MSE 4499 — Mechatronic Design Project

Electric Autonomous Tree-Planting Robot for Reforestation and Forest Management

by

Matt Haverko; Ryan McCuaig; Josh Sugar; Thorben Wennemer

Mechatronic Systems Engineering

Final Report

Faculty Advisor: Joshua Pearce, Ph.D.; M.D. Naish, Ph.D., P.Eng.

Date Submitted: April 5th, 2025

Word Count:

Main Body – 7813

Overall – 10037

Executive Summary

This report presents the design and development of the Electric Autonomous Tree Planter over the course of the school year; it is a mechatronic system aimed at improving the speed, consistency, and accessibility of tree planting. The motivation for this project stems from the global demand for large-scale reforestation and the limitations of current manual and semi-automated planting methods, which are labor-intensive, costly, and difficult to scale. In particular, the system addresses a growing need for sustainable technologies that can operate effectively in challenging terrains while minimizing physical strain on workers and reducing environmental impact.

The project scope was refined to focus specifically on automating the sapling planting process, excluding autonomous navigation and traversal. This allowed the team to concentrate on developing a modular, mountable planting system that could be integrated into various platforms in future endeavours. The final design includes four key subsystems: a puck-based sapling delivery conveyor, a mechanical ground sensing probe, a hydraulically actuated planting mechanism, and a passive soil tamping unit. Together, these components perform a complete planting cycle in under 20 seconds, including soil hardness testing, hole creation, sapling insertion, and soil compaction.

Design validation was conducted through engineering simulations, mechanical testing, and prototype trials. Finite Element Analysis (FEA) confirmed the structural strength of the planting and sensing subsystems under expected field loads. MATLAB Simscape simulations verified hydraulic actuation speed and pressure control. Prototype testing demonstrated successful sapling delivery and planting in controlled soil conditions, validating key performance targets such as force tolerance, planting depth, and system repeatability.

The final system met the majority of its design objectives and constraints, including operation in varied terrain, inclusive usability, and potential for large-scale deployment. While the sapling feeder subsystem requires further refinement for continuous operation, all critical planting functions performed reliably. The project concludes with recommendations for future development, including higher-precision manufacturing, integration with autonomous mobility systems, and field testing to assess long-term planting success. Overall, the Electric Autonomous Tree Planter provides a promising foundation for next-generation reforestation tools that are efficient, scalable, and environmentally conscious.

Table of Contents

List of Figures

List of Tables

Response to Comments/Critique

Feedback from the previous two reports completed (Phase 1 Report and Detailed Design Documentation) was reviewed and summarized, and these critiques were utilized to improve the quality of this Final Report. The tables below summarize the issues that were highlighted in the feedback for the reports, as well as how the team addressed them and what modifications occurred.

Table 1: Feedback items & how the team addressed them based on Phase 1 Report

Report Feedback Item	How Team Addressed Item
More concise scope required Define subsystem more clearly	Scope was refined to planting system only 3 primary subsystems identified (Feeding, Planting & Sensing)
Objectives should use the words *reduce* & *increase*, instead of *maximize* & *minimize*	Objectives were rewritten such that targets are set to maximize/minimize aspects
Constraints are separate from objectives Set benchmarks rather than optimizations	Properly separated constraints and objectives Benchmarks established for constraints
Constraints & objectives need rationale	Explanations were included for the
Subsystem sections need visual aids	Additional figures and photos of the prototype/auto-CAD were included
More in-depth, better explained Design Validation section required	Advanced engineering tools utilized More in-depth descriptions and analysis
Links for resources & budget items are necessary	Hyperlinks and sources included with each budget/resource item

Table 22: Feedback items & how the team addressed them based on Detailed Design Documentation

Report Feedback Item	How Team Addressed Item
Lacking proper engineering analysis tools Simulation software required to validate testing results	Results were verified with SolidWorks, MATLAB SimScape, SolidWorks Simulation, KiCad, and Arduino IDE
Evaluation & validation of the design were lacking breadth and depth	As mentioned above, software simulations and longer, better quality explanations were added
Set range for sapling sizes to be used with final product	As per 53mm puck inner diameter, maximum sapling plug diameter set as 50mm
Subsystems should include more visuals to help reader understand written content	As mentioned above, more renderings and photos were included
Provide a preamble for each subsystem explaining its functionality	Subsystems are described in detail when introduced, supplemented with CAD renderings

Introduction

It is worth noting that this is a very worthwhile endeavour to have invested time, resources, and effort into through the completion of this course project. The most direct application that arises from the implementation of this autonomous tree-planting mechanism is an automated, reliable system that can be incorporated into self-traversing vehicles or as implemented behind forestry equipment. Resultantly, it serves as a versatile and effective method to combat issues of carbon emissions and deforestation both by planting saplings in previously unforested areas, as well as repopulating trees in areas where they have been lost (such as via logging, spread of disease, or forest fires).

Another benefit to the versatility of the incorporation of the device onto a vehicle, the terrain that it can operate and plant in, and the choice of sapling that is being planted is that many other prevalent issues can be tackled simultaneously. For example, during consultation with project advisor Dr. Joshua Pearce, it was discussed that there was the potential for this mechanism to not only combat deforestation but also to alleviate hunger in areas affected by famine. By choosing to plant saplings that will grow into fruit or nut trees in large numbers, this serves as a sustainable farming method that could provide sustenance to communities in need.

Background Information

Reforestation has been a national priority in Canada for nearly a century, with programs beginning in British Columbia in the 1930s. To date, more than 7.5 billion trees have been planted across the country. Despite ongoing efforts, the vast majority of reforestation continues to rely on manual labour. Workers commonly plant up to 2000 saplings per day using handheld tools. Although this method can yield high planting rates by experienced workers, it remains physically demanding, labour-intensive, and challenging to scale.

In the past decade, multiple efforts have been made to introduce automation into the tree planting process, but these have fallen short due to key limitations. A project developed at the University of Victoria employed a pneumatic system to create planting holes and insert seedlings. However, this design featured a low sapling capacity of just 10 units and required frequent manual reloading. Furthermore, the use of pneumatics necessitated a large onboard compressor, reducing the system's efficiency and portability.

Figure 1: Pneumatic Spike Based Sapling Planter

The Trovador hexapod robot, introduced in 2023, was designed to execute a multi-step planting cycle involving digging, seedling placement, and soil compaction. Despite the sophistication of the sequence, the system could carry only six saplings and operated at a low planting rate, limiting its usefulness for large-scale applications.

Figure 2: Trovador Hexapod Robot

A third approach, aerial reforestation using drones, allows for the deployment of seed pods at high speed and with significant coverage—up to five pods per second and 1600 pods per flight. However, this method faces major drawbacks. Seed pod germination rates remain low due to inconsistent soil contact, environmental exposure, and predation by wildlife, resulting in poor long-term reforestation success.

Figure 3: Seed Pod Drone

These prior attempts illustrate a common technological gap in current reforestation automation efforts: limited planting capacity, low planting speeds, and unreliable planting quality. Existing systems fail to combine high throughput with consistent, ground-verified planting.

The proposed capstone project addresses this gap through the development of a modular, ground-based tree planting system. The system features a high-capacity feeder capable of holding approximately 400 saplings and utilizes a hydraulically actuated three-blade planting mechanism. Prior to each planting cycle, ground suitability is assessed using an analog soil sensing subsystem. The design emphasizes efficient, repeatable planting cycles that can be executed with minimal human intervention. It is adaptable for trailer-mounted deployment or integration with autonomous platforms, offering flexibility for future expansion.

To ensure the system meets its performance targets, several engineering tools were applied throughout the design process. SolidWorks was used for mechanical modeling, enabling detailed design and dimensional verification of components such as the planting blades, sensor housing, and structural frame. To evaluate stresses of the components subjected to soil resistance, manual calculations were done using soil mechanics principles commonly used in Civil Engineering. These were supported by Finite Element Analysis (FEA) simulations that were conducted within SolidWorks to evaluate stress concentrations and verify the structural integrity of different components and subsystems. MATLAB and Simscape Fluids were employed to simulate the hydraulic subsystem, aiding in the selection of appropriate pumps, valves, and cylinders to meet the force and stroke requirements of the planting sequence. For electrical system development, KiCad was used to design and validate the circuit schematics, ensuring proper power distribution, switching, and sensor integration. These tools allowed for iterative refinement and functional integration across mechanical, hydraulic, and electrical domains, ultimately supporting the development of a cohesive and testable prototype. These engineering efforts collectively aim to provide a scalable, reliable, and field-ready solution to modern reforestation challenges.

Problem definition

While it may seem contrived for this project, there are applicable safety, cultural, and gender equity considerations that apply to the team's development of an automatic tree-planting mechanism. As fourth year students graduating a quarter of the way into the 21st century, these considerations are important to reflect on as they will be life-long considerations as they navigate careers in the field of engineering with others who have much different experiences.

The first point to note is that the majority of manual tree-planting jobs are completed by individuals in North America; primarily Canada and the United States. Heavily dependent upon the trees planted per shift and the company worked for, the average Canadian tree planter makes between CAD$200-450 per day at a pay rate of CAD$0.10-0.45 per tree. [1] On the other hand, there are tree-planting jobs executed in other countries around the world, including developing countries. However, these jobs are often even more grueling than in North America in worse conditions and for lower pay; the average tree-planter in India makes approximately ₹20,100 per month (at the writing of this report, this translates to roughly CAD$335). [2] [3] This is certain to say that North American tree planters, while exerting the same physical effort as a tree-planter in the Indian subcontinent, are more heavily rewarded for their efforts. The introduction of an automated, readily available, system such as ours to countries like India would allow individuals to exert less effort and become operators for a system for the same – or more – pay than the status quo allows. Combined with the fact that automatic tree-planting will contribute to combatting deforestation in developing countries while potentially planting trees that will yield nourishing fruits and nuts, the opportunity for individuals to become operators instead of labourers allows a multitude of opportunities.

This year in MSE 4499, we aim to develop an autonomous system capable of efficiently planting trees across a variety of challenging environments, ultimately improving upon the limitations of manual labor and existing automated methods. Such a solution should be versatile, compatible with a variety of traversal systems, and feasible for deployment at a large scale. This project will explore and evaluate multiple design options that address the key requirements of effective tree planting.

Design Requirements, Scope, Objectives and Constraints

Following a detailed review and guidance from faculty advisors, the original goal of developing a fully autonomous tree planting system was refined to better align with the available timeline, resources, and expertise of a fourth-year undergraduate team. The revised project scope centers on automating the critical components of the tree planting process, excluding autonomous traversal and navigation. This refined focus preserves the core objective of improving planting efficiency and precision while reducing the physical strain associated with manual planting.

The finalized design consists of a sapling planting mechanism capable of site assessment, soil penetration, and automated sapling placement. Ground suitability is evaluated through a mechanical probing system with analog feedback, which determines whether the site is free of obstacles such as rocks or surface debris. Upon identifying a suitable location, a hydraulically actuated blade mechanism creates an opening in the soil. A sapling is then dispensed from a puck-based feeder system and placed into the hole. To finalize the process, the soil is compacted using angled arms with attached wheels that apply consistent pressure while navigating surface irregularities. This modular system is mounted on a trailer for demonstration and potential field deployment.

Equity, cultural, and gender-related considerations were addressed during the design process. The planting system is designed to minimize physical exertion, helping reduce the gender bias often associated with physically intensive forestry roles. By lowering the physical strength required for operation, the system promotes broader inclusivity across operators regardless of gender or physical capability. A social impact that this system could impose is the inherent loss of jobs that are created when automating the tree-planting process. However, operators are still required to reload saplings, perform maintenance, and charge the system when required.

The resulting system demonstrates reliable operation within a controlled environment, with fatigue and efficiency assessments supporting planting performance comparable to, or exceeding, manual methods. The design also establishes a scalable foundation for future integration of autonomous mobility and enhanced environmental sensing technologies.

Design Objectives and Constraints

Each objective has been developed to directly address the identified technological gap in modern reforestation while considering feasibility, usability, and inclusivity. The associated constraints reflect real-world limitations that impact system performance and implementation. To ensure cultural and gender sensitivity, one objective explicitly targets minimizing the physical demands of tree planting, ultimately, enabling broader accessibility across gender and physical ability lines.

Table 3: Design Objectives and Constraints

Objectives	Constraints
Optimal site detection and planting – Use of analog probes to verify planting location is free of obstacles that may damage the planting mechanism.	Speed – System should complete each planting cycle in under 15 seconds to be competitive with manual methods.
Scalability and efficiency – Designed to plant up to 400 saplings per load, minimizing downtime and improving operational throughput.	Hole depth – Must consistently achieve a planting depth of 10–15 cm suitable for common sapling plugs.
Adaptability to adverse terrain – Modular trailer-mount design allows use in uneven or partially obstructed planting locations.	Cost and economic limitations – Total material and fabrication cost constrained to $25, 000.
Low environmental impact – Use of recyclable materials and minimal disturbance to surroundings during planting.	Environmental constraints – Must operate in varied temperature and moisture conditions without mechanical failure.
High survival rate of planted trees – System aims to match or exceed 85% survival rate typical of experienced manual planting.	Weather resistance – All exposed components must resist light rain and dust to ensure durability.
System adaptability and modularity – Capable of integration with autonomous or remote-controlled platforms in future phases.	Sapling carrying capacity – Limited to 400 saplings based on space and weight constraints of feeder system.
Easy installation and maintenance – Components should be field-replaceable with common tools.	Total system weight – Must remain within towing limits of typical ATVs or utility vehicles (<500 kg).
Inclusive operation – Reduce required physical effort to support operation by individuals of all gender identities and strength levels.	Ethical, legal, and regulatory compliance – Adherence to all safety and environmental guidelines.

Concept Generation, Evaluation and Selection of Concepts

The final design of the sapling planting system was developed through an iterative process guided by various concept iterations, prototyping and testing, and environmental constraints. The system is comprised of four subsystems: the sapling delivery conveyor, ground sensing probe, planting mechanism, and soil tamping assembly. Each was designed to operate autonomously in sequence to complete a planting cycle quickly and reliably in a variety of terrain conditions. While multiple concept variations were considered during the early design phase, the final configuration reflects selections that balance performance in terms of speed, repeatability, and reliability. Manufacturability and cost-effectiveness were other considerations that were also valued.

Sapling Delivery Subsystem

The sapling delivery system utilizes a puck-based conveyor mechanism. Saplings are preloaded into open-bottom cylindrical pucks that travel along a track supported by rails. These pucks are driven by eight synchronized 12V DC gear motors, each fitted with rubber drive wheels to provide direct contact and pushing force. As each puck reaches the hole in the track, positioned above the planting system, its presence is detected by a sensor, halting the motors and dropping the sapling into the planter. This method was chosen over a previously considered gantry-mounted gripper as seen in the figure below, which, although compatible with nursery trays, introduced complexity, cost, and was prone to failure in outdoor conditions. The puck system offers a robust and simple solution, requiring minimal maintenance while remaining scalable for future automated reloading.

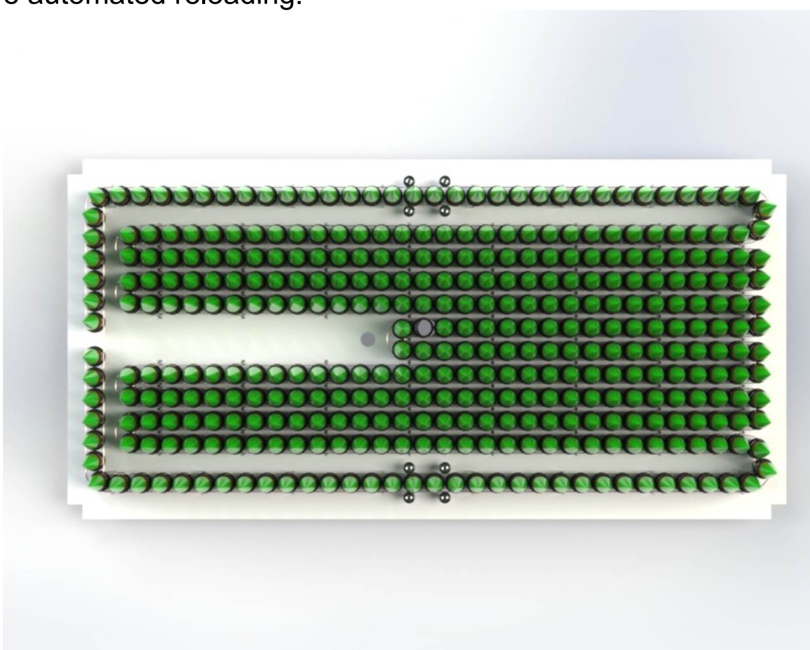


Figure 4: Superior View of Sapling Delivery System

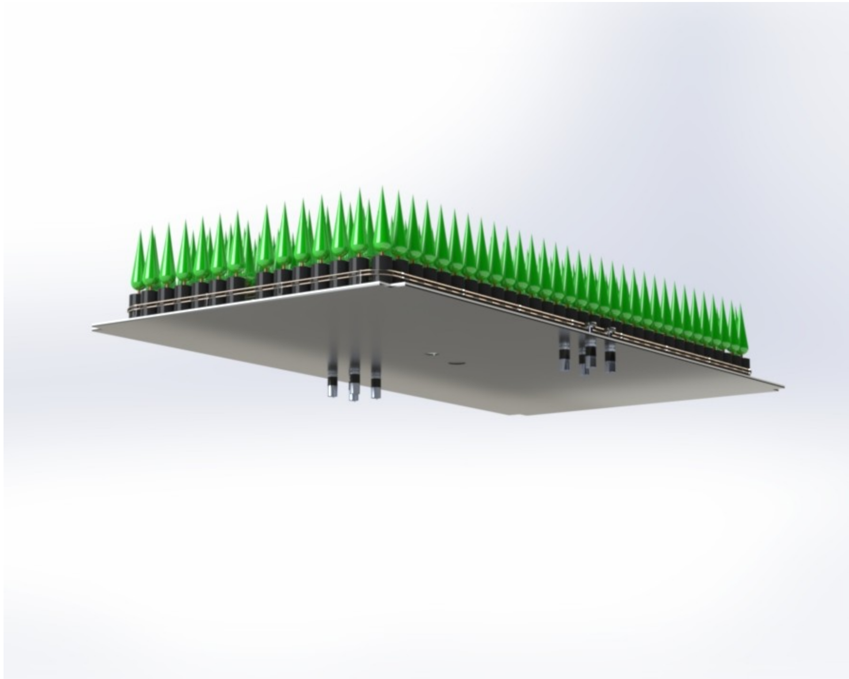


Figure 5: Isometric Underside View of Sapling Delivery System

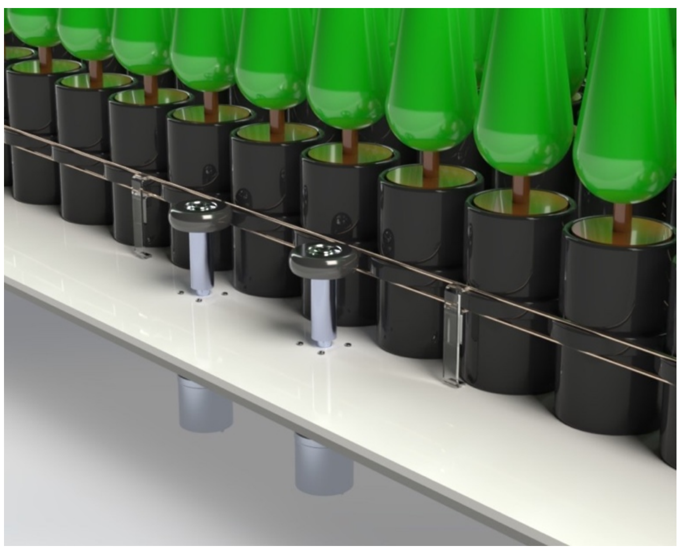


Figure 6: Close-up View of Sapling Pucks and Drive Mechanism

Planting Subsystem

The planting function is performed by a hydraulically actuated planting mechanism rated to a force of 100kg. A three-blade spade system encapsuling a sapling is driven into the ground to the optimal planting depth of the sapling determined by an ultrasonic proximity sensor. The blades are then opened, and the system is retracted before closing to load the next sapling. Blade actuation is driven by a 14 mm stroke double-acting hydraulic cylinder through a toggle linkage mechanical design (figure 9). Vertical movement is managed by a 500 mm stroke double-acting hydraulic cylinder, which lowers and raises the entire planting mechanism with a speed of 2 seconds per stroke. Hydraulic actuation was selected over linear actuators and auger-based excavation methods due to its ability to apply high force, operate reliably in soil and dusty environments, and aid in achieving the speed constraint outlined previously. The hydraulic system is powered by a 1.6 kW 12V hydraulic power unit and controlled via two 4/3 directional solenoid valves operated by an Arduino-controlled relay module. This configuration allows precise timing and coordination with the sensing and delivery systems, ensuring consistent depth.

Figure 7: Planting Subsystem Isometric View

Figure 8: Planting Subsystem Isometric View


Figure 9: Planter and hydraulic cylinder with toggle linkage mechanism

Ground Sensing Subsystem

Planting location suitability is verified using a sensing subsystem to ensure our planting mechanism is not damaged due to hard surfaces and debris above or below the soil (ex: rocks). The system consists of a sensor plate with five steel probes mounted in linear bearings and opposed by compression springs (figure 10). The system is attached to the planting mechanism and is driven into the ground by the 500 mm stroke double-acting hydraulic cylinder. The displacement of each probe while being driven into the ground is recorded by a linear potentiometer that is in contact with the top of the probe as seen in figure 10. These displacement values are converted into force using Hooke's Law ($F = kx$), and the total force across all probes is summed. If this force exceeds 981 N, equivalent to 100 kg, the planting location is deemed unsuitable, and the sequence is aborted by retracting the mechanism and moving to another location. This analog sensing approach was selected in place of commercial force sensors or mechanical limit switches due to its superior durability, lower cost, and higher resolution. After a suitable site is confirmed, meaning the summed force is less than 100kg, the sensing arm rotates 90° using two 12V servo motors to clear the path for the planter. It is also equipped with a keyed locking mechanism to protect the servos as seen in figure 13. The locking pins are driven by two 15mm stroke linear actuators to prevent rotation and absorb the vertical force on the system.

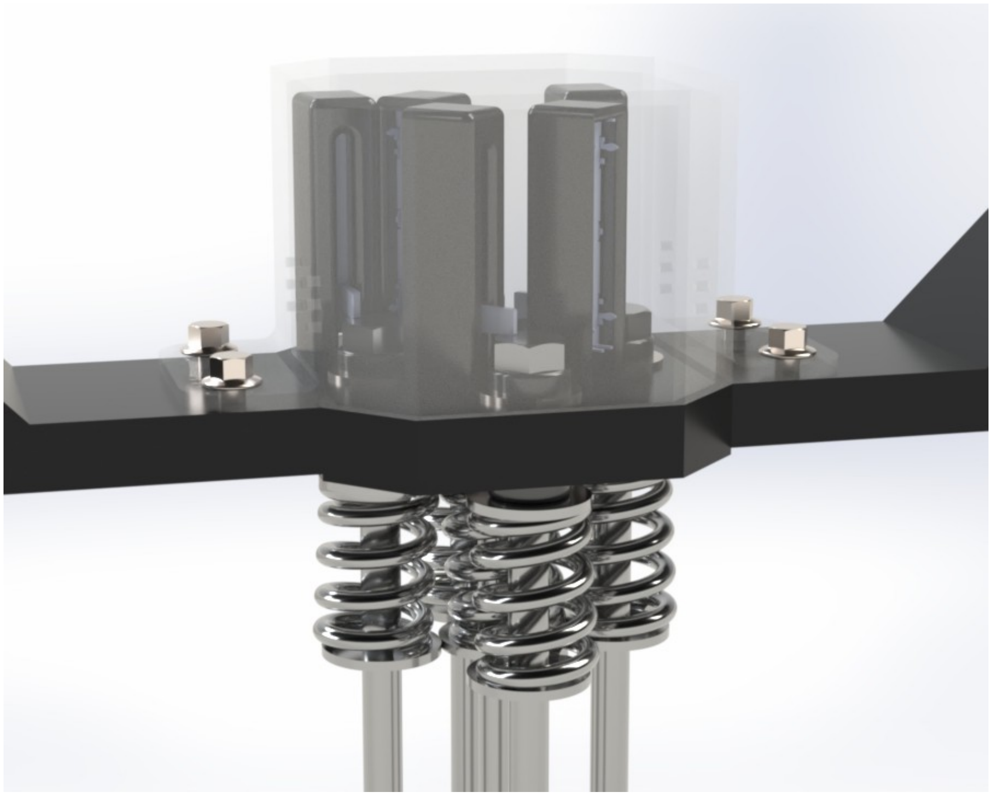


Figure 10: Sensor probing system springs and linear potentiometers

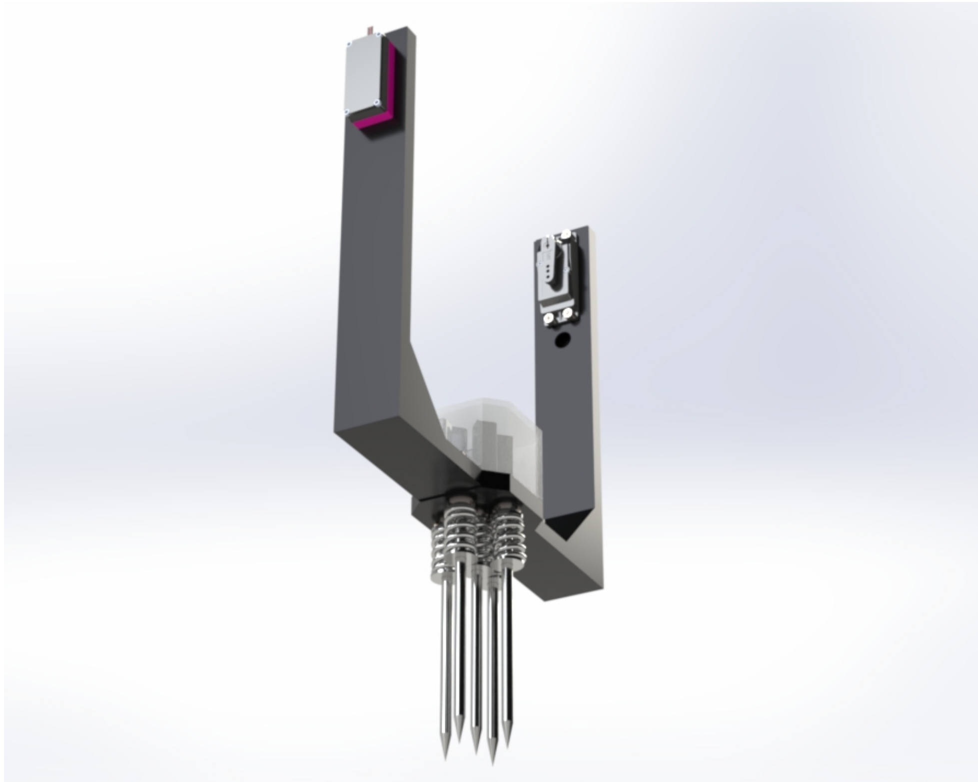


Figure 11: Probe subsytem iso view

Figure 12: Probe subsystem iso view

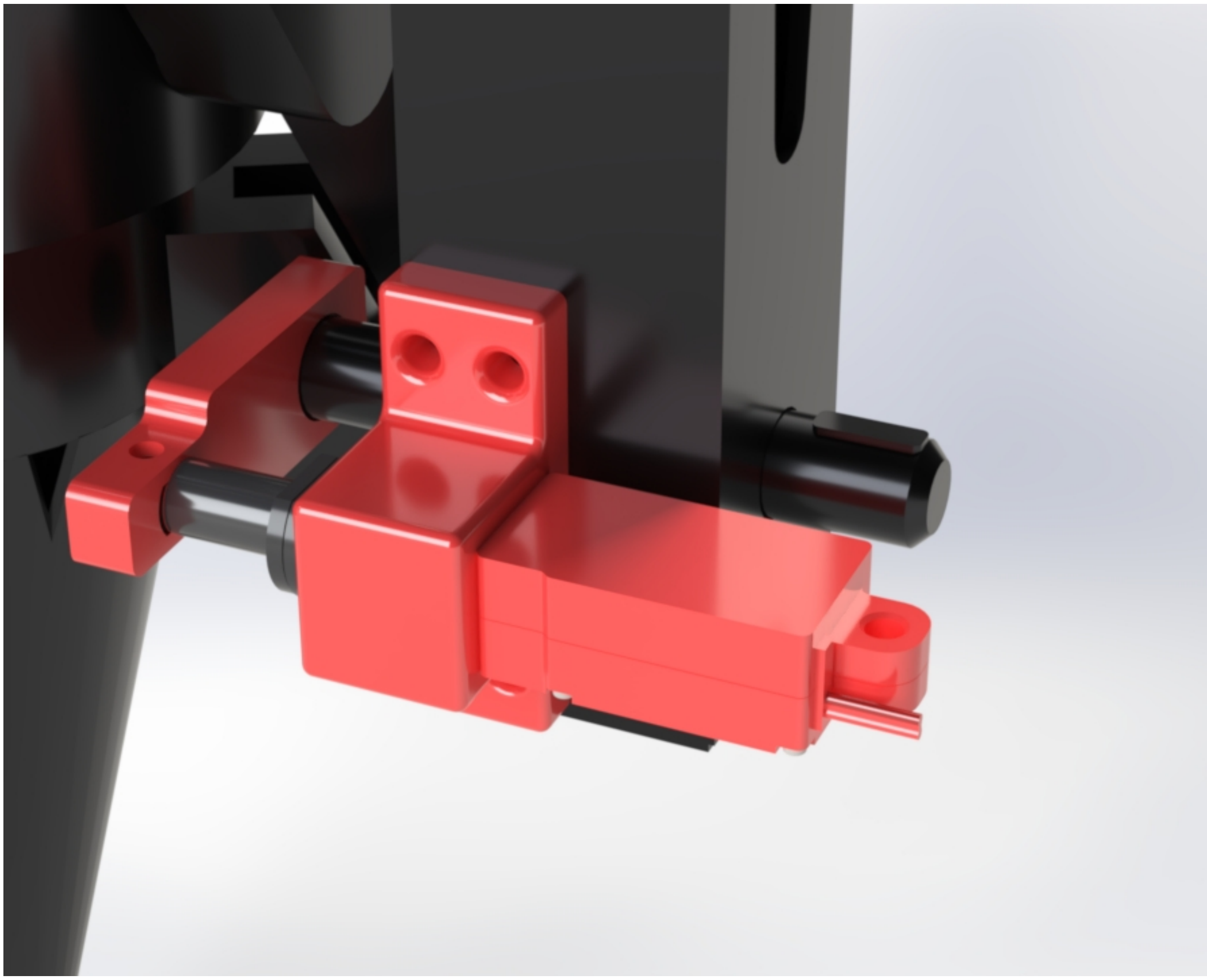


Figure 13: Locking mechanism

Soil Tamping Subsystem

To complete the planting cycle, a soil tamping subsystem follows the planting mechanism. It consists of wheels mounted on two arms with gas struts that press the soil around the sapling as the system advances. These arms can articulate vertically to conform to uneven ground while absorbing impacts from branches or rocks. The use of a passive tamping system reduces complexity and power requirements while contributing to the overall planting quality by improving soil compaction and increasing sapling stability.

Figure 14: Tamping Mechanism on gas struts

System Summary and Justification

Each subsystem in the final design was selected based on quantitative and qualitative assessments conducted throughout the design process. Concepts such as seed pod planters, plow-based excavation tools, and gantry-style feeders were ultimately discarded due to lower reliability, reduced survival rates, or unnecessary complexity. The final system satisfies all major project objectives and constraints: it operates autonomously, supports modular deployment, completes a full planting cycle in approximately 15 seconds, and is designed for trailer mounting with future adaptation to autonomous mobility platforms. Safety features include pressure relief valves in the hydraulic circuit, fused electrical loads, an emergency stop button, and mechanical designs capable of withstanding outdoor operating conditions. Environmental considerations such as the use of recyclable metals and reusable components have been incorporated to align with sustainable design practices.

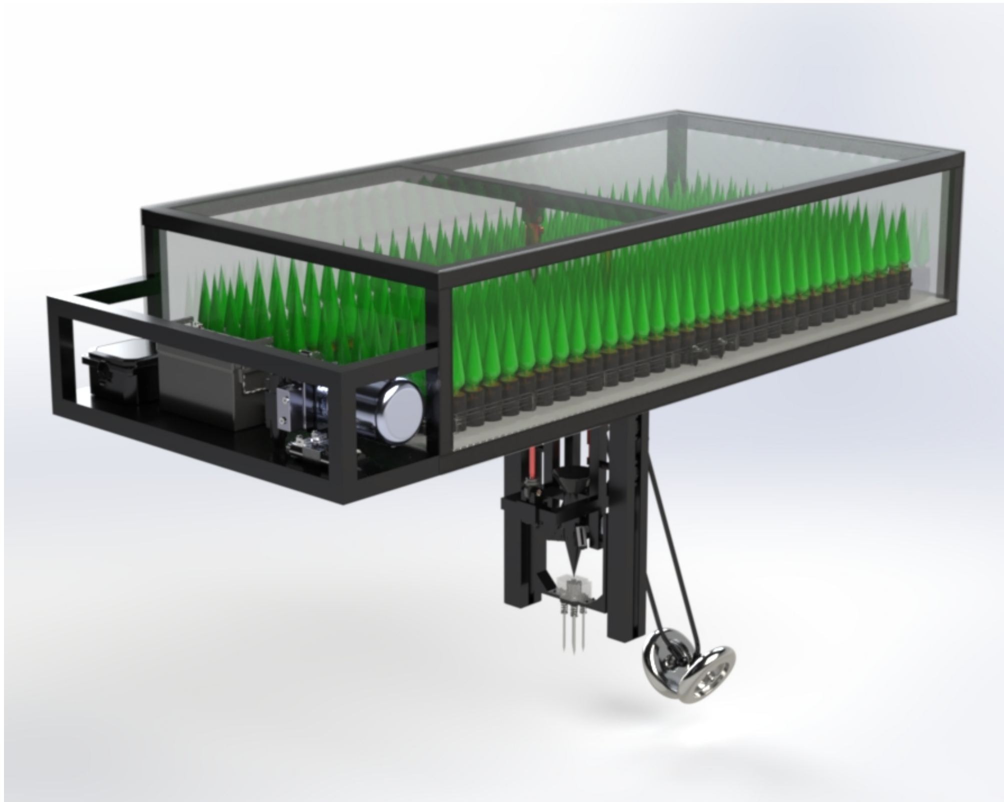


Figure 15: tree planting system iso view

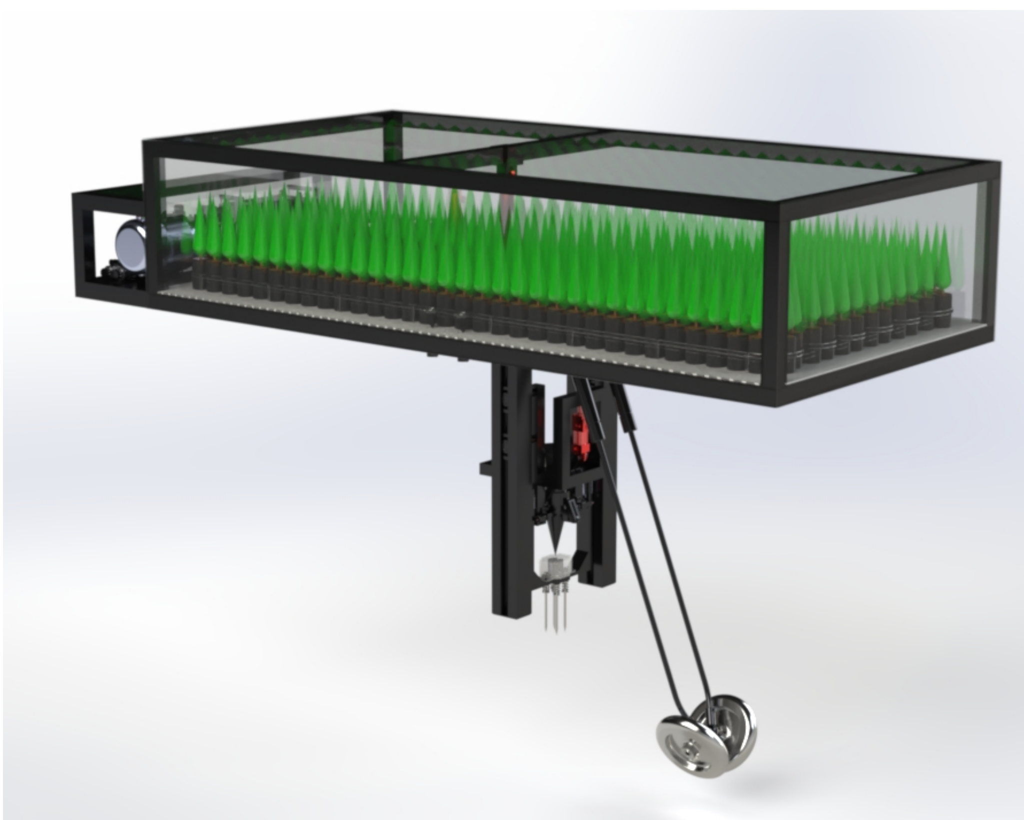


Figure 16: Tree Planter System iso view

Design Validation

This section summarizes the analytical, experimental, and simulation-based techniques used to validate the structural, functional, and operational integrity of the autonomous tree-planting system. Each major subsystem—planting, sensing, and feeding—was subjected to rigorous analysis using mechanical testing, Finite Element Analysis (FEA), and dynamic simulation in MATLAB Simscape Fluids. The purpose of these validation methods was to confirm that the final design meets defined functional requirements while addressing constraints related to safety, durability, manufacturability, and environmental operating conditions.

Planting Mechanism Force Validation

The vertical force required to insert the planting blades into compacted soil was measured experimentally using a standard handheld transplanter equipped with a load cell. A test fixture was constructed with the load cell mounted between a steel cap and the planting tool. Testing was conducted in compacted black earth soil to replicate field conditions. The maximum recorded insertion force ranged from 28 kg to 73 kg as can be seen Figure 17. To ensure safe operation and account for variability in soil density, the planting mechanism was designed to withstand a vertical force of 100 kg (981 N), corresponding to a safety factor of approximately 1.33.

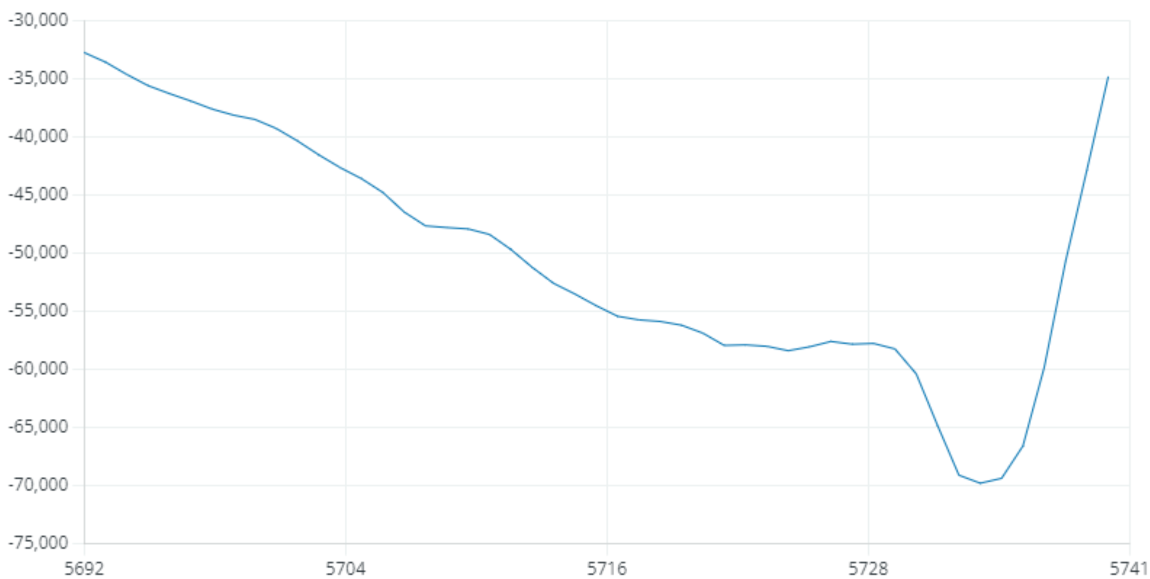


Figure 17: Graph showing test results in Force (kg) vs. Time

This design decision directly informed the selection and sizing of the 500 mm stroke double-acting hydraulic cylinder responsible for vertical motion. Validation confirmed that the cylinder's rated output exceeded this force requirement while providing sufficient stroke length to insert saplings at the required 15 cm depth.

Figure 18: Load cell testing setup for sapling insertion force measurement

Sensing Subsystem Force Analysis

The ground sensing mechanism includes five spring-loaded probes used to detect subsurface obstructions or excessive soil hardness. Validation of this subsystem involved static force calculations to ensure that the system accurately distinguishes between plantable and non-plantable soil.

Using soil mechanics equations, the tip resistance (q_c) and sleeve friction (f_s) acting on the probes were calculated for two soil types: coarse sand and peat. [4] These values were then used to determine the axial stress acting on the probe cone using the formula:

$$q_c = \frac{Q_c}{A_c}$$

(1)

Where Q_c is the tip force and A_c is the cone area (195 mm²). The worst-case stress value of 4.08 MPa was observed in coarse soil. [5] With a factor of safety of 2.5, a critical design stress of 10.2 MPa was defined. Low-alloy steel was selected to satisfy this requirement due to its high yield strength and corrosion resistance. [6]

In the final system, linear potentiometers mounted behind each probe measure displacement during soil penetration. Displacement is converted into force using Hooke's Law:

$$F = kx$$

(2)

Where k is the spring constant and x is the measured displacement. The total probing force is computed as the sum of all five probe forces. If the total exceeds 981 N, the planting cycle is aborted. This method provides analog feedback and reduces susceptibility to false positives compared to earlier limit switch implementations.

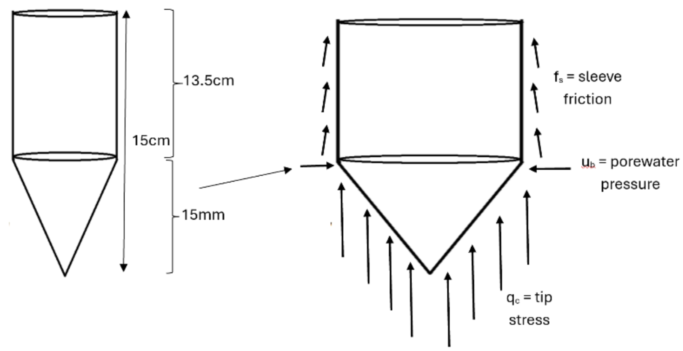


Figure 19: Soil resistance for sensing probes showing axial and sleeve friction contributions

Planting Blade Stress Analysis

Each of the three planting blades was analyzed for stress under two primary loading conditions: downward penetration and soil displacement during blade opening. The former generates a normal insertion force; the latter induces a bending moment due to resistance from compacted soil.

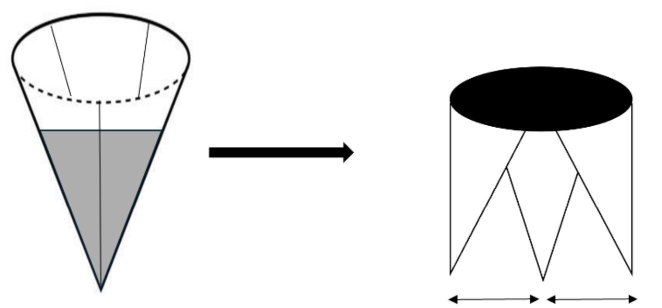


Figure 20: Two Loading Conditions on Planting Blades

The maximum penetration stress per blade was calculated to be 20.92 kPa, while the opening phase produced a bending stress of 128 MPa. The blades were modeled as triangular panels with thickness of 3 mm. A simplified beam bending analysis yielded the maximum stress using:

$$\sigma = \frac{My}{I}$$

(3)

Where M is the moment from the distributed load, y is the distance from the neutral axis, and I is the second moment of area. Applying a safety factor of 2.5 resulted in a critical design stress of 320 MPa. Low-alloy steel was selected due to its strength and superior fatigue performance in cyclic loading conditions. [7]

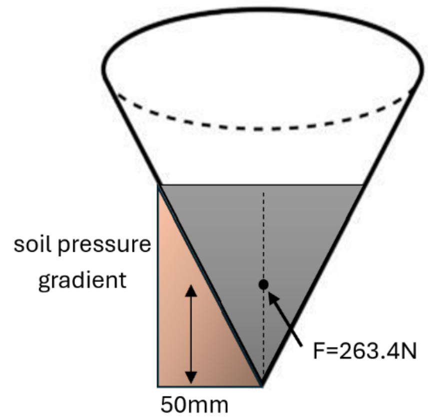


Figure 21: Soil Pressure Gradient and Equivalent Force on Blades

Feeder Subsystem Torque Analysis

To validate the motorized puck conveyor, a torque calculation was performed based on the system mass, material friction, and curvature resistance. The feeder system carries approximately 450 saplings in bottomless pucks, with a total load mass of 67.5 kg.

With a coefficient of friction of 0.2 (PVC on HDPE), the frictional resistance was calculated and adjusted for 11 180° bends and two 90° bends in the track. A resistance multiplier of 1.7 was applied, increasing the effective friction force to 225.1 N. Using a drive wheel radius of 40 mm, the torque required was:

$$T = F \times r = 225.1\ N\ \times\ 0.04\ m = 9.0\ N \cdot m$$

(4)

Eight motors were selected, each rated at 4.1 N·m, to provide redundancy and reduce the duty cycle per motor. The system therefore exceeds the torque requirement while improving long-term reliability and fault tolerance.

Finite Element Analysis (FEA)

Comprehensive FEA simulations were conducted to verify mechanical performance under load. The planting and sensing subsystems were analyzed:

1. **Sensing Probe FEA**:

   The sensing probes was designed to withstand a maximum insertion force of 100 kg (981 N) before aborting the planting sequence. Based on Hooke's Law, with a spring constant k = 38.6 N/mm, the expected displacement at this force was calculated as:

$$x = \frac{F}{k} = \frac{981\ N}{38.6\ N/mm} = 25.4\ mm$$

(5)

In the simulation, a vertical force of 981 N was applied to the tip of a single probe while it remained constrained in a linear bearing. The results showed a maximum displacement of 26.27 mm, closely matching the theoretical value. This confirms the accuracy of the mechanical spring model and validates that the linear potentiometer can reliably measure displacement in correlation with applied force.

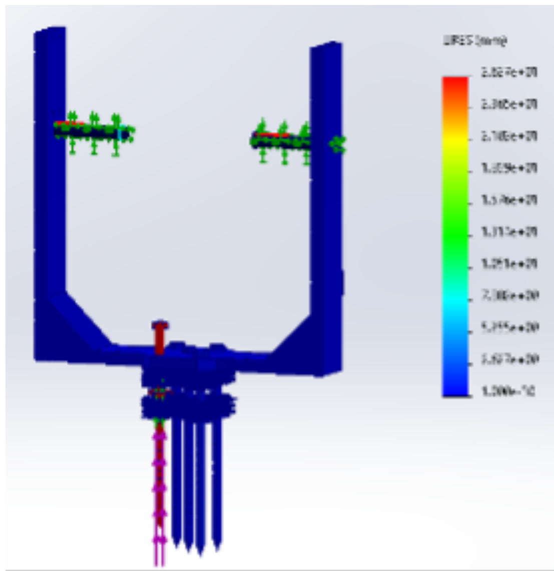


Figure 22: single probe sensor FEA stress

The stress remained well below the yield strength of the selected low alloy steel, indicating that the material selection is sufficient for repeated use under expected loads.

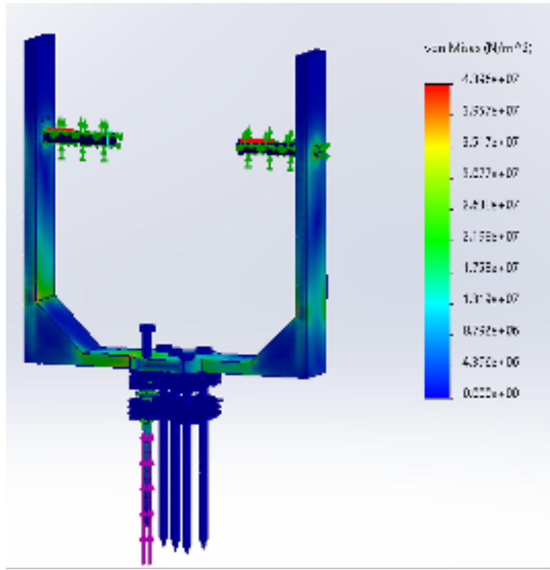


Figure 23: Single probe sensor FEA displacement

2. **Complete Sensing System FEA:**

   Next, the entire sensing system was analyzed with a total downward force of 100 kg (981N) distributed across all five probes. This gives a theoretical displacement of 5.08 mm per probe:

$$x = \frac{F}{k} = \frac{981 \div 5\ N}{38.6\ N/mm} = 5.08\ mm$$

(6)

The FEA displacement result for the same loading condition was 5.375 mm, representing a 5.8% deviation from the calculated value. This small margin validates the accuracy of the simplified analytical model and confirms the probe system's spring calibration.

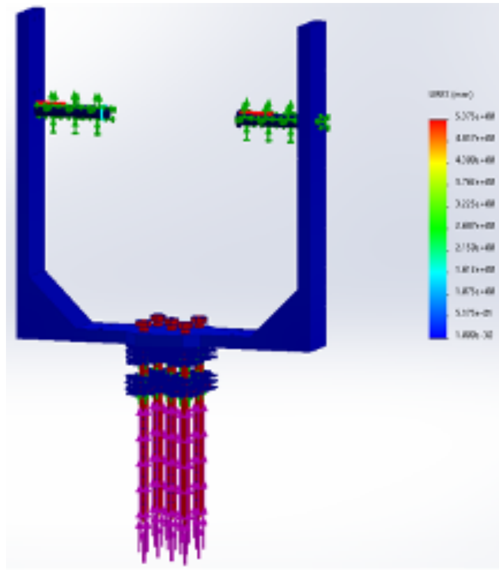


Figure 24: 100kg distributed force sensor FEA stress

Additionally, stress distribution in the probe assembly remained well below material yield strength, with a maximum von Mises stress of approximately 14.7 MPa. The simulation confirms the sensing mechanism can reliably detect soil resistance while avoiding mechanical failure during field operation.

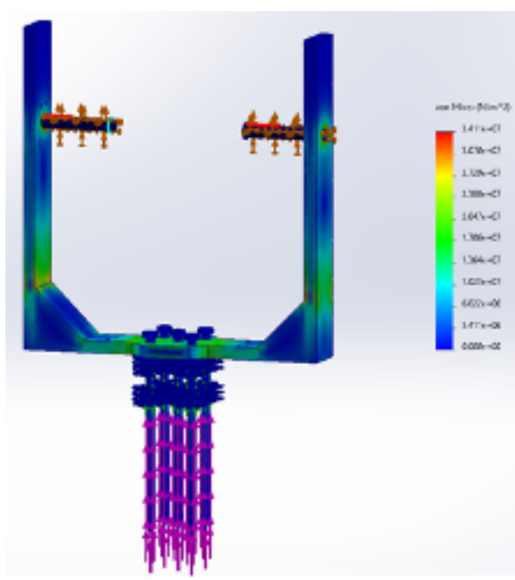


Figure 25: 100kg distributed force sensor FEA displacement

3. **Blade Assembly FEA**:

The figure below shows the total displacement of the planting blade assembly under the same loading conditions. The maximum displacement observed is 1.78 cm, located at the tip of the blades. This value is acceptable for the planting operation and confirms that the mechanism will retain dimensional accuracy and stability during use.

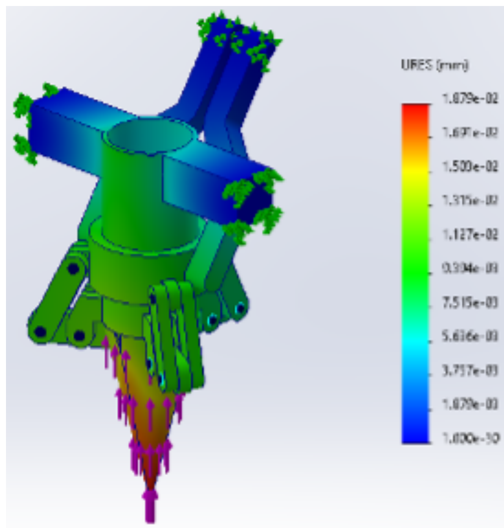


Figure 26: 100kg force on planter FEA stress

The next figure displays the resulting von Mises stress distribution. The maximum stress observed in the planting mechanism is approximately 23.44 MPa. This value is well below the yield strength of low alloy steel, indicating a very large safety margin and confirming that the component will not fail under expected operating conditions.

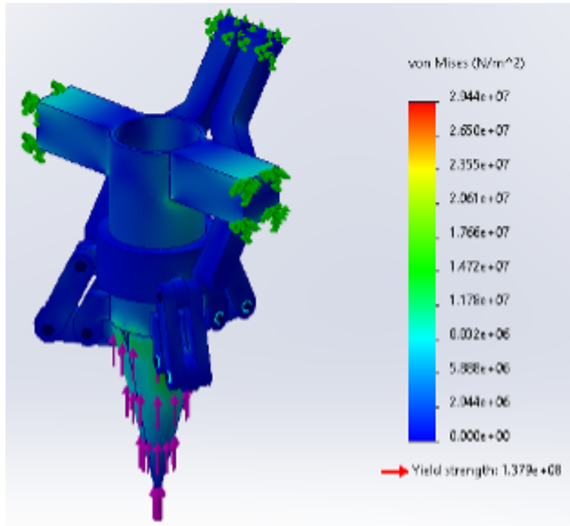


Figure 27: 100kg force on planter FEA displacement

4. **Planting Mechanism Assembly FEA**:

   The total displacement when the entire planting mechanism is subjected to a 981N upward force is 2.71 mm, occurring at the upper support for the small hydraulic cylinder. This deflection is minimal and does not interfere with planting performance. The system is sufficiently stiff and mechanically stable under expected loading.

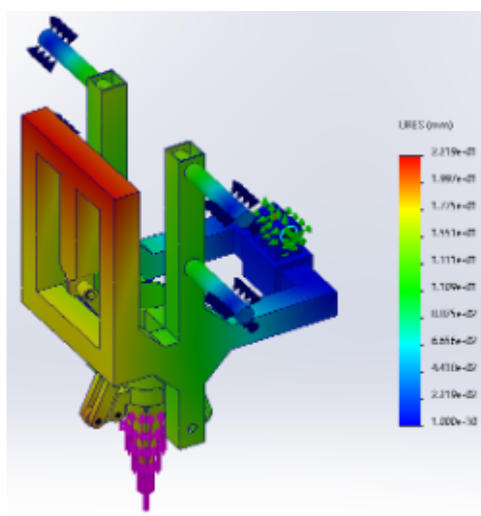


Figure 28: 100kg planter with frame FEA stress

The von Mises stress simulation shows a maximum stress of 4.37×10^7 N/m², well below the material's yield strength of 1.379×10^8 N/m². Stress concentrations appear near mounting points for the bearing shafts, but all values remain within safe limits, confirming structural integrity during operation.

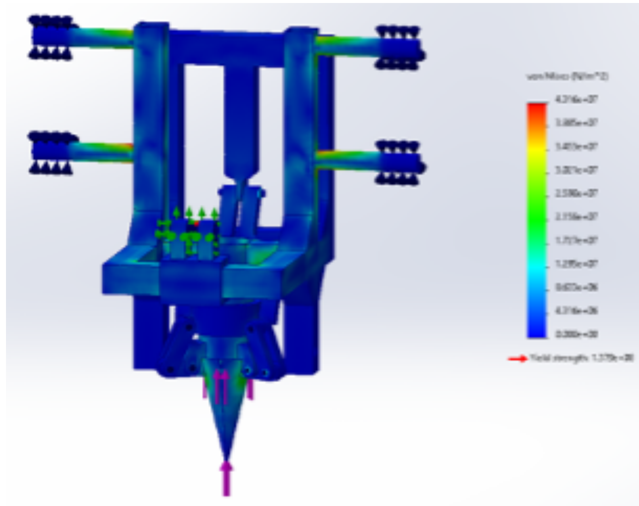


Figure 29: 100kg planter with frame FEA displacement

5. **Full Planting and Sensing Assembly FEA:**

Finally, FEA was conducted on the entire planting and sensing assembly to ensure that it could withstand the maximum loading condition. The figure below presents the corresponding displacement. The maximum displacement is approximately 4.35 mm, which again can be seen in the sensing probes. This confirms this assembly is subjected to a 981N force, it will not cause any significant displacement or misalignment in the rest of the frame.

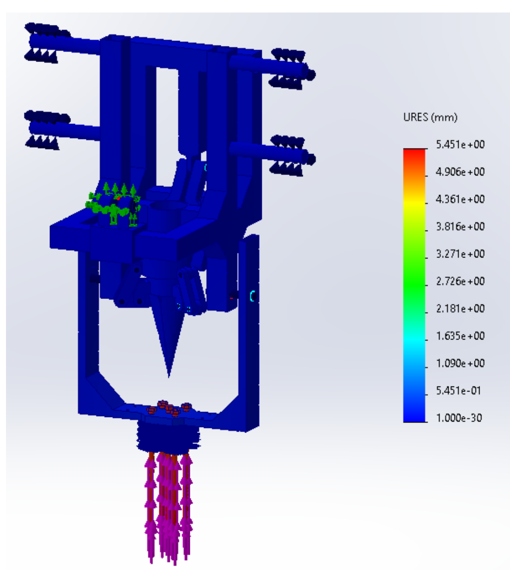


Figure 30: 100kg sensor with frame FEA stress

Next, one can observe the von Mises stress distribution. The maximum observed stress is on the order of 35.2 MPa, which is significantly below the material's yield strength of, indicating that the structure can safely withstand the maximum planting force without risk of yielding or failure.

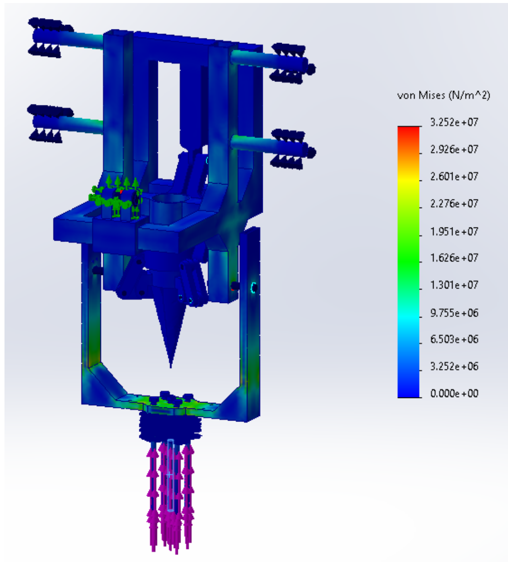


Figure 31: 100kg sensor with frame FEA stress

These FEA studies confirm that the planting system is structurally sound and mechanically efficient under expected field conditions.

Hydraulic Design and Simulation

MATLAB Simscape Fluids was used to simulate the hydraulic system controlling the planter's vertical motion and blade actuation. The model included two double-acting cylinders, directional control valves, and a fixed-displacement pump regulated by a relief valve.

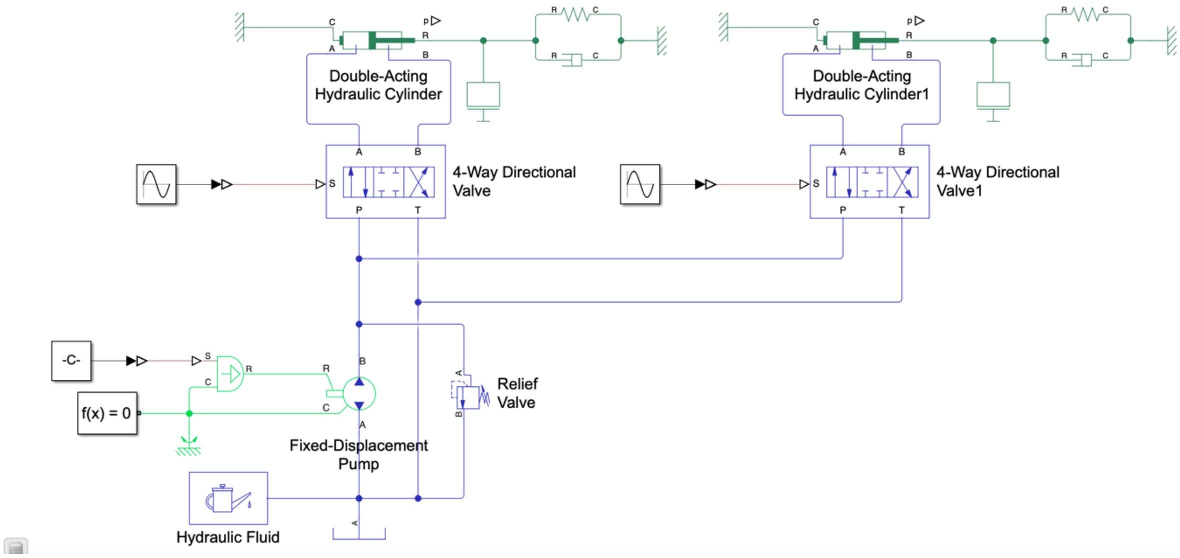


Figure 32: MATLAB Simscape Fluids simulation for hydraulic validation

Simulations validated that the system could respond to control signals within appropriate timeframes. The planting cycle could be completed in under 15 seconds, consistent with the design target. As can be seen below in Figure 33, the stroke time for the larger hydraulic cylinder is just over three seconds allowing us to meet the constraint of 15 second cycle time. The relief valve ensured safe operating pressures throughout the system.

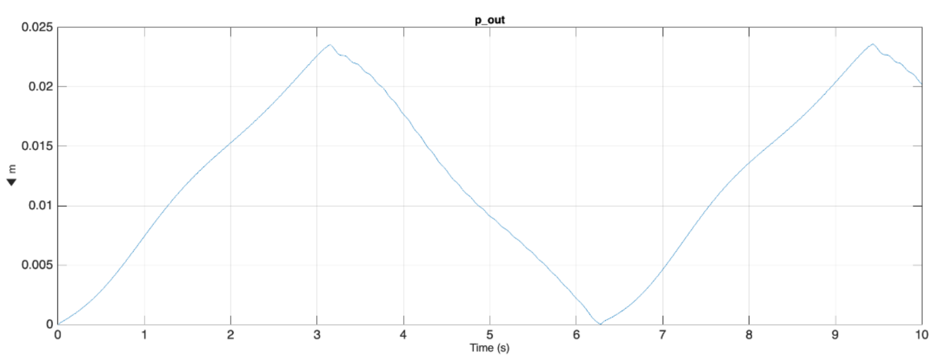


Figure 33: Extension and Retraction Timing for Hydraulic Cylinder

Prototype Development Summary

A full-scale prototype was developed for the sensing and planting subsystems along with a scaled down version of the feeding subsystem. The tamping system was not included in the prototype design as it is a simplistic mechanical design that was already verified by manually rolling two wheels along side a sapling planted by our prototype. The overall, planting subsystem, and sensing system frames were made from wood with additional gussets and supports to closer mimic the structural integrity of metal. Key aspects such as the sensor probes and planting mechanism remained as metal to ensure validation for our design. The prototype was successful in validating our design as it successfully senses force, allowing it to avoid planting locations with obstructions and it successfully plants a sapling at the correct depth. We were able to validate our objectives and constraints of repeatedly planting a tree within 15 seconds at the correct planting height. For our sapling delivery system, we were able to validate that it can move saplings forward and is a viable option but unfortunately, we did not have the tools and machinery to make a precise enough track to the level of wire forming manufacturing or to have precise motor placement to have a continuous running conveyor.

Design Validation Summary

Overall, our design has been validated by engineering principles through simulations and prototype test results. Our simulation results proved that our design is rated for 100kg, our tested rating with a safety factor, and our prototype proved that we can consistently plant a tree in a quick and reliable manor while avoiding poor planting location. The only discrepancy being our feeding mechanism not running continuously due to lack of proper machinery. A lot was learned throughout the process from solid mechanics to hydraulic implementations and FEA analysis in assemblies.

Design Refinement

The refinement of the sapling planting system was guided by continuous evaluation through structured design reviews and engineering analysis. The initial concept featured an autonomous robot capable of both navigation and sapling planting. However, early feasibility assessments revealed that integrating autonomous traversal significantly exceeded available resources and timelines. As a result, the scope was narrowed as previously mentioned to focus exclusively on the planting mechanism. Seed pod-based planting systems were ruled out due to their low germination rates and poor planting consistency, despite offering simpler handling. Similarly, excavation-based methods using plows or augers were discarded based on simulation results and field considerations, which revealed high failure potential in varied terrain and increased system complexity.

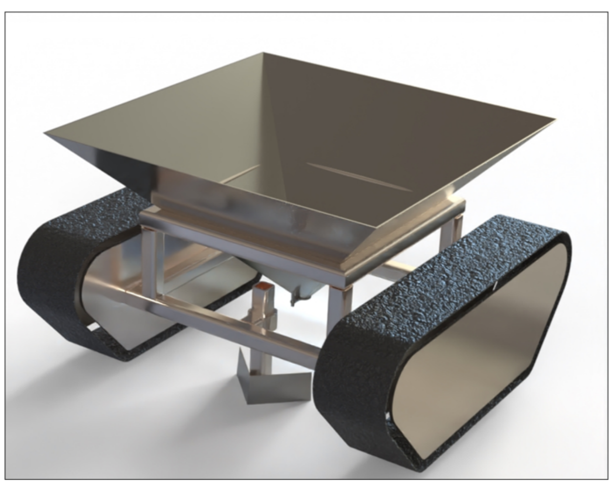


Figure 34: First design concept iteration

The sapling delivery system transitioned from a rail-mounted gantry gripper as seen below to a puck-based conveyor system after evaluations showed that the former was sensitive to misalignment and debris. The puck system, with direct-contact rubber drive wheels, demonstrated better robustness and scalability with minimal added control complexity.

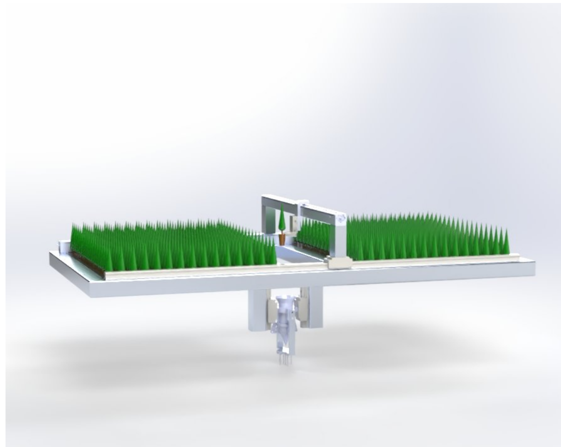


Figure 35: Second design concept iteration

The sensing subsystem also evolved from an initial concept using commercial load cells to a spring-displacement model with potentiometer feedback. The final design allowed accurate detection of unsuitable planting sites by translating probe deflection into force using Hooke's Law. This analog method provided sufficient resolution and ruggedness while eliminating the cost and environmental sensitivity of electronic force sensors.

Throughout the design cycle, hydraulic actuation was maintained as the preferred method of driving the planting mechanism. Design refinements focused on optimizing stroke lengths, cylinder configurations, and control logic to meet speed and reliability targets.

Key deficiencies identified during testing and modeling, such as probe displacement accuracy, soil resistance under varied conditions, and feeder track friction, were addressed through iterative component redesign and calibration opportunities enabled by the prototype. These refinements collectively improved the system's repeatability and overall performance while reducing the likelihood of failure in field operation.

The major modifications that would be made to have a confident prospective prototype would be in manufacturing techniques and component selection. A wire forming machine with lower gauge thicker metal would be used to create a precise track to reduce friction. CNC manufacturing would be used to create the mounting holes for the motors to assure exact locations. The shaft and wheel would be manufactured out of metal to prevent uneven rotation and molded pneumatic rubber tires would be implemented. The cups would also be injection molded to have precise tolerance rather than sliding 3D printed donuts onto cut abs pipe. Ideally with a higher budget all components would be made from their designed material for the next prototype to allow for life cycle testing.

The resulting system is highly reliable and well-suited for future deployment and adaptation. Confidence in the performance of the prospective prototype with the modifications outlined above is high, supported by a rigorous design process and extensive subsystem-level refinement.

Prototype Planning and Development

The prototype was developed to represent the critical functional elements of the final tree-planting system while optimizing for fabrication time, material costs, and testing effectiveness. It incorporates the most essential subsystems at full scale—including the sapling feeder, mechanical sensing probe, planting mechanism, and hydraulic actuation—allowing for reliable evaluation of the planting process in controlled conditions.

The structure of the prototype is a simplified version of the final system. The frame is constructed from wood rather than metal, as the prototype remains stationary during demonstrations and is not subjected to the mechanical fatigue or loading conditions expected in the field. This decision allows for rapid assembly and modification, enabling focused testing of dynamic subsystems without compromising safety or stability. To conserve space and reduce component cost, a scaled-down conveyor was implemented in place of the full-length puck track. While the final design uses a winding path for sapling transport, the prototype's shortened track effectively replicates puck motion, motor-driven advancement, and positioning. This provides sufficient detail for assessing feeder reliability and puck delivery accuracy without introducing excessive complexity or risk of failure due to debris. The prototype planting mechanism mirrors the final design, including the three-blade spade system actuated by hydraulic cylinders. The probing subsystem is also implemented at full scale, with five spring-loaded probes equipped with linear potentiometers. These sensors provide displacement data, enabling real-time force estimation using Hooke's Law. This subsystem is particularly important for testing planting suitability. To power the hydraulic actuation system, a standalone hydraulic power unit was selected over separate motor-pump-reservoir components. This integration simplifies fluid routing, reduces failure points, and maintains consistent pressure control during repeated testing. It also closely mimics the output behavior of the final system, allowing validation of planting motion and speed under realistic load conditions. All electronics, including the 12V battery, hydraulic controller, relays, and Arduino Mega 2560, are mounted to the conveyor surface. This arrangement supports easy access for troubleshooting. This design choice also reduces interference with the mechanical operation of the planting cycle and improves maintainability.

To facilitate demonstration and testing, the prototype is elevated on a wooden stand that ensures correct height alignment between the probing system and the soil. This stand enables reliable operation of both probing and planting subsystems and simulates field conditions by supporting real-time trials with compacted dirt. Positioning ensures that the full stroke of the hydraulic cylinders is used as intended. While scaled back in some non-essential areas, this prototype preserves all critical functionality and enables effective testing of subsystem interaction and mechanical integrity. The puck feeder, probing arm, and planting mechanism operate in coordinated cycles, enabling verification of sensor-actuator integration, motor timing, and real-world actuation forces. This provides a high level of confidence in the system's ability to meet design objectives in a full implementation. The selected prototyping approach is both cost-conscious and technically justified. It demonstrates originality in the use of a modular puck delivery system and mechanically calibrated probing unit—elements not observed in other automated reforestation systems. The structure and subsystem integration allow comprehensive testing of performance-critical functions, making this a high-confidence platform for validating the design.

Prototype Testing and Evaluation

Our testing strategy aimed to validate the functionality of each subsystem individually, followed by integrated testing of the full system. For each test, we defined a specific goal, designed a method with measurable outcomes, and evaluated performance based on whether it met design constraints.

Force Test

Purpose: Determine the range of force required to insert a sapling into soil and verify the planting system is structurally capable.

Hypothesis: Insertion force will fall between 20-100kg depending on soil type. System must withstand peak values.

Method: Used a load cell to measure force required to push a sapling into different soil conditions (loose, moist, compact).

Result: Recorded forces ranged from 23 kg in loose soil to 70kg in compacted soil.

Conclusion: Based on results, and using a factor of safety of 1.33, we designed the planting subsystem to withstand up to 100kg of force to include a safety margin to validate the actuator sizing and material selection.

Feeding Test

Purpose: Assess functionality of the sapling delivery subsystem and verify that pucks can reliably move saplings along the track

Hypothesis: Pucks will move smoothly among the track without jamming or slippage

Method: A scaled-down prototype was built using a simplified track and manual motor actuation. Multiple saplings were loaded into packs and moved forward manually and with intermittent motor control.

Result: The system successfully demonstrated that pucks could move forward reliably and deliver saplings. However, due to limited access to wire-forming tools and precision manufacturing, we could not achieve a fully continuous, motor-driven conveyor in this iteration.

Conclusion: While the feeding system was not fully automated, the scaled prototype validated the concept. With proper manufacturing tolerances and motor placement, continuous feeding is feasible and aligned with our final design intent.


Figure 36: Feed System Testing

Sensing Test

Purpose: Confirm that the sensing probe can withstand up to 100kg of force and that force data can be reliably captured using a spring and linear potentiometer.

Hypothesis: The sensing-probe system will survive high loading and provide measurable displacement data proportional to applied force.

Method: Applied increasing loads to the spring-loaded probe while recording displacement using the linear potentiometer. Compared results to theoretical spring compression (Hooke's Law) to back-calculate force.

Result: The probe withstood forces to 100kg without damage. The potentiometer readings showed consistent, measurable deflection that aligned with expected spring behaviour.

Conclusion: The sensing subsystem is structurally sound and capable of capturing soil resistance data for obstacle detection and planting decisions.


Figure 37: Sensing Testing

Planting Test

Purpose: Test planting mechanism's ability to reach depth and release sapling within the desired cycle time.

Hypothesis: The mechanism will consistently plant saplings at 10-15cm depth within 15 seconds.

Method: Activated the hydraulic blade mechanism on the prototype and measured planting depth and timing over multiple cycles. Used ultrasonic proximity sensor for depth feedback and stopwatch for timing.

Result: Planting depth ranged from 10.2 to 11.8cm, and the full planting cycle averaged 14.5 seconds.

Conclusion: The system meets depth and timing requirements. The planting subsystem performs reliably and repeatedly under test conditions.

Figure 38: Planting Testing

Combined Test

Purpose: Test end-to-end integration of sensing, planting, and feeding subsystems.

Hypothesis: The full cycle will operate sequentially without subsystem conflict and complete a full planting operation.

Method: Ran the full prototype system in a controlled environment. Simulated a complete cycle from obstacle detection to sapling planting using scaled-down feeder and full-scale planting/sensing subsystems.

Result: The system successfully completed full cycles with correct sequencing of sensing, planting, and sapling delivery at an average time of 18 seconds overall. Minor misalignments in the feeder subsystem occurred due to limitations in track precision but did not affect planting.

Conclusion: The integrated system functions cohesively and demonstrates the feasibility of the full planting cycle. Refinements in feeder hardware would allow for continuous automated operation.

Prototype Modifications and Improvements

The feeding and dispensing system for the saplings was the subsystem that underwent the latest alterations. Earlier on in the project, it was confirmed that the planting would be completed via a 3-bladed planting mechanism and the probing would be completed via 5 sensors that penetrated the ground. On the other hand, after the first iterations, the dispensing system was to be completed via a rail-and-gantry system. As the rail-guided puck system was developed later, it was only natural that adjustments were necessary to be made after observing its function when producing the prototype. For example, the radii in the bends within the rail system was increased; regardless of all efforts to reduce the friction within the system, the open-bottomed pucks' friction against the surface still contributed significant resistance when operating together. Increasing the radii of the bends allowed for less resistance for the pucks in those locations and imparted less resistance for the motors to overcome in shuffling them against one another.

Regarding the planting subsystem, initial testing revealed that the wooden structure of the prototype was too weak to properly absorb the impulse and force of the fast-acting opening operation of the smaller hydraulic cylinder. Resultantly, extra supports were added involving gussets and additional beams to mimic the behaviour expected of the metal frame/structure of the final product. In doing so, this better allowed the prototype to act as a testing mechanism to validate the capability of the final product to handle the expected forces, instead of a prototype that was simply to show the function of the device. Another alteration that was made immediately upon construction of the prototype was that a limit switch was implemented at the bottom of the smaller hydraulic cylinder to adjust its maximum stroke to 14mm (the cylinder's stroke is 4in, or 106mm). In the original design, pre-prototype, the team thought that this action could be easily controlled through proper timing in the code. Instead, however, it became evident that the cylinder was so fast acting that it was overshooting the expected travel and causing damage to the prototype. The limit switch allowed for quicker and more appropriate action to occur in stopping its travel at the proper time and position.

An important aspect to note is that the team underestimated the impact of not choosing proper materials for the prototype in efforts to reduce the cost of prototyping. While crucial subsystems were composed of proper materials, the frame of the prototype was comprised of wood as the team constructed it from readily available materials. Expanding upon the issues yielded by the smaller cylinder, the set screw that held it in an angled position failed when the maximum forces of the system were imparted upon it, and undesirable rotational movement began to occur. In response to this occurrence, an additional beam to support the maximum operational load was added which did indeed prevent undesirable torque/moments from occurring in the subsystem. As has been aforementioned, this was a downfall in the team's prototype; a metal frame structure would support this load, without undesired twisting, and also well within a proper Factor of Safety. This is what the Final Product's frame design consists of, and these undesired effects of the wood in the prototype further confirm the steel material choice.

Upon initial testing of the hydraulic system in completing the necessary actuation, it was evident that the smaller cylinder was operating too fast. There were many iterations made that led to the final design and operation of the hydraulic system as this was a new field to all of the team members involved. With the implementation of the limit switch, the cylinder was originally acting too fast that it was not properly detecting the actuation and stopping it in time. This led to the introduction of a flow control valve that slowed the introduction of hydraulic fluid into the cylinder and, hence, allowed time for the limit switch to properly be triggered and stop its motion.

One of the latest alterations introduced into the Final Project was extra supporting members that relieved force from the servo motors that actuate the sensing mechanism in a 90-degree rotation to allow the planting action to occur. Additionally, an unplanned modification made while midway through the construction of the prototype was the positioning of the locking mechanism. As per the original design, the locking mechanism was located underneath the servo motors, as the goal was for everything to be positioned in an organized, visually-appealing vertical manner. It was quickly realized, however, that this positioning of the locking mechanism interfered with the planting mechanism and did not allow it to execute its function properly. This prompted a redesign of the locking mechanism that consisted of a 90-degree rotation to now be located beside the servo motors. The figure below depicts the altered position of the locking mechanism on the prototype. The most visible items in the foreground are the linear actuator and its housing (the metal rod on the right/black box on the left), which are linked to the actual locking pin via the black cross-member on the right side facing along the axis into the page. The servo motor is housed within the wooden frame on the left side, easiest found by tracing where the white wire leads to.

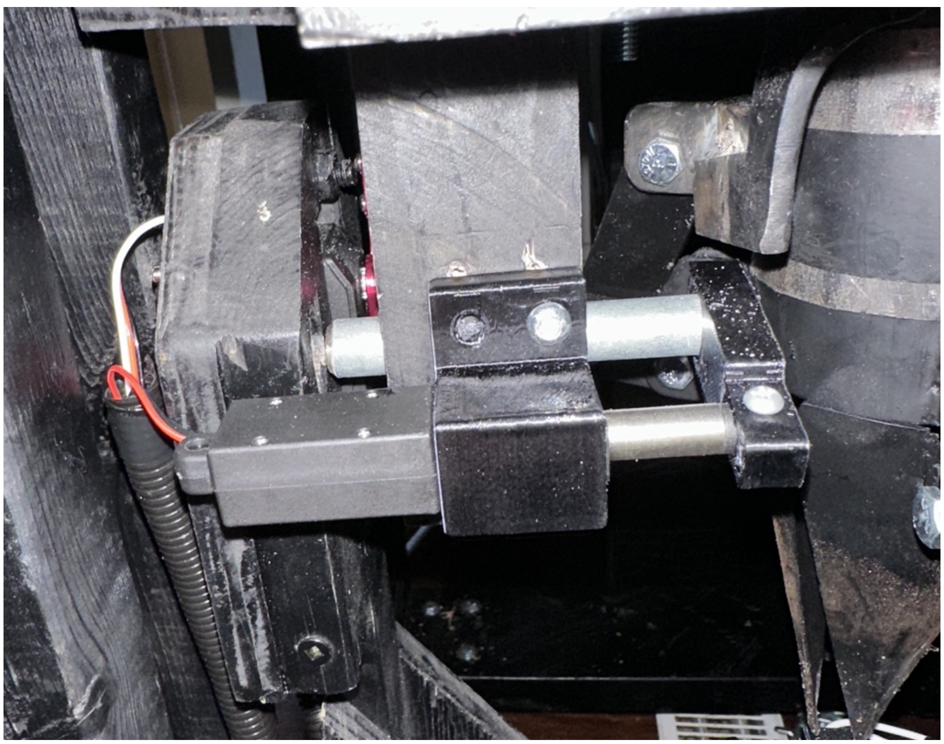


Figure 39: Image of one servo motor taken with the locking mechanism in the foreground

An unanticipated incident actually validated the proper operation, locking function, and stress tolerance of the locking mechanism. Late one evening while completing testing on the prototype, the hydraulic cylinder began actuating and malfunctioned by continuing to extend past the distance indicated in the code. This caused the sensing probes to penetrate the floor and one side of the prototype began to completely raise itself up off the ground. Once the Arduino was unplugged from the computer this actuation stopped, and the cylinder was promptly retracted. No major damages occurred to any of the subsystems and the locking mechanism held the sensing subsystem completely vertical without any significant strain. As the prototype weighs approximately 70kg, this event would have imparted approximately 13.65MPa of axial stress upon the sensing probes which translates to 2.73MPa per probe. This resultant axial stress value is roughly two orders of magnitude lesser than the yield strength of the sensors' material and, as such, allows much confidence in the strength of the sensors and the function of the locking mechanism. It is worth noting that the weight of the final product will be significantly higher, with the entire mechanism being four times the size of the prototype and its material being twice as heavy with no wooden components (i.e. an expected weight of 315kg, not considering the weight of the trailer/implement/vehicle/etc. that the mechanism traverses upon). This extremely high Factor of Safety also provides assurance that even if additional forces/stresses contribute to the maximum stress on the probes/locks, and considering the weight of the final product, these components will not fail.

All conclusions reached in terms of the prototype's projected function were framed in the context of prior knowledge relating to the project, as well as general Engineering practice. For example, the function was quickly refined to be solely focused upon the operation of planting saplings. This decision was made based on the team members' experiences in prior engineering projects in both previous courses and internships; it is always more beneficial to hone the project scope and create a well-refined, reliable system rather than developing a greater encompassing device that does not execute its core functions properly. With the focus solely upon the planting mechanism, the team was able to produce a modular mechanism that can be integrated onto a traversal system with optimized planting capabilities. Furthermore, prior knowledge and research completed highlighted that prior attempts to creating tree-planting devices often resulted in large, bulky vehicles that are quite specific to the terrain operated in and the application they were developed for. In this project, a lighter-weight, adaptable mechanism was produced that can be operated autonomously or in conjunction with a vehicle in a wide variety of terrains. In the earlier months of the project, the final product was designed to plant seeds and the planting mechanism was becoming quite complex and contrived. After a Design Review and completing research on tree-planting operations, it was realized that the project function should be modelled with the goal of achieving the same operation as manual methods, but in an automatic fashion. This prompted the team to design the final product to plant saplings (as this is done by manual tree-planters due to increased survival rates), as well as to model the planting subsystem after the implements used by tree-planters. *Figures #12* & *#13* depict a tool operated manually by tree-planters and the planter of the prototype to indicate how the design was encouraged by current manual methods.

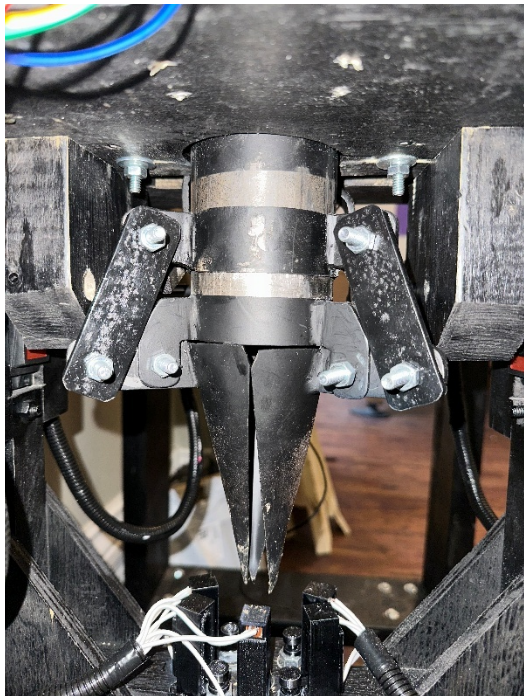


Figure 40: Close-up view of planter component of planting subsystem

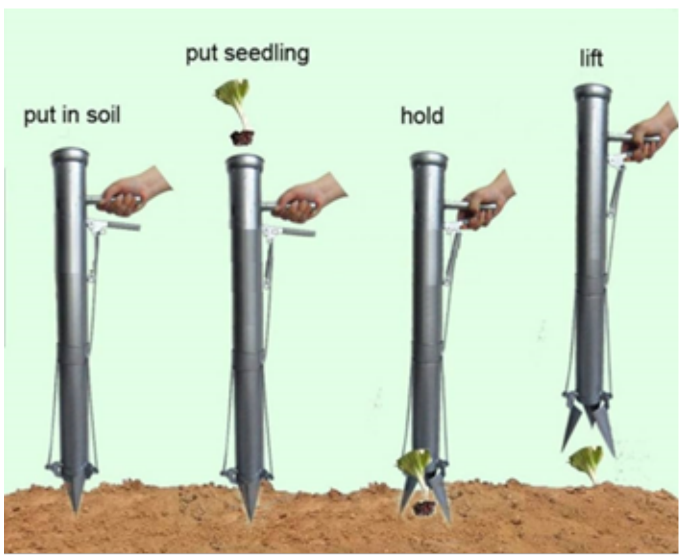


Figure 41: Seedling Planting Tool

Through completing the prototype and finalizing the design for the final product, recommendations for future work were developed. The foremost item is that the final product should be reintegrated with a vehicle capable of traversal, navigation & position sensing, in order to achieve the originally desired full autonomy. This could be done by the team if the project were continued, or in conjunction with another engineering team responsible for developing as advanced of a traversal/navigation system as the planting system is. Additionally, since the prototype continued to be refined after the Showcase Presentation, the next step for validation and analysis would be to conduct field testing with it. This would simulate the final product’s projected function and also allow for observation of the survival/growth rates of saplings planted by the device. Finally, with a refined final product, cost optimization could be crucial to allowing more affordability and access of the device. With the projected function having the potential to combat reforestation and climate change reversal efforts, a more accessible final product would allow it to be utilized by more developing countries and those in underprivileged/impoverished communities.

The conveyor system did not perform as planned with the resources we had. Further prototyping with high precision tools and machining would allow for this concept to be further tested and validated. Other alternatives would be the original proposed gantry system or an already existing, reliable track conveyor system with a latch door. Unfortunately, these solutions have a much higher cost, which is why we were not able to implement these in our prototype and decided to attempt this new conveyor design concept. Besides the actual movement of the pucks all other software and electrical components of the feeder subsystem worked as anticipated.

Overall, for the rest of the system the team was very impressed with the results as it performed its projected function according to the objectives and constraints as anticipated. The only discrepancy being that the tree is planted in 20 seconds rather than 15 seconds due to the flow rate of the prototype’s power unit being smaller than that of the actual power unit in the design because of cost. Therefore, with the other power unit it would most likely be faster than 15 seconds. To further optimize the time, the software could be adjusted to have the closing function and sensor removal, and return occur simultaneously with the raising and lowering of the planting system.

Resources and budget

The project team strategically leveraged a diverse set of technical skills to meet the engineering and fabrication requirements of both the prototype and full-scale design. Each member contributed specific expertise that eliminated the need for external contracting or consulting. Thorben led the CAD modeling and automation aspects, drawing on experience from industrial design internships and past work involving actuator selection, feeder mechanisms, and electrical schematics. Ryan provided additional strength in CAD and programming, along with design-for-manufacture knowledge gained through mechanical drafting experience in SolidWorks and AutoCAD. Matt offered hands-on fabrication and practical mechanical insight, gained from his work in farming and plumbing trades, as well as exposure to automated manufacturing techniques through a specialized engineering course in Germany. Josh contributed heavily to the structural and FEA simulations and also led the scheduling and project management efforts, ensuring adherence to deliverables and deadlines.

Material and Equipment Access

A combination of personal resources and outsourced work supported the design and construction phases. Our personal resources allowed for 3D printing basic machining, which allowed the team to fabricate components efficiently. Additionally, personal workshops and tools were used to build the physical prototype, minimizing costs. Component sourcing was carried out through Digikey and Amazon as they offer short lead times.

Prototype Budget

The total cost of the prototype system came to approximately $3,082.19 CAD. This budget includes the hydraulic power unit, large and small hydraulic cylinders, eight DC gear motors, servo motors, Arduino Mega 2560, and linear actuators. Structural materials for the frame and feeder track, such as 2x4s, plywood, and ABS pipe, were also included. Passive electrical components such as MOSFETs, diodes, transistors, and limit switches were purchased in bulk to reduce cost and ensure redundancy during assembly. Every line item was costed from publicly available sources and cross-referenced for quality and price competitiveness.

	Item	Link	Quantity	Price Per Unit	Total
1	Buck Converter	https://www.a	1	$ 2.41	$2.41
2	DC Gear Motor	https://www.a	8	$ 19.28	$154.24
3	IRLZ44N MOSFET	https://www.a	10	$ 2.10	$21.00
4	1N5819 Shottcky	https://www.a	10	$ 0.22	$2.20
5	1N4007 Diode	https://www.a	10	$ 0.08	$0.84
6	2N2222A Transistor	https://www.a	4	$ 0.26	$1.04
7	8 Channel Relay Module	https://www.a	1	$ 13.99	$13.99
8	Servo Motors	https://www.a	2	$ 48.98	$97.96
9	Linear Actuator	https://www.a	2	$ 27.95	$55.90
10	Limit Switches	https://www.a	1	$ 2.14	$2.14
11	Ultrasonic Sensor	https://www.a	1	$ 6.40	$6.40
12	Slide Potentiometer	https://www.a	5	$ 2.92	$14.60
13	Springs	https://www.r	2	$ 14.97	$29.94
14	Prototype Board	https://www.a	1	$ 13.98	$13.98
15	1N5822 Schottcky	https://www.a	5	$ 0.49	$2.45
16	8 ft Pine 2x4	https://www.l	5	$ 3.98	$19.90
17	12 ft ABS Pipe	https://www.l	1	$ 28.98	$28.98
18	2x4 ft Hardboard	https://www.l	1	$ 11.48	$11.48
19	2x4 ft Plywood	https://www.l	1	$ 31.71	$31.71
20	8 ft Pine 2x2	https://www.l	1	$ 3.87	$3.87
21	8 ft Pine 1x2	https://www.l	1	$ 1.96	$1.96
22	Arduino Mega 2560	https://www.a	1	$ 27.95	$27.95
23	12v Car Battery	https://www.a	1	$ 144.99	$144.99
24	Hydraulic Power Unit	https://www.p	1	$ 499.99	$499.99
25	Large Hydraulic Cylinder	https://www.p	1	$ 184.99	$184.99
26	Small Hydraulic Cylinder	https://www.p	1	$ 119.99	$119.99
27	Directional Valves	https://www.p	2	$ 129.99	$259.98
28	4 ft 3/8" Hydraulic Lines	https://www.p	2	$ 22.99	$45.98
29	6 ft 3/8" Hydraulic lines	https://www.p	2	$ 26.99	$53.98
30	Hydraulic Fluid	https://www.a	1	$ 39.99	$39.99
31	Flow Control Valve	https://www.p	1	$ 59.99	$59.99
32	Fuse Block	https://www.p	1	$ 32.99	$32.99
33	Fuses	https://www.p	1	$ 11.99	$11.99
34	25 ft 16 AWG Wire	https://www.a	1	$ 14.99	$14.99
35	25 ft 18 AWG Wire	https://www.a	2	$ 11.99	$23.98
36	100 ft 20 AWG Wire	https://www.a	1	$ 29.99	$29.99
37	25 ft 20 AWG Wire	https://www.a	2	$ 8.99	$17.98
38	Hydraulic Hose Fittings	https://www.p	8	$ 3.99	$31.92
39	Caster Wheels	https://www.l	4	$ 10.84	$43.36
40	Hydraulic Manifold Block	https://www.p	2	54.99	$109.98
41	E-stop	https://www.p	1	13.99	$13.99
42	Start Button	https://www.p	1	11.99	$11.99
43	Bar Stock Steel	https://www.l	3	11.16	$33.48
44	3" Tube Steel	https://www.r	1	22.95	$22.95
45	1/2" x 8" Bolt	https://www.l	1	7.02	$7.02
46	3/4" x 6" Bolt	https://www.p	1	7.99	$7.99
47	Battery Cables	https://www.a	2	19.99	$39.98
48	Steel Wire	https://www.l	1	9.87	$9.87
49	1 kg 3D Printer Filament	https://www.a	1	23.99	$23.99
50	Ring Terminals	https://www.p	1	6.99	$6.99
51	Butt Connector	https://www.p	3	5.99	$17.97
Tax (Esitmated)					$306.99
TOTAL					$3,082.19

Figure 42: Prototype Budget

The prototype was selectively simplified to focus on validating the system's core functional elements: sapling planting, obstruction sensing, and hydraulic actuation. For example, while the final design features a precision-machined metal track, the prototype used 3D-printed components and off-the-shelf pipe to create a cost-effective stand-in. This allowed the team to demonstrate and calibrate the puck feeding mechanism while managing material expenses. Despite these simplifications, the prototype accurately reflects the final design's geometry and control behavior, making it an effective tool for system validation.

Full-Scale System Budget Considerations

Scaling the design to field-ready deployment would require refinements in materials and manufacturing techniques. Instead of the wooden frame used in the prototype, the final system would employ a welded or bolted metal chassis to support sustained hydraulic loads and field transport. The feeder track would be constructed using wire-formed steel, with CNC-machined motor mounts and injection-molded pucks to ensure mechanical precision and repeatability. Pneumatic rubber tires would replace 3D-printed inserts to provide consistent traction, and molded parts would eliminate tolerance issues inherent in additive manufacturing.

	Item	Link	Quantity	Price Per Uni	Total
1	Buck Converter	https://www.a	1	$ 2.41	$2.41
2	DC Gear Motor	https://www.d	8	$ 19.28	$154.24
3	IRLZ44N MOSFET	https://www.d	10	$ 2.10	$21.00
4	1N5819 Shottcky	https://www.d	10	$ 0.22	$2.20
5	1N4007 Diode	https://www.d	10	$ 0.08	$0.84
6	2N2222A Transistor	https://www.d	4	$ 0.26	$1.04
7	8 Channel Relay Module	https://www.a	1	$ 13.99	$13.99
8	Servo Motors	https://www.a	2	$ 48.98	$97.96
9	Linear Actuator	https://www.a	2	$ 27.95	$55.90
10	Limit Switches	https://www.d	1	$ 2.14	$2.14
11	Ultrasonic Sensor	https://www.d	1	$ 6.40	$6.40
12	Slide Potentiometer	https://www.d	5	$ 2.92	$14.60
13	Springs	https://www.n	2	$ 14.97	$29.94
14	Prototype Board	https://www.a	1	$ 13.98	$13.98
15	1N5822 Schottcky	https://www.d	5	$ 0.49	$2.45
16	Mild Steel Rectangular Tube	https://www.n	1	$ 416.68	$416.68
17	12 ft ABS Pipe	https://www.n	1	$ 62.18	$62.18
18	4x8 ft HDPE	https://plasticv	1	$ 197.00	$197.00
19	4x8 ft Sheet Steel	https://www.n	1	$ 433.75	$433.75
20	8 ft Steel 2x2	https://www.n	1	$ 69.19	$69.19
21	8 ft Steel 1x2	https://www.h	1	$ 62.18	$62.18
22	Arduino Mega 2560	https://www.a	1	$ 27.95	$27.95
23	12v Car Battery	https://www.c	1	$ 144.99	$144.99
24	Hydraulic Power Unit	https://www.p	1	$ 499.99	$499.99
25	Large Hydraulic Cylinder	https://www.p	1	$ 184.99	$184.99
26	Small Hydraulic Cylinder	https://www.p	1	$ 119.99	$119.99
27	Directional Valves	https://www.p	2	$ 129.99	$259.98
28	4 ft 3/8" Hydraulic Lines	https://www.p	2	$ 22.99	$45.98
29	6 ft 3/8" Hydraulic lines	https://www.p	2	$ 26.99	$53.98
30	Hydraulic Fluid	https://www.c	1	$ 39.99	$39.99
31	Flow Control Valve	https://www.p	1	$ 59.99	$59.99
32	Fuse Block	https://www.p	1	$ 32.99	$32.99
33	Fuses	https://www.p	1	$ 11.99	$11.99
34	25 ft 16 AWG Wire	https://www.c	1	$ 14.99	$14.99
35	25 ft 18 AWG Wire	https://www.c	2	$ 11.99	$23.98
36	100 ft 20 AWG Wire	https://www.c	1	$ 29.99	$29.99
37	25 ft 20 AWG Wire	https://www.c	2	$ 8.99	$17.98
38	Hydraulic Hose Fittings	https://www.p	8	$ 3.99	$31.92
39	Caster Wheels	https://www.h	4	$ 10.84	$43.36
40	Hydraulic Manifold Block	https://www.p	2	$ 54.99	$109.98
41	E-stop	https://www.p	1	$ 13.99	$13.99
42	Start Button	https://www.p	1	$ 11.99	$11.99
43	Bar Stock Steel	https://www.h	3	$ 11.16	$33.48
44	3" Tube Steel	https://www.n	1	$ 22.95	$22.95
45	1/2" x 8" Bolt	https://www.h	1	$ 7.02	$7.02
46	3/4" x 6" Bolt	https://www.p	1	$ 7.99	$7.99
47	Battery Cables	https://www.c	2	$ 19.99	$39.98
48	Steel Wire	https://www.h	1	$ 9.87	$9.87
49	1 kg 3D Printer Filament	https://www.a	1	$ 23.99	$23.99
50	Ring Terminals	https://www.p	1	$ 6.99	$6.99
51	Butt Connector	https://www.p	3	$ 5.99	$17.97
52	Solidworks License	https://www.s	2	$ 4,917.37	$9,834.74
53	Microsoft 365 Subscription	https://www.n	4	$ 115.00	$460.00
54	Labour	4 x $35/hr	32	$ 5,600.00	$179,200.00
Tax (Esitmated)					$455.59
TOTAL					$194,017.21

Figure 43: Full Scale Budget

Although the exact cost of the full-scale system would depend on batch size and fabrication method, the team has outlined all necessary upgrades and estimated their feasibility. With a larger budget, all components would be made from their specified design materials, enabling long-term testing and field trials. These improvements are based on standard industry practices and are supported by engineering analysis conducted throughout the design process.

Conclusions

The Electric Autonomous Tree Planter complete as this year's Capstone project achieved its primary goal of developing a functional and reliable system capable of automating the sapling planting process. Through a focused design scope, the team successfully created and validated key subsystems including a puck-based sapling delivery conveyor, a hydraulic planting mechanism, and a ground-sensing probe. The prototype demonstrated the ability to complete a full planting cycle within the target timeframe and under realistic conditions, meeting most of the defined design constraints.

A major milestone was the validation of the planting mechanism's structural strength and soil penetration capability using FEA and experimental testing. The analog sensing approach using spring-loaded probes and linear potentiometers also proved effective in detecting unplantable ground. The team overcame challenges related to fabrication limitations by adapting materials and implementing design refinements throughout the prototyping phase. These adaptations confirmed the mechanical viability of the design and provided critical insight into future iterations.

Overall, the project demonstrated the feasibility of a modular, semi-autonomous planting system that can reduce the physical demands of reforestation work while improving consistency and efficiency. The experience also underscored the importance of system integration, calibration, and iterative development in addressing complex, multidisciplinary engineering challenges.

Recommendations

Based on the design, validation, and prototyping phases of the sapling planting system, several key recommendations are offered to guide future engineering teams pursuing comparable projects. These recommendations are grounded in the team's experience with functional integration, performance optimization, and real-world constraints encountered throughout the design process.

Optimize and Synchronize Subsystem Motion to Increase Throughput

One of the most impactful improvements to enhance planting rate is optimizing the timing between sensing, planting, and sapling delivery motions. While the current system completes a planting cycle in approximately 15 seconds, a more tightly synchronized sequence could significantly reduce downtime between operations. Using sensor feedback and hydraulic flow regulation to eliminate unnecessary wait states can meaningfully improve cycle time without requiring changes to hardware.

Use Saplings with Plug Root Systems

The design is highly dependent on the compatibility of the sapling's root structure with the planting mechanism. It is strongly recommended that plug-type saplings be used, as they ensure uniformity in shape and size, which aligns with the constraints of automated handling and consistent soil contact. Bare-root or irregular saplings increase the risk of jamming during delivery or poor soil integration after planting. Engineering teams should ensure that the system design—including puck geometry and spade dimensions—is specifically tailored to the dimensions of standard plug trays used in nurseries.

Avoid Overcomplication of Delivery Systems

While initial concepts such as gantry-mounted grippers offer high degrees of control, they are vulnerable to outdoor contamination and increase mechanical complexity. The puck-based drag conveyor proved to be a more robust and scalable solution, especially for harsh terrain. Future teams should consider simple, modular, and dirt-resistant delivery methods that can operate continuously and tolerate variability in field conditions.

While initial concepts such as gantry-mounted grippers offer high degrees of control, they are vulnerable to outdoor contamination and increase mechanical complexity. The puck-based conveyor proved to be a more robust and scalable solution, especially for harsh terrain. Future teams should consider simple, modular, and dirt-resistant delivery methods that can operate continuously and tolerate variability in field conditions.

Prioritize Modularity and Maintainability

Subsystems such as the planter, feeder, and sensing probe should be modular in design, allowing for independent servicing, replacement, or upgrading. In the prototype phase, this approach was critical for troubleshooting and allowed iterative changes without affecting the entire system. Final designs should continue this approach to simplify assembly, improve reliability, and reduce downtime during operation.

Incorporate Lifecycle Durability in Component Selection

While 3D-printed and wood-based components were effective for the prototype, any future build intended for long-term field deployment should use fatigue-resistant materials like stainless or alloy steel for high-stress components, and molded rubber or polyurethane for moving mechanical interfaces. Material upgrades will reduce mechanical wear, resist environmental degradation, and enable continuous operation across planting seasons.

References

[1] Sawyer, "“For The Sake of Sustainability: A Closer Look at Canadian Treeplanting,”," sawyer.com, November 2024. [Online]. Available: https://www.sawyer.com/blog/confessions-of-a-canadian-treeplanter?utm_source=chatgpt.com. [Accessed 4 April 2025].

[2] Wise, "“Indian Rupees to Canadian Dollars Exchange Rate. Convert INR/CAD - Wise.”," [Online]. Available: https://wise.com/gb/currency-converter/inr-to-cad-rate. [Accessed 4 April 2025].

[3] Glassdoor, "Tree Planter," 2025. [Online]. Available: www.glassdoor.co.in/Salaries/tree-planter-salary-SRCH_KO0%2C12.htm?utm_source=chatgpt.com. . [Accessed 3 April 2025].

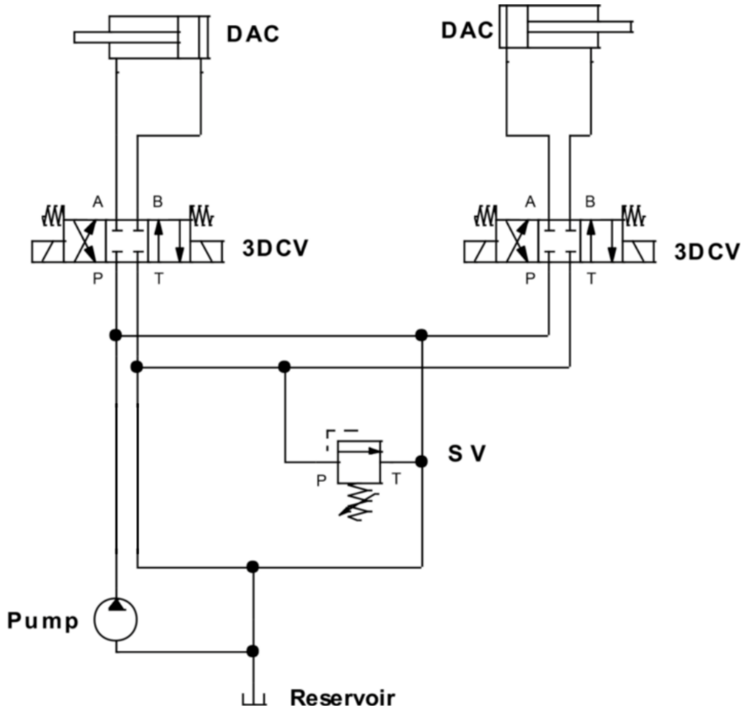
[4] E. Abolfazl and M. Eslami, Piezocone and Cone Penetration Test (CPTu and CPT) Applications in Foundation Engineering, Amsterdam: Elsevier Ltd., 2019.

[5] Beggeman, "Cone penetration resistance of calcareous sand - Scientific Figure on ResearchGate.," [Online]. Available: https://www.researchgate.net/figure/Suggested-values-of-friction-ratios-for-different-soil-types-Begemman-1965_tbl1_225113489. [Accessed 27 February 2025].

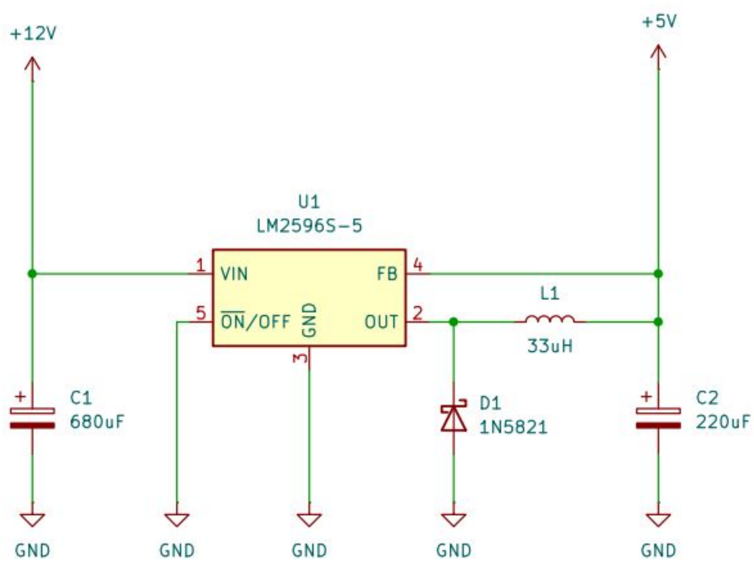
[6] E. Basiw, Methodology for Obtaining Optimal Sleeve Friction and Friction Ratio Estimates from CPT Data, Vancouver: Basiw Consulting Engineers, 2023.

[7] T. Balint, "The Hollow Test and the True Triaxial Test," [Online]. Available: http://gf.uns.ac.rs/~wus/wus07/web4/cpt.html. [Accessed 16 February 2025].

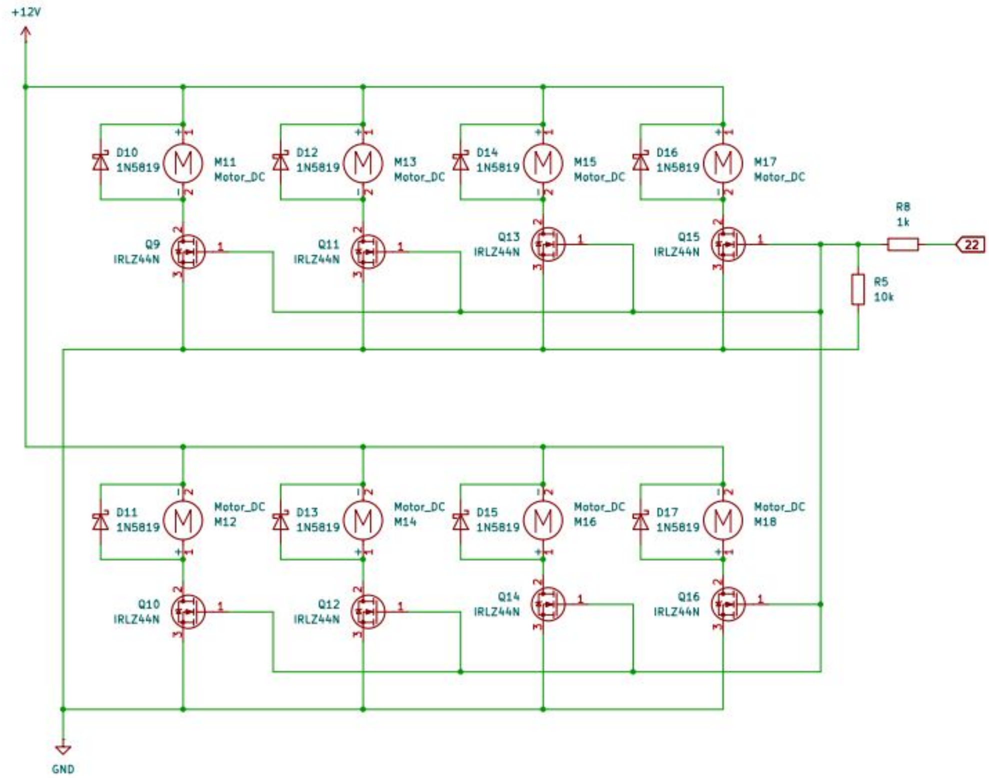
Appendix I – Hydraulic Schematic



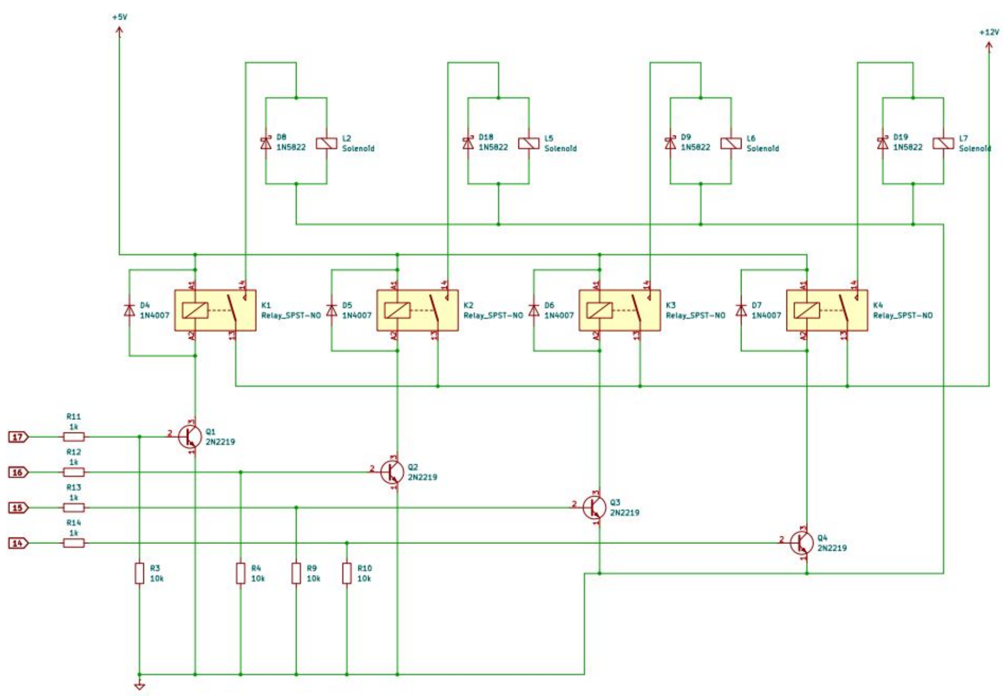
Appendix II – Electrical Schematics



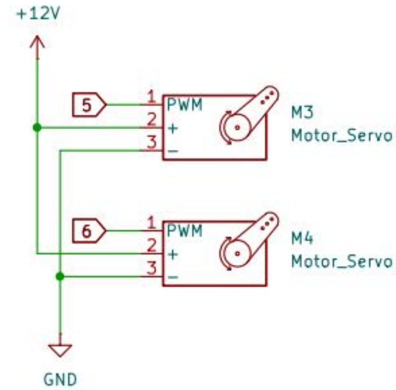
Buck Converter Schematic



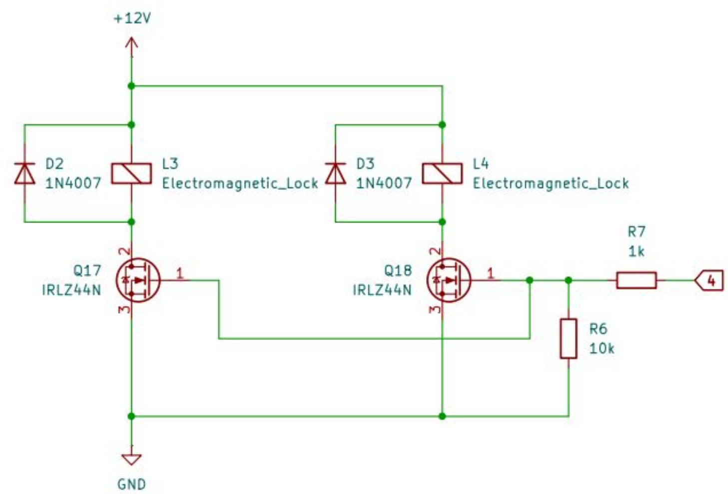
Feeder Motor Schematic



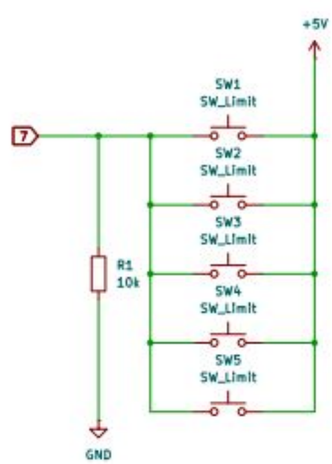
Solenoid and Relay Schematic



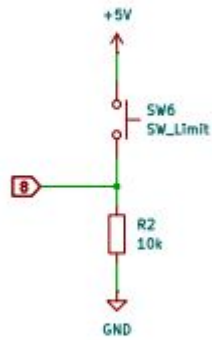
Servo Motor Schematic



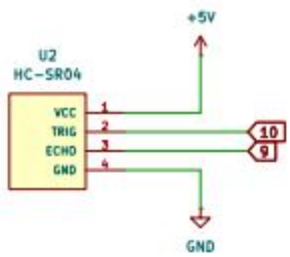
Locking Mechanism Schematic



Sensing Limit Switch Schematic



Conveyor Puck Limit Switch Schematic



Ultrasonic Sensor Schematic

Appendix III – Arduino Sketch

```
#include <Servo.h>

//Conveyor Motors
const int motorControl = 46;
const int PucklimitSwitch = 48; // Limit switch input
int puckSwitchState = LOW;

//Servo
const int servoRelay = 11;
Servo servo1;
Servo servo2;
// Starting angles (assumed midpoints)
int currentAngle1 = 87;
int currentAngle2 = 97;

//Linear Actuator
const int Lock1 = 12;
const int Lock2 = 13;

//Start Button
```

```
const int startButtonPin = 36;
bool startButtonState = false;

//Hydraulics
const int powerUnit = 10;
const int smalloneup = 7;   // Opening planting mechanism (extend)
const int smallonedown = 6; // Closing planting mechanism (retract)
const int bigonedown = 8;
const int bigoneup = 9;
const int Stroke = 5000;
const int limitSwitchPin = 5; // Limit switch input
int switchState;

//Proximity Sensor
const int trigPin = 28;
const int echoPin = 26;
const float sensDist = 40.0;

//Linear Potentiometers
const int potPins[5] = {A11, A12, A13, A14, A15}; //Analog input pins
int potValues[5]; //Array to hold potentiometer values
const int badPlantingValue = 50;

void setup() {
  Serial.begin(9600);
  //Conveyor Motors
  pinMode(motorControl, OUTPUT);
  digitalWrite(motorControl, HIGH);
  pinMode(PucklimitSwitch, OUTPUT);


  //Hydraulics
  pinMode(powerUnit, OUTPUT);
  pinMode(bigoneup, OUTPUT);
  pinMode(bigonedown, OUTPUT);
  pinMode(smalloneup, OUTPUT);
  pinMode(smallonedown, OUTPUT);

  digitalWrite(powerUnit, HIGH);
  digitalWrite(bigonedown, HIGH);
  digitalWrite(bigoneup, HIGH);
  digitalWrite(smallonedown, HIGH);
  digitalWrite(smalloneup, HIGH);

  pinMode(limitSwitchPin, INPUT);  // Assuming external pull-down or proper wiring
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
```

```
//Raise and close planter
digitalWrite(powerUnit, LOW);
digitalWrite(bigoneup, LOW);
digitalWrite(bigonedown, HIGH);
delay(Stroke);

digitalWrite(bigonedown, HIGH);
digitalWrite(bigoneup, HIGH);

digitalWrite(smalloneup, LOW);
digitalWrite(smallonedown, HIGH);
delay(2500);

digitalWrite(smalloneup, HIGH);
digitalWrite(smallonedown, LOW);

switchState = digitalRead(limitSwitchPin);
while (switchState == LOW) {
  switchState = digitalRead(limitSwitchPin);
}

digitalWrite(smallonedown, HIGH);
digitalWrite(smalloneup, HIGH);

digitalWrite(powerUnit, HIGH);

//SERVO
pinMode(servoRelay, OUTPUT);
servo1.attach(3);  // Control pin for servo 1
servo2.attach(4);  // Control pin for servo 2

delay(5000);                    // Delay to allow for setup time
digitalWrite(servoRelay, LOW);  // Enable power to servos

// Move to assumed starting position
servo1.write(currentAngle1);
servo2.write(currentAngle2);
delay(1000);
digitalWrite(servoRelay, HIGH);

//Linear Actuators
pinMode(Lock1, OUTPUT);
pinMode(Lock2, OUTPUT);

digitalWrite(Lock1, LOW);
digitalWrite(Lock2, LOW);
delay(1350);
digitalWrite(Lock1, HIGH);
```

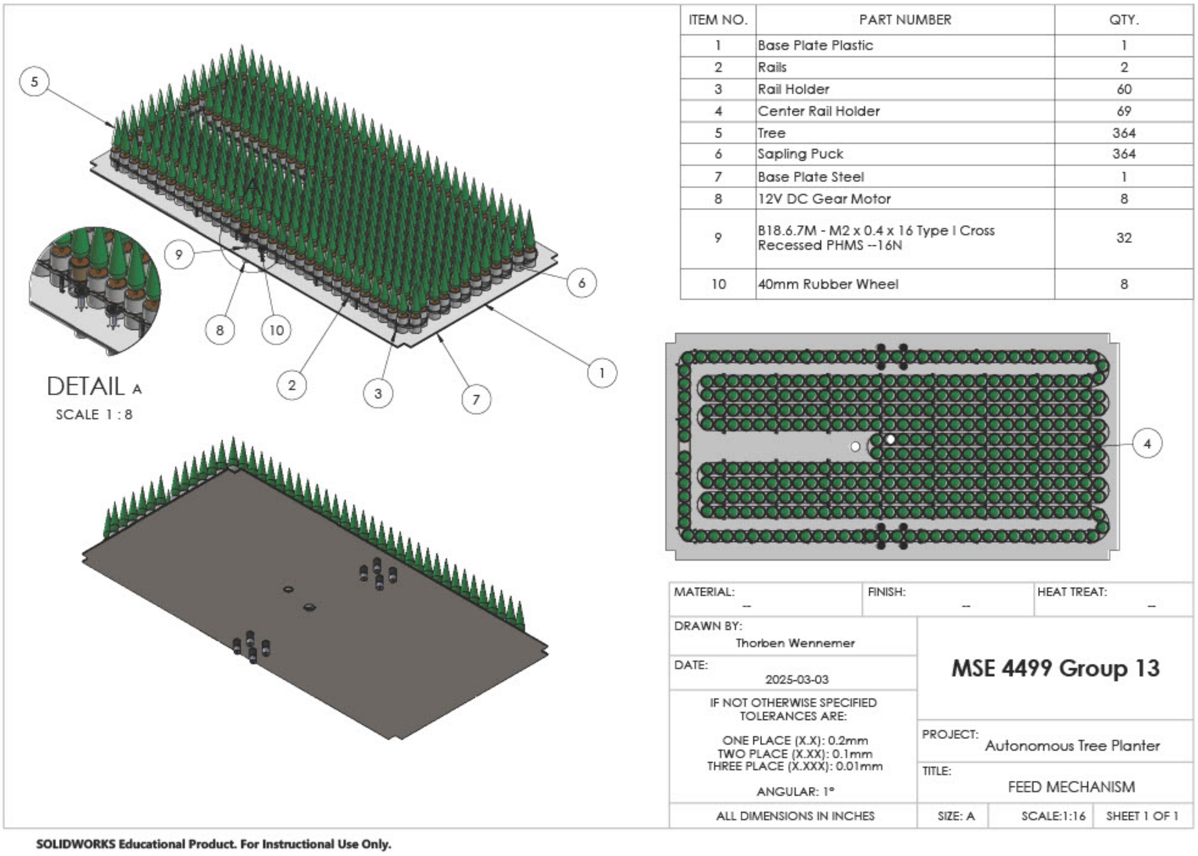
```
  digitalWrite(Lock2, LOW);

  Serial.println("Setup complete");

}

void loop() {
  int StartButton = digitalRead(startButtonPin);
  if(StartButton == HIGH)
    startButtonState = true;

  while(startButtonState){
    Serial.println("Start Button Pressed");

    //FEEDING
    digitalWrite(motorControl, HIGH);
    puckSwitchState = digitalRead(PucklimitSwitch);
    while (puckSwitchState == LOW) {
      puckSwitchState = digitalRead(PucklimitSwitch);
    }

    digitalWrite(motorControl, LOW);

    //SENSING
    //Lower Planter
    digitalWrite(powerUnit, LOW);
    digitalWrite(bigoneup, HIGH);
    digitalWrite(bigonedown, LOW);
    Serial.println("Lowering");

    long duration;
    float distanceCm = 100.0;
    int totalCompression = 0; //Distance closing
    Serial.println("Starting While loop");
    while (distanceCm > sensDist && totalCompression < badPlantingValue){

      //Distance to Ground
      digitalWrite(trigPin, LOW);
      delayMicroseconds(2);
      digitalWrite(trigPin, HIGH);
      delayMicroseconds(10);
      digitalWrite(trigPin, LOW);
      duration = pulseIn(echoPin, HIGH); //Read the echo time
      distanceCm = duration * 0.0343 / 2;

      //Force Calculation
      for (int i = 0; i < 5; i++) {
        potValues[i] = analogRead(potPins[i]);
```

```
      }
      totalCompression = (potValues[0] - 30) + (potValues[1]) + (potValues[2] - 18) +
(potValues[3]-22) + (potValues[4] - 18);

      Serial.print("Distance: ");
      Serial.print(distanceCm);
      Serial.print(" cm  total Compression");

      delay(200);
    }

    Serial.println("OUTSIDE LOOP");

    if (totalCompression > badPlantingValue) {
      digitalWrite(bigoneup, LOW);
      digitalWrite(bigonedown, HIGH);
      delay(5000);
      digitalWrite(bigoneup, HIGH);
      digitalWrite(bigonedown, HIGH);
      digitalWrite(powerUnit, HIGH);
      Serial.println("Bad Planting Spot");
      startButtonState = false;
      break;
    }

    Serial.println("Good Planting Spot");

    //Raise Planter
    digitalWrite(bigoneup, LOW);
    digitalWrite(bigonedown, HIGH);
    delay(3000);
    digitalWrite(bigoneup, HIGH);
    digitalWrite(bigonedown, HIGH);
    digitalWrite(powerUnit, HIGH);
    Serial.println("Planter Raised");


    //Unlock Sensor (Linear Atuators)
    digitalWrite(Lock1, LOW);
    digitalWrite(Lock2, LOW);
    delay(1350);
    Serial.println("Sensor Unlocked");
    digitalWrite(Lock1, HIGH);
    digitalWrite(Lock2, LOW);

    //Remove Sensor (Turn Servos)
    digitalWrite(servoRelay, LOW);
```

```
//Move servo1 +63°, servo2 -63°
for (int i = 0; i <= 67; i++) {
  servo1.write(currentAngle1 + i);  // Clockwise
  servo2.write(currentAngle2 - i);  // Counterclockwise

  Serial.print("Servo 1 Angle: ");
  Serial.print(currentAngle1 + i);
  Serial.print(" | Servo 2 Angle: ");
  Serial.println(currentAngle2 - i);

  delay(10);
}
Serial.println("Sensor Removed");


//PLANTING
//Lower Planter
digitalWrite(powerUnit, LOW);
digitalWrite(bigoneup, HIGH);
digitalWrite(bigonedown, LOW);
delay(Stroke);  //Change to sonar distance
digitalWrite(bigoneup, HIGH);
digitalWrite(bigonedown, HIGH);
digitalWrite(powerUnit, HIGH);

//Open Planter
digitalWrite(powerUnit, LOW);
digitalWrite(smalloneup, LOW);
digitalWrite(smallonedown, HIGH);
delay(2000);
digitalWrite(smalloneup, HIGH);
digitalWrite(smallonedown, HIGH);
digitalWrite(powerUnit, HIGH);

//Raise Planter
digitalWrite(powerUnit, LOW);
digitalWrite(bigoneup, LOW);
digitalWrite(bigonedown, HIGH);
delay(Stroke);
digitalWrite(bigoneup, HIGH);
digitalWrite(bigonedown, HIGH);
digitalWrite(powerUnit, HIGH);

//Close Planter
digitalWrite(powerUnit, LOW);
digitalWrite(smalloneup, HIGH);
digitalWrite(smallonedown, LOW);
```

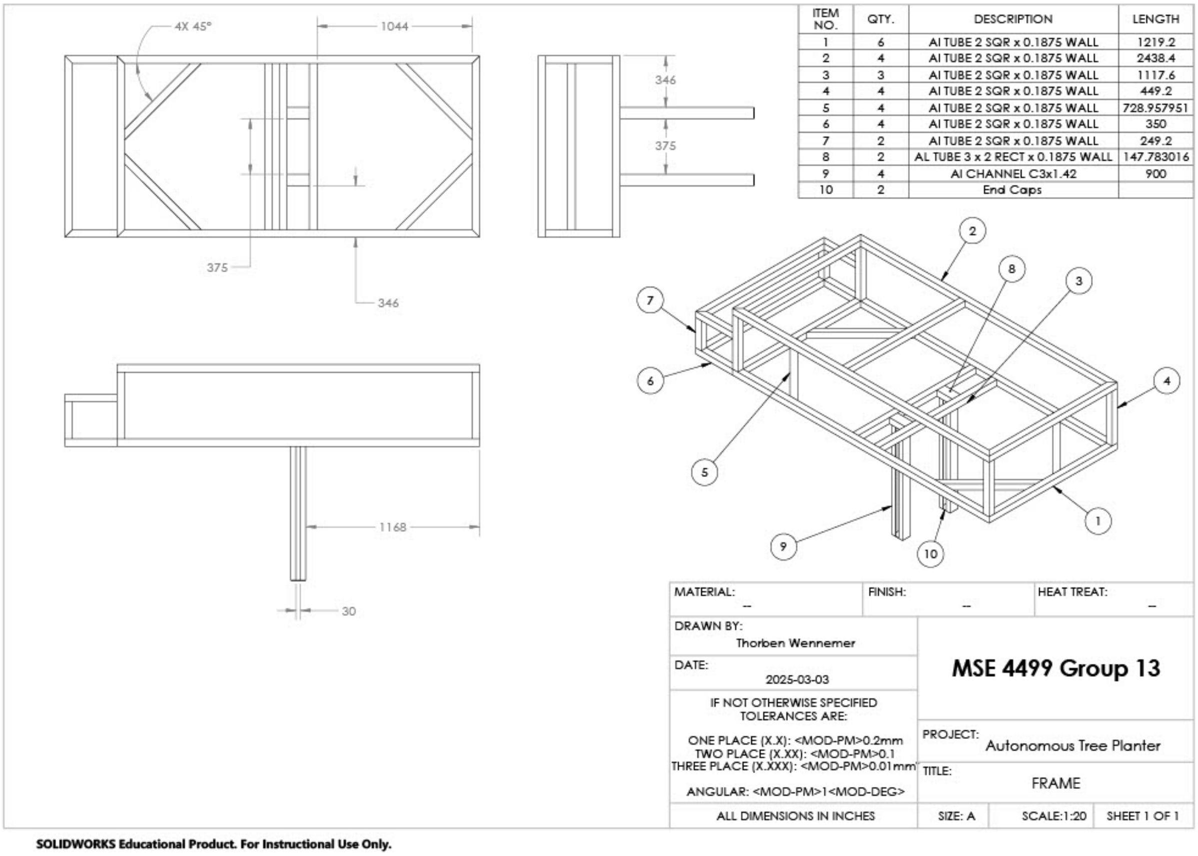
```
    switchState = digitalRead(limitSwitchPin);
    while (switchState == LOW) {
      switchState = digitalRead(limitSwitchPin);
    }

    digitalWrite(smalloneup, HIGH);
    digitalWrite(smallonedown, HIGH);
    digitalWrite(powerUnit, HIGH);

    // Return both servos to their original positions
    for (int i = 0; i <= 67; i++) {
      servo1.write(currentAngle1 + 67 - i);
      servo2.write(currentAngle2 - 67 + i);

      Serial.print("Servo 1 Angle: ");
      Serial.print(currentAngle1 + 67 - i);
      Serial.print(" | Servo 2 Angle: ");
      Serial.println(currentAngle2 - 67 + i);

      delay(10);
    }
    // Lock final positions (back at original)
    servo1.write(currentAngle1);
    servo2.write(currentAngle2);
    digitalWrite(servoRelay, HIGH);


    //Locking
    digitalWrite(Lock1, HIGH);
    digitalWrite(Lock2, HIGH);
    delay(1350);
    digitalWrite(Lock1, HIGH);
    digitalWrite(Lock2, LOW);

    startButtonState = false;

  }

  delay(1000);

}
```

Appendix IV – Engineering Drawings

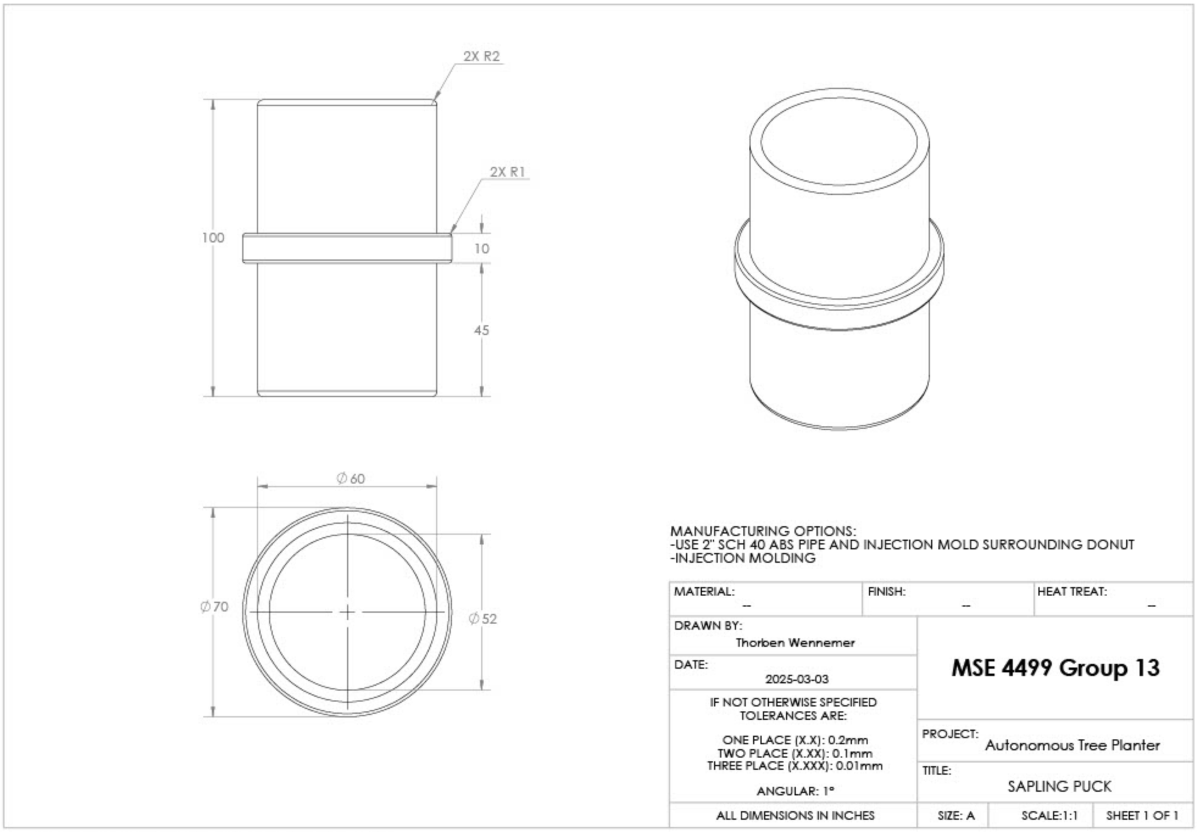


ITEM NO.	PART NUMBER	QTY.
1	Base Plate Plastic	1
2	Rails	2
3	Rail Holder	60
4	Center Rail Holder	69
5	Tree	364
6	Sapling Puck	364
7	Base Plate Steel	1
8	12V DC Gear Motor	8
9	B18.6.7M - M2 x 0.4 x 16 Type I Cross Recessed PHMS --16N	32
10	40mm Rubber Wheel	8

Feeder Subsystem

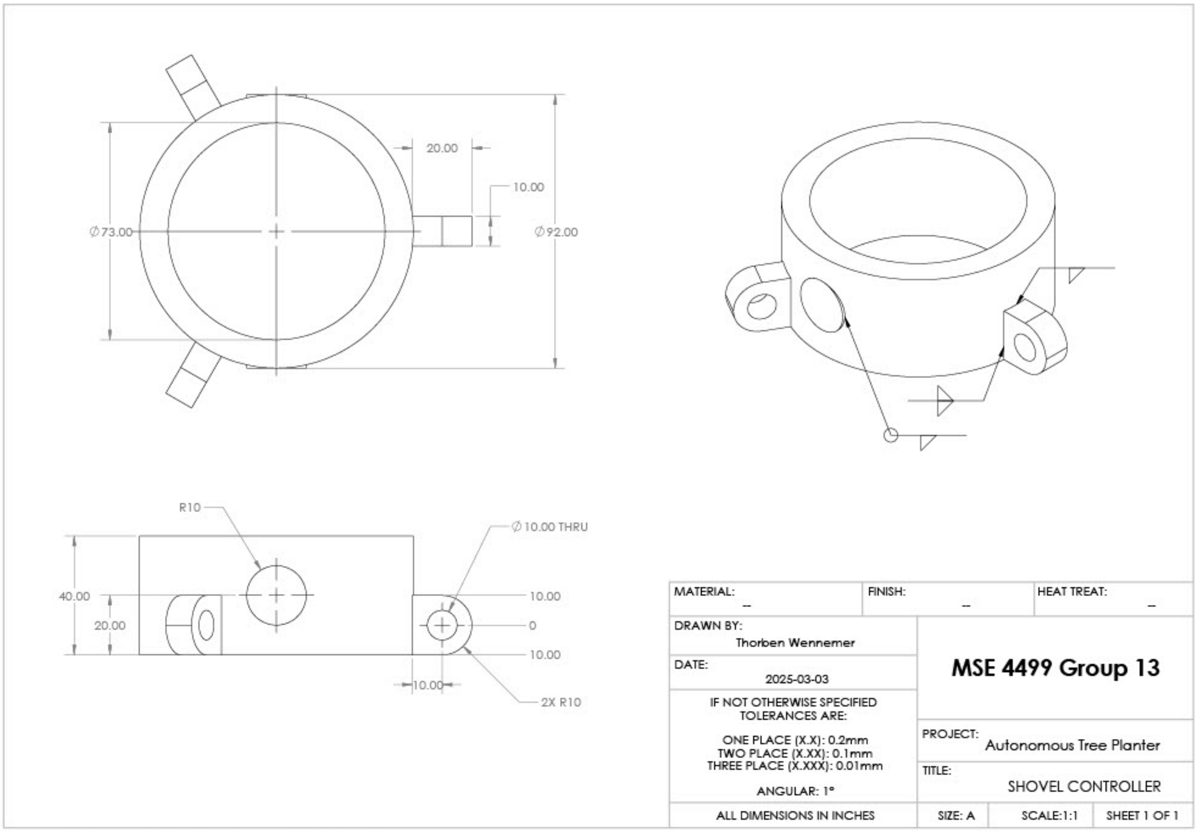


Complete Frame



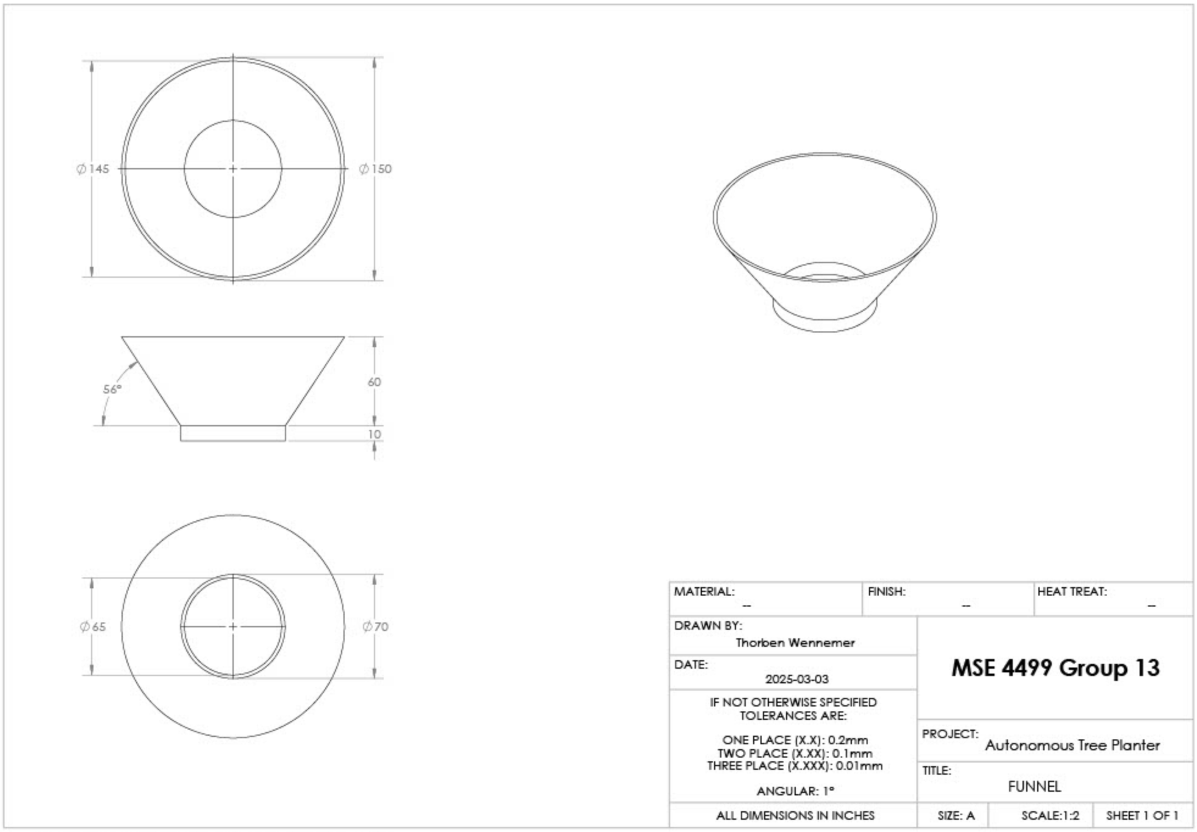
SOLIDWORKS Educational Product. For Instructional Use Only.

Conveyor Pucks



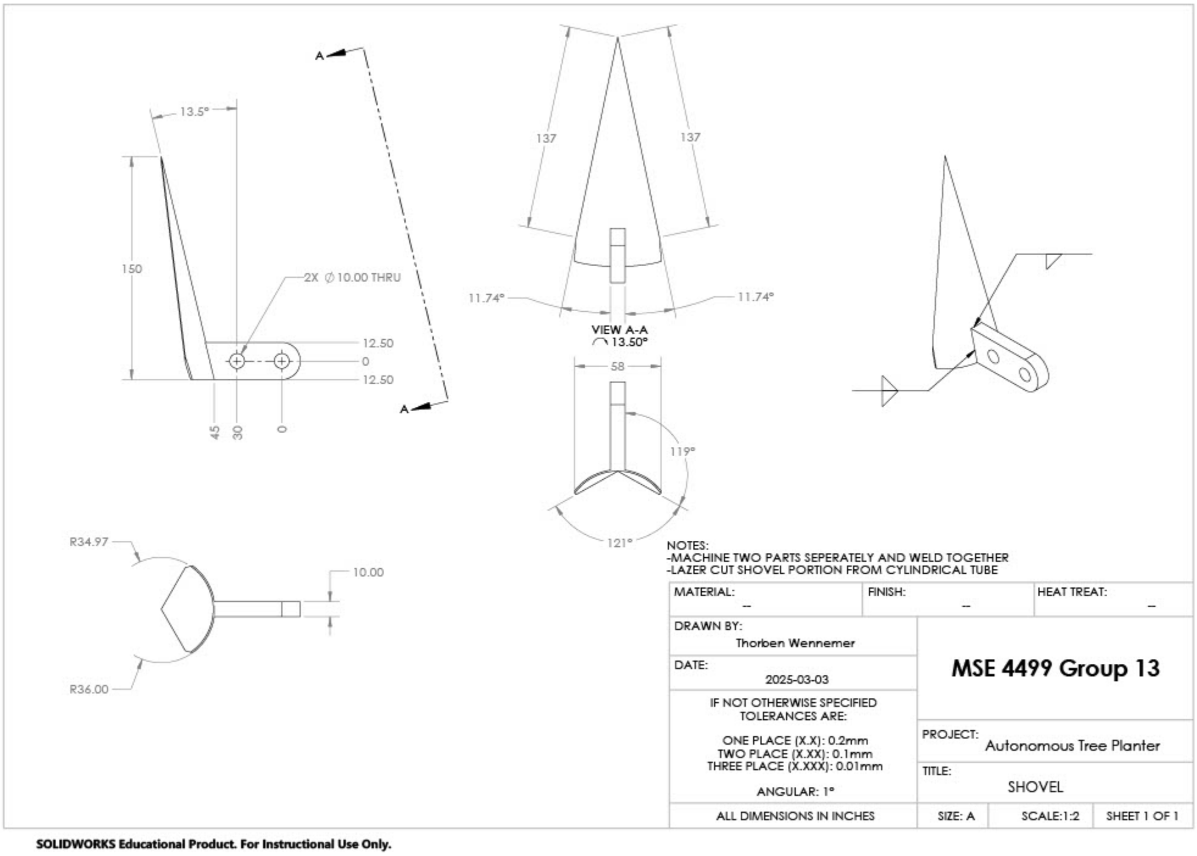
SOLIDWORKS Educational Product. For Instructional Use Only.

Planting Mechanism Collar

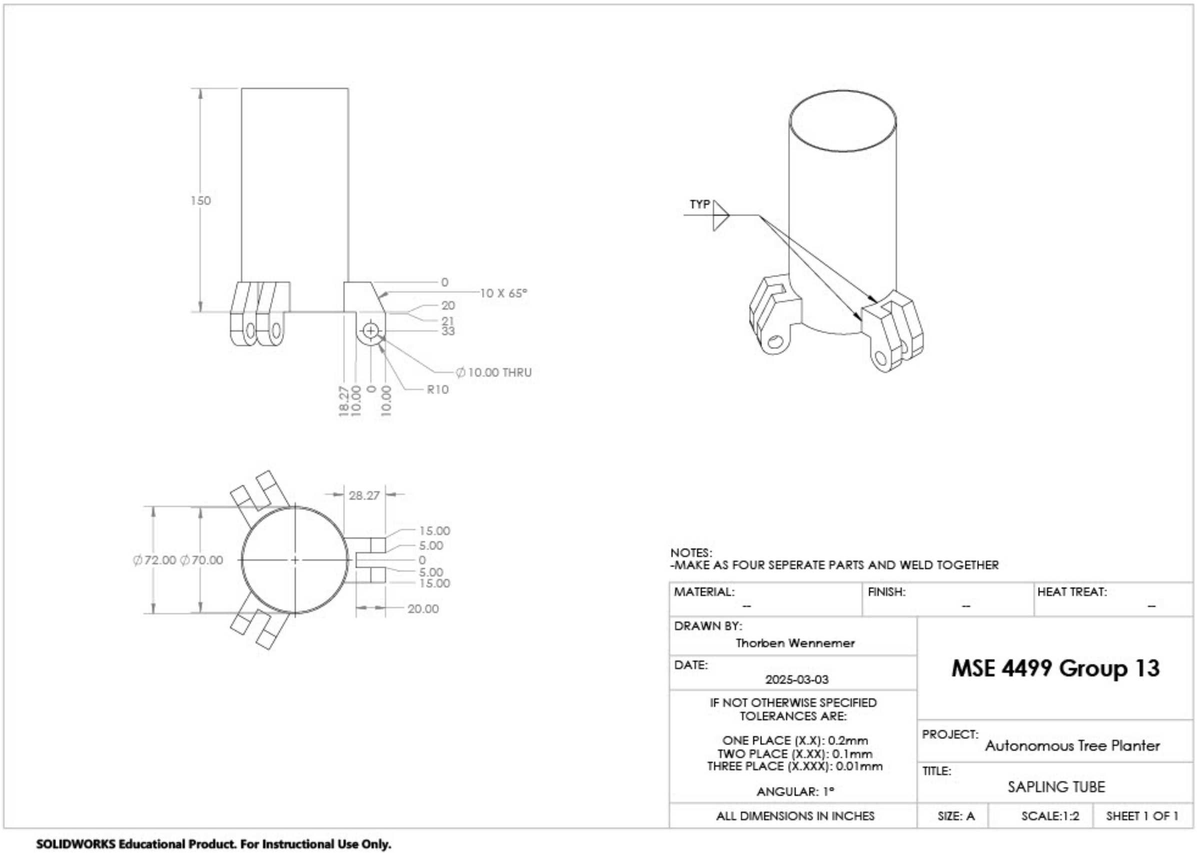


SOLIDWORKS Educational Product. For Instructional Use Only.

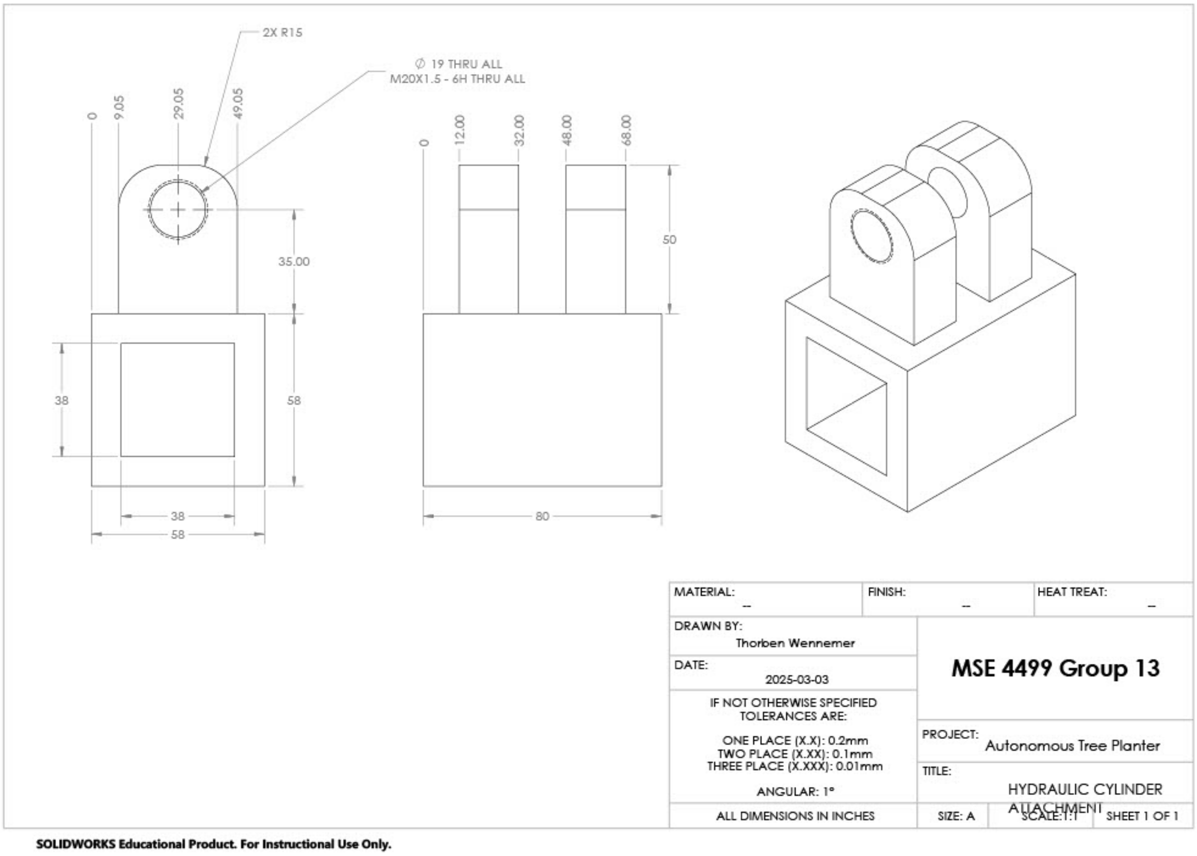
Funnel for Sapling Delivery to Planting Mechanism



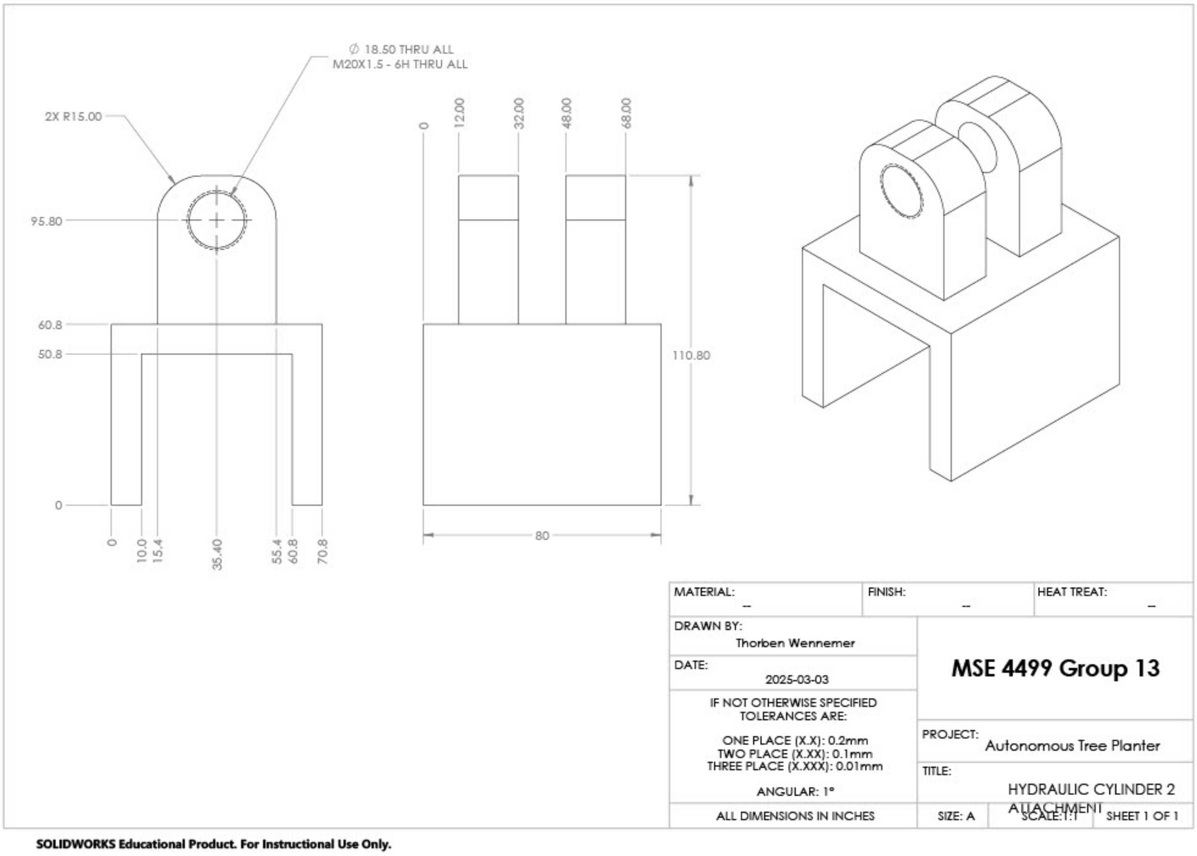
Planting Mechanism Shovels



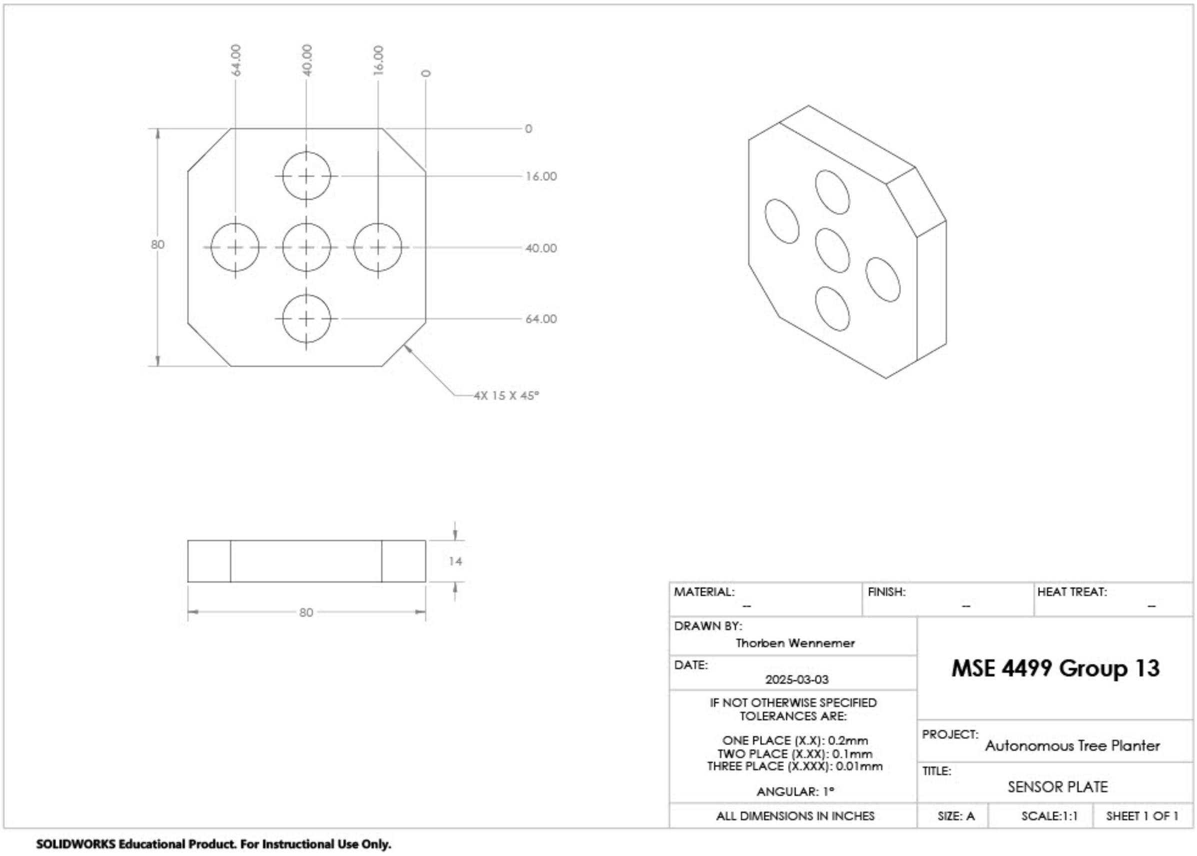
Planting Mechanism Tube Assembly



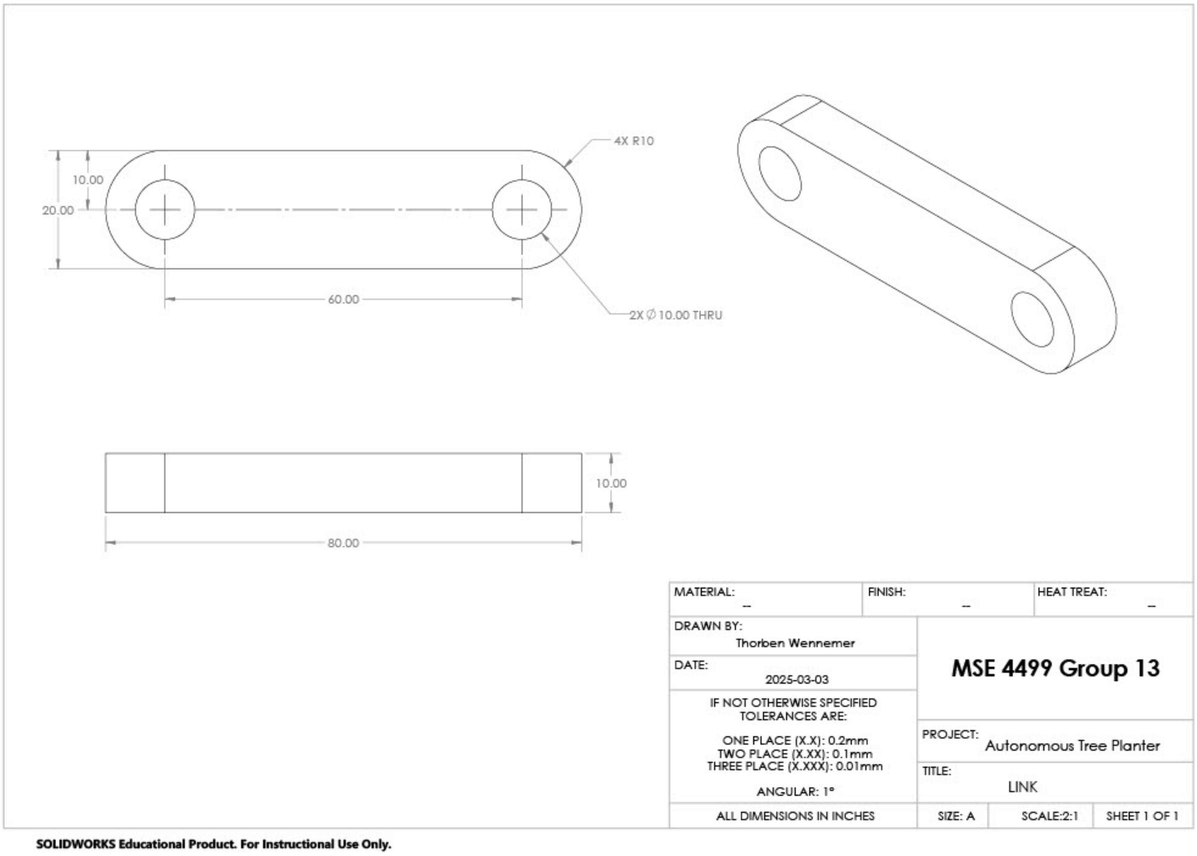
Hydraulic Cylinder Mount



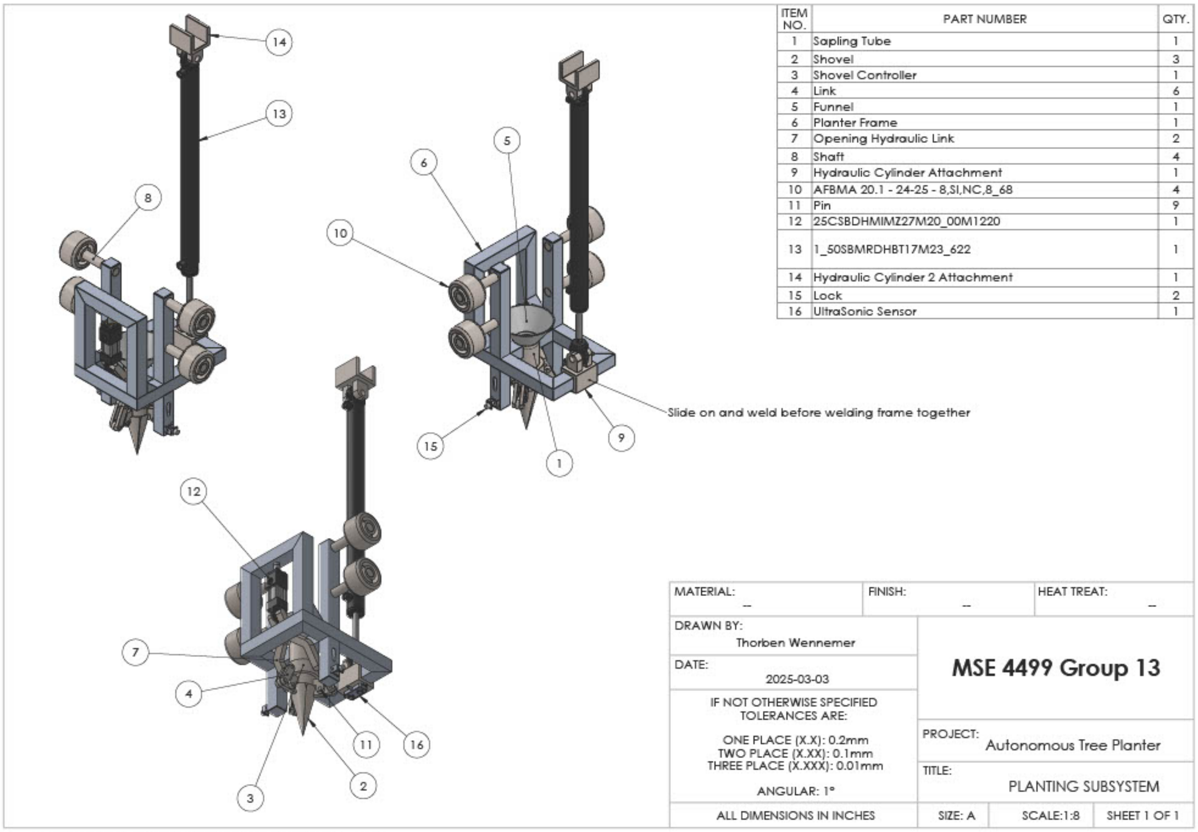
Hydraulic Cylinder Mount



Sensing Subsystem Plate



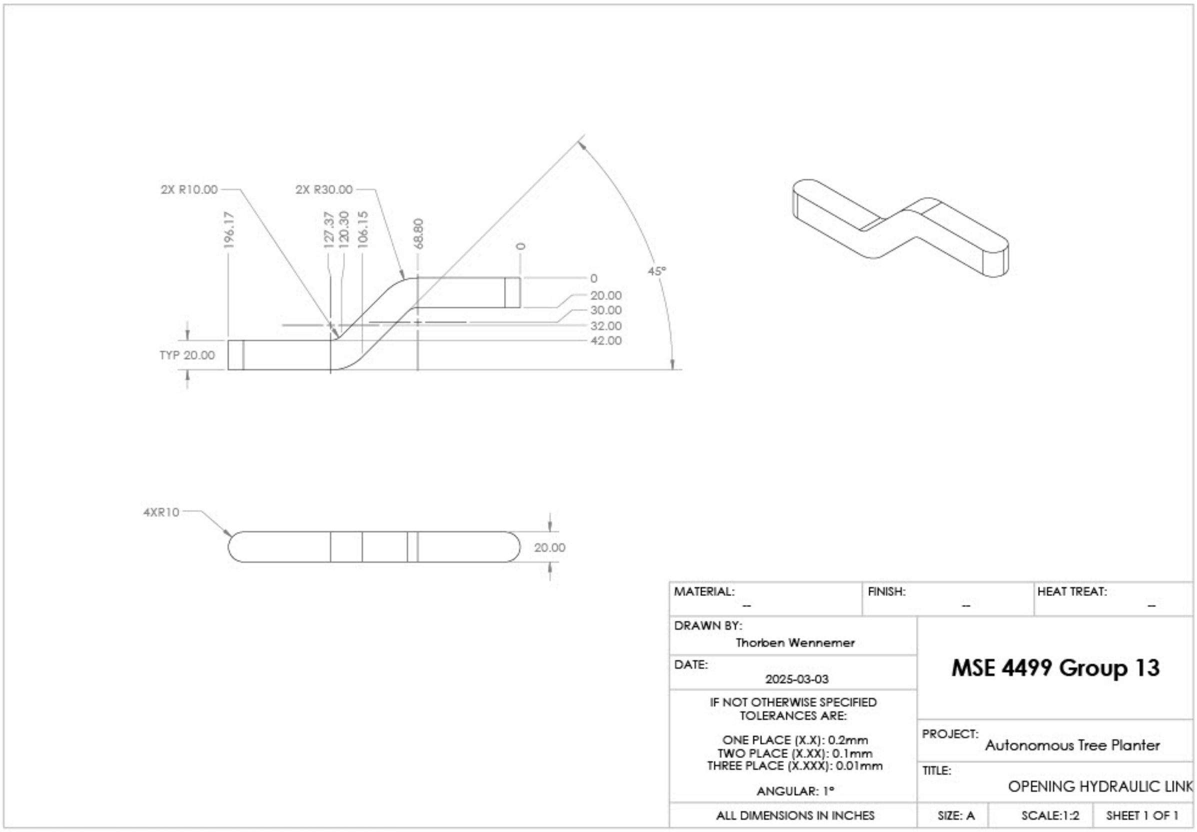
Planting System Linkage



ITEM NO.	PART NUMBER	QTY.
1	Sapling Tube	1
2	Shovel	3
3	Shovel Controller	1
4	Link	6
5	Funnel	1
6	Planter Frame	1
7	Opening Hydraulic Link	2
8	Shaft	4
9	Hydraulic Cylinder Attachment	1
10	AFBMA 20.1 - 24-25 - 8,SI,NC,8_68	4
11	Pin	9
12	25CSBDHMIMZ27M20_00M1220	1
13	1_50SBMRDHBT17M23_622	1
14	Hydraulic Cylinder 2 Attachment	1
15	Lock	2
16	UltraSonic Sensor	1

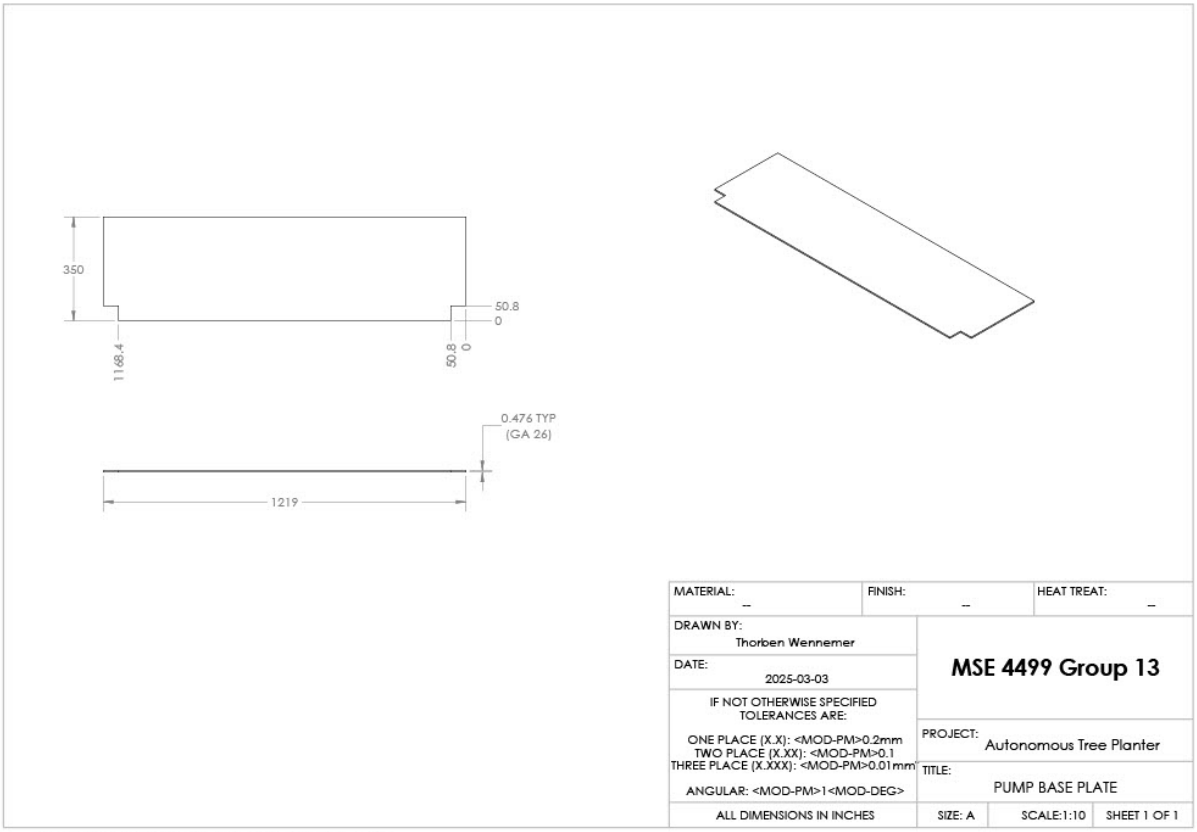
SOLIDWORKS Educational Product. For Instructional Use Only.

Complete Planting Mechanism Assembly



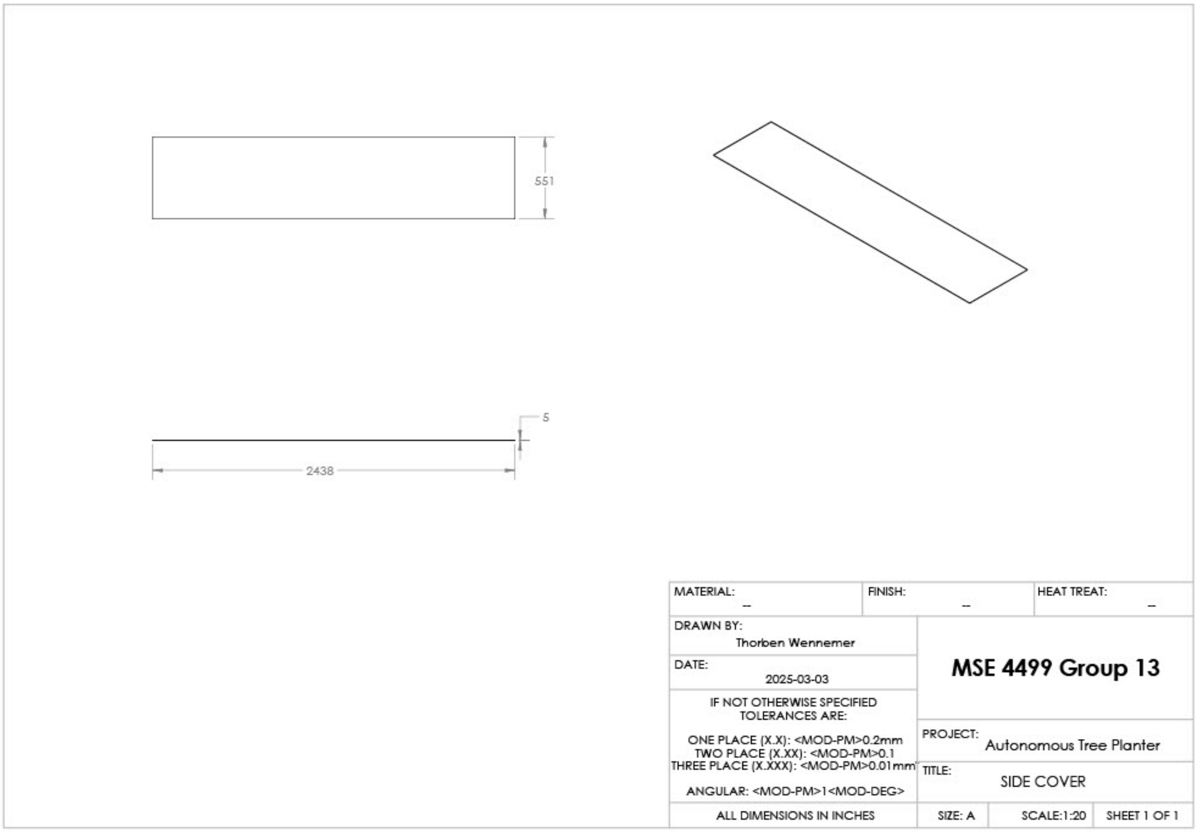
SOLIDWORKS Educational Product. For Instructional Use Only.

Actuating Linkages for Planting Mechanism



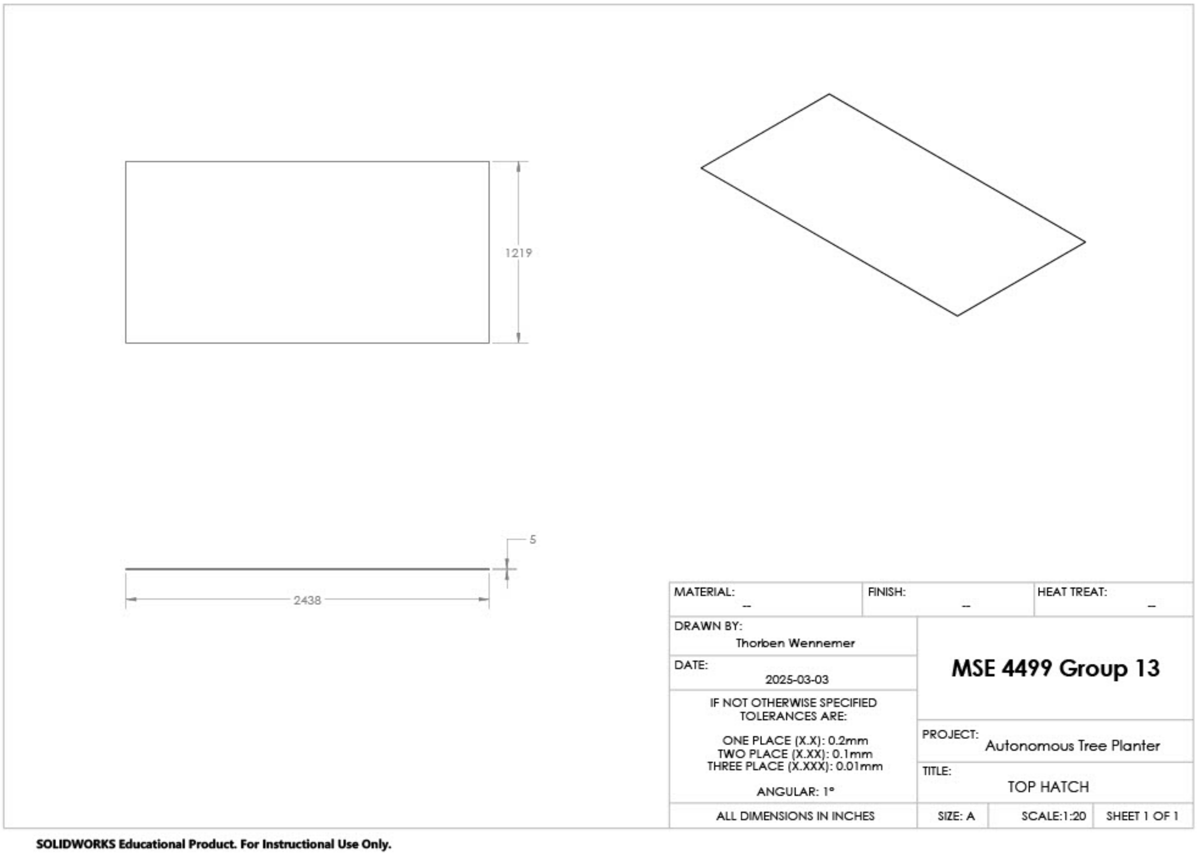
SOLIDWORKS Educational Product. For Instructional Use Only.

Battery/Hydraulic Power Unit Tray

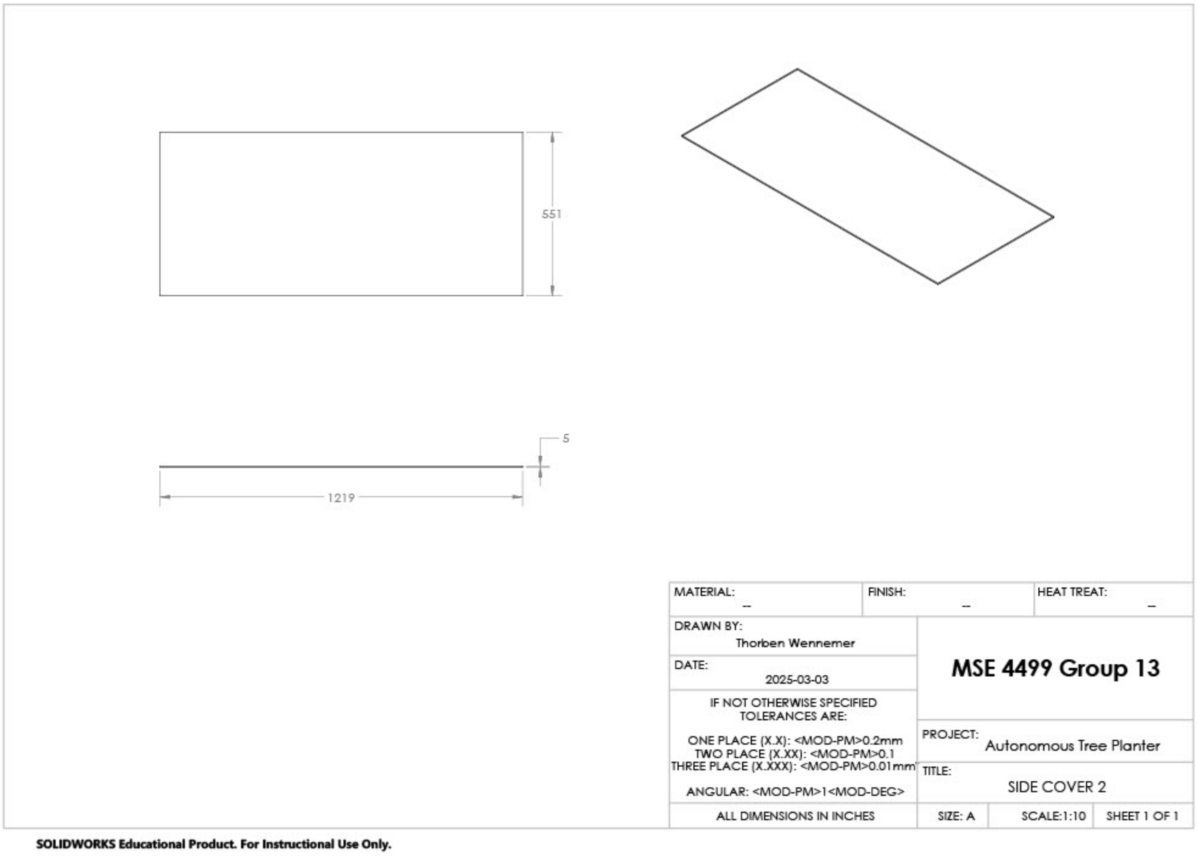


SOLIDWORKS Educational Product. For Instructional Use Only.

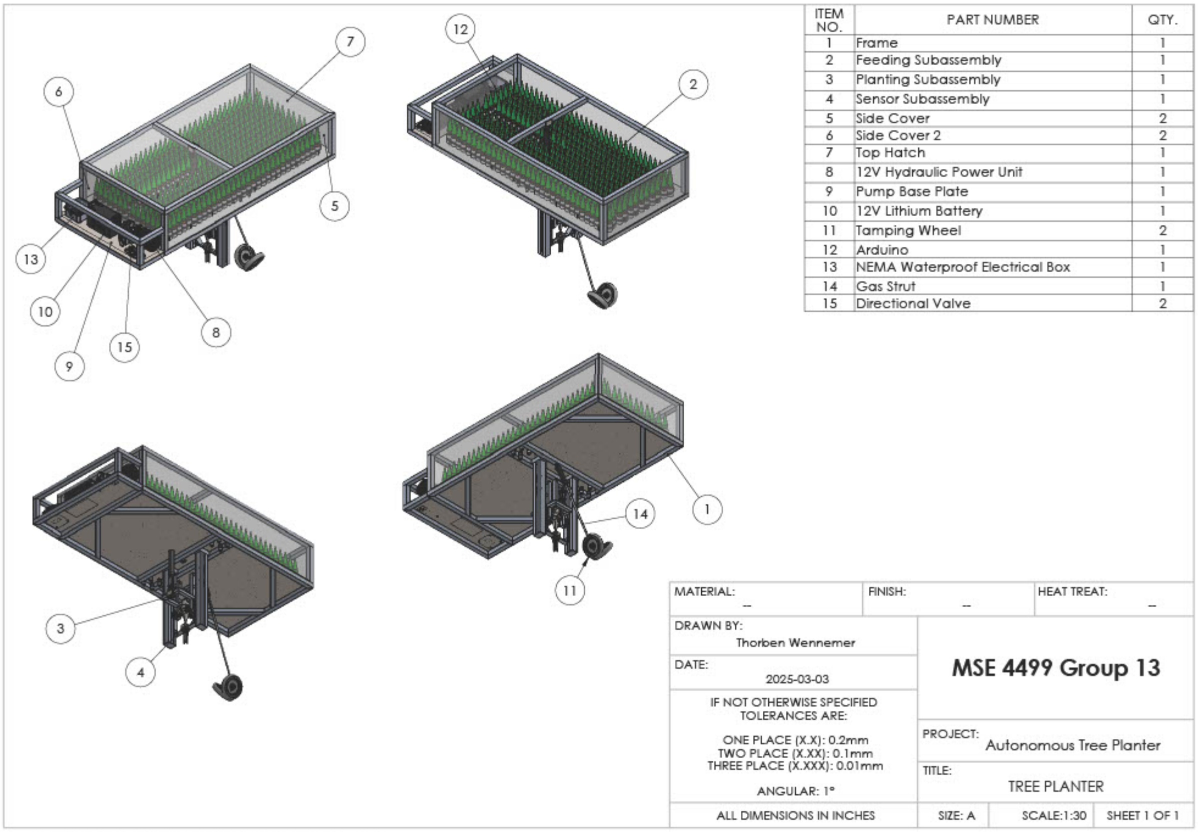
Protective Acrylic Panel



Protective Acrylic Panel

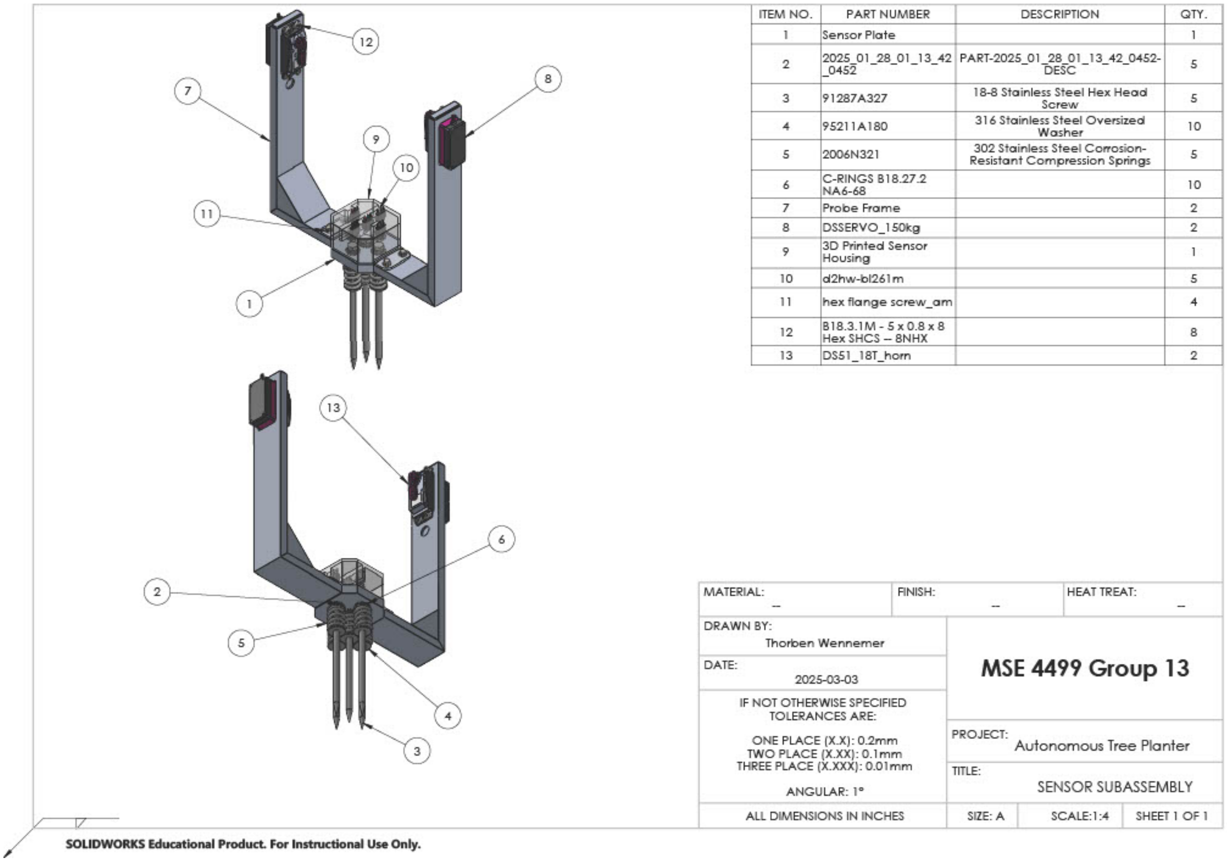


Protective Acrylic Panel



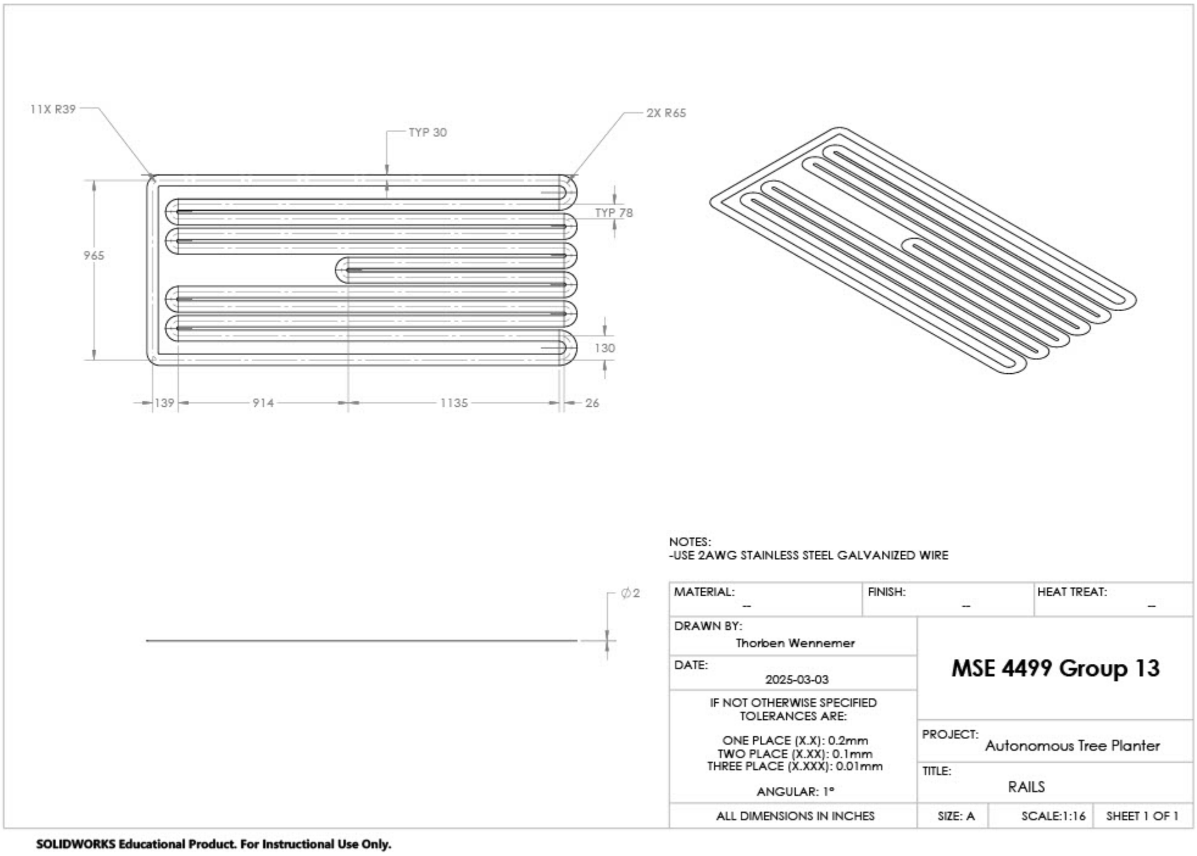
SOLIDWORKS Educational Product. For Instructional Use Only.

Complete Assembly

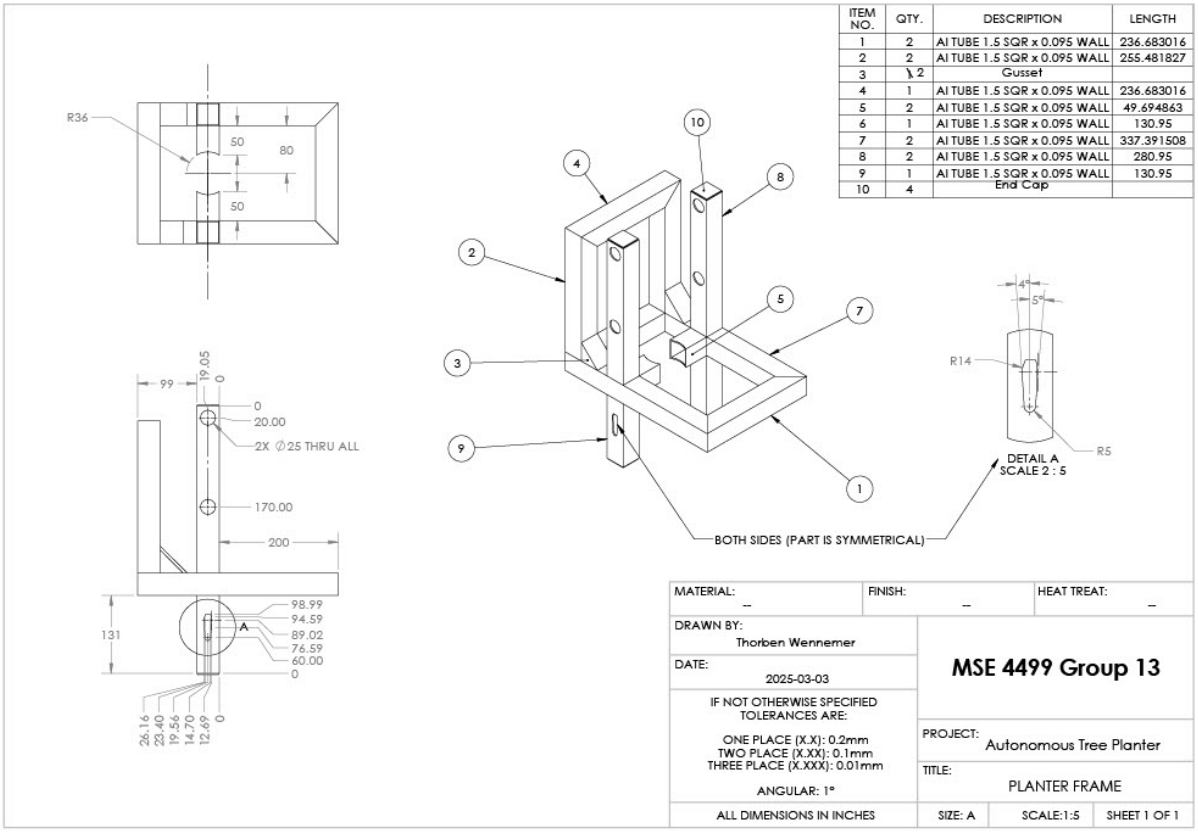


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Sensor Plate		1
2	2025_01_28_01_13_42_0452	PART-2025_01_28_01_13_42_0452-DESC	5
3	91287A327	18-8 Stainless Steel Hex Head Screw	5
4	95211A180	316 Stainless Steel Oversized Washer	10
5	2006N321	302 Stainless Steel Corrosion-Resistant Compression Springs	5
6	C-RINGS B18.27.2 NA6-68		10
7	Probe Frame		2
8	DSSERVO_150kg		2
9	3D Printed Sensor Housing		1
10	d2hw-bl261m		5
11	hex flange screw_am		4
12	B18.3.1M - 5 x 0.8 x 8 Hex SHCS -- 8NHX		8
13	DS51_18T_horn		2

Sensing Subsystem Assembly

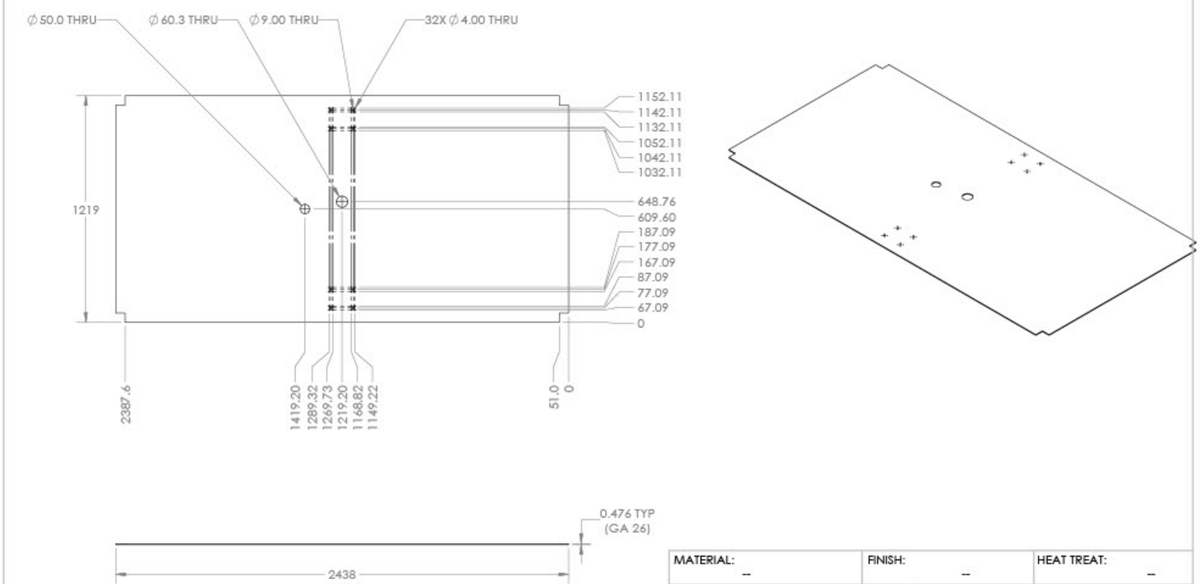


Conveyor Track Layout



SOLIDWORKS Educational Product. For Instructional Use Only.

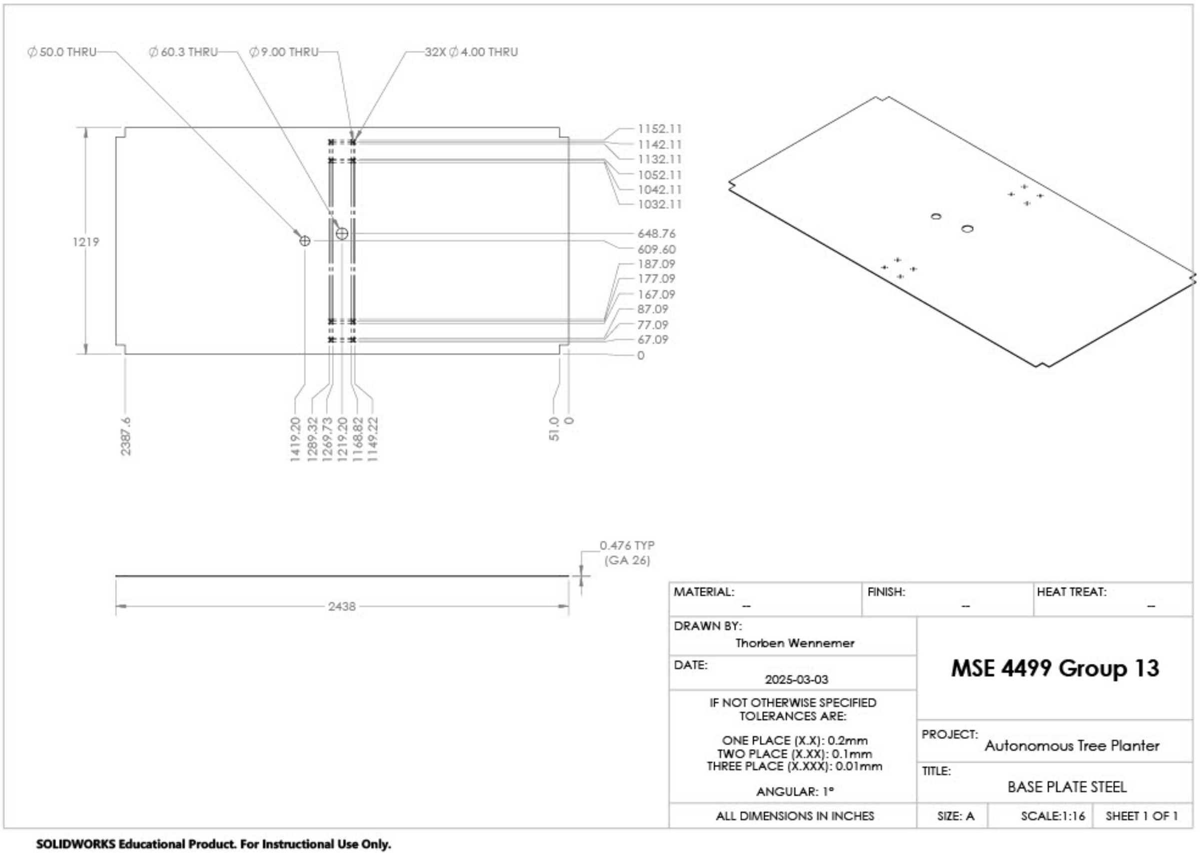
Planting Mechanism Frame



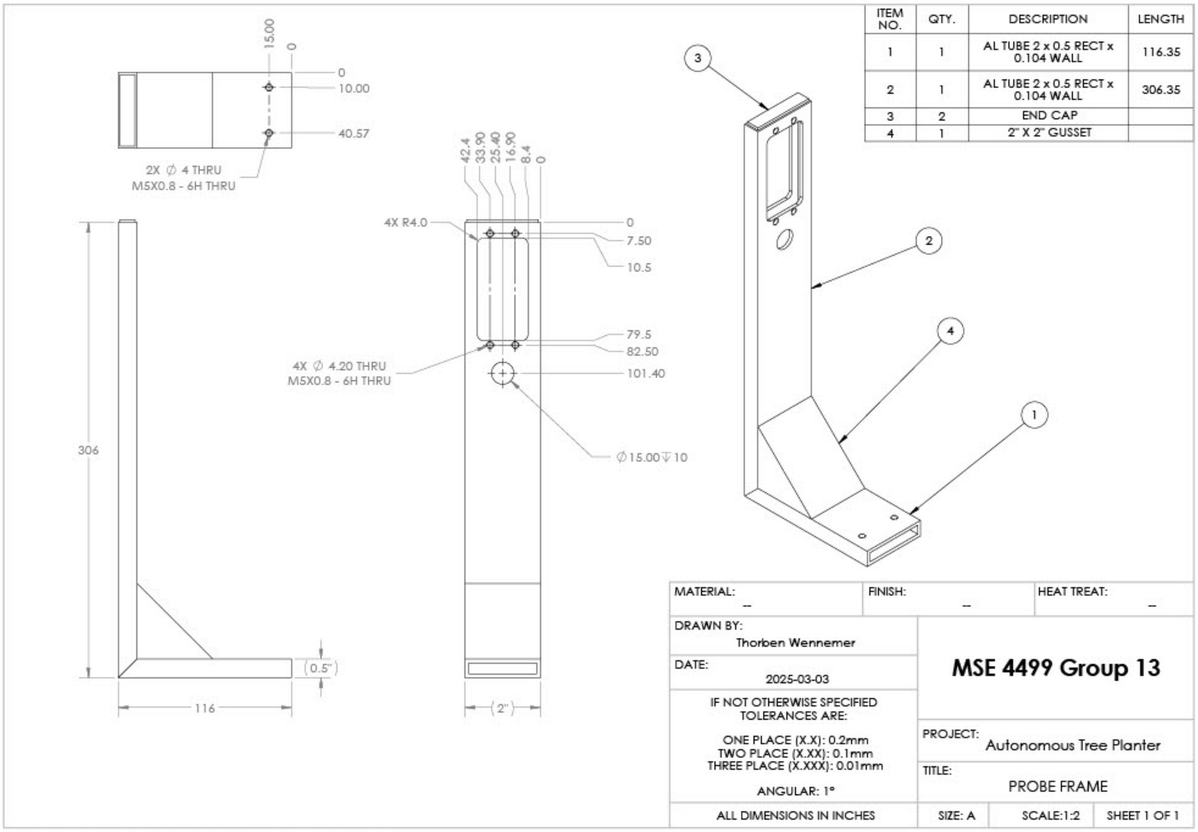
MATERIAL: --	FINISH: --	HEAT TREAT: --
DRAWN BY: Thorben Wennemer	MSE 4499 Group 13	
DATE: 2025-03-03		
IF NOT OTHERWISE SPECIFIED TOLERANCES ARE: ONE PLACE (X.X): 0.2mm TWO PLACE (X.XX): 0.1mm THREE PLACE (X.XXX): 0.01mm ANGULAR: 1°	PROJECT: Autonomous Tree Planter	
	TITLE: BASE PLATE PLASTIC	
ALL DIMENSIONS IN INCHES	SIZE: A	SCALE:1:16 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

HDPE Conveyor Surface Plate



Steel Conveyor Surface Plate



SOLIDWORKS Educational Product. For Instructional Use Only.

Sensing Subsystem Arm