Fall 2018

The Wellness Companion Portable Fitness Device

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Executive Summary

Designed to combat the unhealthy effects of sitting for long periods of time, the wellness companion is a portable treadmill that one can easily bring to school, to the office, to the library, or anywhere else one may be at for long periods of time. The companion can shrink up to ⅓ of its extended length using interlocking drawer sliders. In its collapsed form, the companion exists as three panels stacked on top of each other. In its extended form, these panels can slide out to tension the belt and provide a smooth walking surface. The current prototype makes use of a pre-existing treadmill from which a 2.5 HP motor, circuit board and speed controller was salvaged, and was built using medium-density fibreboard from Home Depot. A budget of $250 was allotted for this project, of which $137.67 was used. The wellness companion can easily hold over 200 lbs, and can be easily set up or put away in less than a minute. Future improvements are being considered, which include additional belt tension, a motor casing and a carrying suitcase for easy storage.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

Project Name

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1 INTRODUCTION

In light of ever-growing obesity rates in the U.S. and the rest of the world, the concept of a sedentary lifestyle has been fueled by the technological revolution of past decades. This has led to rising levels of sitting in many contexts, particularly working and educational environments, promoting the unhealthy effects of staying still for long periods of time. This lifestyle is further enhanced due to the limited accessibility of gyms and workout equipment in these environments, where people are spending more of their time in the day.

Under the direction and supervision of concept creator Muhammad Elahi, we plan to engineer a new type of treadmill meant to counter these unhealthy and concerning trends of today. The device is a portable treadmill designed to be shrunken down in size when not in use to make it easy to carry, such as to an office or school setting, and be extended to full length whenever needed for any period of walking exercise. The portability and ease of use are core to the functionality of the project, as they will provide for accessibility to workout equipment anywhere the user is and make it convenient for them to be active on their own time.

Ultimately, the idea is to design a fully-functional machine that can be used for walking and jogging anywhere, whether in the comfort of the home, or the office, or the campus, etc. With concerns of a generation of busy, occupied, inactive human beings, we hope to bring to fruition a device that can promote a healthier lifestyle and do so both functionally and conveniently. For the purposes of this report, the terms "Fitness Device" and "Wellness Companion" will be interchangeable.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing Design 1: InMotion T900 Manual Treadmill

Figure 1: InMotion T900

A non-motorized treadmill that is powered by the users own motion. The lack of need for an electrical outlet means that this treadmill is slightly more portable and versatile than a standard treadmill. Can be adjusted between two incline settings, but cannot be used at a zero degree incline since it is motorless. The treadmill weighs about 52 lbs and takes up a surface area of about 4 ft x 2 ft, making it only slightly more portable than the average treadmill. It is not designed to be carried around and used wheels to achieve its portability [1].

2.1.2 Existing Design 2: Xebex Runner

Figure 2: Xebex Runner

A motorless, curved treadmill that is powered by the users own motion. The curved belt allows the user to run at their own desired speed at a zero degree incline. The treadmill is no more portable than the average treadmill with a weight of 315 lbs, but can be used in many more locations due to it being self-powered. The unit takes up an area of about 5 ½ ft x 3 ft and uses wheels and a lifting bar for transport [2].

2.1.3 Existing Design 3: ProGear 190 Space-Saving Treadmill

Figure 3: ProGear 190 Space-Saving Treadmill

A treadmill designed to fold up into a compact shape for easy storage. The treadmill uses flywheels to smoothly use the users own motion to move the belt. With a weight of 50 lbs and a usage area of about 4 ft x 2 ft, the treadmill is versatile in where it can be operated. The folded dimensions are about 2 ft x 2 ft x 4 ft and it can support a weight of up to 230 lbs. While it does have the ability to become more compact, the weight is still too high for the desired portability aspect of the device [3].

2.1.4 Standard 1: Standard Specification for Fitness Equipment, Active Standard ASTM F2276 – 10(2015)

This standard specifies design and manufacturing parameters for fitness equipment meant to be used by people 12 or older. The parameters listed include specifications for stability, support, edges, corners, and tube ends, moving parts. It also mentions guidelines for guarding/enclosing any points of squeezing/shearing/crushing, adjustment/locking, handgrips, foot support, any type of loading, and load-transmitting components. Lastly, adequate warnings and labels about any hazards associated with the device are mentioned. For our design, this means the inclusion of proper handrails that can likely be attached and removed for portability; we will also have to design covers for any moving parts and ensure the treading belt has enough tension and material rigidity to stay tight over time. We will also print cautionary labels and apply them to the device.

2.1.5 Standard 2: Medical devices – Part 1: Application of usability engineering to medical devices, IEC 62366-1:2015

Specifies a process of manufacturing to analyze, develop, and evaluate the usability of a medical device as it relates to safety; this process, known as usability/human factors engineering, will help us assess and reduce the risks associated with the normal use of the healthcare device. This will allow us to better design it and put the appropriate safety measures into the prototype to most effectively counter the risks, as well as assess or predict any issues that may arise from abnormal use of the product.

2.1.6 Patent 1: US20160096064A1

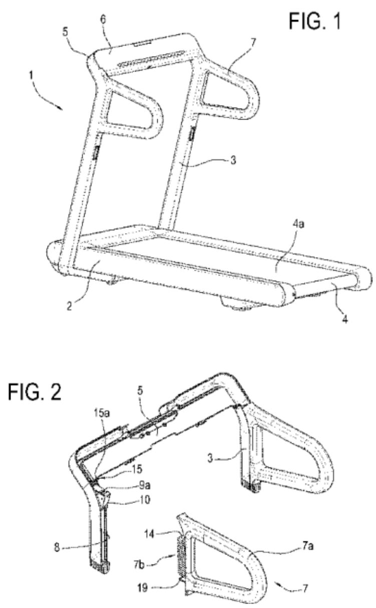


Figure 4: Drawing for Treadmill with Removable Handles

This is a patent for a fairly traditional treadmill design that includes the frame and uprights where the handles can be removed and reattached, potentially saving space and helping enhance the portability of the design. The treadmill in the patent additionally includes a control panel with a UI, a belt, and a motor on at least one of the rollers for activating belt motion.

2.1.7 Patent 2: US4757987A

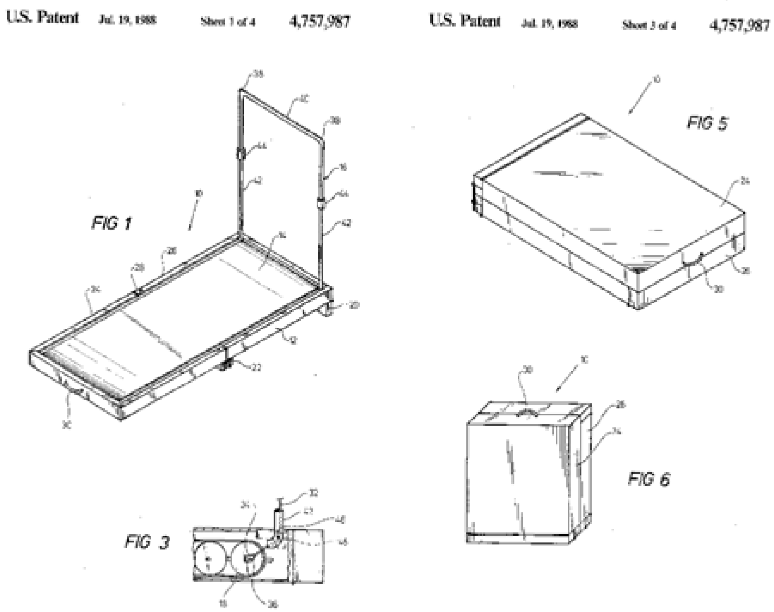


Figure 5: Patent Drawings for Folding Treadmill Design, with Open and Closed Configurations

This patent describes a portable treadmill designed to be foldable to reduce its size when not in use. It utilizes telescoping handles that can release tension in the belt, and the pivotal attachment of two housing sections so that the entire device can be folded in half to a compact size, ideal either for better portability or for optimized storage purposes.

2.2 USER NEEDS

Table 1: Customer Needs Interview

Product: Fitness Device
Customer: Muhammad Elahi

Notes: The interview was conducted over conference call, about 40 minutes long.

Address: Urbauer 318, Washington University in St. Louis, Danforth Campus
Date: September 7, 2018

Question	Customer Statement	Interpreted Needs	Importance
Reason for invention	Stay fit at home, office or library	Easily transportable	5
Target audience	The more people this device can accommodate, the better	Useable by children Hides machinery so children cannot get hands or feet caught	2 3
Noise level	Should be useable in a library without disturbing anyone	Inaudible	3
Ideal life-cycle	Small motor, so energy shouldn't be an issue If size becomes an issue, don't use a battery	Small battery Battery is not bulky	3 2
Ideal size change	Short version ideally half the extended size	Shrinking tech - either extends, folds up, disassembles, etc.	5

Table 2: Interpreted Customer Needs

Need Number	Need	Importance
1	FD is easily transportable	5
2	FD is usable by children	2
3	FD hides machinery so children cannot get hands or feet caught	3
4	FD is inaudible	3
5	FD uses a small battery	3
6	FD's battery is not bulky	2
7	FD either folds up, extends, disassembles, or shrinks in some other way	5

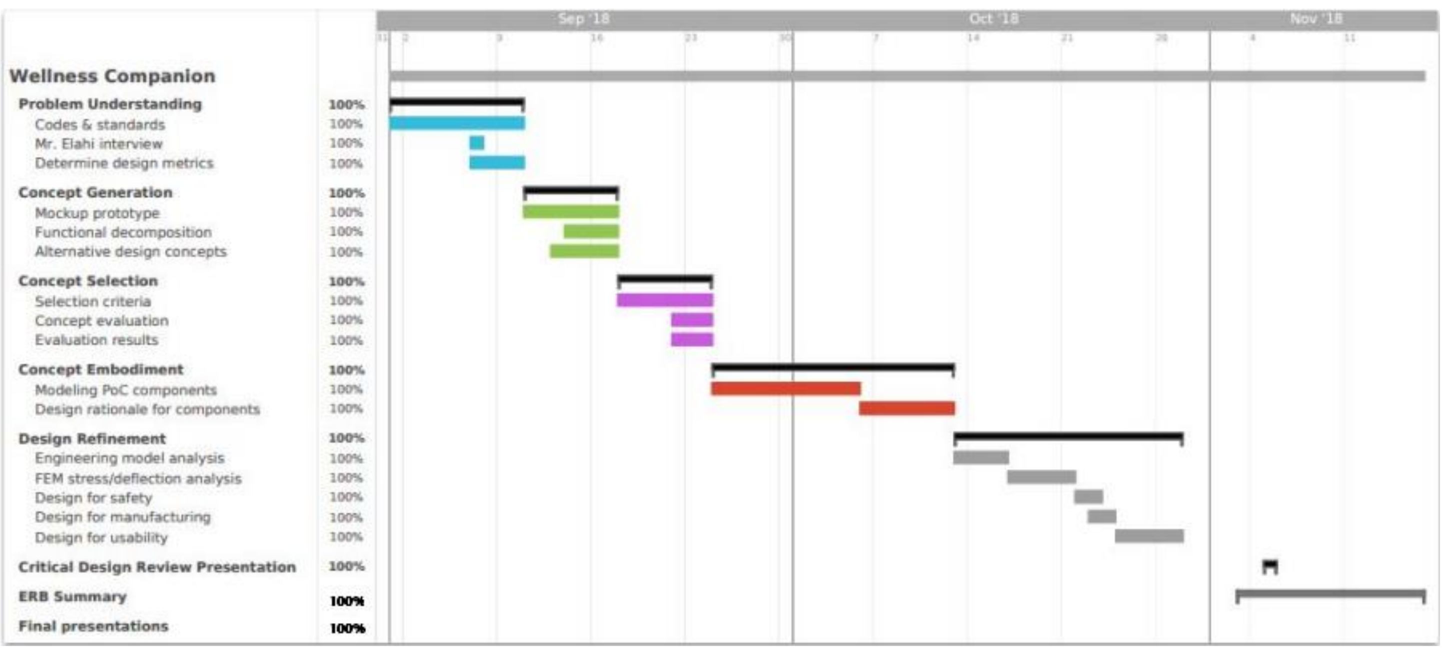
2.3 DESIGN METRICS

Table 3: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1, 6	Total weight	kg	< 20	< 10
2	1, 7	Extended volume	ft^3	< 10	< 6
3	2, 3	Rating of "family friendly" by focus groups	avg. score	> 3/5	> 4/5
4	4	Operable decibel level	dB	< 40	< 30
5	5, 6	Hours operable before battery depletion	integer	> 20	> 40
6	7	Ratio of extended to reduced size	integer	2	3

2.4 GANTT CHART

Table 4: Project Gantt Chart



3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

For our mockup we started with the idea of having a device that could fold in half, so that it could easily become portable and compact. The back side of the device was designed to be slightly smaller than the front half of the device so that when folded, the back half would fit inside of the front half. From our low-tech mockup, we saw that this type of design would put some serious restrictions on our machine's functionality, since the possible hinge locations interfered with the other necessary parts of the device. We therefore decided that a sliding shell-based design would be more compatible with the other required features of the device. Images of the mockup in all its configurations can be seen in Figures 6, 7, and 8.

Figure 6: Mockup in Closed Form

Figure 7: Underside of Prototype Revealing Sliding Mechanism

Figure 8: Mockup in Fully Extended Form

3.2 FUNCTIONAL DECOMPOSITION

The primary function of the Wellness Companion is to allow for an individual to stay active during the day. The function tree shown as Figure 9 breaks apart what the device needs to do to accomplish this goal. Figure 10 shows a morphological chart displaying multiple solutions to perform the specified sub-functions.

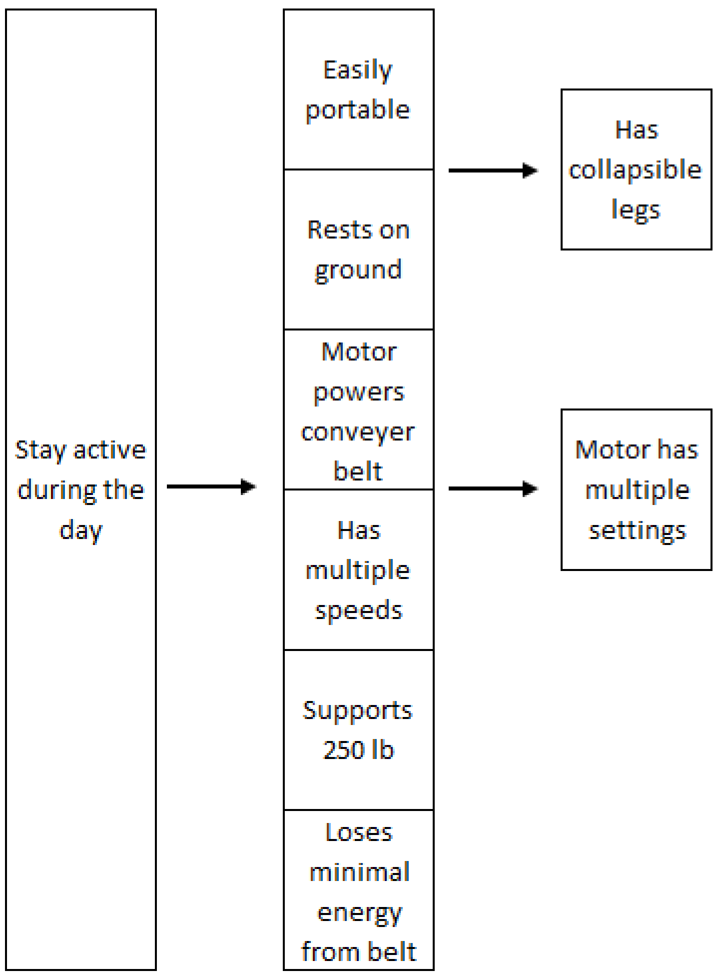


Figure 9: Function Tree of Wellness Companion

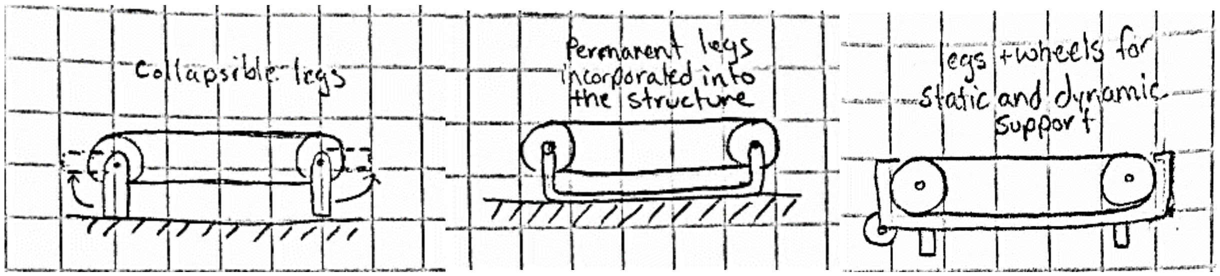
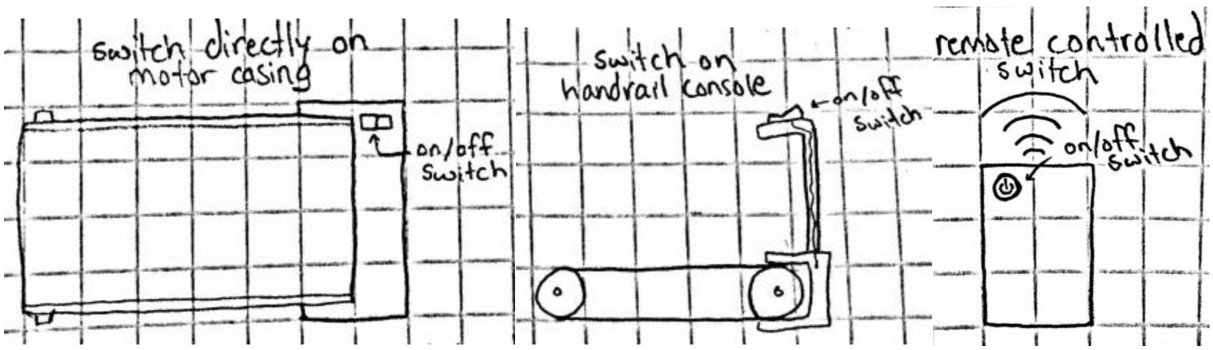
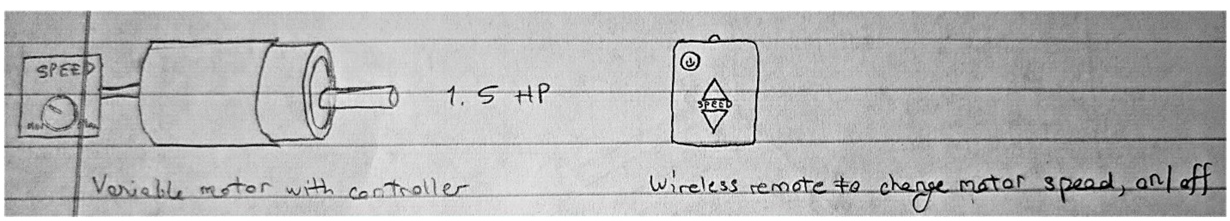
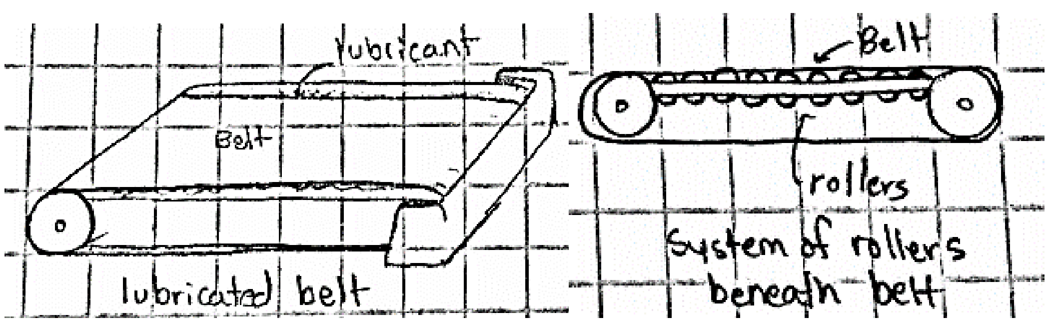
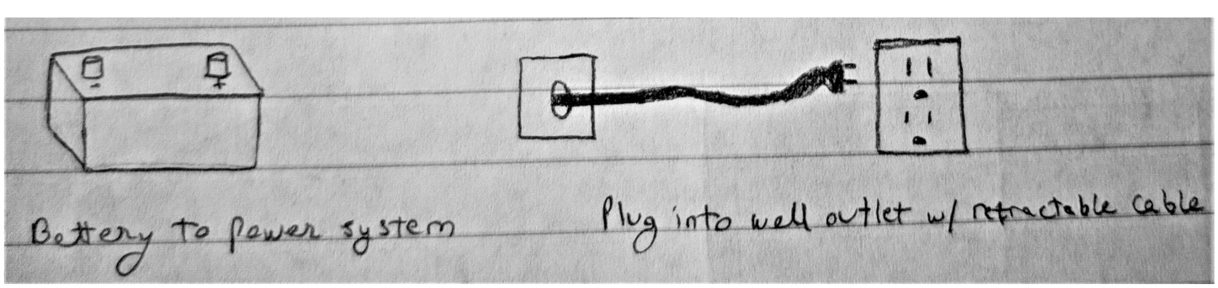
1 – Interface with floor	
2 – Switch motor on and off	
3 – Allow motor to vary power output/speed	
4 – Allow exercise belt to move with the motor on the frame with minimal friction	
5 – Supply energy to controller console and variable motor	

Figure 10: Morphological Chart for Wellness Companion

3.3 ALTERNATIVE DESIGN CONCEPTS

Concept 1 Name: "Accordion-Style Fitness Device"
Group Member: Nolan Knapp

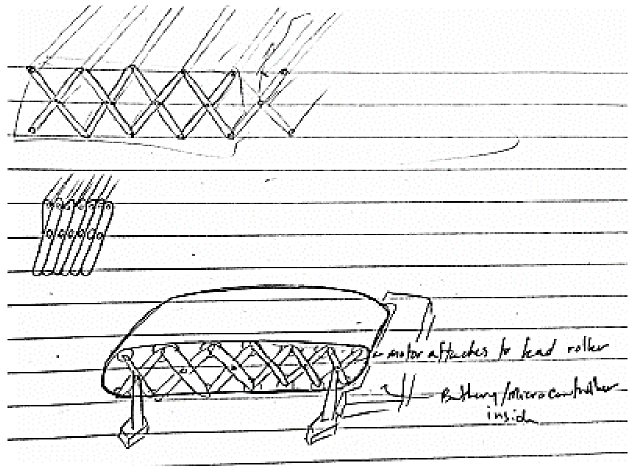


Figure 11: Preliminary Sketches of the Accordion-Style Concept

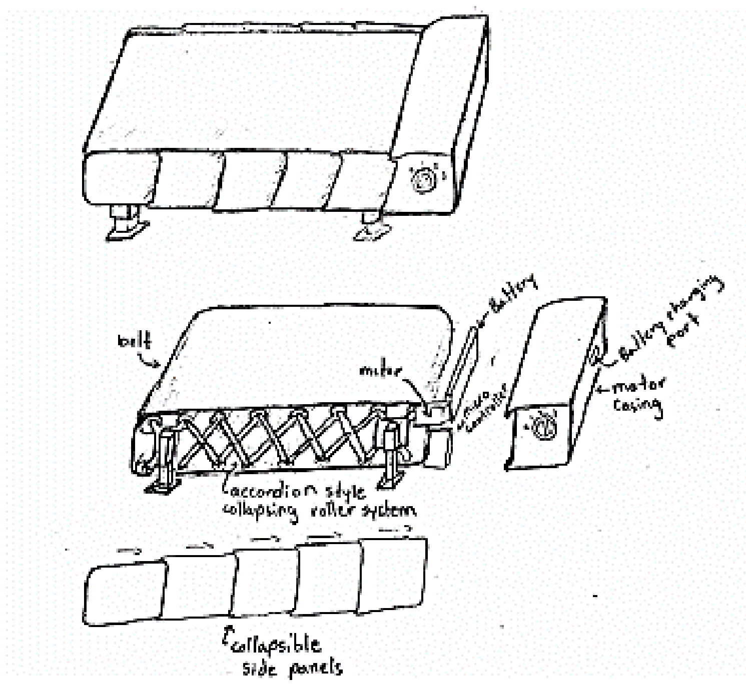


Figure 12: Final Sketches of the Accordion-Style

Description: A dial switch and microcontroller control the motor and speed output. The motor is attached to the lead roller pin in the system, which drives the belt. These are all encased in a protective plastic shell at the head of the device. The device is able to become compact via the accordion style roller system in which the X-shaped supports are able to fold horizontally. The collapsing legs are attached to the front and rear X-shaped supports. These features are hidden on either side of the device by a system of shell-shaped collapsing panels. When in portable form, the excess belt is rolled up and held tight with two straps.

Solutions:

1. Collapsing legs
2. Switch directly on motor casing
3. Dial for speed variation
4. System of rollers beneath belt
5. Powered by rechargeable battery

Concept 2 Name: “Foldy Hinge”
Group Member: Chris Wenndt

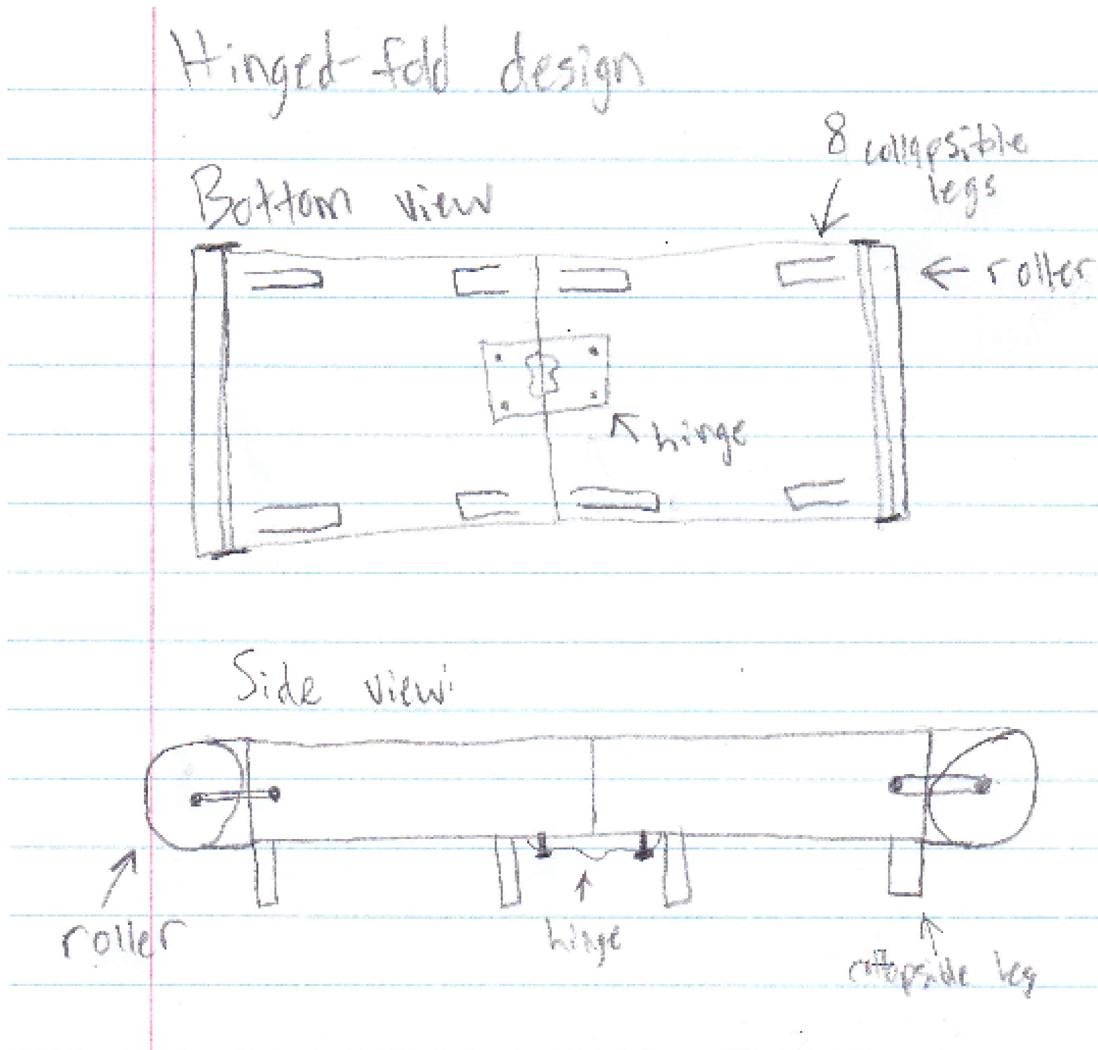


Figure 13: Preliminary Sketches of the Foldy Hinge Concept

Description: A belt slides over the rectangular treadmill lengthwise. The motor (unshown) is attached to a gear and pinion combination. The gears spin at constant angular velocity. The pinions are attached to either end of the belt. When the gears spin, the pinions cause the belt to slide along the length of the treadmill, creating the desired linear motion. Attached to the device are 8 legs, which can collapse and be stored within the device. The portability factor comes from the fact that the treadmill is divided into two sections, which are attached via a hinge shown in the sketch. The hinge will allow the device to fold upon itself, making its travel length half of its expanded length. Additional tweaks need to be made to ensure the motor, gears and pinions do not interfere with the folding tech, and to ensure sure the gears and pinions do not easily detach.

Solutions:

1. Collapsible legs
2. Gear and pinion system
3. Folds easily via hinge
4. Switch on motor casing
5. Battery-powered
6. High-friction rollers

Concept 3 Name: “Slide-Out Treadmill”
Group Member: Faizan Khan

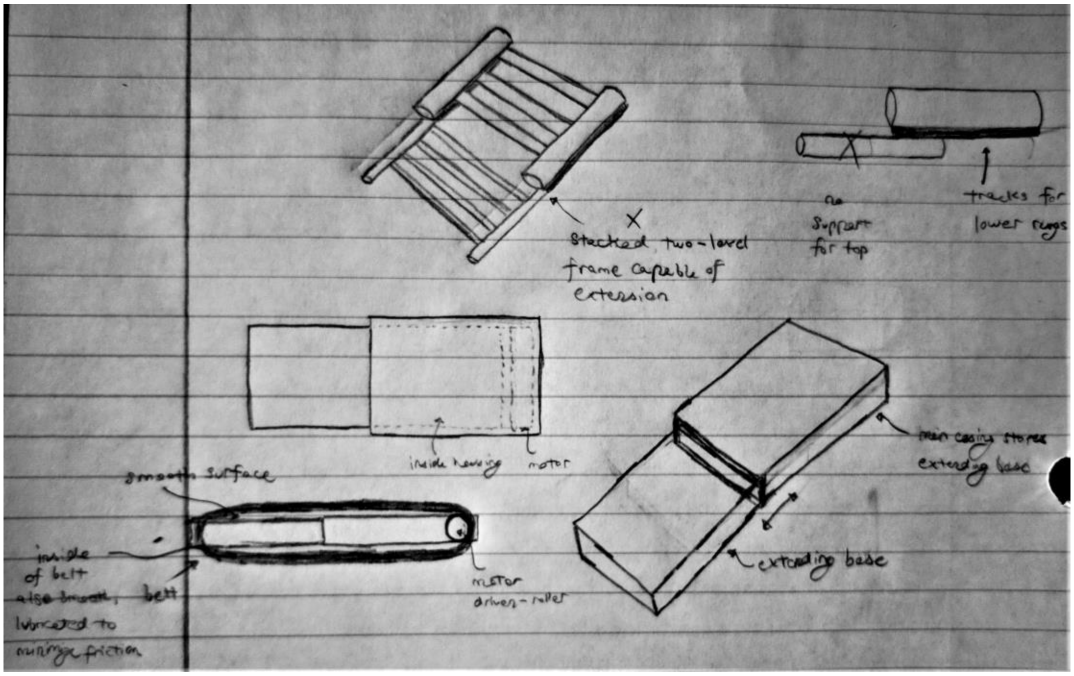


Figure 14: Preliminary Sketches of Slide-Out Treadmill Concept

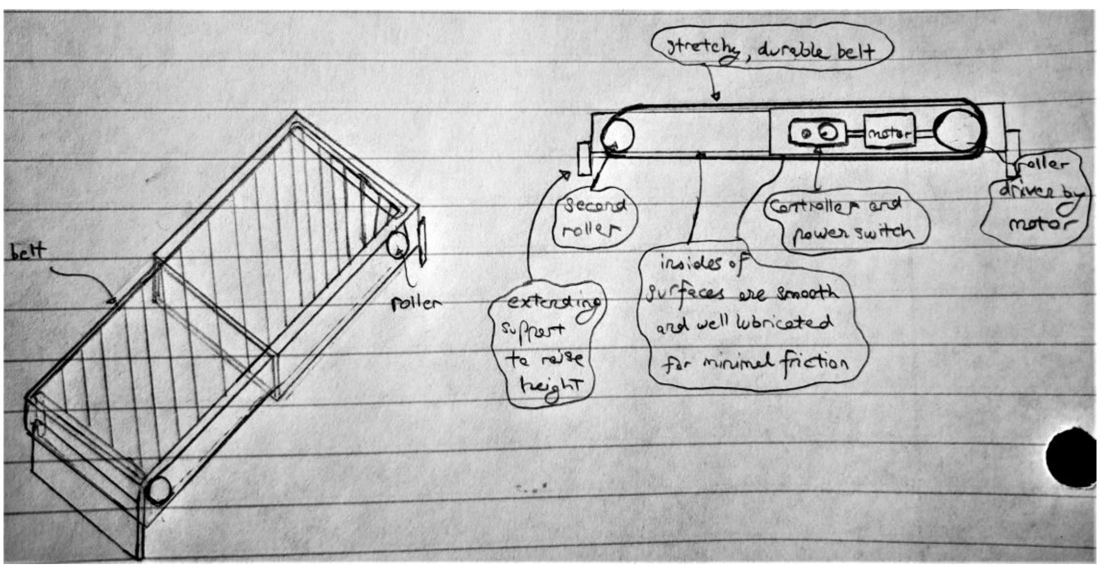


Figure 15: Final Sketches of Slide-Out Treadmill Design

Description: The frame of the portable treadmill design consists of two parts, the main shell and the slightly shorter platform housed inside that can be easily pulled out. The main part also has the variable motor attached to the front roller and a controller to change the speed. The motor drives the front roller, while the back roller keeps the attached belt on track and in tension. The insides of the belt and the surfaces of the frame in contact with the belt are finished smoothly and lubricated to minimize friction. The ends of the frame also have vertically-extending support bases to raise the height of the treadmill.

Solutions:

1. Treadmill rests on floor, can be raised up
2. Has driving motor
3. Motor has variable settings to change speed
4. Belt is attached to two rollers and lubricated
5. Retractable power cable

4 CONCEPT SELECTION

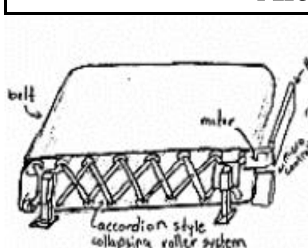
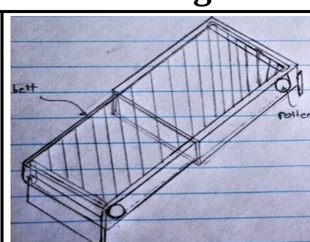
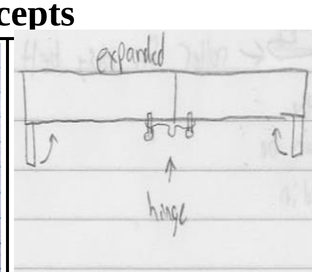
4.1 SELECTION CRITERIA

Table 5: Analytic Hierarchy Process

	Portability	Maximum Load	Minimum Noise	Durability	Safety/child-friendly	Price	Row Total	Weight Value	Weight (%)
Portability	**1.00**	3.00	5.00	3.00	5.00	5.00	22.00	0.36	35.87%
Maximum load	0.33	**1.00**	3.00	1.00	5.00	3.00	13.33	0.22	21.74%
Minimum noise	0.20	0.33	**1.00**	0.33	1.00	3.00	5.87	0.10	9.57%
Durability	0.33	1.00	3.00	**1.00**	5.00	3.00	13.33	0.22	21.74%
Safety/child-friendly	0.20	0.20	1.00	0.20	**1.00**	1.00	3.60	0.06	5.87%
Price	0.20	0.33	0.33	0.33	1.00	**1.00**	3.20	0.05	5.22%
						Column Total:	**61.33**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Table 6: Weighted Scoring Matrix

		Alternative Design Concepts					
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Portability	35.87	3	1.08	1	0.36	1	0.36
Maximum load	21.74	3	0.65	4	0.87	2	0.43
Minimum noise	9.57	3	0.29	3	0.29	3	0.29
Durability	21.74	3	0.65	5	1.09	3	0.65
Safety/child-friendly	5.87	3	0.18	5	0.29	4	0.23
Price	5.21	3	0.16	5	0.26	5	0.26
	Total score	**3.000**		**3.156**		**2.228**	
	Rank	**2**		**1**		**3**	

4.3 EVALUATION RESULTS

Based on the results from Table 5, Concept 2—the slide-out concept—was evaluated to be the most functional model based on the selected criteria, although only by a very minor margin compared to the reference, the accordion-style design. Portability, the criterion given the most weight based on the client's needs, is not a strong point of Concept 2 because of its boxy, shell-based design that still requires the device to be approximately half its fully-extended length; this makes for an unideal transportation experience for the user. This concept, however, has clear advantages in nearly every other aspect. The maximum load rating will be higher due to the shell-based aluminum chassis versus the accordion design. Noise levels should be fairly comparable across the concepts, particularly with lubrication solutions to minimize friction between the belt and the standing platforms. Concept 2's shell design additionally helps it stay both more durable and safe, with significantly less intricacies and moving parts in the system than the reference concept. It will also be less expensive to manufacture because of its much simpler and more traditional design.

4.4 ENGINEERING MODELS/RELATIONSHIPS

4.4.1 Beam Deflection Model

This model reflects how much a single roller on the treadmill is allowed to bend when bearing the full weight of an adult. In this model moment balances were applied to two ends of a beam fixed on two ends, with a load P pressing down one third of the way along the length. In this model we assume that the person steps on the treadmill with their left foot a third of the length from the left endpoint, and steps down with their right foot a third of the length from the right endpoint. In this system, F_1 and F_2 are the supporting forces at either end of the roller, P is the weight or maximum load the treadmill can support, L is the length of the roller, a is a third of the length ($L/3$), δ is the deflection of the roller at a point, E is the roller's elastic modulus and I is the roller's inertia about its center of mass. With the equations in this model worked out, and a maximum weight chosen of 250 lbm chosen for an adult, we can determine how much support our roller must be able to provide at both ends, as well as how much the roller can be expected to bend under a person's weight. With a set deflection δ and weight P chosen, we can build our structure out of the right material to ensure it meets specifications.

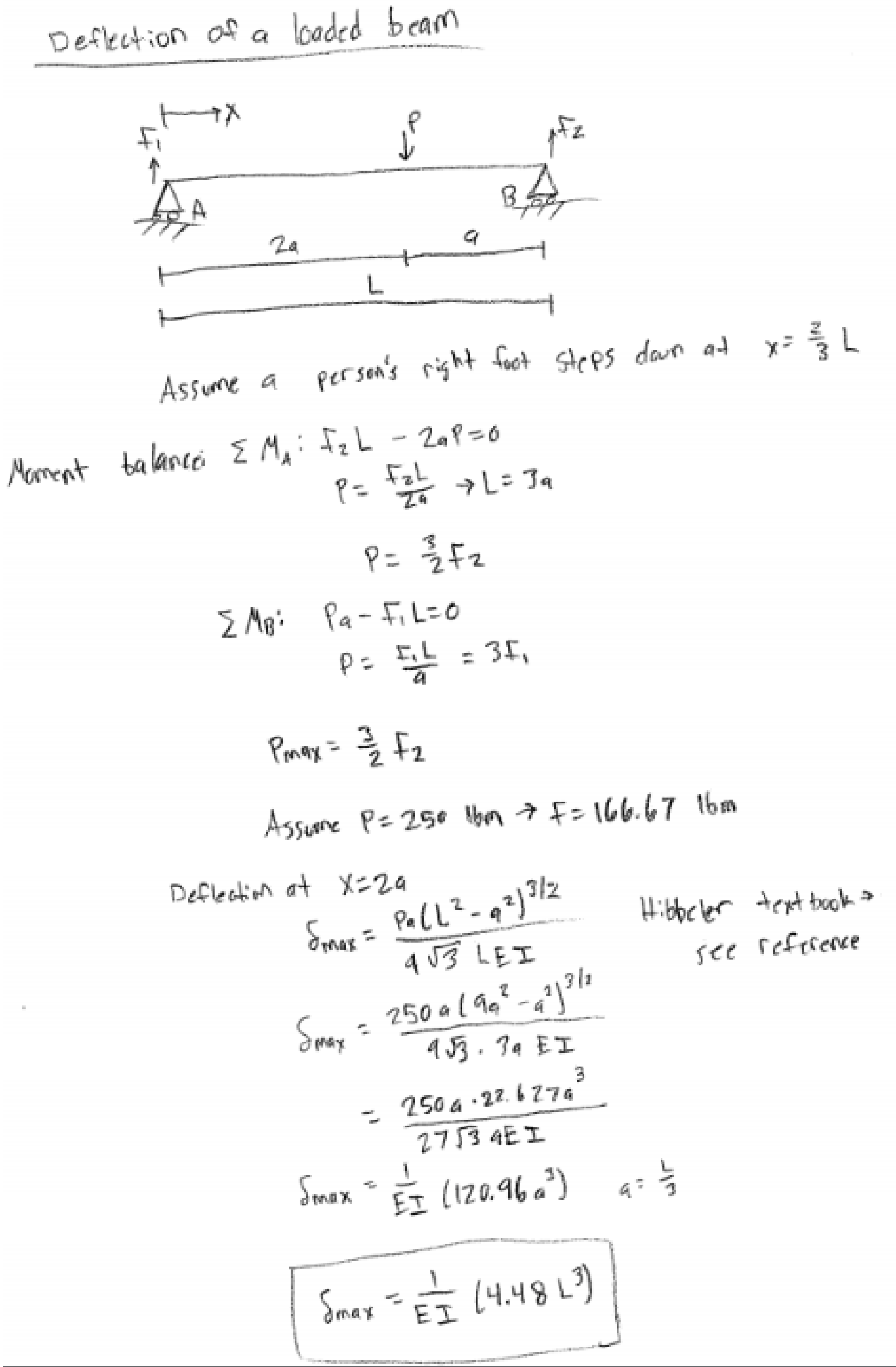


Figure 16: Beam Deflection Model [4]

4.4.2 Belt Tension Model

This model is important for the usability of the belt used in the device, and consequently important for the usability of the device as a feasible exercise machine. The system above is modeled after professional conveyor belts used in the same fashion as the belt on a treadmill. Belt tension is an important consideration in the design of the system since too much tension in the belt can lead to belt failure, rendering the device unusable and unsafe. The tension in the belt is attributed to several factors that will most likely all exist in the final product: rotation of the electric drive, weight of the object on the belt, and any load due to idlers in the configuration.

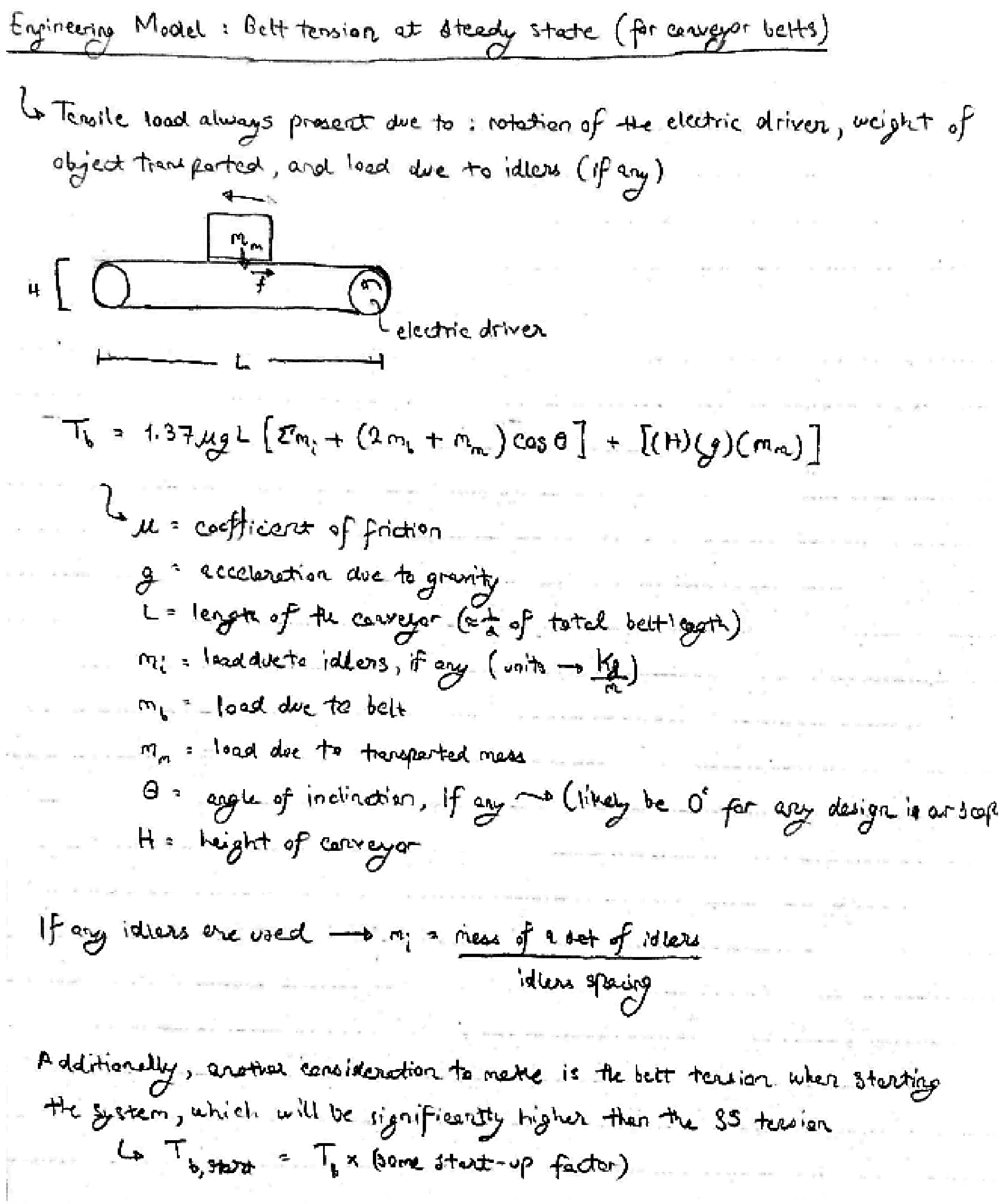


Figure 17: Belt Tension Model

4.4.3 Energy Supply Model

The purpose of this model is to determine the required energy for a motor used in the fitness device. The energy is calculated using the running power of the chosen motor and the desired running time. The running power of the motor can be calculated using the torque and desired velocity of the device. This model is extremely important due to the desired portability of the device. Determining the required energy of the device will allow us to determine a reasonable battery that can be used to power the motor. Improper calculations of the torque can cause the belt to move improperly when in use.

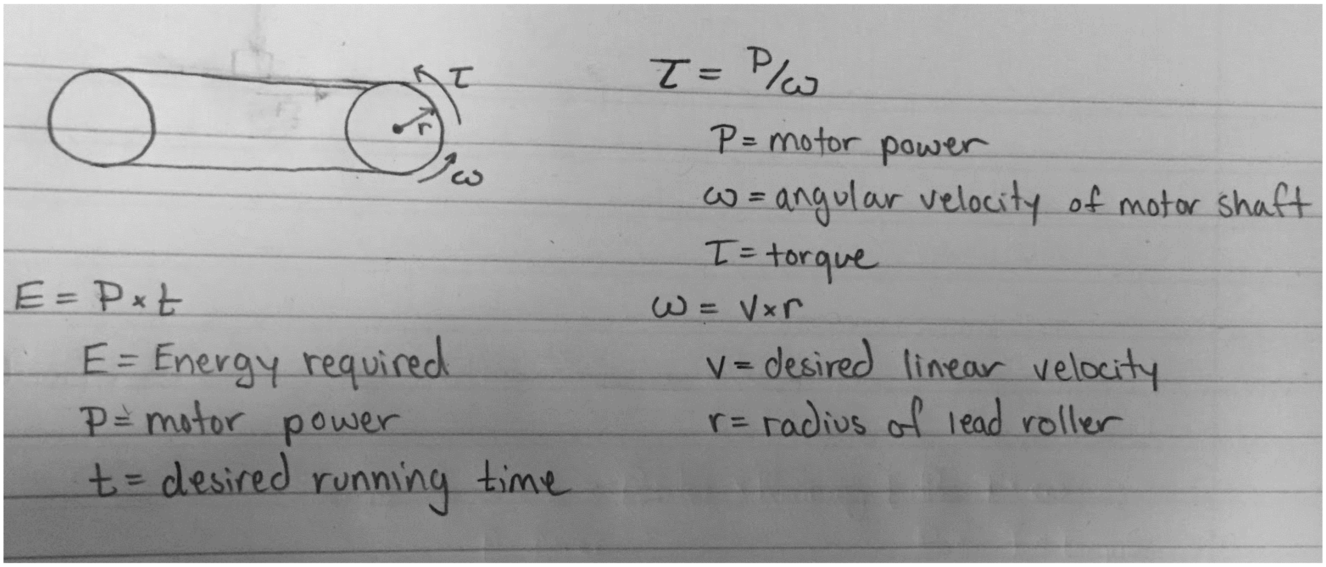


Figure 18: Energy Supply Model

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

The concept embodiment is a set of parameters describing the design parts, shape, and properties. These details are documented below through CAD drawings, a bill of materials, and a parts list. From these, an initial physical embodiment of the design can be made and tested. An initial concept embodiment of the assembled device is shown in Figure 19, with an exploded view in Figure 20.

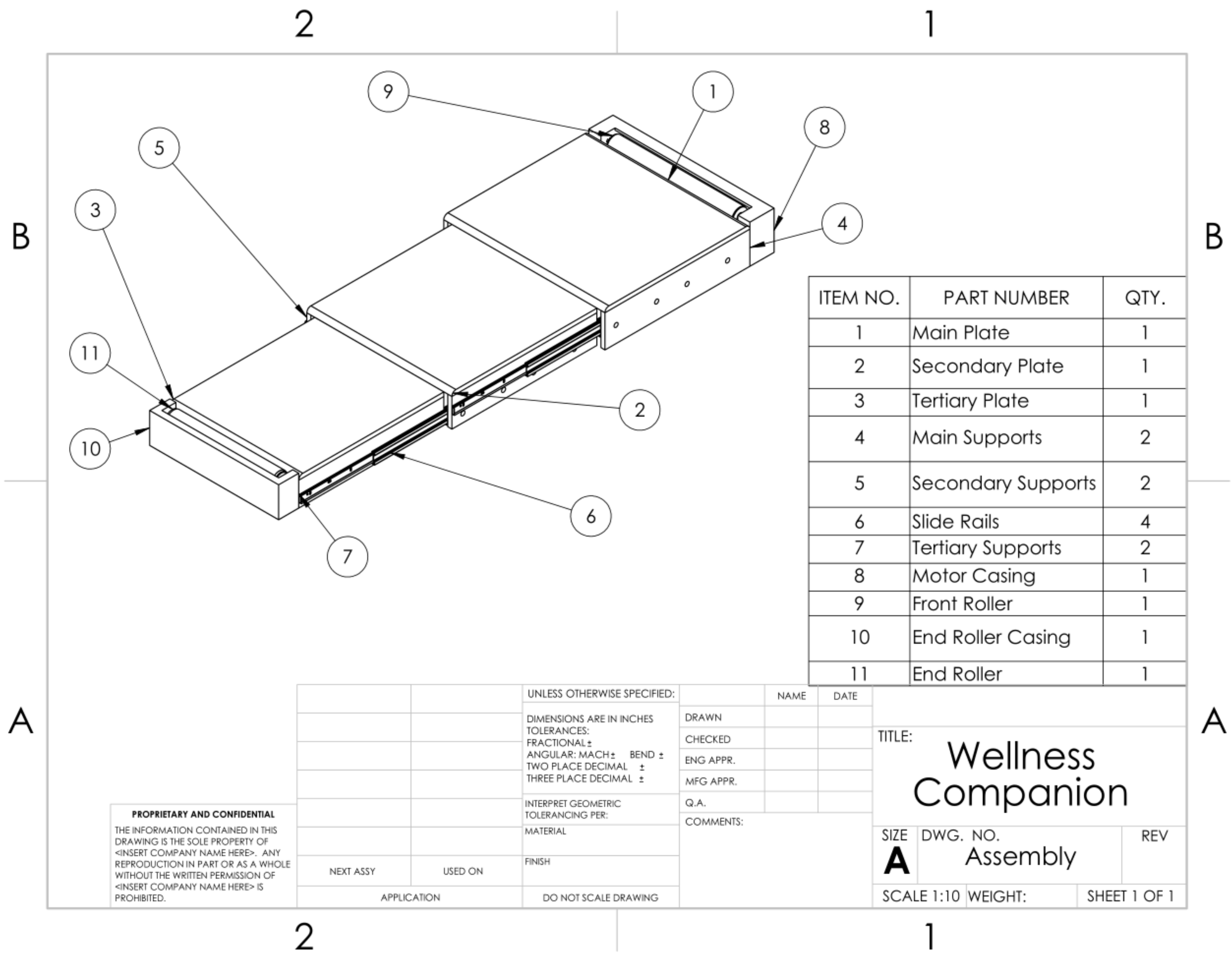


Figure 19: Initial Embodiment CAD Model with Bill of Materials and Balloons

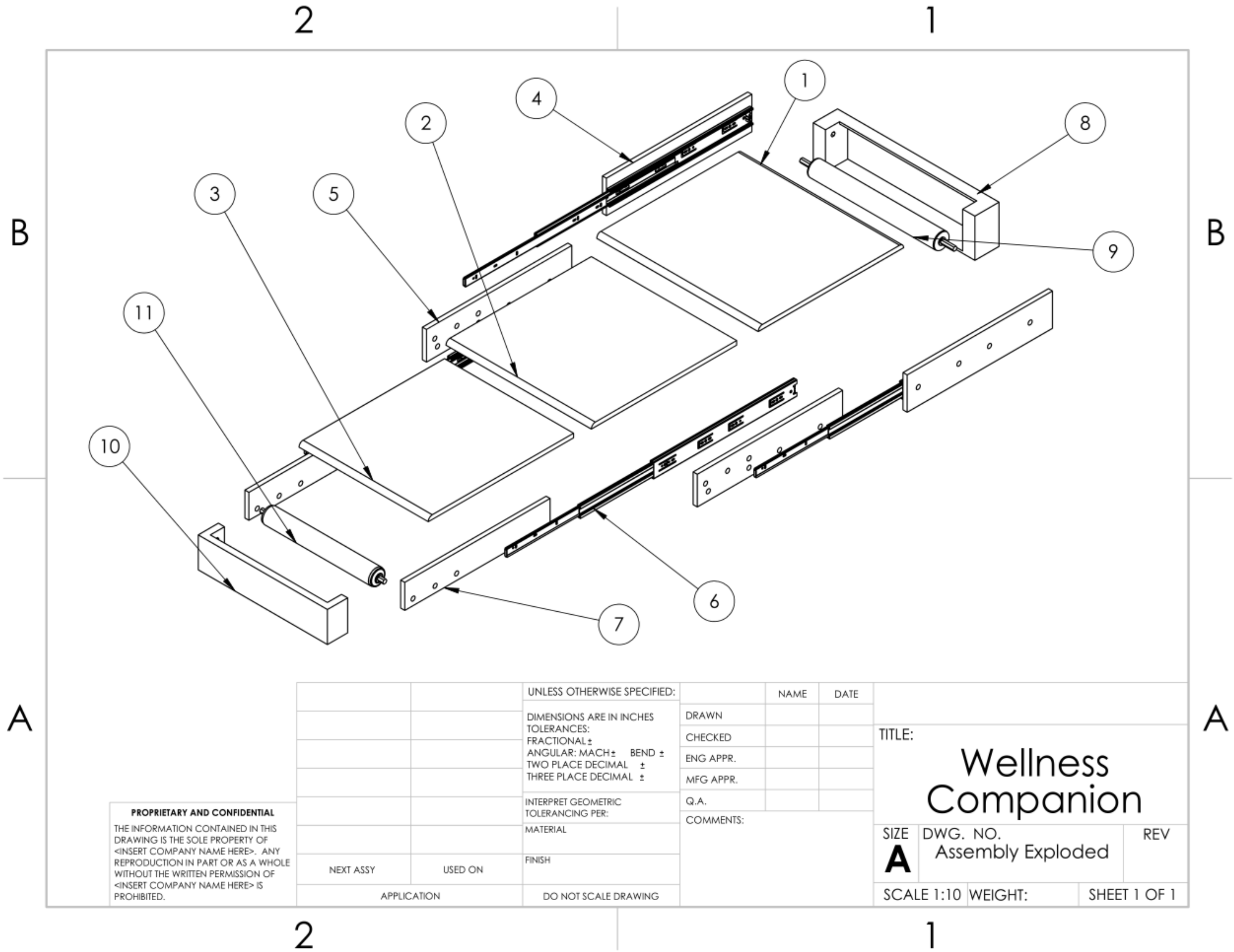


Figure 20: Exploded View of the Initial Embodiment

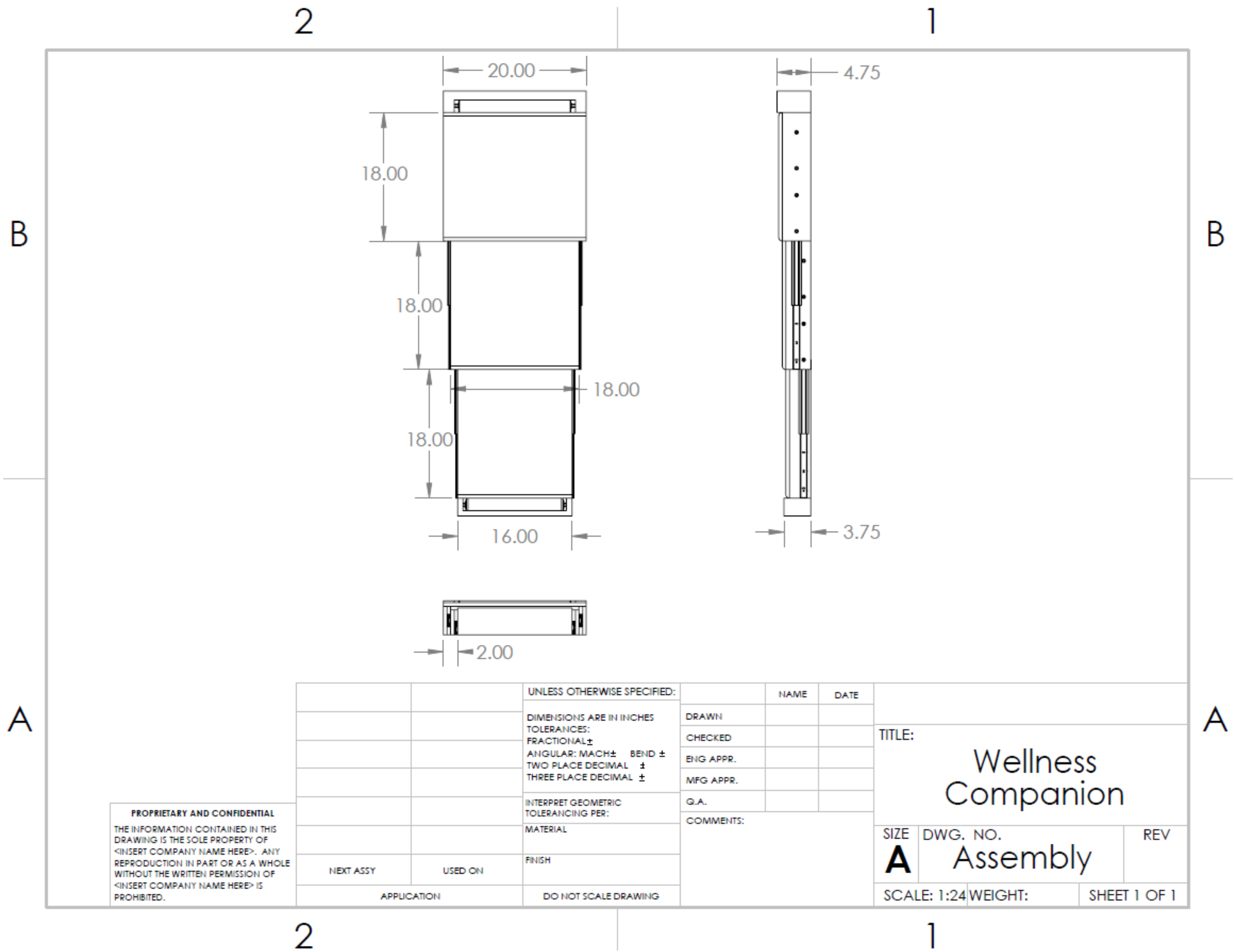


Figure 21: Top, Front, Side Views with Basic Dimensions

Table 7: Initial Parts List of Prototype Components

	Part	Source link	Supplier Part Number	Color, TPI, other part IDs	Unit Price	Quantity	Total price
1	Large aluminum case plate	McMaster	89155K46	24x24x0.5in	$319.38	1	$319.38
2	Medium aluminum case plate	McMaster	89155K29	18x18x0.5in	$182.37	2	$364.74
3	Large aluminum side plate	McMaster	8975K215	18x4x0.5in	$38.85	2	$77.7
4	Medium aluminum side plate	McMaster	8975K621	18x3.5x0.5in	$30.15	2	$60.30
5	Small aluminum side plates	McMaster	8975K513	18x3x0.5in	$29.13	2	$58.26
6	Slider rail (pair)	McMaster	11435A25	18 in Closed Length	$17.79	2	$35.58
7	V-Groove Conveyor Roller	McMaster	12975N5	1.9 in Diameter, 16 in Roller Length	$28.28	1	$28.28
8	Plastic Housing	McMaster	8752K115	12x12x0.5	$17.87	2	$35.74
9	Rear Conveyor Roller	McMaster	2277T18	1.9 in Diameter, 16 in Length	$12.49	1	$12.49

The performance goals set for the prototype are as follows:

1. Device will collapse to one-third of its fully extended size in less than 3 minutes.
2. Device will operate under 60 decibels from a distance of 1 meter.
3. Device will support 200 lbs. at 3 mph for 5 minutes.

5.2 PROOF-OF-CONCEPT

5.2.1 Proof of Concept Model Components

The proof of concept model contains:

- 3 cardboard platforms to simulate the aluminum chassis of the entire device
- Drawer sliders connected to the boards to allow for extension
- A belt made from duct tape
- 2 steel rollers, one attached to the front of the first cardboard platform and the second to the end of the third platform, to allow for the belt to rotate
- A small 1.5 HP brushless DC motor to power the front roller
- A battery to power the motor

5.2.2 Design Rationale for Components

Design rationale for the Proof of Concept components is based on the following engineering models:

1. **Deflection Model**

   Taking the deflection model from section 4.4.2, we can now apply it to our system. For this model, recall that we assume that the person steps down at a distance two thirds of the width of the treadmill, giving maximum deflection at that point.

With the performance goal of a 200 lb person using the wellness companion, we can plug in values for L, E and I to find the deflection. Assuming that the system is made of aluminum 6061 (E = 9990 ksi), and has a width L = 19 in and material thickness h = 0.5 in to find the inertia I = $(\frac{1}{12})bh^3$, we can find the maximum deflection of the fitness device for these conditions, which is found to be 0.0124 in.

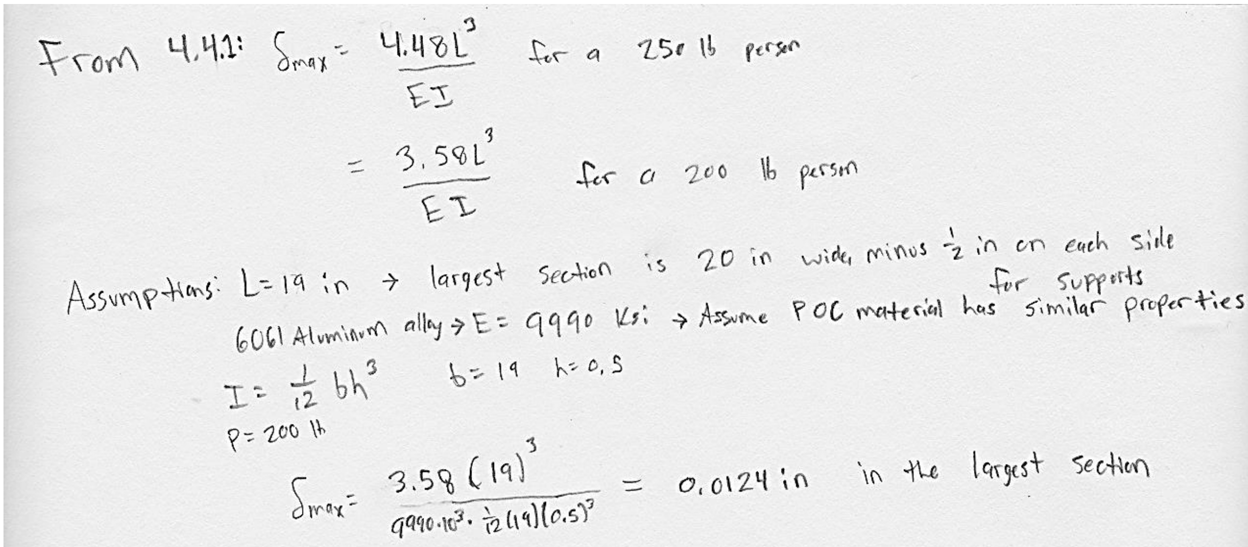


Figure 22: Deflection Model Values and Assumptions

Alternatively, we can plug in values for L, I and δ to find the minimum needed elastic modulus of our material. If we want a maximum deflection of 0.1 in, and leave all other variables unchanged and solve for E, we get the following.

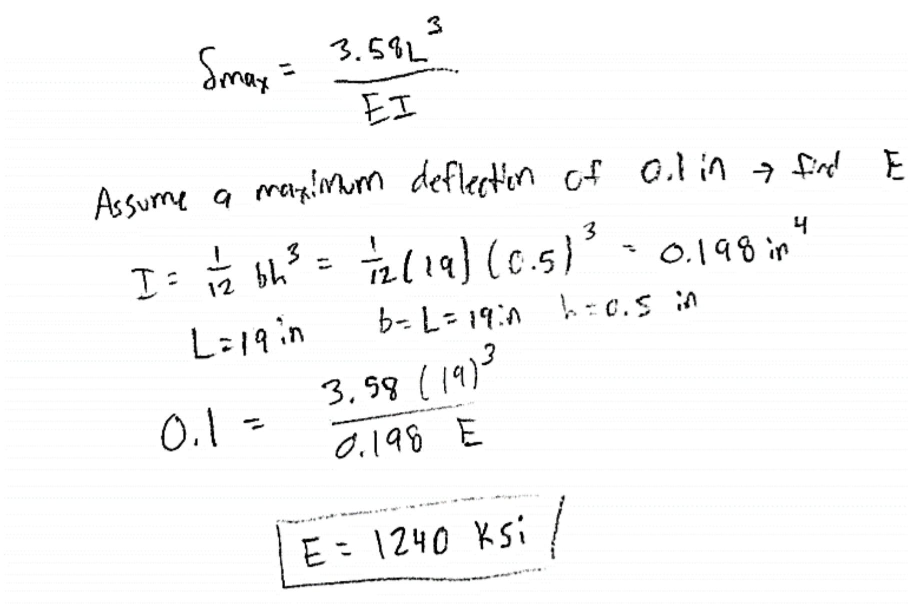
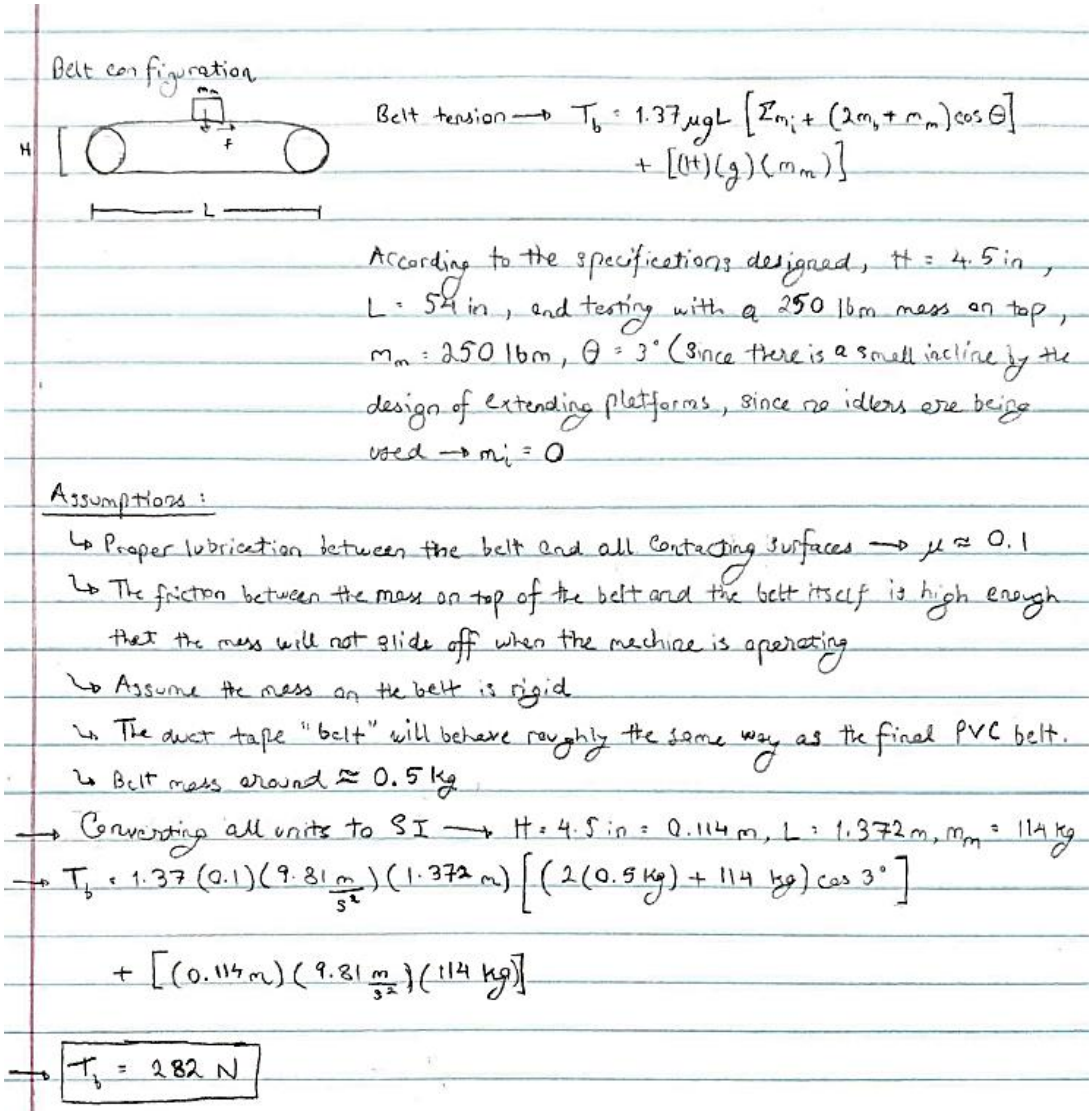


Figure 23: Deflection Solution for Desired Elastic Modulus

A minimum elastic modulus of 1240 ksi is needed to keep a 200 lb person from bending the treadmill more than 0.1 inches given the current dimensions we are considering. This is lower than most metals, and suggests that our treadmill could remain stable if the thickness was less than half an inch.

2. Belt Tension Model



Belt configuration

Belt tension → $T_b = 1.37 \mu g L \left[\Sigma m_i + (2m_b + m_m)\cos\theta\right] + \left[(H)(g)(m_m)\right]$

According to the specifications designed, H = 4.5 in, L = 54 in, and testing with a 250 lbm mass on top, m_m = 250 lbm, θ = 3° (since there is a small incline by the design of extending platforms, since no idlers are being used → $m_i = 0$

Assumptions:

- Proper lubrication between the belt and all contacting surfaces → $\mu \approx 0.1$
- The friction between the mass on top of the belt and the belt itself is high enough that the mass will not glide off when the machine is operating
- Assume the mass on the belt is rigid
- The duct tape "belt" will behave roughly the same way as the final PVC belt.
- Belt mass around ≈ 0.5 kg

→ Converting all units to SI → H = 4.5 in = 0.114 m, L = 1.372 m, m_m = 114 kg

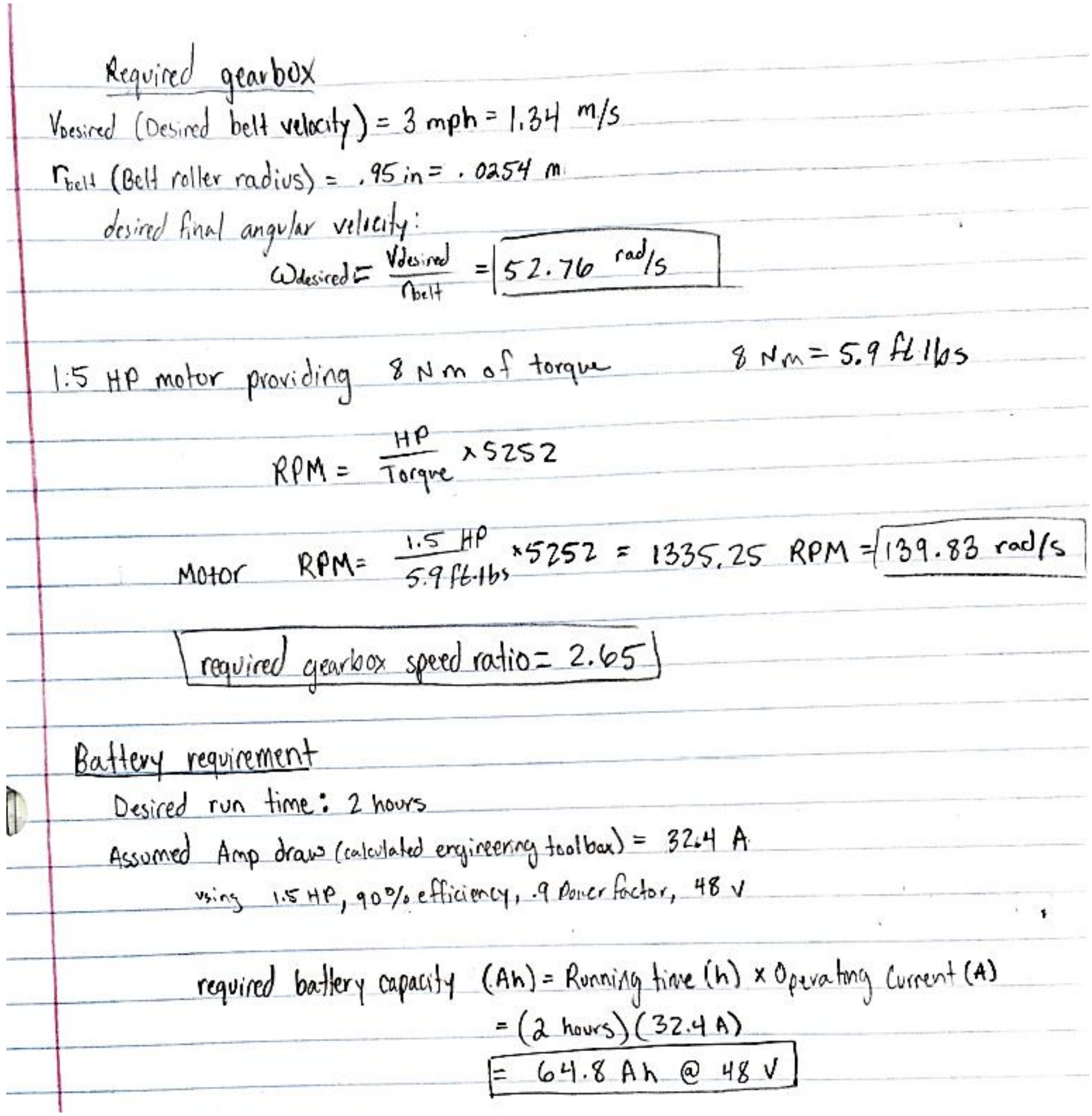
→ $T_b = 1.37(0.1)(9.81\ \frac{m}{s^2})(1.372\ m)\left[(2(0.5\ kg) + 114\ kg)\cos 3°\right] + \left[(0.114\ m)(9.81\ \frac{m}{s^2})(114\ kg)\right]$

→ T_b = 282 N

Figure 24: Belt Tension Model Calculations

For this model, values as specified in the CAD embodiment were plugged in to the belt tension equation when a mass of 250 lb. applied a load on the system. Several key assumptions include proper lubrication between the belt and all contacting surfaces, leading to a low coefficient of friction of approximately 0.1. We also assume the mass is rigid and will not slide while the machine is in operation. The core assumption is that the duct tape "belt" will behave in roughly the same manner as the final PVC belt. The final tension on the belt with these parameters set and the assumptions made is 282 N.

3. Gearbox and Battery Requirements Model



Required gearbox

$V_{Desired}$ (Desired belt velocity) = 3 mph = 1.34 m/s

r_{belt} (Belt roller radius) = .95 in = .0254 m

desired final angular velocity:

$$\omega_{desired} = \frac{V_{desired}}{r_{belt}} = \boxed{52.76 \text{ rad/s}}$$

1.5 HP motor providing 8 N m of torque   8 Nm = 5.9 ft lbs

$$RPM = \frac{HP}{Torque} \times 5252$$

$$\text{Motor } RPM = \frac{1.5 \text{ HP}}{5.9 \text{ ft-lbs}} \times 5252 = 1335.25 \text{ RPM} = \boxed{139.83 \text{ rad/s}}$$

required gearbox speed ratio = 2.65

Battery requirement

Desired run time: 2 hours

Assumed Amp draw (calculated engineering toolbox) = 32.4 A

using 1.5 HP, 90% efficiency, .9 Power factor, 48 V

required battery capacity (Ah) = Running time (h) x Operating Current (A)

= (2 hours)(32.4 A)

= 64.8 Ah @ 48 V

Figure 25: Gearbox and Battery Requirements Model

This model describes the requirements for both the motor gearbox and the motor battery. Using the desired belt velocity, the angular velocity of the lead roller pin was calculated. This was used in conjunction with the motors estimated output angular velocity to calculate the required speed ratio for the gearbox. The battery specifications were calculated using the operating current of the motor, as well as the desired run time of the device.

6 WORKING PROTOTYPE

6.1 OVERVIEW

The core changes from the proof-of-concept design made were the inclusion of top panels for the first and second extensions. Since a major problem in the PoC was the uneven, step-like walking surface, we created an effective and low-cost solution by adding spaced notches to the top surfaces of the extensions. Then, using appropriately-sized notched wood panels that were the same height as the height difference between the surfaces of each extension, we leveled out the entire walking surface of the prototype to the same height. CAD embodiments of this solution are shown in the figures that follow.

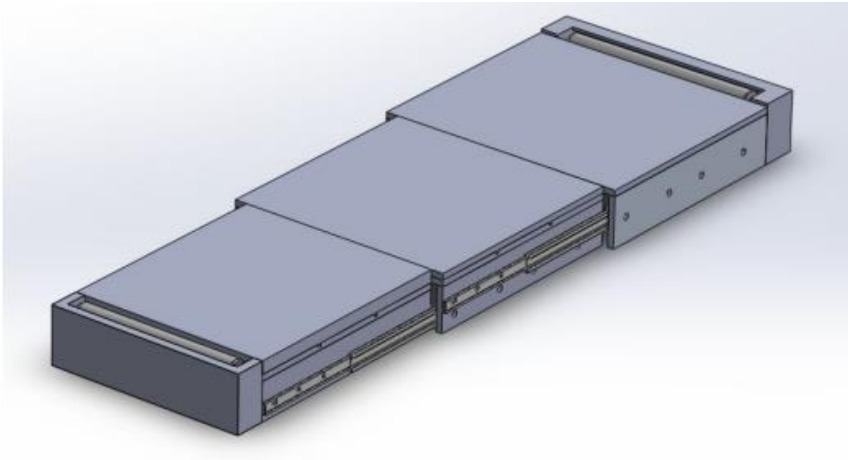


Figure 26: Isometric View of the Working Prototype with Top Leveling Panels

Figure 27: Working Prototype Side View of the Notches and Leveling Panel Solution

6.2 DEMONSTRATION DOCUMENTATION

The working prototype chassis is shown in its collapsed, portable state, as well as its fully extended final form in Figures 28, 29, and 30.

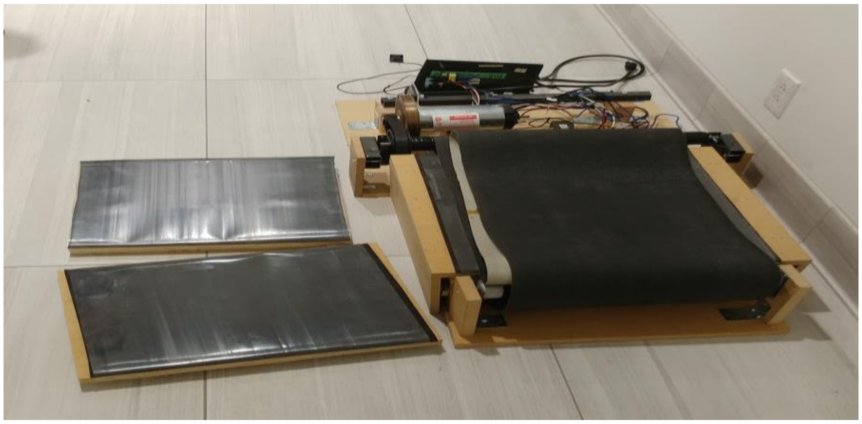


Figure 28: Prototype in Collapsed Form

Figure 29: Working Prototype Close-up

Figure 30: Prototype in Extended Form

6.3 EXPERIMENTAL RESULTS

The prototype ended up meeting all three of the goals that we set. The portability goal was met perfectly, since we were able to extend and shrink the device in well under 3 minutes. The device shrunk to slightly less than one third of the full length due to the size of the motor housing, but layout changes could be made to reduce the amount of space taken by the motor. The sound goal was met perfectly, with the device only producing 60 dBs from within a distance of 1 meter. The weight support goal was met for the most part. While the device could support a weight of over 250 lbs. for well over 5 minutes, the belt was not in enough tension for it to continue running when weight was added. This cause the rollers to free spin without moving the belt.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

The design consists of three telescoping panels, as shown below. The FEM analysis was done on the largest of these panels, as the applied load would produce the largest stress in this case. The bottoms of the side supports were set as fixed geometry, since they are designed to be in constant contact with the ground. A load of 890 N was distributed over the top of the panel, since on a treadmill the user would likely not be stepping in a single spot on the panel. This is shown in Figures 31 & 32.

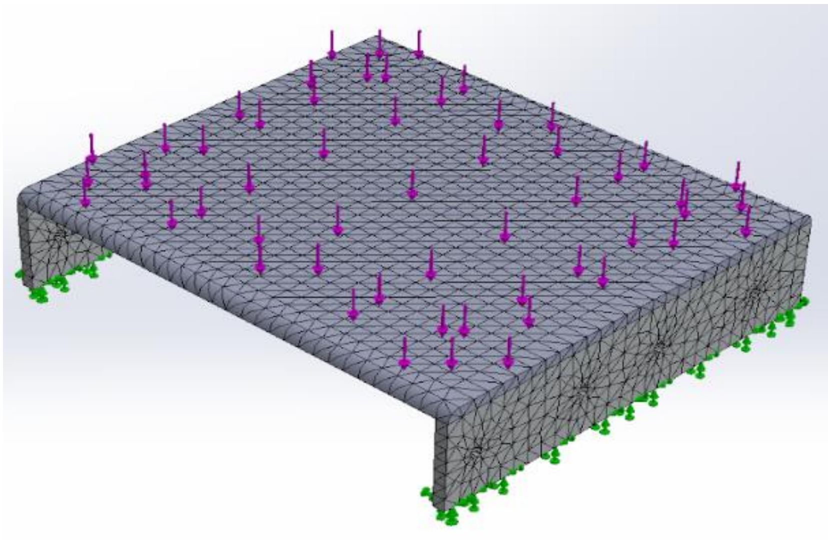


Figure 31: FEM Analysis

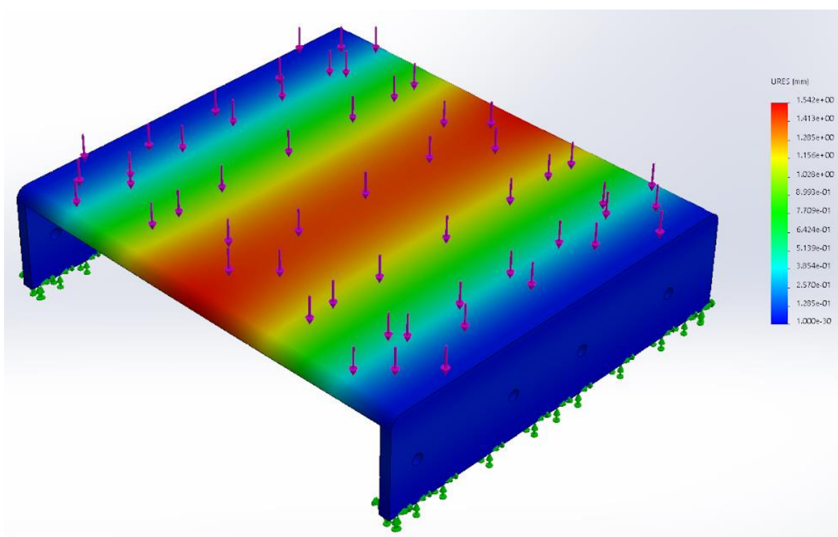


Figure 32: URES Values in FEM Analysis

The deflection that would be needed to produce a significant problem would basically be a deflection that would exceed the stretching capabilities of the belt. If the panel deflects more than the belt is able to stretch, then the belt would end up supporting the full weight of the user and could fail. Our study shows a max deflection of 1.5 mm in the center of the panel, and we believe that this will not exceed the constraints that the belt has.

From our stress analysis, we can see in Figure 33 that the maximum Von Mises stress that we should expect is 2.515 MPa, in the center of the board. Our selected material, Medium Density Fiberboard (MDF), has a rated Ultimate Tensile stress of 18 MPa [5]. From the following formula:

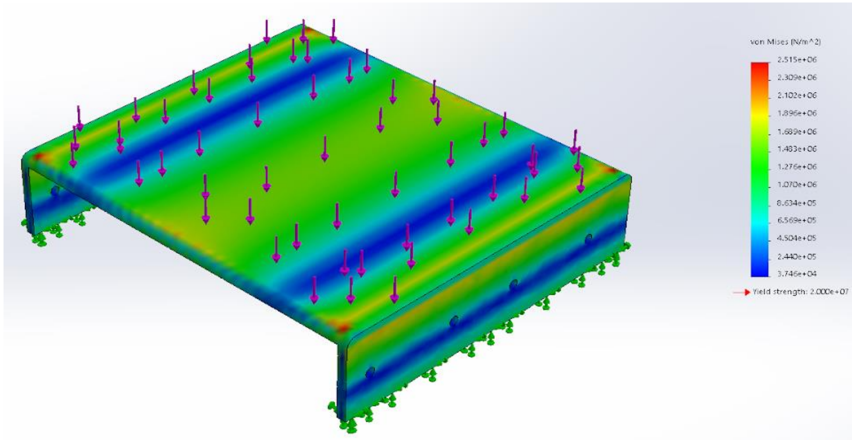


Figure 33: von Mises Stress in FEM Analysis

$$Factor\ of\ Safety = \frac{Yield\ Stress}{Working\ Stress}$$

We calculate that our minimum factor of safety is **7.16**.

7.2 DESIGN FOR SAFETY

The heat map shows the most significant risks to consider occurring when the device is in use—shown in Figure 34.

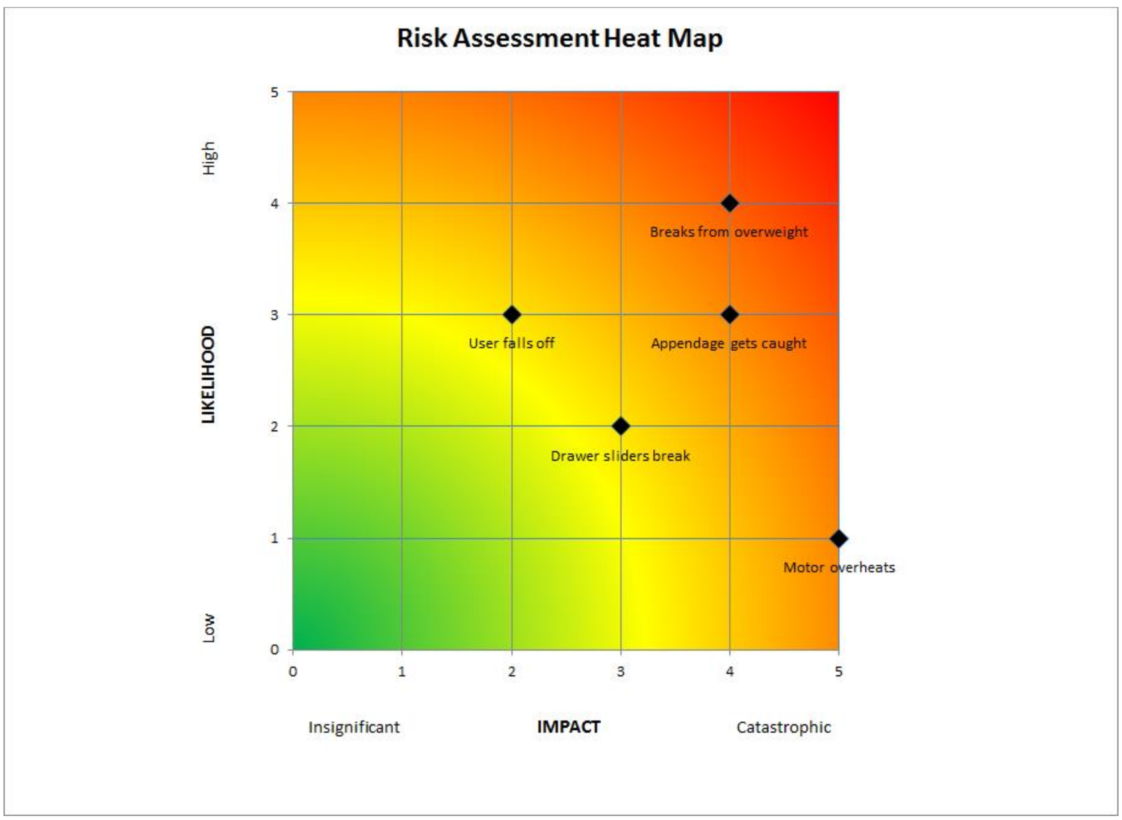


Figure 34: Risk Assessment Heat Map

Risk Name: Breaks from overweight

Description: Granted treadmills should be useable by out-of-shape people, but in order for portability to remain a main factor there must necessarily be a maximum operable load. Our current maximum load is 200 lbs. A good number of people do not read warning labels or safety concerns when buying a product, and there is a high chance that a large enough person

uses the device to cause it to fracture, rendering the device indefinitely inoperable. There is no good way around this problem, as simply adding more safety labels will not affect the user's disregard.
Impact: 4. Once the device begins to bend, there is no longer a usable walking surface.
Likelihood: 4. It is inevitable that someday a person too-large would attempt to use this device as they would a normal treadmill.

Risk Name: Appendage gets caught
Description: There are many mechanical parts to the treadmill, including drawer sliders, spinning rollers and moving belts. If a user is not careful, or allows children near the device unsupervised, it will be easy for a finger or toe to become caught in one of these parts, causing severe injury to the user. Our final prototype will have casings covering these parts to minimize personal risk.
Impact: 4. A finger or toe getting caught in the v-belt or drawer sliders could do irreparable harm, and certainaly hospitalize the user.
Likelihood: 3. A motor casing will be provided to protect the motor and v-belt, and the drawer sliders do not require human contact to operate.

Risk name: User falls off
Description: The user could fall off the treadmill. his is not very likely to happen, as the device moves at less than 3 mph, and the speed does not vary. The device is also low to the ground, reducing the collision impact of a user and the ground. It is more likely that a user could twist their ankle while operating or using the treadmill.
Impact: 2. The user is already close to the ground, and no damage would be done to the treadmill itself.
Likelihood: 3. The device does not have hand rails, meaning any imbalance could cause a fall.

Risk name: Drawer sliders break
Description: The drawer sliders could break due to the user extending or shrinking the treadmill past its useable lengths. This will cause torsion in the screws and could misalign the treadmill's components, significantly affecting its shrinking technology.
Impact: 3. Without the drawer sliders restricting motion in purely one direction, the device would not remain stable enough for use.
Likelihood: 2. The sliders will only break if too much force is applied by the user vertically on a single panel, which should never be needed.

Risk name: Motor overheats
Description: This is a low risk, as our device operates at a maximum speed of 3 mph, and can be easily torqued down to limit its power output capability. However, most of the treadmill is flammable (made of wood!) and thus a fire potential is a risk to consider, however unlikely.
Impact: 5. An overworked motor is a fire hazard, and could cause irreparable harm not just to the fitness device, but to the user and their surroundings.
Likelihood: 1. Little power is needed by the motor to provide a walking speed of 3 mph.

7.3 DESIGN FOR MANUFACTURING

In order to maximize the ease of manufacturing of the device, two parts were evaluated to assess the challenges that will come with producing the machine parts, and what design modifications can be made to make them easier to manufacture. Two methods in SolidWorks were employed to conduct these changes: draft analysis, and DFM Analysis.

7.3.1 Draft Analysis

For this part, a simple support leg from the middle section of the device was analyzed. In SolidWorks, using the Draft Analysis feature, a draft angle of 2° was created. The initial shape of the part is shown in Figure 35 on the left, while the final shape with the recommended draft angles added is shown on the right.

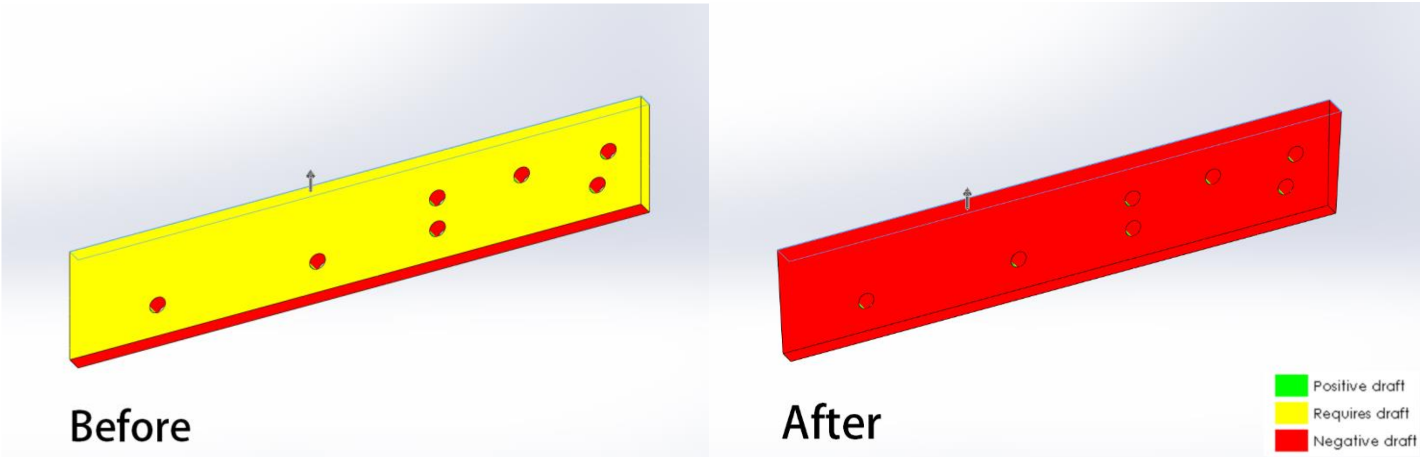


Figure 35: Before and After Images of Middle Supporting Leg Part Using SolidWorks Draft Analysis

7.3.2 DFM Analysis

Using the Xpress Product DFMXpress in SolidWorks on a more complicated part, the end motor housing of the device, an analysis was conducted using the program's default settings. We had multiple sharp corners in the part that would be impossible to make with a mill. Making these filleted would more closely represent the finished product if this part was milled. We also had 2 features (two holes for the roller axle) that would be difficult to access with most machining processes. Images of the errors caught by the analysis are shown in Figures 36 and 37.

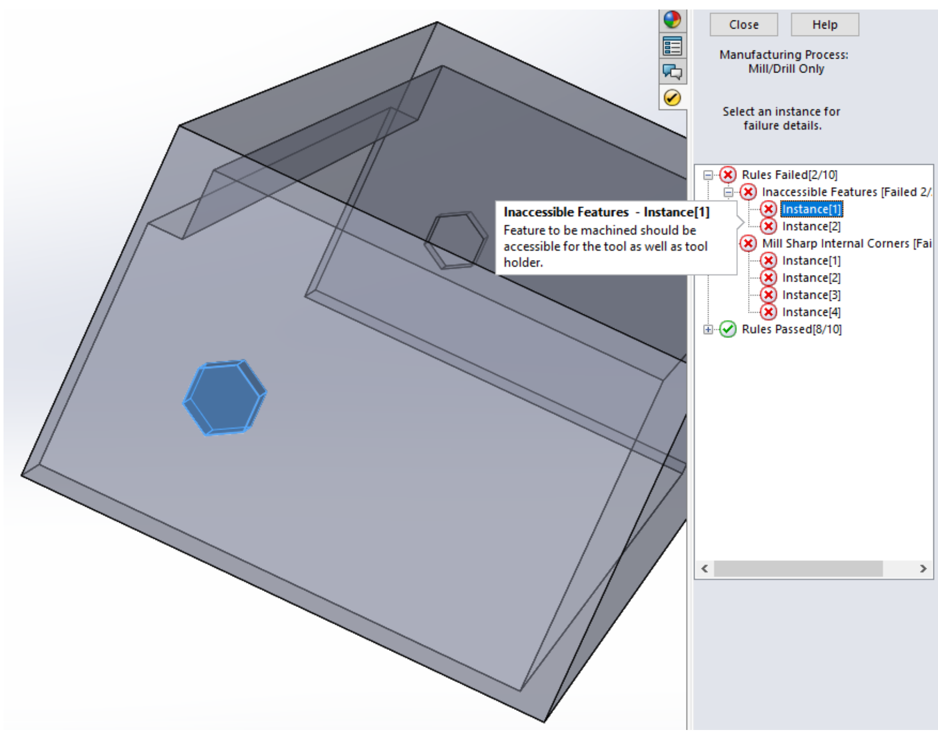


Figure 36: DFM Analysis Inaccessible Feature Error

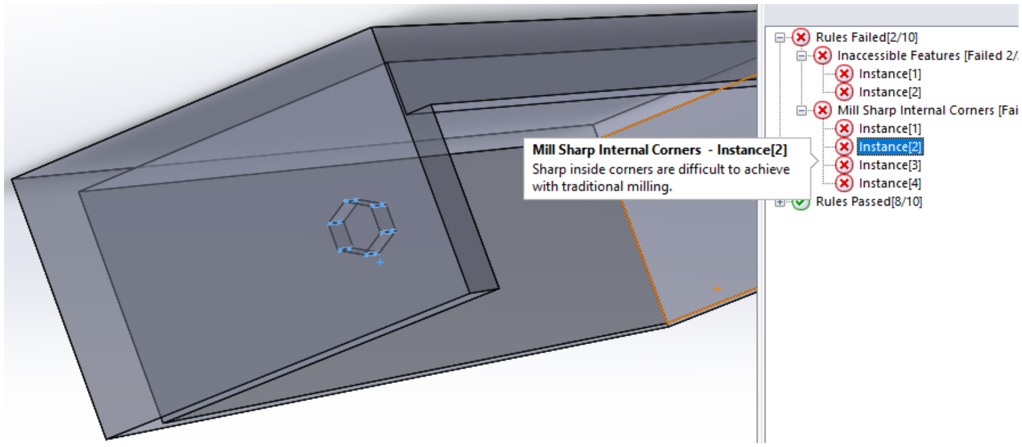


Figure 37: DFM Analysis Sharp Milling Issue

7.4 DESIGN FOR USABILITY

Next, the device was evaluated for its usability in the multiple areas, and to allow for design considerations that account for the Wellness Companion to be inclusive of as many groups as possible. Each type of impairment and its design influences is listed in the following subsections.

7.4.1 Vision

Any kind of color-blindness will likely not be a great issue since the use of color in the design itself is minimal; no LEDs are being used in the current prospective final design, but if any are added due to controllers or emergency lights, bright or neutral colors will be used; since presbyopia affects a very large number of potential users, and signs or labels on the device will be large and bold-texted to be easily visible in the vicinity of its usage.

7.4.2 Hearing

No sounds, except motor and machine operation noise, are used in the device; however, someone with a hearing disability may not be able to hear if a part in the machine, particularly the motor, is functioning improperly; therefore, any risks or mechanical failures that could occur may not get caught in time, leading to potentially hazardous situations. To improve on this, we will incorporate a motor that has been properly tested from a trusted manufacturer, and set the recommended life cycle of the machine to be in line with the tested life cycle of the motor.

7.4.3 Physical

Given the nature of a treadmill as a physical workout device, it is not recommended that a person with physical disabilities use this device; this is especially true for anyone with lower body disabilities, which includes muscle weakness in the feet, gluteus, quadriceps, and other muscle groups close to these regions. Anyone with concerns of limb immobilization should most definitely not use this equipment as it relies heavily on the proper functioning of limbs. For people physically capable of using the machine, usability and user comfort will be improved by tapering and smoothing the transition from one platform to the next to create smoother rolling motion of the belt.

7.4.4 Language

All the labels and instructions used on the device, as well as any included instruction manuals and paperwork, will be written in English, as well as a few other popular languages; the selection of these languages will be based on the market in which the device will be catered to (for example, in North America, a strong list will be English, Spanish, Chinese, and French) so as to ensure the largest number of users can properly use the device and be aware of any hazards with its usage.

7.4.5 Control

Any use of a fitness machine while distracted or excessively fatigued can create serious hazards and is not recommended; warnings against this will be included and highly emphasized in the associated paperwork, including medication side effects, which could include sleepiness, nausea, drowsiness, and so on, will also create safety concerns while using the device.

Design considerations accounting for these include a short height of the device, with the legs being tall enough to support the body, maintain good structural integrity while in use, and provide enough clearance for the belt to move comfortably; at the same time, the legs will be short enough so a potential fall from the machine will minimize damage by minimizing distance from the ground.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

8.1.1 Does the final project result align with its initial project description?

For the most part, yes, it does align with the initial description of the project. The treadmill features a method of shrinking down to roughly on third of its fully extended length and has a fully functional variable speed motor. The treadmills portability is less than desired due to weight, but this is due to material constraints caused by the low budget. The belt was not able to continue motion when weight was applied, but this issue could be easily fixed with either lead screws or a CAM locking system applied to the rear roller. The initial project description was ambitious and envisioned a finished product, while the class aims towards a working prototype. Our result met the goals that we set for the prototype but would need further development to meet the expectations set in the project description.

8.1.2 Was the project more or less difficult than expected?

The project was about as difficult as expected. A large amount of work was expected for the process of building the frame and these aspects of the project did indeed take the most amount of time. We did not however, expect that finding a usable motor would be such a difficult part of the process. Lightweight yet strong motors are typically quite expensive and would require a gearbox. We found that this would far exceed our given budget and were forced to resort to cheaper options. When a cheaper motor was found, we discovered that it was far too large and heavy, and the set up required for it was not within our skillsets. To resolve this issue, we ended up purchasing an old treadmill and salvaging the motor and control system out of it after cutting out all of the unnecessary features.

8.1.3 On which part(s) of the design process should your group have spent more time? Which parts required less time?

More time should have been spent on the proof of concept than was allotted. That would have raised attention to additional problems we did not encounter until building the final prototype. These concerns include the interference fit of angle brackets, giving the belt enough tension to slide without slipping, and the total weight of the device. There is no part of the project that was given too much attention, each problem was given its allotted time before moving on to the next one.

8.1.4 Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

Assembling the interlocking panels was harder than anticipated. For the proof-of-concept, we had trouble using screws to assemble the device without splitting the wood panels, even with pre-drilled holes. To get around this issue, we used angle brackets while building the main prototype. However, when the main frame was assembled, not enough of a tolerance was left for the medium and small panels to slide past the angle brackets supporting the large panel. To accommodate for this, the medium and smaller sections were angled at the edges so as to remove the interference. However, this just meant that less of the weight was being supported by the boards, meaning even more angle brackets had to be used just to support the required weight as well as supporting the main frame.

8.1.5 In hindsight, was there another design concept that might have been more successful than the chosen concept?

No. We are confident that this design is the most practical in terms or usability and portability in terms of our available resources and efforts. It would be better to make additional improvements to this design than to choose another design concept.

8.2 DESIGN RESOURCES

8.2.1 How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

We specifically looked at patents for existing treadmills to see what type of codes and standards we should use, and also accounting for the 'medical device' usage of the product. These did influence our concepts, most especially in designing for safety and making sure we were abiding by standards set in place for devices that are used for similar purposes as ours. They helped us be more specific about features we should and should not include.

8.2.2 Was your group missing any critical information when it generated and evaluated concepts?

It was difficult to gauge how the features in the concept designs would actually interact physically rather than just interlocking parts drawn together. For example, we had a folding hinge design that was expected to work well on paper, but designing and engineering a mock-up of that concept together proved more difficult than we originally imagined and did not work very well mechanically the way we had modeled it.

8.2.3 Were there additional engineering analyses that could have helped guide your design?

More eletro-mechanical models would have served very helpful in getting parts that were best optimized for our particular design, especially taking into account weight and dimensions. A more efficient design could have also been produced with a good actuator and power source model, as well as a power and torque graph/model for a brushless DC motor, which would have been a more ideal choice given its greater versatility and quietness.

8.2.4 If you were able to redo the course, what would you have done differently the second time around?

Additional time would be spent studying motors. A large problem of ours was not having enough information to find an appropriate, budget-friendly motor. Weight, horsepower, torque, and speed were all considered but a suitable motor that matched our specifications for all four requirements could not be found online, plus we also would have needed a gearbox to torque down the motor output. We ultimately used a motor gutted from a pre-existing treadmill after failing to find a suitable model online.

8.2.5 Given more time and money, what upgrades could be made to the working prototype?

There are a number of ways to improve the current prototype. The most obvious improvement would be to additionally tension the belt so that the device is useable as a treadmill by an adult. This would require use of leadscrews or ratchets that could extend the device to a length beyond what the average person could by simply pulling it apart. By use of leadscrews, the system could easily extend to a length that would tension the belt enough to remove slippage.

The device would also be improved by use of a stronger, more durable material such as aluminum. Aluminum was not used for this prototype because it would have been very expensive to buy for just one device, and to minimize the metal's weight would require milling with tools not accessible to us. For mass-producing however, a CAD model could easily be created that webs the metal in such a way to remove most of the weight and keep the design sturdy. This would be the ideal material when the prototype is finished.

The final way to improve the prototype is to redesign the motor casing. Ideally the motor and circuit components would sit above the roller to minimize the length of the device. Repositioning these sections would decrease the current length of the device by about 14 inches, and would make the finished device much easier to carry. A motor casing also needs to be designed to hide the motor and keep prying fingers safe.

Once these modifications are in place to the prototype itself, the final step is to craft a carrying case to make transporting the device easier. This case could work as a rolling suitcase, which one can easily keep in their car or at home to suit their needs.

8.3 TEAM ORGANIZATION

8.3.1 Were team members' skills complementary? Are there additional skills that would have benefitted this project?

The team members' skills were well balanced. Between the three members, there were exceptional SolidWorks skills and satisfactory machine shop abilities. The team was well-balanced between designing the project and actually building it. There are no considered skills that the team was sorely lacking.

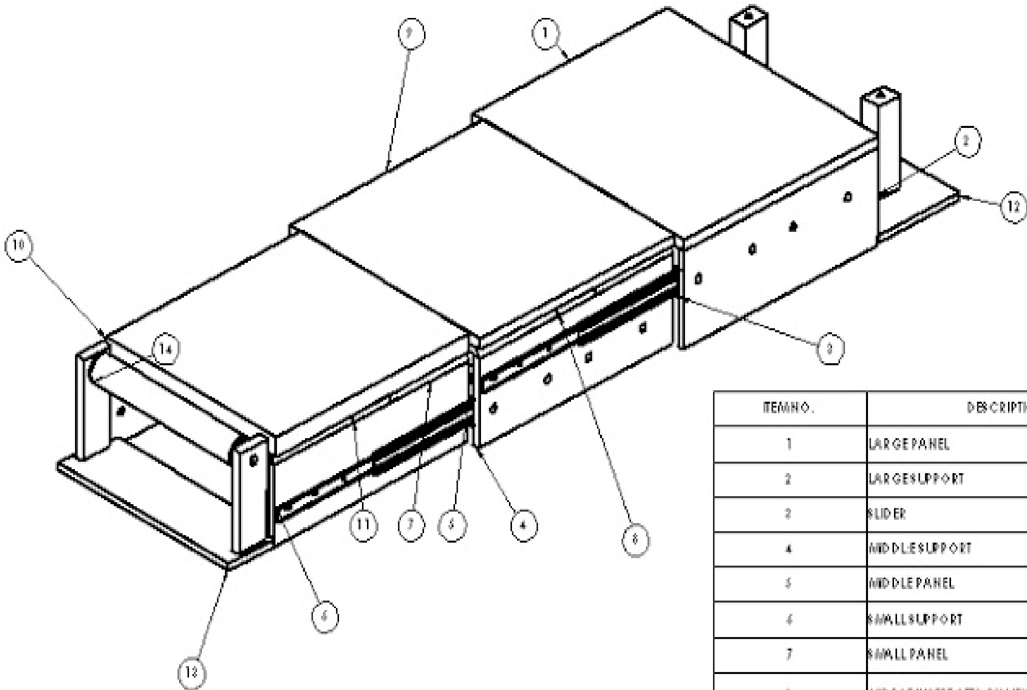
8.3.2 Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

Yes, we have talked about either carrying on with this project or finding a new design concept to start on. The idea of a healthcare device interests us, and we have thought of trying to come up with a more realistic concept than making an entire treadmill portable. For example, a portable rowing machine like device seems much more feasible to create, as there is no motor or large flat surface required.

APPENDIX A – COST ACCOUNTING WORKSHEET

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	Standard Wire Connectors	Home Depot	783250792979	Blue, 30 pack	$2.71	1	$2.71
2	MDF Boards	Home Depot	99167733357	1/2 2x4	$10.95	1	$10.95
3	MDF Boards	Home Depot	099167223032	3/4 2x4	$13.06	1	$13.06
4	Corner Brace	Home Depot	30699185894	1"	$7.48	1	$7.48
5	Corner Brace	Home Depot	30699185641	1.5"	$8.98	1	$8.98
6	Corner Brace	Home Depot	30699150519	2"	$3.57	4	$14.28
7	Corner Brace	Home Depot	30699145393	2.5"	$5.28	2	$10.56
8	Corner Brace	Home Depot	30699152704	4"	$7.24	1	$7.24
9	Wood Screws	Home Depot	887480017526	6x1/2	$3.82	1	$3.82
10	Duct Tape	Campus Bookstore	8510633	1.88x20yd	$7.99	1	$7.99
12	MDF boards	Home Depot	0000-279-388	1/2 2x4	$10.95	2	$21.90
13	MDF boards	Home Depot	0000-219-743	3/4 2x4	$13.06	1	$13.06
14	Corner Brace	Home Depot	0000-610-949	1" zinc, 20 pack	$7.48	1	$7.48
15	Screws	Home Depot	0000-442-293	Sheet metal screw pan, SS, 6x1/2	$3.51	1	$3.51
16	Sales Tax				$4.65	1	$4.65
Total:							$137.67

APPENDIX B – FINAL DESIGN DOCUMENTATION



ITEM NO.	DESCRIPTION	QTY.
1	LARGE PANEL	1
2	LARGE SUPPORT	2
3	SLIDER	4
4	MIDDLE SUPPORT	2
5	MIDDLE PANEL	2
6	SMALL SUPPORT	2
7	SMALL PANEL	2
8	MIDDLE INSERT ATTACHMENT	1
9	MIDDLE INSERT PANEL	1
10	SMALL INSERT PANEL	1
11	SMALL INSERT ATTACHMENT	1
12	MOTOR SUPPORT	1
13	BACK ROLLER MOUNT	1
14	STEEL ROLLER	1

Figure 38: Final CAD Design with BOM

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1. InMotion T900, https://staminaproducts.com/product/inmotion-t900-manual-treadmill/
2. Xebex Runner, http://xebexfitness.com/xebexrunneractt03.html
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