Teddy Bear Wheelchair Final Team Report

0104-10, Japan

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Date: November 24, 2022

Prepared for: Professor J. Donald and Professor S. Mattucci

Statement: The authors take shared credit and responsibility for the content within this report.

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1.0 TBWC Summary

1.1 Introduction

Section 0104, Team 10, consists of 5 multidisciplinary engineering students representing Japan. Following our prototype test, we designed and built a completely new Teddy Bear Wheelchair to perform in the hurdles, tipping, mass, and archery competitions.

Our goal, when designing our final Teddy Bear Wheelchair, was to work collaboratively to design and construct a wheelchair that was safe, consistent, and aesthetically pleasing. We have successfully created a long and sleek chassis with two layers to accommodate the teddy bear, breadboard, Arduino, batteries, launcher and two motors which is notable in the various technical view of our wheelchair. Our vehicle is front wheel and two-wheel drive, which we were able to accomplish by securing the wheels to the axel and powering the axel directly with a pulley system. The tires are spaced out enough to stabilize the chassis and elevate it off the ground to clear obstacles. The launcher is located on the right side of the top layer, conveniently balancing the motor weight evenly across the body. It consists of a simple SolidWorks “spoon” part that is directly attached to a mouse trap and released with a string connected to a second motor. To tie everything together, our wheelchair consists of many cultural Japanese elements which contribute to our aesthetics and make our design visually pleasing.

The design process was lengthy and consisted of many phases of design, especially error analysis as well as team dynamic re-adjustments. Overall, we succeeded in yielding consistent, acceptable results with room for improvement.

1.2 Pictures

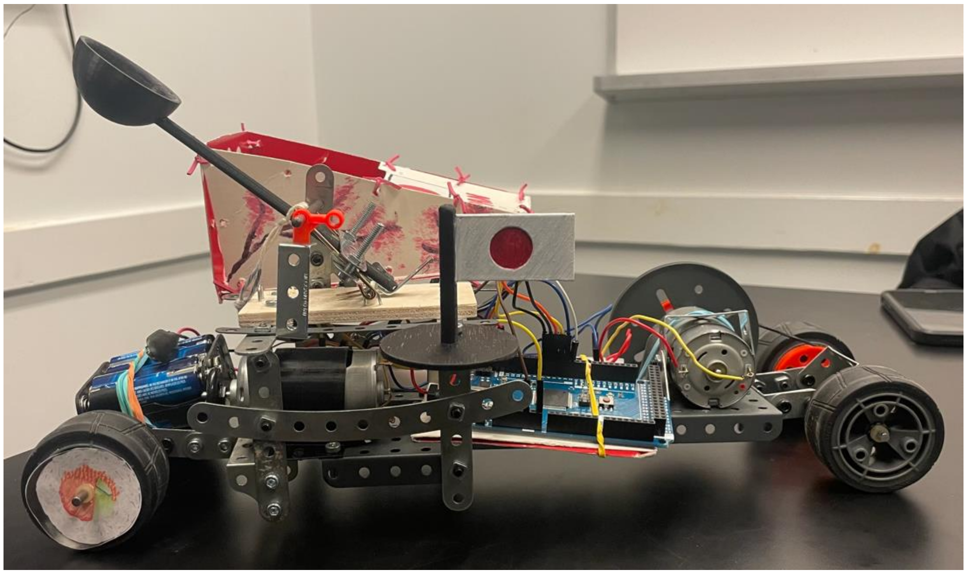


Image 1: Side View

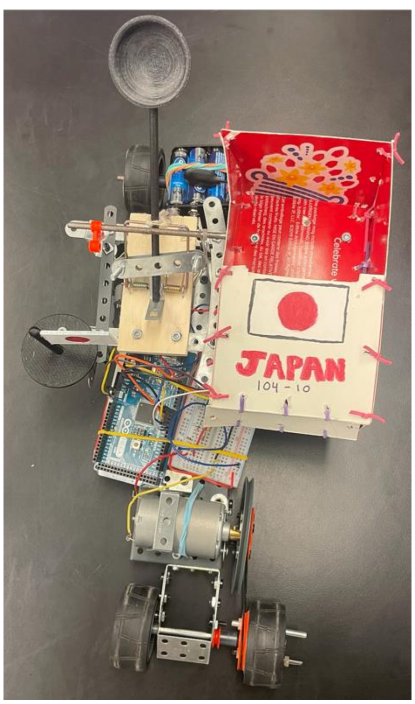


Image 2: Top View

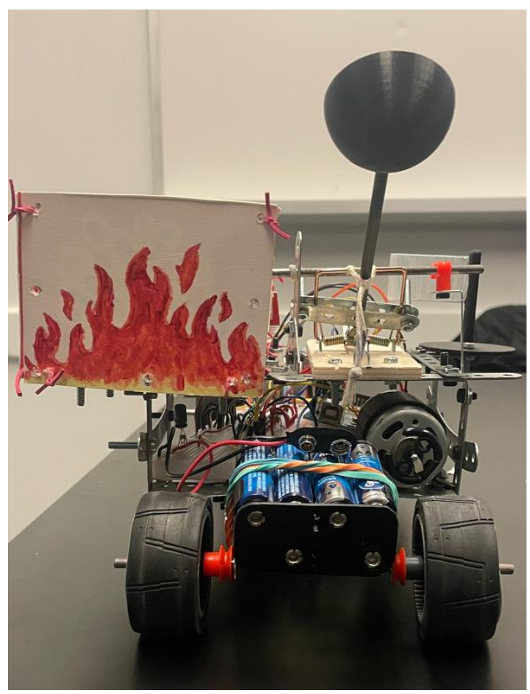
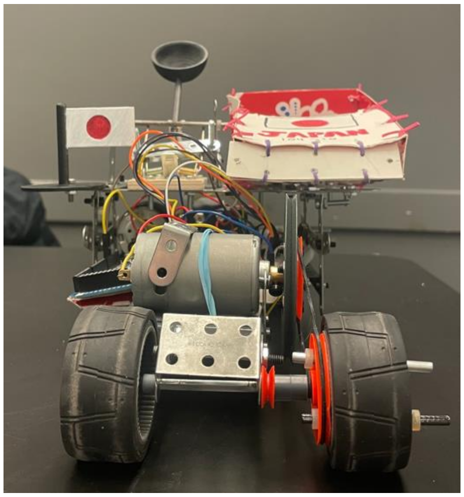


Image 3: Rear view



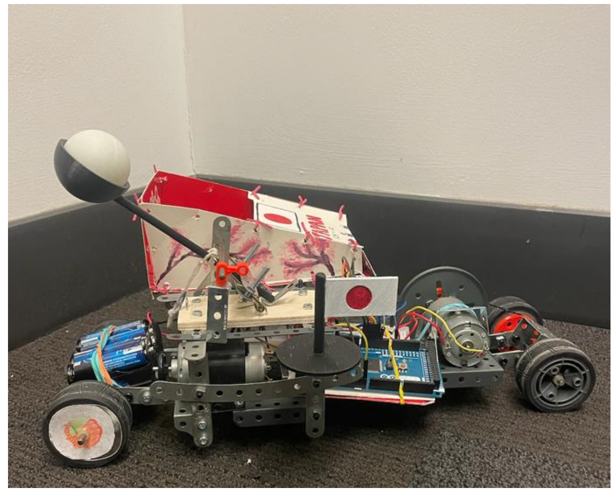
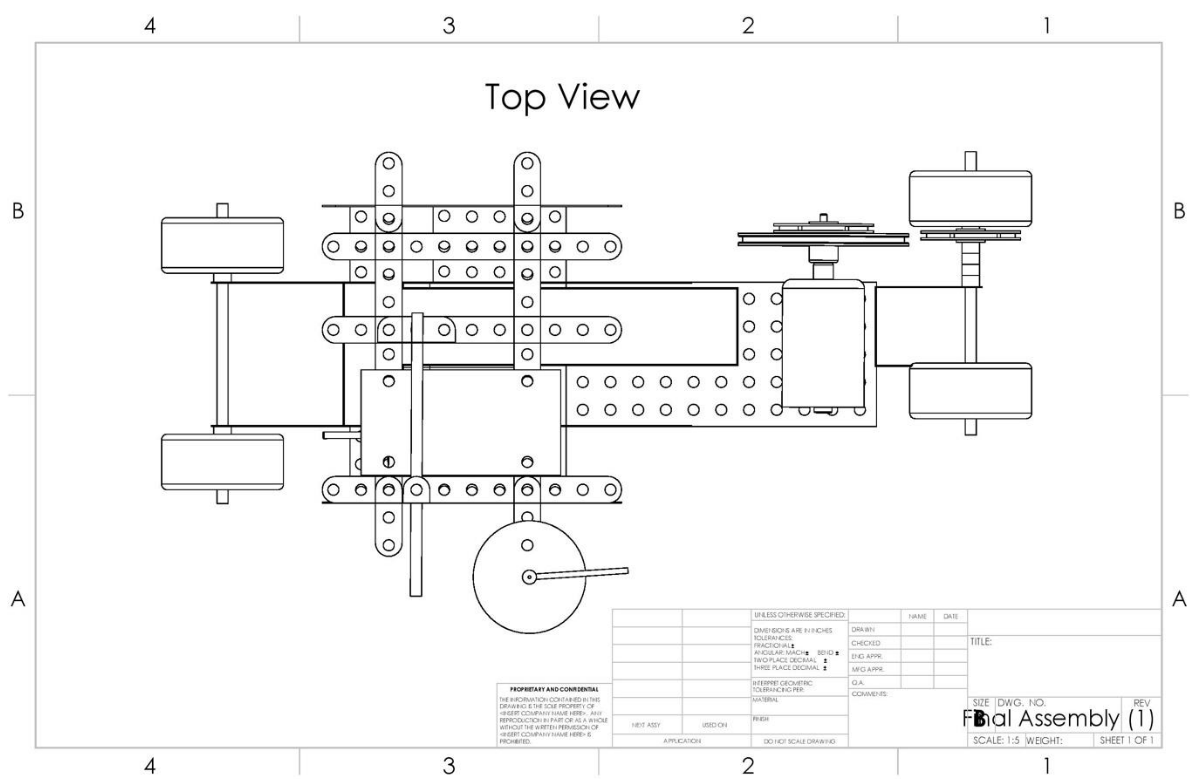


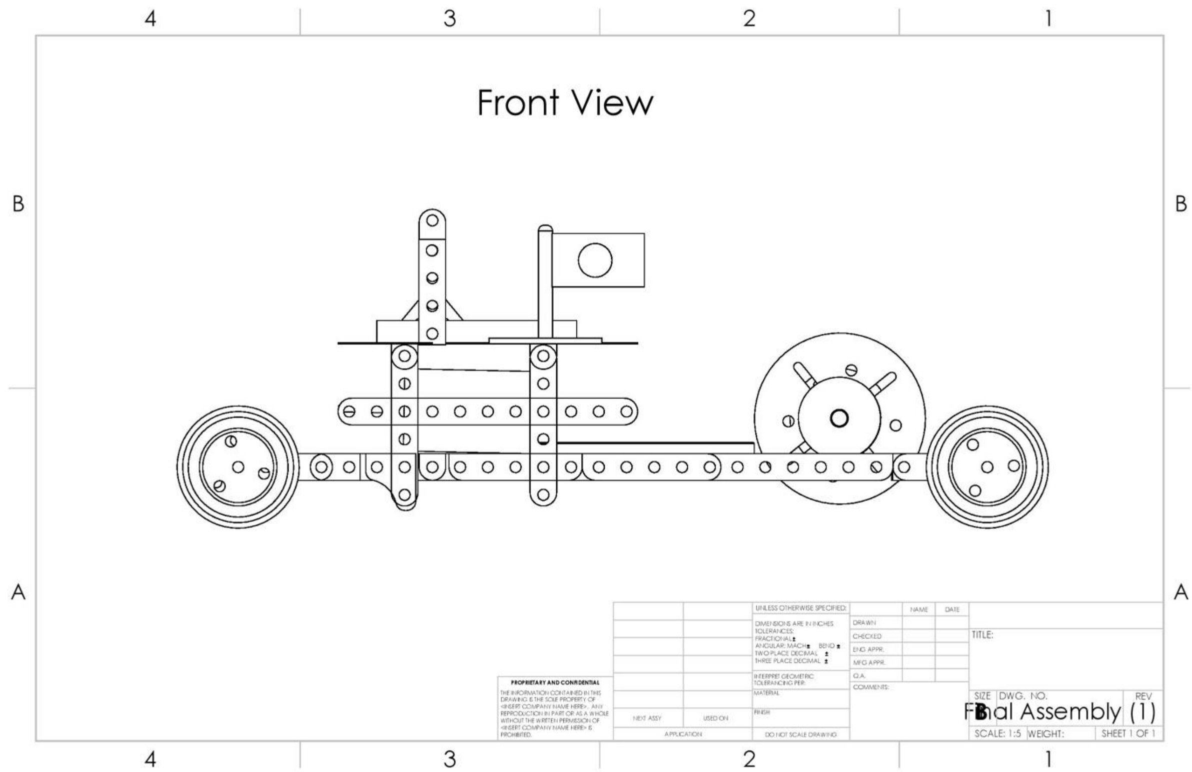
Image 4: Front View

Image 5: Isometric View

1.3 Technical Views

1.3.1 SolidWorks 2D





Front View
Final Assembly (1)
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SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
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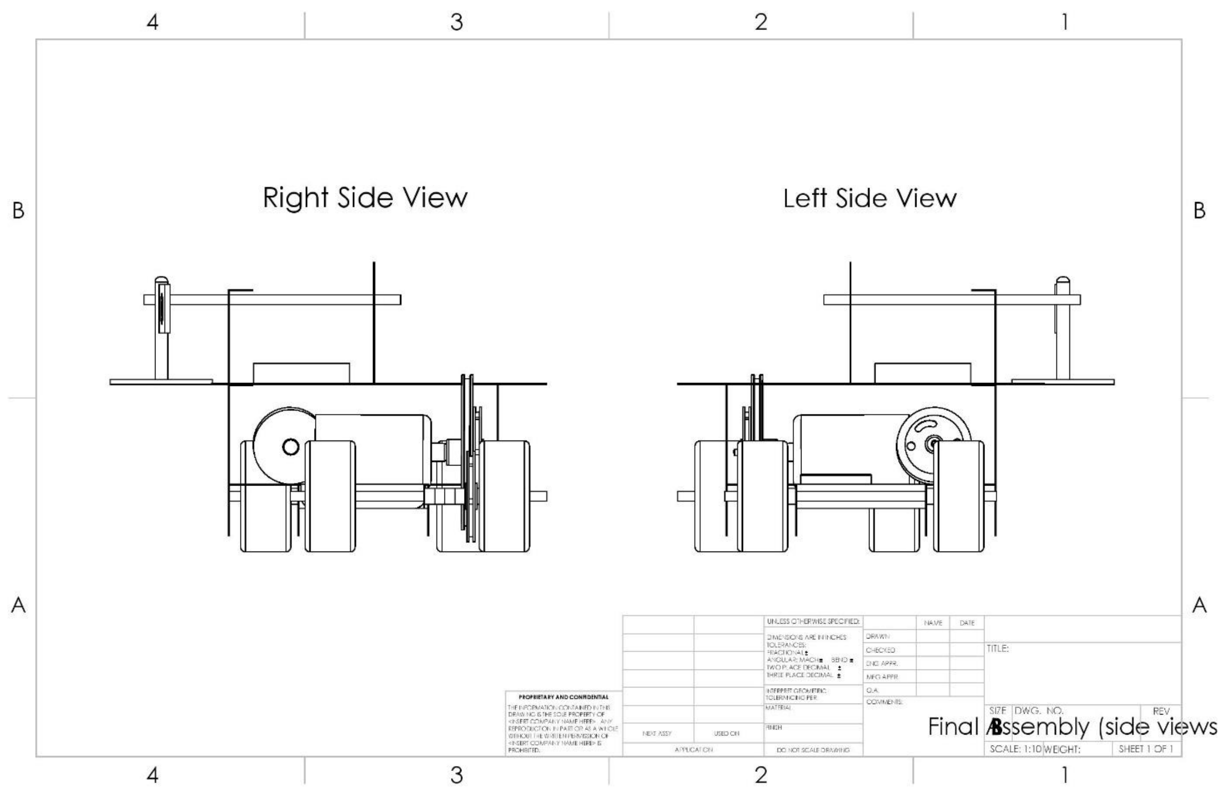

Right Side View
Left Side View
Final Assembly (side views
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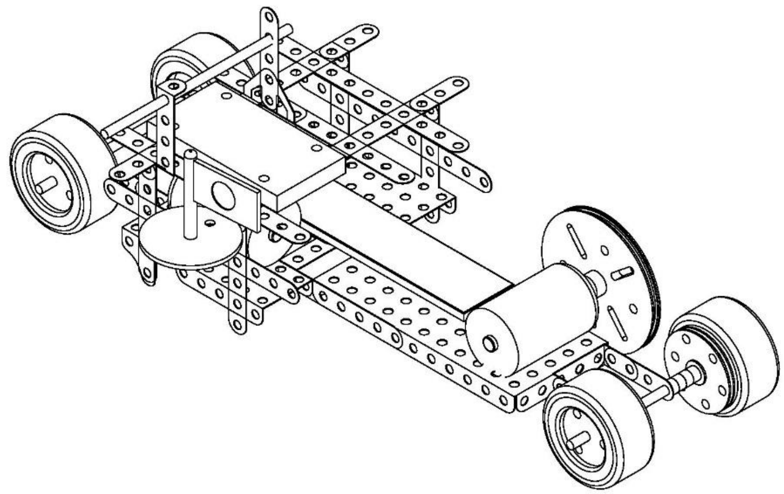
Isometric View



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			Q.A.		
			COMMENTS:		

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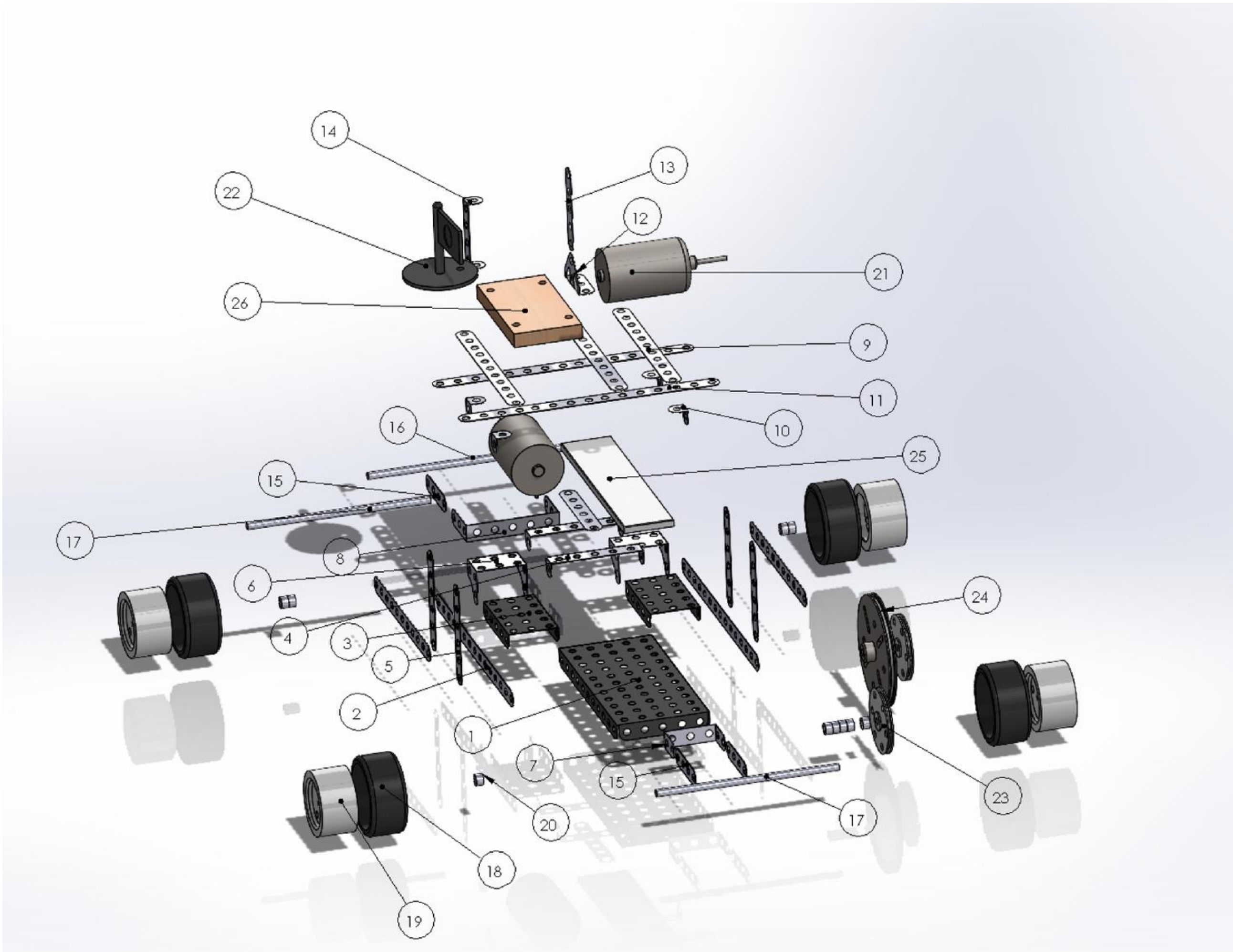
SIZE	DWG. NO.	REV
B	Final Assembly	(1)
SCALE: 1:10	WEIGHT:	SHEET 1 OF 1

1.3.2 SolidWorks Exploded



1.4 Bill of Materials

TBWC Materials (reference views above)

Part	Quantity	SolidWorks Number
Base Piece	1	1
Plate (15 holes)	2	2
Platform Bracket (51F)	2	3
Plate (5 holes)	2	4
Plate (6 holes)	5	5
Bracket, platform with 3 hole curved sides (51D)	2	6
Bracket, 3 hole plate with 2 hole sides (46A)	1	7
Bracket, 5 hole plate with 3 hole side (47)	1	8
Plate (11 holes)	5	9
Small Bracket (12)	4	10
Plate (15 holes)	2	11
Triangle Bracket (126)	1	12
Plate (5 holes)	1	13
Bracket (4 holes with one hole sides)	1	14
Plate (4 holes)	4	15
Long axel	1	16
Small axel	2	17
Tire	4	18
Wheel	4	19

Spacer (large)	10	20
Motor	2	21
3D printed Japan flag	1	22
Medium pulley	2	23
Large pulley	1	24
Breadboard	1	25
Mouse trap base	1	26

1.5 Cost Analysis Tables

Table 1: TBWC Development Cost – SOE Supplied Material

Date	***Material***	***Qty***	***Unit***	***Cost/Unit ($)***	***Cost ($)***	***Cost Source***
2022-09-25	Arduino	1	Indiv.	$40	$40	TBWC Project Document
2022-09-25	Starter AA Batteries	8	Indiv.	$1.00	$8.00	TBWC Project Document
2022-09-25	Large Rod	2	Part	$3.00	$6.00	TBWC Project Document
2022-09-25	DC Motor	2	Indiv.	$20.00	$40.00	TBWC Project Document
2022-09-25	Small Rod	2	Part	$2.00	$4.00	TBWC Project Document

2022-09-25	Wheels	4	Part	$1.00	$4.00	TBWC Project Document
2022-09-25	AA Battery Holder	1	Indiv.	$5.00	$5.00	TBWC Project Document
2022-09-25	Medium Orange Pulley	2	Part	$1.00	$2.00	TBWC Project Document
2022-09-25	Breadboard	1	Indiv.	$5.00	$5.00	TBWC Project Document
2022-09-25	Pulley O-ring	1	Indiv.	$0.10	$0.10	TBWC Project Document
2022-09-25	Nuts, bolts and spacers	3	Bundle	$3.00	$6.00	TBWC Project Document
2022-09-25	Wires	-	Bundle	$5.00	~$5.00	TBWC Project Document
2022-09-25	Motor driver	2	Indiv.	$10.00	$20.00	TBWC Project Document
2022-09-25	Capacitors	3	Bundle	$5.00	~$5.00	TBWC Project Document
2022-09-25	Resistors	2	3-Pack	$1.5	~$3.00	TBWC Project Document

2022-09-25	Large Modular Part (11 Holes)	7	Hole	$0.10	$7.70	TBWC Project Document
2022-09-25	Medium Modular Part (6 Holes)	11	Hole	$0.10	$6.60	TBWC Project Document
2022-09-25	Small Modular Part (3 Holes)	8	Hole	$0.10	$2.40	TBWC Project Document
2022-09-25	Small “L-Shaped” Bracket	6	Hole	$0.10	$1.2	TBWC Project Document
	Total	-	-	-	$171.00	

Table 2: TBWC Development Cost – Team Purchased or Sourced Material

Date	***Material***	***Qty***	***Unit***	***Cost/Unit ($)***	***Cost ($)***	***Cost Source***
2022-10-19	AA Batteries	2	Package	$13.99	$13.99	Walmart
2022-10-19	Elastics	1	Package	$2.99	$2.99	Campus Bookstore
2022-10-19	Acrylic Paint	1	Package	$13.85	$13.85	Walmart
2022-10-19	Paint Brushes	1	Package	$8.99	$8.99	Walmart
2022-10-19	Screws	1	Package	$6.89	$6.89	Canadian Tire
2022-11-11	Cardboard	35	g	$0.01	$0.35	TBWC Project Document
2022-11-18	Mouse Trap	1	Package	$6.99	$6.99	Canadian Tire
2022-11-18	3D Flag	1	Cubic Inch	$5.00	$5.00	TBWC Project Document
2022-11-18	3D Launcher	1	Cubic Inch	$5.00	$5.00	TBWC Project Document
2022-11-18	3D Motor Holder	1	Cubic Inch	$5.00	$5.00	TBWC Project Document
2022-11-18	3D Spacer	1	Cubic Inch	$5.00	$5.00	TBWC Project Document
2022-10-25	Modular Base	1	Part	$6.00	$6.00	TBWC Project Document
	Total	-	-	-	$75.05	

Table 3: TBWC Material Production Cost

Date	Material	Qty	Unit	Cost/Unit ($)	Cost ($)	Cost Source
2022-10-19	AA Batteries	2	Package	$13.99	$13.99	Walmart
2022-10-19	Elastics	1	Package	$2.99	$2.99	Campus Bookstore
2022-10-19	Acrylic Paint	1	Package	$13.85	$13.85	Walmart
2022-10-19	Paint Brushes	1	Package	$8.99	$8.99	Walmart
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2022-11-18	3D Spacer	1	Cubic Inch	$5.00	$5.00	TBWC Project Document
2022-10-25	Modular Base	1	Part	$6.00	$6.00	TBWC Project Document

2022-09-25	Arduino	1	Indiv.	$40	$40	TBWC Project Document
2022-09-25	Starter AA Batteries	8	Indiv.	$1.00	$8.00	TBWC Project Document
2022-09-25	Large Rod	2	Part	$3.00	$6.00	TBWC Project Document
2022-09-25	Small Rod	1	Part	$2.00	$2.00	TBWC Project Document
2022-09-25	Wheels	4	Part	$1.00	$4.00	TBWC Project Document
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2022-09-25	Pulley O-ring	1	Indiv.	$0.10	$0.10	TBWC Project Document
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2022-09-25	Wires	-	Bundle	$5.00	~$5.00	TBWC Project Document

2022-09-25	Motor Driver	2	Indiv.	$10.00	$20.00	TBWC Project Document
2022-09-25	Motor	2	Indiv.	$20.00	$40.00	TBWC Project Document
2022-09-25	Capacitors	3	Bundle	$5.00	~$5.00	TBWC Project Document
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2022-09-25	Large Modular Part (11 Holes)	7	Hole	$0.10	$7.70	TBWC Project Document
2022-09-25	Medium Modular Part (6 Holes)	11	Hole	$0.10	$6.60	TBWC Project Document
2022-09-25	Small Modular Part (3 Holes)	8	Hole	$0.10	$2.40	TBWC Project Document
2022-09-25	Small "L-Shaped" Bracket	6	Hole	$0.10	$1.2	TBWC Project Document
	Total	-	-	-	$246.05	

1.6 Aesthetics Discussion

Our final wheelchair design is long, sleek, and double layered to accommodate all the necessary components. To add to its visual appeal, we have emphasized country pride through the incorporation of various cultural elements. The cherry blossom, traditionally an important symbol in Japan, is located on the teddy bear seat. The cherry blossom is a Japanese flower that is symbolic of new beginnings, transition and reflection. In a similar manner, our team was brought together and like the changing cherry blossoms, we transitioned and continually reflected upon our strengths and areas for improvement. The 3D printed Japanese flag, with its signature colors, in addition to the flag on the teddy bear seat, shows the country's pride and perseverance. Additionally, the wheels have laminated sushi rolls on them, further integrating another fun cultural element into our design.

1.7 Design Process Summary

The design process was quite extensive, as it took our team multiple attempts to build various configurations of the chassis to finalize our current model. Our first prototype consisted of a chassis base using various parts available to as we were missing the main plate. We made three attempts to try to build a base that was be stable and supported all the components of this project; however, we realized that the design was faulty and unstable, and we disassembled what had been built following the week 7 prototype test. Luckily, we were awarded a main component at the prototype presentation, the main plate (part 52), which we incorporated into our final design. We kept the same group roles as before and separated tasks based on skills and interests.

Needs Assessment

Moving forward, our team incorporated the needs assessment design phase into our approach. We discussed and researched new ideas and inspirations for the final design before starting construction, contrary to our approach for the prototype design. For example, we researched pulley and 2-wheel drive systems before deciding to secure a pulley to the front axle and make a 1-to-1 gear ratio to maximize speed and not stress the motor or chassis. Additionally, we researched launching methods and decided on a mouse trap design due to its light weight and incorporation of a 3D printed part.

Synthesis

We executed our ideas during the second design phase. We constructed a long chassis with the medium modular parts and the large base in order to accommodate all the necessary components. We built a second level onto our design to hold the teddy bear and mouse trap. We also added and wired the second motor for the launcher as well as an infrared sensor. The code was prepared to incorporate all these components. The launcher was made with a 3D printed SolidWorks “spoon” part attached to the mouse trap and secured to the base. A string was tied around the mouse trap and spoon and hooked around a gear attached to the second motor. In theory, when the motor was turned on, the spinning would release the string and the ping pong ball would fly as the mouse trap returned to equilibrium.

Design analysis

During the design analysis phase, we tested all the subsystems and thought of ways to improve our design. We found that the main issue with the chassis and drive train was that it did not move forward consistently. This meant that the pulley system was not secure, and the wheels were not spinning in tandem with the axel. Additionally, the infrared sensor did not always detect the black tape due to the speed of the chassis and the chassis would not move backwards despite the coding. We determined that the motor driver was fried and thus prevented the chassis from changing directions. In terms of our launcher, we determined that the spoon did not release consistently and did not shoot high enough.

Implementation

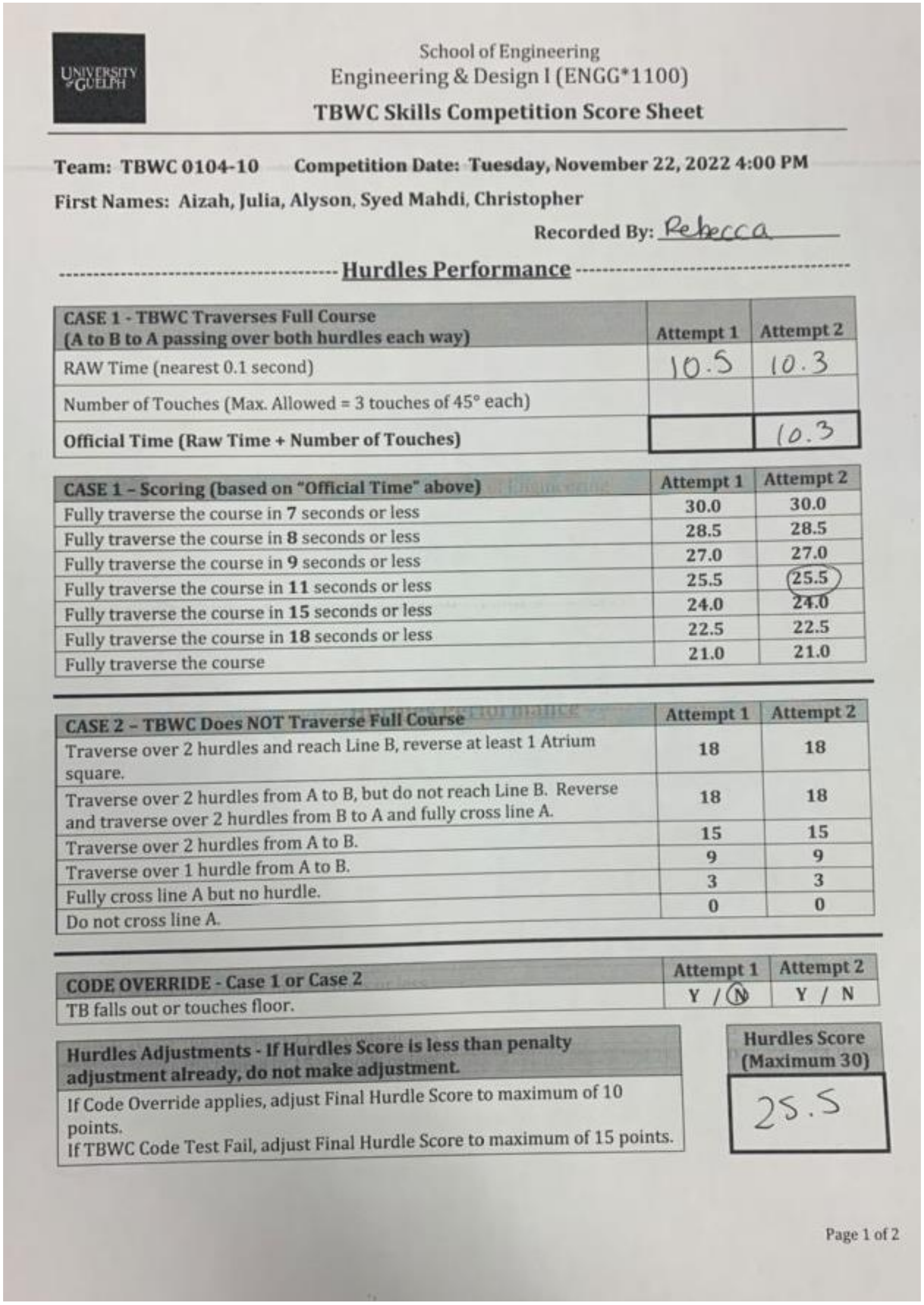
To address the issues determined in the previous design step, we first decided to abandon the infrared sensor idea. The sensor was too weak to detect things considering the speed of the chassis, and coding for timing was a more effective method at maximizing speed. To address the directional challenges of the chassis, we got a new motor driver part and printed a small axel to connect the wheels to the pulley and secure the drive train. To improve the launching mechanism, we added an axel in front of the mouse trap to cause an abrupt stop in motion and release the ping pong ball with more momentum.

Testing and validation

Finally, we tested our wheelchair on the practice fields of play leading up to the competition. Our changes during the implementation stage proved to be effective. The launcher did not shoot high or far enough but there was minimal time to address these issues. Better time management leading up to competition day would have helped us perfect this subsystem.

2.0 Performance Summary

2.1 Testing Document



UNIVERSITY of GUELPH

School of Engineering

Engineering & Design I (ENGG*1100)

TBWC Skills Competition Score Sheet

Team: TBWC 0104-10 Competition Date: Tuesday, November 22, 2022 4:00 PM

First Names: Aizah, Julia, Alyson, Syed Mahdi, Christopher

Recorded By: Rebecca

Hurdles Performance

CASE 1 - TBWC Traverses Full Course (A to B to A passing over both hurdles each way)	Attempt 1	Attempt 2
RAW Time (nearest 0.1 second)	10.5	10.3
Number of Touches (Max. Allowed = 3 touches of 45° each)		
Official Time (Raw Time + Number of Touches)		10.3

CASE 1 – Scoring (based on "Official Time" above)	Attempt 1	Attempt 2
Fully traverse the course in **7** seconds or less	30.0	30.0
Fully traverse the course in **8** seconds or less	28.5	28.5
Fully traverse the course in **9** seconds or less	27.0	27.0
Fully traverse the course in **11** seconds or less	25.5	25.5
Fully traverse the course in **15** seconds or less	24.0	24.0
Fully traverse the course in **18** seconds or less	22.5	22.5
Fully traverse the course	21.0	21.0

CASE 2 – TBWC Does NOT Traverse Full Course	Attempt 1	Attempt 2
Traverse over 2 hurdles and reach Line B, reverse at least 1 Atrium square.	18	18
Traverse over 2 hurdles from A to B, but do not reach Line B. Reverse and traverse over 2 hurdles from B to A and fully cross line A.	18	18
Traverse over 2 hurdles from A to B.	15	15
Traverse over 1 hurdle from A to B.	9	9
Fully cross line A but no hurdle.	3	3
Do not cross line A.	0	0

CODE OVERRIDE - Case 1 or Case 2	Attempt 1	Attempt 2
TB falls out or touches floor.	Y / N	Y / N

Hurdles Adjustments - If Hurdles Score is less than penalty adjustment already, do not make adjustment.
If Code Override applies, adjust Final Hurdle Score to maximum of 10 points. If TBWC Code Test Fail, adjust Final Hurdle Score to maximum of 15 points.

Hurdles Score (Maximum 30)
25.5

Page 1 of 2

Archery Performance

	Attempt 1	Attempt 2	Attempt 3	Total Points
Archery Points (see Scoring Matrix)	5	6	6	17

Scoring Matrix (per shot):

- **10** Hits Bull's eye
- **9** Hits within 2nd ring
- **8** Hits within 3rd ring
- **7** Shoots in air over centre line of Bull's eye at target
- **6** Shoots in air over line at C (8 Blocks from line at A)
- **5** Releases shot in shooting zone
- **4** Releases shot outside shooting zone (before line D, beyond line E)
- **3** Crosses line at D but no shot (ping pong ball doesn't leave TBWC)
- **2** Fully crossed line at A. Does not cross D and no shot
- **0** Does not fully cross line at A
- **0** Teddy Bear falls out on shot
- **0** TBWC tips over

Bulls Eye Adjustment; Apply if greater than Total Archery Points and the Teddy Bear did not fall out and the TBWC did not tip over.
• One (1) Bull's Eye – Minimum Score = 24 Points
• Two (2) Bull's Eyes – Minimum Score = 27 Points
TBWC Code Test Adjustment – Apply adjustment if any Code Test Fails

Archery Score (Maximum 30)
17

TBWC Code 202209a

Static Tipping Fail – Adjust Archery Score to maximum of 10 points		
Static Tipping Test – 4 Directions	Pass	Fail
Security and Comfort Fail – Adjust Archery Score and Hurdles Score to maximum of 15 points each		
Teddy Bear Security and Comfort – Turn Upside Down Test	Pass	Fail
Teddy Bear Security and Comfort – 240° Line-of-Sight - Horizontal	Pass	Fail
Teddy Bear Head higher than rest of Teddy Bear Torso	Pass	Fail

TBWC Mass Scoring

TBWC Mass Scoring	
Less than **1200** grams	30
Less than **1300** grams	27
Less than **1400** grams	24
Less than **1500** grams	21
Less than **1600** grams	18
Less than **1700** grams	15
Greater than or equal to 1700 grams	12

TBWC Mass (Grams)
1527

Mass Score (Maximum 30)
18

Additional Score Overrides

Meccano Kit: Inventoried, fully disassembled and returned on time. (15% penalty)	Pass	Fail
Arduino, Breadboard, Motor, Motor Controllers returned on time.(15 % penalty)	Pass	Fail
TBWC Meets the spirit of the Competition (25% penalty)	Pass	Fail
3D Part check – 1 to 3 parts incorporated into the TBWC (10 % spirit penalty)	Pass	Fail

2.2 Summary Table

Overall, our Teddy Bear Wheelchair met the standard we expected and performed well in comparison to competing wheelchairs. Our results were consistent but did not exceed our expectations. We performed well in the hurdles, safety, and aesthetics sections, but could have improved in the weight and archery sections to maximize our scores. Avoidable errors were primarily due to lack of preparation and minimal use of resources before competition day.

Performance Table

Item	***Performance***	***Notes***
Hurdles Course Times	Test 1- 10.5s Test 2- 10.3s Best: 25.5/30 points	-The wheelchair successfully completed the course for both trials and obtained scores below 11s. -The teddy bear remained safe and secure during both trials. -Small release time and code adjustments were made for the second trial, but the wheelchair performed consistently yielding very similar timing results between trials.
Archery Points	Test 1- 5 points Test 2- 6 points Test 3- 6 points Total: 17/30 points	-We aimed to receive a 6/10 for every shot, as the launcher was only capable of launching small distances. -The timing was slightly off for the first trial and the wheelchair did not

		enter the shooting zone far enough, resulting in the shot not exceeding line C. -The code timing was adjusted for the second and third tests, which successfully produced the results we were looking for. -The teddy bear remained safe and secure during all trials.
Mass Measured (g)	1527g Total: 18/30 points	-The mass was not calculated before the test day and therefore could have been adjusted if we had had access to a scale beforehand. -The extra 3D parts, double layer chassis and "cage" structure likely caused the mass increase.
Safety	Tipping Test- Pass Line of vision- Pass Upside down test- Pass Teddy Bear upright- Pass	-Our wheelchair excelled in the safety tests and passed all required safety regulations. -This was thoughtfully considered during the design process.
Aesthetics	Craftsmanship- 4.6 points Creativity- 4.6 Branding/appeal- 4.0	-Our wheelchair aesthetics were well received by peers and faculty.

	Expression- 4.6 Total: 8.9/10 points	-The points are very consistent for every category, but we could improve in the appeal/expression area.
Mass Calculated (g)	1496.75g	-This mass was calculated via SolidWorks including all major parts. -It is similar to the measured mass (~30g difference). -The slight difference is likely due to the absence of bolts and nuts in the solid works calculation.
Center Mass Location (x,y,z in cm)	(21.47, 8.05, 3.29)	-The center of mass was calculated by taking each major part of the wheelchair and measuring it from a fixed reference point in the x, y, and z axis. -Comparing it with the SolidWorks values, they are quite similar, however have slight deviations, due to human error in taking precise measurements of small parts.
Methane Gas Emission (g CH_3)	9.723g	-This value was obtained via excel by determining the mass of major objects from the chassis, indicating their material and multiplying by the

		standard CH3 emission value (kg/tonne). -It indicates that the production of our chassis does have a reasonable impact on the environment.
Greenhouse Gas Emission (g CO2)	3871.1g	-This value was obtained via excel by determining the mass of major objects from the chassis, indicating their material and multiplying by the standard CO2 emission value (kg/tonne). -It indicates that the production of our chassis does have a considerable release of carbon dioxide emission.
Water Cyanide Contamination (g CN)	0.0521g	-This value was obtained via excel by determining the mass of major objects from the chassis, indicating their material and multiplying by the standard CN emission value (kg/tonne). -It indicates that the production of our chassis does have a small amount of cyanide emission.

Battery Consumption	8x3 batteries	-One pack of batteries was used during the design and testing process, one when coding for the timing distances and one for test day.

3.0 Reflection

3.1 Hurdles and Speed

Our wheelchair received 25.5/30 points for being under 11s for both the hurdles' trials. Our wheelchair performed slightly better with a difference of 0.2s after a minor code and release time adjustment for the second trial. The timing results are very consistent, and the wheelchair moved straight, which were key components we aimed for in our design process. Although the wheelchair was slightly slower than expected, we were quite pleased with our results. With this said, we realize that a decreased weight would have resulted in faster times. Had our group tested the wheelchair with the teddy bear before competition day, it could have helped us determine the speed for the code and possibly decrease the time. Our wheelchair performed well in this section without compromising teddy bear safety and not testing the limits of our chassis.

3.2 Archery

The launching mechanism was completely re-invented in comparison to the original prototype design. Like the hurdles and speed competition, the launcher performed consistently, moving and shooting straight each time. We had to adjust our goals and expectations leading up to the competition day as our launcher did not have enough power or height to reach the target whatsoever. Instead, we aimed to make sure the launcher released in the shooting zone consistently each time and passed the “C-line”. We were able to achieve this other than a slight timing issue during the first test where the wheelchair did not enter the shooting zone far enough. To improve in this area, the launcher could have been mounted vertically to gain height and could have been pulled back further towards the motor and more taught to gain stored energy for release.

3.3 Mass

The mass results were disappointing and did not meet our expectations. We could have avoided extra mass if we had had access to a scale prior to the competition and adjusted accordingly. The extra mass is primarily due to the addition of various extra structural components such as the second layer design and “cage” structure to hold everything in. These elements could have been replaced with elastics to limit mass. The chassis could have been more compact by stacking the Arduino and electrical components instead of lengthening the chassis to accommodate them. The aesthetics pieces also added extra mass, such as the flag and teddy bear chair. Perhaps the flag could have been replaced with a lighter cardboard version.

3.4 Aesthetics

The aesthetics of our design were well received by faculty and peers. We excelled in this area and ultimately received a grade of 8.9/10. We incorporated many cultural elements such as cherry blossoms, a flag and sushi wheels into our design. Our aesthetic choices were simple, yet effective, in conveying cultural pride and appreciation. The points we received in the areas of craftsmanship, creativity, and expression were very consistent; however, we lacked branding and appeal. This is because our cultural elements lacked originality and integrity. Our wheelchair was not easily identifiable as “team 10”. We could have amped the integration of team 10 elements to represent our “brand”.

3.5 Safety

Our wheelchair met all the safety requirements as expected. It completed all courses safely with the teddy bear secure. This was something we ensured and tested in our design process. The tipping test was tested in advance to ensure the chassis met the standards. The "toboggan" shaped teddy bear seat functioned well, as it was lightweight and allowed the teddy bear to securely sit upright but fall out when turned upside down. Additionally, our motor holder 3D part kept the launcher motor secure. This could have been replicated with the main motor to maximize security. The wires from the bread board are quite messy, which could be considered a hazard. A box of some sort could have been built around the breadboard to isolate it from the teddy bear and thus maximize safety.

3.6 Cost Analysis

Our wheelchair has a total production cost of $246.05. This is quite expensive as we did not consider cost during the design process. As mentioned before, the chassis was made with more components than necessary, ultimately sacrificing the weight and cost of the wheelchair. Limiting the extra components would in turn lessen the total cost. Based on our cost analysis tables, there were many team purchased items which quickly accumulated costs. This is largely because many items were purchased in bundles, leaving us with many unused items such as acrylic paint, extra mouse trap and elastics. In order to decrease these costs, we could have split these bundles and associated costs with other groups, in addition to purchasing items at discounted prices as a means of limiting spending in this area. Additionally, the four 3D printed parts were expensive and could have been replaced with items made from recyclable material, such as a cardboard flag.

3.7 Life Cycle Analysis

The life cycle analysis was completed via excel and cross checked with hand calculations. The materials of our chassis parts used to complete the calculations were determined through personal knowledge and educated estimations. The primary materials used were stainless steel (modular components), zinc/copper (batteries/conductors), polystyrene (3D parts), Iron (motors) and synthetic rubber (rubber stoppers). In total, the methane emission was 9.723g, the carbon dioxide emission was 3871.1g and the cyanide emission was 0.0521g. These values indicate that the production of our wheelchair does have a considerable environmental impact that should be addressed through more thoughtful design. To begin, the stainless steel due to the modular parts contributed to a large amount of the CO_2 emissions. This material could have been replaced with an alternative such as steel, which has a lower CO_2 emission value (2600g vs 4100g). Additionally, the battery consumption (zinc) was not minimized throughout the design process. In total, we used 3 8-packs of batteries, which could have been limited during test runs to prevent further environmental impact. Finally, extra aesthetic components such as our 3D printed flag made of polystyrene could have been replaced with paper, a material that is considerably less impactful on the environment. This would have been more environmentally friendly and cost efficient.

4.0 Team Reflection

Following the prototype test and report during week 7, we collectively reflected that our team time management and communication needed to be addressed. Although we thrived in overcoming obstacles, dividing tasks, and supporting each other throughout our prototype design, we were often stressed for time and our approach to design was unstructured. Unfortunately, this was repeated during the construction and testing of our final design. Although we managed to meet deadlines, the quality of work could have been better if more time management among group members was apparent. In terms of things that improved since the prototype test, our approach to the design process was more effective. We often researched ideas before implementing them instead of relying on trial and error. This made the design process go by much quicker. Additionally, we learned when to recognize the appropriate time to abandon a plan. Despite all the work put into it, the infrared sensor was too weak and not effective at controlling the chassis. We recognized that we had to abandon this idea and code for timing last minute before the competition. Leading up to the final design test, our meeting times decreased and communication between group members worsened. Group members would often be very late to team meetings and design labs or not attend without warning. Unfortunately, the short timeframe did not allow for this to be addressed. A group meeting and contract review would have been appropriate during this time. Overall, this project allowed team members to reflect on the importance of time management and communication, in addition to working with individuals while maintaining a positive and collaborative work environment.

In response to our challenges and strengths listed above, we have added a no phone policy to our meetings, a plan of action to abandon ideas/projects, a voting system and steps to address group conflict which can be noted in the final team contract below. These concepts will be beneficial to our future endeavors in the engineering field.

4.1 Week 11 Revised Team Contract

Team Contract- Team TBWC 10 (Japan)

1. As a team, we will aim to submit good quality work on time, establish good communication and work together with efficiency. Furthermore, we aim to learn how to deal with problems and come up with creative solutions together.
2. All group members will refrain from cell phone use during team meetings.
3. A voting system will be used when deciding to abandon a plan/original idea.
4. All changes to the design must be discussed by the group first and undergo a majority vote.
5. All design ideas must be drawn and finalized before starting to build.
6. We agree to regularly meet at least two out of three times a week at the Thorn building in the atrium or thinktank. Meetings are acceptable in person or via an online call depending on the task and availability of group members. Group meetings approaching deadlines must be in person.
7. Meetings will still run as long as 3/5 people attend. Other group members will be caught up on what was discussed if they were absent. Absence is expected to be communicated in advance.
8. In the case of group conflict, we will set up a group meeting to discuss concerns openly and brainstorm a solution that everyone is satisfied with. The importance of a non-judgmental workspace is emphasized.
9. Primary contact is through an Instagram group chat and through Microsoft Teams. Reports will be completed via shared Word documents.
10. Everyone will have a role, but they will be flexible when needed: Aizah is responsible for programming, Chris will cover assembly/design, Julia and Alyson will work on written reports and submissions, and Mahdi will do design and electronics.
11. Respect will always be a priority and maintained within the group.

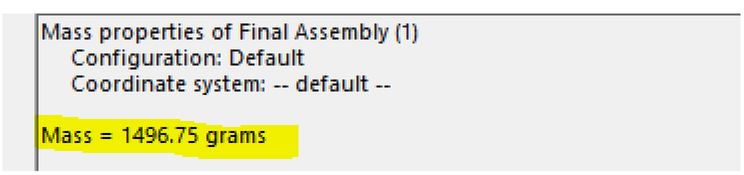
12. We all agree to complete our portions of the workload and communicate if someone needs extra support
13. In order to stay on schedule, everyone is responsible for contributing to a weekly summary/checklist which will be communicated via the Instagram group chat.
14. All work will undergo a peer review process to maximize its quality and address all concerns before submission.

5.0 Engineering Analysis A-Mass Calculation

Part	**Mass (g)**	**Quantity**	**Total Mass**	**SolidWorks Number**
52 - Plate	65	1	65	1
1B – Plate (15 holes)	12	2	24	2
51F - Bracket	15	2	30	3
48A - Bracket	6	2	12	4
4 – Plate (6 holes)	4	5	20	5
51D - Bracket	8	2	16	6
46A - Bracket	35	1	35	7
47 - Bracket	12	1	12	8
89 – Plate (11 holes)	15	5	75	9
12 - Bracket	2	4	8	10
1B – Plate (15 holes), modified	12	2	24	11
126 - Bracket	6	1	6	12

5 – Plate (5 holes)	4	1	4	13
48A – Bracket (modified to 4 hole plate)	6	1	6	14
6 – Plate (4 holes)	4	4	16	15
318B - Axel	20	1	20	16
317 - Axel	20	2	40	17
142R - Tire	13	4	52	18
187C - Wheel	14	4	56	19
38A – Large spacer	1	10	10	20
770 - Motor	216	2	432	21
Japan Flag (3D printed part)	10	1	10	22
21P3P - Pulley	6	2	12	23
19B - Pulley	44	1	44	24
Breadboard	94	1	94	25
Mouse Trap Base	35	1	35	26

Total Mass (SolidWorks with parts above):



Competition Day Mass: 1527g

Based on the SolidWorks mass and the competition day mass provided above, they are very similar and show consistency in our use of SolidWorks. The SolidWorks mass, 1496g, is

98% of the accepted measured mass, 1527g. This is due to not considering the nuts and bolts, as well as missing minor parts during the SolidWorks assembly. The chosen materials for SolidWorks parts were based off of the Life Cycle material estimations, primarily using stainless steel, iron, synthetic rubber, wood and polystyrene. These choices were proven to be accurate by our resulting SolidWorks mass.

6.0 Engineering Analysis B-Centre of Mass Calculations

Mass Calculations.

Centre of mass :-

↓

$\bar{x}, \bar{y}, \bar{z}$ components

formula to calculate C.O.M :-

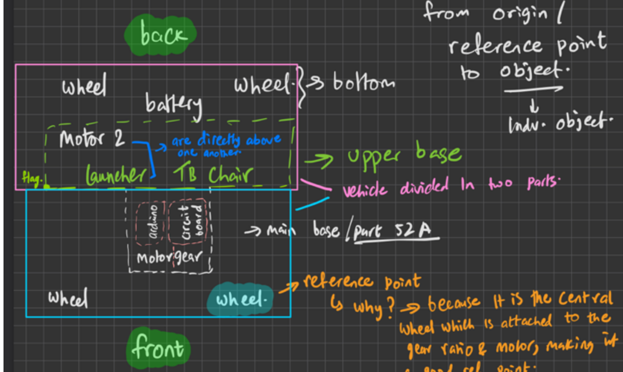
$$\Rightarrow \frac{\sum_{i=1}^{N} m_i x_i}{m_i}$$

$m_i \rightarrow$ mass

$x_i \rightarrow$ C.O.M distance from origin / reference point to object.

↓

Indv. object.



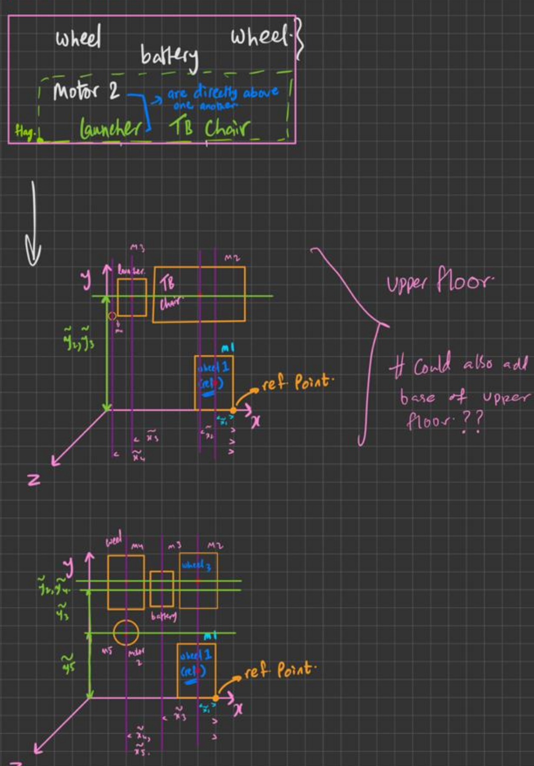
Component	Mass(g)	$\tilde{x}_i$ (cm)	$\tilde{y}_i$ (cm)	$\tilde{z}_i$ (cm)	$m_i \times \tilde{x}_i$ (g·cm)	$m_i \times \tilde{y}_i$ (g·cm)	$m_i \times \tilde{z}_i$ (g·cm)
wheel #1	≈29	2.6	1.2	2.5	75.4	34.8	72.5
wheel #2	≈29	2.6	10.0	2.5	75.4	290	72.5
motor #1	≈216	10.0	7.0	3.9	2160	1620	820.8
part 52A base	≈65	7.5	7.8	1.5	487.5	507	97.5
big grey Pulley	≈44	10.0	3.5	3.8	440	154	167.2
Circuit board	≈94	22.0	5.0	2.0	2068	470	188
arduino.	≈37	18.0	9.8	2.2	666	362.6	81.4
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

y- direction

x- direction

z - direction

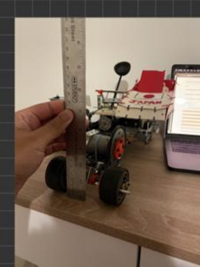
Pink Part :



Component	Mass (g)	$\tilde{x}_i$ (cm)	$\tilde{y}_i$ (cm)	$\tilde{z}_i$ (cm)	$m_i \times \tilde{x}_i$ (g·cm)	$m_i \times \tilde{y}_i$ (g·cm)	$m_i \times \tilde{z}_i$ (g·cm)
TB chair	23	22.5	2.5	9.0	517.5	57.5	207.0
launcher	47	25.0	9.5	6.6	1175.0	446.5	307.9
Flag.	10	20.0	14.5	6.5	200.0	145.0	65.0
motor 2	216	24.6	12.5	3.3	5313.6	2700.0	712.8
far-right wheel.	29	34.2	1.5	2.5	991.8	43.5	72.5
battery	204	33.5	8.3	3.5	6834.0	1693.2	714.0
far- left wheel	29	34.5	10	2.5	1000.0	290.0	72.5
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

y - direction

x- direction



z- direction

Centre of mass In x-axis:

$$\bar{x}_{com} = \frac{\sum m_i \times \tilde{x}_i}{\sum m_i}$$

$$= \frac{30503.1 \, \cancel{g}\text{cm}}{1421 \, \cancel{g}}$$

$$\bar{x}_{com} = 21.47 \text{ cm}$$

Centre of mass In y-axis:

$$\bar{y}_{com} = \frac{\sum m_i \times \tilde{y}_i}{\sum m_i}$$

$$= \frac{11444.2 \, \cancel{g}\text{cm}}{1421 \, \cancel{g}}$$

$$\bar{y}_{com} = 8.05 \text{ cm}$$

Centre of mass In z-axis:

$$\bar{z}_{com} = \frac{\sum m_i \times \tilde{z}_i}{\sum m_i}$$

$$= \frac{4669.25 \, \cancel{g}\text{cm}}{1421 \, \cancel{g}}$$

$$\bar{z}_{com} = 3.29 \text{ cm}$$

Tipping calculations.

Mass of wheel chair = 1527g

↳ 1.527 kg

$F = W = 1.527 \text{ kg} \times 9.8 = 14.9646 \text{ N}$

↳ F_g

determining vector components of the weight

$F_g \cos\theta = F_{g_z}$

$14.9646 \times \cos(35) = 12.26 \text{ N}$

↳ margin of safety.

$F_g \sin\theta = F_{g_y}$

$14.9646 \sin(35) = 8.58 \text{ N}$

Centre of mass ⇒ (x, y, z)

↳ $(21.47, 8.05, 3.27)$

Determining the moments that each vector creates about the tipping point.

$M_1 = F_{g_z} \times d$	$M_2 = F_{g_y} \times d$
$= 12.26 \times 3.27$	$= 8.58 \times 8.05$
$= 40.09 \text{ N/cm}$	$= 69.07 \text{ N/cm}$

The moment keeping the wheelchair from tipping, greater than the moment causing it to tip. hence; we can say that the object does not tip over in all 4 directions.

	component	mass (g)	component CoM			Mi x Xi	Mi x Yi	Mi x Zi
			Xi (cm)	Yi (cm)	Zi (cm)			
	wheel #1	29	2.6	1.2	2.5	75.4	34.8	72.5
	wheel #2	29	2.6	10.0	2.5	75.4	290.0	72.5
	motor #1	216	10.0	7.5	3.8	2160.0	1620.0	820.8
	part 52A base	65	7.5	7.8	1.5	487.5	507.0	97.5
	big grey pulley	44	10.0	3.5	3.8	440.0	154.0	167.2
	citcuit board	94	22.0	5.0	2.0	2068.0	470.0	188.0
	arduino	37	18.0	9.8	2.2	666.0	362.6	81.4
	TB chair	23	22.5	2.5	9.0	517.5	57.5	207.0
	launcher	47	25.0	9.5	6.6	1175.0	446.5	307.9
	flag	10	20.0	14.5	6.5	200.0	145.0	65.0
	motor #2	216	24.6	12.5	3.3	5313.6	2700.0	712.8
	far right wheel	29	34.2	1.5	2.5	991.8	43.5	72.5
	battery	204	33.5	8.3	3.5	6834.0	1693.2	714.0
	far left wheel	29	34.5	10.0	2.5	1000.5	290.0	72.5
	bracket connecting wheel #1	15	4.7	4.8	1.0	70.5	72.0	15.0
	bracket connecting wheel #2	15	4.7	8.5	1.0	70.5	127.5	15.0
	right most bracket holding upper base #1	12	22.0	0.8	4.5	264.0	9.6	54.0
	right most bracket holding upper base #2	12	29.7	0.8	4.5	356.4	9.6	54.0
	curved bracket (right)	15	25.7	0.8	4.5	385.5	12.0	67.5
	left most bracket holding upper base #1	12	22.0	14.9	4.5	264.0	178.8	54.0
	left most bracket holding upper base #2	12	29.7	14.9	4.5	356.4	178.8	54.0
	curved bracket (left)	12	25.7	15.0	4.5	308.4	180.0	54.0
	rightmost black bracket	15	25.0	3.3	1.0	375.0	49.5	15.0
	rightmost grey bracket	8	30.2	3.3	1.0	241.6	26.4	8.0
	leftmost black bracket	15	25.0	13.5	1.0	375.0	202.5	15.0
	leftmost grey bracket	8	30.2	13.5	1.0	241.6	108.0	8.0
	vertical bracket next to motor#2	6	25.5	7.5	1.7	153.0	45.0	10.2
	horizontal bracket next to motor#2	6	23.0	7.5	1.5	138.0	45.0	9.0
	horizontal bracket #2 next to motor#2	8	28.0	7.5	1.5	224.0	60.0	12.0
	bracket connecting back right bracket	24	32.5	4.9	0.0	780.0	117.6	0.0
	bracket connecting back left bracket	24	32.5	11.2	0.0	780.0	268.8	0.0
	long horizontal bracket on 2nd base #1	25	22.0	7.5	6.3	550.0	187.5	157.5
	long horizontal bracket on 2nd base #2	25	29.7	7.5	6.3	742.5	187.5	157.5
	long vertical bracket on 2nd base #1	10	25.5	3.0	6.3	255.0	30.0	63.0
	long vertical bracket on 2nd base #2	10	25.5	7.2	6.3	255.0	72.0	63.0
	black bracket under motor #2	20	24.6	12.5	1.5	492.0	250.0	30.0
	rod	20	6.5	2.6	2.6	130.0	52.0	52.0
	rod #2	20	34.5	8.0	2.5	690.0	160.0	50.0
total		1421				30503.1	11444.2	4669.25

Centre of mass in X axis = (Mi x Xi) / total mass
21.47
Centre of mass in Y axis = (Mi x Yi) / total mass
8.05
Centre of mass in Z axis = (Mi x Zi) / total mass
3.29

SolidWorks Center of Mass Reference:

Center of mass: (centimeters)
X = 3.30
Y = 8.93
Z = 10.23

The center of mass calculated in the x, y and z axis were 21.47cm, 8.05cm and 3.29cm respectively. Comparing it with the SolidWorks values, they are quite similar, however have slight deviations, due to human error in taking precise measurements of small parts. The center of mass was calculated by taking each major part of the wheelchair and measuring it from a fixed reference point in the x, y, and z axis, as demonstrated above. Furthermore, the tipping calculations exhibit that the wheelchair passes the tipping test, exceeding its tipping angle above 35 degrees.

7.0 Engineering Analysis C-Life Cycle Analysis

Material	CO2 Emissions (kg/tonne)	Methane Emissions (kg/tonne)	Cyanide Emissions (kg/tonne)	Weight of Material (g)	Net CO2 (g)	Net Methane (g)	Net Cyanide (g)
Steel	2600	1.4	0.63	52	135.2	0.0728	0.03276
Stainless Steel	4100	8.9	0.0002	637	2611.7	5.6693	0.0001274
Iron	-	-	0.05	384	0	0	0.0192
Copper	3000	-	-	10	30	0	0
Zinc	3000	4	0.000061	180	540	0.72	0.00001098
Polyethylene	1400	17	0.000000016	157	219.8	2.669	2.512E-09
Paper	1500	-	-	6	9	0	0
Polystyrene	2700	18	0.000001	22	59.4	0.396	0.000000022
Synthetic Rubber	4000	-	-	59	236	-	-
Wood	6000	9.8	-	20	120	0.196	-

Hand Calculation Example (Net CO2 for stainless steel):

$$Net\ CO2 = mass\ \times\ emissions = 637g \times 4100\frac{kg}{tonne} \times \frac{1tonne}{1000000g} \times \frac{1000g}{1kg} = 2611.7g$$

The hand calculation above aligns with the value in the table. In total, the methane emission was 9.723g, the carbon dioxide emission was 3871.1g and the cyanide emission was 0.0521g. See the life cycle reflection above for more information.

8.0 Engineering Analysis D-Arduino Code

Hurdles Code

```
#define enA 3 //for motor1 that controls car's motion
#define in1A 5
#define in2A 4
#define enB 2 //motor 2 that controls launcher
#define in1B 6
#define in2B 7

void setup() {
 Serial.begin(9600);
 pinMode(enA,OUTPUT);
 pinMode(in1A,OUTPUT);
 pinMode(in2A,OUTPUT);
 pinMode(enB,OUTPUT);
 pinMode(in1B,OUTPUT);
 pinMode(in2B,OUTPUT);

 digitalWrite(enA, HIGH);
 digitalWrite(enB,LOW);
}

void loop() {

Serial.println("spinning one direction");
digitalWrite(in1A,LOW); //spin motor 1 in counter clockwise direction to move forwards
digitalWrite(in2A,HIGH);
```

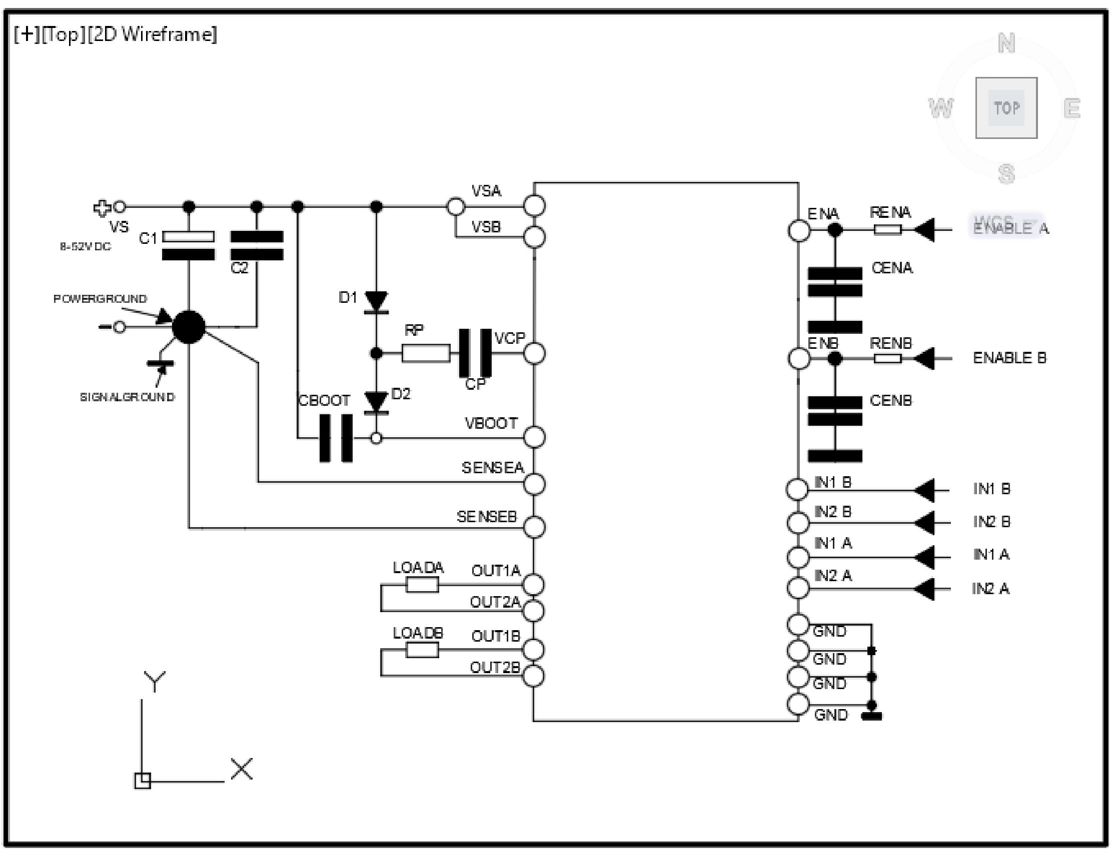
```
delay(4400);

digitalWrite(in1A,LOW); //stop motor 1
digitalWrite(in2A,LOW);

digitalWrite(in1A,HIGH); //spin motor 1 in clockwise direction to move backwards
digitalWrite(in2A,LOW);
delay(10000);

digitalWrite(in1A,LOW); //stop motor 1
digitalWrite(in2A,LOW);
delay(2000);
}
```

Archery Code

```
#define enA 3 //for motor1
#define in1A 5
#define in2A 4
#define enB 2 //motor 2
#define in1B 6
#define in2B 7

void setup() {
  Serial.begin(9600);
  pinMode(enA,OUTPUT);
  pinMode(in1A,OUTPUT);
  pinMode(in2A,OUTPUT);
  pinMode(enB,OUTPUT);
  pinMode(in1B,OUTPUT);
  pinMode(in2B,OUTPUT);

  digitalWrite(enA, HIGH);
  digitalWrite(enB, HIGH);
}

void loop() {

Serial.println("spinning one direction");
  analogWrite(in1A,0); //spin motor 1 in counter clockwise direction
  analogWrite(in2A,150);

  delay(3700);

  analogWrite(in1A,0); //stop motor 1
  analogWrite(in2A,0);
```

```
delay(2000);
digitalWrite(in2B,HIGH); //spin motor 2 in clockwise direction to throw
digitalWrite(in1B,LOW);
delay(2000);
digitalWrite(in2B,LOW); //stop motor 2
digitalWrite(in1B,LOW);

analogWrite(in1A,150); //spin motor 1 in one direction
analogWrite(in2A,0);
delay(10000);

digitalWrite(in1A,0); //spin motor 1 in one direction
digitalWrite(in2A,0);
delay(2000);
}
```

9.0 Engineering Analysis E-TWBC Electrical Circuit



10.0 Engineering Analysis F-List of SolidWorks Parts

Part Number & Description
52 - Plate
1B – Plate (15 holes)
51F - Bracket
48A - Bracket
4 – Plate (6 holes)
51D - Bracket
46A - Bracket
47 - Bracket
89 – Plate (11 holes)
12 - Bracket
1B – Plate (15 holes), modified
126 - Bracket
5 – Plate (5 holes)
48A – Bracket (modified to 4 hole plate)
6 – Plate (4 holes)
318B - Axel
317 - Axel
142R - Tire
187C - Wheel

38A – Large spacer
770 - Motor
Japan Flag (3D printed part)
21P3P - Pulley
19B - Pulley
Breadboard
Mouse Trap Base