Design Tools II Final Report

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1 Design Summary

The overall design for the delivery robot has evolved since the first ideation deliverable. The chassis will remain a rectangular base, utilizing the rear area to house all the motors, batteries and receivers. The robot is rear wheel drive, with two motors individually connected to the two rear wheels in order to achieve the desired torque and RPM. The steering mechanism has changed from skid steering to Ackerman steering. This eliminates any concern with horizontal friction acting on the wheels when they slide, since the Ackerman steering will rotate the front wheels at different angles to create a smoother turn. As the team continued in the design process, focus shifted to designing the Task E mechanisms. As a challenge, the goal was set to accomplish two Task E tacks, both the raising of the payload and the opening of the lid. The final design utilizes a scissor lift to raise the payload and a string to open the lid. The scissor lift is driven from a threaded rod running the length of the robot. As the rod rotates it drives a horizontally fixes beam along the length, converting the motors rotational motion into the linear motion which will contract and expand the scissor lift. As the scissor lift raises the payload, a fixed length of cord affixed to the base frame and the lid of the payload will become taut which will pull down on a rod attached parallel to the box lid.

2 Concept Generation

For the original product design, multiple iterations for each subsystem were compared against each other. During the brainstorming phase, each member of the team separately came up with some ideas for the different components of the GrubHub Robot; the different components brainstormed were chassis design, steering system, and a mechanical task E component, shown in Figure 1.

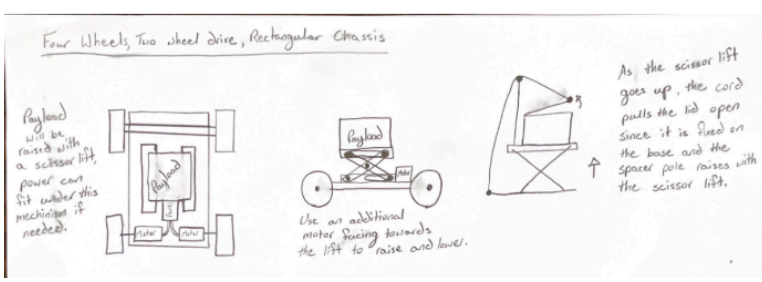


Figure 1: Inital sketch that would become the final design.

Similar ideas were then compiled together, and the final subsystems were determined using a decision matrix. The original decision matrix can be found below in Figure 2.

The issue: Chassis	Weight (ensure sum of weights = 100)	Square (same plane)	Rectangle (Payload above)	Trapizoid	The Tank	Hovercraft	Dog
Feasibility - time	15	8	8	5	6	4	3
Feasibility - manufacturing	15	7	7	4	5	3	2
Feasibility - budget	12.5	8	9	6	8	4	4
Weight	12.5	4	5	7	6	8	2
Available Space (Payload)	20	6	7	5	9	6	3
Aesthetic	5	3	4	7	8	10	10
Available Space (Mechinism)	20	5	6	4	7	4	3
Total	100	41	46	38	49	39	27
Weighted Total		610	680	512.5	700	505	320

Figure 2: The original decision matrix.

Although ”the tank” won the decision matrix, during the design process there were a few problems that arose with the steering and the cost. The concern with the skid steering was with the robot’s ability to turn in an off-road setting. In a real world setting this is not a problem for larger machines, however for the scale of the robot it would require much more powerful motors. As such, the team transitioned to the second design, a rectangular chassis with an Ackerman Steering system.

2.1 Task E Design

The Task E design was based on scissor lift style mechanisms. The scissor lift would mesh with the payload container. Attached to the payload container, there was a cord that would also open the box, as the scissor lift raises it. Figure 3 shows an image of the design of the scissor lift.

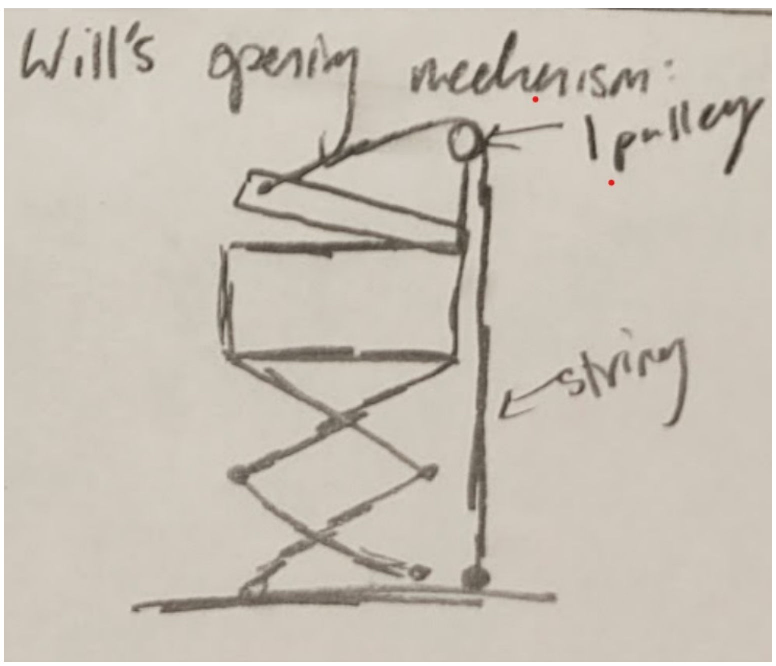


Figure 3: The initial design of the scissor lift/payload opener.

The design was not changed during the creation of the robot.

3 Design Calculations

3.1 DC Motor Calculations

During the DC motor analysis, two motors were found to fit our needs: 312RPM, 24.3[kgf-cm]; 435RPM, 4.7[kgf-cm]. Both of these motors were around the same price, but one of the 312 RPM motors was repurposed from the spare parts drawer. Due to budget constraints the 312RPM motor was selected, to ensure enough budget for the other subsystems.

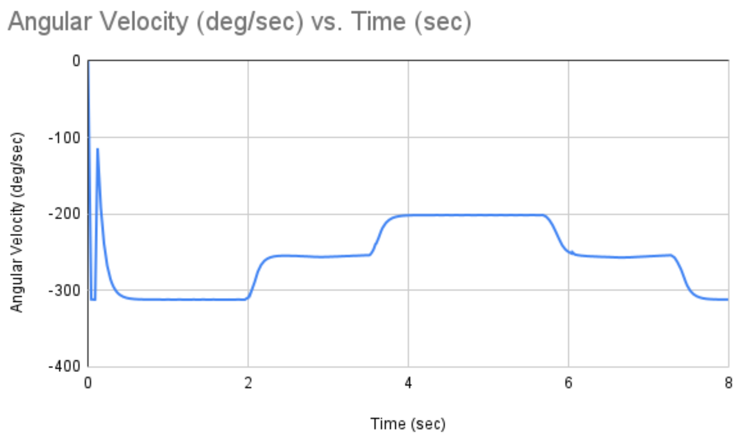


Figure 4: Angular Velocity versus time for 312RPM motor

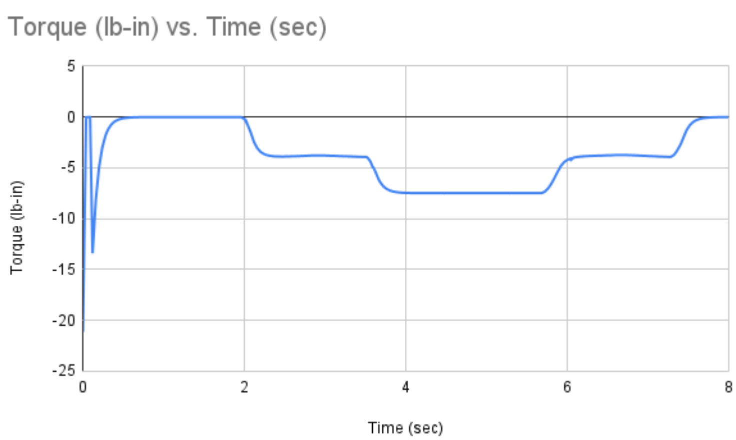


Figure 5: Reaction moment versus time for 312RPM motor.

3.2 Servo Motor Calculations

The calculations for the servo motor which turns the Ackerman steering was based off Equation 1.

$$T_{kp} = W\mu\sqrt{\frac{I_0}{A} + E^2} \tag{1}$$

Where T_{kp} is the kingpin torque, W is the weight on the axle, μ is the coefficient of friction, E is the kingpin eccentricity, and I_0 is the polar moment of inertia of the tire. A simplification can be made if the tire is assumed circular, which is a reasonable assumption, the polar moment divided by the area simplifies and Equation 2 is produced.

$$T_{kp} = W\mu\sqrt{\frac{B^2}{8} + E^2} \tag{2}$$

Where B is the thickness of the tire. When performing the calculations, the values for these parameters were overestimated and a factor of safety was included to make sure that the servo selected would be more than capable of producing the torque required to turn the steering system. The parameters used for the calculations are recorded in Table 1

Table 1: Parameter Values for Calculations and Calculated Kingpin Torque from Equation 2

Description	Value
Weight on Axle	5 [kg]
Coefficient of Friction	1
Kingpin Eccentricity	5 [cm]
Thickness of Tire	4.5 [cm]
Factor of Safety	1.5
Calculated Kingpin Torque	39.35 [kg cm]

From Table 1, a 40 [kg cm] torque servo was confidently selected as the calculations included both overestimations of the parameters and a reasonable factor of safety.

3.3 Finite Element Analysis

The overall design has not changed since Homework 4: FEA Analysis. However the boundary conditions will be explained a little more clearly. First, the properties of the cup are assumed to be that of a 8 oz cup of water, allowing the mass to be approximated as 257g. With this, a boundary condition for the FEA analysis was applied to the upper ring within the cup, saying the force of the cup will be 2.52N. The applied loading can be seen in Figure 6. Additionally, the materials applied during the simulation tried to closely match their real life counter part. For the main body of the cup holder, ABS plastic was used to match the PLA used in the EIH. For testing purposes PLA is a stiffer and stronger material than ABS, meaning the simulation will underestimate the projected strength of the design.

Additionally, during the FEA analysis the displacement of the cup holder was tested and compared against the experimental displacement. Using SOLIDWORKS, the projected displacement was

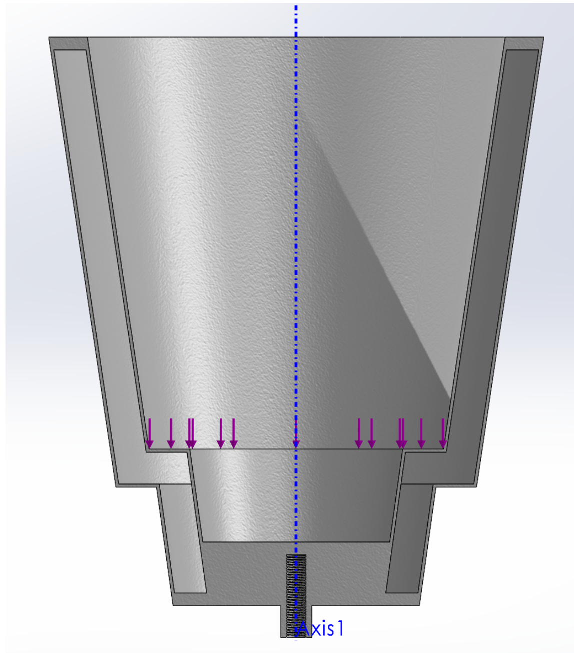


Figure 6: Applied force boundary conditions for FEA analysis.

$5.05e^{-4}$ mm, however the actual displacement was much larger at 0.127 mm. The discrepancy between these two numbers could be from the way that SOLIDWORKS analyzed the cupholder. With the static test, the cupholder was only tested in the direction of the force applied. Which produced the amount of compressive displacement the cup would endure under the testing conditions. Due to the small contact area, the experimental displacement took in other factors such as the leaning angle of the cup.

3.4 Steering Mechanism

For the Ackerman steering system calculations were done to determine the length of the connecting rod when the link length was specified. The model also takes into consideration that the wheels will be constrained such that they cannot rotate past the vertical line shown as this represents the frame. The length of the link was set to 1.5 inches which meant the connecting rod had to be 10.6 inches long. It is important to note that this is the length from the actual joints of the two links, and since the connecting rod had two female ball links one each end, it was actually cut shorter to 10.25 inches. The overall dimensions of the links can be seen in Figure 7.

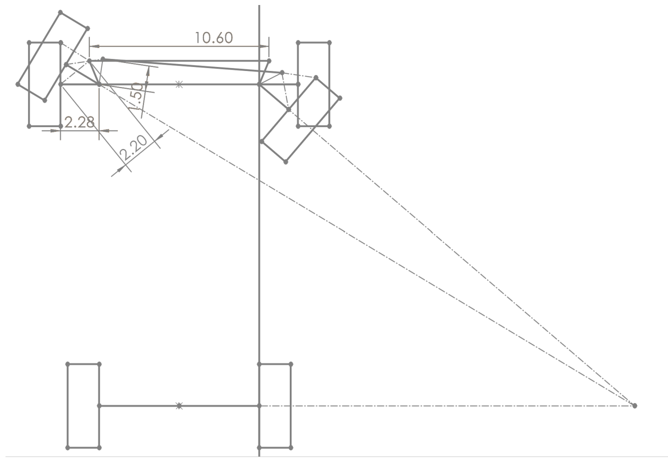


Figure 7: Ackerman steering system reference calculations.

3.5 Task E Calculations

Task E consisted of three possible options with the requirement of only completing one. The team decided to attempt two of the tasks, both raising the payload 2.5 feet above the ground and automatically opening the lid of the payload. The payload was lifted using a scissor lift powered by a third DC motor. Since this lift had to raise the payload up 2.5 feet, it was determined that the lift itself needed to be able to extend 20 inches from its rest configuration. Since the scissor lift would become thinner as it raised, it was important for stability purposed that the required height could be reached without the scissor lift to compress too much. It was reasoned that the absolute minimum the scissor lift should compress would be 6 inches between the the end points. The length of the links were constrained to 12 inches due to the purchased stock material. With basic geometry, it was calculated that when the links were oriented 6 inches apart, they would have a vertical height of 10.39 inches. This meant that with two links, the scissor lift would be able to raise the payload an additional 20.78 inches from the base configuration, which was just above what was needed for the payload to reach the 2.5 feet height requirement of task E. As for the opening mechanism, the goal is to use a simple pulley system that works in harmony with the scissor lift. the rope of the pulley would be connected to the top of the payload and the base of the scissor lift, with the pulley located above the back of the of the top of the container. As the payload is lifted up the restricted length of the rope forces the container to open. The length of cord needed to accomplish this was determined by raising the scissor lift to the desired height, opening the lid of the payload to the desired opening and then measuring from the extended metal beam down to the front U-channel where the cord would be attached. This length was found to be 20 inches and so the cord was cut a little longer to allow for knots to be used to affix it to both components.

4 Evaluation

During the design process, several major changes were made to the initial design. The first was changing the steering system from tread-based to an Ackerman steering system. This was done partially to simplify the design process, but also to improve the speed of the robot to help meet the delivery time requirement. It was feared that the skid steering of the treads would turn much more slowly than the Ackerman steering. One disadvantage of switching to an Ackerman system is a greater turn radius, compared to the nearly zero turn radius of the tread system. This change resulted in a turn radius above 6 inches, which was the target specified earlier in the design process. The actual mechanism of the steering system had to be redesigned, once it was realized that the rotational motion of the threaded rods connecting the wheels to the knuckles could cause the rods to detach from the knuckles. The switch to non-threaded rods also simplified the assembly/disassembly process, which was a customer requirement identified early in the design process. Finally, the scissor lift mechanism for Task E was redesigned, after the first iteration didn't function. Flaws in the original design were identified and corrected, so that the payload could be raised from the height of the robot. In the final iteration, the top of the payload container was able to reach 2.5 ft above the ground when the lift was in its extended position, meeting the requirement. However, one of the engineering specifications the team developed was to be able to open the lid of the payload container in no more than 5 seconds. Due to the slow speed of the motor driving the lift mechanism, and the opening of the container being contingent on the lift extending, it took well over 5 seconds for the lid to open.

5 Team Task Division Table

Task Table

Task	?	Noah (%)	Jack (%)	Greg (%)	Will (%)
TEAM MANAGEMENT					
Meeting Minutes	C		75		25
SOLIDWORKS MODELING					
Modeling (*Cup Holder*)	C			100	
Modeling (*Ackerman Knuckle*)	C				100
Comprehensive Model - Initial	C		100		
Comprehensive model updating	C		60	15	25
Motion analysis - geometry check	C	100			
Motion analysis - DC motor incorporation	C	100			
FABRICATION					
Sourcing stock	C		25		75
Purchasing stock	C				100
Reserve machine time	C		25	75	
Fabricate (*Scissor Lift*) with *(all available tools)*	C	25	25	25	25
Fabricate *(Base Plate)* with *(Bandsaw)*	C	25	25	25	25
Sourcing motor	C	75			25
3D printing x part	C			100	
Electrical system	C	25	25	25	25
DELIVERABLES - GENERAL					
Budget creation and updating	C		50		50
Project schedule creation and updating	C	100			
Team task table tracking and updating	C	50			50

6 Final Project Budget

The final project budget can be found at the end of the Appendices. Of the $250 budget, a combination of resourcefulness and bargaining led to only $208.49 being spent.

DELIVERABLES - SPECIFIC					
Ideation Sketch #1 and BOM #1	C	50	50		
Ideation Sketch #2 and BOM #2	C			50	50
D3 Organization and Submission	C	25	25	25	25
D4 Part 1a Writing	C			50	50
D4 Part 1b Writing	C			100	
D4 Part 1c Writing	C			100	
D4 Part 1d Writing	C			100	
D4 Part 1e Writing	C			50	50
D4 Part 1f Writing	C			100	
D4 Part 4 Writing	C	50			50
D4 Organization and Submission	C			100	
D7 Part 1 Writing	C	10	10	40	40
D7 Part 2 Writing	C	5	15	35	45
D7 Part 3 Writing	C	35	25	20	20
D7 Part 4 Writing	C	100			
D7 Part 7 - Drawings	C	5	20	70	5
D7 Organization and Submission	C	5	80	10	5

Legend

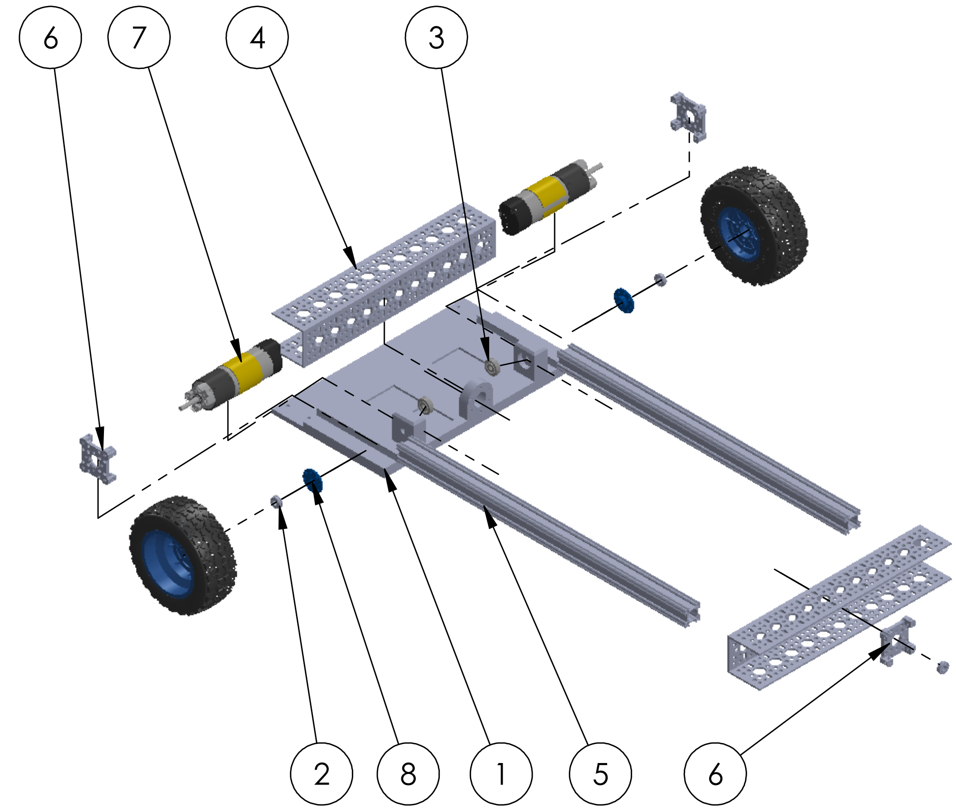
C = Task Completed
P = In Progress
N = Not started yet

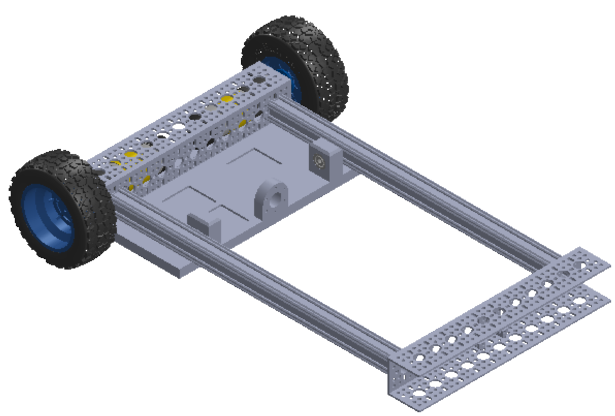
7 Drawings

The sub-system assemblies with exploded views and relative bills of materials are shown in Appendix A. Appendix B shows the entire system, without an exploded view or bill of materials in order to improve clarity.

Appendix A - Sub-System Assemblies

ITEM NO.	PART NUMBER	QTY.
1	BasePlate2	1
2	6mm ball bearing	3
3	5mm ball bearing	2
4	288mm U-Channel	2
5	423mm Go Rail	2
6	motor mount	3
7	motor	2
8	shaft collar drive wheels	2
9	Right Wheel	2





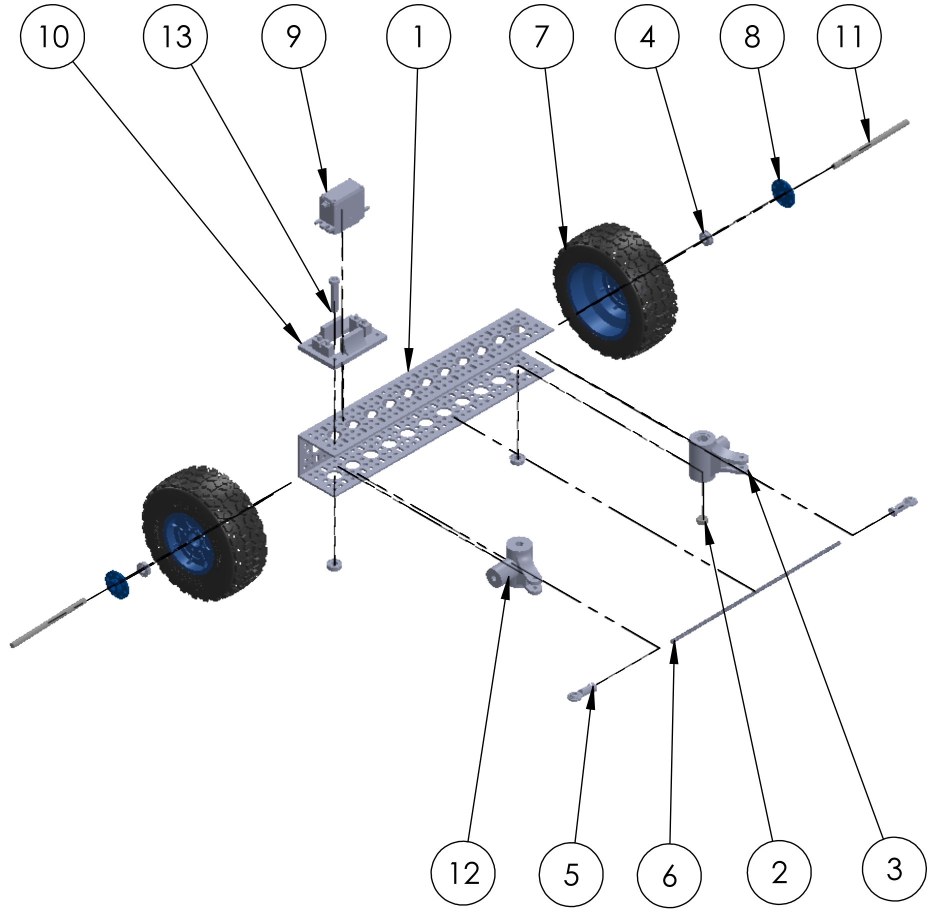
ND ENGINEERING

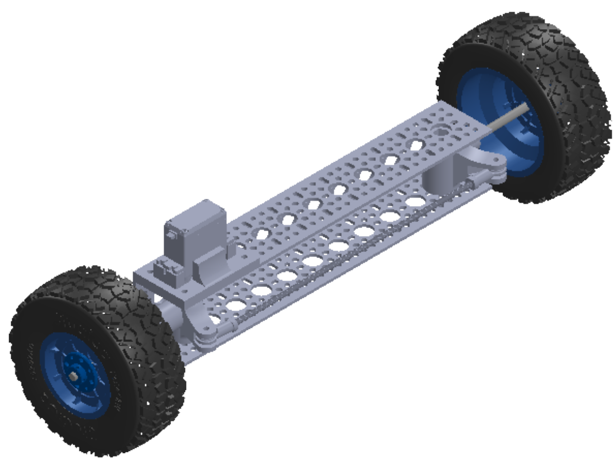
CHASSIS_DRAWING

PROPRIETARY AND CONFIDENTIAL

SIZE	DWG. NO.	REV
A	1	
SCALE:8		SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	288mm U-Channel	1
2	M6 x 1mm Hex Nut	1
3	Ackerman Knuckle	1
4	6mm ball bearing	4
5	Female Link	2
6	300mm M4 Shaft	1
7	Wheel	2
8	Wheel Shaft collar	2
9	Mock Servo	1
10	Servo Bracket	1
12	AckermanKnuckleRight	1
13	Servo Adaptor	1



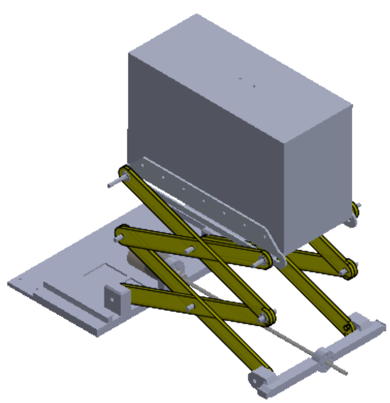


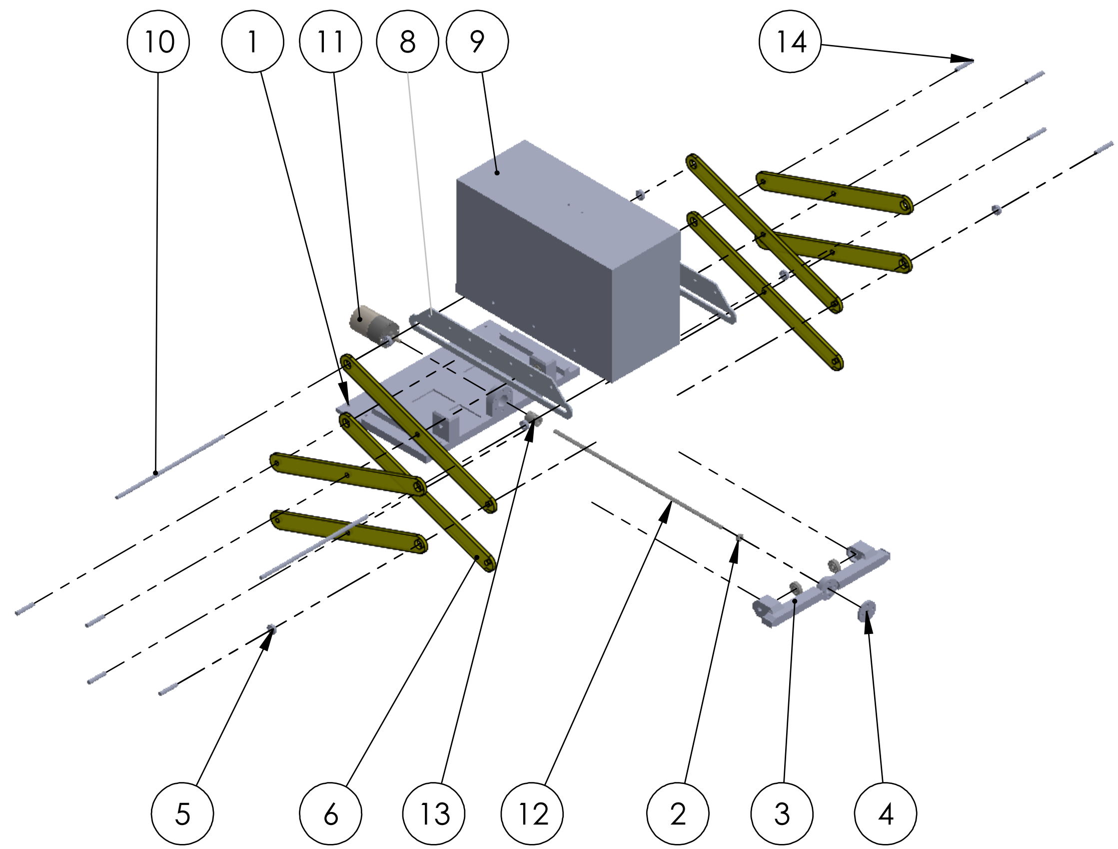
ND ENGINEERING

TITLE: Steering Sub-Assembly

SIZE	DWG. NO.	REV
A	2	
SCALE: 1:10		SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	BasePlate2	1
2	Hex Nut	1
3	ScissorLift	1
4	LiftLockingMechanism	1
5	6mm ball bearing	8
6	acrylic scissor lift arm	8
7	5mm ball bearing	4
8	payload attachment	2
9	Payload_Container	1
10	scissor lift main shaft	2
11	DC_motor_Greartisan	1
12	18-8 Stainless Steel Threaded Rod	1
13	Set Screw Shaft Coupling	1
14	scissorliftmidshaft	8





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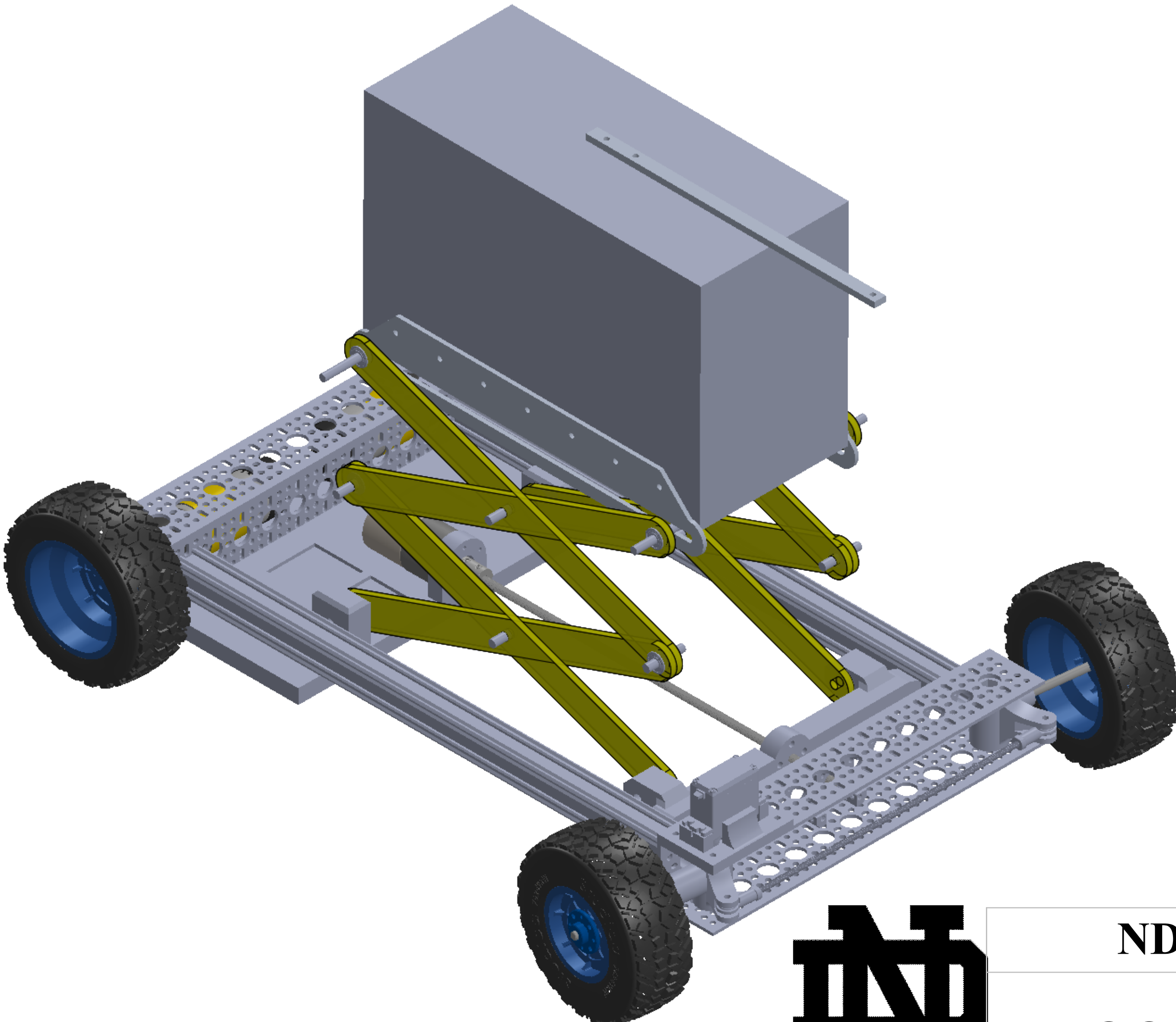
SCISSOR_LIFT_DRAWING

SIZE	DWG. NO.	REV
A	3	
SCALE: 1:16		SHEET 1 OF 1

Appendix B - Comprehensive Assembly



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COMP_ASSEMBLY		
SIZE A	DWG. NO. 1	REV
SCALE1:4		SHEET 1 OF 1

Link	Quantity	Cost	Total		Ordered:		Ordered
goRail	2	11.29	$19.20				Recieved
U-Channel	1	13.99	$11.89	only need to buy 1			Not Orded
Motor Mount	1	6.99	$5.94	only need to buy 1			
M6 Threaded Rod	1	6.74	$6.74				
Wheels	1	39.99	$39.99				
Scissor Lift Motor	0	14.99	$0.00	alr have			
Wheel Shaft Hubs	1	9.99	$9.99				
Wheel Motors	1	42.99	$36.54	only need to buy 1			
Shaft Coupling	1	5.58	$5.58				
Female Ball Links	1	4.99	$4.24				
M4 Threaded Rod	1	3.99	$3.39				
M6 Nuts	1	3.14	$0.00	Generous Donation			
Servo	1	22.99	$22.99				
Servo Shaft	1	9.99	$0.00	Generous Donation			
			$0.00				
Shipping	1	42	$42.00				
Total Spent:	**$208.49**						
Left:	**$41.51**						