Ski Haus Tow Rope

Final Proposal

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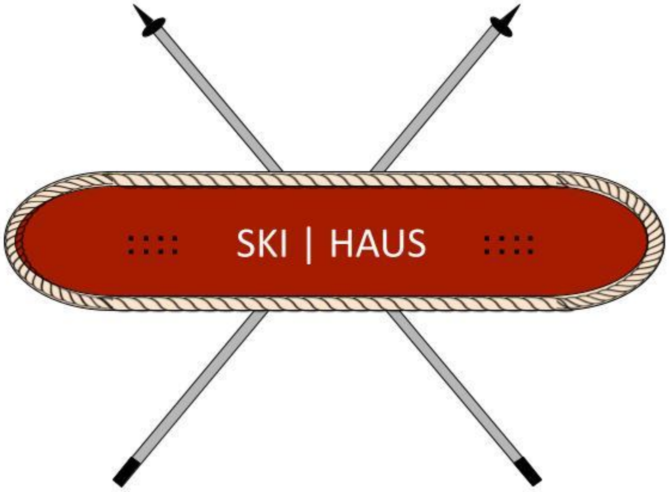

Project Sponsor: Ski Haus
Faculty Advisor/Instructor: David Willy
Sponsor Mentor: Davis Bedient

DISCLAIMER

EXECUTIVE SUMMARY

The Ski Haus rope tow is a transportation device that pulls skiers and snowboarders up the mountain via a rope. Ski Haus is a local retail ski shop in Flagstaff Arizona that hosts the most attended competitive events at Arizona Snowbowl. Despite the successes of the Ski Haus ski and snowboard competitions, issues arose of fatigue in the riders from hiking in the competition area, which became a potential hazard for injury. Ski Haus is sponsoring this capstone team to design a rope tow team will address this issue by building an affordable rope tow that can be easily transported and installed for these temporary event setups to relieve the riders of fatigue and increase their number of runs in the competition. Davis Bendient, co-owner of Ski Haus, is in charge of these competitions and is the client for the team to ensure that the project meets their needs and stays on track.

The progress of the Ski Haus tow rope capstone project started with a need to solve a problem for Ski Haus. A team was created of three engineering students who also have years of experience in snow sports both recreationally and working in the industry. A client and sponsor were established, and a general design was made between the team and client. Customer requirements were established and turned into quantitative engineering requirements. Research was then done on benchmarking and literature reviews performed to educate the team on existing products and specifications. Through concept generation a preliminary design was established. Using this design, the team created a rough bill of materials, budget, and fundraising strategy. The team designed and purchased merchandise to resell, and hosted raffle events to raise money for the project. Next a prototype was designed of a scale model of the tow rope, and that was created to answer analytical questions. Preliminary calculations were executed in order to begin purchasing parts for the final design which will finally be established through the testing procedures and risk analysis for failures. Fabrication resources for custom parts have been contacted and assembly of the final design will begin once final analyses have been completed.

This final proposal report will cover capstone design process and solution while providing visual representations of the analyses, prototype, and final design. Chapter 1 provides a background to the project to explain the problem and team's proposed solution. The customer and engineering requirements are discussed in chapter 2 using a black box model and functional model for decomposition, and a house of quality for analysis. Then the standards, codes, and regulations are then discussed to show that the customer and engineering requirements meet these standard expectations. In chapter 3, testing procedures of the system are executed to test the engineering requirements. Seven test procedures are discussed explaining their objectives, resources required, and schedule of the tests. Risk analysis and mitigation are discussed in chapter 4, looking into critical failures analyzing ten potential failures through failure modes and effects analysis (FMEA). Then the risks and tradeoff analyses are discussed. Lastly, chapter 5 discusses the final design that the team selected, providing a design description and implementation plan. This explains the progress and changes made throughout the semester of the design and shows the most up to date prototype. Justifications for the design choice with visual aids are provided and future plans of the project are considered. The proposal is concluded with a review of the discussions in the paper, reiterating the design and proposed solution as well as the results of the project thus far. References and appendices are provided in chapters 7 and 8.

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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. Functional decomposition models were altered to reflect changes made in the design proposal as well. A house of quality then provides an analytical matrix that relates to 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 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. The changes to the design were within the drive unit train. This is detailed within both functional decomposition models.

2.3.1 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. Figure 1 demonstrates this model and has not changed through the process of design.

The Ski Haus tow rope system detailed the inputs and outputs in terms of materials, energies, and signals. While design changes within the drive unit have been made, none of which alters any inputs or outputs of the system. 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 shut 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 in figure 1.

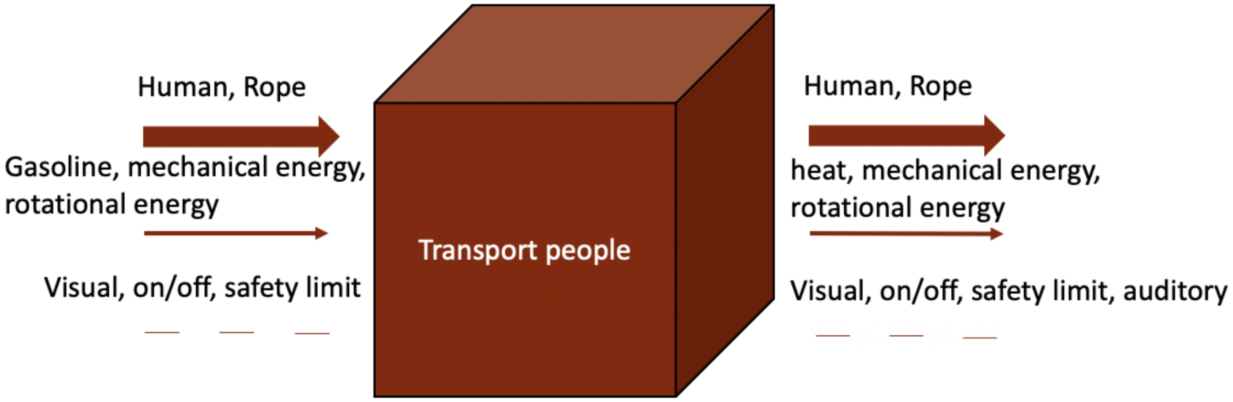


Figure 1: Black box model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

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. Alterations within the drive unit have been made to further break down the flow of energy from the drive shaft to the rope. 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 2 demonstrates this functional model.

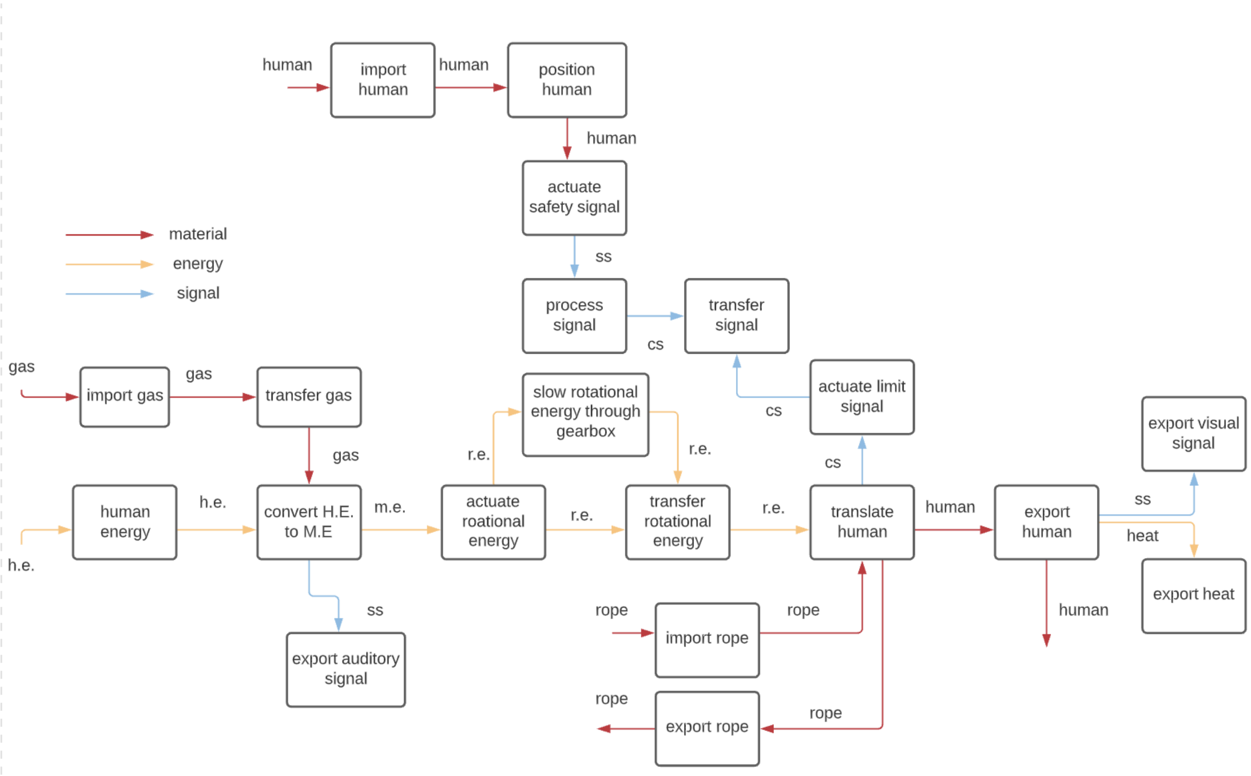


Figure 2: Functional decomposition model of a tow rope

2.4 House of Quality (HoQ)

A house of quality (HoQ) 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. An addition to this revised HoQ are the testing procedures and their correlation to each engineering requirement.

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.

Below the customer needs is a list of seven testing procedures that correspond to both the customer needs and engineering requirements. They are each ranked from 1-5 in accordance with their importance as the 9 customer needs were. Similarly, the same 1,3, 9 scale was used to relate them to the customer needs. Each testing procedure is detailed in section 3 of this document.

Overall, it's crucial to utilize a house of quality to facilitate early group decisions regarding the design. Specifically, the Ski Haus team's HoQ 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 HoQ 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 HoQ 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 HoQ developed great preliminary project planning as a team and led into a baseline for our generated concepts.

2.5 Standards, Codes, and Regulations

Standards for ski lifts depend on each state where it is in use. However, there are a set of national standards for ski lifts set by the American National Standard for Passenger Ropeways-Aerial Tramways, Aerial Lifts, Surface Lifts, Tows, and Conveyors – Safety Requirements [1]. This ANSI B77.1-2011 document was used in creation of relevant standards for the Ski Haus tow rope (Appendix B). Section six of this document specified all standards are regulations relevant to tow ropes. They set a standard for all types of tow ropes with all installations and ropes. Some codes did not relate to this portable tow rope and were omitted (Appendix B).

The table of Standards of practice as applied to the Ski Haus tow rope specifies that standard number from ANSI B77.1-2011, the title of the standard, and how it will be in use for this project. Each of these standards is critical in the design and testing of the Ski Haus tow rope as it specifies needed factors of safety, inspections protocols, safety protocols, and other crucial implementations. The team has designed the tow rope with many of these standards in mind but having a document that specifies all requirements for the device to be suitable for mountain use as well as safe for all riders is beneficial. After compiling all the standards relevant to our tow rope, the team had a better idea of needed testing procedures, what to specify in the design manual, and ways to better the design against failure.

The Table of standards of Practice in Appendix B explains all standards critical for the development of the Ski Haus tow rope. All descriptions are in accordance with the ANSI B77.1-2011 document [1].

3 TESTING PROCEEDURES (TPs)

Once the design process is completed by the team, prototypes must be tested thoroughly in comparison to the constructed engineering and customer requirements. Specifically for the Ski Haus tow rope, an emphasis will be placed on the implemented safety features and load capability. Multiple testing procedures will be detailed below to ensure the designed device can uphold its specifications.

3.1 Testing Procedure 1: Load Capacity

The loading capacity of the tow rope was established originally to pull five people at a time. Calculations based on a specific motor, torque, and sheave wheel set up proved ten people could ride the tow rope at a time. While there are calculations to back this statement up, multiple tests must be conducted to ensure the system can perform correctly under a load that large. The engineering requirement depicted in our house of quality is to increase the towing capacity. Testing the factor of safety and limits of these designs carrying capacity will allow for a proper load capacity to be made. Once the team has constructed a running prototype, multiple people will ride the tow rope to test its loading capabilities.

3.1.1 Testing Procedure 1: Objective

To run this test, a preliminary test must be held to ensure the constructed device can pull at least one person. If everything is working correctly, we will slowly increase the number of people being towed analyzing all the parts that will be mostly impacted by the weight such as the sheave wheels and all anchoring systems. The goal is to at least get five people on the rope at a single time without any failure from the device. If this is done without fault, the load will continue to increase until the team suspects issues to occur. The factor of safety of all designed parts will be high to compensate for any overloading of the tow rope. Knowing how many people can safely ride on this tow rope is a crucial element to the design as well as an important customer need. Testing this will allow the team to specify an exact number of people as a max load capacity for the tow rope.

3.1.2 Testing Procedure 1: Resources Required

To test the tow ropes loading capacity, a large snowy open space containing a sloped hill is necessary. Preferably access to Snowbowl after hours, but the sponsor's backyard would suffice. A working prototype that is very similar to the final design would provide the most accurate results. A minimum of 10-12 people would be necessary as well, assuming the tow rope would be able to accommodate the same load as calculated previously. The goal of this test would be to reach a load capacity before any failures in the device. However, fixing and reworking the design may be necessary in which case spare parts and tools would have to be supplied. Each person aiding in the test would also need to have their own set of skis or snowboards to be towed up the hill.

3.1.3 Testing Procedure 1: Schedule

This test will most likely take a few hours. This time schedule is based on the set up that will need to be done in preparation as well as the time it will take to circulate through multiple increasing loads. This test will hopefully be run in January or February after a solid prototype is constructed. Before this test can be completed, most parts for the final design must be in hand and used in the prototype. This device that will be used to test the load capacity will be very similar to the final design, if not it. The parts that can be omitted for this test would be some safety features at the top as well as the casing of the drive unit. However, these elements will most likely be designed and built alongside this final design and could very well be fully functioning by the time of the procedure.

3.2 Testing Procedure 2: Distance Able to be Traveled

The test to be conducted is the analyzation of the rope length and any coupling that may be used to lengthen or shorten the distance able to be traveled. The original customer needs a towable distance of 200 ft or the average distance between two chairlift towers. More specifically, the distance of a typical rail jam competition set up. The tow rope will most likely be set up with a 400-foot rope to create a towable distance of about 200 feet. However, as the use of this device can vary, so can the available space for competition or practice. Due to this, either rope couplings or various sized ropes must be used. Ultimately, the testing procedure will focus on the durability of the rope used over time and under loading. Similarly, the team will analyze different methods of coupling or knotting the rope as well as the best methods of securing and releasing the rope for set up and take down. This test will likely take multiple days of running the rope through the system and troubleshooting methods for safety and operation.

3.2.1 Testing Procedure 2: Objective

This test will first analyze the longest and most applicable rope for competition. The rope will run continuously through the drive and top unit as riders utilize the tow rope. Ultimately, a fake competition would be held to test the durability of the rope. After use, a full inspection will be performed using methods such as the "rag and visual" to see if there are any visible areas of wear. Assuming the high-quality rope holds up to its specifications, there will not be any damage visible. With that, multiple days of these tests will be performed. This is a physical test for durability and wear within the rope, however, any purchased rope by the team will be chosen based on the manufacturer's safety and wear recommendations. All standards of the rope will be considered during testing and referenced with ANSI B77.1.6.1.4.1. The rope wear and running life is crucial as it will eventually wear down and must be replaced. Understanding the chosen rope and its wear specifications is critical for a safe design.

3.2.2 Testing Procedure 2: Resources Required

The main resources for this test are the rope is question, and a running prototype using the sheave wheels properly fit for the rope. Tools such as rags and pliers, and hand drills will be necessary for fitting the rope into the system and inspection. The location for this test must be outdoors in a large enough space for a 200-foot length rope to be in motion. Once set up the system would just be running continuously at maximum speed.

3.2.3 Testing Procedure 2: Schedule

This test will take multiple hours for about three days. The system would run continuously for at least an hour before inspecting the rope. Parts of this test could be completed at the same time the load capacity is being tested. Many of the physical tests that need to be completed while the device is running can be completed at similar times. It is expected that the team will complete these tests with an almost finalized design early in the second semester.

3.3 Testing Procedure 3: Time to Reach the Top

The customer specified an average amount of people per hour to be towed by this device. Previous calculations have been done to verify if this is possible, but it must also be tested physically. The team was given an average of 60 people per hour to be towed, meaning the motor towing capability and constant velocity must meet this specification. To test this, the tow rope will be set up and the team will evaluate how many people can be towed to the top in an hour. This test will be completed in one day and should only take an hour or two.

3.3.1 Testing Procedure 3: Objective

As this device will mainly be used in competitions, each heat in competition is on a time limit. It is important for the tow rope to be able to move people in a timely manner for this specific use. This test will be completed based on maximum capacity of the tow rope. To begin this test, one team member will keep track of the time while one oversees counting the number of people to reach the top. This will be best evaluated with a lot of volunteers riding the tow rope so that it is always as close to maximum capacity as possible. As the need of the customer is 60 people per hour, once this limit is met the test will be conducted and the time elapsed to meet this will be recorded. According to calculations previously completed, meeting this specification should not be an issue.

3.3.2 Testing Procedure 3: Resources Required

The resources needed for this test are a fully function tow rope, either prototype or final design, and many skiers and snowboarders willing to ride the tow rope. The tow rope must also be set up on sloped ground and at a 200-foot length in rope. A way to watch the time such as a stopwatch or phone is also necessary.

3.3.3 Testing Procedure 3: Schedule

This test will only take one day and no more than three hours including set up and take down. The actual running test will last for 1 hour. It will be completed around the same time as the previous two tests as all of them need a very completed prototype or final design. This test fits into the testing weeks that will be conducted late January early February. This timeline is based on the expected completion of the project in March of 2022.

3.4 Testing Procedure 4: Durability of Construction and Parts

To test the durability of construction and manufactured parts, an inspection test similar to the ANSI B77.1.6.1.1.11 standard will be conducted. This will consist of the system running without loading for a period to ensure there is not any damage to the parts. With this, the system will be loaded both directly and indirectly to analyze any deflection or issues within the structure. As this system will be used continuously for multiple hours, it is crucial that all elements are durable enough for this use. To appropriately test all elements in the design, they will have to be broken up into categories consisting of multiple days of testing. These tests will be conducted beginning in winter break and ongoing until the completion of the design.

3.4.1 Testing Procedure 4: Objective

To test all durability, each item will be loaded as specified by the intended use. The system will run for an extended period while the team inspects all parts for any overheating, deformation, or excessive vibrating. These inspections will be done mainly to the drive unit as well as the base and top pulley system. All sheave wheels will be placed under the unloaded rope stress as well as loaded. The sheaves will be evaluated to ensure there is not any deropement and they are withstanding the loading with a large factor of safety. All anchoring and tensioning systems will be set up and placed under maximum loading of riders. These tests correspond with reliability as well as the constant inspection and multiple durability tests will determine how likely the device is to withstand wear and damage in use. This testing may be the most crucial element as all parts must be designed with large factors of safety and be able to withstand the worst loading conditions. The team will have to place the device under a lot of stress to evaluate how it holds up.

3.4.2 Testing Procedure 4: Resources Required

This test will need all manufactured and designed components to be in hand and built into their desired method for use. A full running system will be needed as well. Similar to before, a sloped hill and people to ride the equipment is necessary. Tools for evaluating the wear and stress on the parts are also needed. Assuming repairs and alterations will need to be made, tools for that must be accessible. Anything that can aid in unconventionally loading the device for factor of safety evaluation will help is creating a better test with more accurate results.

3.4.3 Testing Procedure 4: Schedule

These tests will be continuous from the first build to the final design. They will most likely be run simultaneously with other tests as well as on their own. Testing the durability of the design will be tested during most of the spring semester until the device is fully completed. For this test to be completed fully, the rest of the tow rope design must be as well.

3.5 Testing Procedure 5: Safety Requirements

There will be multiple safety elements designed into the tow rope. All of these must be tested thoroughly to determine their reliability and decrease any failure to occur. The elements to be analyzed during this testing procedure are the emergency stop button, manual speeds, stop gates, and loading and unloading procedures. All electrical elements will be running while people test the elements in a simulated emergency. All safety features will be created in accordance with the ANSI standards stated in section 2.5 as well as appendix B. These tests can be conducted in one day for initial testing but must be reevaluated before every use of the device.

3.5.1 Testing Procedure 5: Objective

The emergency button as well as the stop gates will be electronically wired into the motor. The team must enact these safety features to ensure the connection is working and the reaction time of the motor is quick. These elements must correspond to all ANSI standards such as the entire system stopping within 25 feet. This will be measured during this test as well. The team will practice safe loading and unloading procedures that work with the product best as well as ensuring all motorized elements are encased and out of reach of the public. The speeds on the motor will be evaluated and have a method set for when, how, and why to change the speed of the tow rope. The brake in place will be visually inspected for safety. All of these elements meet the customer's need for safety and provide back-up plans for controlling the tow rope if necessary. Providing this design with ample reliable sources of safety is crucial for the riders and the operators.

3.5.2 Testing Procedure 5: Resources Required

The resources needed for this procedure are fully functioning tow rope. As the safety features will be some of the final touches added to the design, the final model of tow rope will be best for this test. All procedures will be conducted by the team and will not need many tools to do. To measure the length of the rope moved once the emergency button is placed, a measuring tape will be needed. The other safety elements will be tested by simply enacting them and visualizing their response.

3.5.3 Testing Procedure 5: Schedule

This test will be one of the last tests conducted on the tow rope. This is due to the whole device needing to be finalized before being able to properly evaluate. Due to this, the tests will be conducted in late February early March of spring semester. The tests should only take a few days depending on how many elements need to be fixed or changed.

3.6 Testing Procedure 6: Portability

The reason this tow rope is different than other resort tows is the fact that it's portable. This prevents the need of permeant structures to be created while also not conflicting with the snowcats. However, for this tow rope to be portable, it must be able to withstand multiple tests. These tests will include weight measurement, how it can be lifted, how many people are required to move it, methods of towing it up the mountain, and a drop test. These tests will correspond with the customer and engineering requirements of durability, reliability, portability, and weight.

3.6.1 Testing Procedure 6: Objective

To start, the total system will be weighed. A customer requirement is that it is no more than 300 pounds or the equivalent of 3-4 people carrying it. It must also be able to be lifted and transported in the back of a standard truck bed. As a team, the device will be lifted into a truck bed and transported to the mountain. If all parts stay intact and are transported well, the device will be lifted out of the truck bed and carried to the slopes. The goal is to install a handle and sled base so that the drive unit can be pulled or pushed either by people or towed behind a snowmobile. Both methods will be tested. Lastly, a drop test will be conducted. Since the unit is bulky and heavy, there is a chance it could get dropped during transport. To compensate for this the team will secure all parts to the frame and the frame will be made with a durable metal. The drive unit will be dropped from a small height to see how all parts react and what damage may be done. These tests are important in the creation of a portable product of this size and weight. The whole design of the two rope was based on the idea of transportability, so ensuring the final design can withstand this movement is critical.

3.6.2 Testing Procedure 6: Resources Required

To run these tests, a fully encased drive unit similar to the final design is necessary. A truck for transport as well as a snowmobile is needed. Snowbowl has snowmobiles that we will borrow as well as a friend’s truck to transport the unit. All three team members as well as an extra person to lift the tow rope will be required. A heavy weight scale large enough to weight the drive unit will be important in ensuring the engineering requirement is met. This will be acquired through campus or by weighing each component separately and adding for the complied weight. These are the necessary elements for the test as well as using Arizona Snowbowl as a location for testing transport.

3.6.3 Testing Procedure 6: Schedule

Before this test can be run, a completed drive unit and casing is needed. Once this is complete, this test can be completed easily in one day. This test will be conducted before any of the other tests are completed. The drive unit and housing are on the schedule to be completed first and this test will be done after its completion. This is expected to happen in January of spring semester.

3.7 Testing Procedure 7: Ease of Operation

The tow rope will always need a minimum of one operator, supervising and running the system. The operator must be trained, but for simplicity, the tow rope is expected to have minimal operating components. The operator will be in charge or visual supervision of loading and unloading, starting the system, as well as emergency stops. To test this, the team will conduct training for using the system for all Ski Haus employees. This training will explain all elements and how they must be properly used. A demonstration of the devices' limitations and possible failures will be included. This test will take multiple days to ensure everyone is properly trained and the operator understands the entire system.

3.7.1 Testing Procedure 7: Objective

To begin, each team member will test all operating systems and guarantee they are in accordance with all ANSI guidelines (Appendix B). As long as everything is working properly, all possible operators must run a training course put on by our team. This course will go over all buttons, starting and stopping procedures, as well as loading and unloading. Each operator will run and ride the tow rope to understand the device fully. Conducting this training corresponds directly to the ease of operation customer need and guarantees all riders and operators safety.

3.7.2 Testing Procedure 7: Resources Required

For this training, a user manual must be made first for all trained operators to have. This is a deliverable in second semester, so it must be completed before this training. Secondly, the final design must be completed before this as each operator should only be trained on the exact device they will be operating. The training will not require any equipment besides this and will only focus on running the tow rope. This training will be done at Arizona Snowbowl to simulate the most accurate conditions possible.

3.7.3 Testing Procedure 7: Schedule

This test will be one of the last tests to be conducted, projected to occur in March. This is due to the need for a fully complete design. The training and testing of the operation will be trail run of the device and must continue for multiple days to ensure everyone is trained properly. Each day will focus on different parts of the design and possible failures or areas where the public get hurt and preventative measures. Ultimately, these tests will be a critical part of the final design and will not be rushed for safety reasons.

4 RISK ANALYSIS AND MIDIGATION

4.1.1 Potential Critical Failure 1: Loose connection of Drive Shaft Sheave/Sprocket

This failure would be located on the drive shaft or sprocket that connects the moving drive shaft to the gear box to distribute the movement to the rest of the sheaves. The possible failure here is that this pulley needs to be tight on the shaft as the pulley should rotate at the exact same rate as the drive shaft. Here there is also no bearings required so using a tightening technique to ensure a secured connection between the shaft and sheave is critical. This failure if it occurs would affect the rider's safety which is one of the top priorities from the team and the customer. The rider's safety would be jeopardized in the fact that with a loose sheave there could be variable power outputs to the rest of the sheaves and would affect the consistency of the speed. This failure can be mitigated by establishing regular drive shaft and sheave inspections much like what is used in the actual ski lift industry.

4.1.2 1.1.2 Potential Critical Failure 2: Driven sheave or sprocket failure

This potential failure in the system is applied to the driven sheaves on the upper section of the drive unit. These sheaves are meant to effectively and evenly distribute rotational energy both driven sheaves that move the rope. These sheave or sprockets must evenly rotate at the same rate in order to be effective in the subsystem. Possible factors that would affect this failure is the tightening of the sheave on the shafts as this could cause slipping from the contact of the two parts. Another factor that would potentially cause or trigger this failure is any harsh variable loading that might occur during the operation of the tow rope. This meaning any rapid amount of people loading the tow rope in either close time increments or at the same time as this would apply a lot of stress on all parts of the tow rope and especially these sheaves. To prevent this failure becoming realized, the operator would take caution in how many people are loading the tow rope and the frequency in which they are loaded as this is a typical loading technique and precaution that is used to load moving carpet type surface lifts.

4.1.3 Potential Critical Failure 3: Bending stress applied to Idler Pulley

The idler pulley is meant to keep tensioning in the rope as it travels around the drive unit at the bottom of the tow rope. This is very helpful and convenient for riders as they load and unload the tow rope. However, if this tensioning is too tight this can lead to bending stresses applied to the idler pulley and its rotating shaft. As the tensioning is applied to two sides of the pulley, this causes two force moments at those same locations and have the magnitude in the same direction which is likely to cause bending in that direction as well. To prevent this type of failure, the correct support and shaft connections are needed. This failure can be noticed by the shaft being misaligned and having visible slipping in the rope. As soon as these failures are noticed then arises more issues, so avoiding this would be ideal by using the prescribed methods.

4.1.4 1.1.4 Potential Critical Failure 4: Shear and Torsion applied to Extended Shafts for Driven Pulleys

On the upper section of the drive unit, sheaves are either connected by a chain or timing belt that direct rotation to the top driven pulleys. From these pulleys, the rotation in translate vertically via extended shafts. With these extended shafts comes different types of failure where if the shaft is too long then the movement in impeded and the shaft bottoms out in the supports. This could cause the pulleys to fail as well and danger riders that are currently using the rope tow. Also, the effect of a longer shaft would create higher torque that is applied to the shaft itself which is not the desired torque from this project. With a higher amount of torque due to length, this could cause bending in the shaft as well and cause it to rotate off the correct axis. To prevent this failure, the proper loading conditions must be met and regulated and proper support for shaft throughout its length to combat the potential bending stresses.

4.1.5 1.1.5 Potential Critical Failure 5: Bearing Failures in driven Sheaves

The bearings of this assembly help create proper movement and rotation about the multiple shafts and sheaves. With insufficient bearings would cause a lack of efficiency in the motor and the moving parts as a result. This could potentially occur from improper lubrication of the bearings which is statistically 80% of the failure cause. Lubrication failure occurs more often when exposed to and operating in higher temperatures which could be the case for our project as the bearings would operate very close in proximity to a motor that generates heat. However, this tow rope will also be operating in winter conditions which could help mitigate this failure. This failure can be seen through visual inspection where the rolling elements are discolored and can be fixed with using the correct amount and type of lubricating and to avoid any grease loss that might occur.

4.1.6 1.1.6 Potential Critical Failure 6: Anchoring Stake security for top terminal

For riders to reach the top of the hill they must reach the top terminal of the tow rope. Here all the weight of the riders on the tow rope is accounted for here therefore this unit needs to have a lot of security in the anchoring. This is important as the top terminal stays in place while it experiences variable stresses that could cause it to fall down the incline surface. This would be very dangerous for the current riders on the tow rope. The snow conditions would also greatly affect this as the softer the snow then the less secure the anchoring stakes would be to ground down the top terminal. To mitigate this failure, testing would need to be done in many different types of snow conditions with the anchoring systems and tested against load that are much higher than the actual anticipated applied loads.

4.1.7 1.1.7 Potential Critical Failure 7: Drive shaft failure due to Critical Speed Vibrations

The Drive shaft is arguable one of the most important parts in this assembly. As a result, failure in this part should be heavily monitored and assessed as it greatly affects the safety of the riders and can trigger many other failures in various sections of the tow rope. With this specific potential failure, if the drive shaft was rotating at an unsafe rotating speed for the corresponding length of shaft. This failure is related to critical speed vibrations and is a function of the rotating speed, mass and the length of the shaft. During the failure of this effect, when the drive shaft starts to bend off of its normal rotating centerline it either pull out of its slip and cause a catalyst of dangerous failures throughout the tow rope or the drive shaft can whip in all directions and will eventually fracture in the middle of the shaft. For a drive shaft, the critical speed is present for all designs and constrictions and is always unavoidable. However, the critical speed can be mitigated with calculations to find the critical speed and prevent the tow rope from ever reaching this speed. This is done by using a high factor of safety and have a large difference in allowable versus actual speed.

4.1.8 1.1.8 Potential Critical Failure 8: Failure caused by wear in the Worm gear box

The gearbox will translate the rotational movement by 90 degrees in a vertical manner as to move the sheaves in the upper section of the drive unit. With a worm gear box there can be overloading caused where there is too much loading on the mechanisms of the internal gears from the horizontal and vertical shafts. With large overloading factors, this can greatly affect the life of the gear box and will such an essential part of the tow rope this much be avoided. This failure can be caused from increase temperatures, contaminants and debris that get inside the moving parts of the gear box. This can be avoided by regular maintenance to limit these debris and effectively apply proper lubrication techniques to extend the life and mitigate unnecessary wear on the gear box.

4.1.9 Potential Critical Failure 9: Rope Slipping due to load variability

The potential critical failure in accordance with the rope is slipping around the sheave wheels as well as damage from constant use of the rope. This could be caused from the speed of the rope, overloading the rope, as well as not enough tensioning in the rope. The sheaves must be fit to the rope diameter as well or these critical failures would be more likely to occur. If a deropement were to happen, this would endanger the riders as well as the equipment. This failure can be mitigated using idler sheaves for tensioning and well as tensioning at the top pulley with ratchet straps. As specified by the ANSI standards, a deropement catching system must be implemented as well.

4.1.10 Potential Critical Failure 10: Timing Belt Slipping Conditions due to Tensioning

A potential failure to occur in the design is slipping in the timing belt from the drive shaft to the gear box. As the system runs, the belts could lose friction and in turn, slip creating issues in the drive train. This failure is caused from a lack of tension between the belt pulleys as well as a high rotation per minute output from the motor. This slipping can cause extra friction which could create excess heat on the belt and drive shaft. This occurrence could cause premature damage to the belt and create the need for replacement sooner. To mitigate this risk, the belts must be placed with high tension or using chains to eliminate the risk of slipping. The belts must be visually evaluated regularly to assess for slipping damage.

4.2 Risks and Trade-offs Analysis

These failures are very relatable to each other as a lot of the failure are potentially due to bending and stress applied to differing parts of the tow rope. As stress can cause deformation in the shafts, pulleys, or bearings and once one parts experienced this failure mode then all other parts will not work efficiently or safely. By reinforcing the proper parts and sections of the tow rope then this failure mode will be avoided and will not cause a chain effect that will cause failures in the remaining parts of the tow rope. These failures affected the final design of the project as we needed to look at parts and designs that would help avoid the smaller and less likely fails that would trigger larger failures. Such as the use of a simple pulley and belt for the motor drive shaft to the worm gear box was swapped for a timing belt and crankshaft pulley to prevent any slipping from the belt that might occur under the higher rpm that the motor could produce. This change will cost more money from the budget than the original design but what is jeopardized in money will be accounted for in safety and efficiency of the tow rope. For this project safety is one of the most important aspects as many people will be experiencing the operations of this tow rope and preventing these failures would ensure their safety.

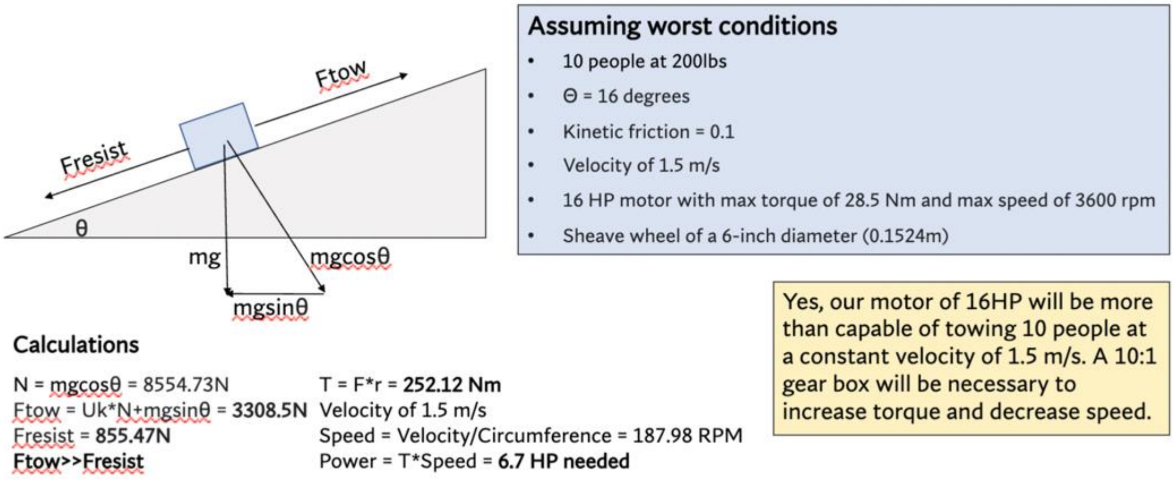
5 DESIGN SELECTED – First Semester

The latest design includes an updated drive unit, frame with housing cover, rope, and new two-wheel top pulley. Several changes have been made since the preliminary report, primarily to the layout of the drive unit components, the rope coupling, and top pulley design.

5.1 *Design Description*

5.1.1 Drive Unit Design

The drive unit layout has been completely rearranged to be more effective. The aim is to maximize torque and use gears and sheave wheels to reduce the speed of the drive shaft that runs at 3600 revolutions per minute to a safe rope velocity of 1.5 meters per second. Using a gearbox alone to make this reduction were extremely expensive, so the team decided to use a series of wheels and belts to find the proper speed. Using a worm gear in the gear box became another important factor because it prevented the rope from going in the wrong direction when loaded with riders. Calculations were done to determine if the chosen motor provided enough horsepower and torque to meet the engineering requirements, shown in figure 3. Using this knowledge, the team decided on the engine that will be purchased which is the DuroMax XP16HP engine shown in figure 4. Attached to the drive shaft of this engine will be a sheave wheel that drives a belt to turn a sheave wheel on the input shaft of the gearbox as shown in figure 5. The ratio of diameters in these two sheave wheels will be one of the contributing factors to the speed reduction. Then the worm gearbox will do additional speed reduction as well as change the horizontal axis of rotation to vertical. The vertical shaft will have a coupling to another shaft for extension purposes. This shaft extension will have two sheaves on in. the lower one will turn a belt to another shaft that will distribute the torque and reduce the stress on each shaft. Then another sheave wheel will be placed on the top of the shaft extension which will be the driving wheel to feed the rope up the hill as shown in figure 6. There will be two other shafts, one of which will solely be for the idler sheave wheel used to tension the rope and the other will be the driven shaft connected to the driving shaft by the sheave with the belt as well as with the upper sheave wheel that turns the rope.



Assuming worst conditions

- 10 people at 200lbs
- Θ = 16 degrees
- Kinetic friction = 0.1
- Velocity of 1.5 m/s
- 16 HP motor with max torque of 28.5 Nm and max speed of 3600 rpm
- Sheave wheel of a 6-inch diameter (0.1524m)

Calculations

N = mgcosθ = 8554.73N
Ftow = Uk*N+mgsinθ = **3308.5N**
Fresist = **855.47N**
Ftow>>Fresist

T = F*r = **252.12 Nm**
Velocity of 1.5 m/s
Speed = Velocity/Circumference = 187.98 RPM
Power = T*Speed = **6.7 HP needed**

Yes, our motor of 16HP will be more than capable of towing 10 people at a constant velocity of 1.5 m/s. A 10:1 gear box will be necessary to increase torque and decrease speed.

Figure 3: Dynamic Analysis

Figure 4: DuroMax XP16HP Engine

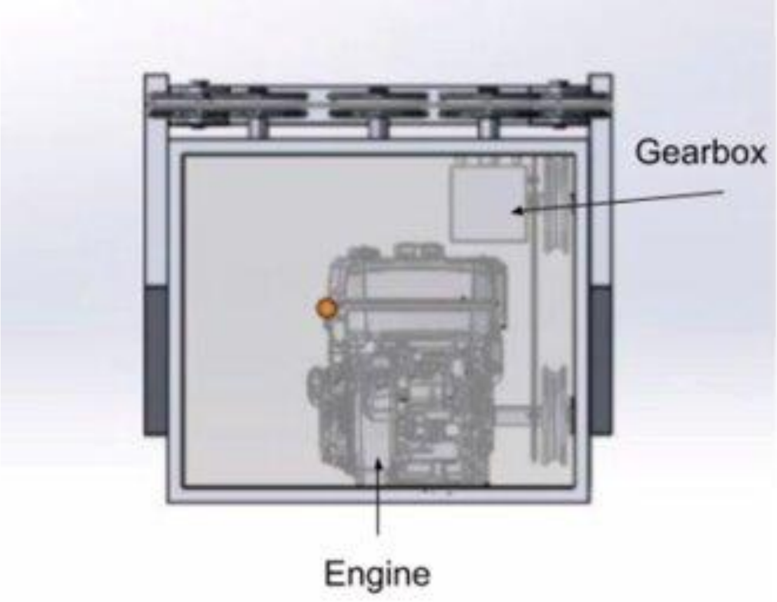


Figure 5: Front CAD view of drive unit

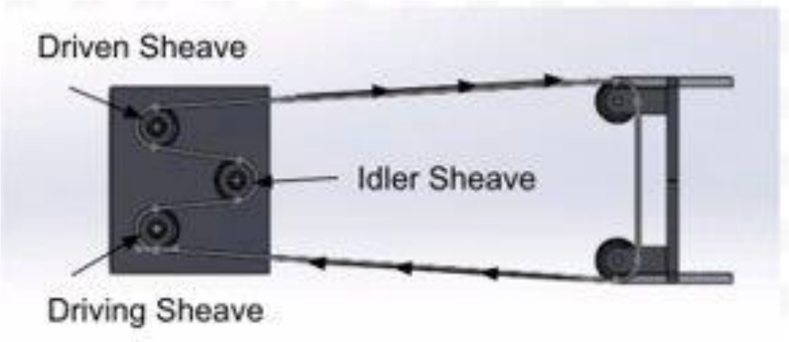
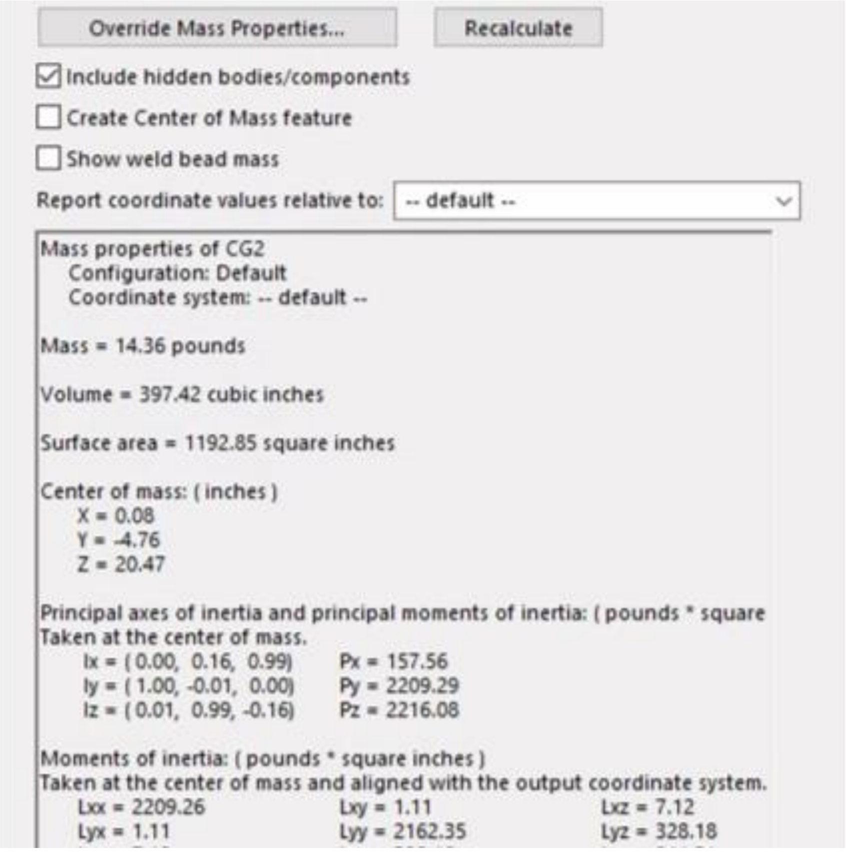


Figure 6: Top CAD view of tow rope

5.1.2 Frame and Housing Design

The frame was tested for weight and adjusted to have more support and simpler mounting system for the drive unit components. Aluminum will be used to keep it lightweight and prevent from rust. There are several steel angle supports to uphold joints and cross pieces that will be used to mount the drive unit components. Of the several designs for housing units, the team chose the one that was second to lightest weight of 14.36 lbs. as shown in figure 7, because the most lightweight choice did not provide nearly as much strength against tension of the rope and the anchors. Transparent fiberglass sidewalls will with a UV filtering tint will be mounted to the frame in order to protect the drive unit from the elements such as the sun drying out a rubber belt or moisture getting to the engine. The semi transparency is important because it allows for the operator to observe the drive unit to make sure everything is running properly. The frame will be mounted to a small trailer that will be custom built, in order for the entire system to be transported via a snowmobile up and down the mountain. This trailer will have room for the spool of rope, the collapsed top pulley assembly, and the drive unit. It will have a hitch that can attach to either a snowmobile or all-terrain vehicle to be as versatile as possible.



☑ Include hidden bodies/components
☐ Create Center of Mass feature
☐ Show weld bead mass
Report coordinate values relative to: -- default --

```
Mass properties of CG2
    Configuration: Default
    Coordinate system: -- default --

Mass = 14.36 pounds

Volume = 397.42 cubic inches

Surface area = 1192.85 square inches

Center of mass: ( inches )
     X = 0.08
     Y = -4.76
     Z = 20.47

Principal axes of inertia and principal moments of inertia: ( pounds * square
Taken at the center of mass.
      Ix = ( 0.00,  0.16,  0.99)       Px = 157.56
      Iy = ( 1.00, -0.01,  0.00)       Py = 2209.29
      Iz = ( 0.01,  0.99, -0.16)       Pz = 2216.08

Moments of inertia: ( pounds * square inches )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 2209.26               Lxy = 1.11                  Lxz = 7.12
     Lyx = 1.11                  Lyy = 2162.35               Lyz = 328.18
```

Figure 7: Weight Analysis of Frame

5.1.4 Top Pulley

The top pulley was altered from originally looking like a mailbox post with one wheel to a stable two-legged collapsible frame with tow pulleys as shown in figure 8. Doubling the pulleys distributes the tension loads between the two rather than all applied to one wheel which could be more likely to fail. The frame is collapsible into two parts, and the rope is easily removable from the sheave wheels for breakdown. The top pulley frame has loops on the back of it that anchoring straps will be attached to and then tensioned to the snow. The height of the top pulley was increased to make it so the rope will be at about waist height. This makes it easier for the rider to approach and grab the rope when loading as well as more comfortable to hold for the ride up. There is a significant distance between the two pulleys to ensure that the riders don't accidentally grab the downhill rope instead of the uphill rope or get caught in it accidentally.

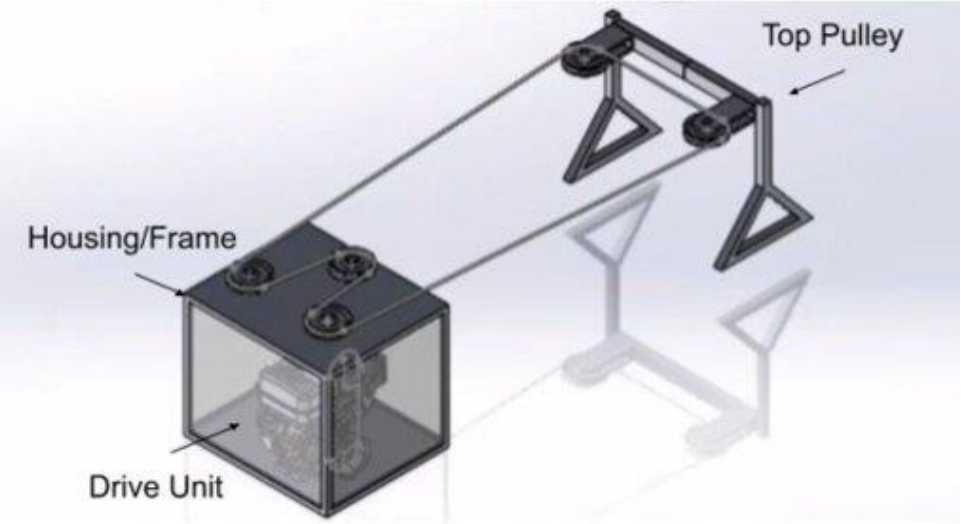


Figure 8: Isometric CAD view of tow rope

5.1.3 Rope

The rope will be 400 feet of weather proofed polypropylene rope that is 1 inch in diameter. It is three-strand twisted which allows it to have a tensile strength of 12,800 lbs. Which is significantly more than what is necessary for this tow rope design. Originally, the rope was going to be connected using a coupling device, however the team decided to have the rope spliced into a permanent loop, as the new drive unit design allows for easy installation of the already spliced rope. This will provide a stronger connection of the rope as well as a smoother flow of the rope through the sheave wheel system and top pulley wheels.

Figure 8: Polypropylene Three-Strand Weatherproof Rope

5.1.4 Prototype

The team designed a scale model of the drive unit for the initial prototype. It consisted of a mini hobby set with a dc motor, sheave wheels, gears, and shafts. A frame was designed in Solidworks to be 3D printed and hold the components together. Shown in figure 9 is the upper layer of the drive unit with the sheave wheel and rope system. Beneath the layer of plastic under the sheave wheels contains the lower compartment with the motor, worm and worm gear system, and power source. One question being asked was will this layout of the sheave wheels, when tensioned, feed the rope through the drive unit successfully. The results were that if the idler pulley was overly tensioning, then the rope stayed in place while the driving and driven sheave wheels turned, and if the idler pulley was not taut enough, then the rope would slip off the entire sheave system. This showed the team that the idler pulley needs to be able to make fine adjustments during installation in order to have the proper tension. Another question was if the layout of the drive unit components would fit in the dimensions of the frame, so the 3D printed box was scaled down proportionally to the sheave wheels and shafts from the dimensions of the actual design, and it was found that there was excess space that could be cut down to make it even more compact. Overall, the results of the prototype provided several more items to consider in the design and a better understanding of the functionality of the system.

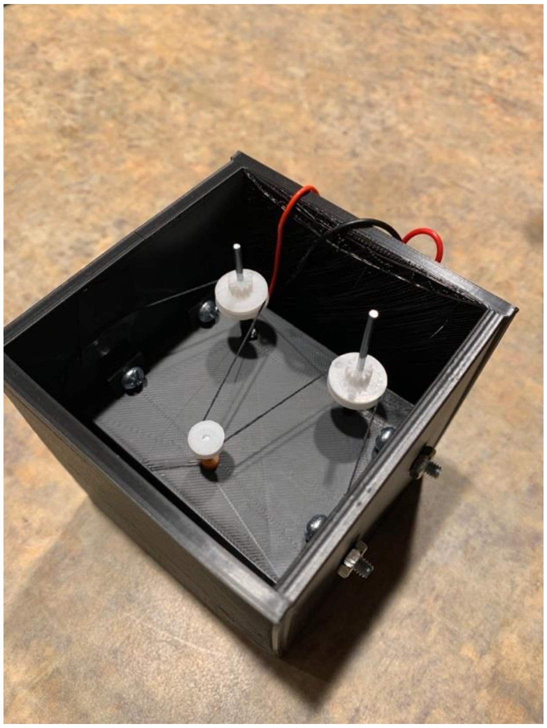


Figure 9: Drive Unit Prototype

5.2 Implementation Plan

The plan to implement the design begins with creating the final prototype. The team fundraised at a ski movie premiere and fundraised enough to purchase the necessary parts for the final prototype such as the engine, wheels, belts, and shafts. A full-size prototype of the drive unit will be made using the actual components for the final design, but rather than using a metal frame, it will be made of wood to minimize cost and allow for easier adjustments. The FAST race team of Flagstaff reached out with interest in using the tow rope and offered to provide certain components with the agreement that the race team gets to use the tow rope for race events, so they are going to provide the rope for the prototype and eventually contribute to the purchases of the final parts. The wood is being provided by the head of mountain operations at Arizona Snowbowl who had left over lumber from the construction of the new Arizona gondola.

Hardware such as screws, nuts, and bolts will be purchased at the local hardware store. Once the final prototype is created, analyzed, and adjusted to a functional system, the production of the full design will begin. All of the metal for the frame of the drive unit and top pulley will be purchased through Coast Aluminum and Architectural in Phoenix Arizona. This company provides discounts to NAU students, which is why it is the most affordable option. The fabrication of the metal will be cut by Jesse Wells and the welds will be done by a peer in the NAU machine shop who offered to help. The sheave wheels were difficult to find in the right dimensions for an affordable price, so the team is outsourcing to a metal fabrication company who will manufacture the appropriate custom wheels. The rope is sold by Uline.com and the team is attending a splicing training day for cables of a chairlift at Arizona Snowbowl on November 19th , and the team hopes to connect with the splice technician to receive help splicing the rope. If not, there is a splicing company in Phoenix that will be used. The remainder of the assembly will be done by the team. The schedule for the order of operations is given in Appendix D and the bill of materials is shown in Appendix E. The projected budget has been increased from $2000 to $3000 so the team has added additional fundraising plans as well. The aim is to have the final fully functioning tow rope done early March in time for the competition season to begin.

6 CONCLUSIONS

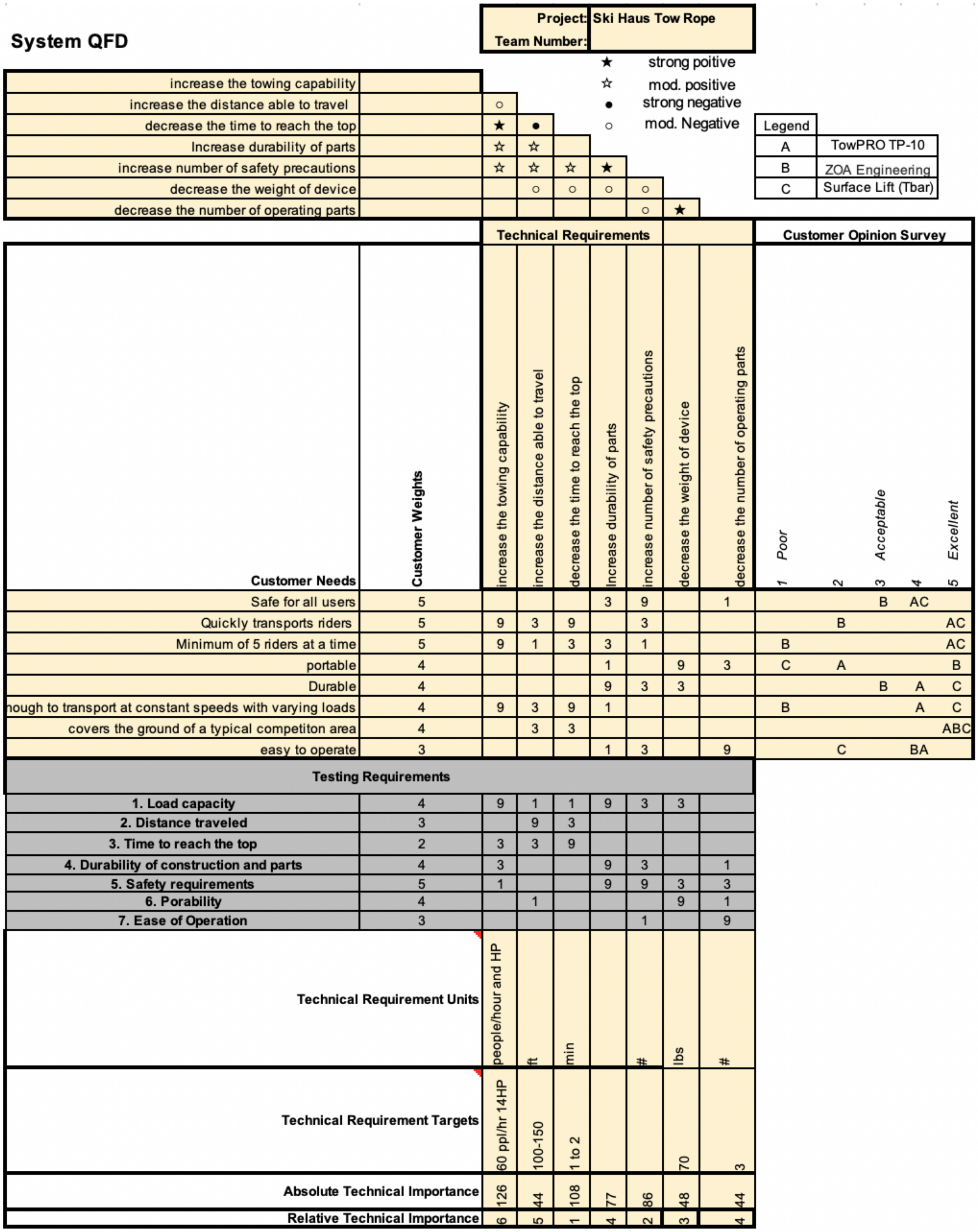
This report details all the final decision made to create a complete design worthy of prototyping and testing in the upcoming semester. Based on all standards and codes, multiple testing procedures were created to evaluate the design and rework any necessary parts. Redesign is a crucial element to the design process, and all work established in this report has led to this next step. The final design was decided on based on the FMEA evaluation and its accordance with the customer and engineer requirements. As this project was described as a towing device capable of transporting multiple people up a slope for competition use, there were many specific needs detailed by the sponsor Ski Haus. All these requirements were compiled into a house of quality and used to create the necessary testing procedures. These requirements focused on safety, durability, portability, and towing capacity. As the team designed multiple ways of solving the problem, a final design was settled on that met all customer and engineering needs as well as compensated for any protentional failures. This design includes multiple safety elements such as emergency buttons and stop gates while transporting people with enough power to exceed the original recommendations. All parts are enclosed from the public while the drive shaft was designed to accurately reduce speed and increase torque while tensioning and displacing the power equally to the rope. Overall, the system corresponds with all ANSI standards and will be easily reworked if needed during testing procedures.

7 REFERENCES

[1] *American National Standard for passenger Ropeways – Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors – Safety Requirements,* ANSI B77.l-2011, 2011.

8 APPENDICES

8.1 Appendix A: House of Quality



System QFD

Project: Ski Haus Tow Rope
Team Number:

★ 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					○	★

		Technical Requirements							Customer Opinion Survey				
Customer Needs	**Customer Weights**	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	*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	1			B				AC
portable	4				1		9	3	C	A			B
Durable	4				9	3	3				B	A	C
hough 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	

Testing Requirements								
1. Load capacity	4	9	1	1	9	3	3	
2. Distance traveled	3		9	3				
3. Time to reach the top	2	3	3	9				
4. Durability of construction and parts	4	3			9	3		1
5. Safety requirements	5	1			9	9	3	3
6. Porability	4		1				9	1
7. Ease of Operation	3					1		9
Technical Requirement Units		people/hour and HP	ft	min		#	lbs	#
Technical Requirement Targets		60 ppl/hr 14HP	100-150	1 to 2			70	3
Absolute Technical Importance		126	44	108	77	86	48	44
Relative Technical Importance		6	5	1	4	2	3	4

8.2 Appendix B: Standards and Codes Relating to This Project

Table 1: Standards of Practice as Applied to the Ski Haus Tow Rope

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ANSI B77.1.6.1.1.1	Design Passenger Weight	As stated, a passenger is considered as having a minimum average weight of 170 lbs. This ensures the design can function properly under the maximum load designed to the device.
ANSI B77.1.6.1.1.2	Capacity and Speed	The loading interval and capacity must be stated by the team in accordance with the limitations of the equipment and slope gradient.
ANSI B77.1.6.1.1.2.1	Speed (fiber rope tows)	The speed of the rope must not exceed 1500 ft per minute when a rider grasps the rope. The overall speed should not exceed 400 feet per minute.
ANSI B77.1.6.1.1.3	Location	Where the system is set up must be taken into account and cannot contain electric power lines and their supports, rock and earth slides, washouts, snow creep and avalanches, icing, conflicting ski trails, rivers and gullies, buried installations, fire hazards, and structures.
ANSI B77.1.6.1.1.3.1	Tow path gradient	The maximum gradient for intended use should be set by the team and the device should never exceed the recommended grade set by the manufacturer. Reverse grades for loading and unloading are permitted.
ANSI B77.1.6.1.1.4.1	Tow path clearing width	A minimum tow path surface clearing width should be a minimum of 36 inches for skiers. This is cleared on each side of the centerline of the towing path.
ANSI B77.1.6.1.1.5	Clearances	All supports and terminals will be installed to provide clearances. Local wind conditions will be taken into consideration for operation of the tow rope.
ANSI B77.1.6.1.1.5.1	Vertical clearances	Nowhere along the tow path should a rope exert a downward force greater than 35 lbs. or upward force of 30 lbs. This is for when

		the device is held 24 inches above snow surface by a rider. Rope should never come in contact with the ground.
ANSI B77.1.6.1.1.6.3	Anchorages	All supporting structures should be capable of carrying the loads imposed by all structural and mechanical elements in static conditions. A required factor of safety of 2 is resisting overturning, sliding, or withdrawal under both static and dynamic loading.
ANSI B77.1.6.1.1.9	Loading and unloading areas	Some sort of platform, corral, or maze should be integrated into both the loading and unloading operation in accordance with 6.1.3.
ANSI B77.1.6.1.1.9.1	Loading areas	All loading areas should be level and free of obstructions. Loading aids should be installed with regards to all passengers.
ANSI B77.1.6.1.1.9.2	Unloading areas	length, profile, and exit path should be designed with respect to the tow rope's speed. The path should be incline downward towards direction of travel and away from the tow.
ANSI B77.1.6.1.1.11	Acceptance inspection and tests	The tow rope must be run to ample amount of time without loading to ensure there isn't any overheating, excessive vibration or deflection of parts, and there is free movement of tension systems and rope.
ANSI B77.1.6.1.1.11.1	Acceptance inspection	Routine inspection is necessary to ensure tightness of all structural connectors, lubrication of all moving parts, alignment and clearance of all gearing, drive unit is aligned, freedom and position of tensioning systems, rope alignment, any electrical components are operating, horizontal and vertical clearances, terminals and correct location and installation.
ANSI B77.1.6.1.1.11.2	Acceptance tests	All stop buttons, gates, must be checked before use. Braking must be proved adequate. The tests must be performed by the team or other qualified personnel.
ANSI B77.1.6.1.2.1	Power units	The motor must be able to handle the worst loading conditions. If using a manual multi

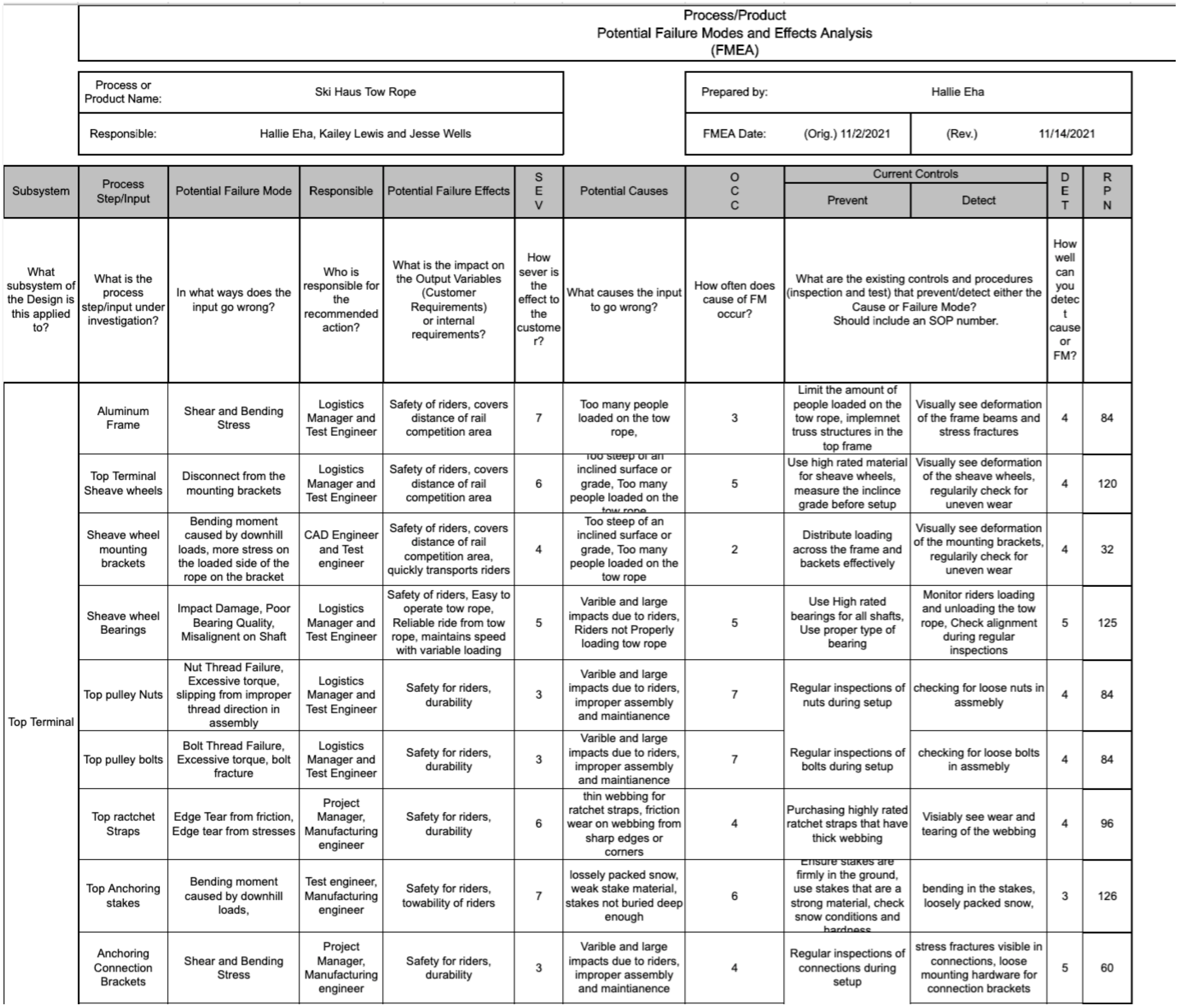
		speed transmission, it must not be shifted while tow is moving.
ANSI B77.1.6.1.2.2	Speed reducers and gearing	Any speed reducers and gearing should be able to handle the most unfavorable loading conditions.
ANSI B77.1.6.1.2.3	Bearings, clutches, couplings. And shafting	All bearings and shafts must be designed or selected based on standard practices. Provision must be made for adjustment and lubrication.
ANSI B77.1.6.1.2.4	Acceleration and speed control	Must be regulated based on tow type, profile, speed, and use. The tow must come to a complete stop if one is initiated before started again
ANSI B77.1.6.1.2.5	Stops and shutdowns	Normal stops- if a service break is needed, it must be applied before the tow rope completes its stop. Emergency shutdown – emergency stop button must be specified on the design.
ANSI B77.1.6.1.2.6	Brakes and rollback device	The tow must have breaks installed. These breaks must be able to comply with daily inspection and occasional testing.
ANSI B77.1.6.1.2.6.1	Service break	The unloaded two must be able to stop in 25 feet while operating at maximum speed. If this cannot happen, an automatic break must be installed to accommodate this distance. This break must be installed with springs, weights, or other approved stored energy systems. Since this system is an internal combustion engine, a positive system must be used to stop the tow rope.
ANSI B77.1.6.1.2.6.3	Rollback device	All two ropes must include a device to automatically prevent reverse rotation of the rope.
ANSI B77.1.6.1.2.7.1	Location of Machinery - General	All moving mechanical parts that could be in reach of personnel must have guards. Guards and casing must be done in conformance to ANSI/ASME, B15. 1-2000 (R2008) Safety Standard for Mechanical Power Transmission Apparatus.

ANSI B77.1.6.1.2.7.3	Machinery housed in a machine room	The drive unit must be adequately ventilated with space for maintenance. A door with a lock must be included.
ANSI B77.1.6.1.2.8.1	Bullwheels and sheaves in terminals and stations - General	All sheaves must be able to withstand static and dynamic loads. All bearings must be installed as specified by the manufactures.
ANSI B77.1.6.1.2.8.2.2	Fiber rope tow bullwheels and sheaves	The sheaves must be designed to prevent stress and wear of the fiber rope. They must be balanced so there is not excessive vibration during operation. A method that keeps the rope in the terminal in case of deropement must be included.
ANSI B77.1.6.1.2.10.2	Tensioning devices for fiber rope tows	Any tensioning system must have provisions for maintaining the tension in the rope.
ANSI B77.1.6.1.2.11	Anchoring devices	The anchoring systems in place must be above finished grade. Any anchoring below ground must be able to be protected against corrosion. Anchoring must be designed with a factor of safety of 6.
ANSI B77.1.6.1.3.1	Return line structures - supports	If the team decides to use line supports, they must be included on return line only.
ANSI B77.1.6.1.3.2	Guards and clearances	Any moving parts that are less than 7 feet above the snow must be contained so the public may not come in contact with it. There must be enough distance between the towing and return rope so that there is not any accidental contact with the wrong rope.
ANSI B77.1.6.1.3.3	Haul rope sheaves and mounts	All sheaves must be designed to have a 10 times greater treat diameter than the nominal diameter of the rope. All sheave mounts must be incredible strong to reduce failure.
ANSI B77.1.6.1.4.1.3	Requirements for haul ropes for fiber rope tows	The rope used must be natural or synthetic fiber rope containing a lay or braid to minimize twisting during operation. The rope must be manufactured for use of a tow for skiing. Any necessary splices must be made by qualified personnel stated by the manufacturers. The minimum factor of safety for the rope must be 5.
ANSI B77.1.6.1.5	Provisions for operating personnel	All operators must be located where they can provide visual surveillance of the tow

		rope. If there is only one operator, they must be able to see the entirety of the tow rope.
ANSI B77.1.6.2.1.1	Applicable codes	Any electrical systems included must comply with the American National Standard, ANSI/NFPA 70-2011, National Electrical Code and the Institute of Electrical and Electronics Engineers, IEEE C2-2007, National Electrical Safety Code
ANSI B77.1.6.2.3.1	Emergency shutdown circuit	The tow rope must include one emergency shutdown circuit. It has to have priority over all other commands.
ANSI B77.1.6.2.3.2	Stop gates	Automatic stop gates must be installed at each terminal that stopes the tow rope if a person actuates the lever. The device must encircle the incoming fiber rope.
ANSI B77.1.6.2.9	Manual control devices	Any controls must be installed at attendants' and operators' work positions. These controls must include an emergency stop button.
ANSI B77.1.6.3.1	General and personnel safety	Any operators must take precautionary measures during operation as it can be dangerous. Working positions must not be placed between the top and base of the tow rope.
ANSI B77.1.6.3.1.2	Signs	Normative Annex D depicts the signs that are necessary for tow ropes. All signed specified in this document will be included in the design.
ANSI B77.1.6.3.2.4.1	Control of passengers	The design will implement a method to contain the riders and safely load and unload them. Fences and gates will be in use.
ANSI B77.1.6.3.2.4.2	Daily Preoperational inspection	Before each use of the tow rope, an inspection will be conducted. During this inspection, a visual overview, assurance of the tension system is functioning, checking all breaks and rope, and inspecting all loading and unloading areas will be performed.
ANSI B77.1.6.3.2.5.5	Damage to towing devices	Any damages must be clearly marked and not used for towing. The device cannot be in use until repaired or replaced.

ANSI B77.1.6.3.2.5.6	Hazardous conditions	The tow rope will not be used in icy or windy conditions.
ANSI B77.1.6.3.3.1	Maintenance - General	Inspections should done regularly and maintenance should be conducted as needed, keeping maintenance logs. Only trained personnel should be maintaining the device. The device will be inspected annually or after each 2000 hours of operation.
ANSI B77.1.6.3.3.4	Fiber rope	The rope should be replaced in accordance with 6.1.4.1 and 6.1.4.1.3

8.3 Appendix C: FMEA

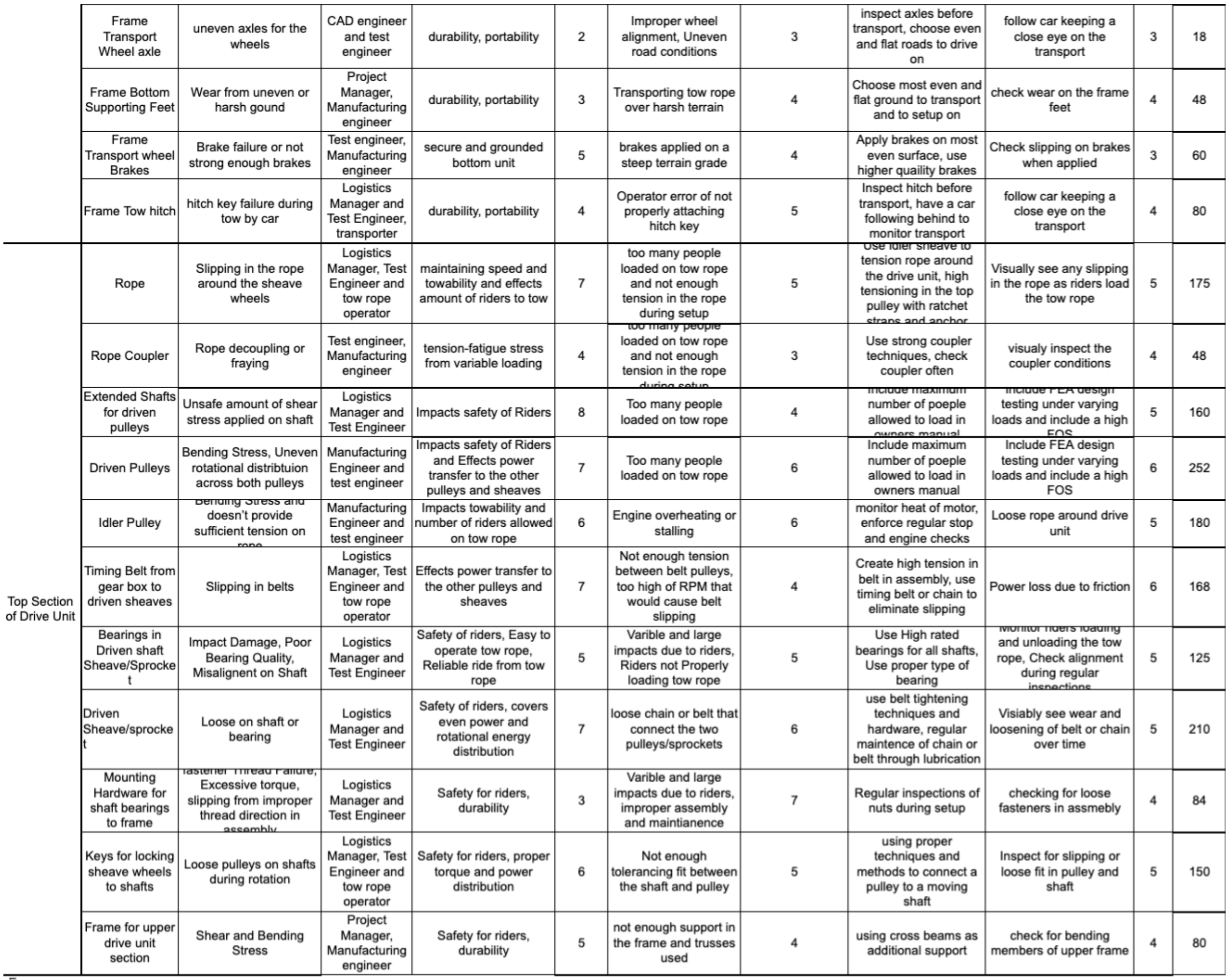


Process/Product
Potential Failure Modes and Effects Analysis
(FMEA)

Process or Product Name: Ski Haus Tow Rope
Responsible: Hallie Eha, Kailey Lewis and Jesse Wells
Prepared by: Hallie Eha
FMEA Date: (Orig.) 11/2/2021 (Rev.) 11/14/2021

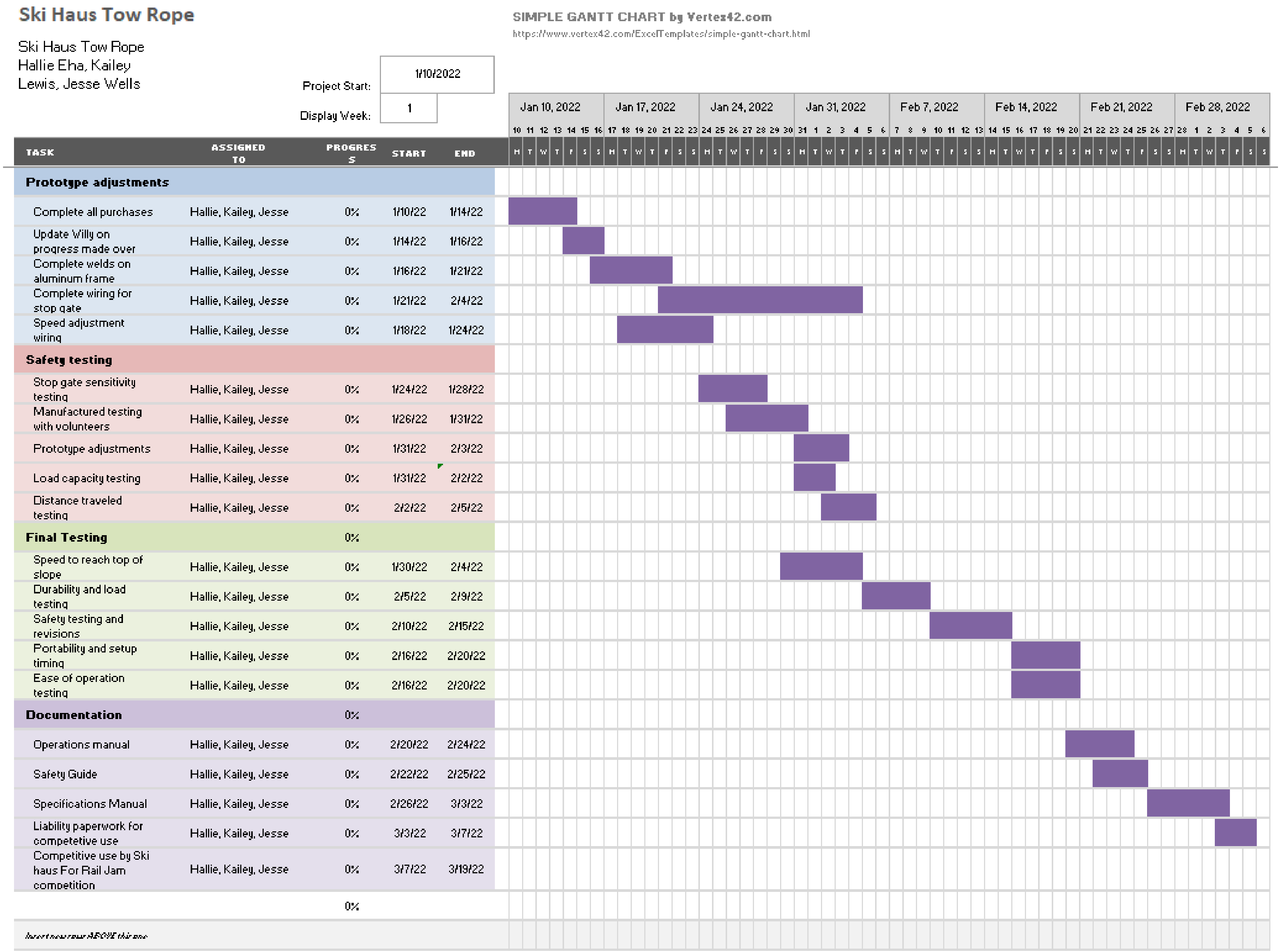
Subsystem	Process Step/Input	Potential Failure Mode	Responsible	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls		DET	RPN
								Prevent	Detect		
What subsystem of the Design is this applied to?	What is the process step/input under investigation?	In what ways does the input go wrong?	Who is responsible for the recommended action?	What is the impact on the Output Variables (Customer Requirements) or internal requirements?	How sever is the effect to the customer?	What causes the input to go wrong?	How often does cause of FM occur?	What are the existing controls and procedures (inspection and test) that prevent/detect either the Cause or Failure Mode? Should include an SOP number.		How well can you detect cause or FM?	
Top Terminal	Aluminum Frame	Shear and Bending Stress	Logistics Manager and Test Engineer	Safety of riders, covers distance of rail competition area	7	Too many people loaded on the tow rope,	3	Limit the amount of people loaded on the tow rope, implemnet truss structures in the top frame	Visually see deformation of the frame beams and stress fractures	4	84
	Top Terminal Sheave wheels	Disconnect from the mounting brackets	Logistics Manager and Test Engineer	Safety of riders, covers distance of rail competition area	6	Too steep of an inclined surface or grade, Too many people loaded on the tow rope	5	Use high rated material for sheave wheels, measure the inclince grade before setup	Visually see deformation of the sheave wheels, regularily check for uneven wear	4	120
	Sheave wheel mounting brackets	Bending moment caused by downhill loads, more stress on the loaded side of the rope on the bracket	CAD Engineer and Test engineer	Safety of riders, covers distance of rail competition area, quickly transports riders	4	Too steep of an inclined surface or grade, Too many people loaded on the tow rope	2	Distribute loading across the frame and backets effectively	Visually see deformation of the mounting brackets, regularily check for uneven wear	4	32
	Sheave wheel Bearings	Impact Damage, Poor Bearing Quality, Misalignent on Shaft	Logistics Manager and Test Engineer	Safety of riders, Easy to operate tow rope, Reliable ride from tow rope, maintains speed with variable loading	5	Varible and large impacts due to riders, Riders not Properly loading tow rope	5	Use High rated bearings for all shafts, Use proper type of bearing	Monitor riders loading and unloading the tow rope, Check alignment during regular inspections	5	125
	Top pulley Nuts	Nut Thread Failure, Excessive torque, slipping from improper thread direction in assembly	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of nuts during setup	checking for loose nuts in assmebly	4	84
	Top pulley bolts	Bolt Thread Failure, Excessive torque, bolt fracture	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of bolts during setup	checking for loose bolts in assmebly	4	84
	Top ractchet Straps	Edge Tear from friction, Edge tear from stresses	Project Manager, Manufacturing engineer	Safety for riders, durability	6	thin webbing for ratchet straps, friction wear on webbing from sharp edges or corners	4	Purchasing highly rated ratchet straps that have thick webbing	Visiably see wear and tearing of the webbing	4	96
	Top Anchoring stakes	Bending moment caused by downhill loads,	Test engineer, Manufacturing engineer	Safety for riders, towability of riders	7	lossely packed snow, weak stake material, stakes not buried deep enough	6	Ensure stakes are firmly in the ground, use stakes that are a strong material, check snow conditions and hardness	bending in the stakes, loosely packed snow,	3	126
	Anchoring Connection Brackets	Shear and Bending Stress	Project Manager, Manufacturing engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	4	Regular inspections of connections during setup	stress fractures visible in connections, loose mounting hardware for connection brackets	5	60

	Frame Flange mounting brackets	Bolt Thread Failure, Excessive torque, bolt fracture	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of bolts during setup	checking for loose bolts in assmebly	4	84
Lower Drive Unit	Drive Shaft	Unsafe amount of shear stress applied on shaft	Logistics Manager and Test Engineer	Impacts safety of Riders	8	Too many people loaded on tow rope	4	Include maximum number of poeple allowed to load in owners manual	Include FEA design testing under varying loads and include a high FOS	5	160
	Drive Shaft Sheave/sprocket	Loose on shaft or bearing	Logistics Manager and Test Engineer	Safety of riders, covers even power and rotational energy distribution	7	loose chain or belt that connect the two pulleys/sprockets	6	use belt tightening techniques and hardware, regular maintence of chain or belt through lubrication	Visiably see wear and loosening of belt or chain over time	5	210
	Timing Belt from drive shaft to gear box	Slipping in belts	Logistics Manager, Test Engineer and tow rope operator	Effects power transfer to the other pulleys and sheaves	7	Not enough tension between belt pulleys, too high of RPM that would cause belt slipping	4	Create high tension in belt in assembly, use timing belt or chain to eliminate slipping	Power loss due to friction	6	168
	Mounting bolts for gear box to frame	Bolt Thread Failure, Excessive torque, bolt fracture	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of bolts during setup	checking for loose bolts in assmebly	4	84
	Mounting nuts for gear box to frame	Nut Thread Failure, Excessive torque, slipping from improper thread direction in assembly	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of nuts during setup	checking for loose nuts in assmebly	4	84
	Worm of Gear Box	Reversed motion of tow rope	CAD engineer and test engineer	Maintaining speed in uphill direction and effects safety of riders	5	too many people loaded on tow rope	2	Using a worm gear box to prevent reversed motion	Visually seeing if row travels in the correct direction	6	60
	Bearings in Drive shaft Sheave/Sprocket	Impact Damage, Poor Bearing Quality, Misalignent on Shaft	Logistics Manager and Test Engineer	Safety of riders, Easy to operate tow rope, Reliable ride from tow rope, maintains speed with variable loading	5	Varible and large impacts due to riders, Riders not Properly loading tow rope	5	Use High rated bearings for all shafts, Use proper type of bearing	Monitor riders loading and unloading the tow rope, Check alignment during regular inspections	5	125
	Horizontal Shaft of Gear Box	Unsafe amount of shear stress applied on shaft	Logistics Manager and Test Engineer	Impacts safety of Riders	8	Too many people loaded on tow rope	4	Include maximum number of poeple allowed to load in owners manual	Include FEA design testing under varying loads and include a high FOS	5	160
	Worm Gear of Gear box	Reversed motion of tow rope	CAD engineer and test engineer	Maintaining speed in uphill direction and effects safety of riders	5	too many people loaded on tow rope	2	Using a worm gear box to prevent reversed motion	Visually seeing if row travels in the correct direction	6	60
	Vertical Shaft of Gear Box	Unsafe amount of shear stress applied on shaft	Logistics Manager and Test Engineer	Impacts safety of Riders	8	Too many people loaded on tow rope	4	Include maximum number of poeple allowed to load in owners manual	Include FEA design testing under varying loads and include a high FOS	5	160
Main Drive Frame	Aluminum Frame	Shear and Bending Stress	Logistics Manager and Test Engineer	Safety of riders, covers distance of rail competition area	7	Too many people loaded on the tow rope,	3	Limit the amount of people loaded on the tow rope, implemnet truss structures in the top frame	Visually see deformation of the frame beams and stress fractures	4	84
	Weldments	Cracking, inclusions, fatigue, weld corrosions	Financial Engineer, Manufacturing Engineer	Safety of Riders, Durability	6	Insufficient welding technique and materials, too many people loaded on tow rope	3	Limit the amount of people loaded on the tow rope, use heavy duty welding techniques and materials	inspection of weld cracking and stress fractures	4	72
	Frame plexiglass	Corrision, heat deformation from motor	Logistics Manager and Test Engineer	Aesthetic appeal, portable, easy to operate	4	thin material used for shell of frame, melting a low temperatures	3	create an exhaust channel for hot fumes	checking temperature throughout current use	4	48
	Plexiglass mounting hardware	fastener Thread Failure, Excessive torque, slipping from improper thread direction in assembly	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of fastener during setup	checking for loose fasteners in assmebly	4	84
	Frame Tow Hitch Lock Key	hitch key failure during tow by car	Logistics Manager and Test Engineer, transporter	durability, portability	4	Operator error of not properly attaching hitch key	5	Inspect hitch before transport, have a car following behind to monitor transport	follow car keeping a close eye on the transport	4	80



	Frame Transport Wheel axle	uneven axles for the wheels	CAD engineer and test engineer	durability, portability	2	Improper wheel alignment, Uneven road conditions	3	inspect axles before transport, choose even and flat roads to drive on	follow car keeping a close eye on the transport	3	18
	Frame Bottom Supporting Feet	Wear from uneven or harsh gound	Project Manager, Manufacturing engineer	durability, portability	3	Transporting tow rope over harsh terrain	4	Choose most even and flat ground to transport and to setup on	check wear on the frame feet	4	48
	Frame Transport wheel Brakes	Brake failure or not strong enough brakes	Test engineer, Manufacturing engineer	secure and grounded bottom unit	5	brakes applied on a steep terrain grade	4	Apply brakes on most even surface, use higher quaility brakes	Check slipping on brakes when applied	3	60
	Frame Tow hitch	hitch key failure during tow by car	Logistics Manager and Test Engineer, transporter	durability, portability	4	Operator error of not properly attaching hitch key	5	Inspect hitch before transport, have a car following behind to monitor transport	follow car keeping a close eye on the transport	4	80
Top Section of Drive Unit	Rope	Slipping in the rope around the sheave wheels	Logistics Manager, Test Engineer and tow rope operator	maintaining speed and towability and effects amount of riders to tow	7	too many people loaded on tow rope and not enough tension in the rope during setup	5	Use idler sheave to tension rope around the drive unit, high tensioning in the top pulley with ratchet straps and anchor	Visually see any slipping in the rope as riders load the tow rope	5	175
	Rope Coupler	Rope decoupling or fraying	Test engineer, Manufacturing engineer	tension-fatigue stress from variable loading	4	too many people loaded on tow rope and not enough tension in the rope during setup	3	Use strong coupler techniques, check coupler often	visualy inspect the coupler conditions	4	48
	Extended Shafts for driven pulleys	Unsafe amount of shear stress applied on shaft	Logistics Manager and Test Engineer	Impacts safety of Riders	8	Too many people loaded on tow rope	4	Include maximum number of poeple allowed to load in owners manual	Include FEA design testing under varying loads and include a high FOS	5	160
	Driven Pulleys	Bending Stress, Uneven rotational distribtuion across both pulleys	Manufacturing Engineer and test engineer	Impacts safety of Riders and Effects power transfer to the other pulleys and sheaves	7	Too many people loaded on tow rope	6	Include maximum number of poeple allowed to load in owners manual	Include FEA design testing under varying loads and include a high FOS	6	252
	Idler Pulley	Bending Stress and doesn't provide sufficient tension on rope	Manufacturing Engineer and test engineer	Impacts towability and number of riders allowed on tow rope	6	Engine overheating or stalling	6	monitor heat of motor, enforce regular stop and engine checks	Loose rope around drive unit	5	180
	Timing Belt from gear box to driven sheaves	Slipping in belts	Logistics Manager, Test Engineer and tow rope operator	Effects power transfer to the other pulleys and sheaves	7	Not enough tension between belt pulleys, too high of RPM that would cause belt slipping	4	Create high tension in belt in assembly, use timing belt or chain to eliminate slipping	Power loss due to friction	6	168
	Bearings in Driven shaft Sheave/Sprocket	Impact Damage, Poor Bearing Quality, Misalignent on Shaft	Logistics Manager and Test Engineer	Safety of riders, Easy to operate tow rope, Reliable ride from tow rope	5	Varible and large impacts due to riders, Riders not Properly loading tow rope	5	Use High rated bearings for all shafts, Use proper type of bearing	Monitor riders loading and unloading the tow rope, Check alignment during regular inspections	5	125
	Driven Sheave/sprocket	Loose on shaft or bearing	Logistics Manager and Test Engineer	Safety of riders, covers even power and rotational energy distribution	7	loose chain or belt that connect the two pulleys/sprockets	6	use belt tightening techniques and hardware, regular maintence of chain or belt through lubrication	Visiably see wear and loosening of belt or chain over time	5	210
	Mounting Hardware for shaft bearings to frame	Fastener Thread Failure, Excessive torque, slipping from improper thread direction in assembly	Logistics Manager and Test Engineer	Safety for riders, durability	3	Varible and large impacts due to riders, improper assembly and maintianence	7	Regular inspections of nuts during setup	checking for loose fasteners in assmebly	4	84
	Keys for locking sheave wheels to shafts	Loose pulleys on shafts during rotation	Logistics Manager, Test Engineer and tow rope operator	Safety for riders, proper torque and power distribution	6	Not enough tolerancing fit between the shaft and pulley	5	using proper techniques and methods to connect a pulley to a moving shaft	Inspect for slipping or loose fit in pulley and shaft	5	150
	Frame for upper drive unit section	Shear and Bending Stress	Project Manager, Manufacturing engineer	Safety for riders, durability	5	not enough support in the frame and trusses used	4	using cross beams as additional support	check for bending members of upper frame	4	80

8.4 Appendix D: Semester 2 Schedule:



Ski Haus Tow Rope

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Ski Haus Tow Rope
Hallie Eha, Kailey Lewis, Jesse Wells

Project Start: 1/10/2022
Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Prototype adjustments				
Complete all purchases	Hallie, Kailey, Jesse	0%	1/10/22	1/14/22
Update Willy on progress made over	Hallie, Kailey, Jesse	0%	1/14/22	1/16/22
Complete welds on aluminum frame	Hallie, Kailey, Jesse	0%	1/16/22	1/21/22
Complete wiring for stop gate	Hallie, Kailey, Jesse	0%	1/21/22	2/4/22
Speed adjustment wiring	Hallie, Kailey, Jesse	0%	1/18/22	1/24/22
Safety testing				
Stop gate sensitivity testing	Hallie, Kailey, Jesse	0%	1/24/22	1/28/22
Manufactured testing with volunteers	Hallie, Kailey, Jesse	0%	1/26/22	1/31/22
Prototype adjustments	Hallie, Kailey, Jesse	0%	1/31/22	2/3/22
Load capacity testing	Hallie, Kailey, Jesse	0%	1/31/22	2/2/22
Distance traveled testing	Hallie, Kailey, Jesse	0%	2/2/22	2/5/22
Final Testing		0%		
Speed to reach top of slope	Hallie, Kailey, Jesse	0%	1/30/22	2/4/22
Durability and load testing	Hallie, Kailey, Jesse	0%	2/5/22	2/9/22
Safety testing and revisions	Hallie, Kailey, Jesse	0%	2/10/22	2/15/22
Portability and setup timing	Hallie, Kailey, Jesse	0%	2/16/22	2/20/22
Ease of operation testing	Hallie, Kailey, Jesse	0%	2/16/22	2/20/22
Documentation		0%		
Operations manual	Hallie, Kailey, Jesse	0%	2/20/22	2/24/22
Safety Guide	Hallie, Kailey, Jesse	0%	2/22/22	2/25/22
Specifications Manual	Hallie, Kailey, Jesse	0%	2/26/22	3/3/22
Liability paperwork for competetive use	Hallie, Kailey, Jesse	0%	3/3/22	3/7/22
Competitive use by Ski haus For Rail Jam competition	Hallie, Kailey, Jesse	0%	3/7/22	3/19/22
		0%		

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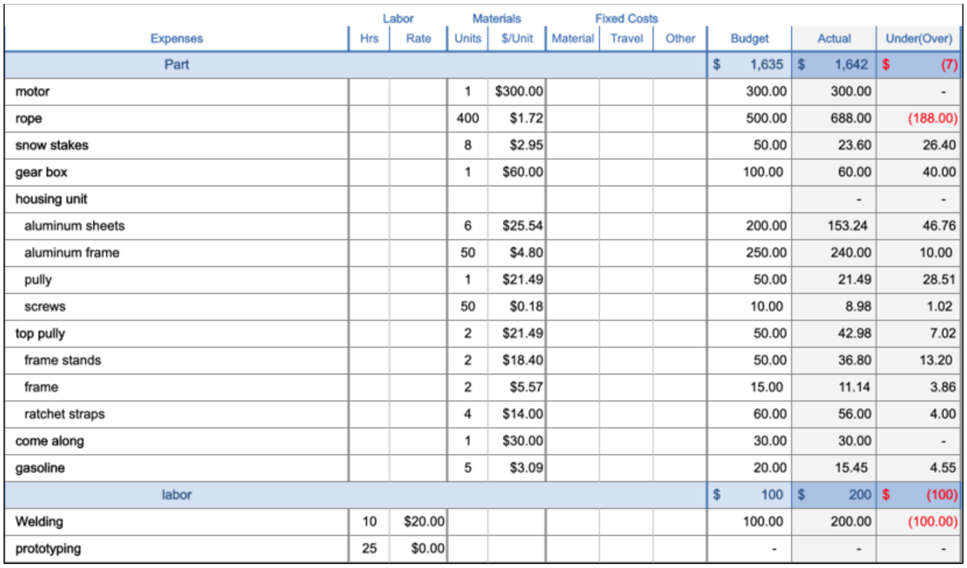
8.5 *Appendix E: Budget and Bill of Materials:*



	Labor		Materials		Fixed Costs					
Expenses	Hrs	Rate	Units	$/Unit	Material	Travel	Other	Budget	Actual	Under(Over)
Part								$ 1,635	$ 1,642	$ (7)
motor			1	$300.00				300.00	300.00	-
rope			400	$1.72				500.00	688.00	(188.00)
snow stakes			8	$2.95				50.00	23.60	26.40
gear box			1	$60.00				100.00	60.00	40.00
housing unit									-	-
aluminum sheets			6	$25.54				200.00	153.24	46.76
aluminum frame			50	$4.80				250.00	240.00	10.00
pully			1	$21.49				50.00	21.49	28.51
screws			50	$0.18				10.00	8.98	1.02
top pully			2	$21.49				50.00	42.98	7.02
frame stands			2	$18.40				50.00	36.80	13.20
frame			2	$5.57				15.00	11.14	3.86
ratchet straps			4	$14.00				60.00	56.00	4.00
come along			1	$30.00				30.00	30.00	-
gasoline			5	$3.09				20.00	15.45	4.55
labor								$ 100	$ 200	$ (100)
Welding	10	$20.00						100.00	200.00	(100.00)
prototyping	25	$0.00						-	-	-