Team Nugget's Hands-Free Door Opener

Phase 3 Progress Report

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<u>Team Nugget</u>

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Executive Summary

The objective of this report is to provide information on Team Nugget's process over the course of phase three, but also the project as a whole. Team Nugget's problem definition did not change moving from phase two to phase three, with the goal of the project remaining constant. Team Nugget's product provides a method for people to open pull side doors by simply stepping on a pedal, letting their body weight be the force that opens the door. Team Nugget chose to improve upon hands-free door opening devices due to the lack of options within the market and the problems the current products have.

Team Nugget began phase one by looking at the market for hands free door openers, choosing StepNPull, Automatic Door and Hardware, and Fort Strong as the team's primary benchmarks. Additionally, a survey was issued and sent to various groups Team Nugget's members were affiliated with to gather data on the desires of customers. Using the team's research and survey results, a house of quality was constructed which more clearly defined Team Nugget's customer requirements, engineering specifications, and competency of the team's benchmarks. From the house of quality, it was determined that the primary customer requirements for the product are that the product must be easy to use, quick, durable and safe.

Accompanied by the house of quality was a look at the financial viability of the product spanning both phase one and phase two. Initial economic research was performed in phase one to determine if the market the product would be introduced in had potential. It was found that the doors market is expanding annually along with the U.S construction market rapidly expanding post lock down. From the customer and market research, we imagined our primary competitor to be StepNPull, hence our predicted sales were based off of StepNPulls sales metrics for the year 2020. Using those metrics and assuming a price point of $85, Team Nugget predicted 30,000 annual sales. In phase two, a more in depth analysis was performed, finding that the selling price for the product was around $600, substantially more than anticipated. This drastic difference in price led Team Nugget to believe that the previously predicted 30,000 annual unit sales was no longer accurate. Team Nugget then recontextualized itself and its place in the market, deciding that our main competitor was no longer StepNPull but Automatic Door and Hardware. Another round of research was done, concluding in a predicted annual sales of 19,200 units, providing a much more accurate financial model.

The design created in phase two was iterated on and the bill of materials was updated. A CAD model of the full product was created along with drawings for each part. Using this model, a prototype demonstrating the basic functionality of the product was constructed using 3d printers. To accompany the prototype, models were constructed to predict and analyze various aspects of the product. Specifically models were created analyzing the pressure plate, the one-way friction device, and the force transformation device. These models are useful for determining both the capabilities of the current product along with if any changes need to be made for the final design.

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I. Introduction

The purpose of this report is to address the problem of a non-user friendly way to open doors and discuss improvements upon our original design ideas. All over the world people need an easier way to open doors hands-free that the current products on the market don't provide. Our team's idea for tackling this product is a foot operated hydraulic unit. We decided that a foot operated door was most convenient for the user and with the incorporation of hydraulics, it remains purely mechanical.

The motivation for this project comes from personal experience with opening doors. Throughout the university, doors have foot openers that take a large amount of force in order to open them. Also, some of the doors are in awkward places which renders the foot opener useless. Along with the foot opener, the automatic door openers take a long time to open the door, which is inefficient. All products today that try to tackle this problem have some part of them that does not satisfy customer needs.

For our problem statement, as previously stated, Team Nugget decided to design a "Foot Operated Hydraulic Unit". While our initial statement said hands-free, any body part other than feet seemed inconvenient to the user. Also, the hydraulics help it function similar to current door closers, so users will not have to deal with a completely new product design. We incorporated that into our final design.

We will begin our report by describing our customer and market research that generated our customer requirements and engineering specifications that we wanted to include in our final design. Following that research, we will talk about improvements and updates to our problem definition and how it has changed over all three phases. Following the problem definition we will describe our final design and CAD models that we created along with explaining our engineering models and the conclusion we found from them. Then, our team will describe our process in making our phase three prototype and how we came up with the final prototype. After the prototype, we will revisit our benchmarks and economic analysis from previous reports and describe some changes made since we last updated our bill of materials. Finally, our team will describe our conclusions from our entire design process and what we have learned through making our final product.

II. Customer and Market Research

At the beginning of the project, Team Nugget conducted a survey in order to better gauge the customers wants and needs for the product in addition to the customer requirements gathered through research. The results of the survey and research showed that the qualities customers value are that the product is quick, easy to use, durable, and safe. These were Team Nugget's primary customer requirements that were kept in mind when moving forward with the project.

Benchmarks were another critical aspect of research in the early phases of the project. Team Nugget knew that the product would involve the opening of doors, based on the team's earliest problem statement. Going into the project, Team Nugget's primary competitor and bench mark would be StepNPull, as the inadequacies of said product inspired the project. The team decided to expand potential competitors to both Fort Strong and Automatic Door and Hardware. Fort Strong is a company that sells the automatic door closers that are commonly seen on many doors. Fort Strong was selected as a competitor as Team Nugget envisioned the potential product expanding on the functionality of Fort Strong's product. Automatic Door and Hardware is a company that sells the electric handicap door openers commonly seen as the exterior doors on public buildings. Automatic Door and Hardware was selected as a competitor based on the door opening functionality their product provides, which Team Nugget envisioned would be similar in functionality to the potential product. Additionally, some patents were analyzed to fuel ideas of how the product would operate as well as determine if our product falls under any previous patents. The patent analysis determined that the mode of door operation should be the foot, as it follows the hands-free goal of Team Nugget's problem statement and is intuitive.

Using the information gathered, a house of quality was constructed to analyze the customer requirements and engineering specifications. The house of quality was also used to determine what Team Nugget's benchmarks succeeded and failed at, in order to help focus our efforts. From the house of quality it was determined that the highest valued customer requirements were the effort to open the door, the safety of the product, the durability of the product, and the quickness with which the product can open the door. Keeping these along with the other customer requirements and engineering specifications in mind, the benchmarks were analyzed. It was determined that Team Nugget's benchmarks have a wide range of performance, with Fort Strong performing middlingly across the board, while StepNPull and Automatic door and hardware either excel or fail. The benchmarks were additionally used to create target and threshold values for Team Nugget's product. These values were critical for the project moving forward as it gave the team a gauge of how well our product would perform in theory and if the design was up to par.

III. Problem Definition Review and Updates

Team Nugget's problem definition has steadily evolved throughout the semester as the team has identified a greater scope of functionality than what was originally intended. In phase 1, the problem definition plainly stated a need for an improved method for opening doors without using one's hands. The goal behind the hands free door opening system would be to reduce strain on individuals who: (1) open doors very often and/or while carrying heavy objects, (2) need to keep their hands as sterile as possible, and (3) are handicapped. The original inspiration for this product was to improve upon the existing Step N Pull which we can currently see on doors around campus. With this, came an estimated price point of about $85.

In phase 2, the problem definition took a major shift as we started to nail down specific aspects of the design and its overall functionality. The much broader phase 1 statement was narrowed down to a "foot-operated hydraulic unit". This shift was the result of a functional decomposition which led to design creations and then finally, selection. The "foot-operated" portion of the refined problem definition was to eliminate the use of other non-hand body parts such as the knees or elbows since it was decided that foot-operated would be the most convenient for consumers. Given a myriad of different designs proposed, it was decided that a hydraulic powered system would be the most effective design for our product. With this however, came a large increase in product cost due to the greater complexity and functionality of the design. Instead of simply providing a way to open a door without hands, we wanted to be able to open and close the door in a safe, efficient, and purely mechanical manner. By this point, the design had evolved greatly from the original Step N Pull inspiration to a product that would more directly compete against the electric automatic door opening systems. The fact that our product would now be competing against a much more sophisticated product warranted our steeper price point, given the very high costs of current electric door opening systems.

In contrast to phase 2, phase 3 saw virtually no change in the problem definition. By this point, the design had been fully outlined and refined. It would have been difficult to incorporate any changes to the problem definition in phase 3 due to the fact that all of the functional decompositioning and design ideas that were created in phase 2 revolved around the "foot-operated hydraulic unit" definition. To change that definition we would have to go back and redo phase 2 activities before moving on to the more advanced modeling that was conducted in phase 3. This maneuver would have cost the team a large amount of time and effort so it was fortunate that we remained confident in our phase 2 findings through to the completion of phase 3.

IV. The Design

[Design Operational Description, Novel Performance Features, Summary of BOM, Include key manufacturing processes and material choices, Reference Drawings throughout, Assembly sequence overview if relevant]

1. Design Operational Description

This design consists of three major parts: a pressure plate, a force transformation device ("Bob"), and a one-way drag device (OWD). The ultimate goal is to open the door with feet, which potentially could benefit people in many scenarios. To open the door, a person can step on the pressure plate. The plate will push the liquid out from a liquid bag into a fluid tube. Then the fluid flows through the OWD into the piston. At this point, OWD is not creating a lot of drag. As the fluid flows into the piston cylinder, it's also pushing the piston head which is connected to a gear rack. The gear rack moves in a straight line, causing the gear to rotate. The rotating gear can drive and exert torque on the arm, causing the arms to rotate and push against the door. Now the door is opened.

This device should close the door on its own by the springs in the pressure plate. When the person steps away, the two springs push up the plate, causing the fluid bag to expand and suck the fluid back to the bag. Now the fluid is flowing from the piston to the OWD. In this direction, the fluid is guided to a narrower channel in OWD, therefore limiting the flow rate. This will make the closing time to be longer than the opening time. The fluid flows out of the OWD and back to the fluid bag in the pressure plate.

2. Novel Performance Features

The first special feature obviously is that people can open the door without using hands. This can be used in many situations where using hands to open door is difficult for them, such as people who have disabilities or holding a lot of stuffs. The second one is that the closing time can be customized. The time depends on the application and the installation situation. For a heavier door, the closing time would be much longer. For elder people, they need more time to get through, so the closing time should be longer. However, usually we don't want it wait the door to open for so long, therefore OWD creates drag only when the door is closing.

3. Bill of Material

In our newer design, we removed the fluid tank and its accessories and added the one-way drag device. In OWD, there are main casings, ferromagnetic gates and non-ferromagnetic gates. We chose to use magnetic because we can control the gate without the chance of leakage. Now, the casing, opening gaet, and another half of the closing gate are not ferromagnetic. The number of parts are about the same as the previous one, but it's easier to assemble and install. The installation of the gates are straight forward. Every piece is unique, so there is no chance of incorrect installation.

To reduce the total part number, we chose to use the same screws and nuts everywhere, named with a prefix Universal (UN). In the pressure plate, we added more parts, such as the spring holders and a rotating pin, to make it more specific and realistic. Nothing is changed in "Bob" because it was the best design we could think of. Overall, the price increased a little, but it's still acceptable.

V. Engineering Modeling

1. Pressure Plate

The pressure plate component is designed to receive a downward weight force from the user and then transfer this force to the door opening component of the product. To do so, the pressure plate is fitted with an internal hydraulic fluid repository which experiences a pressure shift due to the applied force on the top of the plate. The resultant pressure shift is then transmitted through hydraulic tubing connecting the pressure plate to the door mounted portion of the device. This hydraulic pressure is directed into a piston mounted at the top of the door.

2. "Bob" - Force Transformation Device

"Bob" transfers the linear motion from the piston into the rotational motion on the door. When the fluid is pushed into the piston, the piston expands and pushes the gear rack out. When the gear rack is moving in one direction, it rotates a gear and a main shaft. The main shaft connects the gear and the scissor arm. The rotation of the gear causes the scissor arm to rotate and push against the door frame to open the door. It works similar to the ordinary door closing device. As a result, we did an analysis on what force would be required for the bar to be able to push open the door. Then, using this, we found a model that shows us the relative velocity and angular velocity when the door is opening. In the model, it shows how the max velocity is at the beginning and end of the door opening process, which will affect how a person can go through the door. The middle is the slowest part of the door opening process, which allows the user to hurry through the door before it closes again. We also found that a medium amount of force would be required to open the door so We may have to find a way to lower this in order to allow for easier access for children or any smaller adults. All in all, the model shows we are doing well in our design process, but we still need some improvements in order to create a completely finished product.

As "Bob" is a very significant aspect of the design, two models were performed. The second model focuses on the interactions between the pressure of the fluid and the size of the gear versus the output torque of the system. This was analyzed as, depending on where the unit is mounted and the size of the lever arm, different torques may be necessary to open a door. This model took two variables into account, fluid pressure in psi and gear radius in inches. The model plotted the torques produced from fluid pressures between 150 and 310 psi in increments of 20 psi and gear radii between .5 and 1.5 inches in increments of .125 inches, the graph of which is seen in figure 15. In essence, this allows the Team Nugget to know what scale of gear is needed along with if the pressure plate needs to be adjusted in order to guarantee door opening capabilities. This model relies on the results of other models in order to allow Team Nugget to innovate and iterate on the current product.

3. One-Way -Drag Device

One-Way Drag (OWD) is a device that can slow the door when it's closing by limiting the flow rate of the hydraulic fluid passing through it. Its input is the position of the magnet outside of the casing, and the output are the different flow rates. By doing this, we can adjust the closing time of the door. As a result, the higher the position of the magnet is, the faster the door closes.

VI. Phase 3 Prototype

The prototyping process began with the finalization of the CAD model of the entire system, including all the parts from the BOM. From this point, a question of necessity and efficiency was posed, that being "how much of this design must be present to demonstrate functionality?" This question was posed due to the limited amount of time and funds that are able to be dedicated to prototyping, as to fully produce Team Nugget's product would be costly and time intensive. It was determined that the main parts that were needed were a rudimentary hydraulic system (seen in figure 19), the step (seen in figure 18), and the internal gear-shaft system (seen in figures 19). This heavily reduced the parts that were printed, as a large amount of parts were not necessary for demonstrating functionality. Additional parts had to be designed in order to accommodate the shift from a proper hydraulic cylinder to two 200mL syringes connected by tubing. The piston holder model was adjusted to fit said syringes and a connector to hold the gear rack was designed to easily attach the gear rack to one of the syringes. A rudimentary structure to display the gear rack and gear interaction was also designed and fabricated.

The prototype truly put the scale of the components into view, which is not gained by simply having a to scale CAD model. All the parts fit within a roughly 120 cubic inch space, which is hard to visualize how little space that is when the largest component as reference is that 120 cubic space. Fabricating the parts that were deemed necessary revealed that the most critical components of the product could fit in the palm of one's hand.

VII. Benchmark Comparisons

For our benchmarks, we found five designs and patents that are used in the market, and had the best reviews or we have seen around in public. Out of these five, three of them were actually produced whereas two of them did not make it past the patent stage. These two designs are the foot operated door opener and the foot-operated door opener.

(1). Step N Pull: Step N Pull (Figure 1)is a piece of aluminum that is attached to the bottom of a door away from the rotating axis. It has a sawtooth design on the hook to provide enough grip to open the door by foot. This little awkward-to-use aluminum piece that takes maximum effort to open costs $30. Its patent was granted in 2015 and is still active (US9115530B2)[1].

(2). Automatic Door and Hardware: It requires people to push a button to activate the system and open the door. This wheelchair-friendly door costs $300 to $600. It's slow to open, and its angular velocity can not be changed.

(3). Foot-operated door opener (Figure 2): this relatively small product is complicated to build. People will step on a pedal to unlock the trigger and open the door. This product was invented by Robert Stuart, and its currently expired patent was granted on September 18th, 2007 (US7270352B1) [2].

(4). Foot operated door opener (Figure 3): This simple and install-friendly product has a similar name to the previous one. It should be installed very close to the axis of rotation, so people won't step and push for a long distance to open it. A close-to-axis design requires a large force to open. It was invented by Garritt Darling, and its currently expired patent was granted on March 26th, 2002 (US6360488B1) [3].

(5). FortStrong: this product can close the door very slowly by itself and make people feel harder to open because of the internal resistance. This expensive device only does the door closing job and costs about $150.

Our final design compares to these benchmarks in a variety of ways. First, it is cheaper in price than the Automatic Door and Hardware model, however it is more expensive than the StepNPull and FortStrong products. In addition, we have made our design so that it is more comfortable to the user, which is a requirement the StepNPull did not meet as seen in our customer research. Team Nugget has made our final design so that there is ample time to get through the door and it is easy to open. With this, the final design used hydraulics in order to have a small amount of force needed to open the door. Both of these features are something not seen in any of the previously mentioned benchmarks. Finally, we have made the product wheelchair accessible, which is something that only the Automatic Door and Hardware product focuses on. All in all, our final design has pros and cons to it, but overall it meets more of the customer requirements and engineering specifications than anything on the market right now.

VIII. Economic Analysis

Team Nugget's financial Analysis was informative and challenged the team to reframe our products' financial references and assumptions. Team Nugget performed several iterations of the financial analysis as we realized that our initial assumptions were no longer valid due to the massive increase in price, scaled those assumptions to the new price, and then realized that our reference point was lacking as due to the differences in each product's functionality. Team Nugget's current iteration of the financial analysis sees 57,600 product sales over the three year production period, a number based on the team's new market research and shown in Figure 4. From these estimated sales, we find that the product will break even within the 8th quarter. The upfront costs include R&D and tool and fixture costs which total to be $553,264. The graphs showing the products net worth over the production cycle can be seen in Figure 7 in the Appendices section. From the analysis it was concluded that the return on investment for the product is 46.83% while the rate of return for the project is 69.19% as seen in Figure 5.

Some key takeaways from this economic analysis is that our product is feasible. We break even within the 8th quarter, and start making a profit up until the end of the 15th quarter. Our final net present value we found was $737,230, which is at the end of the 15th quarter. As our financial model shows, we will be profitable and be able to sustain growth and any dips in the market, even though we do not expect that to happen. Finally, the difference between our estimated manufacturing cost ($166.11 from our BOM in Figure 6) and our retail price ($529.48) shows that we will roughly be making $360 per unit. Using this number, we found that selling 19,200 units annually will keep us financially stable and allow us to continue selling units for years to come.

IX. Conclusions

Throughout the third phase of our product, our team has been working to refine our final product through cad models and engineering models. We have also been analyzing our final product design financially through our two prototypes. All this data collection and analysis has allowed the team to construct a complete understanding of what our product must be able to achieve given the customer requirements which were translated into engineering specifications.

In our final design stages, we have come across some of the strengths and weaknesses. Some of the strengths of our design are that it is easy to use and there is low effort to open the door. While small adults or children may have a small amount of trouble opening the door, an average adult will have no problems. Also, our design allows plenty of time for the consumer to get through the door before it slowly closes. Some of the weaknesses of our design are the cost and the space filled by the unit. These were two of our customer requirements that we could look back on and try to improve our design in these areas.

Moving forward Team Nugget will try to further enhance our design to meet our customer requirements and engineering requirements. We will try to work on our medium prototype and get a more finished product in order to analyze further. In doing this, we will add our wheelchair part to the step so that it is accessible to everyone. We will also try to use other materials and refine our bill of materials to reduce cost for the consumer.

Finally, Team Nugget will look to improve upon design constantly to make the best product for the consumer. Some of the key takeaways from this project and this phase in particular were that the force required could be lowered in order to incorporate even the smallest consumer, and what size parts needed would be most efficient from our engineering models. All in all, our Team has made good progress on our design and will continue to improve upon it.

X. References

Benchmarks and Patents:

[1] https://patents.google.com/patent/US20090145037?oq=US9115530B2
[2]https://patents.google.com/patent/US7270352B1/en?q=hands+free+%22door%22+opener&oq=hands+free+%22door%22+opener
[3] https://patents.google.com/patent/US6360488?oq=US6360488B1

XI. Appendices

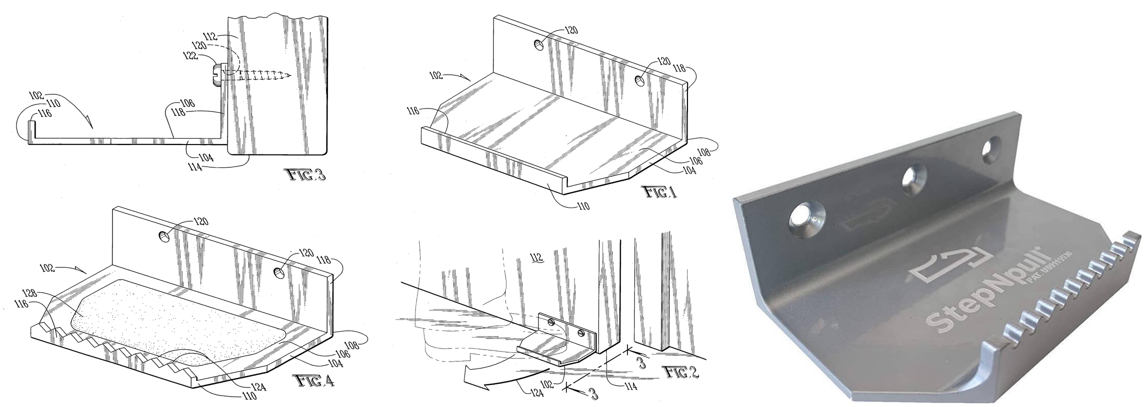


Figure 1 (left to right): Step N pull, patent No. US9115530B2

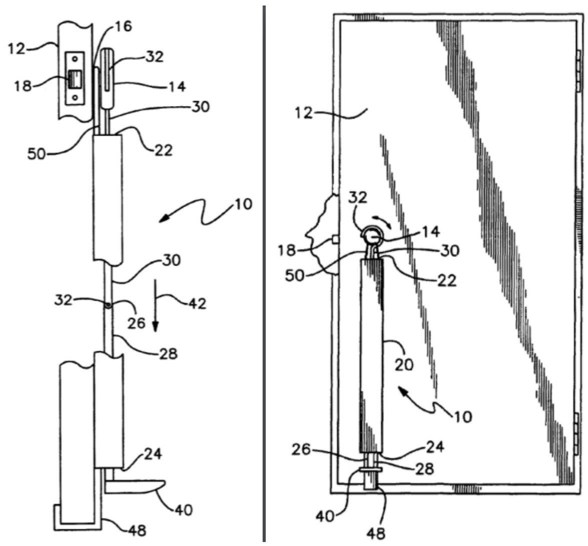


Figure 2: foot operated door opener (1), patent No. US7270352B1

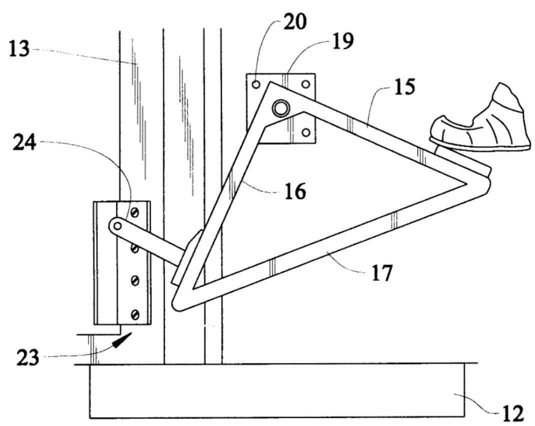


Figure 3: Foot operated food opener (2), patent No. US6360488B1

Input		
Interest Rate / year	8	%
Analysis Periods / year	4	#
Tooling and Fixtures	419000	
Annual Production	19200	#
Estimated Purchased Parts	58.57	$
Estimated Fabricated Parts	58.8	$
Estimated Assembly Cost	15	$
R&D Costs	134264	$
Cost % of Retail	25	%
Return to Project % of Retail	30	%

Calculated		
Intereset Rate per Period	0.02	rate/period
Estimated Mfg. Cost	132.37	$
Retail Price	529.48	$
Build per Period	4800	#
Total Program Build	57600	#
Total Retail Sales	30498048	$
Return to Project	9149414.4	$
Net Present Value	737.23	$(000)
Net Worth (excl. interest)	971.64	$(000)

Figure 4: Input and Calculated values for Financial Analysis

ROI=	46.83	% per year	Min production with no interest=	1741
ROR=	69.19	% per year	Min production with interest=	2005
PB=	8th	Quarter		
NPV=	737.23	$(000)		

Figure 5: Final Outputs from Financial Analysis

Total Purchased Parts $	98.20
Total Custom Manufactured Parts $	52.92
Total Assembly Cost $	15.00
Total Cost $	166.11

Figure 6: aggregated BOM

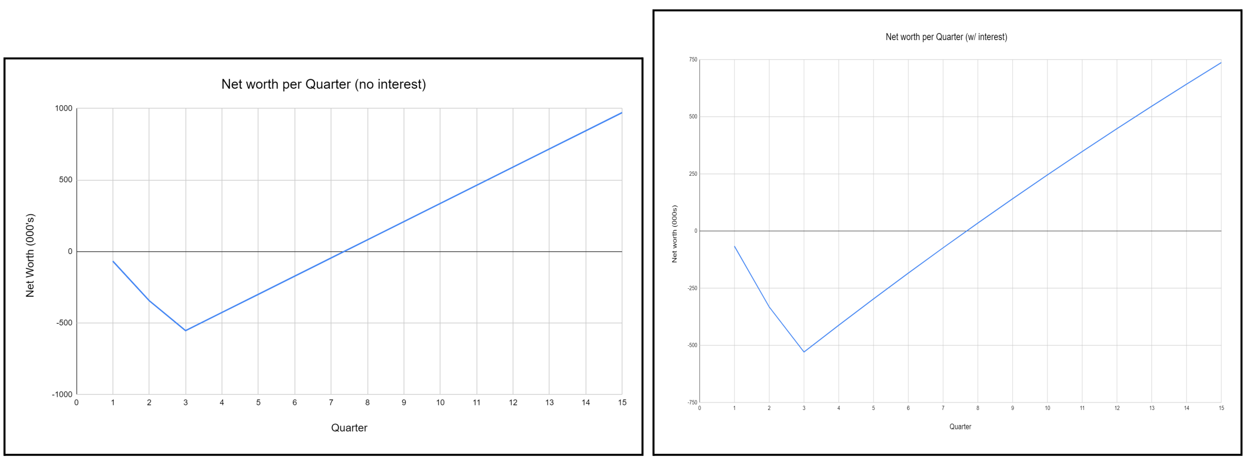


Figure 7: net worth charts with and without interest

HOUSE OF QUALITY	Who (Customers)					How (ES)									Now (Benchmarks)		
						Force of operation	Strength of material	Longevity	Unit Cost	Size of Unit	Use of Standardized Parts	Sound Produced	Time to open door	Number of Pinching Parts			
						Newton	ksi	years	$	in^3	#	Decibles(dB)	Seconds	#			
What (Customer Requirements)	Warehouses	Handicapped People	Hostpital	Universities	Weight averages	↓	↑	↑	↓	↓	↓	↓	↓	↓	Automatic Door and Hardware	StepNPull	FortStrong
Effort to open the door	10%	15%	11%	7%	10.75%	9	1	1	0	0	0	0	3	0	5	1	3
Ease of operating the door	17%	12%	13%	10%	13.00%	9	0	3	0	1	0	1	3	0	5	1	3
Time required to operate door	10%	9%	5%	5%	7.25%	0	0	0	3	0	0	0	9	0	2	3	4
Space filled by unit	3%	5%	5%	5%	4.50%	0	1	0	1	9	3	0	0	1	5	5	5
Ease of installation	8%	5%	8%	10%	7.75%	0	0	3	3	3	9	0	0	1	2	5	4
Low Cost	10%	5%	8%	14%	9.25%	3	3	3	9	1	1	0	0	0	1	4	2
Durability	15%	11%	12%	14%	13.00%	1	9	9	3	0	1	3	0	0	4	5	4
Aesthetically pleasing	0%	5%	5%	5%	3.75%	0	1	0	3	1	1	9	0	1	3	3	3
Ease of repair	11%	7%	7%	6%	7.75%	1	1	3	1	1	9	0	0	0	2	5	3
Safe to operate	10%	10%	13%	10%	10.75%	3	9	0	0	1	0	0	3	9	5	4	4
Retro-Compatibility	3%	5%	8%	8%	6.00%	0	0	1	1	3	3	0	0	0	4	5	4
Quiet	0%	5%	5%	5%	3.75%	1	1	0	3	0	0	9	1	1	4	5	4
Purely Mechanical	0%	3%	0%	1%	1.00%	0	0	1	3	3	3	1	1	1	1	5	5
Customizability of door operation time	3%	3%	0%	0%	1.50%	0	1	0	1	1	9	0	9	0	4	3	3
Total	100%	100%	100%	100%	100.00%	27	27	24	31	24	39	23	29	14	47	54	51
					Automatic Door and Hardware	67	~30	N/A	$1,600	269	~3	N/A	6	3			
					StepNPull	67	~40	N/A	$30	30	0	N/A	3	0			
					FortStrong	67	~30	N/A	$130	372	~3	N/A	2	3	<= these are values for ES in proper units		
					Target (Delighted)	22	45	15	$10	100	6	10	1.5	0			
					Threshold (Disgusted)	132	25	3	$1,600	500	0	70	10	6			

Ratings Legends:
Now vs What:
1 = does not meet requirement
2 = meets requirement slightly
3 = meets requirement somewhat
4 = meets requirement mostly
5 = meets requirement completely
How vs What:
blank (=0), 1, 3, 9
Who vs What:
weights summing to 100

Figure 8: House of quality

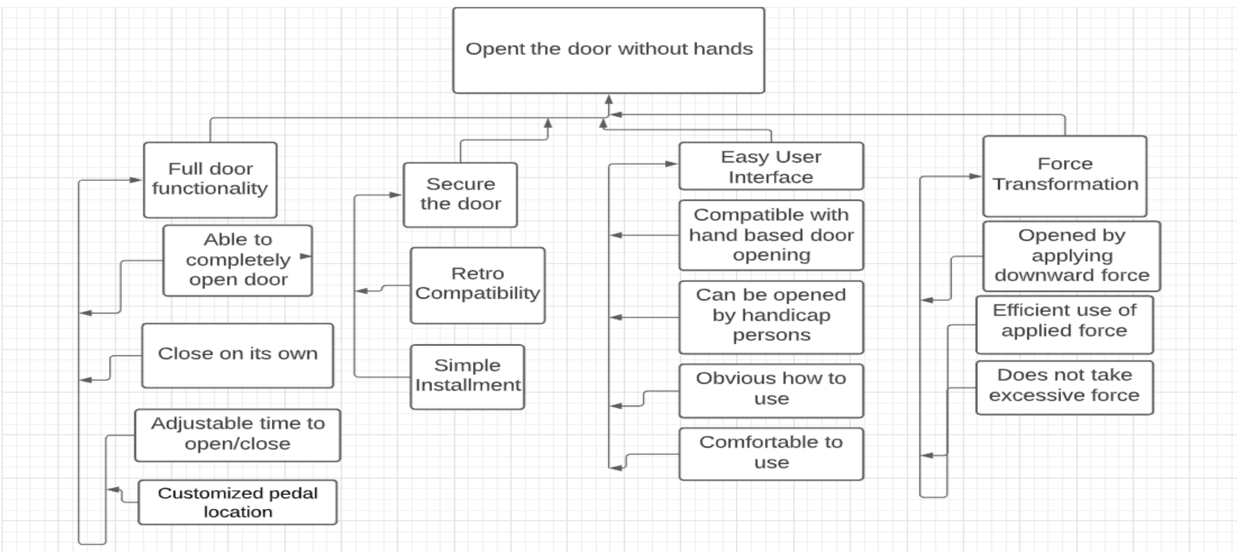
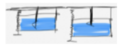
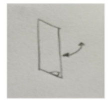
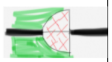
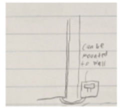
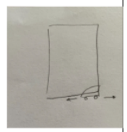
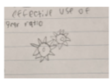
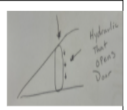


Figure 9: functional decomposition

Adjustable time to open/close				
Customized pedal location				
Opened by applying downward force				
Efficient use of applied force				

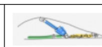
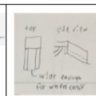
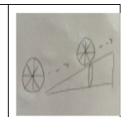
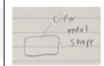
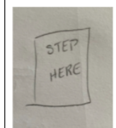
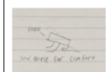
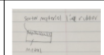
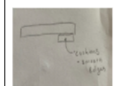
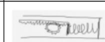
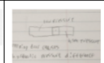
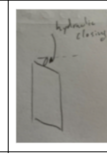
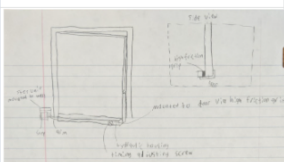
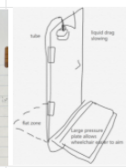
Can be opened by handicapped persons				
Obvious how to use				
Comfortable to use				
Closes on its own after opening				

Figure 10-11: concept generation overview

Customer Requirements		
Effort to open the door (low)	1	1
Ease of operating the door (easy)	1	1
Time required to operate door (short)	1	0
Space filled by unit (small)	0	-1
Ease of installation (easy)	0	0
Low Cost (low)	-1	-1
Durability (durable)	0	1
Aesthetically pleasing (good)	0	1
Ease of repair (easy)	-1	0
Safe to operate (safe)	1	1
Retro-Compatibility (compatable)	1	1
Quiet (true)	1	1
Purely Mechanical (true)	1	1
Customizability of door operation time	0	1
Total +	7	9
Total -	-2	-2
Overall Total	5	7
Weighted Total	14	18

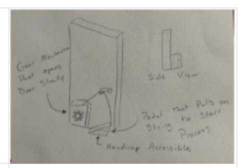
Customer Requirements	Weights		
Effort to open the door (low)	4	1	1
Ease of operating the door (easy)	5	1	1
Time required to operate door (short)	3	0	-1
Space filled by unit (small)	2	1	-1
Ease of installation (easy)	3	0	0
Low Cost (low)	4	0	-1
Durability (durable)	5	0	0
Aesthetically pleasing (good)	1	0	-1
Ease of repair (easy)	2	0	-1
Safe to operate (safe)	4	1	1
Retro-Compatibility (compatable)	2	1	1
Quiet (true)	1	1	-1
Purely Mechanical (true)	1	1	1
Customizability of door operation time	1	1	1
	Total +	8	6
	Total -	0	-6
	Overall Total	8	0
	Weighted Total	20	4

Figure 12-13: concept selection

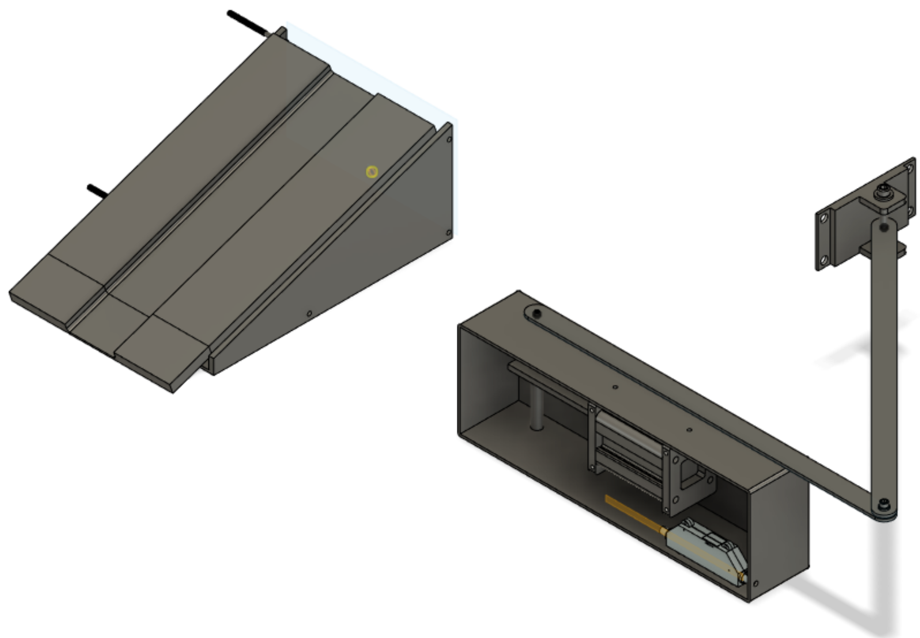


Figure 14: CAD Model of Full Assembly

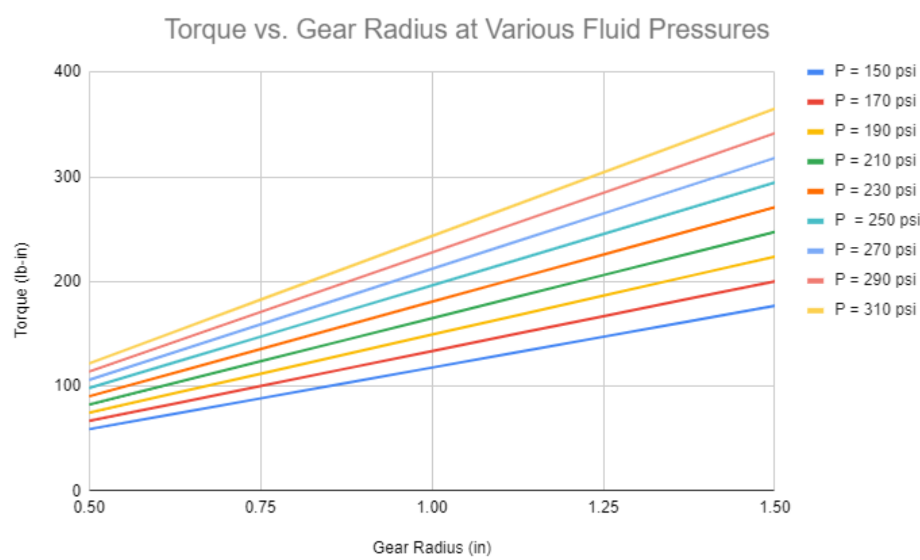


Figure 15: Torque vs. Gear Radius at Various Fluid Pressures

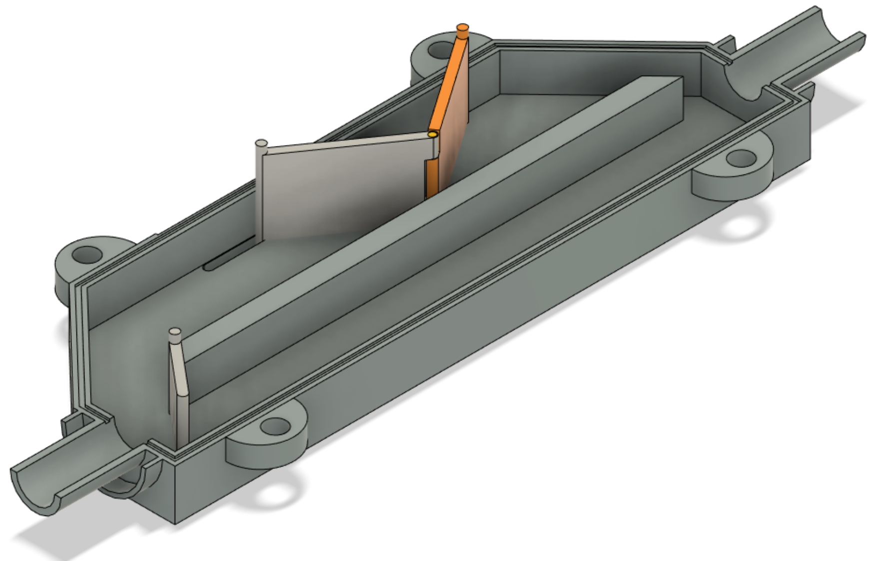


Figure 16: One-Way Drag Device

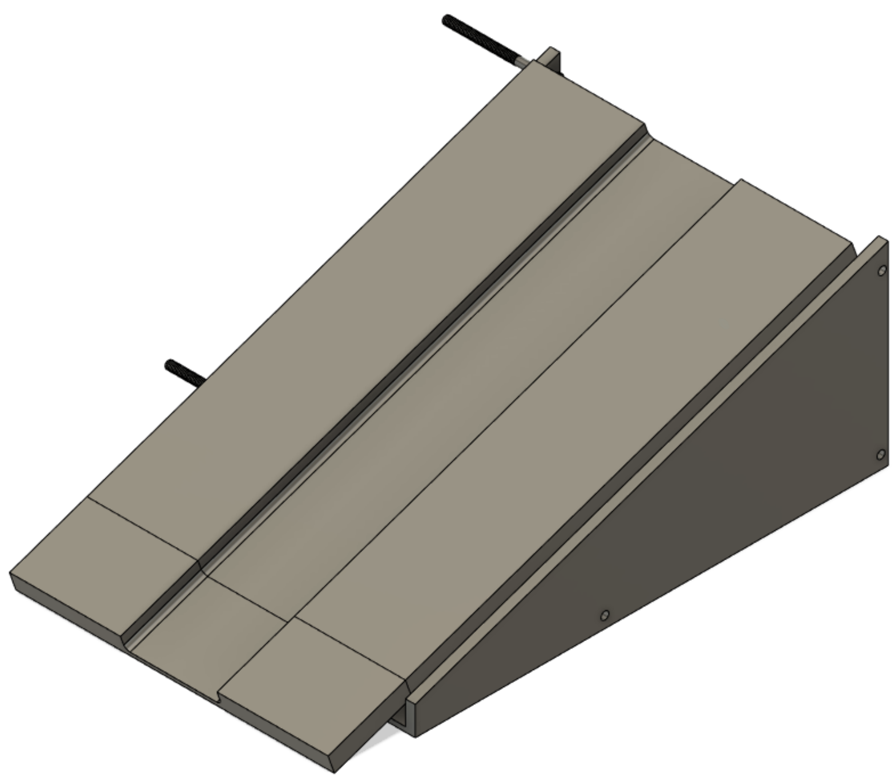


Figure 17: Pressure Plate

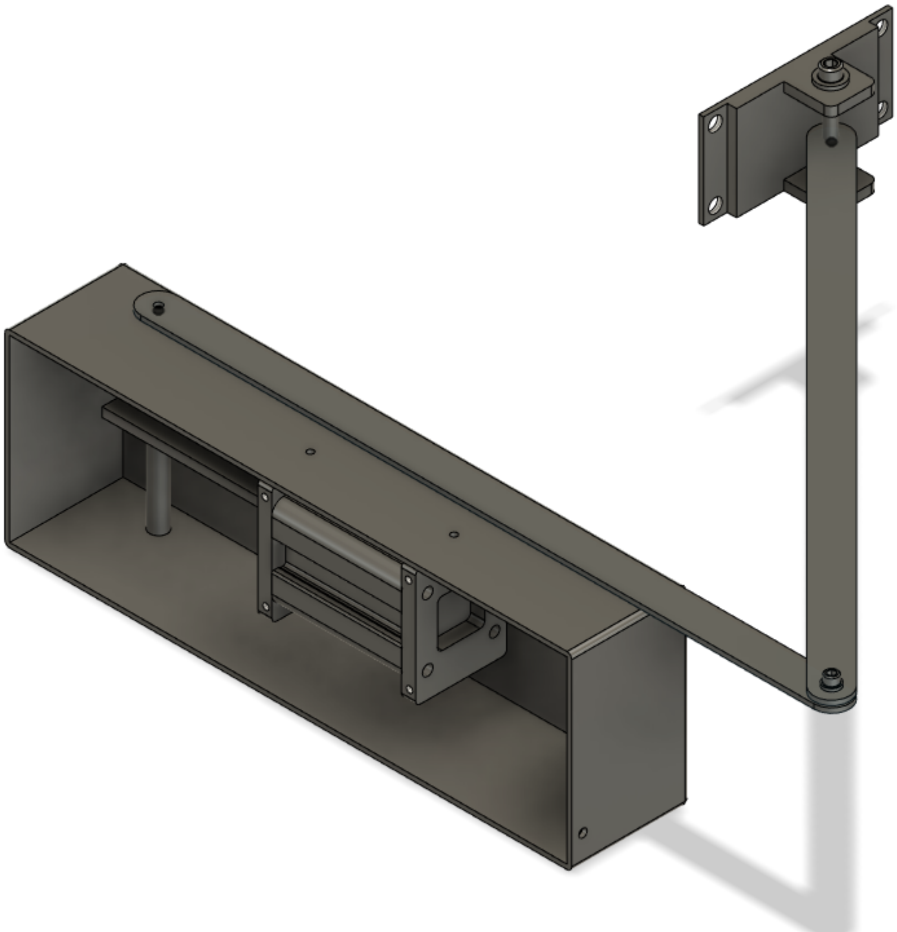


Figure 18: Force Transformation Device

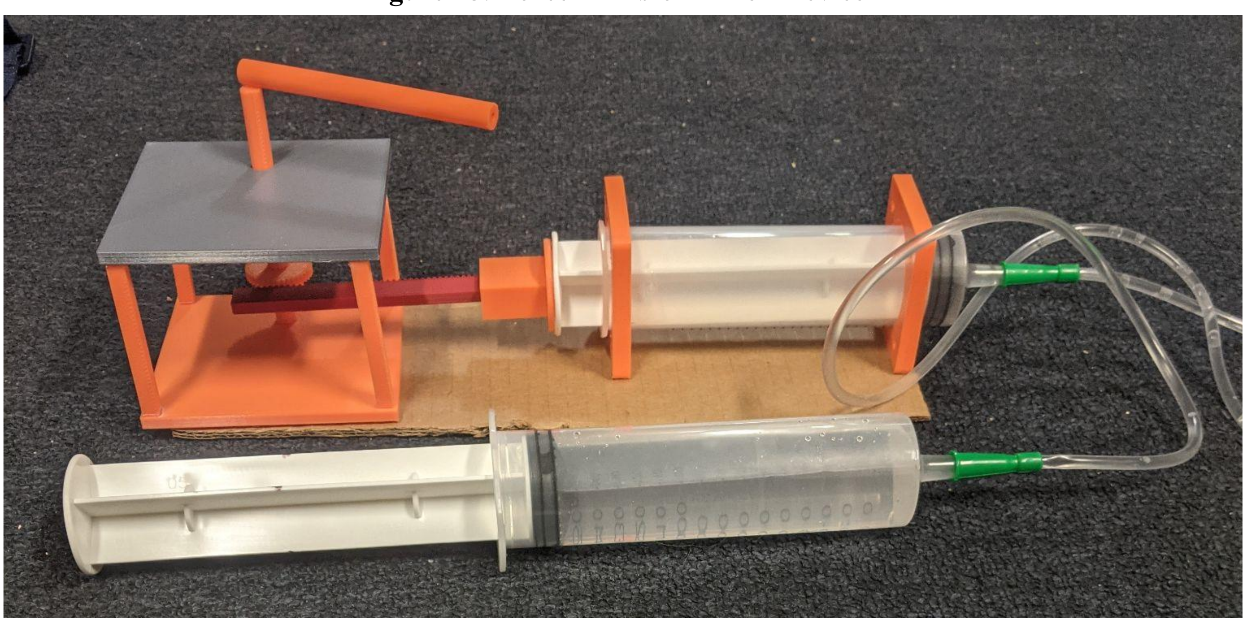


Figure 19: Prototype of Force Transformation

Figure 20: Prototype of Pressure Plate

Figure 21: Prototype of One-Way Drag Device