November 17, 2017

FreeBoots Enterprises
Dept. of Mechanical Engineering
Faculty of Applied Science
The University of British Columbia
2066-6250 Applied Science Mall
Vancouver BC V6T 1Z4

Dear Mr. Bill Rawlings and Mr. Hooman Esfandiari:

Subject: MECH 328 Final Report - "Backcountry Skiing Equipment Tow"

In response to your request for a formal report summarizing the design process for the MECH 328 Design Project, we have prepared the enclosed report entitled "Backcountry Skiing Equipment Tow".

The report presents an investigation into our interpretation of and proposed solution for the design problem outlined in the "Backcountry Skiing Ascender Proposal" document provided to us by FreeBoots Enterprises. The body of the report articulates the background of the project and the needs and requirements that were associated with the final recommendations. Detailed descriptions, sketches, and calculations for the major subsystems of our proposed solution, the Equipment Tow, are also included. The report also recommends improvements to the team's final design and proposes next steps for prototyping. Limitations and prototyping requirements associated with the team's recommendations are also described.

Please note that the physical report does not include the full appendices, only Appendix P: References. Complete appendices are, instead, included in the electronic copy of the report.

We would like to thank you for your support throughout this project. We hope that the contents of our final report have been completed according to the requirements put forward at the beginning of the project and that our final recommendations are beneficial to the client in moving forward with our design.

Sincerely,
Team 21

Enclosure: Signature Page, Report Section Responsibilities, Project Final Report

November 17, 2017

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Dept. of Mechanical Engineering
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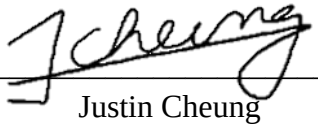
To whom it may concern:

Subject: MECH 328 Acknowledgement of Individual Report Contributions

This letter is an acknowledgement of each team member's individual contribution to the overall report according to the "Report Section Responsibilities" document.

By signing this letter, the individual not only acknowledges that the contents of the "Report Section Responsibilities" document is accurate to the best of their knowledge, but also that they have read and approved all the contents of the attached report.

Sincerely,
Team 21



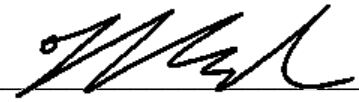
Justin Cheung



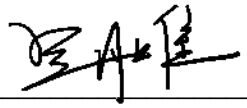
Cole Dunn-Apeldoorn



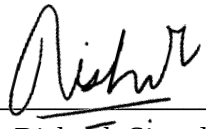
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Danwei Luo



Rishabh Singal



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Report Section Responsibilities

Section	Responsible Individual	Section	Responsible Individual
1.0 Introduction	J.L.	Appendix H.1	R.S.
2.0 Project Scope	J.L.	Appendix H.2	R.S.
3.0 Presentations of Solutions	Team	Appendix H.3	R.S.
4.0 Cost Estimates	D.L., J.C.	Appendix H.4	R.S.
5.0 Development Completion Estimate	C.D.	Appendix H.5	R.S.
6.0 Conclusions	C.D., J.L	Appendix H.6	C.D.
7.0 Recommendations	C.D.	Appendix H.7	R.S.
Appendix A	D.W.L.	Appendix H.8	C.D.
Appendix B	D.W.L.	Appendix H.9	J.L.
Appendix C .1	A.T	Appendix H.10	D.W.L.
Appendix C.2	D.W.L	Appendix H.11	D.W.L.
Appendix C.3	C.D.	Appendix H.12	R.S.
Appendix C.4	D.W.L.	Appendix H.13	J.C.
Appendix C.5	D.W.L	Appendix H.14	J.C.
Appendix C.6	R.S.	Appendix H.15	D.W.L.
Appendix C.7	R.S.	Appendix I	C.D.
Appendix C.8	J.L.	Appendix J	J.C.
Appendix D	A.T.	Appendix L	C.D., D.W.L., D.L
Appendix E	D.W.L., J.C.	Appendix M	C.D., A.T
Appendix F.1	A.T.	Appendix N	A.T.
Appendix F.2	J.L.	Appendix O	A.T.
Appendix G	D.L.	Appendix P	Team

Backcountry Skiing Equipment Tow

Prepared for

MECH 328 Instructors and Teaching Assistants

Prepared by

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Submitted: November 17, 2017

Department of Mechanical Engineering

UNIVERSITY OF BRITISH COLUMBIA

Vancouver, BC, Canada

Fall 2017

SUMMARY

"Backcountry Skiing Equipment Tow"

By Justin Cheung, Cole Dunn-Apeldoorn, Tran Xuan Duy (Jason) Le, Ga Hyun (Juliana) Lee, Danwei Luo, Rishabh Singal, Amanda Tuey

This report serves to illustrate the design process behind the development of the Equipment Tow - a mechatronic backcountry ski aid. This device was developed in response to a project proposal from FreeBoots Enterprises. The Equipment Tow concept functions by reducing the load carried by a backcountry skier during ascents. The key points of this report, beyond the illustration of the design process, include: a restructured, comprehensive list of requirements, detailed test outlines to provide guidance for further concept development, and limitations and recommendations of and for the Equipment Tow which are to be considered by FreeBoots Enterprises. In addition, a thorough collection of appendices, containing all relevant engineering calculations and design tools, are included.

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1.0 INTRODUCTION

The purpose of this report is to recommend a solution that fulfills the design problem outlined by FreeBoots Enterprises. The design problem outlined is to decrease the energy required to ascend hills in backcountry skiing terrain.

Due to the wilderness aspect of backcountry skiing, the terrain varies significantly from shallow inclines to mountaineering (which requires ice picks to climb cliffs of ice). In addition, all skiers must travel is groups of two or more. The group should collectively carry a first aid skit, a small ski repair kit, and a GPS. In addition, the individual should carry a snow shovel, a beacon, and a probe. Food, water, extra layers of clothing, and an avalanche airbag are optional but highly recommended. This typical results in 10kg of cargo carried by each skier. Further information on the project background information can be found in Appendix A, B, and C (p.17, 19, 23).

The main objectives of this device (refer to Table D-3, p.62) consist of the following:

- Device reduces, but does not eliminate, the effort required to ascend hills
- Device weighs less than 2kg when ascending and 4 kg when descending
- Device accommodates different skis with minor adjustments
- Device does not negatively affect the experience of skiing
- Device is quieter than 78 dB
- Device withstands typical conditions found in backcountry skiing terrain
- Device does not increase the risk of an avalanche
- Device operates at an altitude up to 3000m
- Device utilizes rechargeable batteries
- Device withstands temperatures as low as -35℃ for durations of 8 hours or longer
- Device possesses a 5-year design live for non-replaceable components
- Device functions at a maximum cost of $20 per day
- Device costs less than $500 USD in volumes of 1000 units
- Device can be sold by retailers across North America

2.0 PROJECT SCOPE

Backcountry terrain is highly variable; therefore, in order to narrow our scope, the device's target audience is proposed as

- ski resorts (with a backcountry skiing program) and
- low impact skiing groups (i.e., professional guides leading tours, experienced backcountry skiers who have retired due to age or injury, or new backcountry skiers).

This limitation in target audience allows the terrain to be restricted to inclines less than 40^{o} since our target audience will not be seeking terrain requiring ski mountaineering.

2.1 Project Stakeholders

Keeping our target audience in mind, the relevant stakeholders were identified (refer to D-2.1 p.56) as:

- Consumers,
- Backcountry Users (i.e., non-skiers),
- Safety Regulatory Bodies,
- The client,
- Product Regulatory Bodies, and
- Engineers/Designers.

Each primary stakeholder was characterized by their areas of concerns and their reasoning behind their investment in the development of the Equipment Tow. A detailed analysis of stakeholders, both primary and secondary, as well as the two aforementioned parameters were used in first establishing target specifications and then determining the importance of each specification (refer to D-2.2, p.56).

2.2 Needs, Requirements, and Evaluation Criteria

As mentioned, the identification of needs, requirements, and evaluation criteria were developed with stakeholders in mind, though the process that led to the final state was much more iterative than the process for identifying stakeholders.

Many factors, primarily the introduction of new information, resulted in the iteration of needs (because of scope redefinition) as demonstrated in Appendix D-1 (p.46). Sources of new information included the client Q/A (p.19), literature research (p.23), interviews (p.23), and the concept generation phase (p.72). The final list of target specifications is extensive and, therefore, can be found in Appendix D-3 (p.61) where Table D-3: Final Revision of Needs (p.62) shows both the needs as expressed by the client and the corresponding need statements.

With the final list of needs, requirements and evaluation criteria were also established. Table D-5: Comparison between Final Design and Project Requirements (p.65) shows the final status (i.e., whether or not the needs and requirement was satisfied with the final design) and corresponding rationale of each requirement.

3.0 PRESENTATION OF SOLUTIONS

Initially, 19 concepts were ideated during the concept generation phase. However, only two concepts, the Trail Breaker and the Equipment Tow, continued to an in-depth concept evaluation phase. Ultimately, the Equipment Tow proceeded to the detail design phase where subsystems were established and assessed; a final design resulted from the combining of the subsystems.

3.1 Concept Generation and Selection

Using a combination of ideation techniques, such as collaborative sketching and brainstorming (refer to E-2, p. 72), the following 19 concepts were incepted:

- Grappling Hook
- Snowshoe Attachment
- Trail Breaker*
- Ankle Assist
- Ankle Assist (Motorized)
- Actuated Ski Teeth*
- Exoskeleton
- Equipment Tow*
- Ski Snow Removal
- Snow Gripper (Actuated)
- Propeller Thrust
- Mobile Skis*
- Thermal Friction
- Jack
- Jack (Mechatronic)
- CO_2 Propulsion
- O_2 Mask
- Ski Poles (Hooks)*
- Snow Gripper

Concepts marked with an asterisk were brought to the Pugh Chart phase (refer to E-3, p.95). During the Pugh Chart phase, the Mobile Skis concept was consistently ranked last (E-4, p.97); additionally, vital input from an avid backcountry skier resulted in the winnowing of two more concepts (refer to C-1, p.23). Ultimately, the Pugh Chart retained the Equipment Tow and the Trail Breaker; these became the two concepts which were carried forward to the WDM stage (refer to E-5, p.99).

3.2 Final Design

The final developed design, the Equipment Tow, is composed of five main sub-systems and components. The device functions as an aid to backcountry skiers, by providing the option to ascend inclined slopes without being burdened with non-essential equipment.

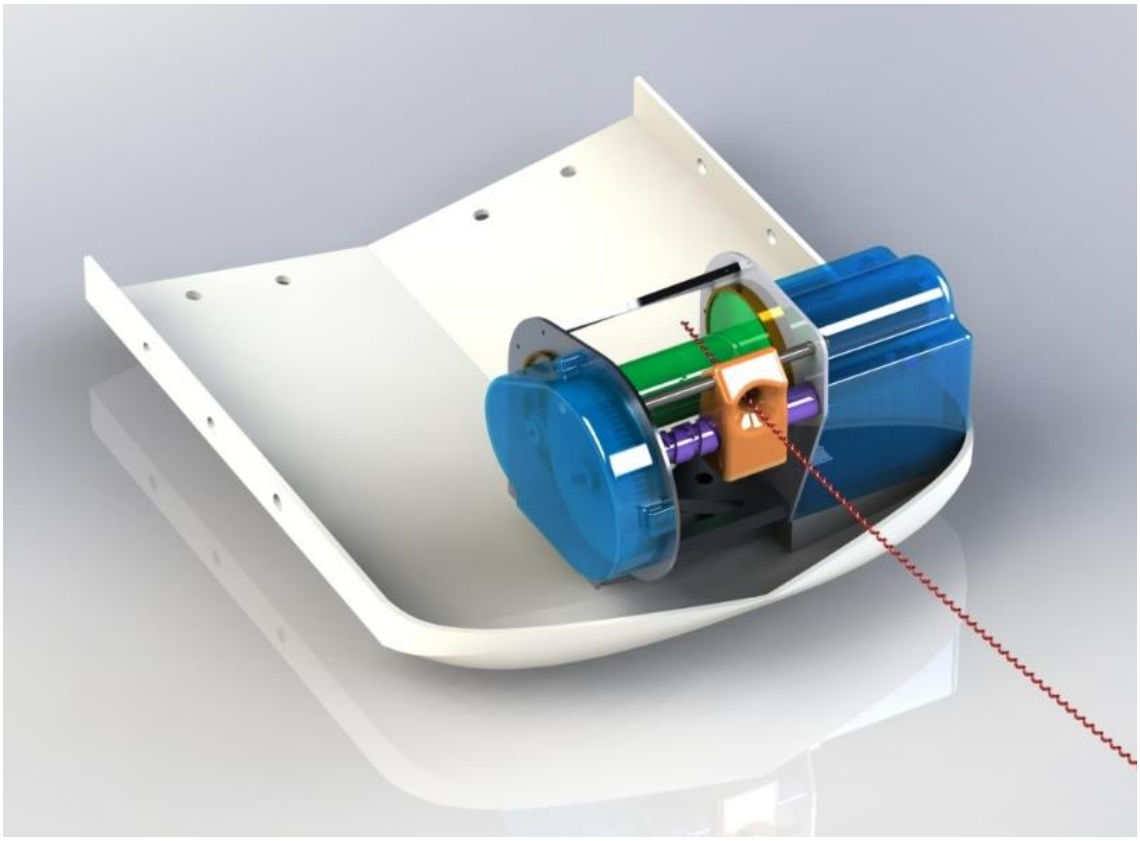


Figure 3-1: Final Design of the Equipment Tow 3D Rendering

As a complete system, the Equipment Tow operates by providing an empty sled which a user can use to secure their backpack. No longer carrying their backpack and its associated weight, the user ascends while holding the free end of a rope. The other end of the rope is attached to the sled. Once the user has ascended a distance equal to the length of the winch's rope, the user remotely activates the device's winch. The sled mounted winch proceeds to retract and pulls the sled, and user's secured equipment, uphill to the user's new position.

Specific calculations used to demonstrate the concept met requirements during different stages of design. The calculations were primarily conducted during winnowing and the Pugh Chart phase, which can be found in Appendix H-2 (p.158) and Appendix H-3 (p.160). Based on calculations found in Appendix H-12 (p.181) and H-1 (p.154), final specifications are summarized in the table below.

Table 3-1: Equipment Tow Final Specifications

Specification	Value
Energy Required for 3 Hours of Operation	153.41 Wh
Force Required for Operation	88.61 N
Winch Rotation Speed	82.8 rpm
Motor Efficiency at Operating Torque	55.83%
Motor Torque	3.38 Nm
Device Traverse Speed	0.275 m/s
Device Mass	6.87 kg
Device Dimensions	8.5” x 13.65” x 9.2”
Net Elevation Increase Per Day	10%

Detailed engineering drawings for all custom components and a master assembly drawing (exploded view) can be found in Appendix G-1 (p.132) and G-3 (p.151), respectively. Moreover, the following subsections and how they address the final needs can be interpreted from Table D-5 (p.65). Overall, all but three needs were satisfied - maximum costs, mass, and volume.

3.2.1 Motor and Battery

Since the required torque to pull the device is computed to be 3.4 Nm, as demonstrated by the iterative MATLAB script found in section H-1 (p.154), a high torque, low rpm DC motor (the AndyMark’s PG71 DC) was chosen.

It was determined that the device needed to operate for 3 hours per day as shown in calculations found in Appendix H-3 (p. 160).Therefore, the Panasonic NCR18650B lithium ion batteries were chosen because they provide the highest gravimetric (most energy per kg) and volumetric energy rates (most energy per litre). Furthermore, since freezing temperatures drastically decrease the performance of lithium ion batteries, an insulating material is wrapped around the battery to maintain its temperature above sub-zero. Thermal simulation was conducted in Solidworks to validate the insulation design (H-7, p.172).

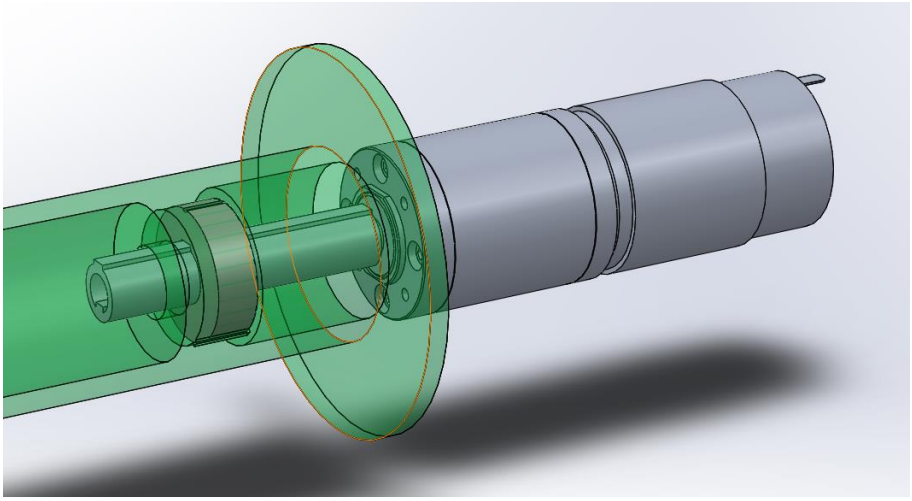


Figure 3-2: Motor and Power Transmission 3D Rendering

3.2.2 Power Transmission

From motor research, located in Appendix C-7 (p.42), a gear ratio of 100:1 was required to provide the necessary torque gain. The initial direction of approach was to design a planetary gear train which would be attached to the motor. However, an appropriate integrated gear and motor system was found 'off-the-shelf'.

A one-way clutch bearing, rated for the appropriate torque, was selected to transmit torque from the motor shaft to the drum because a torque transmitted in the opposite direction would decrease the efficiency of the system. The inner diameter of the bearing did not match with the diameter of the shaft; therefore, an adaptive custom bearing sleeve was required. The bearing, sleeve, and motor shaft are assembled with keys.

3.2.3 Winch and Rope

Based on load requirements determined in Appendix H-8, a 50ft rope with a minimum density, diameter, and cost was chosen to maximize system performance. On the winch, an automatic rope level-winding mechanism was developed - based on existing industry designs - to ensure correct rope arrangement and avoid rope self-entanglement which could lead to possible failure of the drum's operation. The main components of this mechanism (depicted in the figure below) consists of a level-wind shaft that is essentially a double-crossed power screw and a moving carriage. The needle, located inside of the carriage, moves along the power screw which in turn pushes the carriage in a linear motion relative to the rotation of the shaft. The purpose of the double-crossed grooves is to induce reversal of the carriage without altering the direction of the driving shaft rotation.

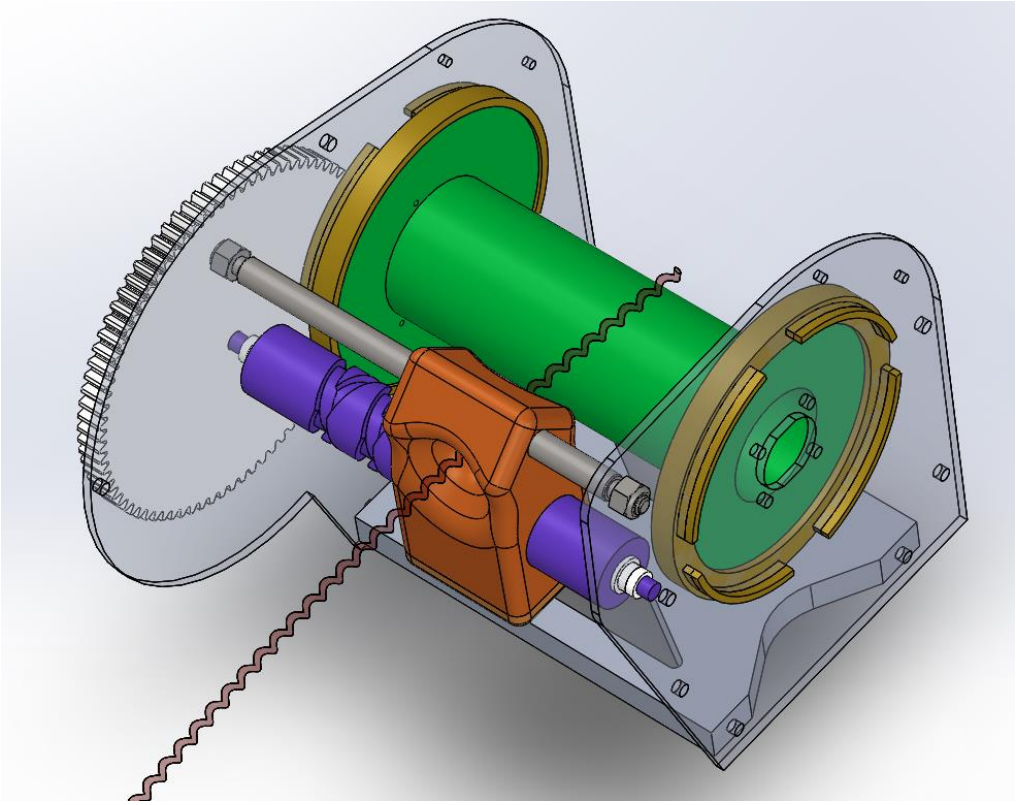


Figure 3-3: Winch and Rope 3D Rendering

The rope is pulled through the level-winding mechanism by the drum which is designed with integrated mounting for the transmission subsystem as well as a stacking design with custom bushings. Such a design eliminates the need for a bearing system for the drum and the transmitting shaft. Ultimately, this reduces cost, weight and volume.

3.2.4 Enclosure

To ensure waterproofing, one continuous rigid body was chosen over a combination of components to enclose electrical components. This solution reduced the complexity and cost to seal the enclosure while decreasing the possibility of water penetration. Additionally, all fasteners between the enclosure and supporting plates were isolated from the areas that required waterproofing, so that they did not require sealant. Lastly, to account for the sudden changes in pressure, a venting feature was integrated into the enclosure. This vent is covered with a venting pad which allows pressure relief while preventing contamination.

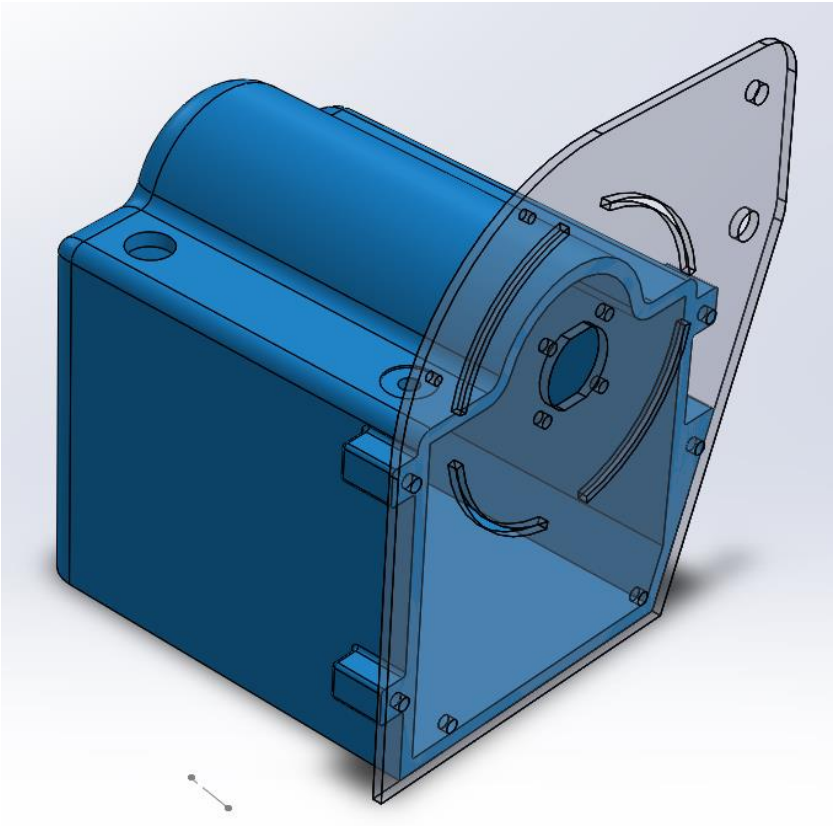


Figure 3-4: Enclosure 3D Rendering

3.2.5 Sled

As the main structural body of the device, the sled provides a space for users to secure their backpack while reducing the resistance forces experienced by the motor during ascent. The sled subsystem is among the least determinative components of the Equipment Tow because the surface area that is required to be in contact with the snow to prevent the device from sinking was calculated to be significantly less than what would be required based on the geometry of the winch and the users' backpack (refer to Appendix H-8 on p.175 for calculations on minimum required contact area).

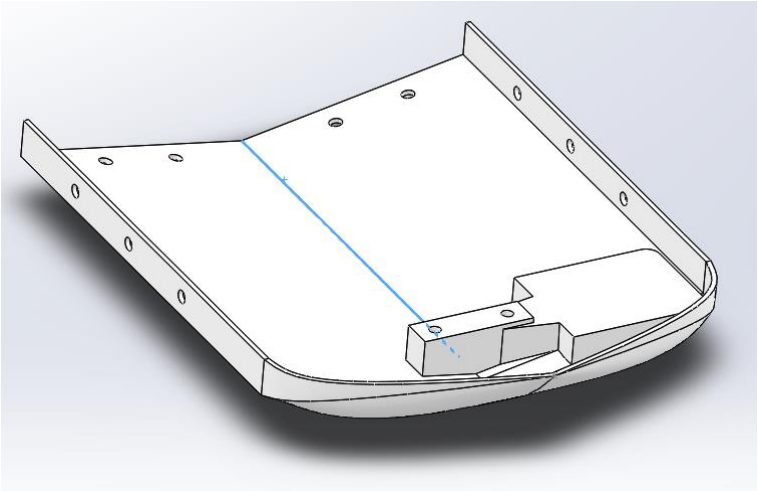


Figure 3-5: Sled 3D Rendering

3.2.6 Controls

The controls are designed such that they are 'easy-to-use' for non-technical users. The battery is connected to a toggle switch which the user toggles between a charging and operating mode. Once in charging mode, the user connects the labelled female connector to the male connector mounted on the outside of the enclosure. The charger delivers a constant 5A current to the battery. If the switch is toggled to the operating mode, the user is then able to easily swithc the motor on and off using a Geekcreit 1Ch Transmitter. When the user pushes the transmitter's 'on' button, the Geekcreit 1Ch receiver activates a MOSFET which allows current to flow through the motor. When the user pushes the 'off' button, the MOSFET enters cut-off mode and no current flows through the motor (refer to Appendix G-2 on p.149 for control schematics).

4.0 Cost Estimates

The Bill of Materials (refer to J-2, p.204) was created and updated as the detailed design phasewas completed; however, considering only the retail cost of the components was not reflective of the true cost to manufacture. Factors such as wholesale pricing, shipping, packaging, labour costs, tooling and setup costs, contingency costs, and import tariffs were researched and applied to the Bill of Materials to obtain a more accurate estimate of the total manufacturing costs. This was difficult without contacting companies; therefore, the estimated costs were based off research, data, and, ultimately, our judgement.

Whenever wholesale pricing was unavailable for a component, a similar product, with readily available wholesale data, was found so that a discount, of the same magnitude, could be applied to the specified component. Unfortunately, this approach did not work for all components; thus, a baseline wholesale model discount was adopted for these components (refer to J-1.1, p.198). Shipping data (J-1.2 p.198) was accumulated from several suppliers on the BOM and an average of 2% was applied to each product. Packaging data (J-1.3 p.199) was conservatively estimated from an article which selected the packaging to be a rigid box at an order volume of 1000 (“How Much Does Packaging Cost,”2013). A time study of our manufacturing process (J-1.4 p.200) based off prior experience in assembly lines was used to estimate assembly time and, ultimately, labour cost; assembly tools were also considered in manufacturing costs. The contingency rates described in lecture of 50% for custom items and 10% for common items were adapted in the BOM. Additionally, import tariffs (J-1.7 p.203) of a baseline 5% GST were applied (“Step-by-Step Guide to Importing Commercial Goods into Canada,” 2015).

The total cost analysis for the Equipment Tow pre-contingency for a single unit produced in quantities of 1000 is $638.27. With contingencies, as outlined in J-1.6 (p.203), the total cost becomes $799.25. Further discussion of the price justifications (i.e., the steps required to reduce the device cost) can be found in Appendix J-3 (p.211). The only operational cost of the Equipment Tow is the cost of electricity; the device uses 153 Wh of power to fully charge. This translates to $0.01 per charge (“BC Hydro Residential Rates,” 2015). Lastly, discussion on end of life disposal procedures may be found in K-2 (p.212).

5.0 Development Completion Estimate

For the Equipment Tow to fully satisfy all requirements, further development is required. The specific actions and results that must be achieved to finish developing the Equipment Tow are described in detail in prototype tests Appendix I (p.191). The following are summaries of the most important tests:

- I-2.1 Device Usage Data Collection (p.192)
  - This test helps to identify how long the average user will require the battery to last.
  - Estimated cost of $5494.25, with an estimated completion time of 3 weeks.
- I-2.2 Device Operating Conditions Data Collection (p.194)
  - This test helps to identify the operating conditions of the device.
  - Estimated cost of $2315.20, with an estimated completion time of 2 months.
- I-2.3 IP-68 Sealing Certifications (p.195)
  - This test is needed to certify that the Equipment Tow is waterproof.
  - Estimated cost of $799.25, with an estimated completion time of 1 day.

6.0 CONCLUSIONS

The Equipment Tow shows promise as a viable solution for the project proposed by FreeBoots Enterprises for the specified target audience of ski resorts and low impact skiing groups. This is done by decreasing the energy required to ascend hills in a backcountry skiing terrain by approximately 10%. The device has a weight of 6.87 kg, a dimension of 8.5” x 13.65” x 9.2”, a production cost without contingencies (in quantities of 1000 units) of $638.27, and a production cost with contingencies (in quantities of 1000 units) of $799.25. All but three needs (mass, cost, and volume) were met. While the device in its current proposed state does not meet all needs, given further developmental resources, the Equipment Tow shows great potential for market feasibility.

7.0 RECOMMENDATIONS

With the current proposed state of the Equipment Tow, some limitations have yet to be addressed. Primary influential limitations include:

- the effects of ascending laterally on routes (these routes have not been analyzed in depth),
- the device exceeding the required maximum volume,
- the capacity of the batteries (a significant reduction of mass would subsequently allow optimization of the battery capacity),
- the possibility of a reduced device lifetime (resulting from the cycling of the battery charge at lower temperatures), and
- the device is lacking a printed circuit board (the purpose of which ensures that all 16 cells are maintained at the same voltage during charging and discharging, the voltage supply from the battery is terminated when the voltage of any cell drops below 3V, and the charging current is terminated when the voltage of any cell exceeds 4.2V).

These primary limitations do not include instances where out-of-scope needs and requirements were not met. Factors that require consideration moving forward, but are not limiting factors for device operation, include:

- experimental data detailing a more accurate estimate of mean device usage for a given day of operation and
- experimental data detailing the average weather conditions experienced by the device.

Specific plans of action for addressing these limitations and other factors are detailed in Appendix I (p.191).

Other than the prototype tests outlined in Appendix I, which details required further development and high value return development, the above limitations can be addressed and mitigated with the following overall recommendations:

- address the effects of ascending laterally on routes by conducting a sample user test where the user provides feedback which allows the product developers to gauge the importance of a straight ascension path,
- redesign the sled to be modular so that it may be carried by multiple skiers to satisfy the volume requirement,
- ensure that the load is equally distributed on the batteries by implementing a battery management system (ultimately preventing circular charging), and
- optimize battery usage by measuring the discharge rates at negative temperatures found in the prototype test (I-2.2, p.194) so that more accurate and applicable data can be used for calculations instead of data from the technical sheets provided by the manufacturers (the number of required batteries can reduced, and consequently, the cost and weight are reduced).

APPENDICES

APPENDIX A: BACKGROUND INFORMATION

The customer, FreeBoots Enterprises, requested a mechatronic device which can improve the backcountry skiing experience by decreasing the energy required to ascend hills. This is because backcountry skiing is in untracked snow, therefore the skier must use considerable energy and time to reach the top of the hill before they can enjoy downhill skiing. In addition, the device should use rechargeable batteries and be operational in typical backcountry conditions (FreeBoots Enterprises, page 6, 2017). Ultimately, the amount of time spent skiing downhill is maximized by the requested device by minimizing the time required to ascend.

Each of the following paragraphs will separately summarize key pieces of information, from the project proposal relevant to the design process of the device. These summaries, in addition to Appendix B and C, allow needs and requirements, stated in Appendix D, to be formed.

Existing products and devices allow backcountry skiing to be accessed with less energy. Some examples include snowmobiles, heli-skiing, jet powered snowboarding, screw propelled snowboarding, Skizee utilization, and cat skiing. However, these products and services have an associated high cost, high noise level, and other unfavourable conditions which decrease backcountry skiing accessibility to the average skier (FreeBoots Enterprises, page 2, 2017). In addition, the needs clearly state that the device should be quieter than a cordless drill and have a production cost of $500 USD per unit in volumes of 1000 units, and possess an operating cost of a maximum of $20 a day. Therefore, the device should meet these needs and not negatively affect the downhill experience (FreeBoots Enterprises, page 6, 2017).

Backcountry skiing is usually a self-propelled recreating which requires a high physical ability of strength and endurance (FreeBoots Enterprises, page 2, 2017). However, the project proposal states that the device should appear to former backcountry skiers who are retired from age or injury (FreeBoots Enterprises, page 3, 2017). Therefore, the needs of the device being less than 2kg in net weight and small in volume should be met (FreeBoots Enterprises, page 6, 2017).

There are two main styles of backcountry skiing – alpine touring and telemark skiing. Alpine skiing allows the heel to be free when ascending yet fixed when descending; telemark skiing is characterized by a constantly free hill (FreeBoots Enterprises, page 4, 2017). The two styles

require differing equipment, apart from ski skins. Ski skins are placed underneath the ski to increase the friction force between the snow and ski while only allowing a friction force to be exerted in one direction to prevent the skier from sliding down the hill (FreeBoots Enterprises, page 2, 3, and 5, 2017). Ultimately, equipment affects the design of the device, therefore the device must only require small modification of existing equipment and be compatible with different types of equipment (FreeBoots Enterprises, page 6, 2017).

While ski resorts manage the safety of snow, backcountry skiers must assess their own risks in terms of avalanches by carefully pre-planning routes, reviewing weather, testing the snow, and familiarizing themselves with the avalanche history of their designated path (FreeBoots Enterprises, page 3 and 4, 2017). Therefore, mandatory safety equipment, such as the beacon, snow shovel, and probe, are carried by all backcountry skiers. This means that the device should not reduce the effectiveness of the safety equipment nor increase the probability of being in an avalanche (FreeBoots Enterprises, page 6, 2017).

Other additional needs that were explicitly stated in the proposal consist of the device being operational at an altitude up to 3000m, the device withstanding temperatures as low at -35℃ for a minimum period of 8 hours, the device having a minimum life of 5 years for non-replaceable components, and the device being marketable across north American retailers (FreeBoots Enterprises, page 6, 2017).

APPENDIX B: INTERNAL RESEARCH

Internal research is defined as all information from the client that was relayed to all the project groups (e.g. Client Q&A, documents provided on connect, etc.). Below are key lists and summaries, organized by source, of the pertinent information.

B-1 Client Q/A Information

During ongoing communication with the client, the following information was obtained:

- If an incline is greater than 50^{O}, the skier will choose to climb the incline at a rate of rise of 15-20%.
- Ideal slope conditions consist of large quantities of powder at inclines of 30^{O}- 45^{O}.
- The client would like to minimize all weight when skiing, therefore a device that can replace and existing product or combine products is encouraged.
- The client prefers continuous usability over efficiency.
- Gasoline powered devices are not an option.
- The device must be useable over multiple slopes in the same day.
- Approximately 6 complete ascensions and descensions occur in one day.
- Typical day trip cargo consists of food, water, a snow shovel, a probe, spare clothes, a beacon, a GPS, and possibly an avalanche air bag (the maximum weight for all cargo is approximately 10 kg).
- Backcountry skier's travel in groups of 2 or more for safety reasons and the group should possess a first aid kit and ski repair kit.
- the device may be purely mechanically operated or consist of mechatronic components
- The current target audience only consists of adults.
- If the device is to fit inside a backpack, it should ideally be 2 L or less in volume.
- The average backcountry skier skis approximately 10-20 times a year.
- If the device is too carried downhill, the net weight can increase an additional 2 kg.
- The device is aimed for those who require additional energy when backcountry skiing or for those who enjoy using leading technology.

- The average skier's weight is 75-90 kg.
- The target MSRP for the device is $2000.
- The average backcountry skier skis for approximately 65% of daylight hours.
- Ideally the device is removable and can be used with multiple sets of equipment (but it does not have to be compatible with a split board).
- The device should be quieter than 78 dB.
- On a typical day, 1000m vertically is ascended while longer days may be up to 2000m.
- A modular device, split between a minimum of 2 people, is acceptable.
- The average hiking speed for a backcountry skier is 3 km/hr.
- Ideally the device would be sold at sport-specialized retailers.
- The device may require users to get in and out of bindings.
- The device should not increase the size of a backpack by more than 0.5m.
- A limited lifetime is desirable by the client to increase repeat purchases.
- Sustainability of the device may be important to the skier but not to the client.
- Backcountry skiers rely on their feel of the snow and their experiences interacting with snow, therefore a device which limits this capability or replace this capability would not be popular with users.
- The lower temperature limit for the conditions in which the device will be used is -15^{O}C.
- We should assume that the user is capable of doing kick turns, side stepping, and other typical maneuvers that back country skiers utilize to ascend hills.

B-2 Summary of Existing Products

The client provided three existing devices which save the user energy, when backcountry skiing, yet fail to meet the other goals provided by the client. The devices are: the Skizee, the Jet-Powered Snowboard, and the Screw-Propelled Snowboard.

B-2.1 Skizee

This device operates by having the user stand in front of the device, grip the protruding handle bars, and lean onto the seat bar connected to the Skizee. With these contact points, the device pushes the user across the snow. The handles are additionally used for controlling the device since its direction is based on mass balance. This device possesses a 4-stroke combustion engine with a horsepower of 10.5. The Skizee can travel 35-40 km per US gallon of gas. The approximate cost of this device is $2500 USD; however, it is not for sale in the current marketplace. The client is not interested in the Skizee due to its gas engine, size, noise, and weight.



Figure B-1: Skizee

B-2.2 Jet-Powered Snowboard

The Jet-Powered Snowboard utilizes four 8-kW motors which turn spin fan blades. Each spin fan blade can operate at 3000 rpm. If the user is on a flat stretch of land, this device can reach speeds up to 50.1 mph. The device hand held and controlled by a bite-actuated controller or a thumb throttle controller. The client is not interested in this device due to its noise, size, weight and performance.



Figure B-2: Jet-Powered Snowboard

B-2.3 Screw-Propelled Snowboard

The Screw-Propelled Snowboard utilizes a small electric bicycle motor to turn two screws which are located on the ground. When the threads rotate, the snowboard is pushed forward. The device can only be used by the skier on flat terrain and up hills. The device is extremely slow, inefficient, weighs 4-7 kg, and is not available in the market. For these reasons, the client is not interested in this device.



Figure B-3: Screw-Propelled Snowboard

APPENDIX C: EXTERNAL RESEARCH

External research is defined as all research conducted outside of the given sources – which were defined in Appendix B (refer to INTERNAL RESEARCH, p. 19). Below are key findings from this research.

C-1 Interviews with Experienced Backcountry Skiers

Three interviews with 3 different experienced backcountry skiers were conducted. The names of those interviewed are Corwin Shanner, Bryan Starick, and Michael Shynkaeyk.

Corwin Shanner gave insight into the basic background on backcountry skiing. According to Shanner, the ski skin is not ideal because they can become 'iced up' and lose their friction when the temperature is less than 5 degrees Celsius. In addition, skins also slide backwards so that each step taken forward results in a half step back. However, skins can last 5-7 years with good care. Normally, skins can be used for 3-4 seasons without re-gluing. The skier usually avoids hiking in powder with ski boots because the foot can sink 2-3 ft. When skiers attempt to step out, more energy would be used. The skier prefers to ascend enough to enjoy going downhill. The enjoyable downhill must be at least 100 meters or approximately 2 minutes of downhill time. Otherwise, if the downhill skiing consists of less than 2 minutes of downhill time, one would ski not bother to remove the skins and proceed to ski down with the skins on.

Bryan Starick is a geological engineering student who has 4-5 years of backcountry skiing experience. He usually participates in multiple-day trips (4-5 days) if he decides to backcountry ski. From his relayed information, it appears that the experience of the skier significantly affects the gear chosen by the backcountry skier. Starick states that avalanche safety equipment is very important as it makes the entire backcountry skiing industry safer. Therefore, backcountry skiers always travel in at group of at least 2 to ensure safety; a technique where skiers move across from one safe position to the next, one at a time, observed by companions is often used (See Figure) When avalanche safety testing is conducted, 40 minutes is required to dig a snow pit for testing. The snow pit is approximately 2-3 meter deep.

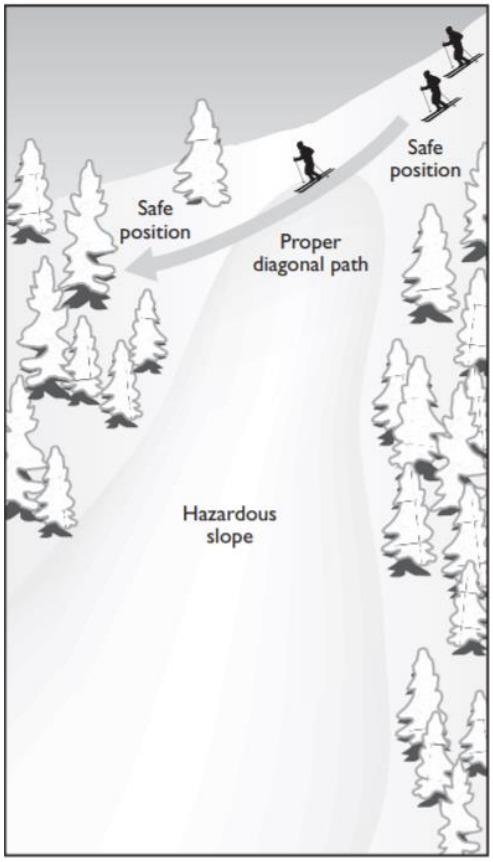


Figure C-1: Safe Travel Technique for Backcountry Skiing (D. McClung and P. Schaerer, 2009)

Starick states that the terrain makes backcountry skiing complex since the skier would never climb slopes inclined larger than 30 degrees. He states that the ski skin is easy to use when the slope is less than 15 degrees. If the slope is greater than 15 degrees but less than 20 degrees, the skin allows ascending to be manageable but with significant effort. Sidestepping is only allowed when the slope is less than 40 degrees. If the slope is greater than 45 degrees, skis need to be removed and technical climbing is required.

If backcountry skiers plan to conduct overnight trips, the most significant difference between a daytrip and an overnight trip is the weight of the skier's backpack. If the skier plans to backcountry ski for a weekend, their bag is usually 40-45 lbs. If they are out for a day, the weight of their bag is approximately 10-15lbs. Starick states that a significant challenge for a backcountry skier is the breaking of trail because the untouched snow ill compress approximately 4-8 inches. This requires 2-3 times more energy because the skier must step out of the snow to take each step or they must trudge through the powder (which would require

additional energy). The second person in the skier pack will compress the snow an additional inch while following individuals would not compress the snow. Lastly, Starick stated that a pound the skier's foot is equivalent to 4 pounds on the skier's back. He additionally stated that an increased weight during descension would be more detrimental than and increase in weight during ascension because balance would be thrown off during descension.

The final interview was conducted with Michael Shynkary; he provided feedback on the proposed concepts. For the trail breaker, the interviewer thought that the concept was unique but not realistic due to the variables that the trail breaker would need to consider. These variables consisted of: terrain angle, snow bearing capacity, trees, and other such examples. Therefore, Shynkary believes that the robot cannot be efficient. He also stated that the skier needs to feel the snow under their skis to assess snow conditions and evaluate avalanche conditions. Therefore, he suggested that the device's use be altered to carry the skier's gear and follow behind them.

Shynkary stated that the current device he utilizes is a homemade device which consists of a basic toboggan made with 7mm cord and a carpet. The sled is similar to the Equipment Tow concept which carries the skier's equipment. His sled is hooked to a loop by a climbing harness and requires the skier to pull the entire device by themselves. When the skier descends, an issue arises as the device is heavy and makes skiing more difficult. Another limitation of the sled is the terrain on which it is efficient; the sled is only useful on glacial and flat terrain. Normally, skiers plan a ski tour as a group of 4 for safety reasons (something Starick mentioned as well). Unfortunately, with the sled, switching pack leaders would be inefficient since the location of the sled would hinder quick leader changes.

For complete notes from all interviews conducted, please refer to the sections below.

C-1.1 Notes from Interviews with Corwin Shanner

Date: October 8, 2017 (with Amanda)

Background on Backcountry Skiing:

- For downhill backcountry skis and at least a foot of unpacked cold powder, one would sink about 10cm.
- If you have skins on (with packed snow), one would not slide much
- For a slope of 45^{o}, one would not be able to climb with skins (or even be able to sidestep up - ski mountaineering is something that would probably be more likely)
- Motion is a lot of sliding, but there is some lifting of the foot (depends on where one is in the line of hikers - the first person would be doing more of a hiking motion)
- Skins Sliding backwards -"every step you take, you can slide about halfway back"
- If you're in -5^{o}C, skins can get iced up and lose their friction
- A lot of this has to due with technique
- Get by with 3-4 seasons without re-gluing them
- Skins last 5-7 years with good care
- If using spikes, they would need to be very long to get any traction on loose powder
- Paddles or something with more width would be more helpful
- Hiking in powder with ski boots is a terrible idea (sinking can be over 2-3 ft)
- In terrain with significant ascending and descending, what do you do?
- Ascend enough to enjoy going downhill (at least 2min of downhill, elevation drop of about 100m) → then switch over to ascending
- Otherwise, if you are skiing less than 2 minutes of downhill, one would ski down with skins on.

Date: October 18, 2017 (with Amanda)

Concept Feedback for the Trail Breaker:

It'd be way easier to have it follow than to have it lead - not sure how the autonomous trail-breaking would work logistically.

C-1.2 Notes from Interviews with Bryan Starick

Date: October 10, 2017 (With Team)

Background Info on Bryan:

- Backcountry Skier - significantly experienced with uphill components
- 4-5 years of experience
- Multi-day trips are normal (4-5 days)
- Uses skins (very effective and only requires 10 minutes to change gear)
- Depending on what kind of bindings, you need to take your skis off at the top of the hill regardless, but taking bindings on/off is not a huge ordeal
- Geological engineering student with a background in snow science

Dry Sand vs. Snow

- Snow has cohesion whereas dry sand does not
- Snow is significantly more variable
- Skins work well because it's a model between little hairs and individual grains of snow

Mechanics of Backcountry Skiing:

- Avalanche Safety (this is a huge point - makes the entire industry safer)
    - Essentials in your backpack include a probe, beacon, and shovel
    - Skiers "centipede" down to stay safe (Always go in at least groups of 2)
    - Takes about 40 min to dig a snow pit and do the testing (Snow pit is about 2-3m)
    - Avalanche Probes (a pressure transducer at the tip gives a snow profile) is very expensive ($2200), digital - provides a graph readout, and requires AAAs or similar
    - Cone Penetration Test (for soil is very similar)
- Two types of backcountry skiing
    - Hike up for long periods of time, ski down for a significant time, 10 minutes at the top to switch
    - Hike up a short period of time and repeat for an extended time

- People that we cater to (out-of-shape skiers, new backcountry skiers = they have lots of similarities); these people would never climb slopes > 30^o
    - Our target audience won't be in icy conditions to need ski teeth or ski crampons
    - Big difference between experienced and new back country skiers is their knowledge of the terrain (could be out of scope)
- Overnight trips can be done with people who have never backcountry skied before; the biggest difference between daytrips is the weight of your pack
- Terrain
    - < 15^o - skinning is easy
    - < 20^o - skinning is manageable but requires significant effort (thus, switch backing is used to reduce the angle to 15^o); kick turns are a technique to do a switch back without moving a lot)
    - < 40^o - sidestepping
    - 45^o - skis need to be removed and technical climbing is required
- Cost is probably also a big issue with people who are starting to get into it or people who are getting back into it; most people will buy cheap gear, see if they like it, then invest
- Backpack weight
    - Our for a day = 10-15 lbs
    - Out for a weekend = 40-50 lbs

Issues with backcountry skiing

- Breaking Trail
    - Person breaking the trail is using 2-3 times more energy. Why? You need to step out of the snow to take each step (snow compresses about 4-8 inches). Second person in the pack will compress the snow about another 1 inch. Each person after doesn't really compress a bunch of snow after
    - Or you can trudge through the powder snow (Which takes up more energy since you're lifting the weight of the skis [comes back to 1/4lb ratio]
- Weight that you are bringing up the hill (huge issue); Weight on your feet is an issue: "A pound on your feet is 4 pounds on your back".

- A heavy backpack will throw you off balance (it is easier to skin up with lighter backpack); Would rather carry weight uphill than downhill. Why? Stability.

Concept Feedback

- Equipment Tow Winch Idea
    - Issues: Switchbacks
    - Gear that is multipurpose is desirable (i.e., Ski Mountaineering)
    - Advantages: Saves weight for the person
- Actuated Ski Teeth
    - Issueseap, light, and easy to use - they are a really high bar to beat (no purpose for this concept if it cannot replace skins)
- Rumba Packer
    - Issues - Check them out as they might have come up with an autonomous snow mobile that you could ride up and it would find you at the bottom
- Ski Poles - Black Diamond Whippet already exists

Lent us “The Avalanche Handbook” with has lots of information on snow science

Date: October 18, 2017 (with Amanda)

Trail Breaker Criticism - Second Opinion

- From a pure energy conservation standpoint breaking trail is intensive, however, issues regarding avalanche safety are valid considerations (i.e., not being able to “feel” the snow below skis)

C-1.3 Notes from Interviews with Michael Shynkaryk

Date: October 18, 2017 (with Amanda)

Concept Feedback on the Trail Breaker

- Autonomous robot would be cool, but breaking trail is an art and takes skill. It is a core competency skill of ski tour guide's exam. He cannot image a machine will do an efficient job.
- Why? Imagine the variable changes in terrain angle, snow bearing capacity, and trees. Plus a guide or ski touring needs to feel the snow under their skis to allow them time to assess snow conditions and evaluate avalanche conditions.
- Weight reduction is a big issue though.
- Likes the idea of having the device follow the user with the single function of carrying gear because it saves energy by lightening the load on the user.

Date: October 23, 2017 (with Amanda)

Sled (Existing Product)

- Description: It was a basic toboggan made with 7mm cord and a crazy carpet. It uses a climbing harness and hooked a rope to a loop on the back. It would be nice to have a sled behind me that would power itself (refer to Figure C-2: Sled used during a Single-Day Travel on a Glacier (M. Shynkaryk, personal communication, October 23, 2017)).
- Key Issues/Advantages: Works, but was a ton of work. Going downhill with the sled: it was heavy to carry on my back and was challenging to ski next too. He basically had to ski between crevasses fast and no let it pass. It worked well. Sleds don't really work in terrain that need switchbacks (red flag)
- The design meet all my needs, wants and limitations of the trip. However, it would not work for day ski touring or short day trips. Glacial terrain or flat terrain is ideal for pull along sleds. Thus it is limited to its application.
- Use this example as a basis of what is bare minimum these days for budget trips.

- As for ski touring, switch back are frowned upon and rounding corners are the norm to building a "Guide" ski track. However, in a pinch a switch back is used in steep terrain (would not bring the "autonomous" sled on such a trip).
- Maybe define that it will be used on ski tracks no steeper than 10 degrees and ideally for glacier travel or long flat slogs into camps. May help in design to define the terrain it would be used. Like a car tire and various road conditions.



Figure C-2: Sled used during a Single-Day Travel on a Glacier (M. Shynkaryk, personal communication, October 23, 2017)

C-2 Research on Backcountry Skiing

Before we started detailed design, we performed general research about backcountry skiing, the mechanics involved, and its safety aspects. This research resulted in some areas that our design should consider. For example, the design should not be too heavy as to affect the downhill skiing experience. Furthermore, weight will expend more of the skier's energy and cause balance issues.

Our research about the body mechanics involved (Volken, Schell, Wheeler), showed us the leg profile of a skiier and how the skier balances themselves using ski poles. We also searched how many calories are burned for winter activities (Calorielab) which allows us to quantify how much energy we wish to save. The research is summarized below.

From Mountain Skill (Roth, 2014), we learnt that there are three primary backcountry touring skills which are setting proper pace, having suitable ski track angle, and avoiding kick turns if possible. Climbing uphill takes almost half of a skiers' day. Skiers are typically out for ~6 hours so accordingly, power capacity needs to be considered. Climbing speed for most people is between 1000 and 1200 vertical feet per hour. Normally, skiers take 5 minutes of break every hour. If a skier spends 6 hours going uphill, they will gain 5000ft of descent. The most efficient inclination is at 14 degrees, despite going straight up being the shortest. The straighter the path of ascent the more energy is burnt; therefore, it is inefficient for a skier to go straight up. The skier will also not take long strides causes instability. The right size stride makes the skier feel like sliding on the snow instead of walking step by step.



Figure C-3: Climbing Uphill in the Backcountry (Roth, 2014)

As mentioned in Evo's article "How to get started backcountry skiing & snowboarding", when skiers are backcountry skiing, they bring an avalanche beacon, shovel, and probe with them for their safety. There primary ascent tool currently used in backcountry skiing are skii skins. Before backcountry skiing, the skier ensures that the skin having software, a good adhesive, and fitting well to their ski.

C-3 Snow Research

As the Equipment Tow device is intended to operate in the snow, a basic knowledge of snow physics was necessary. “The Avalanche Handbook” by D. McClung and P. Schaerer was useful in this regard. An example of the information put to use from this book can be found in H-8 Sled Chassis, Required Area (p.175), to approximate the compressive strength of snow.

Additionally, further snow research was conducted on avalanche safety. Snowpack structures vary greatly as shown in the figure below. Instability tests are the primary tools used to detect weak layers and, if weak layers are found (Figure), skiing should be avoided as the sample snow demonstrates avalanche characteristics.

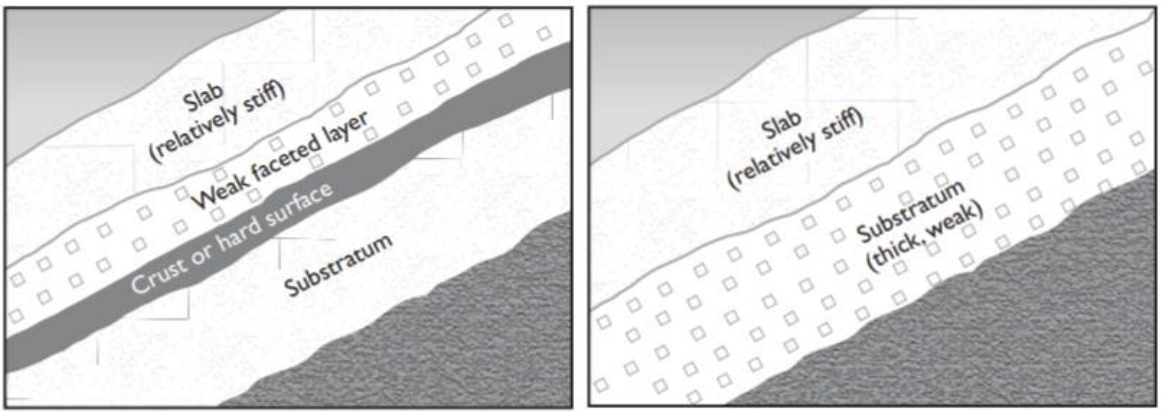


Figure C-4: Weak Snowpack Structures (Shapiro, 1997)

In the interest of time, research was limited to a basic understanding of snow mechanics which, for the scope of this project, was sufficient for preliminary design.

C-4 Summary of Existing Products

After we did our backcountry skiing research, we had a better idea about which aspects our device should focus on like weight, size, and speed. Then, we jumped into the existing product research to get some ideas to begin concept generation. Existing product research also alerted us if there were existing patents, we should skip that concept. Therese are some of products that we found. For example, the Flux snowshoes (YouTube, 2014) which expands and contracts when heel motion is detected. Paris pulk (SkiPulk) is like a ski board. Skiers can put their stuff on it and pull it on the snow. The three other existing products are listed in detail as follow.

C-4.1 Ankle-Assist Device

The ankle assist by Yaskawa helps people who are injured or have walking impediments as shown in the figure below. Ankle assist device uses an electric motor as power; and a sensor placed on the bottom of the device dictates motor operation. This is accomplished by sensing the heel motion within a feedback loop.



Figure C-5: Ankle Assist Device (YASKAWA Electric Corporation, 2013)

The device controls the motor to give a forward center of gravity for the walker to access plantar flexion and dorsiflexion ankle movements. The advantages of this device are its light weight and its ease of wear (YASKAWA Electric Corporation, 2013).

This device is related to our Ankle Assist concept and the Detachable, Inflatable Snowshoe concept (refer to E-2.5 Concepts that Failed Winnowing, p.83).

C-4.2 Exoskeleton

The device is used as a frame to assist workers lift heavy industrial tools. For the use, the heavy tools feel weightless. The most impressive part of this design is it doesn't require any power. Based on the research that the designer did, standing costs 10 watts and working costs 1 kilowatt for people. An unpowered device is important because no battery can provide that much output for a whole day. The main target of this design is construction workers. (Rogers, 2015)

This device is related to our exoskeleton concept (refer to E-2.5 Concepts that Failed Winnowing, p.83).



Figure C-6: Exoskeleton (Rogers, 2015)

C-4.3 Hiking Crampons

This device is like a soccer shoe, but has spinous teeth under it. These teeth dig into the snow or ice to increase the friction force. It is usually used by the skier but also hiking enthusiasts. This device is made by hardened stainless steel to avoid rust. The weight of it is 608g. It is easy to wear and take off. This device is close to the ski teeth concept that we had. (MEC)

This device is related to our ski teeth concept (refer to E-2.3 Concepts that Fell Out of Scope (After Pugh Chart Analysis), p.78).



Figure C-7: Hiking crampons (MEC)

C-5 **Summary of Existing Patents**

At the beginning of the design, we found existing patents. For example, Adjustable ski strap (Shields, 1979) is designed as a ski skin which can provide more friction force to hold the ski and prevent the ski from going backward. This adjustable securing strap is placed at the bottom of the ski. Configurable snowshoe and ski device (Ekberg, 2006) combines the snowshoe and skis into one design. The adjustable snowshoe (Settelmayer,2003) has a floatation shape at the front and a special banding system to connect to the skiier's boots. These two patents are listed in detail below.

C-5.1 Snowshoes

The snowshoes can be use for people crossing the snow, going uphill, or downhill; however, it limits the speed of walking. It also does not work as intended at high speeds. Lightweight material or sheet metal can make it. There is a 3 foot shoe plate bound to the bottom. The front of the snow shoes is shaped as upturned prow which flows the human walking habits. It also avoids build up more snow on the shoe plate. Under the shoe plate, there are some tiny plates assembled with the snowshoes vertically which function as teeth to dig into the snow. (Rodney, 1971)

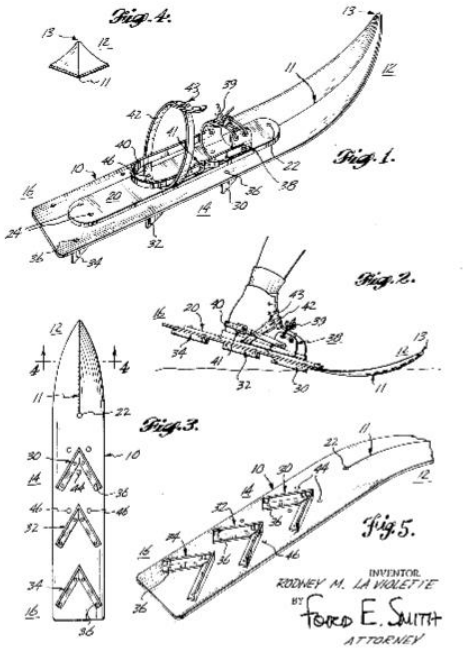


Figure C-8: Snowshoe Patent (Rodney, 1971)

This device is related to our ski teeth and angled automated anchors concept (refer to E-2.3 Concepts that Fell Out of Scope (After Pugh Chart Analysis), p.78).

C-5.2 Compact Snowshoes and Bindings with Method of Assembly

This design uses the frame structure to assemble. Thus, it can be separated into multiple parts, and transformed into a compact design. The structure is made by a light and strong material. There is the binding system to connect your shoe with it. There are also ski teeth placed in front of the shoe to assist climbing (Wing. R. H, Moss. N. R, Francis. D., 1998).

This device is related to our ski jack concept (refer to E-2.3 Concepts that Fell Out of Scope (After Pugh Chart Analysis), p.78).

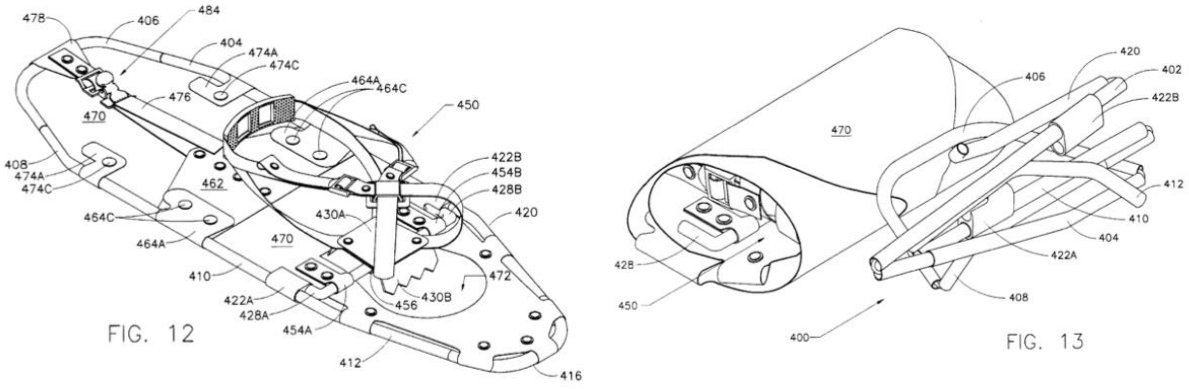


Figure C-9: Compact Snowshoes and Bindings with Method of Assembly (Wing. R. H, Moss. N. R, Francis. D., 1998).

C-6 Battery Research

C-6.1 Type of Batteries

Keeping the mass and volume of the device low was desirable, Lithium-Ion batteries were chosen to act as a power source for the device because it offers highest volumetric and weight energy density (i.e. most power capacity per cm^3 and kg) (refer to Figure).

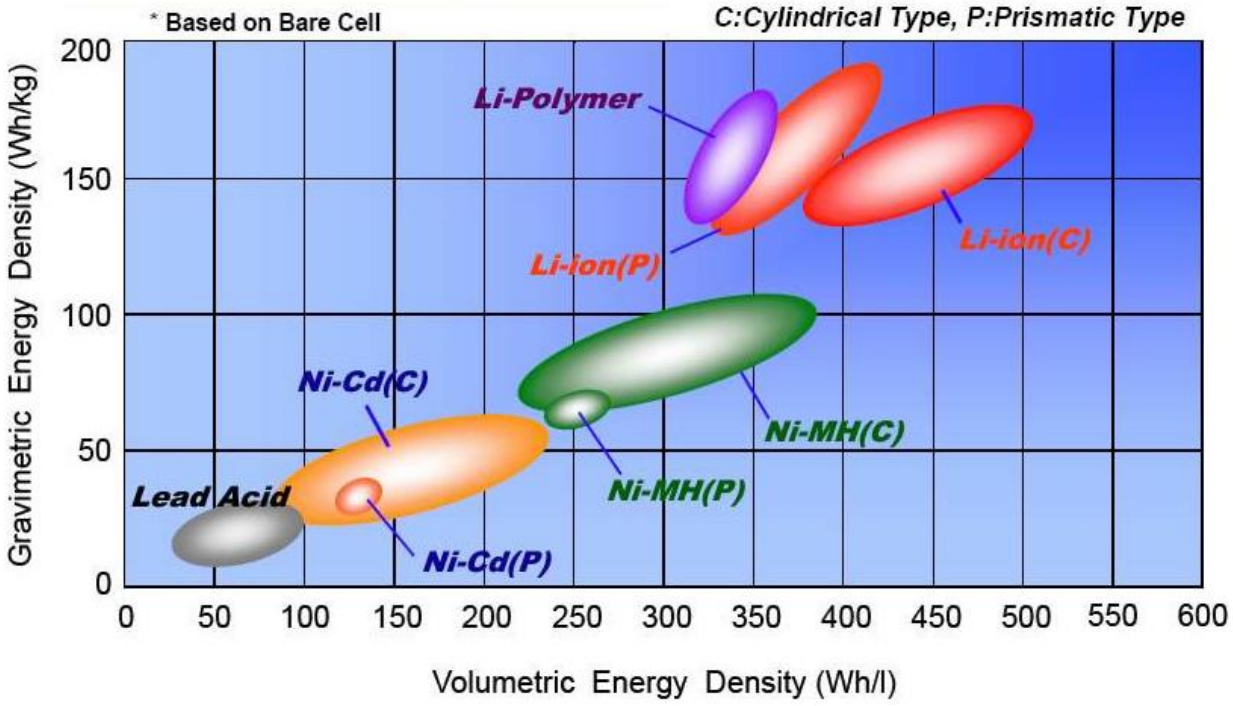


Figure C-10: Graphical representation of gravimetric and volumetric energy densities of various batteries ("Comparison of Energy Density," 2014)

C-6.2 Type of Lithium-Ion Batteries

After determining that the device would be powered using Lithium-Ion battery, extensive research was conducted on the current Lithium Ion batteries that are available on the market. Currently, 18650 Lithium-Ion batteries outperform all other alternatives because they offer comparatively higher gravimetric energy density. Therefore, datasheets of reputed manufacturers selling 18650 Lithium Ion batteries were examined and the results are summarized in Table C-1.

Table C-1: Comparison Between Several 18650 Lithium-Ion Batteries

Battery Type	Sony VTC4	Samsung 25R	Sony VTC5	Panasonic NCR18650B
Capacity [Ah]	2.1	2.5	2.6	3.25
Nominal Voltage [V]	3.6	3.6	3.6	3.6
Weight [g]	45.3	43.71	47.8	48.5
Specific Energy [Wh/g]	0.167	0.206	0.196	0.243
Energy per cell [Wh]	7.57	9.00	9.37	11.79
Volume Footprint [cm3]	21.1	21.1	21.1	21.1
Specific Cost [Wh/$]	2.52	3.16	2.2	2.215
Volumetric Density [Wh/cm3]	0.36	0.43	0.44	0.56

From Table C-1, it is evident that although Panasonic batteries lag behind Samsung and Sony in specific cost category, Panasonic noticeably outperforms other brands in specific energy and volumetric density categories. The cost would be offset because a higher number of Sony and Samsung cells would be required to deliver the same power as fewer Panasonic ones. Hence, we chose to build the battery pack out of Panasonic NCR18650B cells.

C-7 Motor Research

The order of magnitude of torque that is required to rotate the winch drum was determined in the order of 1Nm. Research was conducted into motors whose torque could be amplified to high values but at the same time, the rpm does not drop below 50 rpm.



Figure C-11: DC040B-6 Moto (Left) and PG71 Gearmotor with 10mm Round Output (Right) ("DC040B 40mm Brushed DC Motor", n.d.; "PG71 Gearmotor", n.d.)

Initially, DC040B-6 motor was used to determine the gear ratio required to move the trail breaker. For trail breaker, the required torque is 17.5Nm. With 2 motors, the required torque from each motor is 17.5Nm/2 = 8.75Nm. A gear reduction ratio of 150:1 would output the desired torque of 10.8Nm and speed of 22.6 rpm from each motor. For the equipment tow, the required torque was initially estimated to be 5.77Nm. A gear reduction ratio of 100:1 would have output the desired rated torque of 7.2Nm and rated speed of 33.9rpm.

Table C-2: Motor Specifications (PG71 Gearmotor vs. DC040B-6Motor)

	PG71 Gearmotor with 10mm round output		DC040B-6 Motor
Rated Voltage	12 V	Rated Voltage	48 V
Stall Torque	25 Nm	Rated Torque	0.072 Nm
No load free speed	75 rpm	Rated Speed	3390 rpm
Mass	0.907 kg	Rated Power	26 W
		Mass	0.44 kg

For this reason, Andy Mark's PG-71, 10mm Round Output motor is chosen. This motor has a built-in planetary gearbox which reduces the rpm output by the motor and provides high output torque. Furthermore, this motor has been tested extensively by Beau Galloway and the equations of output power, speed, and current curves were well defined as shown in the figure below. According to Galloway (2012), the "grease inside the gearbox of [motor] 1 is likely to have been warmed and distributed more advantageously."

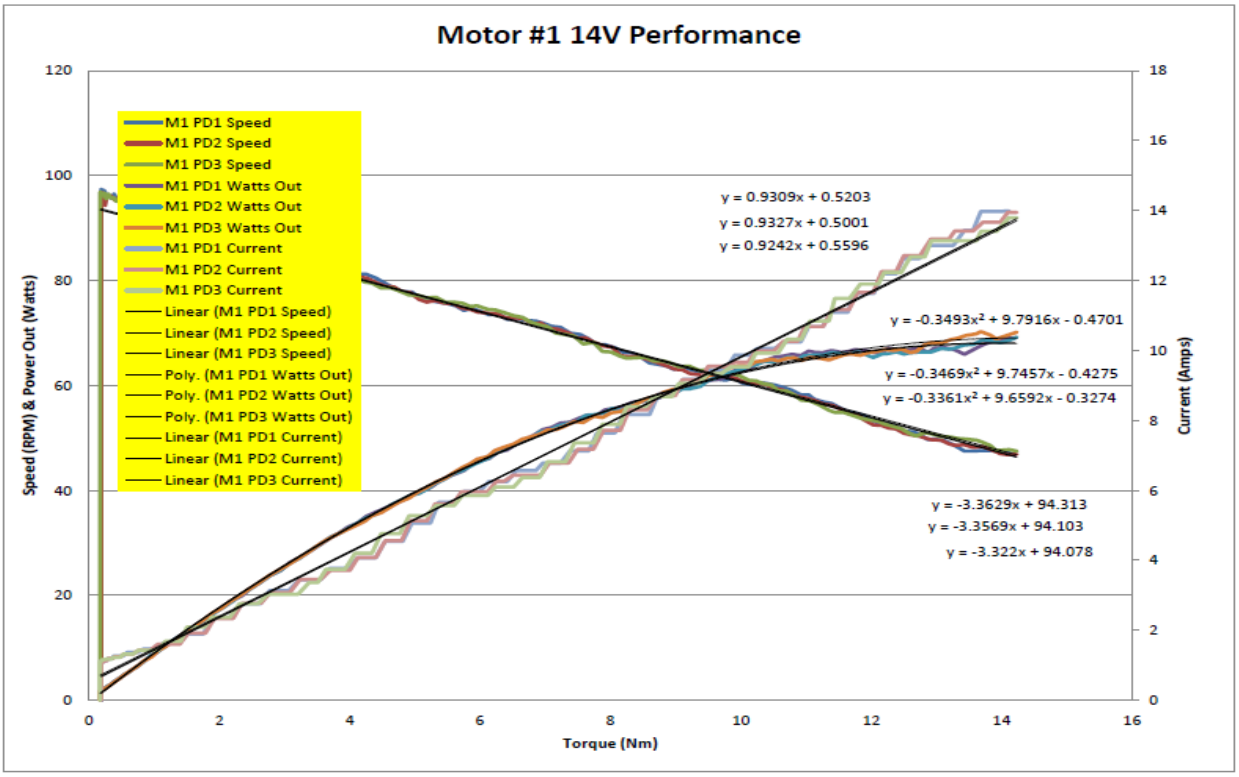


Figure C-12: Output power, speed and current curves defined by testing done by Beau Galloway (Galloway, 2012, p. 3)

C-8 Codes, Regulations, and Standards

Codes, regulations, and standards research was conducted after our requirements were finalized as the topic (of codes, regulations, and standards) was introduced to us during the detailed design phase. Therefore, our requirements were drawn from the client's proposal document. However, our requirements and research (of codes, regulations, and standards) overlap wherever safety is a concern because this research allowed us to quantify numbers for safety requirements.

Table C-3: Relevant Codes, Standards, and Regulations is a summary chart of codes, regulations, and standards research relevant to our design. References to the original codes, standards, and regulations can be found in Appendix P (p.329).

Table C-3: Relevant Codes, Standards, and Regulations

	Standard	Organization	Description
General	ASTM F3027-13	ASTM International	Standard guide for personnel training of those operating in mountainous terrain
	J1142-199402	SAE International	Towability design criteria for smaller vehicles
	49 CFR 178.603	U.S. Government Publishing Office	Standards for performing drop tests for electronic devices
Controls	1588-2008	IEEE	Standard for a precision clock synchronization protocol for networked measurements and control systems
	C37.90.2-2004	IEEE	Standards for withstand capability of relay systems to radiated electromagnetic interference from transceivers
	ISO 13849	ISO	Standards for the safety-related portions of control systems
Motor	C37.96-2012	IEEE	Guide for AC motor protection
	ISO 13373	ISO	Standards for monitoring and diagnosing electric motors
	J544-199608	SAE International	Standard procedure for testing the output performance and plotting the performance curve of electric starting motors, and a graphical method of determining engine cranking speed.
Gears	J1619-199701	SAE International	Standard for bending fatigue tests on gear teeth
	1006-A97	AGMA	Standards for tooth proportions for plastic gears
	18653-A06	AGMA	Standards for evaluating instruments which measure gears
Battery	AIR5561	SAE International	Standards for lithium battery powered portable electronic devices
	J1127-201512	SAE International	Standards for low voltage battery cables
	J3073-201605	SAE International	Standards for battery thermal management
Enclosure	ISO 812	ISO	Standards for determining rubber ductile to brittle temperature
	STP993	ASTM	Standards for mechanically relaxing residual stresses
	STP1150	ASTM	Standards for assessing fire hazards and fire risks
Rope	UIAA 107	UIAA	Standards for low stretch ropes (rock climbing)
	UIAA 101	UIAA	Standards for dynamic ropes (rock climbing)
	UIAA 102	UIAA	Standards for accessory chord (rock climbing)

APPENDIX D: NEEDS, REQUIREMENTS, AND EVALUATION CRITERIA

Project needs, requirements, and evaluation criteria have several applications throughout the design process, mainly in concept selection. The development of a final set of needs, requirements, and evaluation criteria is a rigorous and iterative process with multiple analyses.

D-1 Evolution of Project Needs, Requirements, and Evaluation Criteria

Project requirements were very fluid throughout this project; changes to the requirements resulted from changes in project scope, new background information provided by the client, and new findings in research. The iterative nature of the needs, requirements, and evaluation for this project is portrayed in the revision history below:

- D-1.1 Project Requirements_September 13, 2017 (Original Copy)
  - The original copy of project requirements was created prematurely; the requirements listed are more closely related to project needs rather than requirements.
- D-1.2 Needs, Requirements, and Evaluation Criteria_September 18, 2017
  - Upon realization that the original copy of project requirements had not been properly constructed, the attempt of a more rigorous process was conducted. First, a preliminary stakeholder's analysis was conducted identifying primary stakeholders. Needs were recorded two ways: needs as expressed and need statements (refer to D-3 on p.61 for details on needs). The need statements were also categorized according to Ullman's categories (Ostafichuk, P. et al, 2013, p.194). A requirements (or, on occasion, a set of requirements) were created from each need statement along with a metric and threshold. Metrics were generally specified by the client (either in the client Q/A or in the proposal document - refer to B-1 on p.19 and Appendix A on p.17, respectively). However, some required additional research. For example, the team researched that the typical cordless drill has a measured sound of approximately 78dB ("Noise Management: Electric Drills", 2014).
- D-1.3 Needs, Requirements, and Evaluation Criteria_September 25, 2017

- Preliminary analysis of evaluation criteria is added in the furthermost right column.

– D-1.4 Needs, Requirements, and Evaluation Criteria_September 29, 2017
  - A more thorough look at evaluation criteria is conducted (coloured as light purple) with metrics and thresholds (or more accurately, an indication of how a concept can be ranked more favourably) as the team begins early stages of concept selection. Some criteria also contains an absolute scale for ranking concepts (e.g., level of affordances). Additionally, a few requirements are added based on new findings.
– D-1.5 Needs, Requirements, and Evaluation Criteria_October 2, 2017
  - A more rigorous stakeholders analysis (refer to D-2 Stakeholder Analysis on page 56 for more details) was initiated resulting in a more extensive list of stakeholders (e.g., supply chain, engineers, safety regulation body, etc.). Furthermore, some need statements were reworded for clarity and additional evaluation criteria was added.
– D-1.6 Needs, Requirements, and Evaluation Criteria_October 10, 2017
  - In preparation for the Concept Selection Review (CSR), the rigorous stakeholder analysis initiated previously was completed (refer to D-2 Stakeholder Analysis on page 56 for more details) resulting in rankings of importance for needs (and thus, requirements and evaluation criteria). These rankings were later considered in the weightings of evaluation criteria importance within the Weighted Decision Matrix (WDM). Additionally, a few needs and requirements were labelled out of scope.
– D-1.7 Needs, Requirements, and Evaluation Criteria_October 17, 2017
  - Further requirements and evaluation criteria were found to be out of scope.
– D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy)
  - After the team received feedback from the CSR regarding the number of evaluation criteria in the WDM, the WDM was updated with a condensed number of criteria. The final revision of the needs, requirements, and evaluation criteria contains a new label (coloured as dark purple) for evaluation criteria that was used the WDM. Criteria left in the original label (light purple) is not necessarily out of scope, but instead is either encompassed in existing criteria or is considered relatively insignificant for the purposes of the WDM.

D-1.1 Project Requirements_September 13, 2017 (Original Copy)

Project Requirements

1. **Require less effort than hiking up a hill (cannot fully take the user up the hill without effort)**
2. **Small and light (must be portable and cannot net weigh more than 2 kg)**
3. **Not negatively affect the downhill skiing experience**
4. **Can be accommodated by different skis**
5. **Not require significant alterations of existing ski equipment**
6. **Must not be noisier than a typical cordless drill (~78 dB)**
    a. **https://www.commerce.wa.gov.au/publications/noise-management-electric-drills**
7. **Not increases risk of being caught in an avalanche**
8. **Capable of operating at an altitude of up to 3000m**
9. **Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry**
10. **Use rechargeable batteries if using batteries. Avoid using disposable batteries.**
11. **Withstand temperatures as low as -35 degC for durations of no less than 8 hours**
12. **Have a 5 year design life for non-replaceable components**
13. **Operate with a maximum of $20/day**
14. **Have cost of production of less than $500 CAD per unit in volumes of 1000 units**
15. **Be able to be sold in retail shops across North America**

D-1.2 Needs, Requirements, and Evaluation Criteria_September 18, 2017

Stakeholders	Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				Requirements
Name	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric	Evaluation Criteria
User	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Require less effort than hiking up a hill for people (weight 85-100kg include equipment) (cannot fully take the user up the hill without effort)	Reduced User effort of ascending	Yes/No	Specified in Proposal Document	
				Capable of climbing 15-20 deg slope	climbing 15-20 deg slope	Yes/No	Specified by Client	
User	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle		<= 2L	Specified by Client	
User	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not affect the downhill skiing experience		Yes/No	Specified in Proposal Document	
User	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Be accommodated by different skis		Yes/No	Specified in Proposal Document	
User	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable	Not require significant alterations of existing ski equipment	No More than Ski Binding Modification	Yes/No	Specified by Client	
User	Not increase the net additional weight of the equipment to be carried by the skier by more than 2kg.	Device increases the net weight less than or equal to 2kg	Ergonomic, Storage and Handling	Device is light	Ascend Net Increase	< 2 Kg	Specified in Proposal Document	
				If weight more during decend	Decend Net Increase	<4Kg	Specified by Client	
User, Other skiiers	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Be less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))	
User	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Not increases risk of being caught in an avalanche		Yes/No	Specified in Proposal Document	
Environment, Government, User	Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Use rechargeable batteries if using batteries. Avoid using disposable batteries.		Yes/No	Specified by Proposal Document	
				Not using Gasoline Engine		Yes/No	Specified by Client	
User	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Capable of operating at an altitude of up to 3000m	Astmosphere Pressure	0.69atm	Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)	
						69.7kpa		
						10.11psia		
User	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry				
User	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Withstand temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document	
				Fully Functional between comfortable BC skiing condition	Temperature C	>-15 degC ; <30 degC		
User	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Have a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document	
User	Have an operating cost of less than $20/day	Device has an operating cost of $20/day	Economic	Operate with a maximum of $20/day	Operational Cost	<=$20/day	Specified by Proposal Document	
Manufacturing	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Have cost of production of less than $500 CAD per unit in volumes of 1000 units	Production Cost	<=500 CAD/1000 units in volumes	Specified by Proposal Document	
						<=2000CAD	Specified by Client	
Retailer	Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Be able to be sold in retail shops across North America		Yes/No	Specified by Proposal Document	
User	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan	>= 65% of daylight hours	Specified by client	

D-1.3 Needs, Requirements, and Evaluation Criteria_September 25, 2017

Stakeholders	Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				Requirements
Name	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric	Evaluation Criteria
User	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Require less effort than hiking up a hill for people (weight 85-100kg include equipment) (cannot fully take the user up the hill without effort)	Reduced User effort of ascending	Yes/No	Specified in Proposal Document	Energy Savings
				Capable of climbing 15-20 deg slope	climbing 15-20 deg slope	Yes/No	Specified by Client	
User	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Volume	<= 2L	Specified by Client	Volume
User	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not affect the downhill skiing experience		Yes/No	Specified in Proposal Document	Weight, Downhill Resitance
User	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Be accommodated by different skis		Yes/No	Specified in Proposal Document	Compatability
User	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable	Not require significant alterations of existing ski equipment	No More than Ski Binding Modification	Yes/No	Specified by Client	Compatability
User	Not increase the net additional weight of the equipment to be carried by the skier by more than 2kg.	Device increases the net weight less than or equal to 2kg	Ergonomic, Storage and Handling	Device is light	Ascend Net Increase	< 2 Kg	Specified in Proposal Document	Weight
				If weight more during decend	Decend Net Increase	<4Kg	Specified by Client	
User, Other skiiers	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Be less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))	Noise
User	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Not increases risk of being caught in an avalanche		Yes/No	Specified in Proposal Document	Safety
Environment, Government, User	Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Use rechargeable batteries if using batteries. Avoid using disposable batteries.		Yes/No	Specified by Proposal Document	
				Not using Gasoline Engine		Yes/No	Specified by Client	
User	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Capable of operating at an altitude of up to 3000m	Astmosphere Pressure	0.69atm	Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)	Durability
						69.7kpa		
						10.11psia		
User	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry				Durability
User	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Withstand temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document	Durability
				Fully Functional between comfortable BC skiing condition	Temperature C	>-15 degC ; <30 degC		
User	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Have a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document	Durability
User	Have an operating cost of less than $20/day	Device has an operating cost of $20/day	Economic	Operate with a maximum of $20/day	Operational Cost	<=$20/day	Specified by Proposal Document	Cost
Manufacturing	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Have cost of production of less than $500 CAD per unit in volumes of 1000 units	Production Cost	<=500 CAD/1000 units in volumes	Specified by Proposal Document	Cost
						<=2000CAD	Specified by Client	
Retailer	Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Be able to be sold in retail shops across North America	Meeting North America Retail Standards	Yes/No	Specified by Proposal Document	
User	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan	>= 65% of daylight hours	Specified by client	Endurance

D-1.4 Needs, Requirements, and Evaluation Criteria_September 29, 2017

StakeHolder		Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				LEGEND:	Requirements
Name	Justification of Relevant Stakeholders	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric		Evaluation Criteria
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment)	Work exerted by user	Yes/No	Specified in Proposal Document		
					Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Specified in Proposal Document		
					User is capable of climbing a 15-20 deg slope	Climbing a 15-20 deg slope	Yes/No	Specified by Client		
					Energy Savings	Work exerted by user	Greater the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Litres	<= 2L	Specified by Client		
					Volume	Litres	The smaller the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not obstruct user's range of motion		Yes/No	Interpreted from the proposal document		
					Device does change downhill skiing stance		Yes/No	Interpreted from the proposal document		
					Device does not obstruct downhill skier visibility		Yes/No	Interpreted from the proposal document		
					Device does not increase net downhill run time		Yes/No	Interpreted from the proposal document		
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Compatibility	Levels of compatibility: 1. Fully compatible (no adjustment) 2. Non compatible with non-essential ski equipment (e.g., backpack) 3.Requires slight modification of existing, essential ski equipment 4. Not compatible with different body size 5. Not compatible with all different essential ski equipment				
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipement) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable	Device is light (if being carried by user uphill)	Ascend Net Increase	< 2 Kg	Specified in Proposal Document		
					Device is light (if being carried by user downhill)	Decend Net Increase	<4Kg	Specified by Client		
Consumer, Client, Supply Chain, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need	Not increase the net additional weight of the equipment to be carried by the skier by more than 2kg.	Device increases the net weight less than or equal to 2kg	Ergonomic, Storage and Handling	Weight	Mass	Smaller the better			
Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcounter Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Be less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))		
					Noise	dB	Smaller the better			
Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcounter Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't twant to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Not increases risk of being caught in an avalanche		Yes/No	Specified in Proposal Document		
					Decrease avalanche-related risks	Levels on decreasing avalanche-related risks: 1.				
Client, Consumer, Safety Regulation Body, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (want's the rechargeable device to be durable/strong enough to do its job) - Client: directly invested in consumer interests (wants a rechargeable battery that satifies customers' needs) - Safety Regulatory Body: rechargeable device must not put users in danger, therefore needing to be rescued - Product Regulatory Body: rechargeable device must not put users in danger due to product malfunctioning - Engineers: design the device which satisfies this need	Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Use rechargeable batteries if using batteries. Avoid using disposable batteries.		Yes/No	Specified by Proposal Document		
					No usage of a gasoline engine		Yes/No	Specified by Client		
Consumer,Client, Supply Chain, Engineers	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Capable of operating at an altitude of up to 3000m	Astmosphere Pressure	0.69atm, 69.7kpa, 10.11psia	Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)		
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry		Yes/No			
					Product Failure Durability Thresholds (Destructive Testing)	Some areas of concern: - Water penetration - Force Application - Temperature Changes/Extreme Temperatures - Altitude Changes/Extreme Altitudes				
Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Withstand temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document		
					Fully Functional between comfortable BC skiing condition	Temperature C	>-15 degC ; <30 degC	Specified by Client		
Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Have a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document		
					Product Lifetime (How long can the device function under normal use?)	Product Lifetime	The greater, the better			
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic	Operate with a maximum of $20/day	Operational Cost	<=$20/day	Specified by Proposal Document		
					Cost for user per day	Operational Cost	The smaller the better			
Client, Supply Chain, Engineers	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Have cost of production of less than $500 CAD per unit in volumes of 1000 units	Production Cost	<=500 CAD/1000 units in volumes	Specified by Proposal Document		
						Retail price	<=2000 CAD	Specified by Client		
					Reduce the cost to produce the device	Production Cost	The smaller the better			
Supply Chain, Client, Product Regulatory Bodies, Consumer, Engineers	- Supply Chain: directly affected since they will be the ones packaging, shipping, and directly selling the product to consumers - Client: relevant because they want to know if they can sell this product in mass production to make money - Product Regulatory Bodies: relevant because in order to allow this product into retailers, it must pass their standards - Consumer: product must be available for them to buy it via the Supply Chain - Engineers: design the device which satisfies this need	Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Device can be sold in retail shops across North America	Meeting North America Retail Standards	Yes/No	Specified by Proposal Document		
					Device can be sold internationally (International retail viability)	International Availability	More markets the better	Intuition		
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan	>= 65% of daylight hours	Specified by client		
					Device Endurance					
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	Is easy to use	Device has been designed wtih affordances	Functionality	Device has been designed wtih affordances	Level of affordances: 1. How to use the device can be learned within an hour of introduction 2. How to the use the device can be learned between 1 to 2 hours of introduction 3. How to use the device can be learned after a couple of runs				
Client, Supply Chain, Engineers	- Client: directly invested how many units can be shipped in each order (production costs) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need	Device is easy to handle and ship	Device is easily packageable (volume wise)	Ergonomic, Storage and Handling	Device pacakging uses an efficient amount of volume	Volume	Smaller the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality	Device negligibly impacts users' ability to conduct Rutschblock Test	Levels of Impact: 1. Device improves the Rutschblock Test 2. Device has no effect on the Rutschblock Test 3. Device negatively affects the Rutschblock Test				

D-1.5 Needs, Requirements, and Evaluation Criteria_October 2, 2017

StakeHolder			Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				LEGEND:	Requirements
Name	Justification of Relevant Stakeholders	Priorities of Needs [1]	Need as expressed	Need Statement	Type [2]	Description	Entity to be measured	Threshold	Justification of Metric		Evaluation Criteria
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment)	Work exerted by user	Yes/No	Specified in Proposal Document		
						Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Specified in Proposal Document		
						User is capable of climbing a 30-45 deg slope	Climbing a 30-45 deg slope	Yes/No	Specified by Client		
						User is capable of climbing a steep slope (i.e., conditions for sidestepping)	Degrees of Slope	The greater the better	Specified by Client		
						Energy Savings (reducing work exerted by user in ideal conditions)	Work exerted by user	The less the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Litres	<= 2L	Specified by Client		
						Volume	Litres	The smaller the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not obstruct user's range of motion		Yes/No	Interpreted from the proposal document		
						Device does change downhill skiing stance		Yes/No	Interpreted from the proposal document		
						Device does not obstruct downhill skier visibility		Yes/No	Interpreted from the proposal document		
						Device does not increase net downhill run time		Yes/No	Interpreted from the proposal document		
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need		Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Compatibility	Levels of compatibility: 1. Fully compatible (no adjustment) 2. Non compatible with non-essential ski equipment (e.g., backpack) 3.Requires slight modification of existing, essential ski equipment 4. Not compatible with different body size 5. Not compatible with all different essential ski equipment				
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipement) - Client: directly invested in consumer interests - Supply chain: directly invested in marketability - Engineers: design the device which satisfies this need		Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable						
Consumer, Client, Supply Chain, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need		Not increase the net additional weight of the equipment to be carried by the skier by more than 2kg.	Device increases the net weight less than or equal to 2kg	Ergonomic, Storage and Handling	Device is light (if being carried by user uphill)	Ascend Net Increase	< 2 Kg	Specified in Proposal Document		
						Device is light (if being carried by user downhill)	Decend Net Increase	<4Kg	Specified by Client		
						Weight	Mass	Smaller the better			
Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcounter Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need		Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Be less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))		
						Noise	dB	Smaller the better			
Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcounter Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't want to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need		Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Not increases risk of being caught in an avalanche		Yes/No	Specified in Proposal Document		
						Decrease risk of triggering an avalanche					
						Decrease risk of injury from a fall					
						Increase risk of surviving an avalanche					
Client, Consumer, Safety Regulation Body, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (want's the rechargeable device to be durable/strong enough to do its job) - Client: directly invested in consumer interests (wants a rechargeable battery that satifies customers' needs) - Safety Regulatory Body: rechargeable device must not put users in danger, therefore needing to be rescued - Product Regulatory Body: rechargeable device must not put users in danger due to product malfunctioning - Engineers: design the device which satisfies this need		Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Use rechargeable batteries if using batteries. Avoid using disposable batteries.		Yes/No	Specified by Proposal Document		
						No usage of a gasoline engine		Yes/No	Specified by Client		
Consumer,Client, Supply Chain, Engineers	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need		Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Capable of operating at an altitude of up to 3000m	Astmosphere Pressure	0.69atm, 69.7kpa, 10.11psia	Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)		
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need		Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry		Yes/No			
						Product Failure Durability Thresholds (Destructive Testing)	Some areas of concern: - Water penetration - Force Application - Temperature Changes/Extreme Temperatures - Altitude Changes/Extreme Altitudes				
Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need		Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Withstand temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document		
						Fully Functional between comfortable BC skiing condition	Temperature C	>-15 degC ; <30 degC	Specified by Client		
Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need		Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Have a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document		
						Product Lifetime (How long can the device function under normal use?)	Product Lifetime	The greater, the better			
Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need		Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic	Operate with a maximum of $20/day	Operational Cost	<=$20/day	Specified by Proposal Document		
						Cost for user per day	Operational Cost	The smaller the better			
Client, Supply Chain, Engineers	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need		Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Have cost of production of less than $500 CAD per unit in volumes of 1000 units	Production Cost	<=500 CAD/1000 units in volumes	Specified by Proposal Document		
							Retail price	<=2000CAD	Specified by Client		
						Reduce the cost to produce the device	Production Cost	The smaller the better			
Supply Chain, Client, Product Regulatory Bodies, Consumer, Engineers	- Supply Chain: directly affected since they will be the ones packaging, shipping, and directly selling the product to consumers - Client: relevant because they want to know if they can sell this product in mass production to make money - Product Regulatory Bodies: relevant because in order to allow this product into retailers, it must pass their standards - Consumer: product must be available for them to buy it via the Supply Chain - Engineers: design the device which satisfies this need		Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Device can be sold in retail shops across North America	Meeting North America Retail Standards	Yes/No	Specified by Proposal Document		
						Device can be sold internationally (International retail viability)	International Availablility	More markets the better	Intuition		
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan	>= 65% of daylight hours	Specified by client		
						Device Endurance	Daily lifespan	The more the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		Is easy to use	Device has been designed wtih affordances	Functionality	Device has been designed wtih affordances	Level of affordances: 1. How to use the device can be learned within an hour of introduction 2. How to the use the device can be learned between 1 to 2 hours of introduction 3. How to use the device can be learned after a couple of runs				
Client, Supply Chain, Engineers	- Client: directly invested how many units can be shipped in each order (production costs) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need		Device is easy to handle and ship	Device is easily packageable (volume wise)	Ergonomic, Storage and Handling	Device pacakging uses an efficient amount of volume	Volume	Smaller the better			
Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need		Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality	Device negligibly impacts users' ability to conduct Rutschblock Test	Levels of Impact: 1. Device improves the Rutschblock Test 2. Device has no effect on the Rutschblock Test 3. Device negatively affects the Rutschblock Test				

D-1.6 Needs, Requirements, and Evaluation Criteria_October 10, 2017

StakeHolders				Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				LEGEND:	Requirements	Need Out of Scope
Name	Justification of Relevant Stakeholders	Stakeholder Focus Level	Ranking	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric		Evaluation Criteria	
1. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment) compared to available products (e.g, skins)	Work exerted by user	Yes/No	Specified in Proposal Document			
							Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Specified in Proposal Document			
							User is capable of climbing a 30-45 deg slope with the device	Climbing a 30-45 deg slope	Yes/No	Specified by Client Q/A			
							User is capable of climbing a steep slope (i.e., conditions for sidestepping)	Degrees of Slope	The greater the better	Specified by Client Q/A			
							Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	Work exerted by user	The less the better	Interpreted from the proposal document			
							Device increases the number of metres of elevation traversed per day	Meters of Elevation/Day	The greater the better	Interpreted from the client Q/A User climbs at 1000m/day in average and 2000m/day in a long day			
2. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Litres	<= 2L	Specified by Client Q/A			
							Device usage results in a decreased influential volume (uphill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
							Device usage results in a decreased influential volume (downhill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
3. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not obstruct user's range of motion	N/A	Yes/No	Interpreted from the proposal document			
							Device does change downhill skiing stance	N/A	Yes/No	Interpreted from the proposal document			
							Device does not obstruct downhill skier visibility	N/A	Yes/No	Interpreted from the proposal document			
							Device does not increase net downhill run time	Total time (in seconds)	Yes/No	Interpreted from the proposal document			
4. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Device is compatible (See the pre-defined/agreed on levels of compatibility)	Levels of compatibility (from worst to best): 1. Not compatible with all different essential ski equipment 2. Not compatible with different body size 3.Requires slight modification of existing, essential ski equipment 4. Non compatible with non-essential ski equipment (e.g., backpack) 5. Fully compatible (no adjustment)		Interpreted from the proposal document			
5. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipement) - Client: directly invested in consumer interests - Supply chain: directly invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable							
6. Consumer, Client, Supply Chain, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need	12.25	1	Not increase the net additional weight of the equipment to be carried by the skier during ascent by more than 2kg.	Device increases the net weight less than or equal to 2kg during ascent	Ergonomic, Storage and Handling	Device net influential weight (uphill movement) is small	Ascend Net Increase	< 2 Kg	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Decend Net Increase	<4Kg	Specified by Client Q/A			
							Device net influential weight (uphill movement) is small	Mass	Smaller the better	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Mass	Smaller the better	Even though increased weight for descent would increase skiier downhill belocity, we assume that a large influential weight for descent is undesirable because of the existance of a maximum threshold for the net weight for skier descent.			
7. Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcounter Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need	8.7	7	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Devie is less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	Specified in Proposal Document 78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))			
							Device is quiet	dB	Smaller the better	Specified in Proposal Document			
8. Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcounter Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't want to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need	11.6	3	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Device does not increase the risk of being caught in an avalanche	N/A	Yes/No	Specified in Proposal Document			
							Device decreases the risk of triggering an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., increasing concentrated loads AND increasing increasing the frequency of concentrated loads) 2. Minimally increases risk (e.g., increasing concentrated loads OR increasing increasing the frequency of concentrated loads) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device decreases the risk of injury from a fall (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., sharp items on body) 2. Minimally increases risk (e.g., increase weight) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device increases the risk of surviving an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk 2. Minimally increases risk 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
9. Client, Consumer, Safety Regulation Body, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (want's the rechargeable device to be durable/strong enough to do its job) - Client: directly invested in consumer interests (wants a rechargeable battery that satifies customers' needs) - Safety Regulatory Body: rechargeable device must not put users in danger, therefore needing to be rescued - Product Regulatory Body: rechargeable device must not put users in danger due to product malfunctioning - Engineers: design the device which satisfies this need			Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Device uses rechargeable batteries if using batteries. Avoid using disposable batteries.	N/A	Yes/No	Specified by Proposal Document			
							Device does not use a gasoline engine	N/A	Yes/No	Specified by Client Q/A			
10. Consumer,Client, Supply Chain, Engineers	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Device is capable of operating at an altitude of up to 3000m	Maximum Operationg Atmosphere Pressure	0.69atm, 69.7kpa, 10.11psia	Specified by Proposal Document Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)			
11. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Deviec functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry	N/A	Yes/No	Specified by Proposal Document			
							Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	Resiliency Categories: - Water penetration - Force Application - Temperature Changes/Extreme Temperatures - Altitude Changes/Extreme Altitude	The more the better	Interpreted from the proposal document			
12. Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need	10.05	4	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Device withstands temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document			
							Device is fully functional in typical BC skiing conditions	Temperature C	>-15 degC ; <30 degC	Specified by Client Q/A			
13. Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need	8.85	6	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Device has a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document			
							Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?)	Product Lifetime in Years	The greater, the better	Interpreted from Proposal Document			
14. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	7.85	10	Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic	Device operates with a maximum of $20/day (variable cost)	Operational Cost ($$) /Day	<=$20/day	Specified by Proposal Document			
							Device has a low daily operations cost (variable cost)	Operational Cost ($$) /Day	The smaller the better	Interpreted from Proposal Document			
15. Client, Supply Chain, Engineers	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need	6.1	11	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Deivce has a production cost of less than $500 CAD per unit in volumes of 1000 units	Production Cost ($$)	<=500 CAD/1000 units in volumes	Specified by Proposal Document			
								Retail price ($$)	<=2000CAD	Specified by Client Q/A			
							Device has a low production cost	Production Cost ($$)	The smaller the better	Interpreted from Proposal Document			
16. Supply Chain, Client, Product Regulatory Bodies, Consumer, Engineers	- Supply Chain: directly affected since they will be the ones packaging, shipping, and directly selling the product to consumers - Client: relevant because they want to know if they can sell this product in mass production to make money - Product Regulatory Bodies: relevant because in order to allow this product into retailers, it must pass their standards - Consumer: product must be available for them to buy it via the Supply Chain - Engineers: design the device which satisfies this need			Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Device can be sold in retail shops across North America	North American Availability (Meeting North America Retail Standards)	Yes/No	Specified by Proposal Document			
							Device can be sold internationally (i.e, international retail viability)	International Availablility (Meeting International Market Standards)	More markets the better	Interpreted from Proposal Document			
							Device can be packed and shipped through aboard	International Availablility (Meeting International Market Standards)	Yes/No	Specified by Client Q/A			
17. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan (Hours)	>= 65% of daylight hours	Specified by Client Q/A			
							Device may be operated uninterrupted for long periods of time (i.e., device endurance)	Daily lifespan (Hours)	The more the better	Interpreted from Client Q/A			
18. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	9.4	5	Is easy to use	Device has been designed wtih affordances	Functionality	Device has been designed wtih affordances (See the pre-defined/agreed on affordances)	Level of affordances: 1. How to use the device can be learned within an hour of introduction 2. How to the use the device can be learned between 1 to 2 hours of introduction 3. How to use the device can be learned after a couple of runs		Interpreted from Mechanical Design ProcessTextbook (MECH2 Textbook)			
19. Client, Supply Chain, Engineers	- Client: directly invested how many units can be shipped in each order (production costs) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need	6.1	11	Device is easy to handle and ship	Device is easily packageable (volume wise)	Ergonomic, Storage and Handling	Device pacakging uses an efficient amount of volume	Litres	Smaller the better	Interpreted from Stakeholder Analysis			
20. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality	Device negligibly impacts users' ability to conduct Rutschblock Test (See the pre-defined/agreed on levels of impact)	Levels of Impact: 1. Device improves the Rutschblock Test 2. Device has no effect on the Rutschblock Test 3. Device negatively affects the Rutschblock Test		Interpreted from class discussion on backcountry skiing			

D-1.7 Needs, Requirements, and Evaluation Criteria_October 17, 2017

StakeHolders				Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				LEGEND:	Requirements	Need Out of Scope
Name	Justification of Relevant Stakeholders	Stakeholder Focus Level	Ranking	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric		Evaluation Criteria	
1. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment) compared to available products (e.g, skins)	Work exerted by user	Yes/No	Specified in Proposal Document			
							Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Specified in Proposal Document			
							User is capable of climbing a 30-45 deg slope with the device	Climbing a 30-45 deg slope	Yes/No	Specified by Client Q/A			
							User is capable of climbing a steep slope, which is 30-40 Deg slope (i.e., conditions for sidestepping)	Degrees of Slope	The greater the better	Specified by Client Q/A			
							Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	Work exerted by user	The less the better	Interpreted from the proposal document			
							Device increases the number of metres of elevation traversed per day	Meters of Elevation/Day	The greater the better	Interpreted from the client Q/A User climbs at 1000m/day in average and 2000m/day in a long day			
2. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Litres	<= 2L	Specified by Client Q/A			
							Device usage results in a decreased influential volume (uphill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
							Device usage results in a decreased influential volume (downhill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
3. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not obstruct user's range of motion	N/A	Yes/No	Interpreted from the proposal document			
							Device does change downhill skiing stance	N/A	Yes/No	Interpreted from the proposal document			
							Device does not obstruct downhill skier visibility	N/A	Yes/No	Interpreted from the proposal document			
							Device minimizes time spent for adjustment	Total time (in seconds)	The smller the better	Interpreted from the proposal document			
4. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Device is compatible (See the pre-defined/agreed on levels of compatibility)	Levels of compatibility (from worst to best): 1. Not compatible with all different essential ski equipment 2. Not compatible with different body size 3.Requires slight modification of existing, essential ski equipment 4. Non compatible with non-essential ski equipment (e.g., backpack) 5. Fully compatible (no adjustment, substitution with no loss of functionality compared to the idea it replaces, or totally new addition to existing gear)		Interpreted from the proposal document			
5. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipement) - Client: directly invested in consumer interests - Supply chain: directly invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable							
6. Consumer, Client, Supply Chain, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need	12.25	1	Not increase the net additional weight of the equipment to be carried by the skier during ascent by more than 2kg.	Device increases the net weight less than or equal to 2kg during ascent	Ergonomic, Storage and Handling	Device net influential weight (uphill movement) is small	Ascend Net Increase	< 2 Kg	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Decend Net Increase	<4Kg	Specified by Client Q/A			
							Device net influential weight (uphill movement) is small	Mass	Smaller the better	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Mass	Smaller the better	Even though increased weight for descent would increase skiier downhill belocity, we assume that a large influential weight for descent is undesirable because of the existance of a maximum threshold for the net weight for skier descent.			
7. Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcounter Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need	8.7	7	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Devie is less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	Specified in Proposal Document 78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https: //www.commerce.wa.gov.au/publications/noise-management-electric-drills))			
							Device is quiet	dB	Smaller the better	Specified in Proposal Document			
8. Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcounter Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't want to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need	11.6	3	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Device does not increase the risk of being caught in an avalanche	N/A	Yes/No	Specified in Proposal Document			
							Device decreases the risk of triggering an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., increasing concentrated loads AND increasing increasing the frequency of concentrated loads) 2. Minimally increases risk (e.g., increasing concentrated loads OR increasing increasing the frequency of concentrated loads) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device decreases the risk of injury from a fall (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., sharp items on body) 2. Minimally increases risk (e.g., increase weight) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device increases the risk of surviving an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk 2. Minimally increases risk 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
9. Client, Consumer, Safety Regulation Body, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (want's the rechargeable device to be durable/strong enough to do its job) - Client: directly invested in consumer interests (wants a rechargeable battery that satifies customers' needs) - Safety Regulatory Body: rechargeable device must not put users in danger, therefore needing to be rescued - Product Regulatory Body: rechargeable device must not put users in danger due to product malfunctioning - Engineers: design the device which satisfies this need			Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Device uses rechargeable batteries if using batteries. Avoid using disposable batteries.	N/A	Yes/No	Specified by Proposal Document			
							Device does not use a gasoline engine	N/A	Yes/No	Specified by Client Q/A			
10. Consumer,Client, Supply Chain, Engineers	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Device is capable of operating at an altitude of up to 3000m	Maximum Operationg Atmosphere Pressure	0.69atm, 69.7kpa, 10.11psia	Specified by Proposal Document Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)			
11. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Devieo functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry	N/A	Yes/No	Specified by Proposal Document			
							Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	Resiliency Categories: - Water penetration - Force Application - Temperature Changes/Extreme Temperatures - Altitude Changes/Extreme Altitude	The more the better	Interpreted from the proposal document			
12. Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need	10.05	4	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Device withstands temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document			
							Device is fully functional in typical BC skiing conditions	Temperature C	>-15 degC ; <30 degC	Specified by Client Q/A			
13. Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need	8.85	6	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Device has a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document			
							Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?)	Product Lifetime in Years	The greater, the better	Interpreted from Proposal Document			
14. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	7.85	10	Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic	Device operates with a maximum of $20/day (variable cost)	Operational Cost ($$) /Day	<=$20/day	Specified by Proposal Document			
							Device has a low daily operations cost (variable cost)	Operational Cost ($$) /Day	The smaller the better	Interpreted from Proposal Document			
15. Client, Supply Chain, Engineers	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need	6.1	11	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Deivce has a production cost of less than $500 CAD per unit in volumes of 1000 units	Production Cost ($$)	<=500 CAD/1000 units in volumes	Specified by Proposal Document			
								Retail price ($$)	<=2000CAD	Specified by Client Q/A			
							Device has a low production cost	Production Cost ($$)	The smaller the better	Interpreted from Proposal Document			
16. Supply Chain, Client, Product Regulatory Bodies, Consumer, Engineers	- Supply Chain: directly affected since they will be the ones packaging, shipping, and directly selling the product to consumers - Client: relevant because they want to know if they can sell this product in mass production to make money - Product Regulatory Bodies: relevant because in order to allow this product into retailers, it must pass their standards - Consumer: product must be available for them to buy it via the Supply Chain - Engineers: design the device which satisfies this need			Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Device can be sold in retail shops across North America	North American Availability (Meeting North America Retail Standards)	Yes/No	Specified by Proposal Document			
							Device can be sold internationally (i.e, international retail viability)	International Availablility (Meeting International Market Standards)	More markets the better	Interpreted from Proposal Document			
							Device can be packed and shipped through aboard	International Availablility (Meeting International Market Standards)	Yes/No	Specified by Client Q/A			
17. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan (Hours)	>= 65% of daylight hours	Specified by Client Q/A			
							Device may be operated uninterrupted for long periods of time (i.e., device endurance)	Daily lifespan (Hours)	The more the better	Interpreted from Client Q/A			
18. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	9.4	5	Is easy to use	Device has been designed wtih affordances	Functionality	Device has been designed wtih affordances (See the pre-defined/agreed on affordances)	Level of affordances: 1. How to use the device can be learned within an hour of introduction 2. How to the use the device can be learned between 1 to 2 hours of introduction 3. How to use the device can be learned after a couple of runs		Interpreted from Mechanical Design ProcessTextbook (MECH2 Textbook)			
19. Client, Supply Chain, Engineers	- Client: directly invested how many units can be shipped in each order (production oosts) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need	6.1	11	Device is easy to handle and ship	Device is easily packageable (volume wise)	Ergonomic, Storage and Handling	Device pacakging uses an efficient amount of volume	Litres	Smaller the better	Interpreted from Stakeholder Analysis			
20. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality	Device negligibly impacts users' ability to conduct Rutschblock Test (See the pre-defined/agreed on levels of impact)			Interpreted from class discussion on backcountry skiing			

D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy)

StakeHolders				Needs			Requirements (Must Haves) and Evaluation Criteria (Nice to Have)				LEGEND:	Requirements	Need Out of Scope
Name	Justification of Relevant Stakeholders	Stakeholder Focus Level	Ranking	Need as expressed	Need Statement	Type [1]	Description	Entity to be measured	Threshold	Justification of Metric		Evaluation Criteria	Evaluation Criteria in WDM
1. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional	Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment) compared to available products (e.g, skins)	Work exerted by user	Yes/No	Specified in Proposal Document			
							Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Specified in Proposal Document			
							User is capable of climbing a 30-45 deg slope with the device	Climbing a 30-45 deg slope	Yes/No	Specified by Client Q/A			
							User is capable of climbing a steep slope, which is 30-40 Deg slope (i.e., conditions for sidestepping)	Degrees of Slope	The greater the better	Specified by Client Q/A			
							Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	Work exerted by user	The less the better	Interpreted from the proposal document			
							Device increases the number of metres of elevation traversed per day	Meters of Elevation/Day	The greater the better	Interpreted from the client Q/A User climbs at 1000m/day in average and 2000m/day in a long day			
2. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling	Same size as 2 1L Nalgene Bottle	Litres	<= 2L	Specified by Client Q/A			
							Device usage results in a decreased influential volume (uphill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
							Device usage results in a decreased influential volume (downhill movement)	Litres	The smaller the better	Specified by Client Q/A If the device attaches to the client's body, it should not "stick out" more than 0.5m from the user.			
3. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output	Device does not obstruct user's range of motion	N/A	Yes/No	Interpreted from the proposal document			
							Device does change downhill skiing stance	N/A	Yes/No	Interpreted from the proposal document			
							Device does not obstruct downhill skier visibility	N/A	Yes/No	Interpreted from the proposal document			
							Device minimizes time spent for adjustment	Total time (in seconds)	The smller the better	Interpreted from the proposal document			
4. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Be adaptable to a wide range of skis, so that customers aren't bound to buy a spcific ski to use the system/device.	Device accomodates a wide range of skis	Modularity, accessibility	Device is compatible (See the pre-defined/agreed on levels of compatibility)	Levels of compatibility (from worst to best): 1. Not compatible with all different essential ski equipment 2. Not compatible with different body size 3.Requires slight modification of existing, essential ski equipment 4. Non compatible with non-essential ski equipment (e.g., backpack) 5. Fully compatible (no adjustment, substitution with no loss of functionality compared to the idea it replaces, or totally new addition to existing gear)		Interpreted from the proposal document			
5. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipement) - Client: directly invested in consumer interests - Supply chain: directly invested in marketability - Engineers: design the device which satisfies this need	8.25	8	Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable							
6. Consumer, Client, Supply Chain, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need	12.25	1	Not increase the net additional weight of the equipment to be carried by the skier during ascent by more than 2kg.	Device increases the net weight less than or equal to 2kg during ascent	Ergonomic, Storage and Handling	Device net influential weight (uphill movement) is small	Ascend Net Increase	< 2 Kg	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Decend Net Increase	<4Kg	Specified by Client Q/A			
							Device net influential weight (uphill movement) is small	Mass	Smaller the better	Specified in Proposal Document			
							Device net influential weight (downhill movement) is small	Mass	Smaller the better	Even though increased weight for descent would increase skiier downhill belocity, we assume that a large influential weight for descent is undesirable because of the existance of a maximum threshold for the net weight for skier descent.			
7. Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcounter Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need	8.7	7	Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable	Devie is less noisier than a typical cordless drill	Noise Level - dB	<=78 dB	Specified in Proposal Document 78dB is a typical cordless drill noise, published by Deparrtment of Mines, Industrial Regulartion and Safety / Goverment of Western Australia ((https://www.commerce.wa.gov.au/publications/noise-management-electric-drills))			
							Device is quiet	dB	Smaller the better	Specified in Proposal Document			
8. Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcounter Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't want to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need	11.6	3	Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety	Device does not increase the risk of being caught in an avalanche	N/A	Yes/No	Specified in Proposal Document			
							Device decreases the risk of triggering an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., increasing concentrated loads AND increasing increasing the frequency of concentrated loads) 2. Minimally increases risk (e.g., increasing concentrated loads OR increasing increasing the frequency of concentrated loads) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device decreases the risk of injury from a fall (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk (e.g., sharp items on body) 2. Minimally increases risk (e.g., increase weight) 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
							Device increases the risk of surviving an avalanche (See the pre-defined/agreed on levels of risk)	Levels of Risk (from worst to best): 1. Significantly increases risk 2. Minimally increases risk 3. Has no effect of risk 4. Minimally reduces risk 5. Significantly reduces risk		Interpreted from the proposal document			
9. Client, Consumer, Safety Regulation Body, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (want's the rechargeable device to be durable/strong enough to do its job) - Client: directly invested in consumer interests (wants a rechargeable battery that satifies customers' needs) - Safety Regulatory Body: rechargeable device must not put users in danger, therefore needing to be rescued - Product Regulatory Body: rechargeable device must not put users in danger due to product malfunctioning - Engineers: design the device which satisfies this need			Avoid using disposable batteries	Device uses reusable batteries if needed	Undesirable	Device uses rechargeable batteries if using batteries. Avoid using disposable batteries.	N/A	Yes/No	Specified by Proposal Document			
							Device does not use a gasoline engine	N/A	Yes/No	Specified by Client Q/A			
10. Consumer,Client, Supply Chain, Engineers	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality	Device is capable of operating at an altitude of up to 3000m	Maximum Operationg Atmosphere Pressure	0.69atm, 69.7kpa, 10.11psia	Specified by Proposal Document Approximate pressure value based on 3000m above sea level (https://www.mide.com/pages/air-pressure-at-altitude-calculator)			
11. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	8.05	9	Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality	Deviec functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry	N/A	Yes/No	Specified by Proposal Document			
							Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	Resiliency Categories: - Water penetration - Force Application - Temperature Changes/Extreme Temperatures - Altitude Changes/Extreme Altitude	The more the better	Interpreted from the proposal document			
12. Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need	10.05	4	Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperautes as low as -35 deg C for up to 8 hours	Durability, Functionality	Device withstands temperatures as low as -35 degC for durations of no less than 8 hours	at -35degC ; >=8 hours	Yes/No	Specified by Proposal Document			
							Device is fully functional in typical BC skiing conditions	Temperature C	>-15 degC ; <30 degC	Specified by Client Q/A			
13. Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need	8.85	6	Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability	Device has a 5 year design life for non-replaceable components	Non-replacable component life span	>=5 year	Specified by Proposal Document			
							Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?)	Product Lifetime in Years	The greater, the better	Interpreted from Proposal Document			
14. Consumer, Client, Supply Chain, Engineers	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need	7.85	10	Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic	Device operates with a maximum of $20/day (variable cost)	Operational Cost ($$) /Day	<=$20/day	Specified by Proposal Document			
							Device has a low daily operations cost (variable cost)	Operational Cost ($$) /Day	The smaller the better	Interpreted from Proposal Document			
15. Client, Supply Chain, Engineers	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need	6.1	11	Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic	Deivce has a production cost of less than $500 CAD per unit in volumes of 1000 units	Production Cost ($$)	<=500 CAD/1000 units in volumes	Specified by Proposal Document			
								Retail price ($$)	<=2000CAD	Specified by Client Q/A			
							Device has a low production cost	Production Cost ($$)	The smaller the better	Interpreted from Proposal Document			
							Device is easy to design (Risk of Development)	Complexity	Level of risk (based on personal experience of the team)	Personal experience dictates that risk of development should be an important evaluation criteria (espeically since time spent on the device by the engineers translates into billable hours)			
16. Supply Chain, Client, Product Regulatory Bodies, Consumer, Engineers	- Supply Chain: directly affected since they will be the ones packaging, shipping, and directly selling the product to consumers - Client: relevant because they want to know if they can sell this product in mass production to make money - Product Regulatory Bodies: relevant because in order to allow this product into retailers, it must pass their standards - Consumer: product must be available for them to buy it via the Supply Chain - Engineers: design the device which satisfies this need			Be able to be sold in retail shops across North America and possibly abroad.	Device is sellable across North America and internationally	Regulatory	Device can be sold in retail shops across North America	North American Availability (Meeting North America Retail Standards)	Yes/No	Specified by Proposal Document			
							Device can be sold internationally (i.e, international retail viability)	International Availablility (Meeting International Market Standards)	More markets the better	Interpreted from Proposal Document			
							Device can be packed and shipped through aboard	International Availablility (Meeting International Market Standards)	Yes/No	Specified by Client Q/A			
17. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality	Is usable 65% of the daylight hours as a bare minimum	Daily lifespan (Hours)	>= 65% of daylight hours	Specified by Client Q/A			
							Device may be operated uninterrupted for long periods of time (i.e., device endurance)	Daily lifespan (Hours)	The more the better	Interpreted from Client Q/A			
18. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	9.4	5	Is easy to use	Device has been designed wtih affordances	Functionality	Device has been designed wtih affordances (See the pre-defined/agreed on affordances)	Level of affordances: 1. How to use the device can be learned within an hour of introduction 2. How to the use the device can be learned between 1 to 2 hours of introduction 3. How to use the device can be learned after a couple of runs		Interpreted from Mechanical Design ProcessTextbook (MECH2 Textbook)			
19. Client, Supply Chain, Engineers	- Client: directly invested how many units can be shipped in each order (production costs) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need	6.1	11	Device is easy to handle and ship	Device is easily packageable (volume wise)	Ergonomic, Storage and Handling	Device pacakging uses an efficient amount of volume	Litres	Smaller the better	Interpreted from Stakeholder Analysis			
20. Consumer, Client, Engineers	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need	12	2	Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality	Device negligibly impacts users' ability to conduct Rutschblock Test (See the pre-defined/agreed on levels of impact)			Interpreted from class discussion on backcountry skiing			

D-2 Stakeholder Analysis

Stakeholder analyses are crucial for a detailed and accurate set of needs, requirements, and evaluation criteria.

D-2.1 Identification of Stakeholders

The first step taken in the stakeholder analysis was the identification of stakeholders; the following stakeholders were identified:

- Consumer (e.g., backcountry skiers, ski guides, gear hounds, performance skiers)
- Backcountry Users (e.g., indigenous people, recreational/professional users, backcountry inhabitants, wildlife)
- Safety Regulatory Bodies (e.g., the Association of Canadian Mountain Guides, SaR)
- Client (FreeBoots Enterprises)
- Product Regulatory Bodies (e.g., Consumer Product Safety Commission, Health Canada, Canada Consumer Product Safety Act)
- Environmental Regulatory Bodies (e.g., Parks Canada, National Recreation and Parks Association)
- Supply Chain (e.g., manufacturers, distributors, wholesalers, retailers)
- Engineers/Designers

The following stakeholders eventually were assigned importance weightings (refer to Table D-2: Summary of Preliminary Need Priority Levels Parameters, p.59) resulting a set of primary and a set of secondary stakeholders.

D-2.2 Stakeholders' Relevant Needs

To ensure clear connections between requirements, evaluation criteria, and needs and their respective origins, a document titled "D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy)" on p.55 exists to showcase the entire development process of project requirements and evaluation criteria. Within the document, there are also justifications of why certain needs are relevant for certain stakeholders; a summary of this information can be shown in Table D-1: Relevant Stakeholders for Needs on p.57.

Table D-1: Relevant Stakeholders for Needs

Stakeholders	Need Statement	Justifications for Relevant Stakeholders
Consumer, Client, Supply Chain, Engineers	Device increases the net weight less than or equal to 2kg during ascent	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Supply Chain: will need to ship the product (cost-savings with a lighter device) - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device increases the number of runs the user can accomplish per day	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device is usable a minimum of 65% of the daylight hours per day	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device increases user energy efficiency	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device fits a standard-size backcountry skiing backpack.	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device negligibly affects the downhill skiing experience	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need
Consumer, Client, Backcountry Users, Safety Regulatory Bodies, Environment Regulatory Bodies, Engineers	Device negligibly impacts risk of being caught in an avalanche	- Consumer: relevant as the primary users (doesn't want to increase risk of being in an avalanche) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to create avalanches, thereby disrupting local ecosystems - Backcountry Users: doesn't want someone else's use of the product to increase their risk of being in an avalanche - Safety Regulatory Bodies: doesn't want to have to rescue more people in avalanches due to the product putting them in danger - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Safety Regulatory Bodies, Engineers	Device withstands temperatures as low as -35 ^{o}C for up to 8 hours	- Consumer: relevant as the primary users (wants to know that product will work in harsh conditions) - Client: directly invested in consumer interests (asked for the product to withstand harsh conditions) - Safety Regulatory Bodies: need all components of the product to be safe at these conditions - Supply Chain: want to advertise that product is function in harsh conditions - Engineers: design the device which satisfies this need
Consumer, Client, Engineers	Device has been designed with affordances	- Consumer: relevant as the primary users - Client: directly invested in consumer interests - Engineers: design the device which satisfies this need

Consumer, Client, Supply Chain, Product Regulatory Bodies, Engineers	Device possesses a minimum design life of 5 years for non-replaceable components	- Consumer: relevant as the primary users (they want a durable product therefore they want it to last longer) - Client: directly invested in consumer interests - Supply Chain: retailers want to be able to advertise durability to consumer - Product Regulatory Bodies: invested in the life cycle of a device (sustainability) - Engineers: design the device which satisfies this need
Consumers, Backcountry Users, Environment Regulatory Bodies, Engineers	Device is quieter than a typical cordless drill	- Consumer: relevant as the primary users (doesn't want device to be loud and take away from the backcountry experience) - Client: directly invested in consumer interests - Environment Regulatory Bodies: doesn't want the device to negatively affect the backcountry environment with loud noises - Backcountry Users: don't want their backcountry experience negatively impacted by loud noise - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Engineers	Device accommodates a wide range of skis	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Engineers	Device requires negligible alteration of existing ski equipment	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: directly invested in marketability - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Engineers	Device operates at an altitude of up to 3000m	- Consumers: relevant as the primary users - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Engineers	Device functions in all ski weather conditions	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need
Consumer, Client, Supply Chain, Engineers	Device has an operating cost of less than $20/day	- Consumers: relevant as the primary users (want to be able to use with current ski equipment) - Client: directly invested in consumer interests - Supply chain: invested in marketability - Engineers: design the device which satisfies this need
Client, Supply Chain, Engineers	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	- Client: invested in profit margins (which are affected by production costs) - Supply chain: directly invested in how many units produced - Engineers: design the device which satisfies this need
Client, Supply Chain, Engineers	Device is easily package-able (volume wise)	- Client: directly invested how many units can be shipped in each order (production costs) - Supply Chain: will need to ship the product (cost-savings with a more compact device) - Engineers: design the device which satisfies this need

Additionally, these needs were ranked from highest to lowest importance. Generally, for each need, a preliminary priority level (which, eventually, acts as a starting block for evaluation criteria weightings in the WDM) is determined using the following equation:

$$\begin{matrix} Preliminary\ Need \\ Priority\ Levels \end{matrix} = \sum_{Stakeholders} \left[\begin{matrix} Stakeholder \\ Importance \end{matrix} \cdot \begin{matrix} Stakeholders' Area \\ of\ Concern\ Weighting \end{matrix} \right]$$

Values for both stakeholder priority and stakeholders' area of concern weighting parameters are summarized in the table below. While justifications are provided for stakeholder priority values, stakeholders' area of concern weightings were determined from the team's personal experience.

Table D-2: Summary of Preliminary Need Priority Levels Parameters

Stakeholder	Areas of Concern	Stakeholder Importance	Justification
Consumer	20% - Value (Low price, Long expected life, Premium construction, Compatibility) 15% - Safety (Avalanche Risk, Not increase risk of danger if device fails) 15% - Reliability (Long lifespan, Device can be used in all weather conditions) 50% - Use of device (Weight, Volume/size, Energy savings, Intuitiveness, No negative effects on downhill experience, Ease of assembly)	4	The needs of consumers define the primary function of the device.
Backcountry Users	50% - Not increase risk of danger 50% - Not affect their backcountry experience (Does not negatively impact environment, Noise)	1	The needs of backcountry users strongly overlap with those of consumers

Safety Regulatory Bodies	100% - Abides by all acts and laws (Easy to contain risk, Redundancy for safety, Not increase risk of dangerous event for first responders)	2	Most needs are entirely expressed as requirements
Client	50% - Satisfies consumer needs (see above) 10% - Marketability 30% - Cost Margin 10% - Easy to support (technical support)	7	The source of funding for the design
Product Regulatory Bodies	100% - Abides by all acts and laws	1	Needs are entirely expressed as requirements, no evaluation criteria
Environment Regulatory Bodies	100% - Abides by all acts and laws	1	Needs are entirely expressed as requirements, no evaluation criteria
Supply Chain	25% - Easy to handle (Shipping, Storage) 25% - Marketability 50% - Easy to manufacture (Less manufacturing time, Common material, Small tooling costs)	1	The needs of the supply chain should reflect a subset of the needs of the designers
Engineers /Designers	65% - Satisfies the needs of all other stakeholders (see above) 35% - Ensures that the product is delivered in time within the allocated budget	10	Needs of the designer and engineer include reflected from the client and needs the client did not identify.

D-3 Target Specifications

Target specifications (also known as needs) can either be expressed directly by the client or developed from a stakeholder's analysis. In this project, need statements were mainly developed from needs expressed by the client; nevertheless, a stakeholder analysis was conducted. As shown in D-1 Evolution of Project Needs, Requirements, and Evaluation Criteria (p.46), the development of needs was iterative and some needs were found through this process. For example, the stakeholder analysis yielded need statements such as "device has been design with affordances" and "Device is easily package-able (volume-wise)".

The complete list of needs can be found in Table D-3: Final Revision of Needs (p.62) in order of descending importance. Throughout the project, these needs required frequent clarification through further internal and external investigation. For example, in an interview with an experienced backcountry skier (refer to C-1 on p.23 for more details), it was illuminated that the need statement "device increases the net weight less than or equal to 2kg during ascent" was especially critical because of weight's effect on a skier's center of gravity. Thus, the need is highly-ranked in terms of importance. Another example can be found in the Client Q/A (refer to B-1, p. 19) where it was clarified that the need statement that the "device withstands temperatures as low as -35 ^{o}C for up to 8 hours" did not require the device to be functional in those conditions, but instead to endure extreme conditions while in storage.

Lastly, need statements were categorized according to Ullman's categories (Ostafichuk, P. et al, 2013, p.194) to guarantee breadth of need ranges considered; in Table D-3: Final Revision of Needs, these categories are referred to as a need "type".

Table D-3: Final Revision of Needs

Need as Expressed	Need Statement	Type
Not increase the net additional weight of the equipment to be carried by the skier during ascent by more than 2kg.	Device increases the net weight less than or equal to 2kg during ascent	Ergonomic, Storage and Handling
Increases number of runs per day	Device increases the number of runs the user can accomplish per day	Functionality
Is usable throughout the whole day on the slopes	Device is usable a minimum of 65% of the daylight hours per day	Functionality
Reduce the net effort required to go uphill	Device increases user energy efficiency	Functional
If carrying is required, be small and light enough to be carried in a backpack along with typical back country skiing gear (ideally, for multi-day outings).	Device fits a standard-size backcountry skiing backpack.	Ergonomic, Storage and Handling
Not negatively affect the downhill skiing performance of the skis	Device negligibly affects the downhill skiing experience	Input/Output
Not increase the risk of being caught in an avalanche	Device negligibly impacts risk of being caught in an avalanche	Safety
Withstand temperatures as low as -35 degrees C for durations of no less than 8 hours as may occur on overnight trips	Device withstands temperatures as low as -35 deg C for up to 8 hours	Durability, Functionality
Is easy to use	Device has been designed with affordances	Functionality
Have a minimum design life of 5 years for non-replaceable components	Device possesses a minimum design life of 5 years for non-replaceable components	Durability
Not be any noisier than a typical cordless drill	Device is quieter than a typical cordless drill	Regulatory, undesirable
Be adaptable to a wide range of skis, so that customers aren't bound to buy a specific ski to use the system/device.	Device accommodates a wide range of skis	Modularity, accessibility
Not require any significant modification of skis, boots, or bindings	Device requires negligible alteration of existing ski equipment	Modularity, undesirable
Be capable of operating at an altitude of up to 3000m	Device operates at an altitude of up to 3000m	Durability, functionality
Permit operation in snow, rain and in atmospheric conditions that can reasonably be expected when skiing in the backcountry.	Device functions in all ski weather conditions	Durability, functionality
Have an operating cost of less than $20/day	Device has an operating cost of less than $20/day	Economic
Have a cost of production of less than $500 CAD per unit in volumes of 1000 units	Device has a cost of production less than $500 CAD/unit in volumes of 1000 units	Economic
Device is easy to handle and ship	Device is easily package-able (volume wise)	Ergonomic, Storage and Handling

D-4 Justifications for Evaluation Criteria Weightings for the Weighted Decision Matrix

Based on the needs discussed previously, requirements and evaluation criteria were created; Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy) on page 55 shows the complete relationship between the originating needs and resulting requirements and criteria used for concept evaluation. Specifically, requirements were used for winnowing while evaluation criteria was used primarily for the Weighted Decision Matrix (WDM). Criteria weights in the WDM result from a number of factors including external research (e.g., interviews), the priority of needs (discussed in D-2.2 Stakeholders' Relevant Needs, p.56), and team members' intuition. Based on a reasonable compromise of the major stakeholders' preferences, justifications for the evaluation criteria can be found in the table below.

Table D-4: Evaluation Criteria Weighting Justifications

Evaluation Criteria	Weight	Justification
Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?) Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	6.00%	The client would like to have return buyers, therefore a midrange lifetime is desired; however, a consumer would rather have a device that has a high lifetime. Additionally, the device should not be subjected to extreme conditions frequently (because of our scope).This translated into a low weighting because this evaluation criteria is split between clients and consumers.
Device may be operated uninterrupted for long periods of time (i.e., device endurance)	6.00%	A requirement for the device is to be operational for 65% of the daylight hours as a bare minimum. It is desirable to have additional operational time, but not highly important because, in reality, the device will have periods of time when it is not in use (when the skier takes a break)
Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	8.00%	The purpose of the device is to reduce the energy required to climb uphill. However, the primary function of the device is to achieve more runs per day, for which there are two ways to achieve this function: energy savings and time savings (going uphill). As such, these two evaluation criteria are highly weighted together (and are equally weighted because they contribute equally to the primary function when separate).
Device minimizes time spent for adjustment	8.00%	

Device decreases the risk of injury (e.g. from a fall)	10.00%	If a person injures themselves, serious consequences could arise. However, the likelihood of a person injuring themselve is also low. Therefore a midrange weighting is given.
Device is compatible	10.00%	Consumers would be more likely to buy a product that is compatible with their equipment, thus increasing the client's profit. This is corroborated by interviewee feedback.
Device usage results in a decreased influential volume	10.00%	Volume is mid-range in importance because it only affects the skier's stability if it alters their center of gravity (as opposed to weight which is detrimental regardless of where it is attached to the skier). Absolute volume is also a factor for downhill skiing because it takes up backpack space. In addition, downhill influential volume is more important than uphill influential volume as it affects the downhill experience.
Device has a low production and operating cost	13.50%	A low production cost would increase the client's profits and make it more attractive to the consumer (especially consumers within our scope that may be new to backcountry skiing and not wanting to invest in equipment); therefore, a high weighting is given.
Device net influential weight is small	13.50%	Weight is one of the most important factors (as corroborated by interviews and our weekly meetings with our prof/TA). Additionally, downhill weight affects the user more than uphill weight because it changes the stability of the skier. Both criteria still maintain a relatively high weighting because weight, in general, affects the skier's ability to ascend and their downhill experience.
Risk of development	15.00%	It was made clear to us that having a product that worked was better than having a product which did not work. Additionally, as an engineering team, our limited time as engineering student must be efficiently spent so that a higher cost is not assumed by a client. Furthermore, because we are engineering students, our technical abilities are limited; therefore, a difficult project would require exponentially more time (which, in the real world, would translate into billable hours).

D-5 Comparison between Final Design and Project Requirements

The final design addresses the final revision of project requirements as shown in the table below; evidently, the device fulfills 90% of the requirements. Both satisfied and unsatisfied requirements are discussed in the table below.

Table D-5: Comparison between Final Design and Project Requirements

Requirement	Metric	Threshold	Status	Notes
Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment) compared to available products (e.g., skins)	Work exerted by user	Yes/No	Yes	Accomplished through allowing the user to ascend without carrying their equipment.
Device does not fully eliminate the need for user to exert work	Work exerted by user	Yes/No	Yes	
User is capable of climbing a 30-45^{o} slope with the device	Climbing a 30-45^{o} slope	Yes/No	Yes	Device can achieve this angle range, though it is not designed to operate at such extreme angles consistently.
Same size as 2 1L Nalgene Bottle	Litres	$\leq$ 2L	No	
Device does not obstruct user's range of motion	N/A	Yes/No	Yes	
Device does change downhill skiing stance	N/A	Yes/No	Yes	
Device does not obstruct downhill skier visibility	N/A	Yes/No	Yes	

Device net influential weight (uphill movement) is small	Ascend Net Increase	< 2 Kg	Yes	Device operation focuses on reducing he weight users need to carry uphill.
Device net influential weight (downhill movement) is small	Descend Net Increase	< 4Kg	No	Net mass has large rom for optimization as outlined in Appendix J
Device is less noisier than a typical cordless drill	Noise Level - dB	≤ 78 dB	Yes	
Device does not increase the risk of being caught in an avalanche	N/A	Yes/No	Yes	
Device uses rechargeable batteries if using batteries. Avoid using disposable batteries.	N/A	Yes/No	Yes	
Device does not use a gasoline engine.	N/A	Yes/No	Yes	
Device is capable of operating at an altitude of up to 3000m	Max Operation Pressure	0.69atm, 69.7kpa, 10.11psia	Yes	Conditions that exceed these assumptions can also be handled, at the cost of reduced battery capacity.
Device functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry	N/A	Yes/No	Yes	
Device withstands temperatures as low as -35 ^{o}C for durations of no less than 8 hours	at -35^{o}C, ≥ 8 hours	Yes/No	Yes	

Device is fully functional in typical BC skiing conditions	ºC	>-15 ºC <30 ºC	Yes	
Device has a 5 year design life for non-replaceable components	Non-replaceable component life span	≥ 5 year	Yes	
Device operates with a maximum of $20/day (variable cost)	Operational Cost (USD) /Day	≤ $20/day	Yes	
Device has a production cost of less than $500 CAD per unit in volumes of 1000 units	Production Cost (USD)	≤500 USD /1000 units	No	Optimization options for reducing costs have room for improvement, and are discussed in depth in Appendix
Device can be sold in retail shops across North America	North American Availability	Yes/No	Yes	
Is usable 65% of the daylight hours as a bare minimum	Daily lifespan (Hours)	≥ 65% of daylight hours	Yes	

APPENDIX E: CONCEPT DEVELOPMENT AND CONCEPT SELECTION

In our design process, after we clarified and understood our specifications, we jumped to conceptualization. Thus, we used the function decomposition to separate complex issue to sample parts which helped us to understand. Our initial ideas started from the concept brainstorming which based on the internal and external research that we did about the existing product and patents. The concept brainstorming gave us a lot of ideas and designs. Therefore, we started to evaluate each design by winnowing which quickly sifted out the unsuccessful device. Then, we used the Pugh chart to rank 5 concepts which passed winnowing and did rough detail calculation about each concept. Finally, there were two concepts in the weighted decision matrix. By comparing the detail calculations of them and the evaluation criteria, the equipment two became our final design.

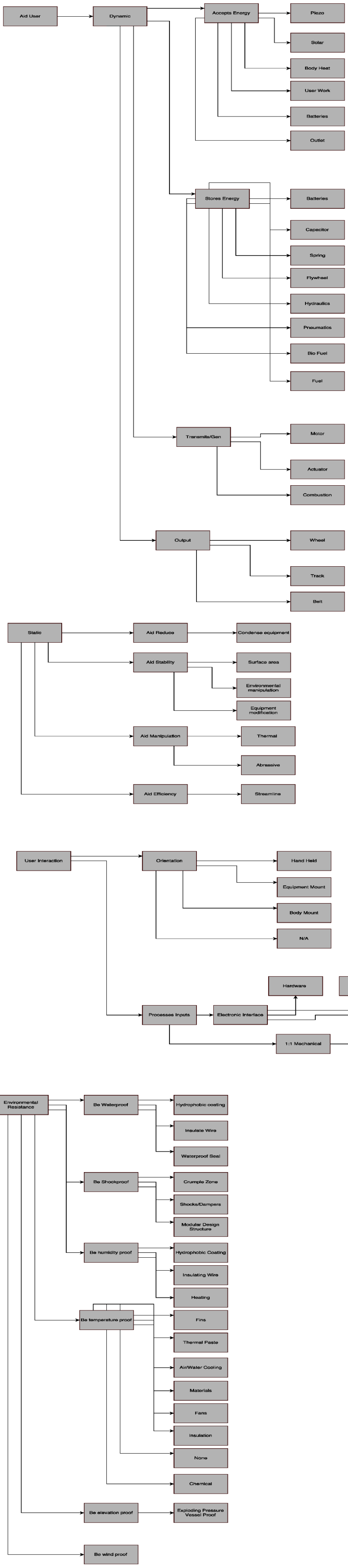
E-1 Functional Decomposition

A systematic approach, such as the one detailed in the Mech 2 design process, was used to generate concepts. After identifying our stakeholders and needs, requirements, and evaluation criteria, the design problem was broken into sub-sections using a Function Decomposition Chart. This methodical process guided the concept generation process in the right direction, ensured that no function or concept fragment was overlooked, and helped show synergies between concept fragments.

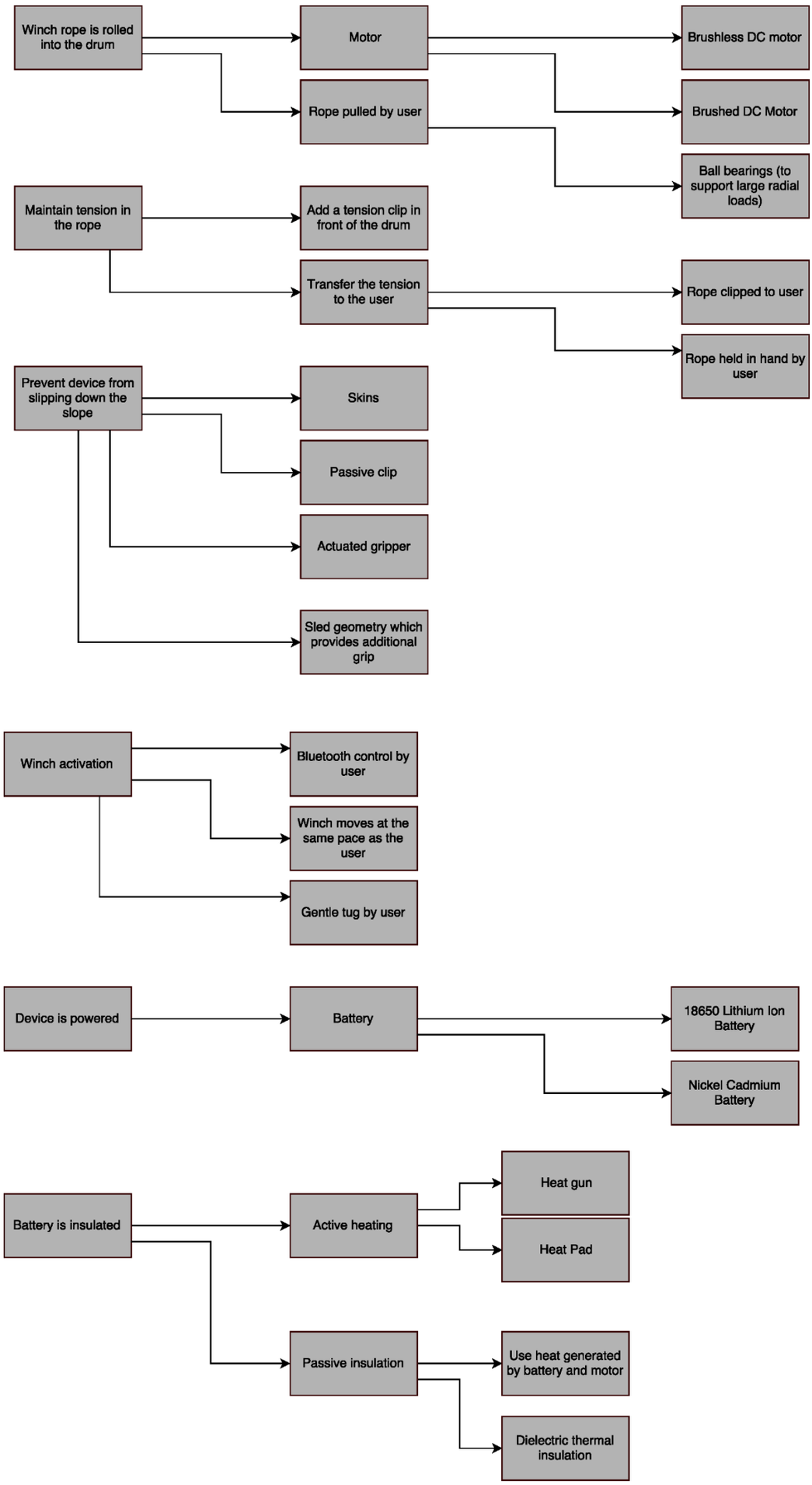
Throughout the project, the team created two Function Decomposition Charts:

- E-1.1 Function Decomposition Chart_September 14, 2017
  - The first was created prior to the development of concepts. This process began with top level functions and then slowly working down to less determinative functions. After all functions were listed, we went through each function and listed out concept fragments which could accomplish each function.
- E-1.2 Function Decomposition Chart_October 25, 2017
  - The second iteration was created during the detail design phase. The process was identical to the first function decomposition; however, the purpose was to list out functions that were specific to our device.

E-1.1 Function Decomposition Chart_September 14, 2017



E-1.2 Function Decomposition Chart_October 25, 2017



E-2 Concept Generation

The next step in the concept generation process following function decomposition was to develop full concepts for evaluation. As part of the preliminary research process, existing products and patents were examined prior to concept generation for inspiration and avoid introducing concepts which already exist. Brainstorming techniques such as C-Sketch were employed to spark creativity. In total, 19 full concepts were generated:

- E-2.1 Concepts that Passed the WDM (p.73)
  - Equipment Tow Line
- E-2.2 Concepts that Failed the WDM (p.75)
  - Trail Breaker
- E-2.3 Concepts that Fell Out of Scope (After Pugh Chart Analysis) (p.78)
  - Actuated Ski Teeth
  - Ski Poles
- E-2.4 Concepts that Failed the Pugh Chart (p.82)
  - Mobile Skis
- E-2.5 Concepts that Failed Winnowing (p.83)
  - Ski Snow Removers (Mechanical)
  - Grappling Hook
  - Snowshoes Attachment
  - Ankle Assist (Mechanical)
  - Ankle Assist (Actuated)
  - Exoskeleton
  - Ski Snow Removal
  - Snow Gripper (Actuated)
  - Thermal Friction
  - Jack (Mechanical)
  - Jack (Actuated)
  - CO_2 Propulsion
  - O_2 Mask
  - Snow Gripper
  - Propeller Thurst

A detailed summary of all concepts generated including discussion of synergies, main features, and addressed needs is provided for below.

E-2.1 Concepts that Passed the WDM

Equipment Tow Line

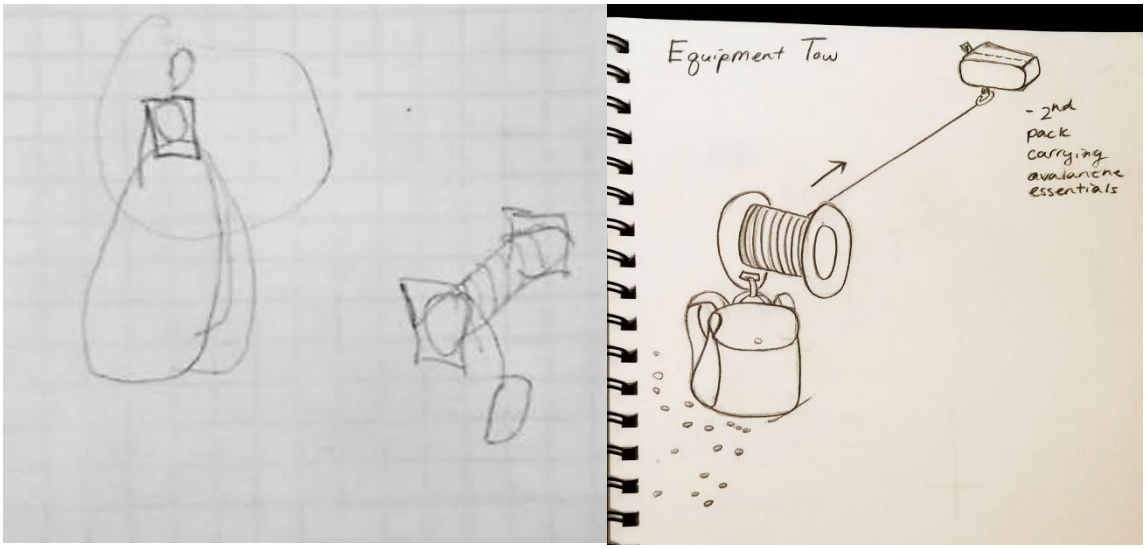


Figure E-1: Equipment Tow Concept on September 30, 2016 (Left) and October 7, 2017 (Right)

Status: Going into WDM: This concept also possesses high development risk, but can offer high rewards in terms of massive energy savings to skiers who are traversing uphill because the winch will do the work of pulling the load uphill

Fragment: Battery, Body mount, Aid efficiency, Motor, Gear, Microcontroller

User input, Output, Equipment modification

Description: Winch attaches to backpack or other gear allowing the user to ascend cargo-free. While ascending the user brings the free end of the winch with them to then allow the winch to do the work required to elevate the skier's gear.

Function: Saves energy required to carry equipment while climbing up

Main Feature 3 components:

Backpack (we need to design)
Small zip off backpack for essentials

Backpack is being dragged behind you (small sled attachment)
Winch (we need to design)
Winch calculations references
Rope (based on volume)
MAX Length 100m

MIN Length 25m (Closer is safer in case backpack gets caught, but benefit increases when rope is longer)

Note: Vertical climb per day = 1000-2000 m

During Decent, carrying it down in backpack/attaches to backpack

Relative Size Dependent on winch

Relative Weight Dependent on rope length used

By Cole, Rishabh,Amanda, Danwei

Addressed Needs

Need*	Feature
1	Winch + Rope system carries cargo, reducing the energy consumed from carrying that weight for the user
2/3/6	Size and weight is flexible, limitations addressed in detailed design
4/5	Backpack, since the device is carried by the user as a backpack it doesn't interact with skis; is compatible
7	Since the winch & rope system is attached to cargo far from user, noise is negligible
8	Essential avalanche gear remains in smaller detached backpack with user
9-19	Addressed in detailed design; nothing suggests otherwise
20	Winch + Rope system allows user to use energy that would be spent on carrying cargo to be transferred into additional elevation and runs

*See D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy) for need references

E-2.2 Concepts that Failed the WDM

** *Note: The needs addressed are referenced to according to their number in the Needs, Requirements, and Evaluation Criteria Document. The remaining needs that are not listed were determined to be solely met based off detailed design.*

Trail Breaker (and possible bag carrier)

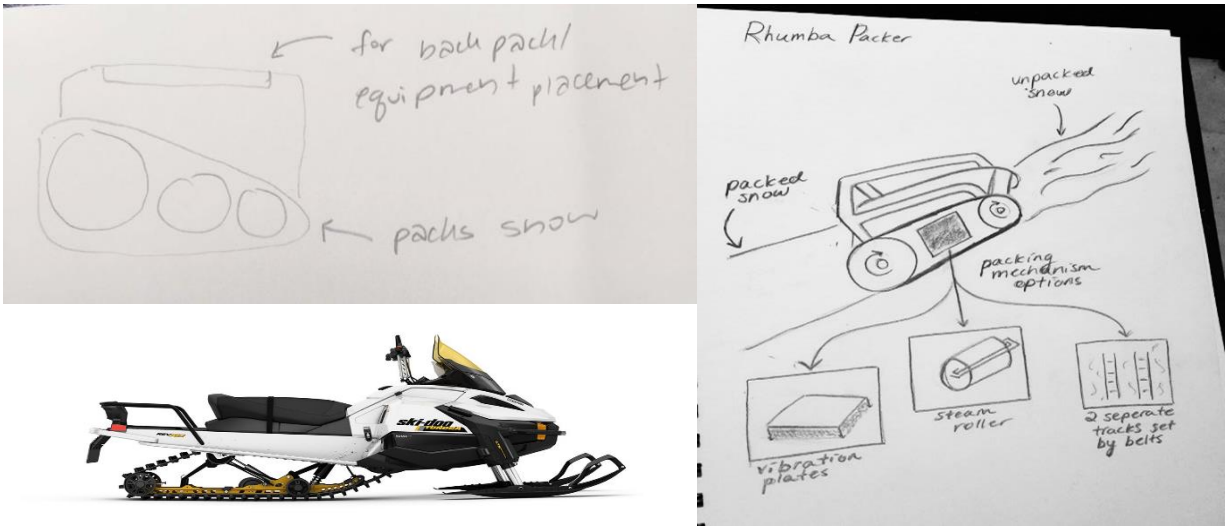


Figure E-2: Figure: Trail Breaker (Top Left) and Reference Snowmobile (Bottom Left) (Added: September 30, 2017) and Trail Breaker Concept (Added: October 8, 2017)

Status: Going into WDM: This concept inherently possesses high development risk, but it proposes a very creative way of helping the skiers, i.e., by reducing the load carried by the while traversing uphill

Fragment: Battery, Body mount, Aid efficiency, Motor, Actuator, Gear, Microcontroller

Description: Autonomous robot travels in front of the user, packing down the snow using belts/weight of the robot. The device also possess a holding area for equipment/ backpack. The device could be pre-programmed or controlled in real time using an application on a phone; it keeps a certain programmable distance from the user using sensors until it is told to stop moving via the app.

Synergies: The functionality of ‘mobile ski’ (refer to page 15) and ‘equipment tow’ (refer to page 6) is synergistically combined in this concept as it uses a

similar movement as mobile ski and helps the user in a similar way as equipment tow by reducing the load they have to carry uphill

Function:

Autonomously packs snow in front of user
If the device is not heavy enough to pack the snow, additional snow can be place in the device
Eliminate loose powder snow, but not turn snow into ice
Also prevents snow from getting on top of skis
Could have compartments to carry equipment
Requires skins

Main Feature

Packing Mechanism
Vibration plate packing
Steam roller packing
Two belts that create separate paths for each individual ski
Plate pushing down
Compartment Organization
Make it collapsible (modular)
Weighted base plate
Zipper/detachable compartment on top (compartment is shallow to keep center of gravity low)

Descent:

Carry it down (for large downhill descents- basically, when skins are removed when descending)
Autonomously descend (intermittent small slopes - basically, when skins stay on when descending)

Relative Size

Needs to be at least shoulder width wide (17-18” for average male)
Length is dependent on weight requirement

Relative Weight

Dependent on design (< 4kg), if extra packing weight is needed can design a temporary compartment filled with snow weight

By:

Amanda, Rishabh, Jason, Cole, Danwei

Addressed Needs

Need*	Feature
1/20	Packing mechanism + weight + equipment holding compartment
2	Size
3	Size, Weight
6	Weight
4/5	Device is not dependent on skis, therefore can be accommodated by all
7	Entire system is no louder than 78 dB (depends on design details)
8	Device is operated in front of the user, therefore it travels on the same path as the user and weighs less than the user (might even prevent the user from being caught in an avalanche)
9/14	Will operate using reusable batteries
10/11/12 /16/17	Entire device is built to operate at up to 3000m and in all ski conditions, as low as -35 degrees Celsius for up to 8 hours for 65% of the daylight hours per day (depends on design details)
13	Device is built to possess a minimum design life of 5 years for non-replaceable components (depends on design details)
15	Device costs less than $500 CAD/unit in volumes of 1000 (depends on design details)
16/19	Can be efficiently sold across North America because it is in compliance with existing consumer laws and is packaged minimally (depends on design details)
18	Outward design reflects the purpose of the device so that it is easy to use (depends on design details)

*See D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy) for need references

E-2.3 Concepts that Fell Out of Scope (After Pugh Chart Analysis)

Ski Teeth (Actuated)

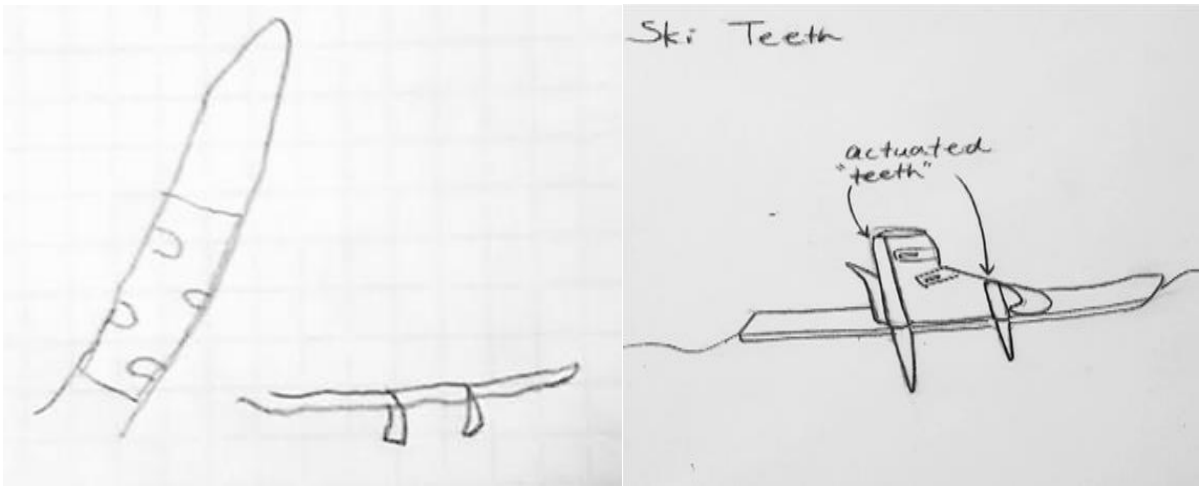


Figure E-3: Ski Teeth Concept from September 30, 2017 (Left) and October 7, 2017 (Right)

Status: Going into WDM

Fragment: Battery, Equipment mount, Aid efficiency, Motor/actuator, Microcontroller, User input, Equipment modification

Description: Similar to snow grippers concept, teeth are used to provide anchored points of contact with each stride uphill. Ski opposite to the one in stride is anchored to prevent backwards motion (very similar to the mechanics of skins). Teeth are actuated with appropriate sensors. Device remains on the boot during ascent and descent (saves time spent from taking skins on /off).

Synergies: This concept seeks to improve the existing static crampon technology and eliminate the need for skiers to put skins under their ski
The functionality of 'actuated snow grippers' (refer to page 19) and 'angled automated anchors' (refer to page 31) is also synergistically combined in this single device as it anchors the user's ski to the snow but in an unobstructive manner

Function: Replaces skins functionality while saving time spent taking skins on/off

Main Feature	Actuated teeth Can be made of a non-metal material Actuates based on heel movement Attaches on the boot, will not affect accidental ski crossing Stays on during all descent
Relative Size	Dependent on length of teeth required
Relative Weight	Dependent on material selected and device dimensions
By:	Danwei, Cole, Juliana, Justin

Addressed Needs:

Need *	Feature
1	Teeth replaces skin's function, less the effort of taking the skins on and off and allows the user to ski normally down intermediate descents during climb
2/6	Addressed in detailed design, nothing to suggest that the size and weight will not meet requirements
3	The teeth actuate on the medial and lateral sides of the boot, will not obstruct range of motion
4/5	Attaches to the boot, might require minor alterations to the boot but the skis will remain unaltered
7	Addressed in detailed design, since device operates at snow level; nothing to suggest a noise level above requirements
8	Avalanches are more likely to occur due to a shear force (ie. a ski stride) rather than the compressive force of the teeth Teeth are actuated and will be designed with safety features to avoid accidents when falling
9-19	Addressed in detailed design; nothing suggests otherwise
20	Teeth replaces skin's function, less the time of taking skins on and off. This should consequently increase the number of runs the user is able to do

*See D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy) for need references

Ski Poles

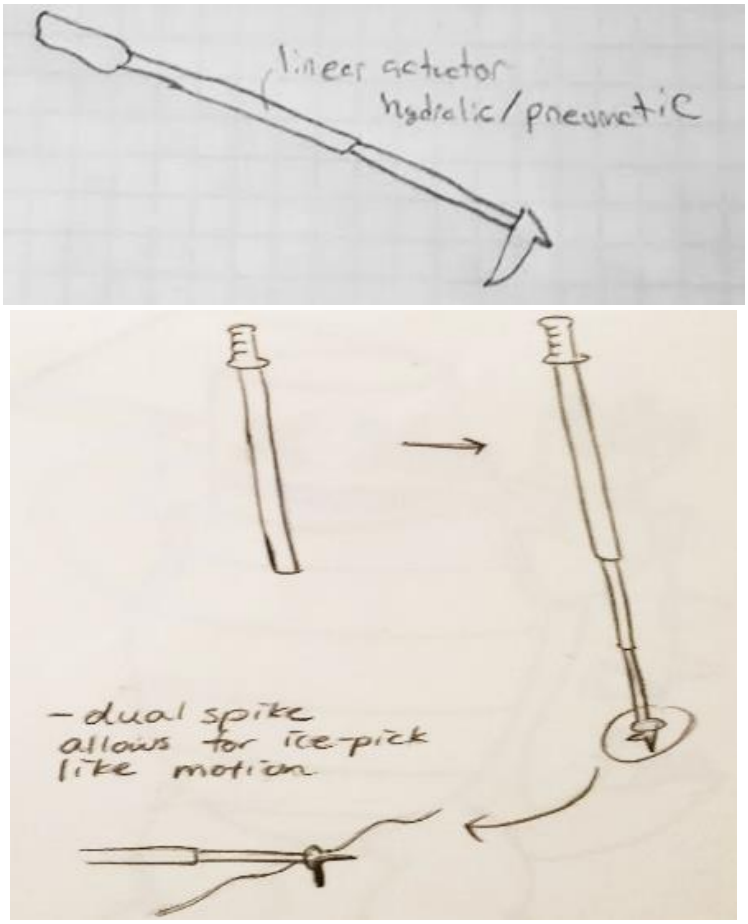


Figure E-4: Extendable Poles from September 30, 2017(Top) and October 7, 2017 (Bottom)

Status: Going into WDM

Fragment: Equipment modification, Aid Stability, Aid efficiency, Handheld, User input, Actuator

Description: Modified ski poles that possess linear actuation and rigid hooks to allow the user to reduce effort in ascending steep gradients. Increases stability.

Function: A telescoping ski pole, plus it can extend out further (to allow anchoring)
Further anchor points result in an increase of stability

Main Feature Telescoping ski pole (fulfills regular telescoping ski pole needs)
Good for sidestepping (increased stability in rough terrain)
Used like regular ski poles during descent

Relative Size	Slightly thicker than regular ski poles with possible extra component for hook and extension
Relative Weight	Slightly heavier than regular ski poles
By:	Cole, Jason, Amanda, Justin

Addressed Needs

Need*	Feature
1/20	Linear actions + rigid hooks to increase stability
2	Size
3	Size, Weight
6	Weight
4/5	Device is not dependent on skis, therefore can be accommodated by all
7	Entire system produces no noise on its own
8	Device is operated like a regular ski pole, therefore it poses no additional risk
9/14	Device will use reusable batteries if batteries are required
10/11/12/17	Entire device is built to operate at up to 3000m and in all ski conditions, as low as -35 degrees Celsius for up to 8 hours for 65% of the daylight hours per day (depends on design details)
13	Device is built to possess a minimum design life of 5 years for non-replaceable components (depends on design details)
15	Device costs less than $500 CAD/unit in volumes of 1000 (depends on design details)
16/19	can be efficiently sold across North America because it is in compliance with existing consumer laws and is packaged minimally (depends on design details)
18	Outward design reflects the purpose of the device so that it is easy to use (depends on design details)

*See D-1.8 Needs, Requirements, and Evaluation Criteria_October 25, 2017 (Final Copy) for need references

E-2.4 Concepts that Failed the Pugh Chart

Mobile Skis/ Conveyor Belt Step Booster

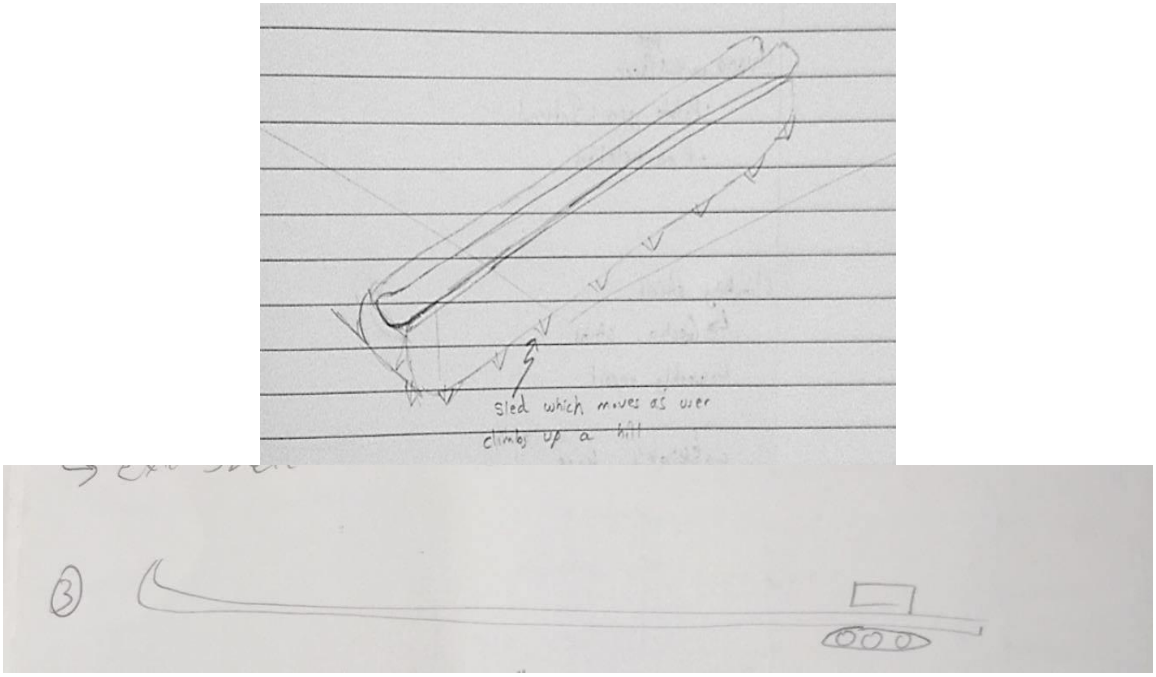


Figure E-5: Mobile Skis from September 30, 2017

Status: Failed Pugh Chart

Fragment: Belt, Track, Motor, Equipment mount, Microcontroller, Button, Other weather resistance

Description: The track is attached to bottom of the track with the ski's length or shorter track. There is some control system for user or passive activation system to sense every step.

Function: Motorized conveyer belt attached to the back of the ski that would give a "push" every time the user stepped on its (humans walk in a heel-toe fashion, therefore the extra force exerted by the heel would trigger the device).
During descent:

Carry it down (for large downhill descents- basically, when skins are removed when descending)

Keep on (for intermittent small slopes - basically, when skins stay on when descending)

By: Rishabh, Cole, Justin, Jason

E-2.5 Concepts that Failed Winnowing

Ski Snow Removers (Mechanical)

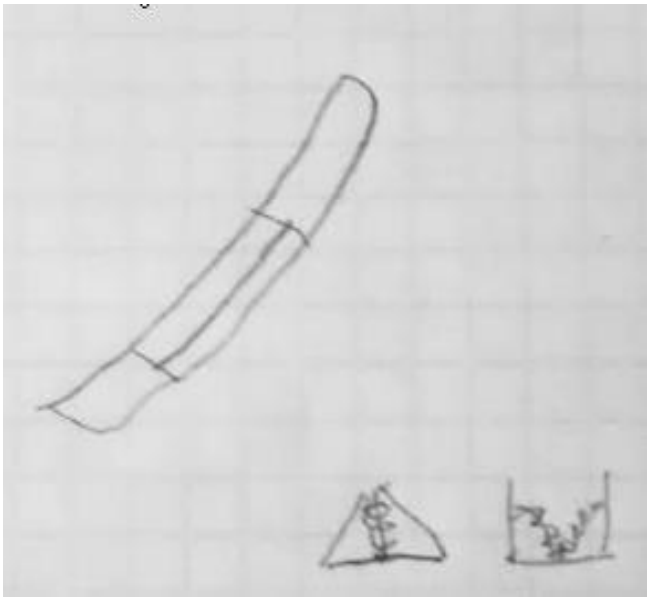


Figure E-6: Ski Snow Remover from September 30, 2017

Status: Failed Winnowing

Fragment: User input
Equipment mount
Gear
1:1 mechanical/ gear train
Equipment modification
Other weather resistance

Description: Device that lays flat along a variable length of ski with flap that nominally merge to ski upper surface and with spring to reload energy from user weight and gear to transmit power

Function: Device actuates either with each step or from direct input from user to clear snow build up on skis, reducing the effort to take each step to lift up ski from deep, powder snow.

By: Cole, Jason, Amanda, Juliana

Thermal Friction Reducer

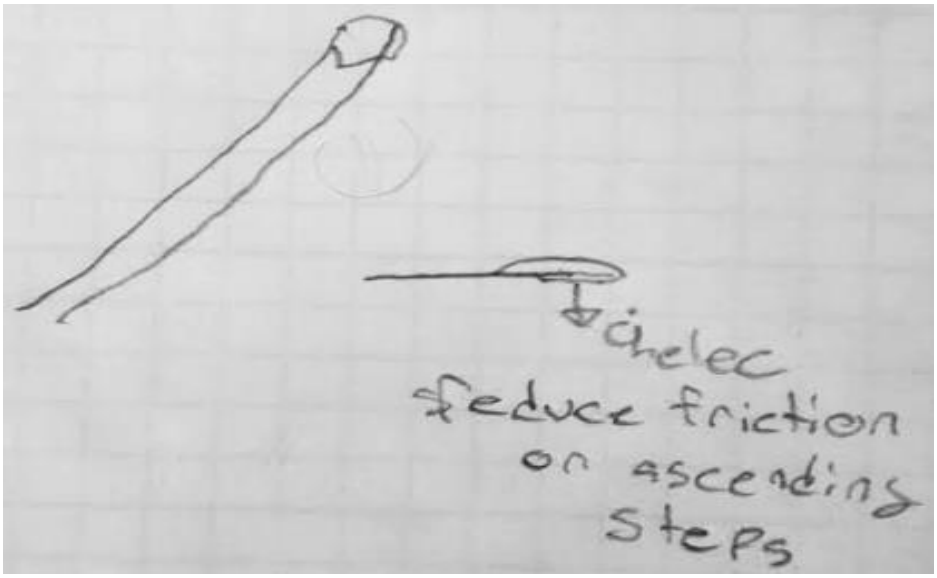


Figure E-7: Thermal Friction Reducer from September 30, 2017

Status: Failed Winnowing

Fragment: Battery
Equipment mount
Aid Manipulation: thermal
Equipment modification
Outlet
Solar
Other weather resistance

Description: Attached to the tip of the ski with electrical coil heater, device constantly on

Function: Electrical heat is used to slicken the snow in front of the ski, reducing friction on and upward sliding stride.

By: Cole, Rishabh, Danwei, Justin

Actuated Snow Grippers

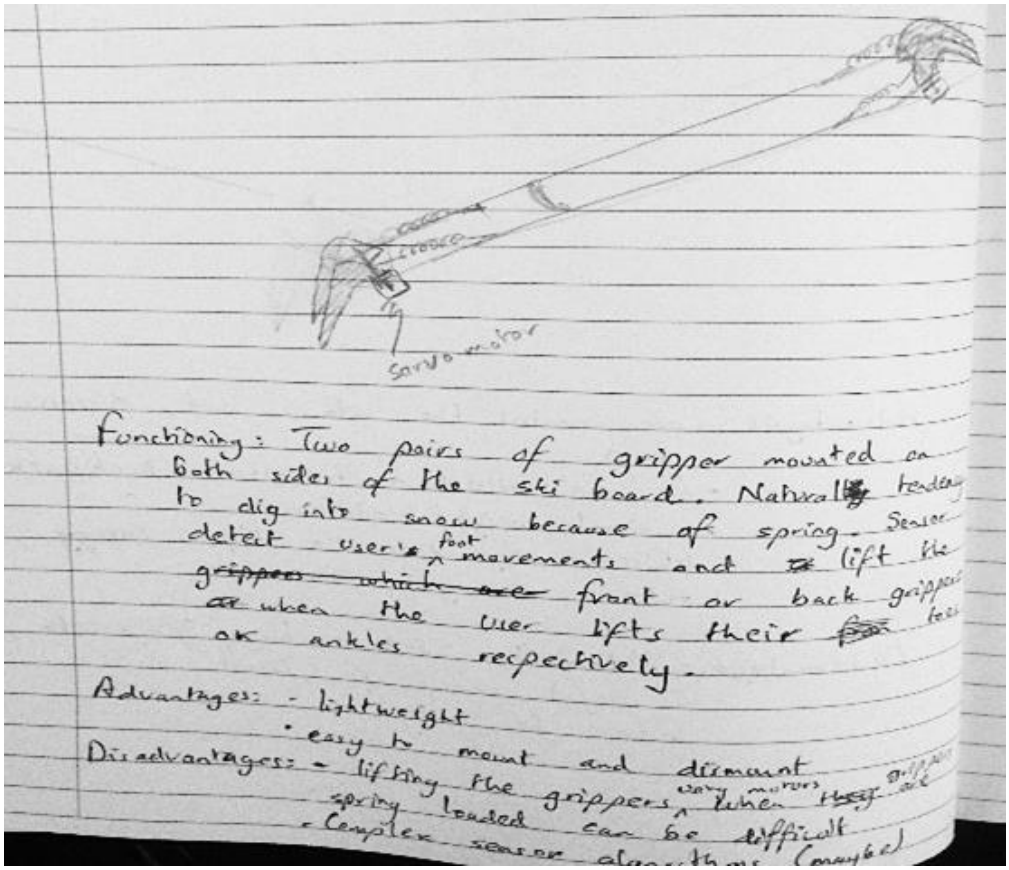


Figure E-8: Actuated Snow Grippers from September 30, 2017

Status: Failed Winnowing

Fragment: Battery, Equipment mount, Motor, Gear, Spring, Equipment modification, Outlet, Other weather resistance

Description: Pair of grippers mounted on both ends of the ski with microcontroller and battery.
Device means to replace skins - never have to remove, even with descent

Function: They have a natural tendency to dig into the snow because of the spring. Sensor detects user's foot movements and pulls the front or back grippers out of the snow when the user lifts their toes or ankles respectively.

By: Rishabh

Grappling Hook with Rope - Shot from a 'gun' (Dynamic)

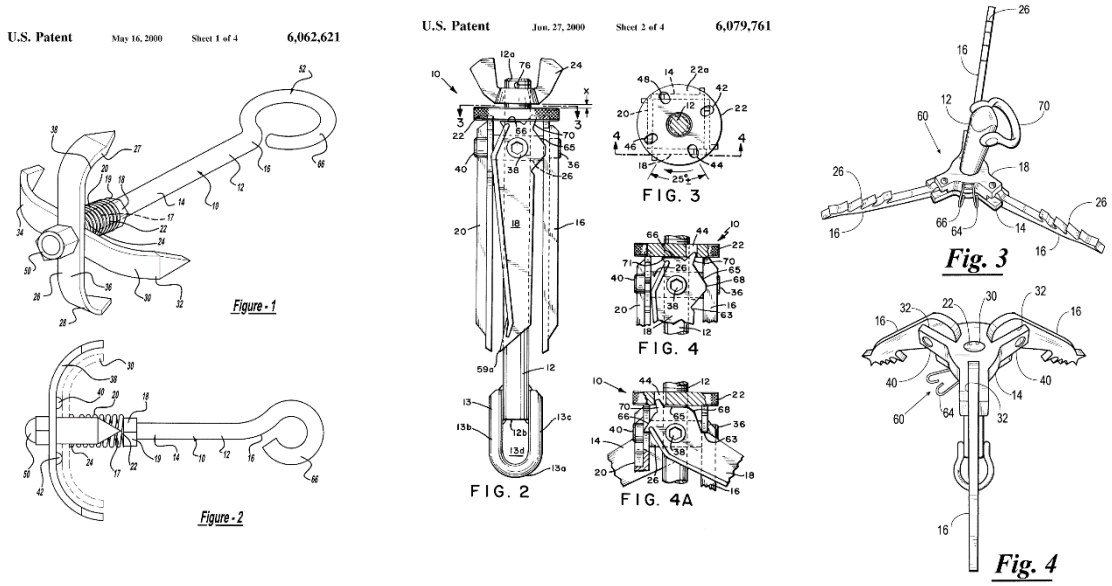


Figure E-9: Grappling Hook with Rope

Status: Failed Winnowing

Fragment: Battery
Equipment mount/Handheld
Motor
Gear
Compressed gas
Other weather resistance

Description: A retractable graphing hook that is projected from a cannon-type object. The projectile is launched using either pneumatics or fuel.

Function: Device shoot a grappling hook to a rock or tree along the ascent to assist user by pulling their own body weight. Device can also design so that it can tow up other equipment in attempt to reduce carrying weight user

By: Amanda

Snowshoe Attachment (Static)

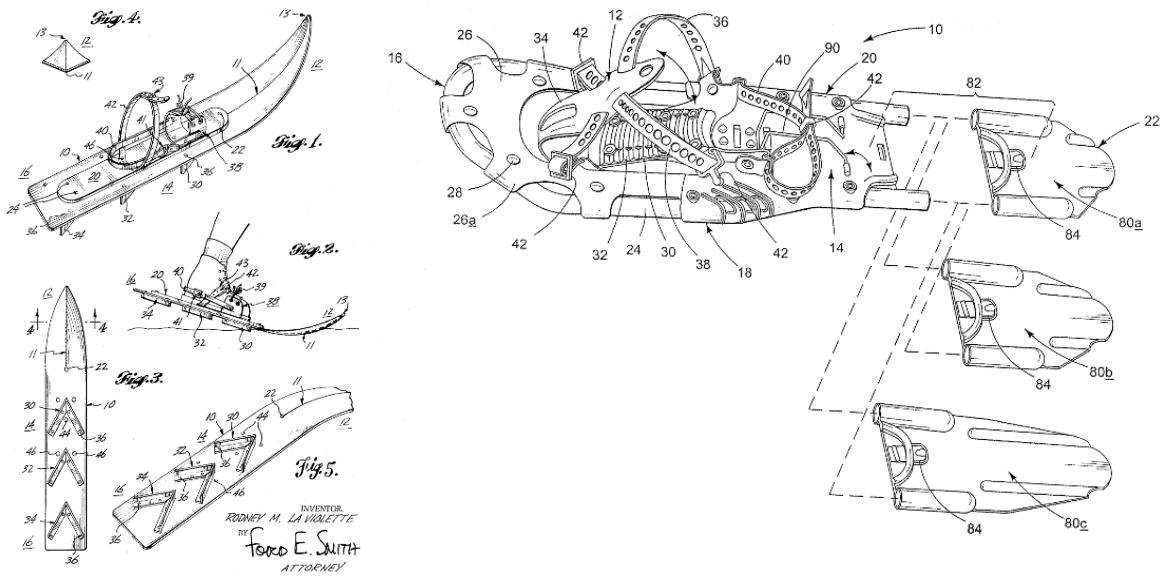


Figure E-10: Left (Snow show patent from 1971); Right (Adjustable Snowshoe Patent)

Status:	Failed Winnowing
Fragment:	Aid Stability: surface area Equipment mount Equipment modification User input Other weather resistance
Description/ Research:	Modular snowshoe-like attachment that can be used in addition to skis (i.e., one doesn't have to remove skis/bindings to wear device).
Function:	Attaching device is aid user to stay "floating" during the ascent hence reducing their effort to remove ski that sink into powder snow
By:	Amanda, Cole, Justin, Danwei

Ankle Assist Device in combination with Detachable, Inflatable Snowshoe

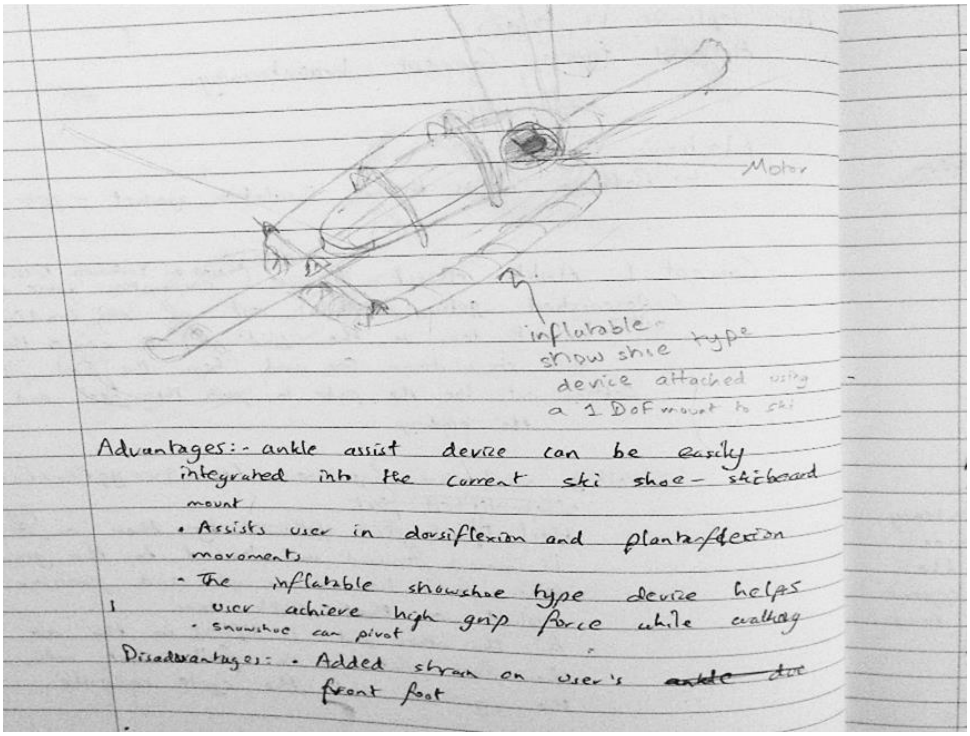


Figure E-11: Ankle Assist Device in combination with Detachable, Inflatable Snowshoe
September 30, 2017

Status: Failed Winnowing

Fragment: Battery, Equipment mount, Motor, Gear, Equipment modification, Aid Stability: surface area, Outlet, Solar, Other weather resistance

Description: User wears an ankle assist exoskeleton which electronically assists them in lifting their heels and toes for walking. This product is developed by Yasra Technologies and is proven to work effectively. In combination with the ankle assist device, we can mount an inflatable snowshoe at the bottom of the ski to provide a large surface area using which the users can climb uphill more efficiently.

Function: Device assists user ankle movement by using technology like skelaton support. The push to forward ankle movement helps to reduce user effort to popell forward.

By: Justin, Juliana, Danwei

Propeller Thrust Assist



Figure E-12: Propeller Thrust Assist from September 30, 2017

Status: Failed Winnowing: This solution is both creative and unusual because there is no such thrust assist system which uses propeller to provide assist in horizontal movement in the world

Fragment: Battery/ Engine/fuel, Equipment mount/body mount, Motor, Gear, Propeller, Equipment modification, Outlet, Other weather resistance

Description: A propeller is mounted on user's backpack with motor,battery and controller inside.

Function: The Device's rpm and direction of the prop is controlled by the user to propel user forward during ascent. Furthermore, while coming down the slope, the propeller spins on its own due to wind draft and the motor becomes a generator, thereby charging the battery.

By: Rishabh

Ski-Jack (similar to ankle assist)

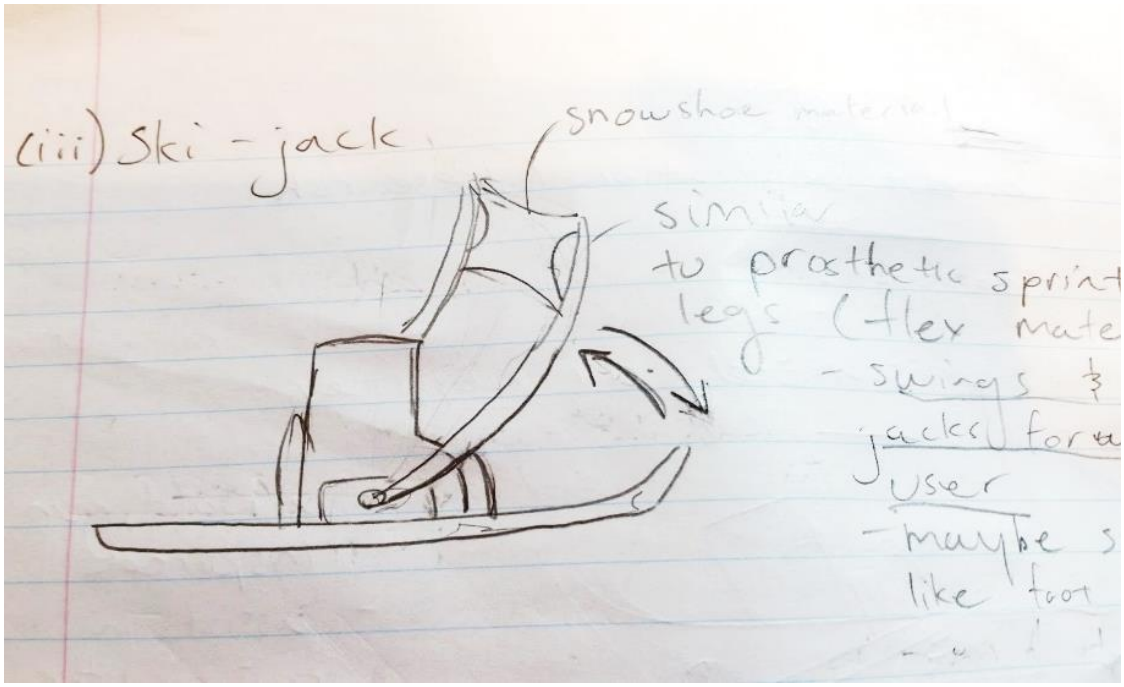


Figure E-13: Ski Jack from September 30, 2017

Status: Failed Winnowing

Fragment: Battery/
Equipment mount/body mount
Motor/ Actuator
Gear
Equipment modification
Other weather resistance

Description: Device equipped to the boots/skis/bindings with motor/actuator, sensor, controller.

Function: As user begins upward motion device swings its “legs” and jacks/assists the user forward.

By: Justin, Danwei

Pressurized Air Booster

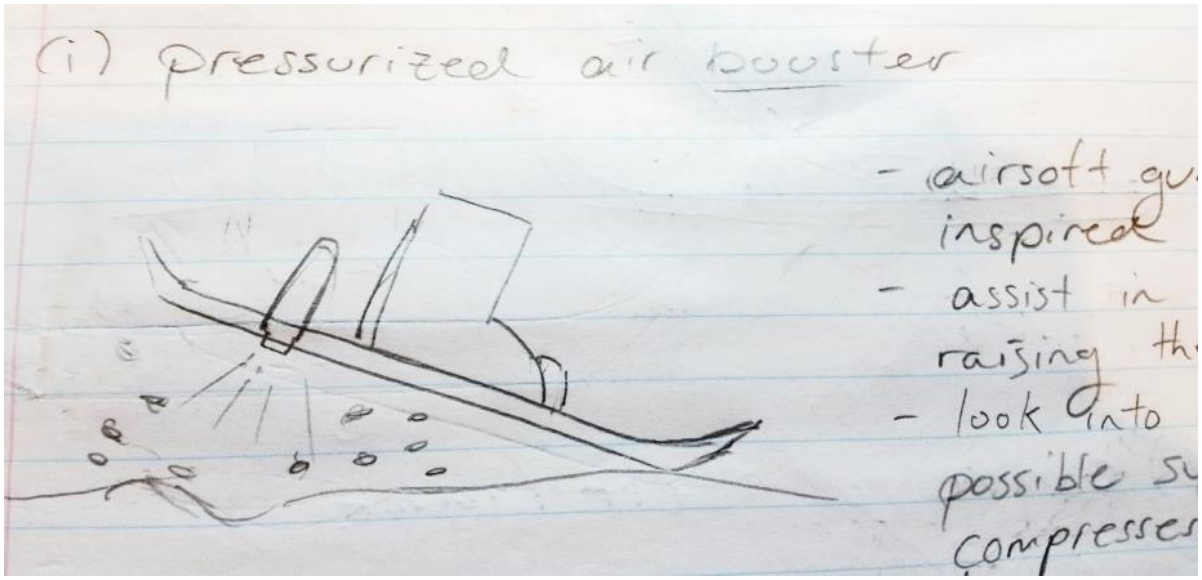


Figure E-14: Pressurized Air Booster from September 30, 2017

Status: Failed Winnowing

Fragment: Compressed gas
Equipment mount
Equipment modification
Aid Manipulation
Other weather resistance

Description: Device have storage compressed gas and nozzle attach to the bottom of the ski

Function: Device assists user in raising ski by providing a vectorized burst of air from powder snow. This can help to reduce user effort of pulling ski out of snow

By: Cole, Justin, Amanda

Oxygen Mask

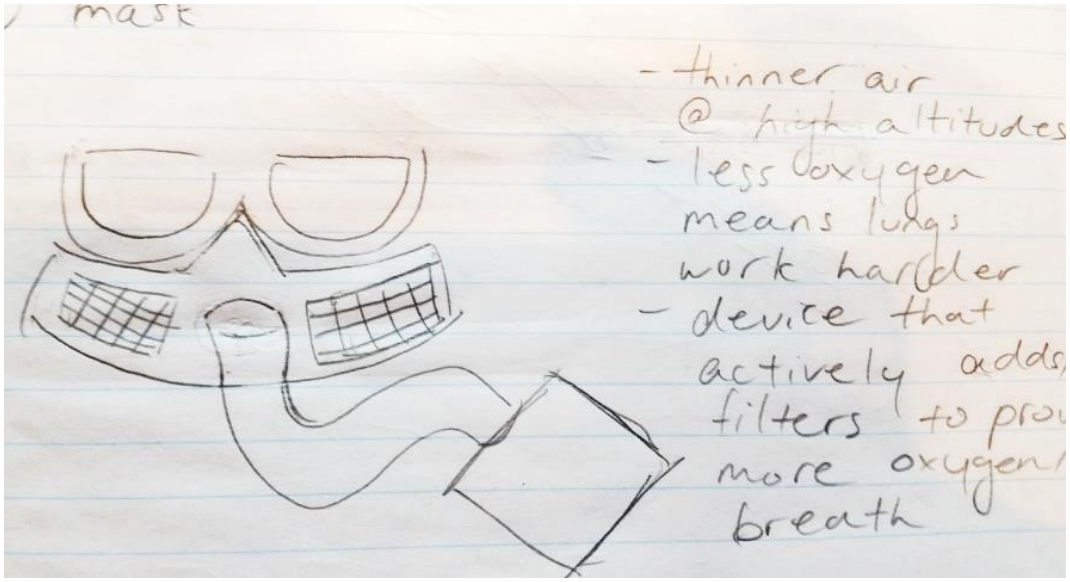


Figure E-15: Oxygen Mask from September 30, 2017

Status: Failed Winnowing

Fragment: Compressed gas
Body mount
Aid efficiency
Other weather resistance

Description: Device have storage compressed oxygen or self-generated unit

Function: Device provides user with more oxygen/breath to reduce the work of the lungs.

By: Juliana, Amanda, Danwei

Exoskeleton

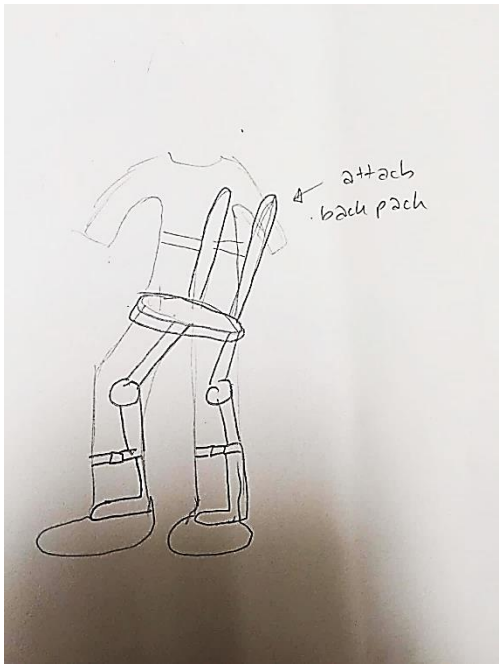


Figure E-16: Exoskeleton from September 30, 2017

Status: Failed Winnowing: This solution is unusual for backcountry skiing scenario because its application is currently only limited to aiding the body movement of patients with neurological health problems

Fragment: Battery
Body mount
Aid efficiency
Motor
Actuator
Gear
Microcontroller

Description: A human exoskeleton is attached to user body.

Function: Passive exoskeleton similar to this design with an attached back support that would take the weight of the backcountry ski equipment off of the user.

By: Juliana, Justin, Cole, Jason

Angled Automated Anchors

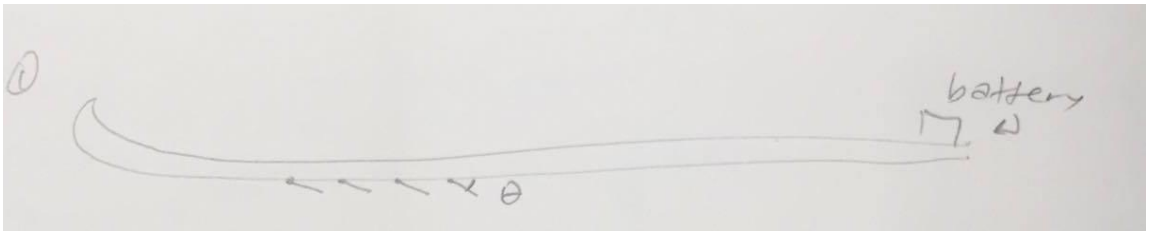


Figure E-17: Angled Automated Anchors from September 30, 2017

Status: Failed Winnowing

Fragment: Battery
Body mount
Aid efficiency
Motor
Actuator
Gear
Microcontroller

Description: Small angled pieces of metal (anchors) would be attached to the bottom of the ski with tail gears similar to skins. The metal anchors would be connected to each other so that the battery and motor at the rear of the ski would control unanimous movement of the anchors.

Function: The motor would open up the anchors to a certain degree matching the pace of the user so that the anchors would open up as the user's foot is in the air, anchor the user's ski into the ground, and close up as the user lifts their foot.

By: Rishabh, Cole, Amanda, Danwei

E-3 Winnowing

Concepts were evaluated through a three-stage process of Winnowing, a Pugh chart, and, finally, a Weighted Decision Matrix (WDM). To save time, our plan was to go straight to the Pugh chart as we believed all our concepts would pass winnowing or could be modified slightly to pass. However, after the lecture on September 28th, 2017, we learned that we made some misassumptions regarding the ski climbing mechanics (predominantly a striding versus a stepping motion), that skis often overlap, and some information on avalanche gear and procedure. With this new information, we decided that winnowing would be an efficient use of our time, which we did using requirements from Appendix D (p. 46). Our winnowing table is provided for reference below.

E-3.1 Winnowing_September 30, 2017 (Final Copy)

	Grapper Hook	Snowshoe Attachment [1]	Trail Breaker	Ankle Assist	Ankle Assist (Actuated)	Propeller Thust	Snow gripper	Snow gripper (Actuated)	Mobile Skis [2]	Equipment Tow	Ski tooth [3]	Snow Poles	Ski Snow Removal	Thermal Friction	Jack	Jack (Actuated)	CO2	O2	Exoskeleton
Feasibility [4]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Requirements:																			
Device results in less energy exerted by the user during the uphill climb (average weight of person is 85-100kg, include equipment)	Yes	No	Yes	No	No	Yes	No	-	Yes	Yes	Yes	Yes	N/A	NO	No	No	No	-	Yes
User is capable of climbing a 30-40 deg slope	Yes	-	Yes	-	-	Yes	-	-	Yes	Yes	Yes	Yes	N/A	-	-	-	-	-	Yes
Device does not fully eliminate the need for user to exert work	Yes	-	Yes	-	-	Yes	-	-	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-	Yes
Same size as 2 1L Nalgene Bottle	No	-	N/A	-	-	No	-	-	Yes	Yes	N/A	N/A	Yes	-	-	-	No	-	N/A
Device does not obstruct user's range of motion	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	No	-	-	-	-	-	Yes
Device does change downhill skiing stance	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	No
Device does not obstruct downhill skier visibility	-	-	Yes	-	-	-	-	NO	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Device is light (if being carried by user uphill)	-	-	N/A	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Device is light (if being carried by user downhill)	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Be less noisier than a typical cordless drill	-	-	Yes	-	-	No	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Not increases risk of being caught in an avalanche	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Use rechargeable batteries if using batteries. Avoid using disposable batteries.	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
No usage of a gasoline engine	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Capable of operating at an altitude of up to 3000m	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Functions in snow, rain, and other weather conditions that can be reasonably expected when skiing in backcountry	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Withstand temperatures as low as -35 degC for durations of no less than 8 hours	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Fully Functional between comfortable BC skiing condition	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Have a 5 year design life for non-replaceable components	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Operate with a maximum of $20/day	-	-	Yes	-		-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	-
Have cost of production of less than $500 CAD per unit in volumes of 1000 units	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	No
Device can be sold in retail shops across North America	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	
Is usable 65% of the daylight hours as a bare minimum	-	-	Yes	-	-	-	-	-	Yes	Yes	Yes	Yes	-	-	-	-	-	-	
Technical Readiness	Yes	Yes	Yes	yes	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	No	No
Justification/Comments:	See p. 22 in Rishabh logbook for appropriate calculations	Because the uphill hiking is more of a sliding motion rather than "picking up your foot and stepping", this device would not significantly benefit the user		Because the uphill hiking is more of a sliding motion rather than "picking up your foot and stepping", this device would not significantly benefit the user		Device will create significant noise because of rotating propeller; propeller and motor is larger than 2L with current technology	Device is static and would therefore impede the upward sliding motion of the user.	Skis inevitably will cross/touch and the teeth will contact each other obstructing motion and/or damage equipment					Skis inevitably will cross/touch and the teeth will contact each other obstructing motion and/or damage equipment	Client said no	Because the uphill hiking is more of a sliding motion rather than "picking up your foot and stepping", this device would not significantly benefit the user	Because the uphill hiking is more of a sliding motion rather than "picking up your foot and stepping", this device would not significantly benefit the user	The tank will have to be large to be able to maintain an entire day (possibly more) of backcountry skiing; therefore, will be very heavy.	To have a compact mask that filters O_2 is technically very difficult and not within the team's abilities within the time frame given.	The cost of an exoskeleton unit will be very expensive; designing exoskeletons is also very complex and beyond the team's abilities within the time frame.
Passes Winnowing?	NO	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO

E-4 Pugh Chart

There were 5 concepts remaining entering the Pugh chart phase. In the interest of time, two Pugh Charts with different datums (actuated ski teeth and the trail breaker) were first completed individually via Google sheets according to evaluation criteria which can be found in Appendix D (p. 46). Afterwards, any criteria with discrepancies less than a ratio of 6:1 were further discussed as a group. A summary of the results is provided below.

The Pugh chart revealed that the mobile skis concept performed poorly across most criterion and mediocre in other. The mobile skis concept was ultimately eliminated because it ranked last between both datums. The other concepts were further researched to quantify their performance criteria for the Weighted Decision Matrix.

E-4.1 Pugh Chart_October 4, 2017 (Final Copy)

Evaluation Criteria	Trail Breaker	Mobile Skis [1]	Equipment Tow	Ski Teeth (Actuated) [2]	Ski Poles
User is capable of climbing a steep slope	-	-	-	S	S
Energy Savings	+	+	+	S	S
Volume	-	-	-	S	S
Device does not increase net downhill run time	-	-	-	S	S
Compatibility	+	S	+	S	-
Weight	+	-	-	S	+
Noise	-	-	-	S	+
Decrease avalanche-related risks	S	S	-	S	S
Decrease risk of injury from a fall	+	-	-	S	S
Increase risk of surviving an avalanche	S	S	S	S	S
Product Failure Durability Thresholds (Destructive Testing)	-	-	-	S	S
Product Lifetime (How long can the device function under normal use?)	-	-	-	S	+
Cost for user per day	-	-	-	S	+
Reduce the cost to produce the device	-	-	-	S	+
Device can be sold internationally (International retail viability)	S	S	S	S	S
Device Endurance	-	-	-	S	+
Device has been designed wtih affordances	S	-	S	S	+
Device pacakging uses an efficient amount of volume				S	
Device negligibly impacts users' ability to conduct Rutschblock Test	S	S	S	S	S
∑+	4	1	2	0	7
∑S	5	5	4	18	9
∑-	8	11	11	0	1
Total	**-4**	**-10**	**-9**	**0**	**6**
Rank	**3**	**5**	**4**	**2**	**1**
User is capable of climbing a steep slope	S	S	-	+	+
Energy Savings	S	S	S	-	-
Volume	S	-	S	-	S
Device does not increase net downhill run time	S	S	S	+	+
Compatibility	S	-	-	-	-
Weight	S	-	-	-	-
Noise	S	S	S	+	+
Decrease avalanche-related risks	S	S	-	S	S
Decrease risk of injury from a fall	S	-	-	-	-
Increase risk of surviving an avalanche	S	S	S	S	S
Product Failure Durability Thresholds (Destructive Testing)	S	-	-	-	-
Product Lifetime (How long can the device function under normal use?)	S	S	S	S	S
Cost for user per day	S	+	+	+	+
Reduce the cost to produce the device	S	+	+	+	+
Device can be sold internationally (International retail viability)	S	S	S	S	+
Device Endurance	S	S	+	+	+
Device has been designed wtih affordances	S	S	S	S	S
Device pacakging uses an efficient amount of volume	S	S	S	S	+
Device negligibly impacts users' ability to conduct Rutschblock Test	S	-	S	S	
∑+	0	2	3	6	8
∑S	19	11	10	7	5
∑-	0	6	6	6	5
Total	**0**	**-4**	**-3**	**0**	**3**
Rank	**2**	**5**	**4**	**2**	**1**

E-5 Weighted Decision Matrix (WDM)

The last stage of concept selection was the Weighted Decision Matrix (WDM). Four concepts remained after completing the Pugh chart; ski teeth, ski poles, trail breaker, and the equipment tow. While researching information to quantify the ski poles performance, we discovered that a similar product and patent exists, something we overlooked in the preliminary research stage. As a result, we discarded the ski poles concept.

After some rough calculations on the ski teeth, it was concluded that they could assist the ski skins but wouldn't be able to replace their function. When conducting an interview with an avid backcountry skier, Bryan Starick, we were informed that there is no market for a device that works in conjunction with the ski skins; there is only interest for something that fully replaces ski skins. Given this information the ski skins were also eliminated.

The WDM has been updated several times throughout the project. The revision history of the WDM below throughout the project highlights its iterative nature:

- E-5.1 Weighted Decision Matrix (WDM)_October 10, 2017 (Original Copy)
  - When we were doing the first weighted decision matrix, we rated the trail breaker and the equipment tow by the relative scale. For each evaluation criteria, the different design had different performance which gave us different rating. The weight of the evaluation criteria based on the weight of each stakeholder. We considered how many stakeholders care about each evaluation criteria and how important of each evaluation criteria for different stakeholders. The result showed us that the trail breaker weighted more.
- E-5.2 Weighted Decision Matrix (WDM)_October 30, 2017 (Final Copy)
  - After our concept selection review, we were told by our instructor that we should use the actual scale instead of the relative scale. In our weighted decision matrix, there were some evaluation criteria weighting 0 percent which we should just delete them. The last important thing was that the design group voted for if we going to change the definition of the compatibility of the equipment tow after we discussed with the instructor. Finally, we decided to change our definition of the compatibility from

"Device requires the purchase of a new backpack (which replaces existing ski equipment)" to "Device requires the purchase of a new backpack (which replaces existing ski equipment) OR the design of a sled that is compatible with the user's existing backpack". The final result showed the equipment tow weighted more. Thus, our decision was change from the trial breaker to the equipment tow.

E-5.1 Weighted Decision Matrix (WDM)_October 10, 2017 (Original Copy)

Evaluation Criteria	Weight (%)	Justifications for Weighting	Trail Breaker			Equipment Tow		
			Rating	Rating Justification	Score	Rating	Rating Justification	Score
Device has been designed wtih affordances (See the pre-defined/agreed on affordances)	0.00%	Not an independent criteria	0.00	N/A	0.00	0.00	N/A	0.00
Device pacakging uses an efficient amount of volume	0.00%	Not an independent criteria	0.00	N/A	0.00	0.00	N/A	0.00
Device increases the number of metres of elevation traversed per day	0.00%	Not an independent criteria	0.00	N/A	0.00	0.00	N/A	0.00
Device is quiet	0.00%	As long as the device is < 78 dB, there is no benefit to a significantly quieter device.	0.00	N/A	0.00	0.00	N/A	0.00
Device has a low daily operations cost (variable cost)	1.50%	If the device functions and is less than $20/day, then there is no benefit in maximizing this criteria.	3.33	Torque requirement is double for trail breaker compared to the equipment tow	0.05	6.67	Torque requirement is double for trail breaker compared to the equipment tow	0.10
Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?)	2.00%	The client would like to have return buyers, therefore a midrange lifetime is desired. This translated into a low weighting.	4.29	Based on the ratio of identified subsystems (3 - e.g., controls, propulsion/drive train, chassis)	0.09	5.71	Based on the ratio of identified subsystems (2 - e.g., chasis, drive train)	0.11
Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	2.00%	The device should not be subjected to extreme conditions frequently, therefore this criteria is given a low weighting.	5.00	While motor and battery are affected most by temperature and the powder consistency of the snow affects the motion of the device, these effects are the same for both devices.	0.10	5.00	While motor and battery are affected most by temperature and the powder consistency of the snow affects the motion of the device, these effects are the same for both devices.	0.10
Device usage results in a decreased influential volume (uphill movement)	2.00%	A smaller volume does not directly correlate with a decrease in energy needed, therefore weighting is low	5.00	Device has no influential ascent volume.	0.10	5.00	Device has no influential ascent volume.	0.10
User is capable of climbing a steep slope, which is 30-40 Deg slope (i.e., conditions for sidestepping and switchbacks)	2.50%	Conditions where side stepping is required do not occur often enough to yield a high weighting. However, when these conditions do occur, they are a severe hinderance. Thus, a weighting of 5% was reached.	5.00	Regardless of time to climb a steep slope, device is capable of operating on a slope of 30-40 degrees.	0.13	5.00	Regardless of time to climb a steep slope, device is capable of operating on a slope of 30-40 degrees.	0.13
Device decreases the risk of injury from a fall (See the pre-defined/agreed on levels of risk) [1]	5.00%	If a person injures themselves, serious consequences could arise. However, the likelihood of a person injuring themselve is also low. Therefore a midrange weighting is given.	5.00	Both devices are either not on the user (uphill) or in the user's backpack (downhill); therefore, they have an equal risk of injuring the user from a fall	0.25	5.00	Both devices are either not on the user (uphill) or in the user's backpack (downhill); therefore, they have an equal risk of injuring the user from a fall	0.25
Device usage results in a decreased influential volume (downhill movement)	6.00%	For the same reason as uphill volume, the weighting is low. However, it is slightly higher because downhill movement affects the skier more than uphill movement.	2.00	Volume is approximately (45 x 44.5 x 60) 0.12015m^3	0.12	8.00	Volume is approximately (10.5 x 11 x11 cm) 0.0115555 m^3	0.48
Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	6.50%	Not an independent criteria	6.99	Device saves 228kJ (for 1000m) because it carries equipment (98.4 kJ) and packs the snow in front of the user (130kJ)	0.45	3.01	Device saves 98.4kJ (for 1000m vertically) because it carries equipment	0.20
Device minimizes time spent for adjustment	6.50%	If the device reverses the effect of ascending faster by increasing the time it takes to descend, the purpose of the device is defeated. Therefore this criteria is given a 6.5 weighting	10.00	Device requires only two instances of time spent (one at the top and one at the bottom) of each hill to assemble and disassemble which we approximate to take a maximum of 10 minutes.	0.65	0.00	Device requires multiple stops (every 50ft) as the user climbs which we approximate to take a maximum of 2 hours (1000m/(0.13m/seconds)/(3600s/hour) ~ 2.13hours)	0.00
Device net influential weight (uphill movement) is small	8.00%	Please refer to corresponding downhill net weight criteria. (Both criteria still maintain a relatively high weighting because weight, in general, affects the skier's ability to ascend)	5.00	Device decreases the uphill influential weight as they contain carrying compartments and are not carrier uphill.	0.40	5.00	Device decreases the uphill influential weight as they contain carrying compartments and are not carrier uphill.	0.40
Device is compatible (See the pre-defined/agreed on levels of compatibility) [2]	9.00%	Consumers would be more likely to buy a product that is compatible with their equipment, thus increasing the client's profit. Therefore, the weighting is relatively high.	10.00	Device does not interfere with any existing backcountry skiing equipment.	0.90	0.00	Device requires the purchase of a new backpack (which replaces existing ski equipment).	0.00
Device may be operated uninterrupted for long periods of time (i.e., device endurance)	10.00%	If the device cannot be used, there is no point to the device, therefore the weighting was relatively high.	5.00	Designs have been specified with the same battery capcaity, to last a full day of skiing	0.50	5.00	Designs have been specified with the same battery capcaity, to last a full day of skiing	0.50
Device has a low production cost	12.00%	A low productiong cost would increase the client's profits and make it more attractive to the consumer. Therefore, a high weighting is given.	3.93	Estimated total cost is approximately ~$850.	0.47	6.07	Estimated total cost is approximately ~$550.	0.73
Device net influential weight (downhill movement) is small	12.00%	This weighting is higher than that of the corresponding uphill criteria because we have been told (by two separate back country skiers) that downhill weight affects the user more than uphill weight because it changes the stability of the skier.	4.29	Estimated total weight (which will have to be carried back down) is ~4kg. Based on the estimated weights for the main components that are in common, the equipment tow is 75% of the weight of the trail breaker.	0.51	5.71	Estimated total weight (which will have to be carried back down) is ~3kg. Based on the estimated weights for the main components that are in common, the equipment tow is 75% of the weight of the trail breaker.	0.69
Risk of development	15%	It was made clear to us that having a product that worked, regardless of efficiency, was better than having a product which did not work. Therefore, this was our highest weighting.	3.75	Device has 3 subsystems (e.g., controls, propulsion/drive train, chassis); calculations involve more assumptions (e.g., everything from the equipment tow plus the snow comparison to dry sand), changes in design are easier to implement	0.56	6.25	Device has 2 subsystems (e.g., chasis, drive train), calculations contain few assumptions (e.g., ~weight, snow friction, etc), changes in design are dificult to implement	0.94
Net Score	**100.00%**				**5.28**			**4.72**
Rank					**1**			**2**

E-5.2 Weighted Decision Matrix (WDM)_October 30, 2017 (Final Copy)

Evaluation Criteria	Weight (%)	Justifications for Weighting	Scale	Trail Breaker			Equipment Tow		
				Rating	Rating Justification	Score	Rating	Rating Justification	Score
Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?) Device has a high resilience to extreme environmental conditions (i.e., a high product failure threshold)	6.00%	The client would like to have return buyers, therefore a midrange lifetime is desired; however, a consumer would rather have a device that has a high lifetime. Additionally, the device should not be subjected to extreme conditions frequently (because of our scope).This translated into a low weighting because this evaluation criteria is split between clients and consumers.	1 - device does not need component replacement in 5 years (the requirements (minimum) and can withstand temperatures of -35degC for 8 hours 5 - device does not need component replacement in "deviation of 2.5 from 10 years" and can withstand temperatures of -40degC for 8 hours (amount of time skiers typically take for sleeping on overnight trips) 10 - device does not need component replacement in 10 years and can withstand temperatures of -45degC for 8 hours (amount of time skiers typically take for sleeping on overnight trips)	1.50	Based on the assumption that the skier skis for 30 days in a year (5 days/month from November to April) and based on the fact that Lithium Ion battery's capacity can drop to as low as 75% after 200 cycles, the battery must be replaced every 7 years to meet the minimum operating hours requirement. Based on identified subsystems (3 - e.g., controls, propulsion/drive train, chassis), the likelihood of component replacement is higher in trail breaker than in equipment tow. Furthermore, this device has a moving component which is actively breaking the trail and is therefore facing higher stresses due to contact with snow.	0.09	3.00	Based on the assumption that the skier skis for 30 days in a year (5 days/month from November to April) and based on the fact that Lithium Ion battery's capacity can drop to as low as 75% after 200 cycles, the battery must be replaced every 7 years to meet the minimum operating hours requirement. Based on the ratio of identified subsystems (2 - e.g., chasis, drive train), the likelihood of component replacement is lower in equipment tow. Furthermore, since this device has a "sled" which slides on the snow, the stresses that it experiences from snow contact are much lower than the trail breaker.	0.18
Device has a high product lifetime (i.e., How long can the device function under normal use/ideal conditions?)	6.00%	A requirement for the device is to be operational for 65% of the daylight hours as a bare minimum. It is desirable to have additional operational time, but not highly important because, in reality, the device will have periods of time when it is not in use (when the skier takes a break)	1 - works 65% of daylight hours (requirement) 5 - works 82.5% of daylight hours 10 - works 100% of daylight hours or more	1.00	Battery has been chosen such that the device meets the minimum requirements of operating for 65% of daylight hours (5.5 hours)	0.06	1.00	Battery has been chosen such that the device meets the minimum requirements of operating for 65% of daylight hours (5.5 hours)	0.06
Device results in less energy (work) exerted by the user during uphill movement (Energy Savings) in ideal conditions	8.00%	The purpose of the device is to reduce the energy required to climb uphill. However, the primary function of the device is to achieve more runs per day, for which there are two ways to achieve this function: energy savings and time savings (going uphill). As such, these two evaluation criteria are highly weighted together (and are equally weighted because they contribute equally to the primary function when separate).	1 - device saves 0J of energy 5 - device saves 100kJ of energy (the energy spent carrying up an average size backpack) 10 - device saves 200kJ of energy (double the energy spent carrying up an average size backpack)	10.00	Assuming that the amount of energy that the device uses is roughly the same as the energy saved by the user, we find that the device saves 228kJ (for 1000m) because it carries equipment (98.4kJ) and packs the snow in front of the user (130kJ)	0.80	4.90	Assuming that the amount of energy that the device uses is roughly the same as the energy saved by the user, we find that the device saves 98.4kJ (for 1000m vertically) because it carries equipment	0.39
Device minimizes time spent for adjustment	8.00%		1 - time used for adjustment from using the device equals 2x more than time saved from using the device 5 - time used for adjustment from using the device equals the time saved from using the device 10 - time used for adjustment from using the device equals 2x less than time saved from using the device (up to 10 minutes which is what is currently spent for adjustment according to interviews)	10.00	Device requires only two instances of time spent (one at the top and one at the bottom) of each hill to assemble and disassemble which we approximate to take a maximum of 10 minutes.	0.80	1.00	Device requires multiple stops (every 50ft) as the user climbs which we approximate to take a maximum of 1 hour. A current skier can travel approximately 1000ft per hour; if we were to be optimistic and say that our device saves the skier 30 minutes of time (i.e., the skier can traverse twice as fast while using the device), the time for adjustment is 2 times more than the time saved.	0.08
Device decreases the risk of injury (e.g. from a fall)	10.00%	If a person injures themselves, serious consequences could arise. However, the likelihood of a person injuring themselve is also low. Therefore a midrange weighting is given.	1 - Significantly increases risk (e.g., sharp items on body) 5 - Has no effect of risk 10 - Significantly reduces risk	5.00	Device is either not on the user (uphill) or in the user's backpack (downhill); however, while in the backpack, the device does not have any sharp edges and would add minimal risk (to what the risk would be from falling with a backpack full of current ski gear).	0.50	5.00	Device is either not on the user (uphill) or in the user's backpack (downhill); however, while in the backpack, the device does not have any sharp edges and would add minimal risk (to what the risk would be from falling with a backpack full of current ski gear).	0.50
Device is compatible	10.00%	Consumers would be more likely to buy a product that is compatible with their equipment, thus increasing the client's profit. This is corroborated by interviewee feedback.	1 - Not compatible with all different essential ski equipment 2. Not compatible with different body size 4 - Requires slight modification for different body sizes 6 - Requires slight modification of existing, essential ski equipment 8 - Non compatible with non-essential ski equipment (e.g., backpack) 10 - Fully compatible (no adjustment, substitution with no loss of functionality compared to the idea it replaces, or totally new addition to existing gear)	10.00	Device does not interfere with any existing backcountry skiing equipment.	1.00	10.00	Device requires the purchase of a new backpack (which replaces existing ski equipment) OR the desgin of a sled that is compatible with the user's existing backpack	1.00
Device usage results in a decreased influential volume	10.00%	Volume is mid-range in importance because it only affects the skier's stability if it alters their center of gravity (as opposed to weight which is detrimental regardless of where it is attached to the skier). Absolute volume is also a factor for downhill skiing because it takes up backpack space. In addition, downhill influential volume is more important than uphill influential volume as it affects the downhill experience.	1 - Volume of existing backpack 0.06m^3 (but device is used outside backpack for uphill movement and can be stored in 2 backpacks for downhill movement based on interviews) 5 - 0.021m^3 (but device is used outside backpack for uphill movement and can be stored in 2 backpacks for downhill movement based on interviews) 10 - Volume increase of 0.002m^3 or less	1.00	Volume is approximately (45 x 44.5 x 60) 0.12015m^3 (which can be split up between 2 backpacks for groups of at least 2 skiers)	0.10	7.50	Volume is approximately (10.5 x 11 x11 cm) 0.0115555 m^3	0.75
Device has a low production and operating cost	13.50%	A low productiong cost would increase the client's profits and make it more attractive to the consumer (especially consumers within our scope that may be new to backcountry skiing and not wanting to invest in equipment); therefore, a high weighting is given.	1 - device production costs 500$ for 1000 units (requirement) 5 - device production costs $300 for 1000 units (requirement) 10 - device is less $100 for 1000 units (based off the average cost of skins)	1.88	Estimated total cost is approximately ~$850 (for a single unit); therefore, our estimated cost for production is half of the estimated cost per unit (to be conservative) which considers discounts for quantity.	0.25	5.63	Estimated total cost is approximately ~$550 (for a single unit); therefore, our estimated cost for production is half of the estimated cost per unit (to be conservative) which considers discounts for quantity.	0.76
Device net influential weight is small	13.50%	Weight is one of the most important factors (as corroborated by interviews and our weekly meetings with our prof/TA). Additionally, downhill weight affects the user more than uphill weight because it changes the stability of the skier. Both criteria still maintain a relatively high weighting because weight, in general, affects the skier's ability to ascend and their downhill experience.	1 - device influential weight is 4kg (requirement) 5 - device influential weight is 2 kg 10 - device influential weight is not relevant (i.e., less than 0.5kg)	1.00	Estimated total weight (which will have to be carried back down) is ~4kg. Based on the estimated weights for the main components that are in common, the equipment tow is 75% of the weight of the trail breaker.	0.14	3.57	Estimated total weight (which will have to be carried back down) is ~3kg. Based on the estimated weights for the main components that are in common, the equipment tow is 75% of the weight of the trail breaker.	0.48
Risk of development	15.00%	It was made clear to us that having a product that worked was better than having a product which did not work. Additionally, as an engineering team, our limited time as engineering student must be efficiently spent so that a higher cost is not assumed by a client. Furthermore, because we are engineering students, our technical abilities are limited; therefore, a difficult project would require exponentially more time (which, in the real world, would translate into billable hours).	1 - first iteration of detail design can be completed within ~3 weeks (based on our Gantt Chart slack time for detail design) 5 - first iteration of detail design can be completed within ~2 weeks 10 - first iteration of detail design can be completed within ~1 week	3.00	Device has 3 subsystems (e.g., controls, propulsion/drive train, chassis); calculations involve more assumptions (e.g., everything from the equipment tow plus the snow comparison to dry sand); based on our current research, we've had difficulty quantifying the material properties of snow and expect to spend much more time on design.	0.45	6.25	Device has 2 subsystems (e.g., chasis, drive train), calculations contain few assumptions (e.g., ~weight, snow friction, etc), changes in design are dificult to implement. Most of the components have had rough calculations made for the purposes of the WDM and the team does not expect to deviate from these calculations very much during the detail deisgn (expect to have difficulty finding off-the-shelf components and/or designing components from scratch).	0.94
Net Score	**100.00%**					**3.74**			**4.20**
Rank						**2**			**1**

APPENDIX F: FAILURE AND SAFETY

To evaluate failure and safety for the equipment tow, a design failure methods and effects analysis (FMEA) was used. An FMEA is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service; failures are any errors or defects, especially ones that affect the customer, and can be potential or actual. The purpose of the FMEA is to study the consequences of those failures.

F-1 Failure Methods and Effects Analysis Rating Definitions

When using the FMEA, severity, occurrence, and detection ratings were defined according to Table F-2: Severity, Occurrence, and Detection Rating Definitions.

- Severity measures the level of impact on a system if failure does occur.
- Occurrence estimates the probability of failure occurring for that reason during the lifetime defined within the project scope.
- Detection estimates how well the controls can detect either the cause or its failure mode after they have happened, but before the effect is felt by the user.

From these three ratings, a risk priority number is calculated; based on this value, recommended actions are executed. To determine what risks are considered high risk, definitions as shown in Table F-1: Risk Priority Number Definitions are created and, generally, only the most significant risks are acted on. (H-9, p.176)

Table F-1: Risk Priority Number Definitions

RPM Value	Description
≥ 250	Significant
100 - 249	Somewhat Important
< 100	Not Important

Table F-2: Severity, Occurrence, and Detection Rating Definitions

Severity		Occurrence		Detection	
10	severe injury or death or major damage	10	certain	10	no chance of detection and action
9	serious injury or damage	9	extreme	9	almost no chance of detection and action
8	injury or major disruption	8	very high	8	very low chance of detection and action
7	very significant customer dissatisfaction	7	high	7	low chance of detection and action
6	significant customer dissatisfaction	6	moderately high	6	low- moderate chance of detection and action
5	customer requires immediate service	5	moderate	5	moderate chance of detection and action
4	customer inconvenienced by premature need for service	4	low	4	moderate-high chance of detection and action
3	customer annoyed but not enough to demand service	3	very low	3	high chance of detection and action
2	customer notices but is not annoyed	2	extremely low	2	very high chance of detection and action
1	effect not noticed by customer (benign)	1	almost never	1	almost certain to detect and correct

F-2 Evolution of Design Failure Methods and Effects Analysis (FMEA)

Throughout the project, three FMEAs were created to evaluate design risks; listed serially, they are as follows:

- F-2.1 Initial FMEA_October 26, 2017
  - The initial FMEA was based on components from the initial definition of subsystems. This allowed the detail design process to further develop as high risk priority numbers (RPNs) identified additionally required subsystems.
- F-2.2 Mid-Range FMEA_October 28, 2017
  - The midrange FMEA was completed using the first comprehensive iteration of the equipment tow. Therefore, the FMEA allowed potential failures due to subsystem combing to be identified.
- F-2.3 Final-Range FMEA_November 4, 2017
  - The final FMEA identified recommendations that need to be relayed to the client because they could not be addressed within the time limitations. It additionally identified recommendations that are in the user manual which will allow the equipment tow user to safely operate the device.

F-2.1 Initial FMEA_October 26, 2017

Part:	Rope	**System or Sub-system:**	Winch
Original date:	2017 - 10 - 26	**Prepared by:**	Juliana
Revision date:	2017 - 10 - 28	**Revised by:**	Amanda

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Rope is coated in snow/ice	rope cannot be wound around the drum, customer can no longer use the device	7	snow/ice is deposited on the drum	7	none	10	490	Design a shield/enclosure to prevent snow from entering	Cole	7	1	10	70
			snow/ice is deposited on the rope	7	none	10	490	Design a shield/enclosure to prevent snow from entering	Cole	7	1	10	70
			snow/ice is pulled into the drum by the rope	10	none	10	700	Design a method of removing snow/ice from rope before it enters the drum	Amanda/Jason	7	1	10	70
			the rope is left outside overnight and the rope becomes coated with snow/ice	5	rope and drum are kept out of snow/ice when not in use	1	35	No action taken					
Rope Shears	rope breaks; customer can no longer use the device	7	rope rubs a sharp object enough to shear rope	5	rope is not used on terrain with sharp areas	5	175	Shear resistant rope is found	Juliana	7	2	5	70
			rope is worn over a surface enough to shear rope	5	rope is not used on terrain with sharp areas	5	175	Shear resistant rope is found	Juliana	7	2	5	70
			rope is twisted enough to shear rope	5	rope is visually checked for shearing before us	1	35	No action taken.					
			rope rubs against itself enough to shear rope	3	rope is visually checked for shearing before us	1	21	No action taken.					
Rope threads unravel	rope breaks, rope cannot pull a load	7	rope is partially cut	5	rope is visually checked for cut threads before use	1	35	No action taken					
			rope ends lose tension	4	rope ends are visually checked for loose threads before use	1	28	No action taken					
			rope is frayed	5	rope is visually checked for loose threads before use	1	35	No action taken					
			individual threads are pinched and pulled apart	4	rope is visually checked for loose threads before use	1	28	No action taken					
Rope Corrodes	rope breaks; rope cannot pull a load	7	rope is exposed to moisture (enough to corrode rope)	10	none	10	700	Pick a rope that can endure moisture	Juliana	7	2	5	70
			rope is exposed to battery fluids (enough to corrode rope)	3	rope is kept away from fluids which are known to cause corrosion	5	105	No action taken					
			rope is exposed to gears (enough to corrode rope)	5	none	10	350	Design the device so that gears are not exposed to the rope	Dan Wei/Jason	7	1	10	70
			rope is exposed to antifreeze (enough to corrod rope)	3	rope is kept away from fluids which are known to cause corrosion	5	105	No action taken					

Part:	Drum/Rope Guiding System	System or Sub-system:	Winch
Original date:	2017 - 10 - 26	Prepared by:	Amanda
Revision date:	2017 - 10 - 28	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
shaft cracks	drum cannot turn; device becomes inoperable	7	fatigue	4	Visually check shaft for cracks.	1	28	No action taken					
			extreme temperature differences	4	Visually check shaft for cracks.	1	28	No action taken					
			bending stresses due to the rope	4	Visually check shaft for cracks.	1	28	No action taken					
			fall during descent	5	Visually check shaft for cracks.	1	35	No action taken					
Rope guiding system does not move	rope coils over the same area; drum becomes jammed and the device is no longer operable	7	jammed by ice or snow	5	None.	10	350	Incorporate some kind of enclosure to prevent debris form entering.	Cole	7	1	10	70
			jammed by rope	5	Physically check if the guiding system is jammed/not operating	3	105	No action taken					
			threads of the lead screw misalign	5	Visually check if lead screw threads are misaligned	3	105	No action taken					
			system guide is misaligned from vibrations	5	None.	10	350	Design the rope guiding system for some sort of self-alignment	Jason/Amanda	7	1	10	70
bushings does not turn	winch does not operate; device is no longer useful	7	bushing is jammed by ice or snow	5	None	10	350	Incorporate some kind of enclosure to prevent debris form entering.	Cole	7	1	10	70
			bushing is damaged due to excess radial load	4	Physically check if the bushings do not turn	3	84	No action taken					
			bushing is increased in size because a shaft is jammed into it	5	Physically check if the bushings do not turn	3	105	No action taken					
			Temperature causes bushings to tighten and become force fitted	4	Physically check if the bushings do not turn	3	84	No action taken					
drum cracks	drum will no longer hold the winch rope; device is completely inoperable	7	fatigue	4	visually check if the drum is cracked	1	28	No action taken.					
			extreme temperature differences	4	visually check if the drum is cracked	1	28	No action taken.					
			bending stresses due to the rope	4	visually check if the drum is cracked	1	28	No action taken.					
			Fall during ascent	4	visually check if the drum is cracked	1	28	No action taken.					

Part:	Powertrain	**System or Sub-system:**	Transmission
Original date:	2017 - 10 - 26	**Prepared by:**	Justin
Revision date:	2017 - 10 - 28	**Revised by:**	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Bending Fatigue	Crack propagation, fracture of teeth or other parts of gear	7	Miscalculations leading to excessive loads on teeth or misestimated life	5	quality check during the production line	2	70	no action taken					
			Stress risers from notches, cracks, residual stress from manufacturing defects	5	calculations checked by another individual	2	70	no action taken					
			unaccounted moments caused by misalignment	5	none	10	350	design chasis that allows for self-aligning	Justin	7	1	10	70
			chosen material does not have an endurance limit	5	appropriate material chosen by designer	2	70	no action taken					
Abrasive Wear	Increases friction in the system; decreasing efficency and increasing temperature	6	Foreign materials in the lubrication system	5	none	10	300	Incorporate some kind of enclosure to prevent debris form entering.	Rish	6	1	5	30
			Gearbox filter is not functioning as intended	4	quality check during production	2	48	no action taken					
			Debris enters the gear box; increasing wear	4	none	10	240	Incorporate some kind of enclosure to prevent debris form entering.	Rish	6	1	5	30
			Weld spatter during manufacturing process, causing excess wear	4	quality check during production	2	48	no action taken					
Pitting	Stress concentrations will originate in areas with pitting; causing cracks; rough operation	6	Incorrect involute profile causes improper gear meshing	3	calculation check by another individual	4	13	no action taken					
			Manufacturing errors causing surface irregularities; incorrect gear meshing	3	quality check during maufacturing	2	11	no action taken					
			Miscalculations causing surface overload; damaging teeth profile	4	calculation check by another individual	2	12	no action taken					
			Incorrect material solution for intended operation	3	check that the correct material is chosen (by going over someone's work)	2	11	no action taken					
Corrosion	Chemical reactions deteriorate surface; at high temperatures chemicals can become actively corrosive; weakens gears, increased interference, pitting,	6	Snow/water enters gearbox causing corrosion	5	none	10	300	Incorporate some kind of enclosure to prevent debris form entering.	Rish	6	1	10	60
			Contaminated lubrication enters gearbox	4	quality check that lubrication is not containated	2	48						
			Improper manufacturing processes chemically damage gear	4	quality check on the manufacturing process	2	48						
			Oil in lubricant breaks down allowing corrosive chemicals to damage gear surface	4	check calculations that correct lubricant is chosen	2	48						

Part:	Sled	System or Sub-system:	Chassis
Original date:	2017 - 10 - 26	Prepared by:	Cole
Revision date:	2017 - 10 - 28	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Fracture	Crack Formation/Propagation	5	Cold temperature Snap	2	Visually check for fracture	1	10	No action taken.					
			Fall during skiing	5	Visually check for fracture	1	25	No action taken.					
			Impacts from unintended path during ascent	2	Visually check for fracture	1	10	No action taken.					
			Sled gets caught on terrain during ascent	3	Visually check for fracture	1	15	No action taken.					
Wear	Decreased efficiency of the sled	3	Friction over snow and ice	7	Predicatable over time	2	42	No action taken.					
			Sliding over rough paths (rocks and twigs)	8	Visual detection	3	72	No action taken.					
			Torque cycles from operation	2	Periodic fastener tightening in manual	5	30	No action taken.					
			Vibrations of bumpy terrain	2	Pre inspection of ascent paths	3	18	No action taken.					
Bearing Stress failure	disconnect of sled from winch	8	Snowbuild up on sled	5	visual inspection and intervention	6	240	Tilt front entry of the sled	Cole	8	2	6	96
			User over loads sled	4	Safetfy markers for overloading	3	96	No action taken.					
			Sled gets caught up on terrain during ascent	3	Pre inspection of ascent paths	3	72	No action taken.					
			User overtightens winch	4	limit on controls	1	32	No action taken.					
Loss of orientation	Loss of equipment	7	Inclined ascent plane	8	Pre inspection of ascent paths	3	168	Implment sqeuring system (net)	Cole	4	8	3	96
			Sled catches on terrain	3	Pre inspection of ascent paths	3	63	No action taken.					
			User loads equipment asymmetrically	5	Warning Label	3	105	No action taken.					
			deviates from intended ascent path	5	Pre inspection of ascent paths	3	105	No action taken.					

Part:	Motor	System or Sub-system:	Transmission
Original date:	2017 - 10 - 26	Prepared by:	Rish
Revision date:	2017 - 10 - 28	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Motor stalls	Winch no longer raises equipment up hill	7	Power distribution board fries	1	Ensure that power distribution board is rated for 3 times the nominal current draw	9	63	No action taken					
			Snowbuild up causing overload of weight	10	Visual Inspection	1	70	No action taken					
			Users attempts to ascend too steep of an incline	5	User manual / Warning Label	1	35	No action taken					
			User exceeds sled's maximum load rating	5	User manual / Warning Label	1	35	No action taken					
internal misalignment	Efficiency of motor is significantly reduced which reduces the number of operating hours	5	physical damage if user falls	4	Design a rigid mount for the motor	2	40	No action taken					
			excessive torque applied to the motor shaft by user misuse	4	appropriate warning label placed on device	3	60	No action taken					
			Shaft couplings fail	3	calculations checked by another individual to ensure tha tthe appropriate coupling is chosen	2	30	No action taken					
			Shaft is loaded unevenly	2	none	10	100	Design chasis that restricts loads to the appropriate location	Rish	5	1	10	50
motor over heats	Reduced Lifetime	7	ice/dirt buildup on fan	5	Visual Inspection	2	70	No action taken					
			fan breaks	4	User Trouble Shooting (Listen for Fan)	2	56	No action taken					
			Snowbuild up causing overload of wieght	5	Visual Inspection	2	70	No action taken					
			Snow buildup on device causes over insulation	4	Visual Inspection	2	56	No action taken					
			Water enters the motor core and shorts the windings	5	Add watertight seal on motor's opening points	2	70	No action taken					
Motor is unmounted	Motor would not deliver any useful torque. In the worst case, motor would start spinning around its own axis which would tangle the power wires.	7	physical damage if user falls	4	Design a rigid mount for the motor	2	56	No action taken					
			Mounting fasteners strip off	4	Spec fasteners which can support moment loads	2	56	No action taken					
			excessive moments produced on motor mounts due to unaccounted forces	5	Have another member check over forces to check that all forces are accounted for	2	70	No action taken					
			threads of fastening components become crossthreads	5	none	10	350	Increase the safety factor	Rish	7	1	10	70

Part:	Battery	System or Sub-system:	Power Generation
Original date:	2017 - 10 - 26	Prepared by:	Rish
Revision date:	2017 - 10 - 28	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned to	Expected Results of action			
	Effect	S	Cause	O	Control	D				S	O	D	RPN'
individual battery cell dies (is 0V)	battery is no longer operable; device is no longer operable	7	chemicals leak (puncture(s) in the battery)	7	ensure that battery is inside rigid enclosure	2	98	No action taken					
			cell overheats	4	check the battery temperature at regular intervals	7	196	check that each cell is functioning before the product is shipped	Rishabh	7	2	7	98
			physical damage if user falls	10	ensure that battery is inside rigid enclosure	1	70	No action taken					
			loss of communication between cells	1	none	10	70	No action taken					
			cell is discharged below 3V	10	Add a beeper which emits loud beeps once the cell voltage drops below 3.6V	1	70	No action taken					
battery spontaneously combusts	battery is no longer operable; device is no longer operable	9	chemicals leak (battery is punctured)	5	ensure that battery is inside rigid enclosure	2	90	No action taken					
			high storage temperature	5	do not place the battery in high temperature environment	5	225	Add label to indicate storage temperature	Rish	9	2	2	36
			physical damage if user falls	5	visually check that the battery is not damaged/bulging	2	90	No action taken					
			battery is charged at lower than 2C	3	do not charge the battery at lower than 2C	3	81	No action taken					
Battery's power and ground wires short	Battery smokes and possibly combusts, and the device is rendered useless	9	insulating coating on wires wear out	4	Put electrical tape/heat shrink on parts where insulation has worn out	2	72	No action taken					
			Battery terminals are unintentionally shorted by user	5	Place warning labels on the battery's connector	2	90	No action taken					
			Water shorts any electronic component on power distribution board	9	None	10	810	Design a waterproof encloser	Rish	9	1	10	90
			Battery is plugged in the wrong way	2	Use connectors which can only be inserted in one way	2	36	No action taken					
battery's capacity is decreased	device operates for less than 5.5 hours	6	inadequate ventilation	7	none	10	420	Design an enclosure with ventilation	Rish	6	1	10	60
			Inadequate thermal insulation	3	battery is thermally isulated	2	36	No action taken					
			battery is charged at higher than 2C	3	do not charge the battery at lower than 2C	3	54	No action taken					
			Battery has undergone too many charging cycles (during the 5 year period)	5	none	10	300	Choose high quality battery	Rishabh	6	1	10	60

F-2.2 Mid-Range FMEA_October 28, 2017

Part:	Rope	**System or Sub-system:**	Winch
Original date:	2017 - 10 - 28	**Prepared by:**	Juliana
Revision date:	2017 - 11 - 01	**Revised by:**	Amanda

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Rope is coated in snow/ice	rope cannot be wound around the drum, customer can no longer use the device	7	snow/ice is deposited on the drum		need some sort of shield (told jason)		0						
			snow/ice is deposited on the rope		need some sort of shield (told jason)		0						
			snow/ice is pulled into the drum by the rope	4	rubber ring which removes snow/ice from the rope before it coils around the drum and the instruction manual specifies that the rubber ring should be regularly changed (with the provided replacements)	2	56	No action taken.					
			the rope is left outside overnight and the rope becomes coated with snow/ice	5	user manual specifies that the rope and drum should be kept out of snow/ice when not in use	3	105	No action taken					
Rope Shears	rope breaks; customer can no longer use the device	7	rope rubs a sharp object enough to shear rope	5	sticker is placed on device to indicate that the user should avoid using the rope on terrain with sharp areas and the user manual specifies that the rope should be visually inspected before each use for shearing	3	105	No action taken					
			a high load places the rope under extreme tension	2	sticker is placed on device indicating that the maximum load is 6000lbs	1	14	No action taken					
			rope is twisted enough to shear rope	3	user manual specifies that the rope should be visually inspected before each use for shearing	3	63	No action taken.					
			rope rubs against itself enough to shear rope	3	user manual specifies that the rope should be visually inspected before each use for shearing	3	63	No action taken.					
Rope threads unravel	rope breaks; customer can no longer use the device	7	rope is partially cut	5	user manual specifies that the rope should be visually inspected before each use for unravelling	3	105	No action taken					
			rope ends lose tension	3	user manual specifies that the rope should be visually inspected before each use for unravelling	3	63	No action taken					
			rope is frayed	4	user manual specifies that the rope should be visually inspected before each use for unravelling	3	84	No action taken					
			individual threads are pinched and pulled apart	3	user manual specifies that the rope should be visually inspected before each use for unravelling	3	63	No action taken					
Rope Corrodes	rope breaks; customer can no longer use the device	7	rope is exposed to moisture (enough to corrode rope)	2	moisture resistent rope is selected and the user manual specifies that the rope should be visually inspected before each use for corrosion	2	28	No action taken					
			rope is exposed to battery fluids (enough to corrode rope)	3	rope is separated from the battery by 2-3 layers of material and the user manual specifies that the rope should be visually inspected before each use for corrosion	2	42	No action taken					
			rope is exposed to gears (enough to corrode rope)	3	rope is separated from the gear by 1-2 layers of material and the user manual specifies that the rope should be visually inspected before each use for corrosion	2	42	No action taken					
			rope is exposed to antifreeze (enough to corrod rope)	5	sticker is placed on device to indicate that the user should store the rope away from corrosive substances and the user manual specifies that the rope should be visually inspected before each use for corrosion	3	105	No action taken					

Part:	Drum	System or Sub-system:	Winch
Original date:	2017 - 10 - 28	Prepared by:	Amanda
Revision date:	2017 - 11 - 01	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
drum bends/distorted	rope does not wind properly around the drum; causes rope to jam; device is no longer useful	7	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the drum should be visually inspected before each use for bending	2	56	No action taken					
			bending stresses due to the rope	4	user manual specifies that the drum should be visually inspected before each use for bending	3	84	No action taken					
			Fall during ascent	5	user manual specifies that the drum should be visually inspected before each use for bending	3	105	No action taken					
			fatigue	4	user manual specifies that the drum should be visually inspected before each use for bending	3	84	No action taken					
bearing keyslot fails	drum does not rotate and rope is not wound around the drum; device is no longer useful	7	key slot becomes too big due to vibrations and wearing, thus the key slides out	3	user manual specifices that the bearing should be physically checked for correct operation before each use	3	63	No action taken					
			key breaks because of excessive force	4	user manual specifices that the bearing should be physically checked for correct operation before each use	3	84	No action taken					
			key shears due to misaslignment	5	quality check in the factory for correct placement	3	105	No action taken					
			debris enters the keyslot, which jams the bearing	3	the bearing is inside the drum, therfore protected from the outside; in addition, user manual specifices that the bearing should be physically checked for correct operation before each use	2	42	No action taken					
bushings do not turn	drum does not rotate and rope is not wound around the drum; device is no longer useful	7	bushing is jammed by ice or snow	3	user manual specifices that the bushings should be physically checked for correct operation before each use	3	63	No action taken					
			bushing is damaged due to excess radial load	4	user manual specifices that the bushings should be physically checked for correct operation before each use	3	84	No action taken					
			bushing size changes because a shaft is jammed into it	4	user manual specifices that the bushings should be physically checked for correct operation before each use	3	84	No action taken					
			Temperature causes bushings to contract/expand	4	user manual specifices that the bushings should be physically checked for correct operation before each use	3	84	No action taken					
drum cracks	drum will no longer hold the winch rope; device is completely inoperable	7	fatigue	4	user manual specifices that the drum should be physically checked for cracks before operation	3	84	No action taken					
			extreme temperature differences	4	user manual specifices that the drum should be physically checked for cracks before operation	3	84	No action taken					
			bending stresses due to the rope	4	user manual specifices that the drum should be physically checked for cracks before operation	3	84	No action taken					
			Fall during ascent	5	user manual specifices that the drum should be physically checked for cracks before operation	3	105	No action taken					

Part:	Level Wind System	System or Sub-system:	Winch
Original date:	2017 - 10 - 28	Prepared by:	Amanda
Revision date:	2017 - 11 - 03	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Power screw threads shear	carriage cannot evenly wind up the rope, causing the rope to jam; device is no longer operable	7	fatigue	4	user manual specifies that the threads should be visually inspected before each use for shearing	3	84	No action taken					
			needle and power screw are misaligned	3	needle guide aligns the power screw and needle; in addition, the user manual specifies that the threads should be visually inspected before each use for shearing	3	63	No action taken					
			bending stresses due to the rope pulling on the carriage/needle	4	user manual specifies that the threads should be visually inspected before each use for shearing	3	84	No action taken					
			fall during descent which applied a force onto the threads	5	user manual specifies that the threads should be visually inspected before each use for shearing	3	105	No action taken					
Needle inside of carriage breaks	rope coils over the same area; drum becomes jammed and the device is no longer operable	7	debris on the surface of the power screw	3	the needle is located inside the needle guide which removed debris; in addition, the user manual specifices that the needle should be physically checked for correct operation before use	3	63	No action taken					7
			carriage has excessive force applied to it by the rope	4	the user manual specifices that the needle should be physically checked for correct operation before use	3	84	No action taken					
			misalignment with the power screw	4	quality check at the factory for correc initial alignment; in addition, the user manual specifices that the needle should be physically checked for correct operation before use	3	84	No action taken					
			vibrations jam the needle into the power screw, causing it to fracture	4	the user manual specifices that the needle should be physically checked for correct operation before use	3	84	No action taken					
bushings do not turn	carriage cannot evenly wind up the rope, causing the rope to jam; device is no longer operable	7	bushing is jammed by ice or snow	3	the bushing is located inside the carraige, threrefore debris should not enter the bearing; in addition, the user manual specifices that the bushings should be physically checked for correct operation before use	2	42	No action taken					
			bushing is damaged due to excess radial load	4	user manual specifices that the bushings should be physically checked for correct operation before use	3	84	No action taken					
			misalignment with the shaft	4	quality check at the factory for correct initial alignment; in additon, the user manual specifices that the bushings should be physically checked for correct operation before use	2	56	No action taken					
			Temperature causes bushings to expand/contract	4	user manual specifices that the bushings should be physically checked for correct operation before use	3	84	No action taken					
carriage breaks	rope cannot be evenly wound around the drum; device is no longer operable	7	fatigue	4	user manual specifices that the carriage should be visually checked for breakage before operation	3	84	No action taken.					
			extreme temperature differences	4	user manual specifices that the carriage should be visually checked for breakage before operation	3	84	No action taken.					
			bending stresses due to the rope	4	user manual specifices that the carriage should be visually checked for breakage before operation	3	84	No action taken.					
			Fall during ascent	5	user manual specifices that the carriage should be visually checked for breakage before operation	3	105	No action taken.					

Part:	Gears	**System or Sub-system:**	Transmission
Original date:	2017 - 10 - 28	**Prepared by:**	Justin
Revision date:	2017 - 11 - 01	**Revised by:**	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Bending Fatigue	Crack propagation lead to fracture of teeth/other parts of gear; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	7	Miscalculations leading to excessive loads on teeth or misestimated life	4	calculations checked by another individual	2	56	no action taken					
			Stress risers from notches, cracks, residual stress from manufacturing defects	5	quality check at the factory for stress risers	3	105	no action taken					
			unaccounted moments caused by misalignment	5	safety factor for each component is appropriately high	3	105	no action taken					
			chosen material does not have an endurance limit	5	appropriate material chosen by designer	2	70	no action taken					
Abrasive Wear	Increases friction in the system; decreasing efficency and increasing temperature; ultimately leads fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	7	gears are are not parallel to each other (misaligned)	5	quality check at factory for correct initial alignment	3	105	no action taken					
			gear profiles are not conjugate	4	quality check during production for conjugate profile	3	84	no action taken					
			Debris enters the gears	4	gears are enclosed	3	84	no action taken					
			excessive torque is applied to the gear	4		2	56	no action taken					
Pitting	Stress concentrations will originate in areas with pitting; causing cracks which propogate to fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	6	Incorrect involute profile causes improper gear meshing	3	quality check during production for conjugate profile	3	12	no action taken					
			Manufacturing errors causing surface irregularities; incorrect gear meshing	4	quality check during maufacturing	3	13	no action taken					
			Miscalculations causing surface overload; damaging teeth profile	3	calculation check by another individual	3	12	no action taken					
			Incorrect material solution for intended operation	3	check that the correct material is chosen (by going over someone's work)	3	12	no action taken					
Corrosion	Chemical reactions deteriorate surface; at high temperatures chemicals can become actively corrosive; weakens gears, increased interference, pitting, ultimately leading to fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	7	Snow/water enters meshing gears causing corrosion	3	gears are enclosed	3	63	no action taken					
			gears are exposed to battery fluid	3	battery and gear are enclosed in to separate compartment	2	42	no action taken					
			Improper manufacturing processes chemically damage gear	4	quality check on the manufacturing process	2	56	no action taken					
			gears are exposed to antifreeze	3	gears are enclosed; in addition, the user manual states that the gears should not be exposed to fluids	2	42	no action taken					

Part:	Gears	System or Sub-system:	Transmission
Original date:	2017 - 10 - 28	Prepared by:	Justin
Revision date:	2017 - 11 - 03	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
shaft cracks	drum cannot turn; device becomes inoperable	7	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the chassis should be visually inspected before each use for bending	2	28	No action taken					
			bending stresses due to the rope	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	28	No action taken					
			Fall during ascent	5	user manual specifies that the chassis should be visually inspected before each use for bending	3	28	No action taken					
			fatigue	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	35	No action taken					
chassis bends/distorts	excess stress is placed on other components due to misalignment caused by bending; these components break; the device falls apart; the device is effectively useless	7	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the chassis should be visually inspected before each use for bending	2	56	no action taken					
			bending stresses due to the rope	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	84	no action taken					
			Fall during ascent	5	user manual specifies that the chassis should be visually inspected before each use for bending	3	105	no action taken					
			fatigue	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	84	no action taken					
chassis breaks	drum falls out of chassis; device no longer functions	7	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the chassis should be visually inspected before each use for bending	2	13	no action taken					
			bending stresses due to the rope	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	14	no action taken					
			Fall during ascent	5	user manual specifies that the chassis should be visually inspected before each use for bending	3	15	no action taken					
			fatigue	4	user manual specifies that the chassis should be visually inspected before each use for bending	3	14	no action taken					
bolts become lose	chassis falls apart; drum falls out; device is effectively useless	7	excess force shears off the threads of the bolt	4	user manual specifies that the chassis should be visually inspected before each use for bolt failure	3	84	no action taken					
			bending stresses cause the bolt to fracture	4	user manual specifies that the chassis should be visually inspected before each use for bolt failure	3	84	no action taken					
			fall during ascent fractures the bolt	5	user manual specifies that the chassis should be visually inspected before each use for bolt failure	3	105	no action taken					
			fatigue causes fracture	4	user manual specifies that the chassis should be visually inspected before each use for bolt failure	3	84	no action taken					

Part:	Sled	System or Sub-system:	Chassis
Original date:	2017 - 10 - 28	Prepared by:	Cole
Revision date:	2017 - 11 - 01	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Fracture	Crack Formation/Propagation; device no longer carries equipment therefore is useless	7	Cold temperature Snap	2	Visually check for fracture	1	14	No action taken.					
			Fall during skiing	5	Visually check for fracture	1	35	No action taken.					
			Impacts from unintended path during ascent	2	Visually check for fracture	1	14	No action taken.					
			Sled gets caught on terrain during ascent	3	Visually check for fracture	1	21	No action taken.					
Wear	wear leads to fracture; device no longer carries equipment therefore is useless	7	Friction over snow and ice	7	Predicatable over time	2	98	No action taken.					
			Sliding over rough paths (rocks and twigs)	8	durable material is chosen so that wearing under normal conditions is minmal	2	112	No action taken.					
			Torque cycles from operation	2	Periodic fastener tightening in manual	5	70	No action taken.					
			Vibrations of bumpy terrain	2	Pre inspection of ascent paths	3	42	No action taken.					
Bearing Stress failure	disconnect of sled from winch; device no longer carries equipment therefore is useless	7	Snowbuild up on sled	5	front entry of sled is tilted	3	105	No action taken.					
			User over loads sled	4	Safetfy markers for overloading	3	84	No action taken.					
			Sled gets caught up on terrain during ascent	3	Pre inspection of ascent paths	3	63	No action taken.					
			User overtightens winch	4	limit on controls	1	28	No action taken.					
Loss of orientation	Loss of equipment; device no longer carries equipment therefore is useless	7	Inclined ascent plane	8	sqeuring system (net)	2	112	No action taken.					
			Sled catches on terrain	3	Pre inspection of ascent paths	3	63	No action taken.					
			User loads equipment asymmetrically	5	Warning Label	3	105	No action taken.					
			deviates from intended ascent path	5	Pre inspection of ascent paths	3	105	No action taken.					

Part:	Motor	System or Sub-system:	Transmission
Original date:	2017 - 10 - 28	Prepared by:	Rish
Revision date:	2017 - 11 - 01	Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	S	Cause	O	Control	D				S'	O'	D'	RPN'
Motor stalls	Winch no longer raises equipment up hill	7	Power distribution board fries	1	Ensure that power distribution board is rated for 3 times the nominal current draw	9	63	No action taken					
			Snowbuild up causing overload of weight	10	Visual Inspection	1	70	No action taken					
			Users attempts to ascend too steep of an incline	5	User manual / Warning Label	1	35	No action taken					
			User exceeds sled's maximum load rating	5	User manual / Warning Label	1	35	No action taken					
internal misalignment	clutch no longer functional due to excessive wear from misalignment; device is no longer operable	7	fall during ascent	4	Design a rigid mount for the motor	2	56	No action taken					
			excessive torque applied to the motor shaft by user misuse	4	appropriate warning label placed on device	3	84	No action taken					
			Shaft couplings fail	3	calculations checked by another individual to ensure tha tthe appropriate coupling is chosen	2	42	No action taken					
			Shaft is loaded unevenly	2	chasis restricts loads to the appropriate location	2	28	No action taken					
motor over heats	excessive heat leads to combustion of the motor; fragments from possible explosion may hurt user; device becomes inoperable	9	ice/dirt buildup on fan	5	Visual Inspection	2	90	No action taken					
			fan breaks	4	User Trouble Shooting (Listen for Fan)	2	72	No action taken					
			Snowbuild up causing overload of wieght	5	Visual Inspection	2	90	No action taken					
			Water enters the motor core and shorts the windings	4	Visual Inspection	2	72	No action taken					
Motor is unmounted	Motor would not deliver any useful torque. In the worst case, motor would start spinning around its own axis which would tangle the power wires.	7	physical damage if user falls	4	Design a rigid mount for the motor	2	56	No action taken					
			Mounting fasteners strip off	4	Spec fasteners which can support moment loads	2	56	No action taken					
			excessive moments produced on motor mounts due to unaccounted forces	5	Have another member check over forces to check that all forces are accounted for	2	70	No action taken					
			threads of fastening components become crossthreaded	5	safety factor of threads is increased	4	140	No action taken					

Part:	Battery	**System or Sub-system:**	Power Generation
Original date:	2017 - 10 - 28	**Prepared by:**	Rish
Revision date:	2017 - 11 - 01	**Revised by:**	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned to	Expected Results of action			
	Effect	S	Cause	O	Control	D				S	O	D	RPN'
individual battery cell dies (is 0V)	open circuit occurs; battery is no longer operable; device is no longer operable	7	chemicals leak (puncture(s) in the battery)	7	ensure that battery is inside rigid enclosure	2	98	No action taken					
			cell overheats	4	quality check at factory that each cell is properly functioning	3	84	No action taken					
			physical damage if user falls	10	ensure that battery is inside rigid enclosure	1	70	No action taken					
			loss of communication between cells	1	none	10	70	No action taken					
			cell is discharged below 3V	10	Add a beeper which emits loud beeps once the cell voltage drops below 3.6V	1	70	No action taken					
battery spontaneously combusts	battery is no longer operable; fragments from possible explosion may hurt user; device is no longer operable	9	chemicals leak (battery is punctured)	5	ensure that battery is inside rigid enclosure	2	90	No action taken					
			high storage temperature	4	sticker indicates that the battery should not be placed in a high temperature environment	3	108	No action taken					
			physical damage if user falls	5	visually check that the battery is not damaged/bulging	2	90	No action taken					
			battery is charged at lower than 2C	3	do not charge the battery at lower than 2C	3	81	No action taken					
Battery's power and ground wires short	Battery smokes and possibly combusts; fragments from possible explosion may hurt user; the device is rendered useless	9	insulating coating on wires wear out	4	Put electrical tape/heat shrink on parts where insulation has worn out	2	72	No action taken					
			Battery terminals are unintentionally shorted by user	5	Place warning labels on the battery's connector	2	90	No action taken					
			Water shorts any electronic component on power distribution board	3	enclosure is sealed with silicone to ensure that water cannot enter	3	81	No action taken					
			Battery is plugged in the wrong way	2	Use connectors which can only be inserted in one way	2	36	No action taken					
battery's capacity is decreased	device operates for less than 5.5 hours	6	inadequate ventilation	4	enclosure is waterproof yet allows for ventilation	3	72	No action taken					
			Inadequate thermal insulation	3	battery is thermally isulated	2	36	No action taken					
			battery is charged at higher than 2C	3	do not charge the battery at lower than 2C	3	54	No action taken					
			Battery has undergone too many charging cycles (during the 5 year period)	3	high quality battery is chosen so that the safety factor for charging cycles is high	3	54	No action taken					

Part:	Enclosure	System or Sub-system:	Enclosure System
Original date:	2017 - 10 - 26	Prepared by:	Rish
Revision date:		Revised by:	Juliana

Failure Mode	Severity		Occurrence		Detection		RPN	Recommended Action	Assigned to	Expected Results of action			
	Effect	S	Cause	O	Control	D				S	O	D	RPN'
waterproof seal breaks	water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	9	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the enclosure should be visually inspected before each use for for seal breakage	2	72	No action taken					
			bending stresses due to the rope	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
			Fall during ascent	5	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	135	No action taken					
			fatigue	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
enclosure fractures	water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	9	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the enclosure should be visually inspected before each use for for seal breakage	2	72	No action taken					
			bending stresses due to the rope	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
			Fall during ascent	5	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	135	No action taken					
			fatigue	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
enclosure bends/distorts	bending leads to crack propogation; water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	9	extreme temperature differences	4	correct material is selected so that temperature does not cause expansion/contraction and the user manual specifies that the enclosure should be visually inspected before each use for for seal breakage	2	72	No action taken					
			bending stresses due to the rope	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
			Fall during ascent	5	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	135	No action taken					
			fatigue	4	user manual specifies that the enclosure should be visually inspected before each use for seal breakage	3	108	No action taken					
enclosure corrodes/wears excessively fast	corrosion/wear leads to crack propogation; water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	6	enclosure is exposed to rough external surfaces	4	material for enclosure is chosen correctly so that normal wear is acceptable	4	96	No action taken					
			enclosure is exposed to battery fluids	3	battery is sealed with a plastic cover	3	54	No action taken					
			enclosure is in contact with the gears	3	quality check at the factory that gears are correctly mounted away from the enclosure	3	54	No action taken					
			enclosure is in contact with the motor and vibrations lead to wear	4	user manual indicates that the user whould periodically check if the motor is tightly fastened to the enclosure	3	72	No action taken					

F-2.3 Final-Range FMEA_November 4, 2017

Table F-3: Final FMEA for the Rope

Part:	Rope		**System or Subsystem:**	Winch	
Original date:	2017 - 11 - 04		**Prepared by:**	Juliana	
Revision date:	2017 - 11 - 06		**Revised by:**	Amanda	

Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Person Responsible**	**Expected Results of Action**			
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S'**	**O'**	**D'**	**RPN'**
Rope is coated in snow/ice	rope cannot be wound around the drum, customer can no longer use the device	The worse case scenario occurs when the snow/ice buildup on the rope prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	snow/ice is deposited on the drum	10	it is almost certain that snow or ice will be deposited on the drum since it is open	none	10	there is no control	700	will recommend to client to design panels which will be attached to the chassis (in between the enclosures on either end of the winch). This will reduce the likelihood of snow being deposited yet still allow the drum to be open and accessible.					
					snow/ice is deposited on the rope	10	it is almost certain that snow or ice will be deposited on the rope since it is open	none	10	there is no control	700	will recommend to client to design panels which will be attached to the chassis (in between the enclosures on either end of the winch). This will reduce the likelihood of snow being deposited yet still allow the rope to be open and accessible.					
					snow/ice is pulled into the drum by the rope	10	it is certain that snow/ice will be pulled into the device	none	10	there is no control	700	recommend to client to add a rubber ring so the carriage that will remove ice/snow from the rope before it wraps around the drum					
					rope is left outside overnight and it becomes coated with snow/ice	4	the probability of a $500+ device being left outside by a user is low, assuming that the user is rational and wouldn't want to damage something they spent a lot of money on	none	10	there is no control	280	have user manual specify that the rope and drum should be kept out of snow/ice when not in use					
Rope Shears	rope breaks; customer can no longer use the device	The worse case scenario occurs when the rope breaks due to shear and prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	rope rubs a sharp object enough to shear rope	5	the probability of the rope rubbing against something sharp is moderate	none	10	there is no control	350	place sticker on device to indicate that the user should avoid using the rope on terrain with sharp areas and have the user manual specify that the rope should be visually inspected periodically for shearing					
					a high load places the rope under extreme tension	2	the probability of an extreme tension on the rope, due to an extreme load greater than 6000 lbs, is extremely low since our use is designed for a load around 10kg (0)	quality check at production to check that each winch can pull a maximum load of 6000 lbs	3	there is a high probability that the control will keep the occurrence low	42	sticker is placed on device indicating that the maximum load is 6000 lbs					
					rope is twisted enough to shear rope	2	the probability of the rope twisting enough to shear is extremely low because it would require extreme levels of twisting	quality check at production to check that each winch can pull a maximum load of 6000 lbs	3	there is a high probability that the control will keep the occurrence low	42	no action taken					
					rope rubs against itself enough to shear rope	2	the probability of the rope rubbing against itself to shear is extremely low because it would require extreme levels of rubbing	quality check at production to check that each winch can pull a maximum load of 6000 lbs	3	there is a high probability that the control will keep the occurrence low	42	no action taken					
Rope threads unravel	rope breaks; customer can no longer use the device	The worse case scenario occurs when the rope breaks due to unravelling and prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	rope is partially cut due to the environment	5	there is a moderate probability of the rope being cut due to normal use	none	10	there is no control	350	place sticker on device to indicate that the user should avoid using the rope on terrain with sharp areas user manual specifies that the rope should be visually inspected periodically for thread unravelling					
					rope ends lose tension	3	there is a low probability of the rope ends becoming lose because they will be clamped together	quality check during production that the ends are properly clamped	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					rope is frayed	5	there is a moderate probability of the rope fraying with regular wear and tear	none	10	there is no control	350	user manual specifies that the rope should be visually inspected periodically for thread unravelling					
					individual threads are pinched and pulled apart	3	there is a very low probability of the rope being pinched and pulled apart due to the braiding of the rope	quality check during production that the ropes are braided properly	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
Rope Corrodes	rope breaks; customer can no longer use the device	The worse case scenario occurs when the rope breaks due to corrosion and prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	rope is exposed to moisture (enough to corrode rope)	2	there is an extremely low probability that moisture will corrode the rope because it is made out of synthetic materials that are resistant to water	quality check during production that the rope is waterproof	3	there is a high probability that the control will keep the occurrence low	42	no action taken					
					rope is exposed to battery fluids (enough to corrode rope)	3	there is a very low probability that the rope will be exposed to battery fluids because the battery will be encased in synthetic shrink wrap then enclosed within a rigid case	quality check during production that the battery is properly sealed	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					rope is exposed to gears (enough to corrode rope)	3	there is a very low probability that the rope will be exposed to the gears because the gears will be enclosed in a rigid case	quality check during production that the gears are properly sealed	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					rope is exposed to antifreeze (enough to corrode rope)	4	there is a low probability that the rope will be exposed to antifreeze, assuming that the user is rational and does not want to damage their expensive device by being careless and letting it be exposed to antifreeze	none	10	there is no control	280	sticker is placed on device to indicate that the user should store the rope away from corrosive substances and the user manual specifies that the rope should be visually inspected periodically for corrosion					

Table F-4: Final FMEA for the Drum

Part:	Drum				**System or Subsystem:**	Winch												
Original date:	2017 - 11 - 04				**Prepared by:**	Amanda												
Revision date:	2017 - 11 - 06				**Revised by:**	Juliana												
Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Person Responsible**	**Expected Results of Action**			
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S'**	**O'**	**D'**	**RPN'**
drum bends/distorted	rope does not wind properly around the drum; causes rope to jam; device is no longer useful	The worse case scenario occurs when the distortion prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	extreme temperature differences	3	the probability of an extreme temperature difference causing the drum to distort is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	63	no action					
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to distort the drum is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	no action					
					Fall during ascent	5	there is a moderate probability of the drum distorting if a user fall on it	none	10	there is no control	350	user manual specifies that the drum should be visually inspected periodically for distortion					
					fatigue	10	the drum will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).					
bearing key slot fails	drum does not rotate and rope is not wound around the drum; device is no longer useful	The worse case scenario occurs when the bearing prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	key slot becomes too big due to vibrations and wearing, thus the key slides out	3	the probability of the vibrations increasing the size of the slot is very low because the key slot is initially placed into a tight fit	quality control during production to ensure a tight fit between the key and the slot	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					key breaks because of excessive force exerted by the user falling	5	there is a moderate probability of the bearing failing if a user fall on it	none	10	there is no control	350	user manual specifies that the bearing should be physically checked for correct operation periodically					
					key shears due to misalignment	3	the probability of misalignment is very low because the key slot is initially placed into a tight fit	quality check in the factory for correct alignment	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					debris enters the key slot, which jams the bearing	2	the probability of debris entering the bearing is extremely low because the bearing is located inside of the drum and sealed off	quality check during production that the bearing is sealed off	3	there is a high probability that the control will keep the occurrence low	42	No action taken					
bushings do not turn	drum does not rotate and rope is not wound around the drum; device is no longer useful	The worse case scenario occurs when the bushings prevent the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	bushing is jammed by ice or snow	2	the probability of debris entering the bushings is extremely low because the bushings are located inside of the enclosure on either side of the drum	quality check during production that the bushings are sealed off	3	there is a high probability that the control will keep the occurrence low	42	no action taken					
					bushing is damaged due to excess radial load	3	the probability of excess radial load is low because the enclosures will take the load before the bushings will	quality check during production that the enclosure is properly installed	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					bushing size changes because the shaft is jammed into it	3	the probability of the shaft being jammed into the bushings is low because we have two bushings (one is locating and the other is load bearing)	quality check during production that one bushing is floating and the other is load bearing	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					Temperature causes bushings to contract/expand	3	the probability of the bushings fluctuating with temperature is low because the chosen bushings are rated for -15dC (L-1.2 , p.216)	quality check during production that the bushings are rated to the appropriate temperatures	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
drum cracks	drum will no longer hold the winch rope; device is completely inoperable	The worse case scenario occurs when the broken drum prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	fatigue	10	the drum will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).					
					extreme temperature differences	3	the probability of an extreme temperature difference causing the drum to crack is low because we have chosen material that can withstand -15 (dC) operating temperatures and -35 (dC) storage temperatures	quality check during production that the drum is rated to the appropriate temperature	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to crack the drum is low because the rope is only 50ft long and the designed load is 15 kg	quality check during production that the drum is rated to the appropriate load	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					Fall during ascent	5	there is a moderate probability of the drum distorting if a user fall on it	none	10	there is no control	350	user manual specifies that the drum should be physically checked for cracks periodically					

Table F-5: Final FMEA for Level Wind System

Part:	Level Wind System	**System or Subsystem:**	Winch
Original date:	2017 - 11 - 04	**Prepared by:**	Amanda
Revision date:	2017 - 11 - 06	**Revised by:**	Juliana

Failure Mode	Severity				Occurrence			Detection			RPN	Recommended Action	Person Responsible	Expected Results of Action			
	Effect	Effect Justification	S	S Justification	Cause	O	O Justification	Control	D	D Justification				S'	O'	D'	RPN'
Power screw threads shear	carriage cannot evenly wind up the rope, causing the rope to jam; device is no longer operable	The worse case scenario occurs when the thread shearing prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	fatigue	10	the power screw will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).					
					needle and power screw are misaligned	3	the probability of misalignment is very low because the needle and power screw are initially placed set into a tight fit	quality check during production for correct alignment	3	there is a high probability that the control will keep the occurrence low	63	no action is taken					
					bending stresses due to the rope pulling on the carriage/needle	3	the probability of the rope exerting a bending stress big enough to shear the power screw threads are very low because the carriage would take the majority of the load	quality check during production that the carriage is properly aligned with the power screw	3	there is a high probability that the control will keep the occurrence low	63	no action is taken					
					fall during descent which applied a force onto the threads	5	there is a moderate probability of the threads shearing if a user falls onto the device	none	10	there is no control	350	user manual specifies that the threads should be visually inspected periodically for shearing					
Needle inside of carriage breaks	rope coils over the same area; drum becomes jammed and the device is no longer operable	The worse case scenario occurs when the needle failure prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	debris on the surface of the power screw	3	the probability of debris on the power screw is because low the needle is located inside the needle guide which removes debris	quality check during production that the guide contacts the power screw	3	there is a high probability that the control will keep the occurrence low	63	No action taken					7
					carriage has excessive force applied to it by the rope	3	the probability of the rope exerting a load big enough to fracture the needle are very low because the carriage would take the majority of the load and our expected loads are lower than our designed loads (H-2 , p.158)	quality check during production that the carriage can handle the appropriate designed load	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					misalignment with the power screw	3	the probability of misalignment is low because the needle and power screw are initially placed set into a tight fit	quality check at the factory for correct initial alignment	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					vibrations jam the needle into the power screw, causing it to fracture	3	the probability of the needle being jammed into the power screw is low because the carriage provides a set distance between them	quality check during production that the distance between the carriage and the power screw are correct	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
bushings do not turn	carriage cannot evenly wind up the rope, causing the rope to jam; device is no longer operable	The worse case scenario occurs when the bushings failing prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	bushing is jammed by ice or snow	2	the probability of snow/ice entering the bushing is the low because the bushings are located inside the carriage, therefore debris should not enter the bearing	quality check during production that the bushing is sealed off	3	there is a high probability that the control will keep the occurrence low	42	no action taken					
					bushing is damaged due to excess load due to the user falling	5	there is a moderate probability of misalignment if a user falls onto the device	none	10	there is no control	350	user manual specifies that the bushings should be physically checked for correct operation periodically					
					misalignment with the shaft	3	the probability of misalignment is low because initial alignment is tightly fitted	quality check at the factory for correct initial alignment	3	there is a high probability that the control will keep the occurrence low	63	no action is taken					
					Temperature causes bushings to expand/contract	3	the probability of temperature causing our bushings to change volume is low because they are rated for temperatures of -15dC	quality check during production that the bushings are rated to the appropriate temperature	3	there is a high probability that the control will keep the occurrence low	63	no action is taken					
carriage breaks	rope cannot be evenly wound around the drum; device is no longer operable	The worse case scenario occurs when the carriage failure prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	fatigue	10	the carriage will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).					
					extreme temperature differences	3	the probability of carriage fracturing due to extreme temperature differences is low because it is rated for an operating temperature of -15 dC	quality check during production that the carriage is rated for the appropriate temperatures	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					bending stresses due to the rope	3	the probability of the rope exerting a load big enough to fracture the carriage is very low because the expected loads on the carriage are smaller than the designed loads	quality check during production that the carriage is rated for the appropriate load	3	there is a high probability that the control will keep the occurrence low	63	no action taken					
					Fall during ascent	5	there is a moderate probability of carriage fracture if a user falls onto the device	none	10	there is no control	350	user manual specifies that the carriage should be visually checked for breakage periodically					

Table F-6: Final FMEA for Gears

Part:	Gears				**System or Subsystem:**		Transmission												
Original date:	2017 - 11 - 04				**Prepared by:**		Justin												
Revision date:	2017 - 11 - 06				**Revised by:**		Juliana												
Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Assigned To**	**Expected Results of Action**					
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S'**	**O'**	**D'**	**RPN'**		
Bending Stress	Crack propagation lead to fracture of teeth/other parts of gear; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	The worse case scenario occurs when the bending fatigue leads to the gears failing which ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Miscalculations leading to excessive loads on teeth or misestimated life	3	probability is very low because the calculations are checked by another individual	calculation check pre-production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Stress risers from notches, cracks, residual stress from manufacturing defects	3	probability is very low because the gears will be checked during production for manufacturing defects	quality check at the factory for stress risers	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					unaccounted moments caused by user falling	5	probability of user falling causing bending stresses are moderate	none	10	there is no control	350	user manual states that all components should be checked for damage if there is an appropriate reason to believe damage (eg if user fall on the device)							
					chosen material does not have an endurance limit	3	probability is very low because the appropriate material will be chosen by designer and calculations checked by another	calculation check pre-production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
Abrasive Wear	Increases friction in the system; decreasing efficiency and increasing temperature; ultimately leads fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	The worse case scenario occurs when abrasive wear leads to the gears failing which ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	gears are are not parallel to each other (misaligned)	3	probability is very low because of initial alignment and the safety factors of each component prevent misalignment	quality check at factory for correct initial alignment	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					gear profiles are not conjugate	3	probability is very low because there will be a quality check for conjugate profiles during production	quality check during production for conjugate profile	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Debris enters the gears	3	probability is very low because the gears are enclosed	quality check during production that the gears are enclosed	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					excessive torque is applied to the gear because of misalignment	3	probability is very low because of initial alignment while safety factors prevent distortions caused by forces within reason	quality check that the motor, shaft, and gear are aligned properly during production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
Pitting	Stress concentrations will originate in areas with pitting; causing cracks which propagate to fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	The worse case scenario occurs when pitting leads to the gears failing which ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Incorrect involute profile causes improper gear meshing	3	probability is very low because there will be a quality check for conjugate profiles during production	quality check during production for conjugate profile	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Manufacturing errors causing surface irregularities; incorrect gear meshing	3	probability is very low because the gears will be checked during production for manufacturing defects	quality check during manufacturing	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Miscalculations causing surface overload; damaging teeth profile	3	probability is very low because the calculations are checked by another individual	pre-production calculation check by another individual	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Incorrect material solution for intended operation	3	probability is very low because the appropriate material will be chosen by designer and calculations checked by another	pre-production calculation check that the correct material is chosen	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
Corrosion	Chemical reactions deteriorate surface; at high temperatures chemicals can become actively corrosive; weakens gears, increased interference, pitting, ultimately leading to fracture; level wind cannot evenly wind rope leading so rope jam; device is no longer operable	The worse case scenario occurs when corrosion leads to the gears failing which ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Snow/water enters meshing gears causing corrosion	3	probability is very low because the gears are enclosed	quality check during production that eh gears are enclosed	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					gears are exposed to battery fluid	3	there is a very low probability that the gears will be exposed to battery fluids because the battery will be encased in synthetic shrink wrap then enclosed within a rigid case	quality check during production that the batteries are appropriately sealed	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Improper manufacturing processes chemically damage gear	3	probability is very low because the gears will be checked during production for manufacturing defects	quality check on the manufacturing process	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					gears are exposed to antifreeze	4	there is a low probability that the rope will be exposed to antifreeze, assuming that the user is rational and does not want to damage their expensive device by being careless and letting it be exposed to antifreeze	none	10	there is no quality check	280	sticker is placed on device to indicate that the user should store the gears away from corrosive substances and the user manual specifies that the rope should be visually inspected periodically for corrosion							

Table F-7: Final FMEA for Sled

Part:	Sled	**System or Subsystem:**	Chassis
Original date:	2017 - 11 - 04	**Prepared by:**	Cole
Revision date:	2017 - 11 - 06	**Revised by:**	Juliana

Failure Mode	Severity				Occurrence			Detection			RPN	Recommended Action	Assigned To	Expected Results of Action			
	Effect	Effect Justification	S	S Justification	Cause	O	O Justification	Control	D	D Justification				S'	O'	D'	RPN'
Fracture	Crack Formation/Propagation; device no longer carries equipment therefore is useless	The worse case scenario occurs when fracture ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Cold temperature Snap	3	the probability of an extreme temperature difference causing the shaft to crack is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
					Fall during skiing	5	there is a moderate probability of the sled fracturing if a user fall on it	none	10	there is no control	350	user manual specifies that the sled should be visually inspected for fracture if there is a reason for concern					
					Impacts from unintended path during ascent	5	there is a moderate probability of the sled fracturing if it faces an impact	none	10	there is no control	350	user manual specifies that the sled should be visually inspected for fracture if there is a reason for concern					
					Sled gets caught on terrain during ascent	5	there is a moderate probability of the sled fracturing if it gets caught on terrain	none	10	there is no control	350	user manual specifies that the sled should be visually inspected for fracture if there is a reason for concern					
Wear	wear leads to fracture; device no longer carries equipment therefore is useless	The worse case scenario occurs when wear ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Friction over snow and ice	3	there is a very low probability of wear due to the safety factor (durable material is chosen so that wearing under normal conditions is minimal)	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
					Sliding over rough paths (rocks and twigs)	3	there is a very low probability of wear due to the safety factor (durable material is chosen so that wearing under normal conditions is minimal)	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
					user overloads the sled	4	there is a low probability of overloading, assuming that the user is logical and listens to the warning labels	none	10	there is no control	280	warning label that indicates to the user than the sled should not support more than the appropriate amount of weight					
					Vibrations due to bumpy terrain	3	there is a very low probability of wear due to the safety factor (durable material is chosen so that wearing under normal conditions is minimal)	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
Bearing Stress failure	disconnect of sled from winch; device no longer carries equipment therefore is useless	The worse case scenario occurs when bending stress failure ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Snow Build up on sled	3	probability is very low because the front entry of the sled is tilted to prevent snow buildup	quality check during production that the sled is tilted	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
					User over loads sled	4	there is a low probability of overloading, assuming that the user is logical and listens to the warning labels (APPENDIX M: , p254.)	none	10	there is no control	280	warning label that indicates to the user than the sled should not support more than the appropriate amount of weight					
					Sled gets caught up on terrain during ascent	5	there is a moderate probability of the bearings failing if it gets caught on terrain	none	10	there is no control	350	user manual specifies that the bearings should be physically inspected for failure if there is a reason for concern					
					User overtightened bolts	3	there is a very low probability of the bearings failing due to over tightening of bolts because they cannot be tightened past a certain threshold	quality check that the bolts cannot be tightened past a certain threshold	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
Loss of orientation	Loss of equipment; device no longer carries equipment therefore is useless	The worse case scenario occurs when loss of equipment ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Inclined ascent plane	3	there is a very low probability of an inclined plane causing the device to lose equipment because of the net system in place	quality check during production that the net system is in place	3	there is a high probability that the control will keep the occurrence low	63	No action taken.					
					Sled catches on terrain	5	there is a moderate probability of the sled losing orientation if it gets caught on terrain	none	10	there is no control	350	user manual specifies that the ascent path should be visually inspected for smooth runs and that the device should be checked for failure if there is a reason for concern					
					User loads equipment asymmetrically	4	there is a low probability of orientation loss, assuming that the user is logical and will attempt to load the sled equally	none	10	there is no control	280	Warning Label indicates that the device should be loaded as equally as possible					
					deviates from intended ascent path	5	there is a moderate probability of the sled losing orientation if it deviates from the intended path and faces obstacles	none	10	there is no control	350	user manual specifies that the ascent path should be visually inspected for smooth runs and that the device should be checked for failure if there is a reason for concern					

Table F-8: Final FMEA for Winch Chassis

Part:	Winch Chassis				**System or Subsystem:**	Transmission													
Original date:	2017 - 11 - 04				**Prepared by:**	Justin													
Revision date:	2017 - 11 - 06				**Revised by:**	Juliana													
Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Assigned To**	**Expected Results of Action**					
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S'**	**O'**	**D'**	**RPN'**		
shaft cracks	drum cannot turn; device becomes inoperable	The worse case scenario occurs when the shaft cracking ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	extreme temperature differences	3	the probability of an extreme temperature difference causing the shaft to crack is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to create a crack in the shaft is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					Fall during ascent	5	there is a moderate probability of the drum distorting if a user fall on it	none	10	there is no control	350	user manual specifies that the shaft should be visually inspected periodically for cracking							
					fatigue	10	the shaft will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).							
chassis bends/distorts	excess stress is placed on other components due to misalignment caused by bending; these components break; the device falls apart; the device is effectively useless	The worse case scenario occurs when the chassis distorting ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	extreme temperature differences	3	the probability of an extreme temperature difference causing the chassis to distort is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to distor the chassis is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Fall during ascent	5	there is a moderate probability of the drum distorting if a user fall on it	none	10	there is no control	350	user manual specifies that the chassis should be visually inspected periodically for distortion							
					fatigue	10	the chassis will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).							
chassis brakes	drum falls out of chassis; device no longer functions	The worse case scenario occurs when the chassis failure ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	extreme temperature differences	3	the probability of an extreme temperature difference causing the shaft to crack is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to create a crack in the shaft is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					Fall during ascent	5	there is a moderate probability of the drum distorting if a user fall on it	none	10	there is no control	350	user manual specifies that the chassis should be visually inspected periodically for failure							
					fatigue	10	the chassis will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).							
bolts become loose	chassis falls apart; drum falls out; device is effectively useless	The worse case scenario occurs when the bolt failures ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	excess force shears off the threads of the bolt	3	the probability of excess force shearing off the threads of the bolt is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					bending stresses caused by the rope cause the bolt to fracture	3	the probability of the rope exerting a bending stress big enough to loosen the bolts is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	no action taken							
					fall during ascent fractures the bolt	5	there is a moderate probability of the bolts becoming loose if a user fall on it	none	10	there is no control	350	user manual specifies that the chassis should be visually inspected before each use for bolt failure							
					fatigue	10	the bolt will certainly see levels of fatigue (however, the severity of the fatigue will most likely be very low)	none	10	there is no control	700	will recommend to client that fatigue calculations need to be completed (although they might be low).							

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Table F-9: Final FMEA for Motor

Part:	Motor				**System or Subsystem:**	Transmission													
Original date:	2017 - 11 - 04				**Prepared by:**	Rishabh													
Revision date:	2017 - 11 - 06				**Revised by:**	Juliana													
Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Assigned To**	**Expected Results of Action**					
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S'**	**O'**	**D'**	**RPN'**		
Motor stalls	Winch no longer raises equipment uphill	The worse case scenario occurs when the motor stalling ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Power distribution board fries	3	there is a very low probability that the power distribution board would fry because it would be rated for 3 times the nominal current draw	quality check during production that the rating is indeed 3 times the nominal current draw	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					Snow Build up causing overload of weight	3	probability is very low because the front entry of the sled is tilted to prevent snow buildup	quality check during production that the sled is tilted	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					Users attempts to ascend too steep of an incline	5	there is a moderate probability that the user will attempt to ascend an incline that is too steep	none	10	there is no control	350	a warning label on the device would warn the user to not attempt inclines greater than 40 degrees							
					User exceeds sled's maximum load rating	4	there is a low probability of overloading, assuming that the user is logical and listens to the warning labels	none	10	there is no control	280	warning label that indicates to the user than the sled should not support more than the appropriate amount of weight							
internal misalignment	clutch no longer functional due to excessive wear from misalignment; device is no longer operable	The worse case scenario occurs when an internal misalignment ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Fall during skiing	5	there is a moderate probability of the sled fracturing if a user fall on it	none	10	there is no control	350	user manual specifies that the motor/gear train should be physically inspected for failure if there is a reason for concern							
					excessive torque applied to the motor shaft by user misuse	4	assuming that the user is logical and would not like to damage an expensive device, the probability is low that an excessive torque would be applied (especially if there is a sticker warning against excessive torque application)	none	10	there is no control	280	warning label placed on device warning against excessive torque application							
					Shaft couplings fail	3	the probability of the shaft coupling failing is low because of their safety factor	calculations checked by another individual to ensure that the appropriate coupling is chosen	3	there is high probability that the control will keep the occurrence low	63	No action taken							
					Shaft is loaded unevenly	4	assuming that the user is logical and would not like to damage their expensive toy, the probability is low that the shaft would be loaded unevenly (especially if there is a sticker warning against loading the shaft unevenly)	none	10	there is no control	280	warning label placed on device warning against loading the shaft unevenly							
motor overheats	excessive heat leads to combustion of the motor; fragments from possible explosion may hurt user; device becomes inoperable	The worse case scenario occurs when the motor overheating ultimately prevents the device from functioning. In addition, this may cause injury to the user, therefore, this effect was chosen.	9	A justification of 9 was chosen because the motor overheating could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	Power distribution board fries	3	there is a very low probability that the power distribution board would fry because it would be rated for 3 times the nominal current draw	quality check during production that the rating is indeed 3 times the nominal current draw	3	there is a high probability that the control will keep the occurrence low	81	No action taken							
					fan breaks	3	there is a very low probability that the fan will fail because of its safety factor	quality check during production that the fan is properly working	3	there is a high probability that the control will keep the occurrence low	81	user manual should state that if the user hears the fan acting up or not working, then the device should immediately be stopped							
					Snow Build up causing overload of weight	3	probability is very low because the front entry of the sled is tilted to prevent snow buildup	quality check during production that the sled is tilted	3	there is a high probability that the control will keep the occurrence low	81	No action taken							
					Water enters the motor core and shorts the windings	3	the probability of water entering the motor core is very low because the motor is sealed off with and enclosing and waterproof seal	quality check during production that the enclosure is properly placed and that the seals are watertight	3	there is a high probability that the control will keep the occurrence low	81	No action taken							
Motor is unmounted	Motor would not deliver any useful torque. In the worst case, motor would start spinning around its own axis which would tangle the power wires.	The worse case scenario occurs when the motor unmounting ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	Fall during skiing	5	there is a moderate probability of the motor unmounting if a user fall on it	none	10	there is no control	350	user manual specifies that the motor/gear train should be physically inspected for failure if there is a reason for concern							
					Mounting fasteners strip off	3	the probability of the fasteners stripping is very low due to its safety factor	Spec fasteners which can support moment loads	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					excessive moments produced on motor mounts due to unaccounted forces	3	the probability of excessive moments unmounting the motor is very low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	63	No action taken							
					threads of fastening components become cross threaded	3	the probability of cross threading is very low due to its safety factor	safety factor of threads is increased	3	there is a high probability that the control will keep the occurrence low	63	No action taken							

Table F-10: Final FMEA for Battery

Part:	Battery	**System or Subsystem:**	Power Generation
Original date:	2017 - 11 - 04	**Prepared by:**	Rishabh
Revision date:	2017 - 11 - 06	**Revised by:**	Juliana

Failure Mode	**Severity**				**Occurrence**			**Detection**			**RPN**	**Recommended Action**	**Assigned to**	**Expected Results of action**			
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S**	**O**	**D**	**RPN'**
individual battery cell dies (is 0V)	open circuit occurs; battery is no longer operable; device is no longer operable	The worse case scenario occurs when the individual battery cell dying ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	A justification of 7 was chosen because the device failing to function would result in "very significant customer dissatisfaction" however, it would not lead to injury.	battery is punctured when user falls	5	there is a moderate probability of the battery puncturing if a user falls on it	none	10	there is no control	350	user manual specifies that the battery should be physically inspected for failure if there is a reason for concern					
					cell overheats	3	the probability of the cell overheating is low because each cell is checked for correct operation before leaving production	quality check at factory that each cell is properly functioning	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					cell is discharged below 3V	3	there is a very low probability of the cell discharging below 3 V as the loud beeper (described in the control) will warn the user to stop use	Add a beeper which emits loud beeps once the cell voltage drops below 3.6V	3	there is a high probability that the control will keep the occurrence low	63	user manual specifies that if the user hears a loud beep, then they should stop use immediately					
					loss of communication between cells	3	there is a very low probability of the cells losing communication because they are checked at production for proper operation	quality check at factory that each cell is correctly wires and communicating to each other	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
battery spontaneously combusts	battery is no longer operable; fragments from possible explosion may hurt user; device is no longer operable	The worse case scenario occurs when the combustion ultimately prevents the device from functioning. In addition, this may cause injury to the user, therefore, this effect was chosen.	9	A justification of 9 was chosen because the motor overheating could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	chemicals leak (battery is punctured)	5	there is a moderate probability of the battery puncturing if a user falls on it	none	10	there is no control	450	user manual specifies that the battery should be physically inspected for failure if there is a reason for concern					
					high storage temperature	4	assuming that the user is logical and would not want to damage their device, they would not expose it to high heat. There fore the probability of a high storage temperature is low.	sticker indicates that the battery should not be placed in a high temperature environment	10	there is no control	360	user manual specifies that the device should be stored in temperatures between -35 dC and 30 dC					
					the lithium portion of the battery is exposed to water	3	the probability of the battery innards being exposed to water is very low since the lithium is encased in a layer of metal, plastic, and finally, a rigid enclosure.	quality check during production that the batteries are correctly sealed	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					battery is charged at higher than 2C	4	assuming that the user is logical and would not want to damage their device, they would not charge the battery at low temperatures (and ignore the warning label indicating so). There fore the probability of a high storage temperature is low.	none	10	there is no control	360	warning label specifies that the device should not be charged at temperatures lower than 2 dC					
Battery's power and ground wires short	Battery smokes and possibly combusts; fragments from possible explosion may hurt user; the device is rendered useless	The worse case scenario occurs when the shortage ultimately prevents the device from functioning. In addition, this may cause injury to the user, therefore, this effect was chosen.	9	A justification of 9 was chosen because the motor overheating could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	insulating coating on wires wear out	3	the probability of the insulation wearing out is low because the wires are not exposed nor moved around very much to induce rubbing/tearing/wearing	electrical tape/heat shrink is placed around the wires to secure them during production	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					Battery terminals are unintentionally shorted by user	5	there is a moderate probability of the terminals shorting due to user misuse.	none	10	there is no control	450	warning labels are placed on the battery's connector to indicate that shorting should be avoided					
					Water shorts any electronic component on power distribution board	3	the probability of the electrical components being exposed to water is very low since they are encased in a rigid enclosure with a waterproof seal	quality check during production that the electrical components are correctly sealed	3	there is a high probability that the control will keep the low	81	No action taken					
					Battery is plugged in the wrong way	2	there is an extremely low probability of the battery being plugged the wrong way since connectors which can only be inserted in one way	connectors which can only be inserted in one way	3	there is a high probability that the control will keep the low	54	No action taken					
battery's capacity is decreased	device operates for less than 5.5 hours	The worse case scenario occurs when the decreases capacity ultimately prevents the device from functioning for a shorter than expected time. Therefore, this effect was chosen.	4	A justification of 4 was chosen because the decrease in capacity would inconvenience the customer by the device's premature need for service	battery is damaged during a fall	5	there is a moderate probability of the battery capacity decreasing if a user falls on it	none	10	there is no control	200	user manual specifies that the battery should be physically inspected for failure if there is a reason for concern					
					battery is exposed to extremely low temperatures	4	assuming that the user is logical and would not want to damage their device, they would not use the device is low temperatures (and ignore the warning label indicating so). There fore the probability of a high storage temperature is low.	none	10	there is no control	160	warning label specifies that the battery's capacity will significantly decrease proportionally to the temperature beyond -15 dC (lower the temperature, lower the capacity)					
					battery is charged at higher than 2C	4	assuming that the user is logical and would not want to damage their device, they would not charge the battery at low temperatures (and ignore the warning label indicating so). There fore the probability of a high storage temperature is low.	none	10	there is no control	160	warning label specifies that the device should not be charged at temperatures lower than 2 dC					
					Battery has undergone too many charging cycles (during the 5 year period)	3	probability is very low because a high-quality battery is chosen so that the safety factor for charging cycles is high	quality check the batteries during production	3	there is a high probability that the control will keep the occurrence low	36	No action taken					

Table F-11: Final FMEA for Enclosure

Part:	Enclosure			**System or Subsystem:**													
Original date:	2017 - 11 - 04			**Prepared by:**	Rishabh												
Revision date:	2017 - 11 - 06			**Revised by:**	Juliana												
Failure Mode	**Severity**							**Detection**			**RPN**	**Recommended Action**	**Assigned to**	**Expected Results of action**			
	Effect	**Effect Justification**	**S**	**S Justification**	**Cause**	**O**	**O Justification**	**Control**	**D**	**D Justification**				**S**	**O**	**D**	**RPN'**
waterproof seal breaks	water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	The worse case scenario occurs when the waterproof seal ultimately prevents the device from functioning. In addition, this may cause injury to the user if an explosion occurs, therefore, this effect was chosen.	9	A justification of 9 was chosen because the waterproof seal failing could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	extreme temperature differences	3	the probability of an extreme temperature difference causing the seal to break is very low because we have chosen an adhesive that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the adhesive will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					bending stresses due to the rope	3	the probability of the seal breaking due to the rope exerting a bending stress is low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					Fall during ascent	5	there is a moderate probability of the seal breaking if a user fall on it	none	10	there is no control	450	user manual specifies that the enclosure should be physically inspected for failure if there is a reason for concern					
					torsion due to uneven loading	4	the probability of the seal breaking due to torsion is low due to its safety factor; in addition, assuming the user is logical, they will want to listent o the label which indicates that the device should be loaded as evenly as possible	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	108	user manual indicates that the user should load the device as evenly as possible					
enclosure fractures	water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	The worse case scenario occurs when the waterproof seal ultimately prevents the device from functioning. In addition, this may cause injury to the user if an explosion occurs, therefore, this effect was chosen.	9	A justification of 9 was chosen because the waterproof seal failing could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	extreme temperature differences	3	the probability of an extreme temperature difference causing enclosure to fracture is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to fracture the enclosure low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					Fall during ascent	5	there is a moderate probability of the enclosure fracturing if a user fall on it	none	10	there is no control	450	user manual specifies that the enclosure should be physically inspected for failure if there is a reason for concern					
					torsion due to uneven loading	4	the probability of the enclosure fracturing due to torsion is low due to its safety factor; in addition, assuming the user is logical, they will want to listent o the label which indicates that the device should be loaded as evenly as possible	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	108	user manual indicates that the user should load the device as evenly as possible					
enclosure bends/distorts	bending leads to crack propagation; water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	The worse case scenario occurs when the waterproof seal ultimately prevents the device from functioning. In addition, this may cause injury to the user if an explosion occurs, therefore, this effect was chosen.	9	A justification of 9 was chosen because the waterproof seal failing could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	extreme temperature differences	3	the probability of an extreme temperature difference causing enclosure to distort is very low because we have chosen material that can withstand and operation temperature of -15 (dC) and a storage temperature of -35 (dC)	quality check during production to test that the material will withstand a -15 (dC) operating temperature and a -35 (dC) storage temperature	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					bending stresses due to the rope	3	the probability of the rope exerting a bending stress big enough to distort the enclosure low due to its safety factor	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					Fall during ascent	5	there is a moderate probability of the enclosure distorting if a user fall on it	none	10	there is no control	450	user manual specifies that the enclosure should be physically inspected for failure if there is a reason for concern					
					torsion due to uneven loading	4	the probability of the enclosure wear due to torsion is low due to its safety factor; in addition, assuming the user is logical, they will want to listent o the label which indicates that the device should be loaded as evenly as possible	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	108	user manual indicates that the user should load the device as evenly as possible					
enclosure corrodes/wears excessively fast	corrosion/wear leads to crack propagation; water penetrates batteries; explosion occurs; fragments hurt user and device becomes inoperable	The worse case scenario occurs when the waterproof seal ultimately prevents the device from functioning. In addition, this may cause injury to the user if an explosion occurs, therefore, this effect was chosen.	9	A justification of 9 was chosen because the waterproof seal failing could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	enclosure is exposed to rough external surfaces	3	there is a very low probability of wear due to the safety factor (durable material is chosen so that wearing under normal conditions is minimal)	quality check the safety factor during production	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					enclosure is exposed to battery fluids	3	there is a very low probability that the enclosure will be exposed to battery fluids because the battery will be encased in synthetic shrink wrap	quality check during production that the batteries are appropriately sealed	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					enclosure is in contact with the gears	3	there is a very low probability that the gears will be in contact with the exposure due to initial alignment and alignment quality check at the factory	quality check during production that the gears and enclosure are properly aligned	3	there is a high probability that the control will keep the occurrence low	81	No action taken					
					enclosure is in contact with the motor and vibrations lead to wear	3	there is a very low probability that the vibrations will lead to wear because of the bolts which will keep everything very tightly fit. In addition, there will be a quality check for the fit and the user manual will specify that the bolts should be periodically tightened	quality check during production that the bolts are properly fastened	3	there is a high probability that the control will keep the occurrence low	81	user manual indicates that the user should periodically check if the motor is tightly fastened to the enclosure					

Table F-12:Final FMEA for Controls

Part:	Controls	**System or Sub-system:**	Control System
Original date:	2017 - 11 - 04	**Prepared by:**	Rish
Revision date:	2017 - 11 - 06	**Revised by:**	Juliana

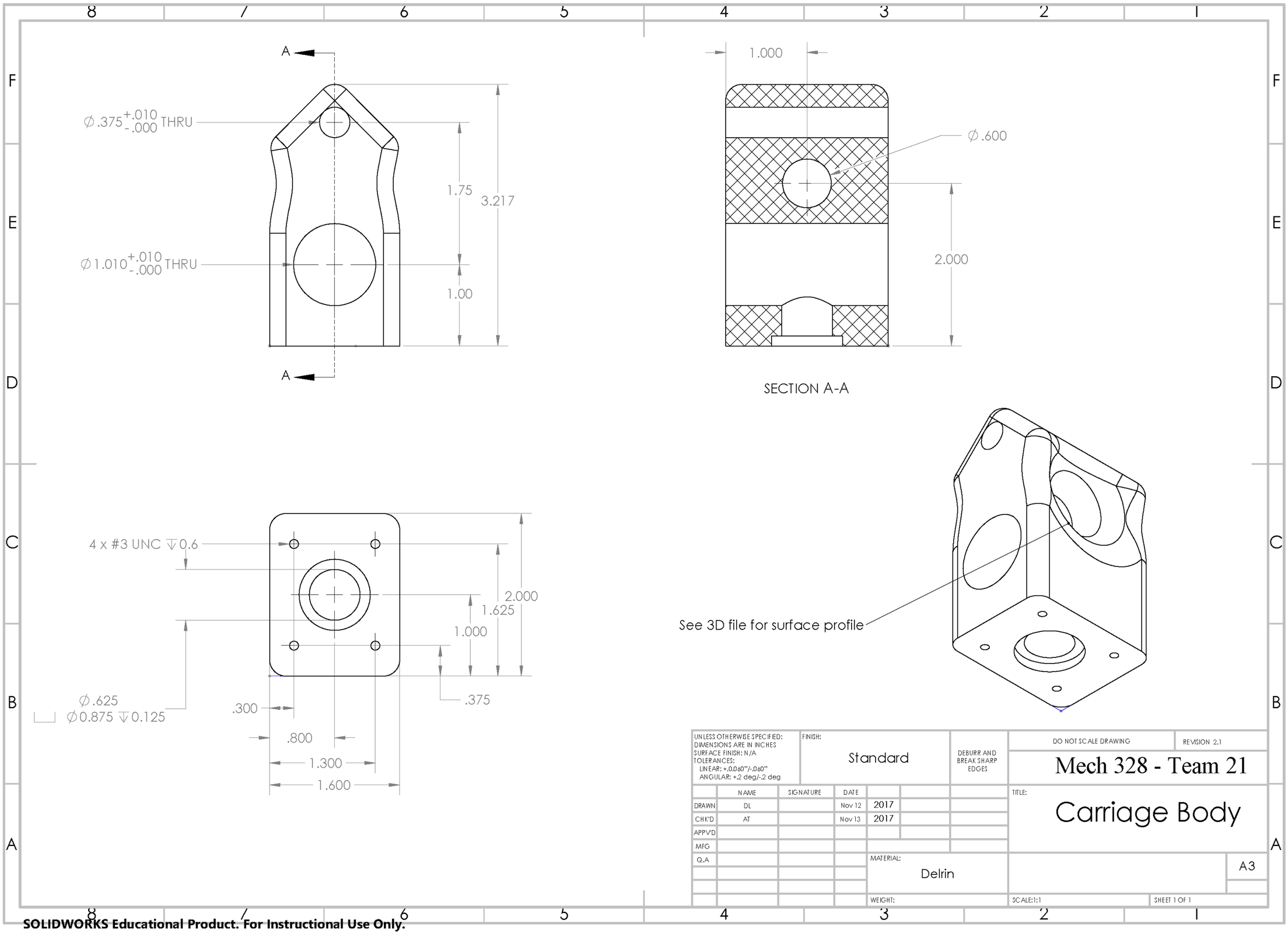
Failure Mode	Severity							Detection			RPN	Recommended Action	Assigned to	Expected Results of action			
	Effect	Effect Justification	S	S Justification	Cause	O	O Justification	Control	D	D Justification				S	O	D	RPN'
Circuits short	circuits short and device becomes inoperable and components burn out	The worse case scenario occurs when a circuit shorts and it ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	The worse case scenario occurs when the circuits shorting ultimately prevents the device from functioning. Therefore, this effect was chosen.	Water enters the enclosure (during general usage)	3	the probability of water entering the device during general use is very low because of our waterproof seal	quality check during production that the seal is waterproof	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					Insulation wears off from wires (during general usage)	2	the probability of the insulation wearing off the wires is extremely low since the wires in the control do not move	quality check during production that the wires are properly insulated	3	there is a high probability that the control will keep the occurrence low	42	No action taken					
					User plugs in the battery charger in opposite polarity	4	assuming that the user is logical and follows the labels which indicate polarity, the probability of the battery charger being plugged into with the incorrect polarity is low	none	10	there is no control	280	labels placed on terminals					
					Air in enclosure becomes moist	2	the probability of this occurring is extremely low because of our waterproof sealing (I-2.3 , p.195)	quality check during production that the seal is waterproof	3	there is a high probability that the control will keep the occurrence low	42	No action taken					
Switch fails	Current arcing in the switch due to indefinite switch state, switch starts to smoke, components burn out, and battery might explodes; device becomes inoperable	The worse case scenario occurs when the switch fails and ultimately prevents the device from functioning. Therefore, this effect was chosen.	9	A justification of 9 was chosen because the switch failing could lead to an explosion and hence, a serious injury. However, it is unlikely that a death would occur.	Switch is not moved to a definite state	4	the probability of this occurring is very low because this would only occur if the user places the switch in between on and off (which is warned against in the user manual)	none	10	there is no control	360	labels warns against leaving the switch in an indeterminate state					
					Current rating of the switch (20A) exceeded	4	the probability of this occurring is low because this would only occur if the sled is overloaded which is warned against with a label indicating that the maximum load is 40 kg	none	10	there is no control	360	user manual warns that the device sled not be overloaded (more than 40 kg)					
					Two terminals of the switch short	1	this would almost never occur unless the terminals are physically forced together in the correct way (against their rigid structures)	quality check during production that the terminals are rigidly located	3	there is a high probability that the control will keep the occurrence low	27	No action taken					
					Schottky Diode in parallel with MOSFET burns which causes inductive spike due to motor back EMF in the switch	1	this would almost never occur because the Schottky diode has voltage rating which is extremely high and will not be exceeded in any worse case scenario	quality check the voltage rating	3	there is a high probability that the control will keep the occurrence low	27	No action taken					
Receiver does not receive transmitter signal	The motor does not spin and device is inoperable	The worse case scenario occurs when the receiver does not receive the signal and ultimately prevents the device from functioning. Therefore, this effect was chosen.	7	The worse case scenario occurs when the receiver failing ultimately prevents the device from functioning. Therefore, this effect was chosen.	User's remote switch sustains damage due to falling	5	there is a moderate probability of the switch becoming damaged if a user fall on it	none	10	there is no control	350	user manual specifies that the controls should be physically inspected for failure if there is a reason for concern					
					Receiver antenna on Device sustains damage due to falling	5	there is a moderate probability of the receiver becoming damaged if a user fall on it	none	10	there is no control	350	user manual specifies that the controls should be physically inspected for failure if there is a reason for concern					
					Battery of remote runs out	3	this is very unlikely because the battery life is long but the user manual indicates that it should be checked periodically	quality check during production that the batteries provided are fully charged	3	there is a high probability that the control will keep the occurrence low	63	No action taken					
					Weather reduction of remote range	5	there is a moderate probability of the weather interfering with the remote range	none	10	there is no control	350	user manual specifies that the controls' range may decrease with bad weather					
Voltage applied unexpectedly to the gate of the MOSFET	The motor spins unexpectedly	The worse case scenario occurs when the receiver does not receive the signal and ultimately prevents the device from functioning. Furthermore, the device may injure the user if the motor spins in the opposite direction. Therefore, this effect was chosen.	8	A justification of 9 was chosen because the waterproof seal failing could lead to the device pulling the user which could lead to an injury. However, it is unlikely that a serious injury would occur.	Pulldown resistor is damaged	3	the probability of this occurring is very low because the resistor voltage rating is being exceeded is unlikely	quality check the voltage rating during production	3	there is a high probability that the control will keep the occurrence low	72	No action taken					
					Users connects 3rd party batteries	1	this would almost never occur assuming that the user is logical and would not take the risk of disassembling the device and replacing a third party battery that may not be compatible to a device they do not fully understand	none	10	there is no control	80	No action taken					
					Users attempts to add additional batteries to extend capacity	1	this would almost never occur assuming that the user is logical and would not take the risk of attaching batteries to a device they do not fully understand	none	10	there is no control	80	No action taken					
					Circuit board damaged in an impact	5	there is a moderate probability of the circuit becoming damaged if a user fall on it	none	10	there is no control	400	user manual specifies that the controls should be physically inspected for failure if there is a reason for concern					

APPENDIX G: ENGINEERING DETAIL DRAWINGS

Many components for the Equipment Tow are custom parts; therefore, manufacturing drawings must be made for fabrication instruction. All drawings follow ANSI standards with appropriate dimensions and tolerances.

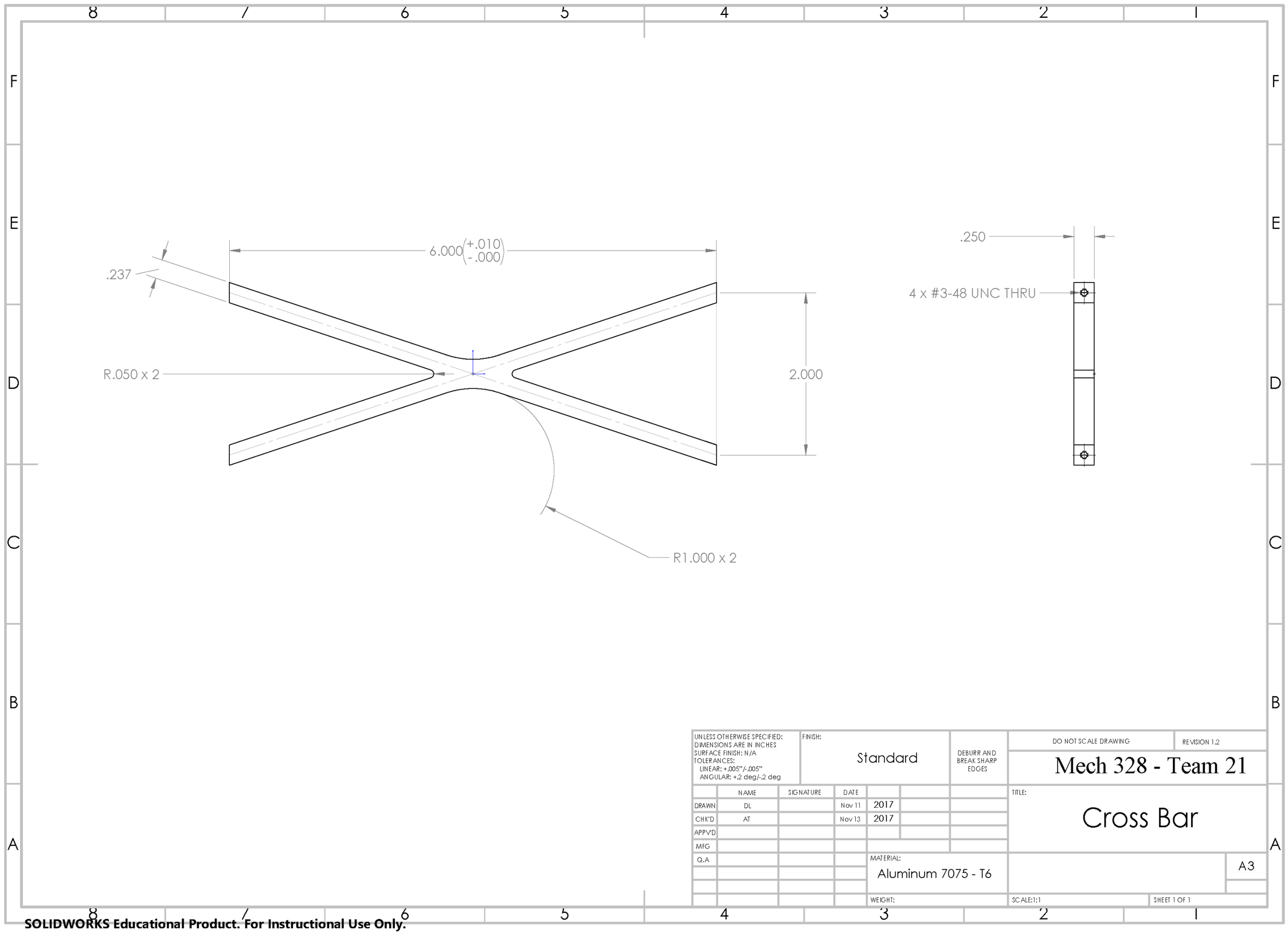
G-1 Manufacturing Drawings

G-1.1 Carriage Body Manufacturing Drawing



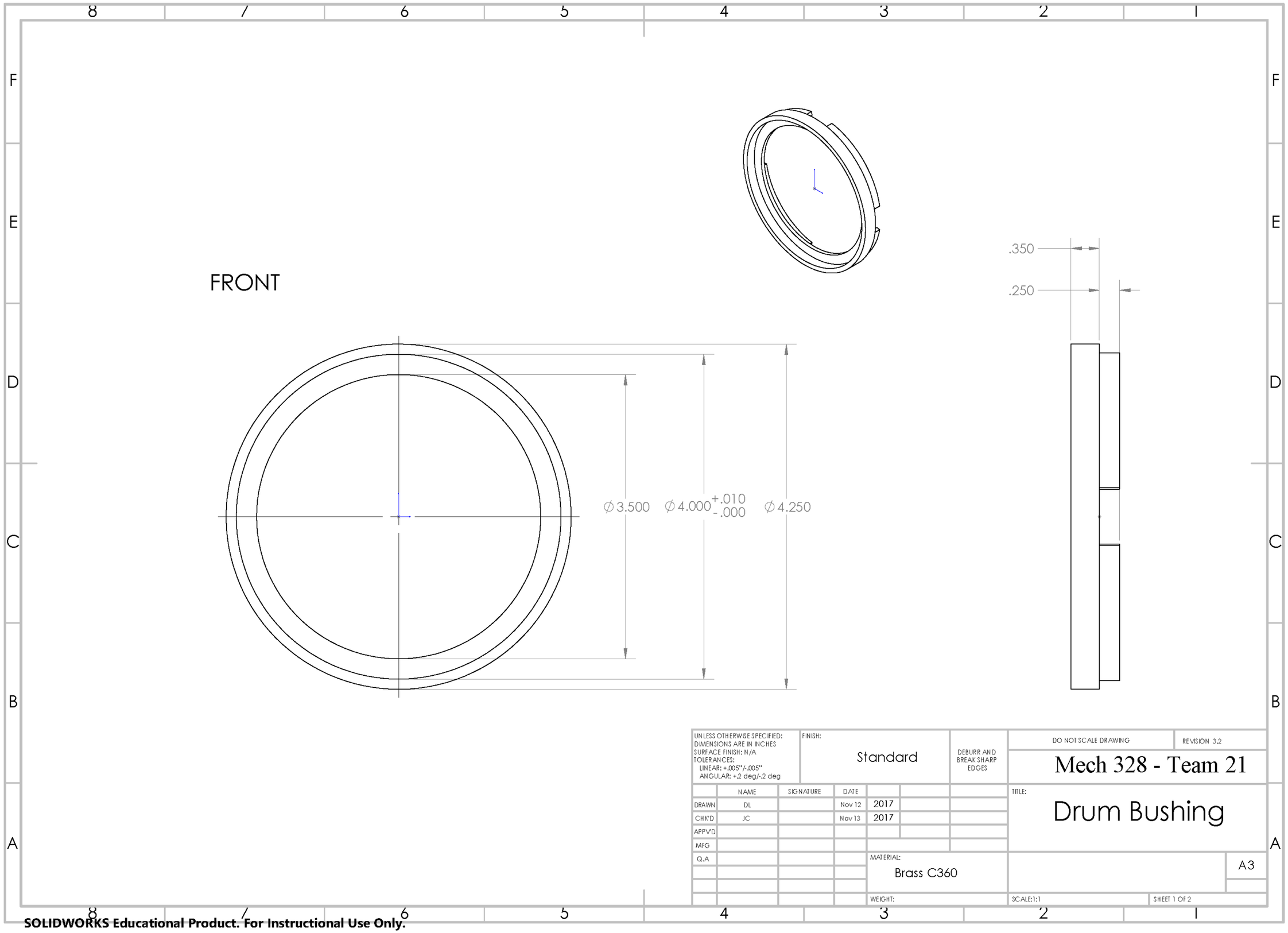
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G-1.2 Cross Bar Manufacturing Drawing



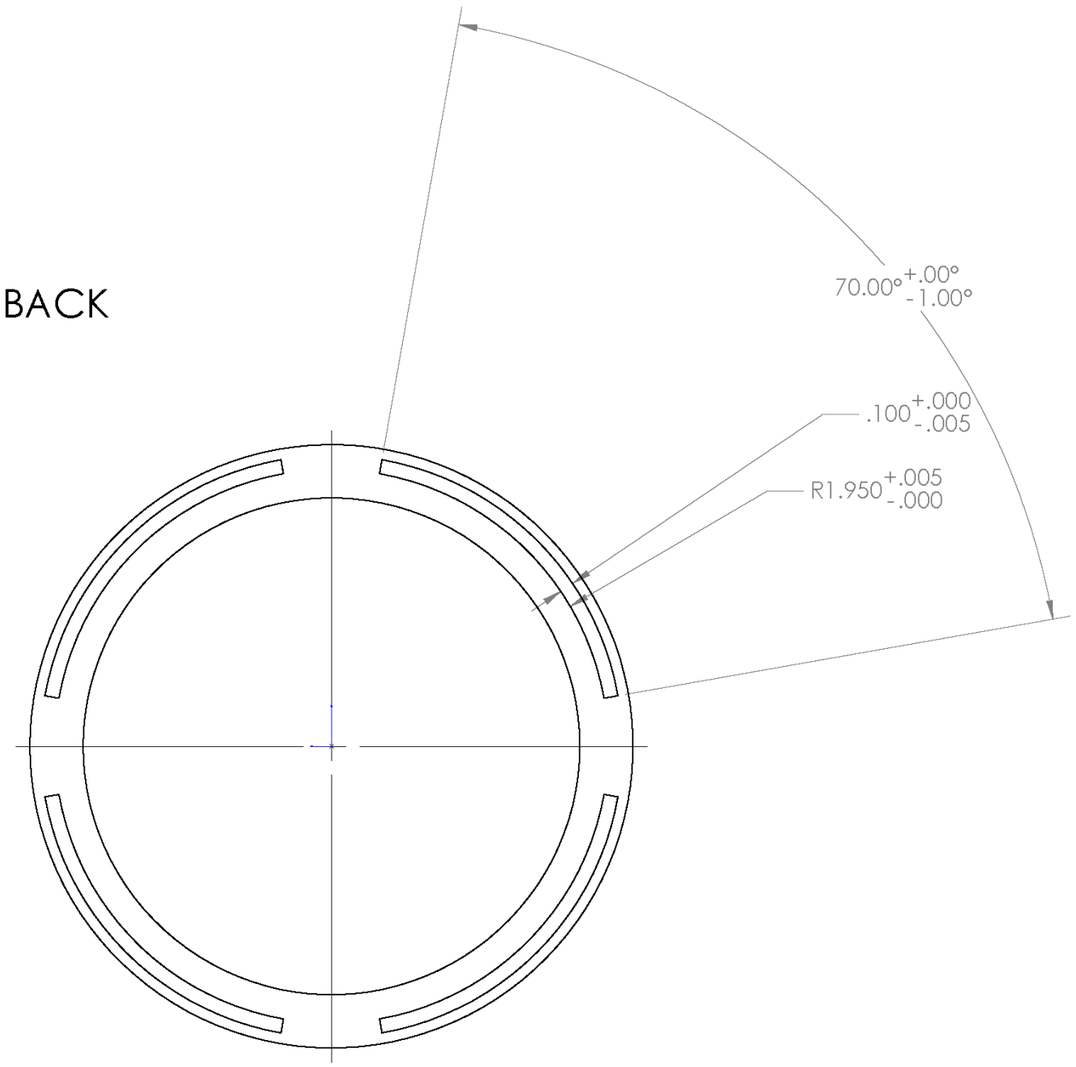
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G-1.3 Drum Bushing Manufacturing Drawing



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: N/A TOLERANCES: LINEAR: +.005"/-.005" ANGULAR: +.2 deg/-.2 deg	FINISH: Standard		DEBURR AND BREAK SHARP EDGES			DO NOT SCALE DRAWING	REVISION 3.2
						Mech 328 - Team 21	
	NAME	SIGNATURE	DATE			TITLE: Drum Bushing	
DRAWN	DL		Nov 12	2017			
CHK'D	JC		Nov 13	2017			
APPV'D							
MFG							
Q.A							
				MATERIAL: Brass C360			A3
				WEIGHT:		SCALE:1:1	SHEET 1 OF 2

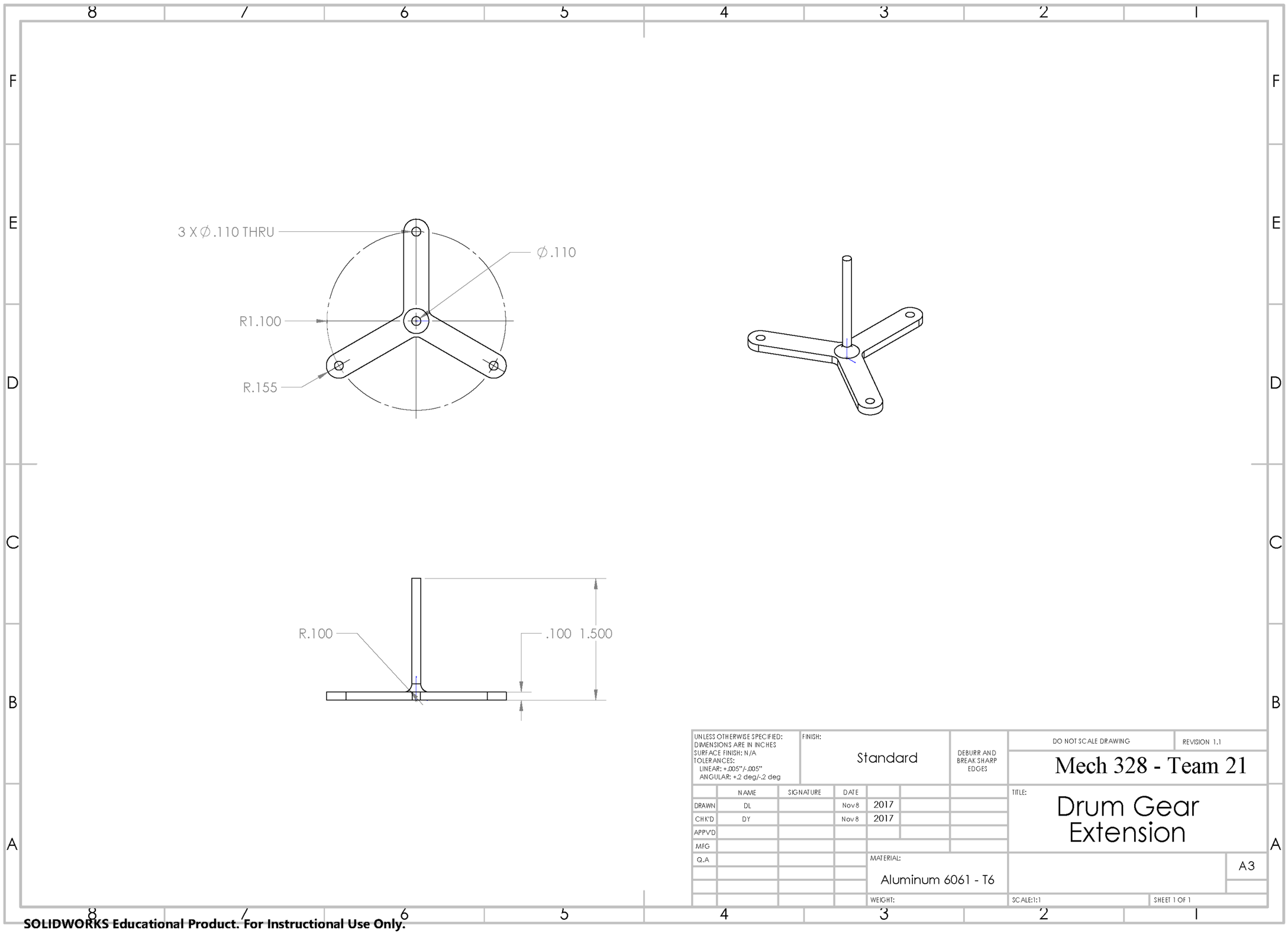
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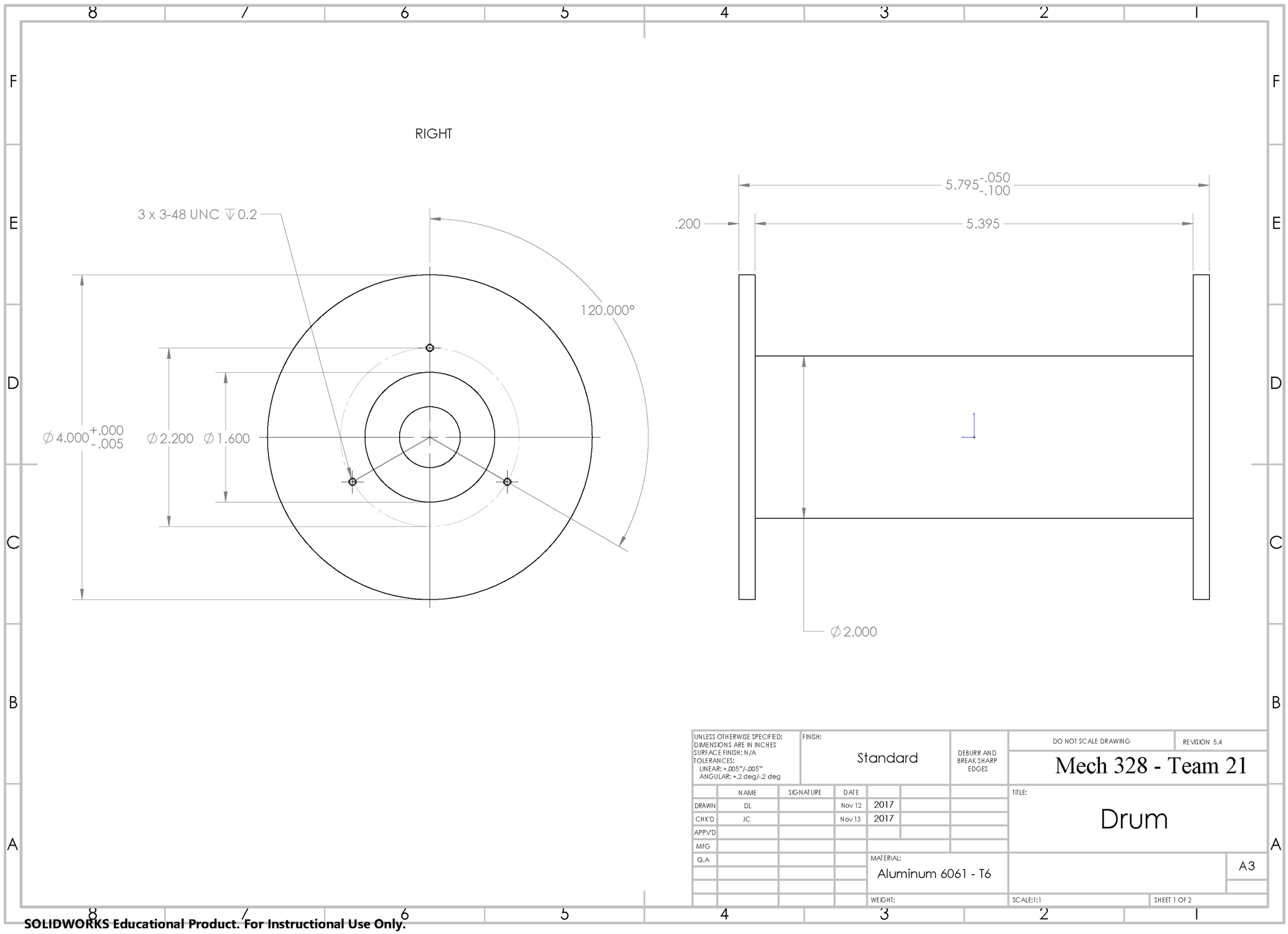
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: N/A TOLERANCES: LINEAR: +.005"/-.005" ANGULAR: +.2 deg/-.2 deg	FINISH: Standard				DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 1.3
	NAME	SIGNATURE	DATE			TITLE: Drum Bushing	
DRAWN	DL		Nov 12	2017			
CHK'D	JC		Nov 13	2017			
APPV'D							
MFG							
Q.A				MATERIAL: Brass C360			A3
				WEIGHT:		SCALE:1:1	SHEET 2 OF 2

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G-1.4 Drum Gear Extension Manufacturing Drawing

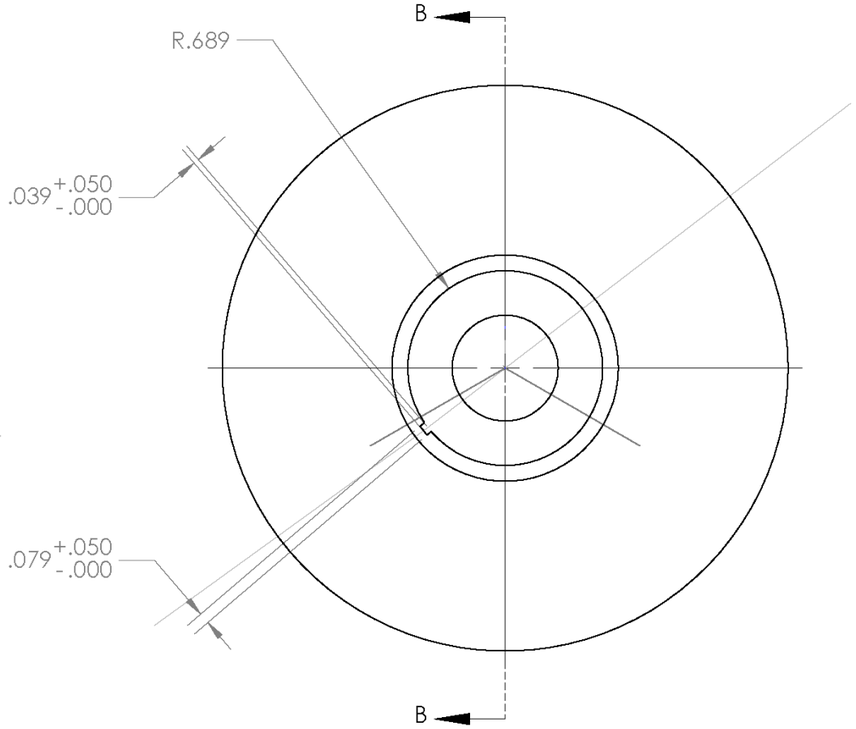


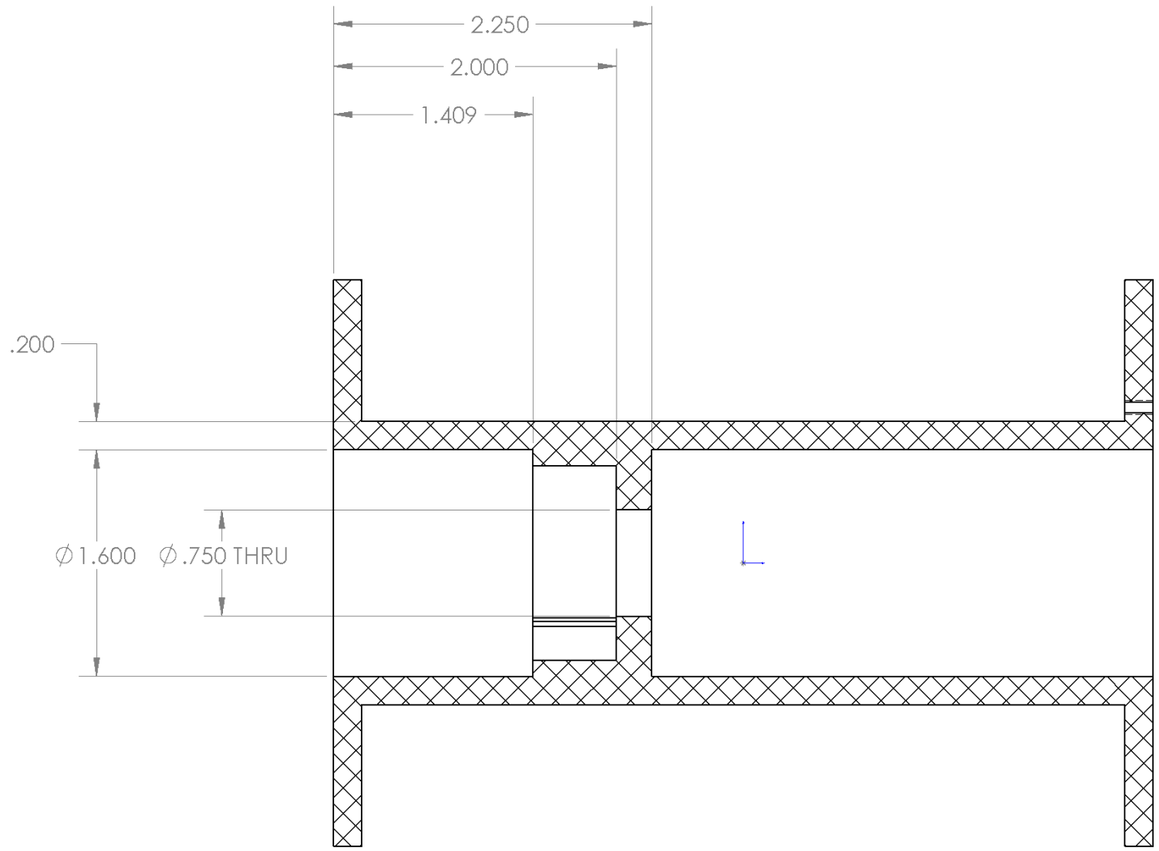
G-1.5 Drum Manufacturing Drawing



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LEFT



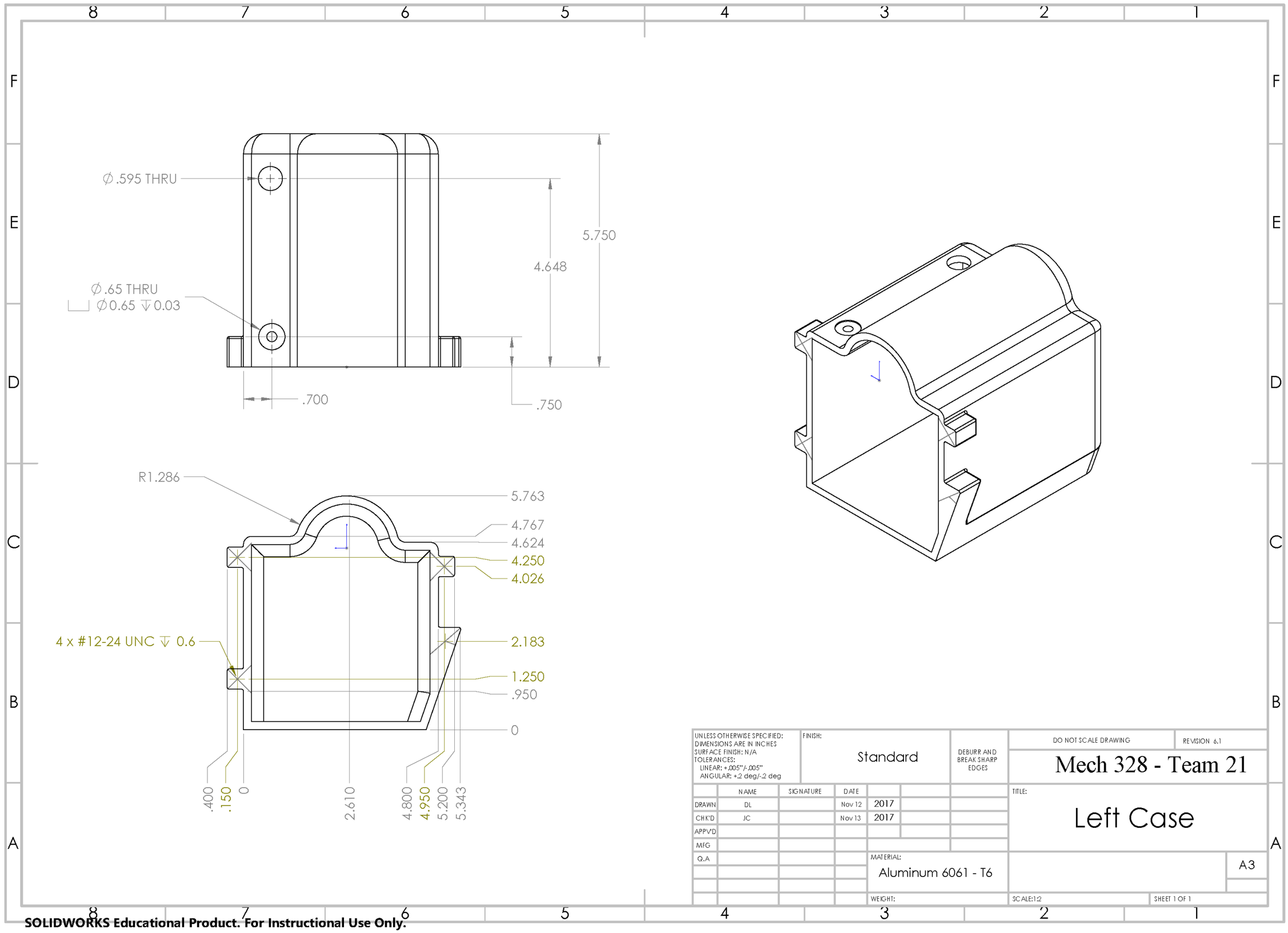


SECTION B-B

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: N/A TOLERANCES: LINEAR: +.005"/-.005" ANGULAR: +-2 deg/-.2 deg	FINISH: Standard				DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 5.4
	NAME	SIGNATURE	DATE			Mech 328 - Team 21	
DRAWN	DL		Nov 12	2017		TITLE: Drum	
CHK'D	JC		Nov 13	2017			
APPV'D							
MFG							
Q.A							A3
				MATERIAL: Aluminum 6061 - T6			
				WEIGHT:		SCALE:1:1	SHEET 2 OF 2

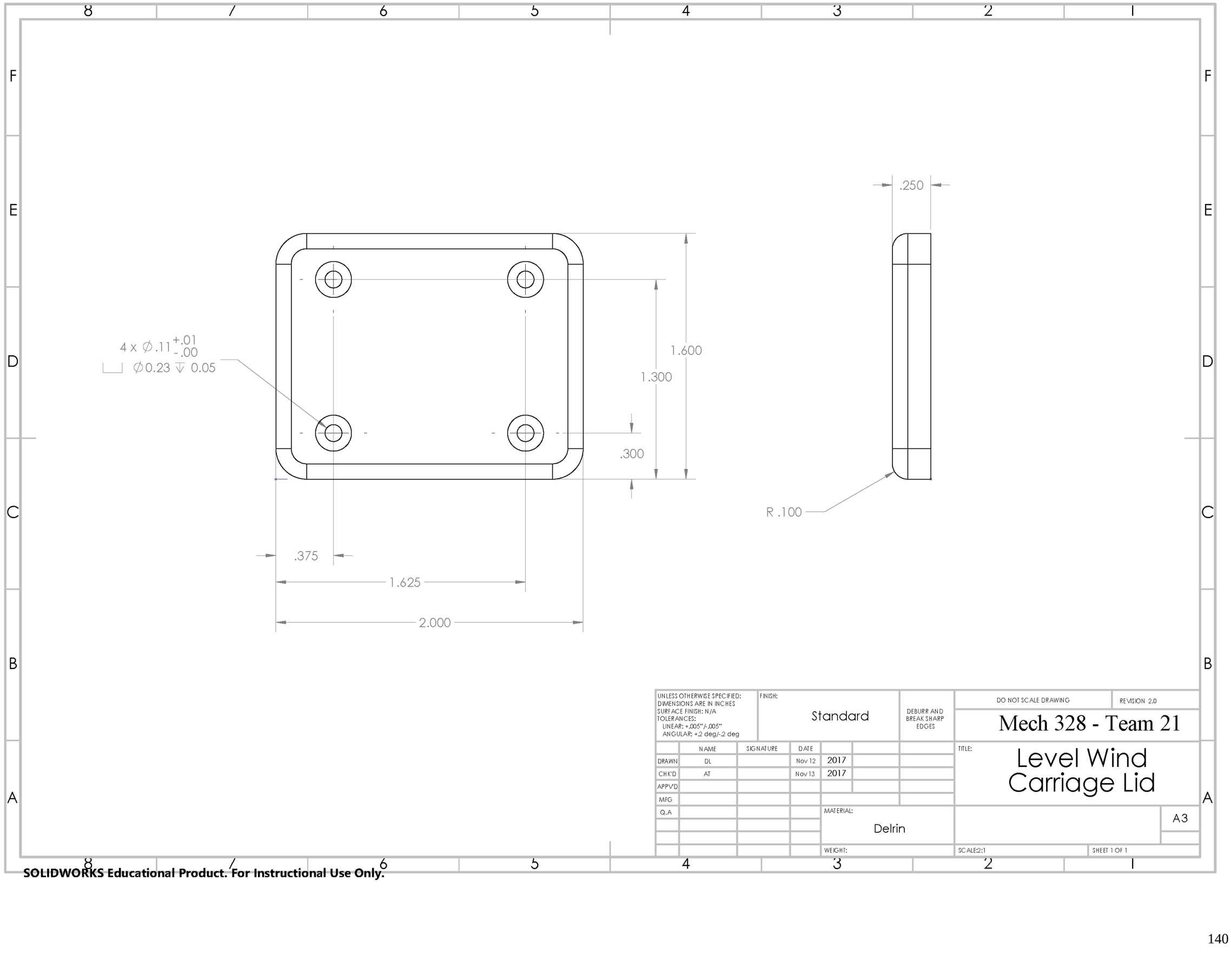
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G-1.6 Left Case Manufacturing Drawing



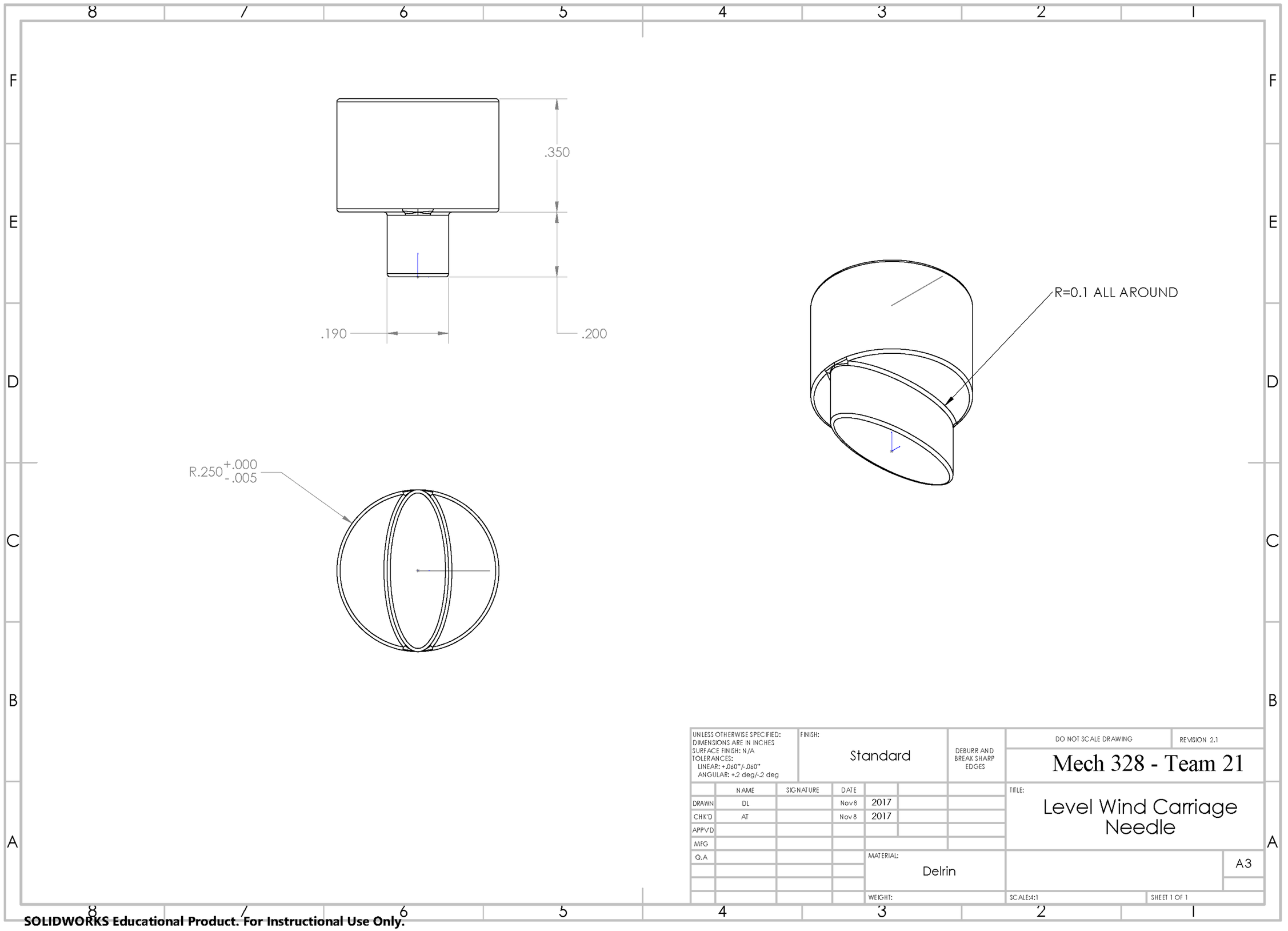
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G-1.7 Level Wind Carriage Lid Manufacturing Drawing



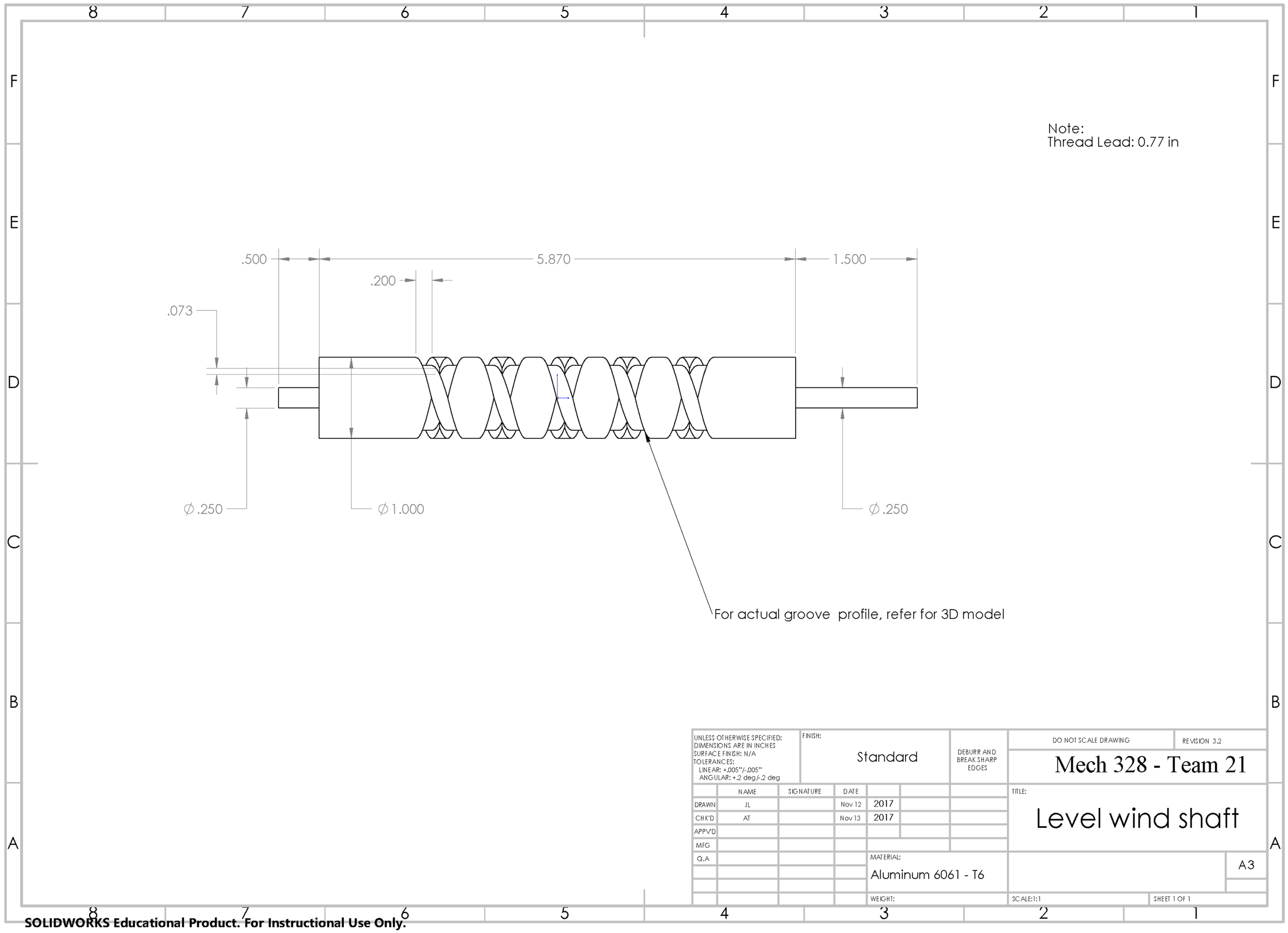
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G-1.8 Level Wind Carriage Needle Manufacturing Drawing



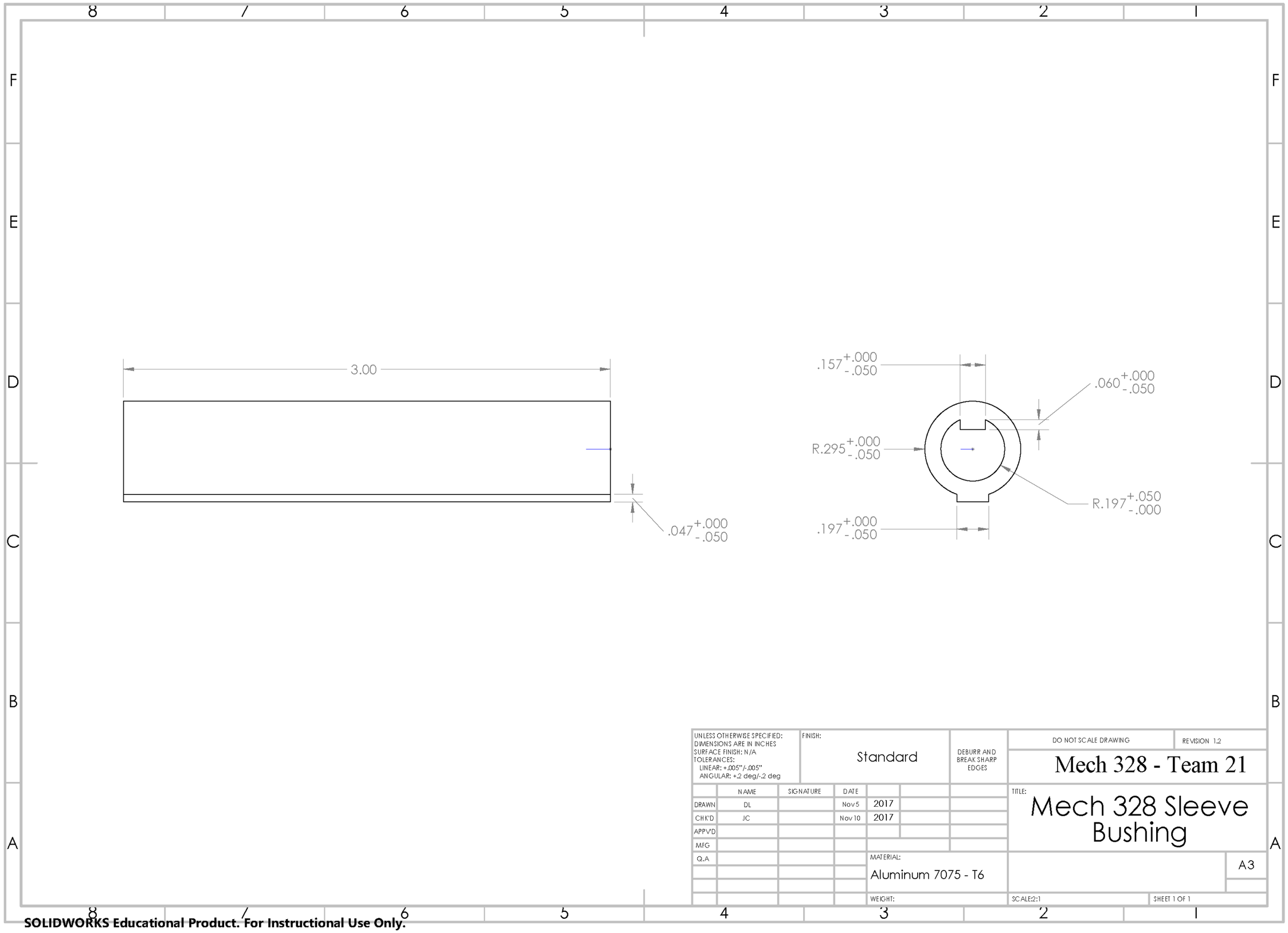
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G-1.9 Level Wind Shaft Manufacturing Drawing



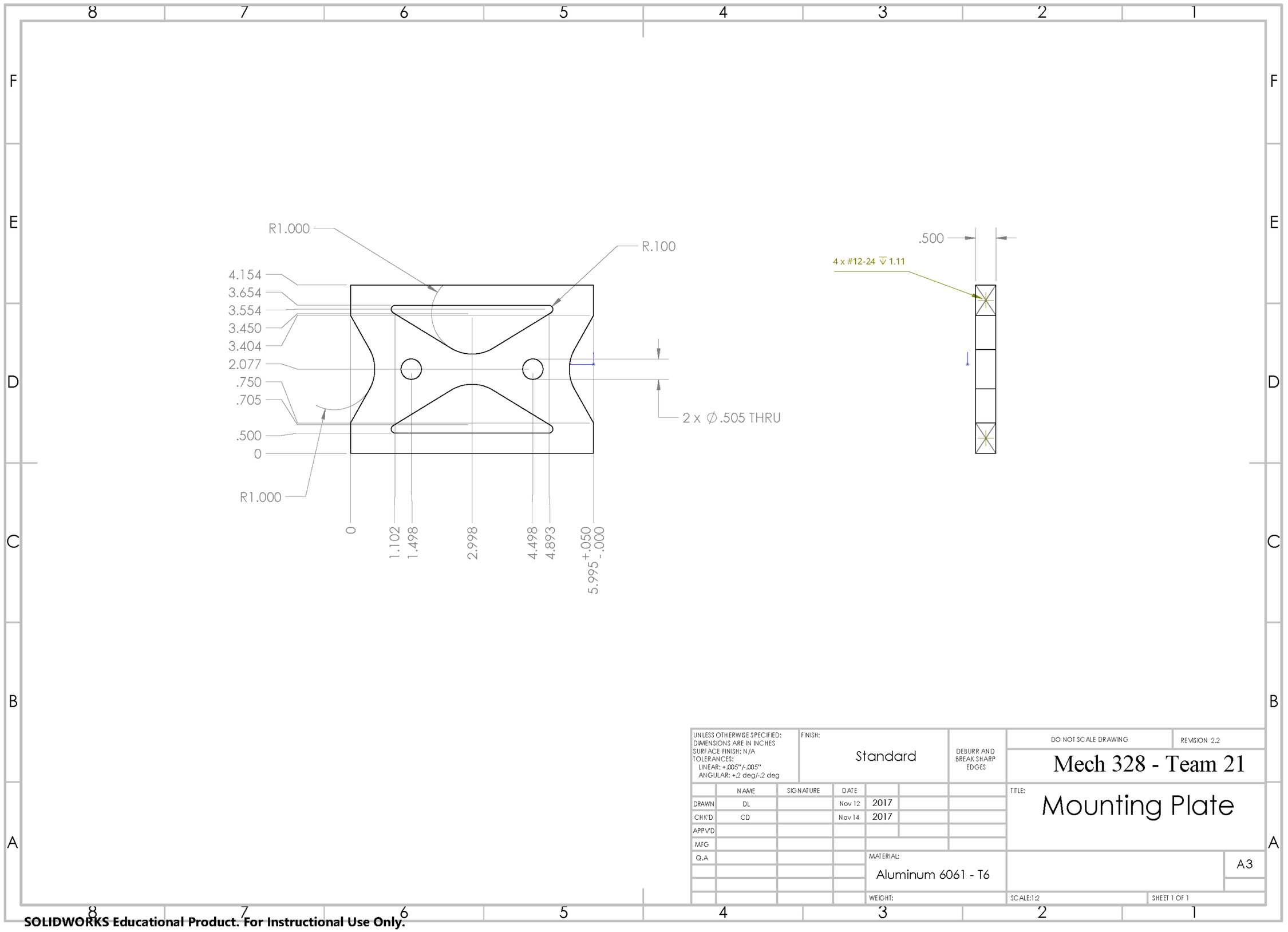
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G-1.10 Sleeve Bushing Manufacturing Drawing

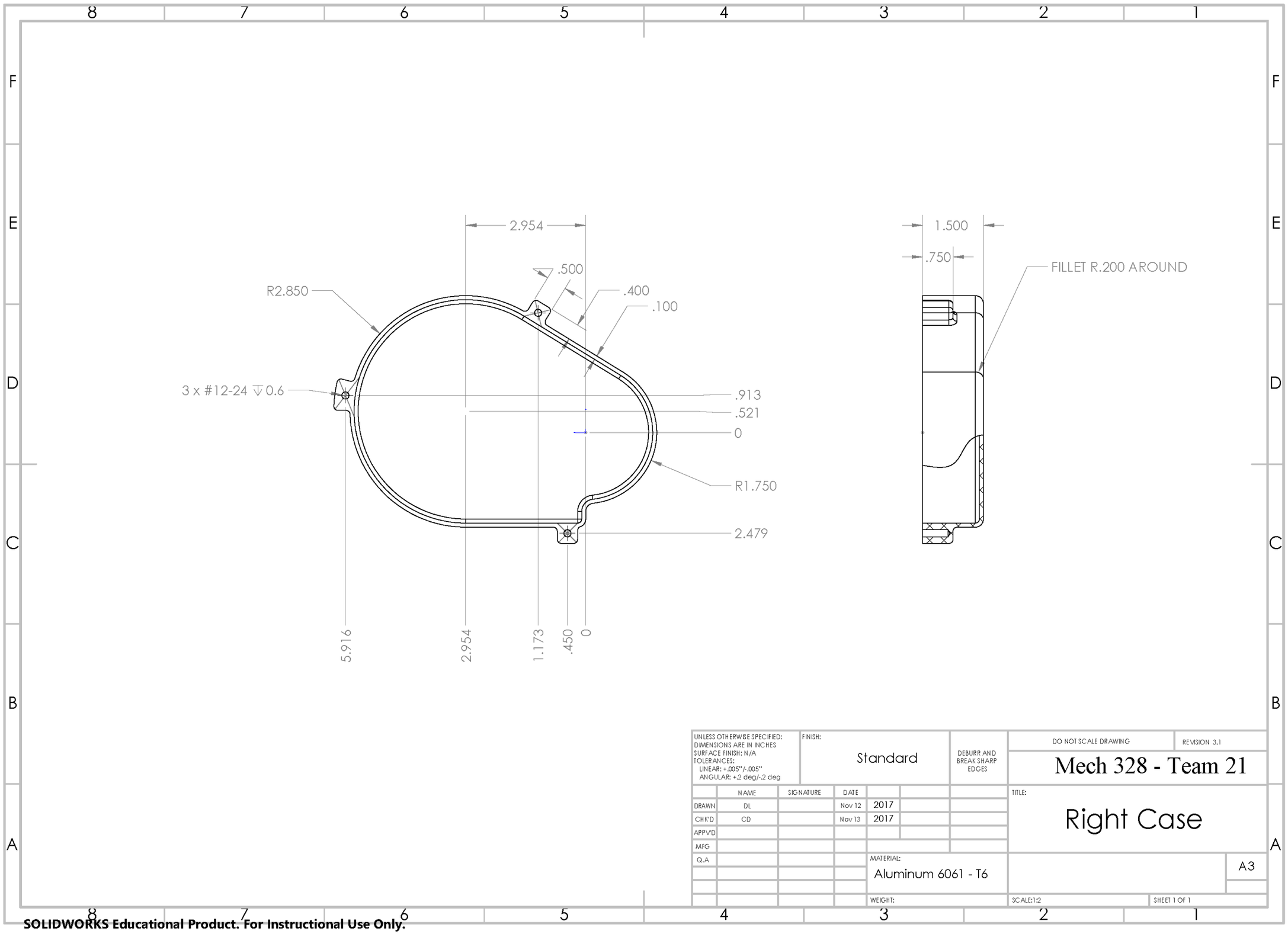


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G-1.11 Mounting Plate Manufacturing Drawing

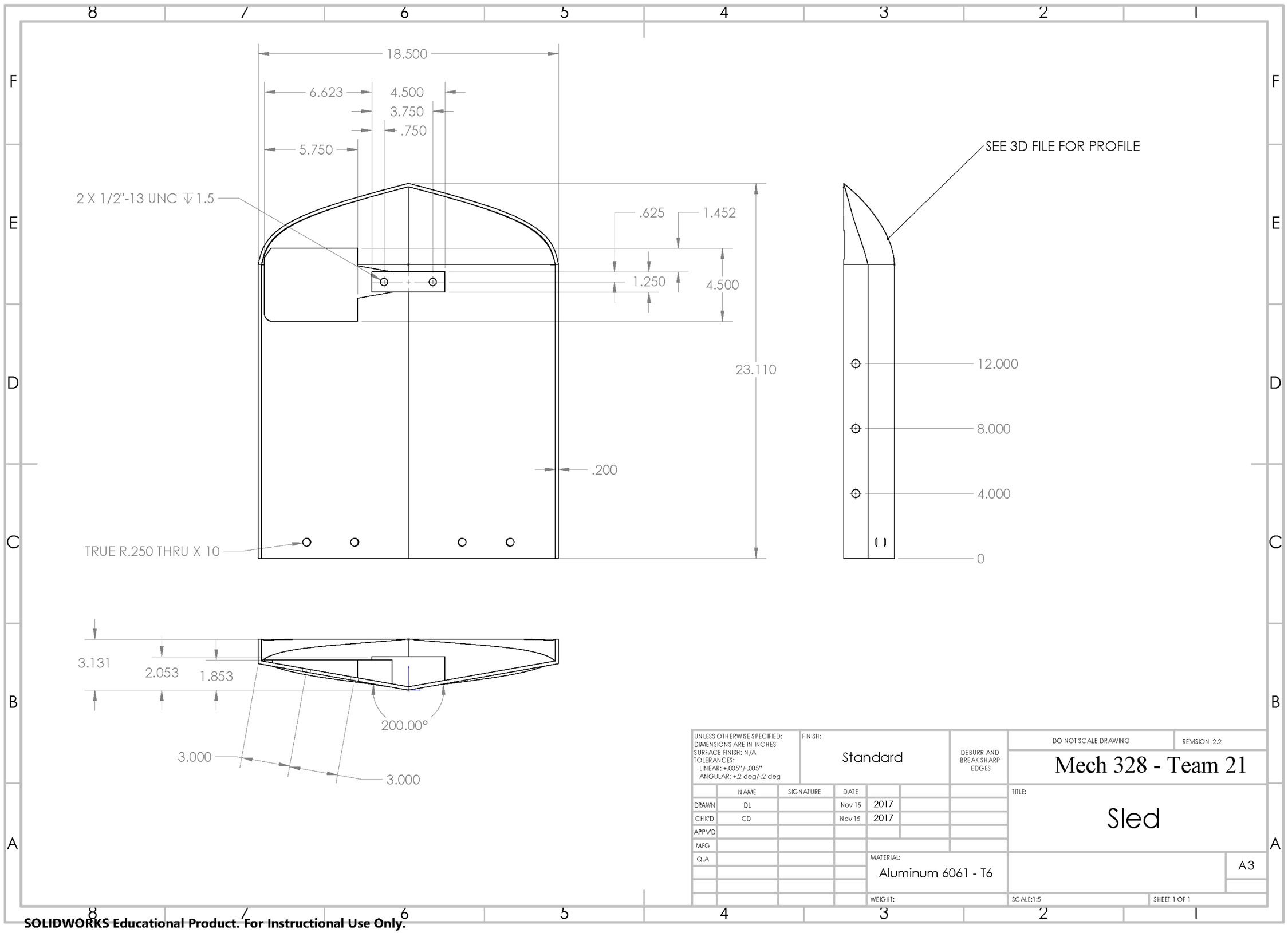


G-1.12 Right Case Manufacturing Drawing



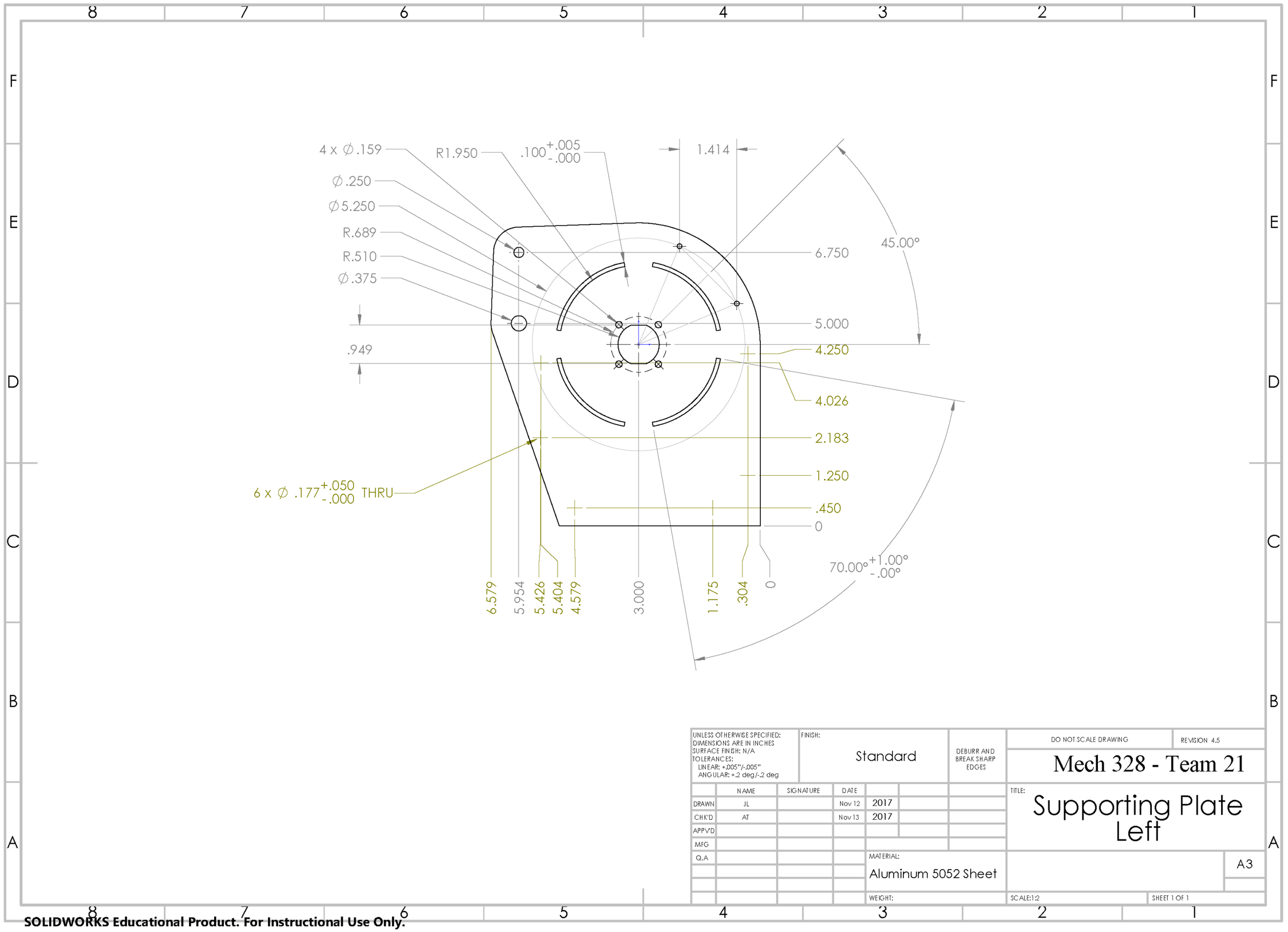
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G-1.13 Sled Manufacturing Drawing



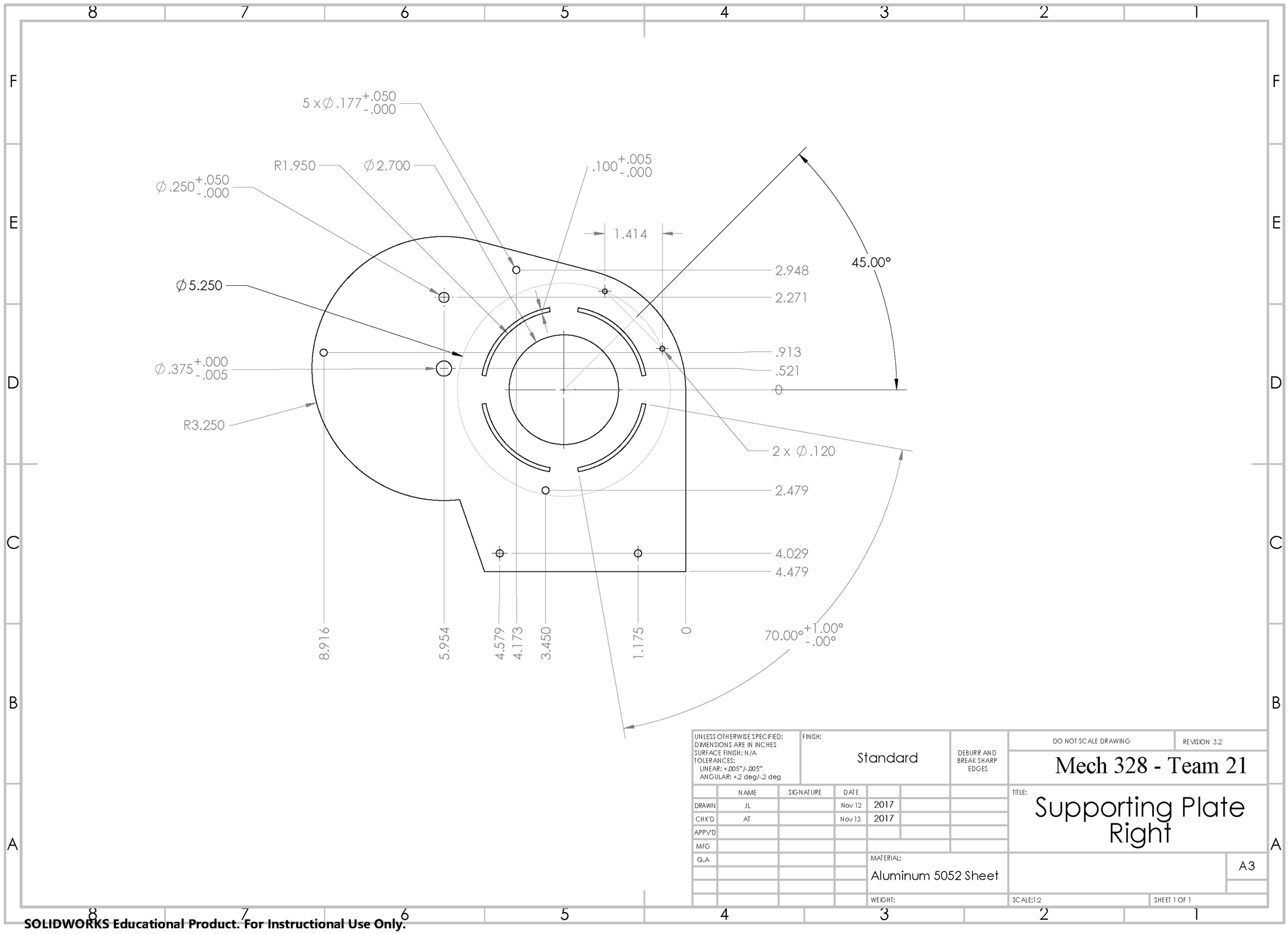
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G-1.14 Supporting Plate (Left) Manufacturing Drawing



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G-1.15 Supporting Plate (Right) Manufacturing Drawing



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G-2 Schematics

As seen in Figure below, the 14.4 Lithiun-Ion battery built out of 16 Panasonic NCR18650B cells is connected to a waterproof switch mounted on the outer surface of the enclosure using which the user toggles between charging and operation mode. Since the Geekcreit receiver operates from 12V DC voltage, LM2596 DC-DC step down converter is used to step down the battery voltage of 14.4V to 12V.

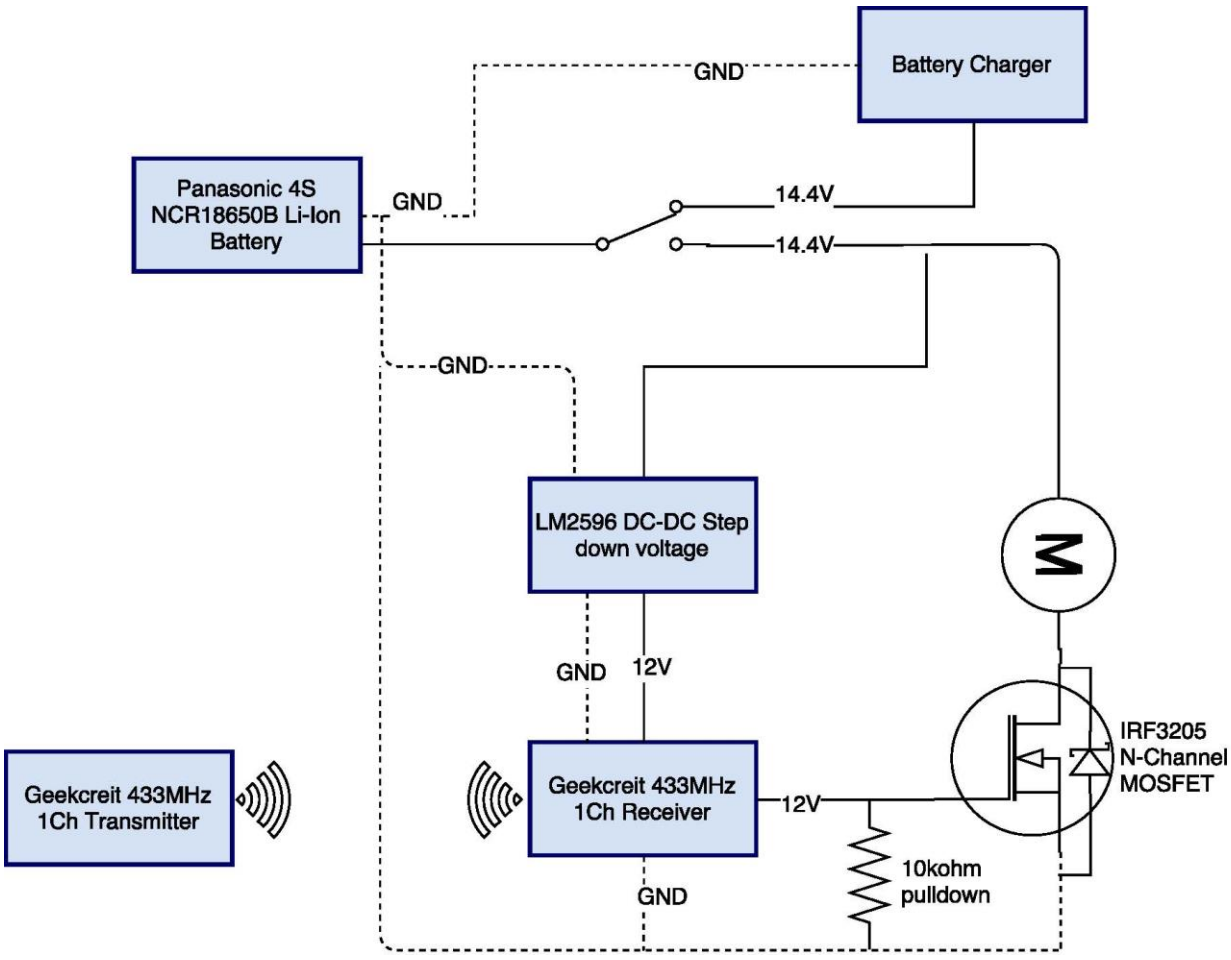


Figure G-1: Control schematic of the equipment tow device ("Geekcreit® DC 12V", n.d.)

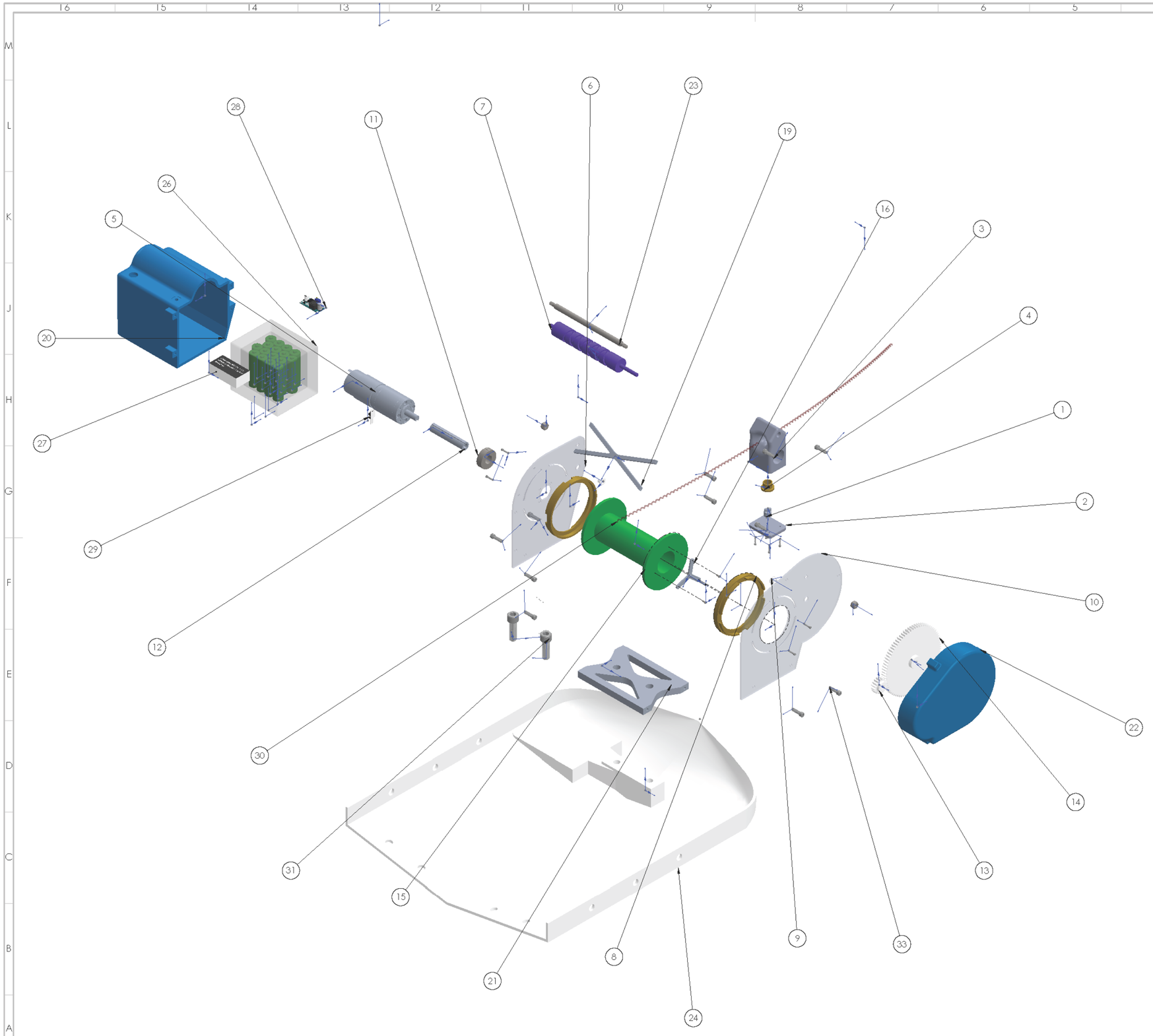
When the user toggles the switch to charging mode, they can connect the female GX16-3pin charger connector to the male GX16-3pin charging connector mounted outside the enclosure which delivers 5A (roughly 0.4C) charging current to the battery.

If the switch on the enclosure is toggled to operation mode, then user is able to easily toggle the motor on and off using a Geekcreit 433MHz 1Ch Transmitter (“Geekcreit® DC 12V”, n.d.). When the user pushes ‘on’ button on the transmitter, then the Geekcreit 1Ch receiver delivers 12V to the gate of the N-channel IRF3205 MOSFET which allows current to pass through the motor and the motor turns on. When the user pushes the ‘off’ button on the transmitter, the receiver stops delivering voltage to the gate of the IRF3205 N-Channel MOSFET which causes the MOSFET to enter the cut-off mode and the motor stops spinning. Since the impedance at the gate of a MOSFET is extremely large, any small electromagnetic field might cause the MOSFET to enter triode mode. Therefore, a pulldown 10kΩ resistor is added to the wire connecting the output of the Geekcreit receiver to the gate of the MOSFET to ground any residue current or electromagnetic fields.



Figure G-2: Circuit connection diagram of Geekcreit 433MHz 1Ch Transmitter (“Geekcreit® DC 12V”, n.d.)

G-3 Final Design Assembly Drawing



ITEM NO.	PARTS	QTY.
1	LEVEL WIND CARRIAGE NEEDLE	1
2	LEVEL WIND CARRIAGE CAP	1
3	LEVEL WIND CARRIAGE BODY	1
4	Level Wind Guide Bushing 1677K800	1
5	Motor PG-71-am-0914	1
6	LEFT SUPPORT PLATE	1
7	LEVEL WIND SHAFT	1
8	DRUM BUSHING	2
9	LEVEL WIND SHAFT BUSHING 6389K231	2
10	RIGHT SUPPORT PLATE	1
11	CLUTCH_BEARING	1
12	SLEEVE	1
13	PINION _ SDP_a_1n_2-y16016	1
14	Gear _ SDP_a_1n_2-y16080	1
15	DRUM	1
16	DRUM GEAR EXTENSION	1
17	LINEAR MOTION SHAFT NUT 97135A210	2
18	DRUM GEAR EXTENSION SCREW92949A325	3
19	CROSS BAR	1
20	LEFT CASE	1
21	MOUNTING PLATE	1
22	RIGHT CASE	1
23	LINER MOTION SHAFT 8350T5	1
24	SLED	1
25	BATTERY PANASONIC NCR18650B	16
26	Ca-Mg-Silicate BATTERY INSULATION	1
27	Geekcruit 1CH WIRELESS RECEIVER	1
28	DC-DC STEP DOWN VOLTAGE REGULARTOR LM2596-ADJ	1
29	TRANSISTOR	1
30	ROPE	1
31	SLED MOUNTING SCREW 91251A716	2
32	CROSS BAR & CARRIAGE SCREW 91251A096	8
33	SUPPORT PLATES & CASES SCREW 91251A460	11

FINISH: SEE PART DRAWINGS

DO NOT SCALE DRAWING | REVISION 1.1

MECH 328 - TEAM 21

	NAME	SIGNATURE	DATE
DRAWN	JL		NOV M
CHK'D	CD		NOV M
APP'D			
MFG			
Q.A			

TITLE: Master Assembly

MATERIAL: ALUMINUM 6061/7075, BRASS C360, DELRIN, SYNTHETIC

WEIGHT: 6.87 KG | SCALE:1/3 | SHEET 1 OF 1 | A1

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APPENDIX H: ENGINEERING CALCULATIONS AND OTHER ANALYSIS

The analysis of the equipment tow was determined through hand calculations, MATLAB scripts, excel spreadsheets, and Solidworks thermal analysis.

Free-body diagrams were drawn to determine the relationship between required torque and the mass of the system. A MATLAB script was developed to determine the final mass of the batteries; this is an iterative process as the increase of battery mass increases the required torque of the device, increasing the number of required batteries. The masses of various sub-systems on the equipment tow device which were pre-determined (for example, winch drum, bearings, mount plates, rope leveler, enclosure, etc.) were declared in the MATLAB script. Operating torque of the motor was initially assumed and declared in the script as well. Using the Andy Mark PG-71 motor 14.4V curves, the current draw was determined and the total capacity of Lithium Ion battery was determined. Based on the energy capacity of Li-Ion battery of 243Wh/kg, the mass of the Lithium Ion battery was determined. The additional mass that the battery adds to the system is used to recalculate the operating torque which results in a number higher (or lower) than initially assumed torque. Then the initially assumed operating torque is manually modified and the script is iterated until the assumed and resulting operating torques converge to a single value. When the operating torque values converge, the resulting value of battery power capacity was used to determine the number of Panasonic NCR18650B Lithium-Ion cells required in the battery pack.

Using the discharge vs temperature curves defined in the Panasonic NCR18650B datasheet, the power loss in the battery due to battery's internal resistance was computed. Since it was desirable to keep the Lithium Ion battery above sub-zero degrees Celsius temperatures, the heat generated by the battery due to power loss is conserved using low thermal conductivity insulation material which keeps the battery warm during operation in cold temperatures on ski slopes. The thickness of the material is determined using thermal simulation in Solidworks.

Furthermore, the sled is designed to minimize friction between its bottom surface and the snow, remain stationary as the user is climbing, support the load of the backpack and the rest of the

device. In order to ensure that the winch rope does not get entangled as it is wrapped in and out, a rope leveler is designed which translates with respect to the winch drum and ensures even wrapping of the rope on the drum.

Finally, stress calculations were done for the gears connecting the winch drum shaft to the rope leveler to ensure that gears remain operational for at least 6 years.

We conclude that the equipment tow allows the user to achieve a 10% higher vertical ascent compared to traditional climbing methods.

Appendix F-2.3: Final-Range FMEA_November 4, 2017 (p.121)contains justifications for how each high RPN issue for mechanical components of equipment tow is tackled. The high RPN issues identified for motor and battery are discussed in the relevant sections in this appendix.

H-1 MATLAB Script

The MATLAB script is explained part-by-part in relevant sections of Appendix H which follow.

Declare constants

```
OPERATION_HOURS = 3;

LEVEL_WIND_MASS = 0.37/2.2; %mass in kg
MOTOR_MASS = 0.907; %mass in kg
SUPPORTING_PLATE_LEFT_MASS = 0.5/2.2; %mass in kg
LEVEL_WIND_SHAFT_MASS = 0.43; %mass in kg
BUSHING_MASS = 0.68/2.2; %mass in kg
SUPPORTING_PLATE_RIGHT_MASS = 0.64/2.2; %mass in kg
CLUTCH_BEARING_MASS = 0.15/2.2; %mass in kg
SLEEVE_BUSHING_MASS = 0.05/2.2;%mass in kg
GEARS_MASS = 0.29/2.2; %mass in kg
WINCH_DRUM_MASS = 0.41/2.2; %mass in kg
DRUM_GEAR_EXTENSION_MASS = 0.02/2.2; %mass in kg
FASTENER_MASS = 0.02/2.2; %mass in kg
CROSS_BAR_MASS = 0.07/2.2; %mass in kg
LEFT_CASE_MASS = 0.96/2.2;%mass in kg
WINCH_SUPPORT_MASS = 0.92/2.2; %mass in kg
RIGHT_CASE_MASS = 0.24/2.2; %mass in kg
LEVEL_WIND_GUIDE_SHAFT = 0.2/2.2; %mass in kg
CONTROLS_MASS = 0.15; %mass in kg
SLED_MASS = 4.53/2.2; %mass in kg
ROPE_MASS = 0.181; %mass in kg
BACKPACK_MASS = 10; %mass in kg

FRICTION_COEFFICIENT = 0.041; %friction coefficient based on research
 paper
GRAVITY_ACCEL = 9.81;
SLOPE = 30 * pi/180; %slope in radians
WINCH_DRUM_DIAMETER = 3 * 0.0254; %drum diameter in m

% Assume a value of operating torque and refine it based on calculated
% operating torque (This value of 3.44Nm is obtained after re-running
% (iterating) this script multiple times
OPERATING_TORQUE = 3.38; %in Nm

%Energy density of NCR18650B Panasonic Li-Ion battery [Wh/kg]
BATTERY_ENERGY_DENSITY = 243;
VOLTAGE14 = 14;
NOMINAL_VOLTAGE_4S = 3.6*4; %Nominal voltage of 4-cell Li-Ion battery
```

Motor 1 at 14.4 V

```
torque = linspace(0, 20, 2001); %create a torque vector
```

```
%The following equations are obtained from page 3 of
%'AM-0914-Whirlpool-Results-Summary' document
current = 0.9327.*torque + 0.5001; %in amps
powerOut = -0.3469.*(torque.^2) + 9.7457.*torque - 0.4275; %in watts
speed = -3.3569.*torque + 94.103; %in rpm
powerIn = current.*VOLTAGE14; %in W
efficiency = powerOut./powerIn * 100; %in percentage
[efficiency_max, index] = max(efficiency);

indexOperatingTorque = find(torque==OPERATING_TORQUE);

%subplot(2,1,1)
plot(torque, current, torque, powerOut, torque, speed,...
    torque, powerIn, torque, efficiency,...
    torque(index), efficiency_max, 'k*')  ;
operating_line2 = get(gca,'ylim');
hold on
plot([torque(indexOperatingTorque)
 torque(indexOperatingTorque)],operating_line2, 'k--');

title('PG71 motor at 14V input voltage');
legend('Current [A]', 'Power Out [W]', 'Speed [rpm]', 'Power Input
 [W]', 'Efficiency [%]',...
    'Max Efficiency [%]', 'Operating Line');
xlabel('Torque [Nm]');
ylabel('Multiple parameters');
ylim([0 200]);
grid('on');

currentOperatingTorque = current(indexOperatingTorque);

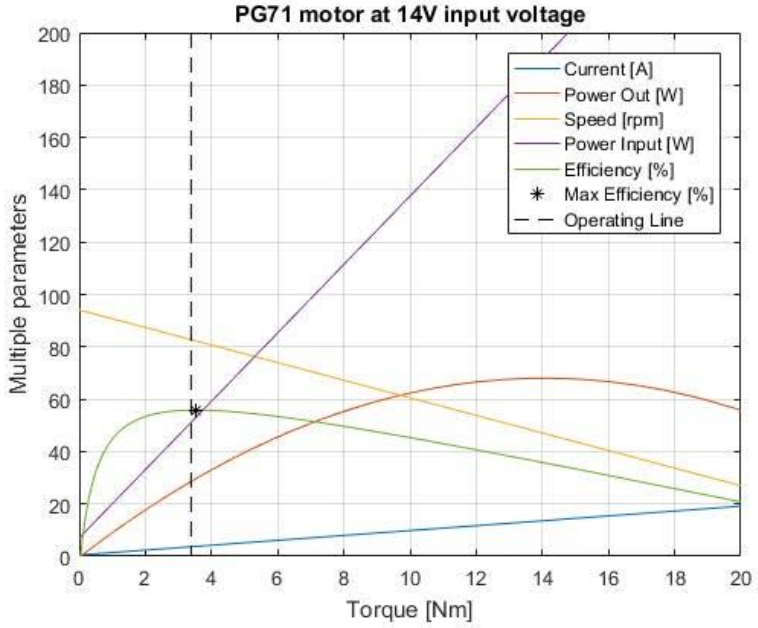
%efficiency and input electrical power at operating torque are
 determined
efficiencyOperatingTorque = efficiency(indexOperatingTorque);
powerInOperatingTorque = powerIn(indexOperatingTorque);

%battery mass is calculated such that device can run for 5.5 hours
totalEnergyBattery = powerInOperatingTorque * OPERATION_HOURS;
capacity14VBattery = totalEnergyBattery / NOMINAL_VOLTAGE_4S;
batteryMass = totalEnergyBattery / BATTERY_ENERGY_DENSITY ;
speedOperatingTorque = speed(indexOperatingTorque);

fprintf('MOTOR CHARACTERISTICS AT 14V INPUT VOLTAGE\n');
fprintf('Speed at operating torque = %f rpm\n', speedOperatingTorque);
fprintf('Efficiency at operating torque = %f\n',
 efficiencyOperatingTorque);
fprintf('Current input at operating torque = %f A\n',
 currentOperatingTorque);
fprintf('Power input at operating torque = %f W\n',
 powerInOperatingTorque);
fprintf('Total energy of 14.4V Li-Ion battery = %f Wh\n',
 totalEnergyBattery);
```

```
fprintf('Capacity of 14.4V Li-Ion battery = %f Ah\n',
 capacity14VBattery);
fprintf('Mass of 14.4V Li-Ion battery = %f kg\n', batteryMass);
fprintf('\n\n');
```

```
MOTOR CHARACTERISTICS AT 14V INPUT VOLTAGE
Speed at operating torque = 82.756678 rpm
Efficiency at operating torque = 55.830364
Current input at operating torque = 3.652626 A
Power input at operating torque = 51.136764 W
Total energy of 14.4V Li-Ion battery = 153.410292 Wh
Capacity of 14.4V Li-Ion battery = 10.653493 Ah
Mass of 14.4V Li-Ion battery = 0.631318 kg
```



Calculation of total force and resulting load torque

```
fprintf('CALCULATIONS OF FORCE AND TORQUE BASED ON INPUT VOLTAGE OF
 14.4V\n');
```

```
TotalMass = batteryMass + LEVEL_WIND_MASS + MOTOR_MASS +
 SUPPORTING_PLATE_LEFT_MASS +...
```

```
    LEVEL_WIND_SHAFT_MASS + BUSHING_MASS + SUPPORTING_PLATE_RIGHT_MASS
 +...
    CLUTCH_BEARING_MASS + SLEEVE_BUSHING_MASS + GEARS_MASS +...
    WINCH_DRUM_MASS + DRUM_GEAR_EXTENSION_MASS + FASTENER_MASS+...
    CROSS_BAR_MASS + LEFT_CASE_MASS + WINCH_SUPPORT_MASS+...
    RIGHT_CASE_MASS + LEVEL_WIND_GUIDE_SHAFT + CONTROLS_MASS + ...
    SLED_MASS + ROPE_MASS + BACKPACK_MASS;

%Operating torque is recalculated using calculated 14.8V battery mass
 which
%produces different torque from the initially assumed operating
 torque.
%This new value of torque is then set as the OPERATING_TORQUE and the
%script is re-run until the calculated and assumed operating torques
 are
%equal to each other.
ForceWinch = TotalMass * GRAVITY_ACCEL * (FRICTION_COEFFICIENT *
 cos(SLOPE) + sin(SLOPE));
fprintf('Force required to pull the device up = %f N\n',ForceWinch);
Torque = ForceWinch * WINCH_DRUM_DIAMETER/2; % Torque in Nm
fprintf('New torque required to pull the device up = %f Nm\n',Torque);
fprintf('Total mass of the device (excl. backpak) is = %f kg\n',
 TotalMass - BACKPACK_MASS);
```

```
CALCULATIONS OF FORCE AND TORQUE BASED ON INPUT VOLTAGE OF 14.4V
Force required to pull the device up = 88.610443 N
New torque required to pull the device up = 3.376058 Nm
Total mass of the device (excl. backpak) is = 6.867500 kg
```

Published with MATLAB® R2016b

H-2 Winch Force and Torque Calculations

Assumptions

- Maximum mass of the backpack which contains non-critical items such as food and water is 10kg
- Coefficient of friction between the sled and snow is 0.041 (Hasler et. al, 2016, p. 26)
- Slope of the hill is 30^o
- Number of hours that the device operates for = 3 hours
- The motor exhibits same power output and speed characteristics at 14.4V input voltage as it does at 14V

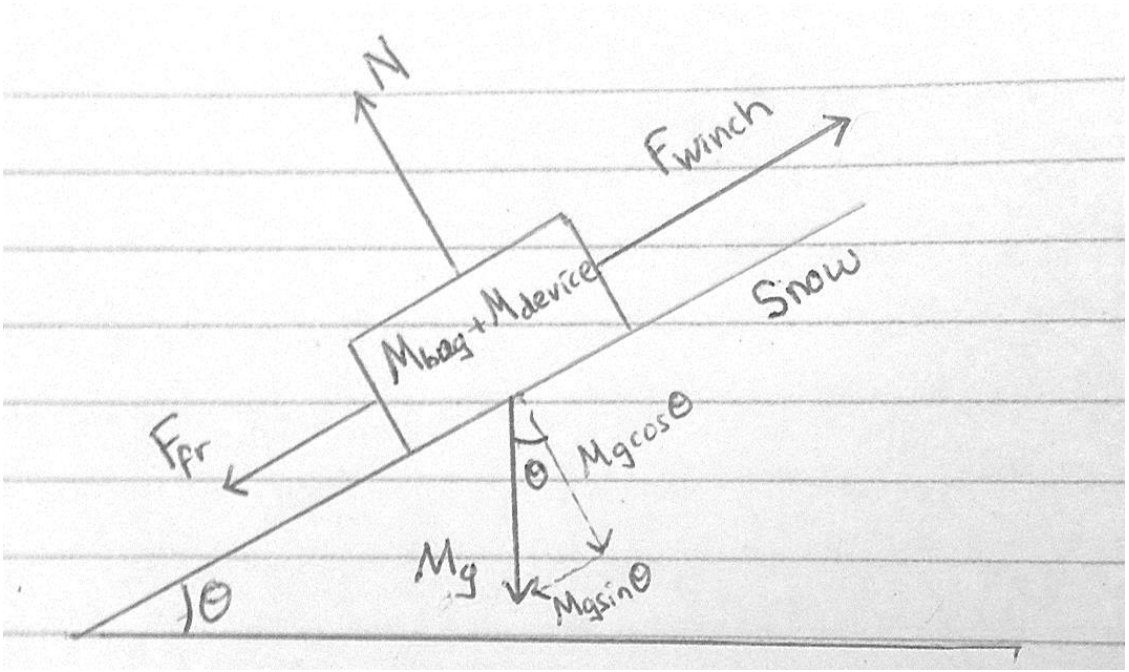


Figure H-1: Free Body Diagram of the Equipment Tow Device

In the figure above, following are the values for the shown parameters:

- $\Theta = 30^o$
- $M_{bag} + M_{device} = 10\ kg + M_{device}$ (M_{device} is determined to be around 6.8kg using MATLAB script described in section H-3)
- $\mu = 0.041$

From the FBD analysis,

$$F_{winch} = F_{fr} + Mgsin(\Theta) = \mu N + Mgsin(\Theta) = \mu Mgcos(\Theta) + Mgsin(\Theta) = Mg\,(\mu cos(\Theta) + sin(\Theta))$$

$$F_{winch} = 9.81 * (10 + M_{device}) * (0.041*cos(30^o) + sin(30^o))$$

$$F_{winch} = 52.533 + 5.2533 * M_{device} \quad [N] \qquad (1)$$

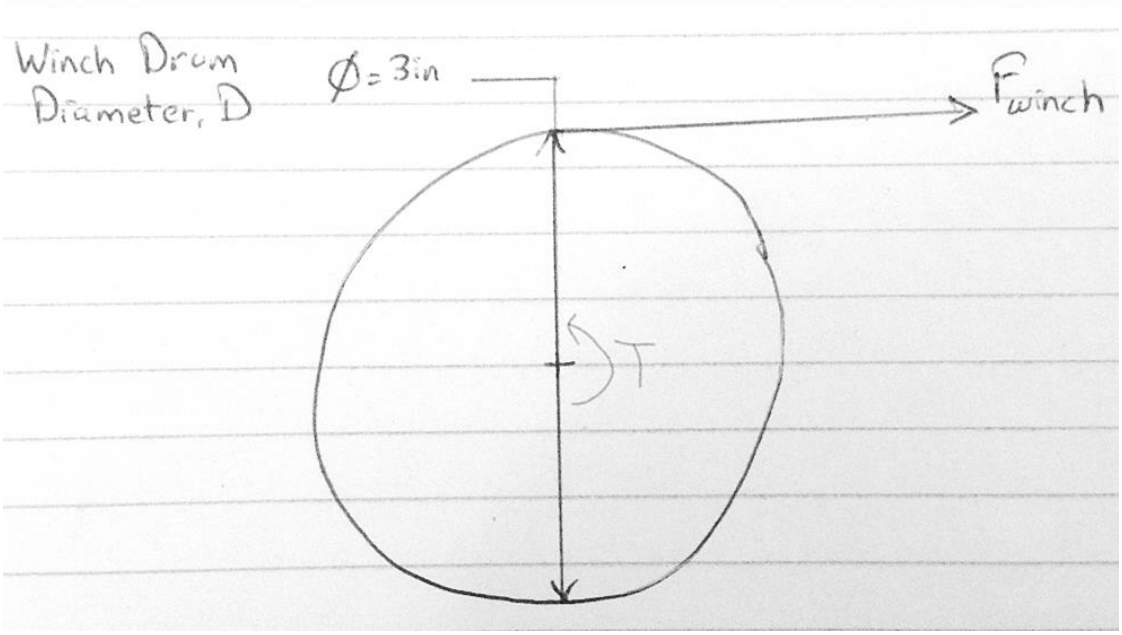


Figure H-2: Free Body Diagram of the Winch Drum

Winch drum diameter is obtained from section G-1.5 (p.137). Based on the figure above, we can determine the torque using the following equation:

$$T = F_{winch}\,\frac{D}{2}$$

$$T = F_{winch}\,\frac{(3 * 0.0254)}{2}$$

$$T = 0.0381 F_{winch}\,[Nm] \qquad (2)$$

H-3 Operation Hours Calculation

From the client, it is known that the skier climbs 5000’ vertically per day. Based on the slope of the hill of 30^o, it can be determined that the distance which the skier traverses is given by the relationship:

$$\text{Distance traversed by the user} = \frac{Vertical\ Distance\ clibed}{\tan(slope)} = \frac{5000'}{\tan(30^o)} = 8521.7\text{ft}$$

The mean diameter of the winch drum is 2.5” (refer to G-1.5 Drum Manufacturing Drawing, p.137).

RPM of the motor output shaft ~ 80 rpm

$$\text{Motor operation time (in min)} = \frac{Distance\ Traversed\ [in]}{\pi * Winch\ mean\ diameter[in] * RPM\ of\ motor\ shaft\ [rpm]}$$

$$= \frac{8521.7*12}{\pi*2.5*80}$$

$$= 162.75 \text{ minutes} = 2.712 \text{ hours}$$

Round the operation time up to 3 hours to account for the fact that

- the user will be able to climb higher because they would not be carrying a 10kg backpack during ascent, and
- the user will be climbing hills of varying slopes which will affect the total distance traversed for a given vertical ascent.

The figure below shows the initialization of variables in MATLAB script. The mass numbers of various sub-systems are obtained using the following methods:

- Solidworks CAD: Level wind, supporting plates, winch drum, cross bar, left case, winch support, level wind guide shaft, sled
- Manufacturer Datasheets: PG71 Motor, winch rope, bushing, bearings, gears, fasteners, controls, battery

```
%% Declare constants

OPERATION_HOURS = 3;

LEVEL_WIND_MASS = 0.37/2.2; %mass in kg
MOTOR_MASS = 0.907; %mass in kg
SUPPORTING_PLATE_LEFT_MASS = 0.5/2.2; %mass in kg
LEVEL_WIND_SHAFT_MASS = 0.43; %mass in kg
BUSHING_MASS = 0.68/2.2; %mass in kg
SUPPORTING_PLATE_RIGHT_MASS = 0.64/2.2; %mass in kg
CLUTCH_BEARING_MASS = 0.15/2.2; %mass in kg
SLEEVE_BUSHING_MASS = 0.05/2.2;%mass in kg
GEARS_MASS = 0.29/2.2; %mass in kg
WINCH_DRUM_MASS = 0.41/2.2; %mass in kg
DRUM_GEAR_EXTENSION_MASS = 0.02/2.2; %mass in kg
FASTENER_MASS = 0.02/2.2; %mass in kg
CROSS_BAR_MASS = 0.07/2.2; %mass in kg
LEFT_CASE_MASS = 0.96/2.2;%mass in kg
WINCH_SUPPORT_MASS = 0.92/2.2; %mass in kg
RIGHT_CASE_MASS = 0.24/2.2; %mass in kg
LEVEL_WIND_GUIDE_SHAFT = 0.2/2.2; %mass in kg
CONTROLS_MASS = 0.15; %mass in kg
SLED_MASS = 4.53/2.2; %mass in kg
ROPE_MASS = 0.181; %mass in kg
BACKPACK_MASS = 10; %mass in kg

FRICTION_COEFFICIENT = 0.041; %friction coefficient based on research paper
GRAVITY_ACCEL = 9.81;
SLOPE = 30 * pi/180; %slope in radians
WINCH_DRUM_DIAMETER = 3 * 0.0254; %drum diameter in m

% Assume a value of operating torque and refine it based on calculated
% operating torque (This value of 3.44Nm is obtained after re-running
% (iterating) this script multiple times
OPERATING_TORQUE = 3.38; %in Nm

%Energy density of NCR18650B Panasonic Li-Ion battery [Wh/kg]
BATTERY_ENERGY_DENSITY = 243;
VOLTAGE14 = 14;
NOMINAL_VOLTAGE_4S = 3.6*4; %Nominal voltage of 4-cell Li-Ion battery
```

Figure H-3: Constants and Assumed Operating Torque Declared in MATLAB Script

H-4 Motor Selection and Characterization

Based on equation (2) in section H-2, it can be observed that the required torque is in the order of magnitude of 1Nm. This implies that a high torque, low rpm DC motor is required to rotate the winch drum. Therefore, in appendix C-7, Andy Mark's PG-71, 10mm Round Output motor is chosen. Please note that the motor which is used to obtain the curves in the figure below was in operation before testing. According to Galloway (2012), the "grease inside the gearbox of [motor] 1 is likely to have been warmed and distributed more advantageously." Therefore, before integrating the motor into the assembly of the equipment tow, it will be turned on and run for a few minutes at the assembly line to advantageously distribute grease inside the moving components of the motor.

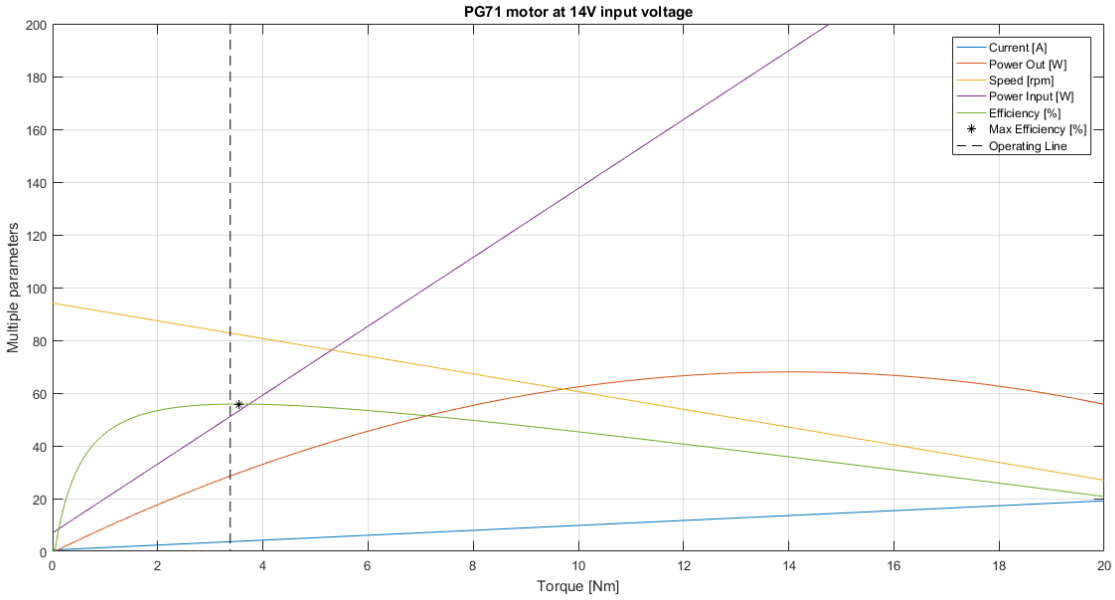


Figure H-4: Input current, output power, output speed, input power and efficiency curves plotted in MATLAB using the equations defined on page 3 of Galloway, 2012

From Figure H-4, it can be observed that motor current draw reaches 20A at 20Nm (which amounts to around 40kg load applied on equipment tow). From Controls FMEA in appendix F-2.3 (p.121), it is evident that the switch starts smoking if the current draw exceeds 20A. Therefore, a warning label is placed on the sled which states that the user should not load more than 10kg on the sled.

H-5 Battery Pack Design

Section C-6 describes the reason why Panasonic NCR18650B cells are chosen to build the battery pack out of. In Figure H-4, the operating torque is plotted as a black, vertical dashed line. The value of electrical input power is computed using MATLAB at the operating torque once the script has been iterated several times and the values of assumed and recalculated operating torques converge to a single value.

Using the determined value of input power, the total energy that the battery needs to deliver is computed based on the relationship:

Total Energy [Wh] = Input Power [W] * Number of Operations Hours [h]

= 51.137W * 3 hours = **153.41Wh**

Nominal voltage of the battery pack has to be greater than or equal to the motor input voltage of 14V. Therefore, 4 cells are put in series to obtain a nominal output voltage of 3.6V * 4 = 14.4V. Furthermore, number of cells required can be computed by dividing total energy required by the energy contained in each cell = 155.76Wh/11.79Wh = 13.2 cells. However, it is known that at least 4 cells will be required in series to obtain output voltage of 14.4V. Therefore, 16 cells are used to build the battery pack of equipment tow device. In this configuration, 4 packs of 4 cells each will be connected in series and the 4 cells in each pack will be connected in parallel (as shown in the figure below). This gives a nominal output voltage of 14.4V and capacity of 3.25Ah * 4 = 13Ah.

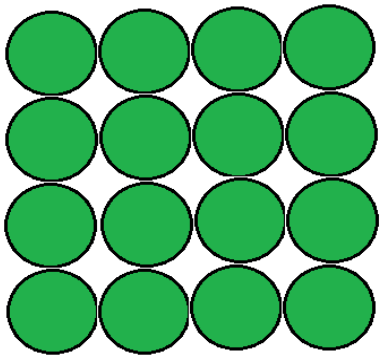


Figure H-5: 16 cell configuration of the 18650 battery pack used to power equipment tow

The amount of useful energy delivered by the Lithium-Ion battery is dependent on three factors:

- The rate at which current is drawn from the battery
- The temperature at which the battery operates
- The number of charge and discharge cycles that the battery has undergone

In Panasonic NCR18650B (2014) datasheet, the effects of all three aforementioned factors are presented in the form of discharge curves. Therefore, the useful energy delivered by each Panasonic NCR18650B cell can be determined by measuring the area under the discharge curves.

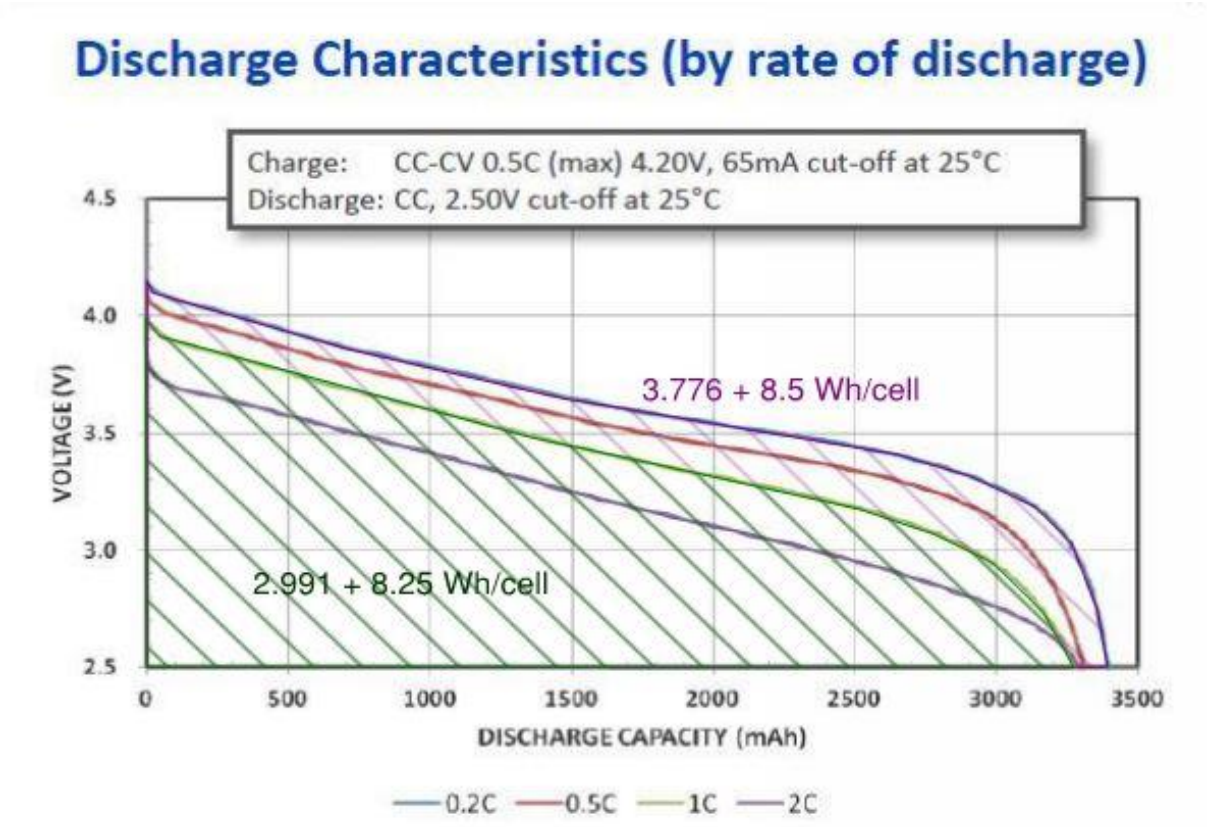


Figure H-6: Discharge characteristics of Panasonic NCR18650B batteries at different current draw rates (1C – 3.25A/cell vs 0.2C – 0.65A/cell) (Panasonic NCR18650B, 2014)

When current is drawn from each cell at 1C (3.25A/cell), the total energy delivered by each cell is 2.991+8.25 = 11.24Wh/cell. When current is drawn from each cell at 0.2C (0.65A/cell), the total energy delivered by each cell is 3.776+8.5 = 12.276Wh/cell. Therefore, the cell would

deliver (12.276/11.24 =) 1.092 times the energy when current is drawn from it at 0.2C as compared to 1C. From the MATLAB script, the current drawn by motor to operate the device = 3.653A. In the 16-cell battery pack, current is discharged at (3.653A / 13Ah) = 0.281C.

Since the discharge curve of Panasonic NCR18650B batteries is documented for 1C current draw (as seen in Figure), we can use the multiplier of 1.092 to determine the usable energy delivered by the battery at different temperatures at 0.2C current draw.

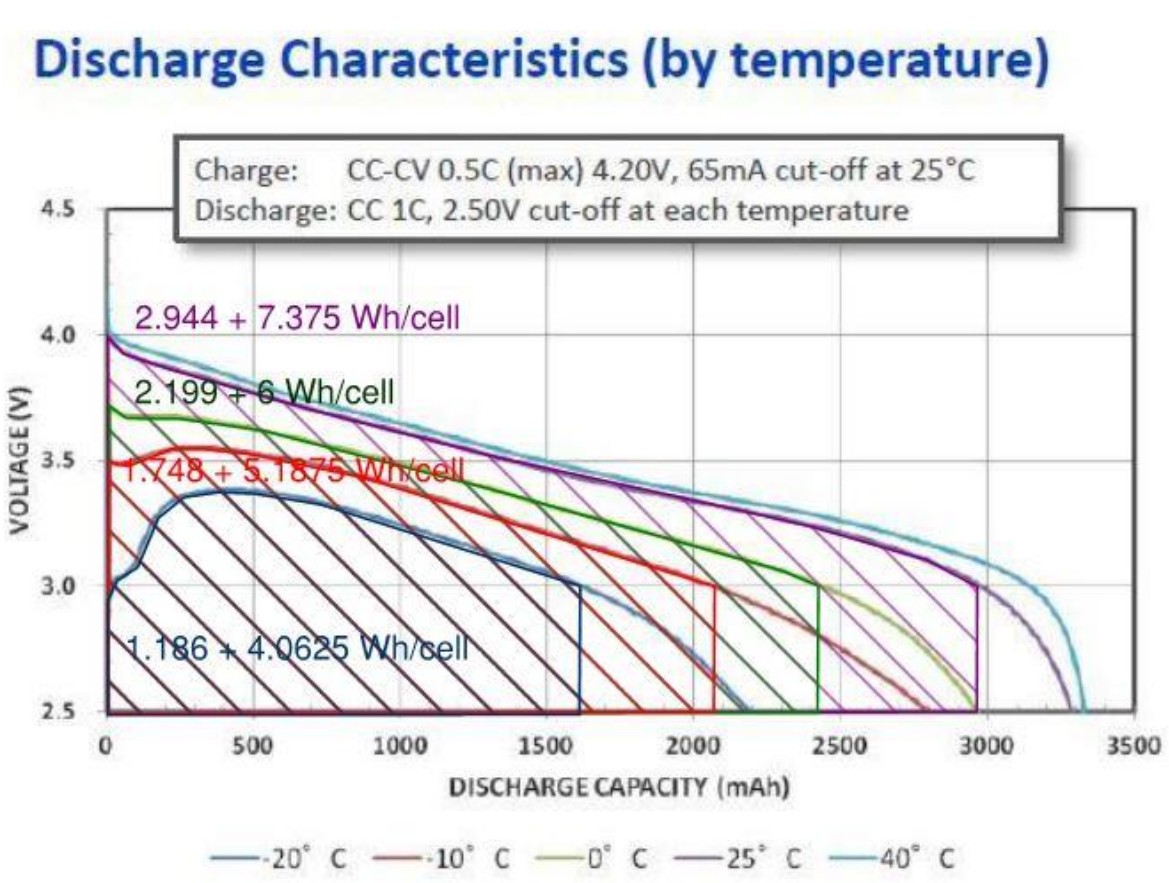


Figure H-7: Discharge characteristics of Panasonic NCR18650B batteries at different temperatures at 1C discharge rate (3.25A/cell) (Panasonic NCR18650B, 2014)

In the figure above, areas under the discharge curve drawn at different temperatures determine the total energy delivered by one Panasonic NCR18650B cell. Since it is not ideal to discharge the battery to 2.5V, it is assumed that the battery would be discharged from the max voltage of 4.2V to 3.0V per cell to elongate the battery life.

Table H-1: Energy calculations for Panasonic NCR18650B batteries

Temperature [^{o}C]	25	0	-10	-20
Energy per cell [Wh] (obtained from Figure)	10.319	8.199	6.9355	5.2485
Energy delivered by 16 cells (at 1C) [Wh]	165.104	131.184	110.968	83.976
Energy delivered by 16 cells (at 0.2C) [Wh]	180.306	143.263	121.185	91.708
Number of hours	3.526	2.802	2.370	1.793
Total energy in 16 cells [Wh]	188.64	188.64	188.64	188.64
Energy loss in the battery [Wh]	8.334	45.377	67.455	96.932
Power Loss in the battery/hour [W]	2.364	16.197	28.464	54.050

Earlier, the total energy that the battery needs to deliver to run the device for 3 hours is computed to be 153.41Wh. Based on that value and the energy values determined from the areas under discharge curves in Figure , the total number of hours that the device would operate for at different temperatures can be determined using the formula:

Number of hours = Energy delivered by 16 cells (at 0.2C) / 153.41Wh * 3 hours

From Table H-1, it is evident that the number of hours that the battery can run the motor for drops drastically (reduces to almost half) at -20^{o}C compared to 25^{o}C. Hence, it is desirable to conserve heat generated from the battery because of power loss due to internal resistance.

It can also be seen that every Panasonic NCR18650B cell stores 11.79Wh of energy. Therefore 16 cells store (11.79Wh/cell * 16cells =) 188.64 Wh of energy. Now, energy loss at each temperature can be computed using the equation:

Energy Loss from 16 cells (battery pack) [Wh] = Total energy stored in 16 cells [Wh] - Energy delivered by 16 cells (at 0.2C) [Wh]

Now, power loss from battery [W] = energy Loss from 16 cells [Wh] / number of operation hours [hours]

Section H-7 examines how passive insulation is used to conserve the power loss heat and keep the battery temperature at around 0^oC even when the ambient temperature is -20^oC.

From power source FMEA in appendix F-2.3, it is mentioned that the battery should be charged at 0.5C to extend lifetime. Therefore, battery charger is chosen such that it delivers a charging current of 5A (= 5/13 = 0.38C) to the battery. Furthermore, in FMEA, it is mentioned that the battery must only be charged at above 0^oC temperatures. Therefore, the user manual states that user must charge the battery at greater than 0^oC temperature.

H-6 Active Heating System for Electronics

In order for an electromechanical device to operate as intended in sub-zero temperatures, due diligence is required on an analysis of the device as a thermal system. Two main options were considered, passive and active heating. Specifically, passive heating in this context pertains to capturing the heating given off of batteries due to their internal resistance, while active heating refers to dedicating energy to be used for heating through external resistors.
The analysis of the viability and value in an active heating system is detailed as follows.

The battery capacity available for running the proposed Equipment Tow device varies with the operating temperature. The relationship for available energy capacity to operating temperature is based off of a manufacturer provided datasheet. Refer to appendix L-5 for battery capacity and temperature relationship specifications.

This information highlights a design trade-off with potential for optimization. The trade-off is balancing the battery capacity dedicated to device operation and the capacity dedicated to maintaining device temperature. A first principles method was taken to optimize the distribution of energy capacity, achieved through estimating the total energy required for device operation at different operating for a given environment temperature.

Two main tools were used to perform this optimization. The first is a MATLAB script that iteratively gives the amount of energy required to operate the Equipment, without accounting for thermal effects. This script's operation is described above in section H-3.

The second is an excel sheet that combines the results of the MATLAB code and includes the energy required to operate at different environment temperatures. Under the assumption that the surrounding environment is at -20 degrees C, the excel sheet produces an estimate of the required energy to run a device and maintain an internal temperature for the required time frame of 3 hours.

0.2C / 1C Energy Multiplier	1.092073659	Obtained by finding the ratio between the discharge curves at 1C and 0.2C draw			Surface Area		0.1654				
Capacity required to run for 3 hours	147.926016	Refer to MATLAB results			Radius		0.2294525118		Possible Insulation		
Number of cells	16	Change this parameter by adding 4 cells at a time			K	0.1	W/mK		http://uk.rs-online.com/web/p/thermal-insulating-sheets/8405517/		
Capacity/cell	3250	mAh							http://uk.rs-online.com/web/p/thermal-insulating-sheets/7757801/		
Nominal voltage	3.6	V									
Mass/cell	48.5	g			Cp	830	J/Kg				
Total Mass	776	g			INsul Thickness	0.01	m				
Operation Hours	3										
Diameter of each cell	18.5	mm									
Number of cells in one row	4										
Lenght of battery pack	92.5	mm									

	Temperature [oC]	Power Capacity of each cell [Wh]	Power delivered by 32 cells (at 1C) [Wh]	Power delivered by 32 cells (at 0.2C) [Wh]	Number of hours	Excess Energy [Wh]	Excess Energy [J]	Power loss in the battery [Wh]	Power Loss in the battery/hour [W]	Active Heating Energy [J]	Total Energy Required for 3 Hours [J]
~~4.2V to 3.5V~~	~~35 degC~~	~~11.307~~	~~180.912~~	~~197.6603008~~	~~7.346774847~~	~~40.64331378~~	~~378746~~	~~10.36020075~~			
	~~0 degC~~	~~9.748~~	~~155.92~~	~~170.3761248~~	~~6.330663776~~	~~22.3501089~~	~~208400~~	~~16.03183761~~			
	~~-10 degC~~	~~9.335~~	~~149.36~~	~~163.1131317~~	~~6.064630777~~	~~15.1861067~~	~~141570~~	~~24.5878783~~			
	~~-20 degC~~	~~6.871~~	~~109.936~~	~~120.0642008~~	~~4.463864105~~	~~27.86780625~~	~~259834~~	~~47.14170023~~			
							0				
4.2V to 3V	25	10.319	165.104	180.3057294	6.70390198	32.37971338	116567	6.894270616	1.028396691	3075243.474	3607777
	0	8.199	131.184	143.2625909	5.326610363	-4.663425127	-16788	43.93740913	8.248662119	1366774.877	1899309
	-10	6.9355	110.968	121.1852298	4.505757553	-26.74078622	-96267	66.01477022	14.65120337	683387.4387	1215921
	-20	5.2485	83.976	91.70797758	3.409771251	-56.21803842	-202385	95.49202242	28.00540429	0	532534

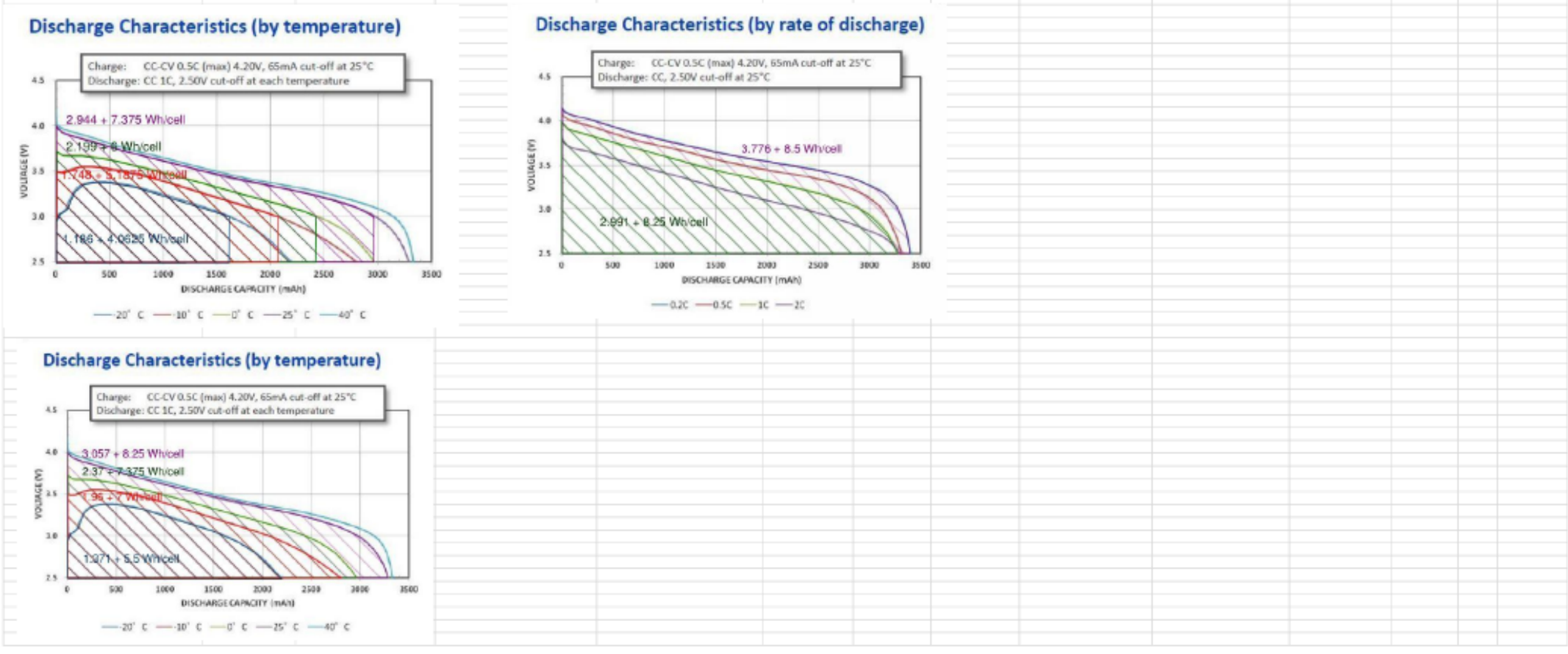


Figure H-8: Excel Battery Power Loss and Thermal Analysis

Assumptions

- environment temperature of -20 degrees C
- spherical geometry
- no energy would be required to initially raise the device temperature
- any energy spent actively heating the device would only go to heating the batteries, no other components

For these assumptions the following equation was used to determine the total energy required to run with specific internal temperatures of 25, 0, -10, -20 degrees. The following equation governs was used to determine the results.

$$Total\ Energy = Operation\ Energy + \frac{4\pi k(\Delta T)}{\frac{1}{r-\delta} - \frac{1}{r}} \cdot t$$

The operation energy here is the value calculated by the prior mentioned MATLAB script, k is the thermal conductivity of the insulation used, δ is the thickness of insulation, and t is the time required to maintain the difference between internal and outside temperatureΔT. δ Was approximated as 1 cm, a generous estimate based on the available space in a 3D model of the device at the time. k was taken as 0.1 W/mK, from the manufacturer datasheet for the tentative choice for insulation should active heating prove a beneficial course of action.

The results from our optimization were as follows:

Table H-2: Active Heating Battery Capacity Optimization Results

Internal Temperature [^{o}C]	Total Required Battery Capacity [Joules]
25	3607777
0	1899309
-10	1215921
-20	532534

Using total required battery capacity as a measure of the required batteries and total energy required for a given day of operation, our results strongly indicated the active heating is not a beneficial solution to the capacity reducing effect that cold operating temperatures introduce. This optimization shows that the best use of battery capacity is you dedicated energy directly to device operation, not maintaining device temperature. As such, no active heating system was implemented.

H-7 Passive Insulation for Battery

Passive insulation is examined because FMEA for power source in Appendix F-2.3 mentions that energy delivered by Lithium Ion batteries drops drastically below -15^{o}C. In fact, from Table H-1, it is evident that the number of hours that the battery can run the motor for drops drastically (reduces to almost half) at -20^{o}C compared to 25^{o}C.

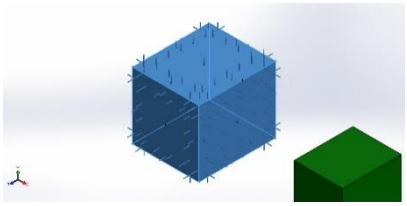
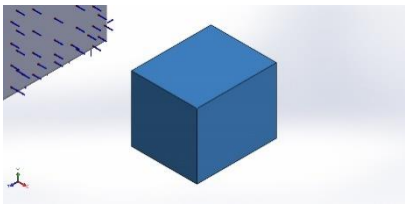
Therefore, various types of thermal insulation materials were considered which can wrap around the battery and conserve the heat generated due to power loss as a result of internal resistance in the battery. Finally, Calcium-Magnesium Silicate thermal insulation sheet is chosen as the insulation material as it offers a cost-effective and efficient way of insulating the battery.

Table H-3: Material properties of Calcium-Magnesium-Silicate thermal insulation (Calcium-Magnesium Silicate Thermal Insulation Sheet, n.d.)

Material	Calcium-Magnesium Silicate
Thermal Conductivity	0.232 W/mK
Density	0.128 kg/m^3
Max Operating Temperature	+1150^{o}C
Flame Retardant	Yes
Thickness	13mm

Furthermore, the dimensions of each Panasonic NCR18650B cell are provided in the datasheet (Panasonic NCR18650B, 2014). Based on those dimensions, the height, width and length of the battery pack containing 16 cells can be determined and modeled in Solidworks. The power loss values of the battery at different temperatures are listed in Table H-1 and they are used in the Solidworks thermal study to validate the effectiveness of using insulation.

Table H-4: Thermal loads applied to insulation and battery pack in the solidworks thermal study

Load name	Load Image	Load Details	
Temperature (Thermal Insulation)		Entities: Temperature:	6 face(s) -20°C
Heat Power (Battery Pack)		Entities: Heat Power Value:	1 component(s) 16.197 W (at 0°C from Table H-1)

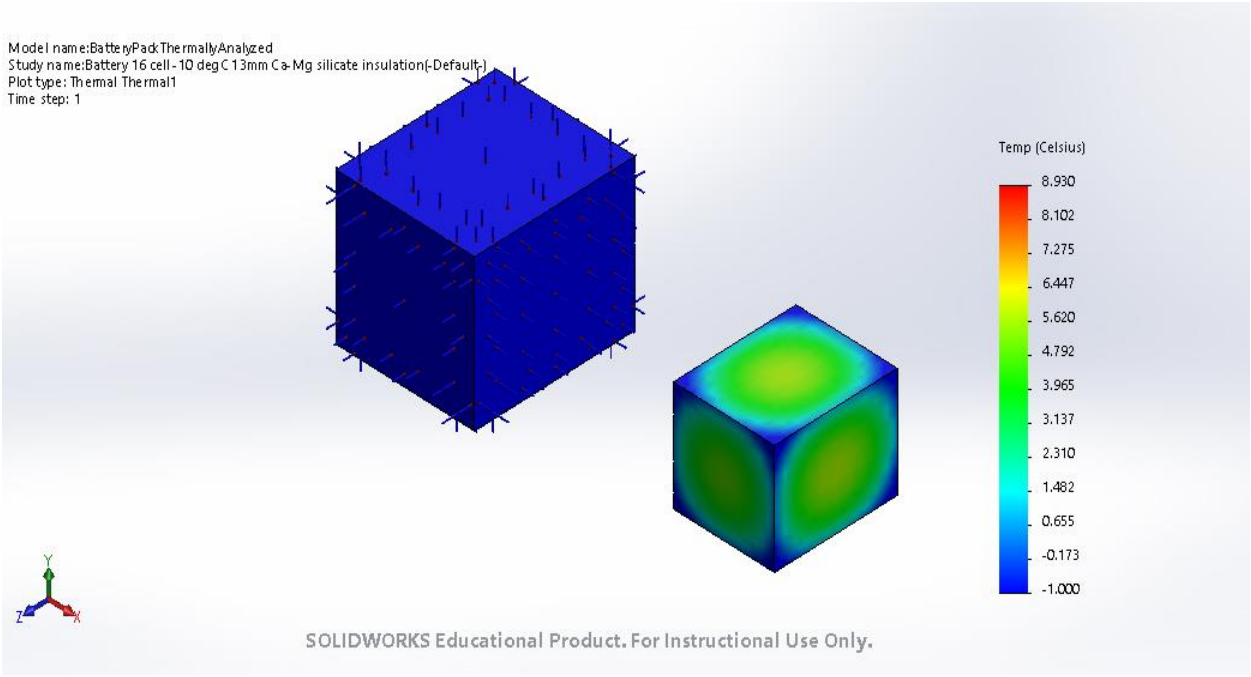


Figure H-9: Result of solidworks thermal study conducted on the battery pack and insulation (exploded view)

Assumptions

- The outer faces of the insulation material are at ambient temperature (in this case, -20^{o}C). This assumption is very conservative because the battery pack is inside a sealed enclosure and the temperature of the outside layer of the insulation material is likely going to be higher than ambient temperature.
- Battery pack is generating power (in this case, 16.197W) equally throughout its volume.
- There is zero contact resistance between the battery and the insulation material.
- Temperature reaches the steady value of above 0^{o}C quickly which implies that transient effects do not need to be considered.
- Insulation sheet is perfectly wrapped around the battery pack (i.e., there are no thermal leaks).

Procedure

1. Battery pack is modeled in solidworks and a 13mm thick shell is created outside it to model the thermal insulation sheet.
2. Temperature of the battery is initially assumed at a steady state value of -10^{o}C (with the listed assumptions).
3. Power loss value of 28.5W (from Table H-1**)** is entered for the battery pack and study is run. However, the results show temperatures of battery exceeding 10^{o}C in many regions.
4. Therefore, the steady state temperature of the battery is then assumed to be 0^{o}C and power loss value of 16.197W (from Table H-1**)** is input.
5. From Figure , it is evident that the mean steady state temperature of the battery is between 2 ^{o}C and 5^{o}C.

From the thermal study, it is confirmed that the steady state temperature of the battery will be above 0^{o}C when 13mm thick Calcium-Magnesium Silicate thermal sheet is wrapped around the battery pack and the outside ambient temperature is -20^{o}C. Based on Table H-1, this implies that the battery would run for the required time of 3 hours. It only costs $1.61 to insulate each battery and the total mass of insulation material on each battery is only around 78g.

H-8 Sled Chassis, Required Area

In determining the minimum required area of the sled sub component of the Equipment tow, heavy use of "The Avalanche Handbook" by D. McClung and P. Schaerer (2009) and "Snow Mechanics" by L.H. Shapiro (1997) were made.

The primary useful information from these texts were in the form of snow structural failure descriptions. Table 7.2 in the handbook details different failure conditions for different load levels during a Rutschblock tests. In this table, "fair" stability snow is described as failing under the load of a single person jumping with skis.

Assumptions

- The average weight of a skier is 80 Kg
- The Average Weight of a set of ski's is 6.82 Kg or 15 Lbs
- Average ski dimensions of 1.8 meters in length and 10 cm in width, resulting in an area of 0.36 square meters for a set of skis.

Together, these pieces of information were used to approximate the compressive strength of snow. This strength was then used to estimate the required surface area the Equipment tow's sled would require to not significantly sink into the snow.

$$\sigma = \frac{(Mass_{Skier} + Mass_{Skis}) \cdot Gravity}{Ski\ Area} \qquad \frac{(80 + 6.82) \cdot 9.81}{.36} = 2365.845\ Pa$$

$$Required\ Sled\ Area = \frac{(Mass_{Backpack} + Mass_{Device}) \cdot Gravity}{\sigma} = \frac{(10 + 4) \cdot 9.81}{2365.845} = 0.0581\ m^2$$

With a value of 0.0581 square meters required for the sled to not sink into snow during operation, the geometry of other subcomponents and ensure sufficient space to attach the other subcomponents to the sled became the sole driver of sled size and geometry.

H-9 Rope Leveler Design

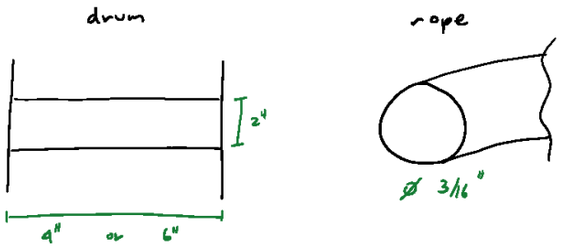
Oct 28, 2017 — Rope Layer Calculations — Juliana Lee

1.0 Problem — Calculate the number of layers and length of rope wound around a 6" and 4" long drum of diameter 2" to achieve 50ft.

2.0 Assumptions — Rope wraps evenly around the drum. Diameters are taken from the center of the rope.

3.0 Method — Use geometry and account for drum diameter changing with each layer of rope.

4.0 Sketch



5.0 Equations — circumference = $\pi \cdot$ Diameter

6.0 Calculations — Number of times rope wraps around drum for one layer.

4" Drum	6" Drum
$4 \div \frac{3}{16} = 21.33$	$6 \div 3/16 = 32$
use 21	use 32

Diameter of Each Layer

$D_1 = 2 + 3/16 = \frac{35}{16}$"

$D_2 = D_1 + 3/16 = 19/8$"

$D_3 = D_2 + 3/16 = 41/16$"

$D_4 = D_3 + 3/16 = 11/4$

Length of Rope Used Per Layer

4" Drum	6" Drum
$L_1 = (21)(\pi)(D_1) = 144.3$"	$L_1 = (32)(\pi)(D_1) = 219.9$"
$L_2 = (21)(\pi)(D_2) = 156.7$"	$L_2 = (32)(\pi)(D_2) = 238.8$"
$L_3 = (21)(\pi)(D_3) = 169.1$"	$L_3 = (32)(\pi)(D_3) = 257.6$"
$L_4 = (21)(\pi)(D_4)$	$L_{Total} = 716.3$"
$L_4 = (21)(\pi)(D_4) = 181.4$"	$L_{Total} = 716.3$" $= 59.7$ ft
$L_{Total} = 651.5$" $= 54.3$ ft	

7.0 Summary — For a 4" drum, ~4 layers of rope are required to achieve 50ft. For a 6" drum, ~3 layers of rope are required to achieve 50ft.

H-10 Winch Gear Interference Calculations

November 13th, 2017 | Pinion & Gear Interference: calculation | Donwei Luo. | Pg 1/3

1. Problem: Make sure the pinion & Gear watch and not interference.

2. Method: "Shigley's Mechanical Engineering Design" — 10 edition

Pg 679: Interference calculation.

$$N_p = \frac{2K}{(1+2m)\sin^2\phi}\left(m + \sqrt{m^2+(1+2m)\sin^2\phi}\right)$$

$$N_G = \frac{N_p^2\sin^2\phi - 4K^2}{4K - 2N_p\sin^2\phi}$$

3. Data: $K = 1$

$m = 5$

$\phi = 20^\circ$

$$N_p = \frac{2K}{(1+2m)\sin^2\phi}\left(m + \sqrt{m^2+(1+2m)\sin^2\phi}\right)$$

$$= \frac{2}{(1+2\times5)\sin^2 20^\circ}\left(5 + \sqrt{5^2+(1+2\times5)\sin^2 20^\circ}\right) = 15.74 \text{ teeth} \approx 16 \text{ teeth}$$

$$N_G = \frac{N_p^2\sin^2\phi - 4K^2}{4K - 2N_p\sin^2\phi} = \frac{16^2_{\text{teeth}}\sin^2 20^\circ - 4\times1^2}{4\times1^2 - 2\times16_{\text{teeth}}\times\sin^2 20^\circ} = 101.07 \text{ teeth}.$$

$\therefore$ $N_p = 16$ teeth.

$N_G = m \times N_p = 5 \times 16 \text{ teeth} = 80 \text{ teeth} < 101.07 \text{ teeth}.$

From this calculation, we found that the minimum number of teeth for the pinion is 16 teeth and the maximum number of teeth for the gear is 101 teeth in order to avoid issues with gear interference. These findings are summarized in the figure below.

Interference		
m	5	
pressure angle	0.35	rad
Np-min	15.74	teeth
Choose-Np	16	teeth
Ng-max	101.07	teeth

Figure H-10: Pinion and Gear Interference Calculations in Excel

H-11 Winch Gear Stress Calculations

November 13th, 2017. | pinion Bending & contact Stress calculations | Danwei Luo | Pg 2/2

1. Problem : Calculate the Bending & contact Stress of pinion.
Calculate the safety factor of the stress to make sure the pinion will not break.

2. Assumptions : a. Power source & Driven machine are uniform.
b. pinion has uncrowned teeth
c. Commercial condition
d. Straddle-mounted pinion with $S_1/S \geq 0.175$
e. Use other condition for Ce.
f. $m_B = \frac{t_R}{h_t} \geq 1.2$.
g. 99% Reliability

3. Method : "Shigley's Mechanical Engineering Design" -10 edition
Pg 758 : Spur Gear Bending & Spur Gear Wear.

$$\sigma = W^t K_o K_v K_s \frac{P_d}{F} \cdot \frac{K_m K_B}{J}$$

$$S_F = \frac{S_t Y_N / (K_T K_R)}{\sigma}$$

Spur Gear Wear

$$\sigma_c = C_p \left(W^t K_o K_v K_s \frac{K_m}{d_p F} \cdot \frac{C_f}{I} \right)^{1/2}$$

$$S_H = \frac{S_c Z_N C_H / (K_T K_R)}{\sigma_c}$$

4. Data:

N = 16 teeth	A = 0.127	$C_f = 1$
$d_p = 1$ in	B = 0.0158	$m_N = 1$
$P_d = 16$ teeth/in	$C = -9.3 \times 10^{-5}$	E = 450000psi
$n_p = 78.7$ rpm	Ce = 1	$\nu = 0.39$
T = 2.5N/m	$K_b = 1$	$S_c = 125000$psi
$K_o = 1$	J = 0.27	$Z_n = 1.1$
$K_v = 0.7$	$S_t = 15000$psi	$C_H = 1$
Y = 0.503	$Y_n = 1$	
Face width = 0.375in	$K_L = 1$	
C-mc = 1	$K_r = 1$	
C-mp = 1.1		

Torque : $2.5 \text{Nm} \times 8.850 \frac{\text{lb·in}}{\text{N·m}} = 22.13 \text{ lb·in}$

November 13th, 2017 | Pinion Bending & Contact Stress Calculation | Danwei Luo | Pg 3/3

Power: $\frac{Tn}{63025} = \frac{22.13 lb\cdot in \times 78.7 rpm}{63025} = 0.03\ hp$

Velocity: $\frac{\pi d_p n}{12} = \frac{\pi \times 1in \times 78.7 rpm}{12} = 20.6\ ft/min$

$Wt = \frac{33000 \times Power}{V} = \frac{33000 \times 0.03 hp}{20.60\ ft/min} = 44.25 lb$

$K_s = 1.192 \times \left(\frac{F\sqrt{Y}}{P}\right)^{0.0535} = 1.192 \times \left(\frac{0.375 \times \sqrt{0.503}}{16}\right)^{0.0535} = 0.96$

$C_{-ma} = A + BF + CF^2 = 0.127 + 0.0158 \times 0.375 + (-9.3 \times 10^{-5}) \times 0.375^2 = 0.13$

$C_{-pf} = \frac{F}{10 d_p} - 0.025 = \frac{0.375}{10 \times 1in} - 0.025 = 0.01$

$K_m = 1 + C_{mc}(C_{pf} C_{pm} + C_{ma} C_e) = 1 + 1(0.01 \times 1.1 + 0.13 \times 1) = 1.15$

$\therefore \sigma = W^t K_o K_v K_s \frac{P_d}{F} \cdot \frac{K_m \cdot K_B}{J} = 44.25 lb \times 1 \times 0.7 \times 0.96 \times \frac{16 \frac{teeth}{in}}{0.375 in} \times \frac{1.15 \times 1}{0.27} = 5373.93 psi$

$N = 78.7 \frac{rev}{min} \times 60 \frac{min}{hour} \times 0.65 \times 8 hour \times \frac{20 day}{year} \times 5 year = 2.46 \times 10^6 cycles.$

$S_F = \frac{S_t Y_N / (K_T K_R)}{\sigma} = \frac{15000 psi \times 1/(1 \times 1)}{5373.93 psi} = \boxed{2.79}$

Contact stress:

$I = \frac{\cos\phi_t \sin\phi_t}{2 m_N} \cdot \frac{m_G}{m_G + 1} = \frac{\cos 20° \sin 20°}{2 \times 1} \cdot \frac{5}{5+1} = 0.13.$

$C_p = \left[\frac{1}{\pi C \left(\frac{1-\nu_p^2}{E_p} + \frac{1+\nu_G^2}{E_G}\right)}\right]^{1/2} = \left[\frac{1}{\pi \times 2 \times \left(\frac{1-0.29^2}{450000 psi}\right)}\right]^{1/2} = 290.6\ psi^{0.5}$

Contact stress: $\sigma_c = C_p \left(W^t K_o K_v K_s \frac{K_m}{d_p F} \cdot \frac{C_f}{I}\right)^{1/2}$

$= 290.6 (psi^{0.5}) \times \left(44.25 lb \times 1 \times 0.7 \times 0.96 \times \frac{1.15}{1in \times 0.375 in} \times \frac{1}{0.13}\right)^{1/2}$

$= 7563.08 psi$

$\therefore S_H = \frac{S_c Z_N C_H / (K_T K_R)}{\sigma_c} = \frac{125000 Psi \times 1.1 \times 1/(1 \times 1)}{7563.08 psi} = \boxed{1.82}$

From these calculations, we find that the bending and contact stress for the gears have safety factors of 2.79 and 1.82, respectively. Because our device does not directly affect the safety of human life or similar high-risk scenarios, these factors are acceptable for the level wind transmission. These findings are summarized in the figure below.

Bending stress					Contact stress			
Np	16	teeth			dp	1	in	
dp	1	in			Velocity	20.60361182	ft/min	
Pd	16	teeth/in			Wt	44.25	lb	
np	78.7	rpm			Face-width	0.375		
Torque	2.5	N.m			mG	5		
Torque	22.13	lb.in			Pressure-angle	0.35	rad	
Efficiency	55.30%				Ko	1		
Power-operating	0.03	hp			Kv	0.7		
Velocity	20.60	ft/min			Ks	0.96		
Wt	44.25	lb			Km	1.15		
Ko	1	Pg 758	Uniform		Cf	1	Pg 759	
Kv	0.7	http://sdp-si.com/	Pg 748		mN	1	Pg 747	spur gear
Ks	0.96	Pg 751			I	0.13	Pg 747	
Y	0.503	http://sdp-si.com/	Pg 730		Cp	290.63	psi^0.5	Pg 736
Face-width	0.375	in			E	450000	psi	
Km	1.15	Pg 751			v	0.39	http://www.goodf	Assume
C_mc	1	Pg 752	Uncrowned teeth		Contact stress	7,563.08	psi	
C_pf	0.01	Pg 752	Face<1in		Safety-factor	1.82		
C_pm	1.1	Pg 752	Assume_Larger stress		Sc	12500	psi	
C_ma	0.13	Pg 752			Zn	1.1	Assume base on Figure 14-15	
A	0.127	Pg 752	commercial		Ch	1	Gear only	
B	0.0158	Pg 752			Kt	1		
C	-9.30E-05	Pg 752			Kr	1		
Ce	1	Pg 751	Assume_Larger stress					
Kb	1	Pg 756	Assume_Larger stress					
J	0.27	Pg745	Read-Figure14-6					
Bending stress	5,373.93	psi						
Safety-factor	2.79							
St	15000	psi	Nylon Data sheet					
Yn	1	Assume base on	Figure 14-14					
Cycles_N	2.46E+06							
Kt	1	Pg 758	T<250F	Pg 740				
Kr	1	Pg756	0.99-Reliability					

Figure H-11: Bending and Contact Stress Calculation of Pinion in the Excel

H-12 Energy Savings for User

Based on the sub-systems selected and designed in the previous sections, the final mass of the device is determined to be 6.87kg (refer to Figure 1). The calculation assumes that the device can operate for 3 hours at a minimum ambient temperature of -20°C with a 10kg load placed on it.

```
MOTOR CHARACTERISTICS AT 14V INPUT VOLTAGE
Speed at operating torque = 82.756678 rpm
Efficiency at operating torque = 55.830364
Current input at operating torque = 3.652626 A
Power input at operating torque = 51.136764 W
Total energy of 14.4V Li-Ion battery = 153.410292 Wh
Capacity of 14.4V Li-Ion battery = 10.653493 Ah
Mass of 14.4V Li-Ion battery = 0.631318 kg


CALCULATIONS OF FORCE AND TORQUE BASED ON INPUT VOLTAGE OF 14.4V
Force required to pull the device up = 88.610443 N
New torque required to pull the device up = 3.376058 Nm
Total mass of the device (excl. backpak) is = 6.867500 kg
```

Figure H-12: Final Parameters of the equipment tow device from the MATLAB script

Before delving into the energy savings calculations, there are a few key assumption which must be explored:

- The coefficient of friction between ski and snow is 0.128 (Hasler et. al, 2016, p. 26)
- The combined mass of the user, essential safety equipment and skiing equipment and accessories is 85kg.
- The mass of the backpack which carries non-essential items and which would be carried by the equipment tow device is 10kg.
- The user is climbing parallel to the slope of the hill (i.e. no kick-turning).
- The maximum slope of the hill is 30° (specified by the client as a need).
- The user spends a fixed amount of energy per day no matter how much load they are carrying

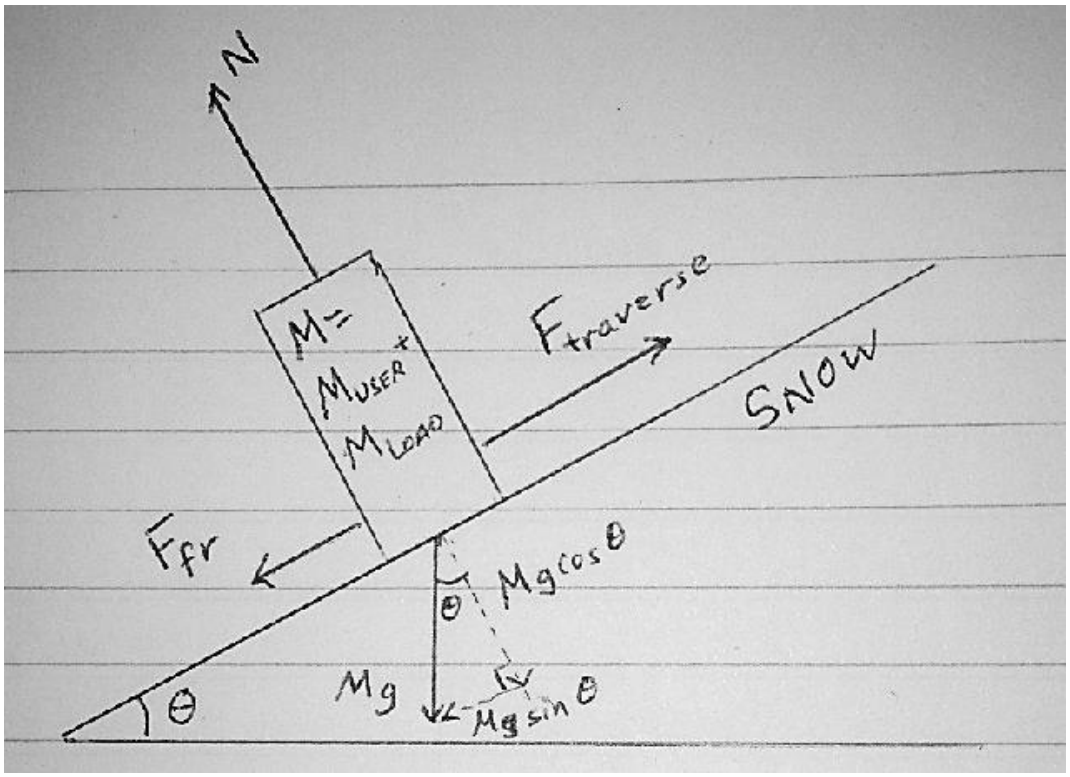


Figure H-13: FBD of the user on the ski slope

Since the user is carrying 10kg less load during the ascent, the energy savings of the user can be computed. Based on FBD shown in Figure 2, the equation for the force require to traverse the slope can be determined.

$$F_{traverse} > \mu N + Mgsin(\theta) = \mu Mgcos(\theta) + Mgsin(\theta) = Mg(\mu\cos(\theta) + \sin(\theta))$$

$$F_{traverse} > g(M_{user} + M_{load})(\mu\cos(\theta) + \sin(\theta))$$

Now, work required by the user to climb the hill is given by the relationship:

$$W = F_{traverse} * distance\ traversed$$

With the 10kg backpack, the effective mass carried by the user including their body is 95kg. Substitute the number in Force and work equations:

$$F_{traverse\ with\ backpack} > 9.81 * 95 * (0.128 * \cos(30^o) + \sin(30^o)) = 569.3N$$

$$F_{traverse\ without\ backpack} > 9.81 * 85 * (0.128 * \cos(30^o) + \sin(30^o)) = 509.4N$$

In section H-3, the distance traversed by the user with the backpack on is determined to be 8521.7’ = 2598.1m.

Now, the total work done by the user with 10kg backpack on = 569.3N * 2598.1m = 1479.1kJ

With the 10kg backpack off the user, the user can still do the same amount of work but the distance that they can traverse will increase.

$$Distance_{without\ 10kg\ backpack} = \frac{F_{traverse\ with\ backpack} * Distance\ traversed}{F_{traverse\ without\ backpack}}$$

$$Distance_{without\ 10kg\ backpack} = \frac{1479.1 * 10^3 J}{509.4N} = 2903m$$

New vertical distance climbed = 2903tan(θ) = 2903tan(30^o) = 1676.05m = **5497ft**

Compared to the previous vertical ascent value of 5000ft/day, this new value represents a 10% increase in the vertical distance that the user can climb per day with the help of the equipment tow device. To conclude, the device does achieve the goal of helping the user achieve climb more vertical feet per day and is a technically feasible project to undertake for the client.

H-13 Trail Breaker Motor Selection Calculations

Oct 9th, 2017 Justin Cheung

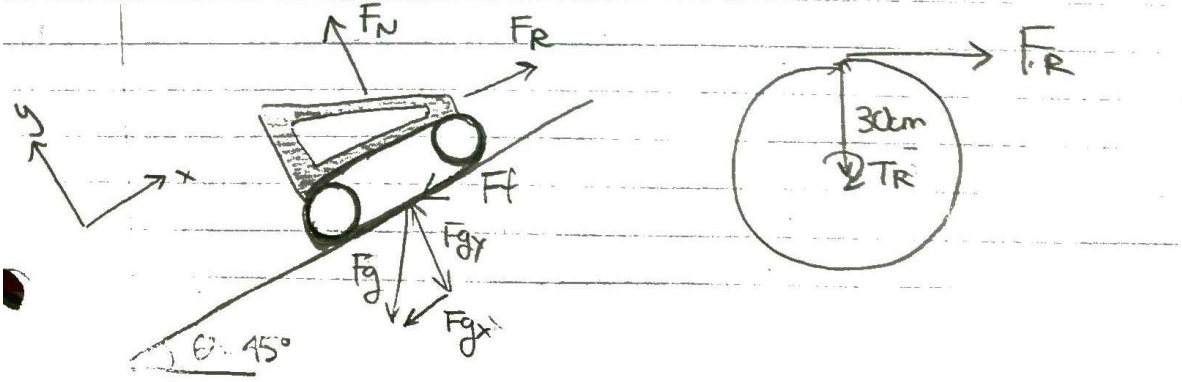
Trail Breaker Motor Selection

1.0 Problem — Calculate required torque and rpm to select a motor for trail breaker concept

2.0 Assumptions
- mass of device is max (ie. 10kg cargo + 4kg device)
- friction of snow is $\mu = 0.2$
- device wheel diameter is 30 cm
- device isn't accelerating

3.0 Method
- force balance to determine T_R
- simple calc to determine operating speed of motor

4.0 Sketches



5.0 Sample Calculation

5.1 Force Required

$$\Sigma F_y = 0$$
$$F_N - F_g \cos\theta = 0$$
$$F_N = 14(9.81)\cos 45$$
$$F_N = 97.11\ N$$

$$\Sigma F_x = 0$$
$$F_R - F_f - F_{gx} = 0$$
$$F_R = F_g \sin\theta + \mu F_N$$
$$F_R = 14(9.81)\sin 45 + 0.2(9$$
$$F_R = 116.53\ N$$

5.1.2 Motor Torque

$d = 30cm \rightarrow r = 15cm$

$$T_R = F_R(r)$$
$$= 116.53N(0.15m)$$
$$= \underline{17.47\ N\cdot m}$$

5.2 Motor RPM

$$1500\ \frac{m}{day} \times \frac{1\ day}{5\ h} \times \frac{1\ h}{3600s} = 0.09\ \frac{m}{s}$$

$$\omega = \frac{v}{r} = \frac{0.09\frac{m}{s}}{0.15m} = 0.6\ \frac{rad}{s}$$

$$rpm = \frac{\omega}{2\pi}(60) = \underline{5.88\ rpm}$$

6.0 Summary

Motor Torque = 17.47 N.m
Motor RPM = 5.88 rpm

7.0 Conclusion

Using the torque & RPM calculated, we can spec out a motor and possibly a gear train

By specing out a motor it gives us quantitative information for the WDM

H-14 Trail Breaker Energy Savings Calculations

Oct 9th 2017 Justin

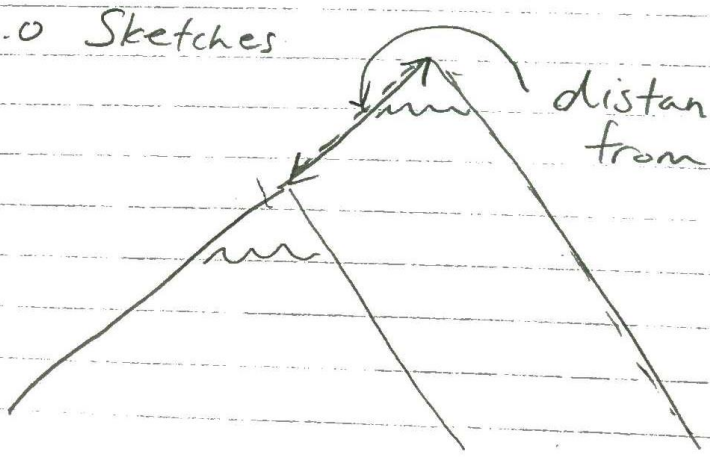
Trail Breaker Energy Savings

1.0 Problem — Quantify the energy saved / meters gained by Trail Breaker concept

2.0 Assumptions
- energy saved is solely potential
- user spends a fixed amount of energy / day
- energy spent on packed snow is 20% less than on powder

3.0 Method
- use PE = mgh to determine energy saved
- convert energy savings to m using info.

4.0 Sketches



5.0 Sample Calculations

5.1 Energy to Meters Transversed Ratio

$(70\,kg + 10\,kg\ bag)(1000\,m)(9.81) = 784.8\,\frac{kJ}{day}$

Meters : Energy Ratio

$$\frac{1000\,\frac{m}{day}}{784.8\,\frac{kJ}{day}} = 1.274 : \frac{m}{kJ}$$

5.2 Bag Weight

$PE = (10\,kg)(9.81)(1000) = 98.1\,kJ$

$\therefore$ meters gained $= 98.1\,kJ\left(1.274\,\frac{m}{kJ}\right)$

$= 125\,m$

5.2.1 Packed Snow

$E_{packed} = \frac{784.8\,kJ}{1.2} = 654\,kJ$

$E_{saved} = 784.8\,kJ - 654\,kJ = 130.8\,kJ$

$\therefore$ meters gained $= 130.8\,kJ\left(1.274\,\frac{m}{kJ}\right)$

$= 167\,m$

6.0 Summary

	PEnergy Saved	Meters Gained
Bag	98.1 kJ	125 m
Packed Snow	130.8 kJ	167 m
Total	228.9 kJ	292 m

7.0 Conclusion

The Trail Breaker concept will gain the user an additional 292m / day if the user spends a fixed amount of energy per day

H-15 Ski Teeth Calculations

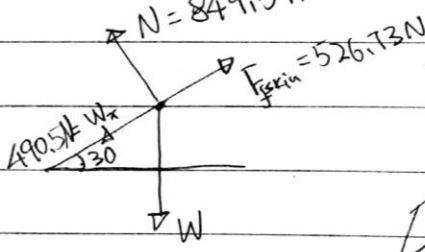
October 9th, 2017 10:55PM → 11:16PM.

Make feasibility calculation in formal from.

Ski skin length : 1.8 m. → Area of skin : L×d = 0.18 m²

SKi skin width : 0.1 m. Coefficient of skin : 0.62.

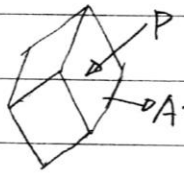
Clamb slope : 30° Weight of skier : 981 N.



Pressure on the ski = $\frac{N}{A}$ = 4719.84 Pa

F = 4719.84N

m = $\frac{F}{g}$ = 481.6 kg.



If we take off skin, there is abit friction force on the ski.

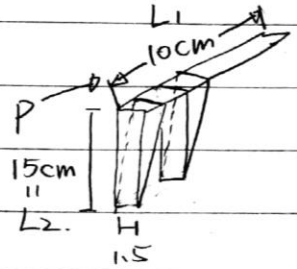
U_{ski} = 0.15 (bigger one)

∴ $F_{f\,ski}$ = 0.15 × 849.57N = 127.4N

∴ F_f required for ski teeth = 526.73N − 127.4N = 400N

∴ Each teeth will take 100N.

$A = \frac{F}{P} = \frac{100N}{4719.84} = 0.0212\ m^2$.



Assume we have 10 teeth.

∴ $A = \frac{0.0212}{10} = 0.0021\ m^2 = 21cm^2$. = 1.5cm × 15cm

max than what we had

When side stepping : A = 10cm × 15cm = 150cm²

∴ $F = PA = 150 \times 10^{-4}\ m^2 \times 4719.84\ Pa = 71N < 100N$. slid down.

APPENDIX I: PROTOTYPE TESTING

I-1 Identification of Areas of Concern

The following areas have been identified as areas of the design either required moving forward, or areas that stand to provide a high return in value for further resource dedication:

- Device performance when ascending paths that deviate from the slope's gradient.
- Device mass optimization - this area of concern is heavily influenced by other areas of concern.
- Cold temperature effects on battery lifetime.
- Accurate values for predicted device usage for a given day.
- Accurate values for predicted weather conditions the device would be exposed to during a given day.
- Proof of IP-68 certified sealing.

I-2 Proposed Tests

Dedicating further resources is required to continue development of the Equipment tow concept. Proposed here are testing that would provide that greatest value for investment of resources. Two tests are suggested moving forward have the purpose of collecting data to better predict the device's operating conditions, ideally allowing for less conservative demands on the Equipment tow's torque and battery capacity requirements.

I-2.1 Device Usage Data Collection

Required Resources

- 5 Equipment Tow Devices
- 5 Time Sheets
- 5 Test User

Objective

To collect data detailing an estimate of how much a user use the Equipment tow on a given outing. This data ideally will highlight a more accurate timeframe that the device will be run under. This information directly ties to the required battery capacity, which is also directly influences the design's overall mass and cost.

Test Outline

1. Provide separate test user parties with an Equipment tow device
2. Compensate users in exchange for their recording of their usage of the device over a given ski trip.
3. Iterate this process in 3 different backcountry locations.
4. Using the recorded data, recalculate the required battery capacity to operate the device for the new mean running time.

Result Evaluation Criteria

Due to nature and purpose of this test being to optimize the design with more informed operating parameter estimates, there is no positive result that needs to be reached to justify moving forward

with development. However, should the results of this test demonstrate that the already conservative estimate of required battery capacity for a run time of 3 hours is insufficient, then continuing further development cannot be recommended or justified with the proposed design. Should the results show that an increase of battery capacity is required, many other parameters of the design will similarly scale beyond the required limits.

Should estimates for required battery capacity increase based on test user's usage of the device exceeds the initial estimate, further development for the Equipment tow should not continue without revaluation of potential markets with potentially different requirements.

Cost of materials

Table I-1: Cost of Materials for Device Usage Data Collection Testing

Expense	Cost [$]
5 Equipment Tow Devices at Single Unit Production Cost	$3996.25
User Monetary Compensation for 15 test users for 8 hours (5 users in 3 locations)	$1362.00 (120 hours, at minimum wage)
Data Scientist Wages for Recalculations	$136.00 (4 hours, at $34 dollars per hour)
Total Cost	$5494.25

Refer to Appendix P (p.329) for the source of a data scientist's hourly wage estimate

Timeline

With a total test time of 8 hours per location for three locations, a total of three work days is expended on data collection. However, is unreasonable to perform this test at all three locations simultaneously. Performing data collection at one location per week, a rough estimate of 3 weeks can be used to approximate the time required for data collection. The time dedicated to data collection is the determinative factor for this test, as processing the results is only a recalculation using more accurate data. Conservatively estimating the time required for recalculation at half of a productive work day does not significantly impact the time required to perform this test. As such it is appropriate to estimate the time from initiation to delivery of value at 3 weeks.

However, this test requires an active ski season to accomplish. Total time frame of this test varies heavily with the access to regions in an active skiing season.

I-2.2 Device Operating Conditions Data Collection

Required Resources

- 1 Test Backcountry Skier
- 1 Temperature Record Sheets

Objective

To collect data detailing an accurate estimate of the temperature our target audience chooses to ski in. This data ideally will highlight a more accurate environmentally temperature approximation that the device will be run under. This information directly ties to the required battery capacity, as at cold temperatures battery capacity decreases. Battery capacity also directly influences the design's overall mass and cost.

Test Outline

1. Provide record sheets to test user
2. Compensate user in exchange for their recording of local ambient temperature over the course of a given skiing season. A season is approximated as a weekly single, 8 hour, day ski trip for 2 months
3. Concurrently iterate this test in 3 different locations.
4. Using the recoded data to establish an accurate estimate of the average temperature the target market would use the Equipment tow in
5. Recalculate the operating temperature difference established with passive heating, and the corresponding battery capacity

Result Evaluation Criteria

Due to nature and purpose of this test being to optimize the design with more informed operating parameter estimates, there is no positive result that needs to be reached to justify moving forward with development. However, should the results of this test indicate that the existing estimates of temperatures users would choose to use the Equipment tow were insufficient, then continuing

further development cannot be recommended or justified with the proposed design. Should the results demonstrate harsher average conditions than initially predicted, the available energy provided by each battery will diminish, increasing the required quantity of batteries per unit. More batteries equate to a larger mass, which in turn results in higher loads and further energy requirements.

Cost of materials

Table I-2: Cost of Materials for Device Operating Conditions Data Collection Testing

Expense	Cost [$]
User Monetary Compensation for 3 test users for 64 hours (1 users in 3 locations)	$2179.20 (192 hours, at minimum wage)
Data Scientist Wages for Recalculations	$136.00 (4 hours, at $34 dollars per hour)
Total Cost	$2315.20

Please refer Payscale, Human Capital. (2017) in Appendix P (p.329) for the source of a data scientist's hourly wage. estimate.

Timeline

With the test data collection phase spanning a single skiing season, approximated as two months, in conjunction with negligible time required to process results estimated at less than a full work day, it is appropriate to estimate the time from initiation to delivery of value at 2 months.

However, this test requires an active ski season to accomplish. Total time frame of this test varies heavily with the access to regions in an active skiing season.

I-2.3 IP-68 Sealing Certifications

Required Resources

- 1 Equipment Tow Device
- 1 Cubic meter tank of Water, or a similarly large body of water

Objective

The purpose of this test is to ensure that the device can operate in the expected harsh weather conditions, where snow can represent issues of solid and liquid ingression of the device.

Test Outline

1. Fully charge an operational but empty Equipment tow
2. Fully submerge the device, and let sit for 5 minutes
3. Remove device, and ensure winch subsystem operates as intended without electrical malfunction
4. Let device dry overnight or procure as new Equipment tow
5. Apply a thin layer of snow (roughly 1 inch) of snow to all exposed surface on the device such that al potential ingresses into the internal portion of the Equipment Tow's enclosure are fully covered
6. Ensure that the device functions as intended without electrical malfunction

Result Evaluation Criteria

To ensure the Equipment tow device is fully protected against solids particulate and liquid ingress (as per IP-68), neither of the above test condition should cause failure in the device. Should the Equipment tow fail either to prevent liquid or slid ingress, the waterproofing of the enclosure must be re-evaluated.

Cost of materials

Table I-3: Cost of Materials for Device Operating Conditions Data Collection Testing

Expense	Cost [$]
Device Cost	$799.25
Total Cost	$799.25

Timeline

This test takes negligible time to complete, as the entire test may be completed within a single work day. From initiation to collection of useful results this test requires one work day.

I-3 Further Testing

After other determinative tests have been completed, the Equipment tow will almost certainly require an extreme condition failure test. As this test is dependent on the success of the above outlined tests as well as the further development decision based upon their results, defining a specific failure test for a complete design is not an effective use of resources. However it should be noted that should the prior outlined tests support the continued development of the Equipment tow, the completion of an extreme failure condition test of the production ready design will be required to define the safe operation condition ranges.

APPENDIX J: COST OF GOODS DECISIONS

The final cost of the equipment tow device accounts for wholesale pricing, shipping, packaging, assembly labour, tooling and setup, contingencies, and import tariffs. Research and estimation findings are summarized in this appendix.

J-1 List of Assumptions

J-1.1 Wholesale Bulk Discounts

For products without wholesale pricing available, the team's plan was to find similar items which had bulk pricing available and apply a discount of the same scale to our product. However, even this approach was challenging with uncommon items; thus, the team adapted a wholesale discount model found from online research. The estimates using this model are rational as they fall in line with actual wholesale data from research. The research results are summarized in Table J-1.

Table J-1: Summary of Bulk Discounts

Item	Single Unit [$]	Bulk ≤ 1000 [$/unit]	Wholesale Discount [%]	Source*
Bearings	4.60	0.76	83.5	Bearings Canada; VXB
Electric Motor	25	10.35	58.8	The Mechanical Design Process (4th Ed.)
Wholesale Model Discount			40	Tom Gray; Entrepreneur

*For complete references, please see Appendix P.

J-1.2 Bulk Shipping Costs

The approach used to estimate wholesale pricing was also used to estimate bulk shipping. Data was taken from multiple retailers and the average, rounded up to 2%, was used as the shipping cost.

Table J-2: Summary of Bulk Shipping Costs

Item	Price [$]	Quantity	Total [$]	Shipping [$]	Percentage of Cost [%]
McMaster Keystock	14.43	1000	14430	30	0.2079
Wych Clutch Bearing	17.15	450	7717.5	213.76	2.7698
Winch Rope	24	1000	24000	0	0
Andymark Motor	113	60	6780	221	3.2595
				Average	1.5593

J-1.3 Packaging

Likewise to wholesale shipping, packaging estimates were difficult to obtain without actually contacting the shipping companies. Thus, packaging costs were estimated through an article found on packaging costs ("How much does packaging cost", 2013). It is assumed that rigid boxes will be used as they offer the most protection; furthermore, cost was estimated on the high range to be conservative.

$$\frac{Packaging}{Cost}: \quad \frac{\$10}{device} + \left(\frac{\$1200}{1000\ devices}\right) = \frac{\$11.20}{device}$$

Cost of Rigid Boxes

Volume Classification	Volume (Units)	Investment $	Tooling
Prototypes	1 – 100	$250 – $5,000 TOTAL	$0 – $1,200
Short Run	500 – 1000	$5 – $10	$500 – $1200
Mid Run	2500 – 100,000	$5	$500 – $1200

Figure J-1: Cost of Rigid Boxes (How to Buy Packaging)

J-1.4 Assembly Time Study

A time study of the assembly process was done to approximate the time of assembly, and ultimately, the labour cost for each device. Each step in the assembly process was estimated based off our team member's experience in assembly and wiring. Time spent moving or reorienting device is negligible because our device is light. To account for any underestimates, the total assembly time was multiplied by two to obtain our final time to estimate labour cost.

Table J-3: Assembly Time Study

Sub-system	Step	Step name	Description	Time to complete
General	1.0	Component Inspection	Inspection of incoming components from suppliers that meet expectation and standard	5 minutes
Power Train	2.0	Attach Motor to Left Support	Align motor to Left Support Install 4 screws to secure motor-gearbox assembly	30 seconds
	2.1	Install sleeve to motor shaft	Tap lightly the sleeve to motor shaft using a mallet	15 seconds
	2.2	Install bearing to sleeve	Tap lightly the bearing to installed sleeve on motor shaft by a mallet	15 seconds
Level Wind	3.0	Insert bushing to Carriage body	Insert the appropriate bushing to Carriage body	15 seconds
	3.1	Insert Level Wind Shaft	Slide in the level wind shaft to its slot	10 seconds
	3.2	Insert Level Wind Carriage Needle	Insert level wind needle into install bushing on Carriage body Align Needle tip to the shaft groove	15 seconds
	3.3	Close Carriage Cap	Close carriage cap Install 4 screws to secure the carriage assembly	30 seconds
	3.4	Install Linear Shaft	Slide in the linear motion shaft to the completed assembly	10 seconds
Drum	4.0	Install Bushing	Insert Level Wind Shaft bushings to Left and Right Supports Insert drum bushing on booths plate	30 seconds
	4.1	Waterproofing bushing	Apply silicon sealant to connecting feature between Drum Bushings and Left Support and Right Support	45 seconds

	4.2	Cut Bearing Key	Cut Stock Bearing Key to appropriate length	5 seconds
	4.3	Install Bearing Key	Insert Bearing Key to its slot on the drum	15 seconds
	4.4	Clamping Drum	Slide in the motor-gear box-left support to the drum while align bearing to the installed key Slide in Level Wind Shaft - Linear Motion Shaft sub-assembly to Clamp the assembly with Right Support - installed Bushings sub-assembly	1 min 30 seconds
	4.5	Bolting Linear Shaft	Hand install Nuts to Linear Motion Shaft Wrench to appropriate torque	20 seconds
	4.6	Install Cross Bar	Align Cross Bar to pre-cut holes install 4 screws to secure	45 seconds
	4.7	Instal Mounting Plate	Align Mounting Plate to pre-cut holes Install 4 screws to secure	45 seconds
Gear Train	5.0	Prepare Gears for Installation	Drill a setscrew hole on each gear hubs by using drill press Tap each hole	1 minute
	5.1	Install Drum-Gear Extension	Align the extension to the drum on the Right Support Install 3 screw to secure	30 seconds
	5.2	Install Gears	Slide in the gears to desired position and secure using 2 set screws	45 seconds
Battery/Control	6.0	Battery Assembly	Solder battery cells to metal connector Put heat shrink tube on battery and shrink it	5 minutes
	6.1	Install Connector, switch	Silicon the edges between connectors, switch and Left Case Secure connector and switch to the Left Case	45 seconds
	6.2	Wrapping Battery with Thermal Insulation	Wrap battery unit with Thermal Insulation	30 seconds
	6.3	Wiring	Connect battery, control units, connector with appropriate wires.	3 minutes

	6.4	Install Battery to Enclosure	Apply glue and slide in battery to the Left Case	20 seconds
	6.5	Install Control Units	Apply glue and install control units to it position on the top of battery.	20 seconds
Enclosure	7.0	Waterproofing Left Case	Apply silicon sealant to the Left Case edges	1 minute
	7.1	Install Left Case	Align Left Case assembly to the drum assembly Secure with 4 screws Clean up excess Sealant	3 minutes
	7.2	Install Venting Pad	Peel the venting pad and apply to venting hole and apply pressure to assure waterproofing	10 seconds
	7.3	Waterproofing Right Case	Apply silicon sealant to the Right Case edges	1 minute
	7.4	Install Right Case	Align Right Case to the drum assembly Secure with 3 screws Clean up excess Sealant	3 minutes
Sled	8.0	Install device to sled	Align the device to the sled install 2 screw to secure	30 seconds
General	9.0	Electronic Testing	Verify battery functionality Verify wiring, connections Verify motor functionality Verify Control units functionality	3 minutes
	9.1	Mechanical Testing	Verify Drum functionality Verify Level Winding functionality Verify mechanical attachment	2 minutes
	9.2	Waterproof Testing	Perform Waterproofing Test	2 minutes
			Total Time	2360 seconds
			Margin	50 %
			Expected Assembly Time (Total Time x Margin)	3390 second
			Expected Assembly Labour Cost (@ $70/hour)	$ 65.91

J-1.5 Manufacturing Tools

The tools selected for manufacturing were based off the types of fasteners on our device and prior assembly experience. Because some of these tools are prone to wear and will lose their effectiveness over time, we assumed that they would need a replacement for every 1000 devices. Refer to the Bill of Materials (BOM) for details on the manufacturing tools.

J-1.6 Contingency/Margin

The contingency or margin cost multiplier is to account for unforeseen circumstances. The rate of 50% was used for custom parts due to their niche nature and 10% for all other items.

J-1.7 Import Taxes

All items are subjected to a minimum 5% GST tariff. Items that are imported outside of Canada can subjected to additional tariffs ("Step-by-Step Guide to Importing Commercial Goods into Canada," 2015). To determine if these tariffs applied to the items listed in Bill of Materials, the following steps were taken:

1. Determine the 10 digit Harmonized System (HS) code for products
2. Lookup the 10 digit code in the CBSA customs tariffs document
3. If the Most Favored Nation (MFN) tariff is listed as free, only apply GST
4. Otherwise, apply MFN tariff rate plus GST

In the interest of time, not all items were looked up in the CBSA document. All items were tagged MFN FREE; thus, only GST will be considered for importing our components.

Table J-4: Summary of Import Taxes (Canada Border Services Agency)

Item	HS Code	MFN Rate
Bearings	8483.20.00 00	Free
Electric Motor	8501.10.00 00	Free
Screws, bolts, and nuts	7415.33.00 00	Free
Batteries	8506.10.10 00	Free
Bungee Rope	7312.10.00 00	Free

J-2 Final Bill of Materials

The total cost analysis for the Equipment Tow pre-contingency for a single unit produced in quantities of 1000 is $638.27. With contingencies as outlined in J-1.6 (p.203), the total cost becomes $799.25. The cost for a single unit prototype would be $5700.90.

Table J-5: Cost Summary for the Equipment Tow Production

Equipment Tow Production Cost Summary				
Sub-system	Number of Component	Total Cost for Single Unit	Total Pre-Contingency Cost for Large Quantity	Total Post-Contigency Cost for Large Quantity
Sled	3	$526.90	$14.52	$19.96
Rope	1	$24.00	$14.40	$15.84
Winch	49	$3,959.48	$285.98	$406.53
Motor/Battery	36	$337.78	$187.06	$205.76
Powertrain	3	$269.91	$9.54	$13.16
Controls	9	$12.42	$6.90	$7.59
Labour/Manufacturing	12	$570.41	$78.12	$78.12
Subtotal		**$5,700.90**	**$596.52**	**$746.96**
GST (5%)			**$29.83**	**$37.35**
Shipping (2%)			**$11.93**	**$14.94**
TOTAL			**$638.27**	**$799.25**

Table J-6: Bill of Materials for the Sled

Sled														
							Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Contingency Rate	Unit Cost	Cost	Order Quantity	Unit Cost	Pre-contingency Cost	Cost	Source	Comment
1		Sled Form	1	Custorm Part - Xometry	093C8-15007	50.00%	$519.32	$519.32	1000	$9.98	$9.98	$14.97		
2		Bungee Straps 4 pack	2	Sold by Lowes'	Item No. 329566 Mnfr No. 61551	10.00%	$3.79	$7.58	2000	$2.27	$4.54	$4.99	L-3.1, p.234	-Wholesale model discount applied
		Total Components	3		Total Cost (Single unit)			$526.90	Total Cost (Single unit)		$14.52	$19.96		
	Version Control													
	Version	Change Description							Date	Made by				
	1.0	Initial Entry							2017-10-30	CD				
	1.1	Updated Sled form to support bungee straps. Updated quote							2017-10-31	CD				
	1.2	Update Sled dimension, from form							2017-11-13	JL				

Table J-7: Bill of Materials for the Rope

ROPE														
							Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Contingency Rate	Unit Cost	Cost	Order Quantity	Unit Cost	Pre-Contingency Cost	Cost	Source	Comment
1		Dyneema Synthetic ATV Winch Rope	1	Ranger	SY25-CA	10.00%	$24.00	$24.00	1000	$14.40	$14.40	$15.84	L-1, p.215	Rope rated for required load; Wholesale model discount applied
		Total Components	1		Total Cost (Single unit)			$24.00	Total Cost (Single unit)		$14.40	$15.84		
	Version Control													
	Version	Change Description							Date	Made by				
	1.0	Initial Entry							2017-10-30	JL				
	2	Updated Wholesale Price							2017-11-13	JC/DL				

Table J-8: Bill of Materials for the Winch

Winch														
							Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Contingency Rate	Unit Cost	Cost	Order Quantity	Unit Cost	Pre-contingency Cost	Cost	Source	Comment
1		Ultra-Low-Friction Oil-Embedded Flanged Sleeve Bearings with PTFE	1	McMaster-Carr	1677K8	10.00%	$1.64	$1.64	1000	$0.98	$0.98	$1.08	L-1.2, p. 216	- For level wind carriage guide Needle; Wholesale model discount applied
2		16 Teeth MOLDED SPUR GEARS • 16 PITCH	1	Stock Drive Products Sterling Instrument	A 1N 2-Y16016	10.00%	$4.11	$4.11	1000	$2.72	$2.72	$2.99	L-1.3, p. 217	- Pinion gear for speed reduction of level wind shaft
3		80 Teeth MOLDED SPUR GEARS • 16 PITCH	1	Stock Drive Products Sterling Instrument	A 1N 2-Y16080	10.00%	$15.79	$15.79	1000	$13.33	$13.33	$14.66	L-1.4, p. 218	Mating gear for speed reduction of level wind shaft
4		Drum	1	Custom - Xometry	093C8-15007	50.00%	$638.79	$638.79	1000	$38.87	$38.87	$58.31	L-1.14, p228	
5		Drum Bushing	2	Custom - Xometry	093C8-15008	50.00%	$218.08	$436.16	2000	$20.03	$40.06	$60.09	L-1.14, p228	
6		Level Wind Shaft	1	Custom - Xometry	093C8-15007	50.00%	$308.40	$308.40	1000	$9.21	$9.21	$13.82	L-1.14, p228	
7		Level Wind Needle	1	Custom - Xometry	093C8-15007	50.00%	$99.52	$99.52	1000	$3.92	$3.92	$5.88	L-1.14, p228	
8		Level Wind Carriage - Body	1	Custom - Xometry	093C8-15007	50.00%	$175.66	$175.66	1000	$11.14	$11.14	$16.71	L-1.14, p228	
9		Level Wind Carriage - Cap	1	Custom - Xometry	093C8-15007	50.00%	$292.29	$292.29	1000	$7.04	$7.04	$10.56	L-1.14, p228	
10		Cross Bar	1	Custom - Xometry	093C8-15007	50.00%	$199.06	$199.06	1000	$17.45	$17.45	$26.18	L-1.14, p228	
11		Drum - Gear Extension	1	Custom - Xometry	093C8-15007	50.00%	$117.42	$117.42	1000	$13.27	$13.27	$19.91	L-1.14, p228	
12		Left Case	1	Custom - Xometry	093C8-15007	50.00%	$604.67	$604.67	1000	$39.65	$39.65	$59.48	L-1.14, p228	
13		Right Case	1	Custom - Xometry	093C8-15007	50.00%	$286.17	$286.17	1000	$11.28	$11.28	$16.92	L-1.14, p228	
14		GORE® Protective Vents - Adhesive Series	1	Gore	Series VE9	10.00%	$0.60	$0.60	1000	$0.36	$0.36	$0.40	L-1.5, p. 219	- This product cost is estimated based on experience with the same product and similar application in Jason's coop experience; Wholesale discount applied
15		Mounting Plate	1	Custom - Xometry	093C8-15007	50.00%	$304.11	$304.11	1000	$22.40	$22.40	$33.60	L-1.14, p.228	
16		Left Support Plate	1	Custom - Xometry	093C8-15007	50.00%	$239.04	$239.04	1000	$4.67	$4.67	$7.01	L-1.14, p.228	
17		Right Support Plate	1	Custom - Xometry	093C8-15007	50.00%	$173.79	$173.79	1000	$10.91	$10.91	$16.37	L-1.14, p.228	
18		Light Duty Dry-Running Sleeve Bearing	2	McMaster-Carr	6294K444	10.00%	$1.36	$2.72	2000	$0.82	$1.64	$1.80	L-1.6, p.220	- Bushing for level wind shaft - Wholesale model discount applied
19		Alloy Steel Linear Motion Shaft	1	McMaster-Carr	8350T50	10.00%	$51.34	$49.89	1000	$30.20	$30.20	$33.22	L-1.7, p.221	- Level Wind Guide Shaft - Wholesale model discount applied
20		High-Strength Steel Nylon-Insert Locknut Grade 8, Zinc Yellow-Chromate Plated, 1/4"-20 Thread Size	2	McMaster-Carr	97135A210	10.00%	$0.14	$0.28	2000	$0.08	$0.16	$0.18	L-1.8, p.222	- Level Wind Guide Shaft nuts - Wholesale model discount applied
21		18-8 Stainless Steel Hex Drive Rounded Head Screw	3	McMaster-Carr	92949A325	10.00%	$0.07	$0.21	3000	$0.04	$0.12	$0.13	L-1.9, .p223	- Drum Gear Extension bolts; Wholesale model discount applied
22		Black-Oxide Alloy Steel Socket Head Screw 1/2"-13 Thread Size, 1-1/2" Long	2	McMaster-Carr	91251A716	10.00%	$1.03	$2.06	2000	$0.62	$1.24	$1.36	L-1.10, p.224	- For mounting plate to Sled - Wholesale model discount applied
23		Black-Oxide Alloy Steel Socket Head Screw 3-48 Thread Size, 1/2" Long	8	McMaster-Carr	91251A096	10.00%	$0.06	$0.51	8000	$0.04	$0.32	$0.35	L-1.11, p.225	- Level Wind Carriage bolts / Cross Bar Bolts - Wholesale model discount applied
24		Black-Oxide Alloy Steel Socket Head Screw 12-24 Thread Size, 3/4" Long	11	McMaster-Carr	91251A460	10.00%	$0.60	$6.60	11000	$0.36	$3.96	$4.36	L-1.12, p.226	- For Cases to supporting plates, mounting plate to supporting plates; Wholesale model discount applied
25		Alloy Steel Cup-Point Set Screw Black-Oxide, 1-72 Thread, 5/16" Long	2	McMaster-Carr	91375A067	10.00%	$0.90	$1.80	2000	$0.54	$1.08	$1.19	L-1.13, p.227	- Secure gears to shaft; Wholesale model discount applied
		Total Components	49		Total Cost (Single unit)			$3,959.48	Total Cost (Single unit)		$285.98	$406.53		

Version Control			
Version	Change Description	Date	Made by
1.0	Initial Version	2017-10-30	DL/AT/DWL
1.1	Update new gear train, added bushing for level shaft	2017-11-01	DWL/AT
1.2	Update bushing for level shaft, add linear motion shaft, change Left Case Dimension	2017-11-03	DL
2	Up 12-24 screw quality and eliminate 1/8 screw, change left case dimension and design, update left, right plates design, update drum dimension and design, level wind shaft dimension	2017-11-06	DL
2.1	update linear shaft nuts	2017-11-07	AT
2.2	Update dimension of Level Wind carriage	2017-11-11	DL
2.3	Update left and right case mounting position for manufacturability	2017-11-013	DL
3	Updated Wholesale Price	2017-11-13	JC/DL

Table J-9: Bill of Materials for the Motor

Motor														
							Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Contingency Rate	Unit Cost	Cost	Order Quantity	Unit Cost	Pre-contingency Cost	Cost	Source	Comment
1		High torque, low speed motor with in-built planetary gearset	1	AndyMark	PG71 Gearmotor, 10mm round output with 775 motor and encoder (am-2971)	10.00%	$89.00	$89.00	1000	$36.85	$36.85	$40.54	L-4.1, p.235	- Motor with characteristic curves giving required torque and rpm; built in gearbox with 71:1 reduction; Wholesale model discount applied
2		Battery	32	Panasonic	NCR18650B	10.00%	$6.99	$223.68	32000	$4.20	$134.40	$147.84	L-4.2, p.235	- Wholesale model discount applied
3		Calcium-Magnesium Silicate Thermal Insulation Sheet (can be used to insulate 85 batteries)	0.012	RS	724-8912	10.00%	$137.02	$1.61	12	$82.21	$0.97	$1.06	L-4.3, p.236	- Insulation for battery; Wholesale model discount applied
4		16.8V 5A Charger 4S 14.8V Smart Li-ion Battery Charger 14.8V Lithium polymer battery Charger	1	AA Portable Power Corp	WATE-16805J	10.00%	$20.99	$20.99	1000	$12.59	$12.59	$13.85	L-4.4, p.236	- Wholesale model discount applied
5		3pin 16mm GX16-3	1	GX16	9SIAB964U04448	10.00%	$2.50	$2.50	1000	$2.25	$2.25	$2.48	L-4.5, p.237	- Wholesale model discount applied
		Total Components	36		Total Cost (Single unit)			$337.78	Total Cost (Single unit)		$187.06	$205.76		

Version Control			
Version	Change Description	Date	Made by
1.0	Initial Version	2017-10-30	RS
1.1	Updated Battery Quantity	2017-11-07	RS
2	Updated Wholesale Price	2017-11-13	JC/DL

Table J-10: Bill of Materials for the Powertrain

Powertrain														
						Contingency Rate	Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number		Unit Cost	Cost	Order Quantity	Unit Cost	Pre-contingency Cost	Cost	Source	Comment
1		Sprag Clutch One Way Bearing with Keyways	1	Wych Bearings	CSK15PP	10.00%	$17.40	$17.40	1000	$2.87	$2.87	$3.16	L-2.1, p.232	- Bearings for transmitting torque from motor to the drum
2		Bearing Sleeve	1	Custom - Xometry	093C8-15007	50.00%	$251.76	$251.76	1000	$6.65	$6.65	$9.98	L-2.2, p.232	- Sleeve adapter to connect bearing to motor shaft
3		Metric 316 Stainless Steel Machine Key Stock	0.052	McMaster Carr	90457A100	10.00%	$14.43	$0.75	1000	$0.46	$0.02	$0.03	L-2.3, p.233	- Key to secure bearing to drum; Wholesale model discount applied
		Total Components	3		Total Cost (Single unit)			$269.91	Total Cost (Single unit)		$9.54	$13.16		

Version Control			
Version	Change Description	Date	Made by
1.0	Initial Entry	2017-11-02	JC
1.1	Added Bearing Sleeve	2017-11-03	JC
2	Updated Wholesale Price	2017-11-13	DL/JC

Table J-11: Bill of Materials for the Motor

Controls														
							Single Unit		Large quantity					
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Contingency Rate	Unit Cost	Cost	Order Quantity	Unit Cost	Pre-Contingency Cost	Cost	Source	Comment
1		Geekcreit® DC 12V 10A Relay 1CH Channel Wireless RF Remote Control Switch Transmitter With Receiver	1	Geekcreit	1040721	10.00%	$6.60	$6.60	1000	$3.96	$3.96	$4.36	L-5.1, p.238	- Device control system; Wholesale model discount applied
2		LM2596 Buck Converter (DC-DC step down voltage)	1	LM2596	200102-10	10.00%	$1.50	$1.50	1000	$0.90	$0.90	$0.99	L-5.2, p.238	- Wholesale model discount applied
3		N-channel MOSFET	1	DSky	IRF3205	10.00%	$0.50	$0.50	1000	$0.30	$0.30	$0.33	L-5.3, p.239	- Wholesale model discount applied
4		XT60 connector	1	Hobbyking	XT60	10.00%	$0.80	$0.80	1000	$0.48	$0.48	$0.53	L-5.4, p.240	- Wholesale model discount applied
5		10k resistor	1	Not Given	4894462369098	10.00%	$0.00	$0.00	1000	$0.00	$0.00	$0.00	L-5.5, p.240	- Wholesale model discount applied
6		12V 20A Adapted Rocker Toggle Switch Waterproof	1	Not Given	M1EG	10.00%	$1.19	$1.19	1000	$0.71	$0.71	$0.78	L-5.6, p.241	- Wholesale model discount applied
7		Turnigy 16AWG Silicone Wire 20m (Black)	0.02	Hobbyking	150000106-0	10.00%	$18.02	$0.36	20	$10.81	$0.22	$0.24	L-5.7, p.241	- For wiring of electronic systems; Wholesale model discount applied
8		Turnigy 16AWG Silicone Wire 20m (Red)	0.02	Hobbyking	150000107-0	10.00%	$18.02	$0.36	20	$10.81	$0.22	$0.24	L-5.8, p.242	- Wholesale model discount applied
9		Turnigy Heat Shrink Tube 100mm Black (1m)	0.16667	Hobbyking	9171000639-0	10.00%	$6.67	$1.11	170	$0.67	$0.11	$0.12	L-5.9,	- Wholesale model discount applied
10								$0.00				$0.00		
			9		Total Cost (Single unit)			$12.42	Total Cost (Single unit)		$6.90	$7.59		

Version Control			
Version	Change Description	Date	Made by
1.0	Initial Version	2017-11-02	RS
1.1	Add Heat Shrink Tube	2017-11-08	RS
2	Updated Wholesale Price	2017-11-13	JC/DL

Table J-12: Summary of Manufacturing and Labour Costs

Manufacturing/Labour										
	Image	Name	Quantity	Manufacturer	Manufacturer's Part / Quote Number	Order Quantity	Unit Cost	Cost	Source	Comment
1		GE waterproof Silicone	0.05	GE - Sold by HomeDepot Canada	Model # SE2182 24C | Store SKU # 1000409866	50	$6.97	$0.35	L-6.1, p.243	Assume one container of 290 ml yield 20 units
2		Economy Combination Inch Wrench Set	0.002	McMaster-Carr	5201A7	2	$41.59	$0.08	L-6.3, p.244	Assume need 2 sets for 1000 units
3		Ultra-Grip Screwdriver 5/32" Hex	0.002	McMaster-Carr	7400A18	2	$5.00	$0.01	L-6.4, p.245	Assume 2 units needed every 1000 devices
4		Ultra-Grip Screwdriver 3/8" Hex	0.002	McMaster-Carr	7400A26	2	$8.39	$0.02	L-6.5, p.246	Assume 2 units needed every 1000 devices
5		Ultra-Grip Screwdriver 5/64" Hex	0.002	McMaster-Carr	7400A13	2	$4.63	$0.01	L-6.6, p.247	Assume 2 units needed every 1000 devices
6		Soft Rubber Hammer	0.001	McMaster-Carr	5917A1	1	$11.74	$0.01	L-6.7, p.248	Assume 1 units needed every 1000 devices
7		9 Piece Hex Screwdriver Set	0.002	McMaster-Carr	5759A12	2	$32.67	$0.07	L-6.8, p.249	1/16" and 0.028" needed
8		Economy Benchtop Drill Press; 120V AC, 10" Maximum Workpiece Diameter	0.001	McMaster-Carr	28015A51	1	$224.73	$0.22	L-6.9, p.250	Assume 1 units needed every 1000 devices
9		Tap Wrench with Fixed T-Handle, 2-3/4" Long	0.001	McMaster-Carr	2546A23	1	$17.88	$0.02	L-6.2, p.243	Assume 1 units needed every 1000 devices
10		Machine Tool Tap for Through-Hole Threading; Long-Life Titanium Nitride Coated High-Speed Steel, 1-72 Thread Size	0.004	McMaster-Carr	2762A32	4	$18.10	$0.07	L-6.10, p.251	For set screw on gears , assume 2 units needed every 1000 gears
11		135 Degree Point Long-Life Drill Bit Wire Gauge 53	0.008	McMaster-Carr	29045A811	8	$3.02	$0.02	L-6.11, p.252	For set screw on gears , assume 4 units needed every 1000 gears
12		Flush-Cut Bolt and Chain Cutter ; for 3/8" Soft Steel and 5/16" Medium-Hard Steel Maximum Diameter	0.001	McMaster-Carr	3772A12	1	$118.57	$0.12	L-6.12, p.253	Assume 1 unit needed for every 1000 devices
13		Packaging	1	n/a	n/a	1	$11.20	$11.20	J-1.3, p.199	Estimated using Rigid Box type with 1000 units run: Tooling $1200 + $10 per unit
14		Labour	0.9416666667	n/a	n/a	941.6666667	$70.00	$65.92	J-1.4, p.200	
		Total Components	12			Total Cost (Per unit)		$78.12		

Version Control				
Version	Change Description	Date	Made by	
1.0	Initial Entry	2017-11-05	DL / JC	
1.1	Add 5/64" Hex Driver, Tap, Tap handle, drill bits, drill press	2017-11-13	DL	

J-3 Price Justification

Our final device cost is $799.25 which is above the $500 requirement; however, there are reasons to believe that the actual cost is lower than expected. Additionally, there are steps that the client can take to further reduce cost.

There are similar products that exist on the market for less. The Warn Vantage 2000-S-Winch is an ATV winch which has a retail price of $385.99 on 4 Wheel Parts' website. The Winch uses a motor with similar specifications as our device, uses a synthetic rope, and also weighs about the same. The major difference is that the Vantage-2000-S-Winch is powered by the ATV battery, while our design is battery powered which makes up 20% of our cost; thus, this comparison should be taken conservatively. Nevertheless, this suggests that further optimization can achieve the sub $500 cost requirement.

Additionally, there are steps in the manufacturing process that can cut costs. If possible, outsourcing labour to another country such as India would drastically reduce labour costs. The manufacturing labour cost in India is $2.70/hour as opposed to the $70/hour we considered for our device ("India's organized manufacturing sector", 2013). Another step that can be taken is to find standardized parts that can replace the customized parts; this reduces the contingency rate from 50% to 10% for those components and as a result, decreases the total cost.

APPENDIX K: LIFETIME COSTS AND CONSIDERATIONS

K-1 Lifetime Operating and Maintenance Costs

The only operational cost of the equipment tow device is the cost of electricity. The battery in the device uses energy of 153 Wh to fully charge. Based on BC Hydro's rate of $0.0858/kWh ("BC Hydro Residential Rates", 2015), the operational cost of our device is $0.01 per charge of battery.

K-2 Disposal Cost

As the issues of sustainability and life cycle analyses become increasingly relevant, end of life disposal considerations should be given a high priority.

K-2.1 Metals

Components that fall under this category include:

- Sled
- Flanged Sleeve Bearing
- Drum
- Drum Bushing
- Level Wind Shaft
- Cross
- Drum - Gear Extension
- Left Case
- Right Case
- Mounting Plate
- Left Support Plate
- Right Support Plate
- Light Duty Sleeve
- Linear Motion Shaft
- High Strength Locknut
- Head Screw
- 13 thread Socket Head Screw
- 3-48 thread socket screw
- 1-72 thread set screw
- Bearing
- Bearing Sleeve
- Metric 316 Key stock
- Wire

To properly dispose of metals, take components to an authorized metal recycle depot. For a complete list refer to BC SSA Approved Metal Dealer List ("Metal Recycling – Province of British Columbia," 2015). In terms of pricing, North Shore Metal Recycling (2015) offers to recycle and buy metals including aluminum, brass, and steel which encompasses all the metals equipment tow is made of. It is expected that other metal depots offer similar services.

K-2.2 Plastics

Components that fall under this category:

- Bungee tie down straps
- Molded Spur Pinion
- Molded Spur Gear
- Level Wind Needle
- Level Wind Carriage - Body
- Level Wind Carriage - Cap
- Synthetic Rope

To properly dispose of plastics, take components to a plastic recycling depot. For most convenient location search on Metro Vancouver Recycles (2009) website. The website states that recycling is free if plastics are dropped off at depot for most plastics.

K-2.3 Electronics

Components that fall under this category:

- Battery Charger
- 3 pin connector
- Motor
- Remote control
- Buck Converter
- MOSFET
- XT60 Connector
- Resistor
- Toggle switch

All electronics can be returned at Return it Electronic locations in Metro Vancouver. Pricing ranges from $0.40-$2.50 (“Electronics Recycling | Encorp Pacific (Canada),” 2015).

K-2.4 Batteries (Lithium Ion)

Components that fall under this category:

- Batteries

It is not regulated that batteries be properly disposed of; however, it is good practice to do so because of their hazardous and environmentally damaging nature. The North American program Call2Recycle offers free battery disposal under 5kg which our device qualifies for. Locations can be found on the Call2Recycle (2016) website.

APPENDIX L: TECHNICAL DATA

The following catalog pages were used for specifying components, both custom-made and off-the-shelf, for the final Bill of Materials (BOM), which can be found in J-2 Final Bill of Materials, p.204).

L-1 Winch and Rope Technical Specification Pages

L-1.1 Dyneema Synthetic ATV Winch Rope (Ranger)



Figure L-1: Dyneema Synthetic ATV Winch Rope (Ranger)

L-1.2 Oil-Embedded Flanged Sleeve Bearings with PTFE (Mcmaster-carr)

McMASTER-CARR

Find

Oil-Embedded Flanged Sleeve Bearings with PTFE

Ultra-Low-Friction, for 1/2" Shaft Diameter, 5/8" OD, 1/2" Long



Each

ADD TO ORDER

In stock
$1.64 Each
1677K8

Bearing Type	Plain
Plain Bearing Type	Flanged
For Shaft Diameter	1/2"
ID	0.502"
ID Tolerance	0.001" to 0.002"
OD	5/8"
OD Tolerance	0.002" to 0.003"
Length	1/2"
Length Tolerance	-0.005" to 0.005"
Flange	
OD	7/8"
Thickness	1/8"
Material	SAE 841 Bronze
Dynamic Load Capacity	500 lbs. @ 150 rpm
For Load Direction	Radial, Thrust, Combined Radial and Thrust
Shaft Mount Type	Press Fit
Lubrication	Lubricated
Lubrication Method	Embedded
Lubricant Type	Oil
Lubricant	SAE 80 Oil with PTFE
Temperature Range	10° to 220° F

Figure L-2: Oil-Embedded Flanged Sleeve Bearings with PTFE (Mcmaster-carr)

L-1.3 16 Teeth Molded Spur Gears - 16 Pitch (Stock Drive Products Sterling Instrument)

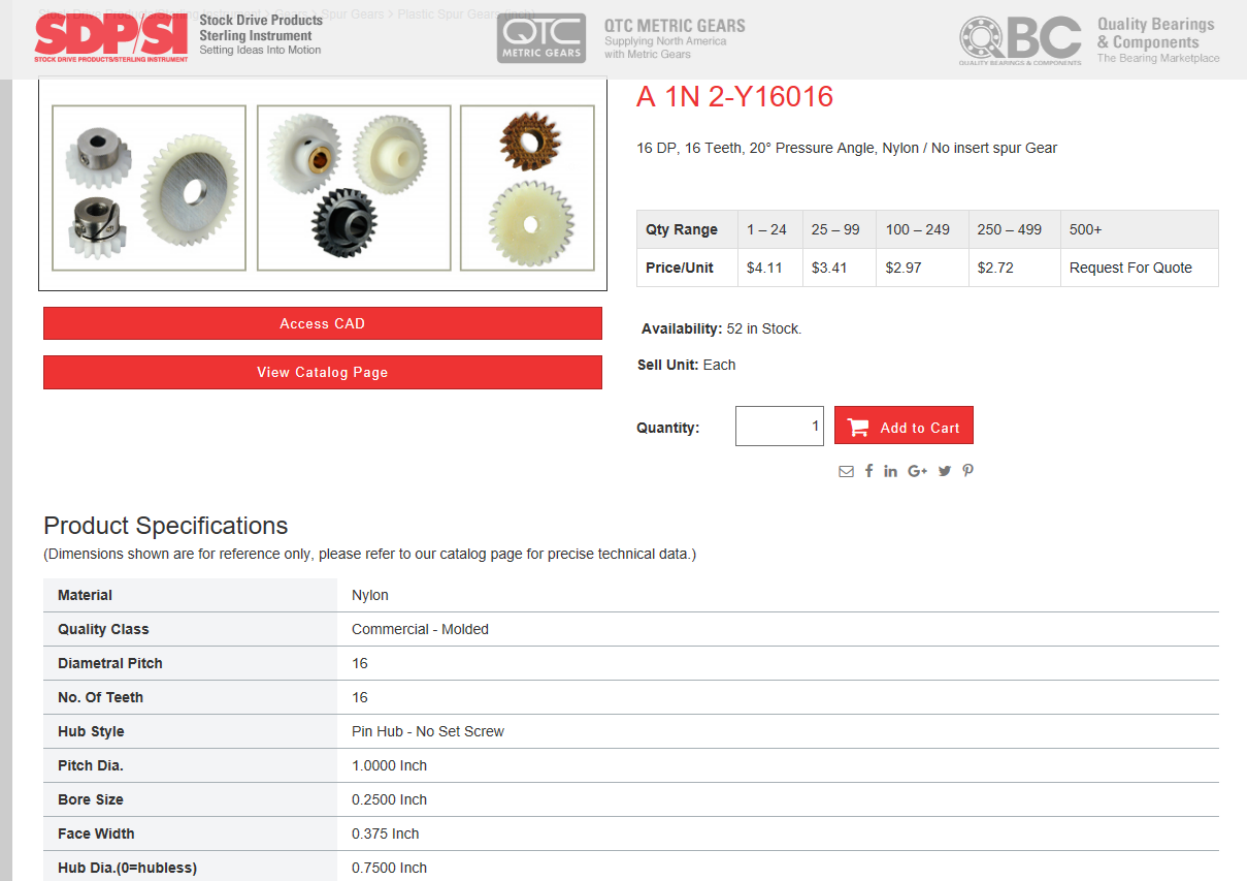


Figure L-3: 16 Teeth Molded Spur Gears - 16 Pitch (Stock Drive Products Sterling Instrument)

L-1.4 80 Teeth Molded Spur Gears - 16 Pitch (Stock Drive Products Sterling Instrument)

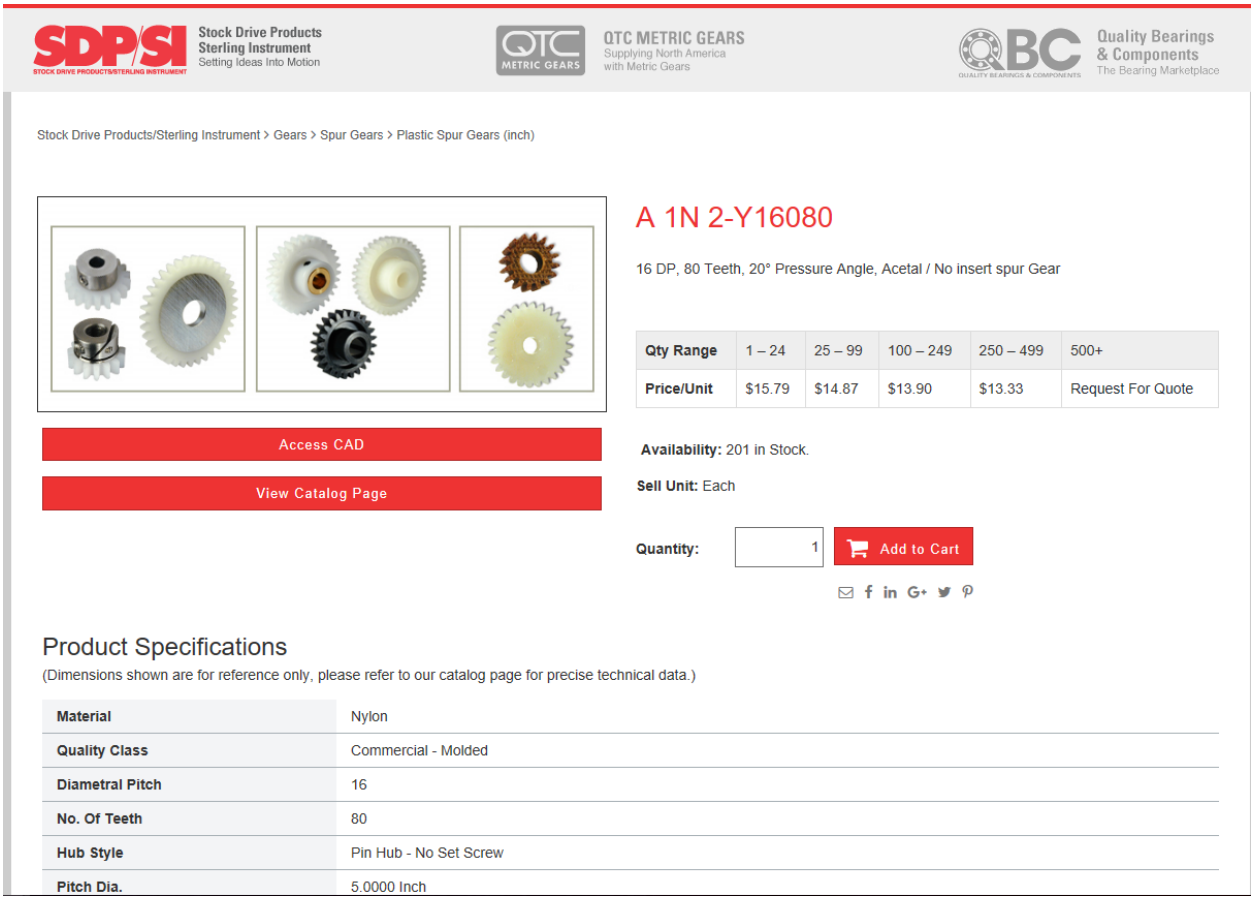


Figure L-4: 80 Teeth Molded Spur Gears - 16 Pitch (Stock Drive Products Sterling Instrument)

L-1.5 GORE® Protective Vents - Adhesive Series (Protective Vents)

PRODUCT INFORMATION

	Series VE8	Series VE7	Series VE9
Material Performance			
Typical airflow (ΔP = 70 mbar)	3300 ml/min/cm²	290 ml/min/cm²	1150 ml/min/cm²
Product Characteristics			
Membrane type	ePTFE		
Membrane characteristic	Oleophobic		
Membrane color	White	Black	White
Backing material	PET nonwoven	None	
Backing material color	White	None	
Adhesive type	Acrylic	Silicone	
Typical thickness (see figure on next page)	0.26 mm	0.34 mm	0.32 mm
Mounting location	Interior of the housing	Interior or exterior of the housing	

ENVIRONMENTAL PERFORMANCE

GORE® Protective Vents Adhesive Series have been tested by independent laboratories and meet these performance standards.

✓ – passed

Ingress Protection Testing

Vent protection against ingress of particulates and water
IP ratings are housing design, part size and mounting location (interior & exterior) dependent

- IEC 60529, 2nd Ed.
- IP68 was tested for extended immersion: 2 meters for 1 hour

IP Rating		VE8	VE7		VE9	
Particulates	Water	Interior	Interior	Exterior	Interior	Exterior
6	4	✓	✓	✓	✓	✓
6	5			✓		✓
6	6			✓		✓
6	7	✓	✓	✓	✓	✓
6	8		✓	✓	✓	✓

Flammability/UV Testing

ePTFE membrane resistant to flames and ultraviolet light

METHODS:

- UL 94-V-0 f2: VE7
- UL 94-VTM0 f2: VE9

Humidity Testing

Vent durability in hot, humid environments

METHOD:

- IEC 60068-2-78

TEST CONDITIONS:

- 85°C
- 85% relative humidity
- 1,000 hours

Salt Fog Testing

Vent resistance to salty environments

METHODS:

- IEC 60068-2-11 (salt fog)
- IEC 60068-2-52 (cyclic salt fog)

Salt Spray Testing

Vent resistance to salt spray

METHOD:

- DIN 50021-SS:1988-06 (7-day test)
  No penetration of salt crystals through the membrane into the housing

Corrosive Gas Testing

Vent durability in corrosive gas environment (e.g., NO_x, SO_x, H_2S, Cl_x)

METHOD:

- GR-3108-CORE (telecom)

Temperature Testing

Vent durability in a range of temperatures

METHODS:

- IEC 60068-2-1: (low temperature of –40°C)
- IEC 60068-2-2: (high temperature of 100°C) VE8
- IEC 60068-2-2: (high temperature of 125°C) VE7, VE9
- IEC 60068-2-14: (cycling temperatures between –40°C and 100°C) VE8
- IEC 60068-2-14: (cycling temperatures between –40°C and 125°C) VE7, VE9

Figure L-5: GORE® Protective Vents - Adhesive Series (Protective Vents)

L-1.6 Light Duty Dry-Running Sleeve Bearing (Mcmaster-carr)

Light Duty Dry-Running Sleeve Bearing

Flanged, MDS-Filled Nylon, for 1/2" Shaft Diameter, 1/4" Length



Each

ADD TO ORDER

In stock
$1.36 Each
6294K444

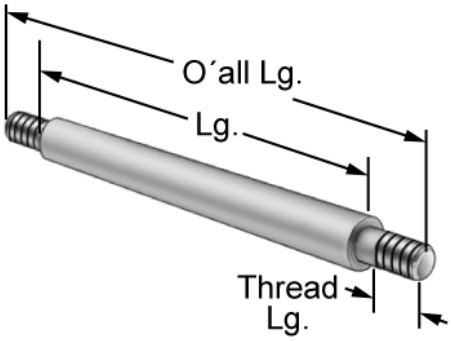
Bearing Type	Plain
Plain Bearing Type	Flanged
For Shaft Diameter	1/2"
ID	0.500"
ID Tolerance	Not Rated
OD	5/8"
OD Tolerance	Not Rated
Length	1/4"
Length Tolerance	0" to -0.0087"
Flange	
OD	7/8"
Thickness	1/16"
Material	MDS-Filled Nylon
Color	Black
Dynamic Load Capacity	50 lbs. @ 60 rpm
For Load Direction	Radial, Thrust, Combined Radial and Thrust
Shaft Mount Type	Press Fit
Lubrication	Not Required
Temperature Range	-40° to 170° F
RoHS	Compliant

Figure L-6: Light Duty Dry-Running Sleeve Bearing (Mcmaster-carr)

L-1.7 Alloy Steel Linear Motion Shaft (Mcmaster-carr)

52100 Alloy Steel Linear Motion Shaft

with Two Threaded Ends, 3/8" Diameter, 8" Long



Each

In stock
$51.34 Each
8350T21

ADD TO ORDER

Material	52100 Alloy Steel
Diameter	3/8"
Length	8"
Number of Threaded Ends	2
Thread	
Size	1/4"-20
Length	19/64"
Overall Length	9"
Diameter Tolerance	-0.0006" to -0.0002"
Straightness Tolerance	0.002" per ft.
Length Tolerance	-0.02" to 0.02"
Surface Smoothness (RMS)	16 microns
End Shape	Chamfered
Hardness Rating	Very Hard
Hardness	Rockwell C60
Heat Treatment	Surface Hardened
Yield Strength	128,000 psi
Surface Yield Strength	Not Rated
For Motion Type	Linear
For Linear Bearing Type	Ball, Plain
Shaft Type	Round
End Type	Threaded
RoHS	Compliant

Figure L-7: Alloy Steel Linear Motion Shaft (Mcmaster-carr)

L-1.8 High-Strength Steel Nylon-Insert Locknut (Mcmaster-carr)

High-Strength Steel Nylon-Insert Locknut

Grade 8, Zinc Yellow-Chromate Plated, 1/4"-20 Thread Size



Packs of 25

ADD TO ORDER

In stock
$3.43 per pack of 25
97135A210

Material	Zinc Yellow-Chromate Plated Steel
Fastener Strength Grade/Class	Grade 8
Thread Size	1/4"-20
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	7/16"
Height	5/16"
Insert Maximum Temperature	220° F
Drive Style	External Hex
Nut Type	Locknut
Hex Nut Profile	Standard
Locking Type	Nylon Insert
System of Measurement	Inch
RoHS	Not Compliant

Figure L-8: High-Strength Steel Nylon-Insert Locknut (Mcmaster-carr)

L-1.9 18-8 Stainless Steel Hex Drive Rounded Head Screw (Mcmaster-carr)

18-8 Stainless Steel Hex Drive Rounded Head Screw

3-48 Thread Size, 1/4" Long



Packs of 100

In stock
$6.98 per pack of 100
92949A325

ADD TO ORDER

Thread Size	3-48
Length	1/4"
Threading	Fully Threaded
Head Diameter	0.188"
Head Height	0.052"
Drive Size	1/16"
Material	18-8 Stainless Steel
Hardness	Rockwell B55
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.099"
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 3A
Thread Direction	Right Hand
Head Type	Rounded
Rounded Head Style	Button
Rounded Head Profile	Standard
Drive Style	Hex
System of Measurement	Inch
RoHS	Compliant

Figure L-9: 18-8 Stainless Steel Hex Drive Rounded Head Screw (Mcmaster-carr)

L-1.10 Black-Oxide Alloy Steel Socket Head Screw 1/2"-13 Thread Size, 1-1/2" Long (Mcmaster-carr)

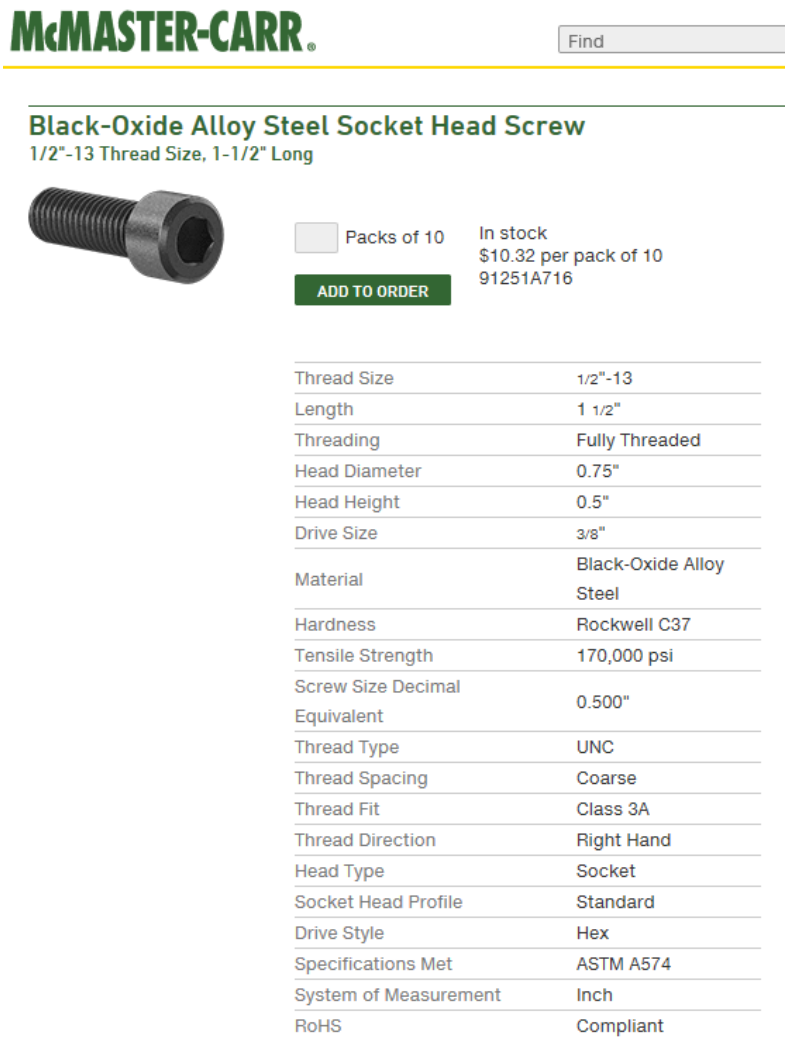


Figure L-10: Black-Oxide Alloy Steel Socket Head Screw 1/2"-13 Thread Size, 1-1/2" Long (Mcmaster-carr)

L-1.11 Black-Oxide Alloy Steel Socket Head Screw 3-48 Thread Size, 1/2" Long (Mcmaster-carr)

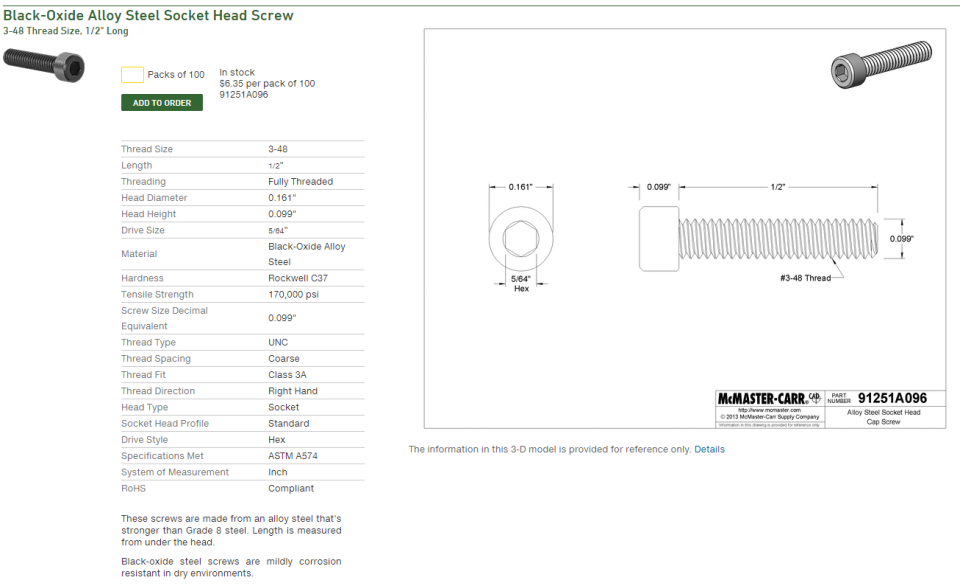


Figure L-11: Black-Oxide Alloy Steel Socket Head Screw 3-48 Thread Size, 1/2" Long (Mcmaster-carr)

L-1.12 Black-Oxide Alloy Steel Socket Head Screw 12-24 Thread Size, 3/4" Long (Mcmaster-carr)

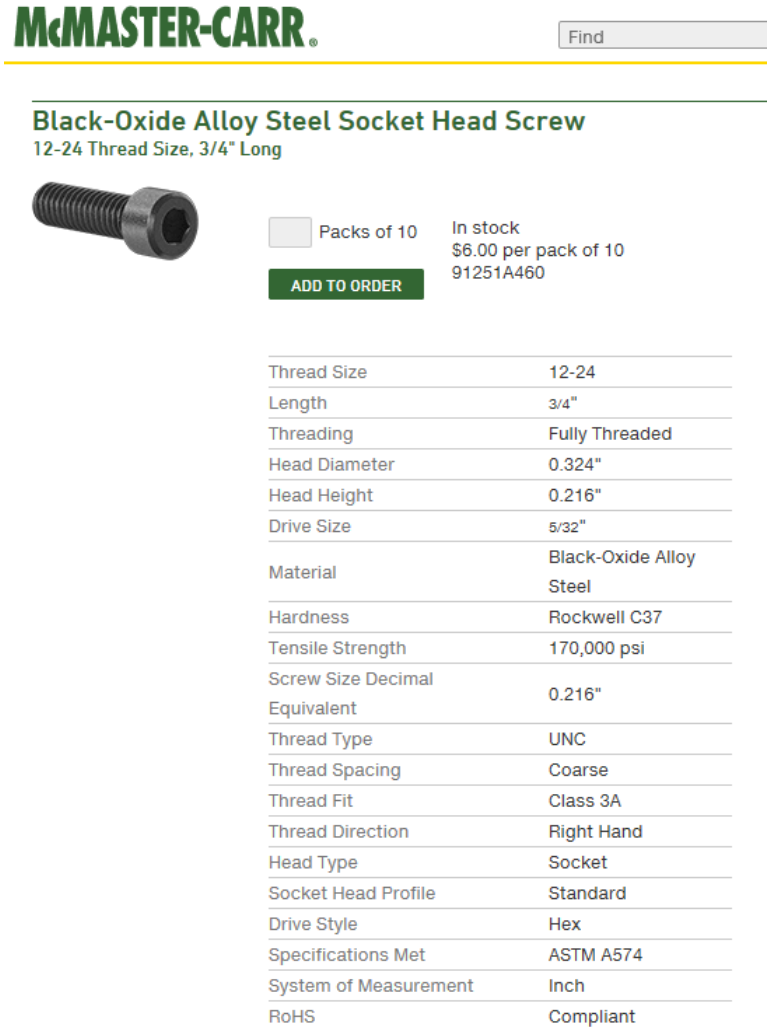


Figure L-12: Black-Oxide Alloy Steel Socket Head Screw 12-24 Thread Size, 3/4" Long (Mcmaster-carr)

L-1.13 Alloy Steel Cup-Point Set Screw Black-Oxide, 1-72 Thread, 5/16" Long (Mcmaster-Carr)

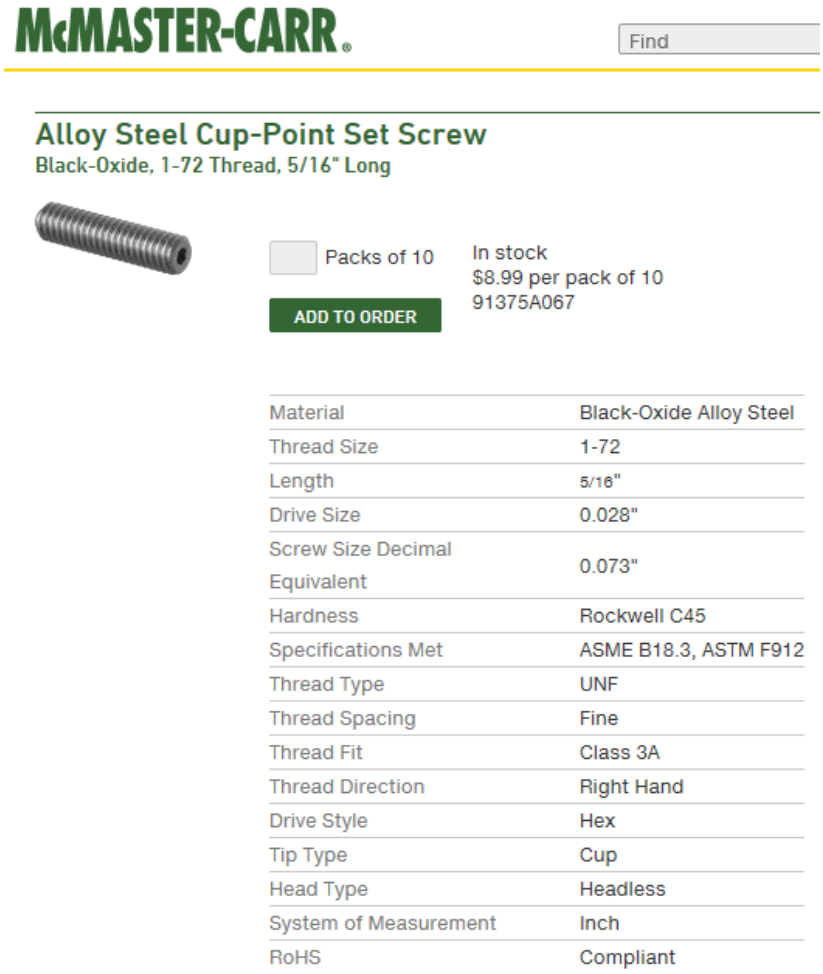


Figure L-13: Alloy Steel Cup-Point Set Screw Black-Oxide, 1-72 Thread, 5/16" Long (Mcmaster-carr)

L-1.14 Custom Winch Parts (Xometry)

Xometry

7951 Cessna Avenue | Gaithersburg, MD | 20879 | 240-252-1138

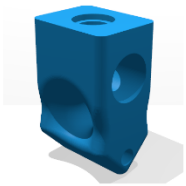
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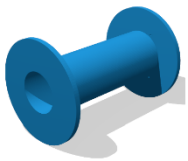
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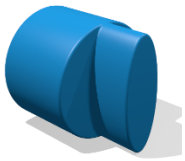
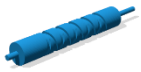
Contact Info: jason le

Estimated Lead Time: 30 business days + transit time

Requirements:

Part ID	Description	Qty.	Unit Price
 0066C8D	Carriage.SLDPRT **Bounding Box:** 81.72mm x 50.80mm x 40.64mm 3.22in x 2.00in x 1.60in **Material:** Black Delrin (Acetal) **Finish:** Standard **Notes:** N/A	100	$11.14
 0066C91	Level wind guide cap.SLDPRT **Bounding Box:** 50.80mm x 40.64mm x 6.35mm 2.00in x 1.60in x 0.25in **Material:** Black Delrin (Acetal) **Finish:** Standard **Notes:** N/A	1000	$7.04

Part ID	Description	Qty.	Unit Price
 0066C8A	Cross Bar.SLDPRT **Bounding Box:** 152.40mm x 57.15mm x 6.35mm 6.00in x 2.25in x 0.25in **Material:** Aluminum 7075 T6 **Features:** Threads/Tapped Holes: 4 **Finish:** Standard **Notes:** N/A	1000	$17.45
 0066C8B	Drum Gear Extension.SLDPRT **Bounding Box:** 56.26mm x 49.78mm x 38.10mm 2.22in x 1.96in x 1.50in **Material:** Aluminum 6061-T6 **Finish:** Standard **Notes:** N/A	1000	$13.27
 0066C8C	Drum.SLDPRT **Bounding Box:** 147.19mm x 101.60mm x 101.60mm 5.79in x 4.00in x 4.00in **Material:** Aluminum 6061-T6 **Finish:** Standard **Notes:** N/A	1000	$38.87

Part ID	Description	Qty.	Unit Price
 0066C8E	Level wind guide.SLDPRT **Bounding Box:** 13.97mm x 12.70mm x 12.70mm 0.55in x 0.50in x 0.50in **Material:** Black Delrin (Acetal) **Finish:** Standard **Notes:** N/A	100	$3.92
 0066C90	Level wind shaft.SLDPRT **Bounding Box:** 199.90mm x 25.40mm x 25.40mm 7.87in x 1.00in x 1.00in **Material:** Aluminum 6061-T6 **Finish:** Standard **Notes:** N/A	1000	$9.21
 0066C92	Part1.sldprt **Bounding Box:** 152.27mm x 125.84mm x 12.70mm 5.99in x 4.95in x 0.50in **Material:** Aluminum 6061-T6 **Finish:** Standard **Notes:** N/A	1000	$22.40

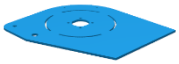
Part ID	Description	Qty.	Unit Price
 0066C98	Supporting Plate Right.SLDPRT **Bounding Box:** 233.78mm x 209.54mm x 3.17mm 9.20in x 8.25in x 0.12in **Material:** Aluminum 6061-T6 **Finish:** Standard **Notes:** N/A	1000	$10.91
 0066861	Supporting Plate Left.SLDPRT **Bounding Box:** 189.96mm x 168.69mm x 3.17mm 7.48in x 6.64in x 0.12in **Material:** Aluminum 5052 Sheet **Finish:** Standard **Notes:** N/A	1000	$4.67

Figure L-14: Custom Winch Parts (Xometry)

L-2 Power Transmission Technical Specification Pages

L-2.1 Sprag Clutch One Way Bearing with Keyways (Wych Bearings)



Figure L-15: Sprag Clutch One Way Bearing with Keyways (Wych Bearings)

L-2.2 Custom Sleeve Bushing (Xometry)

Xometry
7951 Cessna Avenue | Gaithersburg, MD | 20879 | 240-252-1138

Quote ID: 093C8-15007

Date: 11/15/2017 UTC

Contact Info:	**Estimated Lead Time:**	**Requirements:**
jason le	30 business days + transit time	

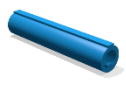
Part ID	**Description**	**Qty.**	**Unit Price**
 0066D43	Mech 328 Sleeve Bushing.SLDPRT **Bounding Box:** 76.20mm x 15.77mm x 15.00mm 3.00in x 0.62in x 0.59in **Material:** Aluminum 7075 T6 **Finish:** Standard **Notes:** N/A	1000	$6.65

Figure L-16:Custom Sleeve Bushing (Xometry)

L-2.3 Metric 316 Stainless Steel Machine Key Stock (Mcmaster-carr)

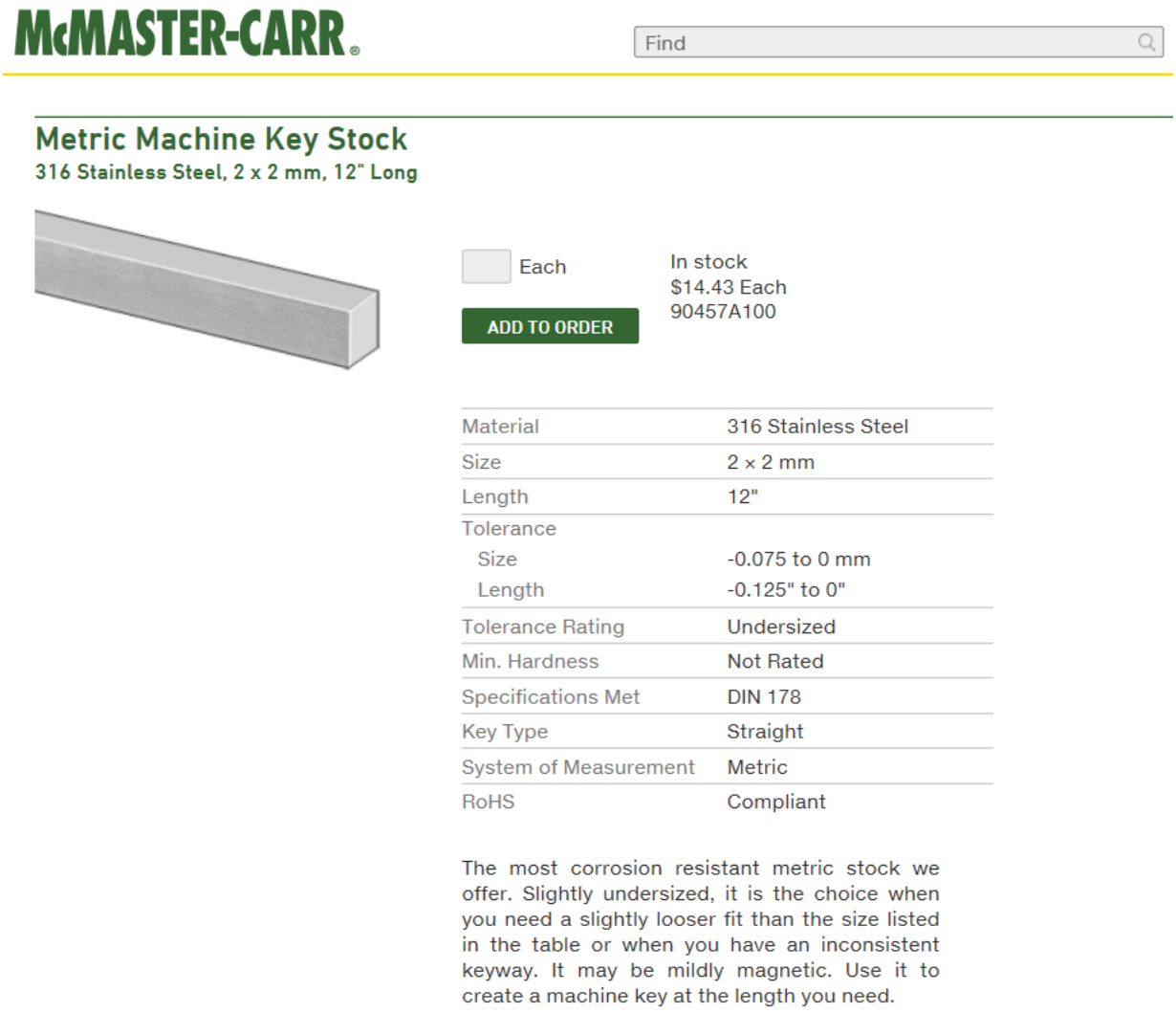


Figure L-17: Metric 316 Stainless Steel Machine Key Stock (Mcmaster-carr)

L-3 Sled Technical Specification Pages

L-3.1 Bungee Straps 4 pack (Lowe's)



Figure L-18: Bungee Straps 4 pack (Lowe's)

L-3.2 Custom Sled (Xometry)

Xometry

7951 Cessna Avenue | Gaithersburg, MD | 20879 | 240-252-1138

Quote ID: 093C8-15007

Date: 11/15/2017 UTC

Contact Info:	**Estimated Lead Time:**	**Requirements:**
jason le	30 business days + transit time	

 0066C96	Sled.SLDPRT **Bounding Box:** 587.00mm x 469.90mm x 79.54mm 23.11in x 18.50in x 3.13in **Material:** Aluminum 5052 Sheet **Finish:** Standard **Notes:** N/A	1000	$9.98

Figure L-19: Custom Sled (Xometry)

L-4 Motor and Battery Technical Specification Pages

L-4.1 High torque, low speed motor with in-built planetary gearset (AndyMark)

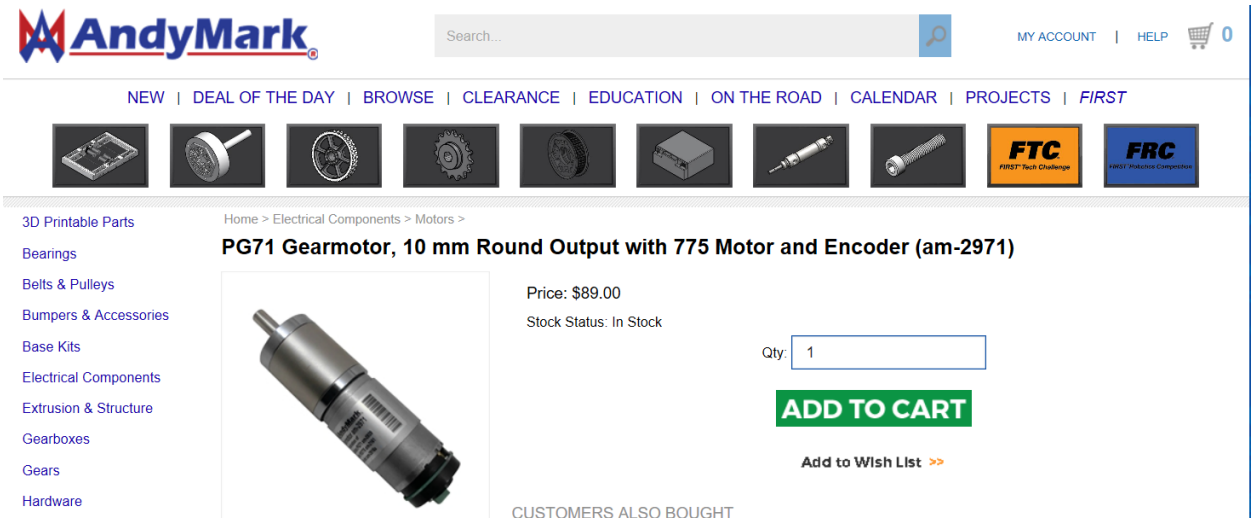


Figure L-20: High torque, low speed motor with in-built planetary gearset (AndyMark)

L-4.2 Battery (Liion)

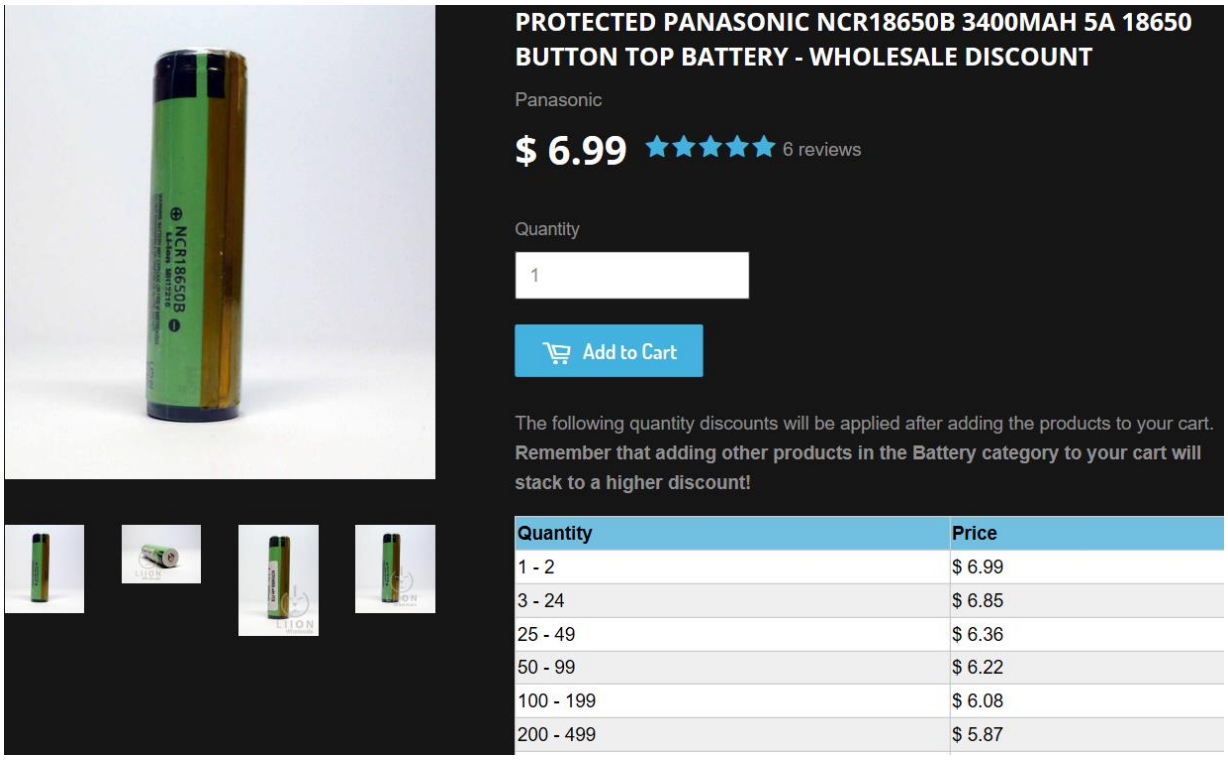


Figure L-21: Battery (Liion)

L-4.3 Calcium-Magnesium Silicate Thermal Insulation Sheet (RS Pro)

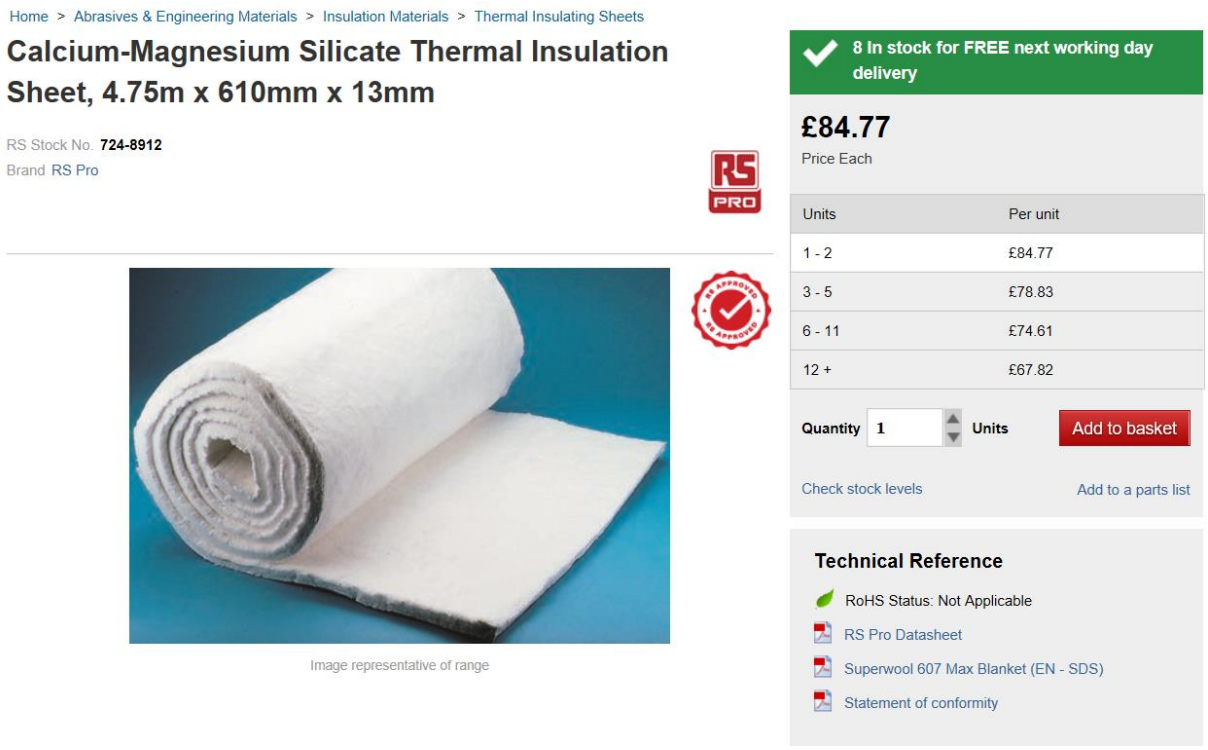


Figure L-22: Calcium-Magnesium Silicate Thermal Insulation Sheet (RS Pro)

L-4.4 16.8V 5A Charger 4S 14.8V Smart Li-ion Battery Charger 14.8V Lithium polymer battery Charger (Amazon)

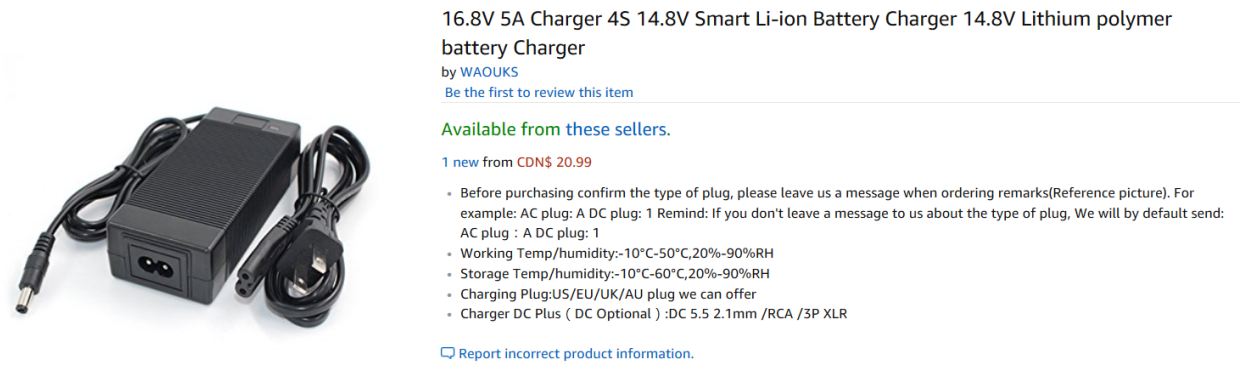


Figure L-23: 16.8V 5A Charger 4S 14.8V Smart Li-ion Battery Charger 14.8V Lithium polymer battery Charger (Amazon)

L-4.5 4 pin male cannon plug (AA Portable Power Corp)



Figure L-24: 4 pin male cannon plug (AA Portable Power Corp)

L-5 Controls Technical Specification Pages

L-5.1 Geekcreit® DC 12V 10A Relay 1CH Channel Wireless RF Remote Control Switch Transmitter with Receiver (Bang good)

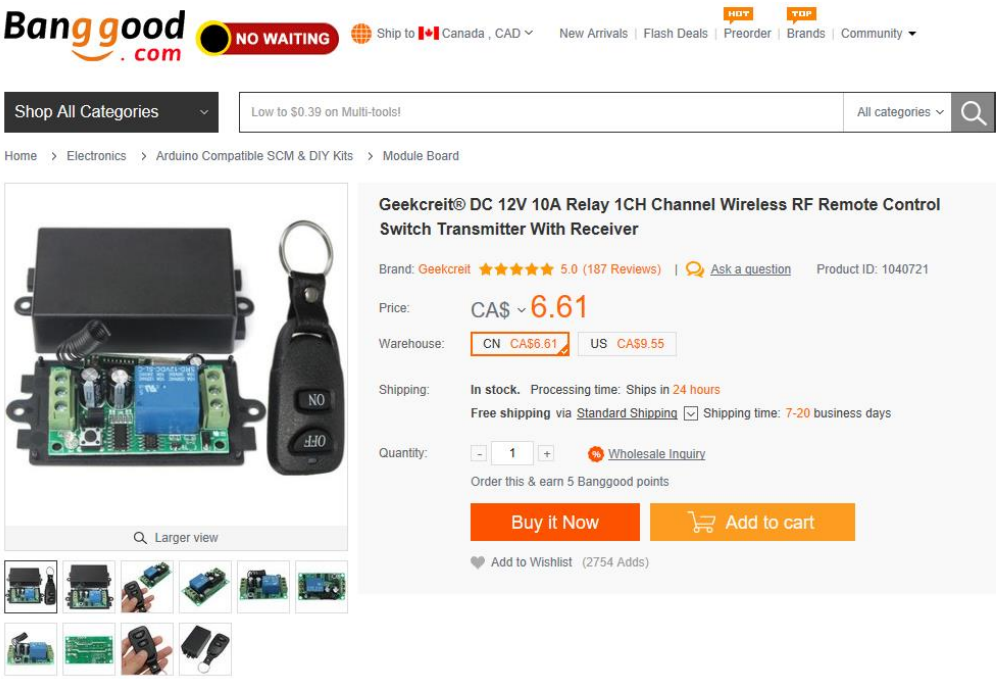


Figure L-25: Geekcreit ® DC 12V 10A Relay 1CH Channel Wireless RF Remote Control Switch Transmitter with Receiver (Bang good)

L-5.2 LM2596 Buck Converter (DC-DC step down voltage) (Amazon)

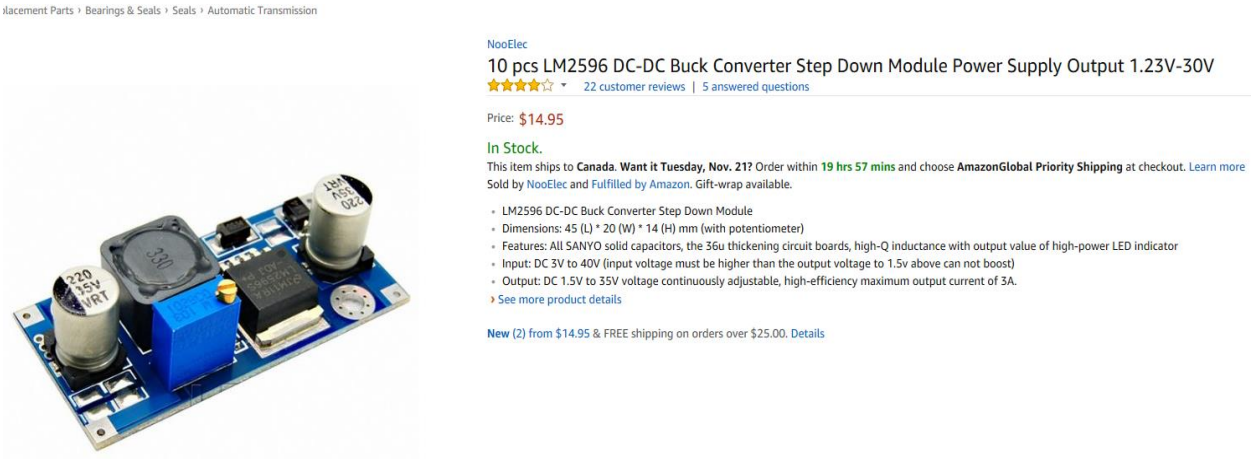


Figure L-26: LM2596 Buck Converter (DC-DC step down voltage) (Amazon)

L-5.3 N-channel MOSFET (ebay)

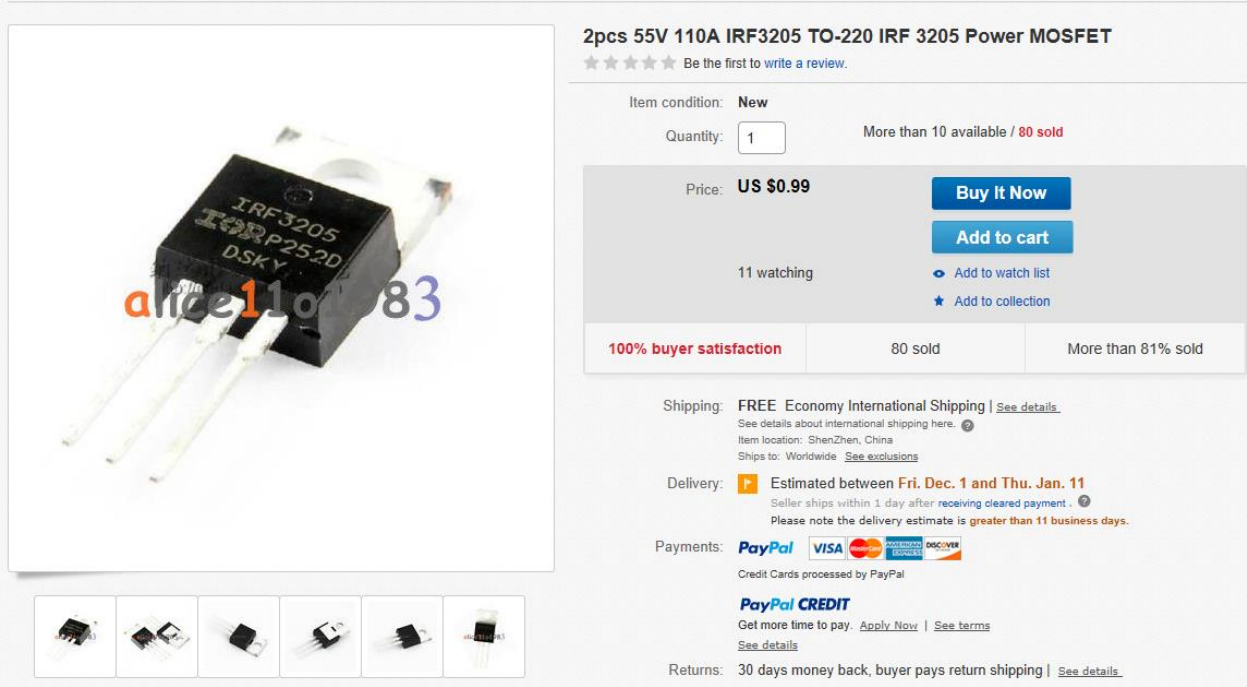


Figure L-27: N-channel MOSFET (ebay)

L-5.4 XT60 connector (Hobbyking)

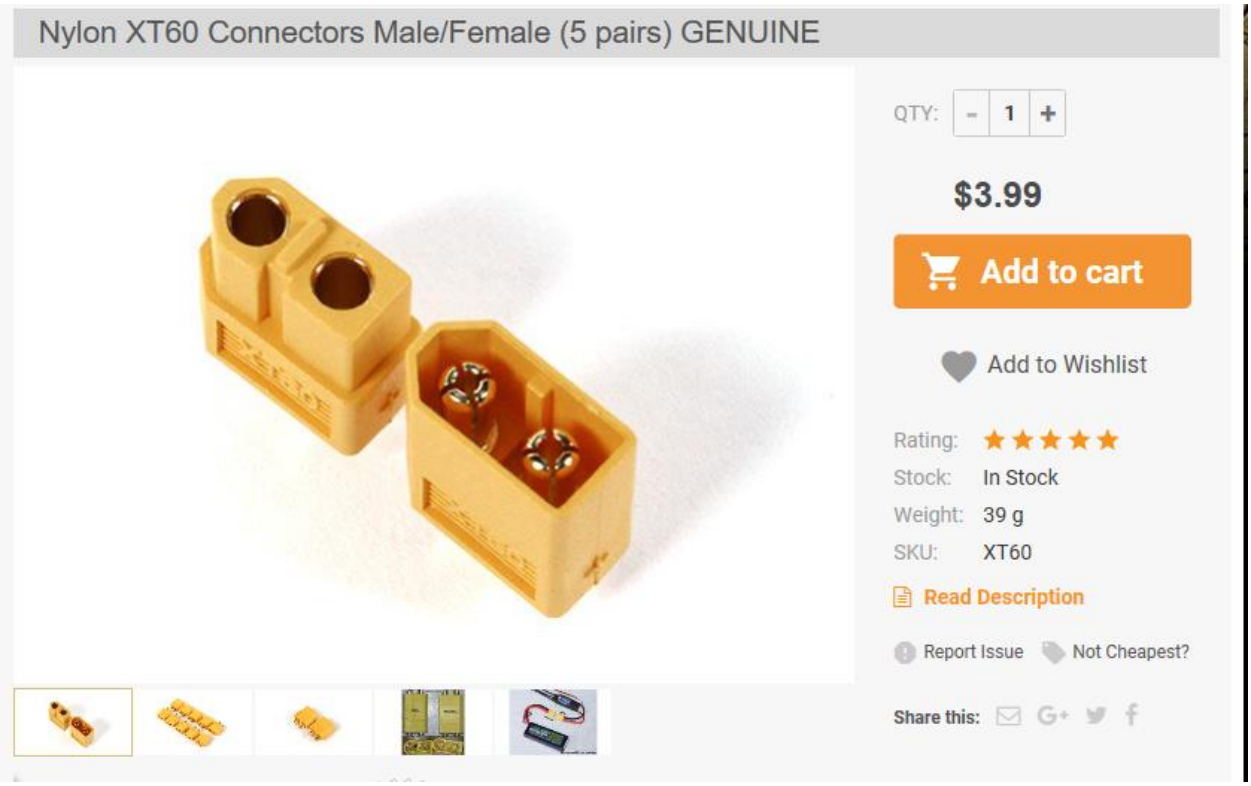


Figure L-28: XT60 connector (Hobbyking)

L-5.5 10k resistor (ebay)



Figure L-29: 10k resistor (ebay)

L-5.6 12V 20A Adapted Rocker Toggle Switch Waterproof (ebay)

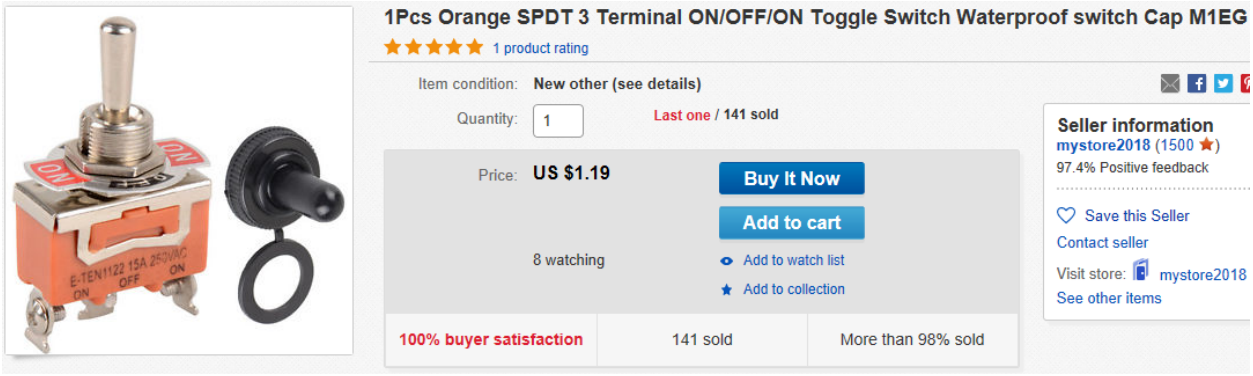


Figure L-30: 12V 20A Adapted Rocker Toggle Switch Waterproof (ebay)

L-5.7 Turnigy 16AWG Silicone Wire 20m (Black) (Hobbyking)

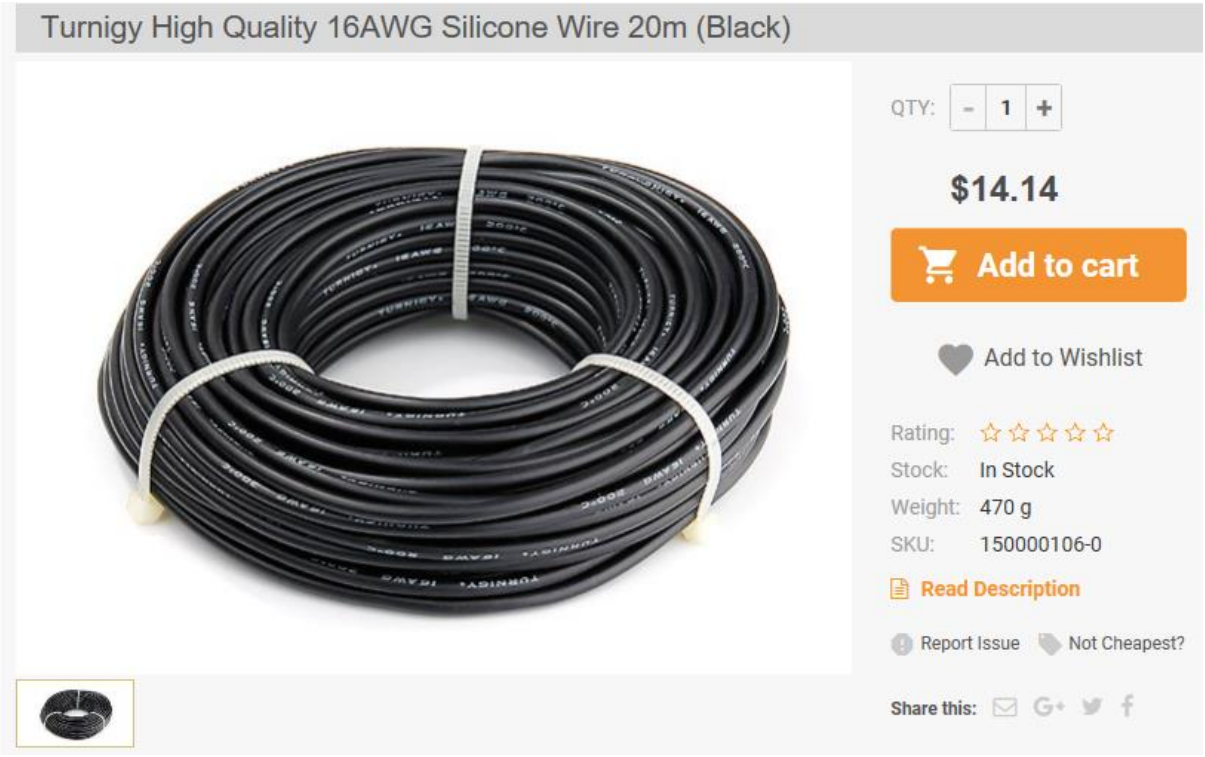


Figure L-31: Turnigy 16AWG Silicone Wire 20m (Black) (Hobbyking)

L-5.8 Turnigy 16AWG Silicone Wire 20m (Red) (Hobbyking)



Figure L-32: Turnigy 16AWG Silicone Wire 20m (Red) (Hobbyking)

L-5.9 Turnigy Heat Shrink Tube 100mm Black (1m) (Hobbyking)



Figure L-33: Turnigy Heat Shrink Tube 100mm Black (1m) (Hobbyking)

L-6 Labour and Manufacturing Technical Specification Pages

L-6.1 GE waterproof Silicone (The Home Depot)

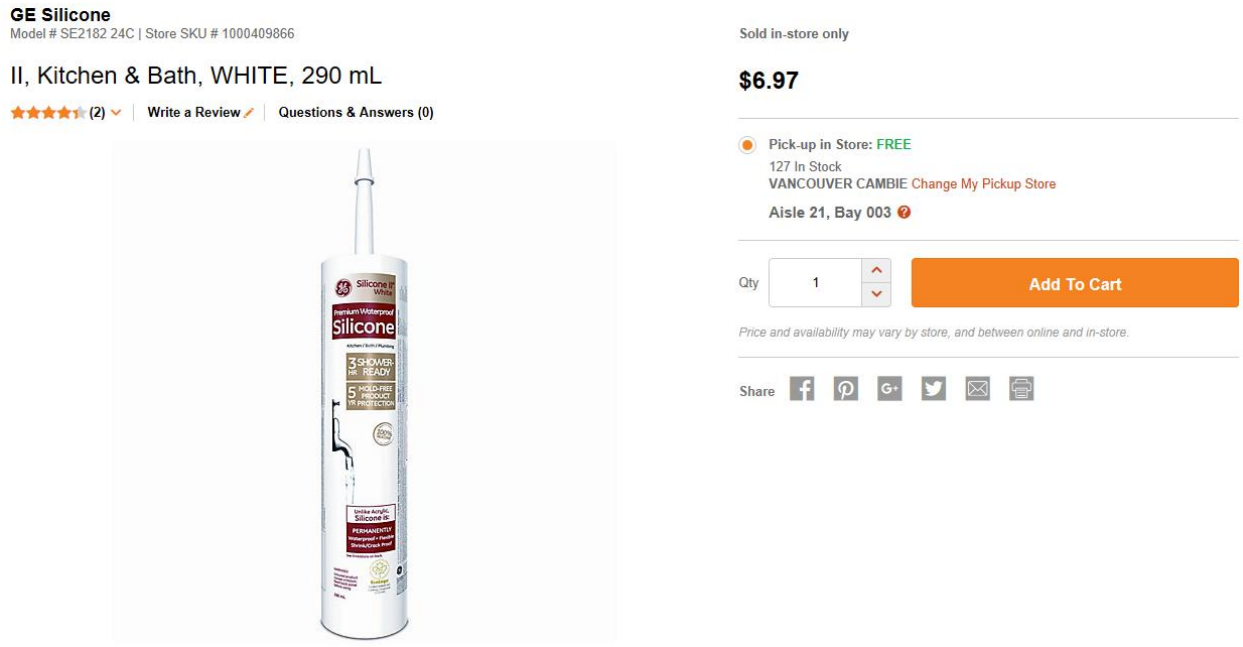


Figure L-34: GE waterproof Silicone (The home depot)

L-6.2 Tap Wrench with Fixed T-Handle, 2-3/4" Long (Mcmaster-carr)

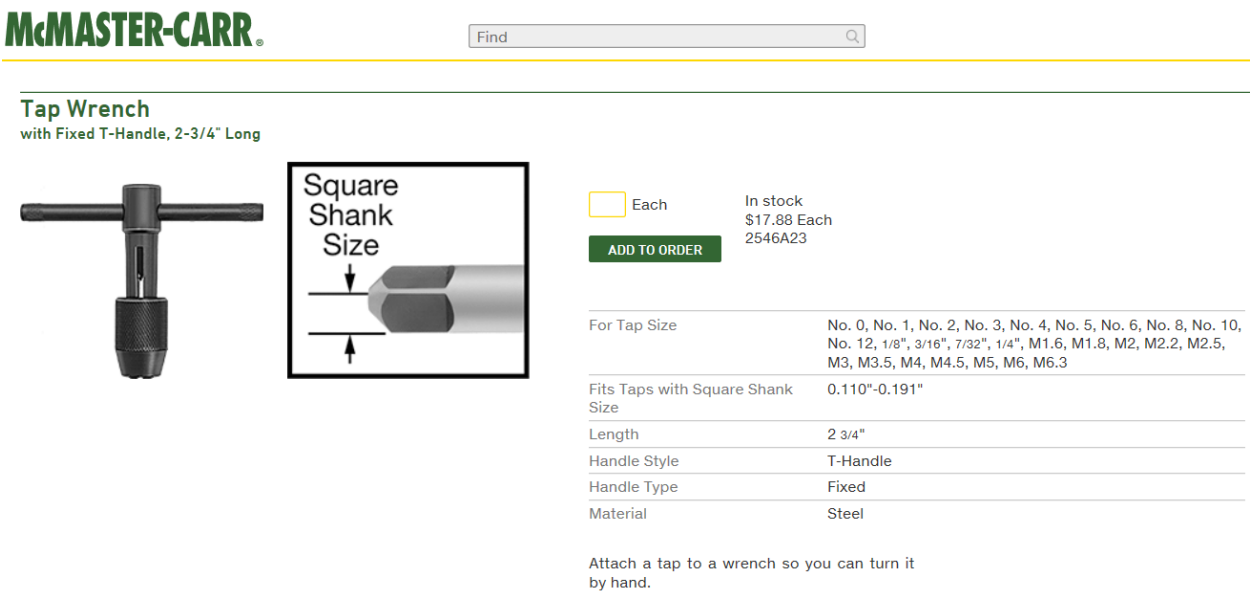


Figure L-35: Tap Wrench with Fixed T-Handle, 2-3/4" Long (Mcmaster-carr)

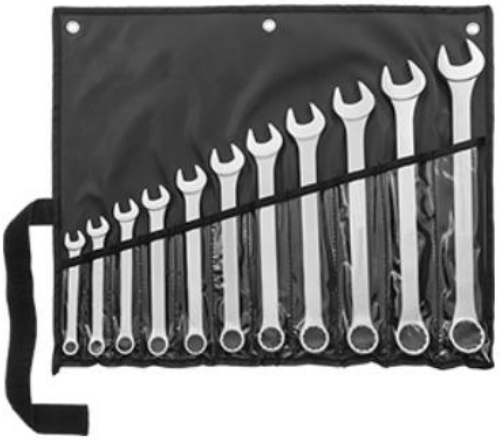
L-6.3 Economy Combination Inch Wrench Set (Mcmaster-carr)

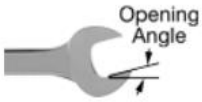
McMASTER-CARR

Find

Economy Combination Inch Wrench Set

11-Pieces







Each

In stock
$41.59 Each
5201A7

ADD TO ORDER

Number of Pieces	11
Size	3/8" 7/16" 1/2" 9/16" 5/8" 11/16" 3/4" 13/16" 7/8" 15/16" 1"
Overall Length	5 1/8"-13 1/2"
Head Offset Angle	15°
Box End	
Wrench Style	Box
Opening Shape	12-Point
For Drive Style	External 12-Point, External Hex
Head Style	Offset

Figure L-36: Economy Combination Inch Wrench Set (Mcmaster-Carr)

L-6.4 Ultra-Grip Screwdriver 5/32" Hex (Mcmaster-carr)

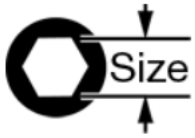
McMASTER-CARR

Find

Ultra-Grip Screwdriver

5/32" Hex





Each

In stock
$5.00 Each
7400A18

ADD TO ORDER

For Drive Style	Hex
Size	5/32"
Overall Length	8"
Shaft	
Length	3 1/2"
Maximum Width	0.156"
Shape	Hex
Material	Steel
Finish	Black
Handle Material	Plastic
End	Standard
Style	Driver
Driver Type	Standard
Power Source	Manual
Individual/Set	Individual
RoHS	Compliant

The soft, contoured handle on these premium screwdrivers provides comfort and the best possible grip for achieving maximum torque.

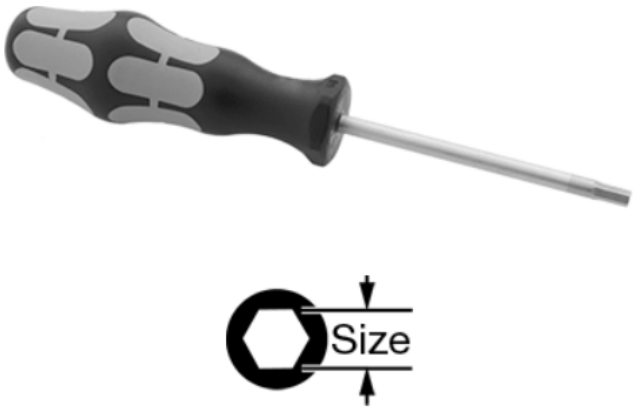
Figure L-37: Ultra-Grip Screwdriver 5/32" Hex (Mcmaster-carr)

L-6.5 Ultra-Grip Screwdriver 3/8" Hex (Mcmaster-carr)

McMASTER-CARR

Find

Ultra-Grip Screwdriver
3/8" Hex



Each

In stock
$8.39 Each
7400A26

ADD TO ORDER

For Drive Style	Hex
Size	3/8"
Overall Length	11 5/16"
Shaft	
Length	6 1/2"
Maximum Width	0.375"
Shape	Hex
Material	Steel
Finish	Black
Handle Material	Plastic
End	Standard
Style	Driver
Driver Type	Standard
Power Source	Manual
Individual/Set	Individual
RoHS	Compliant

The soft, contoured handle on these premium screwdrivers provides comfort and the best possible grip for achieving maximum torque.

Figure L-38: Ultra-Grip Screwdriver 3/8" Hex (Mcmaster-carr)

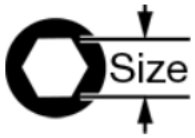
L-6.6 Ultra-Grip Screwdriver 5/64" Hex (Mcmaster-carr)

McMASTER-CARR

Find

Ultra-Grip Screwdriver
5/64" Hex





Each

In stock
$4.63 Each
7400A13

ADD TO ORDER

For Drive Style	Hex
Size	5/64"
Overall Length	5"
Shaft	
Length	2 11/16"
Maximum Width	0.078"
Shape	Hex
Material	Steel
Finish	Black
Handle Material	Plastic
End	Standard
Style	Driver
Driver Type	Standard
Power Source	Manual
Individual/Set	Individual
RoHS	Compliant

The soft, contoured handle on these premium screwdrivers provides comfort and the best possible grip for achieving maximum torque.

Figure L-39: Ultra-Grip Screwdriver 5/64" Hex (Mcmaster-carr)

L-6.7 Soft Rubber Hammer (Mcmaster-carr)

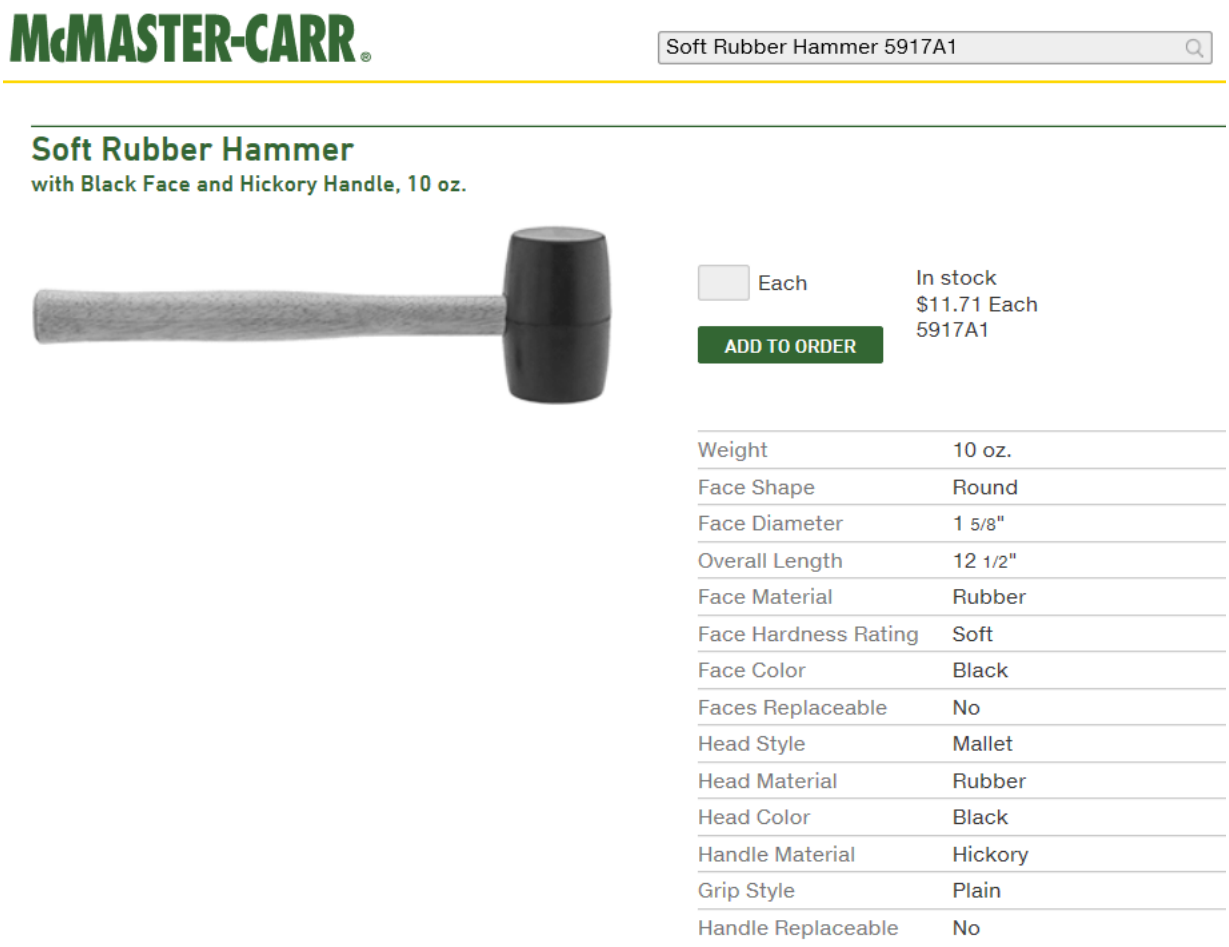


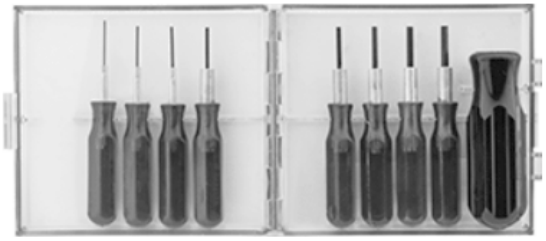
Figure L-40: Soft Rubber Hammer (Mcmaster-carr)

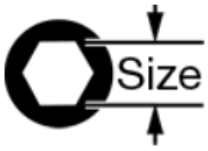
L-6.8 9 Piece Hex Screwdriver Set (Mcmaster-carr)

McMASTER-CARR®

Find

9 Piece Hex Screwdriver Set





Each

In stock
$32.67 Each
5759A12

ADD TO ORDER

Number of Pieces	9
Size (Overall Length)	0.028" Hex (3 1/2") 0.035" Hex (3 1/2") 0.050" Hex (3 1/2") 1/16" Hex (3 1/2") 5/64" Hex (3 1/2") 3/32" Hex (3 1/2") 7/64" Hex (3 1/2") 1/8" Hex (3 1/2")
Material	Steel
Finish	Black
Handle Material	Plastic
Includes	Secondary Screwdriver Handle
Container Type	Plastic Case
End	Standard
Style	Driver
Driver Type	Standard
Power Source	Manual
Individual/Set	Set
RoHS	Not Compliant

Figure L-41: 9 Piece Hex Screwdriver Set (Mcmaster-carr)

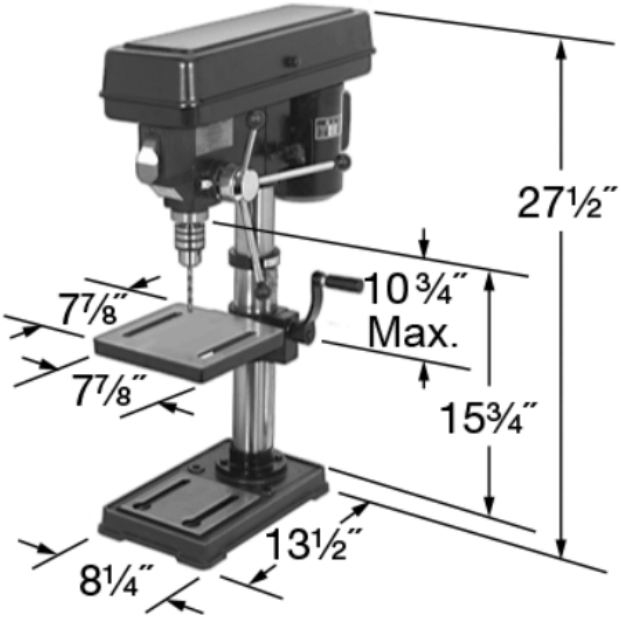
L-6.9 Economy Benchtop Drill Press 120V AC, 10" Maximum Workpiece Diameter (Mcmaster-carr)

McMASTER-CARR

Find

Economy Benchtop Drill Press

120V AC, 10" Maximum Workpiece Diameter



Each

In stock
$224.73 Each
28015A51

ADD TO ORDER

Maximum Workpiece Diameter	10"
Maximum Table Capacity	70 lbs.
For Maximum Drill Bit Size for Cast Iron	1/2"
For Maximum Bit Shank Size	1/2"
Mounting Location	Benchtop
Maximum No-Load Speed	3,070 rpm
Chuck Type	Keyed
Chuck Key Included	Yes
Number of Speeds	5
Power Source	Electric
Column Feed Handle Number of Spokes	3
Column Feed Handle Mounting Location	Right Side
Spindle Shank Type	Jacobs
Spindle Jacobs Taper No.	33
Spindle Travel	2 1/2"
Voltage	120V AC
Frequency	60 Hz

https://www.mcmaster.com/

Figure L-42: Economy Benchtop Drill Press 120V AC, 10" Maximum Workpiece Diameter (Mcmaster-carr)

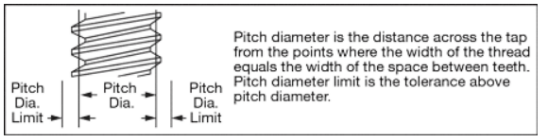
L-6.10 Machine Tool Tap for Through-Hole Threading Long-Life Titanium Nitride Coated High-Speed Steel, 1-72 Thread Size (Mcmaster-Carr)

McMASTER-CARR. Find

Machine Tool Tap for Through-Hole Threading

Long-Life Titanium Nitride Coated High-Speed Steel, 1-72 Thread Size





Each

In stock
$18.10 Each
2762A32

ADD TO ORDER

Thread Size	1-72
Thread Length	3/8"
Overall Length	1 11/16"
Maximum Tapping Depth	3/8"
Drill Bit Size	53
Drill Bit Size Decimal Equivalent	0.0595"
Thread Direction	Right Hand
Number of Flutes	2
For Use On	Steel, Iron, Stainless Steel, Nickel, Aluminum, Brass, Bronze, Copper, Plastics
Material	Titanium Nitride (TiN) Coated High-Speed Steel
For Tool Type	Machine Tools
Flute Style	Straight with Spiral Point
Thread Type	UNF
Pitch Diameter Limit	H2
Pitch Diameter Tolerance	+0.0005" to +0.0010"
Application	Through-Hole Threading
Chamfer Type	Plug

Figure L-43: Machine Tool Tap for Through-Hole Threading Long-Life Titanium Nitride Coated High-Speed Steel, 1-72 Thread Size (Mcmaster-Carr)

L-6.11 135 Degree Point Long-Life Drill Bit-Wire Gauge 53 (Mcmaster-carr)

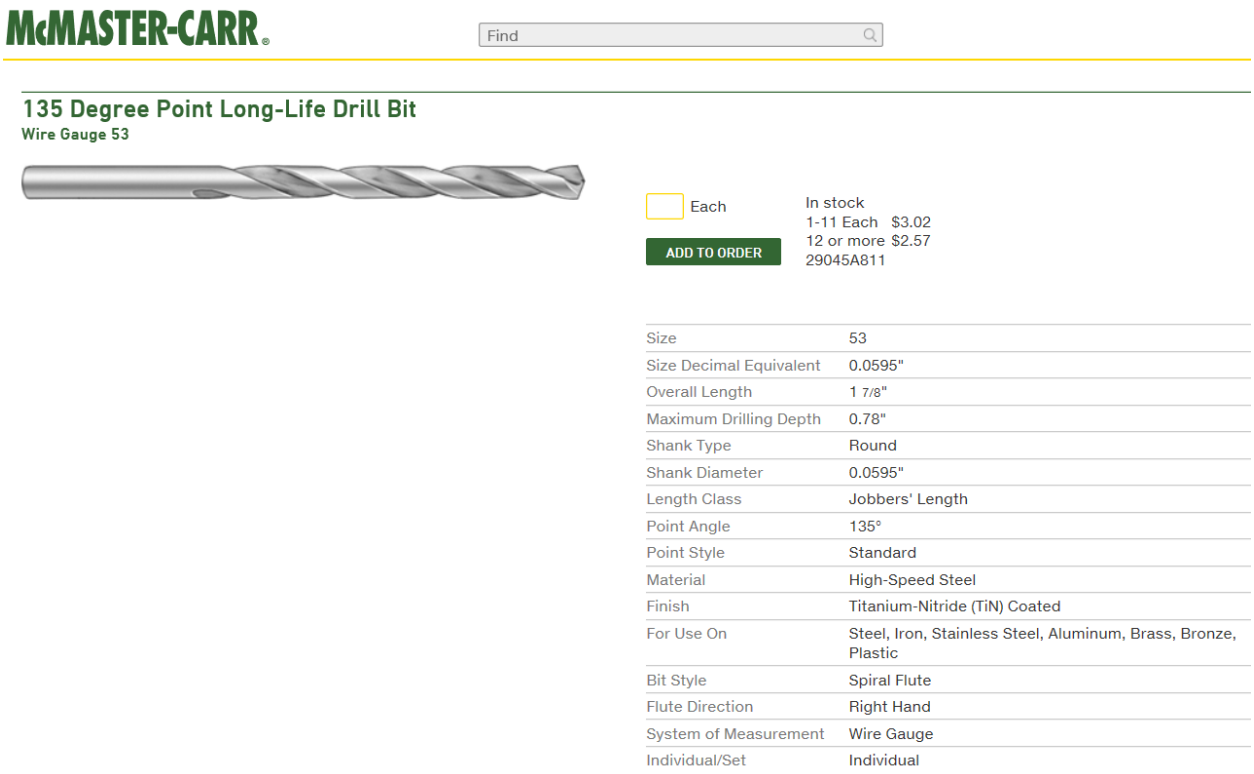


Figure L-44: 135 Degree Point Long-Life Drill Bit-Wire Gauge 53 (Mcmaster-carr)

L-6.12 Flush-Cut Bolt and Chain Cutter (Mcmaster-carr)

McMASTER-CARR

Find

Flush-Cut Bolt and Chain Cutter

for 3/8" Soft Steel and 5/16" Medium-Hard Steel Maximum Diameter





Each

In stock
$118.57 Each
3772A12

ADD TO ORDER

For Cutting	Bolts, Chain, Rods, Wire
For Use On	Soft Steel, Medium-Hard Steel
For Maximum Diameter	
Soft Steel	3/8"
Medium-Hard Steel	5/16"
For Maximum Hardness	
Soft Steel	Rockwell C15, Brinell 200
Medium-Hard Steel	Rockwell C31, Brinell 300
Overall Length	18"
Jaw Material	Steel
Handle Material	Steel
Grip Material	Rubber
Opening Style	Manual

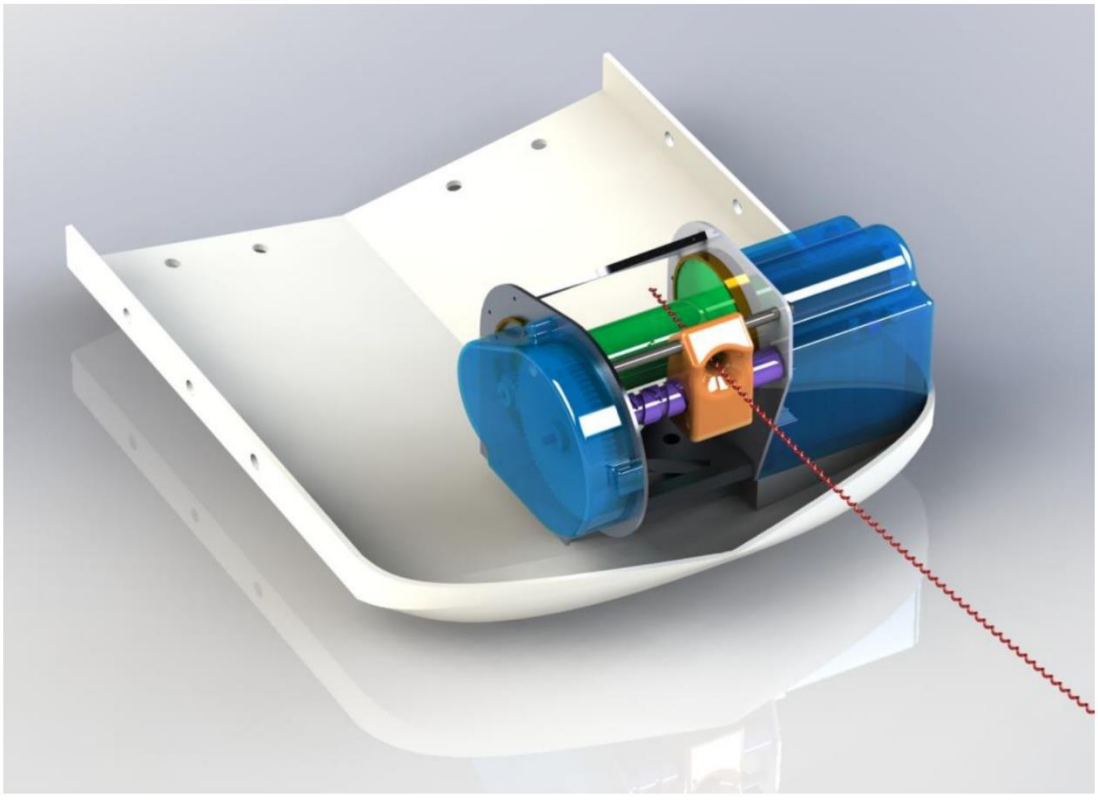
Blades are flat on one side for close-to-the-surface cuts. All cutters have an adjustment screw to align cutting edges. For more leverage, choose a cutter with a longer handle. Not for use on wire rope.

Figure L-45: Flush-Cut Bolt and Chain Cutter (Mcmaster-carr)

APPENDIX M: USER/OPERATOR MANUAL

Mech 328 TEAM 21

EQUIPMENT TOW: USER AND OPERATIONS MANUAL



MECH 328 TEAM 21

Updated: November 15, 2017

INTENDED USE

The intended use of the Equipment tow device is detailed as follows:

1. Remove backpack and secure backpack to the equipment tow sled using the provided bungee straps.
2. After securing the sled in the snow, grasp the free end of the Equipment Tow's rope and ascend while leaving the equipment tow behind.
3. Ensure that the toggle the switch mounted on the enclosure to operation mode.
4. Once finished ascending, or once the rope is no longer slack, tie off the free end of the winch to a nearby rigid structure or grip tightly and brace yourself.
5. Use the 'ON/OFF' button on 1Ch transmitter to operate the motor.
6. In order to charge the battery of equipment tow, toggle the switch mounted on the enclosure to charging mode. Then connect the charger to the 3-pin connector mounted on the outer face of the enclosure.

The Equipment Tow has been designed to last 5 years, under responsible use, for non-replaceable components. Should issues with quality be encountered, contact your retailer or manufacturers for service option details.

> **Disclaimer:**
>
> The Equipment Tow is not a fully developed product and has not yet been certified by relevant regulatory bodies. The content of this manual is subject to changes given further development and input from regulatory bodies. Therefore, no service plan has been developed for the equipment tow.

WARNINGS

In operating the Equipment Tow, be sure to obey the following safety recommendations:

- Ensure the Equipment Tow is loaded with less than 40 kg of equipment
- Do not store the device in areas of 30 degree Celsius or warmer
- The remote control's range may decrease with bad weather
- Ensure winch winding is free of debris before use and shows no visible signs of damage
- Do not use if winch rope shows signs of wear
- Do not attempt to use the Equipment Tow to raise people up hill. Do not ride the equipment tow.

Failure to follow the above safety warnings can result in a decreased lifetime of your Equipment Tow, severe damage to your device, or personal injury.

DISPOSABLE CONSIDERATIONS:

Once the life of the Equipment Tow has ended, the device should be properly disposed. This can be done by dividing the device into the four main categories listed below and returning them to the appropriate depots. Components are organized in their respective categories:

Metals

- Sled
- Flanged Sleeve Bearing
- Drum
- Drum Bushing
- Level Wind Shaft
- Cross
- Drum - Gear Extension
- Left Case
- Right Case
- Mounting Plate
- Left Support Plate
- Right Support Plate
- Light Duty Sleeve
- Linear Motion Shaft
- High Strength Locknut
- Head Screw
- 13 thread Socket Head Screw
- 3-48 thread socket screw
- 1-72 thread set screw
- Bearing
- Bearing Sleeve
- Metric 316 Key stock
- Wire

Plastics

- Bungee tie down straps
- Molded Spur Pinion
- Molded Spur Gear
- Level Wind Needle
- Level Wind Carriage - Body
- Level Wind Carriage - Cap
- Synthetic Rope

Electronics

- Battery Charger
- 3 pin connector
- Motor
- Remote control
- Buck Converter
- MOSFET
- XT60 Connector
- Resistor
- Toggle switch

Batteries (Lithium Ion)

- Batteries

APPENDIX N: PROJECT MANAGEMENT CHARTS

The team incorporated several project management charts throughout this project, all of which were regularly reviewed and updated; these included

- a Team Expectations Document ,
- a Gantt Chart,
- a Critical Path Method (CPM),
- a Work Breakout Structure (WBS) , and
- a Risk Register.

For all of the project management tools listed above, a description of revision history followed by the files, chronologically listed, is provided below.

N-1 Team Expectations

After initial introductions, the first topic of discussion was team expectations. Individuals shared expected levels of commitment, communication, responsibility, and initiative and, eventually, a consensus agreed on by all team members was reached. By allocating time at the beginning of the project (i.e., September 11, 2017) to reach a uniform level of understanding, no further iteration of the Team Expectations Document (N-1.1 Team Expectation: September 11, 2017, p.258) was required.

N-1.1 Team Expectation: September 11, 2017

Team Expectations

General Expectations

Communication

To what degree did this teammate communicate effectively and constructively with other team members, supervisors, and other stakeholders?

- Below Expectations
  - Falling off the face of the planet
  - Not replying to messages
- Met Expectations
  - Checking slack once every 12 hours
  - Picking up phone when called/emergency (or replying if not able to pick up)
  - Trying to have one day of the week for no communication (for now, Sunday) - may change as deadlines approach
  - Be open minded
  - Ask questions

Responsibility

To what degree did this teammate assume responsibility for their work and participate equitably in the project?

- Below Expectations
  -
- Met Expectations
  - Do what you say on time (unless with notice 24 hours)

Initiative

To what degree did this teammate exercise initiative and contribute to team goal-setting and goal achieving?

- Below Expectations
  - Avoiding tasks - doing the bare minimum
- Met Expectations
  - Equal distribution of tasks

Leadership

To what degree did this teammate demonstrate team leadership and/or accept the leadership of others?

- Below Expectations
  - View everyone as equal
  - Being passive aggressive (not directly communicating grievances)
- Met Expectations
  - Asking if there are tasks that need to be done if you have nothing to do
  - Constructive Criticism
  - Democracy-style voting

Meeting Participation

To what degree did this teammate demonstrate team leadership and/or accept the leadership of others?

- Below Expectations
  - Showing up late or being absent without notice or being very late (30 minutes) without notice
- Met Expectations
  - Show up or give notice (the night before)
  - If not possible to come in, telecommuting.

iPeer

Decide how your team will use iPeer. Is iPeer going to be your primary method for giving and receiving feedback? Are you going to discuss any team issues face- to- face before/after giving a critical evaluation on iPeer? What happens if one team member contributes very little to the project? What if one member goes does extra work?

- Sit down a couple of days before it's due and discuss
- Used as a last resort for expressing grievances
  - Always talk to people first

Time Commitment

Discuss your expectations for the amount of time you will invest as a team into the project. Decide as a team on the minimum and maximum number of hours (perhaps per day or per week) you expect to spend working on the project. Also discuss how you are going to make sure everyone has enough time for private studying (for RAP Quizzes and midterms).

- 8 hours minimum (set by instructor)
- Sundays are off limits until the end of the term (don't expect messages to be answered although they can be set)
- Saturday afternoons/evenings will be left for team meetings
- Ample communication ahead of time for meetings

Grade Expectations

Discuss your grade expectations for the project. Discuss as a team whether you share a target grade for the project elements (competition, report, and presentation).

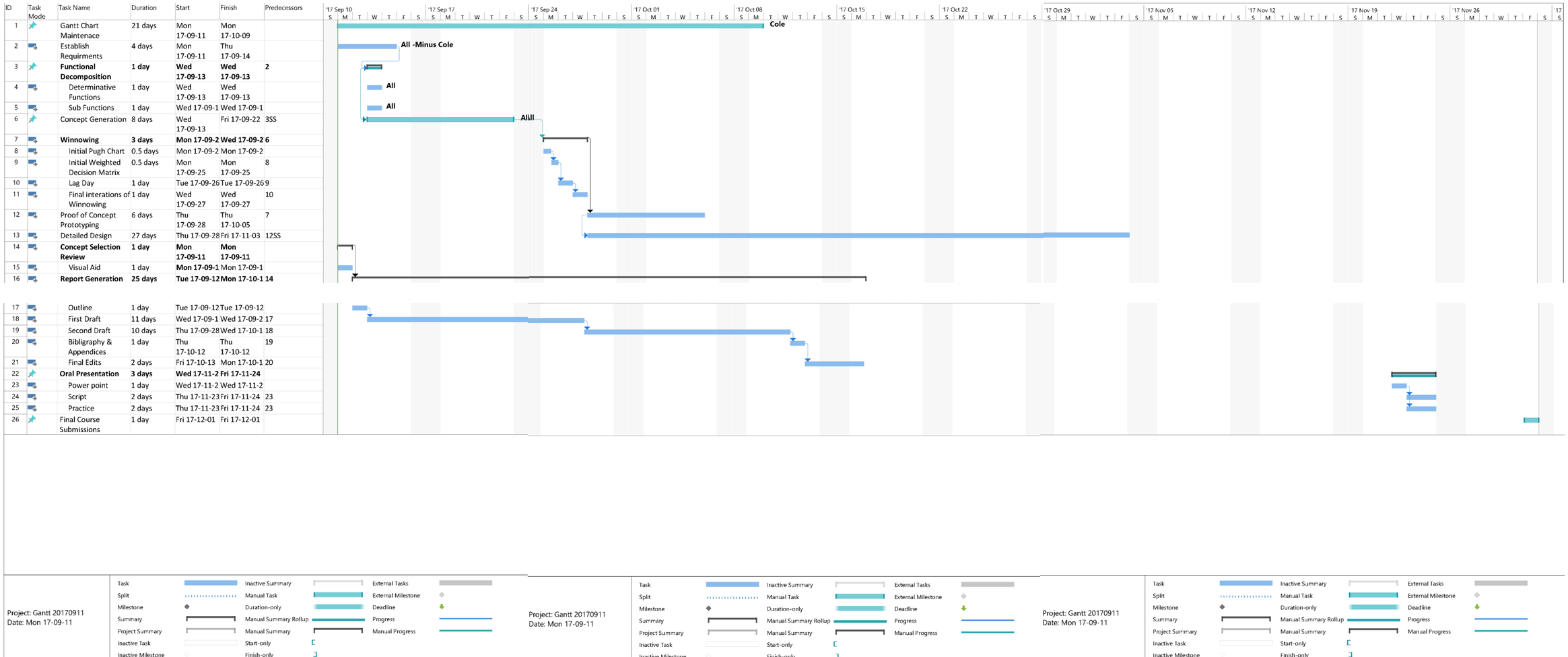
- 80+

N-2 Gantt Chart

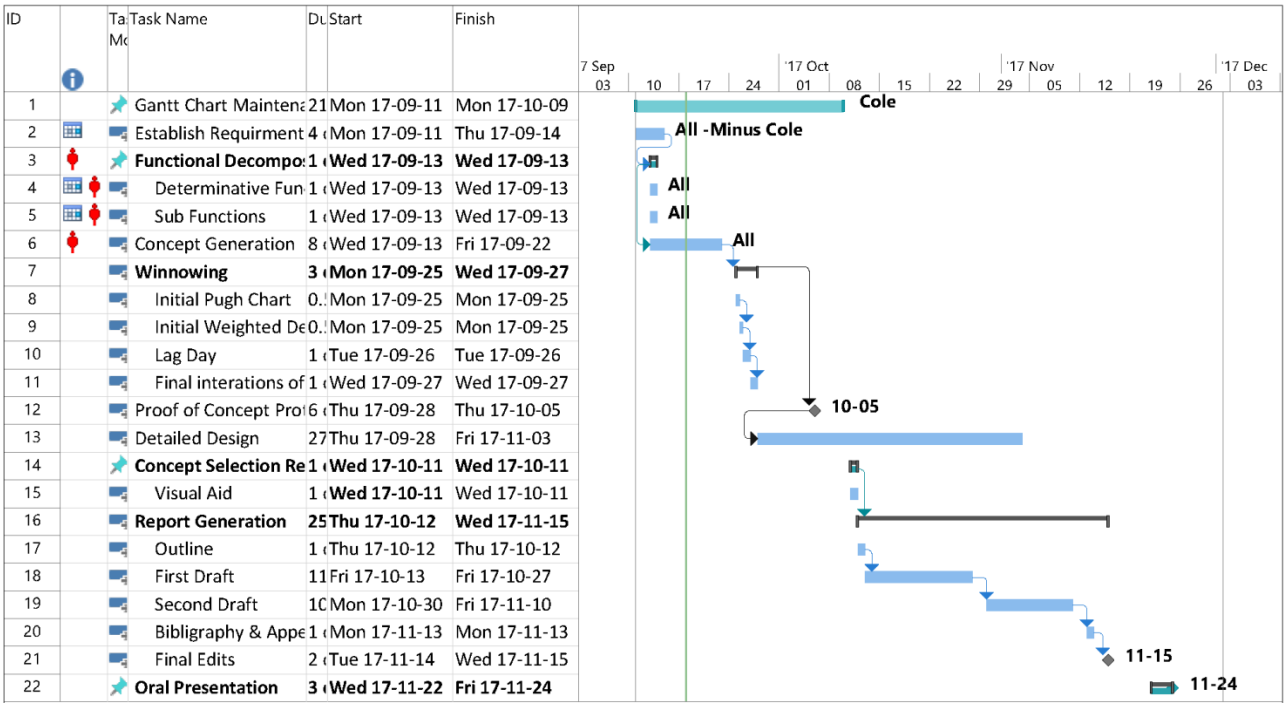
A Gantt Chart (created using Microsoft Project) was used as the team's primary scheduling tool. Important aspects on the chart include milestones (i.e., due dates for deliverables), midterms for other courses, and resource allocation. The revision history of the Gantt Chart below throughout the project highlights its iterative nature:

- N-2.1 Gantt Chart: September 11, 2017 (Original Copy)
  - The original copy of the Gantt Chart contains rough timeline estimates, few resource allocations, and, mainly, top level tasks.
- N-2.2 Gantt Chart: September 18, 2017
  - Minor changes made include date changes and the addition of milestone according to due dates for deliverables (e.g., the Formal Report).
- N-2.3 Gantt Chart: September 25, 2017
  - Minor changes made (e.g., dates) as the team progresses through concept selection.
- N-2.4 Gantt Chart: October 2, 2017
  - Minor changes made (e.g., dates) as the team progresses through concept selection.
- N-2.5 Gantt Chart: October 8, 2017
  - A more thorough breakdown of tasks is included in the Gantt Chart as the team begins to narrow down four possible concepts for further analyses. Additionally, midterm dates for all team members are added to the chart.
- N-2.6 Gantt Chart: October 16, 2017
  - Several sub-tasks are added to the "Further Research for Evaluation" task.
- N-2.7 Gantt Chart: October 22, 2017
  - Several sub-tasks are added to the "Further Research for Evaluation" task.
- N-2.8 Gantt Chart: October 30, 2017
  - "Thermal Analysis" added to the "Further Research for Evaluation" task.
- N-2.9 Gantt Chart: November 6, 2017 (Final Revision)
  - The final revision of the Gantt Chart included minor changes (e.g., dates) as the team progresses through the formal report; otherwise, the chart remained constant for the remainder of the project.

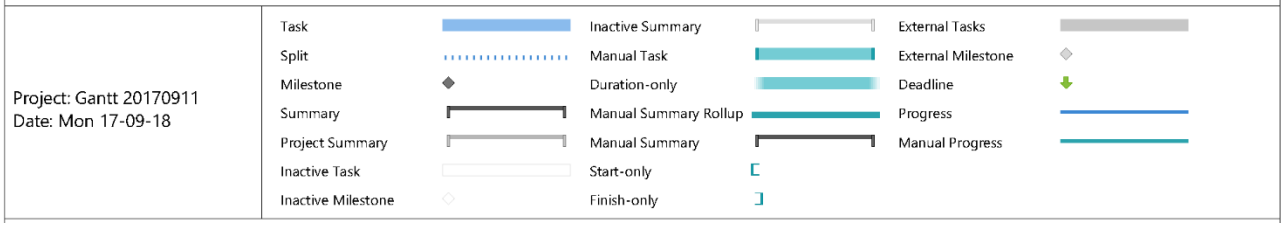
N-2.1 Gantt Chart: September 11, 2017 (Original Copy)



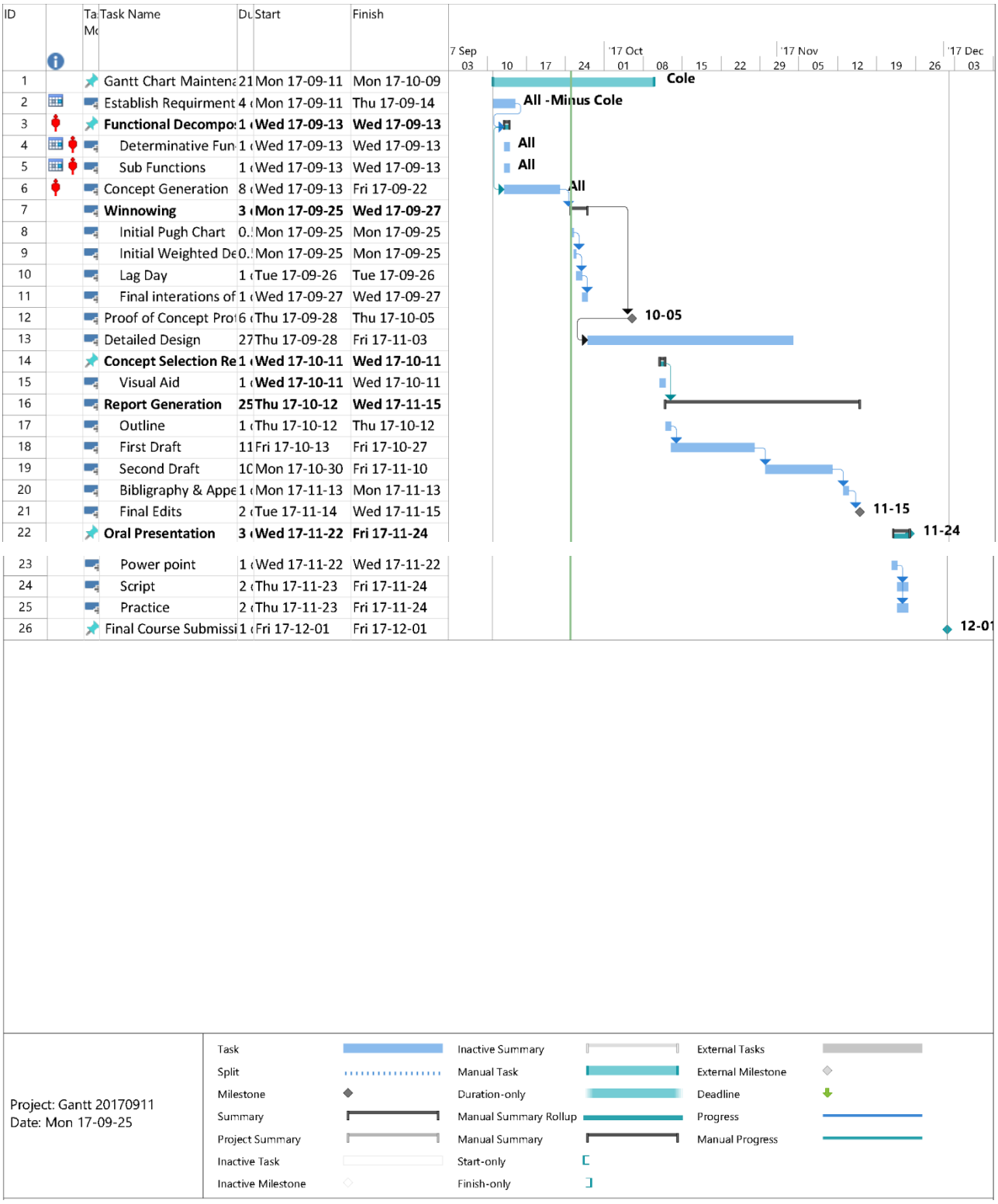
N-2.2 Gantt Chart: September 18, 2017



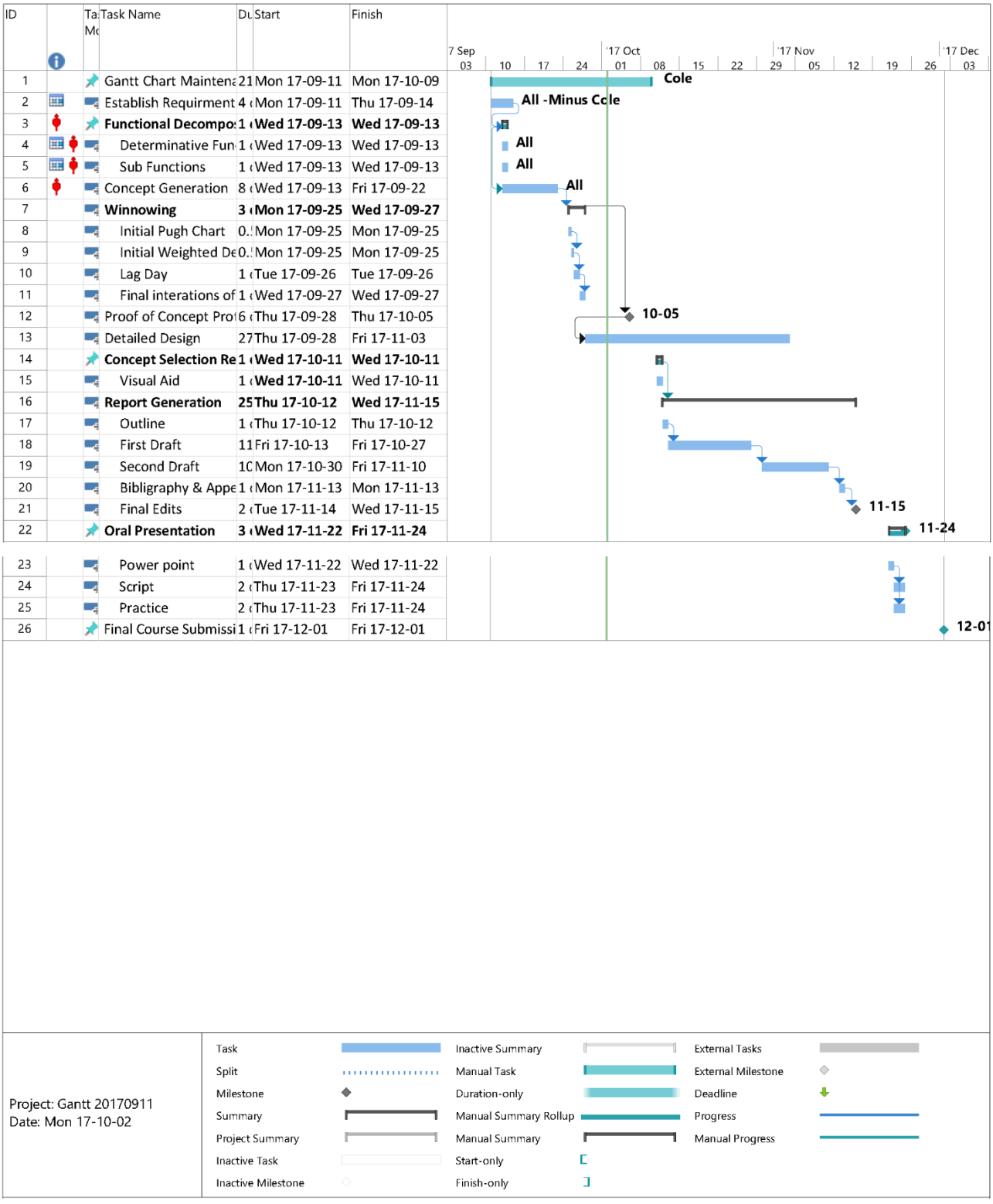




N-2.3 Gantt Chart: September 25, 2017

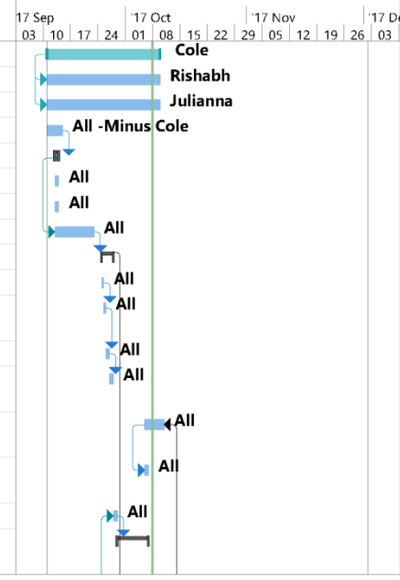


N-2.4 Gantt Chart: October 2, 2017



N-2.5 Gantt Chart: October 8, 2017

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Gantt Chart Maintenace	21 days	Mon 17-09-11	Mon 17-10-09	
2		CPM Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
3		WBS Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
4		Establish Requirments	4 days	Mon 17-09-11	Thu 17-09-14	
5		**Functional Decomposition**	**1 day**	**Wed 17-09-13**	**Wed 17-09-13**	**4**
6		Determinative Functions	1 day	Wed 17-09-13	Wed 17-09-13	
7		Sub Functions	1 day	Wed 17-09-13	Wed 17-09-13	
8		Concept Generation	8 days	Wed 17-09-13	Fri 17-09-22	5SS
9		**Winnowing**	**3 days**	**Mon 17-09-25**	**Wed 17-09-27**	**8**
10		Initial Pugh Chart	0.5 days	Mon 17-09-25	Mon 17-09-25	
11		Initial Weighted Decision Matrix	0.5 days	Mon 17-09-25	Mon 17-09-25	10
12		Lag Day	1 day	Tue 17-09-26	Tue 17-09-26	11
13		Final interations of Winnowing	1 day	Wed 17-09-27	Wed 17-09-27	12
14		Final Concept Selection WDM	3 days	Fri 17-10-06	Tue 17-10-10	21SF
15		Determine Weights of Criteria	1 day	Fri 17-10-06	Fri 17-10-06	14SS
16		Identify Stakeholders	1 day	Thu 17-09-28	Thu 17-09-28	20SS
17		**Stakeholder Analysis/Prioritizing**	**6 days**	**Fri 17-09-29**	**Fri 17-10-06**	**16**
18		Review Needs and stakeholder correlations	4 days	Fri 17-09-29	Wed 17-10-04	
19		Identify Out of Scope Needs	2 days	Thu 17-10-05	Fri 17-10-06	18
20		**Detailed Design**	**27 days**	**Thu 17-09-28**	**Fri 17-11-03**	**9**
21		**Focused Research For Evaluation**	**7 days**	**Thu 17-09-28**	**Fri 17-10-06**	
22		"Equipment Tow"	7 days	Thu 17-09-28	Fri 17-10-06	
23		"Ski Teeth"	7 days	Thu 17-09-28	Fri 17-10-06	
24		"Ski Hook Poles"	7 days	Thu 17-09-28	Fri 17-10-06	
25		"Snow Packer"	7 days	Thu 17-09-28	Fri 17-10-06	
26		Further Research	17 days	Mon 17-10-09	Tue 17-10-31	21
27		Simulation/Prototyping/Ana	17 days	Mon 17-10-09	Tue 17-10-31	21
28		CAD Representation	3 days	Wed 17-11-01	Fri 17-11-03	27
29		**Concept Selection Review**	**1 day**	**Wed 17-10-11**	**Wed 17-10-11**	
30		Visual Aid	1 day	**Wed 17-10-11**	Wed 17-10-11	
31		**Report Generation**	**25 days**	**Thu 17-10-12**	**Wed 17-11-15**	**29**
32		Outline	1 day	Thu 17-10-12	Thu 17-10-12	
33		First Draft	11 days	Fri 17-10-13	Fri 17-10-27	32
34		Second Draft	10 days	Mon 17-10-30	Fri 17-11-10	33
35		Bibliography & Appendices	1 day	Mon 17-11-13	Mon 17-11-13	34
36		Final Edits	2 days	Tue 17-11-14	Wed 17-11-15	35
37		**Oral Presentation**	**3 days**	**Wed 17-11-22**	**Fri 17-11-24**	
38		Power point	1 day	Wed 17-11-22	Wed 17-11-22	
39		Script	2 days	Thu 17-11-23	Fri 17-11-24	38
40		Practice	2 days	Thu 17-11-23	Fri 17-11-24	38
41		Final Course Submissions	1 day	Fri 17-12-01	Fri 17-12-01	
42		**MIDTERMS - Potential Lag days**	**27 days**	**Thu 17-10-05**	**Fri 17-11-10**	
43		MECH 327 MT1	2 days	Thu 17-10-05	Fri 17-10-06	
44		MECH 325 MT1	2 days	Mon 17-10-23	Tue 17-10-24	
45		MECH 326 MT1	1 day	Mon 17-10-30	Mon 17-10-30	
46		MECH 392 MT1	2 days	Tue 17-10-31	Wed 17-11-01	
47		MECH 327 MT2	2 days	Thu 17-11-09	Fri 17-11-10	
48		MECH 360 MT1	2 days	Wed 17-10-11	Thu 17-10-12	
49		MECH 368 MT1	2 days	Thu 17-10-19	Fri 17-10-20	
50		MECH 386 MT1	1 day	Tue 17-10-10	Tue 17-10-10	

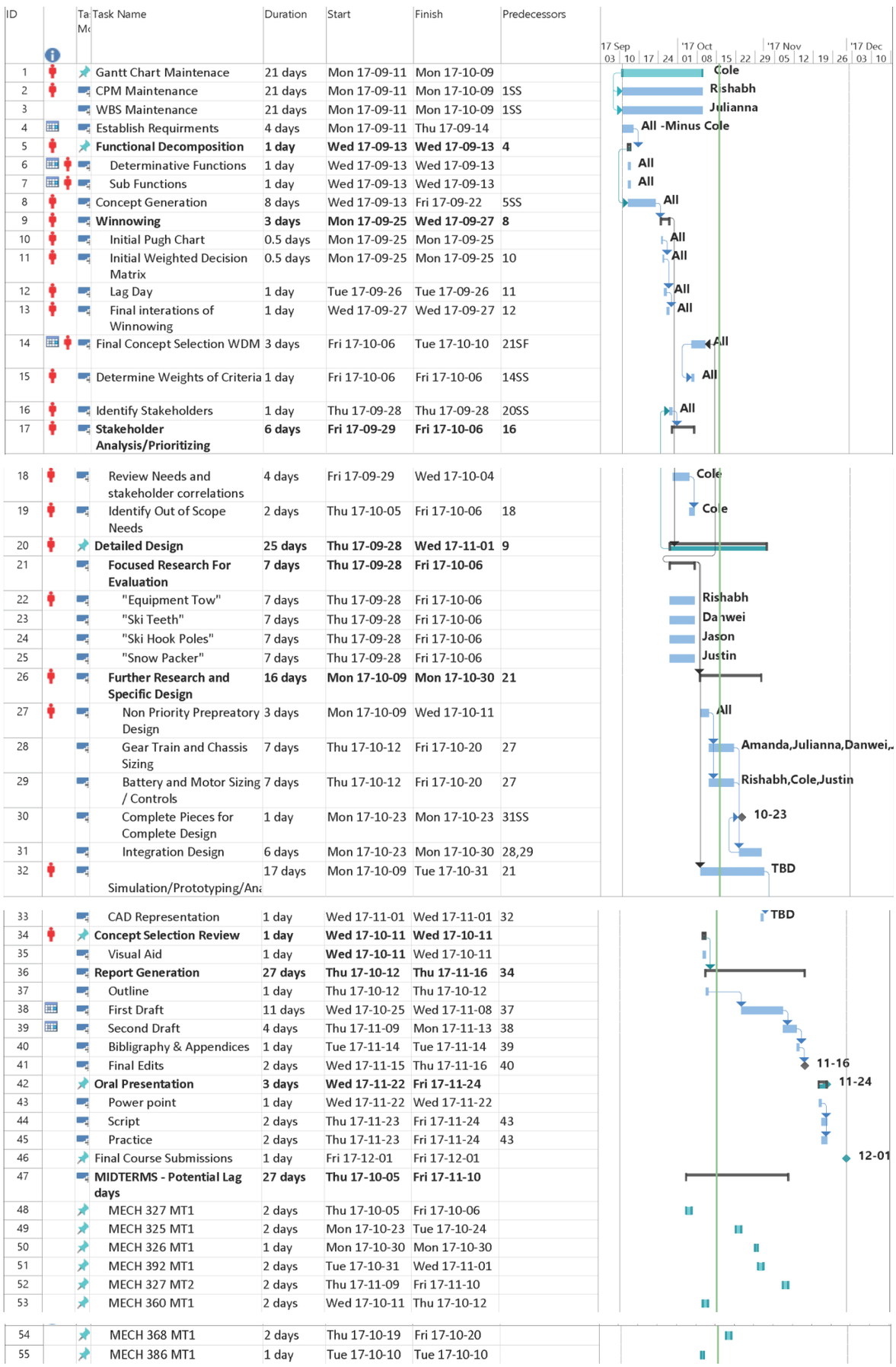


Project: Gantt 20170911
Date: Sun 17-10-08

Task	Inactive Summary	External Tasks	
Split	Manual Task	External Milestone	
Milestone	Duration-only	Deadline	
Summary	Manual Summary Rollup	Progress	
Project Summary	Manual Summary	Manual Progress	
Inactive Task	Start-only		
Inactive Milestone	Finish-only		

N-2.6 Gantt Chart: October 16, 2017

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Gantt Chart Maintenace	21 days	Mon 17-09-11	Mon 17-10-09	
2		CPM Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
3		WBS Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
4		Establish Requirments	4 days	Mon 17-09-11	Thu 17-09-14	
5		**Functional Decomposition**	**1 day**	**Wed 17-09-13**	**Wed 17-09-13**	**4**
6		Determinative Functions	1 day	Wed 17-09-13	Wed 17-09-13	
7		Sub Functions	1 day	Wed 17-09-13	Wed 17-09-13	
8		Concept Generation	8 days	Wed 17-09-13	Fri 17-09-22	5SS
9		**Winnowing**	**3 days**	**Mon 17-09-25**	**Wed 17-09-27**	**8**
10		Initial Pugh Chart	0.5 days	Mon 17-09-25	Mon 17-09-25	
11		Initial Weighted Decision Matrix	0.5 days	Mon 17-09-25	Mon 17-09-25	10
12		Lag Day	1 day	Tue 17-09-26	Tue 17-09-26	11
13		Final interations of Winnowing	1 day	Wed 17-09-27	Wed 17-09-27	12
14		Final Concept Selection WDM	3 days	Fri 17-10-06	Tue 17-10-10	21SF
15		Determine Weights of Criteria	1 day	Fri 17-10-06	Fri 17-10-06	14SS
16		Identify Stakeholders	1 day	Thu 17-09-28	Thu 17-09-28	20SS
17		**Stakeholder Analysis/Prioritizing**	**6 days**	**Fri 17-09-29**	**Fri 17-10-06**	**16**
18		Review Needs and stakeholder correlations	4 days	Fri 17-09-29	Wed 17-10-04	
19		Identify Out of Scope Needs	2 days	Thu 17-10-05	Fri 17-10-06	18
20		**Detailed Design**	**25 days**	**Thu 17-09-28**	**Wed 17-11-01**	**9**
21		**Focused Research For Evaluation**	**7 days**	**Thu 17-09-28**	**Fri 17-10-06**	
22		"Equipment Tow"	7 days	Thu 17-09-28	Fri 17-10-06	
23		"Ski Teeth"	7 days	Thu 17-09-28	Fri 17-10-06	
24		"Ski Hook Poles"	7 days	Thu 17-09-28	Fri 17-10-06	
25		"Snow Packer"	7 days	Thu 17-09-28	Fri 17-10-06	
26		**Further Research and Specific Design**	**16 days**	**Mon 17-10-09**	**Mon 17-10-30**	**21**
27		Non Priority Prepreatory Design	3 days	Mon 17-10-09	Wed 17-10-11	
28		Gear Train and Chassis Sizing	7 days	Thu 17-10-12	Fri 17-10-20	27
29		Battery and Motor Sizing / Controls	7 days	Thu 17-10-12	Fri 17-10-20	27
30		Complete Pieces for Complete Design	1 day	Mon 17-10-23	Mon 17-10-23	31SS
31		Integration Design	6 days	Mon 17-10-23	Mon 17-10-30	28,29
32		Simulation/Prototyping/Ana	17 days	Mon 17-10-09	Tue 17-10-31	21
33		CAD Representation	1 day	Wed 17-11-01	Wed 17-11-01	32
34		**Concept Selection Review**	**1 day**	**Wed 17-10-11**	**Wed 17-10-11**	
35		Visual Aid	1 day	**Wed 17-10-11**	Wed 17-10-11	
36		**Report Generation**	**27 days**	**Thu 17-10-12**	**Thu 17-11-16**	**34**
37		Outline	1 day	Thu 17-10-12	Thu 17-10-12	
38		First Draft	11 days	Wed 17-10-25	Wed 17-11-08	37
39		Second Draft	4 days	Thu 17-11-09	Mon 17-11-13	38
40		Bibligraphy & Appendices	1 day	Tue 17-11-14	Tue 17-11-14	39
41		Final Edits	2 days	Wed 17-11-15	Thu 17-11-16	40
42		**Oral Presentation**	**3 days**	**Wed 17-11-22**	**Fri 17-11-24**	
43		Power point	1 day	Wed 17-11-22	Wed 17-11-22	
44		Script	2 days	Thu 17-11-23	Fri 17-11-24	43
45		Practice	2 days	Thu 17-11-23	Fri 17-11-24	43
46		Final Course Submissions	1 day	Fri 17-12-01	Fri 17-12-01	
47		**MIDTERMS - Potential Lag days**	**27 days**	**Thu 17-10-05**	**Fri 17-11-10**	
48		MECH 327 MT1	2 days	Thu 17-10-05	Fri 17-10-06	
49		MECH 325 MT1	2 days	Mon 17-10-23	Tue 17-10-24	
50		MECH 326 MT1	1 day	Mon 17-10-30	Mon 17-10-30	
51		MECH 392 MT1	2 days	Tue 17-10-31	Wed 17-11-01	
52		MECH 327 MT2	2 days	Thu 17-11-09	Fri 17-11-10	
53		MECH 360 MT1	2 days	Wed 17-10-11	Thu 17-10-12	
54		MECH 368 MT1	2 days	Thu 17-10-19	Fri 17-10-20	
55		MECH 386 MT1	1 day	Tue 17-10-10	Tue 17-10-10	

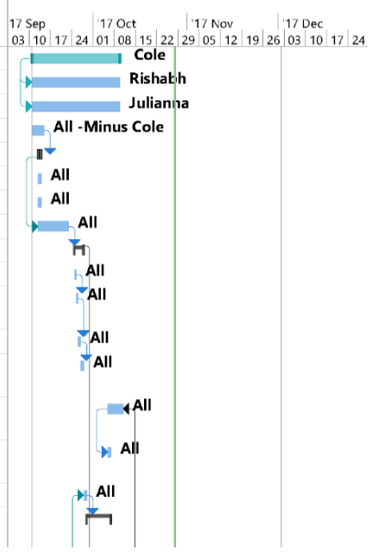


Project: Gantt 20170911
Date: Mon 17-10-16

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			

N-2.7 Gantt Chart: October 22, 2017

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Gantt Chart Maintenace	21 days	Mon 17-09-11	Mon 17-10-09	
2		CPM Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
3		WBS Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
4		Establish Requirments	4 days	Mon 17-09-11	Thu 17-09-14	
5		**Functional Decomposition**	**1 day**	**Wed 17-09-13**	**Wed 17-09-13**	**4**
6		Determinative Functions	1 day	Wed 17-09-13	Wed 17-09-13	
7		Sub Functions	1 day	Wed 17-09-13	Wed 17-09-13	
8		Concept Generation	8 days	Wed 17-09-13	Fri 17-09-22	5SS
9		**Winnowing**	**3 days**	**Mon 17-09-25**	**Wed 17-09-27**	**8**
10		Initial Pugh Chart	0.5 days	Mon 17-09-25	Mon 17-09-25	
11		Initial Weighted Decision Matrix	0.5 days	Mon 17-09-25	Mon 17-09-25	10
12		Lag Day	1 day	Tue 17-09-26	Tue 17-09-26	11
13		Final interations of Winnowing	1 day	Wed 17-09-27	Wed 17-09-27	12
14		Final Concept Selection WDM	3 days	Fri 17-10-06	Tue 17-10-10	21SF
15		Determine Weights of Criteria	1 day	Fri 17-10-06	Fri 17-10-06	14SS
16		Identify Stakeholders	1 day	Thu 17-09-28	Thu 17-09-28	20SS
17		**Stakeholder Analysis/Prioritizing**	**6 days**	**Fri 17-09-29**	**Fri 17-10-06**	**16**
18		Review Needs and stakeholder correlations	4 days	Fri 17-09-29	Wed 17-10-04	
19		Identify Out of Scope Needs	2 days	Thu 17-10-05	Fri 17-10-06	18
20		**Detailed Design**	**25 days**	**Thu 17-09-28**	**Wed 17-11-01**	**9**
21		**Focused Research For Evaluation**	**7 days**	**Thu 17-09-28**	**Fri 17-10-06**	
22		"Equipment Tow"	7 days	Thu 17-09-28	Fri 17-10-06	
23		"Ski Teeth"	7 days	Thu 17-09-28	Fri 17-10-06	
24		"Ski Hook Poles"	7 days	Thu 17-09-28	Fri 17-10-06	
25		"Snow Packer"	7 days	Thu 17-09-28	Fri 17-10-06	
26		**Further Research and Specific Design**	**17 days**	**Mon 17-10-09**	**Tue 17-10-31**	**21**
27		Non Priority Prepreatory Design	3 days	Mon 17-10-09	Wed 17-10-11	
28		Gear Train and Chassis Sizing	7 days	Thu 17-10-12	Fri 17-10-20	27
29		Battery and Motor Sizing / Controls	7 days	Thu 17-10-12	Fri 17-10-20	27
30		Sled	7 days	Thu 17-10-12	Fri 17-10-20	27
31		Complete Pieces for Complete Design	1 day	Mon 17-10-23	Mon 17-10-23	33SS
32		Mid Design FMEA	6 days	Mon 17-10-23	Mon 17-10-30	28,29
33		Integration Design	7 days	Mon 17-10-23	Tue 17-10-31	28,29
34		Simulation/Prototyping/Ana	17 days	Mon 17-10-09	Tue 17-10-31	21
35		Integrated Design FMEA	2 days	Wed 17-11-01	Thu 17-11-02	33
36		CAD Representation	1 day	Wed 17-11-01	Wed 17-11-01	34
37		**Concept Selection Review**	**1 day**	**Wed 17-10-11**	**Wed 17-10-11**	
38		Visual Aid	1 day	**Wed 17-10-11**	Wed 17-10-11	
39		**Report Generation**	**27 days**	**Thu 17-10-12**	**Thu 17-11-16**	**37**
40		Outline	1 day	Thu 17-10-12	Thu 17-10-12	
41		First Draft	11 days	Wed 17-10-25	Wed 17-11-08	40
42		Second Draft	4 days	Thu 17-11-09	Mon 17-11-13	41
43		Bibligraphy & Appendices	1 day	Tue 17-11-14	Tue 17-11-14	42
44		Final Edits	2 days	Wed 17-11-15	Thu 17-11-16	43
45		**Oral Presentation**	**3 days**	**Wed 17-11-22**	**Fri 17-11-24**	
46		Power point	1 day	Wed 17-11-22	Wed 17-11-22	
47		Script	2 days	Thu 17-11-23	Fri 17-11-24	46
48		Practice	2 days	Thu 17-11-23	Fri 17-11-24	46
49		Final Course Submissions	1 day	Fri 17-12-01	Fri 17-12-01	
50		**MIDTERMS - Potential Lag days**	**27 days**	**Thu 17-10-05**	**Fri 17-11-10**	
51		MECH 327 MT1	2 days	Thu 17-10-05	Fri 17-10-06	
52		MECH 325 MT1	2 days	Mon 17-10-23	Tue 17-10-24	
53		MECH 326 MT1	1 day	Mon 17-10-30	Mon 17-10-30	
54		MECH 392 MT1	2 days	Tue 17-10-31	Wed 17-11-01	
55		MECH 327 MT2	2 days	Thu 17-11-09	Fri 17-11-10	
56		MECH 360 MT1	2 days	Wed 17-10-11	Thu 17-10-12	
57		MECH 368 MT1	2 days	Thu 17-10-19	Fri 17-10-20	
58		MECH 386 MT1	1 day	Tue 17-10-10	Tue 17-10-10	

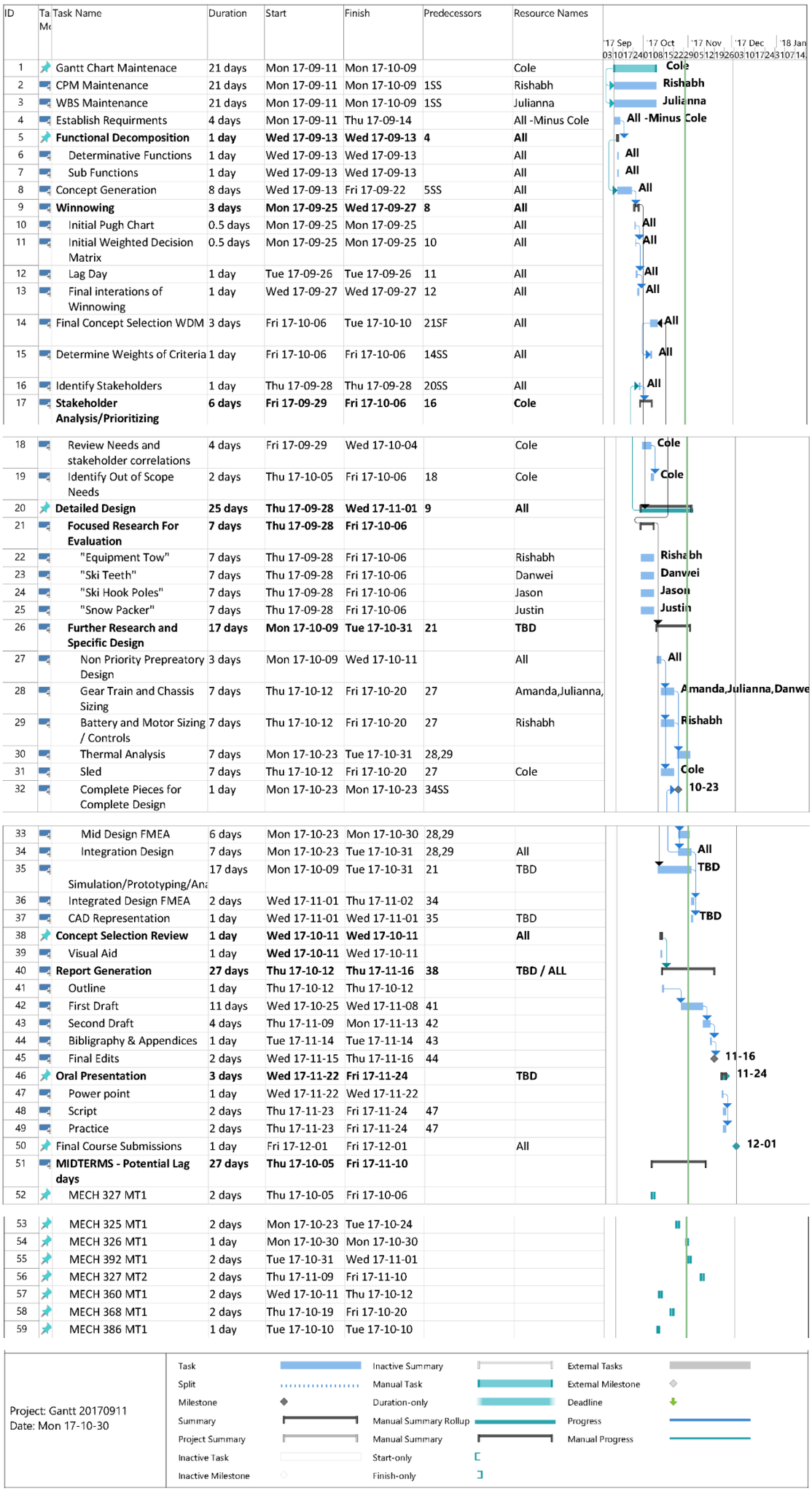


Project: Gantt 20170911
Date: Sat 17-10-28

Task	Inactive Summary	External Tasks	
Split	Manual Task	External Milestone	
Milestone	Duration-only	Deadline	
Summary	Manual Summary Rollup	Progress	
Project Summary	Manual Summary	Manual Progress	
Inactive Task	Start-only		
Inactive Milestone	Finish-only		

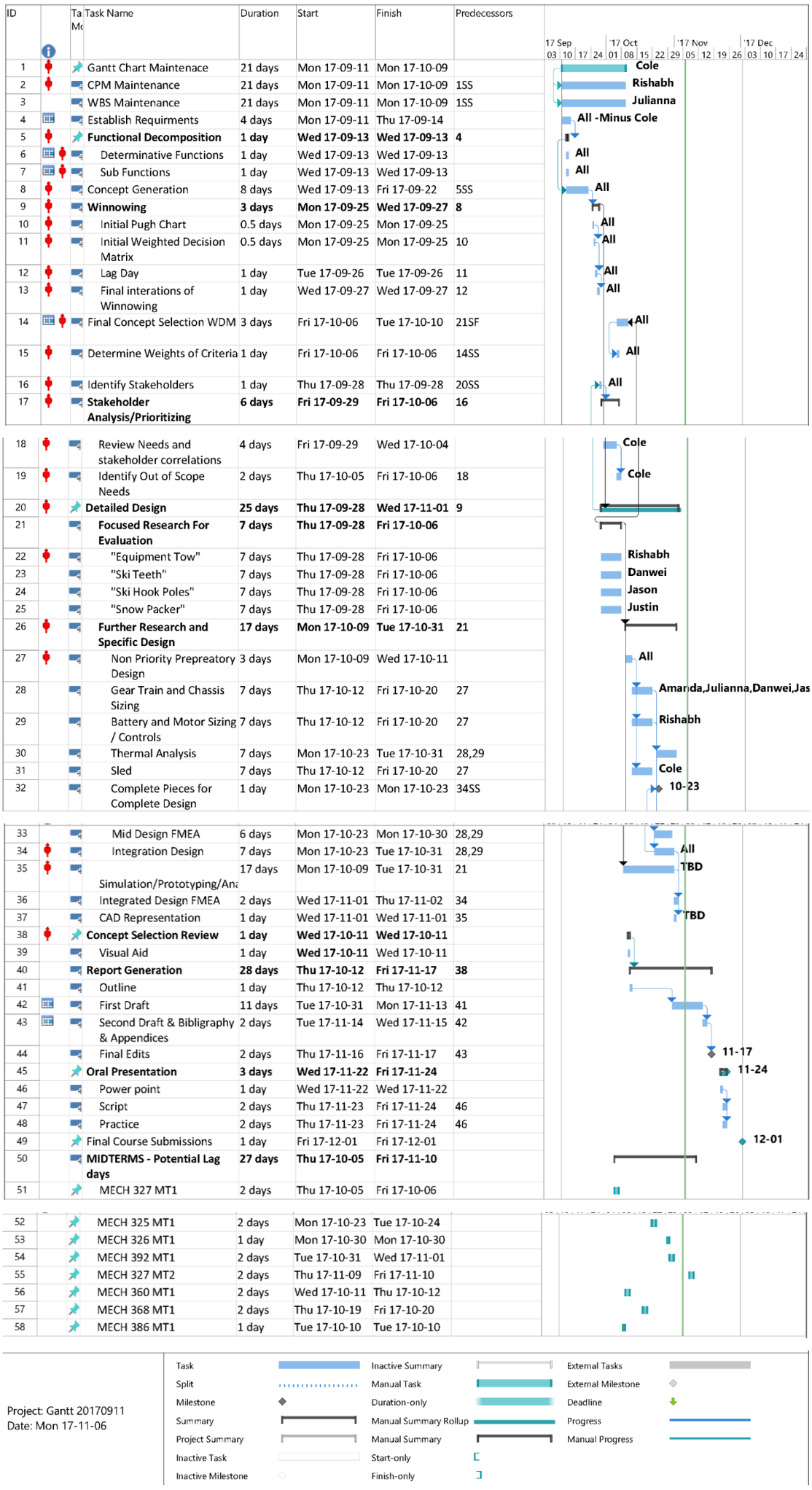
N-2.8 Gantt Chart: October 30, 2017

ID	Ta Mc	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		Gantt Chart Maintenace	21 days	Mon 17-09-11	Mon 17-10-09		Cole
2		CPM Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS	Rishabh
3		WBS Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS	Julianna
4		Establish Requirments	4 days	Mon 17-09-11	Thu 17-09-14		All -Minus Cole
5		**Functional Decomposition**	**1 day**	**Wed 17-09-13**	**Wed 17-09-13**	**4**	**All**
6		Determinative Functions	1 day	Wed 17-09-13	Wed 17-09-13		All
7		Sub Functions	1 day	Wed 17-09-13	Wed 17-09-13		All
8		Concept Generation	8 days	Wed 17-09-13	Fri 17-09-22	5SS	All
9		**Winnowing**	**3 days**	**Mon 17-09-25**	**Wed 17-09-27**	**8**	**All**
10		Initial Pugh Chart	0.5 days	Mon 17-09-25	Mon 17-09-25		All
11		Initial Weighted Decision Matrix	0.5 days	Mon 17-09-25	Mon 17-09-25	10	All
12		Lag Day	1 day	Tue 17-09-26	Tue 17-09-26	11	All
13		Final interations of Winnowing	1 day	Wed 17-09-27	Wed 17-09-27	12	All
14		Final Concept Selection WDM	3 days	Fri 17-10-06	Tue 17-10-10	21SF	All
15		Determine Weights of Criteria	1 day	Fri 17-10-06	Fri 17-10-06	14SS	All
16		Identify Stakeholders	1 day	Thu 17-09-28	Thu 17-09-28	20SS	All
17		**Stakeholder Analysis/Prioritizing**	**6 days**	**Fri 17-09-29**	**Fri 17-10-06**	**16**	**Cole**
18		Review Needs and stakeholder correlations	4 days	Fri 17-09-29	Wed 17-10-04		Cole
19		Identify Out of Scope Needs	2 days	Thu 17-10-05	Fri 17-10-06	18	Cole
20		**Detailed Design**	**25 days**	**Thu 17-09-28**	**Wed 17-11-01**	**9**	**All**
21		**Focused Research For Evaluation**	**7 days**	**Thu 17-09-28**	**Fri 17-10-06**		
22		"Equipment Tow"	7 days	Thu 17-09-28	Fri 17-10-06		Rishabh
23		"Ski Teeth"	7 days	Thu 17-09-28	Fri 17-10-06		Danwei
24		"Ski Hook Poles"	7 days	Thu 17-09-28	Fri 17-10-06		Jason
25		"Snow Packer"	7 days	Thu 17-09-28	Fri 17-10-06		Justin
26		**Further Research and Specific Design**	**17 days**	**Mon 17-10-09**	**Tue 17-10-31**	**21**	**TBD**
27		Non Priority Prepreatory Design	3 days	Mon 17-10-09	Wed 17-10-11		All
28		Gear Train and Chassis Sizing	7 days	Thu 17-10-12	Fri 17-10-20	27	Amanda,Julianna,
29		Battery and Motor Sizing / Controls	7 days	Thu 17-10-12	Fri 17-10-20	27	Rishabh
30		Thermal Analysis	7 days	Mon 17-10-23	Tue 17-10-31	28,29	
31		Sled	7 days	Thu 17-10-12	Fri 17-10-20	27	Cole
32		Complete Pieces for Complete Design	1 day	Mon 17-10-23	Mon 17-10-23	34SS	
33		Mid Design FMEA	6 days	Mon 17-10-23	Mon 17-10-30	28,29	
34		Integration Design	7 days	Mon 17-10-23	Tue 17-10-31	28,29	All
35		Simulation/Prototyping/Ana	17 days	Mon 17-10-09	Tue 17-10-31	21	TBD
36		Integrated Design FMEA	2 days	Wed 17-11-01	Thu 17-11-02	34	
37		CAD Representation	1 day	Wed 17-11-01	Wed 17-11-01	35	TBD
38		**Concept Selection Review**	**1 day**	**Wed 17-10-11**	**Wed 17-10-11**		**All**
39		Visual Aid	1 day	**Wed 17-10-11**	Wed 17-10-11		
40		**Report Generation**	**27 days**	**Thu 17-10-12**	**Thu 17-11-16**	**38**	**TBD / ALL**
41		Outline	1 day	Thu 17-10-12	Thu 17-10-12		
42		First Draft	11 days	Wed 17-10-25	Wed 17-11-08	41	
43		Second Draft	4 days	Thu 17-11-09	Mon 17-11-13	42	
44		Bibligraphy & Appendices	1 day	Tue 17-11-14	Tue 17-11-14	43	
45		Final Edits	2 days	Wed 17-11-15	Thu 17-11-16	44	
46		**Oral Presentation**	**3 days**	**Wed 17-11-22**	**Fri 17-11-24**		**TBD**
47		Power point	1 day	Wed 17-11-22	Wed 17-11-22		
48		Script	2 days	Thu 17-11-23	Fri 17-11-24	47	
49		Practice	2 days	Thu 17-11-23	Fri 17-11-24	47	
50		Final Course Submissions	1 day	Fri 17-12-01	Fri 17-12-01		All
51		**MIDTERMS - Potential Lag days**	**27 days**	**Thu 17-10-05**	**Fri 17-11-10**		
52		MECH 327 MT1	2 days	Thu 17-10-05	Fri 17-10-06		
53		MECH 325 MT1	2 days	Mon 17-10-23	Tue 17-10-24		
54		MECH 326 MT1	1 day	Mon 17-10-30	Mon 17-10-30		
55		MECH 392 MT1	2 days	Tue 17-10-31	Wed 17-11-01		
56		MECH 327 MT2	2 days	Thu 17-11-09	Fri 17-11-10		
57		MECH 360 MT1	2 days	Wed 17-10-11	Thu 17-10-12		
58		MECH 368 MT1	2 days	Thu 17-10-19	Fri 17-10-20		
59		MECH 386 MT1	1 day	Tue 17-10-10	Tue 17-10-10		



N-2.9 Gantt Chart: November 6, 2017 (Final Revision)

ID	Task Name	Duration	Start	Finish	Predecessors
1	Gantt Chart Maintenace	21 days	Mon 17-09-11	Mon 17-10-09	
2	CPM Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
3	WBS Maintenance	21 days	Mon 17-09-11	Mon 17-10-09	1SS
4	Establish Requirments	4 days	Mon 17-09-11	Thu 17-09-14	
5	**Functional Decomposition**	**1 day**	**Wed 17-09-13**	**Wed 17-09-13**	**4**
6	Determinative Functions	1 day	Wed 17-09-13	Wed 17-09-13	
7	Sub Functions	1 day	Wed 17-09-13	Wed 17-09-13	
8	Concept Generation	8 days	Wed 17-09-13	Fri 17-09-22	5SS
9	**Winnowing**	**3 days**	**Mon 17-09-25**	**Wed 17-09-27**	**8**
10	Initial Pugh Chart	0.5 days	Mon 17-09-25	Mon 17-09-25	
11	Initial Weighted Decision Matrix	0.5 days	Mon 17-09-25	Mon 17-09-25	10
12	Lag Day	1 day	Tue 17-09-26	Tue 17-09-26	11
13	Final interations of Winnowing	1 day	Wed 17-09-27	Wed 17-09-27	12
14	Final Concept Selection WDM	3 days	Fri 17-10-06	Tue 17-10-10	21SF
15	Determine Weights of Criteria	1 day	Fri 17-10-06	Fri 17-10-06	14SS
16	Identify Stakeholders	1 day	Thu 17-09-28	Thu 17-09-28	20SS
17	**Stakeholder Analysis/Prioritizing**	**6 days**	**Fri 17-09-29**	**Fri 17-10-06**	**16**
18	Review Needs and stakeholder correlations	4 days	Fri 17-09-29	Wed 17-10-04	
19	Identify Out of Scope Needs	2 days	Thu 17-10-05	Fri 17-10-06	18
20	**Detailed Design**	**25 days**	**Thu 17-09-28**	**Wed 17-11-01**	**9**
21	**Focused Research For Evaluation**	**7 days**	**Thu 17-09-28**	**Fri 17-10-06**	
22	"Equipment Tow"	7 days	Thu 17-09-28	Fri 17-10-06	
23	"Ski Teeth"	7 days	Thu 17-09-28	Fri 17-10-06	
24	"Ski Hook Poles"	7 days	Thu 17-09-28	Fri 17-10-06	
25	"Snow Packer"	7 days	Thu 17-09-28	Fri 17-10-06	
26	**Further Research and Specific Design**	**17 days**	**Mon 17-10-09**	**Tue 17-10-31**	**21**
27	Non Priority Prepreatory Design	3 days	Mon 17-10-09	Wed 17-10-11	
28	Gear Train and Chassis Sizing	7 days	Thu 17-10-12	Fri 17-10-20	27
29	Battery and Motor Sizing / Controls	7 days	Thu 17-10-12	Fri 17-10-20	27
30	Thermal Analysis	7 days	Mon 17-10-23	Tue 17-10-31	28,29
31	Sled	7 days	Thu 17-10-12	Fri 17-10-20	27
32	Complete Pieces for Complete Design	1 day	Mon 17-10-23	Mon 17-10-23	34SS
33	Mid Design FMEA	6 days	Mon 17-10-23	Mon 17-10-30	28,29
34	Integration Design	7 days	Mon 17-10-23	Tue 17-10-31	28,29
35	Simulation/Prototyping/Ana	17 days	Mon 17-10-09	Tue 17-10-31	21
36	Integrated Design FMEA	2 days	Wed 17-11-01	Thu 17-11-02	34
37	CAD Representation	1 day	Wed 17-11-01	Wed 17-11-01	35
38	**Concept Selection Review**	**1 day**	**Wed 17-10-11**	**Wed 17-10-11**	
39	Visual Aid	1 day	**Wed 17-10-11**	Wed 17-10-11	
40	**Report Generation**	**28 days**	**Thu 17-10-12**	**Fri 17-11-17**	**38**
41	Outline	1 day	Thu 17-10-12	Thu 17-10-12	
42	First Draft	11 days	Tue 17-10-31	Mon 17-11-13	41
43	Second Draft & Bibligraphy & Appendices	2 days	Tue 17-11-14	Wed 17-11-15	42
44	Final Edits	2 days	Thu 17-11-16	Fri 17-11-17	43
45	**Oral Presentation**	**3 days**	**Wed 17-11-22**	**Fri 17-11-24**	
46	Power point	1 day	Wed 17-11-22	Wed 17-11-22	
47	Script	2 days	Thu 17-11-23	Fri 17-11-24	46
48	Practice	2 days	Thu 17-11-23	Fri 17-11-24	46
49	Final Course Submissions	1 day	Fri 17-12-01	Fri 17-12-01	
50	**MIDTERMS - Potential Lag days**	**27 days**	**Thu 17-10-05**	**Fri 17-11-10**	
51	MECH 327 MT1	2 days	Thu 17-10-05	Fri 17-10-06	
52	MECH 325 MT1	2 days	Mon 17-10-23	Tue 17-10-24	
53	MECH 326 MT1	1 day	Mon 17-10-30	Mon 17-10-30	
54	MECH 392 MT1	2 days	Tue 17-10-31	Wed 17-11-01	
55	MECH 327 MT2	2 days	Thu 17-11-09	Fri 17-11-10	
56	MECH 360 MT1	2 days	Wed 17-10-11	Thu 17-10-12	
57	MECH 368 MT1	2 days	Thu 17-10-19	Fri 17-10-20	
58	MECH 386 MT1	1 day	Tue 17-10-10	Tue 17-10-10	



N-3 Critical Path Method (CPM)

The Critical Path Method (CPM) was used to identify the tasks for which the project timeline was most dependent. Once identified, tasks along this path were prioritized and resources were allocated accordingly. The structure of the CPM contains numerous boxes with the following the general template as shown in class:

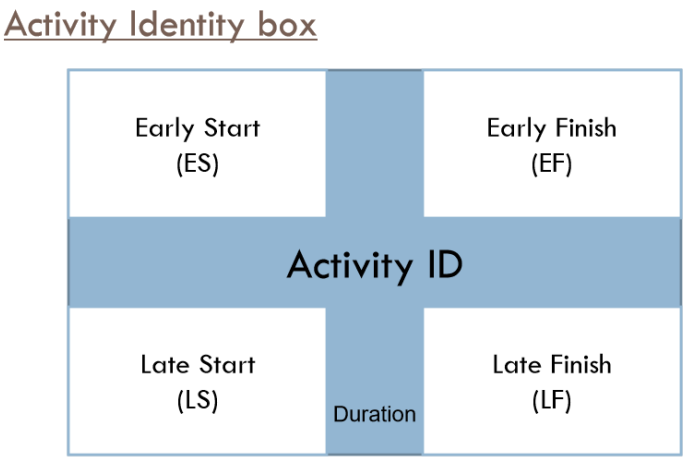
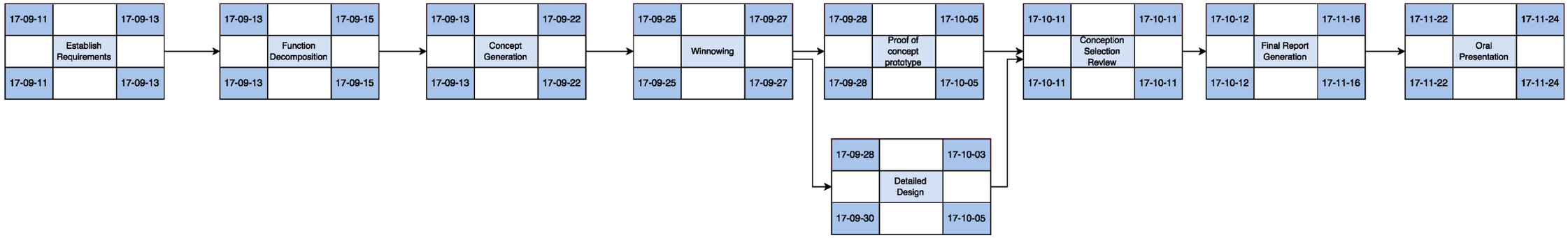


Figure N-1: Template Used for the Critical Path Method (CPM)

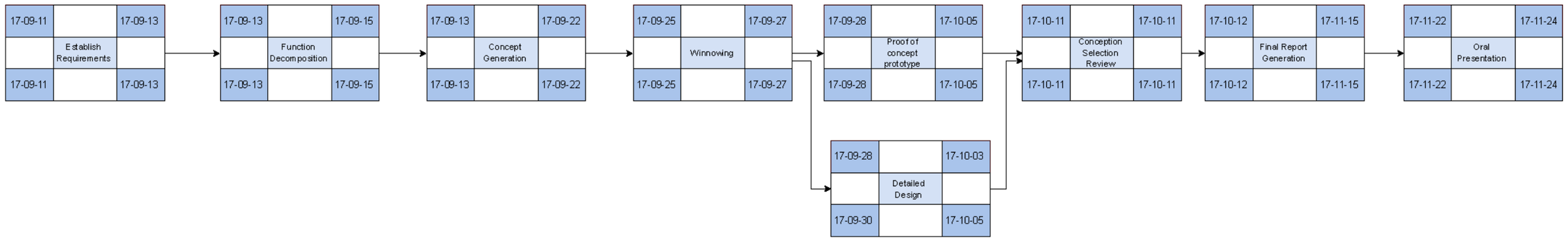
The CPM is generally built from the Gantt Chart; therefore, any major revisions on the Gantt Chart are reflected accordingly. As a result, a thorough revision history will not be provided to avoid redundancy. The CPM's iterative nature can be shown in the sequential list below:

- N-3.1 Critical Path Method (CPM)_September 18, 2017 (Original Copy)
- N-3.2 Critical Path Method (CPM)_September 25, 2017
- N-3.3 Critical Path Method (CPM)_October 2, 2017
- N-3.4 Critical Path Method (CPM)_October 9, 2017
- N-3.5 Critical Path Method (CPM)_October 16, 2017
- N-3.6 Critical Path Method (CPM)_October 30, 2017
- N-3.7 Critical Path Method (CPM)_November 6, 2017 (Final Revision)

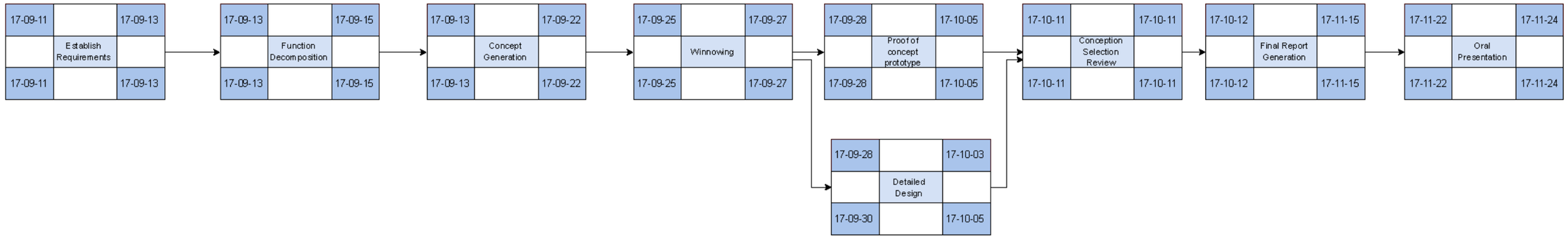
N-3.1 Critical Path Method (CPM)_September 18, 2017 (Original Copy)



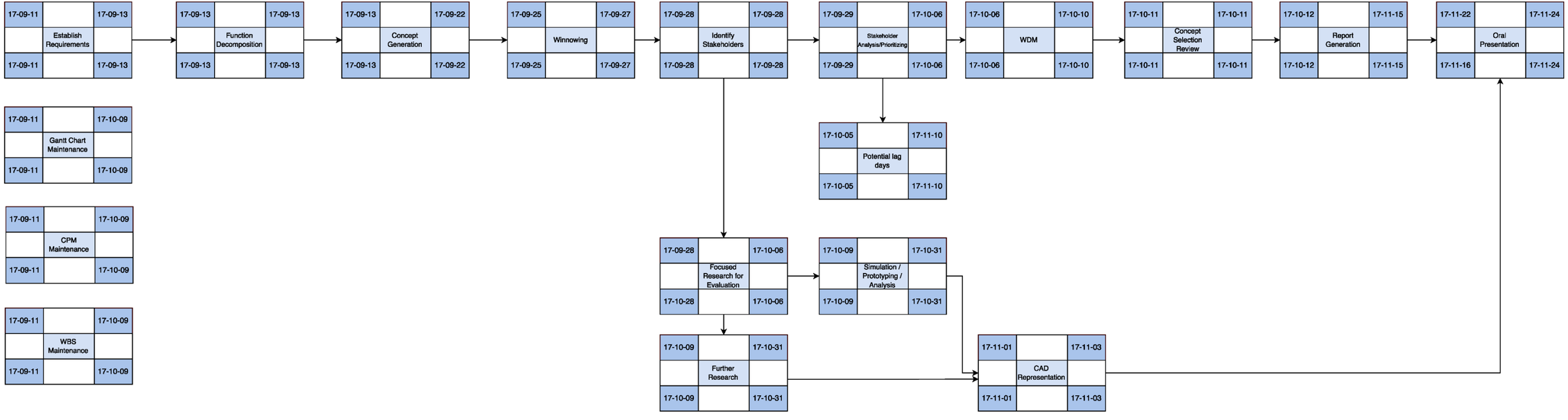
N-3.2 Critical Path Method (CPM)_September 25, 2017



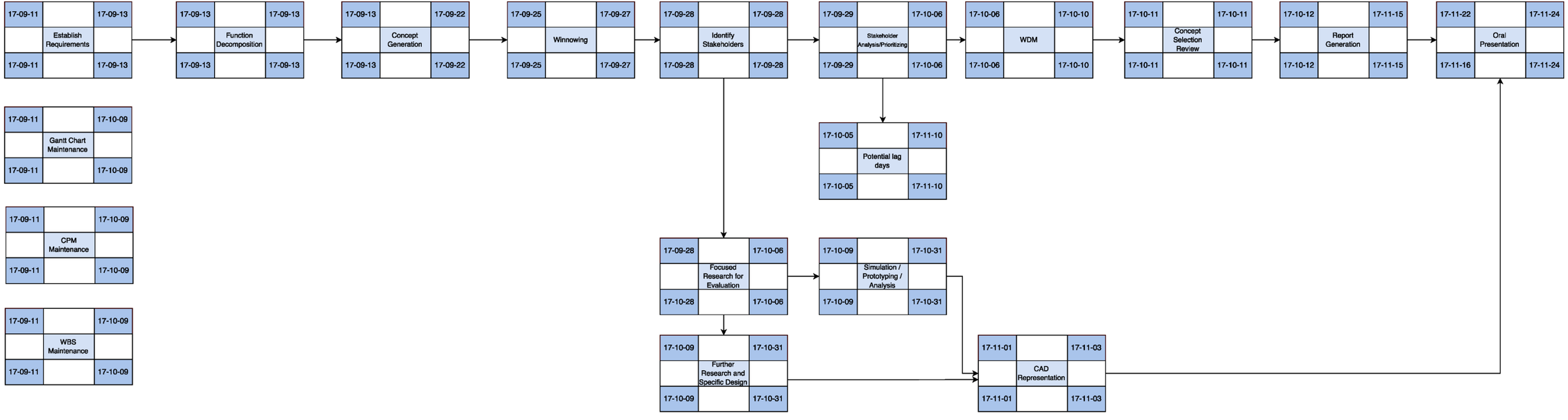
N-3.3 Critical Path Method (CPM)_October 2, 2017



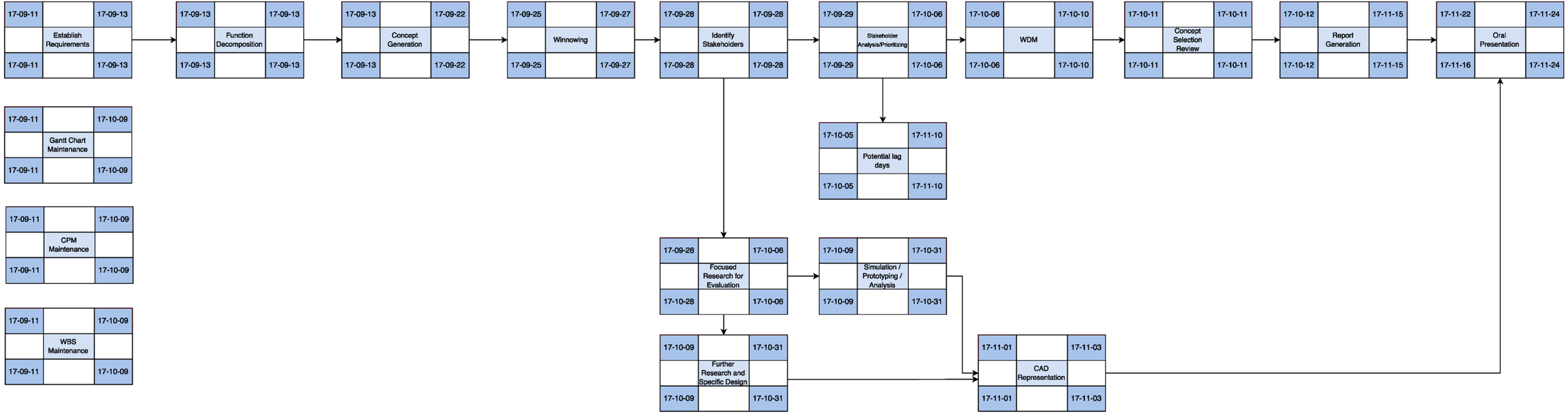
N-3.4 Critical Path Method (CPM)_October 9, 2017



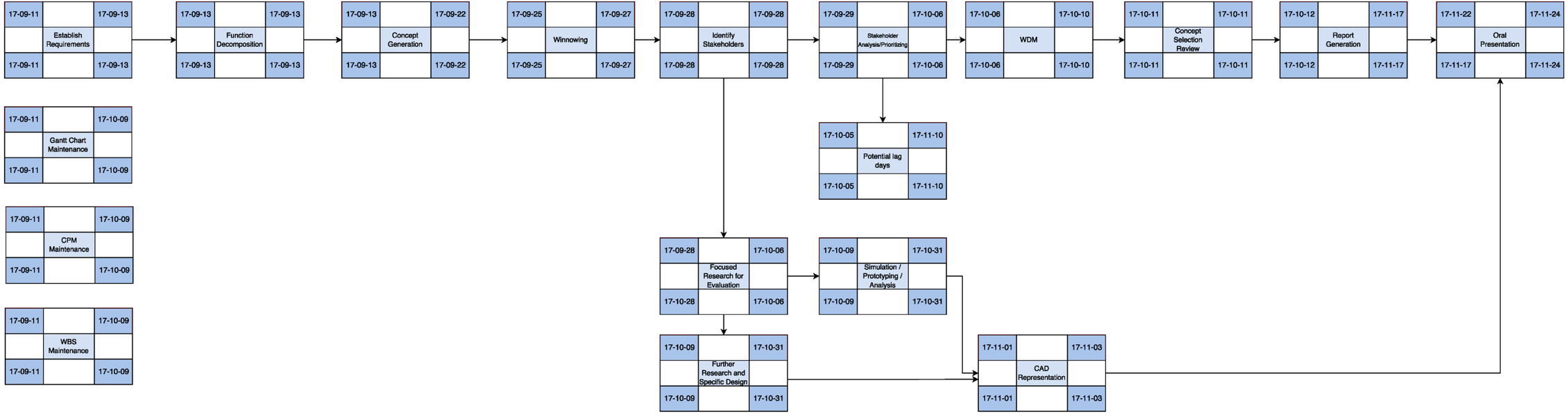
N-3.5 Critical Path Method (CPM)_October 16, 2017



N-3.6 Critical Path Method (CPM)_October 30, 2017



N-3.7 Critical Path Method (CPM)_November 6, 2017 (Final Revision)

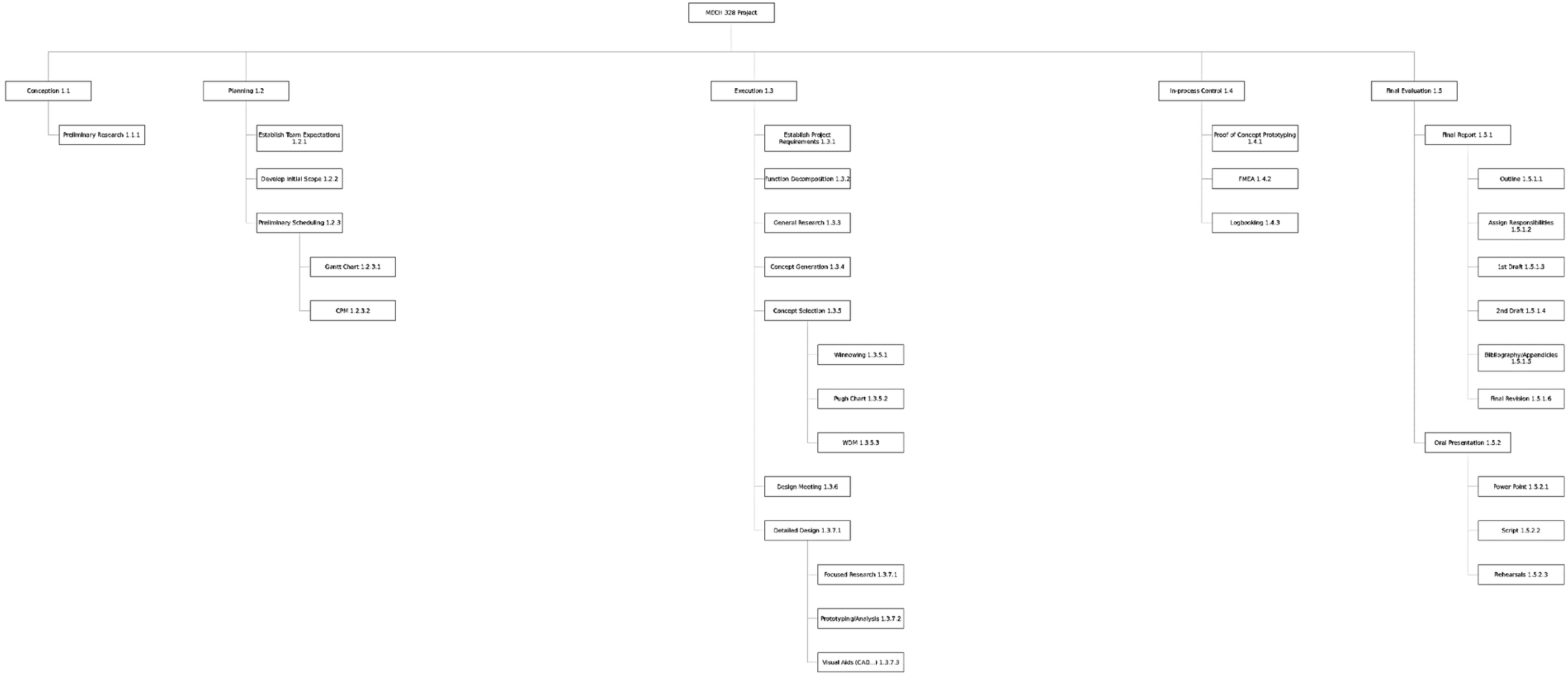


N-4 Work Breakout Structure (WBS)

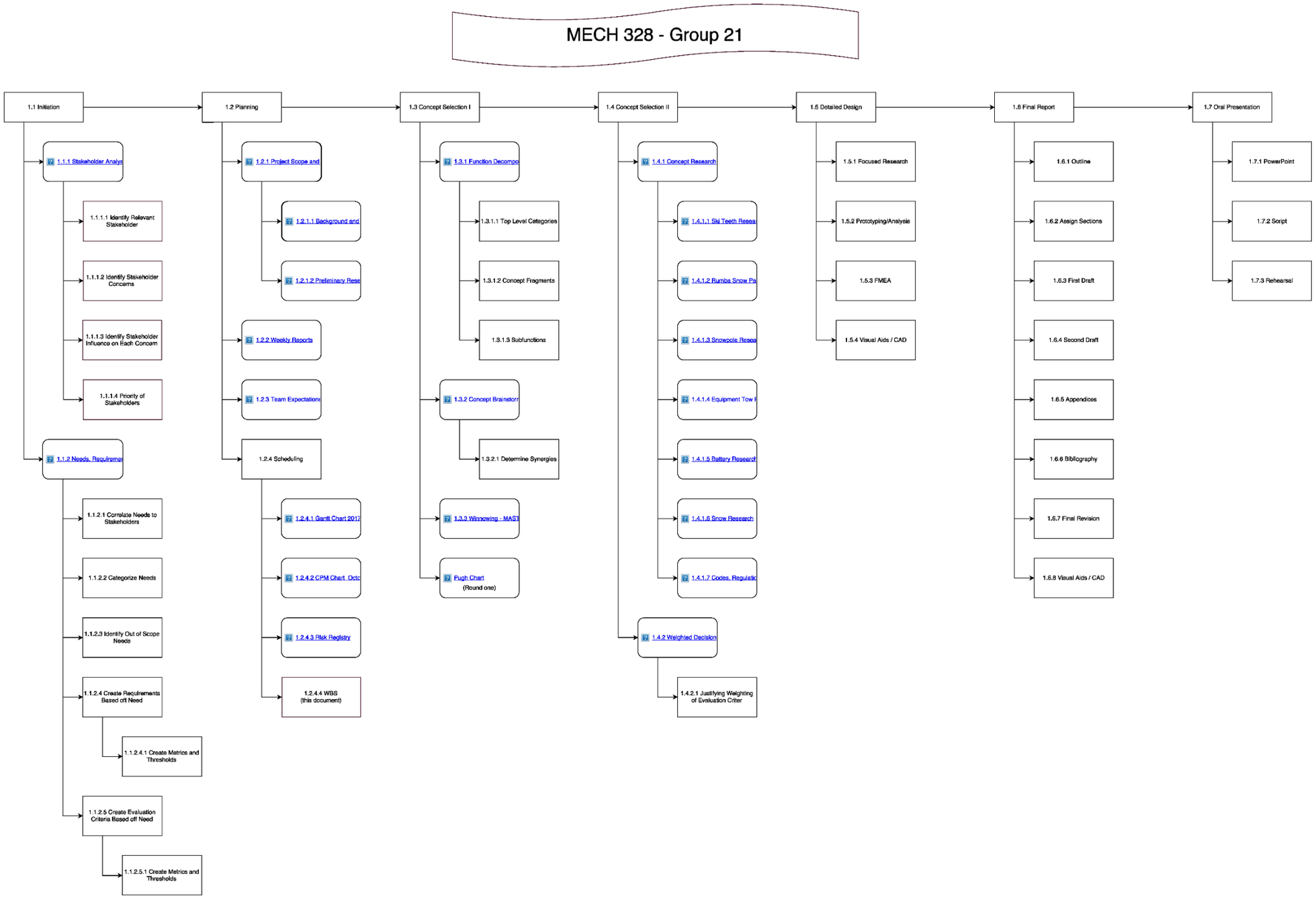
The work breakout structure (WBS) visualizes the 5 phases of project management: concept/ideation, planning, execution, in-process control, and final evaluation. Throughout this project, the WBS was used to keep track of tasks required for each phase and. thus, gave a preliminary outlook on time management (headings with more tasks would require a larger number of resources). The revision history of the WBS below throughout the project highlights its iterative nature:

- N-4.1 Work Breakout Structure (WBS)_September 18, 2017 (Original Copy)
  - The original copy of the Work Breakout Structure (WBS), much like the original copy of the Gantt Chart, contains generally top-level tasks.
- N-4.2 Work Breakout Structure (WBS)_October 8, 2017
  - Tasks (along with the complementary files) were added to the WBS for a more thorough breakdown of tasks. Additionally, the use of the standard five headers was replaced with top-level tasks and the WBS was re-organized correspondingly.
- N-4.3 Work Breakout Structure (WBS)_October 9, 2017
  - After consultation at our weekly meeting, the five standard headings were reinstated and the WBS was re-organized correspondingly.
- N-4.4 Work Breakout Structure (WBS)_October 22, 2017
  - Sub-tasks according to sub-functions of the device (e.g., gears, battery, winch rope, etc.) were added to the WBS under “Detailed Design”.
- N-4.5 Work Breakout Structure (WBS)_October 30, 2017
  - Sub-tasks (e.g., integrated design) were added to the “Detailed Design” sub-heading.
- N-4.6 Work Breakout Structure (WBS)_November 6, 2017 (Final Revision)
  - The final revision of the WBS included minor changes as the team progresses through the formal report; otherwise, the chart remained constant for the remainder of the project.

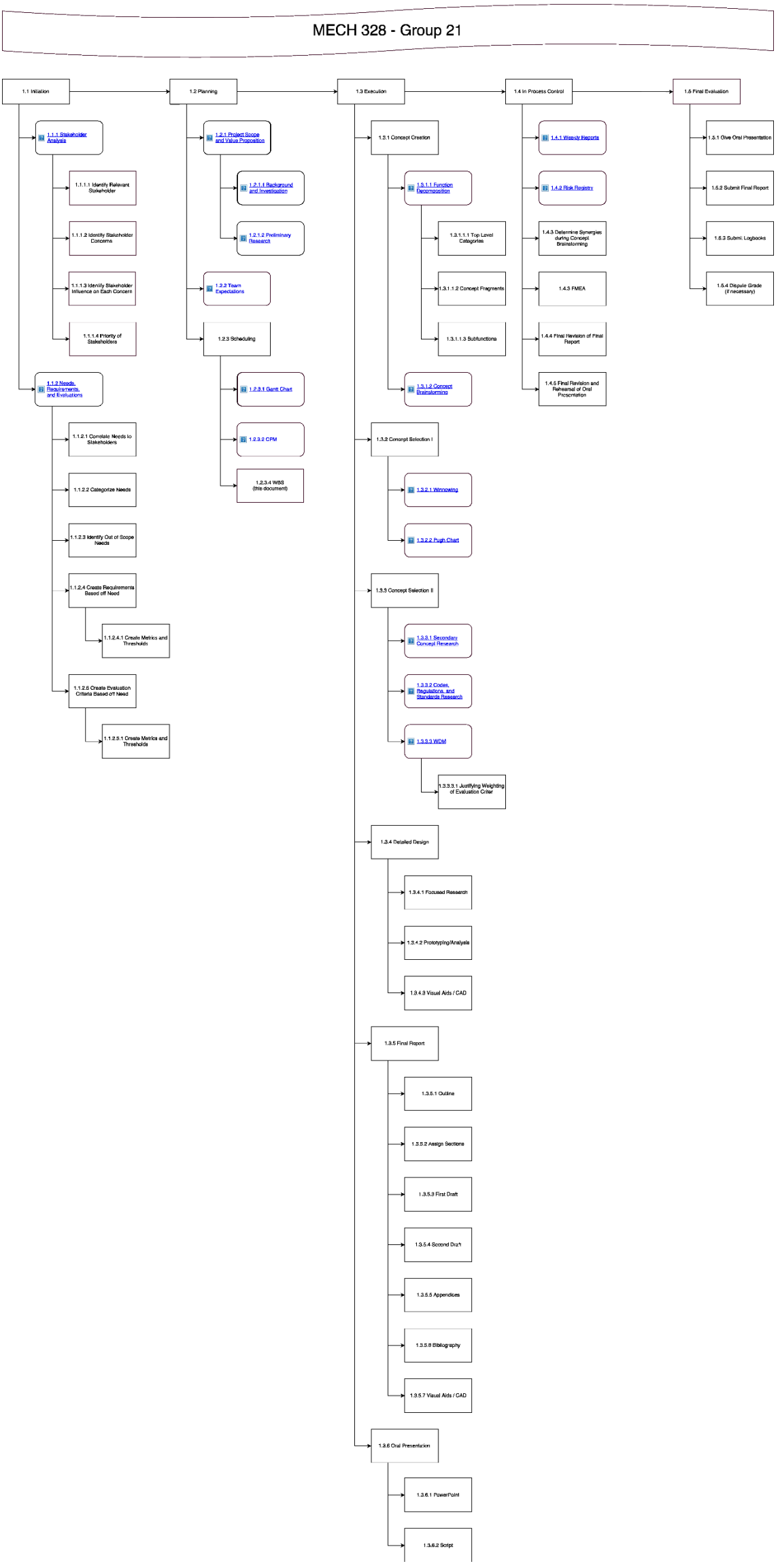
N-4.1 Work Breakout Structure (WBS)_September 18, 2017 (Original Copy)



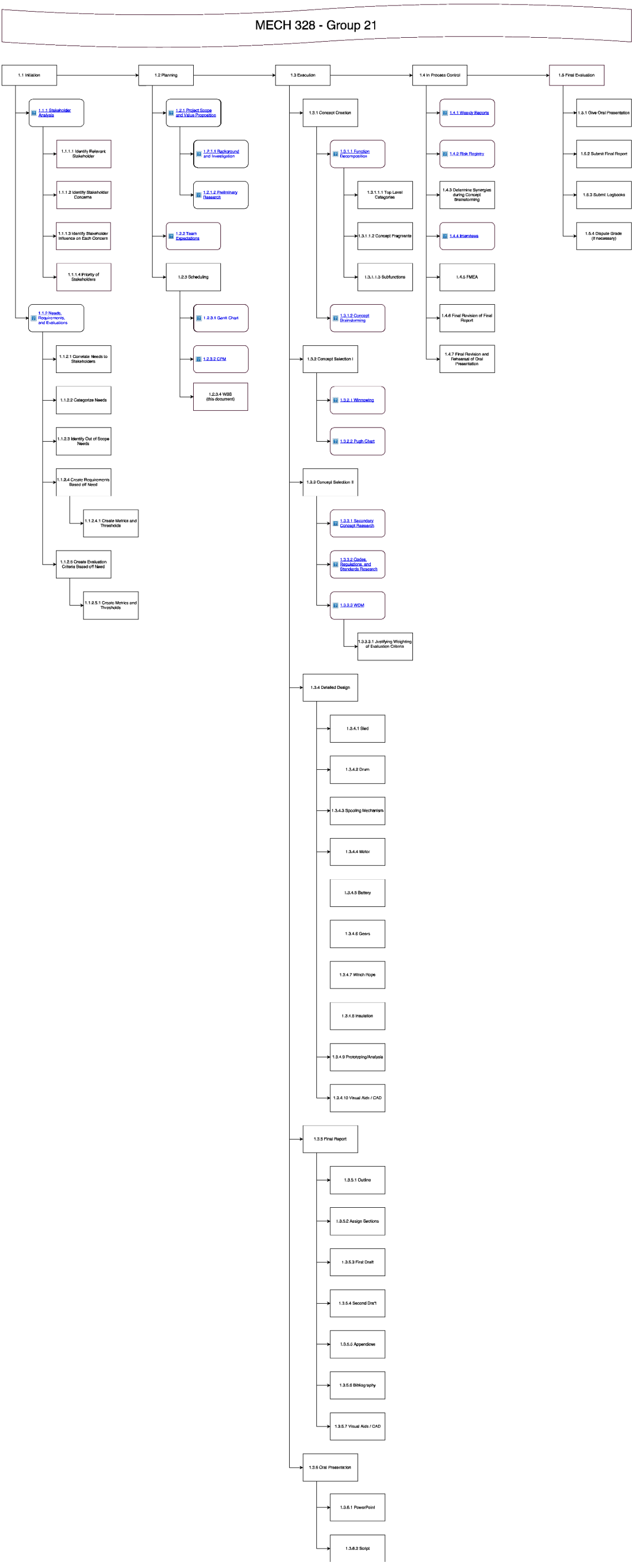
N-4.2 Work Breakout Structure (WBS)_October 8, 2017



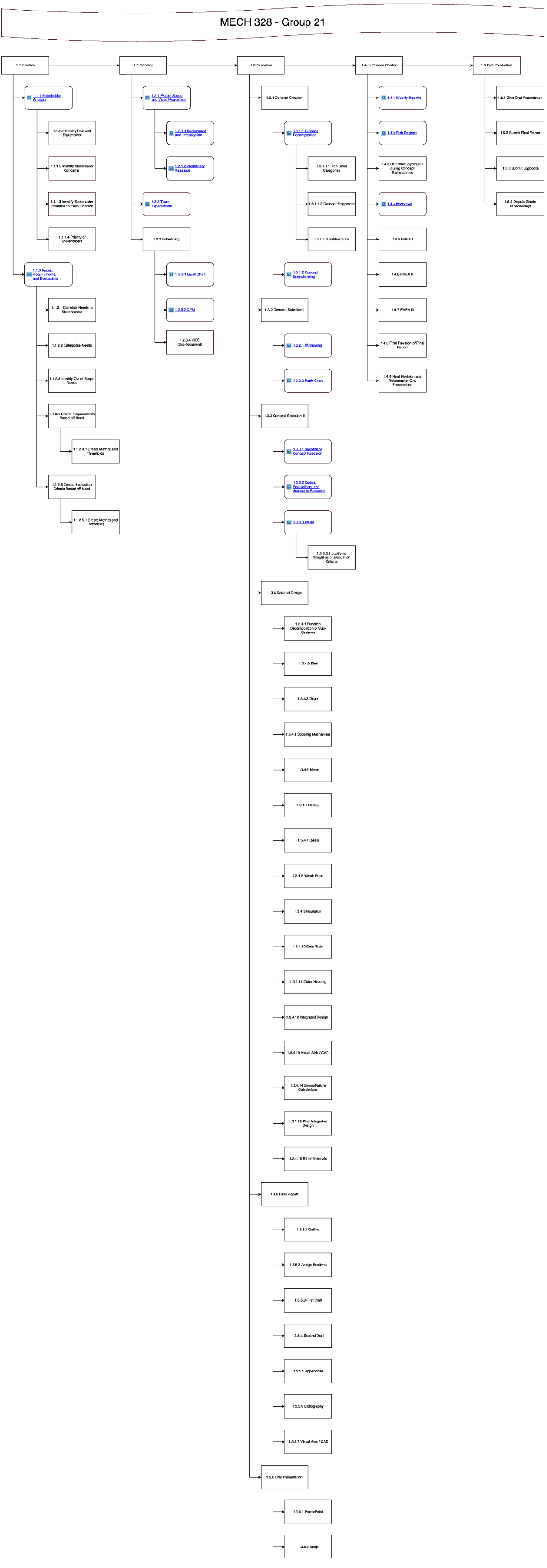
N-4.3 Work Breakout Structure (WBS)_October 9, 2017



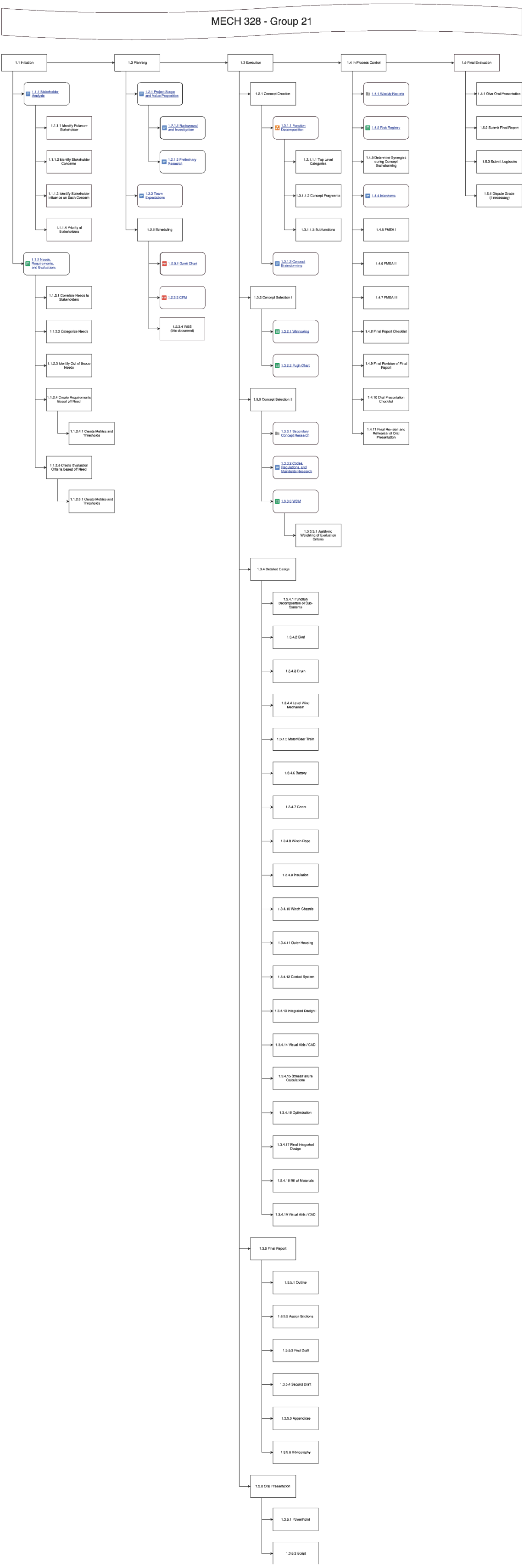
N-4.4 Work Breakout Structure (WBS)_October 22, 2017



N-4.5 Work Breakout Structure (WBS)_October 30, 2017



N-4.6 Work Breakout Structure (WBS)_November 6, 2017 (Final Revision)



N-5 Risk Register

A risk register (which may also be referred to as a Risk Log or Risk Registry) was used after clarification of how to use the tool properly was confirmed by Professor Mehran Mehrandezh mid-September 2017; the specific risk register used was based on a template provided by Dr. Mehran Mehrandezh. The purpose of a risk register is to track issues and address problems associated with project management (i.e., timeline); risk management is crucial to the success of a project. Although typically created during the early planning stages of a project, the circumstances above resulted in the risk register being created approximately a month after the start of the project. The risk register is colour-coded to showcase addressed risks (which may or may not have actions associated) and high risk items (i.e., risks with a combined score of 50 or greater). Additionally, highly-scored risks (i.e., the top two risks which generally had a score of 85 or greater) were shaded in a darker shade.

The risk register has been updated regularly between the end of September 2017 (inception) and November 17, 2017 (report due date). Each week, impact and probability ratings for each risk are adjusted according to the team's progress and depending on any actions made to address high risk items. The iterative nature of the risk register is portrayed below:

- N-5.1 Risk Registry: September 28, 2017 (Original Copy)
  - The first version of the risk register contains risks addressed prior to the inception of the chart mostly regarding project definition and concept generation.
- N-5.2 Risk Registry: October 9, 2017
  - Risk responses were created for the highest ranked risks (completion of the WDM, CSR, and detail design calculations required for the WDM) in the form of extra meetings and delegation of snow research.
- N-5.3 Risk Registry: October 16, 2017
  - A different set of highly-ranked risks were identified based on new impact and probability ratings. Specifically, several risks were labelled as "addressed", the "late completion of detail design calculations" risk was given a lowered score after the risk response was executed, and the onset of midterms for the team was identified as a possible risk trigger for risks associated with detail design.

- N-5.4 Risk Registry: October 23, 2017
  - A sudden change of concept resulted in a newly identified risk trigger and risk ratings were updated accordingly.
- N-5.5 Risk Registry: October 30, 2017
  - Unforeseen issues that arise from the integration of subsystems was identified as a possible risk trigger and risk ratings were updated accordingly.
- N-5.6 Risk Registry: November 6, 2017
  - Risk responses were created for the highest ranked risks (late completion of CAD drawings, late completion of detail design calculations, and late completion of design simulations) in the form of extra meetings and task delegation. As such, risks associated with the formal report receive greater scores as well.
- N-5.7 Risk Registry: November 13, 2017
  - As the final report deadline approaches, all highly-scored risks are related to the report; a risk response is created to mitigate these risks. In addition, several risks were labelled as "addressed" and the remaining risk ratings are updated accordingly.
- N-5.8 Risk Registry: November 17, 2017 (Final Version)
  - The final version of the risk register (that can be shown in this report) contains two outstanding risks associated with the oral presentation; both are scored at a level that does not require immediate action at this time.

N-5.1 Risk Registry: September 28, 2017 (Original Copy)

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	28-Sep-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Already happened	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Already happened	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Already happened	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	7.5	WDM should be easy to fill out (little discussion as decisions should all be justified via calcualtions), but has a lot of dependencies	8	CSR dependent on deciding on one concept to pursue to detail design	60				
Late completion of feasibility calculations	Concept Evaluation	7.5	Unknowns of powder snow and inexperience in skiing	8	WDM dependent (next big step)	60				
Late completion of concept selection review prep	Concept Evaluation	9	Next deliverable coming up	10	Deliverable that cannot be late	90				
Late completion of CAD drawings	Detail Design	6	Next steps for the team	5	We should have a few lag days for detailed design before the next deliverables	30				
Late completion of detail design calculations	Detail Design	8	Unknowns of powder snow and inexperience in skiing	9.8	Would severely impact WDM completion and CSR	78.4				
Late completion of design simulations	Detail Design	6	Next steps for the team	5	We should have a few lag days for detailed design before the next deliverables	30				
Late completion fo first draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of second draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of appendices	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of bibliography/references	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of final editing	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of report submission	Report	3	Lots of lag days until this is due (not a priority atm)	10	Very few lag days to correct lateness	30				
Late completion of oral presentation slides	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of script	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	8.5	Possibility of last minute rehersal	25.5				

N-5.2 Risk Registry: October 9, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	9-Oct-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Already happened	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Already happened	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Already happened	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Already happened	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	10	WDM is late	8	CSR dependent on deciding on one concept to pursue to detail design	80	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	7.5	Pugh Chart is late	8	WDM dependent (next big step)	60	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	9	Next deliverable coming up	10	Deliverable that cannot be late	90				
Late completion of CAD drawings	Detail Design	7.5	Next steps for the team; hopefully, we'll be back on track by this task (i.e., after the CSR)	5	We should have a few lag days for detailed design before the next deliverables	37.5				
Late completion of detail design calculations	Detail Design	8	Pugh Chart is late	9.8	Would severely impact WDM completion and CSR	78.4	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of design simulations	Detail Design	7.5	Next steps for the team; hopefully, we'll be back on track by this task (i.e., after the CSR)	5	We should have a few lag days for detailed design before the next deliverables	37.5				
Late completion fo first draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of second draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of appendices	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of bibliography/references	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of final editing	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of report submission	Report	3	Lots of lag days until this is due (not a priority atm)	10	Very few lag days to correct lateness	30				
Late completion of oral presentation slides	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of script	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	8.5	Possibility of last minute rehersal	25.5				

N-5.3 Risk Registry: October 16, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	9-Oct-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Already happened	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Already happened	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Already happened	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Already happened	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Already happened	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Already happened	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Already happened	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	8	The trail breaker concept is complex and has a higher developmental risk than other concepts	7.5	We should have a few lag days for detailed design before the next deliverables	60		MIDTERMS		
Late completion of detail design calculations	Detail Design	8	The trail breaker concept is complex and has a higher developmental risk than other concepts	9	Would severely impact CAD drawings and design simulations	72	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of design simulations	Detail Design	8	The trail breaker concept is complex and has a higher developmental risk than other concepts	7.5	We should have a few lag days for detailed design before the next deliverables	60		MIDTERMS		
Late completion fo first draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of second draft	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of appendices	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of bibliography/references	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of final editing	Report	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of report submission	Report	3	Lots of lag days until this is due (not a priority atm)	10	Very few lag days to correct lateness	30				
Late completion of oral presentation slides	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of script	Oral Presentation	3	Lots of lag days until this is due (not a priority atm)	8.5	Possibility of last minute rehersal	25.5				

N-5.4 Risk Registry: October 23, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	23-Oct-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Already happened	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Already happened	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Already happened	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Already happened	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Already happened	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Already happened	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Already happened	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	9	Completely changed concept (we have 2 less days to finish detail design)	8.5	We do not have many lag days left	76.5		CHANGED CONCEPT		
Late completion of detail design calculations	Detail Design	9	Completely changed concept (we have 2 less days to finish detail design)	9	Would severely impact CAD drawings and design simulations	81	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of design simulations	Detail Design	9	Completely changed concept (we have 2 less days to finish detail design)	8.5	We do not have many lag days left	76.5		CHANGED CONCEPT		
Late completion fo first draft	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of second draft	Report	3	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	15				
Late completion of appendices	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of bibliography/references	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of final editing	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of report submission	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	10	Very few lag days to correct lateness	40				
Late completion of oral presentation slides	Oral Presentation	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of script	Oral Presentation	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	8.5	Possibility of last minute rehersal	34				

N-5.5 Risk Registry: October 30, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	30-Oct-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Already happened	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Already happened	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Already happened	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Already happened	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Already happened	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Already happened	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Already happened	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Already happened	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Already happened	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	6	Design is simpler than we thought (and we are doing CAD models as we go). We are still on time.	10	HUGE IMPACT ON FORMAL REPORT	60		Unforseen issues that arise from integration of subsystems		
Late completion of detail design calculations	Detail Design	6	Design is simpler than we thought (and we are doing CAD models as we go). We are still on time.	10	HUGE IMPACT ON FORMAL REPORT	60	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
								Unforseen issues that arise from integration of subsystems		
Late completion of design simulations	Detail Design	9	With the addition of a couple of design iterations, we will be pressed for time when doing simulations	10	HUGE IMPACT ON FORMAL REPORT	90		Unforseen issues that arise from integration of subsystems		
Late completion fo first draft	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of second draft	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of appendices	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of bibliography/references	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of final editing	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of report submission	Report	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	10	Very few lag days to correct lateness	40				
Late completion of oral presentation slides	Oral Presentation	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of script	Oral Presentation	4	Risk is slightly higher than before, but we are still in the detail design stage and hopefully we can finish that stage on time (because the equipment tow is a simpler concept)	8.5	Possibility of last minute rehersal	34				

N-5.6 Risk Registry: November 6, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	6-Nov-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Stage has passed	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Stage has passed	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Stage has passed	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meeting)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Stage has passed	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Stage has passed	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Stage has passed	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Stage has passed	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	10	This risk is currently happening	10	HUGE IMPACT ON FORMAL REPORT	100	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Jason
Late completion of detail design calculations	Detail Design	10	This risk is currently happening	10	HUGE IMPACT ON FORMAL REPORT	100	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
								Unforseen issues that arise from integration of subsystems		
							November 5, 2017	Unforseen issues with thermal insulation of the batteries	Divided the team up so that some members address this issue while others begin working on the formal report	Rishabh and Cole
Late completion of design simulations	Detail Design	10	This risk is currently happening	10	HUGE IMPACT ON FORMAL REPORT	100	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Team
Late completion fo first draft	Report	8	Report is now due in approximately one week; with the upcoming midterms that everyone has, it has been difficult to manage time for this course	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	72				
Late completion of second draft	Report	8	Report is now due in approximately one week; with the upcoming midterms that everyone has, it has been difficult to manage time for this course	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	72				
Late completion of appendices	Report	8	Report is now due in approximately one week; with the upcoming midterms that everyone has, it has been difficult to manage time for this course	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	72				
Late completion of bibliography/references	Report	8	Report is now due in approximately one week; with the upcoming midterms that everyone has, it has been difficult to manage time for this course	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	72				
Late completion of final editing	Report	5	Report is now due in approximately one week; however, editing and formatting should be fairly quick (the team allocated approximately 3 days for this, but this task can be compressed into 1-2 days if needed)	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	25				
Late completion of report submission	Report	4	Report is now due in approximately one week; however, submission is quick and will be met regardless of the state of the report	10	Very few lag days to correct lateness	40				
Late completion of oral presentation slides	Oral Presentation	4	Currently working on the report - the oral presentation will be based heavily on the formal report	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of script	Oral Presentation	4	Currently working on the report - the oral presentation will be based heavily on the formal report	8.5	Possibility of last minute rehersal	34				

N-5.7 Risk Registry: November 13, 2017

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	13-Nov-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Stage has passed	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Stage has passed	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Stage has passed	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Stage has passed	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Stage has passed	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Stage has passed	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Stage has passed	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Jason
Late completion of detail design calculations	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
		0	Stage has passed					Unforseen issues that arise from integration of subsystems		
		0	Stage has passed				November 5, 2017	Unforseen issues with thermal insulation of the batteries	Divided the team up so that some members address this issue while others begin working on the formal report	Rishabh and Cole
Late completion of design simulations	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Team
Late completion fo first draft	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0				
Late completion of second draft	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0				
Late completion of appendices	Report	9	Report is now due in less than one week	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	81	November 10, 2017	A large quantity of information is contained within the appendices	Extra time must be allocated for the final report above other coursework	Team
Late completion of bibliography/references	Report	9	Report is now due in less than one week	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	81	November 10, 2017	A large quantity of information is contained within the appendices	Extra time must be allocated for the final report above other coursework	Team
Late completion of final editing	Report	8	Report is now due in less than one week	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	40		Late completion of the report writing	Proper communication channels will ensure that the report writing is completed with enough time for editing	Amanda
Late completion of report submission	Report	6	Report is now due in less than one week; therefore, risk is slightly higher, but again, it is still relatively unlikely that the team will submit the report late	10	No lag days to correct lateness	60				
Late completion of oral presentation slides	Oral Presentation	4	Currently working on the report - the oral presentation will be based heavily on the formal report	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	20				
Late completion of script	Oral Presentation	4	Currently working on the report - the oral presentation will be based heavily on the formal report	8.5	Possibility of last minute rehersal	34				

N-5.8 Risk Registry: November 17, 2017 (Final Version)

RISK REGISTRY							Legend		Created on:	28-Sep-2017
							Addressed Risks	High Risk	Last Updated on:	17-Nov-2017
Risk Identification		Qualitative Rating					Risk Response			
Risk	Category [1]	Probability [2]	Justification [3]	Impact [4]	Justification [5]	Score [6]	Date [7]	Trigger [8]	Response	Owner
Late completion of stakeholder analysis	Scope/Value Prop	0	Stage has passed	5	Simple edits to needs, requirements, and evaluation critieria sheet to ensure stakeholders have been accounted for	0	September 28, 2017	Project miscommunication (i.e., did not realize a formal analysis was in order)	Shuffled team member responsibilities to reflect added task	Cole
Late completion of value proposition	Scope/Value Prop	0	Stage has passed	8	Potential to change large aspects of the project	0				
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	October 3, 2017	Client Q/A	Updated sheet and notified team members	Danwei
Late completion of needs, requirements, and evaluation criteria	Scope/Value Prop	0	Stage has passed	5	It was easy to propogate changes in wording/clarifications throughout the rest of the documents	0	September 28, 2017	Scope is ill defined (i.e., activities are missing from scope definition)	Shuffled team member responsibilities to reflect added task	Amanda
Late completion of functional decomposition	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of concept generation	Concept Generation	0	Stage has passed	3	Lots of lag days to address issues	0				
Late completion of winnowing	Concept Evaluation	0	Stage has passed	5	Very quick to redo	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests); miscommunication of project expectations	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of pugh chart	Concept Evaluation	0	Stage has passed	8	Takes more time to do (made the team go back to solidify concepts)	0	September 28, 2017	Scope Inflation (due to project team or client adding features that aren't in requirements; i.e., change requests)	Put in extra hours to backtrack (scheduled extra meetings)	Jason/Amanda
Late completion of WDM	Concept Evaluation	0	Stage has passed	8	CSR dependent on deciding on one concept to pursue to detail design	0	October 8, 2017	Pugh Chart was very late and the lateness propogated to the calculations and WDM	Scheduled in an extra meeting to finish before CSR	Team
Late completion of feasibility calculations	Concept Evaluation	0	Stage has passed	8	WDM dependent (next big step)	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
Late completion of concept selection review prep	Concept Evaluation	0	Stage has passed	10	Deliverable that cannot be late	0				
Late completion of CAD drawings	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Jason
Late completion of detail design calculations	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	October 8, 2017	Unknowns of powder snow and inexperience in skiing	Putting extra hours in (team); contacted outside resources to discuss effects of powder snow (Amanda)	Amanda/Team
		0	Stage has passed					Unforseen issues that arise from integration of subsystems		
		0	Stage has passed				November 5, 2017	Unforseen issues with thermal insulation of the batteries	Divided the team up so that some members address this issue while others begin working on the formal report	Rishabh and Cole
Late completion of design simulations	Detail Design	0	Stage has passed	10	HUGE IMPACT ON FORMAL REPORT	0	November 5, 2017	Unforseen issues that arise from integration of subsystems	Divided the team up so that some members address this issue while others begin working on the formal report	Team
Late completion fo first draft	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0				
Late completion of second draft	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0				
Late completion of appendices	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0	November 10, 2017	A large quantity of information is contained within the appendices	Extra time must be allocated for the final report above other coursework	Team
Late completion of bibliography/references	Report	0	Stage has passed	9	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0	November 10, 2017	A large quantity of information is contained within the appendices	Extra time must be allocated for the final report above other coursework	Team
Late completion of final editing	Report	0	Stage has passed	5	Average impact (deliverable due date is relatively far away - not a huge priority atm)	0	November 15, 2017	Late completion of the report writing	Proper communication channels will ensure that the report writing is completed with enough time for editing	Amanda
Late completion of report submission	Report	0	Stage has passed	10	No lag days to correct lateness	0				
Late completion of oral presentation slides	Oral Presentation	6	Oral Presentation is due in less than a week	8	High impact as the oral presentation requires a visual aid	48				
Late completion of script	Oral Presentation	6	Oral Presentation is due in less than a week	8.5	Possibility of last minute rehersal	51				

APPENDIX O: WEEKLY REPORTS

The team has provided nine weekly reports detailing progress between September 6, 2017 and November 8, 2017; these reports were prepared for Bill Rawlings and Hooman Esfandiari (representatives of FreeBoots). They are listed sequentially:

- O-1 Weekly Report 1: September 13, 2017
- O-2 Weekly Report 2: September 20, 2017
- O-3 Weekly Report 3: September 27, 2017
- O-4 Weekly Report 4: October 4, 2017
- O-5 Weekly Report 5: October 11, 2017
- O-6 Weekly Report 6: October 18, 2017
- O-7 Weekly Report 7: October 25, 2017
- O-8 Weekly Report 8: November 1, 2017
- O-9 Weekly Report 9: November 8, 2017

O-1 Weekly Report 1: September 13, 2017

MECH 328 Weekly Progress Report *Dates: September 11th*

Group: 21 **Project Title: MECH 328 Backcountry Ski Assist**

Last Week's Goals: *cut and paste additional entries as required.*

1. N/A

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	Read background documents • Project guide • Project Proposal • Weekly Report Rubrics • Logbook Requirements and Rubric • Oral Presentation Rubric • Formal Report Rubric	3	3
Team	Research more background information on project (specifically backcountry skiing)	4	4
Team	Team Expectations and Introductions • https://docs.google.com/document/d/1ph7q100ipCDvQ-t_RLG1nn9kW4KBQ2knZNdTSleOZXM/edit?usp=sharing	0.75	0.75
Team	Scheduling (Gantt Chart and CPM) • Gantt Chart: https://drive.google.com/file/d/0B8SU_1NAgAHJTnlCTHYzSXVmZEE/view?usp=sharing • CPM is still in the works	1	1
Team	Project Requirements (Initial List) • https://drive.google.com/file/d/0B2wX47Xd68dQUGNYY0w4cEZIRTg/view?usp=sharing	0.75	0.75

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- The team read through all provided material regarding the project (requirements, rubrics, etc.). No team members ski and so we had to put in extra effort in understanding the mechanisms of skiing, the materials one brings to backcountry ski, the different types of equipment, and more.
- Because the team is made up of a mixture of different mechanical engineering years, we spent time familiarizing ourselves with new members, each other's' academic backgrounds, and becoming comfortable with each other in order to increase team cohesiveness.
- The team composed a team expectations document outlining the expectations of each team member in regards to communication, work/life boundaries, responsibility, initiative, leadership, etc. We also discussed the use of iPeer, time commitment, and grade expectations.
- The team created a schedule using a Gantt chart based on the "important dates" given and past experiences. From the Gantt chart, a critical path method (CPM) has been started.
- Project requirements were discussed and a list was created based off of the client's list of needs.
- The team prepared the weekly report for the first TA meeting and created new plans/goals for the next week.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked (this is our first iteration of the schedule):
    - https://drive.google.com/file/d/0B8SU_1NAgAHJTnlCTHYzSXVmZEE/view?usp=sharing
- Project is currently on schedule. Our next big step is to complete the function decomposition on Wednesday, September 13, 2017 and then to begin brainstorming concepts and concept fragments for the next week (where hopefully we will begin to create whole concepts)

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. Review the design process (MECH2 Textbook)
2. Function decomposition
3. Research for concepts and concept fragments personally (min 5 each)
4. Brainstorm, discuss, and generate whole concepts
5. Update Gantt chart and project requirements
6. Complete CPM
7. If have not gotten one, buy a logbook and begin logging work.

Action Items for Next Week: ***What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?***

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Ask professors, TA's, clients, and "stakeholders" for clarification	Wednesday, September 13, 2017
Everyone (Individual)	Review the design process (MECH2 Textbook)	Wednesday, September 13, 2017
Team	Edit the function decomposition on Google drive	Wednesday, September 13, 2017
Everyone (Individual)	Create a minimum of 5 concept generations (whole or fragmented)	Monday, September 18, 2017
Team	Brainstorm, discuss, and generate whole concepts (10 min)	Monday, September 18, 2017
Rishabh	Complete CPM	Wednesday, September 20, 2017
Cole	Update Gantt Chart	Monday, September 18, 2017

O-2 Weekly Report 2: September 20, 2017

MECH 328 Weekly Progress Report *Dates: Sept 12 - 18*

Group: 21 Project Title: Backcountry Skiing Ascender

Last Week's Goals: *cut and paste additional entries as required.*

1. Review the design process (MECH2 Textbook)
2. Function decomposition
3. Research for concepts and concept fragments personally (min 5 each)
4. Brainstorm, discuss, and generate whole concepts
5. Update Gantt chart and project requirements
6. Complete CPM
7. If have not gotten one, buy a logbook and begin logging work.

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	Performed background research on ● Waterproofing (Jason) ● Lipo batteries (Rishabh) ● Kick turns (Amanda) ● Elevations (Amanda) ● Exoskeletons (Juliana) ● Gecko Skins (Juliana) ● Equipment (Justin) ● Thresholds for work complete by the user (Dan Wei) Rough outline of preliminary research can be found here: ● https://docs.google.com/document/d/1laO4yNaYoEaA3zZSLJuPhWSeL6_oAigIsYvXcQn8TSk/edit?usp=sharing	1/person = 6	5 /person
Team	Concept Brainstorming Research (we came up with ideas individually and discussed them at a team meeting where multiple people may have had the same idea) ● https://drive.google.com/file/d/0B9CGIi89LaUHLVVmdU5ES3lPbnM/view?usp=sharing	3/person	3 /person
Team	Update individual log books	1/person	2 /person
Jason	Started the concept evaluation charts ● Morphological Chart	1	1

	○ https://docs.google.com/spreadsheets/d/10bm_PlZZKuZTYs0UUk7QHHq9eNXNwMEc41JK-OMtuNM/edit#gid=0 ● Pugh Chart ○ https://docs.google.com/spreadsheets/d/1uzfZWb-KlpTyUJUu3OxHcHDvbwdfaiyLMw9hMOpcwZA/edit#gid=0 ● Winnowing ○ https://docs.google.com/spreadsheets/d/1SwwL4hlp-YTSC8VkWWP4v4EdElTdm07o15D1UfrgrdY/edit#gid=0 ● WDM ○ https://docs.google.com/spreadsheets/d/1hqrDbMQ68N7tysfW0of7un_U_-aoel-CAeCw7gena44/edit#gid=0		
Cole	Updated/managed the Gantt Chart ● https://drive.google.com/file/d/0B8SU_1NAgAHJZVZVVWVid2lDeVk/view?usp=sharing	1	2
Danwei	Updated the needs and requirements ● https://drive.google.com/file/d/0B2wX47Xd68dQYWtlcWdacGRsVDg/view?usp=sharing	2	3
Rishabh	Created the CPM ● https://drive.google.com/file/d/0B2wX47Xd68dQc2dzd3pxdTVwS1U/view?usp=sharing	1	2
Justin	Created a WBS ● https://drive.google.com/file/d/0B_8LzZVvHA5WOFBRTnlmbk1JMVE/view?usp=sharing	1	1
Amanda	Waiting for response from professor and TA regarding next steps for the risk registry	0.25	0.25
Juliana	Completed the weekly report	0.75	0.75
Team	Team meeting was conducted ● https://docs.google.com/document/d/1HbLNVgjQZ6PIsberu8MJ6WlHgSJspQH9lrKGZdUirnQ/edit#	1.5/person	1.5/person

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- The team researched the topic further, individually, and proceeded to share their findings to the team in a meeting
- The team individually generated 5 concepts (whole or fragment) and shared concepts with each other in a meeting to further move along the concept generation phase
- Each individual team member completed their outlined individual project management task (as listed in the Last Week's Activities Chart)

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked:
  - https://drive.google.com/file/d/0B8SU_1NAgAHJZVZVVWVid2lDeVk/view?usp=sharing
- Project is currently on schedule. Our next step is to complete another round of concept generation (currently schedules for Wednesday, September 20th) in order to evaluate the concepts

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

- Conduct further research on the topic
- Conduct further research on proposed concepts to parameterize them
- Generate more concepts or combine previously mentioned concepts
- Finish the majority of the morphological chart
- Set the scope of our project by evaluating top-level functions; from here, we will be able to undergo another round of concept generation and evaluation accordingly.

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Conduct further research on topic.	September 20th
Team	Further generate whole concepts and concept fragments or combine previously discussed concepts	September 20th
Team	Further expand on previous concepts to create parameters for the concepts	September 20th
Team	Expand on the morphological chart and begin to finalize concepts for winnowing	September 25th
Team	Evaluate top-level functions to narrow the scope of our project	September 25th

O-3 Weekly Report 3: September 27, 2017

MECH 328 Weekly Progress Report *Dates: Sept 18 - 25, 2017*

Group: 21 Project Title: Backcountry skiing ascender

Last Week's Goals: *cut and paste additional entries as required.*

1. Conduct further research on the topic
2. Conduct further research on proposed concepts to parameterize them
3. Generate more concepts or combine previously mentioned concepts
    a. Finish the majority of the morphological chart
4. Set the scope of our project by evaluating top-level functions; from here, we will be able to undergo another round of concept generation and evaluation accordingly.
5. Begin evaluating concepts (Pugh Chart)

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Cole	Updated/managed the Gantt Chart ● https://drive.google.com/file/d/0B8SU_1NAgAHJVFktb2xiU1hzU3M/view?usp=sharing	1	3
Amanda	Completed the weekly report	0.75	0.75
Jason	Created a concept evaluation chart that all of the team can fill out for voting and discussion ● Pugh Chart - see below for link	1	2
Everyone	Updated Project Requirements according to scope ● https://drive.google.com/file/d/0B2wX47Xd68dQRFNCem9CcUJ3b3M/view?usp=sharing	0.75	1.5
Everyone	Concept Evaluation (filled out the pugh chart) ● https://drive.google.com/file/d/0B2wX47Xd68dQSmMtTVpySURpXzg/view?usp=sharing	1	1
Everyone	Conducted three team meeting ● https://docs.google.com/document/d/1Hl5bMXG3ucgeYJWm7f_ZyN0p--wBi1lgsvBDQwOlkpo/edit?usp=sharing ● https://docs.google.com/document/d/1XOTu7eohzMk_VA0aXPPW2IkkvSkiylixKfJvLWQYBdI/edit?usp=sharing	5	

	• https://docs.google.com/document/d/1i5i23nnmd7oYmmGjmYez2d_s2I7LEHIWIQyj6SfGT14/edit?usp=sharing		

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- Complete the functional decomposition chart in the previous week, but forgot to include it in last week's report
  - https://drive.google.com/file/d/0B2wX47Xd68dQVm5BZV9rM1lCZTg/view?usp=sharing
- Each individual team member completed their outlined individual task (as listed in the Last Week's Activities Chart)
- Each team member completed the pugh chart initial evaluation voting section; then, together over multiple meetings, we discussed the results yielding agreed statuses for each concept as well as further depth into each concept.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked above (Gantt Chart) and below (CPM):
  - https://drive.google.com/file/d/0B2wX47Xd68dQSnhUd3I2VUtRcE0/view?usp=sharing
- Project is currently on schedule. Our next step is to complete the first step of the evaluation of concepts.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. Complete Pugh Chart Evaluation
2. Continue Winnowing Process (hopefully, narrow down concepts to less than 5 to continue with)

_Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Winnowing (narrow down concepts)	September 29, 2017
Juliana	Create summary sheet for Pugh Chart	September 27, 2017
Team	iPeer Evaluation	October 2, 2017
Amanda	Risk Registry	September 29, 2017
Amanda	Weekly Report	October 2, 2017
Cole	Update Gantt Chart	October 2, 2017
Rishabh	Update CPM	October 2, 2017

O-4 Weekly Report 4: October 4, 2017

MECH 328 Weekly Progress Report

Dates: Sept. 25 - Oct. 2

Group: Team 21
Ascender

Project Title: MECH 328 Backcountry Skiing

Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of this week, the team should have completed the Pugh Chart Evaluation stage, thus moving onto WDM.
    a. No more than five concepts will have entered into the Pugh Chart Evaluation Stage from Winnowing.
2. By the end of this week, a formal stakeholder analysis will be complete
    a. From this analysis, updated needs, requirements, and evaluation criteria will be created prior to concept evaluation
3. Prepare for Concept Selection Review

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	September 27, 2017 ● Created a formal stakeholder analysis document with stakeholders and their primary areas of concern ○ https://docs.google.com/document/d/1b3iT5MXkdcoU__UIfSEwT0nNA6yVCezh2qhq6KaOUew/edit?usp=sharing ● Reclassified Needs, Requirements, Evaluation Criteria based on stakeholder analysis (with justifications) ○ https://drive.google.com/file/d/0B2wX47Xd68dQSnN5MXM3ZUZXSHM/view?usp=sharing September 28, 2017 ● Decided that we could not skip the winnowing process; therefore, we began winnowing the original 18+ concepts ○ Requirements were elaborated based on discussion September 29, 2017 ● Completed a very thorough discussion on needs and evaluation criteria (elaborated, reworded, ensured proper thresholds and justifications, etc.) ○ Determined stakeholder impact on each need ○ Discussed scope of the project ● Completed winnowing (7 concepts passed) September 30, 2017 ● Solidified concepts (in Concept Brainstorming Doc) so that everyone was on the same page ● Back-tracked to winnowing and adjusted the chart based on agreed-on definitions of each concept October 2, 2017 ● Assigned areas of responsibility for the CSR	Team: 10.75H	Total Team: 20H
Amanda	October 1, 2017 ● Weekly Report - began working on the weekly report ● Risk Registry - began creating the risk registry ● Pugh Chart - filled in the template October 2, 2017	Individual: 4H Group:	Total: 31H

	• Completed Weekly Report	10.75H	
Justin	October 1, 2017 • Pugh Chart - filled in the template • Began creating clearer drawings of the 5 concepts in the Pugh Chart in preparation for the CSR	Individual: 2.5H Group: 10.75H	Total: 25H
Jason	September 30, 2017 • Created Pugh Chart Template for the team to fill out over the weekend • Pugh Chart - filled in the template	Individual: 3H Group: 10.75H	Total: 33H
Cole	October 1, 2017 • Updated Gantt Chart • Pugh Chart - filled in the template	Individual: 2H Group: 10.75H	Total: 28H
Juliana	October 1, 2017 • Pugh Chart - filled in the template • Created the CSR checklist and began assigning areas of responsibility • Started creating the Final Report Checklist	Individual: Group: 10.75H	Total: 31H
Rishabh	October 1, 2017 • Updated Gantt Chart • Pugh Chart - filled in the template • Feasibility Calculations for Equipment Tow Concept	Individual: 4H Group: 10.75H	Total: 30H
Danwei	October 1, 2017 • Pugh Chart - filled in the template • Updated the needs, requirements, and evaluation criteria sheet with new client Q/A responses	Individual: 2H Group: 10.75H	Total: 30H

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- This week, we spent a lot of time working on the project, but also had to backtrack several time because of misunderstandings and communication issues. That being said, we did achieve our goal of completing winnowing and are about 75% through the first round of the Pugh Charts
- We also completed a formal stakeholder analysis; from these results, we updated needs, requirements, and evaluation criteria will be created prior to concept evaluation
- We are still in the midst of preparation for the Concept Selection Review; these tasks will continue into this next week.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
  - Gantt Chart: https://drive.google.com/file/d/0B8SU_1NAgAHJaXBuQXlPTjFPSXM/view?usp=sharing
  - CPM: https://drive.google.com/file/d/0B-Wvqhv4ADyAcnpxZkhMMjVWQVk/view?usp=sharing
- We have made a lot of progress this past week after having a bit of unfortunate back-tracking over the last couple of weeks because of our inexperience with backcountry skiing (e.g., needs, requirements, and evaluation criteria). We are still a couple of days behind schedule, but will hopefully get back on schedule by the end of this week (especially since concept evaluation should run a lot more smoothly now with that the team has struggled together in understanding). This past week, we decided to meet a couple of additional times in order to get onto the same page in terms of concepts. This upcoming week will be crucial is staying on track; we hope to gain a lot of additional feedback/guidance from the Concept Selection Review which will also help the team prioritize time and determine project direction.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of Wednesday (October 3rd), the team should have a complete Pugh Chart (first revision) with no more than 4 concepts continuing onto the WDM.
2. By the end of the week, the team should have performed analysis on feasibility and strengths on at least 3 concepts.
   a. The feasibility calculations should be prepared as formal documents for the concept selection review.
3. By the end of the week, all other concept selection review tasks (as shown in the Concept Selection Review Checklist) should be complete.
4. By the end of the week, the team should have a completed WDM with justifications.
   a. The WDM will be in a state that is suitable for presentation at the CSR.

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Complete Pugh Chart, with no more than 4 concepts continuing onto the WDM	October 3, 2017
Team	Complete WDM evaluation criteria weightings and justifications	October 4, 2017
Team	Perform calculations, research, and feasibility studies on assigned concepts (assignments TBD at next meeting) - Complete WDM based on findings	October 6, 2017
Team	Prepare formal documents containing justifications for each concept in the WDM (assignments TBD at next meeting)	October 9, 2017
Cole	Maintain updated Stakeholders Analysis document for CSR Maintain Gantt Chart for CSR	October 9, 2017
Juliana	Maintain updated CSR Checklist (ensure everyone is on track) Complete Final Report Checlist	October 9, 2017
Rishabh	Maintain updated Concept Generation Docs (Meeting Minutes) according the CSR Rubric Create an FMEA for selected concepts (in preparation for detailed design)	October 9, 2017
Jason	Maintain updated Concept Generation Docs (Meeting Minutes) according the CSR Rubric Maintain updated Concept Evaluation Charts for CSR	October 9, 2017
Danwei	Maintain updated Needs, Requirements, and Evaluation Criteria Doc for CSR	October 9, 2017
Justin	Maintain updated Concept Brainstorming Doc (ensure that all calculations, justifications, etc. for the WDM concepts are complete) for CSR Maintain updated Preliminary Research Doc for CSR	October 9, 2017
Amanda	Maintain updated Risk Registry for CSR Create the weekly report	October 9, 2017

O-5 Weekly Report 5: October 11, 2017

MECH 328 Weekly Progress Report ***Dates: Oct. 4 - Oct. 10***

Group: Team 21 Project Title: MECH 328 Backcountry Skiing Ascender

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Note: Because of last week's different definition of the week (i.e., Tuesday to Monday rather than Wednesday to Tuesday), this week's report will have information from last Tuesday. This information will be clearly marked.

Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of Wednesday (October 3rd), the team should have a complete Pugh Chart (first revision) with no more than 4 concepts continuing onto the WDM.
2. By the end of the week, the team should have performed analysis on feasibility and strengths on at least 3 concepts.
    a. The feasibility calculations should be prepared as formal documents for the concept selection review.
3. By the end of the week, all other concept selection review tasks (as shown in the Concept Selection Review Checklist) should be complete.
4. By the end of the week, the team should have a completed WDM with justifications.
    a. The WDM will be in a state that is suitable for presentation at the CSR.

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities* (What was done)	Hours Worked**	
		Last Week	Total
Team	October 3, 2017 *(TUESDAY MEETING FROM LAST WEEK)* ● Finished Pugh Chart (concluded that mobile skis should be removed from consideration as they consistently were the lowest ranked concept) https://drive.google.com/file/d/0B2wX47Xd68dQUjNlT21uVkNrRU0/view?usp=sharing ○ Four concepts continued (equipment tow, rumba snow packer, ski teeth, ski poles) ● Attempted to begin feasibility calculations (5% complete) October 4, 2017 ● Received feedback from Hooman and Bill regarding weekly reports ● Clarified questions regarding the Concept Selection Review (CSR) ● Asked about risk registry (redirected to Mehran) ● Discussed stakeholder analysis, level of influence calculations, and their effect on needs (75% complete) https://docs.google.com/document/d/1b3iT5MXkdcoU__UIfSEwT0nNA6yVCezh2qhq6KaOUew/edit?usp=sharing ● Discussed snow properties ○ Related snow to dry sand well based on research found online ○ From these results, we find that we can do order of magnitude physics to complete our calculations ○ We will also speak to outside sources regarding means to quantify the material properties of snow ● Allocated detail design calculations among the group	Team: 8.75H	Total Team: 28.75H

	• Began detail design calculations as a group (5% complete) October 6, 2017 • Determined weightings for WDM evaluation criteria from rough scale of needs' importance, based on stakeholder level of influence https://docs.google.com/spreadsheets/d/1hqrDbMQ68N7tysfW0of7un_U_-aoel-CAeCw7gena44/edit?usp=sharing • Continued design calculations as a group (15% complete) https://drive.google.com/drive/folders/0B2wX47Xd68dQanJGNGRjQmpOaGc?usp=sharing October 10, 2017 *(HAS NOT TAKEN PLACE)* • A Geological Engineer is expected to speak to the group regarding the material properties of snow and avalanche-related risks. • WDM is expected to be completed; thus no more than two concepts will continue into further detailed design • Concept Selection Review Prep Work is expected to be completed ○ Presentation rehearsal is expected to take place		
Amanda	October 4, 2017 • Reworded and reorganized needs, requirements, and evaluation criteria with clear justifications https://drive.google.com/file/d/0B2wX47Xd68dQWlZMSTV2MVFlZkE/view?usp=sharing October 8, 2017 • Reached to several contact regarding snow research - arranged for one particular contact to speak with the rest of the team October 9, 2017 • Completed the weekly report • Began creating a CSR presentation outline/google drive • Completed and updated risk registry https://drive.google.com/file/d/0B2wX47Xd68dQbHRFV3ZtZXVvQ3c/view?usp=sharing • Elaborated meeting minutes with more detail to accurately showcase progress https://drive.google.com/drive/folders/0B2wX47Xd68dQeVlWb29wdG92NjQ?usp=sharing • Added more detail to Project Scope and Value Proposition Doc https://docs.google.com/document/d/1pXiZ-LVh0hEdGqlnVYk-s4_tutNhBS3LupZSLHHEo28/edit?usp=sharing	Individual: 8.5H Group: 7.5H	Total: 47H
Justin	October 4, 2017 • Finished final concept sketches for remaining concepts going to WDM • Began WDM calculations for Rhumba Packer got the required motor specs October 6, 2017 • Continued WDM calculations on Rhumba Packer got the energy savings from the weight of the backpack October 8, 2017	Individual: 8H Group: 7.5H	Total: 40.5H

	• Finished Concept Brainstorming doc with Juliana (connected features to needs) https://docs.google.com/document/d/1uxjQK-GlOjddL5p7nEsKdPVHU5DVfgO9AqmDCC7le6Y/edit?usp=sharing October 9, 2017 • Finished WDM calculations for Rhumba Packer (elevation gained, approximated cost, volume, and weight)		
Jason	October 4, 2017 • Calculated weight,strength for different materials of snow pole. October 6, 2017 • Discussed solution for snow shear strength with Danwei. • Researched on impact of exercise to muscle (to evaluate quantitatively snow pole's benefit) • Completed feasibility on snow pole October 9, 2017 • Updated logbook • Reformatted Concept Brainstorming Doc for CSR (see above for link)	Individual: 8.5H Group: 6.75H	Total: 48.25H
Cole	October 4, 2017 • Re-evaluated stakeholder levels of influence, conclusive results obtained October 9 , 2017 • Filtering and compiling relevant codes and standards to concepts in WDM https://docs.google.com/document/d/1y_ncqR1R9judUvyJBd5pmRVsnmdvIdFdNdoVx15hX_I/edit?usp=sharing • Added further detail and resource allocation to Gantt Chart	Individual: 5.5 H Group: 8.75	Total: 42.25H
Juliana	October 4, 2017 • Completed Final Report Checklist • Conducted snow research (put research in snow research doc) October 5, 2017 • Recreated WBS on Draw.io (Planhammer free trial expired) October 8, 2017 • Updated WBS with more detail • Added more detail in the Concept Brainstorming Doc • Added more detailed justifications for the evaluation criteria weightings in the WDM • Email Bill about WBS categories October 9, 2017 • Updated WBS according to Bill's recommendations https://drive.google.com/file/d/0B9CGIi89LaUHZE5UOXROYTJmX2c/view?usp=sharing	Individual: 11.75H Group: 8.75H	Total: 51.5H
Rishabh	• October 4, 2017 ○ Created FMEA table to conduct risk analysis during the detailed design phase of the project • October 5, 2017 ○ Conducted research on motors by browsing different manufacturers' websites to find motors with high torque	Individual: 10H Group: 8.75H	Total: 48.75H

	(in the order of 1Nm) and low rpm (in the range of a few 100rpm) ○ Determined that using a high gear ratio (eg 10:1), we can amplify the output torque and lower the output to required levels ○ Researched different types of batteries (Lithium Polymer, Lithium Ion, Nickel Cadmium to determine which battery is the most optimal for skiing weather conditions ● October 9, 2017 ○ Updated the CPM to reflect the changes made by Cole in the Gantt chart ○ Did more detailed calculations for sizing winch for the equipment tow device which would aid in filling WDM parameters for equipment tow ○ Shortlisted motors which can be used to control the mechatronic devices in the WDM table ○ Selected a battery which would be used in the final concept ○ Helped write the 'Design' document for the concept selection review (specifically sections which talk about "inclusion of creative, unusual solutions" and "combination of fragments focused on synergies")		
Danwei	October 3, 2017 ● Updated Background Research Doc with Client Q/A ● Began research feasibility calculations for ski teeth concept October 4, 2017 ● Researched on snow and soil ● Conducted more feasibility calculations on friction force (related to ski teeth) October 5th, 2017 ● Researched density and compressive strength of snow ● Researched possible materials for ski teeth concept ● Researched climbing axes for penetration information relevant to ski teeth concept October 6, 2017 ● Further ski teeth calculations October 7, 2017 ● Put ski teeth research into a formal document October 8, 2017 ● Further background information on the project https://docs.google.com/document/d/1-d04seogBHIx088rvAXY2DGCwXFi0TQIiFubYLj6dC8/edit?usp=sharing	Individual: 9.8H Group: 6.5H	Total: 46.3H

*Summaries of activity include work expected to be done Tuesday after 11am IF the team has a meeting planned. Individual work conducted after 11am on Tuesdays will be included in next week's report.
**Hours do not include the Tuesday meeting from this upcoming week (as it has not yet taken place), nor does it include any individual hours worked on this upcoming Tuesday. These hours are difficult to predict and if predicted, would result in inaccuracies in this report; therefore, these hours will be recorded in next week's report.

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- The team has completed the Pugh Chart (first revision) on time as indicated from last week's goals. The team then continued on with 4 concepts into detailed design calculations which were then used to complete the WDM.
- The calculations were completed based on the assumption that snow has very similar material properties to dry sand. Formal documents of these calculations have been created in preparation for the CSR on Wednesday (October 11th)
- In addition, CSR tasks (as shown in the Concept Selection Review Checklist) are complete. The team plans to reconvene Tuesday evening to rehearse the presentation
- By Wednesday (October 11), the WDM will also be complete (work will be done to complete the WDM Tuesday evening) and no more than 2 concepts will move forward to detailed design.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
  - Gantt Chart: https://drive.google.com/file/d/0B8SU_1NAgAHJcGNieENTUk5LZkE/view?usp=sharing
  - CPM: https://drive.google.com/file/d/0B-Wvqhv4ADyAdHpuTzdNUXcxX28/view?usp=sharing
- The team had a busy week, especially since midterms are beginning in other courses. However, we are decreasing the amount of time that we are behind our schedule. With the work session we have planned for Tuesday, October 10th, the team will be back on schedule with detailed design. Additionally, the team will be prepared for Concept Selection Review by the end of Tuesday and is confident that the review will run smoothly.
- This upcoming week will not be as busy as the last two weeks', especially since a large majority of the team has multiple midterms to study for in other courses.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of the week, the team should have further design calculations completed to quantify the concept as they are (currently, design calculations are suitable for WDM purposes, but not suitable for extensive detailed design).
   a. Further research on each concept in terms of off-the-shelf components will be complete.
   b. Plans outlining next steps for simulations, prototyping, and CAD models will be initiated (~15%), but not completed.
   c. Additionally, synergies from winnowed concepts are considered and calculations using these modifications are started (~50%).
2. By the end of the week, the team should have a formal document outlining the research conducted on the material properties of snow.
3. By the end of the week, report writing will begin in the form of a formal report outline and formal documents (for all work).

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Allocate detailed design research/work among the team (this will be done on Wednesday's meeting, which is within the dates for next week).	October 11, 2017 (end of the day)
Cole	Maintain Gantt Chart Maintain Codes, Standard, and Regulations doc for 2 final concepts	October, 17, 2017
Juliana	Maintain Final Report Checklist Maintain WBS	October, 17, 2017
Rishabh	Maintain FMEA for 2 final concepts	October, 17, 2017
Jason	Maintain Snow Research Doc	October, 17, 2017
Danwei	Maintain Background Research Doc	October, 17, 2017
Justin	Maintain updated Preliminary Research Doc	October, 17, 2017
Amanda	Maintain updated Risk Registry Maintain updated Needs, Requirements, and Evaluation Criteria Doc Create the weekly report	October, 17, 2017

O-6 Weekly Report 6: October 18, 2017

MECH 328 Weekly Progress Report *Dates: Oct. 18 - 24*

Group: Team 21 Project Title: MECH 328 Backcountry Skiing Ascender

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Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of the week, the team should have further design calculations completed to quantify the concept as they are (currently, design calculations are suitable for WDM purposes, but not suitable for extensive detailed design).
    a. Further research on each concept in terms of off-the-shelf components will be complete.
    b. Plans outlining next steps for simulations, prototyping, and CAD models will be initiated (~15%), but not completed.
    c. Additionally, synergies from winnowed concepts are considered and calculations using these modifications are started (~50%).
2. By the end of the week, the team should have a formal document outlining the research conducted on the material properties of snow.
3. By the end of the week, report writing will begin in the form of a formal report outline and formal documents (for all work).

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	October 10, 2017 (This meeting is technically from last week, but was written down in last week's report as propstive. The entry below shows exactly what was accomplished in the meeting.) ● Interview with Bryan https://docs.google.com/document/d/1a9PeyTzrpV5RoX8Knz5zRHP9TPzN9MtbeoraZfCWgzw/edit?usp=sharing ○ From our discussion with Bryan, we decided that the ski teeth and the ski pole concepts should have failed winnowing (based on our scope) ○ Narrowed/Solidified our project scope https://docs.google.com/document/d/1pXiZ-LVh0hEdGqInVYk-s4_tutNhBS3LupZSLHHEo28/edit?usp=sharing ○ Updated WDM Evaluation Criteria Weightings based on finding with Bryan ■ We determined some out-of-scope evaluation criteria (changes reflected in the "Needs, Requirements, and Evaluation Criteria" doc) https://docs.google.com/spreadsheets/d/1FizqU3-Iy-_xH7_EkKjYzjYYfODCXGVZt3gm4F7pfog/edit?usp=sharing ■ We discovered that cost and weight on skis were larger factors than previously thought ● Completed the WDM based on design calculations ○ The trail breaker (previously named the Rumba Packer) will continue to detail design https://docs.google.com/spreadsheets/d/1hqrDbMQ68N7tysfW0of7un_U_-aoel-CAeCw7gena44/edit?usp=sharing	Team: 11H	Total Team: 39.75H

	• Prepared for Concept Selection Review (i.e., made slides, gathered important documents into a single folder, etc.) https://drive.google.com/drive/folders/0B9CGIi89LaUHQnhZREdVNnQxZFE?usp=sharing
	October 11, 2017
	• CSR Prep
	  ○ Reviewed slides (previously formatted by Amanda)
	  ○ Wrote notes for a presentation outline (i.e., a script)
	  ○ Rehearsed the presentation
	• Discussed a timeline for next steps (updated Gantt Chart)
	  ○ Detail design done by the end of November 1st
	  ○ Report First Draft done by the end of November 8th
	  ○ Report Second Draft done by the end of November 12th
	  ○ Final report done and submitted by November 17th
	October 13, 2017
	• Checked-in with how everyone is feeling (iPeer)
	• Discussed CSR feedback
	  ○ Agreed that, overall, the session went well
	  ○ Found that the WDM needs to be very well justified (which we seem to have accomplished)
	  ○ Confirmed that detail design is our next step
	• Detail Design Subteams
	  ○ Went through the final report checklist in order to determine our next steps and items that still need to be addressed.
	  ○ Identified major subsystems for the device to be controls, chassis, propulsion/drive train
	  ■ Within propulsion/drive train, the team split up to work on either motors/battery or powertrain/propulsion mechanism
	October 16, 2017
	• Recapped weekend tasks (i.e., updating risk registry, creating a BOM template, updating WBS, etc.)
	  ○ See below for more details on individual tasks
	• Confirmed deadline to complete sub-system design (Monday)
	• Continued work in subteams
	  ○ Track Research and Calcs https://drive.google.com/drive/folders/0B51eAaBCShc_UzIzNE8wN21INkE?usp=sharing
	  ○ Motor Research and Calcs https://docs.google.com/document/d/1qfQOCwyl05ZfvTNNHep8YhBLnwgSo4WV0rZOSXgFp-I/edit?usp=sharing		

Amanda	October 10, 2017 • Formatted CSR Presentation Slides October 16, 2017 • Updated Risk Registry https://docs.google.com/spreadsheets/d/1eJdf294C6jD31OFjHC4oHcON69dPCWAgw9tg6P9P-WY/edit?usp=sharing • Completed Weekly Report • Began more in-depth snow research	Individual: 4H Group: 11H	Total: 62H

Justin	October 16,2017 ● Began specifications document for motor/battery in detailed design ● Confirmed preliminary calculations with Rishabh and Cole	Individual: 1H Group: 11H	Total: 52.5H
Jason	October 14, 2017 ● Set up Bill of Material Document https://drive.google.com/open?id=1_YKf46HT1TNlsHhweFoqaq6CYV9pKD4oT3EgACQfc8I ● Research on Technical Drawing Standard ○ Created a preliminary CAD template ● Research on Robot Track https://docs.google.com/spreadsheets/d/1SmEZ27-0NPtiA57qKFc0R3ncLaLq1izi0Jdwt0jJE0A/edit?usp=sharing	Individual: 2.5H Group: 10H	Total: 60.75H
Cole	Oct 15, 2017 ● Updated Gantt chart with more detail and resource allocation (see below) ● Updated the relevant codes and standards page	Individual: 1.75H Group: 11H	Total: 55H
Juliana	October 15, 2017 ● Updated WBS ● Completed the formal report outline (began allocating tasks/responsibilities according to the checklist)	Individual: 1H Group: 11H	Total: 63.5H
Rishabh	October 11, 2017 ● Updated equipment tow design calculations, resulting parameters and references as a pdf to CSR google drive folder ● Updated trail breaker motor calculations and list of resulting estimated parameters ● Continued to work on FMEA Template https://docs.google.com/spreadsheets/d/1frV-iwp4EgYEd-bgIpB5EYmDq714qY-IbuvELlGCvyc/edit?usp=sharing October 16, 2017 ● Researched more about Lithium Ion batteries https://docs.google.com/document/d/1xYcxL6ZwLUWsSAHUUTMqB8JLv-RyUWn9gTcqAgKoRHo/edit?usp=sharing ○ Found cheap 48V 5-10Ah Li-Ion batteries on Alibaba https://docs.google.com/document/d/1yBoXR748DBcyEre1YqT5kzeoj5s7280pkXrYEE-WhjU/edit?usp=sharing	Individual: 1.5H Group: 11H	Total: 59.25H
Danwei	October 16th, 2017 ● Updated Preliminary Research doc	Individual: 1.3H Group: 11H	Total: 58.6H

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- This past week, the team spent about 6 hours working on the WDM in order to come to a decision of which concept will continue into detailed design.
    - The concept that passed the WDM is the Trail Breaker (previously names the "Rumba Packer"). This was the concept that was presented at the Concept Selection Review, which was well-received by our audience.
- Further research on the trail breaker in terms of off-the-shelf components is on-going (~75%); however, research for the rest of the concepts that did not pass the WDM is complete (we used this information to roughly estimate costs for each concept).
    - This type of research is difficult to gauge as our specs change as we continue to reiterate our design, which results in having to research new components for the different specifications.
- As a team, we discussed, in detail, our next steps and decided on a timeline for tasks.
    - We also began executing this plan, which is currently on-going (~15%).
    - The timeline can be seen in our Gantt Chart.
- Synergies from winnowed concepts were not yet considered; the team plans to complete (100%) this goal by the end of this week.
    - The team discovered that this goal was not realistic as it required a complete set of fully-designed subsystems (the goal for this upcoming week).
- The team has added a formal section on research conducted on the material properties of snow to the "Preliminary Research" doc; this section will be complete (100%) by next week.
- The team has created a formal report outline and, because of our CSP prep, all existing documents are presentation-ready (thus, report ready).

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
    - Gantt Chart: https://drive.google.com/file/d/0B8SU_1NAgAHJOTd0cHAtZ1JHRG8/view?usp=sharing
    - CPM: https://drive.google.com/file/d/0B-Wvqhv4ADyATk02TmltX3Y4WEE/view?usp=sharing
- This past week, the team spent over 6 hours on Tuesday preparing for the CSR review; as a result, the team has had a fairly relaxed week comprised mostly of planning. Additionally, the team is officially back on schedule with detail design. With the timeline that was discussed, the team expects to stay on track for the remainder of the project (we have schedule many lag days/contingencies and have considered time management risks).

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of this week, the team expects to have preliminary subsystems complete (100%).
    a. This implies that geometry is complete (input/output requirements) as well as off-the-shelf components have been specified.
2. From these complete designs, the team plans to begin discussing how to integrate the subsystems (~15%).
    a. Synergies from winnowed concepts (goal from last week) will be analyzed and considered to aid in the integration of the various subsystems.
3. By the end of the week, snow research (from the Avalanche Textbook provided by Bryan) will be complete.

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Complete subsystem design ● Motors/Battery - Cole, Rishabh, Justin ● Propulsion Mechanism/Drivetrain - Amanda, Jason, Danwei, Juliana Begin integration of subsystems	October 23, 2017
Cole	Maintain Gantt Chart	October 23, 2017
Juliana	Maintain WBS	October 23, 2017
Rishabh	Maintain CPM	October 23, 2017
Jason	Begin rough CAD Models for subsystems	October 23, 2017
Danwei	Maintain Background Research Doc and Preliminary Research Doc	October 23, 2017
Amanda	Maintain updated Risk Registry and Needs, Requirements, and Evaluation Criteria Doc Complete Snow Research Doc Create the weekly report	October 23, 2017

O-7 Weekly Report 7: October 25, 2017

MECH 328 Weekly Progress Report *Dates: October 18-24*

Group: Team 21 Project Title: MECH 328 Backcountry Skiing Ascender

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Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of this week, the team expects to have preliminary subsystems complete (100%).
    a. This implies that geometry is complete (input/output requirements) as well as off-the-shelf components have been specified.
2. From these complete designs, the team plans to begin discussing how to integrate the subsystems (~15%).
    a. Synergies from winnowed concepts (goal from last week) will be analyzed and considered to aid in the integration of the various subsystems.
3. By the end of the week, snow research (from the Avalanche Textbook provided by Bryan) will be complete.

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	October 18, 2017 ● Discussed CSR Presentation and Next Steps ○ Overall a good presentation ○ A couple of issues with the WDM and the concept that is continuing to detail design (the trail breaker) ■ Bill questions rankings for compatibility and time for adjustment evaluation criteria. ■ Bill worries that the device will become a snow plow rather than a snow packer (snow might clog up the propulsion mechanism) ■ Bill suggests we have a backup device/functionality (reducing skier load) ○ Battery Discussion ■ Hooman suggests that we look into 18-650 D-cells and Battery Clerk ● Weekly Report Feedback - increasingly higher quality (keep it up) ● Interview Recap ○ Michael brings up the point that trail breaking is an art that is difficult to replace with an autonomous robot; though he agrees that reducing the load on the skier is a huge issue ● WDM Discussion ○ Voted to change the definition of "fully compatible" to include "devices that are substitutions to existing equipment as long as no loss of functionality results, devices that are a completely new addition to existing gear, and devices that work with all existing equipment". ○ As a result, the equipment tow is the more highly ranked concept; therefore, it will move on to detail design.	Team: 7H	Total Team: 44.75H

	• Identification of Main Components/Design Tasks for the Equipment Tow
	  ○ Power Train
	  ■ Gear Train
	  ■ Winch Drum Sizing
	  ■ Winch Drum Enclosure
	  ■ Motor Sizing
	  ■ Battery Selection
	  ■ Battery Thermal Insulation
	  ○ Backpack/Sled Design (define geometry of the board)
	  ■ Sled Gripping Mechanism
	  ■ Battery Mounting on Sled
	October 20, 2017
	• Decided that the concept will not require the design of a new backpack, but will instead be compatible with existing backpacks (i.e., sled will attach to backpacks)
	• WDM calculations for the equipment tow were off by a factor of 2 meaning that the concept is even more viable according to the WDM
	  ○ E.g., Time for adjustment is reduced from 2 hour to 1 hour
	October 23, 2017
	• Discussed CSR feedback and marks
	• Worked in subteams
	  ○ Winch Design
	  ■ Began getting quotes for components
	  ■ Continued working on winch CAD
	  ○ Rope
	  ■ Continued with researching off-the-shelf components https://docs.google.com/document/d/1Ntx9yEybq0z3fgAHGdzJbfaR_wrIPWHBI94RS8-i778/edit?usp=sharing		

Amanda	October 18, 2017 (2H) • Updated WDM Doc (https://docs.google.com/spreadsheets/d/1hqrDbMQ68N7tysfW0of7un_U_-aoel-CAeCw7gena44/edit?usp=sharing), Needs, Requirements, and Evaluation Criteria Doc (https://docs.google.com/spreadsheets/d/1FizqU3-Iy-_xH7_EkKjYzjYYfODCXGVZt3gm4F7pfog/edit?usp=sharing), and Concept Brainstorming Doc (https://docs.google.com/document/d/1uxjQK-GlOjddL5p7nEsKdPVHU5DVfgO9AqmDCC7Ie6Y/edit?usp=sharing) with new definition of compatibility and the fact that the equipment tow concept passes into detail design • Interviewed Michael Shynkaryk, Corwin Shanner, and Bryan Starick (online)	Individual: 2.5H Group: 5H	Total: 70.5

	• Updated/Re-organized the Interview Document https://docs.google.com/document/d/1a9PeyTzrpV5RoX8Knz5zRHP9TPzN9MtbeoraZfCWgzw/edit?usp=sharing October 20, 2017 (0.5H) • Weekly Report (20% complete) October 23, 2017 (1H) • Weekly Report • Continued interview with Michael Shynkaryk		
Justin	October 21, 2017 • Researched Planetary Geartrain	Individual: 1H Group: 7H	Total: 60.5H
Jason	October 21, 2017 • Researched and Determined Sizing for Winch Drum • Rough CAD modelling https://drive.google.com/open?id=0B51eAaBCShc_REYtdWx6SVlWRkk October 23, 2017 • Rough Quoting for drum to be made by injection molding https://drive.google.com/open?id=0B51eAaBCShc_WldmUDNjWGVBWUU	Individual: 2H Group: 7H	Total: 69.75H
Cole	Oct 19, 2017 • Determined minimum area for device to snow contact surface	Individual: 2H Group: 7H	Total: 64H
Juliana	Oct 21, 2017 • Finished selecting winch rope Oct 22, 2017 • Updates WBS https://drive.google.com/file/d/0B9CGli89LaUHbkdoOGV5a0hYZzQ/view?usp=sharing • Worked on preliminary research document to adjust links connected to our research	Individual: 1H Group: 5H	Total: 69.5
Rishabh	October 20, 2017 • Recalculated torque required by the motor to lift the equipment tow based on the changed drum diameter and increased mass	Individual: 1H Group: 7H	Total: 67.25H
Danwei		Individual: 0H Group: 7H	Total: 65.6H

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- This past week, the team has completed 75% of the design of preliminary subsystems.
    - Geometry of the subsystems have been sketched and are in the midst of being modeled using CAD software.
    - Off-the-shelf components have been specified (if needed) for the rope; the batteries and motor have not been chosen, but a shortlist has been created.
- Integration of the subsystems has begun (perhaps prematurely), which is partly why the individual subsystems are not yet complete; however, when they are complete, less effort will be spent on the integration of the subsystems as that consideration is currently being considered.
- Snow research (from the Avalanche Textbook provided by Bryan) is complete.
    - From this research, dimensions for the backpack's sled have been calculated.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
    - Gantt Chart: https://drive.google.com/file/d/0B8SU_1NAgAHJOTd0cHAtZ1JHRG8/view?usp=sharing
    - CPM: https://drive.google.com/file/d/0B-Wvqhv4ADyATk02TmltX3Y4WEE/view?usp=sharing
- This past week, the team had yet another major change. Based off of feedback from Bill and Hooman, the team decided to re-evaluate the WDM which resulted in the equipment tow concept being more highly ranked than the trail breaker. Subsequently, the team lost two days of detail design work (spent on the trail breaker); however, the equipment tow concept is expected to be much simpler (development risk is lower) and, therefore, expected to be easier to complete the detail design. In terms of timeline, the team has not yet fallen behind and plans to complete a design by the end of the next week.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of the week, the team expects to have an integrated design concept
    a. This implies that geometry is complete (input/output requirements) as well as off-the-shelf components have been specified.
2. By the end of the week, the team expects to begin the first round of FMEA on the completed concept (10% complete).

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Complete preliminary deisgn • Motors/Battery - Cole, Rishabh • Planetary Gear Train - Justin • Winch - Amanda, Jason, Danwe • Rope - Juliana Begin FMEA	October 30, 2017
Cole	Maintain Gantt Chart	October 30, 2017
Juliana	Maintain WBS	October 30, 2017
Rishabh	Maintain CPM	October 30, 2017
Jason	Complete CAD models	October 30, 2017
Danwei	Maintain Background Research Doc and Preliminary Research Doc	October 30, 2017
Amanda	Maintain updated Risk Registry Maintain Needs, Requirements, and Evaluation Criteria Doc Maintain Interviews Doc Create the weekly report	October 30, 2017

O-8 Weekly Report 8: November 1, 2017

MECH 328 Weekly Progress Report *Dates: Oct 25 - Nov 1*

Group: Team 21 Project Title: MECH 328 Backcountry Skiing Ascender

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Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of the week, the team expects to have an integrated design concept
    a. This implies that geometry is complete (input/output requirements) as well as off-the-shelf components have been specified.
2. By the end of the week, the team expects to begin the first round of FMEA on the completed concept (10% complete).

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	October 25, 2017 ● Discussed CSR Feedback and Marks with Bill and Hooman ○ Drafted an e-mail to Bill to forward regarding clarifications on the CSR marks/feedback ○ Issues that need to be addressed are the numerous WDM Evaluation Criteria (muddles out the importance of evaluation criteria and did not adequately justify the weighting of "risk of development") ■ Also, the presentation did not make it clear how concepts passed the pugh chart (specifically the dollar and mass values) ● Weekly Report Feedback ○ WDM should be changed now rather than later so that the process is linear and comparisons can be made ■ Make sure to highlight the major components on how we chose the evaluation ○ An absolute scale is better to use than a relative scale, even if there are only two concepts in the WDM ■ Relative scale is too black/white ○ Functional Decomposition Chart is required ● Completed Functional Decomposition Chart ● Updated WDM (V2 is the second sheet) ○ Cut down the evaluation criteria to the most important ones (combined a few that were too similar) and ensured that weights did were not smaller than 5% ○ Created an absolute scale for each evaluation criteria ○ Re-scored both concepts ■ The equipment tow ranked higher by 0.40 points October 26, 2017 ● Worked on the initial FMEA ● Detail Design Group Work Session ○ Found a website for motors that have integrated gear trains to achieve gear reductions that we need	Team: 18H	Total Team: 62.75H

	○ Specified rope and winch drum ○ Decided that the winch requires a level wind to guide the rope into the drum ■ Researched the LeBus Counterbalanced Spooling System as another mechanism for ensuring that the rope lies flat on the drum ■ Researched self-reversing screws October 27, 2017 ● Detail Design Group Work Session ○ Specified the motor (has 50% efficiency - will continue to optimize in the second round of detail design) ○ Researched transmission mechanisms (clutch bearings and motor shaft mounting) ○ Specified ring bushings at ~$12/unit (need 2 per device) ○ Continued the design of the level wind ■ Completed the CAD for the self-reversing screw ■ Completed the CAD for the carriage October 28, 2017 (3) ● Detail Design Group Work Session ○ Summaries of Component Research ○ Began filling in the Bill of Materials ○ CAD files are underway ● Completed 85% of the subsystem design October 31, 2017 *(HAS NOT TAKEN PLACE)* ● Completed (expected) integrated concept design (CAD) ● Completed (expected) Bill of Materials (initial)		
Amanda	October 28, 2017 ● Began the weekly report (60% complete) ● Formatted and filled in the initial FMEA October 30, 2017 ● Updated the risk registry ● Completed the weekly report	Individual: 3H Group: 13.5H	Total: 87H
Justin	October 25, 2017 ● Initial FMEA for powertrain-gears October 27, 2017 ● Researched/Designed bearing/power transmission system October 28, 2017 ● Selected bearings and began designing bushing adapter sleeve for motor shaft	Individual: 2H Group: 15H	Total: 77.5H
Jason	October 25, 2017 ● Researching Levelwind existing system, planetary gears and clutch October 27, 2017 ● Researched/Designed winch supports October 30, 2017 ● Put together initial assembly of sub system, design supporting plate, modifying drum/level wind shaft	Individual: 7H Group: 17H	Tota: 93.75H

Cole	October 27, 2017 • Gantt Chart Updates, FMEA Justifications, Battery insulation Work October 30, 2017 • Gantt Chart Updates, FMEA Scoring	Individual: 4H Group: 14H	Total: 82H
Juliana	October 27, 2017 • Researched bushings for drum October 30, 2017 • Updated WBS • Completed FMEA Scoring • Updated BOM	Individual: 2H Group: 18H	Total: 89.5H
Rishabh	October 26, 2017 • Researched PG71 motor which delivers high torque and low rpm • Plotted the given curves for 12V and 14V input voltages for that motor using MATLAB • Decided to use 14V input voltage curves for the motor because 4-cell 18650 Lithium Ion Battery's nominal voltage (14.4V) is very close to 14V • Input masses of several subsystems in the MATLAB script • Used iterative calculation in MATLAB to determine the final operating torque and mass value of the equipment tow device October 28, 2017 • Improved the MATLAB model by inputting masses of smaller components and reperformed iterative calculation October 29, 2017 • Added missing columns in FMEA (Expected results of recommended actions) • Added causes of failures to battery and motor sections and assigned scores for severity, occurrence, and detection October 30, 2017 • Researched different vendors selling 18650 Lithium Ion batteries (Sony, Panasonic, LG, Samsung) and chose Panasonic's NCR 18650B batteries due to high energy density • Updated the CPM according to match the latest Gantt chart	Individual: 9.5H Group: 13H	Total: 84.75H
Danwei	October 26,2017 • Gear interference calculation • Search for gears October 29,2017 • Select bushing for idler gear	Individual: 2H Group: 16H	Total: 85.6H

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- The team has completed the design of all subsystems and expects to have the integrated design complete by the end of their Tuesday meeting.
    - Because during the design of subsystems, consideration for the integration of subsystems had to be taken into effect (i.e., motor/battery design fed parameters to transmission), the integration of the subsystems is partially complete (50%). On Tuesday, only the smaller details (e.g., shaft welding) will be discussed and determined.
    - The initial BOM (for both off-the-shelf components and components that require custom manufacturing) is complete.
    - CAD models of subsystem are complete (especially for components that require custom manufacturing).
- The initial FMEA is complete and the completion of the mid-range FMEA has begun (5%).
- The functional decomposition chart, specific for the equipment tow, is complete.
- The updated WDM which addresses issues such as a large number of evaluation criteria and a relative scale is complete.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
    - Gantt Chart
    - CPM
- The team had spent considerably more time (18H of group hours) on the project this week; all team members understand what is not expected, and so meetings were dedicated to group work sessions rather than typical meetings. Although the team had to address a few issues with past documents (brought to light from CSR feedback and weekly meeting discussion), the team is still on schedule with the detail design. Initially, the detail design stage did not account for multiple iterations of the final design. However, the team has decided that in order complete a more in-depth detail design phase, it will split up into two groups (one to begin report writing and another to complete a second round of detail design optimization). Because the team has been documenting their progress well, the report writing should be easier to complete. In terms of risk, this decision increases the risk of falling behind in terms of the report writing, but the team has decided that the benefits of a second look at the final design is worth this risk.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of next week, the team will have completed the second round of detail design (i.e., the final concept will be complete).
    a. This implies that the final BOM will be complete.
    b. This implies that CAD models, assemblies, and drawings will be complete.
    c. This implies that the mid-range and final FMEA will be complete.l
2. By the end of this week, the team will have completed 75% of the appropriate simulations
3. By the end of next week, the team will have completed 75% of the first draft of the final report and appendices.

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Finish the second round of detail design Complete mid-range and final FMEA Complete 50% of design simulations Complete 75% of the first draft of the formal report (delegate sections)	November 6, 2017
Amanda	Maintain updated Risk Registry Maintain updated Needs, Requirements, and Evaluation Criteria Doc Create the weekly report Complete CAD drawings (for machining)	November 6, 2017
Justin	Complete CAD assembly for first iteration and final iteration of full design Complete CAD drawings (for machining)	November 6, 2017
Jason	Complete CAD assembly for first iteration and final iteration of full design Complete design CAD animations	November 6, 2017
Cole	Maintain Gantt Chart Complete stress analysis and simulation for sled Complete thermal insulation for batteries	November 6, 2017
Juliana	Maintain final BOM Main mid-range FMEA Maintain WBS	November 6, 2017
Rishabh	Maintain CPM Complete simulation for motor	November 6, 2017
Danwei	Maintain Background Research Doc and Preliminary Research Doc Complete design CAD animations	November 6, 2017

O-9 Weekly Report 9: November 8, 2017

MECH 328 Weekly Progress Report *Dates: Nov 1 - Nov 7*

Group: Team 21 Project Title: MECH 328 Backcountry Skiing Ascender

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Last Week's Goals: *cut and paste additional entries as required.*

1. By the end of next week, the team will have completed the second round of detail design (i.e., the final concept will be complete).
    a. This implies that the final BOM will be complete.
    b. This implies that CAD models, assemblies, and drawings will be complete.
    c. This implies that the mid-range and final FMEA will be complete.l
2. By the end of this week, the team will have completed 75% of the appropriate simulations
3. By the end of next week, the team will have completed 75% of the first draft of the final report and appendices.

Last Week's Activities: *list activities include hours worked by each group member.*

Name (Who)	Activities (What was done)	Hours Worked	
		Last Week	Total
Team	October 31, 2017 (This meeting is technically from last week, but was written down in last week's report as propstive. The entry below shows exactly what was accomplished in the meeting.) • Completed initial BOM, initial FMEA, and CAD models • Began mid-range FMEA, Began mid-range BOM • Began second round of design (i.e., optimization and secondary design considerations) November 1, 2017 • Received weekly report feedback from Bill and Hooman • Received clarifications on the formal report November 6, 2017 • Updated the team with individual progress over the weekend • Discussed final report formatting rules and method • Discussed word count allocation for the report • Allocated final report sections	Team: 7H	Total Team: 69.75H
Amanda	November 5, 2017 • Created a final report document • Completed first draft of the letter of transmittal November 6, 2017 • Completed weekly report • Updated the risk registry	Individual: 7H Group: 7H	Total: 101H
Justin	October 31, 2017 • Designed bushing sleeve on SOLIDWORKS November 3, 2017 • Researched and estimated shipping costs for bulk orders • Researched duties and tariffs November 4, 2017 • Researched/estimated bulk orders for components	Individual: 6H Group: 7H	Total: 90.5H

Jason	November 2nd • CAD left and right support, gear assembly. November 3rd • CAD Left Case, battery placement. • Calculated torque applied to gears. • Ran simple simulation for Level Wind Carriage needle. November 4th • CAD Right Case, cross bars. November 5th • CAD bottom attachment • Modified sled design and drum/level wind shaft/guide shaft dimensions. • Addressed waterproofing.	Individual: 11H Group: 7H	Total: 111H
Cole	November 3, 2017 • Passive Heating Calculations, Results: Not Feasible November 6, 2017 • Gantt Maintenance	Individual: 5.5H Group: 7H	Total: 94.5H
Juliana	November 3, 2017 • Mid-range FMEA November 4, 2017 • Mid-range FMEA	Individual: 3H Group: 7H	Total: 99.6H
Rishabh	October 31, 2017 • Matlab script to determine battery mass and number of cells • Completed the CAD of the battery pack using Panasonic NCR18650B cells • Completed the battery and motor sections in the FMEA • Battery Power Loss and Mass calculation: Computed the power loss due to battery's internal resistance and determined the exact mass of the battery November 6, 2017 • Updated the CPM • Updated the battery pack CAD so that it fits inside the enclosure • Battery Capacity vs Temperature Curves: To optimize the amount of insulation and additional electrical energy required to ensure that the device can operate for 5.5 hours	Individual: 4H Group: 7H	Total: 95.75H
Danwei	November 2, 2017 • Conducted a stress analysis on the Nylon 101 pinion November 3, 2017 • Conducted a stress analysis on the steel pinion November 4, 2017 • Conducted a stress analysis on the Nylon 101 pinion (with updated values November 5, 2017 • Found a keyway for pinion	Individual: 10.5H Group: 7H	Total: 103.1H

Summary of progress: *Write a short summary of the progress you have made over the past week with reference to the goals listed above and the current schedule.*

- The team has completed the second round of detail design; however, the corresponding documents (e.g.,final FMEA, CAD models, final BOM) still have minor details that have yet to be added.
- The team has completed 75% of the simulations within the scope of this project.
    - This includes analysis on the sled force analysis, stress analysis on the winch design, and a rough optimization analysis of weight and volume of the entire design.
    - An analysis for the thermal insulation of the batteries has been started, but is not yet complete.
- The team is currently writing the formal report (%15). Because of other courses and a bit more focus on the final design itself, the team has little in the report document itself, but most of the sections can be mostly copied/pasted from documents maintained throughout the project.

Assessment of Overall Progress: *Attach your schedule showing the current date and state of completion of each task. Is the project on schedule? If there are major issues what must be done to overcome them?*

- Please refer to the schedule linked below:
    - Gantt Chart
    - CPM
- The team spent a total of 7 hours in collaborative work this last week. This was due to work becoming more independent with less area of overlap occurring. As such, the majority of productivity this week came from individual efforts. The team primarily met the goal of having a detailed design finished for Nov 6th; however, some minor miscommunication has caused the number of batteries required to be reevaluated. Barring this recalculation, which does not require a large portion of the team's resources, the timeline for an initial rough final report draft completed for Nov 13th is unaffected. A good portion of the team, however, is still in the midst of midterms and it has been acknowledged that many sections of the report will not have significant progress made before the weekend.

Goals for Next Week: *List targets for completion for next week. If work is ongoing, indicate the target percentage of completion of tasks. Make additional entries as required.*

1. By the end of next week, the team expects to have the final report complete, printed, professionally bound, and ready for submission.
2. By the end of next week, the team expects to begin organizing the oral presentation (10% complete).

Action Items for Next Week: *What action is to be taken, which goal(s) is this addressing, who will do it, and what is the scheduled date for completion?*

Name (who)	Action(s) (what)	Due Date(s) (when)
Team	Complete first draft of Final Report ● Specific Section Responsibilities	November 13, 2017

APPENDIX P: REFERENCES

ASTM International. Standard Guide for Training of Personnel Operating in Mountainous Terrain (Mountain Endorsement) (ASTM F3027-13). Retrieved from: https://www.astm.org/Standards/F3027.htm

ASTM. Mechanical Relaxation of Residual Stresses (STP993). Retrieved from https://www.astm.org/DIGITAL_LIBRARY/STP/SOURCE_PAGES/STP993.htm

ASTM. Fire Hazard and Fire Risk Assessment (STP1150). Retrieved from https://www.astm.org/DIGITAL_LIBRARY/STP/SOURCE_PAGES/STP1150.htm

AGMA. Tooth Proportions for Plastic Gears (1006-A97). Retrieved from http://members.agma.org/ItemDetail?iProductCode=1006-A97&Category=STANDARDS

AGMA. Gears - Evaluation of Instruments for the Measurement of Individual Gears (18653-A06). Retrieved from http://members.agma.org/ItemDetail?iProductCode=18653-A06&Category=STANDARDS

AndyMark. Retrieved from: https://www.andymark.com/PG71-Gearmotor-With-Encoder-p/am-2971.htm

Amazon. Retrieved from: https://www.amazon.com/ref=nav_logo

AA Portable Power Corp. Retrieved from: http://www.batteryspace.com/component-connector4pinmalecannonplugforch-z-usc-259v-60ch-z-usc-370v5achargeretc.aspx

B. Galloway. Test Summary. Andy Mark Geared DC Motor. Jan. 2012.

Bang good. Retrieved from: https://www.banggood.com/DC-12V-10A-Relay-1CH-Wireless-RF-Remote-Control Switch-Transmitter-Receiver-p-1040721.html?cur_warehouse=CN

B. (n.d.). Geekcreit® DC 12V 10A Relay 1CH Channel Wireless RF Remote Control Switch Transmitter With Receiver. Retrieved November 10, 2017, from https://www.banggood.com/DC-12V-10A-Relay-1CH-Wireless-RF-Remote-Control-Switch-Transmitter-Receiver-p-1040721.html?cur_warehouse=USA

B. Galloway. AM-0914 (PG71 Gearmotor) Dynamometer Test Method. Andy Mark Geared DC Motor. Jan. 2012.

Calcium-Magnesium Silicate Thermal Insulation Sheet, 4.75m x 610mm x 13mm. (n.d.). Retrieved November 10, 2017, from: http://uk.rs-online.com/web/p/thermal-insulating-sheets/7248912/

Calorielab. Calories burned search results for Winter activities. Retrieved from: http://calorielab.com/burned/?mo=se&gr=19&ti=winter+activities&q=&wt=150&un=lb&kg=68

Comparison of Energy Density in Battery Cells [Digital image]. (2014, February 28). Retrieved September 30, 2017, from http://www.epectec.com/batteries/cell-comparison.html

Comparing the Biomechanical Demands of Different Running Surfaces. (2015, January 13) Retrieved from: https://www.freelapusa.com/comparing-the-biomechanical-demands-of-different-running-surfaces/

Call 2 Recycle. (2016, January 15) Retrieved from: https://www.call2recycle.ca/

Deep groove ball bearings 6802-2RS. Retrieved from: http://www.vxb.com/Wholesale-Lot-1000-6802-2RS-Ball-Bearing-p/6802-2rs-wholesale.htm

DC040B 40mm Brushed DC Motor. Retrieved from: http://www.haydonkerkpittman.com/products/motors/brushedmotors/dc040b

Ekberg. L. (2006, December 19). Configurable snowshoe and ski device. Retrieved from: https://www.google.com/patents/US7150464

Evo. How to get started backcountry skiing & snowboarding. Retrieved from: https://www.evo.com/guides/how-to-get-started-backcountry-skiing-snowboarding

Ebay. Retrieved from: https://www.ebay.com/

FreeBoots Enterprises. (2017) Backcountry Skiing Ascender Proposal. Retrieved from: https://connect.ubc.ca/webapps/blackboard/execute/content/file?cmd=view&content_id=_4457966_1&course_id=_103696_1&framesetWrapped=true

Greasley. S. (2013, August 29). How Much Does Packaging Cost. Retrieved from: https://howtobuypackaging.com/how-much-does-packaging-cost/

Gray. T. H. (2012, April 26). Reasonable Markup to Distributors. Retrieved from: http://www.tom-gray.com/2012/04/26/reasonable-markup-to-distributors/

Hobbyking. Retrieved from: https://hobbyking.com/en_us

India’s Organized Manufacturing Sector. (2013, August 28). Retrieved from: https://www.bls.gov/fls/india.htm

IEEE. IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems (1588-2008). Retrieved from: http://standards.ieee.org/findstds/standard/1588-2008.html

IEEE. Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers (C37.90.2-2004). Retrieved from http://standards.ieee.org/findstds/standard/C37.90.2-2004.html

IEEE. IEEE Guide for AC Motor Protection (C37.96-2012). Retrieved from http://standards.ieee.org/findstds/standard/C37.96-2012.html

ISO. Rubber, Vulcanized or Thermoplastic − Determination of Low-temperature Brittleness (ISO 812). Retrieved from https://www.iso.org/obp/ui#iso:std:iso:812:ed-4:v1:en

ISO. Safety of machinery − Safety-related parts of control systems − Part 1: General principles for design (ISO 13849). Retrieved from: https://www.iso.org/obp/ui#iso:std:iso:13849:-1:ed-3:v1:en

ISO. Condition Monitoring and Diagnostics of Machines − Vibration Condition Monitoring − Part 9: Diagnostic Techniques for Electric Motors (ISO 13373). Retrieved from https://www.iso.org/obp/ui#iso:std:iso:13373:-9:ed-1:v1:en

Liion. Retrieved from: https://liionwholesale.com/products/protected-panasonic-ncr18650b-3400mah-li-ion-18650-button-top-battery?variant=1925834564

Lowe's. Retrieved from: https://www.lowes.ca/tie-downs-bungee-cords/secure-tite-mini-bungees-4 pack_g1600452.html

Latham, N. Y. (1967, December 7). Gear Failures. Retrieved from: http://www.xtek.com/pdf/wp-gear-failures.pdf

Lithium Ion Rechargeable Battery Technical Information. (2012, June 29). Retrieved from: https://cdn.shopify.com/s/files/1/0674/3651/files/Sony_VTC4.pdf?838

Lithium Ion Rechargeable Battery Technical Information. (2013, August 26). Retrieved from: https://www.powerstream.com/p/us18650vtc5-vtc5.pdf

MEC. (N/A). Kahtoola K-10 Hiking Crampons ‐ Unisex. Retrieved from: https://www.mec.ca/en/product/5044-167/K-10-Hiking-Crampons

McClung, D., & Schaerer, P. A. (2009). The Avalanche Handbook. Seattle, WA: Mountaineers Books.

M. Hasler et. al, Chapter 2: Friction Between Ski and Snow, in The Engineering Approach to Winter Sports, ed. by F. Braghin, F. Cheli, S. Maldifassi, S. Melzi, E. Sabbioni (2016), pp. 17-32.

McMaster Carr. Retrieved from: https://www.mcmaster.com/

Monosoff. T. (2006, November 27). Demystifying Profit Margins and Markups. Retrieved from: https://www.entrepreneur.com/article/170964

Metal Recycling. (2015, February 10) Retrieved from: https://www2.gov.bc.ca/gov/content/safety/crime-prevention/metal-recycling

Metro Vancouver Recycles. (2009, A) Retrieved from: http://www.metrovancouverrecycles.org/Header/AboutUs

Noise management: Electric drills. (2014, May 13). Retrieved September 16, 2017, from https://www.commerce.wa.gov.au/publications/noise-management-electric-drills

Ostafichuk, P., Hodgson, A., & Fengler, M. (2013). The engineering design process: an introduction for mechanical engineers. Vancouver, British Colombia.

Panasonic NCR18650B [PDF]. (2014, May 12). Osaka City: Panasonic.

Payscale, Human Capital. (2017, November 3). Data Scientist, IT Salary (Canada). Retrieved November 12, 2017, from https://www.payscale.com/research/CA/Job=Data_Scientist%2C_IT/Salary

PG71 Gearmotor, 10 mm Round Output with 775 Motor and Encoder (am-2971). (n.d.). Retrieved October 15, 2017, from https://www.andymark.com/PG71-Gearmotor-With-Encoder-p/am-2971.htm

Protective Vents. Retrieved from:https://www.gore.com/sites/g/files/ypyipe116/files/2017-08/GORE_PTV_AdhesiveVents_EN_WEB.pdf

RS Pro. Retrieved from: http://uk.rs-online.com/web/p/thermal-insulating-sheets/7248912/

Rodney, M. L. V. (1971, August 24). Snowshoes. Retrieved from: https://www.google.com/patents/US3600829

Roth. D. (2014, October 20). Mountain skills: Get the most out of the up hill. Retrieved from: https://backcountrymagazine.com/stories/skills-get-uphill/

Rogers, A. (2015, April 28). We Try a New Exoskeleton for Construction Workers. Retrieved from: https://www.wired.com/2015/04/try-new-exoskeleton-construction-workers/

Ranger. Retrieved from: http://www.ultranger.com/sy25.html

Rasul. T. (2007, January 10). Coefficients of Friction for Snow. Retrieved from: https://hypertextbook.com/facts/2007/TabraizRasul.shtml

Residential Rates. (2015, February 6) Retrieved from: https://www.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/residential-rates.html

SAE International. Towability Design Criteria and Equipment Use - Passenger Cars, Vans, and Light-Duty Trucks (J1142-199402). Retrieved from http://standards.sae.org/j1142_199402/

SAE International. Electric Staring Motor Test Procedure (J544-199608). Retrieved from http://standards.sae.org/j544_199608/

SAE International. Single Tooth Gear Bending Fatigue Test (J1619-199701). Retrieved from http://standards.sae.org/j1619_199701/

SAE International. Lithium Battery Powered Portable Electronic Devices (AIR5561). Retrieved from http://standards.sae.org/air5561/

SAE International. Low Voltage Battery Cable (J1127-201512). Retrieved from http://standards.sae.org/wip/j1127/

SAE International. Battery Thermal Management (J3073-201605). Retrieved from http://standards.sae.org/j3073_201605/

Settelmayer. J. (2003, January 5). Adjustable snowshoe. Retrieved from: https://www.google.com/patents/US20030101623

Shanner, C. (2017, October 8). Personal Interview.

Shanner, C. (2017, October 18). Personal Interview.

Shapiro, L. H. (1997). Snow mechanics: review of the state of knowledge and applications. Hanover, NH: U.S. Army Cold Regions Research and Engineering Laboratory.

Shields. M. (1979, February 27). Adjustable ski strap. Retrieved from: http://www.google.com/patents/US4141565

Shynkarik, M. (2017, October 18). Personal Interview.

Shynkarik, M. (2017, October 23). Personal Interview.

SkiPulk. Paris pulk. Retrieved from: https://www.skipulk.com/product/paris-pulk/

Starick, B. (2017, October10, 2017). Personal Interview.

Starick, B. (2017, October 18, 2017). Personal Interview.

Stock Drive Products Sterling Instrument. Retrieved from: http://www.sdp-si.com/

Sealed Bearing 6802-2RS 15x24x5 Ball Bearings. Retrieved from: https://www.bearingscanada.com/10-Sealed-Bearing-6802-2RS-15x24x5-Ball-Bearings-p/10-sealed-6802-2rs-15x24x5.htm

Step-by-Step Guide to Importing Commercial Goods into Canada. (2015, November 10). Retrieved from: http://www.cbsa-asfc.gc.ca/import/guide-eng.html

Steward Update. (2017, October 2nd). Retrieved from: http://epra.ca/wp-content/uploads/2017/10/2017-National-list-EN-Oct-EHF-table-v3-1.pdf

Torres-Greasley, S. (2013, August 29). How Much Does Packaging Cost? Retrieved November 15, 2017, from https://howtobuypackaging.com/how-much-does-packaging-cost/

The home depot. Retrieved from: https://www.homedepot.ca/en/home/p.ii-kitchen--bath-white-290-ml.1000409866.html

U.S. Government Publishing Office. Drop Test (49 CFR 178.603). Retrieved from: https://www.law.cornell.edu/cfr/text/49/178.603

UIAA. Mountaineering and Climbing Equipment ‘LOW STRETCH ROPES’ (UIAA 107). Retrieved from: http://www.theuiaa.org/documents/safety-standards/107_Low-Stretch-Rope_UIAA_March-2013update11.2016-1.pdf

UIAA. Mountaineering and Climbing Equipment ‘DYNAMIC ROPES’ (UIAA 101). Retrieved from: http://www.theuiaa.org/documents/safety-standards/UIAA_101_7_ropes_may_2016.pdf

UIAA. Mountaineering and Climbing Equipment ‘ACCESSORY CORD’ (UIAA 102). Retrieved from: http://www.theuiaa.org/documents/safety-standards/UIAA_102_Accessory_Cord_2013.pdf

Volken. M, Schell. S, Wheeler. M. backcountry skiing: Skill for Ski Touring and Ski Mountaineering. Retrieved from: https://books.google.ca/books?id=fbYMocIZ18YC&pg=PA238&lpg=PA238&dq=how+much+give+does+snow+have+backcountry+skiing&source=bl&ots=1pDQeV3Rmc&sig=ji7anuaM97LBEEfsXTx57-3Oglk&hl=en&sa=X&ved=0ahUKEwiq99ONjq_WAhVqqVQKHRaTCUAQ6AEIMTAC#v=onepage&q=how%20much%20give%20does%20snow%20have%20backcountry%20skiing&f=false

Wing. R. H, Moss. N. R, Francis. D. (1998, April 21). Compactible snowshoes and bindings and method of assembly. Retrieved from: https://www.google.com/patents/US5740621

Wych Bearings. Retrieved from: http://www.wychbearings.co.uk/CSK15PP.html

Warn Vantage 2000-S Winch ‑ 89021. Retrieved from: https://www.4wheelparts.com/Winches-Winch-Accessories/Warn-Vantage-2000-S-Winch-89021.aspx?t_c=18&t_s=299&t_pt=100699&t_pn=WAR89021#overview_Container

Xometry. Retrieved from: https://get.xometry.com/quote/093C8-15007

YASKAWA Electric Corporation. (2013, September 9). Yaskawa Develops an Ankle-Assist Walking Device for Those with Walking Impediments Caused by Stroke and Other Factors. Retrieved from: http://japan-product.com/yaskawa-develops-an-ankle-assist-walking-device-for-those-with-walking-impediments-caused-by-stroke-and-other-factors/

YouTube. (2014, January 22). The surface of flux snowshoes automatically expanded and contracted with down heel and up heel. Retrieved from: https://www.youtube.com/watch?v=5UsCK8x5Y4s