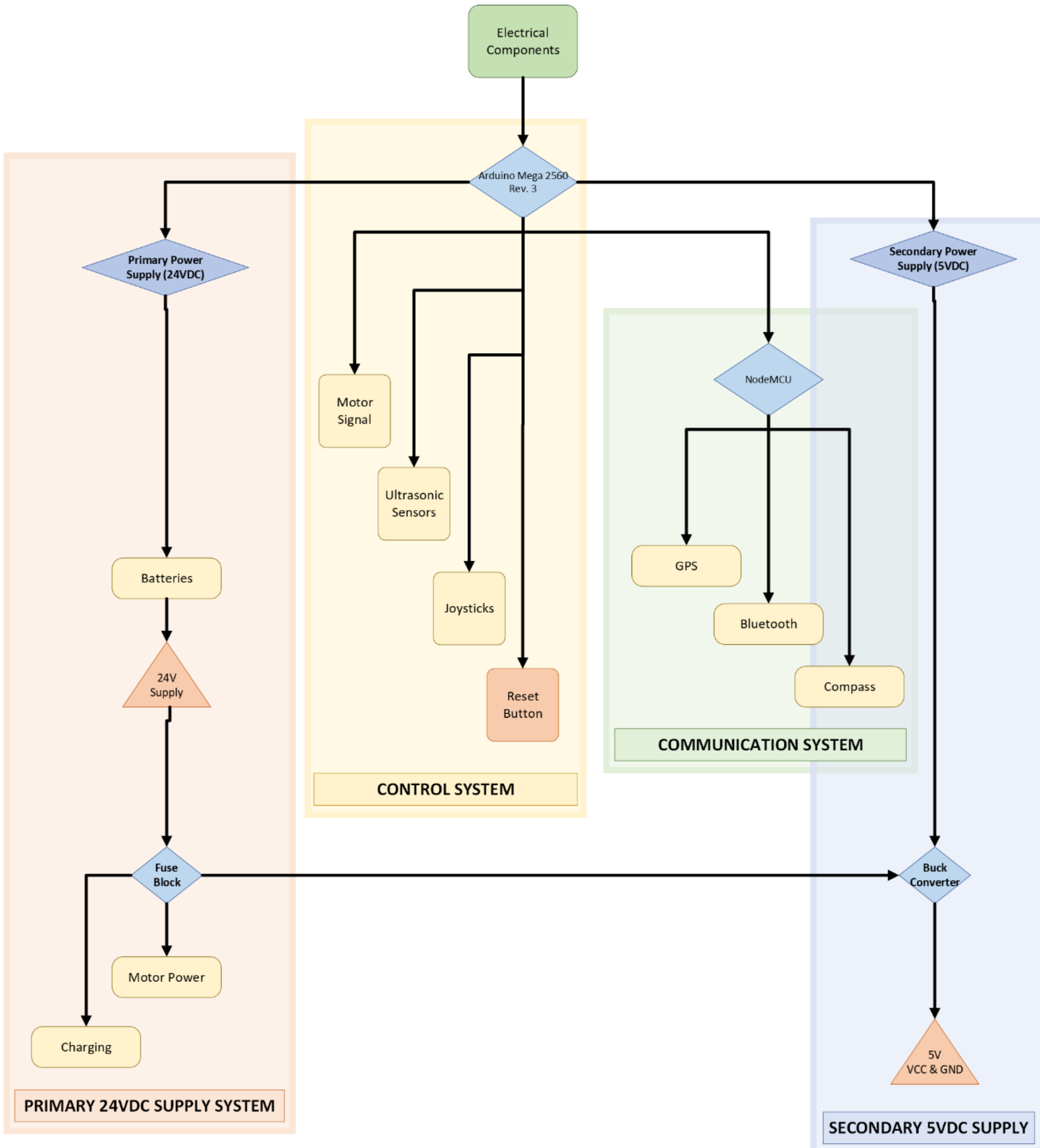


Figure 63: Electrical Block Diagram

14.4 APPENDIX D: SUBSYSTEM BREAKDOWN (Continued)

9.4.3 Functional Block Diagram

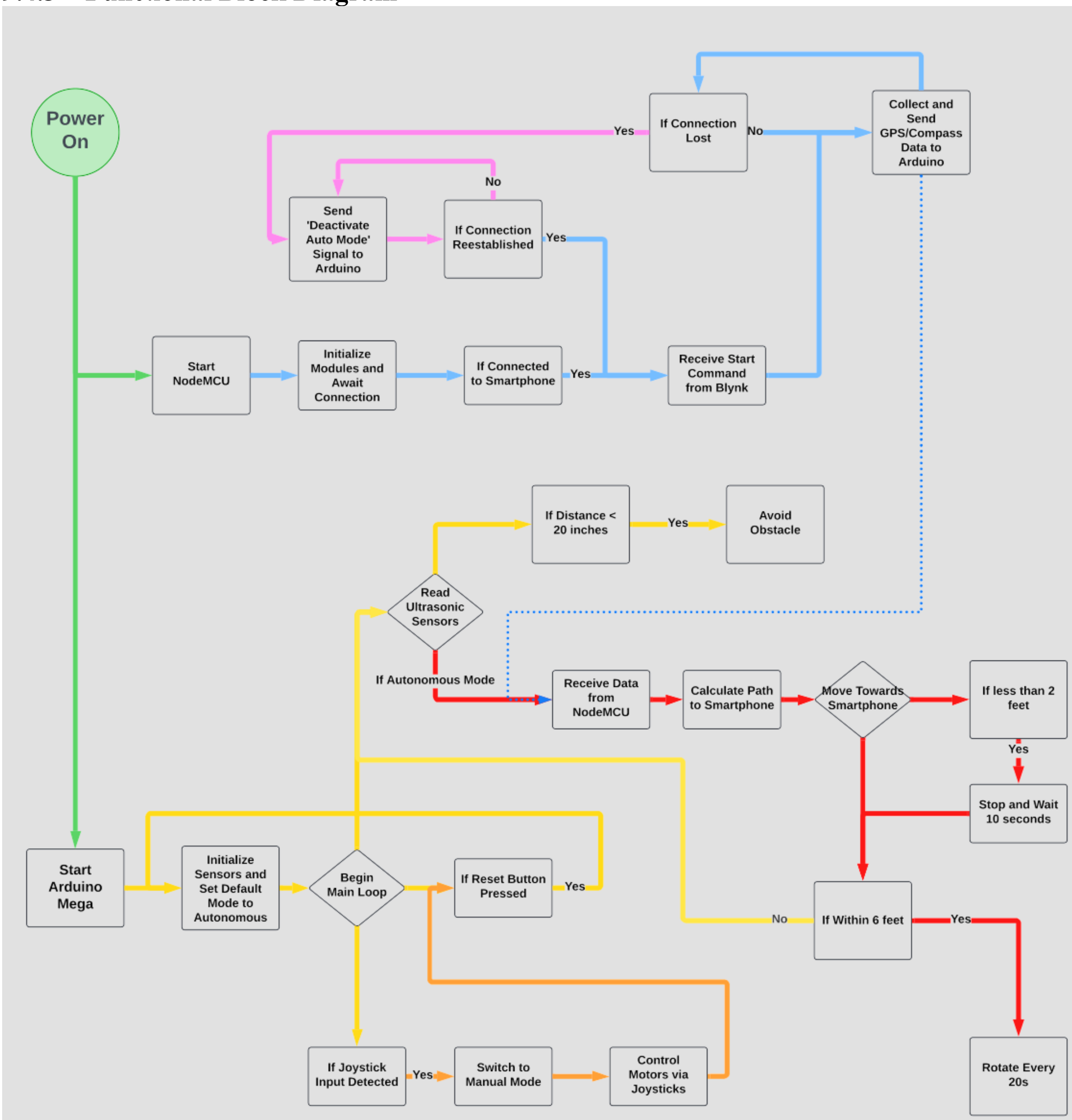
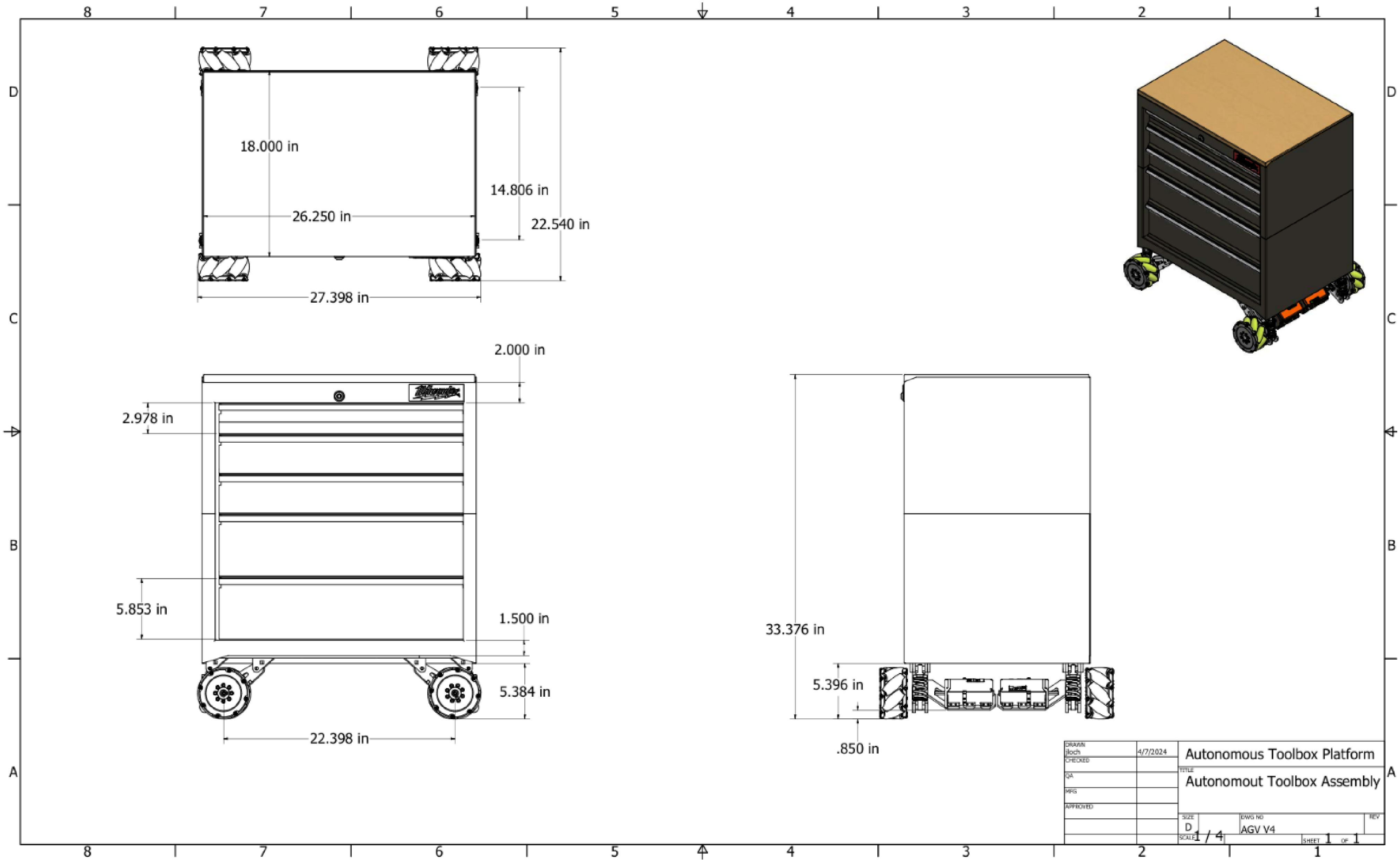


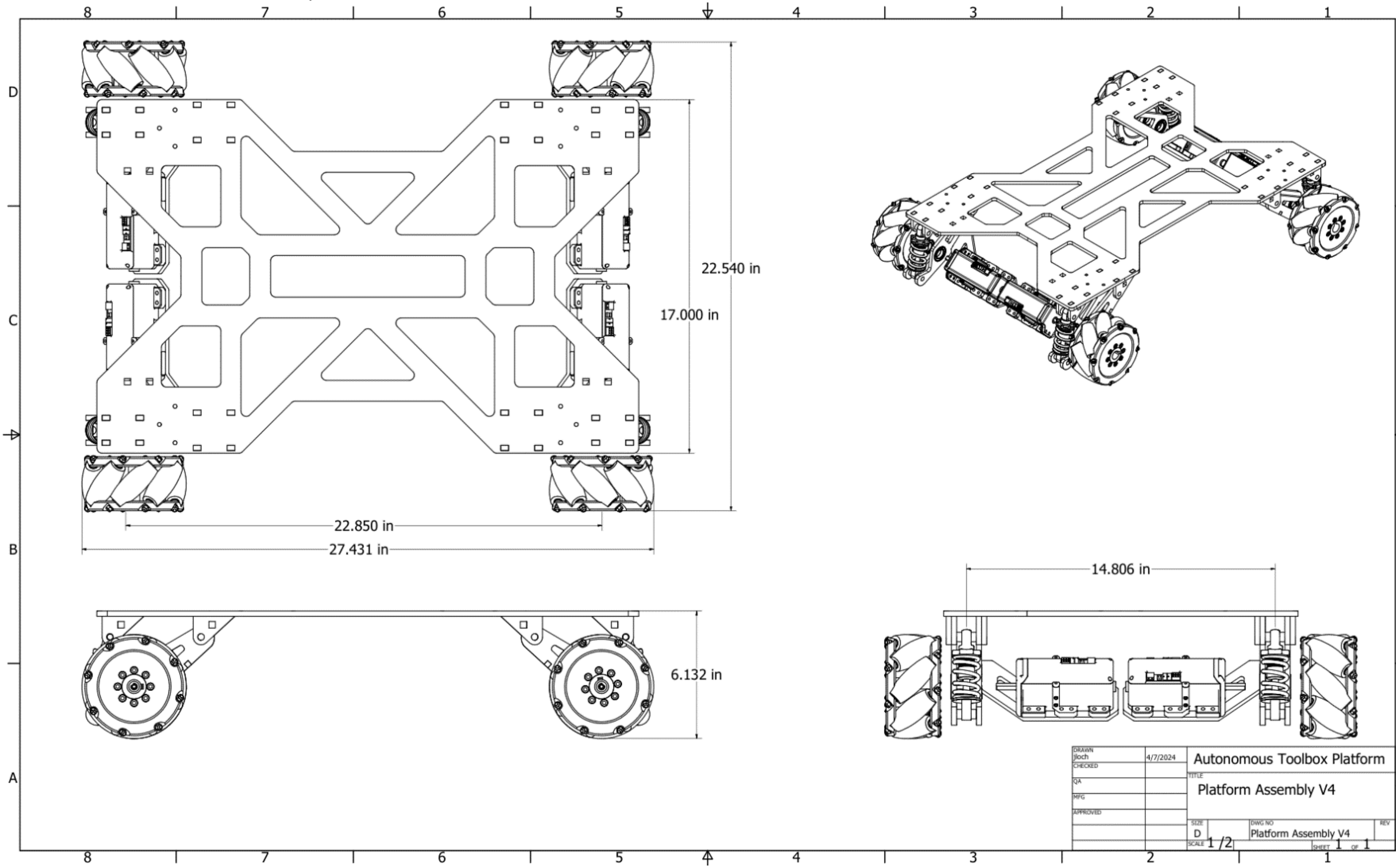
Figure 64: Functional Block Diagram

9.5 APPENDIX E: DETAILED DRAWINGS

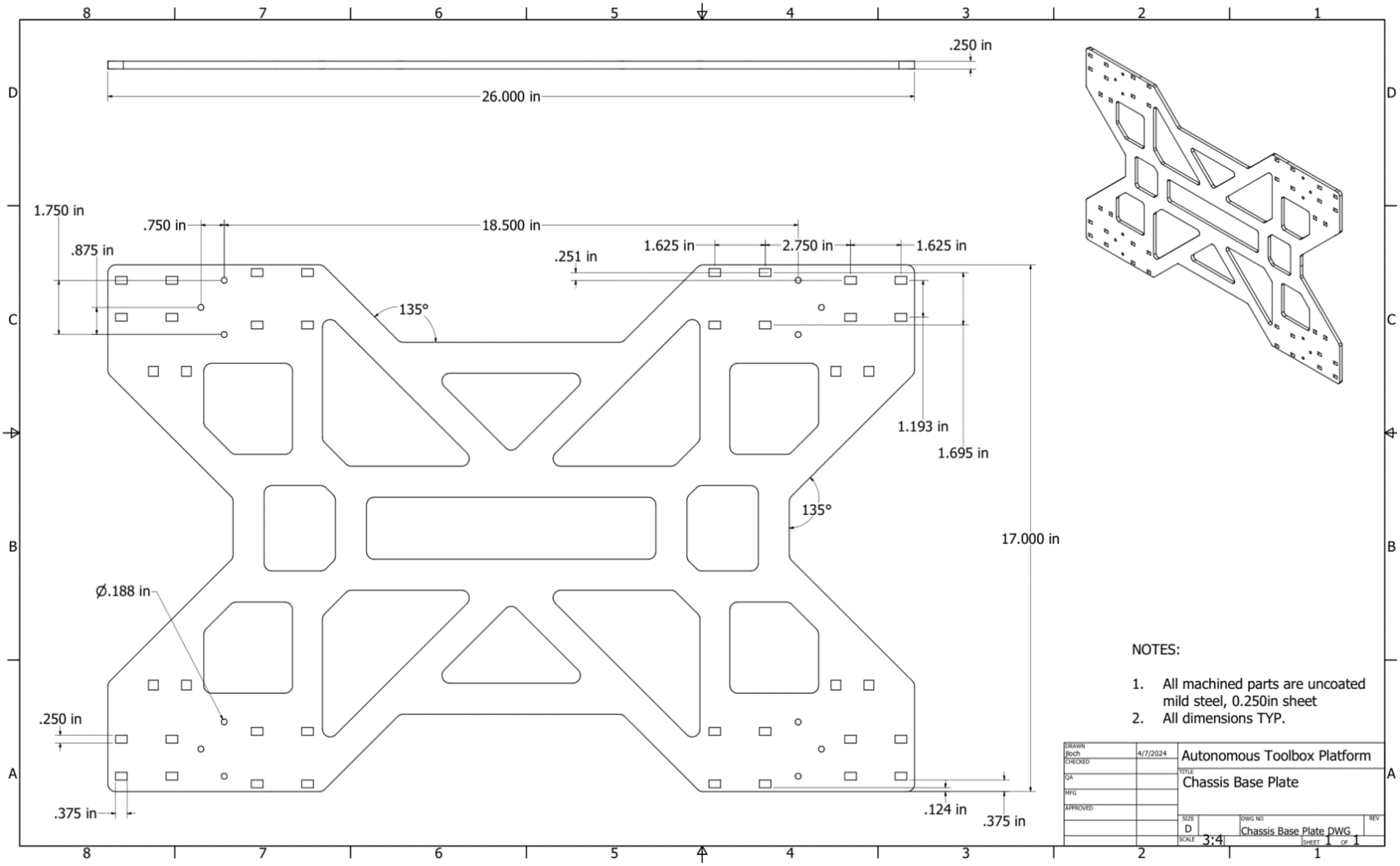
APPENDIX E: Assembled Unit



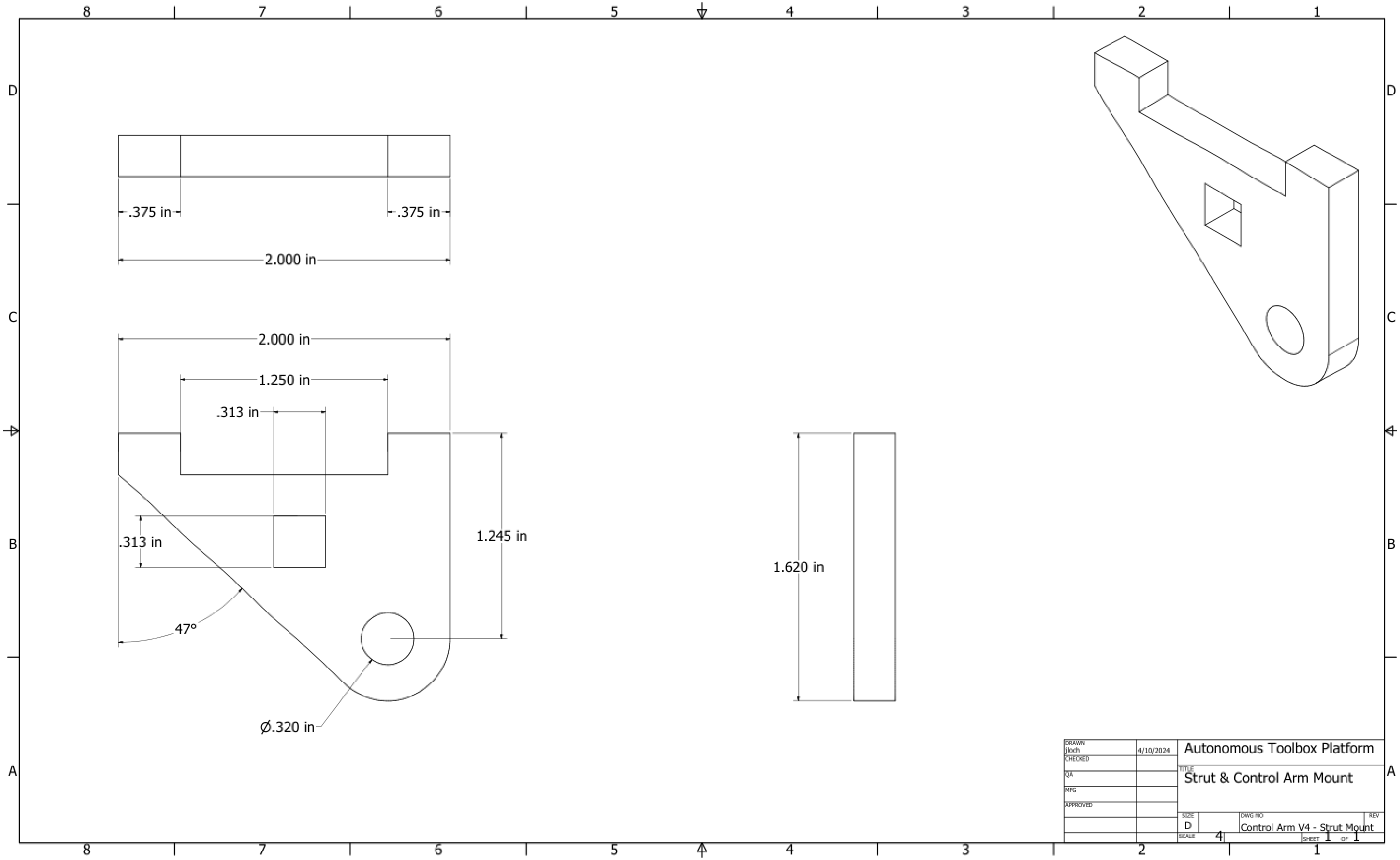
APPENDIX E: Platform Assembly



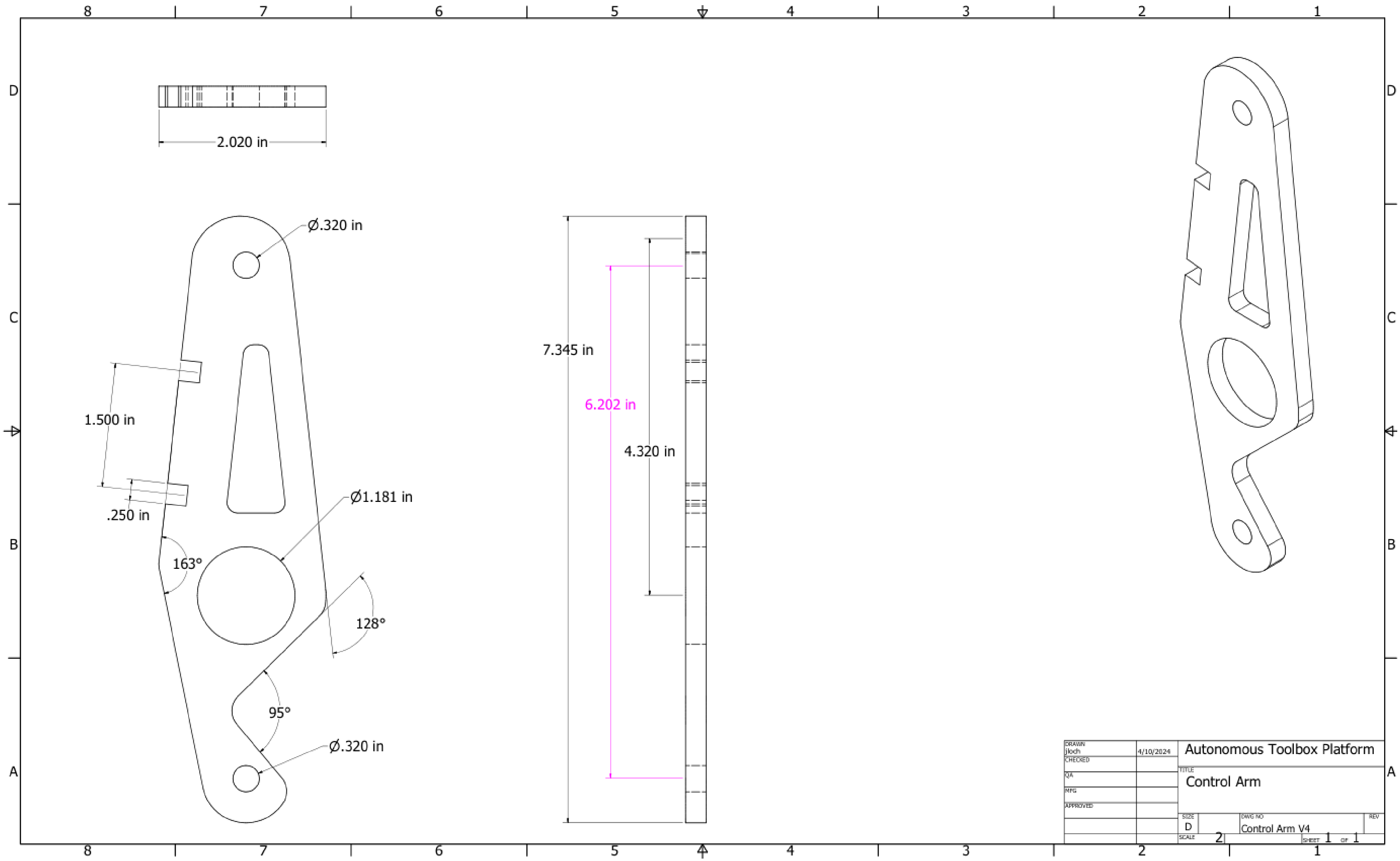
APPENDIX E: Chassis



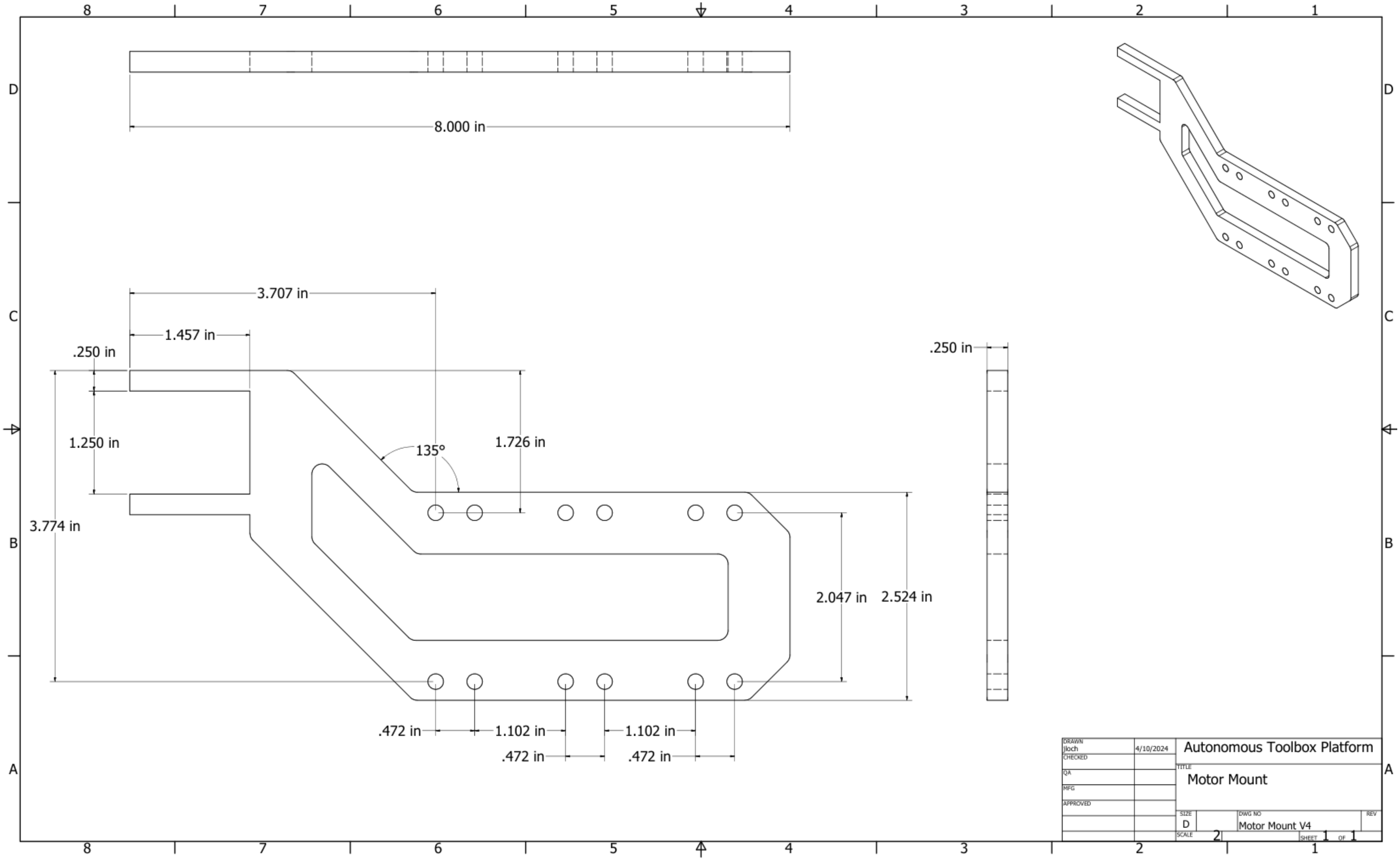
APPENDIX E: Strut & Control Arm Mount



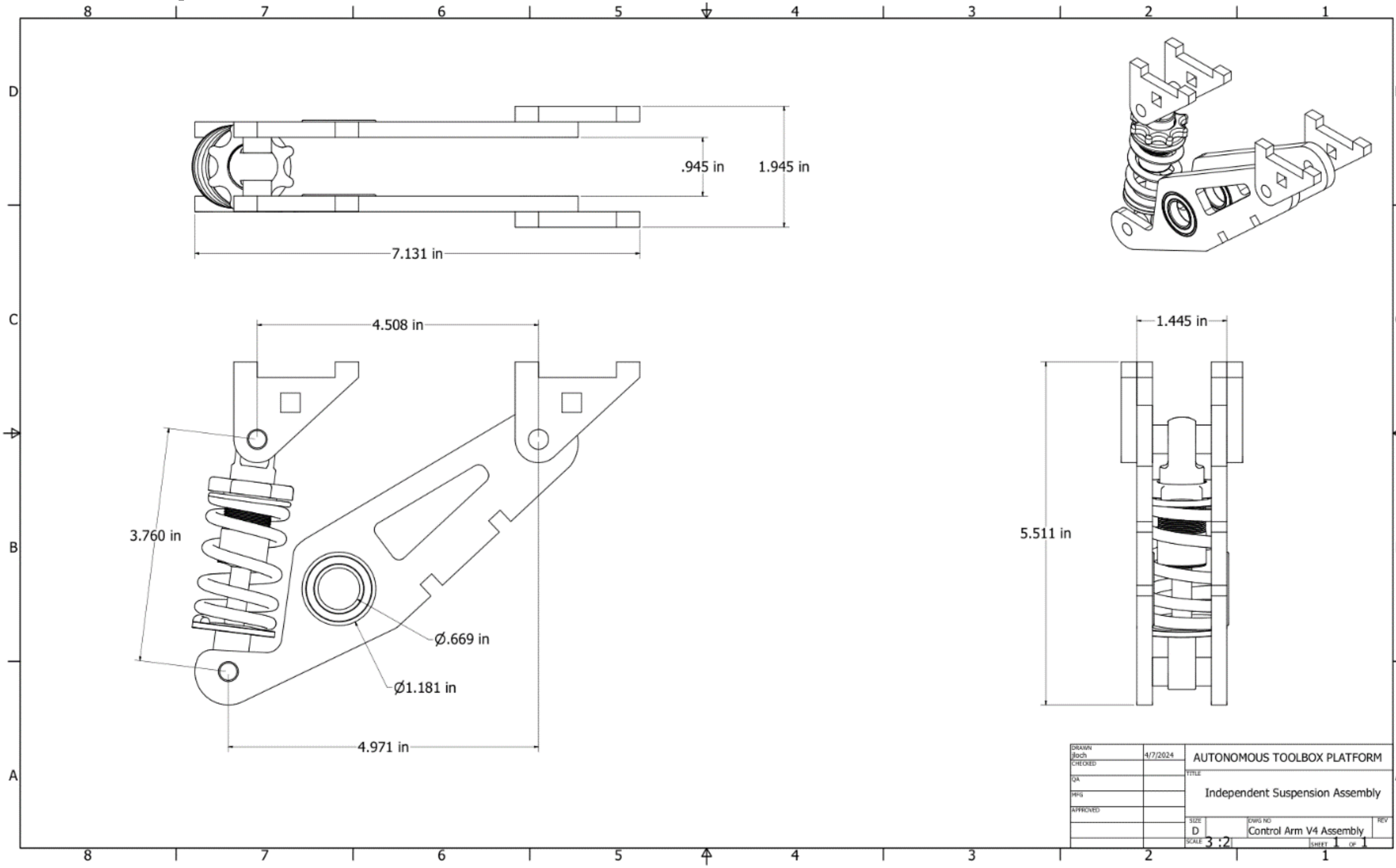
APPENDIX E: Control Arm



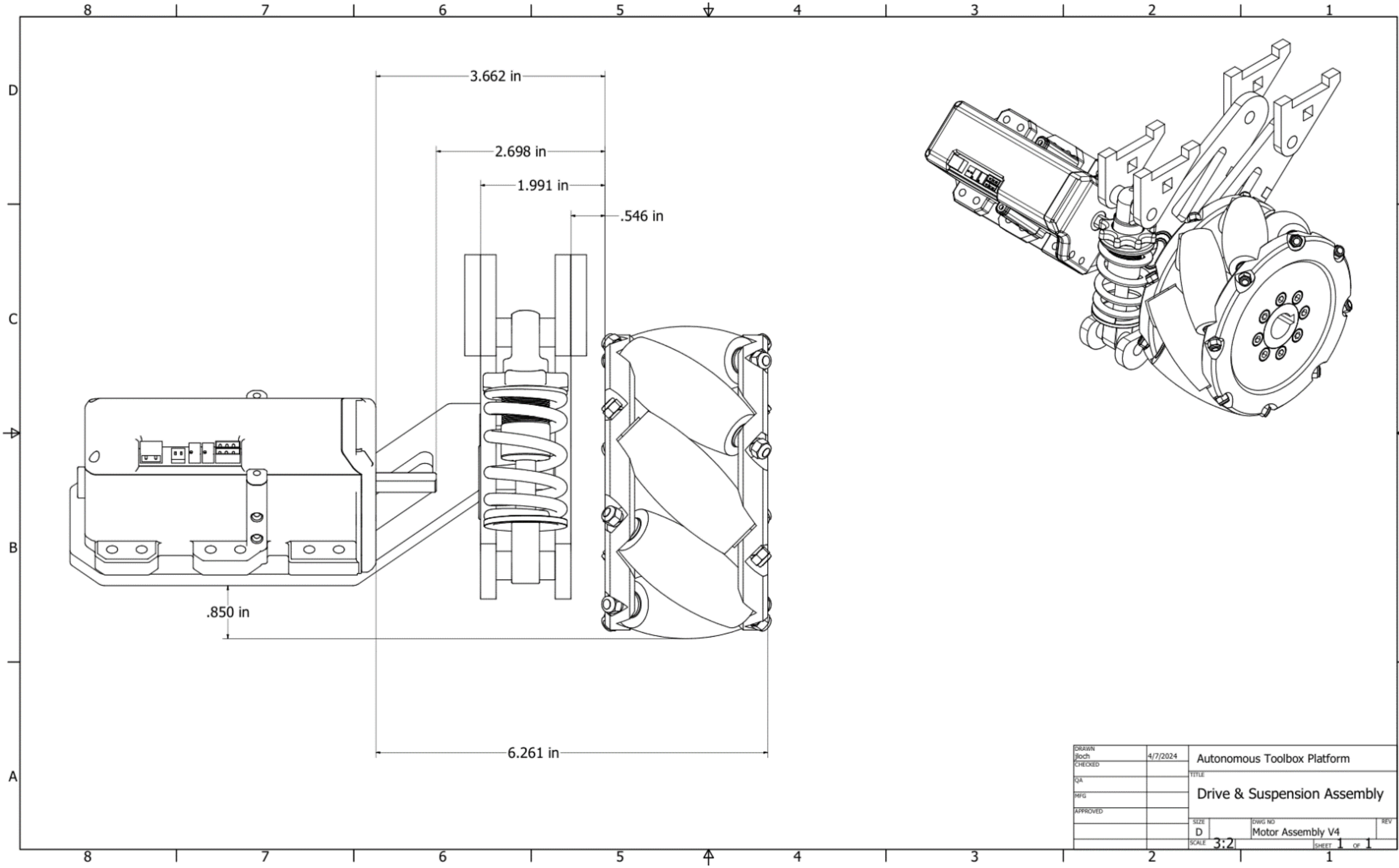
APPENDIX E: Motor Mount



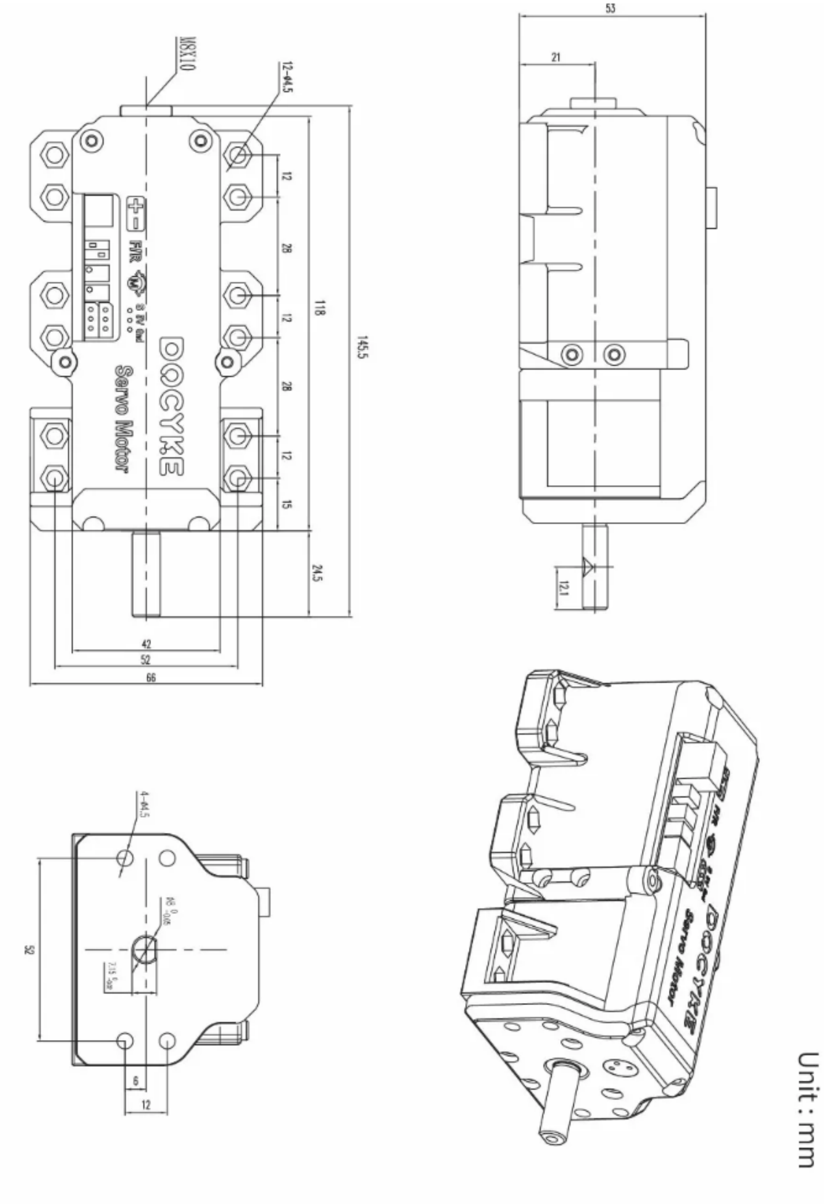
APPENDIX E: Suspension



APPENDIX E: Drivetrain



APPENDIX E: Servo Motor



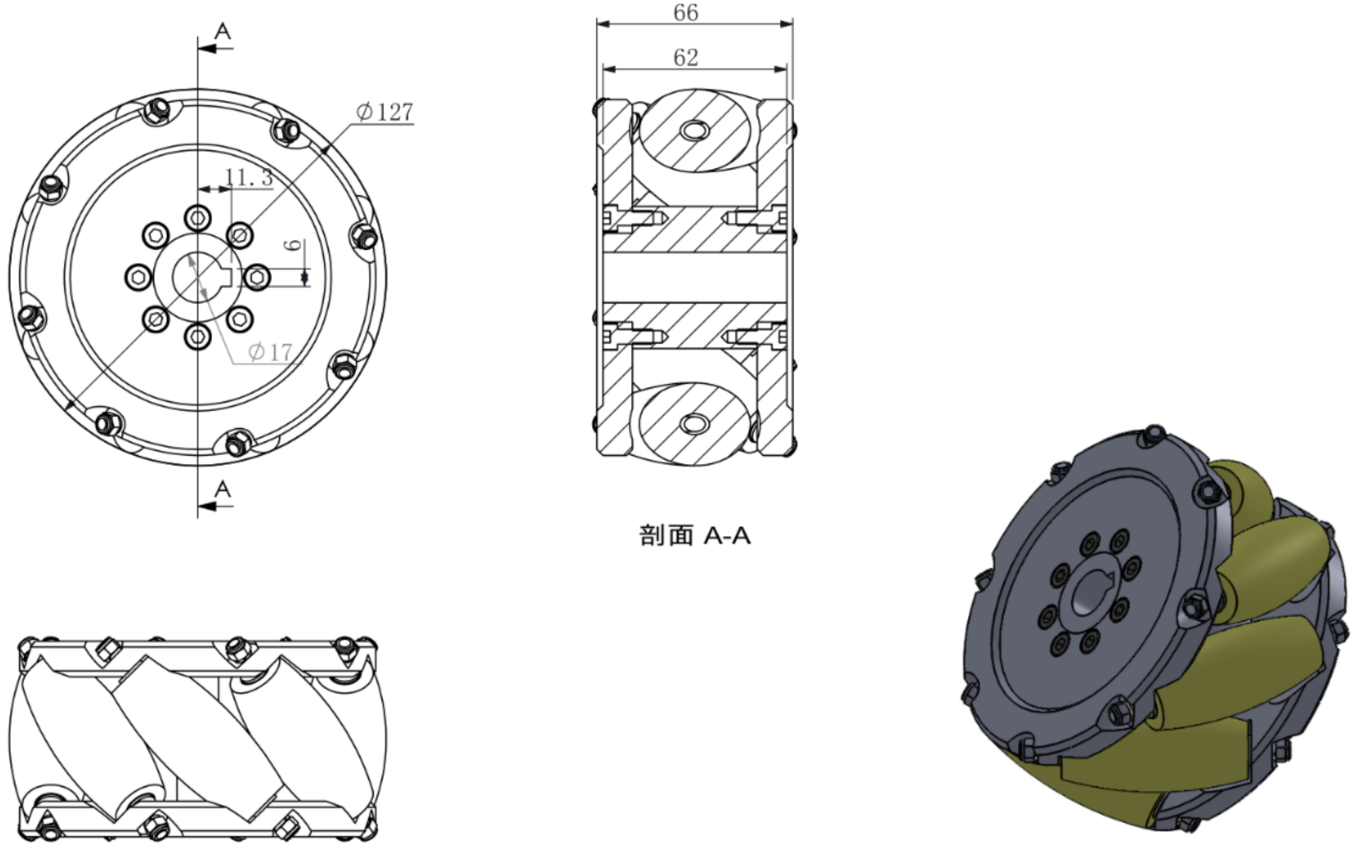
DOCYKE

Servo motor

电话：+8618072220126
邮箱：do@docyke.com
地址：浙江省绍兴市越城区曹江路二号科创园1号楼
Building 1,Science & Tech park, No.2 Caojiang Road, Yuecheng District, Shaoxing City, Zhejiang Province,China

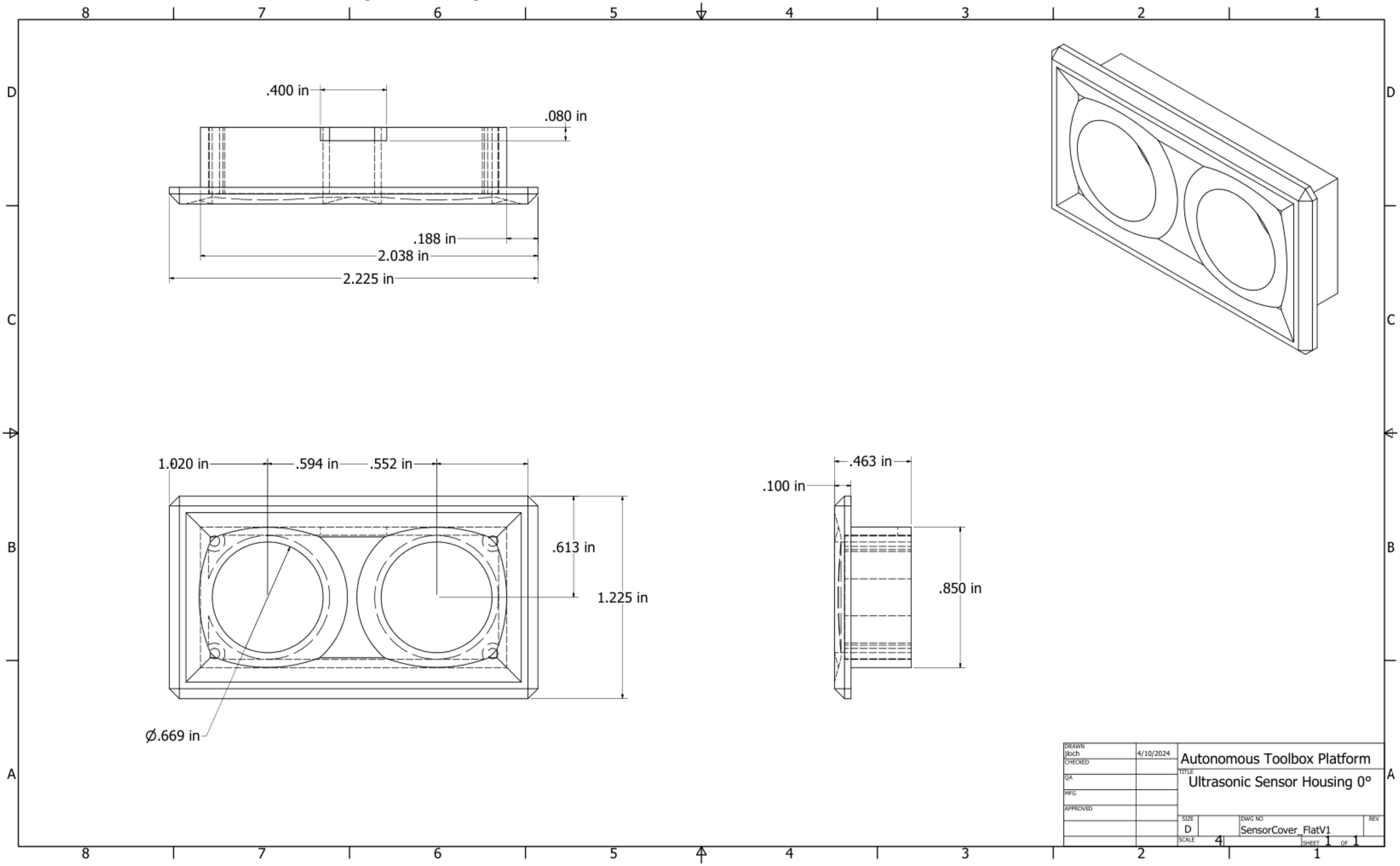
型号/Model	S350	S550
额定电压/Power voltage	18V	
电压范围/Voltage range	12-24V	
额定电流/Rated current	5A	
直流模式转速/Motor speed	0-65r/min	0-45r/min
伺服模式转速/Servo speed	0.16s/60°	
伺服模式角度/Servo angle	0-360°	
精度/Precision	0.32°	
额定扭矩/Rated tonque	12NM	18NM
最大扭矩/Max tonque	35NM	55NM
工作温度/Operating TEMP	-30 ℃ ~ +40 ℃	
反馈传感器/Encoder	Magnetic encoder	
控制方式/Control mode	PWM: 0.5-2.5ms/50HZ	
信号电压/Signal voltage	3.3-5V	
净重/Net weight	550g	

APPENDIX E: Mecanum Wheel

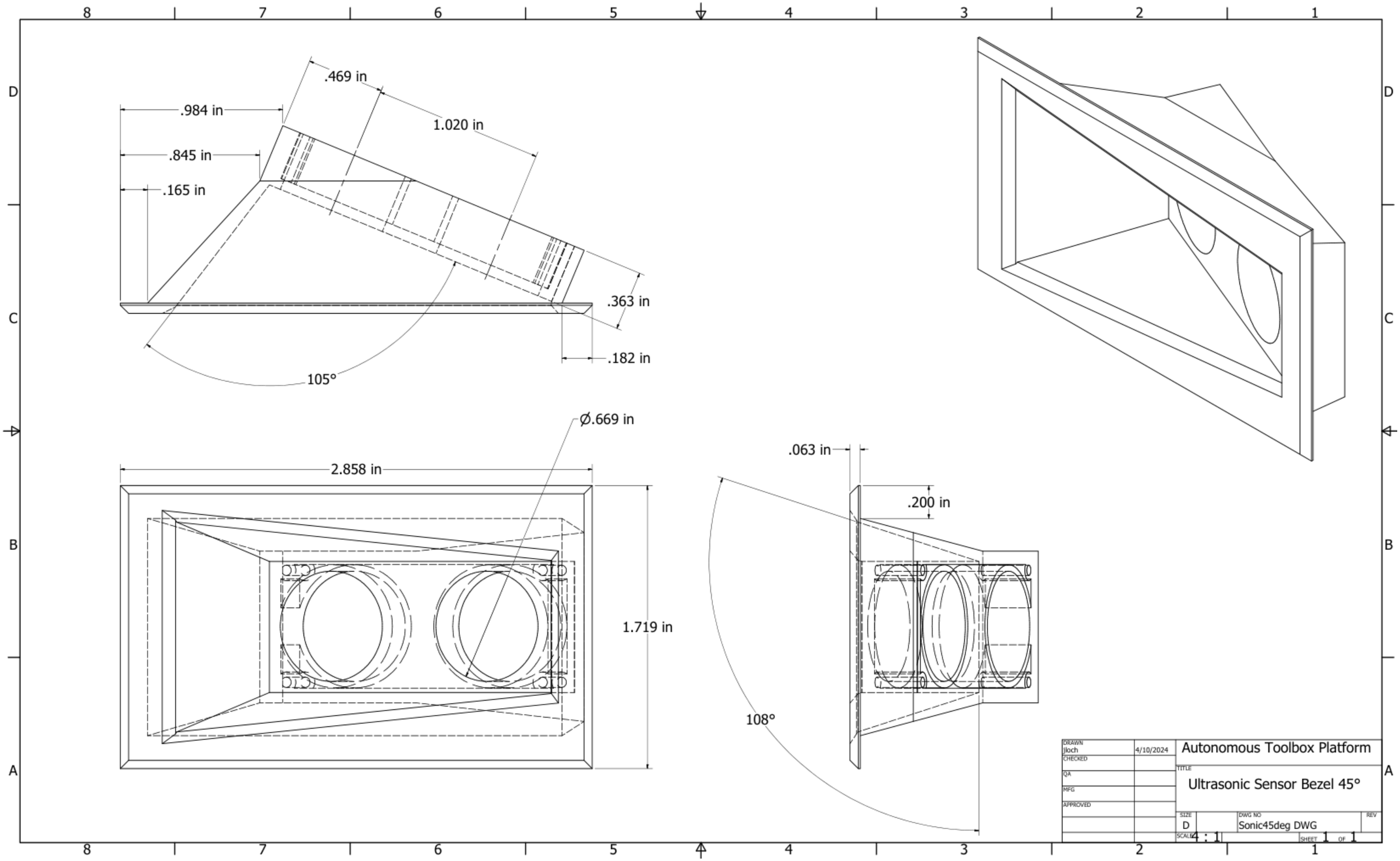


TITLE	NM127A-M0.4 127mm Heavy duty Mecanum Wheel ,Right
DIMENSIONS ARE IN MM	
WWW.NEXUSROBOT.COM	

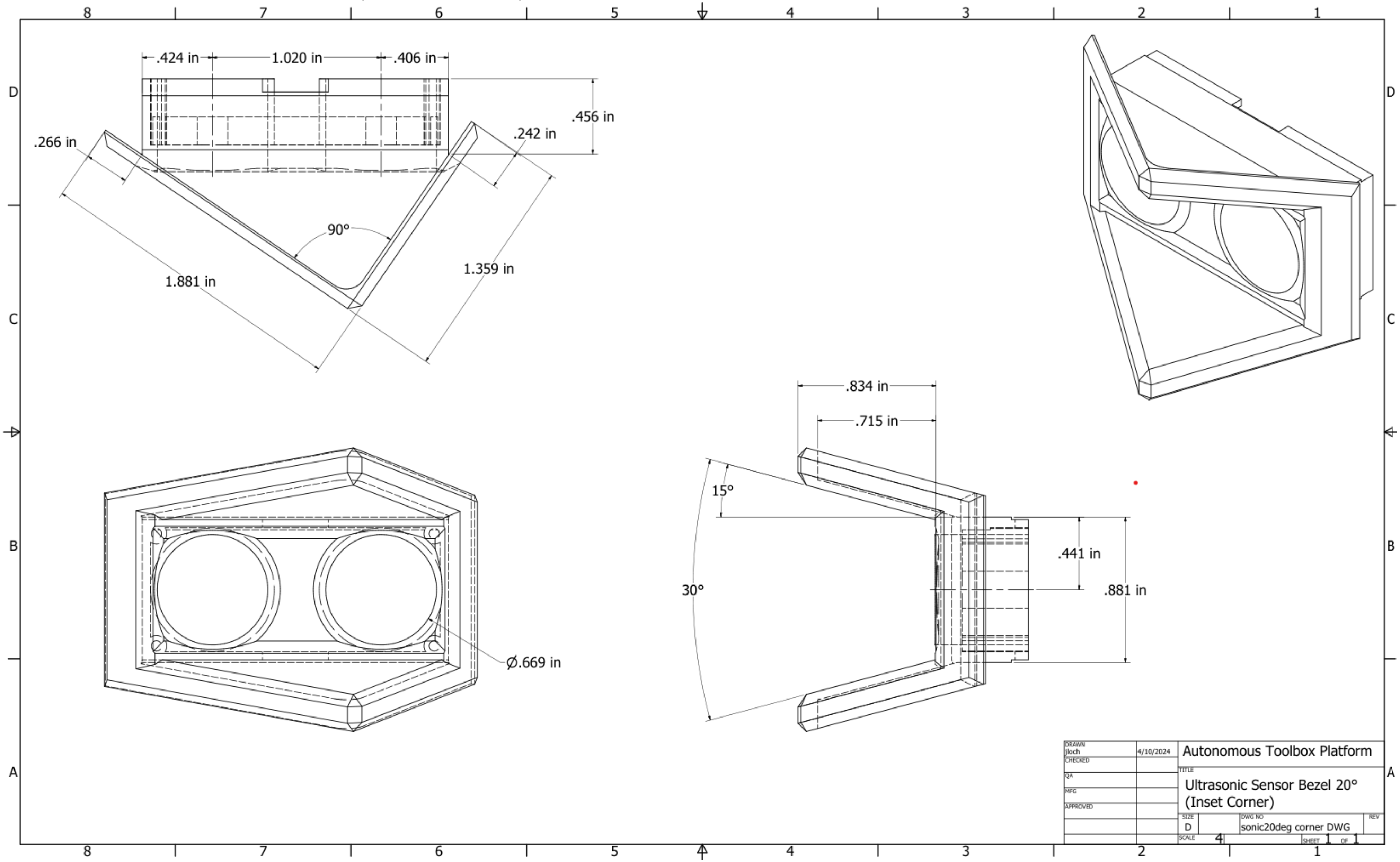
APPENDIX E: Ultrasonic Sensor 20 Degree Housing & Bezel



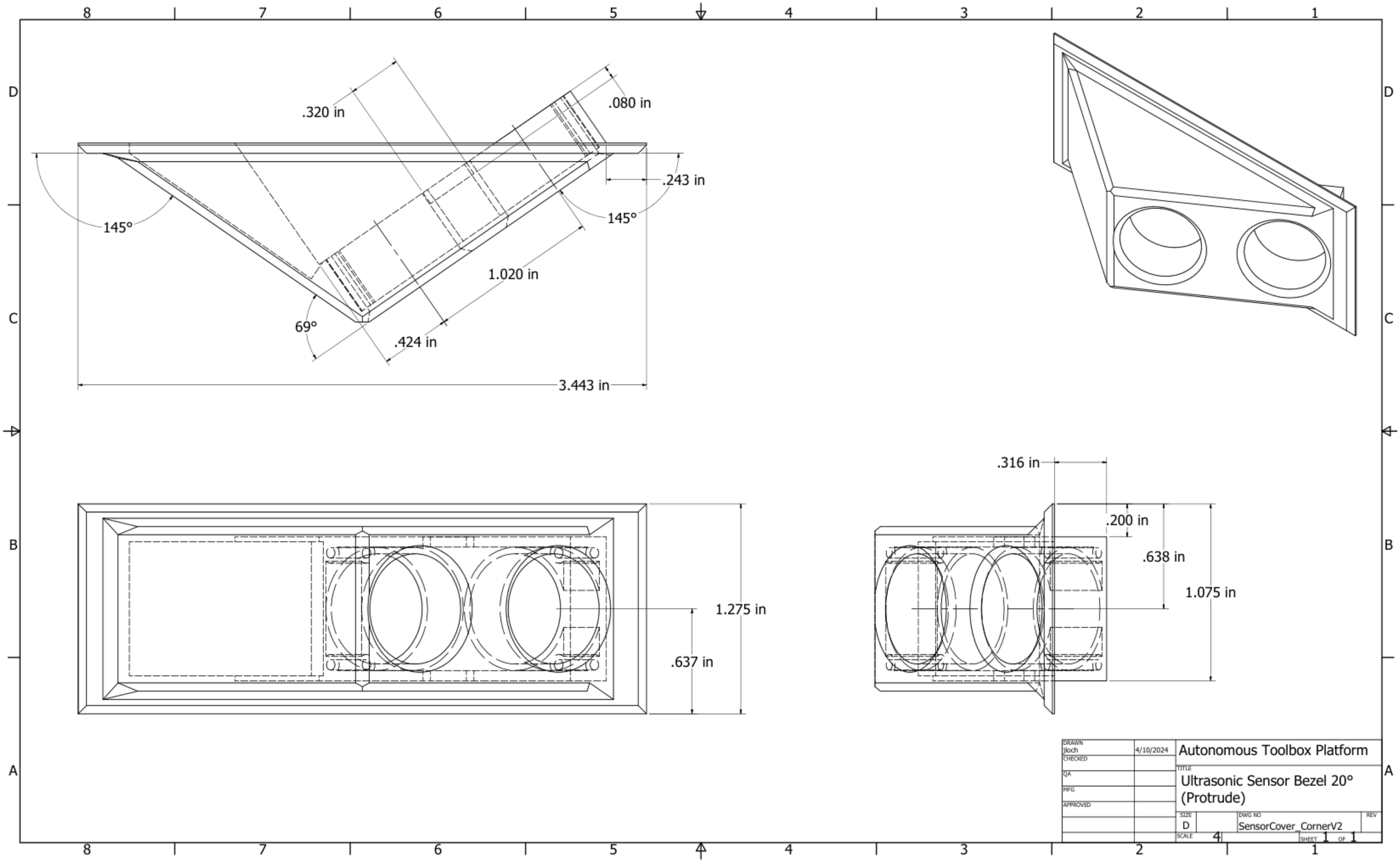
APPENDIX E: Ultrasonic Sensor 20 Degree Housing & Bezel



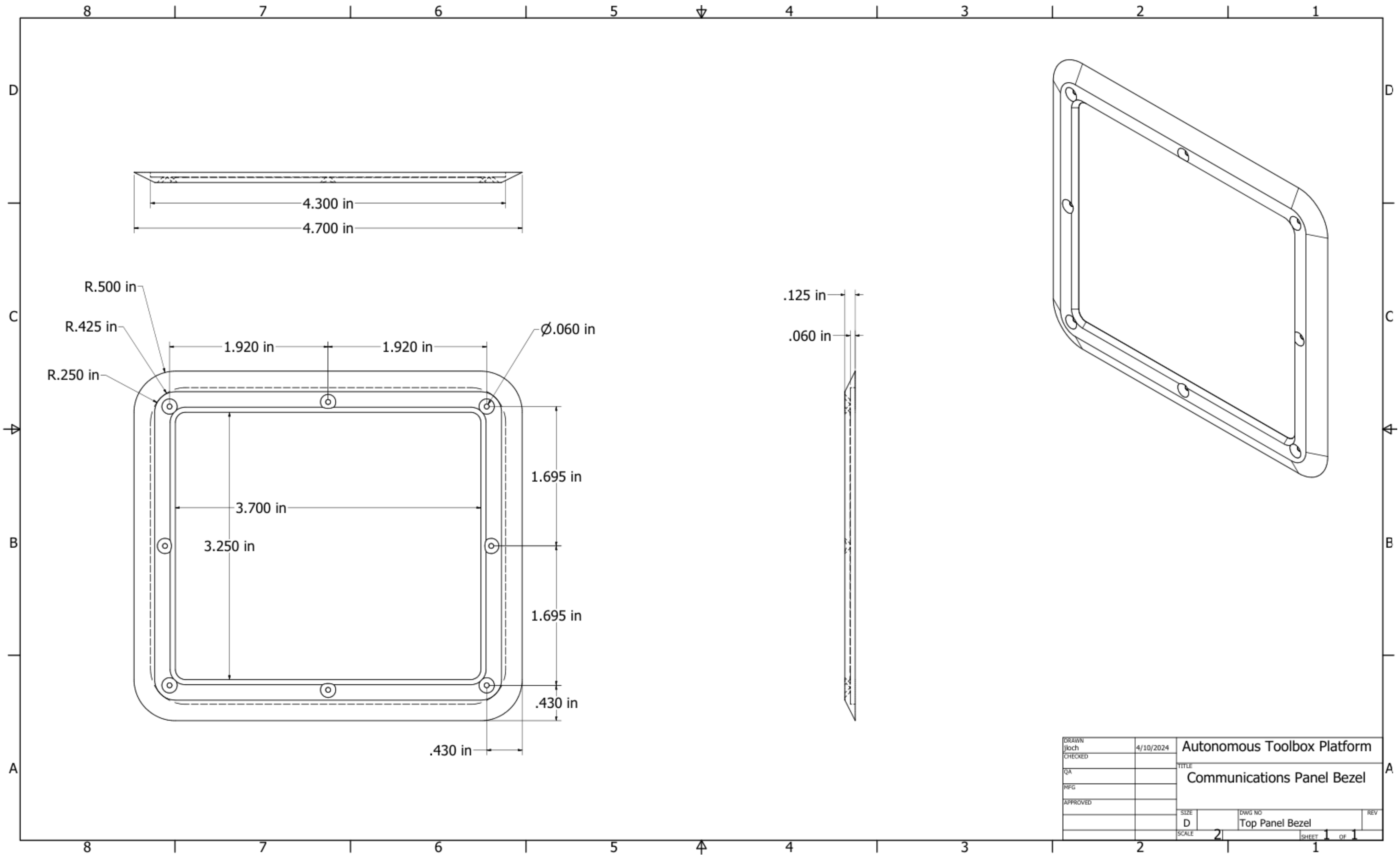
APPENDIX E: Ultrasonic Sensor 35 Degree Inset Housing & Bezel



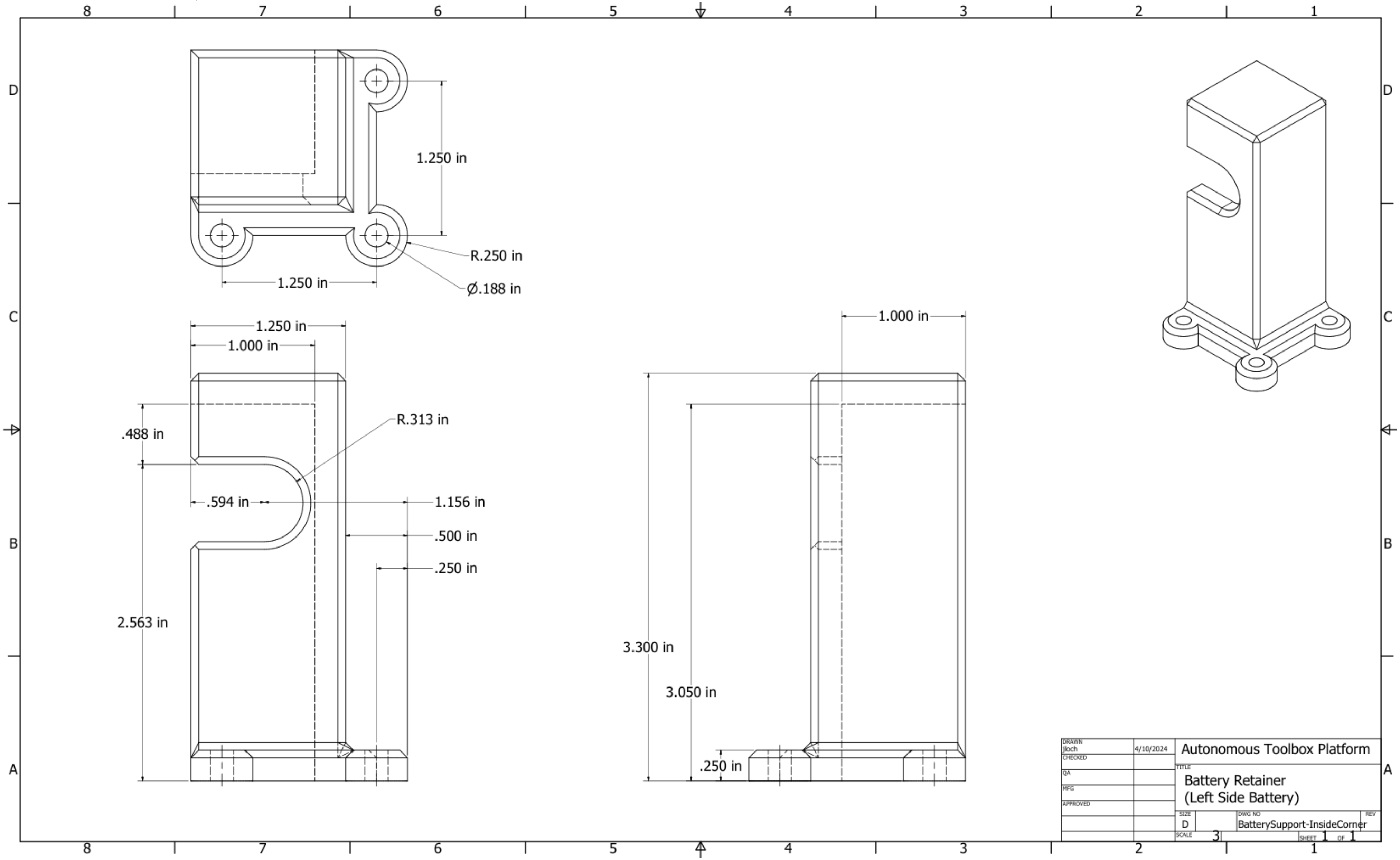
APPENDIX E: Ultrasonic Sensor 35 Degree Protrude Housing & Bezel



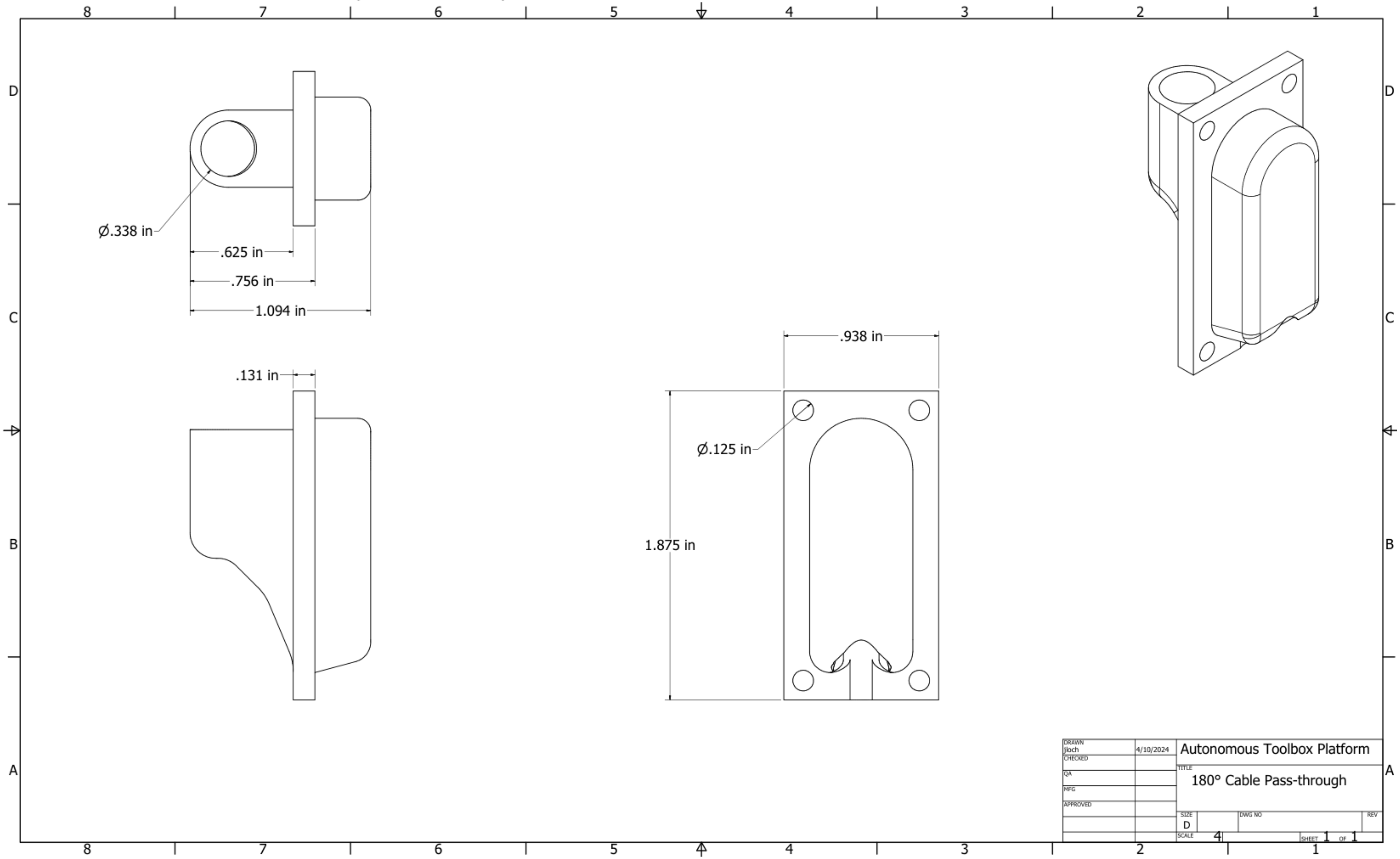
APPENDIX E: Communications Panel Bezel



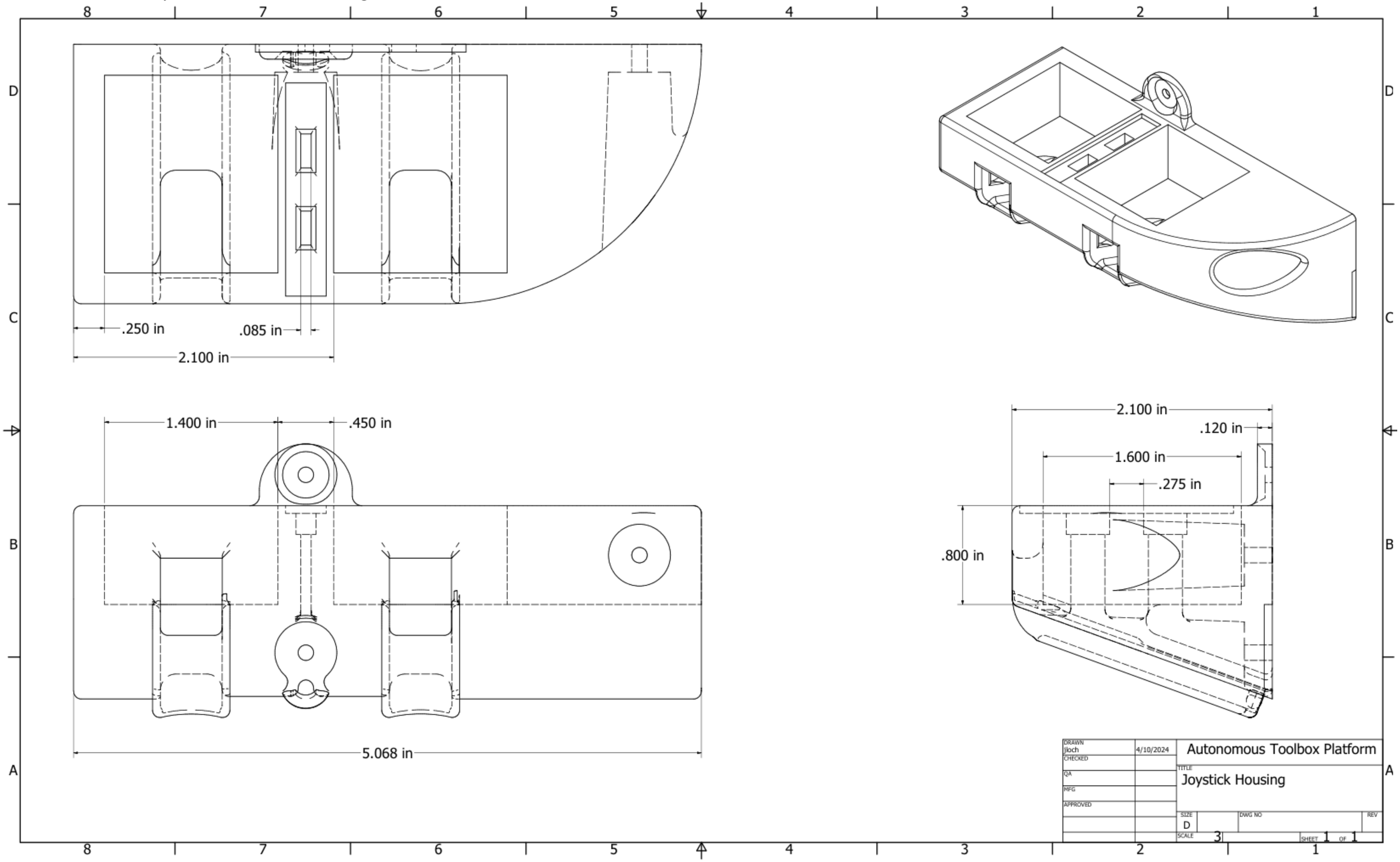
APPENDIX E: Battery Retainer



APPENDIX E: Electrical Cable 180 Degree Pass-Through



APPENDIX E: Joystick Control Housing



9.6 APPENDIX F: FAILURE MODE & EFFECT ANALYSIS

											Action Results			
Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility	New Sev	New Occ	New Det	New RPN
POWER & BATTERY														
Battery.	Degredation	Loss of capacity. Loss of function.	6	Extreme temperatures. Eposure to outside elements.	6	Enclosed battery compartment. Cooling fan.	6	216	Limit extended outdoor use. Prohibit Outdoor storage. Terminal Protectant.	User	6	2	6	72
Battery Terminals	Corrosion	Loss of capacity. Loss of function.	6	Excessive humidity. Eposure to outside elements.	6	Enclosed battery compartment.	6	216	Limit extended outdoor use. Prohibit Outdoor storage. Terminal Protectant.	User	6	2	6	72
Docking Pin Terminals	Corrosion	Loss of charge function.	6	Excessive humidity. Eposure to outside elements.	6	Protective plastic housing. Fused Terminals.	6	216	Limit extended outdoor use. Prohibit Outdoor storage. Terminal Protectant.	User	6	2	6	72
Docking Pin Terminals	accidental Bridging/jumping	Sparks. Blown fuse/breaker. Fire.	9	Excessive moisture. Improper Instalation. Improper use.	3	Protective plastic housing. Fused Terminals.	1	27	Instalation by competent person. Operation by competent person.	Installer.	9	1	1	9
MOTORS & DRIVERS														
Structure. Motor Mounts	Stress crack	Loss of balance.	10	Excessive load. Impact by external force.	1	Mounts and Brackets comprised of steel and aluminum.	10	100	Tilt sensor with alarm sound.		7	1	1	7
FRAME & BODY														
Structure. Motor Mounts	Stress crack	Loss of balance.	10	Excessive load. Impact by external force.	1	Mounts and Brackets comprised of steel and aluminum.	10	100	Tilt sensor with alarm sound.		7	1	1	7
Structure. Frame	Corrosion		9		3		10	270	All metals painted.		9	1	10	90
SOFTWARE & PROGRAM														
Operation	Programming Failure	Total function loss.	5	Bug. Electromagnetic disruption. Power Surege.	5	Adequate FAT/SAT.	3	75	Extensive FAT/SAT. Proper power-on and power-off sequences.	Programmer. User.	5	2	3	30
SENSORS														
Sensor Mounts	Stress crack	Loss of accuracy. Potential project damage.	4	Collision with external forces.	6		10	240	Integrate sensor guards. All metals painted. Integrate sensor status-change alarm.	Designer. User.	4	2	3	24

Effect	SEVERITY of Effect	Rank
Hazardous without warning	Very high severity ranking when a potential failure mode	10
Hazardous with warning	Very high severity ranking when a potential failure mode	9
Very High	System inoperable with destructive failure without	8
High	System inoperable with equipment damage	7
Moderate	System inoperable with minor damage	6
Low	System inoperable without damage	5
Very Low	System operable with significant degradation of	4
Minor	System operable with some degradation of performance	3
Very Minor	System operable with minimal interference	2
None	No effect	1

PROBABILITY of Failure	Failure Prob	Rank
Very High: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Repeated failures	1 in 8	8
	1 in 20	7
Moderate: Occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: Relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	<1 in 1,500,000	1

Detection	Likelihood of DETECTION by Design Control	Rank
Absolute Uncertainty	Design control **cannot** detect potential cause/mechanism and	10
Very Remote	**Very remote** chance the design control will detect potential	9
Remote	**Remote** chance the design control will detect potential	8
Very Low	**Very low** chance the design control will detect potential	7
Low	**Low** chance the design control will detect potential cause/mechanism	6
Moderate	**Moderate** chance the design control will detect potential	5
Moderately High	**Moderately High** chance the design control will detect potential	4
High	**High** chance the design control will detect potential cause/mechanism	3
Very High	**Very high** chance the design control will detect potential	2
Almost Certain	Design control **will** detect potential cause/mechanism and subsequent	1

Figure 65: Failure Mode & Effects Analysis Table

9.7 APPENDIX G: POTENTIAL RELATED CODES/REGULATIONS

1. **29 CFR 1910 - General Industry Standards:**
    - *Subpart S - Electrical:* This standard will guide the design considerations for electrical installations on the platform, ensuring that electrical components are installed and maintained to prevent hazards.
    - *Subpart D - Walking-Working Surfaces:* Essential for the safety of individuals interacting with the platform, especially if it involves movement within a workplace. Compliance with this standard addresses the safe design of walking and working surfaces.
2. **29 CFR 1926 - Construction Standards:**
    - *Subpart K - Electrical:* Tailored to construction activities, this section provides additional guidance on electrical safety, which is relevant if the platform is deployed in construction settings.
3. **29 CFR 1910.212 - Machine Guarding:**
    - Compliance with this standard is crucial if the platform incorporates moving parts or machinery, outlining requirements for machine guarding to prevent worker injuries.
4. **29 CFR 1910.147 - Control of Hazardous Energy (Lockout/Tagout):**
    - Applicable if the platform includes components that require maintenance or servicing, this standard provides guidelines for controlling hazardous energy during maintenance activities.
5. **29 CFR 1910.303 - Electrical, General Requirements:**
    - Specifies general requirements for electrical installations, wiring methods, and components, ensuring the safe use of electrical systems on the platform.
6. **29 CFR 1910.333 - Selection and Use of Work Practices:**
    - Relevant for electrical safety work practices, this standard outlines safety-related work practices and maintenance requirements, ensuring a safe working environment.

As the design and development progress, continuous consideration of these OSHA standards will be essential. Regular updates from OSHA and consultations with safety professionals will be crucial to maintaining compliance with the latest industry standards and regulations. The integration of these codes into the project framework reflects a commitment to safety and regulatory adherence in the development of the Autonomous Toolbox Platform.

While these codes and regulations provide a foundational framework, ongoing awareness of updates and amendments is paramount. Regular checks will be instituted throughout the project lifecycle to address any changes in regulations, thereby maintaining compliance and upholding safety and quality standards. The integration of these considerations enhances the overall reliability and acceptance of the Autonomous Toolbox Platform within the regulatory landscape.

List of Acronyms