Summer 2021

JME 4110: Portable Staircase Escalator

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

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This project was designed to safely move heavy objects up and down stairs with very little hassle. We used a sled-type system with a hand cranking winch to safely move the weight up and down the stairs. The winch was rated for 500 pounds and we calculated that it could potentially pull up to 300 pounds at a maintained minimum safety factor of 2. The main goals of this project were to make sure that someone could safely load the heavy object onto the sled, ensure that they would be out of the danger zone before lowering it, portable, making sure that it operated correctly and worked, as well as that it was green and did not use any electricity and was human powered.

JME 4110
Mechanical Engineering
Design Project

Escalator

John Shaver
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~ note: the parts lists may have the same title but may not be the exact same ~

1 Introduction

1.1 Value proposition / project suggestion

The goal is to design a motor driven escalator that can transport objects (e.g. fridges, safes) up and down a linear set of stairs safely. That way you can transport items down or up the stairs without the risk of falling on the stairs and not being able to see where you are going.

1.2 List of team members

JPG Team Organization

John Shaver	Peter Kersulis	Gregory Kersulis
[Design Engineer]	*[Lead Engineer]*	*[Quality Engineer]*

2 Background Information Study

2.1 Design Brief

The goal is to design a motor driven escalator that can transport objects (e.g. fridges, safes) up and down a linear set of stairs safely. That way you can transport items down or up the stairs without the risk of falling on the stairs and not being able to see where you are going.

2.2 Background summary

Web search results revealed two insights on existing designs reflecting this project's goal:

First URL:

https://www.asme.org/wwwasmeorg/media/resourcefiles/aboutasme/who%20we%20are/engineering%20history/landmarks/26-monongahela-incline-1870.pdf

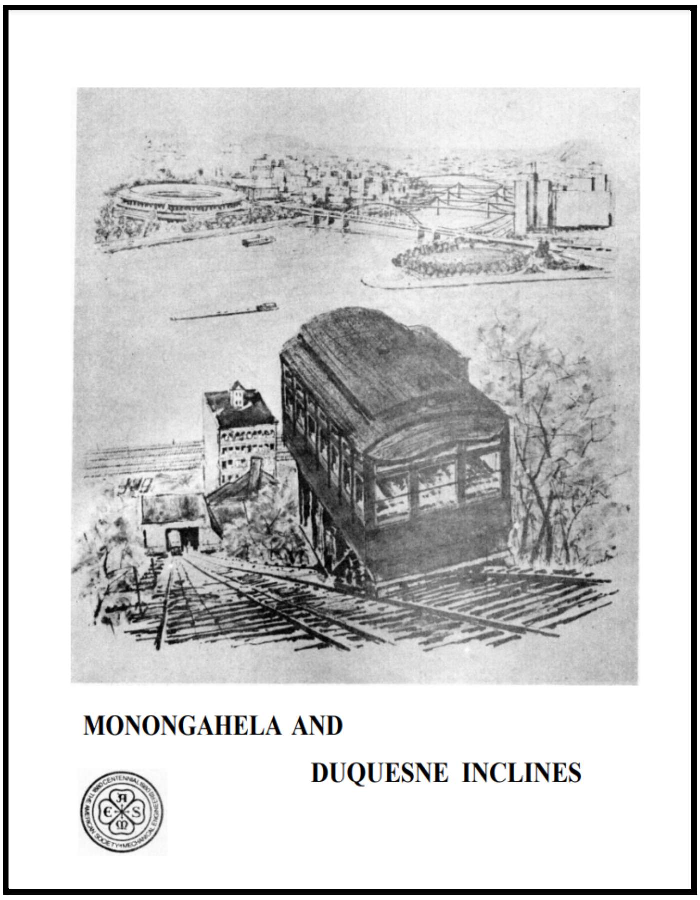

Figure 1: Pittsburgh inclined lift for human passengers

The city of Pittsburgh's two most iconic incline lifts were the Monongahela and Duquesne. Both these lifts were designed to take passengers up and down a steeply inclined mountain. Their track paths are linear (no turns), they have a level platform that has all the weight sitting on it, and the structure supporting the platform is a rigid triangular structure/framework. The simple design of these lifts is what we'll, most likely, end up tailoring our lift to be.

Second URL:

https://www.mach1services.com/tow-truck-work/#:~:text=Flatbed%20Towing&text=A%20flatbed%20tow%20truck%20uses,that%20attach%20to%20the%20flatbed.

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As we said before, this is the safest way to tow a car, as it ensures that any other parts of the car are not damaged in the towing process. Once the car is secured to the yolk with the steel pins, it is ready to be towed.

Efficiency and Quickness

Working with efficiency and quickness is imperative to keeping tow truck drivers safe. In the tow truck driver's case, the only manual labor required is the act of fitting the pins properly through the yolk and the wheels. Other than that, all of the lowering and lifting of the yolk is taken care of mechanically.

This also proves safer for the tow truck driver. At the same time, an experienced tow truck driver can cover this whole process in under a minute. With other methods of towing, finding the right spot to manually connect chains or hooks to the bottom of the car can be a grueling process.

Chain and Hook Towing

Of course, not all tow trucks use a bracket system, and what type of tow truck is used depends on the owner of the tow truck company. Bracket system tow trucks that use a yolk and pins for towing are simply the most modern types of tow trucks. Other tow trucks are still used today and work just as well.

A tow truck that uses a hook and chain works similarly to that of a bracket system tow truck. However, rather than a mechanical steel fixture lifting the car, the truck uses a strong hook that attaches to the underside of the car. It also might require a few extra chains to secure connection to the tow truck. This is an effective method, but as we said before, some people do not like the idea of their car being towed by the parts underneath it.

Flatbed Towing

Another type of tow truck is a flatbed truck. Again, its primary function is the same as any other tow truck; it just works a different way. A flatbed tow truck uses a mechanical system to angle its bed like a ramp, and the car needing a tow is then maneuvered onto the bed.

The car's wheels are fastened with chains running through them that attach to the flatbed. Then, the flatbed is mechanically lower back down to a flat state, and the car is ready to be towed.

The plus side to flatbed tow trucks is that they might be able to tow more than just a car. They can tow construction machines, motorcycles, and many other vehicles. However, they may not be a tower's first pick because of the added labor required.

How Heavy Is A Tow Truck?

The weight of a tow truck depends upon what vehicles it is made to tow. Some trucks are better suited for towing everyday cars like sedans and SUVs, while others might be made to tow large pieces of machinery or buses.

There are three main classifications of tow trucks, and the main characteristic that decides what division a tow truck falls into is its weight.

- **Light-duty tow trucks** weigh between 8,600 lbs. And 10,000 lbs. These trucks can haul most types of cars with no problem and might be the most common type of tow truck you would see on the road on any given day.
- **Medium-duty tow trucks** weigh between 10,001 lbs. And 26,000 lbs. Also pretty standard, these tow trucks can tow regular cars as well as larger cars or trucks. On occasion, they can tow smaller pieces of machinery.
- **Heavy-duty tow trucks** consist of any tow truck that weighs over 26,000 lbs. These trucks do have the ability to tow cars, but they are often used for large vehicles, as mentioned above, like construction machinery, buses, and any other large-scale vehicle.

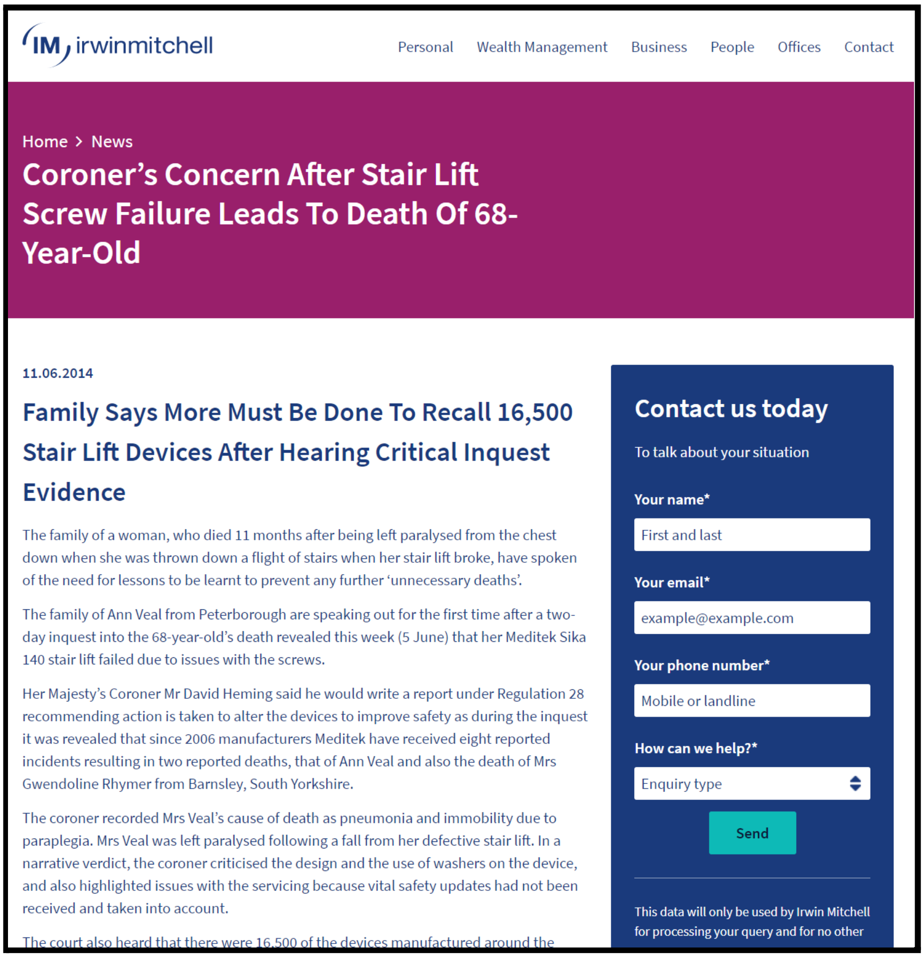
Figure 2: Towing truck comparison to escalator design

Flatbed tow trucks are used to transport vehicles safely from one point to another, they use a hydraulic bed to create an incline and then attach a winch to slowly and safely pull the car up the incline. After the car is all the way up it levels the bed of the truck out and is transported to the location. When dropping the car off they make the bed an incline again and then use the winch to slowly lower the vehicle down the incline to a safe spot.

Additionally, information was found regarding the subject of risks associated with this project's nature:

URL:

https://www.irwinmitchell.com/news-and-insights/newsandmedia/2014/june/coroners-concern-after-stair-lift-screw-failure-leads-to-death-of-68-year-old-jq-701400



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Coroner's Concern After Stair Lift Screw Failure Leads To Death Of 68-Year-Old

11.06.2014

Family Says More Must Be Done To Recall 16,500 Stair Lift Devices After Hearing Critical Inquest Evidence

The family of a woman, who died 11 months after being left paralysed from the chest down when she was thrown down a flight of stairs when her stair lift broke, have spoken of the need for lessons to be learnt to prevent any further 'unnecessary deaths'.

The family of Ann Veal from Peterborough are speaking out for the first time after a two-day inquest into the 68-year-old's death revealed this week (5 June) that her Meditek Sika 140 stair lift failed due to issues with the screws.

Her Majesty's Coroner Mr David Heming said he would write a report under Regulation 28 recommending action is taken to alter the devices to improve safety as during the inquest it was revealed that since 2006 manufacturers Meditek have received eight reported incidents resulting in two reported deaths, that of Ann Veal and also the death of Mrs Gwendoline Rhymer from Barnsley, South Yorkshire.

The coroner recorded Mrs Veal's cause of death as pneumonia and immobility due to paraplegia. Mrs Veal was left paralysed following a fall from her defective stair lift. In a narrative verdict, the coroner criticised the design and the use of washers on the device, and also highlighted issues with the servicing because vital safety updates had not been received and taken into account.

The court also heard that there were 16,500 of the devices manufactured around the

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example@example.com

Your phone number*

Mobile or landline

How can we help?*

Enquiry type

Send

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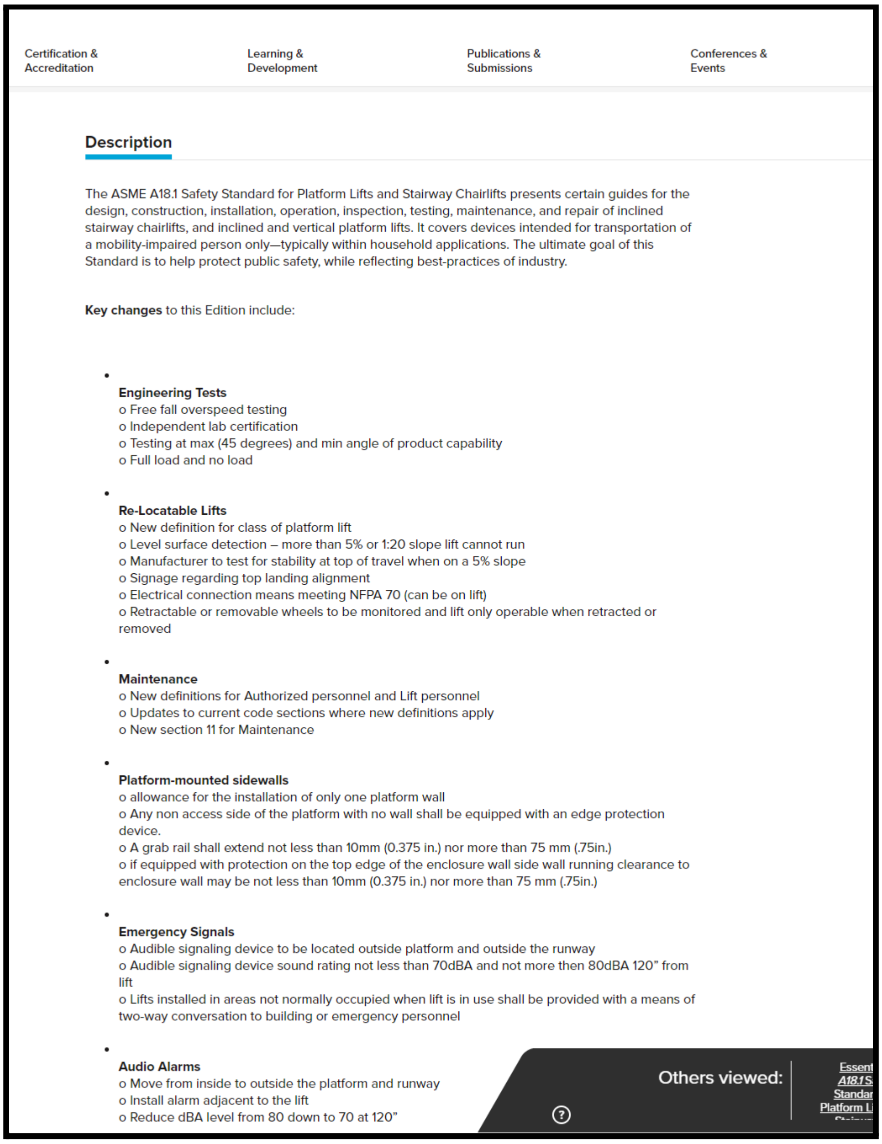
Figure 3: Risk example of lift type device

This article predicates customer concerns on stair lifts, based on a case in which an elderly woman falls to her death using a stair lift-- one that had been installed a mere 11 months prior to the incident. While our lift will not be intended in lifting people, it will lift heavy loads. In the event of machine failure, the loads for which this lift will be designed will be plenty sufficient to cause extreme bodily harm, should someone be caught in the path of its fall below. Proper electronic and mechanical components will be crucial to avoiding this risk.

To the effect of risk reduction and preparation, further online inquiry revealed a litany of insights describing experience-based points of contention and highlighted issues regarding stairlift designs:

URL:

https://www.asme.org/codes-standards/find-codes-standards/a18-1-safety-standard-platform-lifts-stairway-chairlifts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Description

The ASME A18.1 Safety Standard for Platform Lifts and Stairway Chairlifts presents certain guides for the design, construction, installation, operation, inspection, testing, maintenance, and repair of inclined stairway chairlifts, and inclined and vertical platform lifts. It covers devices intended for transportation of a mobility-impaired person only—typically within household applications. The ultimate goal of this Standard is to help protect public safety, while reflecting best-practices of industry.

Key changes to this Edition include:

- **Engineering Tests**
  o Free fall overspeed testing
  o Independent lab certification
  o Testing at max (45 degrees) and min angle of product capability
  o Full load and no load
- **Re-Locatable Lifts**
  o New definition for class of platform lift
  o Level surface detection – more than 5% or 1:20 slope lift cannot run
  o Manufacturer to test for stability at top of travel when on a 5% slope
  o Signage regarding top landing alignment
  o Electrical connection means meeting NFPA 70 (can be on lift)
  o Retractable or removable wheels to be monitored and lift only operable when retracted or removed
- **Maintenance**
  o New definitions for Authorized personnel and Lift personnel
  o Updates to current code sections where new definitions apply
  o New section 11 for Maintenance
- **Platform-mounted sidewalls**
  o allowance for the installation of only one platform wall
  o Any non access side of the platform with no wall shall be equipped with an edge protection device.
  o A grab rail shall extend not less than 10mm (0.375 in.) nor more than 75 mm (.75in.)
  o if equipped with protection on the top edge of the enclosure wall side wall running clearance to enclosure wall may be not less than 10mm (0.375 in.) nor more than 75 mm (.75in.)
- **Emergency Signals**
  o Audible signaling device to be located outside platform and outside the runway
  o Audible signaling device sound rating not less than 70dBA and not more then 80dBA 120" from lift
  o Lifts installed in areas not normally occupied when lift is in use shall be provided with a means of two-way conversation to building or emergency personnel
- **Audio Alarms**
  o Move from inside to outside the platform and runway
  o Install alarm adjacent to the lift
  o Reduce dBA level from 80 down to 70 at 120"

Others viewed:

Figure 4: Stairlift Standards

This link leads to the official ASME purchase/download of their exhaustive list of stairlift codes and standards that must be met within a stairlift design to be marketed to the public. It elaborates on noise-based alarm system requirements, testing extents, overload capacities, maintenance specs, and more-- all the information necessary for identifying every item important to the design of a stairlift, be it for people or objects.

In conclusion, scaling stairs with heavy loads is strenuous and dangerous, and it becomes increasingly unfeasible with advanced age. Therefore, this project endeavor is to design and build an escalator-like machine that serves to hoist heavy loads up and down stairs in the place of direct human physical effort.

The design will imitate in-line rail systems and stairlifts that are used for helping the elderly up and down stairs. The desired outcome is to raise and lower a 150-lb load up and down a straight staircase (no turns, curves, or intermediary landings) that spans one story.

3 Concept Design and Specification

3.1 User Needs and Metrics

3.1.1 Record of the user needs interview

From multiple questionings strewn throughout date range of 6/28/21-7/5/21

Table 1: User Needs

Need #	Need	Importance
1	Payload secured to escalator	5
2	Escalator removable/portable	5
3	Avoid stairwell damage	5
4	Require little strength/effort	5
5	Easy transfer from floor to carriage	4
6	Escalator to be minimal/small	4
7	Avoid payload damage	5
8	Reasonable cost	4
9	Idiot proof (easy to use & understand)	5
10	Should be “green”	2
11	Want it automatic	2
12	Easy/quick to set up	4
13	Enough room to walk by	5

3.1.2 List of identified metrics

Table 2: Metrics

Metric #	Associated Need (s)	Metric	Units	Min–Value	Max–Value
1	4	Stair angle	Degrees	30	50
2	13	Volume of material	Inches Cubed	15,000	100,000
3	4, 6	Escalator weight	Pounds	30	150
4	5, 12	Transfer duration	Seconds	15	60
5	4, 7	Lift Capacity	Pounds	150	300

3.1.3 Table/list of quantified needs equations

Table 3: Weighted Totals

		Metrics					
Needs		1	2	3	4	5	**Weighted Total**
Payload secured to escalator	1	0.5	0	0	0	0.5	1
Escalator removable/portable	2	0	0.3	0.7	0	0	1
Avoid stairwell damage	3	0.3	0.4	0.3	0	0	1
Require little strength/effort	4	0	0	0.35	0.3	0.35	1
Easy transfer from floor to carriage	5	0	1	0	0	0	1
Escalator minimal/small	6	0	0.7	0	0	0.3	1
Avoid payload damage	7	0.4	0.2	0	0.2	0.2	1
Reasonable cost	8	0	0.5	0	0.25	0.25	1
Idiot proof (easy to use & understand)	9	0	0	0	0	0	0
Should be "green"	10	0	0.5	0.25	0.25	0	1
Want it automatic	11	0	0.75	0	0.25	0	1
Easy/quick to set up	12	0	0.4	0.6	0	0	1
Enough room to walk by	13	0	0.7	0	0.3	0	1

3.2 CONCEPT DRAWINGS

Include your 4 concept drawings here

D-1) Hand crank with pulley and sliding load

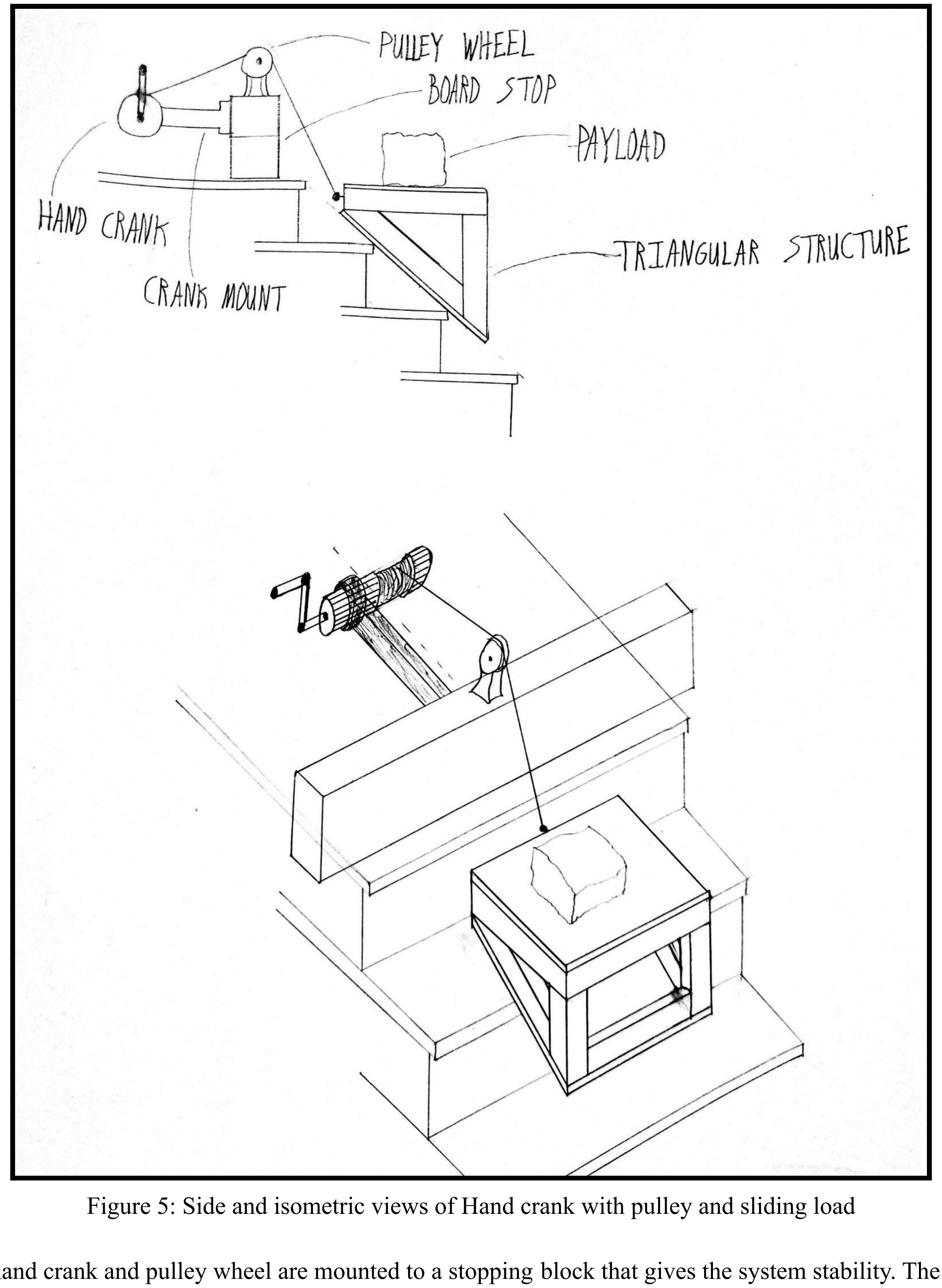


Figure 5: Side and isometric views of Hand crank with pulley and sliding load

A hand crank and pulley wheel are mounted to a stopping block that gives the system stability. The cable is hooked to the triangular structure that rigidly slides along the stairs with the load on top of the platform.

D-2) Rototiller-Style Load-bearing Stair Walker

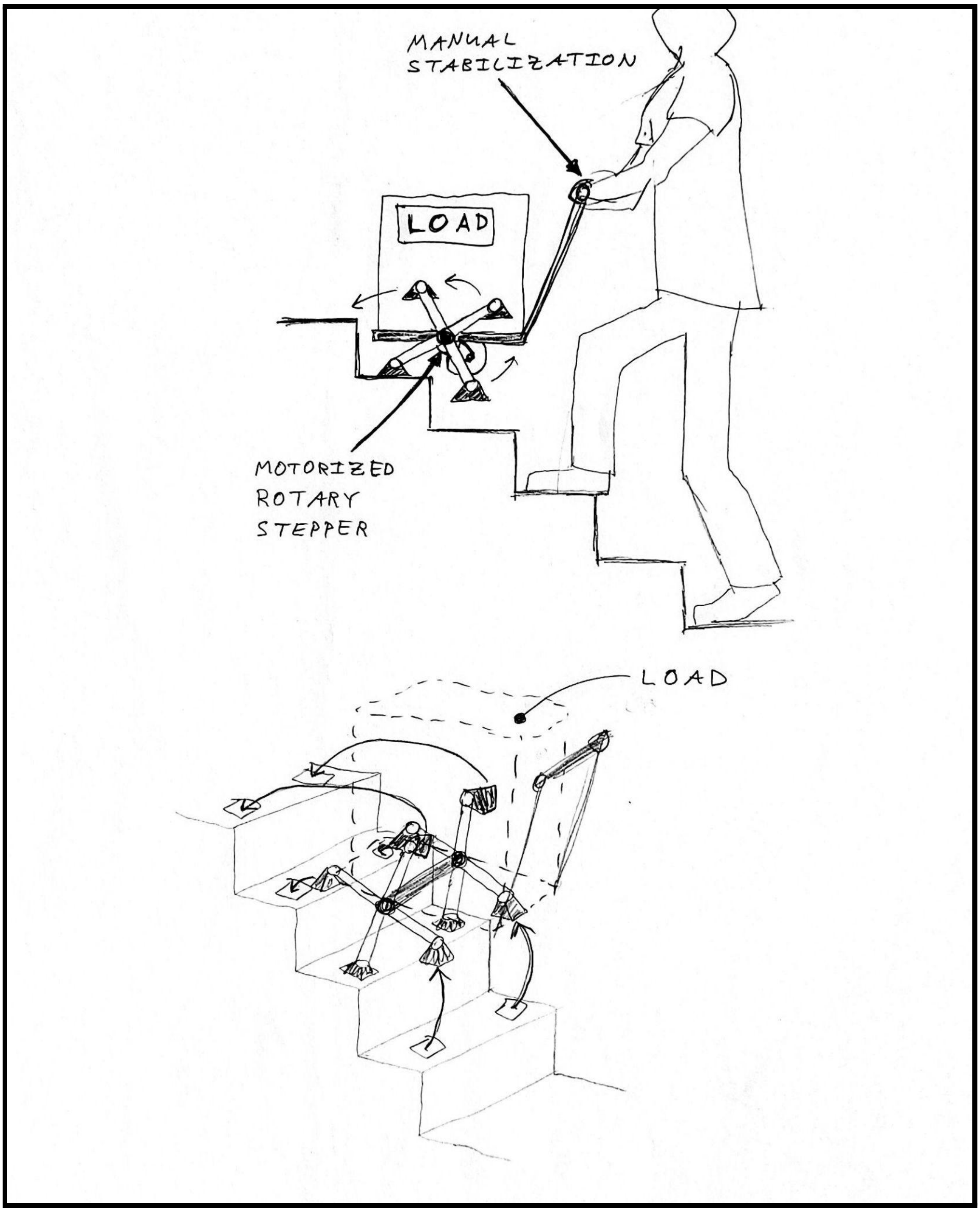


Figure 6: Schematic of Rototiller-Style Load-bearing Stair Walker

A rotary "tiller-blade-style" carousel of padded legs is continuously driven by a motor mounted beneath the load-bearing platform, stepping up (or down) the stairs as each foot cyclically takes its turn coming in contact with the steps. The user applies only the force necessary for stabilization, guiding the load (perhaps also throttling the motor) up and down the stairs.

D-3) Electric Winch with pulleys and hanging load

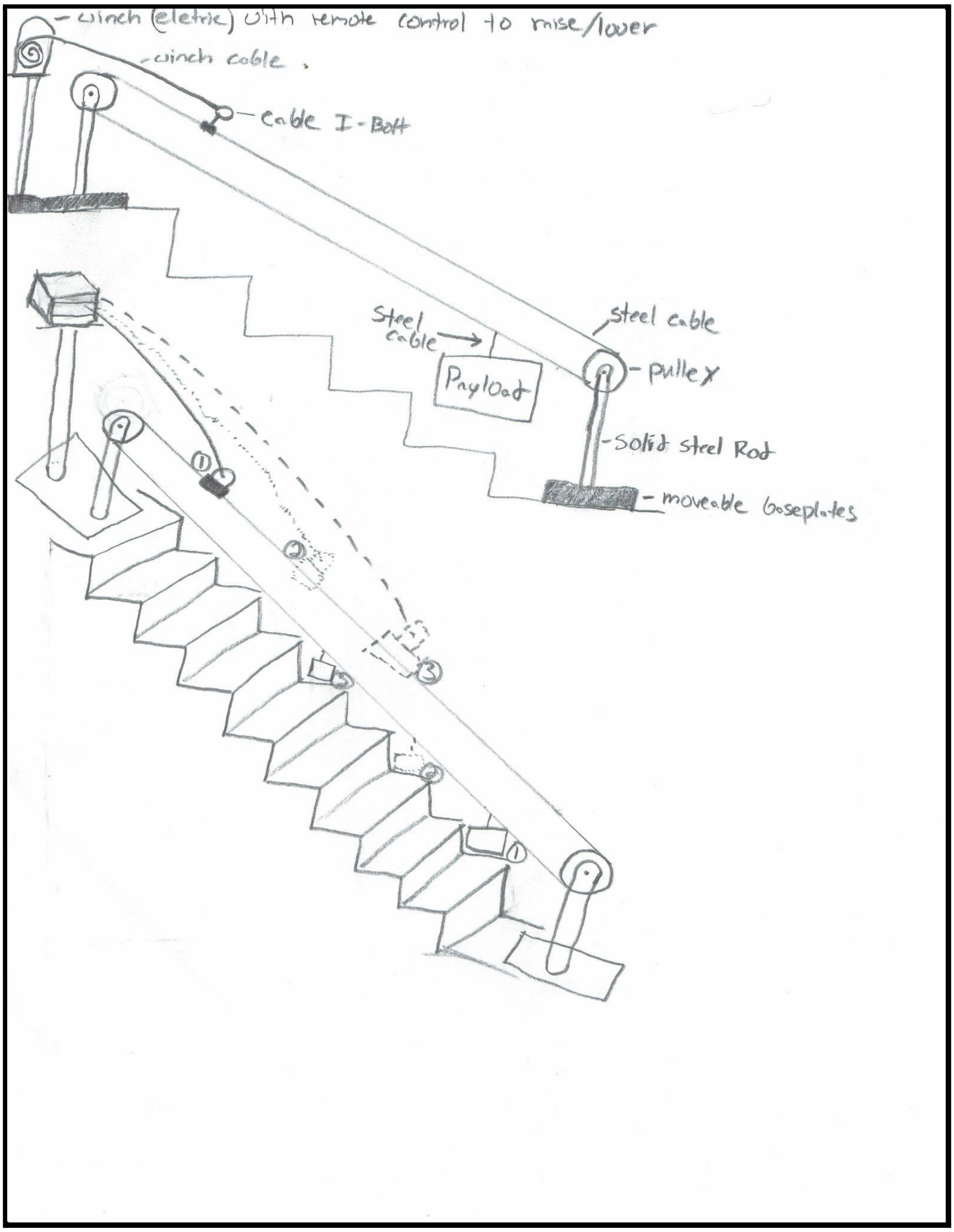


Figure 7: Schematic of Ski-Lift Based Load Transporter

There are two pulley systems that are mounted on ½” steel base plates which are rectangular and can move. The Pulley on the top has another structure on the baseplate which is used to mount the electric winch. In between the pulleys is a steel cable that has a I-Bolt that is spliced into the cable to allow for the winch to connect and raise and lower the payload which is suspended on the bottom of the two steel cables.

D-4) Hand Crank lift that sits on and uses existing railing for different staircase rails.

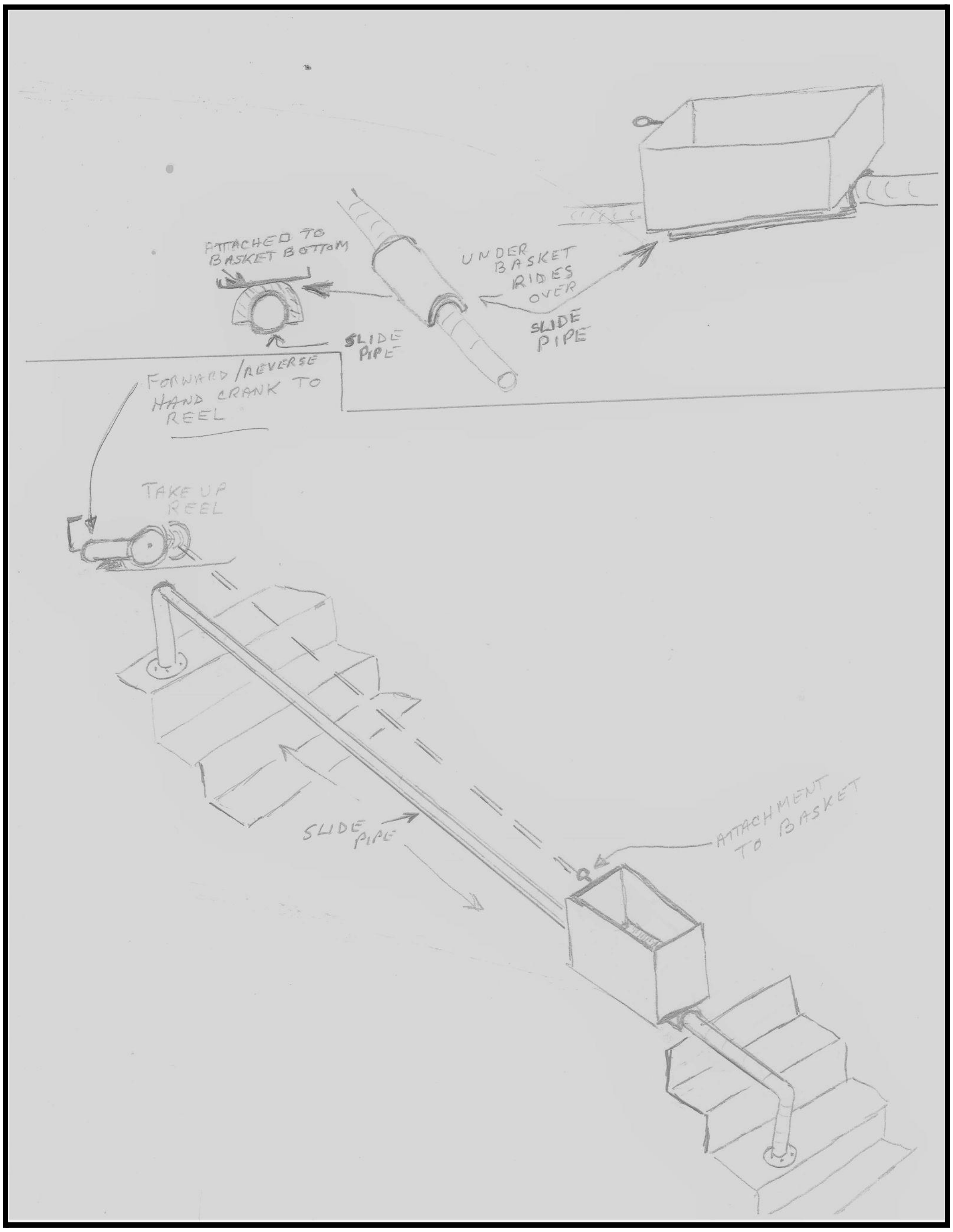


Figure 8: Schematic of Rail Based Basket for Transporting Heavy Items

This design is used for existing staircase rail systems and sits on the top of the rail and uses a hand crank to drag the payload up the railing. Then when descending the railing the hand crank can be unlocked and the weight of the payload would allow for a slow descent to the bottom of the stairs. The payload basket has an upside down U-Shaped hold cut into the bottom which allows for a nice fit onto all different types of railing while giving it the lateral support it needs to not tip over one way or another.

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring (not screening)

Happiness Charts

Table 4: Hand Crank Pulley

Design 1: Hand Crank Pulley		Metric															
		Stair Angle	Volume of Material	Escalator Weight	Transfer Duration	Lift Capacity	Metric 6	Metric 7	Metric 8	Metric 9	Metric 10	Metric 11	Metric 12	Metric 13	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Payload secured to escalator	0.5	0	0	0	0.5									0.833	0.05	0.042
2	Escalator removable/portable	0	0.3	0.7	0	0									0.895	0.15	0.134
3	Avoid stairwell damage	0.3	0.4	0.3	0	0									0.939	0.05	0.047
4	Require little strength/effort	0	0	0.35	0.3	0.35									0.806	0.1	0.081
5	Easy transfer from floor to carriage	0	1	0	0	0									0.941	0.05	0.047
6	Escalator to be minimal/small	0	0.7	0	0	0.3									0.859	0.15	0.129
7	Avoid payload damage	0.4	0.2	0	0.2	0.2									0.899	0.05	0.045
8	Reasonable cost	0	0.5	0	0.25	0.25									0.859	0.05	0.043
9	Idiot proof (easy to use & understand)	0	0	0	0	0									0.000	0.05	0.000
10	Should be "green"	0	0.5	0.25	0.25	0									0.912	0.05	0.046
11	Want it automatic	0	0.75	0	0.25	0									0.928	0.05	0.046
12	Easy/quick to set up	0	0.4	0.6	0	0									0.901	0.1	0.090
13	Enough room to walk by	0	0.7	0	0.3	0									0.925	0.1	0.093
Units		deg	in^3	lbs	sec	lbs	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Unit 13	Total Happiness		0.842
Best Value		38	15000	30	15	300											
Worst Value		50	100000	150	60	150											
Actual Value		38	20000	45	20	250											
Normalized Metric Happiness		1	0.941	0.875	0.889	0.667											

Table 5: Rototiller Stair Walker

Design 2: Rototiller Stair Walker		Metric															
		Stair Angle	Volume of Material	Escalator Weight	Transfer Duration	Lift Capacity	Metric 6	Metric 7	Metric 8	Metric 9	Metric 10	Metric 11	Metric 12	Metric 13	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Payload secured to escalator	0.5	0	0	0	0.5									0.583	0.05	0.029
2	Escalator removable/portable	0	0.3	0.7	0	0									0.854	0.15	0.128
3	Avoid stairwell damage	0.3	0.4	0.3	0	0									0.938	0.05	0.047
4	Require little strength/effort	0	0	0.35	0.3	0.35									0.569	0.1	0.057
5	Easy transfer from floor to carriage	0	1	0	0	0									1.000	0.05	0.050
6	Escalator to be minimal/small	0	0.7	0	0	0.3									0.750	0.15	0.113
7	Avoid payload damage	0.4	0.2	0	0.2	0.2									0.789	0.05	0.039
8	Reasonable cost	0	0.5	0	0.25	0.25									0.736	0.05	0.037
9	Idiot proof (easy to use & understand)	0	0	0	0	0									0.000	0.05	0.000
10	Should be "green"	0	0.5	0.25	0.25	0									0.892	0.05	0.045
11	Want it automatic	0	0.75	0	0.25	0									0.944	0.05	0.047
12	Easy/quick to set up	0	0.4	0.6	0	0									0.875	0.1	0.088
13	Enough room to walk by	0	0.7	0	0.3	0									0.933	0.1	0.093
Units		deg	in^3	lbs	sec	lbs	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Unit 13	Total Happiness		0.772
Best Value		38	15000	30	15	300											
Worst Value		50	100000	150	60	150											
Actual Value		38	15000	55	25	175											
Normalized Metric Happiness		1	1	0.792	0.778	0.167											

Table 6: Ski-Lift Transporter

Design 3: Ski-Lift Transporter		Metric															
		Stair Angle	Volume of Material	Escalator Weight	Transfer Duration	Lift Capacity	Metric 6	Metric 7	Metric 8	Metric 9	Metric 10	Metric 11	Metric 12	Metric 13	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Payload secured to escalator	0.5	0	0	0	0.5									0.500	0.05	0.025
2	Escalator removable/portable	0	0.3	0.7	0	0									0.176	0.15	0.026
3	Avoid stairwell damage	0.3	0.4	0.3	0	0									0.535	0.05	0.027
4	Require little strength/effort	0	0	0.35	0.3	0.35									0.267	0.1	0.027
5	Easy transfer from floor to carriage	0	1	0	0	0									0.588	0.05	0.029
6	Escalator to be minimal/small	0	0.7	0	0	0.3									0.412	0.15	0.062
7	Avoid payload damage	0.4	0.2	0	0.2	0.2									0.695	0.05	0.035
8	Reasonable cost	0	0.5	0	0.25	0.25									0.516	0.05	0.026
9	Idiot proof (easy to use & understand)	0	0	0	0	0									0.000	0.05	0.000
10	Should be "green"	0	0.5	0.25	0.25	0									0.516	0.05	0.026
11	Want it automatic	0	0.75	0	0.25	0									0.663	0.05	0.033
12	Easy/quick to set up	0	0.4	0.6	0	0									0.235	0.1	0.024
13	Enough room to walk by	0	0.7	0	0.3	0									0.678	0.1	0.068
Units		deg	in^3	lbs	sec	lbs	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Unit 13	Total Happiness		0.407
Best Value		38	15000	30	15	300											
Worst Value		50	100000	150	60	150											
Actual Value		38	50000	150	20	150											
Normalized Metric Happiness		1	0.588	0	0.889	0.000											

Table 7: Rail & Basket

Design 4: Rail & Basket		Metric															
		Stair Angle	Volume of Material	Escalator Weight	Transfer Duration	Lift Capacity	Metric 6	Metric 7	Metric 8	Metric 9	Metric 10	Metric 11	Metric 12	Metric 13	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Payload secured to escalator	0.5	0	0	0	0.5									0.833	0.05	0.042
2	Escalator removable/portable	0	0.3	0.7	0	0									0.813	0.15	0.122
3	Avoid stairwell damage	0.3	0.4	0.3	0	0									0.856	0.05	0.043
4	Require little strength/effort	0	0	0.35	0.3	0.35									0.792	0.1	0.079
5	Easy transfer from floor to carriage	0	1	0	0	0									0.765	0.05	0.038
6	Escalator to be minimal/small	0	0.7	0	0	0.3									0.735	0.15	0.110
7	Avoid payload damage	0.4	0.2	0	0.2	0.2									0.864	0.05	0.043
8	Reasonable cost	0	0.5	0	0.25	0.25									0.771	0.05	0.039
9	Idiot proof (easy to use & understand)	0	0	0	0	0									0.000	0.05	0.000
10	Should be "green"	0	0.5	0.25	0.25	0									0.813	0.05	0.041
11	Want it automatic	0	0.75	0	0.25	0									0.796	0.05	0.040
12	Easy/quick to set up	0	0.4	0.6	0	0									0.806	0.1	0.081
13	Enough room to walk by	0	0.7	0	0.3	0									0.802	0.1	0.080
Units		deg	in^3	lbs	sec	lbs	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Unit 13	Total Happiness		0.757
Best Value		38	15000	30	15	300											
Worst Value		50	100000	150	60	150											
Actual Value		38	35000	50	20	250											
Normalized Metric Happiness		1	0.765	0.833	0.889	0.667											

3.3.2 Preliminary analysis of each concept's physical feasibility

D-1: Hand crank with pulley and sliding load

Since this system is dragging the structure along the steps, the bottom of the structure will need a material that won't damage the steps. The structure at the top of the steps that the hand crank is attached to will need to keep the hand crank and load from falling down the stairs and will need to keep the hand crank from shifting while being turned. The structure that the load sits on will be rigid so it will only work for one type of angled stairway, unless the platform was made slightly adjustable to accommodate a wide range of stair angles.

D-2: Rototiller-Style Load-bearing Stair Walker

The use of this device would likely be the simplest, since there is really no set-up involved. The primary design challenge is to determine how powerful a motor would be necessary to torque the carousels of feet. Additionally, there would ideally be a safety measure set in place to reduce the likelihood of injury in the event of a system failure, considering the user would be behind the weight at a point on the stairs lower than the payload. This compromising position would add more challenge to formulating an effective design.

D-3: Electric Winch with pulleys and hanging load

Since it is a hanging load like a ski lift this system would automatically level the load no matter what the angle of the stairs was. The load in transit would cause really high moments of force that would require the stands with the pulleys to either be extremely heavy or attached to the floor, both of which would negatively affect the minimal, mobile, and easy to set up aspects of the customer's desires. Another issue is if tall/long objects need to be moved, it may be impossible to fit poles tall enough in the stairwell to properly transport the object without causing damage or simply not fitting.

D-4: Hand Crank lift that sits on and uses existing railing for different staircase rails

This design would be the most rigid, as fixation to a steel pole offers far more stability than other designs, like hanging baskets (D-3) or walkers that are free-hand guided up and down the stairs (D-2). There are two major hurdles with this design, though. First, figuring out how to keep it removable from the stairwell. This is necessary, as one of the primary goals is to keep this system portable, so a long steel rail would be difficult to handle. And second, the size of the payload is limited to the space within the buckets mounted on the rail. An open platform could be an alternative to enclosed buckets, but this implies shifting of the rail away from the walls/rails of the stairwell, guaranteeing nobody can walk past the machine while it is in use. These two challenges are paramount to this design.

3.3.3 Final summary statement

We considered D-1 (Hand Crank Pulley) to be the best idea. The following paragraphs justify this decision.

D-2 (rototiller stair walker) is a simple idea. It is idiot-proof, sufficiently light-weight, doesn't block the stairwell, and can lift a reasonably heavy load. However, the fact that the user must be downhill from the payload during use is a major strike against safety. Additionally, the design requires an incredibly robust motor and gear-ratio/pulley system mounted beneath the payload platform in order to raise the combined weight of the machine itself and the payload up and down the stairs. Between the safety concern and the extra difficult design hurdles, this idea was rejected.

D-3 (Ski-Lift Transporter) levels itself due to the load hanging and won't rub against any surfaces or structures during the transfer. This design needs something to lift the load into suspension at the top of the steps so that it can pass down the stairwell without hitting the steps, then it needs something at the bottom of the stairwell to lower it back down to the ground. Holding the payload high enough requires a lot of height for the system to work which will prove difficult with big bulky objects. A mechanism also needs to be added to limit the speed at which the payload moves down the pulley line since it will likely be at a 38 degree angle (will want to fall fast unless restrained). The ski lift stands will need a massive amount of weight since the payload weight on the cable will create a massive moment at the top of each pole. All these aspects of this design make it especially hard to keep this minimal, easy/quick to set up, removable, and avoid damage.

D-4 (rail-mounted bucket/platform lift) has great potential, considering its inherent safety far exceeds the stair walker (D-2), and its sturdiness allows for possibly heavier loads than any of the design alternatives. However, the bulky and heavy rail that must be set in place in the stairwell causes multiple serious problems. First, it would be easiest to build it into the existing structure, but that makes it stationary, ruining any hope for mobility. This also keeps a permanent block on a portion of the stairwell room. Second, were it kept portable, the rail system would be very heavy and clumsy to set in place, and would need to be made adjustable for varying stair heights. Its storage would also be much more difficult to supply. Considering its heightened weight, size, cost, lack of mobility, and inherent design difficulty of height adjustment, this idea is rejected.

D-1 (hand-crank-pulley with sliding platform) is the most minimal with its hand crank attached to a wood board at the top of the steps, and it is the simplest with its structure that just slides with the load along the steps. As long as the right material is chosen, all frictional damage can be avoided, and the platform can be kept small enough to get around. Using a hand crank is the most "green" option since it isn't electronic, and the hand crank has a high enough ratio to where it requires little effort to operate; the only concern is making sure it can be cranked quickly enough down the steps, but that design aspect is more on the minor side with respect to the other design aspects. This system is just a level platform attached to a hand crank by a cable, which makes it extremely simple to understand and use.

3.4 Proposed performance measures for the design

The user needs to be able to use this device without straining themselves. This includes an easy transfer from the floor to the device's carriage, a low effort method for the user to put the mechanism into motion, freedom for the user to move around all parts of the device, ease of moving the entire mechanism, easy transfer from the platform to the bottom floor, and no risk of the payload falling off.

3.5 Revision of specifications after concept selection

The original concept for the chosen design had the hand crank attached to a horizontal pillar that jutted out of a massive board; this board was braced up against the stairwell walls. The problem with this design is that it made transferring objects to and from the platform very difficult since the crank and board were in the way. It was unreasonable to expect users to risk lifting heavy loads over the crank and its stopper. This led to us changing the design to where the hand crank is attached to a vertical pillar that is attached to a wooden arch frame; this new wooden frame is now braced up against the stairwell walls. This change gets all the motional mechanics out of the way of the pathway for transferring objects from the floor to the carriage. There is now an opening on the top floor in between the wooden frame that is as spacious as the carriage's platform area. The only other issue is now the hand crank cable in the way. To fix this we added eye bolts on the top station and the triangular structure, along with spring locks and chains. This allowed the top station to attach to and temporarily hold the carriage with the load, instead of the hand crank always holding it. This allows the removal of the hand crank cable which now completely opens up the top floor for easy transfer from floor to platform.

4 Embodiment and fabrication plan

4.1 Embodiment/Assembly drawing

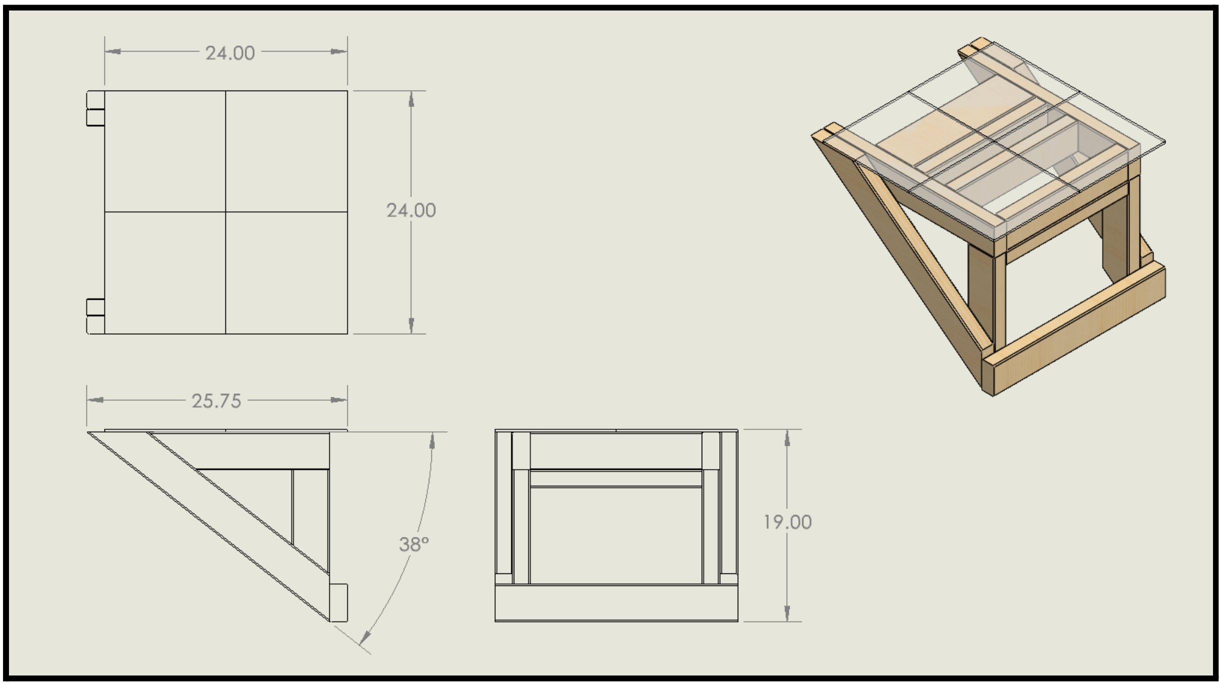
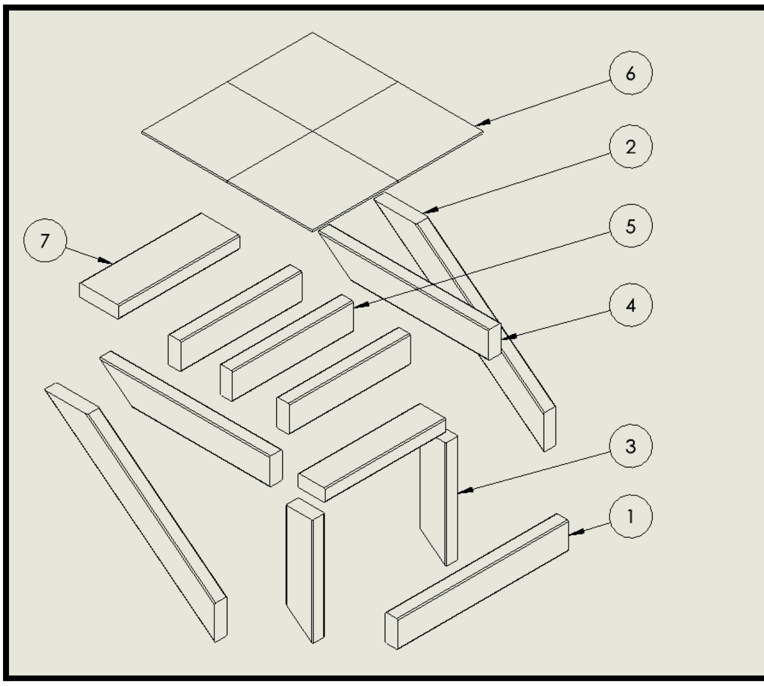


Figure 9: Triangular structure views



ITEM NO.	PART NUMBER	QTY.
1	Stairlift foot beam	1
2	Stairlift angled support beam	2
3	Stairlift vertical support beam	2
4	Stairlift horizontal support beam	2
5	Stairlift cross beam	4
6	Stairlift platform tile	4
7	Stairlift 2x6	1

Figure 10: Triangular structure balloon-exploded

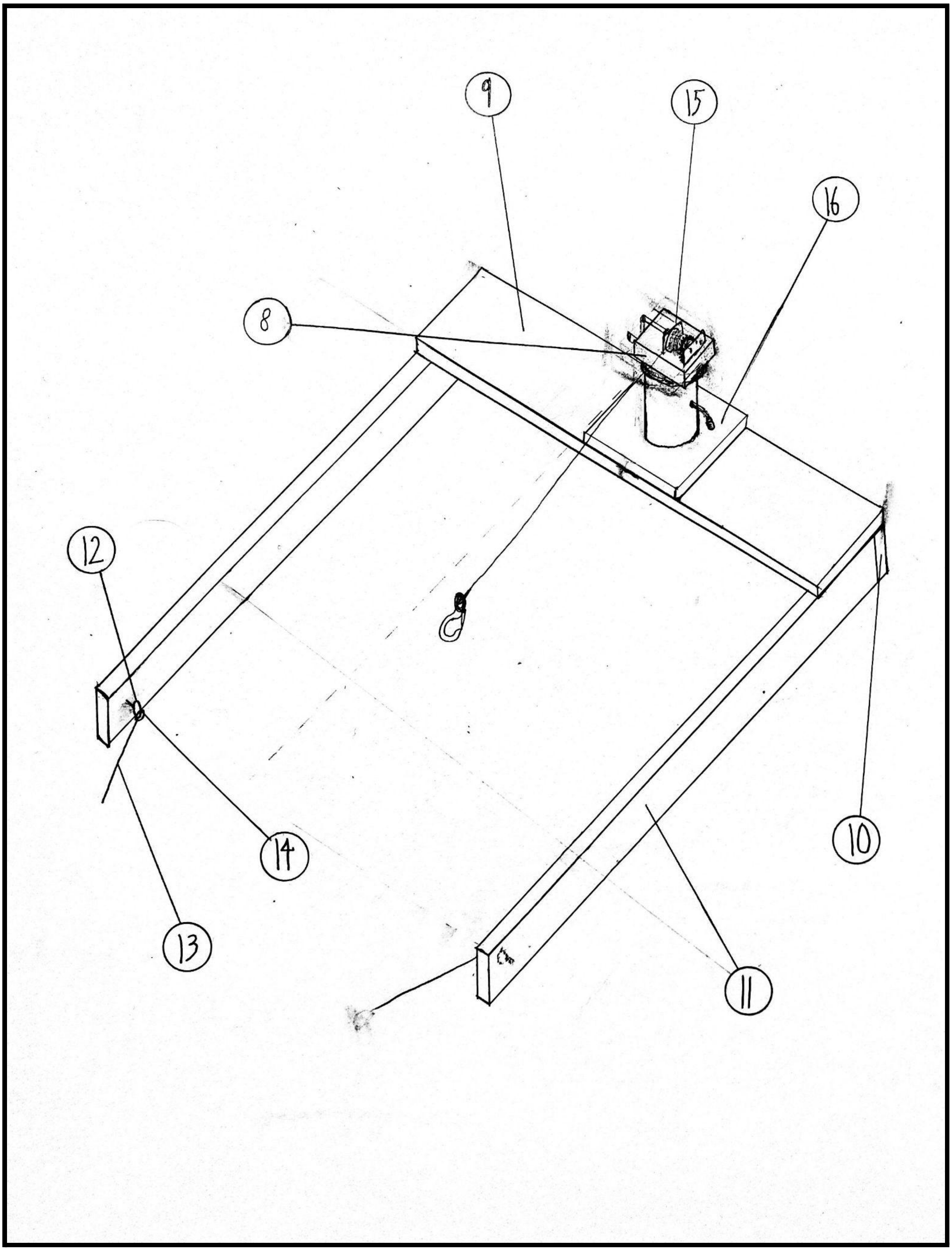


Figure 11: Hand crank set up balloons-isometric

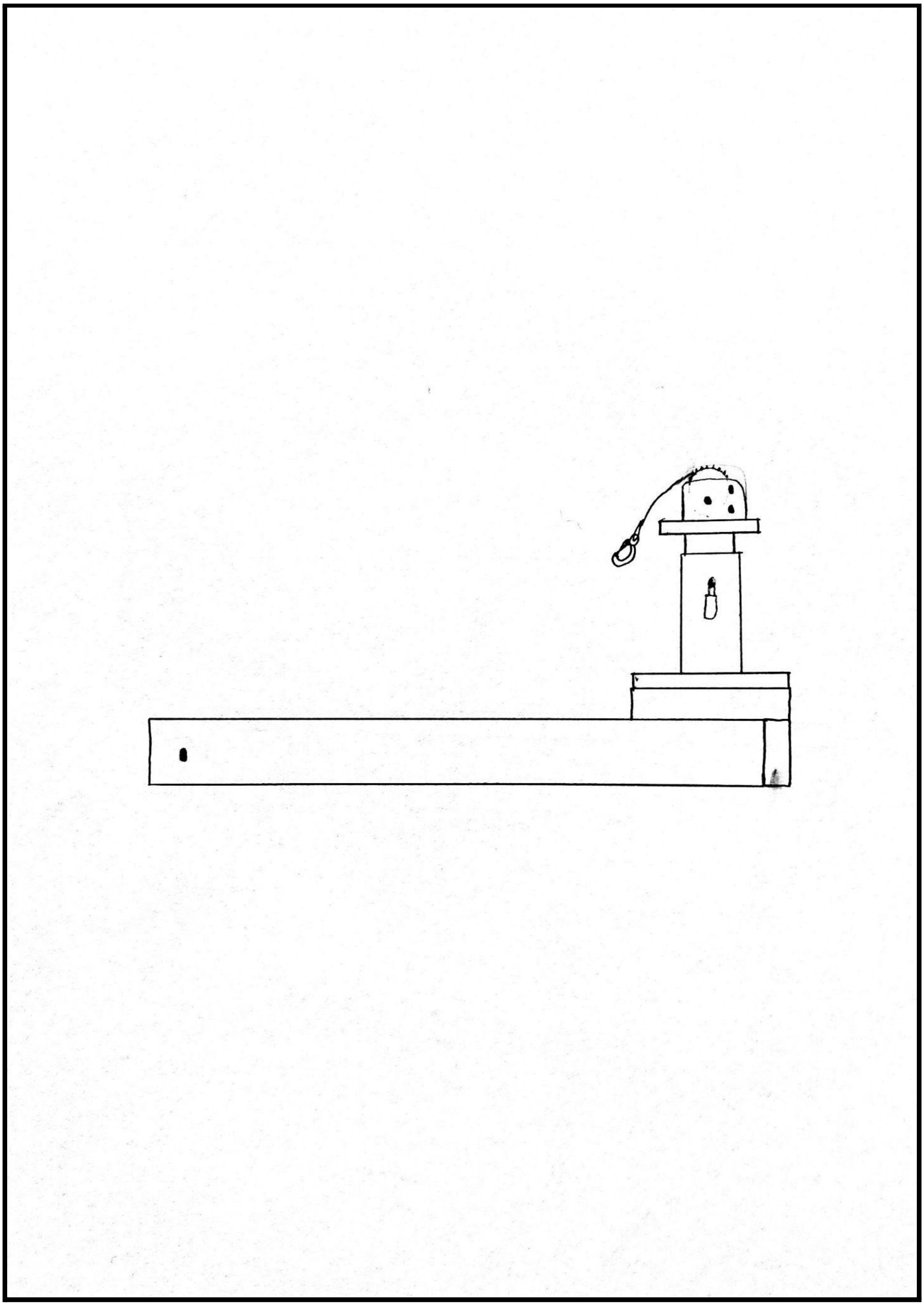


Figure 12: Hand crank set up right view

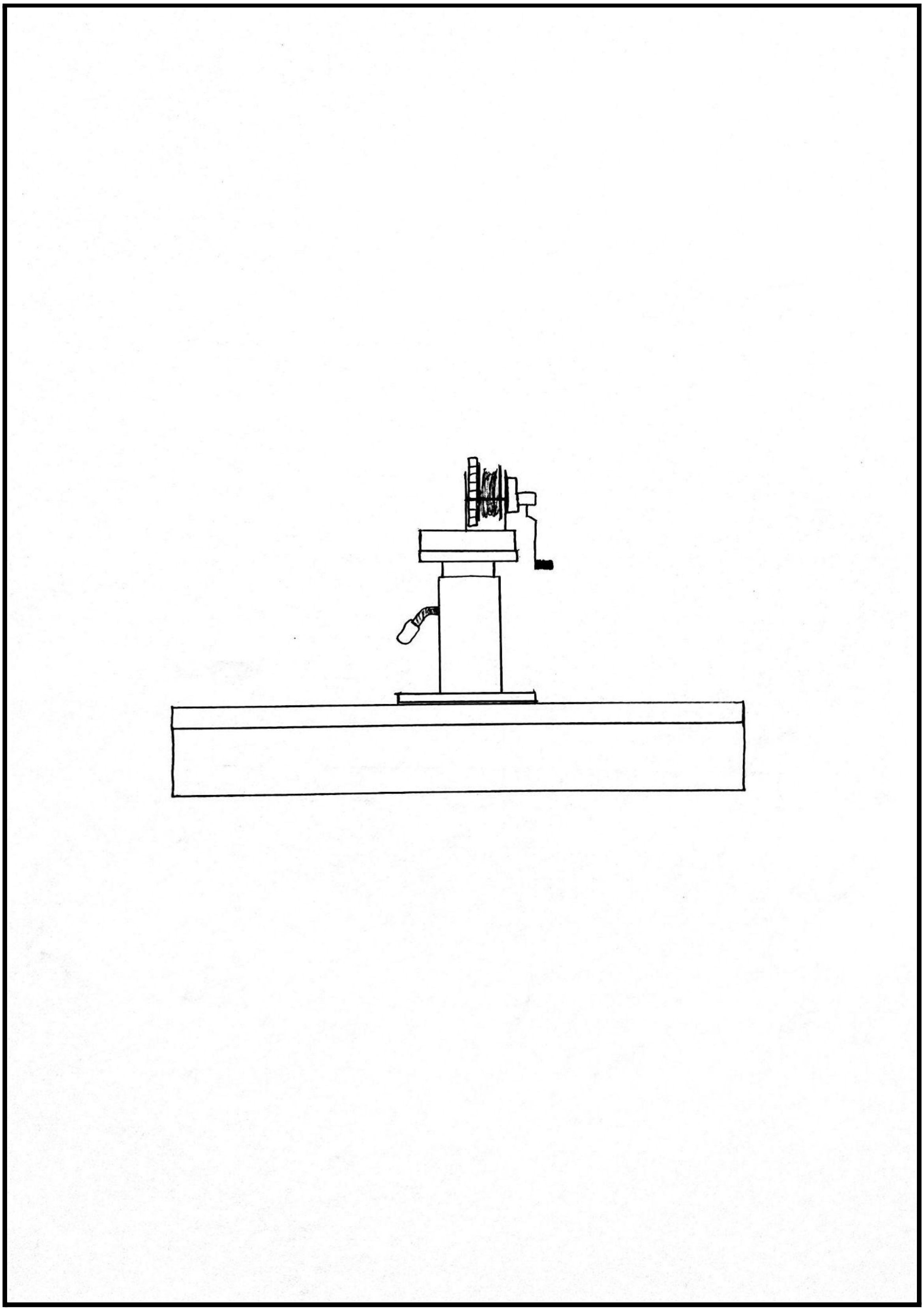


Figure 13: Hand crank set up back view

4.2 Parts List

Table 8: Parts List

#	Description	Defining Dimensions	Quantity	Cost	Link
1	Foot Beam	2x4x24”	1	$1.03/ft	https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061
2	Angled Support Beam	2x4x30.5”	2		
3	Vertical Support Beam	2x4x15”	2		
4	Horizontal Support Beam	2x4x24”	2		
5	Cross Beam	2x4x17”	4		
6	Platform Tile	12x12x1/4”	4	$16.95/sqft	https://www.amazon.com/Acrylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_3?dchild=1&keywords=12x12+1%2F4+plexiglass&qid=1626723166&sr=8-3
7	2x6 Beam	2x6x17”	1	$1.55/ft	https://www.homedepot.com/p/2-in-x-6-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x6x12/206804070
8	SPF Wood	2x8x8	1		SEE #1-5
9	SPF Wood	2x12x44	1		SEE #7
10	SPF Wood	2x4x44	1		SEE #1-5
11	SPF Wood	2x4x36.5	2		SEE #1-5
12	Eye Bolt	⅜ in. x 4 in.	4	$1.05/ea	https://www.homedepot.com/p/Everbilt-3-8-in-x-4-in-

					Zinc-Plated-Eye-Bolt-with-Nut-807206/204273498#overlay
13	Chain	¼ in. x 1 ft.	2 ft.	$2.72/ft.	https://www.homedepot.com/p/Everbilt-1-4-in-x-1-ft-Zinc-Plated-Proof-Coil-Chain-806626/204630506
14	Spring Lock	¼ in. x 2-⅜ in.	4	$2.25/ea	https://www.homedepot.com/p/Everbilt-1-4-in-x-2-3-8-in-Zinc-Plated-Spring-Link-42744/205883098
15	Winch	1,000 lbs capacity	1	$41.99	https://www.amazon.com/AC-DK-Operation-Including-Handles-Trailers/dp/B07YC7B92P/ref=sr_1_1_sspa?dchild=1&keywords=manual+winch+1000+lbs&qid=1626723000&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRjdIUFI3TEVRU0laJmVuY3J5cHRlZElkPUEwOTg5MjQ5MTFWTEpCMVc5VlBIMSZlbmNyeXB0ZWRBZElkPUEwMDk3NTk5MzlUN

					EhMQzJDNFkyVyZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=
16	Base Plate	~	1	$462.42 (minus rest of kit)	https://www.amazon.com/Vestil-WTJ-4-Painted-Extended-Capacity/dp/B00NQZ0QQY

4.3 Draft detail drawings for each manufactured part

No parts are more complicated than cutting materials (wood, plexiglass) and assembling them. There is no need for fabricated parts like custom gears, custom bolts, etc.

4.4 Description of the design rationale

Description of the design rationale for the choice/size/shape of each part

On the stairlift's hoisting apparatus:

The original design had boards right at the top of the stairs which would have made it difficult to lift the payload off the platform, over the boards and winch, and onto the floor. To get around this we added a wood framed structure and brought the winch and structure back away from the steps. This got all structural components out of the way to move the payload onto the floor. After this design change there was only one more issue: the winch cable connecting the winch to the carriage would be in the way of moving the payload from the carriage to the floor. To get around this problem, we added eyebolts with chains that can be temporarily connected to the carriage to hold it in place. This allows the option of disconnecting the winch and moving its cable out of the way, leaving the center completely open for moving objects.

The two 2x4's (balloon #11) that run from the wall away from the staircase are 36.5 in. long to leave enough room to fit the 2x2 ft. payload along with the base plate. Those two boards are both connected to a backboard (balloon #10) which is 44 in. in length, leaving a 41 in. gap between boards to match the stairwell width. On top of those three boards sits a 2x4x12 (or two 2x4x6's) board (balloon #9) that matches the bottom of the base plate dimensions for attaching to. The top of the base plate will have a 2x8x8 (or two 2x4x8's) board (balloon #8) that matches the diameter of the top of the base plate for attaching to. This board allows us to attach the base plate and winch together.

The specific hand crank was mainly chosen because it was convenient to use since one of our group members already had it. The crank also still has a high capacity (1000lbs) which gives a better safety factor, and it will fit well on our system.

The base plate was also chosen for a convenience reason because one of our group members already had it. It allows us to vary the height of the winch depending on how far back the winch is with respect to the stairs, which allows us to adjust the cable's in-tension-angle to 38 degrees to match the stair incline.

The plexiglass was chosen because, once again, we already had some in our group, and plexiglass and wood in contact have a low frictional coefficient for sliding along the stairs.

On the stairlift's angled load-bearing platform:

The platform area was the initial size-determining dimension that drives the size of the supporting structure beneath. The width had to be narrow enough to fit in a standard staircase (taken to be 39 inches wide) while still allowing for someone to sidle past the apparatus to get up/down the stairs during use. And the length was limited by two factors: first, greater length means a larger and heavier stair lift platform, and second, greater length means the heavy object will need to be manually lifted higher in order to bring it to the level of the stairlift's platform when loading/unloading the object at the bottom of the stairs. In the end, an even 2ft-by-2ft platform was the most reasonable.

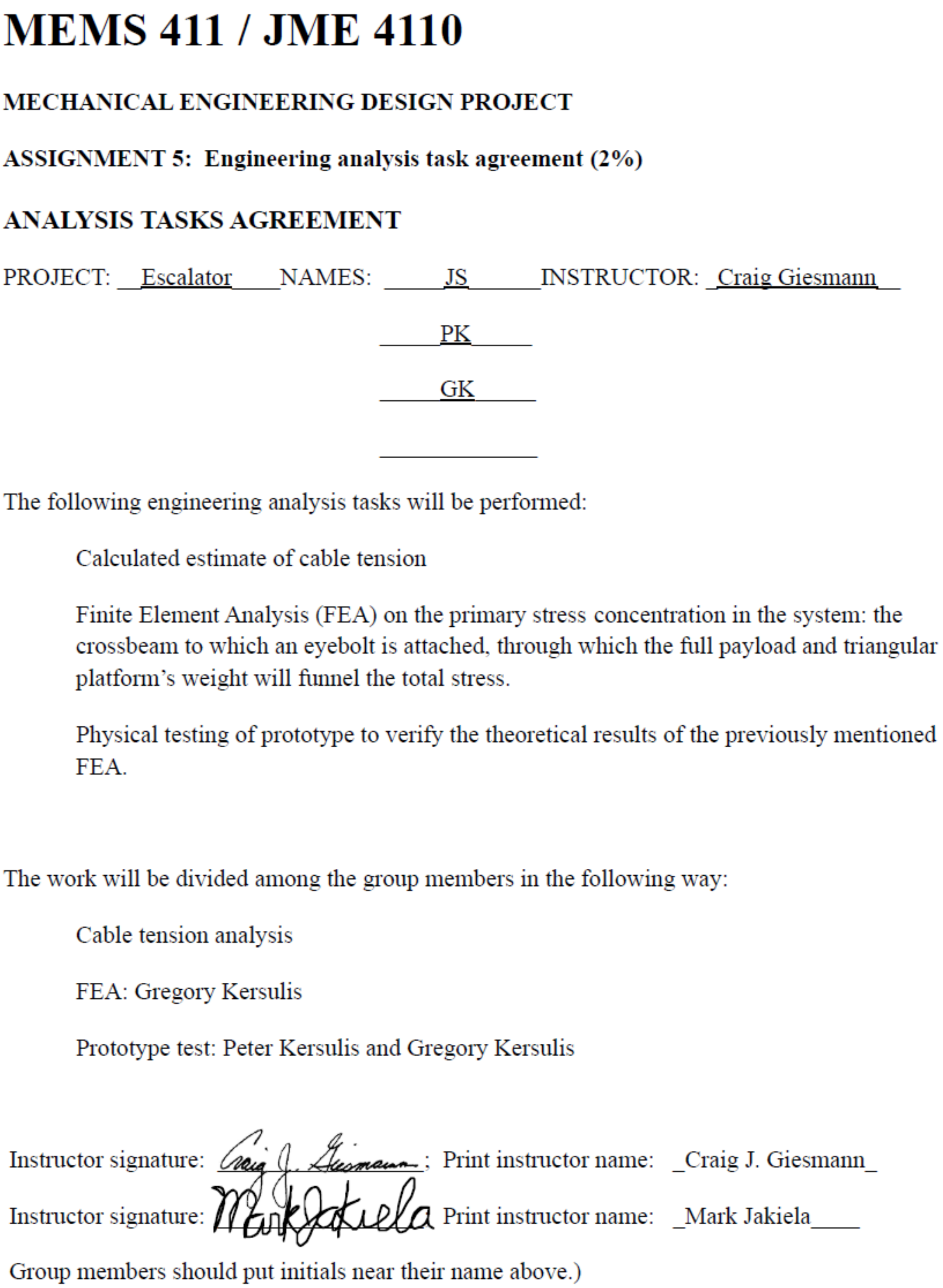
By the time the sharp corners at the tip of the triangular carriage are filed down, the length of the rails that ride on the ledges of the steps will be roughly 30 inches long. Any more than this length would lead to greater platform height which would require the user to lift the heavy object even more in order to mount it on the stairlift platform. But any less would likely lead to teetering of the load as it rises up, in the event that the load momentarily hinges on a single step's ledge. With the 30-inch length, though, the load-bearing platform will always be in contact with at least two ledges, ensuring balance and better load distribution.

The angle of the platform-- at least for the prototype-- was set to a rigid 38 degrees, because this angle is the most commonly employed angle in step construction. It has been chosen because any steeper or shallower makes for an unnatural stride and/or steep descent, both of which lead to falling hazards. Therefore, a 38-degree angle will make this initial platform design (as well as its prototype) maximally universally compatible.

5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 Signed engineering analysis contract



MEMS 411 / JME 4110

MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: __Escalator____NAMES: _____JS______INSTRUCTOR: _Craig Giesmann__

_____PK_____

_____GK_____

____

The following engineering analysis tasks will be performed:

Calculated estimate of cable tension

Finite Element Analysis (FEA) on the primary stress concentration in the system: the crossbeam to which an eyebolt is attached, through which the full payload and triangular platform's weight will funnel the total stress.

Physical testing of prototype to verify the theoretical results of the previously mentioned FEA.

The work will be divided among the group members in the following way:

Cable tension analysis

FEA: Gregory Kersulis

Prototype test: Peter Kersulis and Gregory Kersulis

Instructor signature: ______; Print instructor name: _Craig J. Giesmann_

Instructor signature: ______ Print instructor name: _Mark Jakiela____

Group members should put initials near their name above.)

Figure 14: Signed engineering analysis contract

5.2 Engineering analysis results

5.2.1 Motivation

Before testing, preliminary analysis must be performed to avoid any grave mistakes at the outset of early design. The goal for this engineering analysis, then, is to confirm that the present design is sufficient for testing.

5.2.2 Summary statement

The bolts became an issue at the outset of physical testing, and another date could not be found to meet for retakes. Most importantly, however, what limited the scope of the prototype to less the original target weight capacity and sub-marginal operation on various slopes (30 degrees as well as 38 degrees) and stairway materials (concrete as well as metal) was the project constraints. It was unanimously expected that some such issues as these would arise in the first bout of tests, which is why this prototype would take one—if not two—more iterations before meeting the initial goals. This was not possible, however, given that time and cost were both constrained; therefore, the performance of the project must be accepted for what it is.

5.2.3 Methodology

Three methods will be employed in this analysis:

1) hand calculations based on static force summations

2) finite element analysis for a more dynamic insight into the strength or lack thereof in particular points of interest in the design

3) physical testing of the machine to verify theoretical results

5.2.4 Results

Cable tension:

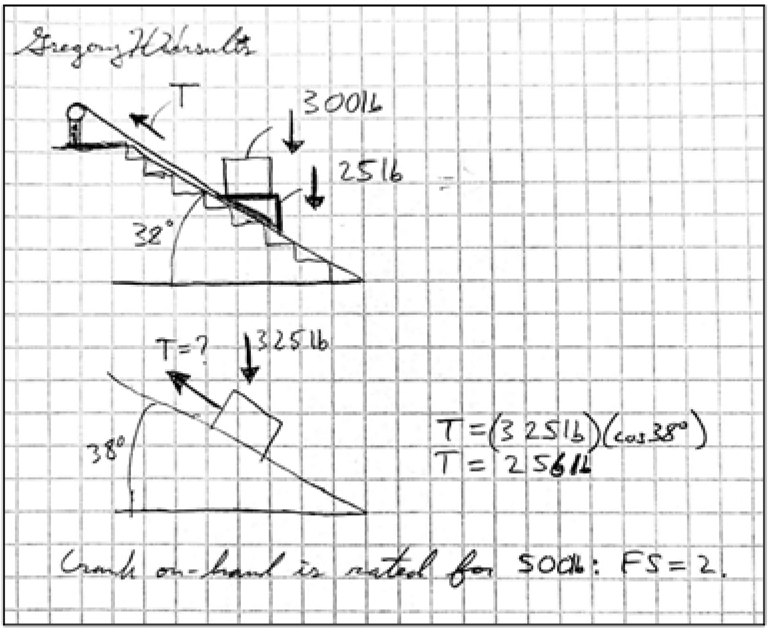
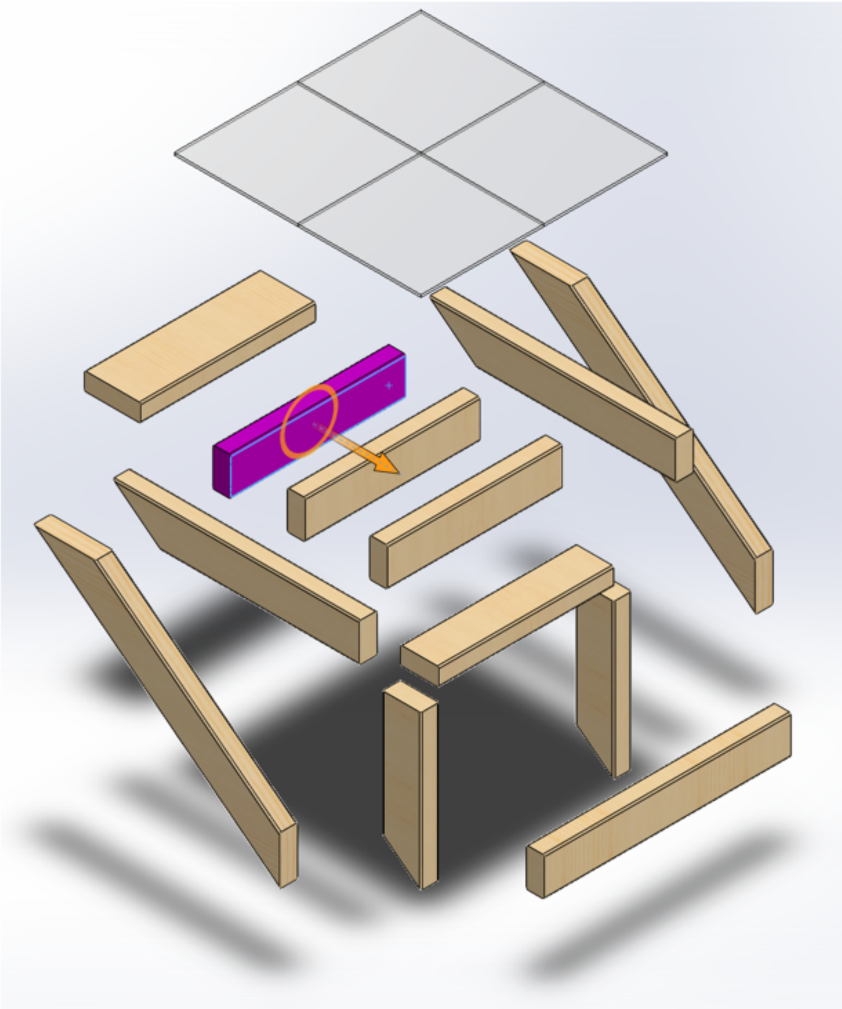
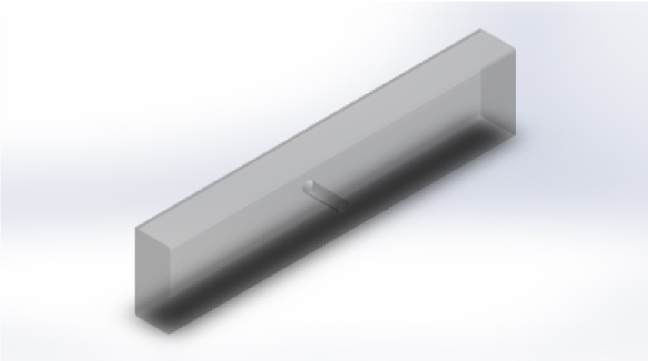


Figure 15: Tension Calculations

Assuming the greatest anticipated weight on this machine of 300 pounds, the maximum cable tension is 256lbs. The cable winch our group already had on-hand is rated for 500 pounds, resulting in a safety factor of 2. These calculations neglect friction for two reasons: first, 300lbs is already beyond the target upper limit for the design, and second, friction will have minimal influence in the set-up since there will be minimal interface area between the platform and the stairs. Additionally, while friction will increase tension during lifting loads up the stairs, friction will conversely reduce tension on the way down. For these reasons, we opted to neglect friction and instead build into our system an accordingly more conservative safety factor and estimation.

Wood Stress Concentration Analysis:





Simulation of Stairlift cross beam

Date: Sunday, August 1, 2021
Designer: Gregory H. Kersulis
Study name: Crossbeam FEA
Analysis type: Static

Table of Contents

Description

This is a finite element analysis (FEA) of the crossbeam member to which the eyebolt will be attached aboard the triangular platform. Platform and payload weight is funneled through this single point at the hole shown, creating an acute stress concentration in the design. This FEA serves to give pre-test confirmation of viable structural design.

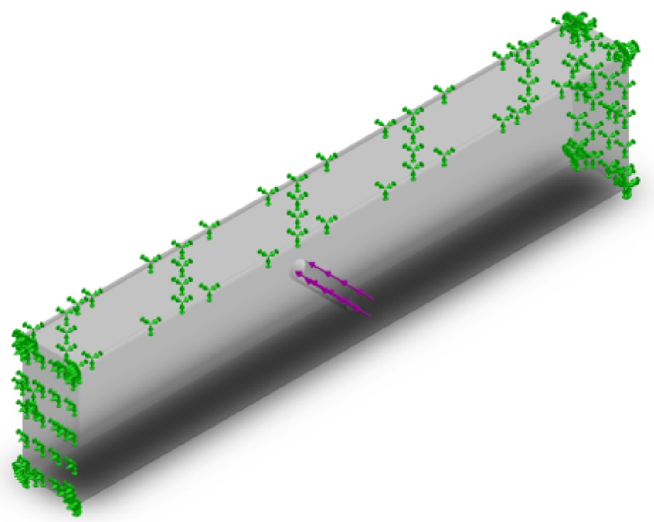
The two end faces of the cross beam and the upper half of the wide face are considered “fixed” in simulation, as the end faces will be screwed in place and the upper half of the wide face will be braced against the spine of a 2x6 beam. The simulated force is 300-lbs one-way, pulling in the direction of the hole. Considering actual forces will be less due to sideways load distribution on stair edges, this weight (300lbs) technically exceeds design goals: this is done for safety factors and theoretical error inherent in FEA.

Assumptions

1) Nylon 6/10 is used in place of wood as the beam's material. Its properties are close enough for approximation since this FEA serves more as a litmus than as a highly accurate simulation. The purpose for this substitute is that SolidWorks' wood material properties are all left blank, and the software prevents manual input of such material property values, rendering simulations incapable of computation.

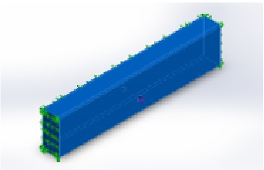
2) Uniformly distributed, constantly applied stress load throughout the simulation.

Model Information

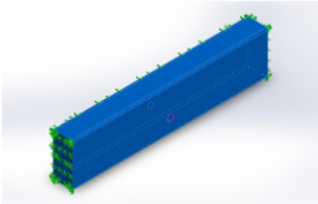


Model name: Stairlift cross beam
Current Configuration: Default

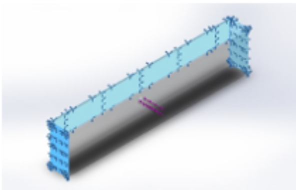
Solid Bodies

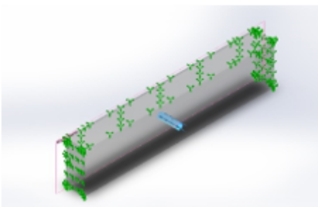
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude1 	Solid Body	Mass:2.54472 kg Volume:0.00181766 m^3 Density:1,400 kg/m^3 Weight:24.9383 N	C:\Users\Sam Akarifox\Documents\Summer 2021\JME4110 - ME Senior Project\SL CAD files\Stairlift cross beam.SLDPRT Aug 1 18:24:02 2021

Material Properties

Model Reference	Properties	Components
	**Name:** Nylon 6/10 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.39043e+08 N/m^2 **Tensile strength:** 1.42559e+08 N/m^2	SolidBody 1(Cut-Extrude1)(Stairlift cross beam)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 3 face(s) **Type:** Fixed Geometry

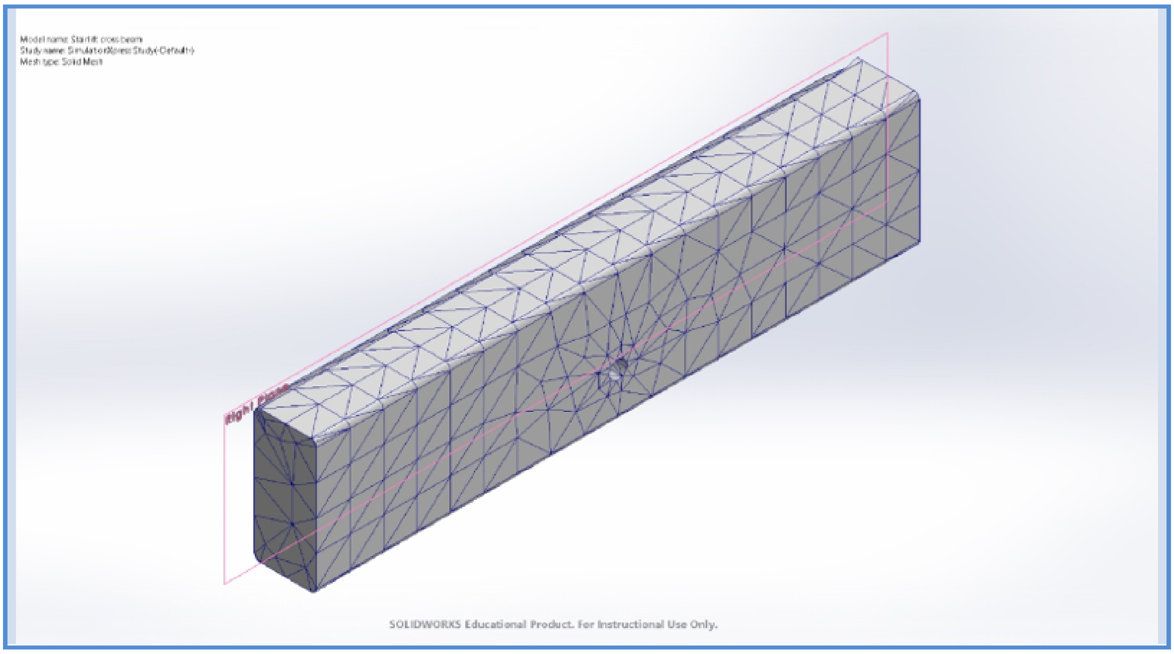
Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s), 1 plane(s) **Reference:** Right Plane **Type:** Apply force **Values:** ---, ---, -,300 lbf

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points for High quality mesh	16 Points
Element Size	0.961151 in
Tolerance	0.0480576 in
Mesh Quality	High

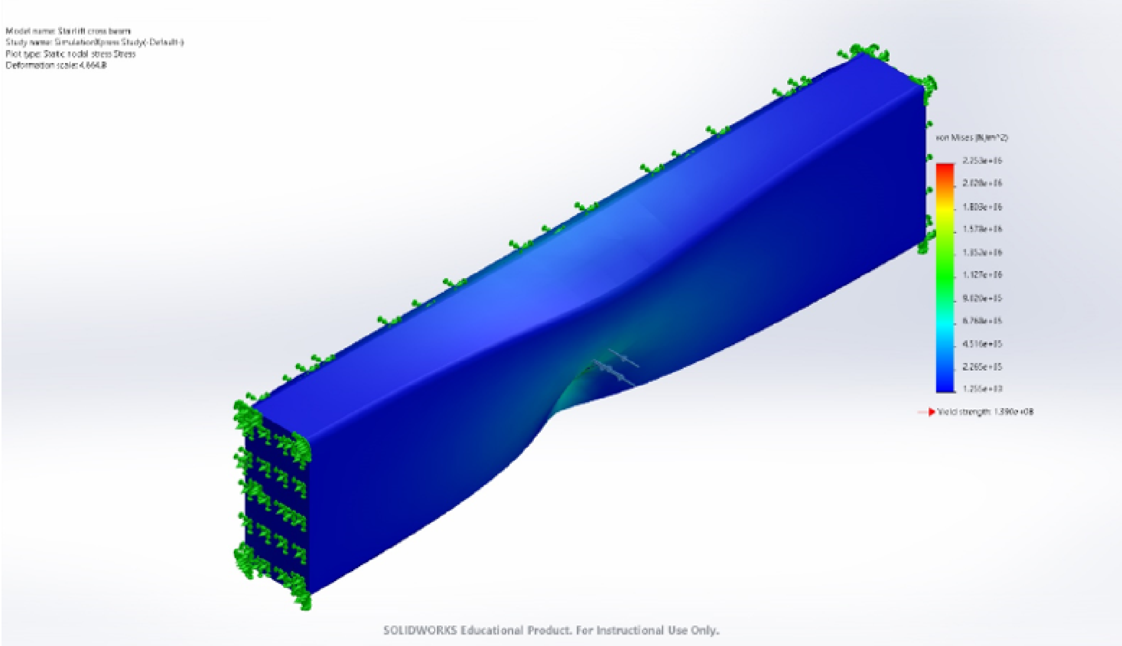
Mesh information - Details

Total Nodes	3409
Total Elements	1916
Maximum Aspect Ratio	11,881
% of elements with Aspect Ratio < 3	77.1
Percentage of elements with Aspect Ratio > 10	4.65
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:01
Computer name:	


Model name: Stairlift cross beam
Study name: SimulationXpress Study(-Default-)
Mesh type: Solid Mesh
SOLIDWORKS Educational Product. For Instructional Use Only.

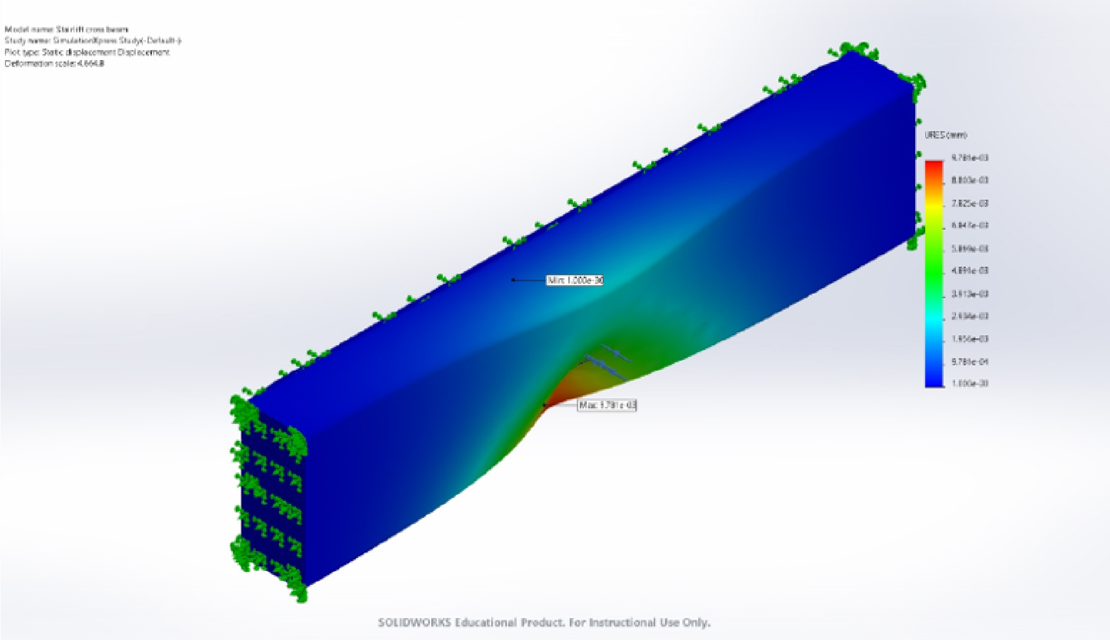
Study Results

Name	Type	Min	Max
Stress	VON: von Mises Stress	1.255e+03N/m^2 Node: 2720	2.253e+06N/m^2 Node: 3397



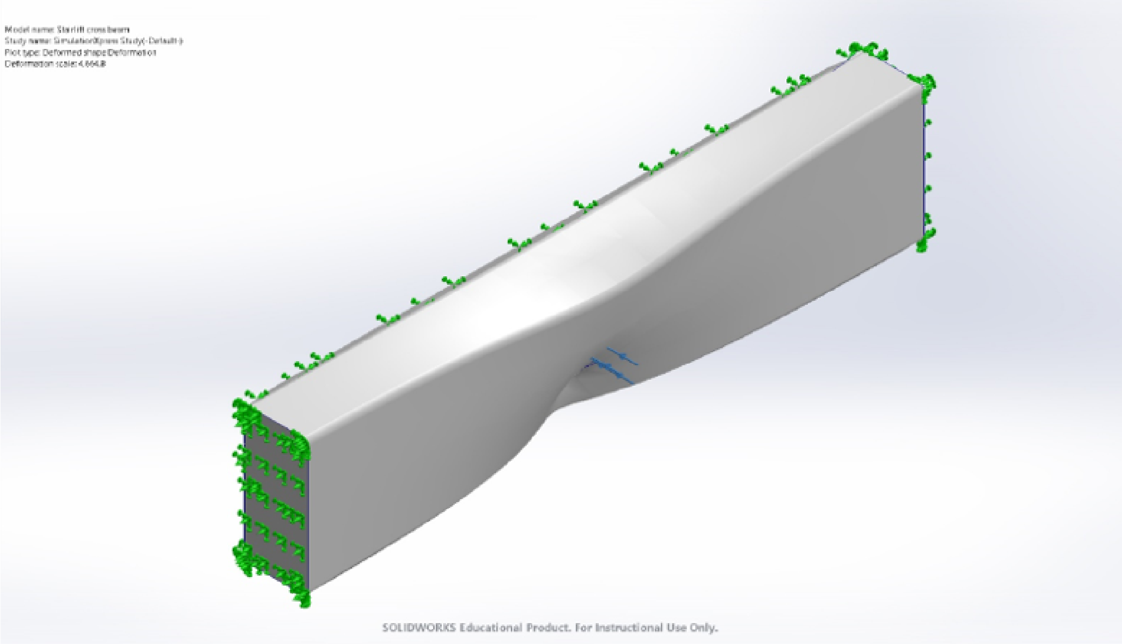
Stairlift cross beam-SimulationXpress Study-Stress-Stress

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0.000e+00mm Node: 26	9.781e-03mm Node: 129



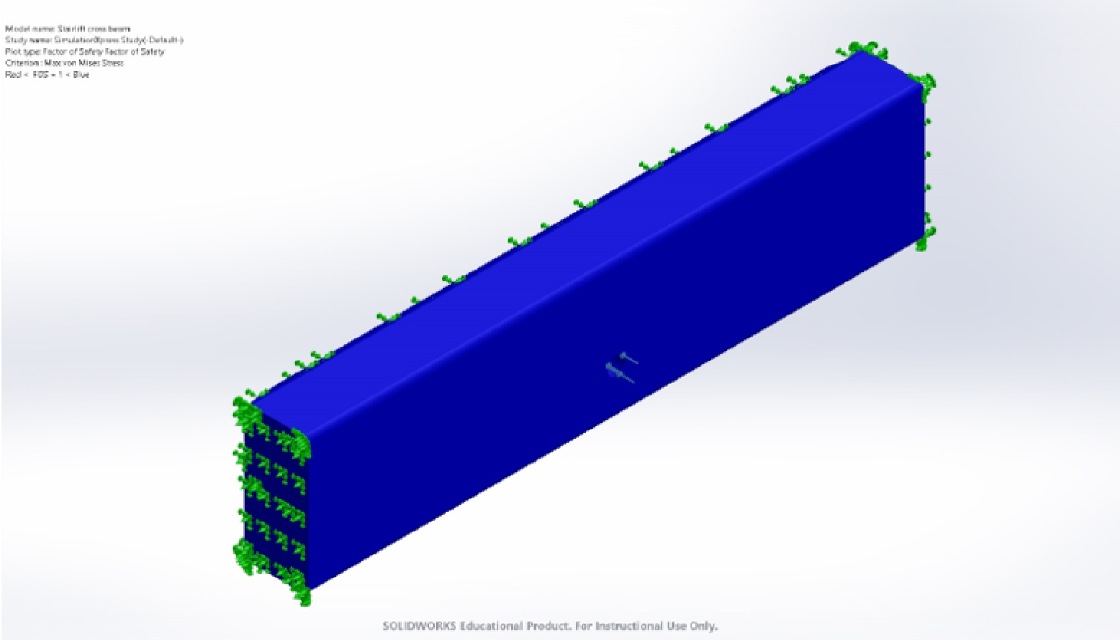
Stairlift cross beam-SimulationXpress Study-Displacement-Displacement

Name	Type
Deformation	Deformed shape



Stairlift cross beam-SimulationXpress Study-Displacement-Deformation

Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	6.171e+01 Node: 3397	1.108e+05 Node: 2720



Stairlift cross beam-SimulationXpress Study-Factor of Safety-Factor of Safety

Conclusion

Simulation shows the maximum occurring von Mises stress is 2.3MPa while material yield strength is 140MPa. Considering the force direction is perpendicular to the wood grains, this yield strength should be reduced: (140MPa)/7 = 20MPa. Since Nylon 6/10 is somewhat stronger than the SPF wood that will actually be used, this yield strength can be conservatively reduced to 16MPa, giving a safety factor of: FS = 16/2.3 = 7.0. This safety factor is comfortably above the minimum desired FS of 5.0, per *ASME17.1-2016/CSAB44-16/5.3.1.9.2: Platforms*. Therefore, this FEA concludes that current theoretical design is sufficient.

Physical testing:

Preemptive theoretical analysis confirmed that the weakest link in the wooden frame was still plenty strong to withstand the testing loads. However, physical testing revealed a stress concentration that did become a problem, namely the two bolts shown in Figure 2 below:

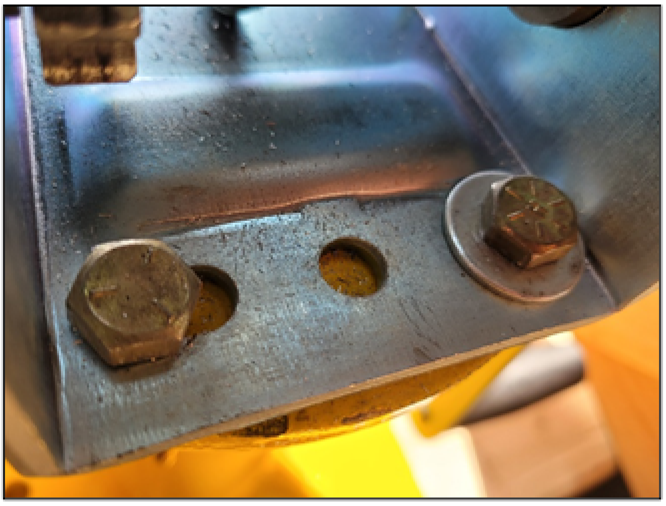


Figure 16: Winch-mounting Bolts Warped after Testing

On staging the machine for the first test, loading down the frame with 170lbs and cranking the winch immediately began to warp and bend the two bolts used to fix the winch to the top face of the yellow baseplate.

5.2.5 Significance

Because of the bolt shortcomings previously mentioned, all testing was done with a 120-lb payload instead of the originally desired 150+ pounds. While this unexpectedly reduced the end performance of the prototype, it meant that the goal of the rest of testing was not to push the limits of raw load capacity but to simply confirm the idea functions as desired.

6 Risk Assessment

6.1 Risk Identification

The following risks were identified:

- System falls down stairs
- Fabrication injury
- Customer opting to move loads up/down stairs through other means
- Competitor releases similar product sooner
- Fabrication equipment failure

6.2 Risk Analysis

* This is based on your project engineering analysis. Tools include simulation, happiness equations, calculation by hand or with SolidWorks, MATLAB, etc. Discuss risk as it pertains to your performance specification, cost, and schedule.

Table 9: Risk Analysis Quantification

Risk Management Register

0	Open Red Risks
1	Open Yellow Risks
1	Open Green Risks
0	Risks w/ no Response Strategy
0	Closed risks

Project Name: Escalator
Project Manager: JPG
Start Date:
Location:
Add'l Info:
Updated On:
Overall Project Risk Indicator: #VALUE!

Risk Level

Probability					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
Impact	1	2	3	4	5

Legend:
Impact: 1 - Negligible; 2 - Marginal; 3 - Significant; 4 - Critical; 5 - Catastrophic
Probability: 1 - Rare; 2 - Unlikely; 3 - Possible; 4 - Likely; 5 - Certain

Item	Project/ Phase	Risk Status	Risk	Potential Impact (Cause and Effect)	Risk Response Strategy	Triggers (Indicators that the risk will occur)	Estimated Schedule Impact (Days)	Maximum Exposure ($000)	Estimated Exposure (Contingency) ($000) $34	Risk Category	Risk Sub Category	Action Owner	Start Exposure	End Exposure	Baseline Risk Scoring: Impact: Tech Perf	Baseline: Schedule	Baseline: Cost	Baseline: Safety	Baseline: Probability	Baseline: Risk Ranking	Current Risk Score: Impact: Tech Perf	Current: Schedule	Current: Cost	Current: Safety	Current: Probability	Current: Risk Ranking
0		Open	System falls down stairs	Damage to susceptible stairs and carriage/system	Repair damage dealt and analyze if falling was due to design flaw	System gives way and starts to slide down	1	$60	$0	Performance	Means to Track and Measure Project Performance	Peter,Greg	07/28/21	08/06/21											1	0
1		Open	Fabrication Injury	Someone fabricating parts sustains minor or major injuries	Tend to injury depending on significance and ensure continued operation is safe	Machinist gets injured while operating	1	$200	$5	Construction	Contractor Safety Program	John,Peter,Greg	07/21/21	07/22/21		1			5	5		5			1	5
2		Accepted	Customers opting to move loads up/down stairs through other means	Escalator product fails to compete in market of stair lifting methods	Further research on the escalator market and what customers want for moving objects along stairs	Product doesn't sell well as an official idea and as a prototype	21	$400	$10	Technology	Technology Maturity	John,Peter,Greg	08/06/21	08/16/21		1			5	5		4	3		1	4
3		open	Competitor releases similar product sooner	Reduce product's success in sales	Market product better or differently than other competitor's design	Similar new product released to market	3	$130	$3	Financial/Regulatory	Key Options Assessed	Greg	07/23/21	08/16/21		2			3	6		4	2		1	4
4		open	Fabrication equipment failure	Can't produce/machine needed parts	Machine part differently, fix machine, or rent/obtain access to a similar machine	Machine being used breaks	2	$150	$16	Construction	Layout and Constructability	John	07/21/21	07/22/21		5			5	25		5	5		2	10
6																1			5	5		3	5		2	10
5																		5	5	25		5			1	5
7																								5	1	5
8																							1		1	1
9																							1		1	1
10																							1		1	1
11																							1		1	1
12																										
13																										
14																										
15																										

6.3 Risk Prioritization

After review of the quantitative analysis of the various identified risks, a qualitative assessment of them was conducted, resulting in the following list of prioritized risks:

Hierarchy of risks by descending order of concern:	Risk Factor
1) Fabrication injury	0
2) System falls down stairs	5
3) Fabrication equipment failure	4
4) Customers opting to move loads up/down stairs through other means	4
5) Competitor releases similar product sooner	10

Immediately obvious is the seeming inverse correlation between the risk factor and the hierarchical position on the priority list. The scope of this project was focused on exploratory ideas and not competitive time to market for new monetary ventures, so even though *Competitor releases similar product sooner* is quantified as being of most concern, engineering judgment among the team members disagrees entirely.

Customers opting to move loads up/down stairs through other means was dropped to the next-lowest position for the same reason: market competition was hardly a concern in this project.

Fabrication equipment failure was just to remain a reasonable concern, as an equipment failure could be large enough to be irreplaceable, rendering all work that requires that piece of equipment to be not doable.

System falls down stairs was the second-highest priority among the risks since, if the complete prototype fell down stairs under load testing (for example), the entire prototype would need repairs or a complete rebuild, drastically increasing both cost and labor hours of the project.

Finally, *Fabrication injury* was top priority. If one of the team members got hurt, the whole project would come to a halt, which cannot be afford given the extreme time constraint on the project.

7 Codes and Standards

7.1 Identification

Code 7.2.3.2 Capacity Plate is on page 249 from the "Safety Code for Elevators and Escalators" catalog which was written by *The American Society of Mechanical Engineers* and became effective 6 months after November 30, 2016 (the date of issuance).

Code 7.2.3.2 Statement: "A capacity plate shall be fastened in a conspicuous place in the car. The plate shall be of such material and construction that the letters and figures stamped, etched, cast, or otherwise applied to the face shall remain permanently and readily legible. It shall indicate the rated load in letters and numerals not less than 6 mm (0.25 in.) high"

Code 7.2.3.4 "No Riders" is on page 253 from the "Safety Code for Elevators and Escalators" catalog which was written by *The American Society of Mechanical Engineers* and became effective 6 months after November 30, 2016 (the date of issuance).

Code 7.2.3.4 Statement: "A sign stating "NO RIDERS" shall be located in the car in letters not less than 13 mm (0.5 in.) high."

Code 5.3.1.9.2 Platforms is on page 188 from the "Safety Code for Elevators and Escalators" catalog which was written by *The American Society of Mechanical Engineers* and became effective 6 months after November 30, 2016 (the date of issuance).

Code 5.3.1.9.2 Statement: "(a) Construction. Platforms shall be of non-perforated metal or wood. If constructed of wood, they shall be laminated. Platforms shall be supported by a platform frame or formed metal support pan attached to the car frame. Platforms and platform frame assemblies shall have a safety factor of 5."

Code 2.10.1 Guarding of Equipment is on page 39 from the "Safety Code for Elevators and Escalators" catalog which was written by *The American Society of Mechanical Engineers* and became effective 6 months after November 30, 2016 (the date of issuance).

Code 2.10.1 Statement: "In machinery spaces, machine rooms, control spaces, and control rooms, the following shall be guarded to protect against accidental contact: (a) driving-machine sheaves and ropes whose vertical projection upon a horizontal plane extends beyond the base of the machine, unless the driving-machine sheave is so located as to minimize the possibility of contact (b) sheaves (c) exposed gears, sprockets, tape or rope sheaves, or drums of selectors, floor controllers, or signal machines, and their driving ropes, chains, or tapes (d) keys, keyways, and screws in projecting shafts Handwinding wheels and flywheels that are not guarded shall have yellow markings."

7.2 JUSTIFICATION

Code 7.2.3.2 Capacity Plate

Adding a capacity plate to the escalator's station at the top and to the moving platform will ensure that the users are always reminded of the exact limitations of this system.

Code 7.2.3.4 "No Riders"

Adding a plate that specifies to not transport humans with the mechanism will, hopefully, encourage users to not do so. Like most transporting devices that move from point 'A' to point 'B', people like to try riding it themselves. This blatant sign will be a reminder to not take the risk since the system isn't designed to the level of safety that allows humans to ride it.

Code 5.3.1.9.2 Platforms

This code offers an exact safety factor of 5 for platforms. This is officially for special application elevators that transport people, which means a factor safety of 5 for our platform will be sufficient.

Code 2.10.1 Guarding of Equipment

The main moving mechanical component that users could reasonably get caught up in is the gears of the hand crank at the top station. Adding something that blocks users from getting caught in or, at least, stands out more to users will further reduce the risk of injury.

7.3 DESIGN CONSTRAINTS

* Include at least one example of the following constraints.

7.3.1 Functional

Code 7.2.3.2 Capacity Plate

This addition will be for user safety and system functionality since unknowingly overloading the system will, likely, lead to the entire mechanism falling down the stairs. This standard doesn't restrict the design in any way. It simply requires us to make or purchase 2 small metal plates to attach to the top station and to the platform at easily visible locations. If desired, these plates can be as small as 0.25 inches high, and can be easily attached to the front of the top station and the front (or top) of the platform.

7.3.2 Safety

Code 5.3.1.9.2 Platforms

Our system is transporting objects, not people, and systems that humans' safety is reliant on will have a reasonable safety factor. Abiding by this code with respect to maintaining a higher safety factor will ensure a safer and more functional system. This code is giving us a safety factor to reach, not the materials to abide by (since it is officially for an elevator).

7.3.3 Quality

7.3.4 Manufacturing

7.3.5 Timing

7.3.6 Economic

7.3.7 Ergonomic

7.3.8 Ecological

7.3.9 Aesthetic

7.3.10 Life cycle

7.3.11 Legal

Code 7.2.3.4 "No Riders"

This addition is for the user's safety since it encourages to avoid improper use, and it is for the legal aspect of getting sued, due to not adequately informing the user of common misuses.

This standard does not alter the current design, it simply requires the addition of a produced or purchased metal plate that is at a minimum height of 0.5 inches. It needs to be located at a conspicuous location for the user to see.

7.4 Significance

Code 7.2.3.2 Capacity Plate

Adding a capacity plate to the escalator's station at the top and to the moving platform will ensure that the users are always reminded of the exact limitations of this system. Capacity information can also be listed on the packaging and the manual, but those are not conspicuous enough for mechanisms of regular use. This addition will be for user safety and system functionality since unknowingly overloading the system will, likely, lead to the entire mechanism falling down the stairs.

This standard doesn't restrict the design in any way. It simply requires us to make or purchase 2 small metal plates to attach to the top station and to the platform at easily visible locations. If desired, these plates can be as small as 0.25 inches high, and can be easily attached to the front of the top station and the front (or top) of the platform. Showing the capacity should be enough, but if we surmise that more information for the user would be better and not distracting/overwhelming, then "Data Plate" text from code 7.2.3.3.2 could be added to the capacity plate to conspicuously inform the user of the manufacturer's name, date of production, rated speed, and car and station weights.

Code 7.2.3.4 "No Riders"

Adding a plate that specifies to not transport humans with the mechanism will, hopefully, encourage users to not do so. Like most transporting devices that move from point 'A' to point 'B', people like to try riding it themselves. This blatant sign will be a reminder to not take the risk since the system isn't designed to the level of safety that allows humans to ride it. This addition is for the user's safety since it encourages to avoid improper use, and it is for the legal aspect of getting sued, due to not adequately informing the user of common misuses.

This standard does not alter the current design, it simply requires the addition of a produced or purchased metal plate that is at a minimum height of 0.5 inches. It needs to be located at a conspicuous location for the user to see.

Code 5.3.1.9.2 Platforms

This code offers an exact safety factor of 5 for platforms. This is officially for special application elevators that transport people, which means a factor safety of 5 for our platform will be sufficient. Our system is transporting objects, not people, and systems that humans' safety is reliant on will have a reasonable safety factor. Abiding by this code with respect to maintaining a higher safety factor will ensure a safer and more functional system.

This code is giving us a safety factor to reach, not the materials to abide by (since it is officially for an elevator). The platform's safety factor is determined through Finite Element Analysis. If the platform is 5 or higher, then the design is fine. If the design is lower than 5, then the weak points of the platform structure will need to be strengthened by adding more trusses, bracing with metal, replacing wood with metal, or replacing SPF wood with laminated/engineered wood.

Code 2.10.1 Guarding of Equipment

The main moving mechanical component that users could reasonably get caught up in is the gears of the hand crank at the top station. Adding something that blocks users from getting caught in or, at least, stands out more to users will further reduce the risk of injury. This addition would be added for safety reasons, because human parts can get caught in gears and so can their clothing if they are leaning over the gears while cranking.

To implement this onto the mechanism we would either need to color the gears yellow so that they stand out much more, or make a plastic cover that snaps onto the hand crank to block anything from getting caught in the gears. Another aspect that could be added to assist with this code/standard would be to add a "Only operate when body is behind line" statement on the back of the station to encourage users to only put their hand on the crank and keep everything else away.

8 Working prototype

8.1 prototype Photos

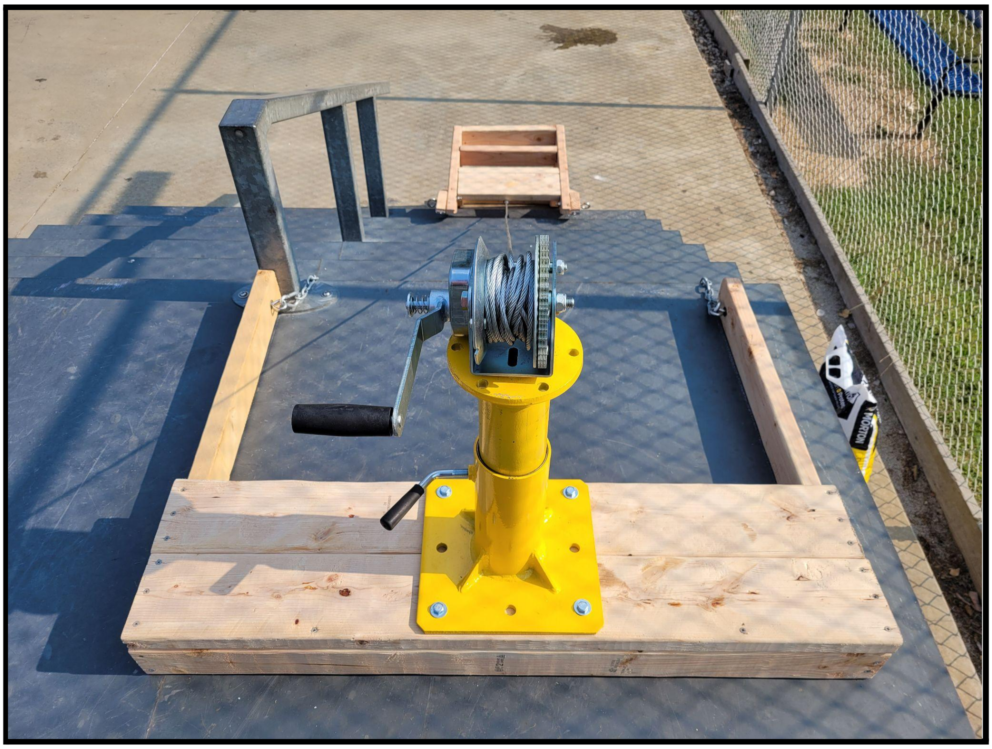


Figure 17: The view from the user's position

This view shows the apparatus from the perspective of the operator, positioned for cranking the load up or down the stairs. Everything the user may be doing from the top position will consist of the following: loading and unloading objects onto the platform, cranking the platform up and down, connecting and disconnecting the chains and winch, and raising and lowering the base plate.

Figure 18: The bottom view of the system

This perspective captures the extension of the cable and the two-by-four foot/backpiece screwed to the bottom of the triangular platform; this backpiece gives structural support and a flat surface area for the triangular structure to rest on when touching the floor/ground at the bottom of the steps. The station at the top weighs 67 pounds (mostly due to the base plate) and the triangular structure weighs 23 pounds.

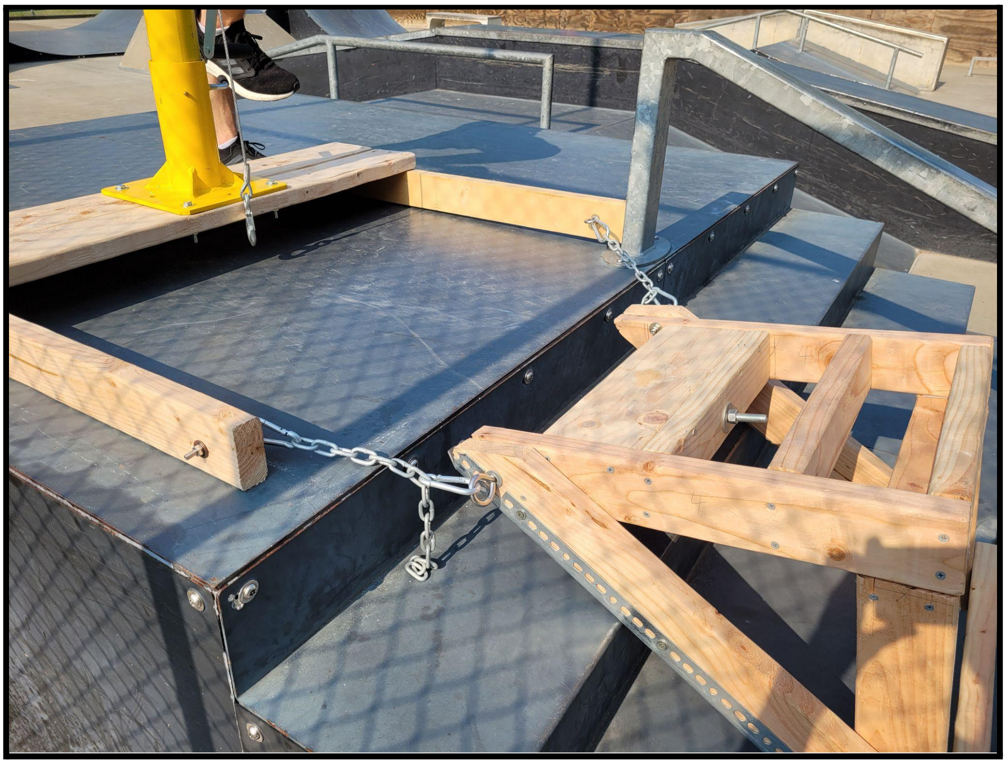


Figure 19: The chain configuration

This shows the chains and their spring locks that attach the platform to the station. With the platform held in place the user can remove the winch cable from the working area at the top of the steps and transfer the payload between the top floor and the platform much more easily.

8.2 Working Prototype Video

A short video clip that shows the final prototype performing. Include a YouTube link. Make sure your video is public

OVERALL PERFORMANCE MEASURE:

Mainly, we want this mechanism to be reasonable for a user to use. Being a reasonable machine for someone to use includes some of the following: easy for them to understand, not straining on them to operate each component, no harmful risk for them while operating the lift, and worth it to them to use the lift to move the load, instead of, walking up or down the stairs while carrying the load.

Video link: https://youtu.be/MdlNVy3r4tA

TESTING RESULTS:

Despite not having an ideal staircase to test on, the mechanism was still able to raise and lower the cargo on the stairs. The crank worked well for pulling the 40 pound salt bags up the stairs with the issue of slightly shimmying left and right as it went up. When lowering the cargo and letting gravity do the work, the platform shimmied slightly more than when going up. The system handled going down the stairs just fine on the skateboard park stairs, but not as well on the concrete stairs. It was hard to tell why it was getting caught on the concrete and not the steel steps, but the concrete could have had a variation in the steps that led to it not having a straight angle along the corners of the steps. The issue didn't appear to be due to concrete having more friction, since the bottom of the triangular structure was physically catching on one of the concrete stairs.

When the load was brought back to the top of the stairs the spring locks were easy for the user to attach on either side. To attach the spring locks, the carriage had to be brought up slightly higher than the top floor's level to be able to attach the spring locks. After attachment the winch was loosened and the carriage settled into place, allowing the user to then detach the winch and move it out of the way. The salt bags were then easy to reach and place onto the landing at the top of the steps. There was enough room to walk onto the side of the steps and move the salt bags onto the landing, of course, in a house this staircase would be less wide. Our lift was designed for the typical household stairwell width, meaning, only one of the top station's two-by-fours could rest against a railing. Since only one had a wall to push against, the system had to be slightly held to make sure the other side didn't start sliding towards the staircase. Neither of these outside staircases had the typical household staircase angle of 38 degrees that our platform was designed for, but it still worked, despite not being the angle it was designed for. As long as the payload can't slide off the cart the lift can be used for a small range of angles around 38 degrees.

8.3 Prototype components

Figure 20: The platform’s eye bolt that the winch attaches to

This eye bolt is where the winch connects to the platform to raise it up and down the stairs. This eye bolt was the part that was considered the bottle neck, which means it is the part/component of the entire system that would break or give first. The board that the eye bolt is run through is braced up against another 2x6 board.

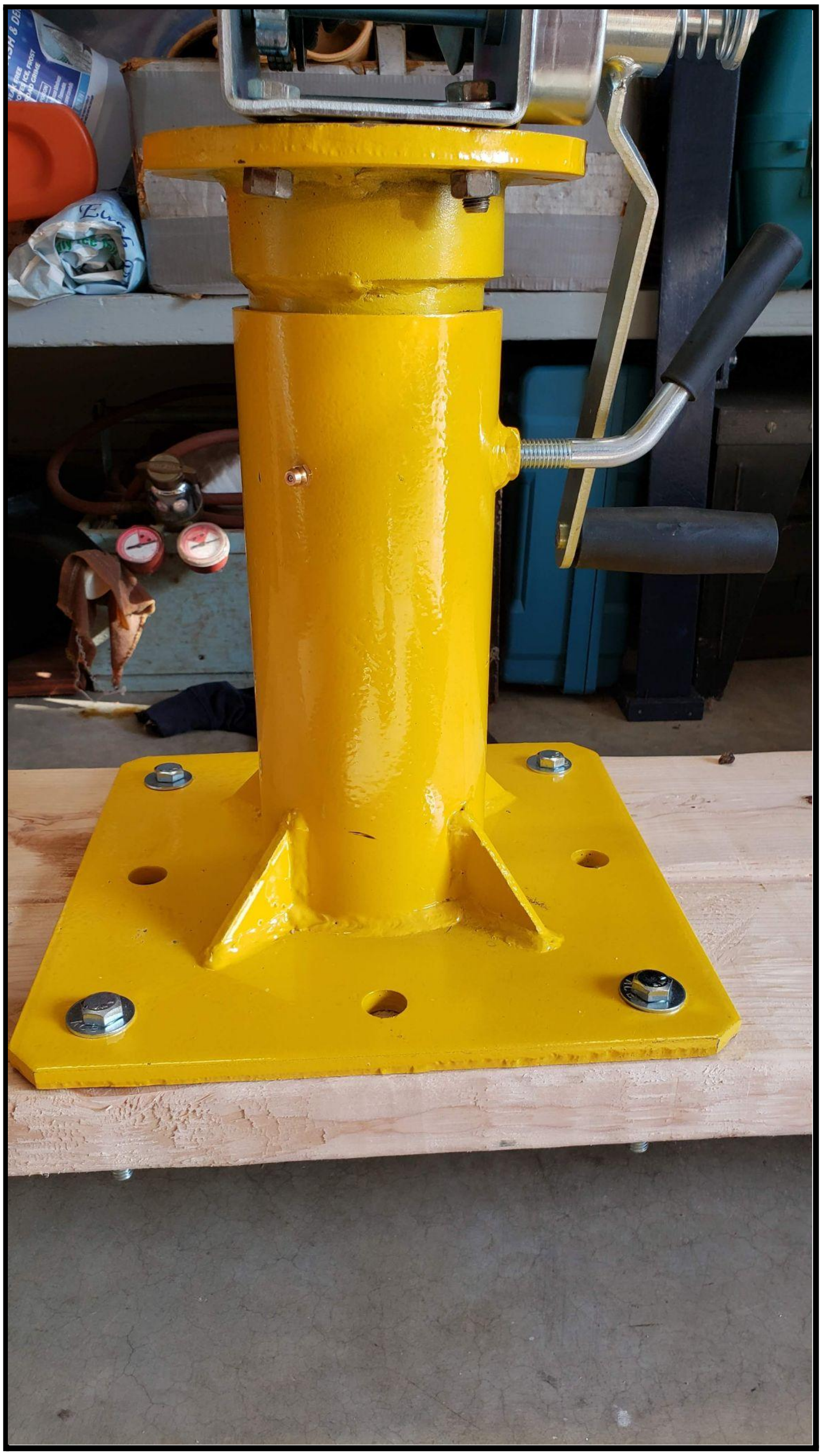


Figure 21: The base plate that links the top station and the winch

This base plate is the component of the system that gives the necessary height for the winch cable to run from the top station to the platform without hitting the stairs. Its height can be increased and can be locked in place with a rotating lever.

position.

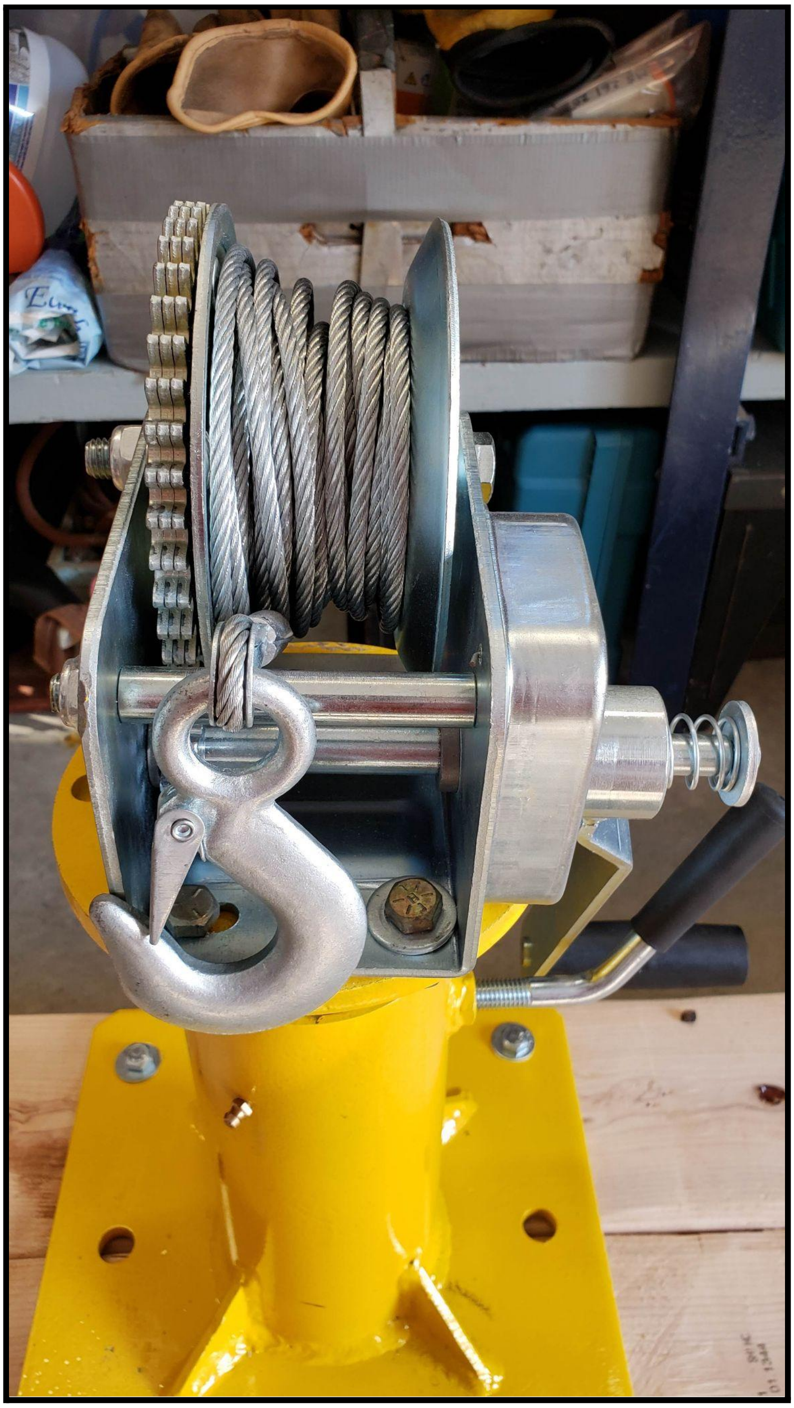


Figure 22: The winch that rests on top of the base plate

The winch's cable can be cranked out for attaching to the platform, and it can be reeled in or out to move the platform up or down the stairs. It has enough of a mechanical advantage to where the user does not have to strain to put the payload into motion. Using the hand crank's full range of rotational motion is comfortable for the user even when the base plate has been extended beyond its docked position.

Figure 23: The eye bolts on the station and platform with the chain and spring locks for linking up

On either end of the top station an eye bolt runs through, and on either end of the platform an eye bolt runs through. The station and platform eye bolts can be linked up with the chain and spring locks. Once the station and platform are linked up on either side, the platform is now held in place by the chains, and the winch cable can now be detached and moved out of the way for easier transfer from the platform to the floor at top of stairs.

Figure 24: The rails that run along the bottom of the platform

The rails run along the bottom of the platform for smoother and less damaging transfer. If we were not worried about risking destroying an indoor wood staircase at someone's house, then we would have attached the original material ideas of plexiglass or felt along the bottom of the platform. Since we were forced to test this prototype outside on a concrete staircase and a skatepark staircase, we chose to use metal L-channel instead. Based on our multiple testings these metal rails were ideal for the typical outside staircase.

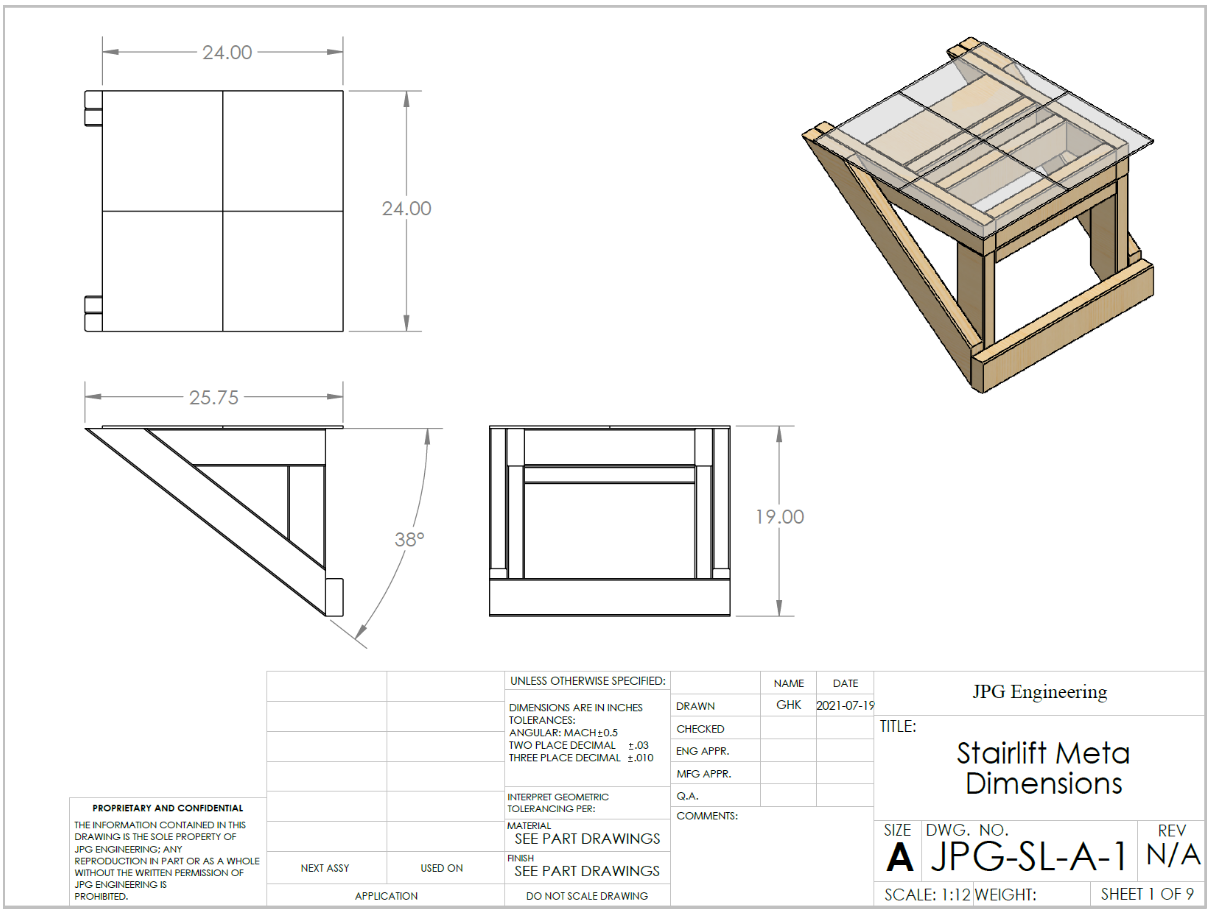
9 Design documentation

9.1 Final Drawings and Documentation

9.1.1 Engineering Drawings

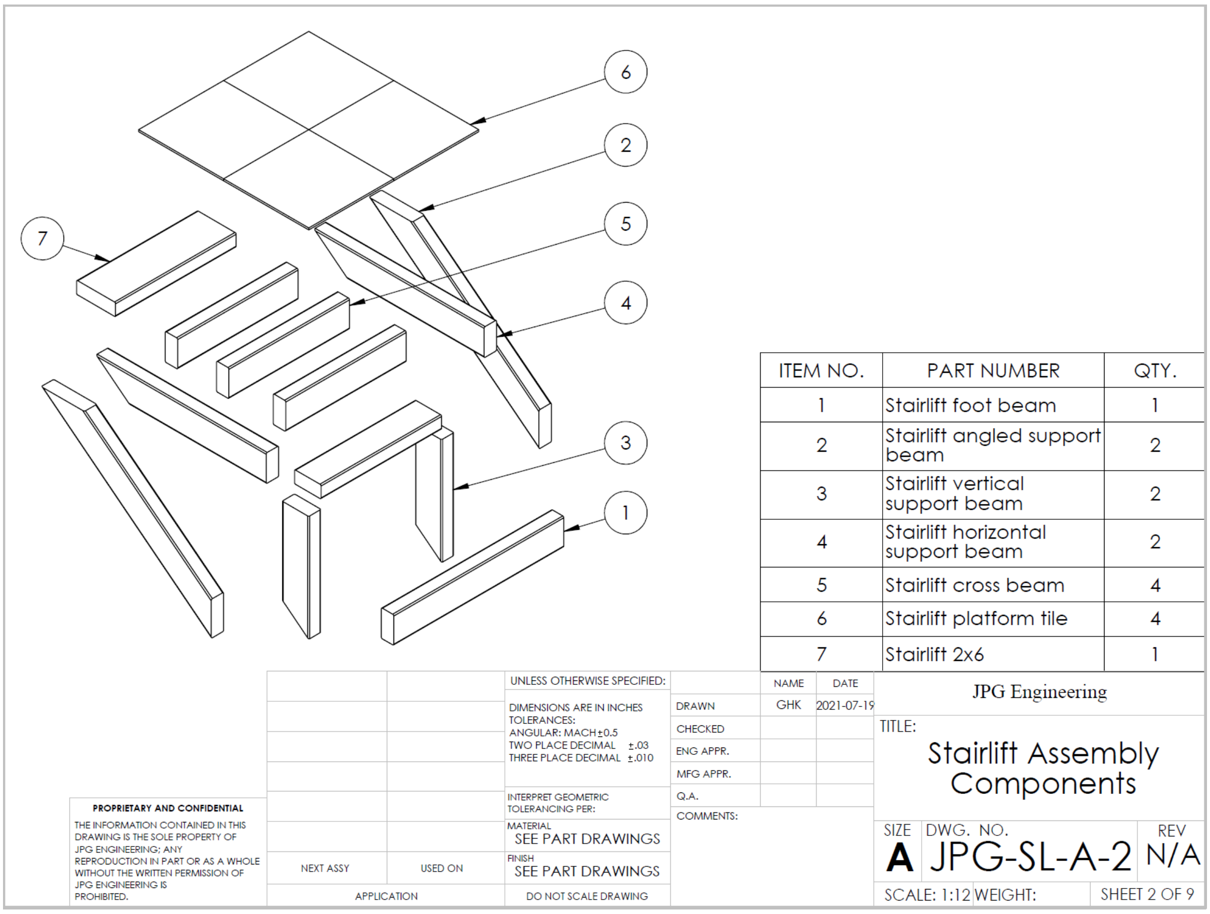
See Appendix C for the individual CAD models.

Here include a set of the final engineering drawings for your prototype. Include units on all CAD drawings.



PART: Triangular Structure Assembly

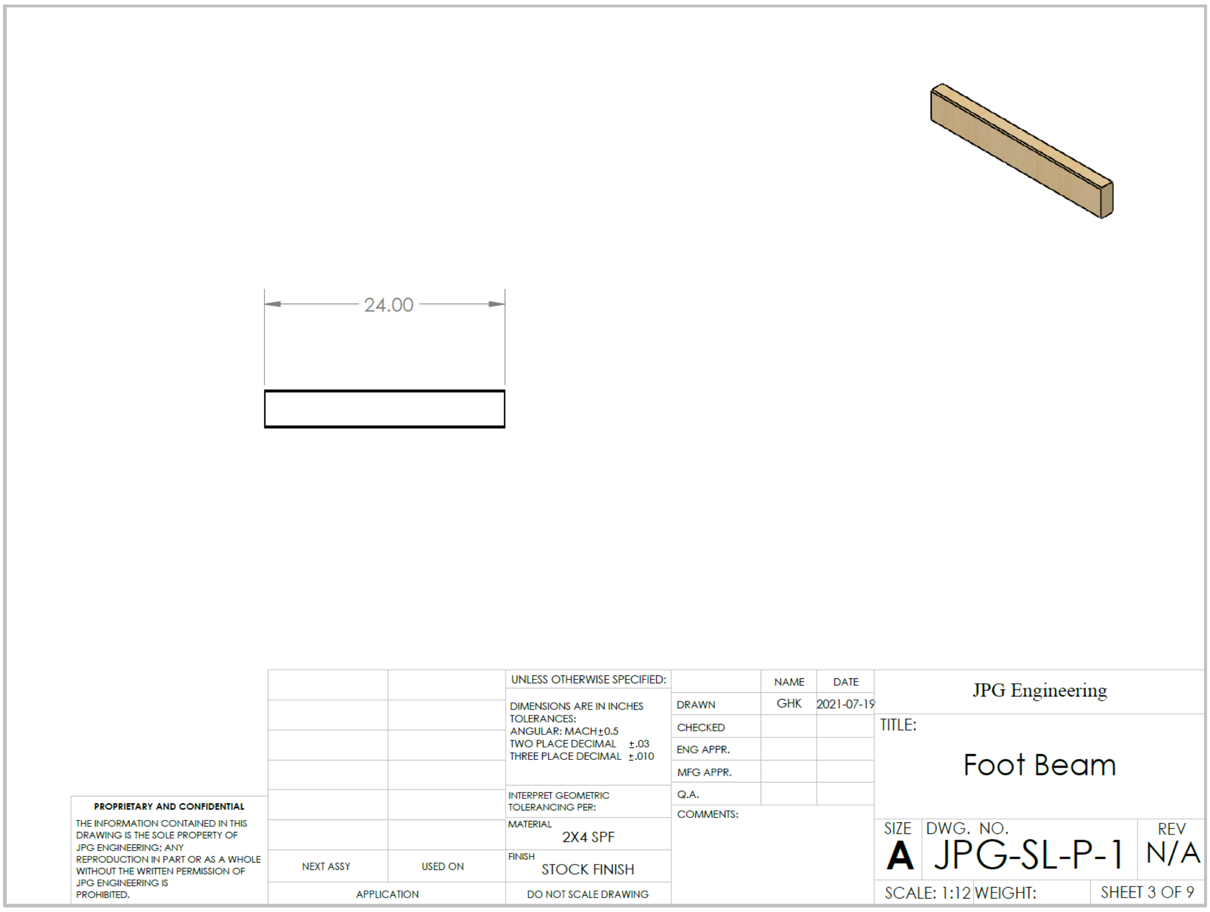
PURPOSE: captures the overall dimensions of the finished product.



ITEM NO.	PART NUMBER	QTY.
1	Stairlift foot beam	1
2	Stairlift angled support beam	2
3	Stairlift vertical support beam	2
4	Stairlift horizontal support beam	2
5	Stairlift cross beam	4
6	Stairlift platform tile	4
7	Stairlift 2x6	1

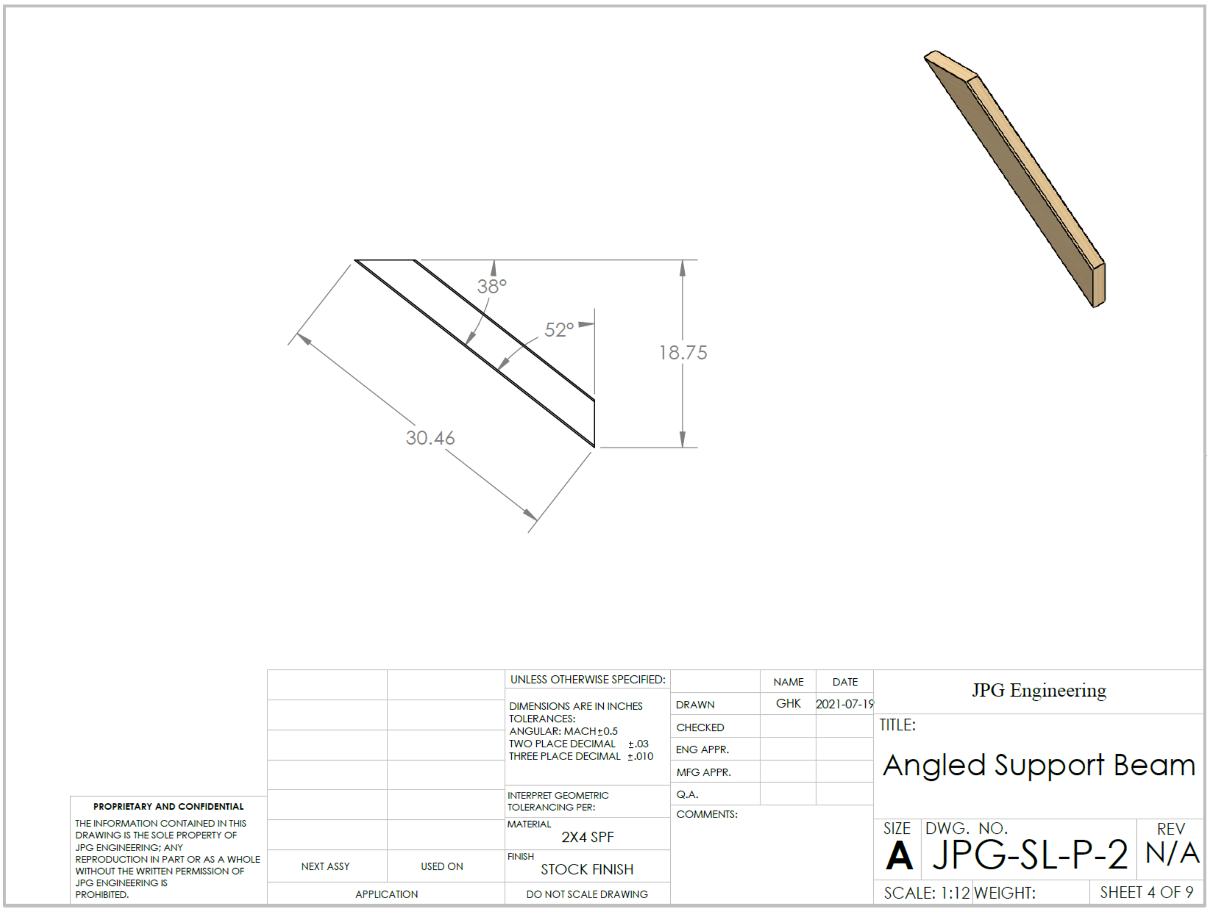
PART: Triangular Structure Components

PURPOSE: ballooned assembly parts and bill of materials.



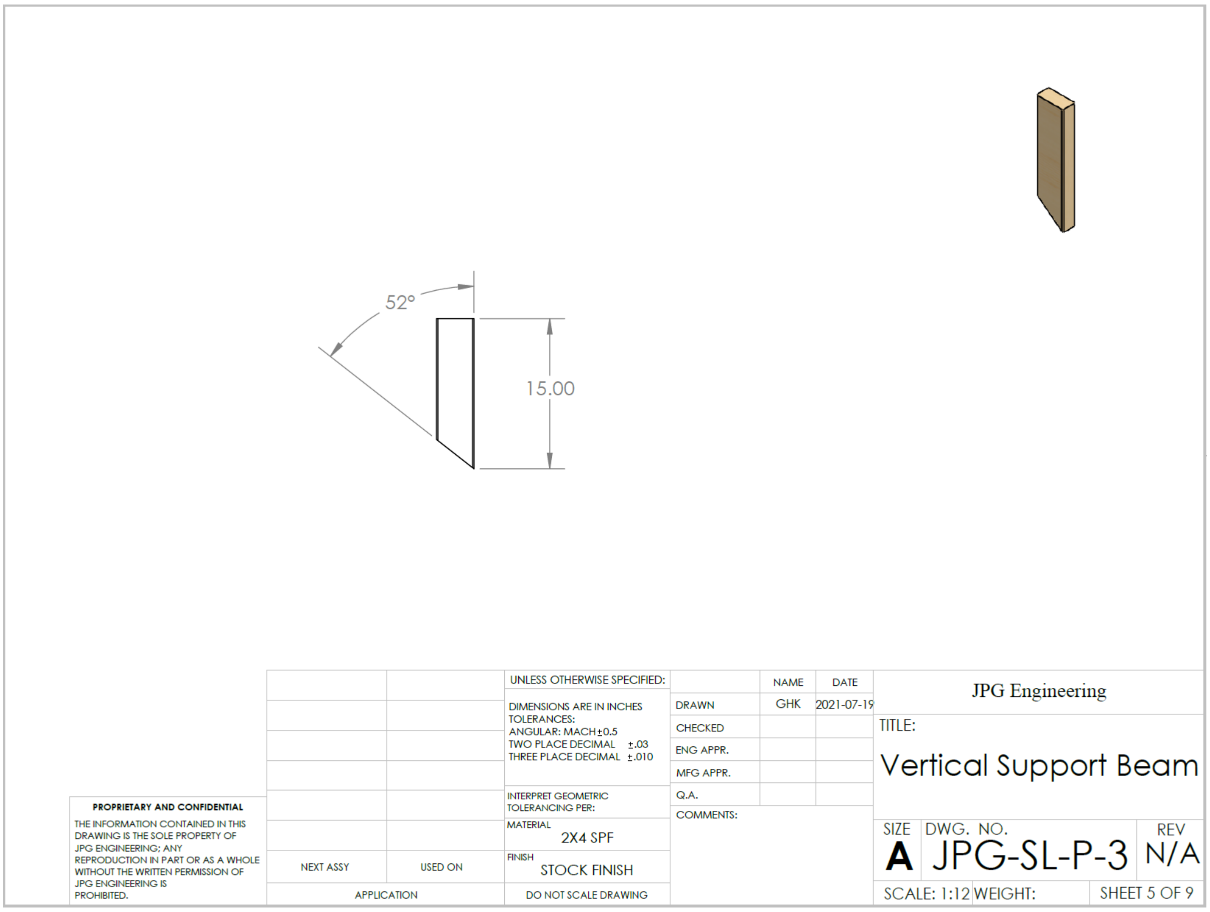
PART: Foot Beam

PURPOSE: this beam runs along the low end of the platform, serving as a buttress to the location where the platform rests on the floor at the bottom-stair position.



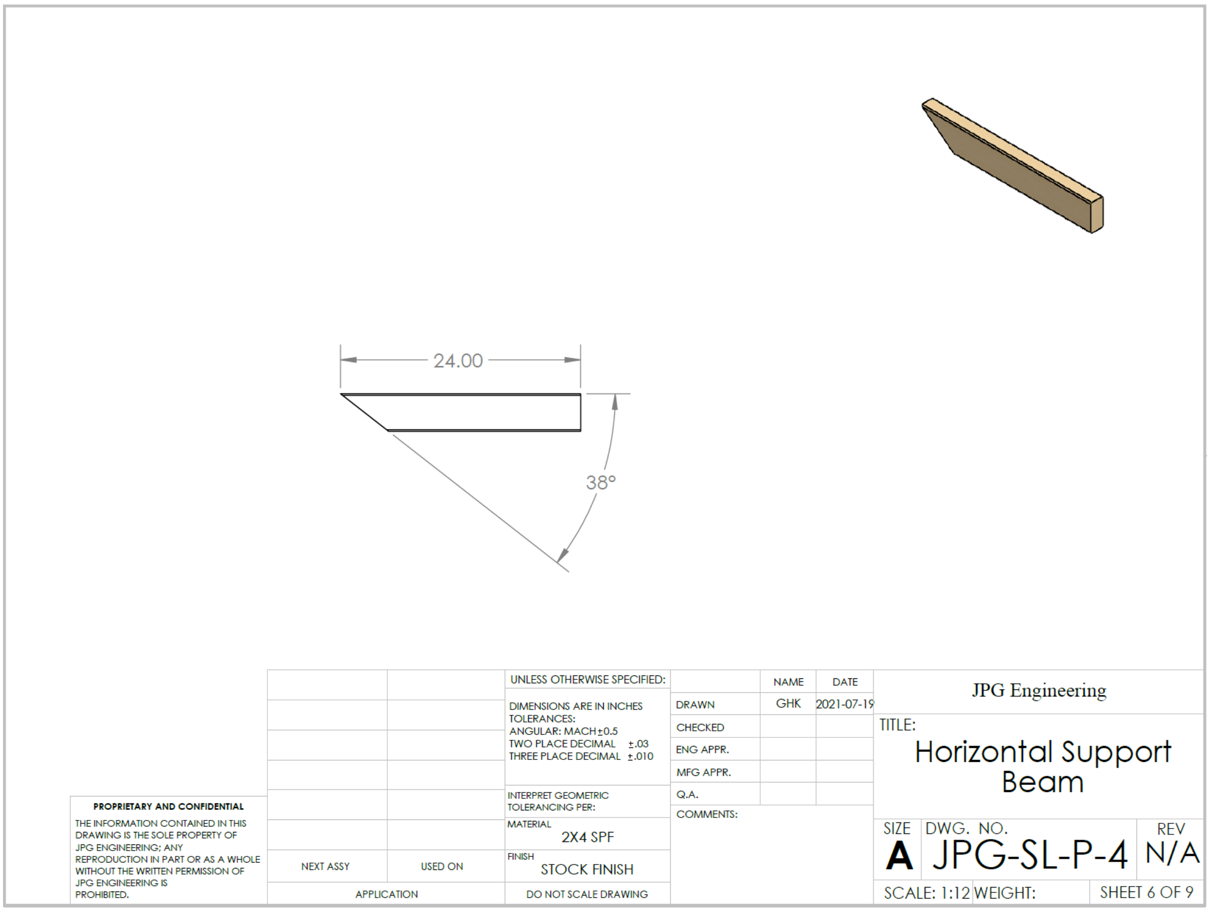
PART: Angled Support Beam

PURPOSE: This part serves as the rail on which the platform rides across the stairs' edges. The angled dimensions in this part are of particular importance, as they determine how level and square the platform sits.



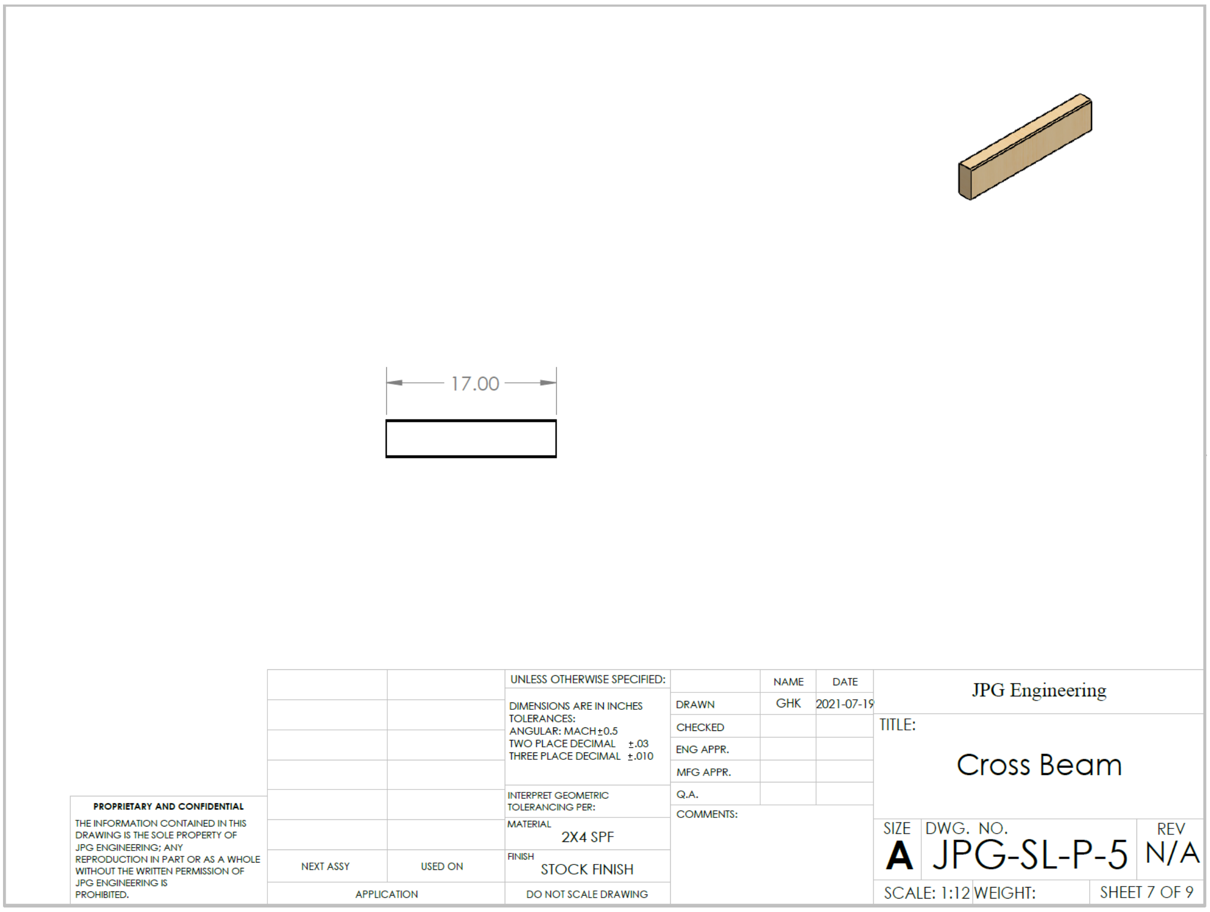
PART: Vertical Support Beam

PURPOSE: this part stands on-end on either side of the platform, closing the triangular structure.



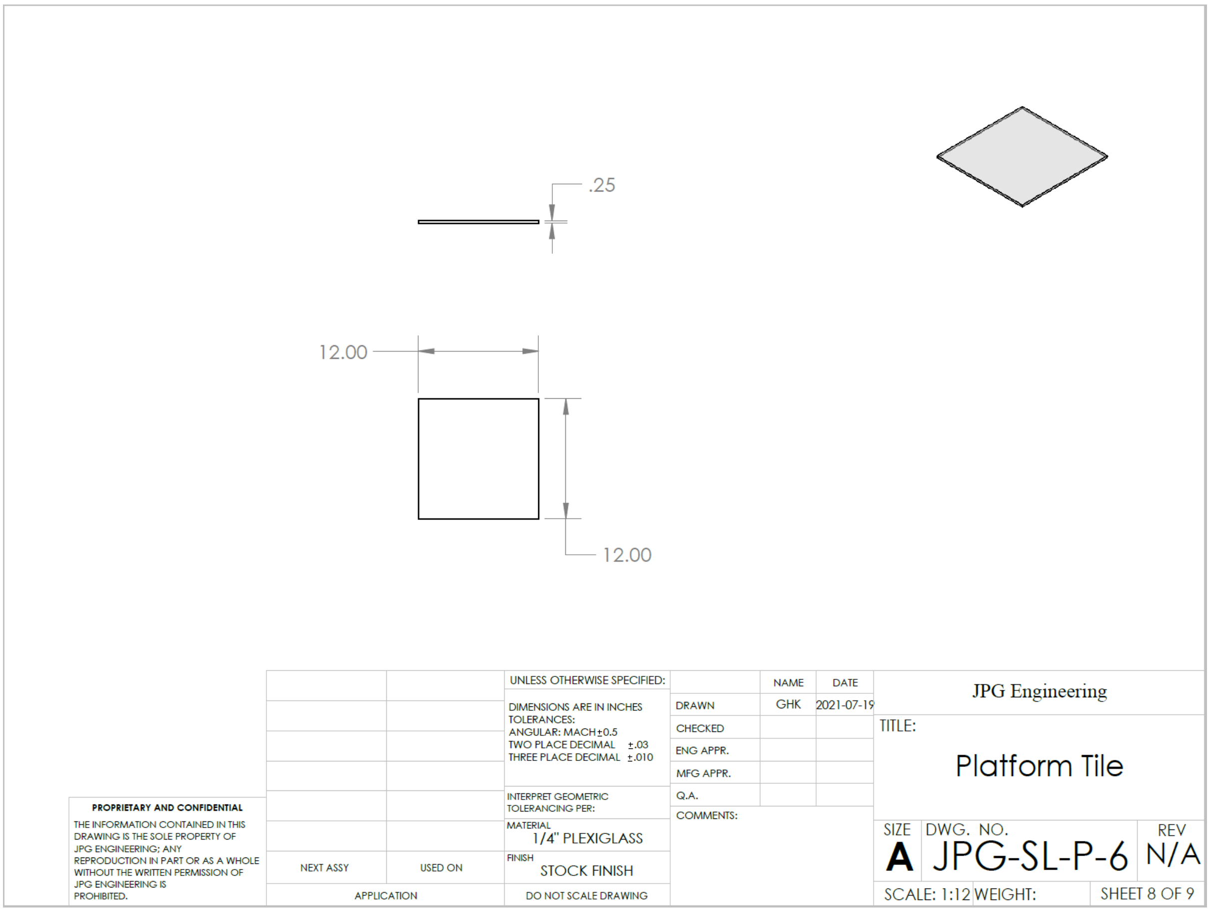
PART: Horizontal Support Beam

PURPOSE: this part runs along either side of the platform, tying the from end to the back end and directly supporting the outside edges of the plexiglass surface.



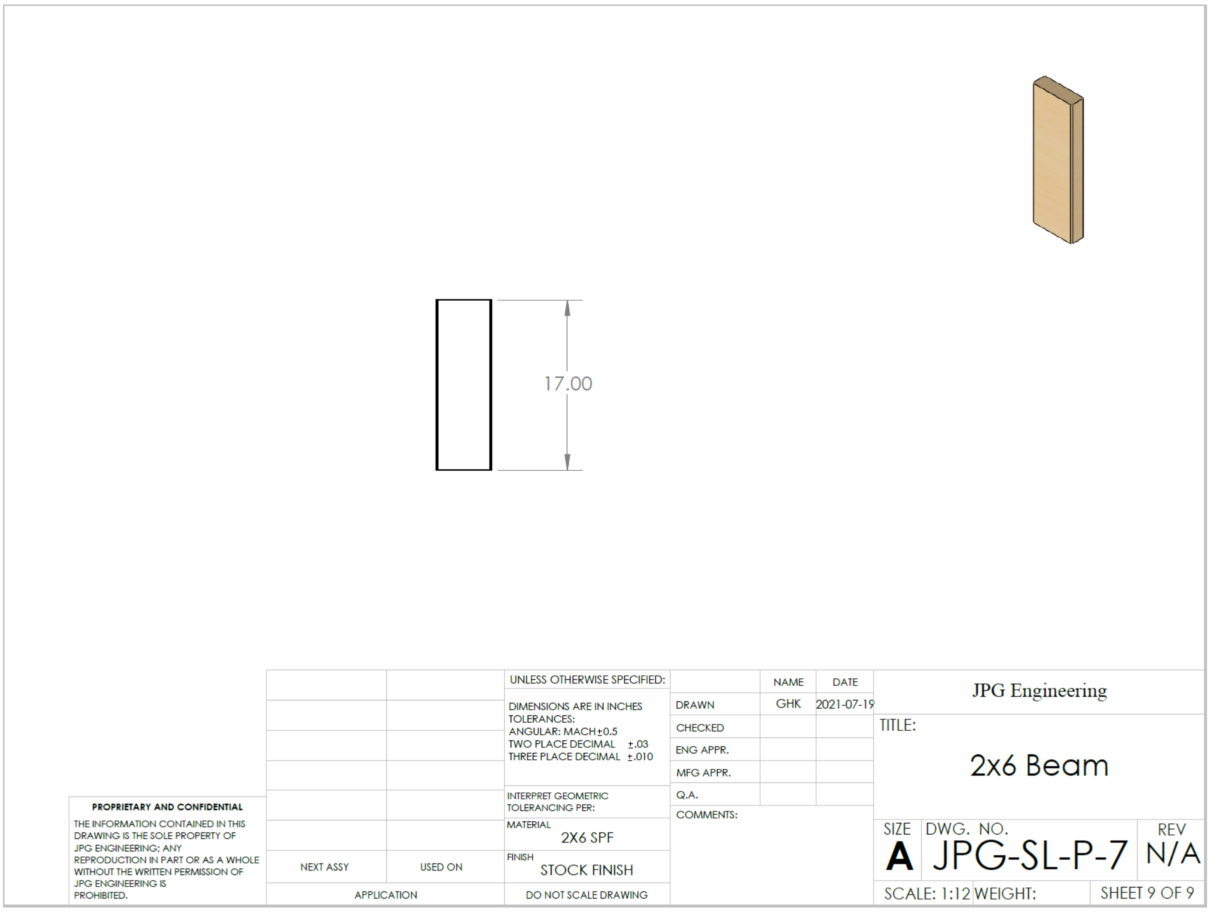
PART: Cross Beam

PURPOSE: this member runs perpendicular to the front-back axis of the platform, serving as support in the frame’s middle opening that is directly beneath where the payload rests.



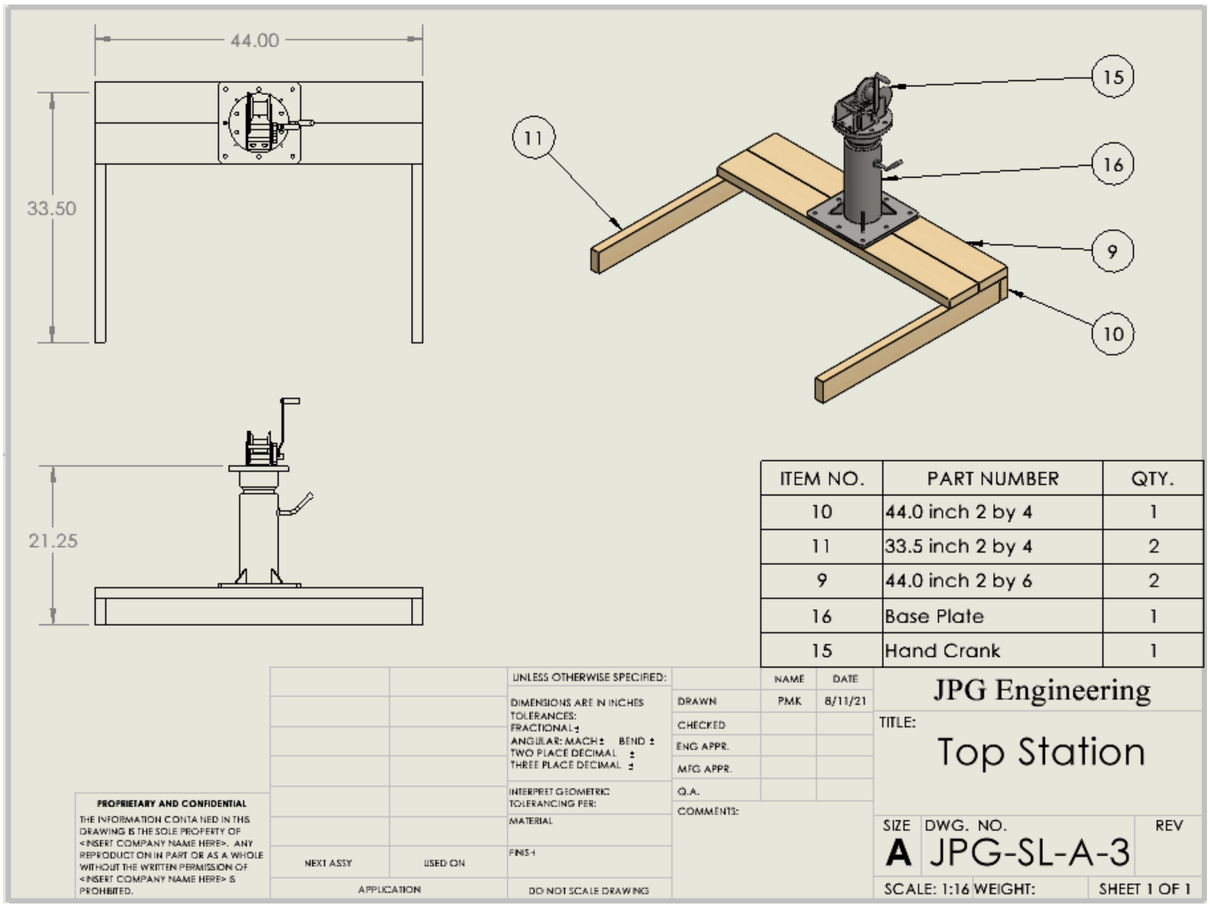
PART: Platform Tile

PURPOSE: this part closes the gaps between the wood members, providing a flat and continuous surface on which cargo can be placed. It prevents cargo from falling through the wood members and interfering with operation.



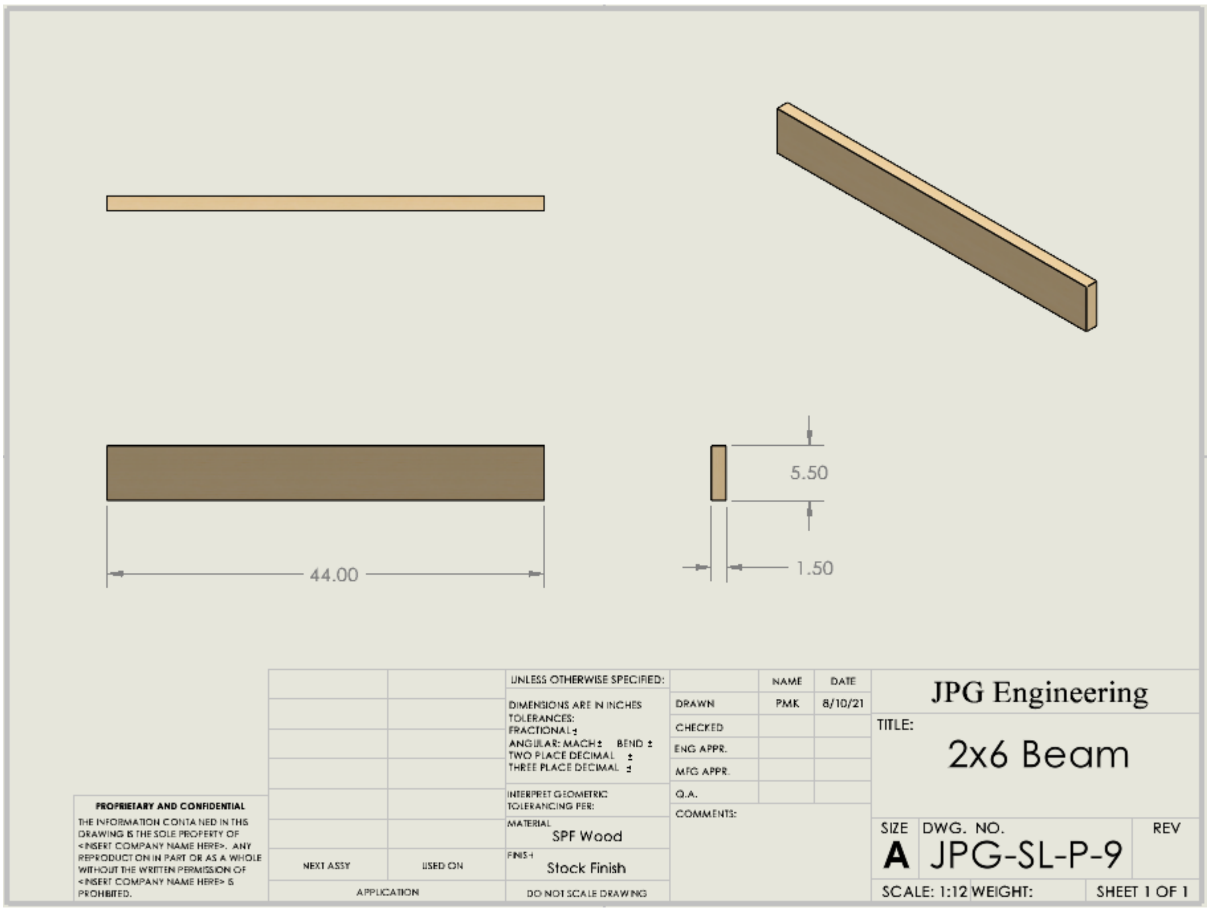
PART: 2x6 Beam

PURPOSE: this beam is set sideways up against the cross beam to which the eyebolt is attached. It serves as inertial support to the primary load-bearing wood member.



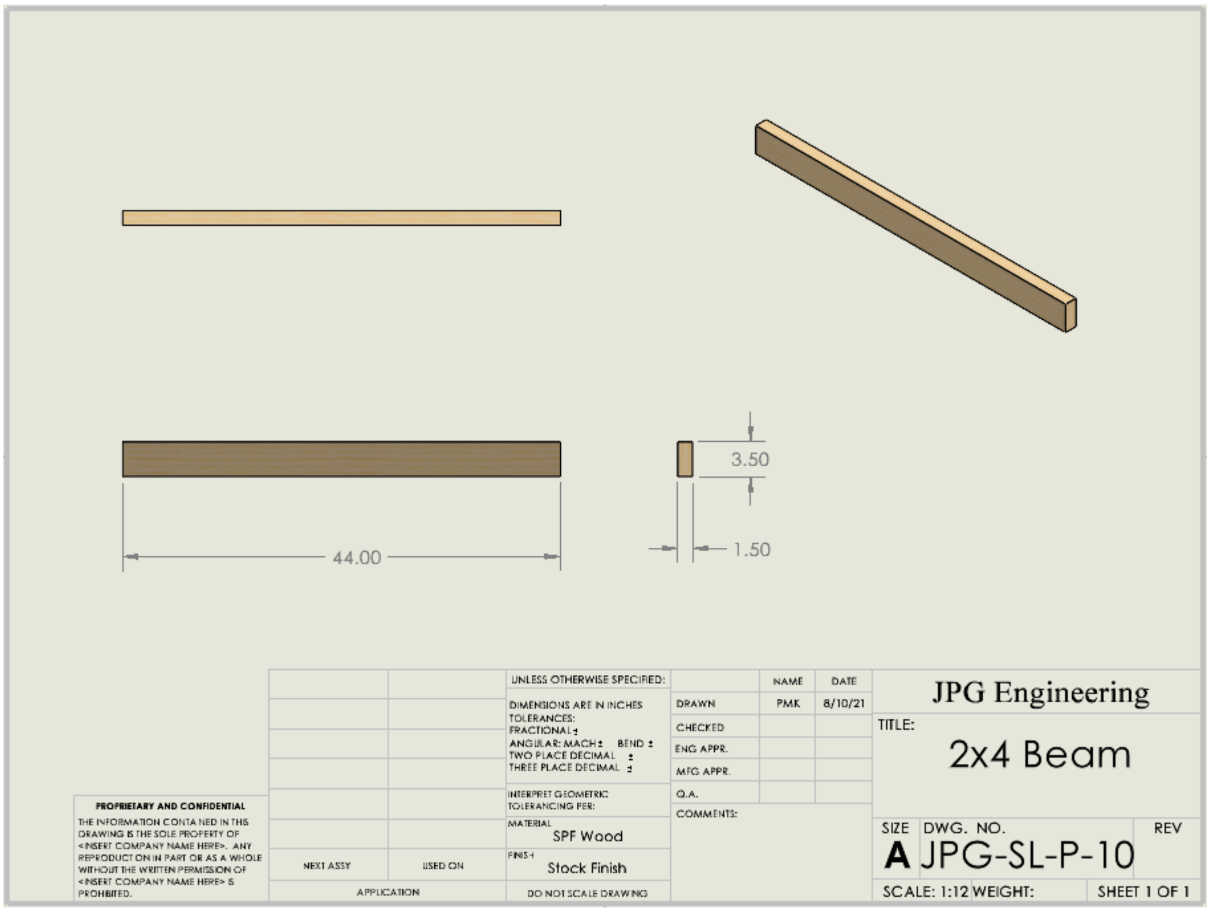
PART: Station Assembly

PURPOSE: as a fully assembled unit, this station will be used to transfer loads up and down stairs, while its wooden frame will prevent it from falling down the stairs through bracing.



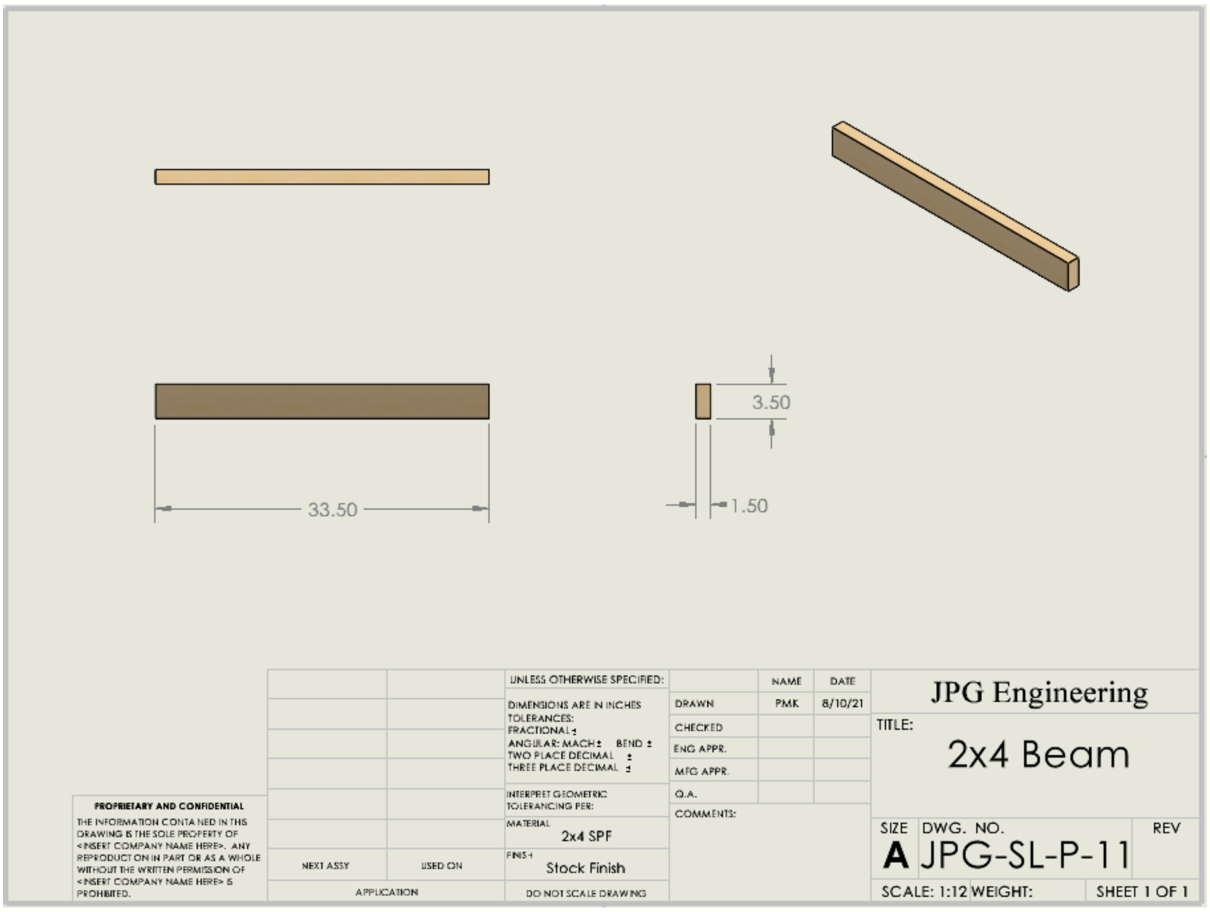
PART: 2x6 Panel

PURPOSE: these two 2x6's will be connected together and placed on the top back of the 2x4 frame of the station. This offers more structure through connecting all the wood and offers a surface for the base plate to rest on and attach to.



PART: 2x4 Backpiece

PURPOSE: this is the back piece of the top of the station. It connects to the two 2x4 runners to cumulatively form an arch shape. This base shape is the foundation of the station that rests directly on the floor.



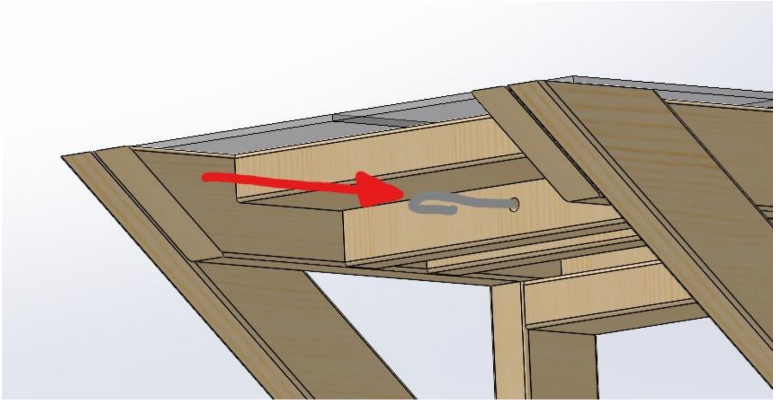
PART: 2x4 Runners

PURPOSE: these two 2x4 boards run from the back of the station to the walls on either side of the staircase. By bracing up against a wall, these boards prevent the station from sliding forward and tumbling down the stairs.

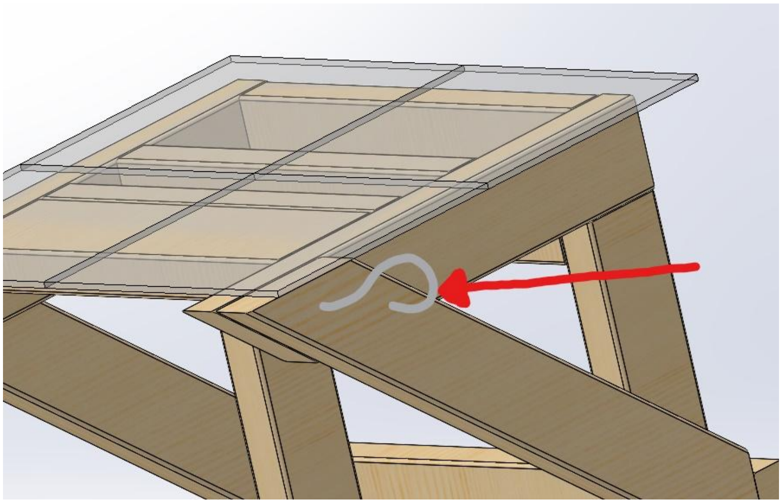
Assembly Instructions:

Triangular Platform:

1) Screw the four Cross Beams and two Horizontal Support Beams together as they lie flat on the floor. (15 screws total, two at each interface)
2) Screw the two Vertical Support Beams to the ends of the embossed Cross Beam. (4 screws total, two at each interface)
3) Screw the two Angled Support Beams on either side of the platform frame, ensuring their angles and orientations are aligned. (15 screws total, two at each interface)
4) Screw the Foot Beam to the bottom end of the platform where the Vertical Support Beams and Angled Support Beams meet. (4 screws total, two at each interface)
5) Fasten the large eye-bolt to the 2x4 as shown in the photo below: (the large eye-bolt, two washers, and the ½” nut)



6) Fasten the side eye-bolt as shown in the photo below: (one ⅜" eye-bolt, two washers, and a ⅜" nut)



7) Fasten the eye-bolt on the opposite side, making for an equivalently placed eye-bolt mirrored on each side. (one ⅜" eye-bolt, two washers, and a ⅜" nut)
8) Apply adhesive to the top surface of the wood frame and place the four Platform Tiles in the four quadrants of the load-bearing surface, with the tiles not protruding beyond the wood members around the perimeter of the platform in the upright position. Allow to cure for 4 hours minimum before use.

Top Station:

1) Screw the two runners into the backpiece to form the arch shape/structure. Make sure the runners' ends are attached to the side of the backpiece, and not the other way around. If you were to stand the arch up the backpiece would be resting on top of the other two boards.
2) Screw one of the 2x6 panel boards on top of the backpiece and the runner boards. Ensure the panel is flush against the backpiece. Now screw in the other 2x6 panel board onto the two runners, and make it flush against the other 2x6 panel.
3) Drill a hole on either end of the runners and put the ⅜ eye bolts through along with washers and hex nuts. Ensure the eye of the bolt is on the inside of the wood framing and not on the outside.

4) Place the base plate on the middle of the 2x11 panel formed by the 2x6's and drill the 4 corner holes through the wood. When drilling through, avoid hitting the backpiece board underneath. Bolt the base plate to the wood panel with 4 hex bolts, 4 hex nuts, and 8 washers.
5) Aline the front holes of the hand crank and the back lip of the hand crank with the holes in the top of the base plate. Run 4 bolts through along with washers and nuts to connect the hand crank. Make sure the hand crank cable is facing towards the inside of the frame or in the direction of the wooden runners.

9.1.2 Sourcing instructions

Table 10: Parts List

#	Description	Defining Dimensions	Quantity	Cost	Link
1	Foot Beam	2x4x24"	1	$1.03/ft	https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061
2	Angled Support Beam	2x4x30.5"	2		
3	Vertical Support Beam	2x4x15"	2		
4	Horizontal Support Beam	2x4x24"	2		
5	Cross Beam	2x4x17"	4		
6	Platform Tile	12x12x1/4"	4	$16.95/sqft	https://www.amazon.com/Acrylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_3?dchild=1&keywords=12x12+1%2F4+plexiglass&qid=1626723166&sr=8-3
7	2x6 Beam	2x6x17"	1	$1.55/ft	https://www.homedepot.com/p/2-in-x-6-in-x-12-ft-

					2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x6x12/206804070
8	SPF Wood	2x8x8	1		SEE #1-5
9	SPF Wood	2x12x44	1		SEE #7
10	SPF Wood	2x4x44	1		SEE #1-5
11	SPF Wood	2x4x36.5	2		SEE #1-5
12	Eye Bolt	⅜ in. x 4 in.	4	$1.05/ea	https://www.homedepot.com/p/Everbilt-3-8-in-x-4-in-Zinc-Plated-Eye-Bolt-with-Nut-807206/204273498#overlay
13	Chain	¼ in. x 1 ft.	2 ft.	$2.72/ft.	https://www.homedepot.com/p/Everbilt-1-4-in-x-1-ft-Zinc-Plated-Proof-Coil-Chain-806626/204630506
14	Spring Lock	¼ in. x 2-⅜ in.	4	$2.25/ea	https://www.homedepot.com/p/Everbilt-1-4-in-x-2-3-8-in-Zinc-Plated-Spring-Link-42744/205883098
15	Hand Crank	1,000 lbs capacity	1	$41.99	https://www.amazon.com/AC-DK-Op

					eration-Including-Handles-Trailers/dp/B07YC7B92P/ref=sr_1_1_sspa?dchild=1&keywords=manual+winch+1000+lbs&qid=1626723000&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRjdIUFI3TEVRU0laJmVuY3J5cHRlZElkPUEwOTg5MjQ5MTFWTEpCMVc5VlBIMSZlbmNyeXB0ZWRBZElkPUEwMDk3NTk5MzlUNEhMQzJDNFkyVyZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=
16	Base Plate	~	1	$462.42 (minus rest of kit)	https://www.amazon.com/Vestil-WTJ-4-Painted-Extended-Capacity/dp/B00NQZ0QQY
17	Exterior Screws	2-½ in.	1	$7.98/lb	https://www.

					homedepot.com/p/Grip-Rite-9-x-2-1-2-in-Philips-Bugle-Head-Coarse-Thread-Sharp-Point-Polymer-Coated-Exterior-Screws-1-lb-Pack-PTN212S1/100173447
18	Zinc Hex Bolt	⅜ in. x 3 in.	4	$0.49/ea	https://www.homedepot.com/p/Everbilt-3-8-in-16-x-3-in-Zinc-Plated-Hex-Bolt-800866/204645565
19	Zinc Hex Nut	⅜ in.	4	$0.15/ea	https://www.homedepot.com/p/Everbilt-3-8-in-16-Zinc-Plated-Hex-Nut-801756/204647890
20	Zinc Flat Washer	⅜ in.	10	$0.17/ea	https://www.homedepot.com/p/Everbilt-3-8-in-Zinc-Flat-Washer-804586/204633114

7.2 Final Presentation

Here is the link to the video presentation: https://youtu.be/zNWAra9EE7w

8 Teardown

~ Not Applicable ~

9 Appendix A - Parts List

* This is an initial list of parts for the cost of raw materials, components, assemblies etc.

Table 11: Parts List

<table>
<tr><th>#</th><th>Description</th><th>Defining Dimensions</th><th>Quantity</th><th>Cost</th><th>Link</th></tr>
<tr><td>1</td><td>Foot Beam</td><td>2x4x24”</td><td>1</td><td rowspan="5">$1.03/ft</td><td rowspan="5">https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061</td></tr>
<tr><td>2</td><td>Angled Support Beam</td><td>2x4x30.5”</td><td>2</td></tr>
<tr><td>3</td><td>Vertical Support Beam</td><td>2x4x15”</td><td>2</td></tr>
<tr><td>4</td><td>Horizontal Support Beam</td><td>2x4x24”</td><td>2</td></tr>
<tr><td>5</td><td>Cross Beam</td><td>2x4x17”</td><td>4</td></tr>
<tr><td>6</td><td>Platform Tile</td><td>12x12x1/4”</td><td>4</td><td>$16.95/sqft</td><td>https://www.amazon.com/Acrylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_3?dchild=1&keywords=12x12+1%2F4+plexiglass&qid=1626723166&sr=8-3</td></tr>
<tr><td>7</td><td>2x6 Beam</td><td>2x6x17”</td><td>1</td><td>$1.55/ft</td><td>https://www.homedepot.com/p/2-in-x-6-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x6x12/206804070</td></tr>
<tr><td>8</td><td>SPF Wood</td><td>2x8x8</td><td>1</td><td></td><td>SEE #1-5</td></tr>
</table>

9	SPF Wood	2x12x44	1		SEE #7
10	SPF Wood	2x4x44	1		SEE #1-5
11	SPF Wood	2x4x36.5	2		SEE #1-5
12	Eye Bolt	⅜ in. x 4 in.	4	$1.05/ea	https://www.homedepot.com/p/Everbilt-3-8-in-x-4-in-Zinc-Plated-Eye-Bolt-with-Nut-807206/204273498#overlay
13	Chain	¼ in. x 1 ft.	2 ft.	$2.72/ft.	https://www.homedepot.com/p/Everbilt-1-4-in-x-1-ft-Zinc-Plated-Proof-Coil-Chain-806626/204630506
14	Spring Lock	¼ in. x 2-⅜ in.	4	$2.25/ea	https://www.homedepot.com/p/Everbilt-1-4-in-x-2-3-8-in-Zinc-Plated-Spring-Link-42744/205883098
15	Winch	1,000 lbs capacity	1	$41.99	https://www.amazon.com/AC-DK-Operation-Including-Handles-Trailers/dp/B07YC7B92P/ref=sr_1_1_sspa?dchild=1&keywords=manual+winch+1000+lbs&qid=1626723000&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRjdIUF

					I3TEVRU0laJmVuY3J5cHRlZElkPUEwOTg5MjQ5MTFWTEpCMVc5VlBIMSZlbmNyeXB0ZWRBZElkPUEwMDk3NTk5MzlUNEhMQzJDNFkyVyZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=
16	Base Plate	~	1	$462.42 (minus rest of kit)	https://www.amazon.com/Vestil-WTJ-4-Painted-Extended-Capacity/dp/B00NQZ0QQY

10 Appendix B - Bill of Materials

* This is the final list of parts for the cost of raw materials, components, assemblies etc. which states the actual bill of your final project.

Table 12: Parts List

#	Description	Defining Dimensions	Quantity	Cost	Link
1	Foot Beam	2x4x24”	1	$1.03/ft	https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061
2	Angled Support Beam	2x4x30.5”	2		
3	Vertical Support Beam	2x4x15”	2		
4	Horizontal Support Beam	2x4x24”	2		
5	Cross Beam	2x4x17”	4		
					https://www.amazon.com/A

6	Platform Tile	12x12x1/4”	4	$16.95/sqft	crylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_3?dchild=1&keywords=12x12+1%2F4+plexiglass&qid=1626723166&sr=8-3
7	2x6 Beam	2x6x17”	1	$1.55/ft	https://www.homedepot.com/p/2-in-x-6-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x6x12/206804070
8	SPF Wood	2x8x8	1		SEE #1-5
9	SPF Wood	2x12x44	1		SEE #7
10	SPF Wood	2x4x44	1		SEE #1-5
11	SPF Wood	2x4x36.5	2		SEE #1-5
12	Eye Bolt	⅜ in. x 4 in.	4	$1.05/ea	https://www.homedepot.com/p/Everbilt-3-8-in-x-4-in-Zinc-Plated-Eye-Bolt-with-Nut-807206/204273498#overlay
13	Chain	¼ in. x 1 ft.	2 ft.	$2.72/ft.	https://www.homedepot.com/p/Everbilt-1-4-in-x-1-ft-Zinc-Plated-Proof-Coil-Chain-806626/204630506

14	Spring Lock	¼ in. x 2-⅜ in.	4	$2.25/ea	https://www.homedepot.com/p/Everbilt-1-4-in-x-2-3-8-in-Zinc-Plated-Spring-Link-42744/205883098
15	Hand Crank	1,000 lbs capacity	1	$41.99	https://www.amazon.com/AC-DK-Operation-Including-Handles-Trailers/dp/B07YC7B92P/ref=sr_1_1_sspa?dchild=1&keywords=manual+winch+1000+lbs&qid=1626723000&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRjdIUFI3TEVRU0laJmVuY3J5cHRlZElkPUEwOTg5MjQ5MTFWTEpCMVc5VlBIMSZlbmNyeXB0ZWRBZElkPUEwMDk3NTk5MzlUNEhMQzJDNFkyVyZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=
16	Base Plate	~	1	$462.42 (minus rest of kit)	https://www.amazon.com/Vestil-WTJ-4-Painted-Extended-Capacit

					y/dp/B00NQZ0QQY
17	Exterior Screws	2-½ in.	1	$7.98/lb	https://www.homedepot.com/p/Grip-Rite-9-x-2-1-2-in-Philips-Bugle-Head-Coarse-Thread-Sharp-Point-Polymer-Coated-Exterior-Screws-1-lb-Pack-PTN212S1/100173447
18	Zinc Hex Bolt	⅜ in. x 3 in.	4	$0.49/ea	https://www.homedepot.com/p/Everbilt-3-8-in-16-x-3-in-Zinc-Plated-Hex-Bolt-800866/204645565
19	Zinc Hex Nut	⅜ in.	4	$0.15/ea	https://www.homedepot.com/p/Everbilt-3-8-in-16-Zinc-Plated-Hex-Nut-801756/204647890
20	Zinc Flat Washer	⅜ in.	10	$0.17/ea	https://www.homedepot.com/p/Everbilt-3-8-in-Zinc-Flat-Washer-804586/204633114

Table 13: Costs

No.	Item Description	Unit	Unit Cost	Qty.	Material	Labor	Total	Links/Sources
1	Foot Beam ~ 2x4x24	ft.	$1.03	2			$2.06	https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061
2	Angled Support Beam ~ 2x4x30.5	ft.	$1.03	2.54			$2.62	
3	Vertical Support Beam ~ 2x4x15	ft.	$1.03	1.25			$1.29	
4	Horizontal Support Beam ~ 2x4x24	ft.	$1.03	2			$2.06	
5	Cross Beam ~ 2x4x17	ft.	$1.03	1.42			$1.46	
6	Platform Tile ~ 12x12x1/4	sqft.	$16.95	4			$67.80	https://www.amazon.com/Acrylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_3?dchild=1&keywords=12x12+1%2F4+plexiglass&qid=1626723166&sr=8-3
7	2x6x17 Beam	ft.	$1.55	1.42			$2.20	https://www.homedepot.com/p/2-in-x-6-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x6x12/206804070
8	Topboard ~ 2x6x44	ft.	$1.55	3.67			$5.69	
9	Backboard ~ 2x4x44	ft.	$1.03	3.67			$3.78	https://www.homedepot.com/p/2-in-x-4-in-x-12-ft-2-and-Better-Prime-Douglas-Fir-Board-HCF-KDDF-PRIME-2x4x12/206804061
10	Runner boards ~ 2x4x36.5	ft.	$1.03	3.04			$3.13	
11	Eyebolt	ea.	$1.05	4			$4.20	https://www.homedepot.com/p/Everbilt-3-8-in-x-4-in-Zinc-Plated-Eye-Bolt-with-Nut-807206/204273498#overlay
12	Chain ~ 1/4 in. dia. x 1 ft.	ft.	$2.72	2			$5.44	https://www.homedepot.com/p/Everbilt-1-4-in-x-1-ft-Zinc-Plated-Proof-Coil-Chain-806626/204630506
13	Spring Lock ~ 1/4 in. dia. x 2-3/8 in.	ea.	$2.25	4			$9.00	https://www.homedepot.com/p/Everbilt-1-4-in-x-2-3-8-in-Zinc-Plated-Spring-Link-42744/205883098
14	Winch 1000 lbs. capacity	ea.	$41.99	1			$41.99	https://www.amazon.com/AC-DK-Operation-Including-Handles-Trailers/dp/B07YC7B92P/ref=sr_1_1_sspa?dchild=1&keywords=manual+winch+1000+lbs&qid=1626723000&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRjdlUFI3TEVRU0laJmVuY3J5cHRlZElkPUEwOTg5MjQ5MTFWTEpCMVc5VlBIMSZlbmNyeXB0ZWRBZElkPUEwMDk3NTk5MzlUNEhMQzJDNFkyVyZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=
15	Base Plate	ea.	$75.00	1			$75.00	https://www.amazon.com/Vestil-WTJ-4-Painted-Extended-Capacity/dp/B00NQZ0QQY
16	Exterior Screws	lb.	$7.98	1	Zinc		$7.98	https://www.homedepot.com/p/Grip-Rite-9-x-2-1-2-in-Philips-Bugle-Head-Coarse-Thread-Sharp-Point-Polymer-Coated-Exterior-Screws-1-lb-Pack-PTN212S1/100173447
17	Zinc Hex Bolt	ea.	$0.49	4	Zinc		$1.96	https://www.homedepot.com/p/Everbilt-3-8-in-16-x-3-in-Zinc-Plated-Hex-Bolt-800866/204645565
18	Zinc Hex Nut	ea.	$0.15	4	Zinc		$0.60	https://www.homedepot.com/p/Everbilt-3-8-in-16-Zinc-Plated-Hex-Nut-801756/204647890
19	Zinc Flat Washer	ea.	$0.17	10	Zinc		$1.70	https://www.homedepot.com/p/Everbilt-3-8-in-Zinc-Flat-Washer-804586/204633114
20								
21								
22								
23								
24								
25								
26								
27								
28								
29	Total Direct costs						$239.96	
30								
31	Indirect Overhead Costs							
32								
33								
34								
35	Total before contingency						$239.96	
36	Contingency (15%)						$35.99	
37	Engineers estimate					Subtotal, Page 1:	$275.95	

11 Appendix C – Complete List of Engineering Drawings

The following link leads to a zipped file that contains the SolidWorks CAD files for the top station, the triangular structure, and each of their respective components.

https://drive.google.com/file/d/14YnZ4zy0SUWrF0qDIiHjs8q9zohRQgTK/view?usp=sharing

12 Annotated Bibliography

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2. The American Society of Mechanical Engineers, "MONONGAHELA AND DUQUESNE INCLINES." 1977,

https://www.asme.org/wwwasmeorg/media/resourcefiles/aboutasme/who%20we%20are/engineering%20history/landmarks/26-monongahela-incline-1870.pdf

3. The American Society of Mechanical Engineers, "Safety Standard for Platform Lifts and Stairway Chairlifts." 2021,

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