Team 2: LeBot James

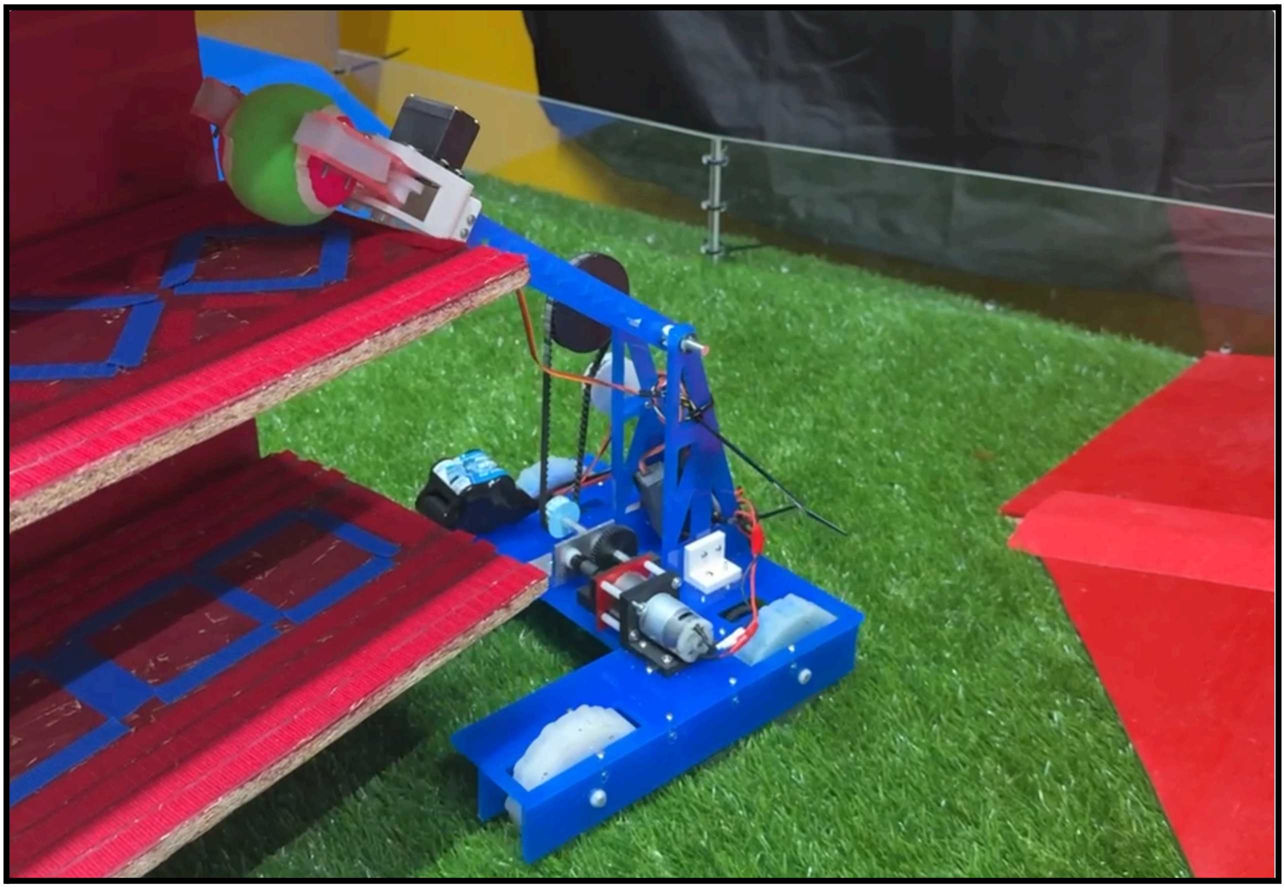

Figure 1.1: Image of LeBot James scoring a tennis ball in the second level

ES-51: Computer Aided Machine Design

Submitted: 12/07/2025

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Abstract

LeBot James is a compact robot built for the ES51Turf Wars competition, where all robots must first fit in an 11 in x 11in x 11 in starting box, otherwise known as the Box of Justice. Robots in this competition must also climb 15- and 30-degree incline ramps and place irregular objects into scoring goals at heights of 7, 14, and 21 inches. Our design uses a rear-wheel-drive system powered by two motor-gearbox assemblies from the ES51 cordless screwdrivers, geared 3:1, along with cast Ecoflex 50 wheels that provide enough traction to climb the steepest ramp, with a safety factor of about 1.6. A third motor-gearbox assembly drives a two-bar arm through a 6:1 reduction, providing more than enough torque to lift a 0.27-pound object at full extension. Concept generation, CAD modeling, prototyping, and weighted Pugh matrices allowed for the development of our robot. The engineering analysis, which included drivetrain torque, friction limits, arm loading, bending stress, center of mass, and tipping stability, ensured that our final design met all competition requirements. During testing, LebotJames was able to consistently climb both ramps, reliably lift objects, and score in the lower and upper goals. Future improvements include increasing speed, reducing arm friction, adjusting weight distribution, and improving maneuverability.

1. Concept Development

1.1 Competition Context and Problem Statement

The playing field is made of turf, including two ramps of varying inclines (15° & 30°), various objects (tennis balls, dog toys, wooden blocks), and three "goals" at heights 7", 14", and 21". Matches are 4 minutes long unless a team connects all 3 objects; Otherwise, the highest scoring team wins. Damage to other robots is prohibited.

Problem Statement: Design and construct a remote-controlled robot that fits inside an 11 in × 11 in × 11 in box, then expands to navigate ramps, control and store objects, and place them into elevated goals quickly and reliably using only ES51-approved materials and tools.

The robot must be simple, durable, fast, and precise under strict size, weight, and manufacturing constraints.

1.2 Constraints

Many key constraints shaped the choices within our design throughout the development process. **Dimensional requirements** insisted our robot begin in a fully enclosed 11 x 11 x 11 "Box of Justice." In addition, the mobility constraint required our robot to climb both 15 and 30 degree ramps without slippage and tipping. To successfully score, our robot needed to comply with the **height constraint**, meaning it must place objects into goals located at 7, 14, and 21-inch heights. Regarding our **mass constraint**, the total mass was aimed to be below 3.0 kg to allow for an advantage in the case of tie-breakers. Power usage further imposed limits, as our robot could only use **three drill motors total**, two dedicated to the drivetrain, and one for the arm. All operations must remain within a safe voltage range of 1.2-1.6 V, with a final testing operating voltage of 1.4 V. Manufacturing limitations played significant roles as well. All parts were produced using tools available in the ES51 ship, including laser cutting, 3D printing, CNC milling, casting, and basic hand tools. Finally, the design needed to satisfy both **robustness and**

gameplay constraints: the structure drivetrain had to withstand repeated ramp climbs without failure, and possible collisions. The robot's object-handling system needed to collect, hold, and release items reliably and consistently without dropping or jamming.

1.3 Design Criteria

To guide the selection of our concept, we established a set of design criteria which was applied in a weighted Pugh matrix during Design Review 2. **Arm height** (weight 5) was a significant factor as they needed to reach the 14-21 inch heights reliably to score. The weight capacity (weight 4) of the arm and claw needed to be high enough to lift irregular objects without deforming, breaking or stalling the mechanism. **Design simplicity** (weight 4) was also emphasised as simpler systems reduce machining time, part counts, and failure points while improving overall durability. The **release mechanism** (weight 3) had to allow objects to be consistently placed into goals without jamming or dropping. **Ramp climbing** (weight 3) was another essential criterion which ensured the drivetrain could produce enough torque and traction to climb both the 15° and 30° inclines. Lastly, the robot's **overall weight** (weight 2) was considered since the reduction of mass would improve acceleration, reduce load on the arm and provide an advantage in tiebreaking scenarios.

1.4 Alternative Concepts

We began the design process by exploring several concepts that could satisfy the constraints of the Turf Wars competition.

Concept 1 – 4WD Forklift-Style Robot

This concept used a front-mounted lifting fork with a simple vertical linkage.
Pros: Very low part count, robust structure, easy to fabricate, and inherently stable when driving.
Cons: Limited maximum reach, poor ability to manipulate irregular objects, and difficulty interfacing with the higher scoring goals. This design lacked the versatility needed for fast scoring.

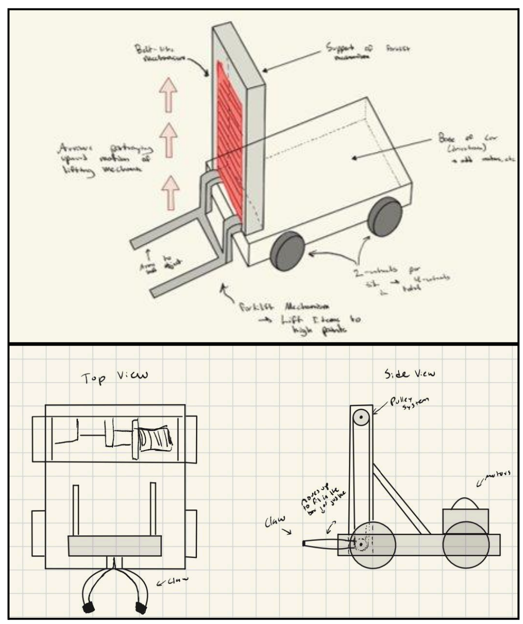

Figure 1.2: First Sketch of Concept 1

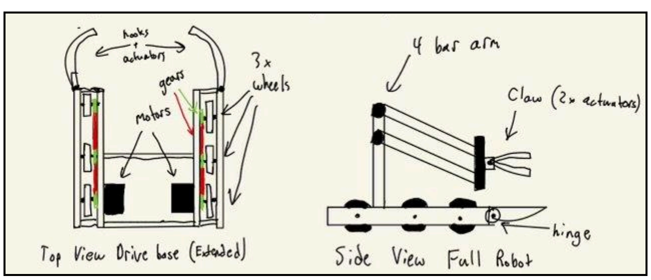

Figure 1.3: First Sketch of Concept 2

Concept 2 – 6WD Clawbot with 4-Bar Linkage Arm
This version used a symmetric 4-bar arm to maintain the claw orientation throughout the lift.

Pros: Consistent claw angle, good reach, flexible scoring positions, and visually intuitive for drivers.
Cons: High joint count, multiple moving links requiring tight tolerances, larger mass, greater machining time, and more failure points. Although mechanically capable, the complexity exceeded what was necessary.

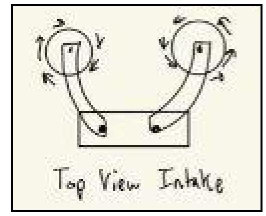

Figure 1.4: Intake

Concept 3 – 6WD Clawbot with 4-Bar Linkage Arm & Rolling Intake
This design added powered intake wheels to rapidly collect objects.
Pros: Fast object acquisition, excellent for multi-object strategies.
Cons: Required additional motors, more wiring, and more space. The added complexity reduced reliability, and the intake worked poorly with the variety of irregular objects used in Turf Wars.
Concept 4 (After Design Review 1) – 4WD Clawbot with 2-Bar Linkage Arm
After Design Review 1, we decided to implement 2 changes to Concept 2 to create a 4th idea

- Transition from a 4-Bar arm to a 2-Bar arm
- We also changed our drive base to 4 wheels rather than 6

Table 1: Weighed Pugh Matrix

	Weight	Elevator w/ Claw	4 Bar w/ Intake	4 Bar Arm	2 Bar Arm
Max. Arm Height	5	-	0	0	+
Object Capacity	4	+	0	0	0
Design Simplicity	4	0	-	+	+
Release Mechanism	3	+	+	+	+
Ramp Climbing	3	-	+	+	+
Robot Weight	2	0	-	-	0
Total	—	-1	0	8	15

1.5 Final Concept: LeBot James
After evaluating all our design concepts, using our weighted Pugh matrix, we selected the four-wheel-drive two bar arm claw bar as our final configuration. This design offered the best balance of reliability, simplicity, manufacturability, and performance capability. The transition from a four bar to a two bar system significantly reduced joint count friction and machining time while still providing a vertical reach to score in the 7 inch and 14 inch goals. Through a four-wheel-drive train we were able to lower weight and improve maneuverability without compromising ramp,

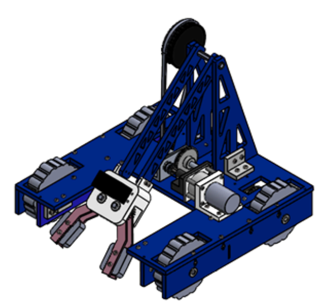

Figure 1.5: Final Concept

climbing performance, the final concept, Lebot James integrates, a compact drive base cast eco flex wheels for traction, and a robust arm mechanism, optimized for controlled object handling, and consistent scoring.

2. Analysis

2.1 Drivetrain Torque and Ramp-Climbing Capability

2.1.1 Motor Data at 1.6 V

The drivetrain uses two identical drill motors, each directly driving a rear wheel. At the operating voltage of 1.6V, the characterization data for each motor is:

- Stall torque: $\tau_{stall} = 0.538\ Nm$
- Maximum continuous torque: $\tau_{max} = 0.269\ Nm$
- No-load angular speed: $\omega_{no-load} = 10.26\ rad/s$
- Maximum operating angular speed: $\omega_{max} = 5.13\ rad/s$

Each rear wheel is driven through a single spur gear stage with a ratio of 3:1, using a 16 T pinion on the motor shaft and a 48 T gear on the wheel shaft (32 DP). There are no additional gearing or chain stages, and both rear wheels have identical gearing.

2.1.2 Wheel Torque

The gear ratio from motor shaft to wheel shaft is:

$$GR = \frac{N_{wheel\ gear}}{N_{motor\ gear}} = \frac{48}{16} = 3$$

The torque at each wheel shaft, using continuous motor torque, is:

$$\tau_{wheel} = GR \cdot \tau_{max} = 3 \cdot 0.269 \approx 0.807\ Nm$$

The corresponding tractive force at the ground from a single wheel is:

$$F_{wheel} = \frac{\tau_{wheel}}{r} = \frac{0.807}{0.0413} \approx 19.5\ N$$

With two driven rear wheels, the drivetrain can theoretically provide:

$$F_{drive} \approx 2 \cdot 19.5 \approx 39\ N$$

This is the torque-limited traction; the actual usable traction is limited by friction with the field.

2.1.3 Required Force to Climb a 30° Ramp

The updated CAD mass of the robot is **4.87 lb**, which converts to: **2.21 kg**

The weight of the robot is:

$$W = mg = 2.21 \cdot 9.81 \approx 10.9N$$

The component of weight acting **parallel** to a 30° incline is:

$$F_{required} = W(sin30°) = 21.7 \cdot 0.5 \approx 10.9\,N$$

So the drivetrain must supply at least **10.9 N** along the ramp surface to climb a 30° ramp at constant speed.

2.1.4 Friction Limit with Ecoflex Wheels

The robot uses two rear wheels cast from Ecoflex 50 silicone, each with radius 1.625 in and width 0.75 in. We do not have a measured coefficient of friction on the Turf Wars carpet, so we assume a reasonable value of: $\mu \approx 0.8$

On a 30° incline, the normal force on the driven wheels is:

$$N_{total} = W(cos30°) = 21.7 \cdot 0.866 \approx 18.7\,N$$

The maximum frictional traction available from both wheels is:

$$F_{fric, max} = \mu \cdot N_{total} = 0.8 \cdot 18.7 \approx 15\,N$$

Torque-limited: $F_{drive} \approx 39\,N$

Friction-limited: $F_{fric, max} \approx 15\,N$

Thus, the drivetrain is friction-limited on the 30° ramp, and the effective available climbing force is:

$$F_{available} = F_{fric, max} \approx 15\,N$$

The safety factor for ramp climbing is:

$$SF_{ramp} = \frac{F_{available}}{F_{required}} = \frac{15}{10.9} \approx 1.4$$

This indicates that the robot can climb a 30° ramp with a safety factor of about 1.4, which is consistent with our observations that the robot can ascend the ramp reliably without wheel slip, while still being traction-limited rather than torque-limited.

For the 15° ramp, the required force mg(sin15°) is significantly smaller (approximately 5.6 N), giving a safety factor of roughly 2.7.

2.2 Arm Torque Analysis

The arm is powered by a third drill motor identical to the drivetrain motors and operating at 1.6V. The arm drive train consists of:

- A 3:1 spur gear reduction (16 T → 48 T)
- Followed by an approximately 5:1 belt/pulley reduction from the gearbox output shaft to the arm pivot axle.

The total reduction from motor shaft to arm pivot is therefore: $GR_{arm} = 3 \cdot 5 \approx 15:1$

2.2.1 Required Torque

The two arm links plus the claw together weigh **0.46 lb**.

At 4.448 N per pound, this is approximately: $W_{arm+claw} = 0.46 \cdot 4.448 \approx 2.05\ N$

The maximum design object weight is **0.2 lb**, or: $W_{object} = 0.2 \cdot 4.448 \approx 0.89\ N$

The arm length from pivot to claw center is: $L = 8.9\ in \approx 0.226\ m$

We model the arm + claw as a distributed mass whose effective center of mass is at approximately **L/2**, and the object as a point load at **L**.

The torque required to hold the arm horizontally with the object at full extension is:

$$\tau_{arm+claw} = W_{arm+claw} \cdot \frac{L}{2} \approx 2.05 \cdot \frac{0.226}{2} \approx 2.05 \cdot 0.113 \approx 0.23\ Nm$$

$$\tau_{object} = W_{object} \cdot L \approx 0.89 \cdot 0.226 \approx 0.20\ Nm$$

$$\tau_{required} = \tau_{arm+claw} + \tau_{object} \approx 0.23 + 0.2 \approx 0.43\ Nm$$

2.2.2 Available Torque

Using the same continuous motor torque at 1.6 V: $\tau_{max} = 0.269$ Nm

The torque at the arm pivot is: $\tau_{arm} = GR_{arm} \cdot \tau_{max} = 15 \cdot 0.269 = 4.04$ Nm

This calculated torque promises no stall

2.3 Beam Bending Analysis of Acrylic Arm Support

To verify that the acrylic arm link could safely withstand lifting loads, we performed a static Finite Element Analysis (FEA) in SolidWorks Simulation. The arm was modeled as a solid acrylic component fixed at the pivot face, with a 4.5 N downward load applied at the claw end to represent the combined weight of the arm, claw, and a worst-case object. A curvature-based solid mesh with high element quality (99% of elements with aspect ratio < 3) was used.

Figure 2.1 shows the von Mises stress distribution across the arm. The maximum stress of approximately 3.0 MPa occurs near the pivot region, which matches expected cantilever behavior. This value is well below acrylic's 45 MPa yield strength, giving a safety factor of roughly 15×.

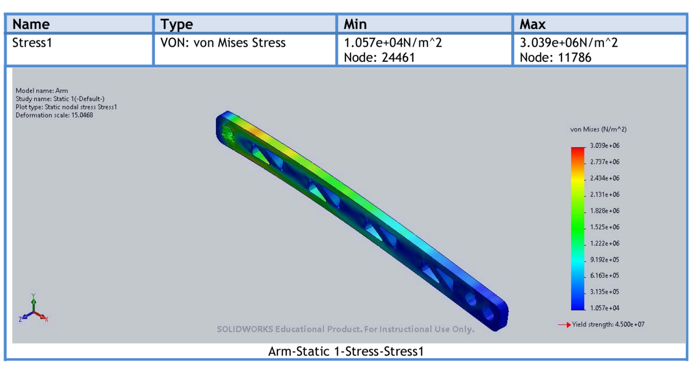

Figure 2.1: von Mises stress distribution of the acrylic arm link

The corresponding displacement results indicate a maximum tip deflection of only 1.52 mm, confirming that the arm is sufficiently stiff and does not significantly deform under load. The combination of low stress and minimal deflection shows that the acrylic arm link provides ample structural capacity for all expected competition loads.

2.4 Vertical Reach Analysis

To ensure that LeBot James could reliably score the 7-inch and 14-inch goals, we analysed the vertical region of the two-bar arm using the measured pivot height and the arm length from the CAD model. The arm pivot is located approximately 9.3 inches above the ground, and the arm length from the pivot to the claw center is 8.9 inches. When fully extended vertically, the claw reaches a maximum height of :

$$H_{max} = H_{pivot} + L_{arm} = 9.3 + 8.9 = 18.2\ in$$

This height exceeds the 14-inch goal requirement, ensuring consistent placement of objects into the middle tier. For scoring in the lower 7-inch goal, the arm is partially raised so that the claw aligns horizontally with the opening, allowing for a controlled release. The maximum reach of 18.2 inches does not meet the 21-inch topical requirement, but because our strategy prioritises speed, reliability and simplicity, we intentionally optimise the arm for the two lower tiers. During testing, the measured reach matched the CAD prediction and allowed the robot to score consistently in the first-level goals.

2.5 Center of Mass

The overall center of mass of the robot at its starting position is located at:

COM = (50.37, 0.36, 101.79) mm

in the robot coordinate frame, where:

- x is measured along the length of the robot
- y is measured laterally (left–right)
- z is measured vertically from the ground

The small lateral offset (y ≈ 0.36 mm) indicates that the robot is effectively symmetric left-to-right. The COM height of 101.79 mm (≈ 4.0 in) sits well above the axle height but below the arm's pivot height, which contributes to overall stability on flat ground and moderate inclines.

2.6 Stability and Tipping Analysis

Wheelbase (distance between front & rear wheel):	L = 0.168 m
Track width (inside distance between left and right wheels):	W = 0.216 m

For tipping in the longitudinal direction, the critical condition occurs when the projection of the COM onto the ramp surface passes through the line of contact of one axle. Approximating the COM as centered between the axles in the longitudinal direction (as suggested by the CAD x-coordinate) and focusing on incline stability, we consider tipping about either the front or rear wheels.

Using the half-wheelbase: $\frac{L}{2} = \frac{0.168}{2} \approx 0.084\, m$

And the COM height: $h_{COM} = 101.79 = 0.1079\, m$

the critical incline angle for tipping (in either forward or backward direction, depending on arm placement) can be approximated by:

$$tan\theta = \frac{L/2}{h_{COM}} = \frac{0.084\, m}{0.102} \approx 0.82$$

$$\theta = tan^{-1}(0.82) = 39.5°$$

Thus, with the arm in its nominal, retracted configuration, the robot is predicted to remain stable on inclines up to approximately 40° before tipping, which is comfortably above the required 30° ramp.

When the arm is fully raised, the COM shifts upward and slightly toward the rear, which reduces the stability margin and makes backward tipping about the rear wheels more likely when climbing. However, even in this configuration, the combination of short wheelbase, relatively low COM height compared to reach, and the 30° maximum competition incline suggests that the robot retains a usable stability margin, as supported by our physical tests where no tipping occurred on the 30° ramp.

3. Final Solution

3.1 Overall Robot Description

LeBot James is a compact rear-wheel-drive clawbot built from laser-cut acrylic, aluminum brackets, and cast Ecoflex 50 wheels. The robot fits inside the 11 in × 11 in × 11 in starting box and has a final mass of 4.87 lb. Two drill motors power the rear wheels through a 3:1 gear reduction, and a third motor drives a 2-bar arm using a 15:1 total reduction. The arm pivot sits roughly 9.3 in above the ground and reaches a maximum claw height of ~17 in, allowing consistent scoring in the 7 in and 14 in goals.

3.2 Functional Operation

LeBot James operates through three coordinated subsystems: the drivetrain, the two-bar arm, and the claw. The rear-wheel drivetrain provides high traction on turf, allowing the robot to accelerate quickly and climb both ramps without slipping. To acquire objects, the driver aligns the robot so the claw surrounds the tennis ball or block, after which the servo closes to secure the object. The arm motor then lifts through the 15:1 reduction, raising the object while maintaining a stable and predictable orientation. Once aligned with a scoring goal, the driver opens the claw to release the object cleanly. At maximum arm height, the claw aligns directly with the 14-inch goal wall, while a partial lift is used for the 7-inch tier. This coordinated behavior allows the robot to reliably execute object acquisition and scoring during competition..

3.3 Competition Performance

Throughout testing and competition LeBot James demonstrated very reliable performance across all required tasks. The drivetrain consistently climbed both the 15° and 30° ramps, matching analytical predictions with a safety factor above 1.4. The Eco flex wheels provided high friction allowing for controlled slip free driving on the turf. The arm mechanism successfully lifted objects of varying shapes and masses, including tennis balls, blocks and dog toys robot consistently scored in both the 7 inch and 14 inch goals meeting the primary design requirement although the arm did not reach the 21 inch goal the team focused on speed and reliability and lower tiers which proved effective gameplay. Overall, LeBot James was durable, intuitive to operate, and able to perform repeated scoring cycles within each match.

3.4 Satisfaction of Criteria and Constraints

LeBot James meets all competition constraints:

- Size Constraint - The robot fits in the “11 x 11 x 11” Box of Justice.
- Mass Constraint - Final mass is 4.87 lb, which is well below the 3.0 kg limit
- Ramp Climbing - Verified experimentally to climb both ramps without tipping or slipping.
- Scoring Requirements - Arm reaches the 14-inch goal and reliably and consistently places tennis balls and blocks.
- Power Constraints - Only three drill motors were utilized, two for the drivetrain, and one for the arm
- Manufacturing Constraints - All parts were fabricated using ES51-approved processes and materials. This included laser cutting, 3D printing, casting, CNC milling, and hand tools, the lathe, band saw and drill press.
- Design Criteria - The chosen concept scored highest in our Pugh matrix based on simplicity, reliability, and scoring reach.

3.5 Advantages and Disadvantages

Advantages

- Simple and tough drivetrain capable of high traction on turf
- Two-bar arm provides sufficient reach with low complexity
- Light overall weight allows for improved acceleration and reduction of load on the arm motor.
- Compact geometry improves stability on ramps
- Easy for drivers to control due to predictable arm motion

Disadvantages

- Arm does not reach 21-inch goal
- Belt reduction introduces friction losses and lowering of arm speed
- Acrylic components require caution to avoid cracking and breaking under impacts
- The claw shape limits performance with unusually shaped objects

3.6 Proposed Improvements

Improvements would enhance future iterations of LeBot James

1. Increase Arm Reach - Using a slightly longer arm or higher pivot would enable and allow for scoring in the 21 inch goal. However this may interfere with the size constraints.
2. Reduce Arm Friction - Switching to ball bearings or bushings in the arm pivot would improve lifting speed.
3. Optimize Weight Distribution - Placing batteries lower could further improve incline stability placing batteries lower could further improve incline stability.
4. Improve Claw Geometry - A redesigned claw with curved compliant surfaces could improve gripping of irregular toys, and prevent breakage. Increase Driving Speed - A lower gear ratio could increase the max velocity while maintaining sufficient torque.

Table 2: Final Design Specifications

Parameter	**Specification**
Geometry & Layout	
Overall Length	10.5 in
Overall With	10.85 in
Overall Height (initial)	10.65 in
Undercarriage Clearance	2.45 in
Wheelbase	6.62 in
Drivetrain	
Drive Type	Rear-wheel drive (2 drill motors)
Wheel Width	0.75 in
Wheel Radius	1.625 in
Wheel Material	Silicone Ecoflex 50
Drivetrain Gear Ratio (motor → wheel)	3:1
Arm & Claw System	
Arm Actuator	Drill motor with belt-driven 2-bar arm
Arm Total Gear Ratio	≈ 15:1 (3:1 x ~5:1 pulley ratio)
Claw Actuator	90° Servo Motor
Mass & Center of Mass	

Robot Mass	4.87 lb (2.21 kg)
Center of Mass	(50.37 mm, 0.36 mm, 101.79 mm)
Performance / Analysis	
Max Incline (stable)	Always Stable for incline < 39.5°
Required Wheel Torque for 30° (per wheel)	0.225 Nm
Available Wheel Torque (per wheel)	0.807 Nm
Required Arm Torque (worst case load)	0.43 Nm
Available Arm Torque	4.04 Nm

4. Appendix

Table 3: Bill of Materials

Description	**Quantity**	**Material**	**3D Print Volume (in^3)**	**Manufacturing Technique**
3D Printed				
Claw Base/Holder	1	PLA	3.1	
Arm Supports	2	PLA	0.36	
Bottom Arm Pulley	1	PLA	0.23	
Top Arm Pulley	1	PLA	2.62	
Claw Gripper Mold	2	PLA	2.17	
Total 3D Print Material			11.01 in^3	
Laser Cut				
Base Plate	1	Acrylic ¼ in		
Outside Side Plate	2	Acrylic ¼ in		
Right Inside Side Pate	1	Acrylic ¼ in		
Left Inside Side Plate	1	Acrylic ¼ in		
Arm Side Plates	2	Acrylic ¼ in		

(Triangular Supports)			
Arm Links	2	Acrylic ¼ in	
Claw Fingers	4	Acrylic ⅛ in	
Machining			**Manufacturing Technique**
Arm Pivot Shaft	1	6061 Aluminum	Band Saw & Lathe
Rear Wheel Axle	2	6061 Aluminum	Band Saw & Lathe
Front Wheel Axle	2	6061 Aluminum	Band Saw & Lathe
Claw Gear Axle	2	6061 Aluminum	Band Saw & Lathe
Milling			
Wheel Mold	1	Wax	CNC Mill
Other			
Motor Gear Box	3	PLA, Aluminum, Acrylic	All
Wheels	4	EcoFlex 50	Casting
Claw Grippers	2	EcoFlex 50	Casting
Lab Materials	**Quantity**	**Lab Materials**	**Quantity**
Timing Belt, 200” Pitch, 18” Outer Circle 16	1	4-40 pan-head screw, ⅝ in long	41
4-40 hex nut	21	4-40 pan-head screw, ½ in long	3
E-Clip 0.25” ID	12	4-40 pan-head screw, ⅛ in long	8
Nylon Washer	20	4-40 flat-head screw, ⅜ in long	1
Retaining Ring	6	Nylon Flange Bushing	14

Table 4: Gear Box Bill of Materials

Item No.	Part Number	Description	Quantity
1	Lasercut Base	Lasercut Base	1
2	Delrin Shaft Support	Delrin Shaft Support	1

3	97431A300	E-Clip 0.25” ID	1
4	95606A120	Nylon Washer	1
5	Washer Small	Washer 0.41” ID, 0.54” OD from Screwdriver	1
6	Motor	Motor from screwdriver	1
7	Planetary Gearbox	Planetary Gearbox from Screwdriver	1
8	Metal Circle	Metal Circle with 6 Notches from Screwdriver	1
9	Hex Drive Shaft	Hex Drive Shaft from Screwdriver	1
10	Washer Large	Washer 0.39” ID, 0.77” OD from Screwdriver	1
11	92010A022	M2.5 x 12 mm Flat Head Screw	2
12	Lasercut Front Plate	Lasercut Front Plate	1
13	91772A116	Pan Head Machine Screw 4-40 Thread 1.25”	4
14	94639A662	Unthreaded Spacers, 3/16” OD, 11/16” Length	4
15	90126A505	Washer #4 Screw Size, 0.125” ID, 0.312” OD	6
16	91772A110	Pan Head Screw, 4-40 Thread 0.5” Length	4
17	Retaining Ring	External Retaining Ring for 10mm Short D	1
18	91772A108	Pan Head Screw, 4-40 Thread ⅜” Length	2
19	Nylon Bushing	Nylon Flange Bushing, ID ¼” OD ⅜”	2
20	Hex Shaft	Hex Shaft	1
21	A 1M 2-TA32016	Acetal Plastic Gear, 16 Teeth, 32 Pitch	1
22	Round Shaft	Aluminum Round Shaft	1
23	A 1M 2-TA32048	Acetal Plastic Gear, 48 Teeth, 32 Pitch	1
24	92373A113	Slotted Spring Pin, 1/16” Diameter, ¾” Long	1
25	Motor Mount	Motor Mount	1
26	Al Shaft Support	Aluminum Shaft Support	1
27	91099A169	Flat Head Screw, 4-40 Thread, ⅝” Length	2

4.1 Technical Drawings

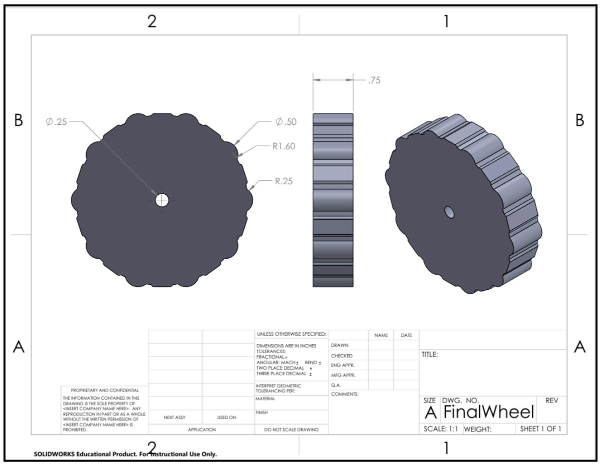

Figure 4.1: Final Wheel

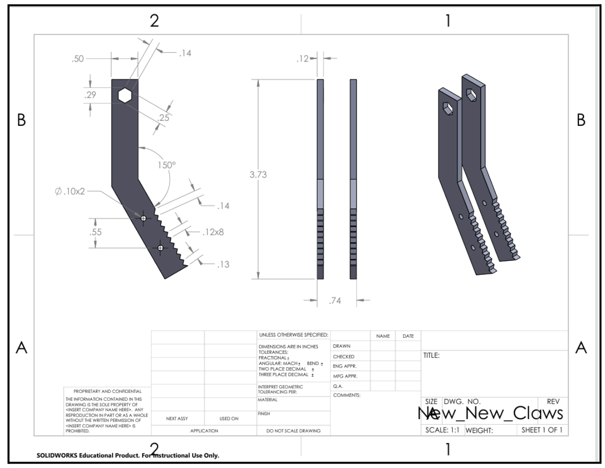

Figure 4.2: Claw

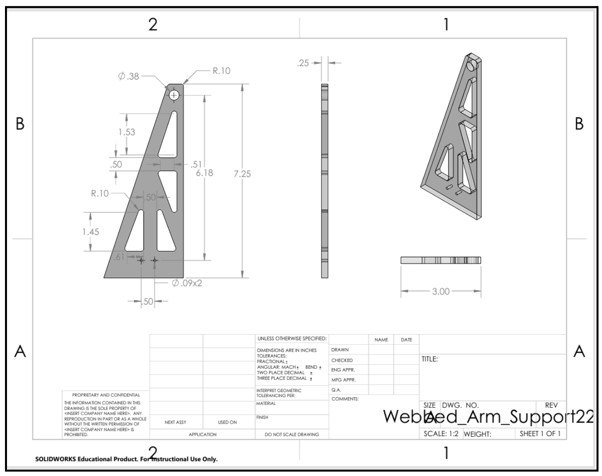

Figure 4.3: Arm Support

4.2 Final Assembly

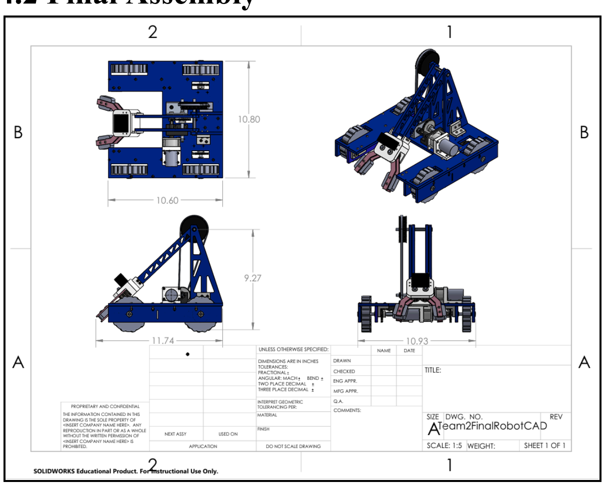

Figure 4.4: Final CAD Drawing

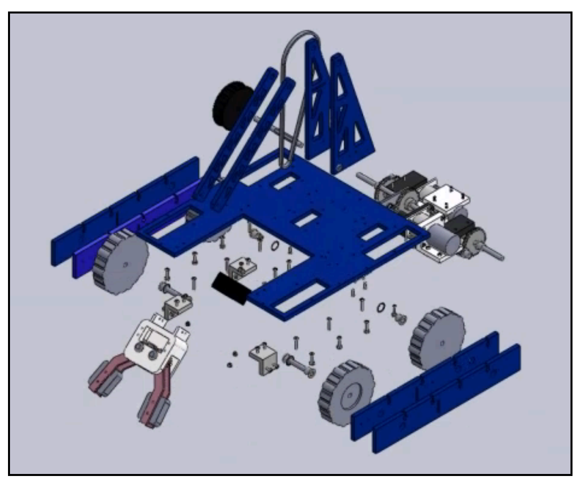

Figure 4.4: Exploded View

4.2 Robot Photographs

Figure 4.6: LeBot James scoring a block on the first level

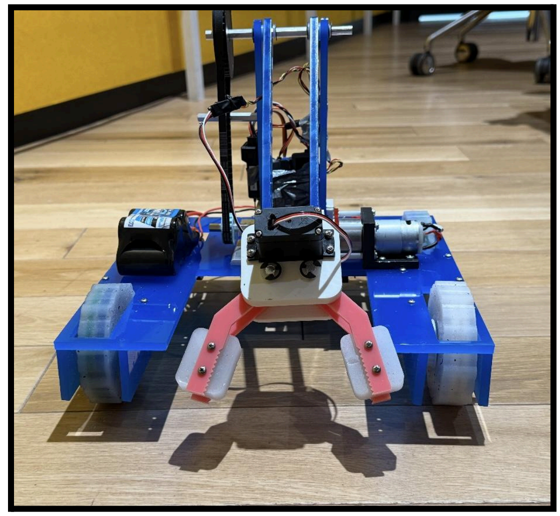

Figure 4.7: LeBot James at its starting position

Figure 4.8: LeBot James scoring a tennis ball on the second level

Contributions:
Marwa
- Concept development
- Final Solution
- Bill of Materials
- Drawings

Alex
- Concept development
- Analysis
- Final Specifications
- Bill of Materials