Ski Haus Tow Rope

Preliminary Report

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DISCLAIMER

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1. BACKGROUND

1.1 Introduction

Freestyle skiing and snowboarding is a growing aspect of ski resorts internationally, terrain parks have been built containing challenging features for riders to attempt aerial maneuvers on. Traditional chairlifts have been found to be too slow for riders who want to complete multiple runs in the terrain park in an efficient manner, so resorts began installing tow ropes to pull the riders up the hill. These tow ropes are industrial and permanent installations, which Arizona Snowbowl does not have the available space nor budget for. Competitive events are the most important application of a tow rope, as there is a time limit to the competition, which a chairlift will waste. Ski Haus, a local winter sports retail and rental shop in Flagstaff Arizona, has begun hosting these rail jam competitions at Arizona Snowbowl. Due to the largest turn out of competitors in 2020, it is only expected to grow. Due to the time limit and hiking requirement of these competitions, Ski Haus has been searching for a portable tow rope that can be utilized to efficiently transport their competitors back up the slope. Unfortunately, existing products are far too expensive and require large vehicles for transportation, creating a contemporary issue that several local ski areas and competition hosts face. This capstone project will center around the design and build of a portable, motorized device able to haul skiers and snowboarders up a slope via a rope. The Ski Haus capstone team will produce a tow rope that satisfies the specifications required by Ski Haus as well as provide complete safety for the users of the device.

The importance of this project is safety. Rail jam competitions are inherently dangerous, but when fatigue from hiking the slope is mandatory, injury is much more prevalent. Ski Haus places a large emphasis on the skiing and snowboarding community. Their goal with these competitions is to give everybody a chance to build their skillset and have fun with riders alike. The safer these competitions are, the more likely they are to continue with a positive outlook. Implementing this tow rope will greatly improve professionalism while preventing potential injury. Due to the time limit in these competitions, efficiently towing these competitors will increase their ride time, directly increasing their score. The portability also allows the device to be utilized for training purposes in both snow and dry land conditions. Overall, it is important to design a safe tow rope for Ski Haus as it will promote a better competition scene as well as a large skiing and snowboarding community centered around safe and professional riding.

1.2 Project Description

Ski Haus, in need of a portable towing device, met with our team and proposed their idea. Following is the original project description provided by the sponsor.

> For the use of our competitions and urban rail jam features, Ski Haus would like to sponsor the design and build of a portable and collapsible tow rope that can pull people up a slope, the length of two ski lift towers. It must be gas powered and implement an emergency stop button with durable parts to withstand transportation and extreme climates. We need this tow rope to be efficient for timed events but overall safe for all users.

This description has outlined our preliminary design and has not been altered much. From the original description, the design has deleted the requirement of being collapsible and put an emphasis on weight over size. This is due to the design emphasizing safety and a collapsible system may jeopardize that. With Ski Haus using the tow rope for urban and backyard set ups as well, interchangeable rope lengths are needed. Overall, Ski Haus's description has stayed consistent from the beginning.

2. REQUIREMENTS

Chapter two contains the necessary requirements to be met through this tow rope design, beginning with the quality needs set by the sponsor Ski Haus. These customer requirements produce a baseline for the design and everything to be included. Next, quantitative requirements were constructed based on the customer needs. A house of quality then provides an analytical matrix that relates the customer's needs and their technical requirements. All these detailed requirements are used to professionally design the Ski Haus tow rope.

2.1 Customer Requirements (CRs)

The presented customer requirements are the specifications deemed necessary by our sponsor, Ski Haus. Based on the project description produced by the sponsor, quality requirements were generated to set a baseline for concept generation. The following customer requirements are the specific design targets that our team must ensure are met through the project. Additionally, all needs have a specific weight that was created with input from the sponsor to guarantee importance over some aspects of the design than others. These weights range from 1 to 5 with 1 obtaining the lowest importance and 5 with the highest.

Through communication with Ski Haus, it was apparent that safety for all riders and operators was the most important aspect of the design. For this reason, it was rated a 5. The main target in the object of the design is to safety transport riders, so developing and incorporating sub-systems that guarantee the safety of all riders is crucial. Next, as this project will be used in timed competition, the sponsor requested a minimum towability of 5 people on the rope at a time. This is the only other need rated at a 5, presenting its importance. This customer need for towing capacity will determine other aspects of the design such as power and durability.

Most of the customer needs were given a weight of 4. This weight depicts a requirement that is crucial to the project but can be altered if needed. This design must be durable as specified by Ski Haus. However, durability as a customer need can be altered by different variables of the design. With this, the design must be portable for its use on and off the mountain. Portability and durability interact with one another, meaning the more durable the product is, the more likely it is to withstand moving the system for its different uses. With portability, the product must be able to be easily pushed or towed with a snowmobile as the weight of the system is not as important to the client. The overall length of the tow rope must be the typical length of a rail jam competition. This customer need was ranked a 4 as the client is willing to interchange rope lengths for different uses. Lastly, the customer asked that the motor is powerful enough to maintain a constant speed with varying loads. This need swayed the team's decision in our motor choice and the amount of power and torque it puts out.

The last customer needs produced from the project statement were weighted at 3. Beginning with a compact design, Ski Haus mentioned that the overall weight and size of the system was not as important as its maneuverability. When designing the motor for the tow rope, there are two main options: internal combustion and electric motors. Ski Haus prefers an internal combustion engine, so the team will put precedence on designs based on this over an electric system. However, the weight of the 3 is due to the freedom for our team to change to an electric motor if necessary. Finally, it is best if the system is user friendly with limited mechanisms for operation. The tow rope will be operated by Ski Haus employees or a member of the team, so the easier it is to operate the better.

Every one of these customer needs allows the team to separate the system and decipher between the most principal elements in concept generation and the final design. The Ski Haus tow rope's goal is to safely transport multiple people up a ski hill for competition and practice. Each need specified by our sponsor accounts for the success of the project meeting this object as well as ensuring a professional design.

2.2 Engineering Requirements (ERs)

Engineering requirements place a value and tolerance to each of the customers' needs. Doing so allows for target values to be met when designing and prototyping the design. Each numerical value assigned to the engineering requirement contains a tolerance or the amount the value is allowed to vary. Including these tolerances provides a space for redesign and promotes a complete functional product where all aspects align.

The Ski Haus tow rope must be capable of towing multiple people, meaning the motor must produce enough power to maintain a constant speed with these varying loads of riders. Specifically, a minimum of 5 people upwards to 10 people will be towed on the rope at a time. A minimum of 5 was delegated by Ski Haus and the maximum10 was chosen through benchmarking motor capabilities and applied loads. The goal is to move 60 people/hour with a tolerance of ± 10 people. The sponsor suggests that the team prioritizes more people on the rope at a time rather than moving the riders at a faster pace, so 60 people/hour was estimated based on the velocity of 1m/s. The device will tow the riders the distance of their competition or practice space. Ski Haus suggested a minimum of 200ft and a maximum of 300ft. This distance will have a tolerance of ± 50ft, however the tow rope will hold the capability to exchange ropes of varied sizes for smaller or larger competitions. Due to the product objective, the device must be portable. Ski Haus suggested that the unit must be able to be lifted by 3 to 4 people, therefore our team will target the weight to be no more than 300lbs ± 50lbs. While the team does not want to exceed this tolerance, developing a product much lighter than the expected weight is encouraged.

Safety for both the users and riders is a crucial element to the design. Due to this, a minimum of 3 safety features must be included. There is no maximum to added safety features, and the team is expected to see an upwards of 5-8 safety elements. Similarly, a factor of safety of 3 is expected for the whole unit with a tolerance of ± 1. This factor of safety was chosen as this device deals with multiple moving mechanical elements and the public, so inherently it's dangerous. Providing a multitude of 3 from its original safety counteracts for any potential user errors where the system could fail. This factor of safety also provides a reliability aspect to the product. The safer the loading on each sheave wheel, rope, or shaft is, the more likely the tow rope is to continue functioning properly, despite as potential problems or misloading. Coinciding with reliability is durability. Lastly, the durability was determined based on aluminum as a manufacturing material. It provides resistance to rust and has a natural aluminum oxide layer protective against corrosion. The ultimate tensile strength of 310 MPa is the unit used in calculating the durability of the designed structure.

2.3 House of Quality (HoQ)

A house of quality (QFD) is an analytical guide that relates the generated customer requirements, quantitative engineering requirements, and benchmarking. This project planning matrix demonstrates how the customer requirements, and their weights correlate to the technical methods needed to achieve these specifications. The house of quality utilizes multiple "rooms" that separate the requirement relations. Additionally, competitor products are analyzed against the generated customer needs and their ability to fill these demands.

After listing the customer needs and engineering requirements, they are related on a 1,3,9 scale in relating to a weak, moderate, or strong relationship, respectively. The more an engineering requirement relates to the customer's need, the greater the technical importance. Similarly, the engineering requirements are correlated to each other and are assessed on their positive or negative effect on the other goal. Doing so provides insight into the impact of holding a higher importance on one technical requirement over another. Summing the product of customer weights and their engineering requirement correlation evaluates absolute technical importance. This value explains which quantitative requirements hold precedence in the design over others. The relative importance is an ordinal ranking of these requirements based on the calculated values.

Overall, it's crucial to utilize a house of quality to facilitate early group decisions regarding the design. Specifically, the Ski Haus team's QFD detailed the importance of safety in the design as it correlated to multiple engineering and customer needs. Increasing safety was evaluated with the greatest technical importance, emphasizing its significance in the product. Increasing the towing capability was also held at a high importance as expected by the team. This QFD emphasized the aspects of the tow rope that will need extra analysis and subsystem development, such as the drive shaft for maximum towability. The benchmarking aspect of the QFD was very beneficial to the tow rope and it demonstrated which designs will be useful for referencing during concept generation. The team suspected TowPRO to provide quality insight into portable towing systems, but directly relating that system to Ski Haus's customer requirements demonstrated where their design excels and what needs improvement. Analyzing all quality and quantitative needs of our design through a QFD developed great preliminary project planning as a team and led into a baseline for our generated concepts.

System QFD

Project:	Ski Haus Tow Rope
Team Number:	21F09

★	strong poitive
☆	mod. positive
●	strong negative
○	mod. Negative

Legend	
A	TowPRO TP-10
B	ZOA Engineering
C	Surface Lift (Tbar)

increase the towing capability						
increase the distance able to travel	○					
decrease the time to reach the top	★	●				
Increase durability of parts	☆	☆				
increase number of safety precautions	☆	☆	☆	★		
decrease the weight of device		○	○	○	○	
decrease the number of operating parts					○	★

Customer Needs	Customer Weights	Technical Requirements: increase the towing capability	increase the distance able to travel	decrease the time to reach the top	Increase durability of parts	increase number of safety precautions	decrease the weight of device	decrease the number of operating parts	Customer Opinion Survey: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
Safe for all users	5				3	9		1			B	AC	
Quickly transports riders	5	9	3	9		3				B			AC
Minimum of 5 riders at a time	5	9	1	3	3	3			B				AC
portable	4				1	3	9	3	C	A			B
Durable	4				9	9	3				B	A	C
owerful enough to transport at constant speeds with varying loads	4	9	3	9	1				B			A	C
covers the ground of a typical competiton area	4		3	3									ABC
easy to operate	3				1	3		9		C		BA	
Technical Requirement Units		people/hour and HP	ft	min		#	lbs	#					
Technical Requirement Targets		60 ppl/hr 15HP	200-3000	1 to 2		3 to 5	300	3					
Absolute Technical Importance		126	44	108	77	132	48	44					
Relative Technical Importance		6	5	1	4	2	3	4					

Figure 1: House of Quality

3. DESIGN SPACE RESEARCH

This chapter focuses on research conducted about the proposed design. Detailed below are the various sources of academic literature analyzed by the team for use in designing the tow rope system. This chapter focuses on research within the tow rope systems and skiing lifts. Similarly, existing tow ropes and similar systems were analyzed for benchmarking. Both full system benchmarking and subsystem benchmarking were evaluated. Lastly, a full function decomposition was determined. The research evaluated for the proposed tow rope establishes familiarity with current systems to initiate a design space for concept generation and analytical calculations.

3.1 Literature Review

The following sections depict literature reviews revolving around ski lift systems and mechanical and dynamic analysis. Many of the writings analyzed were websites, textbooks, and professional journals. Evaluating typical surface lifts and chairlifts was heavily emphasized and gave tons of insight into the design of the team's tow rope. All the following research set the grounds for preliminary concept generation and force analysis.

3.1.1 Student 1 (Hallie Eha)

The mechanical aspects of this project were reviewed through several pieces of literature that pertained to surface ski lifts. First the types of ski lifts and surface lifts were reviewed in order to acquire more knowledge of the terminology and uses of different types of lifts. This piece of literature acted as a directory for 500 ski lifts and passenger ropeways that are used and operate in Australia. The reviewer focused on the surface lifts category of this directory as the project focused on tow ropes which are classified as a surface lift. The uses and locations of use were described in this section and described that the true definition of a rope tow is a surface lift that is not supported by sheaves along the ropeway but only by a rider that simply grasps the rope with their hands and is self-tensioned through this process. These devices of surface lifts were practical for short, sloped distances for either learning riders or to avoid hiking in freestyle terrain setups.

Since our project will be involved in freestyle terrain setups this type of surface lift is ideal to design in this project. This type of surface lift is optimal for "short and gently graded slopes" [1] and is "difficult to hold on to a rope on steep slopes" [1] which describes the conditions our project will endure when in use for Ski Haus rail jam competitions. For a portable tow rope, this design would also include aspects of a typical nutcracker tow. This includes a tensioning system that will keep the rope tight, specifically designed sheave/ pulley system to appropriately tension and space the rope and a weatherproof engine compartment. With knowledge of proper use and terminology of what we should expect for designing our version of a tow rope, our ideas can be better communicated with our client, fellow team members and for part purchases.

To achieve cable tension on this tow rope, more research needed to be done. "Cable-Pulley Interaction with Dynamic Wrap Angle Using the Absolute Nodal Coordinate Formulation" is the second literature being reviewed and it involves the dynamic variations in a wrap angle and cable tensioning. It describes how wrapping a cable through several pulleys, or in our case sheaves, will help naturally tension the rope and create more torque in the device. These aspects are also achieved by the interaction of a static pulley changes with a suspended load. This concept is very applicable to our design as it can be applied to our drive unit in order to increase torque on the drive shaft and create appropriate cable tensioning so that the rope isn't dragging on the ground the entire length of the slope. This piece of literature used a "model that was developed specifically for cases where there are large dynamic variations in the wrap angle and cable tension" [2] which corresponds to the conditions that our design would be subjected to. This would be done through the large dynamic variations described in the model are the skiers and snowboarders that are using the tow rope. Their weight applied to the rope would cause these variations creating movement of the rope on the pulley, however at the same time it would create tensioning in the rope for the wrap angles of the pulley system.

In most ski lifts or surface lifts, their speeds are adjustable to account for emergency cases of riders falling or getting caught on the lift. The next literature that was reviewed was the Comparison of Motor Speed Control Methods which compares multiple techniques of controlling the motor speeds for industrial automation. This is done by limiting the process output of the motor but this method but is not as efficient as Adjustable Speed drives (ASDs) [3]. These ASDs use the relationship between the speed of the motor is a function of the system frequency and the number of poles in the motor which adjusts the operating speed of a normally fixed speed motor. This is also made possible by centrifugally based processes and their equations that relate torque needed compared to speed [3]. This piece of literature also describes several methods of creating speed control in a chart which analyzes the pros and cons of all methods mentioned. These methods commonly use resistors to control speed or construction techniques that are applied to the motor. These techniques of controlling the speed of the motor for this project would provide safer operation that would account for the speed for different types of snow conditions where this would be necessary. This is also important for emergency situations where riders need more time to use the tow rope or somehow get caught or stuck in the mechanism of the tow rope.

To continue more research of safety protocols for our design, a technical guide of proximity sensors was reviewed. Proximity sensors are commonly used in the Ski lift manufacturing industry for stop gates as a fallback system if riders do not load or unload the lift properly. These sensors will determine the presence of a rider and automatically stop the lift. These sensors can be seen as a wand switch which is commonly used on fixed grip ski lifts or a foot engaging cable switch which is commonly used on conveyor carpets for beginner riders. "Proximity Sensor" includes all sensors that perform non-contact detection in comparison to sensors, such as limit switches, that detect objects by physically contacting them which is appropriate for stop systems that would be used for the safety systems for a tow rope [4]. These sensors would be very important to include in a stop gate type system for this tow rope as it would stop all operation of the tow rope if users passed a certain point that deemed unsafe. This would also be helpful as a proximity sensor could stop the by using a sensing distance that would detect a change in distance from the reference distance and automatically stop the tow rope seen in figure 2 [4].

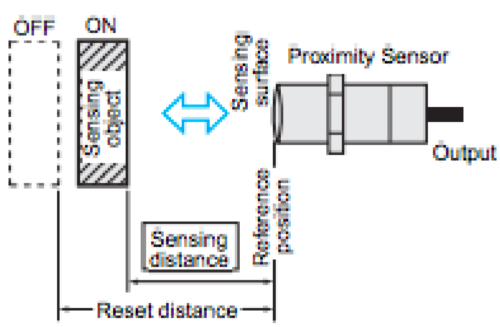

Figure 2: Sensing Distance Proximity Sensor

Anchoring the drive and return units is also another safety concern for this tow rope design. Properly anchoring these systems in the snow requires a certain knowledge of the snow's strength in different weather conditions. There are various failures from the snow that could affect the anchor, in this failure it happens fast enough where the snow anchor comes out of the snow in an explosive manner [5]. With a snow anchor being used to support the top return unit it is very important to avoid this situation as it could cause harm to riders using the tow rope and bystanders that are nearby. For failures under shear, they are still relatively strong when compared to anchors failing under compression [5]. Therefore, when applying this method of anchoring it is important to dig a snow anchor at a correct angle in order to achieve a higher shear strength from the snow. From here the top pulley can be tensioned down as a result of a reliable snow anchor which also allows for more tension in the rope to eliminate any drag.

3.1.2 Student 2 (Kailey Lewis)

The analyzed literature in this section focused on the components of ski lifts and their dynamic movements. Each of the following sources provided insight into skiing towing systems and their components. Knowing the future of our design will demand dynamic calculations for analysis of the system, textbooks and websites are referenced for future use. Overall, these literary sources provided more insight into the ski lift system and the aspects of these larger designs that will benefit the future Ski Haus tow rope.

The first literary source is a book titled, Aerial Tramways, Ski Lifts, and Tows: Description and Terminology. Its purpose was to overview the mechanical equipment used in these systems providing detailed diagrams of bull wheels and drive units for surface lifts, gondolas, and traditional chair lifts [6]. It details the drive systems and their components as well as describe possible motors and their best uses. An important safety aspect of ski lifts is their speed reduction systems, explained to be part of the sheave structure and their different arrangements. Lastly, the book described the brake systems imbedded into all ski lifts. It mentions that some slow-speed surface lifts and tows do not have brake systems, meaning our team must take inspiration from the larger towing systems [6]. This book was a perfect starting place for researching the tow rope because it explained all components that are in use currently. Referencing the definitions of each subsystem was helpful in preliminary designs and allowed for a checklist of items to include.

The next piece of literature is titled Design of a Ski Lift Inspection and Maintenance System. This PDF details the components of a typical chair lift system, specifically the haul rope, terminals, and safety system. This paper was chosen based on its emphasis on safety and inspection protocols of lifts. Part of this paper was detailing the parts of a chairlift. While not directly pertaining to our project, the diagrams and descriptions demonstrated the uses of each part and was easily transferable to the drive unit of a tow rope [7]. Similarly, the PDF included multiple tables descripting each component of a ski lift separated by power, mechanical, and safety. This was crucial and it was easy to reference for all parts included in our design and how they will affect the engineering requirements and customer needs. Lastly, a large section of this paper analyzed safety protocols and failures of the system. It specified the conditions in which the system must meet before public use and the inspections necessary [7]. Another chart was included describing the typical failures of each component and their visible indications of failure. This aspect of the literature is very helpful in our design as safety is one of the main concerns for the system. Understanding what measures must be taken for public use and ways to inspect and maintain the system is very important.

Similarly, a report titled, Blue Chairlift Deropement Investigation Report depicts an incident investigation involving a British Columbian chair lift. This article was reported due to safety standard act requirements. It depicts a deropement of a chairlift at Crystal Mountain Resort causing injuries to four people [8]. It established background on the tensioning systems in place that failed during the incident. The report recommended multiple options for the tensioning system that could have prevented the incident or fixed the issue for the future. This report is beneficial for the Ski Haus tow rope as it allows for insight into possible failures and preventative measures to be taken. The document also evaluates the ropeway system with figures that are useful in configuring our design [8]. Specifically, aspects of the counterweight design can be used in tensioning the top pully system of the tow rope. Ultimately, the incident report depicts safety precautions that should be taken and calculated for before public use of the tow rope.

Understanding the Ski Haus tow rope design will mainly be a mechanical system, the machine design textbook titled, Shigley's 10^{th} ed. Mechanical Engineering Design was reviewed [9]. This textbook will mainly be used for the specs of the gear boxes and shaft design. It also details failure analysis and brake systems, which will be useful for the tow rope drive unit. Specifically, the multiple gears, shafts, and gear boxes will need to be analyzed with the specific rotations per minute of the motor and speed reduction rations. As this system will be used by the public, the factors of safety for all these mechanical parts must be high to account for any issues [9]. This textbook is perfect for reviewing these topics and examples can be utilized to perform the calculations.

Next, an article titled, About the Dynamics of Ski Lift Drive was reviewed. This article explains the dynamic analysis of ski lifts and their specific components. It breaks the motion into rotary motion, moment of inertia, kinetic energy, method of reduction of mass and force quality [10]. The article focuses on the ski lift drive and a reduced set of bodies for the method of reduction as well as the velocity determined through engine power, transmission, and track surface [10]. First, detailed descriptions of the mechanical drive system and basic parameters of the system are determined. Next, a detailed kinematic diagram is given with labeled members. This kinematic diagram, while different from the tow rope design, will be beneficial in designing our diagram for analysis. The steps in determining the dynamic evaluation are detailed in tables depicting the masses, moments of inertia, kinetic energy and angular velocity. These calculated values for each member of the drive shaft are used to evaluate the dynamic motion, conditions of reduction, and power [10]. Following these equations and applying them to the tow rope systems will aid in dynamic movement and evaluate the preliminary decisions made. Ultimately it will guide any redesign if necessary.

3.1.3 Student 2 (Jesse Wells)

The first aspect of the literature studied in this section focuses on the friction coefficient of snow with different consistencies to calculate the friction effects of the users on the tow rope. The next focus is the study of dynamics through an engineering textbook used to better understand the kinetic and kinematic behaviors of the rider and the tow rope. Following is an informational website that evaluates ski resorts and their equipment including their rope tow specifications, which will be used to gain understanding of the details of existing tow ropes and solve unknown variables for calculations. Then the study of welding techniques of aluminum is examined, to find the optimal fabrication process of the drive unit frame and top pulley stand. The final source of literature analyzes the weld strength of aluminum under given parameters to ensure that the design will meet engineering requirements and withstand the forces calculated as reviewed in the preceding literature sources.

In order to calculate the kinetics of one or more rider loaded on the tow rope, an understanding of the friction relationship between the rider and the snow must be established. The Kinetic Friction of Snow is a journal article from Cambridge University that analyzes different sliding surfaces on snow of varying conditions. The study explains that the sliding of a surface on snow, such as skis, is more of hydroplaning on a thin film of water than it is sliding on a frictionless surface [11]. As the velocity of the slider increases, so does the thickness of the water film. There are three states of snow to surface conditions to study friction coefficients of: dry, lubricated, and suction. Dry friction is when the slider is not moving and contacting the solid snow before the water film has developed from movement. Once the slider begins moving, it develops the water film through friction, which is evaluated as a lubricated friction; this is the ideal state for minimal resistance in skiing. At a point in time when the velocity or the ambient temperature are high enough, the film of water becomes too thick, which causes capillary suction, thus the suction coefficient is determined [11]. For calculations in determining the resistance of the rope tow, all three states are worth considering. As the rider loads the rope, there is dry friction and once the rider is moving there is lubricated friction. Arizona Snowbowl is known for its slushy conditions from high temperatures, where there can even be puddles in the runs, which is why suction friction will be considered as well. Though all three values are important, the calculations made will be assuming worst case scenario- or highest friction coefficient- in order to assure that the design stress is greater than the actual stress being applied to the system from the friction and load of riders. The relationship between water film thickness and friction coefficient is displayed in figure 3.

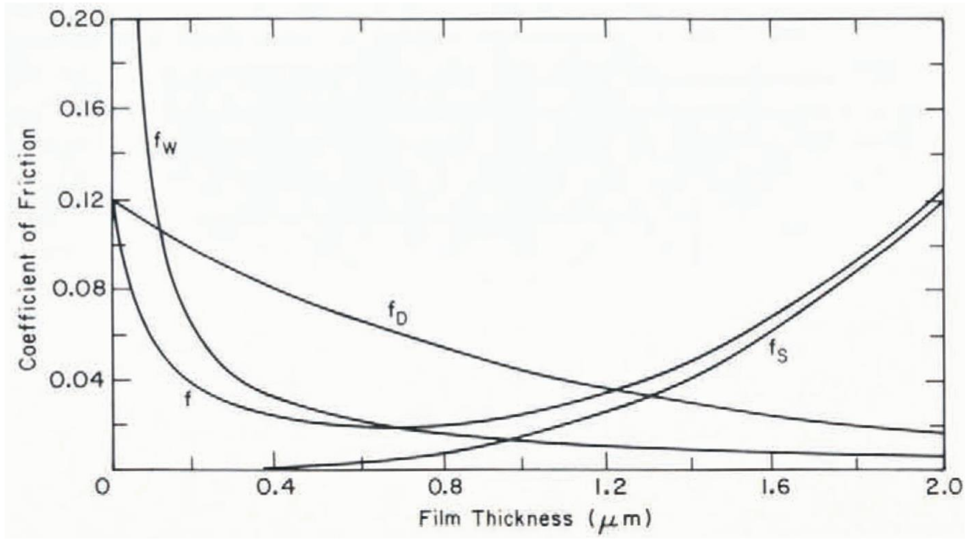

Figure 3: Water Film Thickness versus Coefficients of Friction

A relationship of the three types of friction is developed to create a total friction which is shown as "f" in the above figure. The dry friction decreases as the film thickness increases, while the suction friction does the opposite. The lubricated friction, fw, on the graph shows there is the highest amount of friction just as the film of water develops, and this is where the coefficient of friction will be taken from for the rope tow calculations.

Once the friction coefficient has been established, calculating the dynamics of the tow rope is more attainable. There is both kinetic and kinematic motion involved in the tow rope, so the next form of literature used is Russell C. Hibbler's textbook titled Engineering Mechanics Dynamics. The general problem to be solved is finding the tension in the rope and forces being applied to the top pully and drive unit from pulling a mass up an incline at a constant velocity. A goal the team has is to develop at user manual for the client that provides a table that will show the operator at a given slope, what the load capacity will be. The incline will be variable depending on where on mountain the tow rope setup is, and there must be a calculated maximum number of riders on the rope at one time to assure no damage to the motor is done. Work done by the engine and torque applied to the drive shaft must be calculated to prevent too much strain on the engine. The team aims to design the pulley system to distribute the tension of the rope so it is not all applied directly to the drive shaft, so the dynamics textbook will aid with calculating the angular forces in order to find the best design. When the rider experiences change in momentum at the loading point of the tow rope, or if the tow rope comes to an emergency stop, the rider and the system experience impulse. The dynamics textbook will be used to calculate this change in momentum, in order to minimize the forces of impulse being applied to the system [12].

There are several unknown variables in calculations for the tow rope that must either be found, or assumptions must be made. The third piece of literature that can be used is an informational website about ski resorts' chair lifts and tow ropes named SkiResort.info. The site compares resorts as well as the specifications of chair lift and tow rope speeds, length, vertical displacement, transit time, and carrying capacity. This is a resource that can be used to assign values to some of the variables in calculating specifications for the Ski Haus tow rope. The comparison option is useful because it will help find the average speed of a common tow rope, so that our team's design can match these industry standards. The website states carrying capacity given in number of people transported per hour over the given length of the tow rope [13]; this along with the transit time will allow the team to calculate the carrying capacity per hour and at any given time and design appropriately to those specifications. After doing a comparison of five 150 ft tow ropes on SkiResort.info, the average values were calculated as: Length =150ft, Speed=2m/s, Transit time=1:15 minutes, Carrying capacity=500 people per hour [13]. This is useful because the team will be assuming the same average speed, length, and transit time for calculating our design. Using those values, assuming 5 people on the rope at a time, an estimated 260 people per hour carrying capacity can be evaluated, which is 200 people more than our engineering requirement of 60 people per hour. This shows that that engineering requirements will be easily attained if not exceeded.

The tow rope drive unit must be enclosed in metal housing for transportation and to protect the drive system. This housing will be made of aluminum because it is lightweight and has anticorrosive properties. Fabrication of this metal frame requires knowledge of metal welding, specifically aluminum, which is more complicated to weld than other metals like steel, thus an article from the Universal Technical Institute titled How to Weld Aluminum: The Beginners Guide is the fourth source of literature that will be used. This article explains why it is difficult to weld aluminum, such as its soft characteristics, strong oxidized insulating layer, its porousness, and susceptibility to impurities which can cause weak welds [14]. The article also discusses preparing the material to be welded, and the best techniques to weld aluminum using tig inert gas (TIG) or metal inert gas (MIG) welding [14]. More information such as less common welding techniques, precautions, and how to training programs are discussed. Understanding the right way to weld aluminum and why it is difficult allows the team to properly design the frame so that it is possible to fabricate. Additionally, it will guide the team to hire the proper welder and ask the appropriate questions to ensure the finished product comes out as designed.

There are several benefits to using aluminum for the frame that make it the primary material choice, however the possibility of weak welds is a major disadvantage that needs to be addressed. The frame will be experiencing pulling forces from the rope, the anchors tensioning it to the ground, and the snowmobile towing it. It will also have to be able to withstand impacts from transporting it. A journal article titled The Influence of Deformation Conditions in Solid State Aluminum Welding Processes on the Resulting Weld Strength is the fifth source used to understand if using aluminum will be the appropriate decision to ensure the welds will withstand the tough conditions. This article addresses "deformation parameters important to weld strength: interface strain, strain rate, normal contact stress, temperature, and shear" [15] of solid-state welding techniques. The author breaks down the study into the material science of aluminum welds at a microscopic level, existing calculations and predictions of weld strengths, a proposal of a new experiments for testing weld strength, and results of the physical experiments. This will provide the team with a more in-depth understanding of the parameters of stress and strain that aluminum welds can withstand which will be used in the calculations to for the engineering requirement of durability. These parameters will help determine if aluminum is the acceptable material to use and will be shared with the CAD engineer and welder for them to consider adding necessary supports when designing and fabricating.

3.2 Benchmarking

Based on the proposed tow rope system and the project description given by the sponsor, the team identified cost, weight, compactness, power, and towing capacity as the main measures relevant for benchmarking. Beginning with full systems, three designs comparable to our system were analyzed. Evaluating them against the measures taken from our customer needs provided and starting point for our design. Breaking down the system into the drive unit, housing, and top pully allowed for detailed benchmarking to be conducted. The subsystems each correlated to different customer needs and engineering requirements, where assessing these against current systems provided insight into design alternatives to better meet these goals.

3.2.1 System Level Benchmarking

After establishing customer needs and engineering requirements, research was done to see what existing products were relative and applicable to these parameters. The system level benchmarking first describes three existing designs of tow ropes or similar devices. In the second tier of benchmarking, the tow rope system is broken into three subsystems: the drive unit, the frame, and the top pulley. Three existing designs for each subsystem were researched and discussed. Each component of the benchmarking was compared with the engineering requirements and customer needs as well as analyzed for design advantages and disadvantages. This in-depth comparison allows the team to establish a better understanding of the existing technology as well as use the findings as inspiration and benchmarks when designing the Ski Haus tow rope.

3.2.1.1 Existing Design #1: ZOA PL1 Handheld Winch/Tow Rope

The ZOA PL1 is essentially a handheld winch that the user can attach to a rope to pull them back up the ski slope. The rider must first hike up the slope, tie a rope to a tree, and run the rope down the hill. Once at the bottom of the hill, the rider takes the compact ZOA PL1 shown in figure 4 out of a backpack and attaches it to the rope, which pulls them back up the hill [16]. This is a useful benchmarking design because it serves the same purpose as a tow rope, which is to eliminate the hiking aspect of skiing and allow for simple transportation up the hill without use of a chairlift. The relevance of this design to the Ski Haus tow rope is the aim for compactness, portability, low cost, and being lightweight. The disadvantages about this design compared to the tow rope are that it is limited to one user at a time, whereas the rope tow engineering requirement is at least five users at a time. Another drawback is that it is electric, which requires recharging of a battery. There is generally a lack of power sources on the mountain, so one of the customer requirements is that the tow rope be gas powered so that a gas canister can be the portable source for power. This design is applicable to the tow rope because of its use of sheave wheels and a guiding track to feed the rope through a drive unit. In the tow rope design, there will be a motor driving one or more sheave wheels and the ZOA PL1 provides a good foundation to understand the flow path of the rope to be driven from the sheave wheels. The guiding tracks to keep the rope feeding into the wheels straight and smoothly is going to be a component incorporated in the drive unit of the tow rope, likely using more sheave wheels as guides similar to how a chairlift is designed.

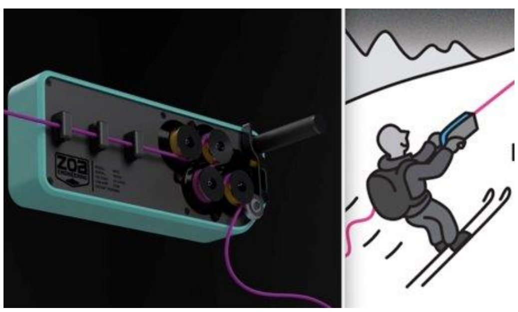

Figure 4: ZOA PL1 Handheld Ski Winch

3.2.1.2 Existing Design #2: TowProTP15 Portable Tow Rope

The TowPro TP15 is one of many models of portable tow ropes made by TowPro. This model shown in figure 5 was chosen because it is the most relevant and applicable to the Ski Haus tow rope. This benchmark is the most relevant because it fits several engineering requirements including being compact, 15 horsepower, portable, and its user capacity is 10-15 people [17]. One disadvantage of this design is that it costs $30,000 where the budget for the Ski Haus rope tow is $3000 with the aim of designing a similar product for a fraction of the price. The circulating rope is parallel on a vertical axis, which is a safety concern due to the possibility of the user getting caught in the lower rope; the Ski Haus tow rope will be designed on a horizontal plane with a significant distance between the ropes to ensure users do not touch the returning rope. Another disadvantage is that this product is electric and requires a generator, which does not meet the customer need for a gas-powered motor. Additionally, it is not as compact or lightweight as the desired design, as it weighs 400lbs and 45”W x 39”L x 19”H [17]. Overall, the TowPro TP15 is the most relevant and applicable benchmark because it is a portable tow rope with similar specifications to the engineering requirements for the Ski Haus tow rope.

Figure 5: TowPro TP15 Portable Tow Rope

3.2.1.3 Existing Design #3: Rewinch Compact High-Speed Winch

The Rewinch is a high-speed winch used to accelerate skiers, snowboarders, and wakeboarders to high speeds to launch them off of a jump when there is the absence of a hill for the rider to gain speed. Though this product is not a tow rope, it is a good benchmark because it has a very similar system design and is a form of transportation for a rider via a rope. The Rewinch shown in figure 6 costs $3545, accelerates to 50mph, weighs 30lbs, and has compact dimensions of 6”W x 13”L x 13” H [18]. It is relatively low cost but above the Ski Haus budget. The main advantages are that it is very compact and lightweight, which will be taken into consideration in the tow rope design. The winch runs at a much higher speed than necessary for a tow rope, but their gear system is worth studying to provide the proper torque needed for the tow rope. The winch rope extends from the drive unit, around a pulley and back, however it does not fully circulate. It only reciprocates back and forth (to be bidirectional for wakeboarding) so that the handle moves from the drive unit to the pulley back on the same side. This is different from the tow rope, where the rope needs to fully circulate. The overall design of the Rewinch is ideal in terms of compactness and simplicity, but it is limited to one user at a time. The power is 12 kW run by an electric motor [17] which does not fit the gas-powered engineering requirement but does meet the power output of the engine that is being considered for the tow rope.

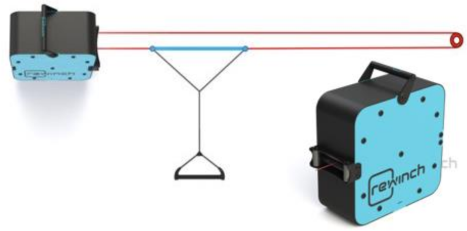

Figure 6: Rewinch High Speed Winch

3.2.2 Subsystem Level Benchmarking

To breakdown all the components of this design, it was separated in to three subsystems. These included the drive unit, the frame or housing and the top pulley. With these subsystems, they were researched for any existing products that are currently used on the market. These benchmarked designs either directly applied to the ski lift industry or in industries that were similar or applicable. The current customer and engineering requirements are applied and compared to each of these benchmarked designs in order for the team to narrow down key design details that would work best for the project.

3.2.2.1 Subsystem #1: Drive unit

This subsystem involves the entire drive unit of the design. The drive unit includes the stopping mechanisms, the motor and the drive unit pulley system. This subsystem is important to the overall project because it is the only section that provides any of the movements for this tow rope to operate correctly. This drive unit will have the rope for the tow rope feeding through that will move riders from their starting point at the bottom of the hill to their ending point at the top. All mechanical and motorized power will be applied to this subsystem that will be translated into movement that can be used by the riders. For this drive unit to meet the engineering and customer requirements and to operate efficiently, existing stop systems, power and torque specifications need to be researched and analyzed.

3.2.2.1.1 Existing Design #1: Leitner Poma Direct Drive system

The LEITNER DirectDrive, is a low-rpm synchronous motor with a gearless drive system that is used for Leitner Poma Detachable ski lifts. Examples of this type of ski lift are located close to Arizona Snowbowl. This design has many safety features as it is designed to operate very large ski lifts and uses large electromagnetic service brakes that act on the bull wheel on the drive terminal. This design relates to our engineering requirements as the speed of the lift can safety move skiers and snowboarders at a maximum rate of 1100 feet per minute [19] and has easily adjustable speeds through its computer system. These speeds can be adjusted to account for different levels of skill in riders, weather conditions and emergency evacuation situations. This design also includes multiple systems for emergency stops through braking systems that act directly on the drive sheave and include their own independent hydraulics [19]. This drive unit is also fully encased and is located above the lift chairs in an overhead terminal which eliminates any dangerous situations of moving parts getting in contact with riders or operators seen in figure 7**.**

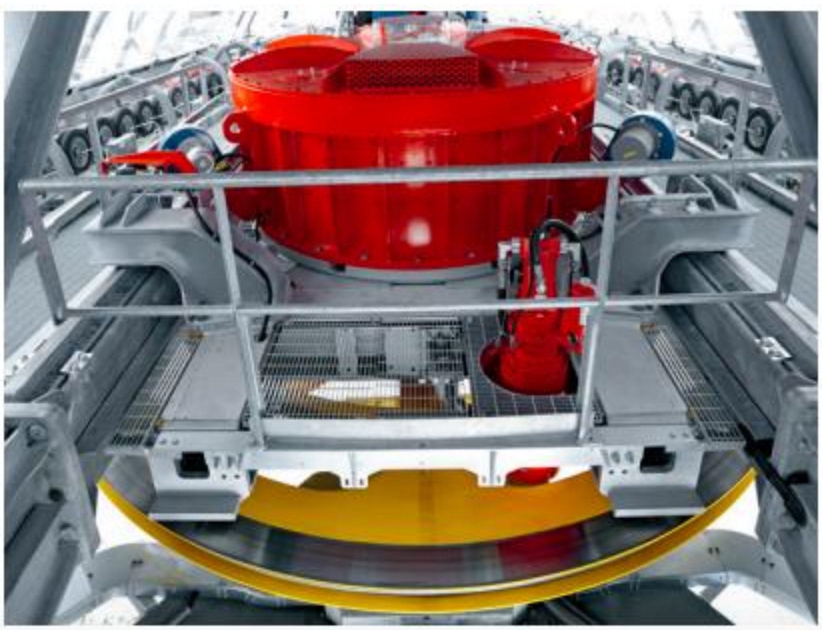

Figure 7**:** Encased Leitner Poma Direct Drive Unit

3.2.2.1.2 Existing Design #2: 6.5 HP Base Model Winch

This design is simpler with less moving parts and mechanisms. This winch is generally applied to wakeboarding, skim boarding, and can be used for skiing and snowboarding if needed. This design includes a 6.5 hp base model with a CVT asymmetrical torque converter which allows for a reduction of rpm of the motor to allow for higher towing capabilities [20]. This aspect of the design is not necessary for skiing and snowboarding as more torque is only required to tow more people rather than for wakeboarding higher torque is needed to create bigger wakes for this sport. This design also includes many anchoring points that are located towards the rear of the device which allows for the winch to be tied or stakes down which would be ideal for our design as well. Since this design is applied mainly to wakeboarding the drive system is more protected from the elements as a result. This design includes splashguards that protect the motor and the operator from water, or any debris that much come from typical use. Because of this feature it covers our customer need for durability for all weather conditions whether this includes snow, rain or severe weather. This design also fits in with our customer needs as it is easy to transport and maneuver as it has inflatable wheels for travel and a 2 in tow hitch to transport by vehicle. The spool for the winch can hold 2400+ feet of wake rope which exceeds our engineering requirement of a towable distance of 150-200 feet [20], however for winch system the direction of the rope is unilateral which is not ideal for a tow rope of this nature. The power of the motor is also less than half of the required horsepower that was described to us by the client which was about 14 hp.

Figure 8: 6.5 hp base model winch

3.2.2.1.3 Existing Design #3: Variable Speed Ski Lift

Ski lift with variable speed linear motor drive and emergency stop apparatus responsive to power loss to the drive is another design that would be similar to our own. This design follows more the traditional detachable chair lift where the lift chairs are disengaged from the hull rope and put on to a separate track where they move at a slower pace to allow too easy loading and unloading. This aspect of the design is not applicable to ours as our design requires no use of lift chairs. The acceleration and speed that is controlled by electromagnetic is important to our design as it would help control the speeds when the electromagnets are energized [21]. This also acts a failsafe to stop the lift in emergency situations when the electromagnets are de-energized [21]. These safety procedures for this lift are important to apply or research more for our own design as it covers the safety features of our engineering requirements of having emergency stop procedures and adjustable speeds. This product is easy to operate as the operating procedure is meant to be simple and the computer system would be coded to account for the varying speeds of the chair as rider load and unload which is a part of the customer requirements. This design is not moveable and is a fixed structure and is very heavy as a result.

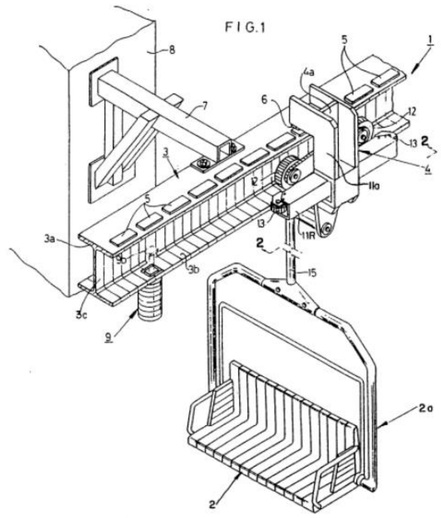

Figure 9**:** Ski lift with variable speed linear motor drive and emergency stop apparatus responsive to power loss to the drive

3.2.2.2 Subsystem #2: Drive unit housing and frame

The housing and frame subsystem is crucial to the design as it not only holds the drive unit but will determine the systems portability and safety. The materials used will evaluate how the system withstands the weather and its encasement will prevent any incidents with users getting pulled into the mechanical system. Similarly, the orientation of the housing will also depict the weight and how it's transported. Some designs benchmarked are permanent installments and therefore don't account for portability. Accounting for safety in the design of the housing is one of the more important specifications depicting the overall design. Following are some established lift housing designs used for benchmarking.

3.2.2.2.1 Existing Design #1: TowPRO Resort Ready Tow Tope

The most relevant tow rope housing is the resort ready towPRO design (Figure 10). This portable tow rope is filled encased with attached handles and a sled base. The entire system 300 lbs [22] but is easily pushed over snow due to the slick base mounts. The housing material is not specified; however, it is most likely aluminum due to their claim of having the lightest weighing system [22]. The base and panels are layered in plastic as well. This housing accounts for the safety of its users by enclosing all mechanical and electrical parts from the public. It is notable portable with the skid plate and pull handles designed into the frame. The company claims that the weight and size of the system can be lifted by 3-5 people and transported in a truck bed [22], detailing the systems durability and transportability. This design meets all customer needs for our tow rope designs and is by far the most comparable to the system Ski Haus is in the market for.

Figure 10: TowPRO Resort Ready rope tow system

3.2.2.2.2 Existing Design #2: Surface Lift

The subsystem depicted in Figure 11 details a typical surface or “T-bar” lift. It is a commonly used at resorts in replacement of chair lifts. A surface lift has a handing pole with a horizontal bar across the bottom that sucres the rider and drags them up the slope. The rider never leaves the ground like a tow rope. The Housing on these systems is similar to traditional chairlifts with an elevated bull wheel. The drive unit is encased above the rider where the bull wheel and cable are located. These systems are very safe as all mechanical and electrical components are lifted and out of reach from the public. Where this system differs from the Ski Haus customer needs is in the transport. These surface lifts are permanent structures and are not designed to be moved. This specific surface lift station is engineering by Leitner. They describe the unit to be compact with simple operations [23]. Understanding the safety and user interface of larger systems like surface lifts provides insight into ways to implement these customer needs into the smaller scaled tow rope.

Figure 11: Surface Lift station

3.2.2.2.3 Existing Design #3: Backyard Tow Rope

The last housing unit used for benchmarking was a backyard-built towrope (Figure 12). A prebuilt shed and tractor were used in designing the tow rope. The site explained the convince build based on the shed's preexistence to the tow rope design. While this tow rope housing system is not professional, it is very functional for the small, scaled need. In terms of safety, the housing itself does enclose any mechanical parts from the user. However, it is mentioned that emergency stop features are included and necessary when designing a tow rope [24]. A shed to this scale certainly is durable and provides storage for the system. The large tow rope is not portable either. While the tractor drive unit may be able to move, it would have to function without the shed housing. Overall, this tow rope was designed for someone's backyard and just to serve its purpose of transporting skiers. It does not meet the Ski Haus customer needs well, but it provided insight into a more robust storing system that can be utilized in preliminary concept variations.

Figure 12: Backyard tow rope

3.2.2.3 Subsystem #3: Top Pulley

The top pulley is the return unit placed at the top of the hill that cycles the rope back downhill to the drive unit. There are important safety factors to consider in its design, including anchoring the device so it does not slide downhill, tensioning the rope, an emergency stop gate to ensure the rider does not run into the top pully, and finally separating the uphill moving rope from the downhill rope so the user does not get caught in the downhill rope that would pull them into the drive unit. The rope must be fed into the pulley(s) in a parallel manner to ensure the rope does not get derailed. It is important to consider the strength of the pulley against the tension of the rope and user load, as well as the opposite direction tension from the anchors.

3.2.2.3.1 Existing Design #1: Embarking Station and Return Unit with Tensioning Tower

The system shown in the red box of figure 13 shows the top pulley system of a chairlift known as the return unit, as well as the embarking and disembarking station. The return unit in this design is the same concept as a top pulley, where it uses a large bull wheel that is fastened to a tensioned frame that cycles the rope back downhill. The embarking and disembarking station are used to stabilize the rope from bounce in the chairlifts and align the rope to feed into the bull wheel. After speaking with Austin Escalante, a member of Leitner Poma's construction team, he emphasized the importance of anchoring and alignment of the rope feed. He explained that if everything isn't perfectly tensioned and the rope is not fed into the bull wheel perfectly straight, there is large risk of derailing the rope which would cause extreme hazard and damage. With that, Austin suggested that for the tow rope, the team focuses on not making the rope too taught either. This is because there needs to be some play for if riders fall while holding onto the rope. This, he said, is part of why the embarking station is so crucial, because it will allow for some slack in the cable until it needs to be taught for the bull wheel [25]. These were points that were not considered in the original design of the tow rope but fit with the engineering requirement for a high factor of safety and will be heavily focused on for the final design.

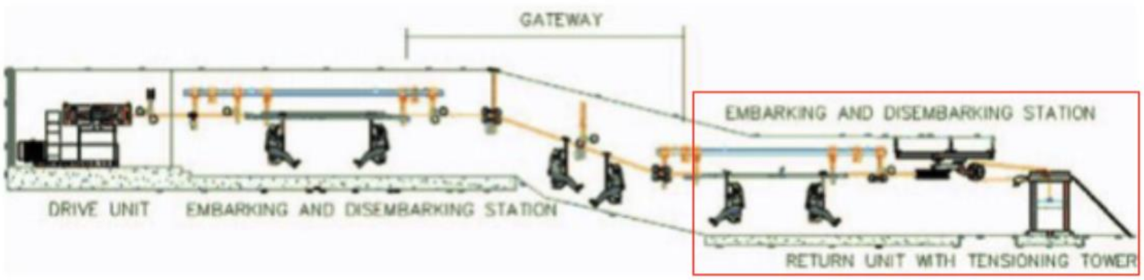

Figure 13: Chairlift Schematic with Embarking Station and Return Unit with Tensioning Tower

3.2.2.3.2 Existing Design #2: Floating Bull Wheel

A floating bull wheel at the top of a chairlift is not as common of a system anymore, however it was used more frequently in the past and is very similar to the needs of a rope tow's top pulley. It is a large pulley that is anchored by a large concrete mass in one direction, and in the opposite direction it is tensioned by the chairlift cable. This design shown in figure 14 is essentially what the top pulley will be except rather than a floating wheel, a sheave wheel will be fixed to a frame and tensioned by come-alongs and snow anchors rather than a concrete block to make it more of a compact system. An advantage of this is that the bull wheel keeps the uphill and downhill rope far apart just as needed for the engineering requirement of the tow rope. It is also a very sturdy structure while allowing a little play in the sheave wheels holding the block to allow for bounce in the chairs. The design is significantly larger than that of a top pulley for a tow rope, however the concepts are similar and worth considering in the final design.

Figure 14: Floating Bull Wheel Top Pully

3.2.2.3.3 Existing Design #3: Ski Resort Tow Rope Top Pulley

The structure shown in figure 15 is a common design for ski resort tow ropes, using a large sheave wheel on a stand with an angle to keep the returning rope side out of reach of the user. Other resorts use the same design with the sheave wheel horizontal, but those sheave wheels are usually much larger, which increases cost. This design is a consideration for the Ski Haus tow rope; however, it makes the device less compact and increases cost because a sheave wheel this large is significantly more expensive than two smaller ones that would separate the rope in the same manner. Another downfall of this design is the lack of anchoring. The frame in figure 15 depends its stability on the depth of the snowpack or being drilled into the earth when the snowpack is too low. This requires long legs which impacts compatibility again.

Figure 15: Ski Resort Angled Top Pulley

3.3 Functional Decomposition

The functional model hierarchy begins with the projects specific goals listed in accordance with the customer needs. Specifically, safety, towing capacity, power, length, and ease of operation. These needs then correspond with each subsystem: drive unit, housing, and the top pully. The operations of these subsystems are evaluated through the functional decomposition diagrams and allow for planning of future concept variants. The main functions of the tow rope system are moving multiple people up a slope while ensuring their safety. Analyzing the specific inputs and outputs of each subsystem and their relevance to the customer goals allowed the team to evaluate what materials, energies, and signals ran through the system.

3.3.1 Black Box Model

Typically, the first step to functional modeling is a black box model. This model identifies the design's overall function in verb-object form and depicts the different materials, energies, and signals that run through the system. It is a basic way to identify all the functions on the proposed system and their relevance to the overarching goal.

The Ski Haus tow rope system detailed the inputs and outputs in terms of materials, energies, and signals. As the system deals with a mechanical energy source and human transport, the only materials imports and exports are humans and the rope. Due to the drive unit system, gasoline powers the motor, mechanical energy and rotational energy move the system and the rope. Output energies include mechanical and rotational energy as well as heat and friction from the system. The towrope will incorporate sensors to slow and shit off the system for safety. This creates visual, auditory, and a limit signal. All signals are both imported and exported. A visual representation of our black box model can be seen below in figure 16.

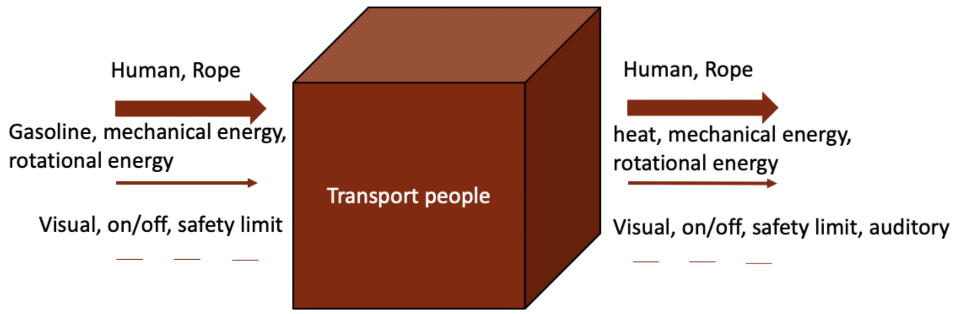

Figure 16: Black box model

The creation of this model was a great starting point to understanding the underlying functions of the tow rope. While the team had a good understanding of the system on a surface level, detailing each material, energy, and signal that runs the system allowed for a better concept generation. It became easier to visualize the more complicated drive unit and how the motor will function with accompanying parts to tow people. Overall, this was just a start to research and development of the different variations of tow rope designs, but it allowed for a better understanding of the system to do so.

3.3.2 Functional Model

A functional model is a visual description of all functions of the product based on the input and output flows identified in the black box model. By doing this, an emphasis is placed on what needs to be done within the system. Evaluating the system in this way provides more creative designs and a greater understanding of the subfunctions and their correlation to customer goals.

The Ski Haus tow rope functional model was created based on evaluating the drive unit, housing, and top pully subsystem and their relevance to safety and towing. The flows used were based on the black box model and the operations that effect these flows were associated with them through the arrows. For visual representation, materials are red arrows, energies are orange, and signals are blue. Using functional basis terminology, the flows describe the transportation of humans via a rope and motor system from start to finish. Figure 17 demonstrates this functional model.

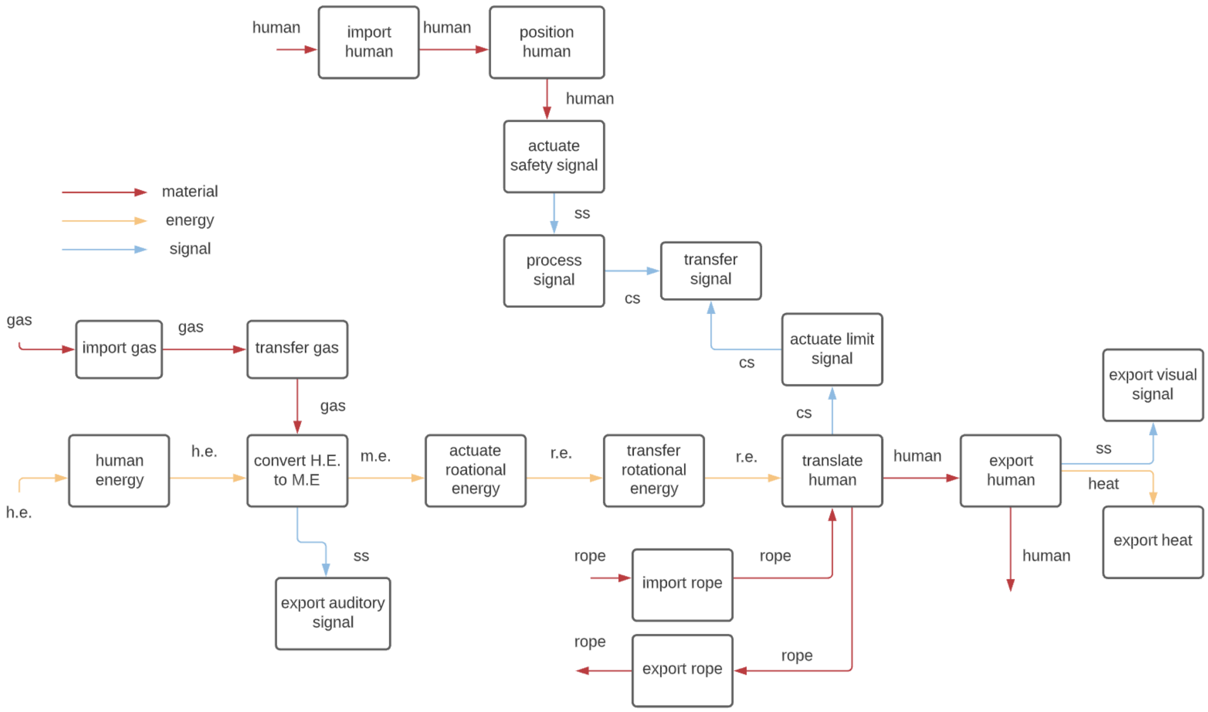

Figure 17: Functional model of a tow rope

4.CONCEPT GENERATION

4. 1 Full System Concepts

The full system concept variants were designed based on the customer needs, engineering requirements, and subsystem variations. They depict the variation in design that could be taken to meet the customer and engineering requirements. Each full system concept below could be used for the final design to begin prototyping with.

4.1.1 Full System Design #1

The first full system design concept incorporates a smaller more maneuverable housing unit that focuses on transportability and safety. Due to the horizontal orientation of the rope, a drive system utilizing three sheave wheels to separate the rope is met on the opposite end with two more sheave wheels separated on a triangle pully system. These three systems work very well together and encompass the original design the team depicted in preliminary discussions with the client. The motor is completely enclosed under the three sheave wheels and will easily fit into the housing unit. Overall, this full system design is very portable, compact, and would tow multiple people up a ski hill. However, it would be a very expensive manufacturing process and the top pully design would need to be altered to withstand the weight and tension in the rope.

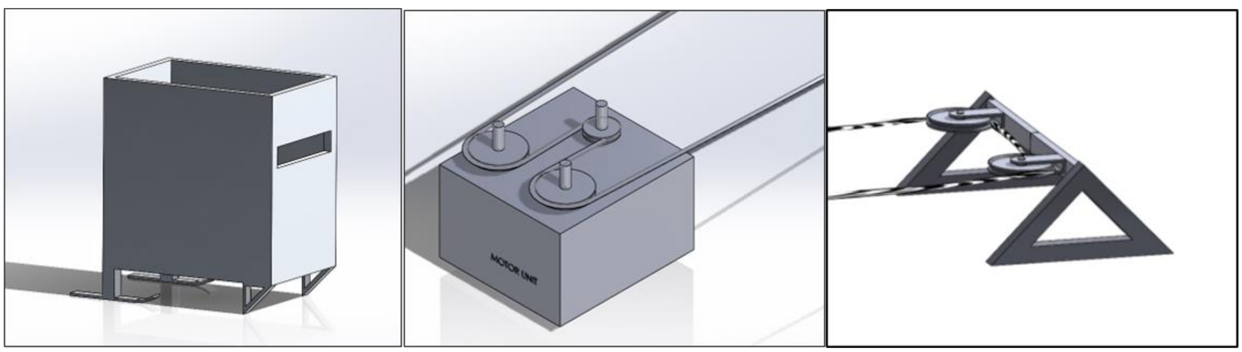

Figure 18: Full System Design 1

4.1.2 Full System Design #2

The second full system design concept incorporates a sturdier design using the heaviest duty and anchorable of the concept variants. The frame and the top pulley have holes for staking into the snow as well as there will be added hooks to attach additional snow anchors and tensioning straps. The Choice of the drive unit was because it turns the ropes in a vertical manner, just as the top pully does; this would prevent any twisting of the rope from bottom to top.

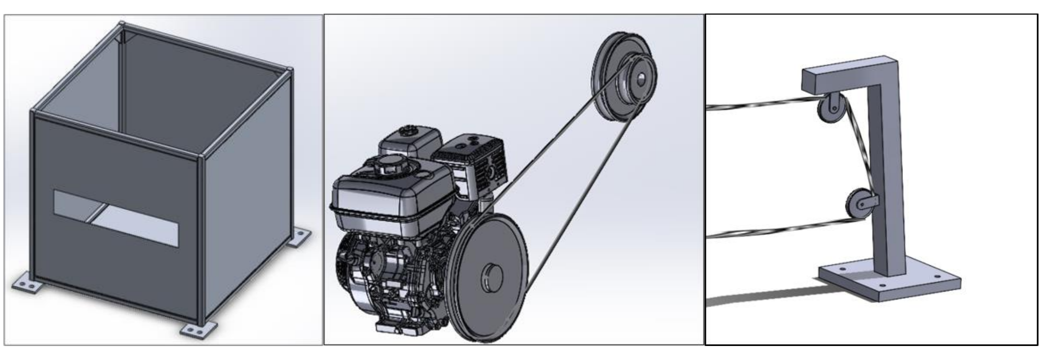

Figure 19: Full System Design 2

4.1.3 Full System Design #3

The third full system design is the most aesthetic as well as fits the majority of engineering requirements and customer needs. This design keeps the uphill and downhill ropes sufficiently separate. The frame has a transparent housing to be able to monitor proper function of the machine and see if anything needs maintenance. The two-wheel top pully and three-wheel drive unit distributes the tension forces to reduce fatigue on the drive shaft and top pulley frame. The unit is the most portable and will incorporate several hooks for additional anchoring.

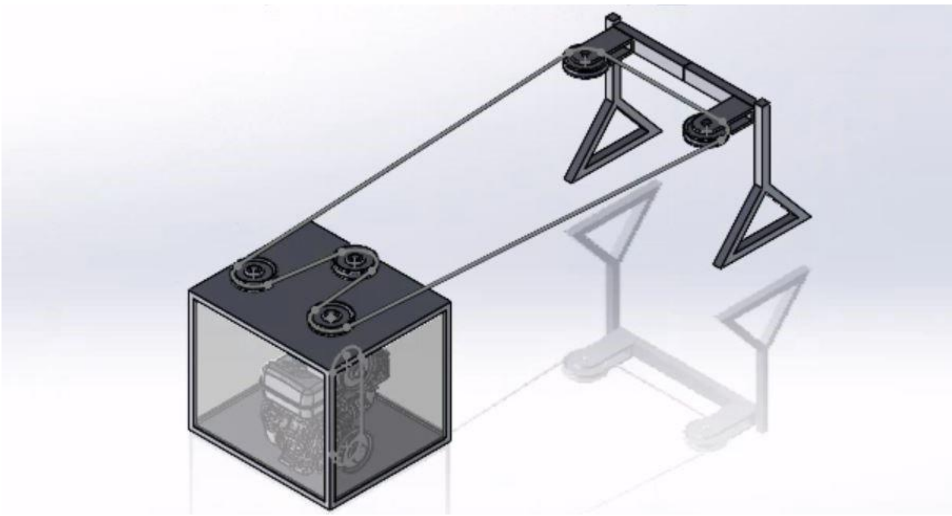

Figure 20: Full System Design 3

4.2 Subsystem Concepts

For each of the described subsystems, concepts were generated for each in order to separate ideas for different functions of the design. This separation allowed for more designs to be generated without overlapping system functions of the design as a whole. This also allowed for more detail to be applied to these concepts as there are fewer overall components to each subsystem rather than the design. These concept generation subsystems were separated into the drive unit, the frame and housing and the top pulley for the return unit.

4.2.1 Subsystem #1: Drive Unit

This subsystem for concept generation is the drive unit that largely involved how the drive shaft would connect to the drive pulley system. This would be dependent on the rope being placed in a horizontal or vertical rotation from the top terminal to the bottom. Both variations of this design were applied to these concepts. This uses the energy from the gas-powered motor that converts this into translational energy to the rider for them to reach the top of the hill.

4.2.1.1 Design #1: Multiple Pulley Drive Unit

This drive unit concept was derived from the benchmarked designs of the tow pro devices. It includes a horizontally positioned rope that allows for a separation of the loaded side of the rope and the unloaded side of the rope to eliminate any confusion a rider would experience. This design also includes a more compact setup where the pulleys are directly above the motor and no space is wasted on the sides of the motor. This allows for easy transportation as a result as the design does not require as much space. When this design is being set up to operate the direction of which the rope needs to go will be difficult to assemble. This is due to the multiple pulleys that the rope will need to be wrapped around in order to create distance between the loaded side of the rope and the unloaded side and to increase torque as more riders as applied to the system. The tensioning of the rope in this design will also pose difficulties as there are not many ways tensioning techniques can be applied with the rope moving through many parts. However, with the rope moving through multiple pulleys, this automatically tensions the rope to some degree as it passes through this section of the device.

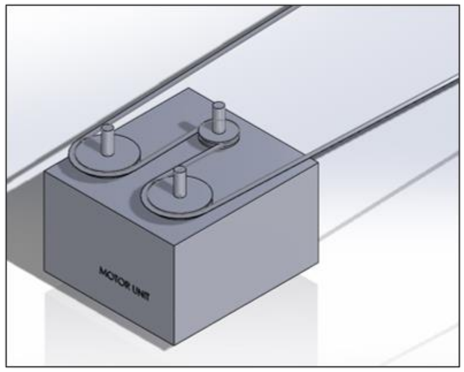

Figure 21: Concept Generation 1 of drive unit

4.2.1.2 Design #2: Winch Inspired Drive Unit

This concept is based off of a winch design in appearance and operates similar as well. However instead of a rope feeding through the motor, a belt/chain system is used that connects to a separate pulley that the rope is on. This creates an easier setup when attaching the rope to the drive unit. This is done by simply wrapping the rope around a single sheave rather than a network of sheaves. With this design as well, the pulleys are compatible with a horizontal drive shaft which eliminates the need for a gear box that would serve to translate the rotational movement of the motor. This would bring down the cost of the design by not needing a gear box. However, the applicability of a gear box in the system would prevent movement and slipping of the rope in the opposite direction which could increase any dangers present. With the rope in this position there would be vertical placement for it. This would decrease the distance between the loaded and unloaded rope and could potentially cause confusion for riders when using the device. As the pulley that connects the drive pulley and the rope is distanced further from the motor, this also would require a larger frame to be used. This would increase the cost of material to make a larger frame and cause the ability to transport the device harder as it would weigh more and larger in volume.

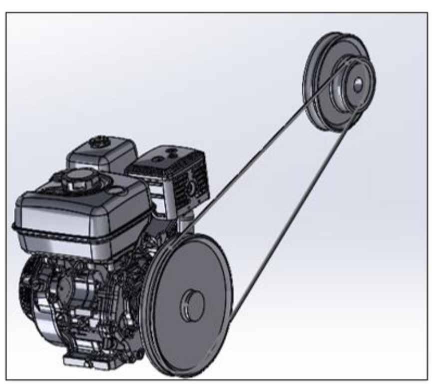

Figure 22: Concept Generation 2 of Drive Unit

4.2.1.3 Design #3: Horizontally Driven Pulley with applied Gear Box

This design almost combines the two previous designs into one. A belt/chain system is used to translate the movement of the motor to the applied gear box. This then applied the rotational movement to the driven pulley that is attached to the rope. Because of this, a horizontally positioned rope is used which is ideal to eliminate riders from grabbing the incorrect direction of rope. For this to be possible, a gear box is needed to be applied to the system to translate the rotational movement 90 degrees. As this eliminates and rollback that could potentially happen from the pulley and drive shaft, this does increase the cost of the overall project as more parts are needed. As there is only one pulley that is connected to the rope, setting up for the rope is easier as well since the rope will not need to be fed through a system of pulleys. It is also evident that this design is considerably taller, which would require a larger frame or a 2-stage frame. This means that the frame would need to include 2 floors that would separate the motor from the pulley that is attached to the rope. This kind of frame would also support the gear box for the upper pulley. As a result, the cost of materials for the frame would increase and cause an unnecessarily complex frame that needed to be built.

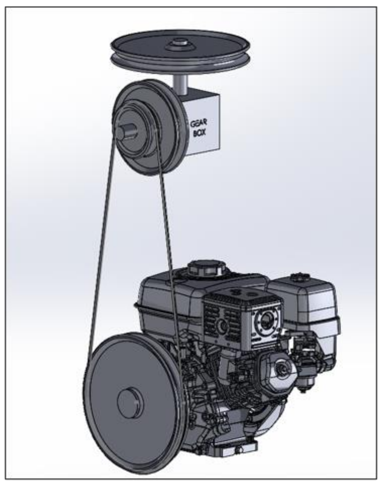

Figure 23: Concept Generation 3 for Drive Unit

4.2.2 Subsystem #2: Drive unit housing and frame

The following subsystem concept generations are for the drive unit housing and its frame. It will pertain to the customer needs revolving safety, portability, and durability. All three systems are constructed of aluminum with similar dimensions. The frame and housing are crucial to holding the whole unit together and is used for importing the rider and beginning their tow up the mountain.

4.2.2.1 Design #1: Basic welded housing unit

The first generated concept for the housing unit began with a 3ft by 3ft share welded frame. Aluminum sheets were then welded onto five sides of the frame with a cut out for rope access in the front. Four bases were welded with drill holes for securing the frame to the snow. While not pictured in Figure 24, the top of the box is another aluminum sheet attached with hinges and a latch for access to the drive unit. In all supporting corners of the frame, triangle gussets were welded to aid in durability. The frame would be very supportive but a very expensive build. Thick aluminum sheets are quite expensive and are a downfall to this concept. It would also be hard to transport up and down the mountain as there are not any wheels, handles or sliding features. However, the frame would easily withstand transport and the weight of the drive shaft. The fully encased system is also very safe and provides a good baseline for the housing and frame for the tow rope.

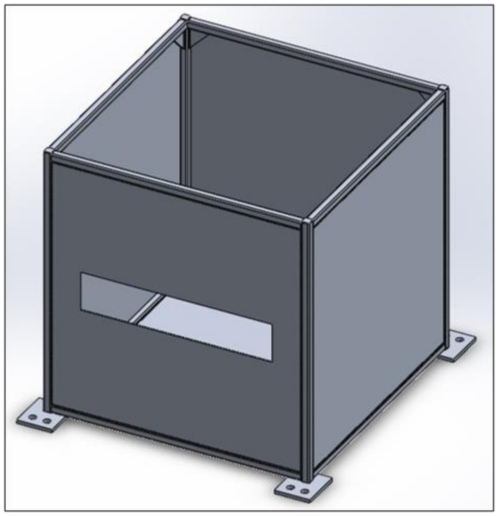

Figure 24: Concept generation 1 for the housing and frame

4.2.2.2 Design #2: Ski frame

The second concept variant utilizes a rectangular frame and transportable base. The design has an elongated frame for specific drive unit configurations. It utilizes the same front opening for rope access as the first concept variant. This design is also fully encased by a top sheet secured with latches and hinges for motor access. Where design two excels is the self-anchoring front feet and sliding back feet. Once the design is on the mountain, the skis on the base will also for the system to be easily pushed up to the desired spot while the spiky front feet will help to secure the system and prevent slipping. This design would also be quite expensive to manufacture and would not provide as much room for the drive unit inside the housing. Regardless, the maneuverability of the unit and lighter design would make this housing unit better for competitive use.

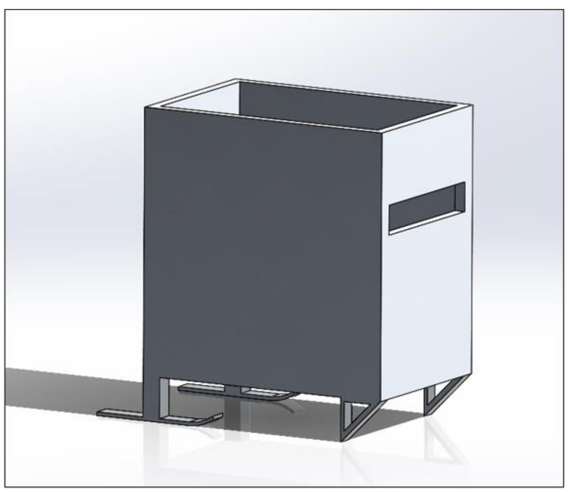

Figure 25: Concept generation 2 for the housing and frame

4.2.2.3 Design #3: Plexiglas housing

The third design incorporated a welded aluminum frame similar to the first, but the paneling is constructed of Plexiglas. The use of Plexiglas was to lighten the cost and weight of the system. Aluminum is expensive and constructing the frame with a cheaper material that can withstand the weather is ideal. Plexiglas paneling also requires less welding for manufacture. This will bring down the cost of the system but sacrifice some strength. Lastly, Plexiglas is see-through, allowing for visual access to the mechanical parts, making it more noticeable if maintenance is needed. This design with its visual appearance produces a lighter frame, more cost-efficient housing, and visual maintenance system. However, it lacks portability and durability as it stands. Even so, the slick plexiglass, if added to the base could enact as a sled and reinforcing structures could be added within to provide stability. These aspects make this system

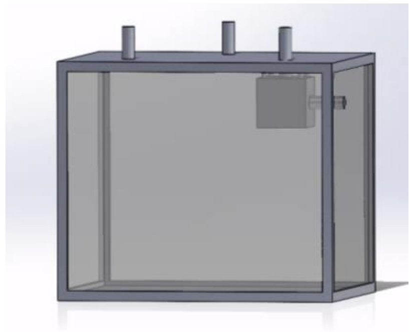

Figure 26: Concept Generation 3 for the housing and frame

4.2.3 Subsystem #3: Top Pulley

The concept generation of the top pulley focused on the engineering requirements and customer needs and used some inspiration from benchmarks to design the optimal structure. A major focus of the top pulley during designing was safety, which included ensuring stability, durability, and keeping the two directions of rope separate. In addition, the top pulleys were designed to be collapsible and portable to meet the need to be compact.

4.2.3.1 Design #1: Single Wheeled Top Pulley

This top pulley design shown in figure 27 is a simple frame with feet that would be buried in the snow, anchoring hooks for the tensioning cables and snow anchors, and a single horizontal sheave wheel to return the rope downhill. A pro of this design is that it is easy to assemble as it is designed to only disconnect from the vertical post and the footing. This ability to disassemble makes it compact. Another pro is that the use of minimal materials and a single sheave wheel makes the design low in cost. The final pro is that the feet are designed be buried and there is plenty of anchoring accommodation so the overall system would be very stable. One con of this design is that it may not be as durable at the joint of the post and the footing, unless significant angled supports are added. Another con is that the sheave wheel is small which causes the uphill and downhill ropes to be too close.

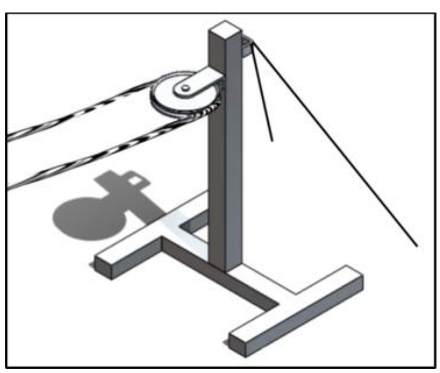

Figure 27: Single Wheeled Top Pulley

4.2.3.2 Design #2: Overarching Two Wheeled Top Pulley

The design shown in figure 28 is inspired by industrial top pulleys used at some ski resorts, where the system feeds the downhill rope at a height that is unreachable from the user. The lower rope is the uphill moving rope that the user would hold onto. The large base is designed to be heavy and be staked into the ground for additional stability. The pros of this design are the heavy-duty structure makes it durable and sturdy, the two sheave wheels keep the two ropes separated, and the foot can be buried for additional anchoring. A con of this design is that it is not compact as the vertical component has to be very tall to keep the rope out of reach. Another issue is that it would be very heavy and thus difficult in Transporation and installation. The final con is that there is a safety hazard in the case that the anchoring fails, and the frame tips, it could cause serious damage and injury.

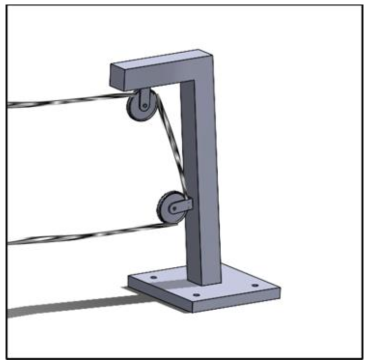

Figure 28: Overarching Two Wheeled Top Pulley

4.2.3.3 Design #3: Two Wheeled Horizontal Feed Top Pulley

The design shown in figure 29 consists of two sheave wheels, anchoring hooks, foot holes for staking, and a frame that can be disassembled. The idea of using two sheave wheels is to distribute the tension force of the rope to two wheels than one to reduce likelihood of damage to the system. One pro of this design is that the sheave wheels are set at a sufficient distance apart from each other to keep the uphill and downhill ropes separate. Another pro is that the frame can be disassembled into four pieces, two horizonal members and the two triangular legs. A third pro of this design is that it accommodates plenty of anchoring with hooks on the back of the horizontal member to attach tensioning anchors to, as well as holes in the four corners of the feet to drive stakes into the snow. Another pro is that the triangular feet corners that are facing downhill can be jammed into the snow as an additional anchor. Additional pros are that the design is low cost and easy to install. The con of this design is that it is more difficult to fabricate the triangular feet with the limited metal work experience the team has. Another con is that with it being able to be disassembled in so many places, these could cause multiple weak points so it may not be as durable; additional supports and tensioning specifications of nuts and bolts would have to be added.

Figure 29: Two Wheeled Horizontal Feed Top Pulley

5. DESIGNS SELECTED – First Semester

Taking the previous concept generations into account for all subsystems, these designs were evaluated on their performance and effectiveness for the overall design. They were evaluated on quantifiable advantages and disadvantages that were found through calculations and software analysis. The Customer and engineering requirements that were specified through the client were also considered when determining the concept selection for all subsystems. Techniques of analyzing the customer and engineering requirements were applied to all concepts for each subsystem that quantifiably narrow down the concepts. This is done by a decision matrix and a Pugh chart that provide justification for the overall design selection.

5.1 Technical Selection Criteria

When determining a design for the final selection that will continue to the next phase of the project, quantifiable analysis is necessary. Concepts that achieve either the customer requirements or engineering requirements can only be compared so much in order to determine an optimal design. Since an important requirement of this project is to produce a Portable tow rope, size and weight are a large factor in this engineering requirement. The entirety of the design must weigh from 150 to 200 lbs in order to transport it safely and easily, which is directly from the engineering requirements. The heaviest section of this design was determined to be the drive unit; therefore, a weight analysis was applied to the concepts of this subsystem. Assuming that each concept will be using the same motor, the weight for this part was eliminated and unnecessary to determine. This weight analysis was achieved through SolidWorks through displaying mass properties which are shown below for each concept for the drive unit.

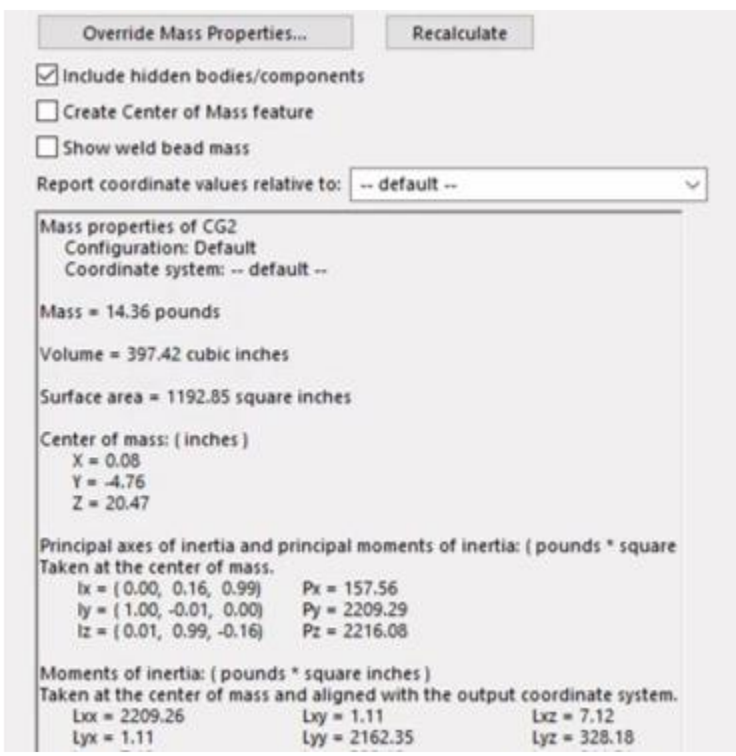

Figure 30: Mass Properties for Concept 1 of Drive Unit

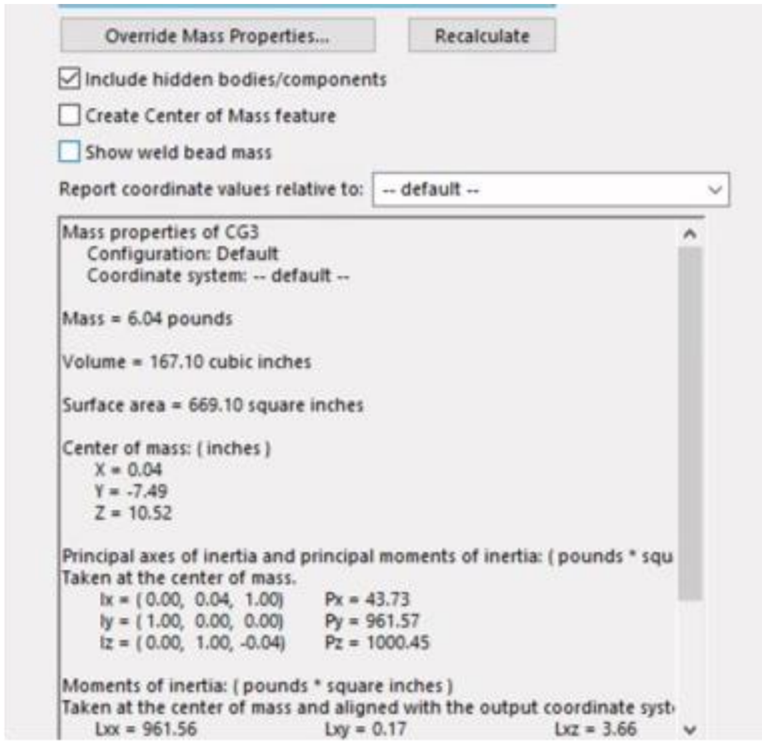

Figure 31: Mass Properties for Concept 2 of Drive Unit

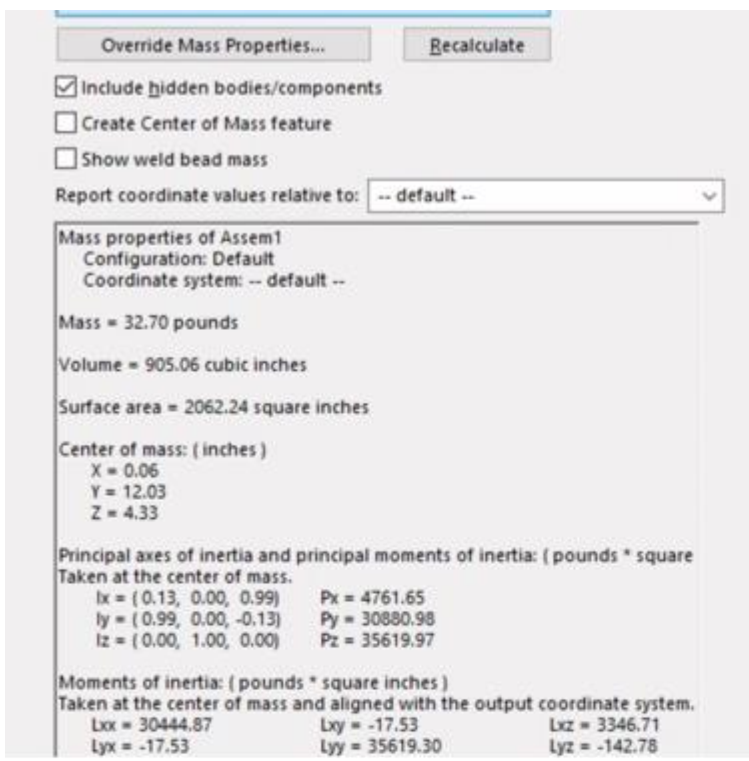

Figure 32: Mass Properties for Concept 3 of Drive Unit

From this analysis the weight of concept 1 was 14.36lbs, concept 2 was 6.04lbs and concept 3 was

32.7lbs. With each of these concepts considerably different in terms of weight, this will affect the overall rationale for the design selection as the heavier the concept is, the lower the score it will receive in this process. This physical factor will affect the transportation abilities of the team as a lighter design will require less effort to move to the desired location on a sloped and snow-covered mountain.

5.2 Rationale for Design Selection

By using the engineering and customer requirements that were previously determined by the client and the team the concepts for each subsystem were rated. A datum was selected for each of the subsystems which was determined by selecting the most feasible and average design for each category. For each subsystem, the datum was determined to be the second concept for each. The remaining designs were rated against the datum in comparison in terms of that design being better or worse. These comparisons were quantified through a score located at the bottom of the Pugh chart shown below in figure 33.

Criteria	drive unit	Design Alternative #1	Design Alternative #2	Design Alternative #3	housing	Design Alternative #1	Design Alternative #2	Design Alternative #3	top pully	Design Alternative #1	Design Alternative #2	Design Alternative #3
Compactness		+	D	+		-	D	+		S	D	-
Cost		-		-		+		S		+		S
weight		S	A	S		S	A	S		S	A	S
ease of operation		S		S		S		S		S		+
safety		+	T	-		S	T	S		S	T	+
Σ+		2		1		1		1		1		2
Σ-		1	U	2		1	U	0		0	U	1
ΣS		2		2		3		4		4		2
Score		1	M	-1		0	M	1		1	M	1

Figure 33: Pugh Chart for all subsystems

From here a decision matrix was used for the narrowed down concepts. This included concepts 1 and 2 for the drive unit, concepts 1 and 3 for the frame and concepts 2 and 3 for the top pulley shown in Figure 34:

Score: 1-5																
Design Criteria	Weight	Drive unit	Design Concept #1		Design Concept #2		Housing	Design Concept #1		Design Concept #3		Top Pulley	Design Concept #2		Design Concept #3	
			Rating	Weight Score	Rating	Weight Score		Rating	Weight Score	Rating	Weight Score		Rating	Weight Score	Rating	Weight Score
Compactness	15%		4	0.6	4	0.6		2	0.3	5	0.75		3	0.45	2	0.3
Cost	20%		3	0.6	3	0.6		3	0.6	3	0.6		3	0.6	3	0.6
Weight	20%		3	0.6	3	0.6		3	0.6	4	0.8		4	0.8	4	0.8
Ease of Operation	15%		3	0.45	3	0.45		3	0.45	3	0.45		2	0.3	4	0.6
Safety	30%		5	1.5	2	0.6		3	0.9	3	0.9		3	0.9	5	1.5
SUM				3.75		2.85			2.85		3.5			3.05		3.8

Figure 34: Decision Matrix for Remaining Concepts

From this decision matrix it can be seen that the design criterion for this matrix was based on the customer and engineering requirements and were rated based off of importance to the team members and to the client. Weight was rated moderately for importance as it related to portability but is not quite as important as the safety rating for each design. Each design was rated from a scale of 1-5 of how well they achieve each design criteria. From here this score was rated by the percent importance of that design criterion and then added together to find the result. The highest number of weighted scores for each subsystem yielded the optimal design. Concept 1 was the best choice out of the concepts as it was rated the highest in the Pugh chart and the decision matrix. This was also supported by the numerical value of the weight of the drive unit as it was moderately light in comparison to the remaining concepts. Concept 3 was the optimal concept for the frame it was also lighter in weight, encased all moving parts of the motor and used cheaper and lighter materials. Concept 3 for the top pulley subsystem was also the optimal choice as it was compact and collapsible for easy transportation and separates the loaded and unloaded ropes which increases safety.

These chosen concepts from each subsystem were realized through a CAD rendering of the overall design shown in figures 35-38.

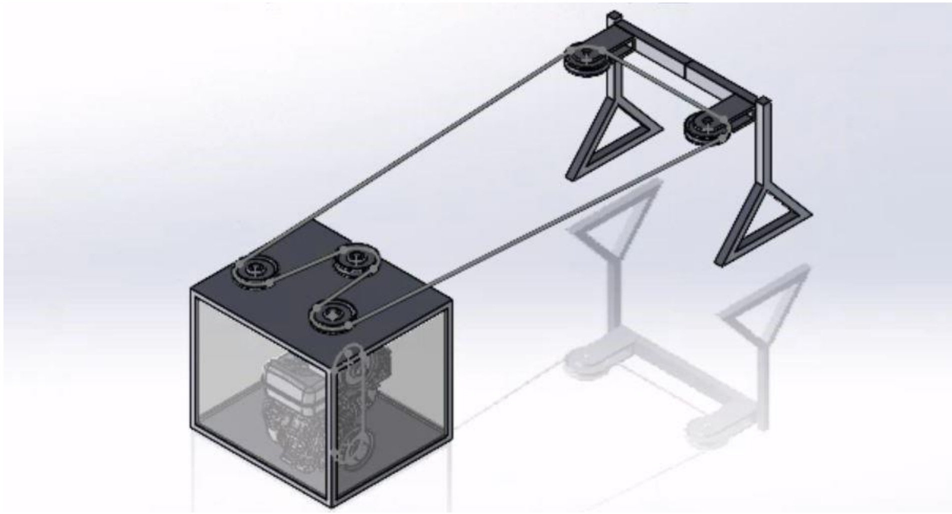

Figure 35: Isometric view of final design

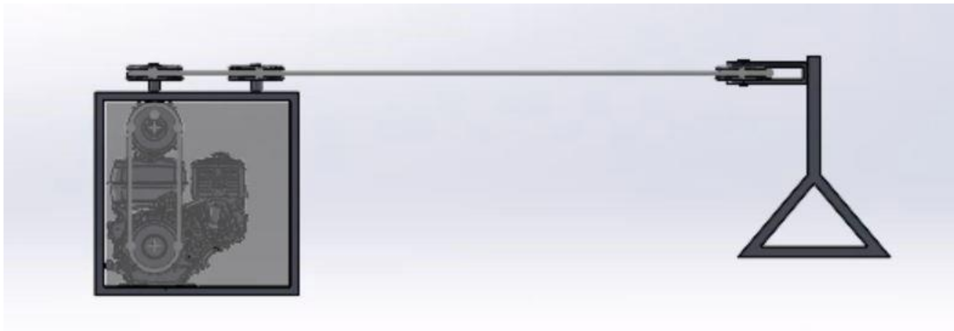

Figure 36: Profile view of final design

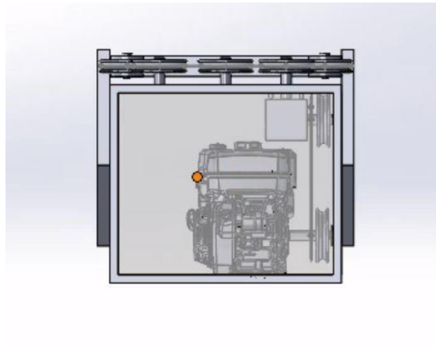

Figure 37: Front view of final design

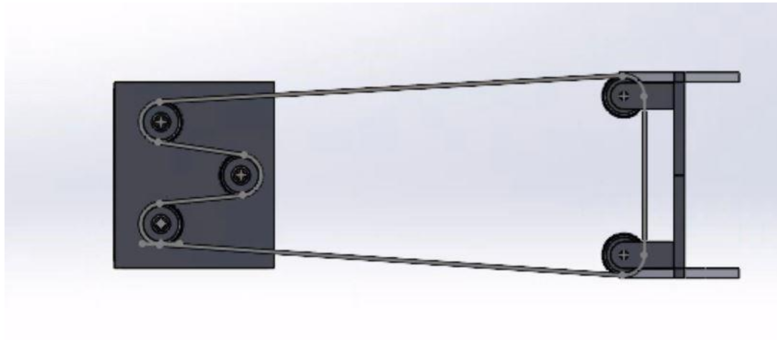

Figure 38: Top view of final design

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