Fall 2018

The Wellness Companion

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Executive Summary

The Wellness Companion is a portable, compactable treadmill that can be used in all locations. This functionality is a reflection of the device's low sound output, collapsing frame, and compact size. The device has two primary states: a compact state for storage and transportation, and a functional fully extended state.

For this project, a focus was primarily placed on the expanding and compacting mechanism with an outlined path for future improvements of the final design. Our design featured a main treadmill frame broken in to three components: a base center platform and two smaller external platforms that have the ability to fold on top of the center module. These components were made of cedar wood and Medium Density Fiberboard (MDF) for the walking platform. Each of these components were connected via slots and links that allow for translation and rotation of the external platforms. To power the device, a salvaged 2.5 Horsepower motor was connected to a driving cylinder located within one of the external components of the frame. Similarly, a salvaged, traditional treadmill belt was affixed around the driving cylinder at the front and a second cylinder in the remaining external platform. Lastly, the length of the treadmill was designed such that the belt would be properly tensioned in the expanding position. These design restrictions, however, could be eliminated in the final design with custom parts tailored specifically to the device needs

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

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1 INTRODUCTION

Issues such as obesity, high blood pressure, and heart disease have been correlated with a sedentary lifestyle. Additionally, many contemporary office jobs consist of deskwork on a computer for almost the entire workday. This can result in back and neck issues. The goal of this project is to limit the harmful effects of sitting for extended periods of time by making an active lifestyle easy and convenient. The device we are making is a portable treadmill that is easy to carry and use in a variety of environments, such as at the library, in school, or at home. As such, the device allows its users to complete their activities while exercising when they would otherwise be sitting.

A feature that sets this treadmill design apart from others is that it can change sizes. With both a compact mode for carrying ease, and full-size mode for walking with a full stride, the device will be the most portable treadmill available. The device will also be light enough to satisfy this. For this project a 60-pound goal was set, however the final design would be able to greatly reduce this number by better material choices with a larger budget. The treadmill speeds will range from 1 to 3 mph to provide a series of walking paces and exercise intensities. Furthermore, since the device will be used in public areas, it will need to be quiet and safe enough to both operate and be stored around young children.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Related Designs

1st Design:

Figure 1: The Steelcase Walkstation

Link to existing design:

https://www.steelcase.com/products/height-adjustable-desks/walkstation/#specifications_standard-optional-features

Description:

The Steelcase Walkstation is an office desk with a built-in motorized treadmill. With a retail price of approximately $5000, the treadmill is designed to provide breaks from extended periods of sitting throughout the workday. The desk has an adjustable speed range from 0-2 mph; furthermore, the counter height can be modified to meet the needs of employees of all heights. A key feature that allows the desk to be successfully integrated into an office environment is its quiet low torque motor. While the desk assembly has wheels for easy transportation, it is not easily transported outside of the office or home.

2nd Design:

Figure 2: InMotion 7900 Manual Treadmill

Link to existing design: https://staminaproducts.com/product/inmotion-t900-manual-treadmill/

Description:

The InMotion T900 Manual Treadmill is a portable, folding treadmill. While the treadmill does not include a desk feature, it has a slim and lightweight design that allows it to be easily transported and later folded for storage. As the name implies, the treadmill is manually powered and requires no motor. For this reason, the treadmill may be used to walk, jog, or run; however, with a track just under four feet in length, there are some limitations on stride length. The simple design also allows the device to be very affordable, with a retail cost of only $200. The InMotion 7900 Manual Treadmill also has a customizable incline feature.

3rd Design:

Figure 3: Stamina InMotion Compact Strider

Link to existing design: https://staminaproducts.com/product/stamina-inmotion-compact-strider-green/

Description:

At 24.5 x 17 x 11.38 inches, the Stamina InMotion Compact Strider provides a highly portable exercise experience. The device easily fits under a desk and can be used while both sitting and standing. Additionally, the compact strider includes a variable knob feature that allows the resistance to be adjusted. One potential setback to the product is that it weighs roughly 24 pounds. This limits the portability the device would potentially have based on size alone. In reviews of the product there have also been problems associated with the pedals beginning to squeak. This would be very problematic when using the device in public setting.

2.1.2 Related Patents

Patent number: US5868648A

Inventor: Bruce Coody, Greg Harris

Figure 5 shows the different drawings representing the patent.

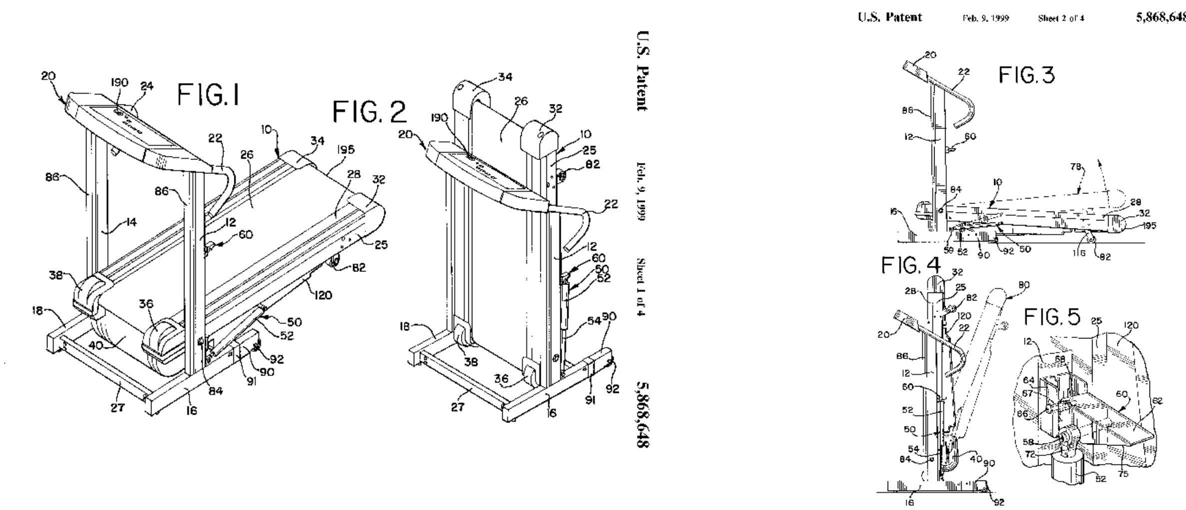


Figure 4: Representation of Patent US5868648A

Patent summary:

This patent is for a foldable treadmill which makes use of two gas springs to assist the user by bearing weight when folding it. Traditional treadmills have heavy track beds, are large, and awkward to store. This technology allows the treadmill to be easily folded with the assistance of springs and subsequently stored in a vertical position. The springs not only lower the effective weight of the treadmill when raising it but also prevent it from falling once in the vertical position.

Patent number: US4757987A

Inventor: Donald R. Allemand

Figure 6 below shows patent US4757987A handrawn.

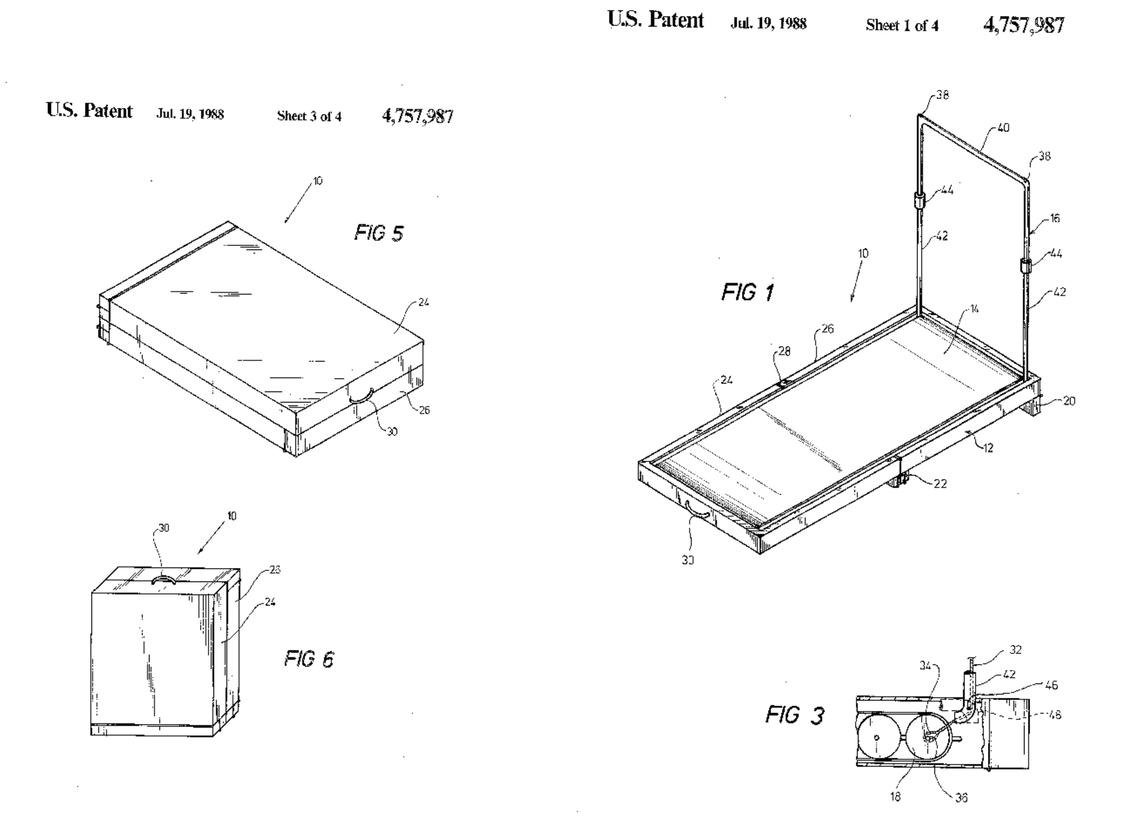


Figure 5: Representation of Patent US4757987A

Patent Summary:

This patent features a foldable treadmill which is easier to transport than other foldable treadmills due to its reasonable weight and compact shape when in the folded position. The design utilizes a telescoping handle as a means to control tension in the belt which is positioned over a plurality of rollers mounted in the treadmill housing. While collapsing the handle releases tension throughout the belt.

2.1.3 Relevant Standards

a. Standard Specification for Fitness Equipment [Ref. ASTM F2276 - 10(2015)]

This standard is specifically made to indicate to its users the parameters required for the design and the manufacturing of a fitness equipment that is to be used by customers over the age of 12. The primary target of the Wellness Companion being workers and students, this standard would be a very useful resource towards the realization of the project. Specifications concerning the construction (support, stability, moving parts) of the product are included and instructions to meet the safety concerns of such equipment (i.e. shear points, endurance loading, hand and foot support and load distribution).

b. Standard Specification for Fitness Equipment and Fitness Facility Safety Signage and Labels [Ref. ASTM F1749 – 15]

As the purpose of this project is to create a product that is usable by as many users as possible, making the device as safe as possible is one of the top priorities. This standard gives all the needed information on how to properly label and signal all the safety requirements to efficiently communicate the guidelines to the customer through pictograms and symbols.

2.2 USER NEEDS

Table 1: Customer Need Interview

Product: Wellness Companion
Customer: Muhammad

Notes: We had a conference phone call with Muhammad and other groups working on the Wellness Companion in Urbauer. It took about 40 minutes to complete. During the discussion we discussed customer needs and motivation for the project.

Address: Urbauer 318, Washington University Danforth Campuss
Date: September 7, 2018

Question	Customer Statement	Interpreted Need	Imp.
Power Source	Wants to have multiple versions of the product utilizing different power sources eventually.	Wellness Companion's power source is convenient	3
Portability	Wants device to change size	Wellness Companion needs to be easy to size-change and transport	5
Location of Use	Wants device to be used in public areas such as schools and libraries	Wellness Companion is very quiet	4
Different treadmill inclines	Would be nice to have but not the main purpose of device	Wellness Companion has varying incline	1
Safety	Device will be around children and in public	Wellness Companion is safe for people 12 and up	5

Table 2: Interpreted Customer Needs

Need Number	Need	Importance
1	Wellness Companion's power source is convenient	3
2	Wellness Companion needs to be easy to size-change and transport	5
3	Wellness Companion is very quiet	4
4	Wellness Companion has varying incline	1
5	Wellness Companion is safe for people 12 and up	5

2.3 DESIGN METRICS

Table 3: Target Specifications

Metric Number	**Associated Needs**	**Metric**	**Units**	**Acceptable**	**Ideal**
1	1	Motor Power*	HP	1.5HP	2.3HP
2	2	Total Weight	lb	< 30	< 15
3	2	Total Volume	ft^3	3*2.5*1 (l*w*h)	3*2*(2/3)
4	3	Noise	dB	<60	<40
5	4	Possible Incline	°	0	15
6	5	Follow Standard ASTM F1749 – 15	Binary	Follow	Follow

*: Assuming we include a motor in our design. However, some design alternatives can be self-running, with the user inducing the pace to the treadmill.

2.4 PROJECT MANAGEMENT

For the project schedule, the following Gantt Chart was created to organize tasks. Task dates are indicated at the top of each figure, with the image on the right corresponding to the beginning of the project.

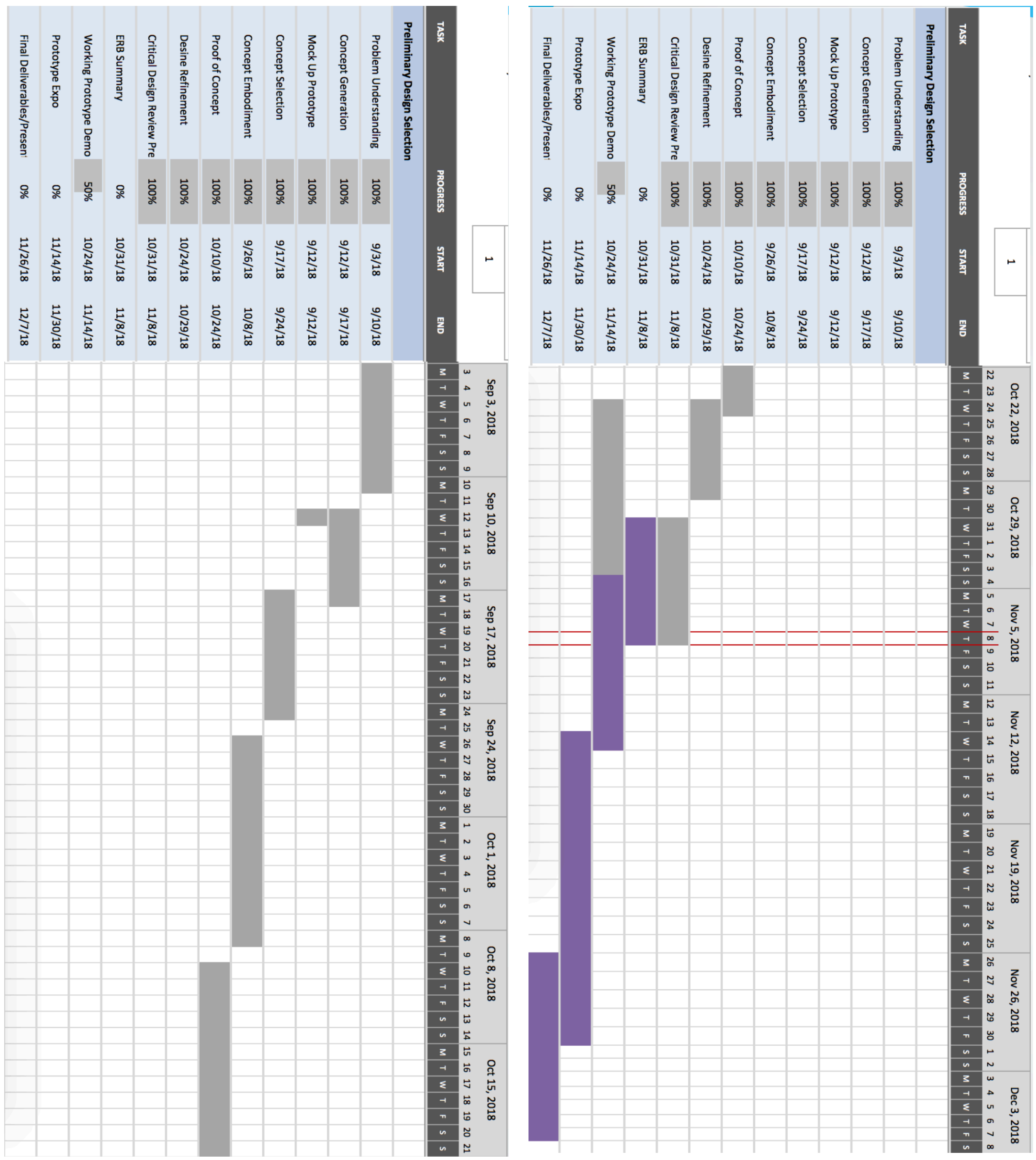


Figure 6: Gantt Chart

3 CONCEPT GENERATION /.

3.1 MOCKUP PROTOTYPE

In creating the mockup, it became evident that designing a compactable treadmill while still maintaining support through out the device would be challenging. Specifically, this activity highlighted the difficulties present in having a design that featured one half sliding within a slightly wider exterior shell. Specifically, once extended, the shell would lack internal support. This prompted the consideration of a folding treadmill about half of its length, however, the use of rubber bands in place of the expandable belt demonstrated that a folding design could not be palpable without first removing the belt.

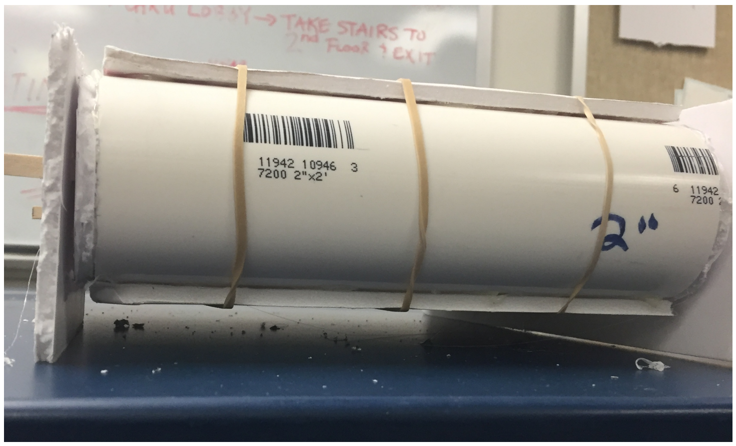


Figure 7: Demonstration of elevated belt design

Rather than attempt to solve this complex problem with the mock up, we decided to use the opportunity to determine the best way to elevate the treadmill off the ground. As shown in Fig. 7 above, this was an important design consideration as the rotation of the surrounding belt needed to be free of surface impedance.

One additional factor that needed to be considered in raising the treadmill was the resulting bending moment. If the device as only supported by legs at either end, there would be considerable stress at the center when subjected to the weight of the user. As such, we decided it was important to connect the external frame along the entire length of the treadmill. This is shown through the use of Styrofoam board in Fig. 8 below.

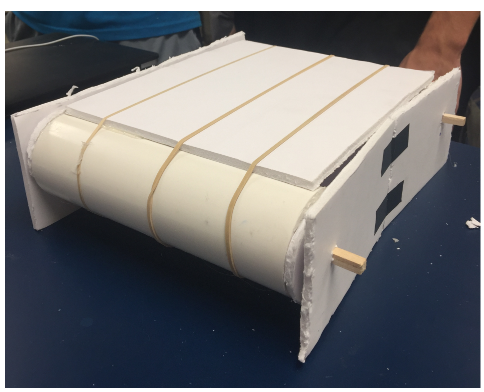


Figure 8: External Support POC

To maintain the compacting element of the design, it was important that the external frame be able to scale down with the walking platform in the final design. As such, we modeled the frame to be able to fold about the center point, effectively reducing its length by a factor of 1/2.

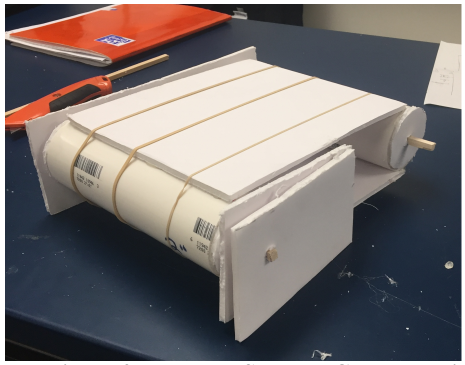


Figure 9: External Support Compactability

3.2 FUNCTIONAL DECOMPOSITION

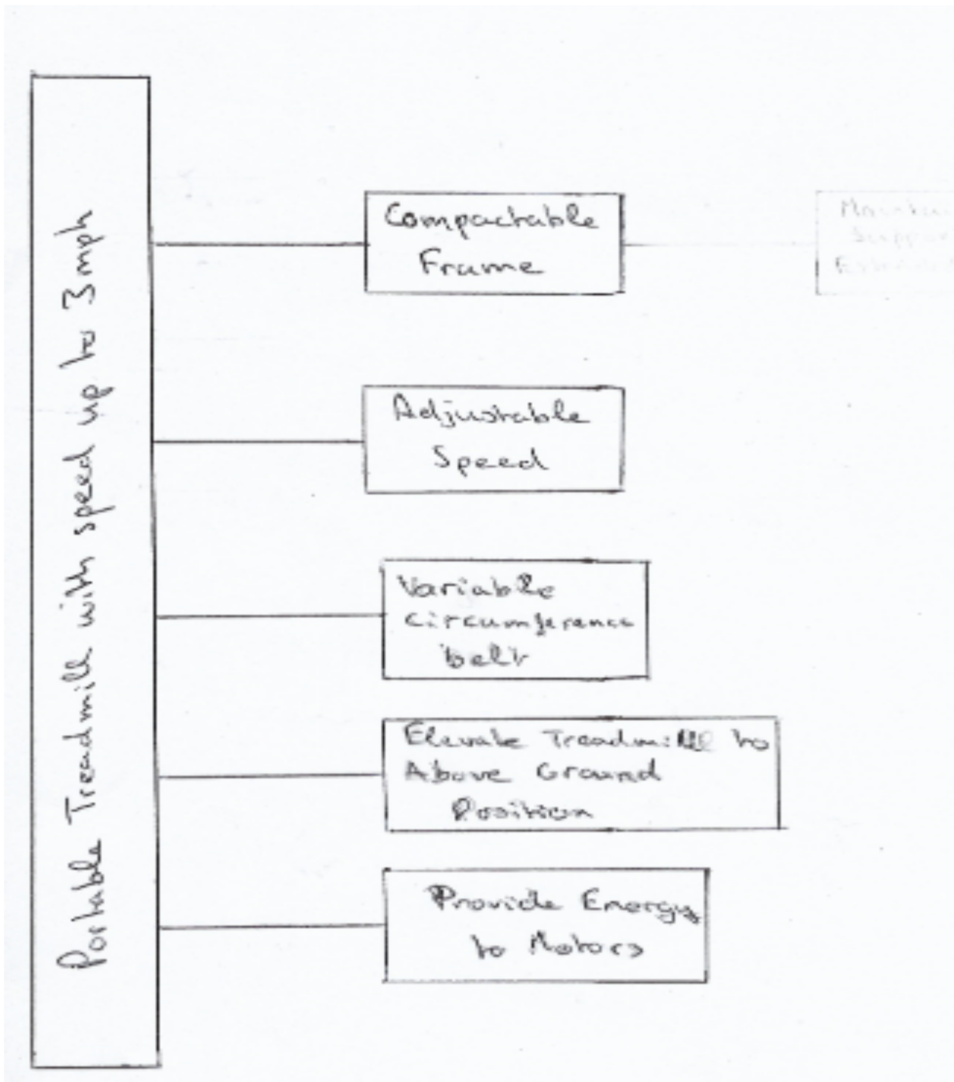


Figure 10: Function Tree of the Wellness Companion

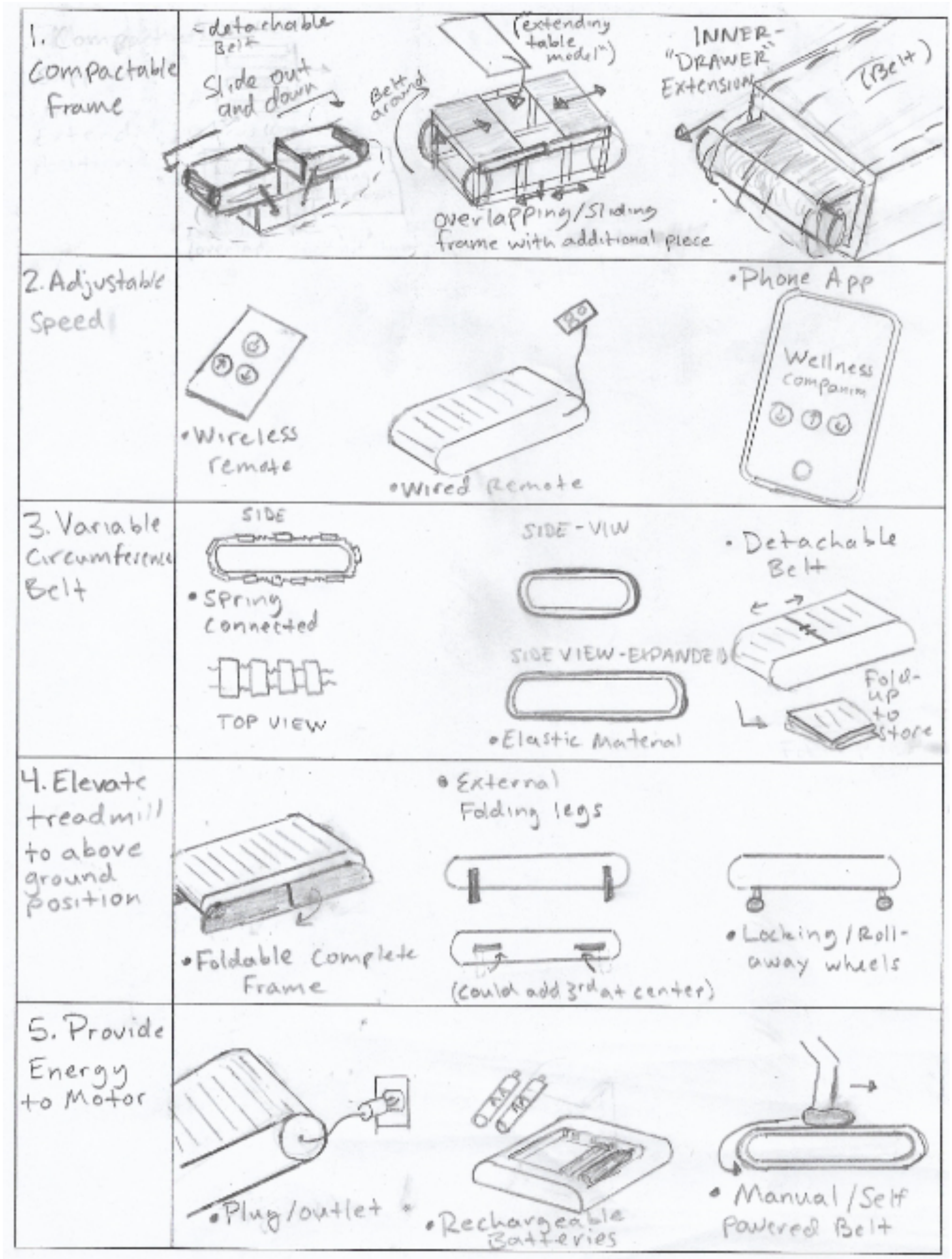


Figure 11: Morphological Chart for the Wellness Companion

3.3 ALTERNATIVE DESIGN CONCEPTS

Concept #1: Collapsible Tri-Panel Design

Group Member: Cory Schovanec

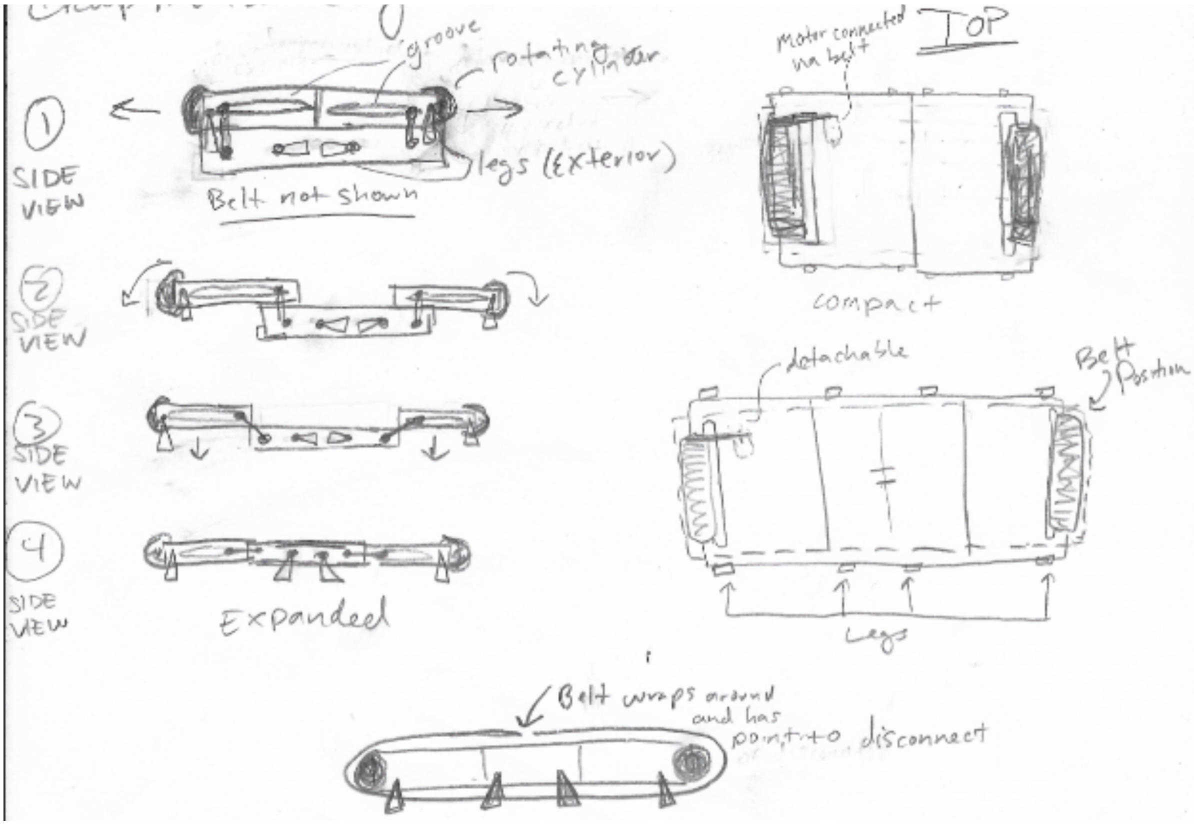


Figure 12: Preliminary Sketches of Concept #1

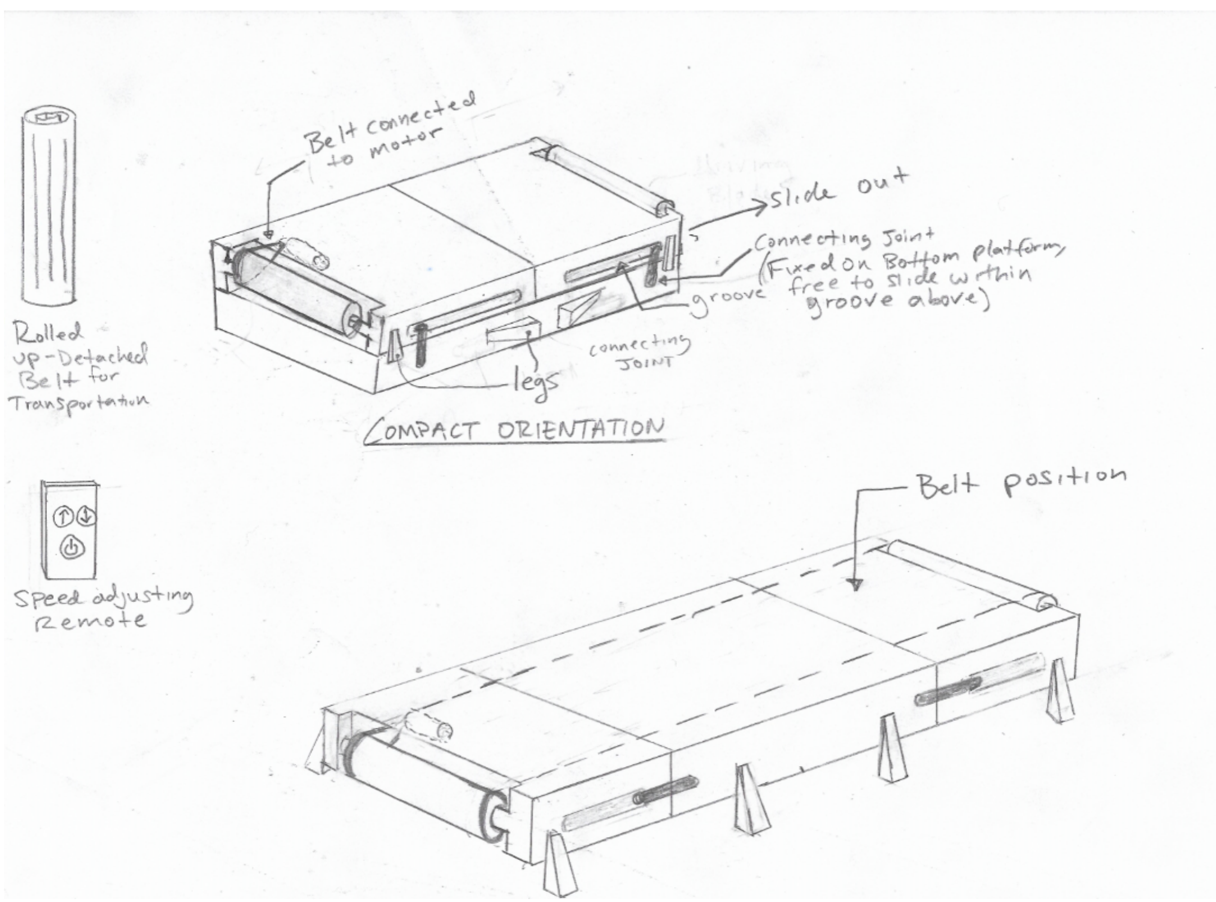


Figure 13: Final Sketches for Concept #1

Description: The Tri-Panel Collapsible design features a three-piece treadmill platform connected via two rotational hinges. In the compact orientation, the two exterior pieces sit directly on top of the center base piece. As such, their length is ¼ of the total design, while the center module makes up ½. The hinge is securely fastened to the center base piece on one end, while the other is free to slide within the grooves of the exterior platform components. These top pieces are able to slide out laterally and rotate downwards. This is demonstrated in the side view of Fig. 12.

For this design, a detachable belt was chosen. While an expanding spring option was considered, that feature could be problematic when the exterior panels approach the complete expanded length and still remain above the baseboard (Side view 3, Fig. 12). Once expanded, the detached belt may be applied directly to the rotating cylinders and connected via clips. One of the cylinders is connected to a driving motor located within an exterior platform component. Lastly, to provide clearance from the ground, 4 foldable legs are included on either side.

Solutions:

1. Slide Out Compactible Frame
2. Wireless Remote
3. Detachable Belt
4. External Folding Legs
5. Batteries

Concept #2: The Extending Table Concept

Group Member: Graham Southwick

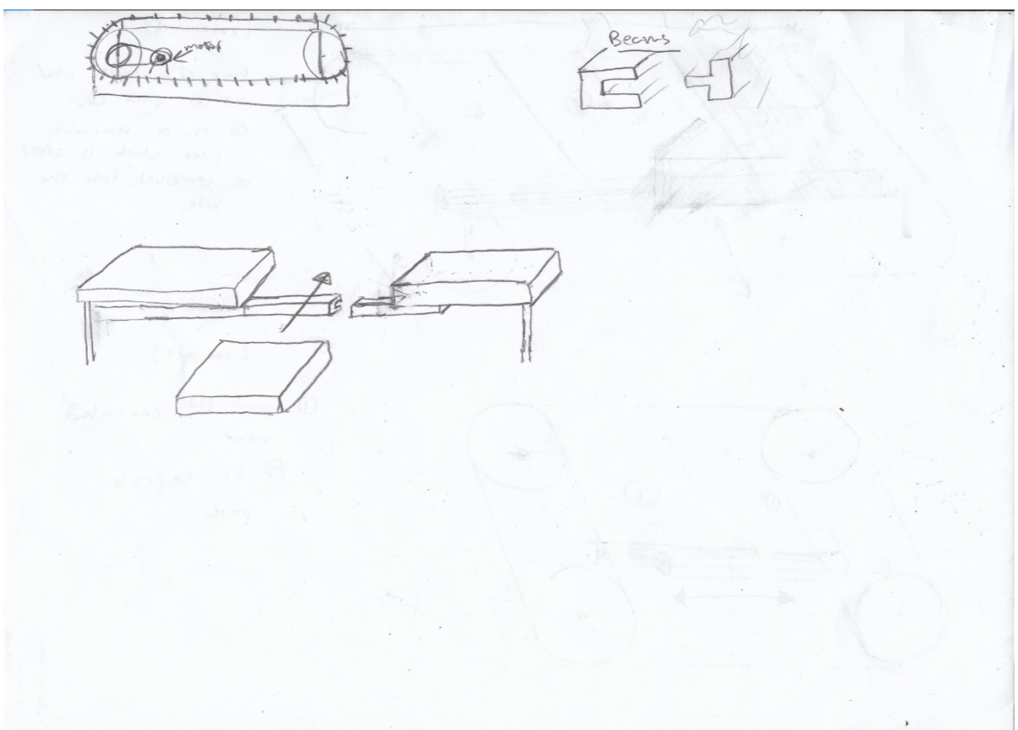


Figure 14: First Set of Preliminary Sketches for Concept #2

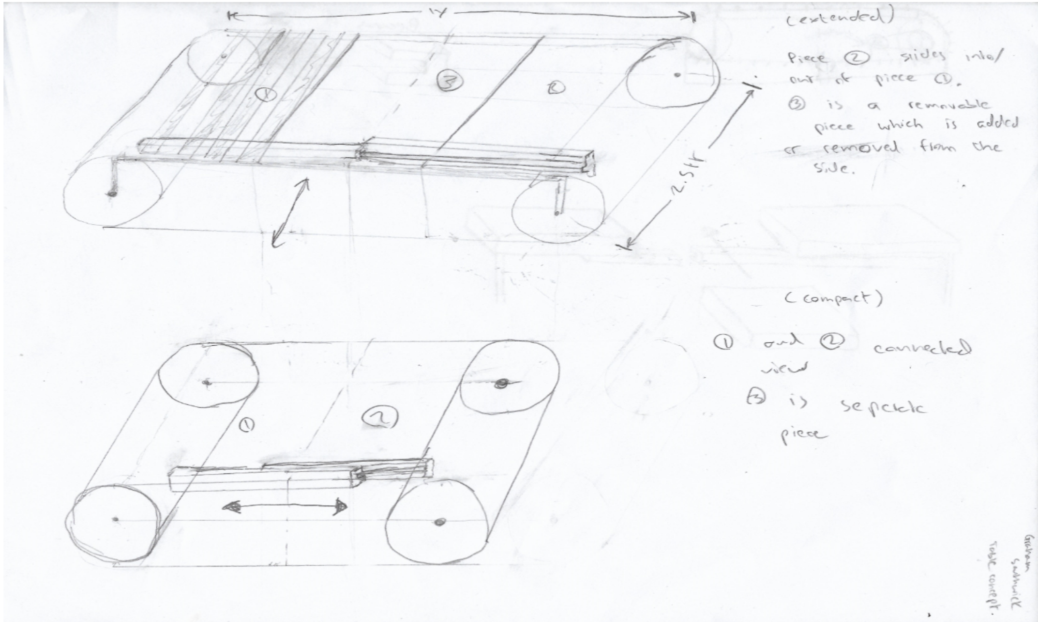


Figure 15: Second Set of Preliminary Sketches for Concept #2

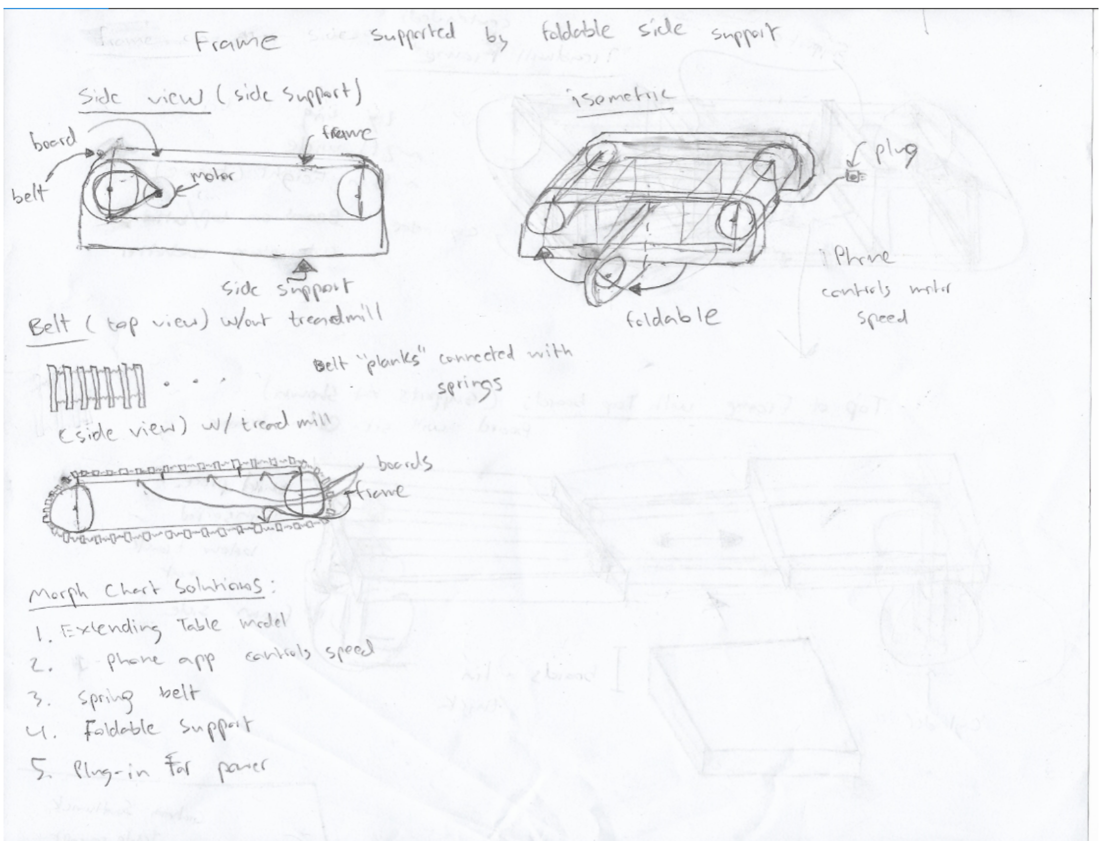


Figure 16: First Set of Final Sketches for Concept #2

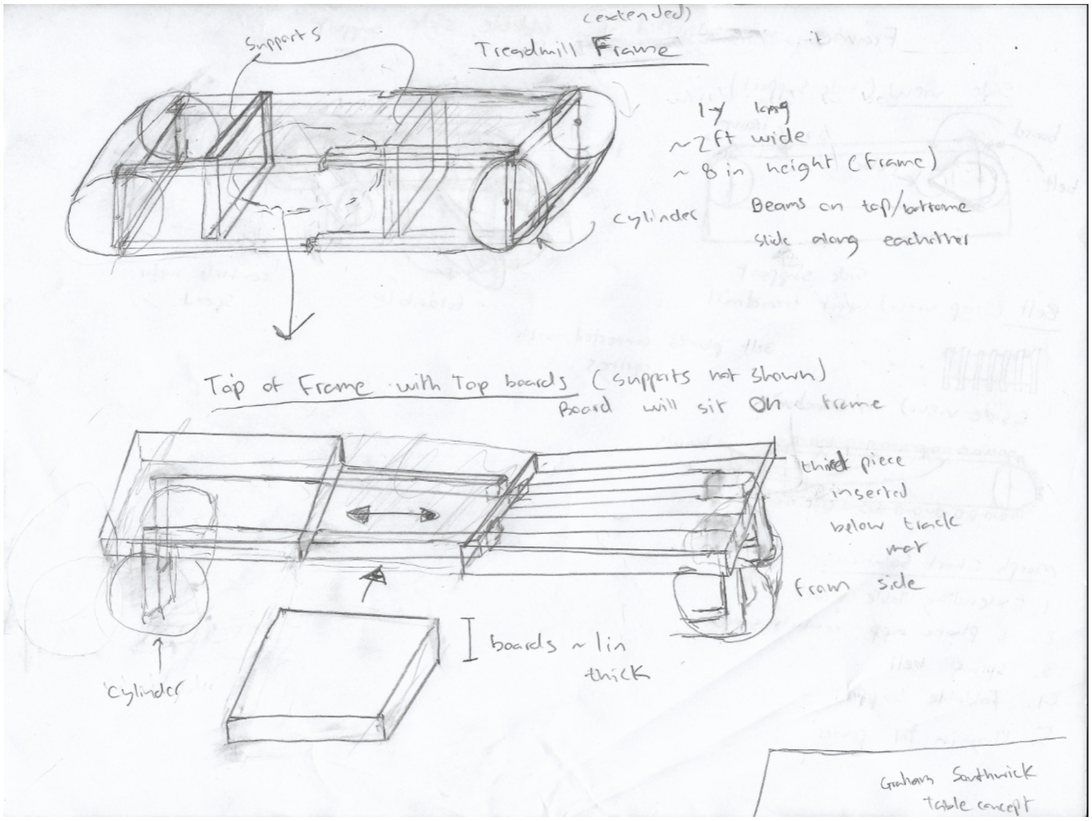


Figure 17: Second Set of Final Sketches for Concept #2

Description:

The inspiration for this concept comes from extendable tables. Extendable tables make use of two table tops attached by beams which can slide alongside each other. To expand the table, one simply unlocks (if there is a locking mechanism) the beams and pulls the two tables apart. Once this is done, all you must do is take the third table top, which comes with the table, and fit it into the slot creating by pulling the original two tables tops apart. Similarly, this concept for a treadmill involves two pieces: the main frame and extra middle piece. To expand the treadmill, one simply would pull the frame apart then slide the middle base treadmill piece into the gap which was created by pulling the frame into the extended position. This concept uses a spring and plank-based track mat so that it can have both a compressed and stretched position. It is powered by an outlet, uses a phone app to control speed, and has a foldable side support system.

Solutions:

1. Extending Table Concept
2. Phone app controller
3. Spring Belt
4. Foldable Support
5. Plug-in to outlet for power

Concept #3: The "Drawer" Design

Group Member: Matthieu MEYER

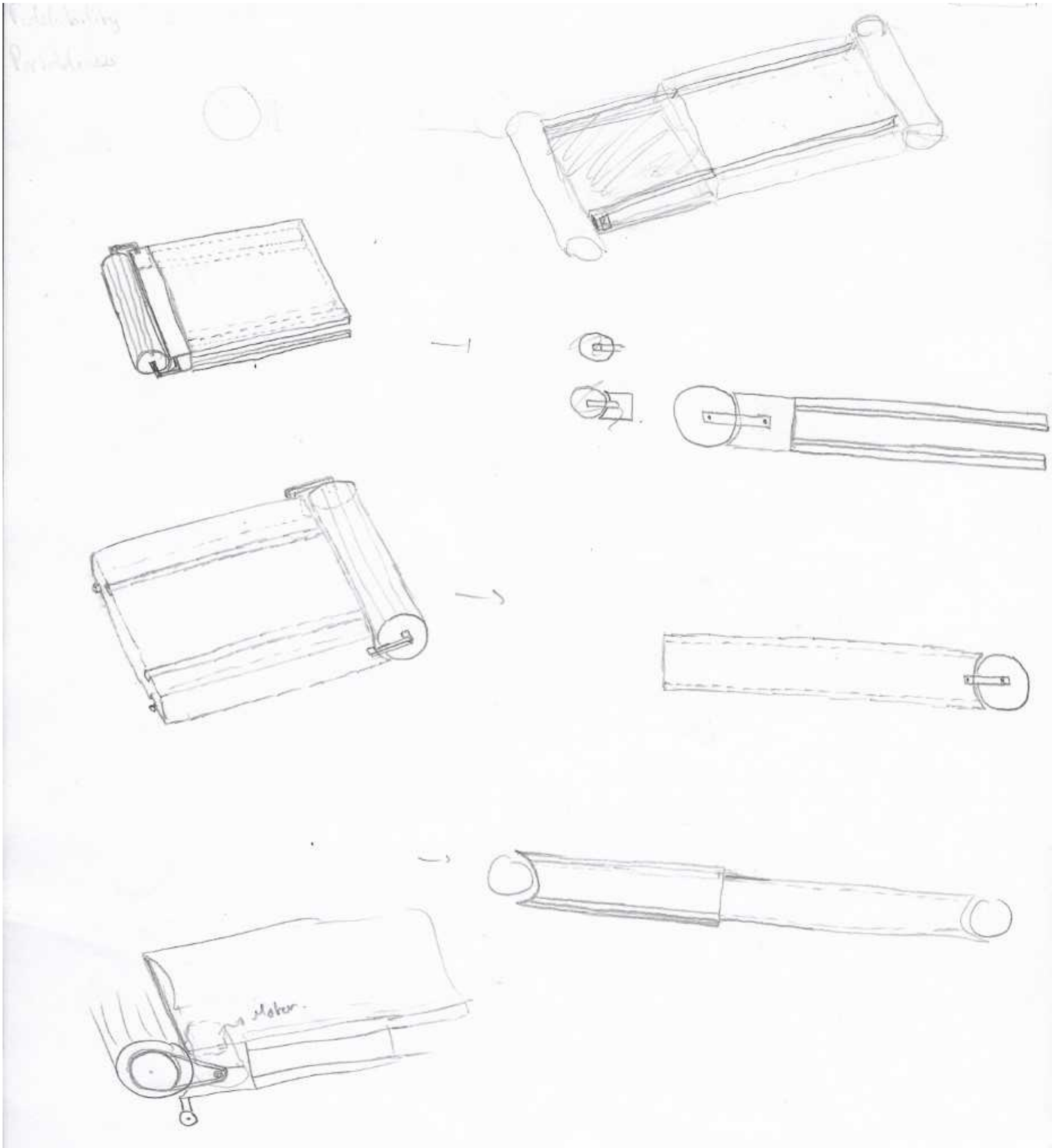


Figure 18: Preliminary Sketches of the "Drawer" design

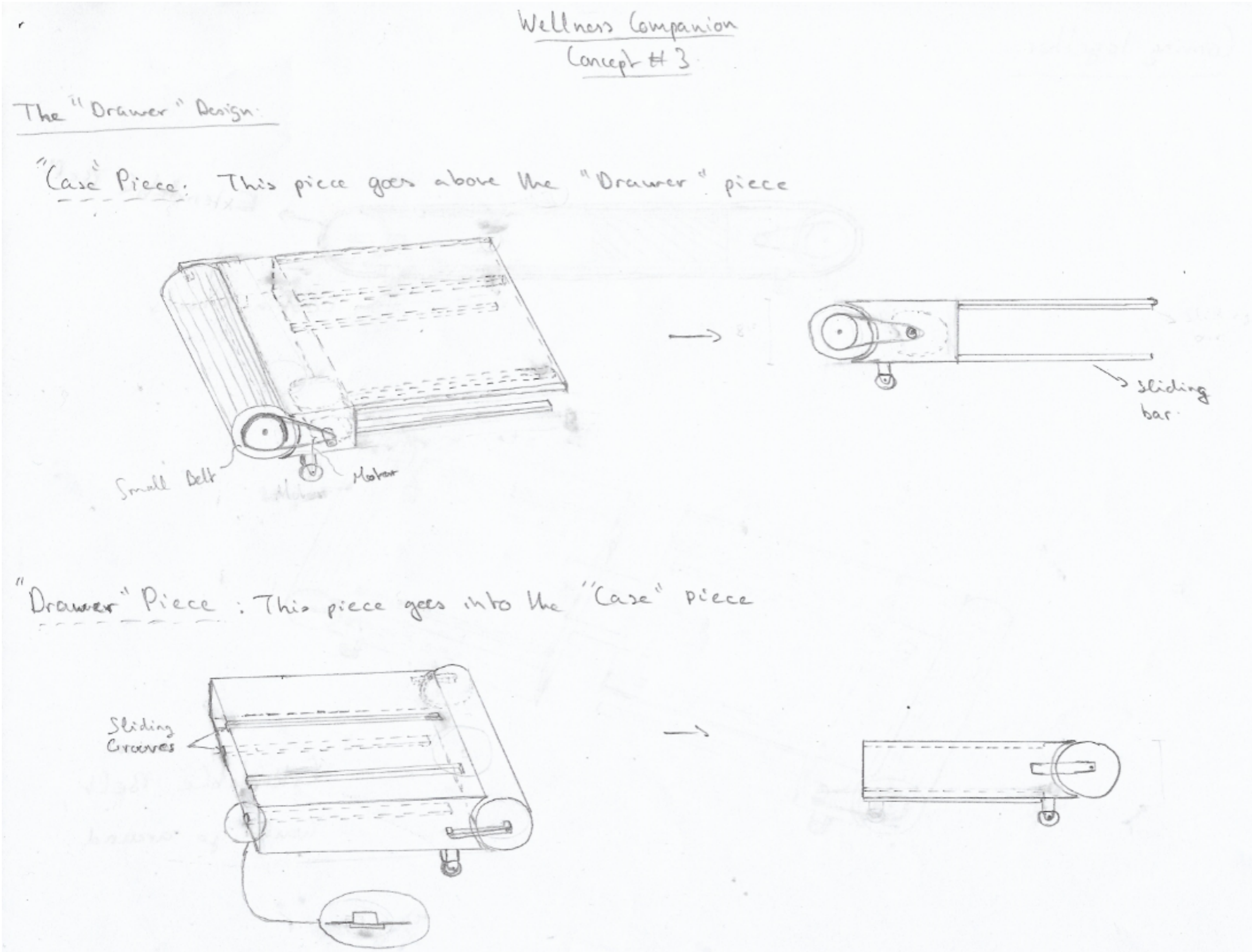


Figure 19: First set of drawings of the "Drawer" design

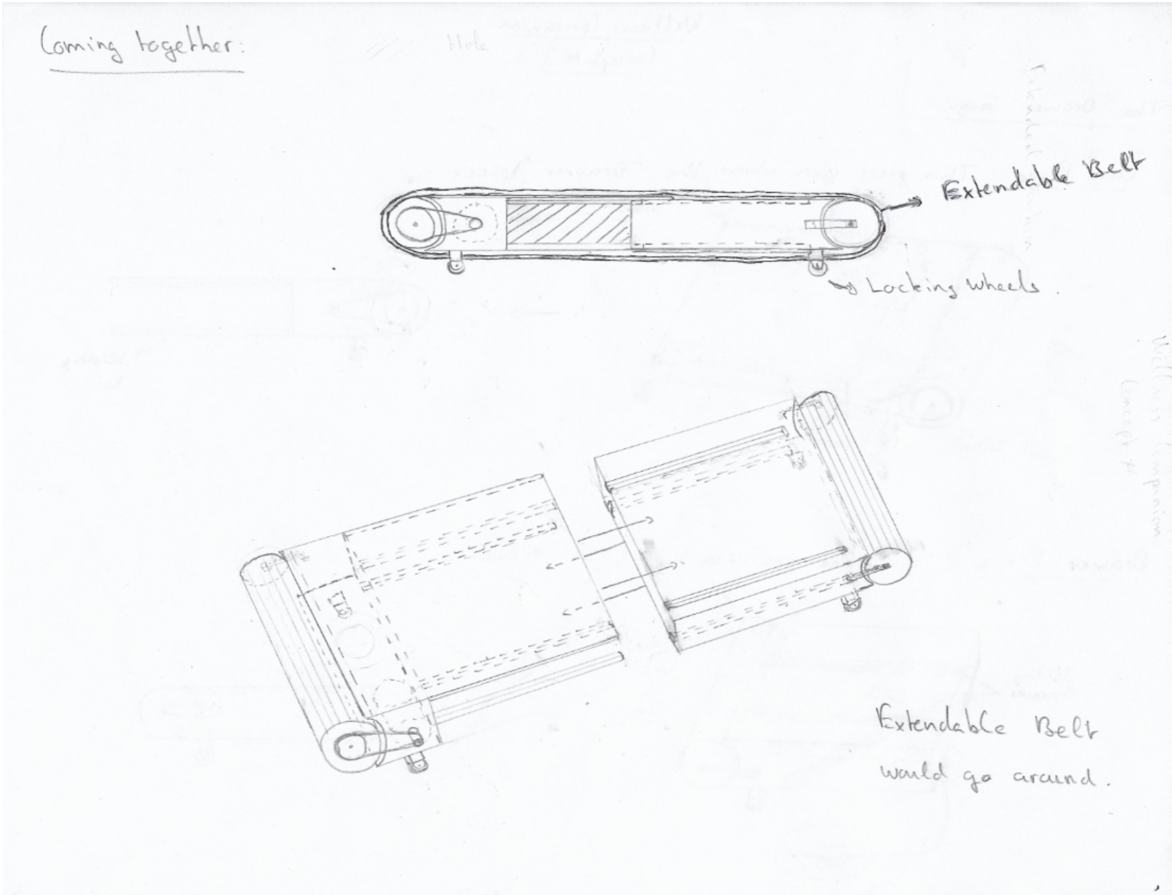


Figure 20: Second set of drawings of the "Drawer" design

Description:

This design of foldable treadmill was inspired by a drawer one could find in the most basic dresser. The treadmill is composed of two pieces, with one being able to slide and be contained into the other, like a drawer. The hollow piece, called the "Case" piece in the drawings, is made of a solid plate with small ridges located below. At the bottom of the "Case" are located two solid bars, called "sliding bars". The "Drawer" piece contains two grooves on its top, and two holes that can welcome the "sliding bars". When the user wants to shorten the treadmill, all he or she needs to do is push the "Drawer" piece into the "Case" piece, and the ridges will slide along the grooves and the bars will go into the holes until the treadmill is its compact phase. To use the treadmill, one must pull the "Drawer" piece until the treadmill is unfolded. To keep the treadmill in an above-ground position, locking wheels are located on the 4 corners of the machine. Finally, an extensible belt is located around the treadmill so that it allows the treadmill to be packed and unpacked without having too much slack.

Solutions:

1. Inner "Drawer" Extension
2. Wireless Remote
3. Elastic Material Belt
4. Locking/Roll-away wheels
5. Rechargeable batteries

4 CONCEPT SELECTION

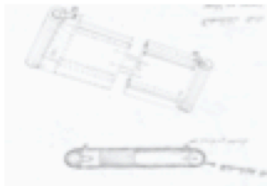
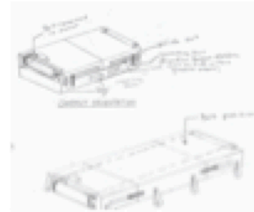
4.1 SELECTION CRITERIA

Table 4: Criteria Matrix

	Compactability	Even Distribution of Stress	Setup Difficulty	Flush Top Surface	Safety	Applicability of Expanding Belt	Row Total	Weight Value	Weight (%)
Compactability	**1.00**	0.33	3.00	9.00	0.20	5.00	18.53	0.23	23.02%
Even Distribution of Stress	3.00	**1.00**	5.00	7.00	0.20	5.00	21.20	0.26	26.33%
Setup Difficulty	0.33	0.20	**1.00**	3.00	0.20	3.00	7.73	0.10	9.60%
Flush Top Surface	0.11	0.14	0.33	**1.00**	0.20	0.33	2.12	0.03	2.63%
Safety	5.00	5.00	5.00	5.00	**1.00**	5.00	26.00	0.32	32.29%
Applicability of Expanding Belt	0.20	0.20	0.33	3.00	0.20	**1.00**	4.93	0.06	6.13%
	Column Total:						**80.52**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Table 5: Design Concept Selection Criterion

Alternative Design Concepts (Drawer, Table, Trifold)							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Compactability	23.02	4	0.92	3	0.69	4	0.92
Even Distribution of Stress	26.33	1	0.26	3	0.79	3	0.79
Setup Difficulty	9.6	4	0.38	3	0.29	2	0.19
Flush Top Surface	2.63	1	0.03	3	0.08	3	0.08
Safety	32.29	2	0.65	3	0.97	3	0.97
Applicability of Expanding Belt	6.13	4	0.25	3	0.18	2	0.12
	Total score	**2.485**		**3.000**		**3.073**	
	Rank	**3**		**2**		**1**	

4.3 EVALUATION RESULTS

After choosing the criteria that are important to the design of the Wellness Companion and that would set any of our designs apart from the products already existing on the market, Group R decided on the most important ones. The three alternative designs were then compared in the Weighted Concept Matrix. It turns out that after comparison, two concepts come out on top (separated by a small difference in the weighted score): the "Table" design and the "Tri-Panel" design. The "Drawer" design was flawed on one of the most important criteria: the ability to provide an even distribution of stress. Indeed, Group R believed that the hollow part of the concept would not be strong enough to withstand the user. The other two designs scored close to even, with the "Tri-panel" coming on top. Even though the "Tri-panel" didn't score as well in "Applicability of Expanding Belt" and "Setup Difficulty", it outscored the "Table" design on "Compactibility". Since this criterion is one of the most important ones, it makes sense that the "Tri-Panel" came out a bit on top.

Moving forward with this project, the "Table" design will not be discarded, as it can be used as another viable option in case of major failure in the "Tri-Panel" design prototyping process.

4.4 ENGINEERING MODELS/RELATIONSHIPS

One of the main functions of the Wellness Companion is to enable users to walk on it at a pace anywhere between 1 to 3 mph. The pace will be set by the belt rotating around the treadmill, which will itself be driven by a motor located at one end of the treadmill. Therefore, the motor needs to be able to drive a belt at a pace of 1 to 3 mph with a person located on it. The belt wraps around cycle cylinders at each end of the treadmill. Therefore, a relevant engineering model to consider is the analysis of the torque created by the user on the cycle cylinders.

The torque can be found by using the following vector equation:

$$\boldsymbol{\tau} = \boldsymbol{r} \times \boldsymbol{F} \quad [1]$$

With $\boldsymbol{\tau}$ being the torque created, $\boldsymbol{F}$ the force applied on the system and $\boldsymbol{r}$ the radial distance from the center of the system to the force applied. In our case, the system would be the cycle cylinder located at the end of the treadmill, and the force applied would be the force due to the user stepping on the belt. However, it must be noted that in all three of the designs, the belt will be driven by cycle cylinders that are connected to the motor shaft by a belt. Therefore, the torque transmission between the motor and the cycle cylinders needs to be analyzed. Figure 1 shows what the system could be simplified to.

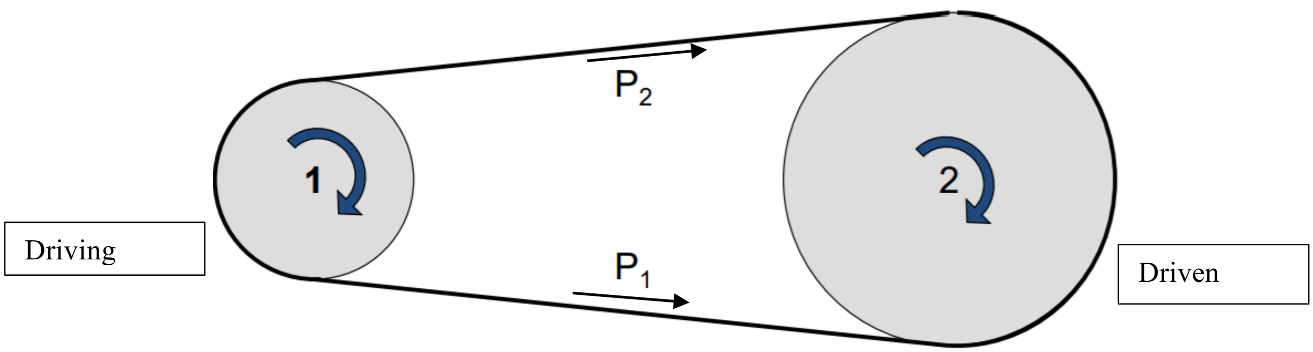


Figure 21: Simplification of the Motor-to-Cycle Cylinder System

If 1 is the shaft coming out of the motor (driving shaft) and 2 is the cycle cylinder's shaft (driven shaft), then the maximum amount of torque that can be transmitted between the two can is:

$$T = (P1 - P2) * r \quad [2]$$

With T being the maximum torque transmissible between the two shafts, r the radius of the driving shaft. P1 and P2 are loadings in the belt that depend on the wrap angle of the belt around the shaft and the friction coefficient between the two.

This model will help the group make an informed decision about the motor size, power and RPM value needed to assure the user a smooth exercising session while using the Wellness Companion. Moreover, the size of the driven and driving shafts as well as the material of the belt can be modified to find the most fitting combination and maximize the torque transmission between the two.

An additional design feature under consideration for the Wellness Companion is the use of an expanding belt. In the treadmill's expanded form the length may be up to two times that of the compact state; as such, the belt needs to not only be able to expand and contract to both circumferences, but the force required to expand the device must also be within a certain limit.

The design of the expanding belt consists of a series of boards connected by springs. The boards have a fixed length, L_B, while the springs have a variable length in order to satisfy both device positions. For this analysis, the expanded spring length will be denoted $L_{S,E}$ and the compact length will be denoted $L_{S,C}$. The circumference of the device in either case can be satisfied by the following equations:

$$C_{COM} = N \cdot L_B + N \cdot L_{S,C} \quad [3]$$

$$C_{EXP} = N \cdot L_B + N \cdot L_{S,E} \quad [4]$$

Here, C_{COM} and C_{EXP} are the circumference of the compact and expanded states respectively. For a complete belt, the number of springs must be equal to the number of boards. In Eq. 3-4, this is denoted by N.

By Hooke's Law,

$$F = kx \quad [5]$$

where k is the spring constant and x is the displacement. Considering Eq. 3-4, the displacement in Hooke's law is equal to the total change in circumference.

$$\Delta C = C_{EXP} - \ C_{COM} = x \quad [6]$$

Simplifying,

$$\left(N \cdot L_B + N \cdot L_{S,E}\right) - \left(\ N \cdot L_B + N \cdot L_{S,C}\right) = N\left(L_{S,E} - L_{S,C}\right) = x \quad [6b]$$

Lastly, for k the springs in the belt are all in series.

Thus,

$$\frac{1}{k_{eq}} = \sum_{i=1}^{N} \frac{1}{k_i} \quad [7]$$

Combining equations 5, 6, and 7, it follows that

$$F = \left(\sum_{i=1}^{N} \frac{1}{k_i}\right)^{-1} N\left(L_{S,E} - L_{S,C}\right) \quad [8]$$

This demonstrates that the amount of force required to expand the treadmill is a function of the spring chosen and the change of circumference. By deciding an upper limit on F, all of the parameters may be varied so long as the expanded and compact circumferences are satisfied.

The last design consideration was the required stability of the treadmill. Here, the force of a human is approximated to go right down through the middle of the treadmill. This assumption is valid since while walking on a treadmill one's center of mass sits right above the center point of the treadmill. Knowing the load, the treadmill and person put downwards is important to deciding how much cross-sectional area we want to include in the leg support design. When finalizing dimensions and materials for the treadmill it will also be important to consider how much stress the frame will be under. Among these, I have modeled the bending and normal stress the middle portion of the treadmill will be under. All of these calculations are vital to deciding how much support our treadmill will need in order not to fail and have an acceptable factor of safety.

This analysis is shown below:

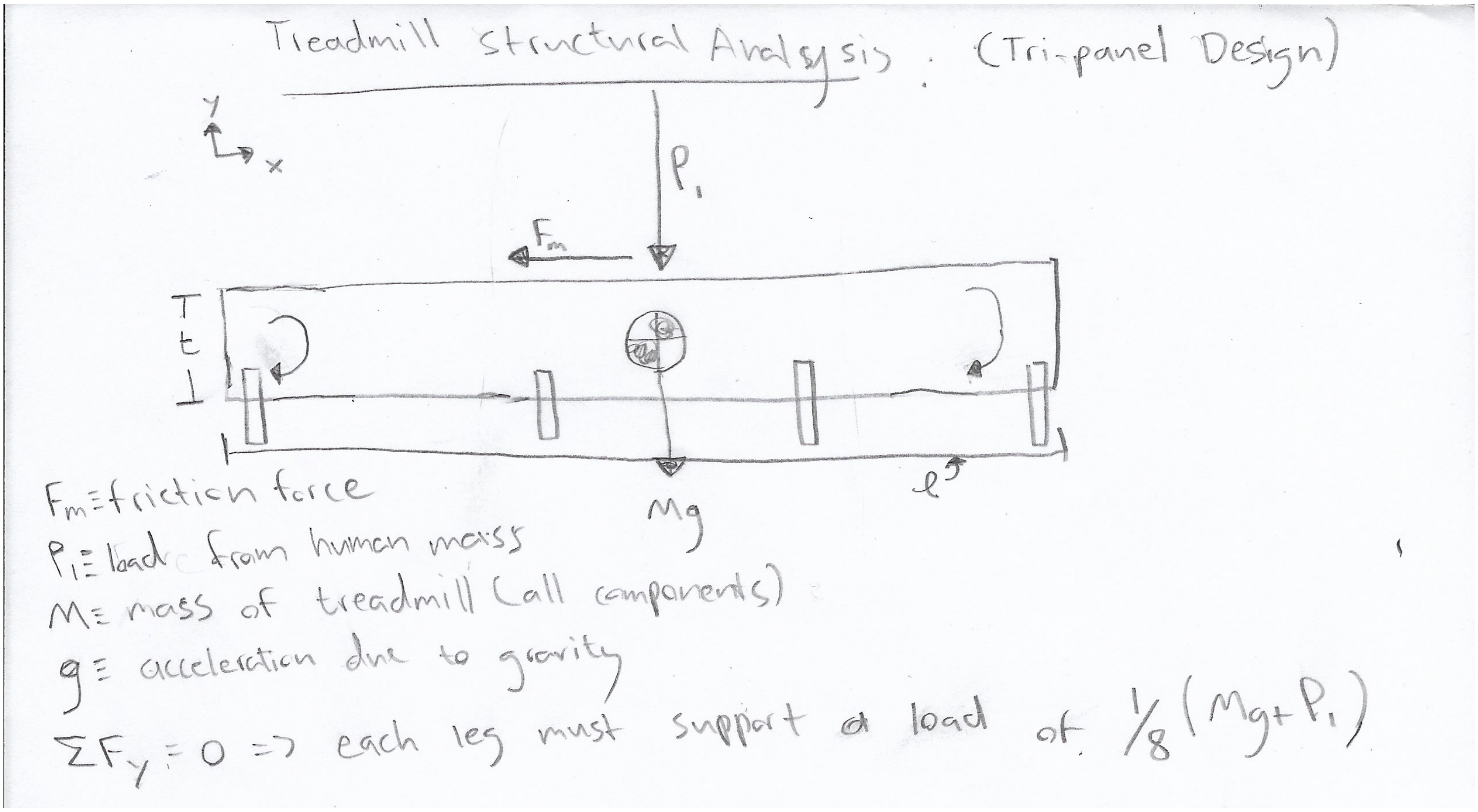


Figure 22: Treadmill Structural Analysis

(Continued on Page 17)

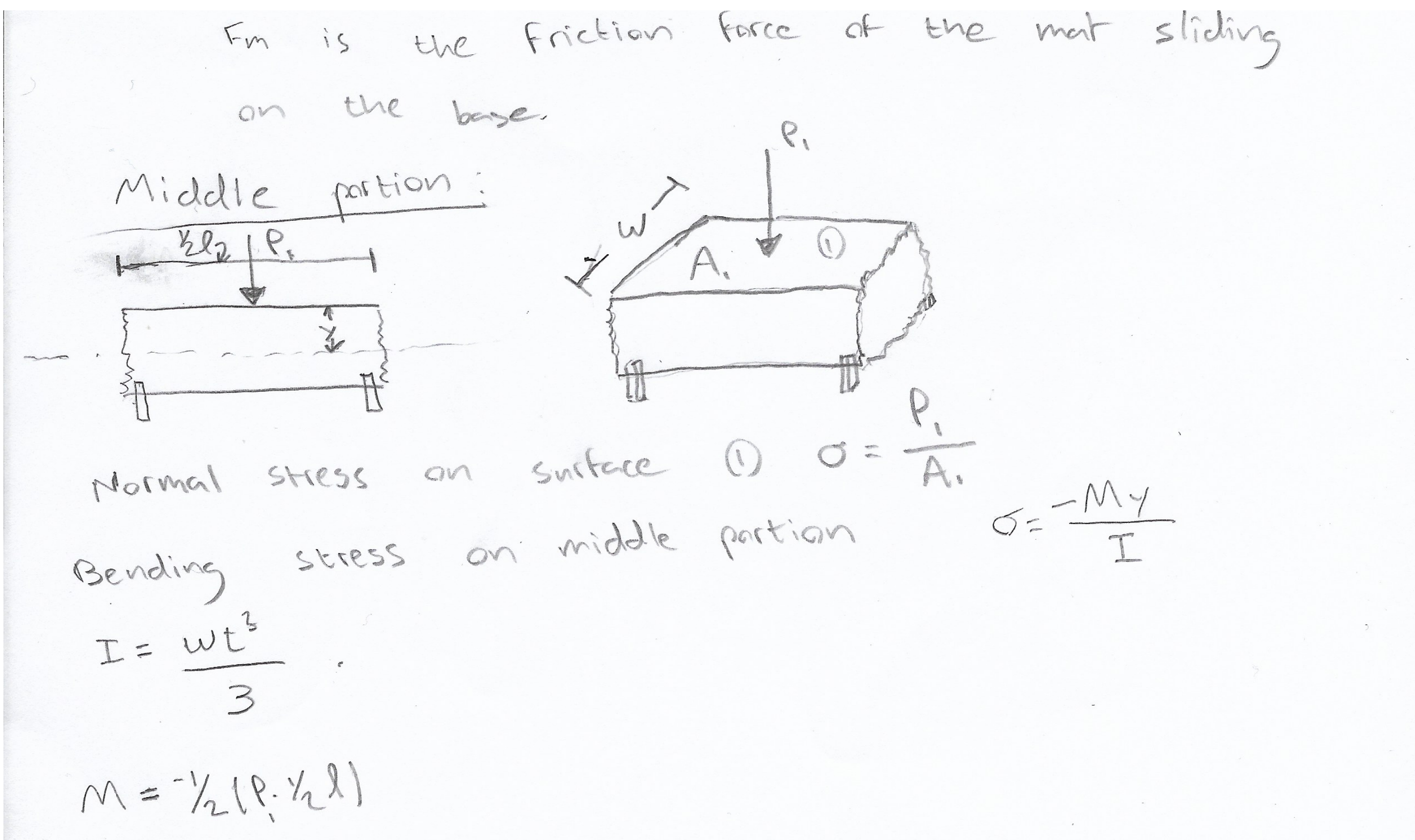


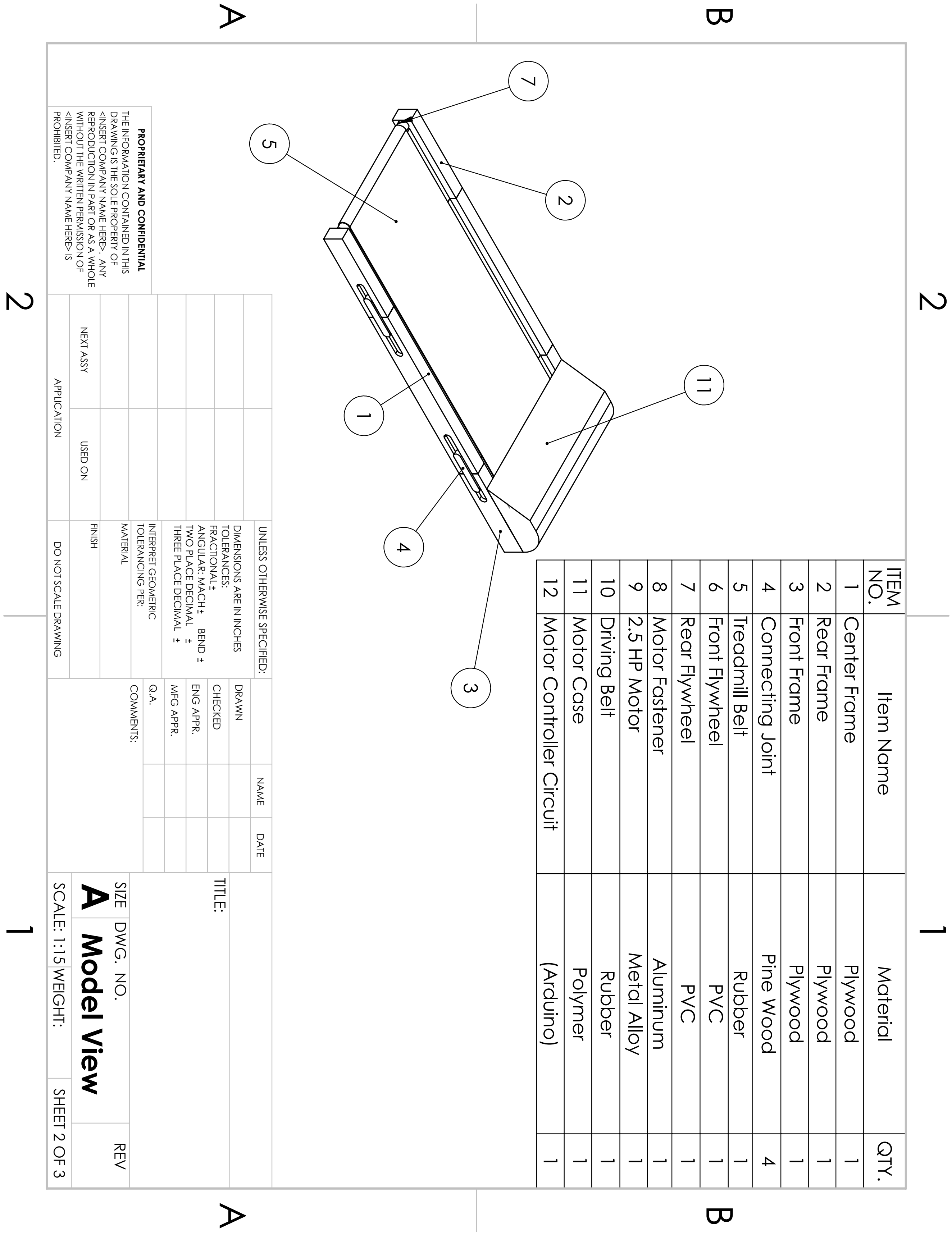
Figure 23: Treadmill Structural Analysis Continued

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

As seen in section 4 above, the Tri-Panel design was selected. However, it was determined that the design could be further improved by implementing concepts from the design alternates. To begin, the thickness of the exterior frame already had to be greater than the thickness of the internal deck to assure proper clearance of the belt. This meant that the exterior leg attachments were unnecessary. Furthermore, the deck size relative to the external supports had to be adjusted to make room for the flywheel on the front cylinder. These changes can be seen below in the updated CAD views.

Figure 24 below includes an isometric rendering of the design concept with a Bill of Materials. In contrast with the design concept in Fig. 13 this version has a motor encasement (Balloon Tag 11). This was added to reduce noise and risk associated with an exposed motor.



ITEM NO.	Item Name	Material	QTY.
1	Center Frame	Plywood	1
2	Rear Frame	Plywood	1
3	Front Frame	Plywood	1
4	Connecting Joint	Pine Wood	4
5	Treadmill Belt	Rubber	1
6	Front Flywheel	PVC	1
7	Rear Flywheel	PVC	1
8	Motor Fastener	Aluminum	1
9	2.5 HP Motor	Metal Alloy	1
10	Driving Belt	Rubber	1
11	Motor Case	Polymer	1
12	Motor Controller Circuit	(Arduino)	1

Figure 24: Cad Embodiment with B.O.M

The complete part make-up of the treadmill can be seen below in the exploded view below

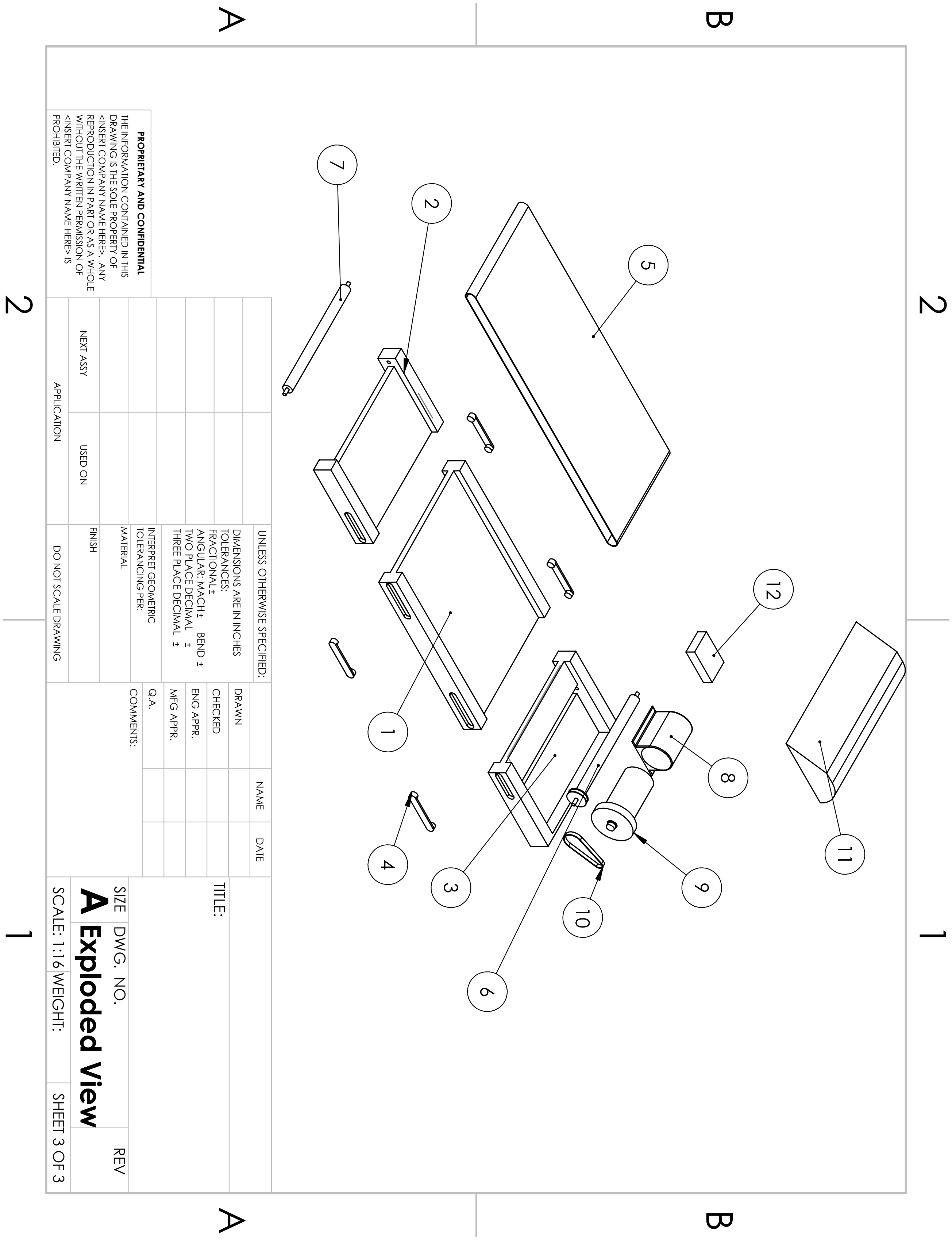


Figure 25: Exploded View of Wellness Companion

Figure 26 provides dimensioned top, side, and front views of the device in the expanded form.

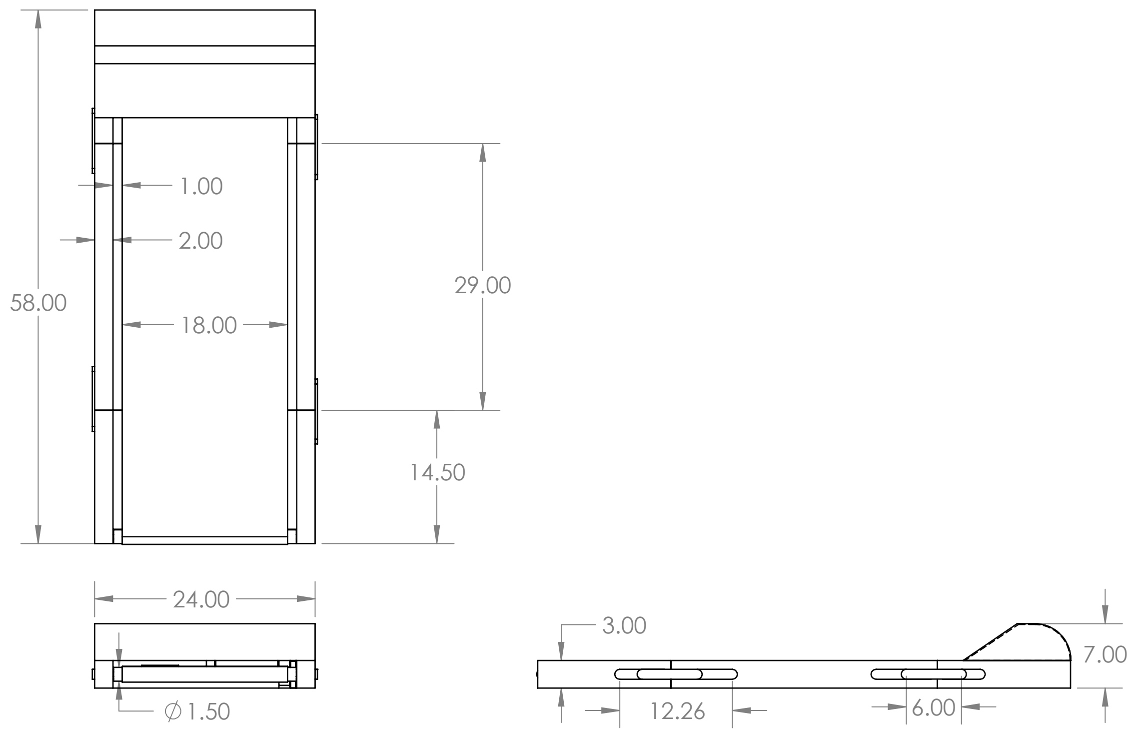


Figure 26: Top, Front and Side Views

Similarly, Fig. 27 shows the compact state.

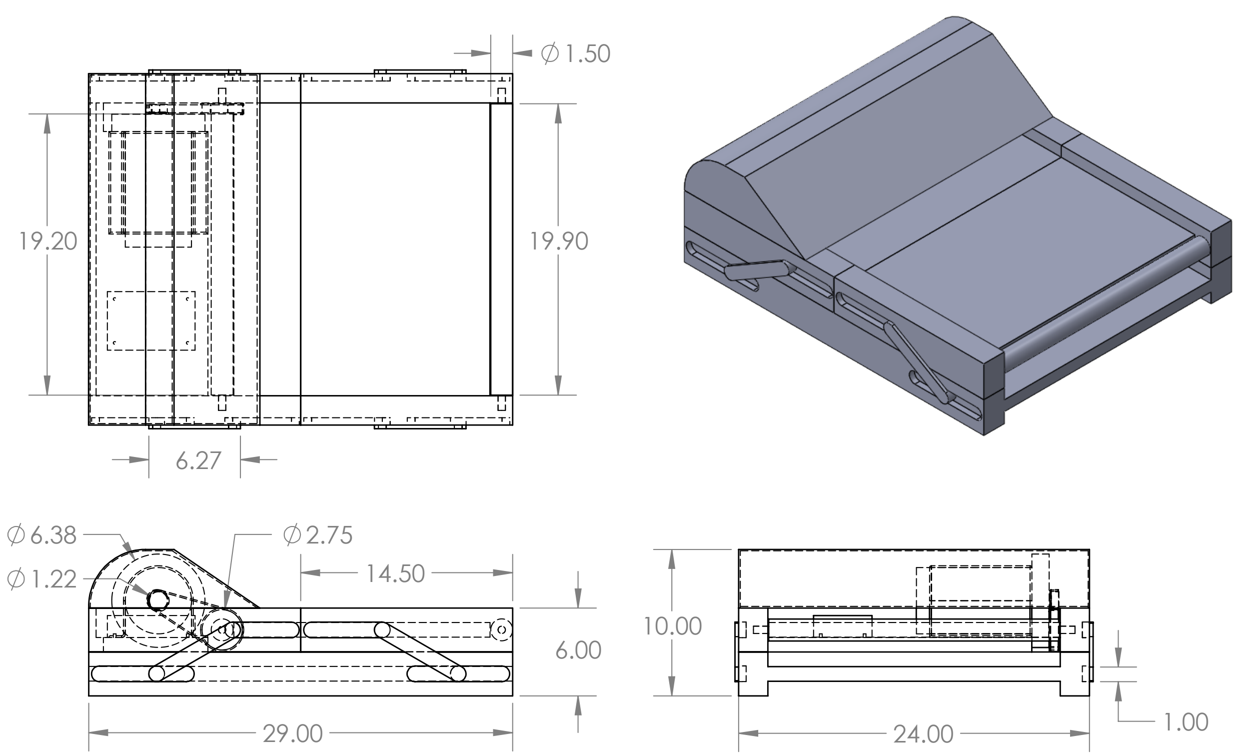


Figure 27: Compact Views

The initial parts list of the tri-panel design is as follows:

Table 6: Initial Parts of Prototype Components

	Part	Source Link	Supplier Part Number	Color, TPI's and other part ID's	Unit Price	Quantity	Total Price (with tax/shipping)
1	Treadmill Walking Belt*	Treadmill Doctor	Belt for PFR5200 treadmill	1 Ply Rubber Treadmill Belt	$89.99	1	$97.98
2	DC Motor*	EBay	10-3029	Black, 4875 RPM @130 VDC	$149.99	1	$149.99
3	Driving Belt	Elliot Electronic Supply	FBM10.2	Black, Rubber Flat belt	$5.50	1	$5.98
4	Rear Flywheel**	To be built or scavenged	-	Grey and black	-	-	-
5	Front Flywheel**	To be built or scavenged	-	Grey and black	-	-	-
6	Arduino Uno	Arduino	A000066	Usual circuit board green	$22	1	$26.99
7	Pin-and Slot -Links of center panel	Designed, to be built	-	3-D Printed Material or Machined		4	
8	Treadmill Lubricant	Treadmill Doctor	-	4-pack of 0.5oz white tubes	$35.16	1	$35.16 (same price if ordered with other parts from website)
9	Treadmill Motor Encasement	Designed, to be built	-	Black, most likely made out of plastic or wood	-	-	-
10	Frames	Designed, to be built	-	-	-	-	-
11	1" Plywood	The Home Depot	#EG-5/4x24x36SPR	Beige Plywood	$66.50	1	$68.99

Total Budget: $ 385.09 (could be reduced without motor/belt)

* Buying the motor or the belt might not be necessary, as those parts could be scavenged on used treadmills

** The flywheels are a part of the design that may also be scavenged, but the reduced size of Group B's design may require them to be built.

5.2 PROOF-OF-CONCEPT

For the project, the following goals were established:

Performance Goals

1. Achieve running speed of 1-3 MPH with 200 pounds user for 5 minutes
2. Be able to be changed from compacted to expanded form under 3 minutes
3. Be under 60 pounds in total weight

These goals were selected specifically to ensure the product could be easily transported and functional under the tri-panel design. While these goals were a main part of the design process for the proof of concept, the goals are ultimately geared toward the final design. As such, it is likely that changes to the design will be necessary following prototype testing. The design rationale to work towards these goals is included below.

1st Model: Torque Analysis

Objective: We want to make sure that the motor we picked to be part of our treadmill will be able to drive the belt when the customer is using the treadmill.

Figure 28 below shows how the motor to front flywheel set up could be simplified.

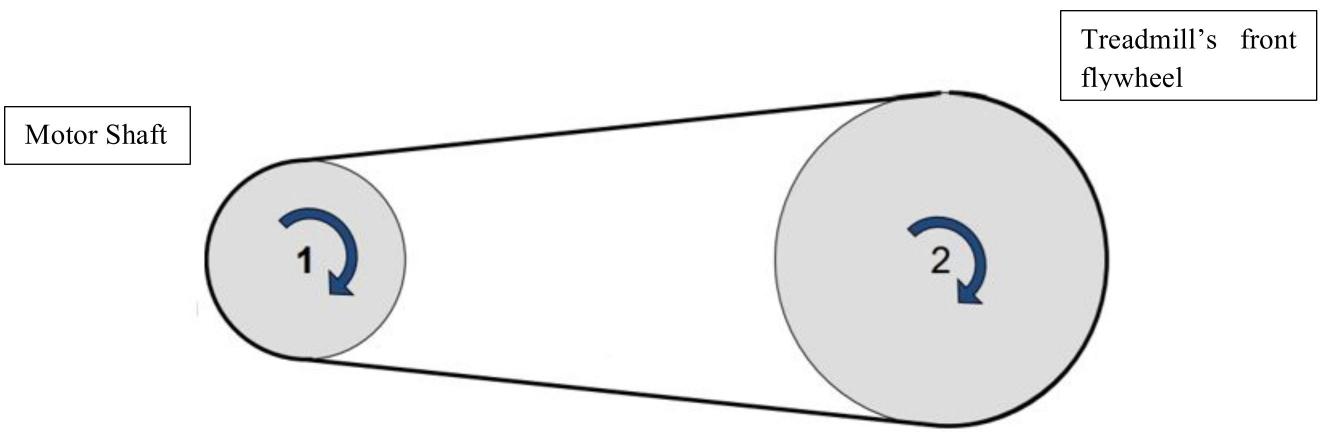


Figure 28: Schematic of Belt linking Motor to Front Flywheel

The typical motor chosen for a walking treadmill has the following characteristics: 2.5 HP (1.865kW), with an ideal RPM rating of about 4000 RPM [1]. For our design, the best closest motor we could find on the market at a fairly affordable price was had the following specifications: 2.5 horsepower, with a RPM rating of 4875 RPM. From those values, it is possible to calculate the torque created by the motor [2].

$$Tin = P * 5252/n \quad (9)$$

With T being torque in N/m, P being power in kW and the number of revolutions per minute in RPM. For the chosen motor, the torque created is 2.69 lb*ft.

Now that the torque created by the motor has been calculated, the amount transmitted to the flywheel can be calculated. To do so, the following equation can be used [3]:

$$Tout = \omega 1 * \frac{\text{Tin}}{\omega 2} \quad (10)$$

With Tout being the resultant torque produced by the flywheel, Tin the torque produced by the motor. ω1 and ω2 are the motor's shaft and flywheel's angular velocities, respectively. Those two can be related using the following equation [3]:

$$\omega 1 R1/R2 = \omega 2 \tag{11}$$

With R1 and R2 being the motor shaft and flywheel's radii, respectively 0.61in and 1.375in. Therefore, the angular velocity of the flywheel, ω2, is 226.5 rad/sec. From this value, the torque produced by the flywheel is 6.06 lb*ft.

Now, if a 200lb user is stepping directly towards on the belt while walking, we can assume the downward force to be a point force. Figure 29 is a schematic of the treadmill part the engineering model considers.

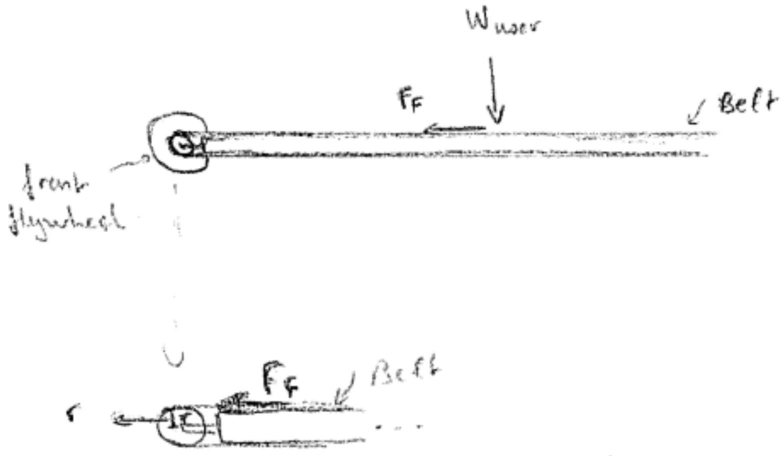


Figure 29: Drawing of Walking Platform as seen from Side

The force of friction F_f can be related to the weight force W_{user} with the following equation [9].

$$F_f = W_{user} * \mu \tag{12}$$

With Wuser being 200 lbs and μ the coefficient of friction between the belt and the walking deck surface located below (assumed to be 0.25, a safe assumption for most treadmills). The value of F_f is calculated to be 50lbs. From this value, the minimum torque that needs to be produced by the front fly wheel to overcome the force of friction and make the belt rotate can be found with the following equation [10]:

$$T = F_f * r \tag{13}$$

With r the radius of the flywheel's cylinder, and T the resulting torque. The value of r being 0.75in (or 0.0625ft), T is equal to 3.125 lb*ft.

Since the flywheel supplies 6.06 lb*ft due to the 2.5 HP motor, the treadmill **will overcome** the force of friction for a 200lb customer.

2[nd] Model: Bending Moment Analysis

For our stress analysis, we will assume most stress is on the center frame shown below.

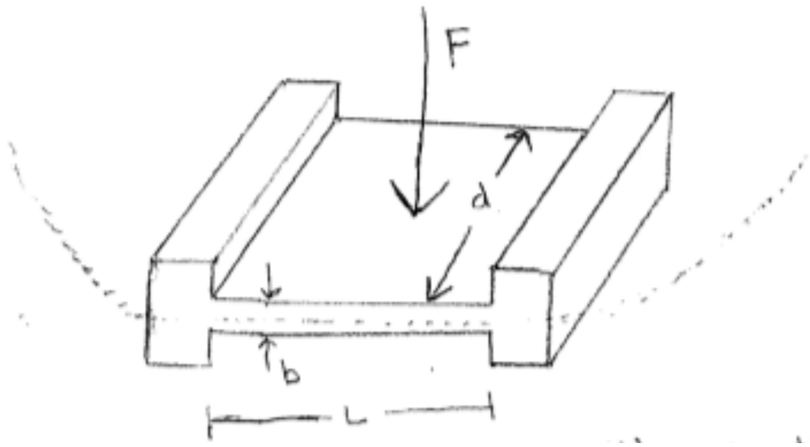


Figure 30: Drawing of Walking Platform for Bending Analysis

Here, force is assumed to be applied at a point in the center of the treadmill. Modeling the stress with a three point flexure model:

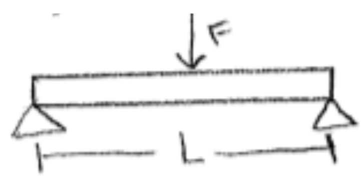


Figure 31: Three Point Bending Model of Platform

The flexure stress can be calculated using equation [11]

$$\sigma_F = \frac{3FL}{2bd^2} \tag{14}$$

with a 200 lb force (approximate upper hand load). As shown in our design we have

L = 20 in,

d = 29 in

b = 1 in

F = 200 lb

For these parameters σ_F is 7.13 psi. From this model for a 1 inch thick platform the bending stress along the width of the treadmill does not appear to be a concern.

6 WORKING PROTOTYPE

6.1 OVERVIEW

In creating the working prototype, 4 main design problems were discovered. First, in order to maintain a secure fit between the motor and the driving flywheel, we knew we could not create our own cylinders. However, we found that the cylinders from the salvaged treadmill were too long to fit within the walking deck. This meant that we had to add additional wood supports outside of our original frame to create an extra ~1.5 inches in width. Next, it was discovered that there was not enough clearance between the walking deck and the ground for the cylinder flywheel so the deck had to be raised another inch as well. Similarly, to maintain tension in the salvaged belt, the length of the Wellness Companion working prototype had to increase.

In addition to the three changes in dimension, the salvaged motor was also very large and heavy. As lighter and more compact motors were outside of the budget, the design had to be temporarily adjusted. The motor could not be supported by the folding platform as initially designed in Fig. 24-25; the wood platform was at risk of fracturing and it would be too heavy for the user to continuously raise and lower while expanding. To solve this problem, we simply created an external board for the remaining circuitry and motor. This is shown below in Fig. 33.

6.2 DEMONSTRATION DOCUMENTATION

The connecting links and motor connection can be seen in the figure below. As the external platform was an imperfect solution to the motor issue, an additional wood wedging was required to tension the motor-flywheel belt.

Figure 32: Expanded Wellness Companion Working Prototype

The complete circuitry on the motor deck is shown below.

Figure 33: Expanded Wellness Companion with Full Motor Deck

Lastly, the compact form of the wellness companion may be seen in Fig. 34.

Figure 34: Compact Wellness Companion Working Prototype

Here, it can be seen that the motor-flywheel belt had to be removed to allow for the motor deck to be separated. Furthermore, the overhang present in this figure is a result of the cylinder lengths, as discussed in Section 6.1.

6.3 EXPERIMENTAL RESULTS

The first performance goal was to have a weight less than 60 pounds. This goal could not be reached for many reasons in our working prototype, though we believe it could be achieved with the same design. To begin, the prototype could be greatly reduced in size. As outlined earlier, the length, width, and even height of the treadmill had to be modified to fit the salvaged treadmill parts. Reducing the dimensions would reduce the required materials and greatly reduce the weight. Furthermore wood was used solely because it was cheap yet study. The final design will almost certainly feature a lightweight composite. Lastly, the motor itself was old and rather large. With a larger budget and the assistance of a material scientist, each of these factors could be addressed.

The second goal was to support a 200 pound user for 5 minutes. For this goal, the structure was strong enough to support a much heavier user as it was originally designed for a running treadmill. No signs of deflection occurred to the walking deck. Regarding the 5 minute run time, this goal could not be tested due to circuitry problems. While the speed could be adjusted and the motor ran the belt efficiently, there was an unknown problem that caused the circuit breaker to almost immediately kick in. This could either be an issue with the motor or potentially the magnetic sensor. On top of this, while the motor could run the belt without a user, it is unknown if it would have been able to overcome the force of someone walking. The belt would have needed to be re-waxed and the tension would have to be extremely high, which is hard to set by hand after compacting and re-expanding.

The final goal was to be able to compact and expand the device in under three minutes. This goal spoke to the true portability of the device as no user would tolerate consistently spending 10-20 minutes for tear down and build up every time they wanted to move the device. This goal was achieved by a wide margin; it was estimated that either process could be completed without any rush in 20-30 seconds with the pin and slot design. This did not include the extra time required to reconnect to the motor under the temporary design, though that still could be completed under 3 minutes.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

A finite element analysis was completed using a Solidworks simulation. The center frame was chosen as the part to be analyzed because it is the location where the majority of the user's load will be located. Our mesh with applied forces is shown below.

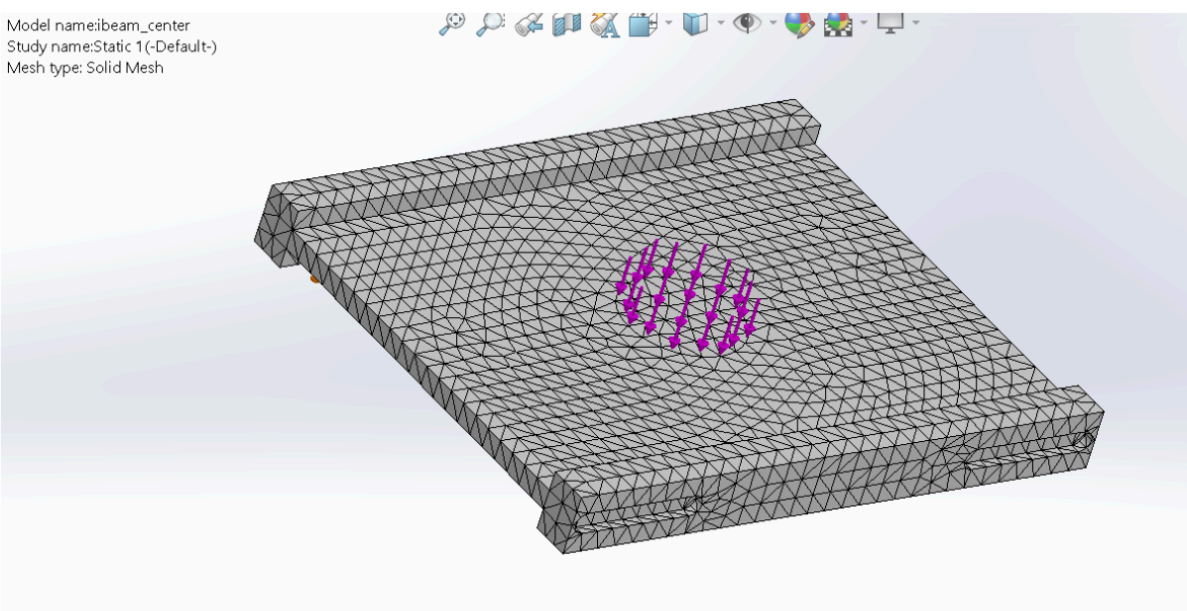


Figure 35: FEA Applied Load and Mesh

A circular load was modeled to estimate the load of the user. This geometry was chosen because it represents the instance at which the maximum load is at a single location. This occurs at the time that the user has one leg on the treadmill pushing down while the other is in stride. At other instances when both feet are down the load is distributed at two different points with lesser magnitudes.

Similarly, the boundary conditions used in the finite element analysis are shown in Fig. 30.

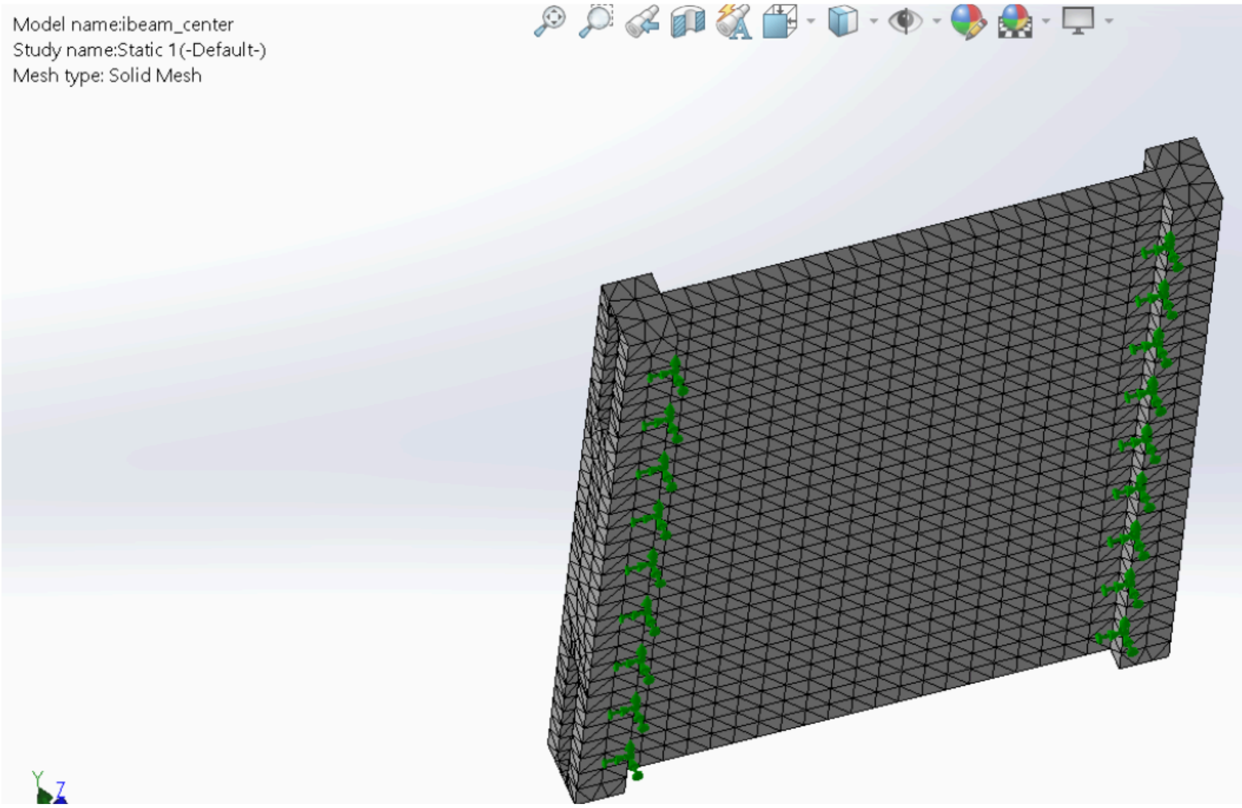


Figure 36: FEA Boundary Conditions

Our boundary condition on the bottom was a fixed geometry applied only to the edge of the part as opposed to the entire bottom surface. This was chosen because in reality the outside edge of the bottom surface may lift off of the ground and not be fixed to it. For the stress analysis a 200 lb load was used in compliance with our performance goal. Below are the results of our Von Mises stress analysis.

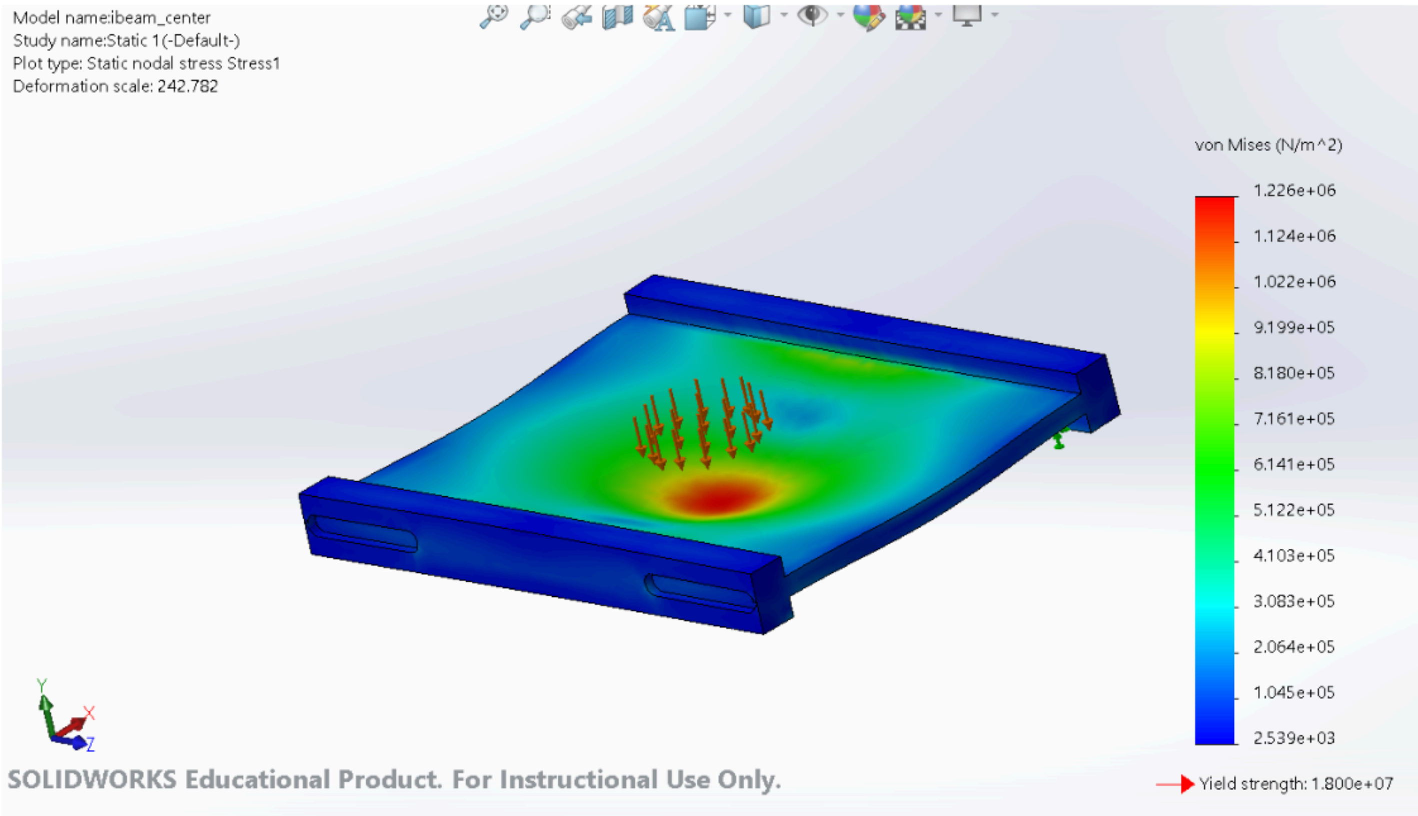


Figure 37: Von Mises Stress Analysis

For our stress analysis we applied a custom Medium Density Fiberboard (MDF) material with a compressive yield strength of 10 MPa. This gives us a minimum factor of safety of !" = 8.16. Here, we used the compressive yield strength of MDF to calculate our factor of safety since it is less than the tensile yield strength and thus MDF will fail first in compression.

7.2 DESIGN FOR SAFETY

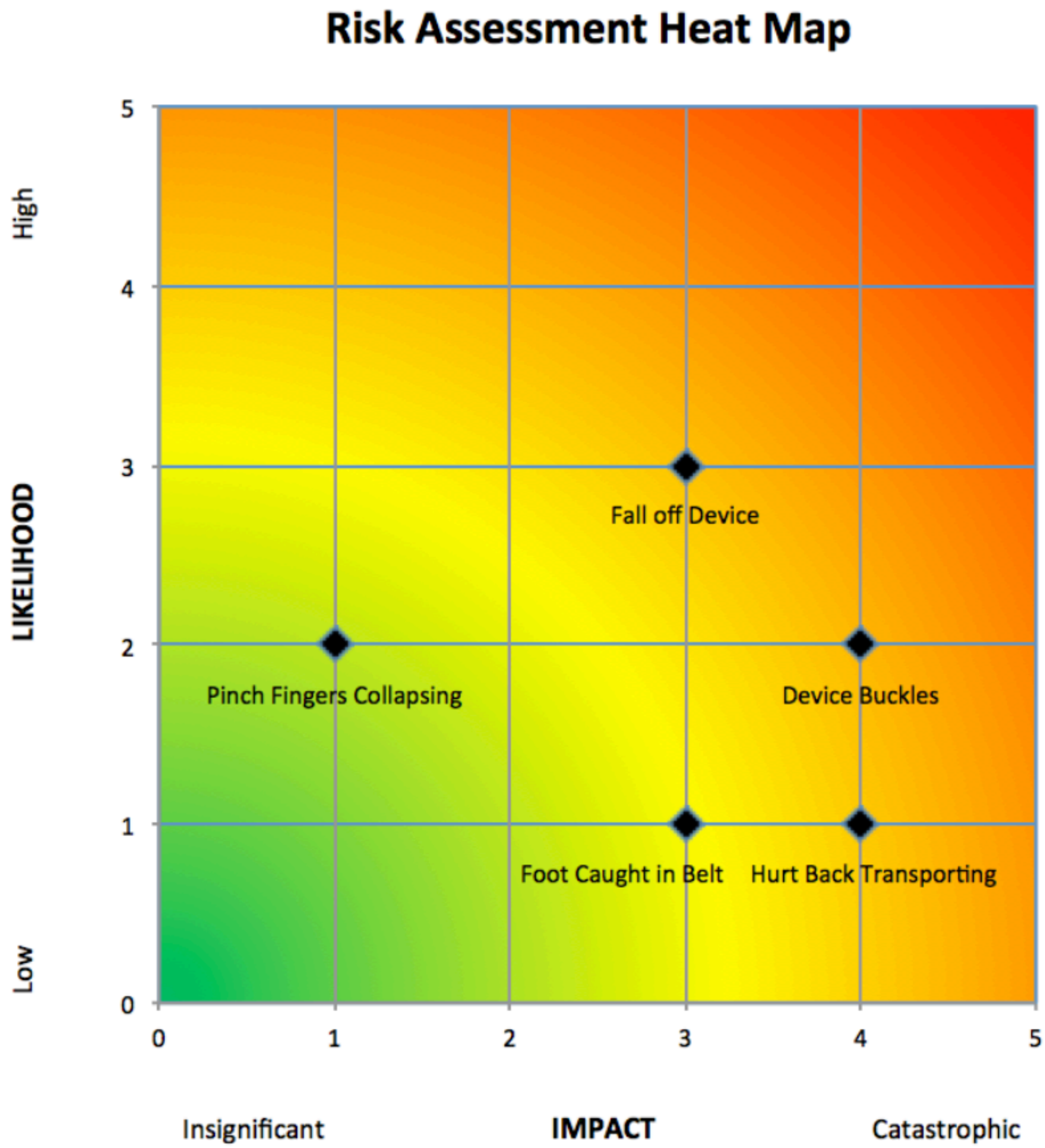


Figure 38: Risk Assessment Heat Map

Five risks were identified for the initial prototype model. As seen in the heat chart, the two risks with the highest priority are the device buckling and the potential of falling off the treadmill. For a portable treadmill there are constraints associated with size; as such, there is not room to add the stationary platforms that are included outside of the walking belt on traditional treadmills. Additionally, there is no room for vertical handrails. Both of these factors increase the likelihood of falling. At the same time, this risk is mitigated by the fact that the treadmill only functions at low speeds (1-3mph). The length and width of the belt were also selected within the norms of traditional treadmills. While the user should be advised to get on the treadmill at the lowest possible speed, no further action is necessary to reduce the risk of falling.

The risk associated with the device buckling refers specifically to the location where the deck components meet in the expanded position. The faces of the adjacent components will naturally tend to rotate inwards toward each other under the load of the user. While buckling could cause the device to fail, this risk is unlikely as long as the faces remain flush. The only way the device could buckle is if a gap is created to provide room for one of the ends to turn inwards, or if one of the decks fracture. For this reason, it may be necessary to add links that secure the device in the proper expanded position.

The remaining risks include the user getting hurt transporting the device, issues associated with becoming caught under the belt, and pinching fingers within the three main components. These are either low impact or unlikely. Rather than carry the device and risk injury, the implementation of a roll away bag for the treadmill can effectively eliminate risks associated with transportation. Furthermore, the tension in the belt makes it almost impossible for the users foot to get caught in the belt, while the low speeds also reduce the likelihood of this event resulting in injury. Lastly, to manage the risk of pinching fingers between the treadmill components, the connecting links were designed to allow for extra space during expansion.

7.3 DESIGN FOR MANUFACTURING

The same component used in the FEA was selected for draft analysis. Originally 12 faces required draft; these can be seen in the "Before" picture below.

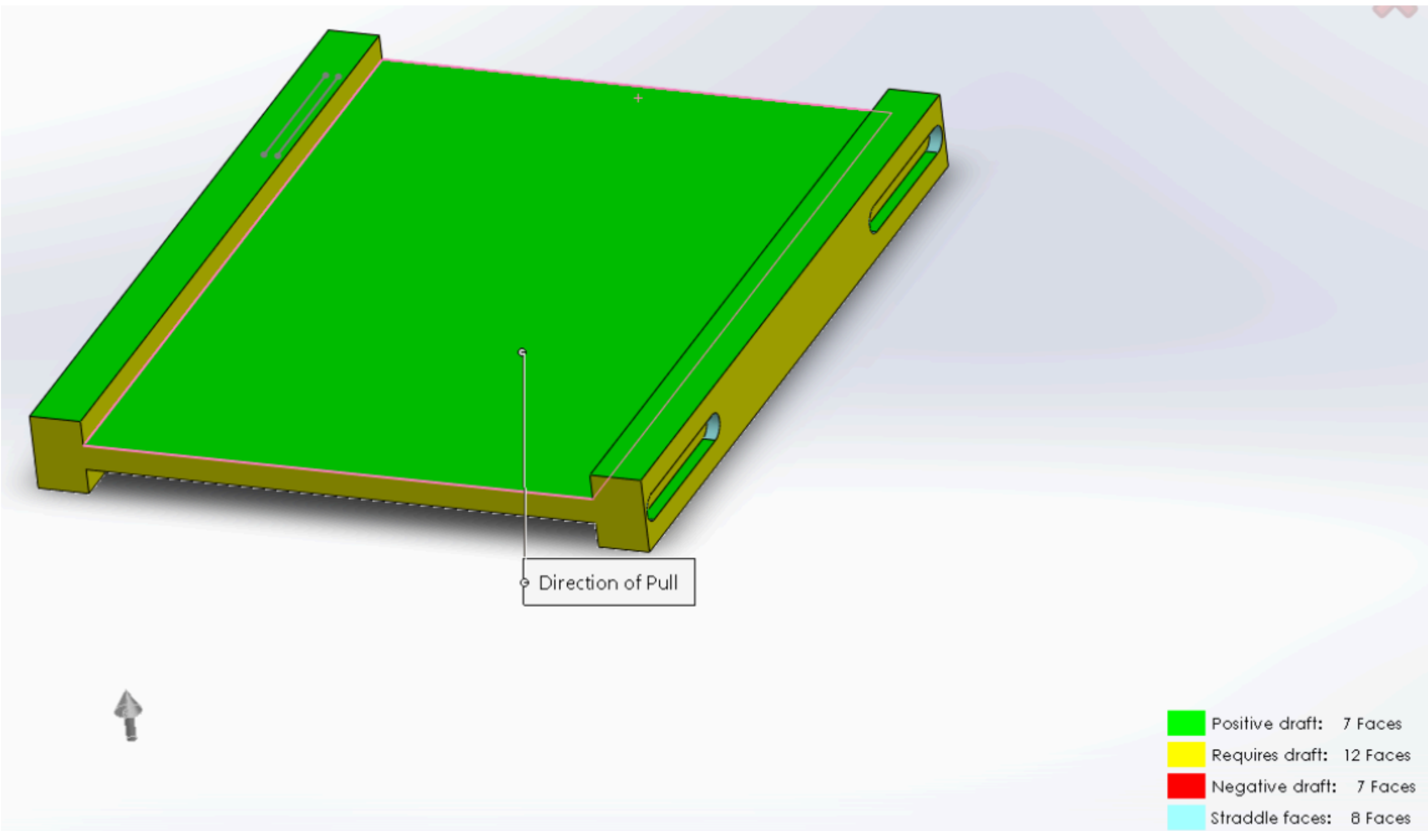


Figure 39: Component Before Draft Analysis

To address this issue, 3 degree draft was added to all vertical walls. Due to the simplicity of the parts involved in the treadmill no other changes were necessary. The thickness of the walls remained the same for both external supports and for the walking deck. Positive drafts existed on the top and external side faces, while a negative draft was present on the underside.

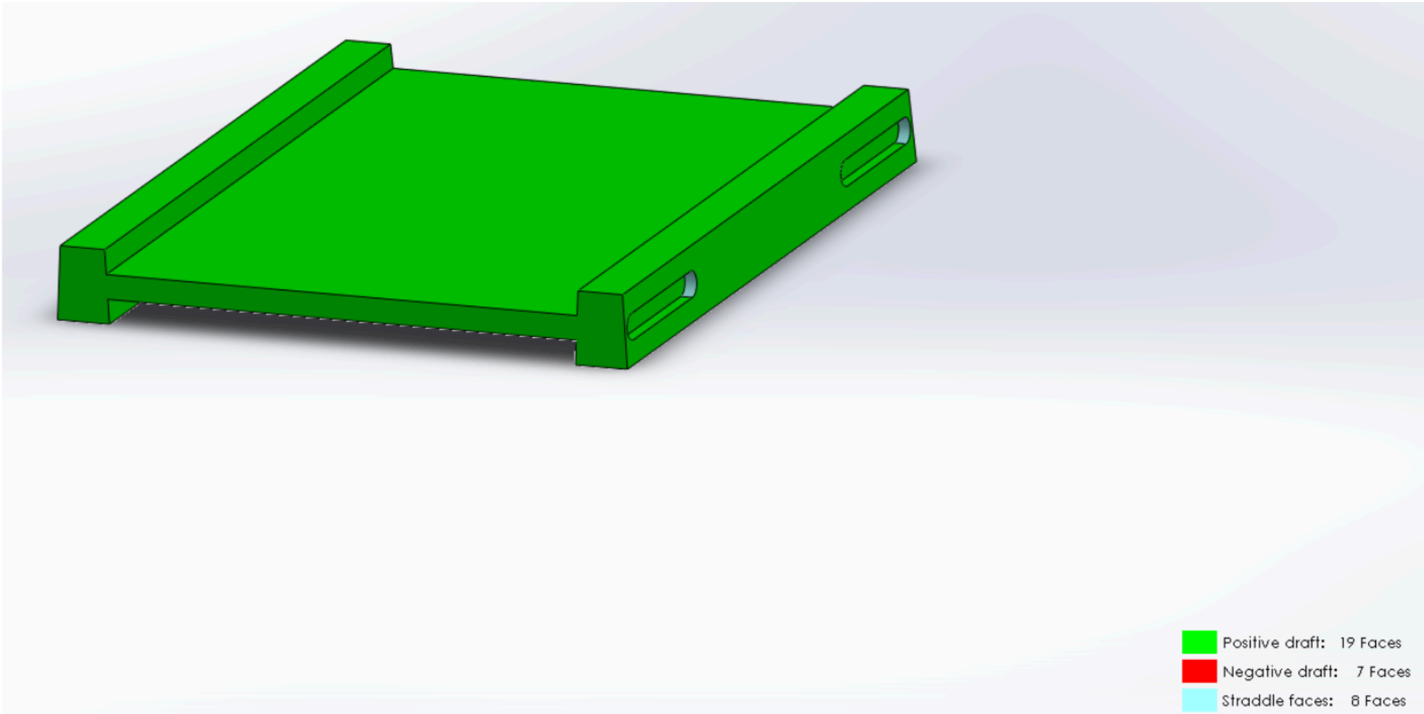


Figure 40: Component after Draft Analysis

In addition to the draft analysis, two manufacturing processes were analyzed. This was performed for the slotted side pieces.

1st Process: Mill/Drill Only

Figure 35 below shows the result of the DFMXpress analysis for the slotted side piece, using the default parameters and the Mill/Drill only manufacturing process.

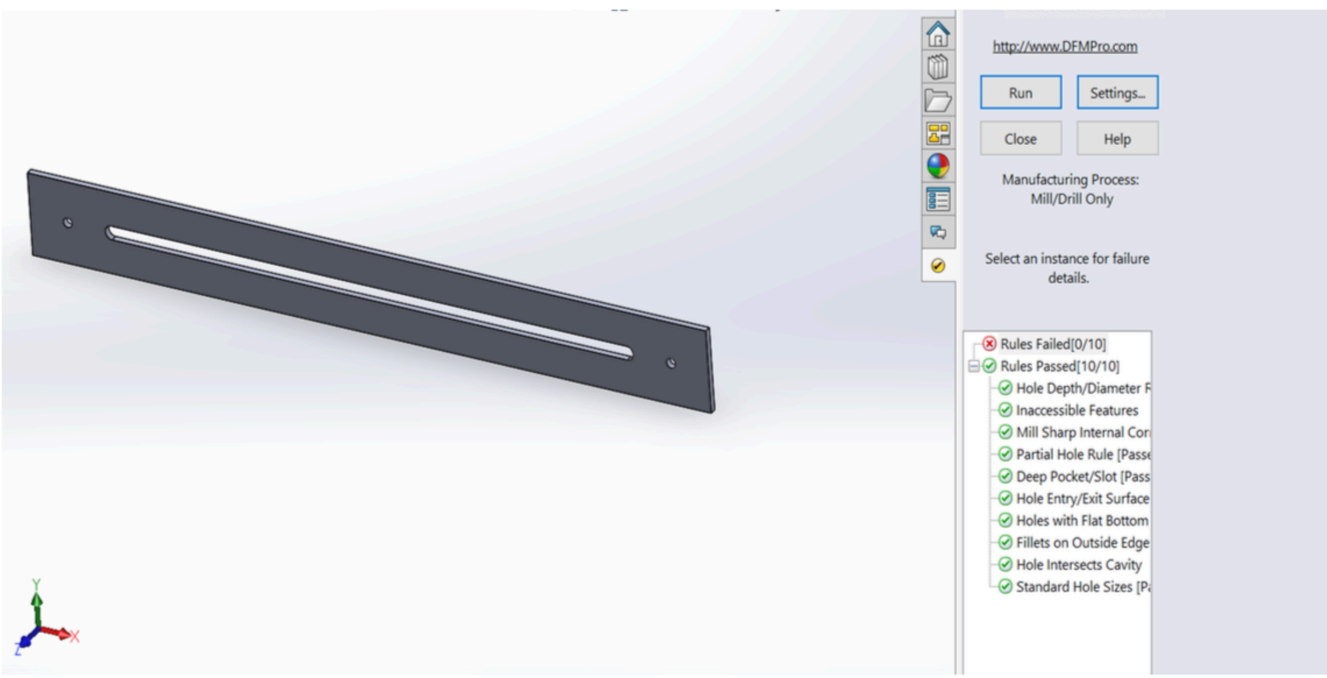


Figure 41: First DFM Xpress Analysis of the Slotted Side Piece

2nd Process: Turn with Mill/Drill

Fig. 42 below shows the DFMXpress analysis considering a second manufacturing process: Turn with Mill/Drill.

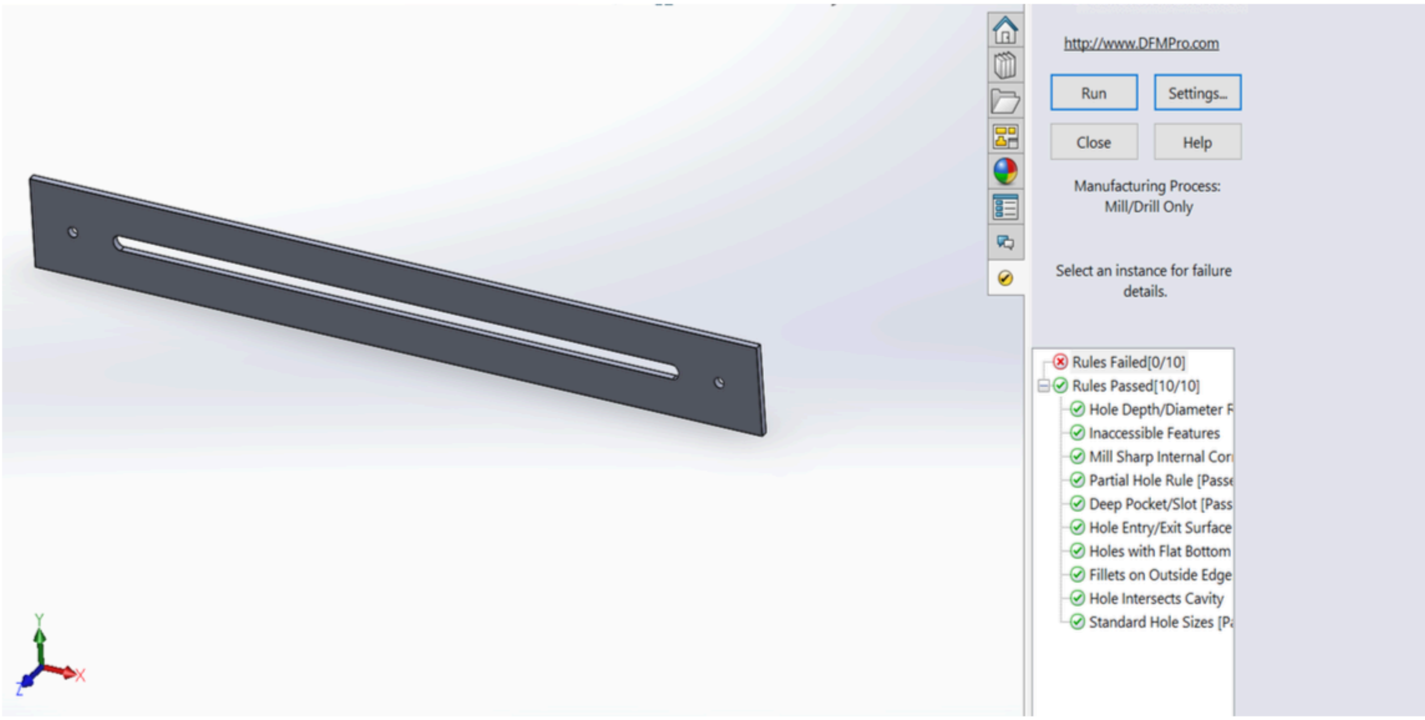


Figure 42: Second DFMXpress Analysis for the Slotted Side Piece

All the rules were passed for both manufacturing processes, indicating that the piece could be machined and used in an actual design. This piece was utilized for the POC Prototype, and was machined by the members of Group R, using both drills and mills. This confirms the finding of the DFMXpress analysis.

7.4 DESIGN FOR USABILITY

1) Vision Impairment

The width of the walking portion of the treadmill is around the same as a regular treadmill, so it is possible to move left and right while being on it. However, it can be dangerous to have a part of your foot down outside of the belt, which can happen if one's vision is impaired. Therefore, high levels of vision impairments can make the usage of the Wellness Companion dangerous. To help users with visibility impairments, the belt could be made with a bright color, to contrast with the dark support deck. That way, the width of the belt can be easily noticeable, even with vision problems, and the user can avoid stepping out of the belt.

2) Hearing Impairment

We do not believe that having hearing impairments would have much effect on the usability of the product. The movement of the belt should indicate the user whether the treadmill is running or not. One of the objectives of the overall design is having a design that is quiet enough to be used in offices or library, so hearing impairments, in the usability of the design, don't affect the Wellness Companion's use.

3) Physical Impairment

The Wellness Companion is a product made to fight the ill effects of sedentary lifestyle by allowing users to exercise anywhere. It therefore requires the ability to walk. Physical impairments of the upper body will not affect the usage of the treadmill, but ones of the lower body will. Not being able to use the lower limbs will make the usage of the Wellness Companion very difficult, even impossible if both legs are immobilized. The handle bars that are usually present on treadmills allow people with lower body disabilities to still use them. Due to the need of compactability, our design doesn't include handle bars. For future designs however, it would be helpful to add handle bars to widen the customer range.

4) Language Impairment

The product itself does not require the user to know English. However, any safety instruction and labels that come with the product need to be in several languages, to enable people that do not speak English to use the Wellness Companion safely. If any buttons are present on the design, symbols should most likely be used rather than words from a specific language.

5) Control Impairment

The Wellness Companion is a product that, if not used the right way, could be dangerous. Indeed, the running belt and the compactable process could lead to users' injuries. Therefore, anybody with control impairments should be very careful when using such a product. Because we know that accidents always happen, we are trying to design the product such that dangerous parts are either covered or well indicated to try and reduce the likelihood of an accident happening, even with someone with control impairments.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

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

The initial project description was primarily focused on an expanding treadmill that satisfied three criteria: an expanding belt, a low sound output for the running device, and a light and compactable design. While the final project presented a means to compact the treadmill by ½ of its expanded length, due to time constraints, budgetary constraints, and a remedial understanding of elastic material properties, not all of these goals could be satisfied. Portability of the device was outlined to potentially align with the initial description with more money and the assistance of an experienced material scientist. Also, a low sound output was also outlined to align with the initial description through the addition of a motor encasement and a better motor, but the problem related to the expanding belt was not solved. As such, the final project result focused more on the overall mechanism motion and belt tensioning.

8.1.2 Was the project more or less difficult than expected?

At the beginning of the project, there were clear challenges associated with the complexity of the expanding belt concept that the primary consumer, Muhammad Elahi, wished to design. As we attempted to design the rest of the mechanism around this concept, we realized that not only would it be difficult to make a spring linked belt that could expand to twice its' compact length, but also that this concept placed many limitations on the possible frame designs. For this reason, we thought that the project would be less difficult if we attempted to design around a traditional treadmill belt. This however was not the case as the tensioning of a fixed circumference belt still proved to be more difficult than expected.

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

A considerable amount of time was spent on the problem of the expanding belt itself. This approach included concepts featuring both springs and a detachable belt. In the end it became evident that these ideas were not within the scope of a semester project and a traditional belt had to suffice. Time allotted to these tasks would have been better spent determining lightweight alternatives to the wood frame. This became evident as the first stock wood we bought easily fractured along the wood seams and we were forced to salvage a relatively heavy MDF board that we knew would be strong enough to support the weight of a 200 pound user.

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

One of the most difficult components to install within the treadmill were the rotating cylinders. As these were parts that we obtained from an old treadmill that we took apart, we did not realize that it would still pose such a challenge. In large part this was because we knew the cylinders needed to a very precise distance apart from one another to properly tension the belt. On top of this, we needed the cylinders to be very securely fixed within the frame to make sure they would not come loose or be able to wiggle about their axes with the belt in position.

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

One of the greatest issues with the other design concepts generated at the beginning of the semester was having enough support to withstand a 200lb user walking on the deck, which is something that the chosen concept did well. Considering portability only, the “drawer” design might have been better. But the walking deck being uneven, added to the lack of support, were real problems that might not have been fixable. For the “table” design, the need of an extra part greatly reduced the portability possibilities. Overall, the chosen design concept was the one combining all the needs, and most likely the most successful one.

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?

At the start of the semester, with the help of library resources, research was done to find the standards relevant to our project. The ones selected contained information about the design and manufacturing of fitness equipment as well as the safety labels and signals required by this type of equipment. Overall, the information was valuable, but most of the time, referred to processes that were outside this class (manufacturing our design, labeling it to give information to new users). However, if this project were to be continued, and the Wellness Companion were to be manufactured on a greater scale, those standards would become a great resource.

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

Group R believes that through the first discussions with the project’s customer, Muhammad Elahi, it had the critical information needed to generate concepts fulfilling the primary goals of the Wellness Companion. However, as the semester went on and the selected concept was refined, parts of the project’s goals that were originally considered had to be ruled out of scope. Creating an expanding belt, for example, would have taken a lot of resources and time as not much information was shared about it. Overall, the information needed to create our final design was given, but for future improvements of the project, more discussion with the customer would be needed.

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

One of Group R’s performance goals was having the weight of the Wellness Companion under 60 lbs. To attain that goal, a fitting material had to be picked. To do so, a material science analysis could be performed. After selecting several materials to choose from and listing a few of their principal material properties (density, yield stress, elastic modulus), calculations could be computed to figure out which of the materials would deflect the least while, at the same time, having the minimum density possible to keep the weight of the treadmill low.

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

If we were to redo the course, we would try to find multiple used treadmills to take home and scrap. This way we can find at least one motor that works. If we did this, we would need to allocate much more time to prototyping as scrapping treadmills is pretty time consuming. Another change I would make is to start prototyping sooner as there are always unforeseen problems that are revealed through prototyping and having some extra time would allow us to try and come up with good solutions to those problems which would be key to creating a good final product.

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

Given time and money one of the biggest problems we would need to attack is reaching our first performance goal which is to have the treadmill be less than 60 lbs. To do this, we would consult the material science department to help us find a material which would be as light as possible while still able to support loads up to around 200 lbs. Then we would need to find ways to build a prototype with that material. We would also need to consult the material science department to see if there is any material that would help us with our belt problem. Ideally the belt would be taught in the compact and expanded positions. It is our conjecture than some sort of elastic material could help with that.

8.3 TEAM ORGANIZTION

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

Our team had skills that meshed together well. We had great problem-solving, CADing, drawing, drilling, woodworking, milling, and general shop skills within the group. However, due to us all being mechanical engineers, our skills overlapped a lot. Having some additional materials, or electrical skill within the group would diversify our skillset and allow us to solve a wider range of problems more efficiently. For example, figuring out why our circuit breaker keeps cutting the power would have been an easier problem to solve with some extra electrical skills on the team.

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

Overall, this design experience has shed light on what to expect if one wants to partake in a design project. With this knowledge we will be better prepared to take on a project. The course did an excellent job at highlighting every step of the design process and the deadlines gave us a realistic view of how long each step would take. So, while I don't think any of us are jumping out of our shoes towards a design project, we are more prepared to for one which I believe increases the likelihood we end up in one.

9 APPENDIX A – COST ACCOUNTING WORKSHEET

Table 7: Cost Accounting Worksheet

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	2ftx4ftx1" Maple Plywood	Lowe's	907227	Clear, Beige Wood	$26.98	2	$53.96
2	Aluminum Flat Bar	Lowe's	215983	Smooth, Grey	$5.99	4	$23.96
3	#10 x 2-1/2 Wood Screws	Lowe's	65618	Gold, flathead	$7.15	3	$21.45
4	#12 x 1-1/2 Wood Screws	Lowe's	68982	Silver, flathead	$6.74	2	$13.48
5	2ftx4ftx0.5" Maple Plywood	Lowe's	907226	Beige	$23.98	3	$71.94
6	Treadmill Motor (salvaged)	Turdan Industry Co.	B2K051	Balck Flywheel, Green Body	$0.00	1	$0.00
7	Treadmill Belt (salvaged)	Unknown	N/A	Black, Rubber	$0.00	1	$0.00
8	Flywheel Cylinders (Salvaged)	Unknown	N/A	Black, Iron	$0.00	1	$0.00
Total:							$184.79

APPENDIX B – FINAL DESIGN DOCUMENTATION

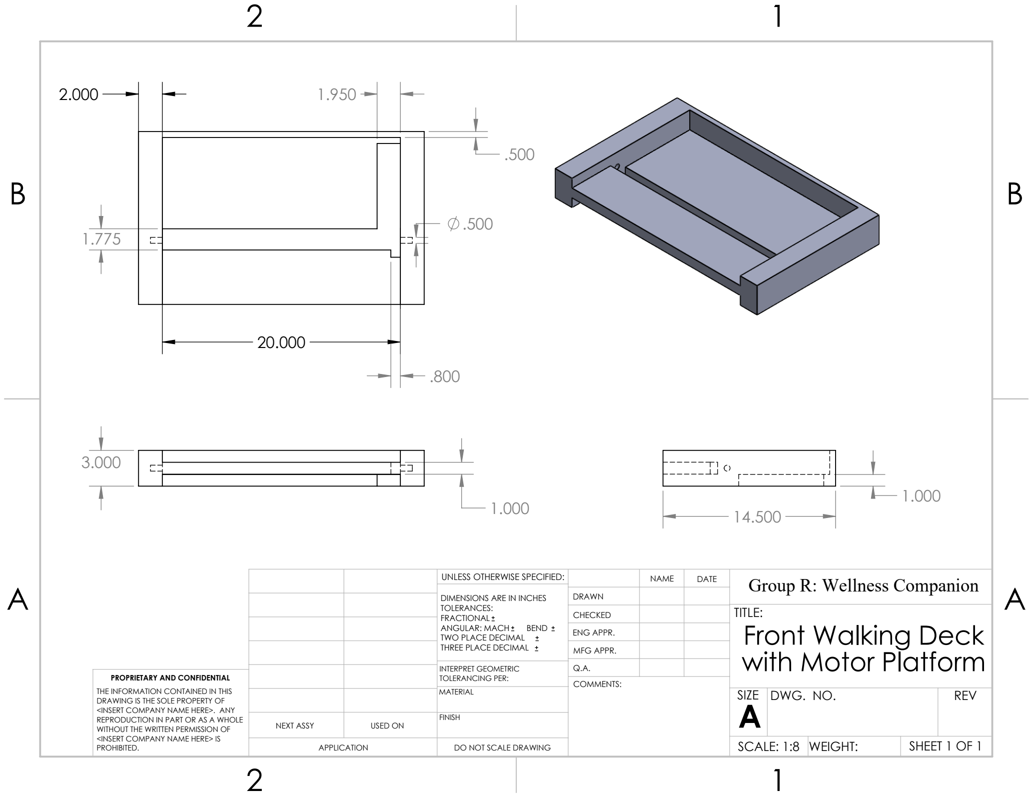


Figure 43: Front Walking Deck with Motor Platform

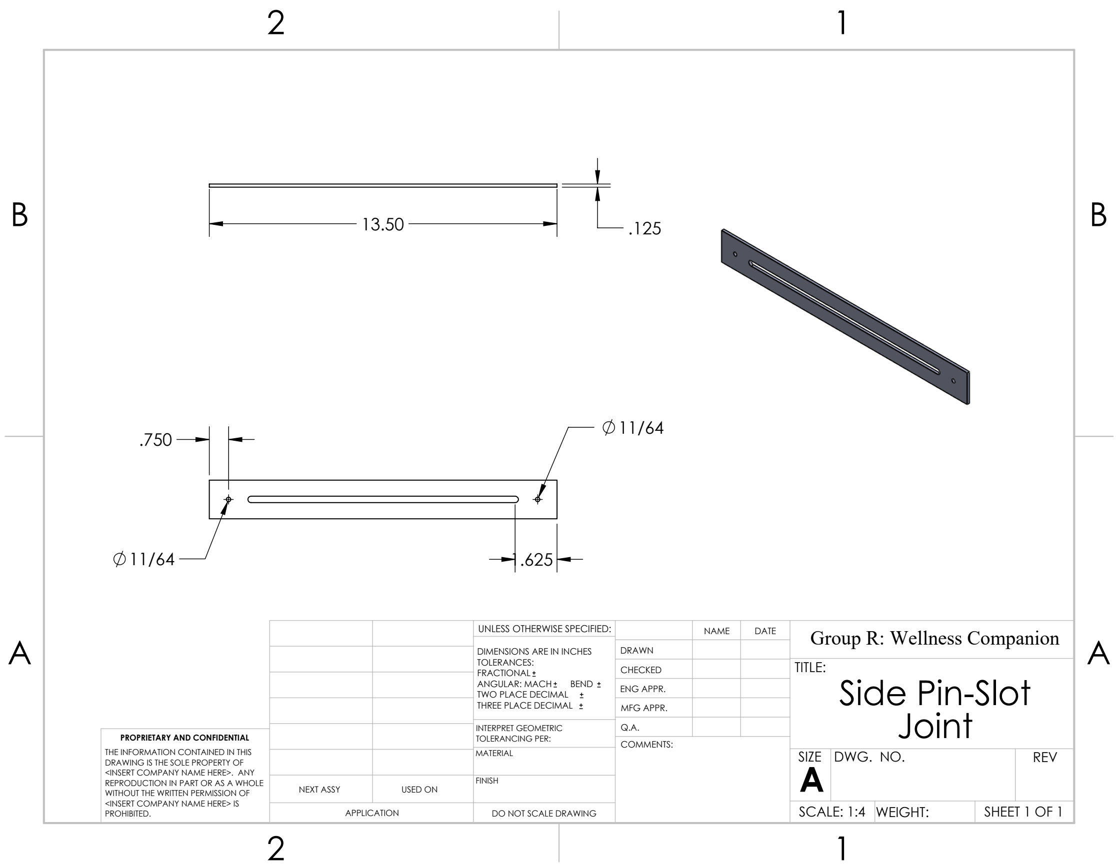


Figure 44: Side Pin-Slot Joint

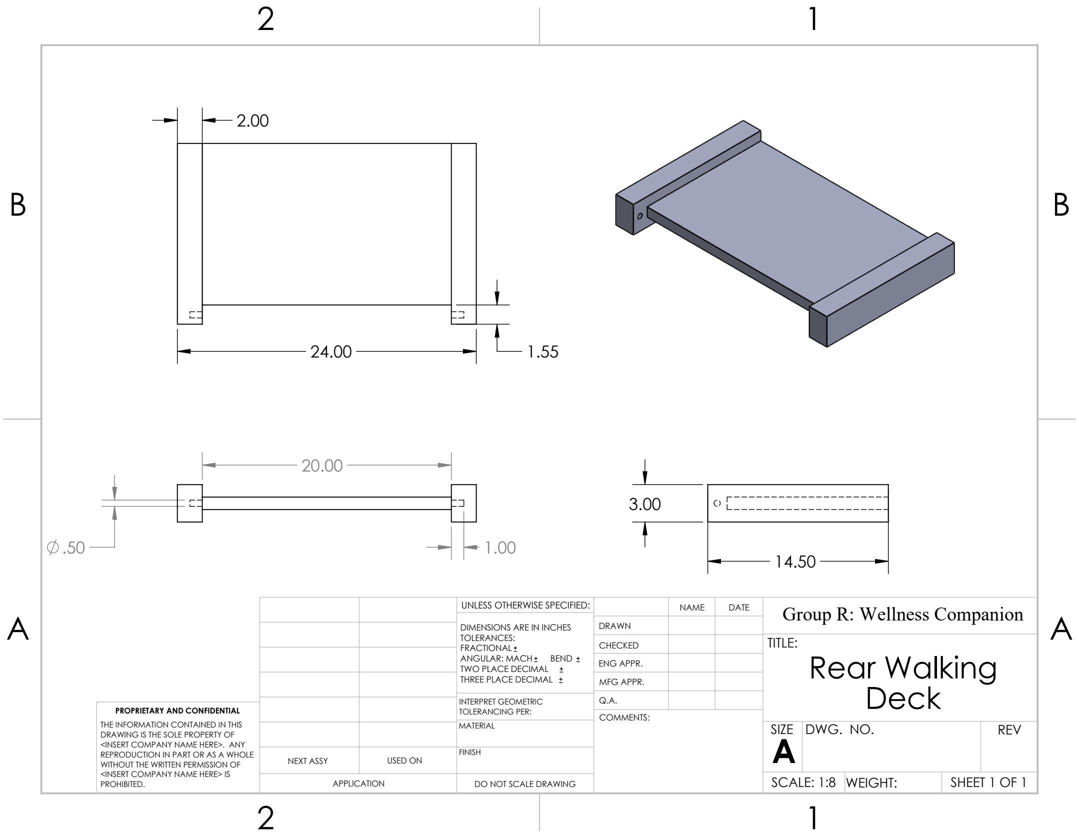


Figure 45: Rear Walking Deck

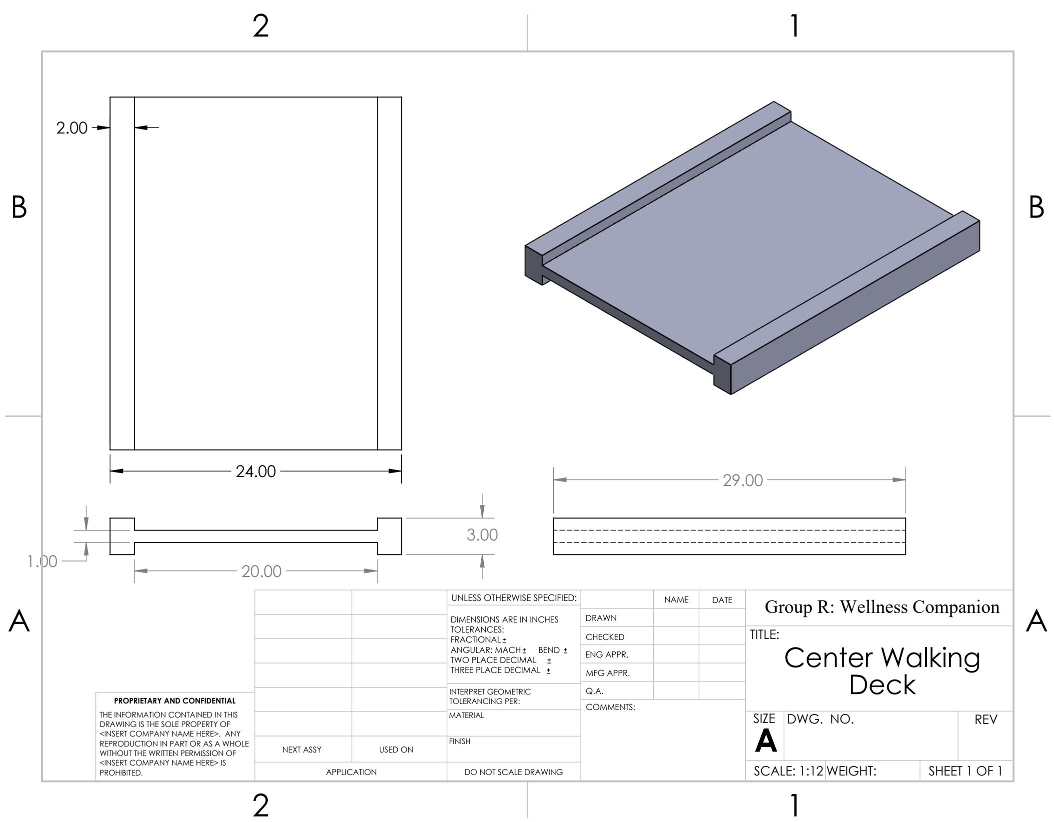


Figure 46: Center Walking Deck

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