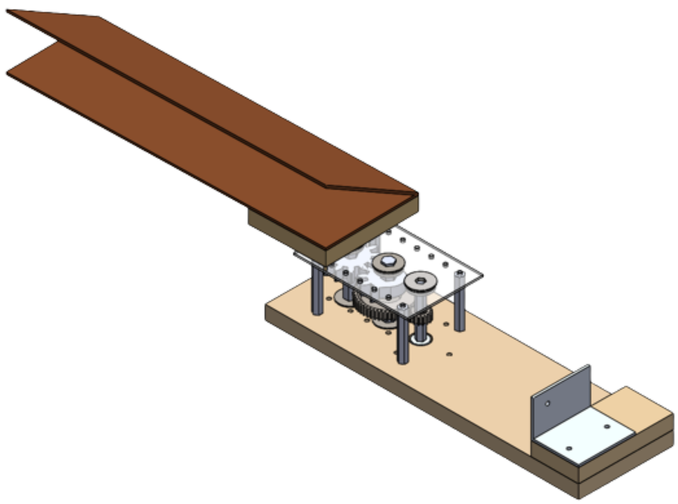
An Assistive Wheelchair-Mountable Frisbee Launcher

Design Study & Final Project Report



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Many people, often as a result of injury, disability, or aging, have lost mobility in their limbs and thus rely on a wheelchair to move around. In the United States alone, an estimated 5.5 million adults have used a wheelchair for mobility at some point in their lives (Taylor, 2018). Often, the same issues that require the aid of a wheelchair, such as paralysis or mobility issues, cause poor mobility or coordination in the upper body as well. Furthermore, surveys such as those conducted by Curtis et al. (1998) have found that over two-thirds of their samples have experienced shoulder pain after beginning wheelchair rehabilitation, adding to an increasing body of evidence that wheelchair use itself contributes to shoulder issues.

The presence of immobility, weakness, or pain in the shoulder or arm makes simple tasks such as throwing objects especially difficult for those who use wheelchairs (R. Bilotta, personal communication). A lack of literature makes it clear that there currently does not exist a device for launching toy projectiles (specifically discs) that is able to be operated by one who uses a wheelchair. Therefore, for the convenience and well-being of the many people who use wheelchairs regularly, it is imperative that one be developed. This device will enable the user to easily and effectively launch a projectile with minimal movement through the use of an electronic control system and motors. The following document details further justification and steps for construction of such a device, as well as the steps taken to test it and an overall final evaluation of its success.

Market Research

Currently available projectile-launching devices utilize a variety of different mechanisms at different price points. Almost all projectile launchers available in the market today are not wheelchair-mountable, making it infeasible for those who use wheelchairs to use them. Many of the existing wheelchair-mounted projectile-launching devices, such as those prototyped by Ameye et al. (2014) or the Cerebra Innovation Centre (Roberts, 2019) are tailored towards launching balls rather than frisbees. Current launchers that launch frisbees or other discs, such as the handheld launcher detailed by Glass & Glass (1991) or the clay pigeon launcher proposed by Whidborne (2013), are not wheelchair-accessible. Although ineffective for the proposed problem, these designs (especially the clay pigeon launcher) contained features that were utilized in prototyping.

Preliminary Designs

There were two designs proposed for the launching mechanism and two proposed for the wheelchair mount, which are summarized below.

Launching Mechanism 1: Flywheel

The first idea for the launching mechanism was a dual-wheel flywheel launcher, a top-down view of which is given in Figure 1. In this design, a frisbee is fed through two spinning wheels (motorized), propelling the frisbee. Downsides included large consumption of energy (constantly running motors), constant noise generation, and specific spinning wheels fitting only certain objects between them.

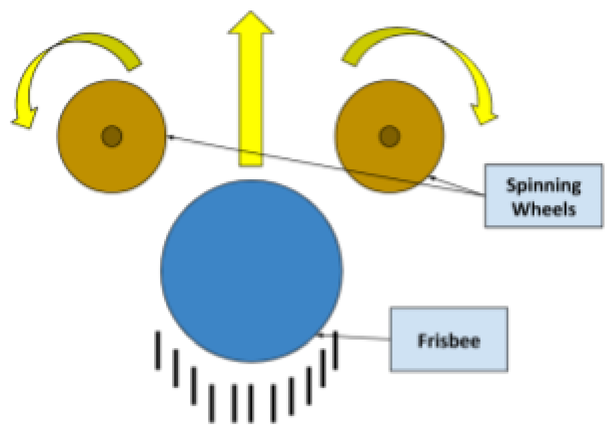

Figure 1: *Diagram of flywheel launcher.*

Launching Mechanism 2: Sidearm Thrower

The second idea for the launching mechanism was a sidearm mechanism. Generally used to launch clay pigeons in shooting sports, it utilizes a rotating arm to hurl a disk (Whidborne, 2013). The mechanism is primarily powered by a spring and a motor. The motor expands the string, increasing the tension and potential energy. When the spring is released, the arm rotates and sends the disk flying. Downsides of this design included a large wait time between launches, large usage of space (for arm rotation), and constraining the size of the projectiles.

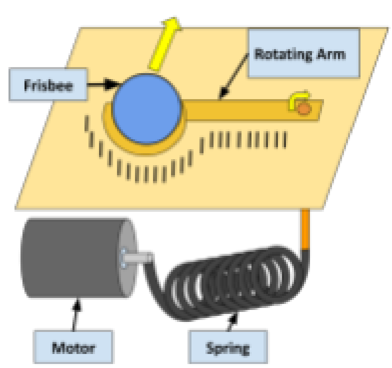

Figure 2: *Drawing of sidearm frisbee launcher.*

Wheelchair Mount 1: Armrest Mount

This design utilizes the arm rest that is commonly found on wheelchairs. The device will rest on the side of the wheel chair using the weight of the wheelchair (shown in Figure 3) and the user to balance out the weight of the device. It is divided up into two compartments: one holding the launching system with the other containing the electronic control system. This compartmentalization enables both subsystems to work together without interference. It is securely attached to the arm mount, and has a protective screen to ensure the safety of the client incase of a malfunction. The arm-mount is easily attachable onto the side of the wheelchair while keeping the mobility of the wheelchair mostly unchanged. Additional assistance for attachment may be required if the wheelchair user has trouble lifting objects.

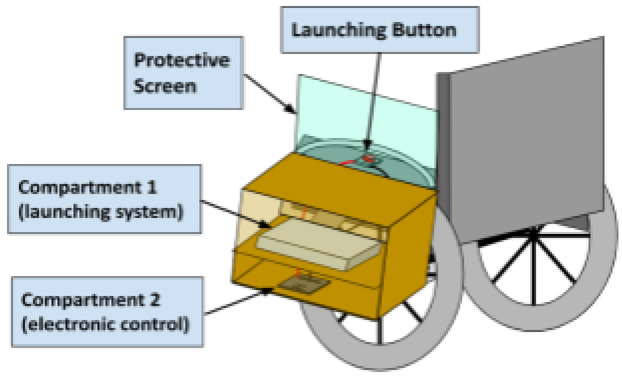

Figure 3: *Diagram of armrest attachment mounting system for device.*

Wheelchair Mount 2: Wheeled Side-Attachment

As shown in Figure 4, this design uses a wheeled leg to stabilize the device as it is attached to the side of the wheelchair. The additional distance between the device and the user provides an added degree of safety in the case of a device breakage. Furthermore, the inclusion of a wheel still allows for relatively easy navigation. However, the additional width may make it difficult for a user to fit into narrow spaces such as doorways.

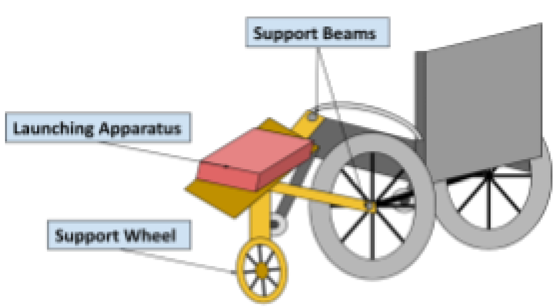

Figure 4: *Diagram of wheeled side-attachment.*

Prototyping and Testing

Intermediate Prototypes

To facilitate construction and create a more power-efficient, less noisy device, subsequent prototypes were progressed with the sidearm thrower launching mechanism and an mounting tray inspired by the armrest mount. The following prototypes were done for the launching mechanism.

Figure 5: *Picture of initial cardboard arm design.*

Prototype 1: Cardboard Launcher

Preliminary designs for this device were based upon the design of the clay pigeon launcher by Whidborne (2013), in which a spring-loaded rotating arm is wound back and released to propel a small disc. The first proof-of-concept, shown in Figure 1, was based upon replicating the walled arm and the mechanism by which it generated spin on the disc during launch.

Prototype 2: Manually-Operated Spring-Loaded Launcher

Figure 6: *Manually operated design launching a frisbee.*

The second design focused on adding a spring to the walled-arm design to store and release power, with the intention of later adding a motor to make it automatic. A smaller version of the cardboard arm attachment was attached onto a wooden base with metal bearings, free to rotate around a metal shaft. A spring was attached to the arm and tensioned ons the base such that when the arm was rotated backwards, the spring stretched, creating a force to rotate the arm back to its original position and thus launch the frisbee when it was released. The device being used to launch a frisbee is shown in Figure

2. Although it was successful at launching, its power was insufficient and it was of course still inaccessible to those who use wheelchairs.

Prototype 3: Motorized Launcher with 3D-Printed Gears

The third design incorporated a motor and a button to wind the arm back automatically to minimize exertion by the user. To transfer power from the motor to the rotation of the arm, two gears were 3D-printed. One gear was printed without half of its teeth to allow free spinning of the arm so that it could launch a frisbee once it was wound back enough. The slip gear (gear with half of its teeth) was attached to the motor, and the gear with full teeth was attached to the shaft of the arm. However, the initial 1:1 gear arrangement, shown in Figure 3, did not have enough torque to stretch the spring, and subsequent arrangements with higher gear ratios for more torque led to the printed gears breaking and losing teeth, causing failure of the system. It was decided, therefore, that the design would need to incorporate metal gears instead of 3D-printed plastic ones.

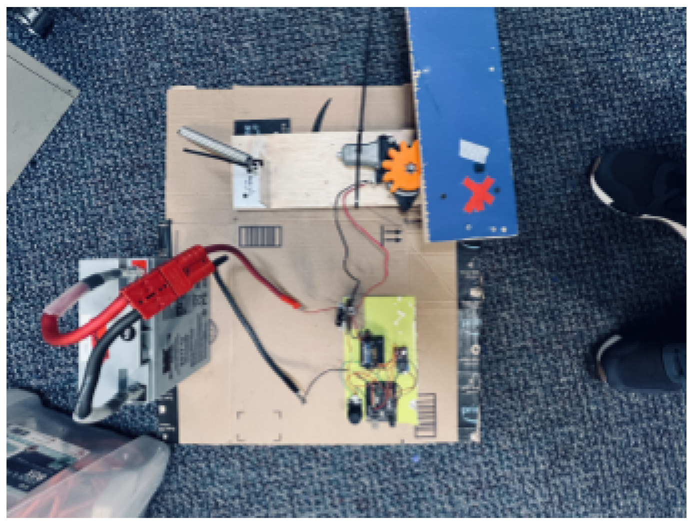

Figure 7: *Motorized launcher shown with electronics and battery.*

Design Studies

Design Study 1: Wheelchair Mounting Stability

The purpose of this design study was to determine how much weight two possible mount designs can hold. The first mount design rests an extendable slide on one of the armrests and extends forwards. The second mount design attaches two extendable slides on one of the armrests and extends sideways. In order for a mount to be effective in holding the launcher, the weight of the launcher must be comfortably supported. If the launcher is too heavy for the mount, the risk of the user dropping the mount increases. Therefore it is imperative the stability of the mount is optimized.

Variables. The independent variable of this design study was weight (kg). Identical 0.5 kg blocks are placed at the position where the launcher would be. Starting with 0 blocks on the mount, the weight is incremented by adding one block at a time.

The dependent variable of this design study is the downward force (N) at the end of the mount, where the blocks are. The force is measured by the spring scale which hooks onto the end. The spring scale is vertical and is attached to a doorknob. The maximum amount of force the spring scale could measure is 500g of weight, or approximately 4.90 N.

The same doorknob and chair (to simulate a wheelchair) is used for both mounts. Additionally, the distance of the weights from the armrest is kept constant at 16 inches. This is important because a greater distance from the chair would mean a greater torque, so the spring scale would measure a greater force. Therefore it is necessary to keep this value constant so both mounts can be assessed fairly. Finally, the starting value of the spring scale is set at 0 N of force when there is no weight.

Materials. The materials are as follows:

- Door handle
- Spring scale
- Spinning black chair when armrests
- 0.5 kg identical blocks
- Both mount prototypes
- Clamps

Methods. To conduct the study, the below methodology was used:

1. Place the mount on the armrest and secure it using clamps. Extend it 16 inches from the armrest.

Figure 8: *The first mount design which extends forward.*

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2. Place a spring scale on the door handle and attach its hook onto the end of the mount.

Figure 9: *Spring scale attached onto door handle and mount.*

3. Make sure that the spring scale is vertical. If the scale reads more than 0g (0 N) when first attached, lower the door handle until it just reaches 0g.

Figure 10: *Lowering the door handle so the spring scale initially reads 0g of weight.*

4. Place a 0.5 kg block on the end of the mount and record what the spring scale reads.

Figure 11: *Placing a block onto the mount.*

5. Continue this process of adding blocks and reading the spring scale. Before placing each block, make sure that the spring scale is at the same value that was just recorded. Do this for until the weight exceeds the spring scales capacity.

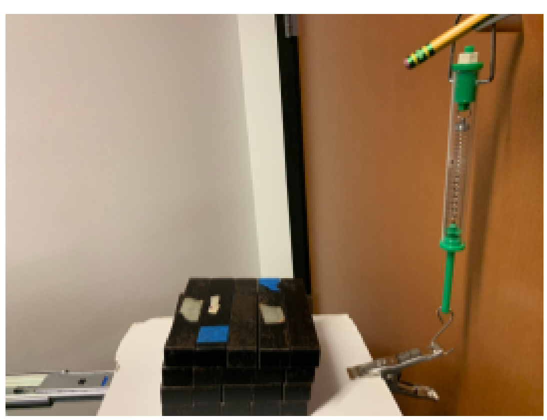

Figure 12: *20 weights resting on the mount to be tested.*

6. Repeat this process for the second design, making sure that it is also 16 inches away from the arm rest.

Figure 13: The second mount design which extends sideways.

Data. The forces measured from this design study are given in Table 1.

Table 1

Force measurements for the first design, 16 inches forward from the armrest.

Number of blocks	Force (g)	Force (N)
0	0	0
1	27	0.26479
2	53	0.51977
3	85	0.83360
4	118	1.15723
5	148	1.45144
6	175	1.71623
7	200	1.96140
8	225	2.20658
9	250	2.45175
10	272	2.66750
11	300	2.94210
12	310	3.04017
13	330	3.23631

14	353	3.46187
15	378	3.70705
16	398	3.90319
17	419	4.10913
18	440	4.31508
19	464	4.55045
20	489	4.79562

Table 2
Force measurements for second design, 16 inches sideways from the arm rest

Number of blocks	Force (g)	Force (N)
0	0	0
1	32	0.31382
2	68	0.66688
3	110	1.07877
4	150	1.47105
5	200	1.96140
6	240	2.35368
7	280	2.74596
8	330	3.23631
9	368	3.608976
10	400	3.9228
11	430	4.21701
12	460	4.51122
13	500	4.9035

Analysis. Plotting the data side by side, it is clear that the sideways-extending mount (Design 2) has more force exerted than the front mount (Design 1). As seen in Figure 7, the sideways mount reads a greater amount of force than the front mount for the same amount of weight especially after 3 kg. Performing linear regression on Design 1 and Design 2 reveals that both have a linear relationship, with R values of 0.9971 and 0.9985 respectively. The slope of the line of best fit for Design 1 is 0.469 N/kg, whereas the slope for Design 2 is 0.777 N/kg. This means that for every additional kg of weight added, the front mount is doing a better job at supporting the weight and preventing it from falling down.

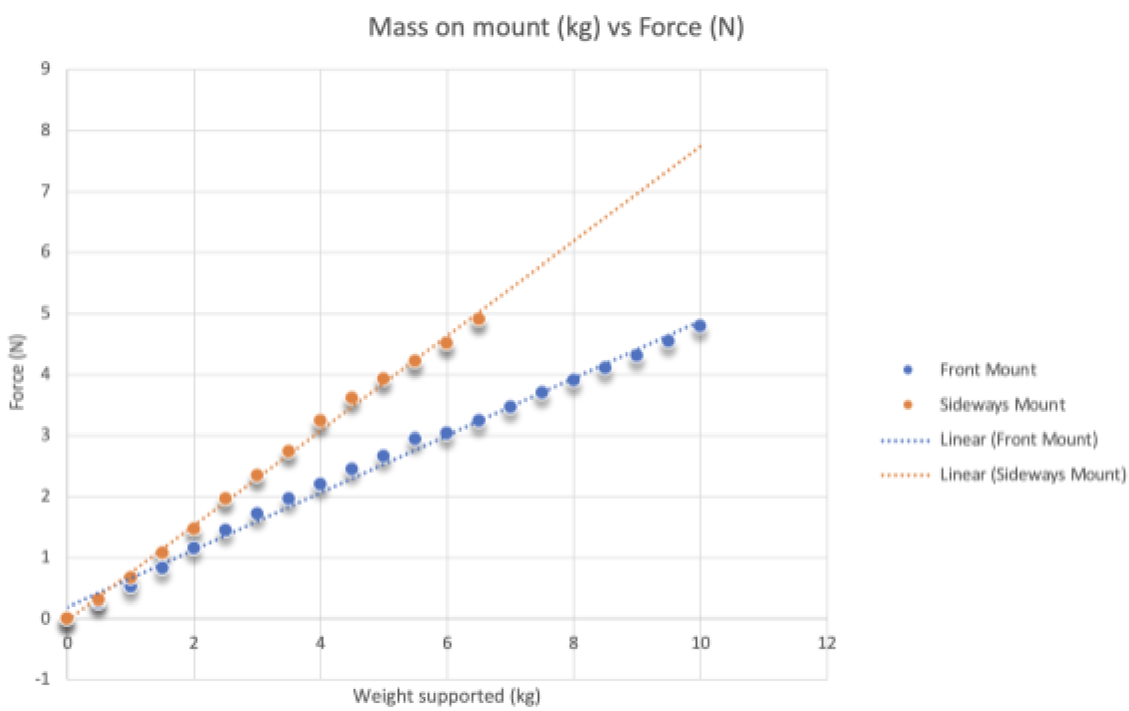

Figure 14: *Plots of data for both designs, with the weight supported on the mount compared to the force read by the spring scale.*

From the data, it can be concluded that the front mount is more effective at holding weight than the sideways mount. Although there is little difference when the weight is between 0 and 3 kg, Design 1 would be a better option to choose for loads heavier than 3 kg. Because the launcher weighs about 2.3 kilograms, either mount would suffice at that given weight. However, this study shows that front mounts are more stable. If additional weight needs to be added to the launcher, the front mount would be the most optimal choice.

Design Study 2: Springs and Launch Distance

This test was aimed at determining the best spring for use in the launcher so that it would launch frisbees the greatest distance. It was anticipated that stronger and stiffer springs would create more launching power and thus more launching distance, however, this needed to be tested under the suspicion springs that were too powerful might cause the frisbee to lose control and leave the launcher prematurely or without having gained enough spin.

Variables. The spring power of the launcher was manipulated by equipping it with one of five springs. As shown in Figure 7, each of the springs was identified with a number, and their strengths were later measured to determine their strength.

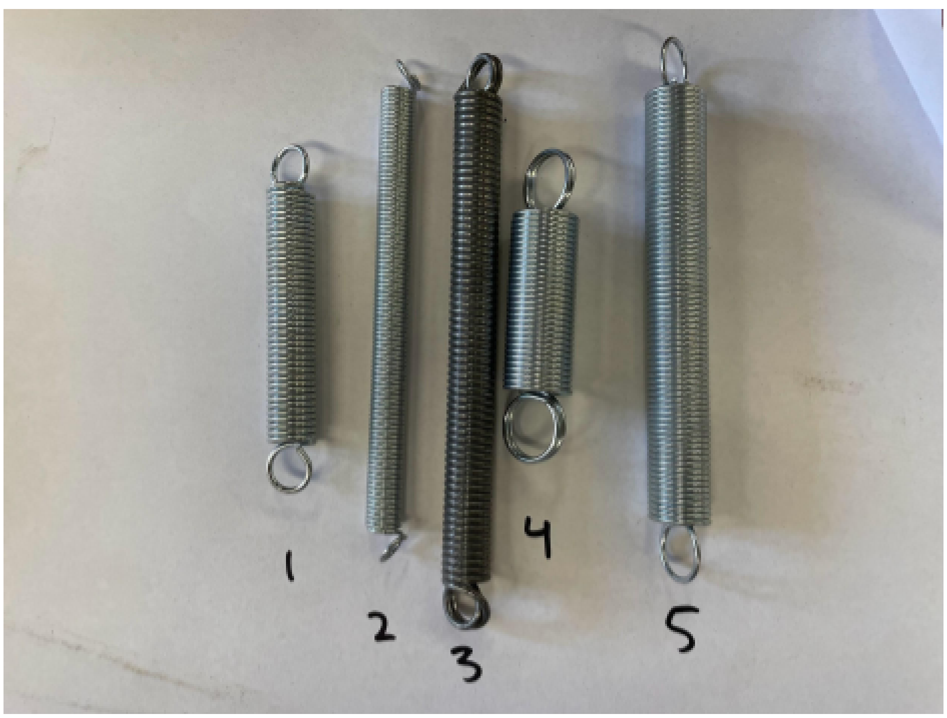

Figure 15: *The five springs tested on the launching mechanism.*

Measurements were taken of the average distance travelled while the launcher was equipped with each spring over five trials.

To control for confounding factors, all trials were conducted on the same day, under the same weather condition, with the same frisbee, and with the same initial spring tension.

Materials. The materials for the design study are as follows:

- Five springs
- Launching mechanism
- Rope and zip ties
- Laser distance sensor
- Frisbee
- Clamps
- Weights and container
- Ring stand
- Ruler
- Spring scale

Methods. To conduct the design study, the procedure below was followed to determine launch distance.

1. If applicable, the previous spring was removed from the launching mechanism by cutting both rope/zip tie attachment points.
2. The spring to be tested was fastened onto the metal bracket on the back of the launching mechanism and the attachment point at the end of the arm, and tensioned until taut but not stretched before being fastened in with rope and zip ties.
3. The launching mechanism was mounted onto a table with clamps, as can be seen in Figure 8.
4. A frisbee was placed into position towards the back of the launching arm.
5. The launching button was pressed to wind the launching arm back and launch the frisbee. The frisbee was allowed to land and slide until it came to a complete stop.

6. The horizontal distance from the launching point to the landing point was measured using a laser distance sensor and recorded.
7. Steps 4-6 were repeated to obtain five measurements total for each frisbee.
8. Steps 1-7 were repeated to obtain measurements for all five springs.

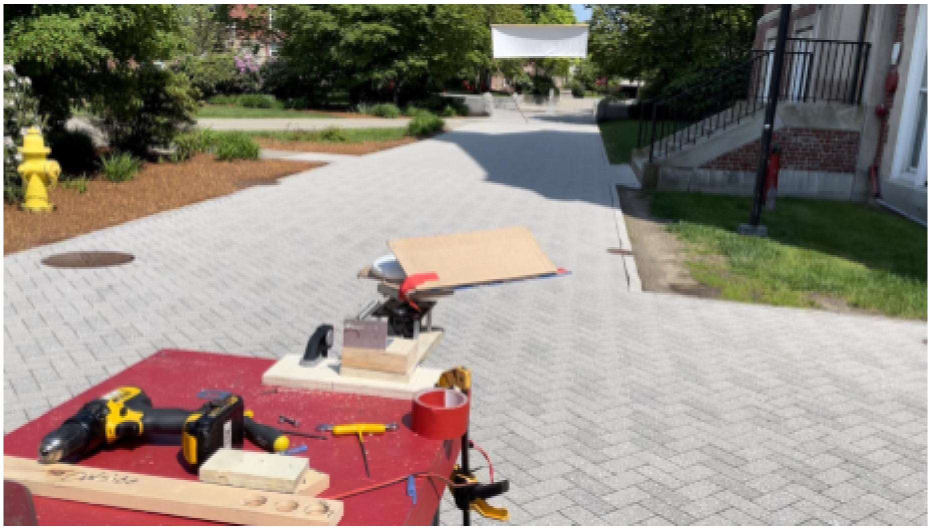

Figure 16: *Example testing setup for launch distance with one spring.*

To determine the strength of each spring, the procedure below was followed.

1. The spring was hung from an attachment on the ring stand, and its equilibrium length was measured with a ruler.
2. A container was attached by rope to the spring while dangling freely from the ground and weights were placed inside of the container until the spring exhibited visible stretching.
3. The stretched length of the spring was measured with a ruler.
4. The weight of the container along with any weights inside was measured with a spring scale.
5. Steps 1-4 were repeated to obtain measurements for all five springs.
6. The spring constant for each spring was calculated using Hooke's law for ideal springs:

$$F = -kx$$

Data. Data of launch distances and spring strengths collected during the study are compiled in Table 2.

Table 2

Launch distances of five different springs across five trials.

	Spring 1	Spring 2	Spring 3	Spring 4	Spring 5
Spring Constant (lbs/in)	11.5	7.3	25.2	3.1	5.5
Trial 1 (ft)	39	20	55	15	16
Trial 2 (ft)	36	15	57	15	15
Trial 3 (ft)	43	14	38	20	17
Trial 4 (ft)	43	13	36	23	14
Trial 5 (ft)	40	16	45	24	14
Average (ft)	**40**	**16**	**46**	**24**	**14**

Additional qualitative observations were also taken during the design study:

- Immediately after launch, the arm would experience a rapid oscillating movement that became more violent as the spring strength increased.
- Repeated launches with the same spring caused the spring tension to reduce.
- Longer springs had a tendency to become caught on nuts or other parts of the design, causing a grating noise.

Spring 1 and 3 demonstrated remarkably better launching distance as compared to the other three strings, which was to be predicted due to their higher strength.

Since springs 1 and 3 demonstrated the best performance by far, it was decided that one of those two springs would be favorable for the final prototype. Spring 1 was ultimately chosen as it was shorter, more compact, and did not catch on any components of the design, likely increasing the reliability and longevity of the prototype.

Design Study 3: Impact of Clip Attachment on Distance

The device had trouble launching larger frisbees as they would fully or partially slide off of the arm while it was winding back, rendering it ineffective. Therefore, the aim was to design a part that would be able to secure the frisbees during the wind-back phase while not significantly impeding them from being ejected during the launch phase.

To achieve this, a plastic clip was heat-molded and attached to the arm, shown in Figure 9. The purpose of this design study was to examine whether the addition of the clip would significantly reduce the launch speed, following a very similar process to Design Study 2.

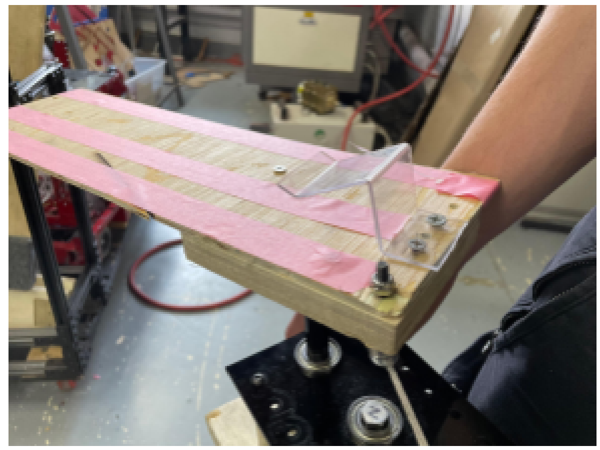

Figure 17: *Launcher arm with plastic clip attached.*

Variables. The independent variable was the presence or absence of the clip, and the dependent variable was the average launch distance of the launcher over five trials. For the case in which the clip was not present, the preexisting data from Design Study 2 with Spring 1 was utilized. Other variables were kept controlled as in Design Study 2.

Materials. The following materials were used to conduct this design study.

- Launching mechanism (with spring and clip attached)
- Laser distance sensor
- Frisbee
- Clamps

Methods. This study follows a similar structure to Design Study 2, as can be seen in the steps below.

1. The launching mechanism was mounted onto a table with clamps.
2. A frisbee was placed into position towards the back of the launching arm.

3. The launching button was pressed to wind the launching arm back and launch the frisbee. The frisbee was allowed to land and slide until it came to a complete stop.
4. The horizontal distance from the launching point to the landing point was measured using a laser distance sensor and recorded.
5. Steps 1-3 were repeated to obtain five measurements total for each frisbee.

Data. Table 3 details the launch distances of the device with and without the clip.

Table 3

Launch distances of five different springs across five trials.

	Without Clip	With Clip
Trial 1 (ft)	39	38
Trial 2 (ft)	36	46
Trial 3 (ft)	43	45
Trial 4 (ft)	43	28
Trial 5 (ft)	40	28
Average (ft)	**40**	**37**

A few qualitative observations were also taken by testers during the design study, listed below.

- The clip seemed to improve stability of the frisbee well during windback: no sliding was observed, even with larger sizes.
- The angle at which the frisbee was launched was skewed towards the left as compared to the launch angle without the clip.

The clip did not impact launch speed significantly, as evident in the data in Table 3, and it also improved stability of the frisbees during the pre-launch phase. As the clip creates minimal drawbacks while simultaneously greatly improving the launcher's ability to hold frisbees, it was decided that it would be beneficial to include it in the final design. Including the clip will make the launcher more adaptable to different shapes and sizes of frisbees.

Final Prototype

Overall, knowledge from previous prototypes and design studies led to the building of a final prototype for the launching mechanism that was more robust, reliable, and effective than the previous ones. Additionally, as observed in Appendix C, our engineering matrix shows that our prototype more met requirements than any of the other existing designs, supporting our final design decision. The complete steps for building this prototype are listed below.

1. Three holes were drilled along a piece of 16.5” x 5” plywood. Spinning hex bearings were inserted into the two on the end, and a motor with a hex adapter was inserted through the third.
2. Holes were drilled and screws and washers were inserted to fasten the bearings in place.
3. Four hex standoffs were fastened in a rectangle around the hex bearings and a laser-cut piece of acrylic was screwed into the four standoffs.
4. Bearings were inserted through the three holes in the laser-cut acrylic such that they aligned with the two bearings and motor hex adapter on the bottom.
5. Gears and shaft collars were placed on top of each hex hole on the base and a hex shaft was inserted through the acrylic, them, and the base. The innermost shaft held one small gear, the middle shaft held a large gear and on top of it a medium gear with half of its teeth removed, and the outermost shaft held a medium gear the same size as the one on the middle one, but with all of its teeth.
6. The gears were adjusted along the shaft such that they meshed together while giving adequate space on either end.

7. A separate wooden arm (a thin piece of wood with a thicker rectangular wooden part on one end) had a hole drilled into it and a 3D-printed plate with a hex-shaped hole inserted into the hole. A bolt was also attached onto the bottom end, in a rear corner of the thicker wooden part.
8. The wooden arm was attached to the tallest hex shaft on the end through the hex-shaped hole on its base. Any torque created by the motor was now transferable to the arm by the gears and the rotation of the bearings in the base.
9. Another thick rectangular piece of wood was fastened with bolts to the end of the base opposite the one with the bearings. A metal bracket was attached to this piece of wood with screws.
10. A spring was attached to both the bolt on the wooden arm and a hole in the bracket by lengths of rope. The strings were tensioned until the spring was taut.
11. The motor was then connected to an electronic control system consisting of a battery, a step-down transformer, programmable circuit board, a relay, and input switches and buttons. This system allowed a push of a button to operate the motor, rotating it in a certain direction depending on the position of the direction switch.
12. A plastic clip was fastened to the rear of the wooden arm with screws.
13. A piece of cardboard was fastened on top of the wooden arm with hot glue.

After completing all of the above steps, the final prototype for the launching mechanism was assembled. An example picture and CAD assembly of this prototype are shown below, in Figure 17.

Figure 18: Picture and assembly of final prototype.

This device was effective at launching frisbees, averaging about 40 feet per launch up to a maximum of 57 feet. The replacement of the 3D-printed gears from the previous prototype with machine aluminum gears increased reliability and ensured that the teeth did not break off even after many uses. However, the measures taken to integrate the launching mechanism with the wheelchair still require refining: the current mount puts the launcher on two linear slide rails which are then clamped to the arms of the wheelchair. While stable, this mounting action requires a caretaker to be done and additionally prevents the user from leaving the wheelchair while the device is mounted. A summary of the device’s ability to meet these and other requirements is shown in Table 4.

Table 4

Device's ability to meet level 1 requirements.

Requirement Description	Pass/Fail	Comments
	Launching System	
Keeps hazardous moving parts out of user's reach	Pass	Wired control box allows user to distance themselves from hazardous springs/gears
Range of 20 feet or more	Pass	Launcher averages about 40 feet of distance
Ability to launch frisbees	Pass	Angled wall allows frisbees to acquire spin and velocity as they are ejected
	Wheelchair Mount	
Able to be independently mounted	Fail	Requires caretaker to tighten clamps; client cannot leave wheelchair while device is mounted
Stays on the wheelchair during routine movements	Pass	Clamps tightly secure device in place even while moving
Does not topple wheelchair during routine movements	Pass	Device is about 5 lbs and thus not heavy enough to destabilize wheelchair
	Electronic Control System	
Operable with minimal hand movement	Pass	Three easily accessible switches: one for power, one for direction control, and one for winding/launching
Powered by at most one primary battery	Pass	Powered by one 12V lithium-polymer battery
	Universal Constraints	
Materials do not exceed $200 in cost	Pass	See Appendix B
Does not exceed 3'x 3'x 3'	Pass	Max dimension is about 33"

Conclusion

Next steps for this device revolve around improving the method by which it attaches to the wheelchair. The ideal result would be an attachment that the user can easily mount and dismount through a hook, but this design may compromise stability. Instead, a more favorable attachment may be similar to the current design with two linear slides but with the addition of a rotating component so that the device can rotate outward and allow the client to exit their wheelchair.

Furthermore, transforming this device into a robust deliverable that a real client may use requires implementation of safety measures in case of the failure of key components. For example, a clear acrylic screen situated between the user and the launcher will shield them from the spring kickback if it detaches from the arm while simultaneously not significantly impeding their view. Furthermore, proper organization of the electronics may reduce the risk for shorting and thus improve lifetime and mitigate a potential fire hazard. Regardless, the device is overall already relatively robust and has potential to be progressed into a stable and professional product.

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Appendix A

External Tools Used

Software/Hardware Name	Purpose
SOLIDWORKS	Creating CAD Designs of all parts
Canva	Making Fair Handout
PowerPoint	Making Fair Poster
Bandsaw	Cutting general materials
3D Printer	Printing parts, such as gears
Laser Cutter	Cutting precise parts, usually with holes. Ex. casing for buttons that requires holes
CNC Router	Precision cuting holes in the plywood base
Grinder Wheel	Remove teeth from aluminum gear

Appendix B

Bill of Materials

Item Description	Vendor	Quantity	Unit Price*** ($)	Total Cost ($)
⅜ in. Hex ID 1.125 in. OD Shielded Flanged Bearing*	AndyMark	1	6.00	6.00
1/2 in. Hex ID 1.125 in. OD Shielded Flanged Bearing*	AndyMark	4	6.00	24.00
Button Head Hex Drive Screw, Black-Oxide Alloy Steel, 8-32 Thread, 1" Long*	McMaster-Carr	16	0.50	8.00
Button Head Hex Drive Screw, Black-Oxide Alloy Steel, 10-32 Thread, 1" Long*	McMaster-Carr	3	0.33	1.00
Low-Strength Steel Thin Nylon-Insert Locknut, Zinc-Plated, 10-32 Thread Size*	McMaster-Carr	3	0.03	1.00
Low-Strength Steel Thin Nylon-Insert Locknut, Zinc-Plated, 8-32 Thread Size*	McMaster-Carr	16	0.03	1.00
Plywood*	Home Depot	1	4.00	4.00
302 Stainless Steel Corrosion-Resistant Extension Spring with Loop Ends, 1" Long, 0.180" OD, 0.029" Wire Diameter*	McMaster-Carr	1	8.00	8.00
34 Tooth 20 DP, 1/2" Hex Bore Gears*	Vex Robotics	2	13.00	26.00
50 Tooth 20 DP 0.5 in. Hex Bore Steel Gear - AndyMark, Inc*	AndyMark	1	12.00	12.00
15 Tooth 20 DP 0.375 in. Hex	AndyMark	1	6.00	6.00

Bore Steel Gear*				
H-Bridge Relay*	Oono	1	20.00	20.00
Arduino Nano*	HiLetgo	1	6.00	6.00
DC Voltage Step-Down*	UCTroniks	1	7.00	7.00
Push Button	RuoFung	1	5.00	5.00
SPST On/Off Switch*		1	3.00	3.00
SPST Flip Switch*	ZUPAYIPA	1	1.00	1.00
Total Cost				**137.00**

**These parts were obtained via a loan or donation, meaning that costs are estimates.*

***General materials include, but are not limited to: Electronic wires, cardboard, glue, etc.*

****All prices are rounded up to the nearest dollar.*

Appendix C

Engineering Matrix

Engineering Matrix							
	Weight	Manual Launcher	**Motorized Launcher**	Clay Pigeon Launcher OpticsPlanet (2014)	Cerebra Innovation Centre (2019)	Ball Launcher Ameye et al. (2014)	Eddy (2020)
Launching Mechanism							
The device must have a range of 20 feet.	1	Fail	**Pass**	Pass	Pass	Pass	Pass
The device must not put any hazardous moving parts within reach of the client.	1	Pass	**Pass**	Pass	Pass	Pass	Pass
The device must be able to launch frisbees.	1	Fail	**Pass**	Pass	Fail	Fail	Pass
The device must be able to launch balls.	2	Fail	**Pass**	Fail	Pass	Pass	Pass
The device must have an adjustable range.	2	Fail	**Fail**	Fail	Fail	Pass	Fail
Wheelchair Mount							
The client must be able to mount the device to the wheelchair independently.	1	Fail	**Fail**	Fail	Fail	Fail	Fail
The device must be able to stay mounted to the wheelchair during any routine movements.	1	Pass	**Pass**	Fail	Pass	Fail	Fail
The device must maintain the balance of the wheelchair during any routine movements.	1	Pass	**Pass**	Fail	Pass	Fail	Fail
The device must extend at most 2 feet from the side of the wheelchair when mounted.	2	Pass	**Pass**	Pass	Pass	Pass	Pass
The device must be mountable to multiple different types of wheelchairs.	3	Pass	**Pass**	Fail	Fail	Fail	Fail
Electronic Control System							
The switch must be operable with minimal	1	Pass	**Pass**	Fail	Pass	Fail	Pass

hand movement only.							
The device must be powered with at most 1 primary battery.	1	Fail	**Pass**	Pass	Pass	Fail	Pass
The electronic control system must engage on 90% or more of switch presses.	2	Pass	**Pass**	Pass	Pass	Fail	Pass
The device must be able to run for at least 20 minutes before needing to be recharged.	2	Pass	**Pass**	Pass	Pass	Fail	Pass
The system must be able to run under rainy conditions.	3	Fail	**Fail**	Pass	Fail	Fail	Pass
Universal Constraints							
All materials must not exceed $200 in cost.	1	Pass	**Pass**	Pass	Pass	Pass	Pass
The device must not exceed the size of a 3' x 3' x 3' box.	1	Pass	**Pass**	Pass	Pass	Pass	Pass
The device must not exceed 30 pounds in weight.	2	Pass	**Pass**	Pass	Pass	Pass	Pass
There must be documentation with every subsystem with the intent of allowing a future group to continue work on this project.	2	Pass	**Pass**	Fail	Fail	Pass	Fail
The device must be aesthetically pleasing to stakeholders by majority vote.	3	Fail	**Pass**	Pass	Pass	Pass	Pass