

SAE CSC Senior Capstone

Skiddadle- CSC Rear Drive

A Formal Report

Presented in Fulfillment of the Requirements for the

ME 424-426 Capstone Design

in the

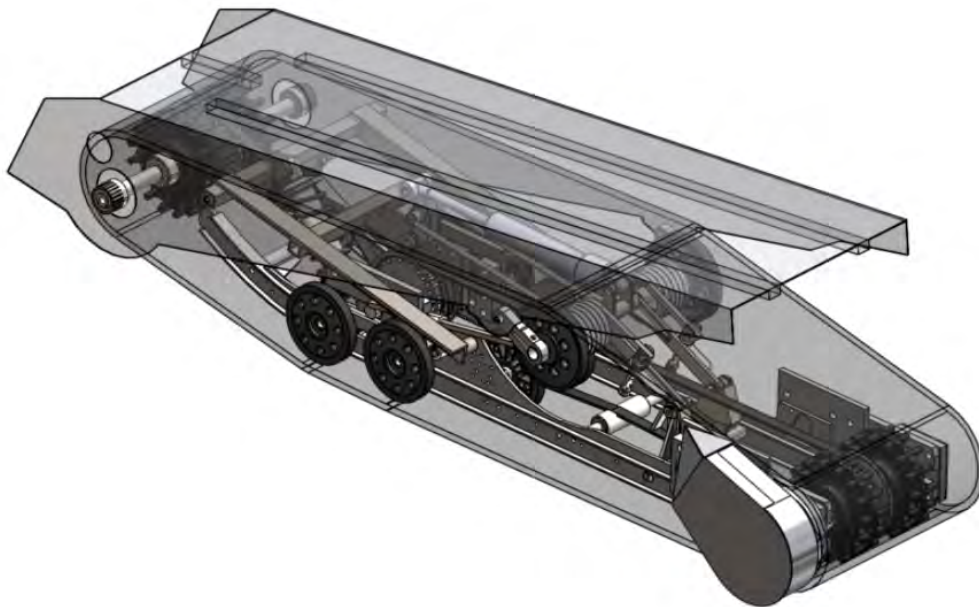
College of Engineering

University of Idaho

by

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Chapter 1: Executive Summary

Currently, snowmobiles are not sold as rear driven snowmobiles as a stock platform without significant aftermarket modifications made and/or purchased. There are also no longer any aftermarket distributors of rear drive systems. The goal is to answer this need by developing a rear driven snowmobile skid that will improve traction and fuel efficiencies, as well as circumvent aftermarket modifications and costs. The purpose of the SAE Clean Snowmobile Competition is to promote technical innovation, however over the last 16 years of the competition there have not been any rear drive configurations that dramatically improve traction in soft snow and therefore increase fuel efficiency. Our team is proposing a variable front/rear drive system for this year's CSC by the University of Idaho team. Our design seeks to have minimal impact on braking system redesign. Although some suspension modifications will be necessary, the design will be easy to swap with the stock configuration and require no input from the user while operated.

Chapter 2: Background

Currently there are not any rear driven snowmobiles on the market. This is mainly due to manufacturers wanting to reduce sled weight and simplify designs. Aftermarket rear driven snowmobile prototypes have been made in the past, however their application is mainly for drag racing snowmobiles. The past CSC projects that have attempted this type of design are detailed below.

2011-2012 This Senior Design Project was the first attempt by the UICSC team at implementing a rear drive snowmobile skid. The design this team created involved a gear and chain system that ran down the center of the tunnel. Having the chain in this configuration meant the team had to redesign the suspension, and complete a finite element analysis. Once the system was fabricated and testing could be done, the team found that their chain would brake too often/quickly; they concluded that they were lacking a chain tensioner.

2014-2015 During this school year another senior design team took a second crack at tackling the rear driven snowmobile. Following findings by previous group, and adapting the built skid from the 2011 project they added a chain tensioner. However due to part retrieval delays the system was not completed not implemented on the sled for competition.

Due to a change in SAE competition rules a chain and gear system would need to be fully shielded and an oil bath and lubrication system would need to be implemented. The amount of modification and weight adage to do this leads our team to explore other avenues of research.

2015 A master's student, Matthew Kologi, looked into this design problem as a part of completing his master's degree. He performed conceptual and ideological experiments in detail to explore the theoretical efficiencies that could be gained from implementing a rear driven skid. In his analysis he explored a drive shaft and pinion gear system. In his road load models he found that once a cruise speed is reached there is little resistance to maintain the cruise speed. Being a conceptual design exploration there isn't any information detailing how such a system would fare on snow.

Chapter 3: Problem Definition

Our teams' goal is to design, fabricate and test a rear driven snowmobile. The implementation of this system is hoped to improve competition activities where handling, fuel efficiency, and overall sled performance is necessary. The system should maintain the full functionality of a stock snowmobile. Minimal weight addition is desirable. Any designs involving the electronic transmission of power from the engine, clutch, and/or crank shaft must be submitted to the SAE competition proprietors prior to the competition for approval. Other deliverables include:

- * Two people should be able to swap out stock and designed skids with relative ease.
- * Detailed 3D model & engineering drawing package.
- * Complete assembly and installation instructions.
- * In-depth FEA for re-designed suspension system.

SAE Clean Snowmobile Competition Requirements:

Description	Value	Unit
Sound Requirement- SAE J1161	< 67	dBA
Endurance Run	100	mi.
Acceleration -10 sec run	500	ft.
Weighted Acceleration	500	lbs.

Chapter 4: Project Plan

The roles and responsibilities associated with the capstone design have been assigned by members volunteering. Team members in charge of budget and purchasing, Aref and Saleh. Team members tasked with client contact and team management, Thomas and Adam. Team member who is wiki-master lead manufacture, certified in all ME Shop tools, Brannon and Omar. Team member in charge of keeping team documentation including keeping meeting minutes, Thomas and Adam. Any other roles and/or responsibilities the team sees necessary to add and assign will be volunteered for similar to the primary responsibilities.

The intended schedule detailed here was the optimistic schedule initially developed by the summer/fall team. The following were the major project milestones:

- Concept Design Development: by July 29th 2019
- Detailed Design CAD & BOM: by Oct. 7th 2019
- Fabricated Prototype: by Nov. 11th 2019
- Design Validation and Testing: Nov. 18th – December 13th 2019

The most current schedule, as seen in Appendix A, shows the incorporated spring semester and the following are the up-to-date major milestones, completed and up-coming:

- Detailed Design CAD & BOM: completed Nov. 11th 2019
- Fabricated Prototype: by Jan. 20th 2020
- Design Validation and Testing: Jan. 20th – March 6th 2020
- SAE competition: week of March 9th 2020

Chapter 5: Concepts Considered

Concept 1: Dual Axle Belt Drive

As shown in the figures below, this design drives the track from the front and the rear axles simultaneously. The front drive is connected with the intermediate axle in the middle by the belt. Likewise, the rear drive is connected with the intermediate axle by another belt. This design would help to avoid brake relocation, easily adaptable and cost effective.

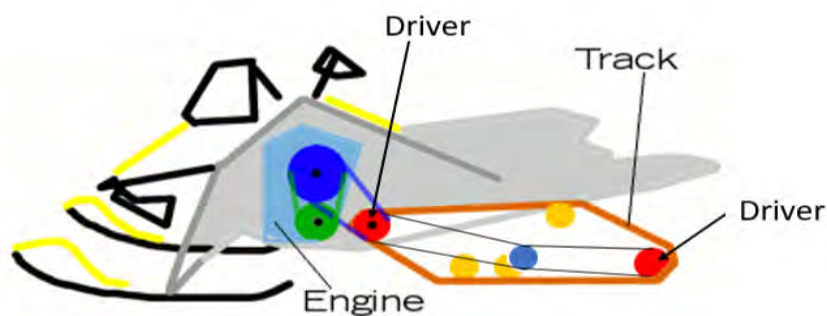


Figure 1: Simple diagram of part location for dual axle driven system

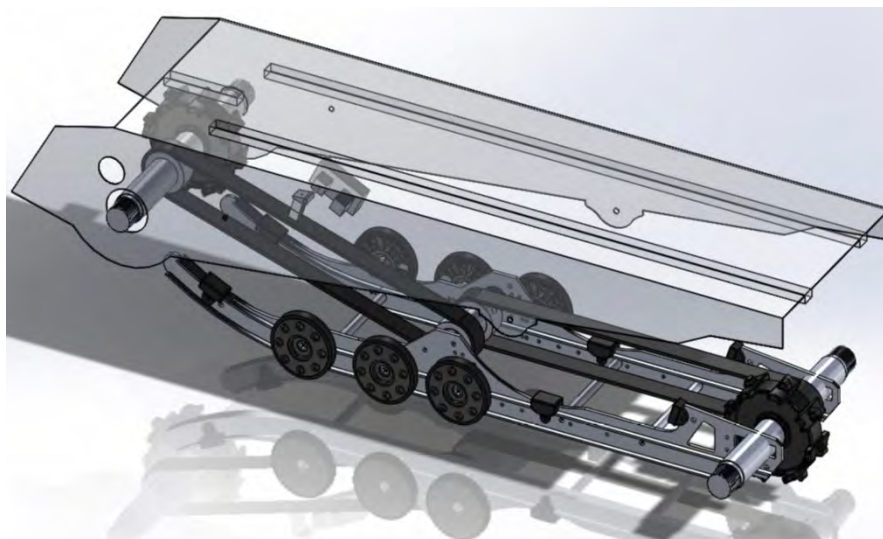


Figure 2: CAD model of dual axle driven system

Concept 2: Electronic Powered Drive

The thought behind the electronic powered drive was to attach an alternator or a similar power generation system to the Crank Shaft and then send that power to an electric motor located on the rear axle of the snowmobile. In order to safely transfer this power the system would need a CAT Bank to manage/store the power coming from the generator. This system would also require a speed controller to manage the power going into the electric motor.

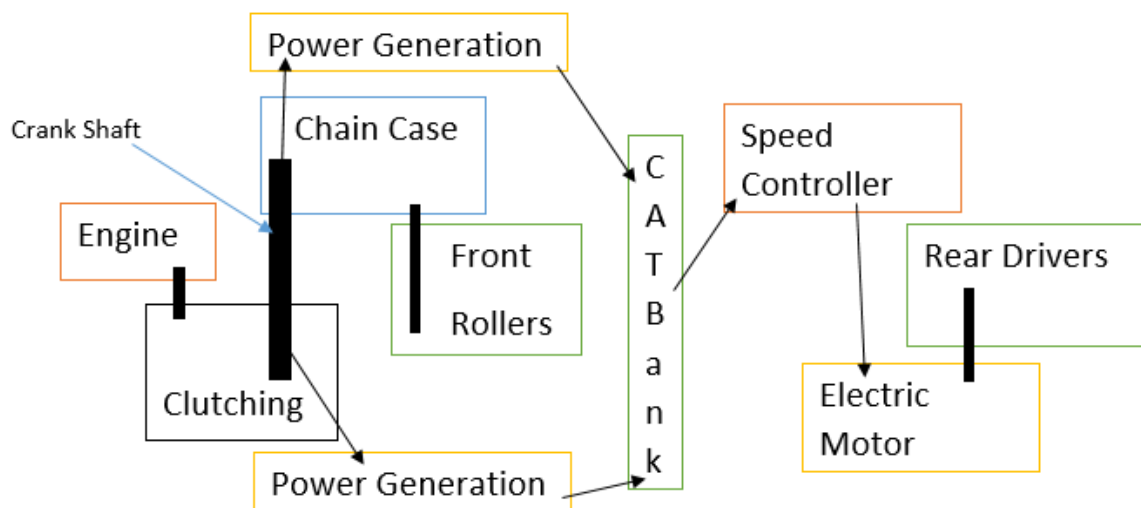


Figure 3: Power flow diagram for the EPT drive system

Due to the size, weight and cost of implementing this system (size being depicted in Figure 4) this system is not ideal for the team's consideration.

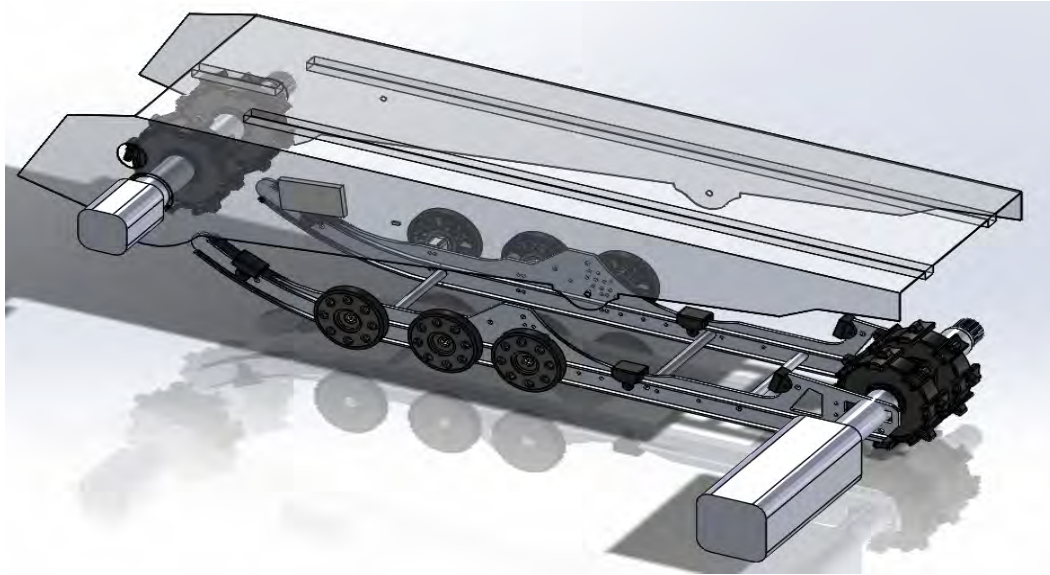


Figure 4: CAD representation of the EPT drive system.

Concept 3: Hydrostatic Drive

The hydrostatic drive consists of a pressure system that would take the energy provided by the crank shaft and transfer this energy to the rear axle via a pressurized hydraulic fluid. In order to implement this system an oil cleaning and re-circulating system would also need to be implemented.

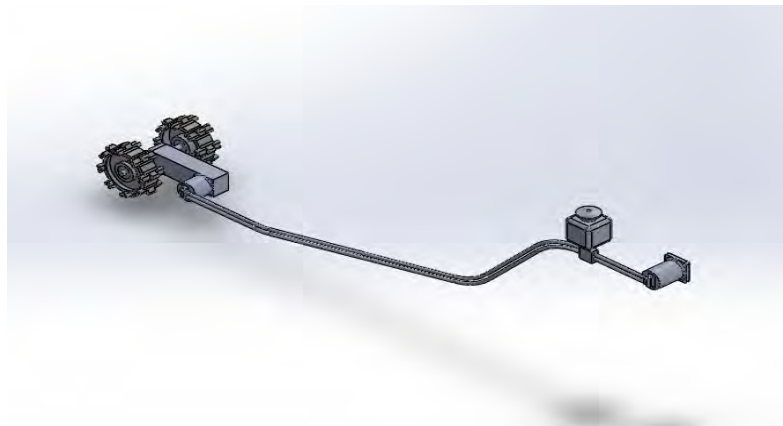


Figure 5: CAD representation of a hydrostatic drive

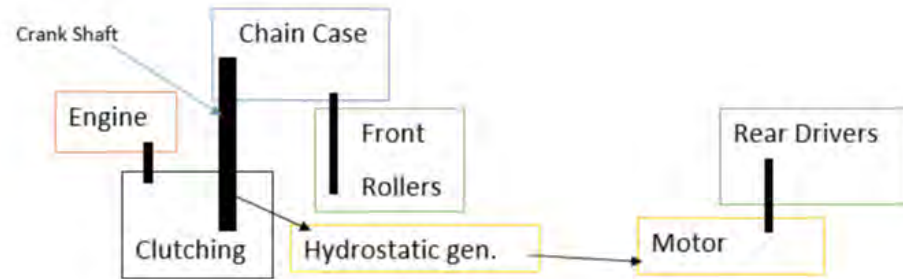


Figure 6: Power flow diagram of the hydrostatic system

Chapter 6: Concept Selection

In order to arrive at a final decision, the team made use of Snapshot Day 1 and a concept design wherein each concept design was presented to the client, lead instructor as well as various department and machine shop faculty. The first snapshot occurred in the second week of July where the basics of each concept design were discussed. After this design review the client and faculty provided the team with areas of information to explore with a concept design review scheduled for the last week of July. After in-depth exploration of each option, weighing the pros and cons, the team suggested pursuit of a rear axle-belt driven system. A decision matrix, found below, supported the teams' suggestion.

Key to the Design Decision Matrix on:	
(A) Weight: How much more weight is added compared to stock skid?	<ul style="list-style-type: none"> • <i>Importance:</i> [5] • <i>Explanation:</i> higher score = less weight
(B) Cost: Does the design require more or less money?	<ul style="list-style-type: none"> • <i>Importance:</i> [9] • <i>Explanation:</i> higher score = less expensive
(C) Drive Efficiency: Drive power transferred to snow without losses.	<ul style="list-style-type: none"> • <i>Importance:</i> [6] • <i>Explanation:</i> higher score = higher efficiency
(D) Design Simplicity: Less added/alterd compared to stock skid.	<ul style="list-style-type: none"> • <i>Importance:</i> [5] • <i>Explanation:</i> higher score = simpler design
(E) Snow Resistance: Will snow/water interfere with the design?	<ul style="list-style-type: none"> • <i>Importance:</i> [4] • <i>Explanation:</i> higher score = less interference
(F) Suspension Alteration: How much will the design require alteration?	<ul style="list-style-type: none"> • <i>Importance:</i> [5] • <i>Explanation:</i> higher score = less expensive
(G) Manufacturability: How easy is it to make/re-produce?	<ul style="list-style-type: none"> • <i>Importance:</i> [7] • <i>Explanation:</i> higher score = easier to man
(H) Maintenance: It should be easy to maintain, and should not need maintenance often.	<ul style="list-style-type: none"> • <i>Importance:</i> [7] • <i>Explanation:</i> higher score = easier to maintain
(I) Assembly: How easy is it to assemble and/or swap with stock skid?	<ul style="list-style-type: none"> • <i>Importance:</i> [7] • <i>Explanation:</i> higher score = easier to assemble

Design Matrix Table with Waited for Importance of each Category

DESIGN	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	TOTAL
Single Driver Belt Drive	2.0	3.6	1.2	1.5	1.6	1.0	2.1	2.1	0.7	15.8
Dual Driver Belt Drive	1.5	2.7	1.2	1.0	1.6	1.0	2.1	2.1	2.8	16
Hydro-static Driven	0.5	1.8	1.8	1.5	0.8	2.0	2.8	1.4	2.1	14.7
Electronic Power Driven	1.0	0.9	2.4	1.0	0.4	2.0	2.1	1.4	1.4	12.6

Chapter 7: System Architecture

This chapter details the entire designed system on a sub-assembly-component basis, describing the functionality of each.

Runners Sub-Assembly

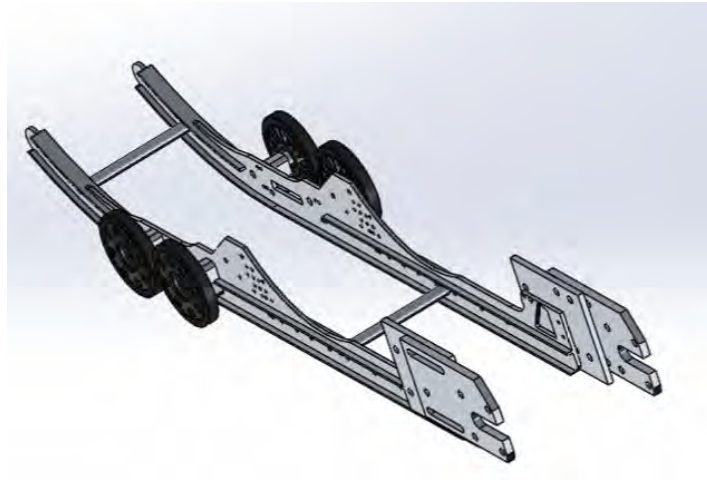


Figure 7: The runner sub-assembly

The runner sub-assembly serves as the base and structure of the entire system. It is comprised of:

- two modified 129" aluminum runners
- two rear axle weld plates
- two rear axle mounting plates
- two intermediate axle mounting plates (detailed in the intermediate axle section)
- four stock idler wheels
- two spacer bars

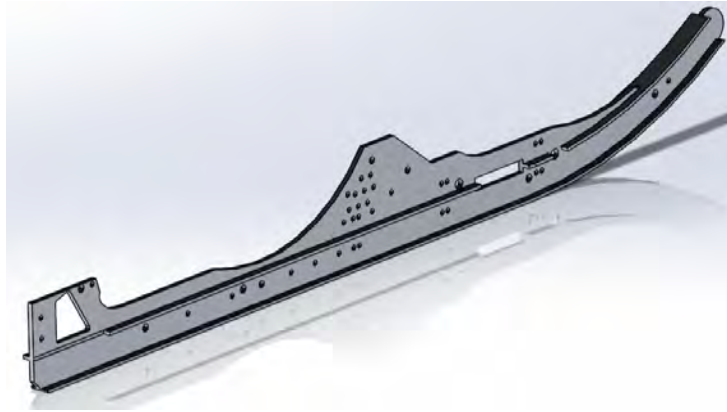


Figure 8: Right runner, outside view

The stock runners are modified to make space for the intermediate axle mounting plate and the rear axle weld plate. The intermediate axle is located toward the front of the runners, in between the two forward idler wheels. To make space for the intermediate axle mounting plate a portion of the top rib is removed on the inner and outer side of each runner as can be seen in Figures 8&9.

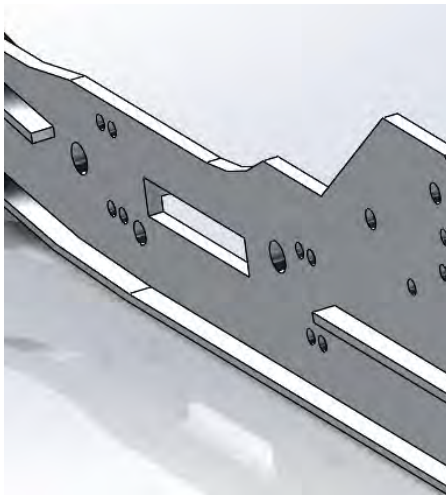


Figure 9: Right runner, inside view of intermediate axle mounting location

The square cut into the runner is placed such that the axles bearing plates, which retain the location of the axle can be mounted/bolted in place.

The rear axles weld plate sits on the rear of the modified runner seen in Figure 10 in a similar fashion by having a portion of the outer rid taken off. This plate is named the “weld plate” because it will be welded to the runner.

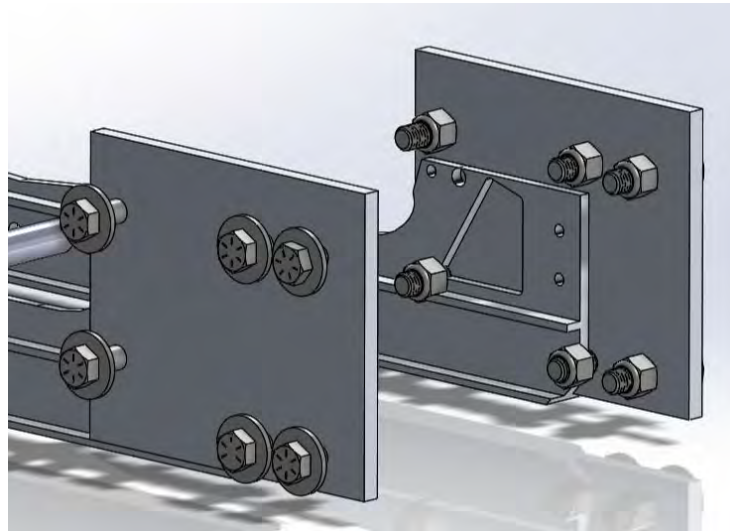


Figure 10: Rear axle weld plates

Bolted to this weld plate will be the rear axle mounting plate, Figure 11. The mouth and four holes on the left side of the plate are for the mounting and bolting of the rear axle. The two long channels on the right side of the plate are where the bolts go to mount this plate to the weld plate. This allows for not only the rear axles location to move on the mount plate, but the location of the mount plate itself to be changed providing two degrees of belt and track tensioning. In order to lock in the location of the mount plate a screw tensioner is attached to the weld plate as seen below in the figure on the right.

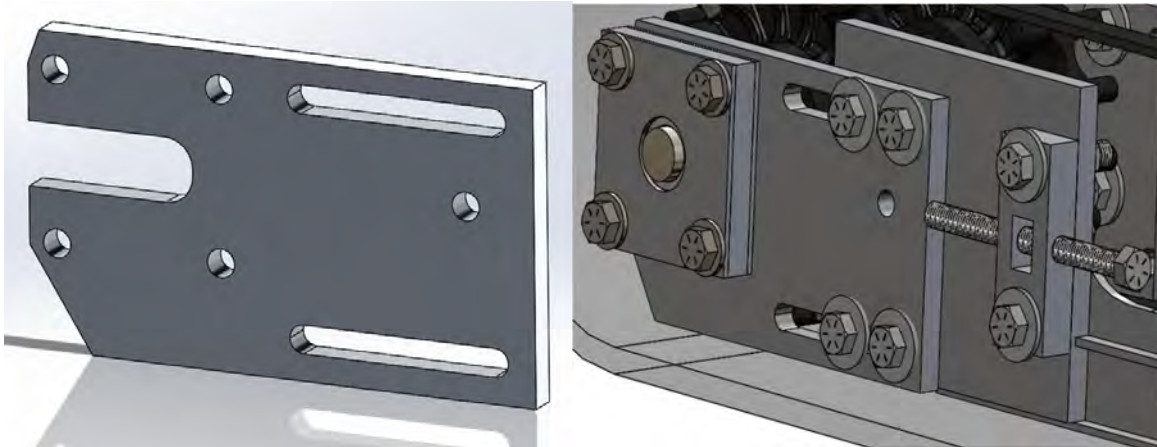


Figure 11: Rear axle mounting plate (left) and bearing-axle tensioning system (right)

Driving Axles

The design has two variable driving axles. Both the forward and the rear axles have been designed with the intent of being able to fix the drivers or unfix the drivers to act as idlers. The main difference between the front and the rear axle are:

- 1) The front axle has two splined ends, the right spline for connection from the chain case and the left spline for connection to the stock brake when the system is set to front axle driving.

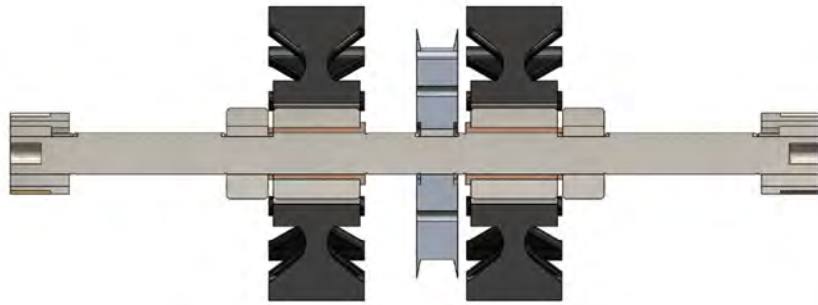


Figure 12: Forward axle section view

- 2) The rear axle only has one splined end on the left to connect to the rear mounted brake for when the system is set to rear axle driving. The rear axle also makes use of two bearing housings; one on each side of the runners (Figure 13). Lastly the rear axles belt cog is bolted to a shear pin hub; this factors in a level of fail-safe design, allowing the shear pin to break before allowing any damage to occur to the belt cog.

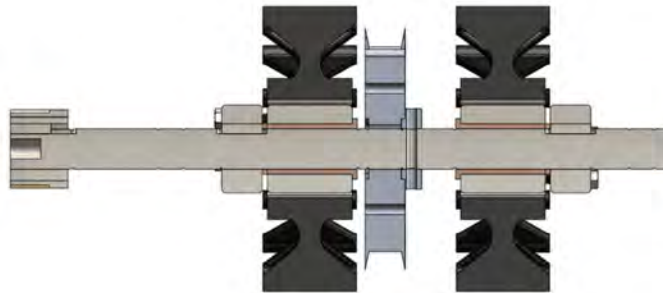


Figure 13: Rear axle section view

Both of the driving axle's set of silent drivers are mounted to the shaft using the following pieces:

- A bronze bushing
- A hub

- A splined driver sleeve
- A keyed dog
- A machine key
- Four set screws

The silent drivers are attached to the axle by welding the splined driver sleeve to the hub and press fitting the silent driver onto these. Inside of the hub sits a bronze bushing. This silent driver assembly can then be bolted to the keyed dog, which is held on the shaft via a machine key and axially fixed using an outer circlip, or it can remain free to spin on the axle while still being axially fixed using an inner circlip. On the outer side(s) of the axles are the various splined ends. No matter which spline end is used they are all attached in a similar fashion. This is done by welding the splined end onto a cutoff weld-in. Then the cutoff weld-in is fixed to the shaft via a machined key. Both driving axles also have a belt cog attached to the shaft by a machine key and are retained axially via the use of two circlips.

Forward Suspension

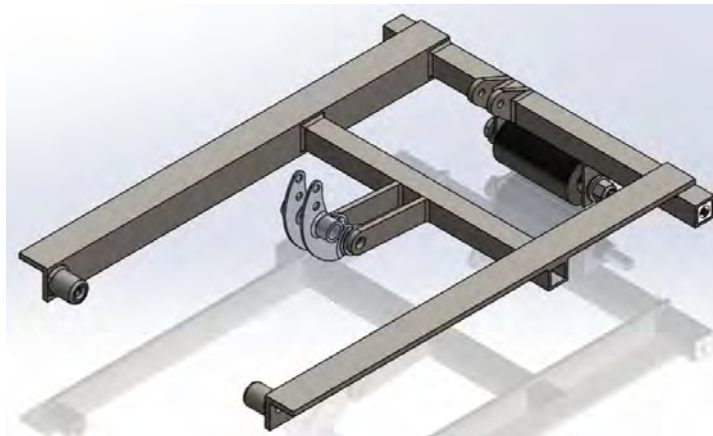


Figure 14: Forward suspension arm assembly

The forward suspension arm is made by welding two steel angle iron sections to two steel square tube sections, one located at the front and another some distance from the front towards the back. Located within the forward cross member are two weld plugs necessary for the mounting of the forward suspension arm to the snowmobile tunnel. Attached to the forward cross member are two plate mounts for the forward shock and two mounts underneath for a delrin roller. The tabs for the forward shock are left off-center that move the forward shock to make room for the forward belt. The

intermediate cross bar has two long tabs that are used to hold the moon shaped connector piece that connects the rear suspension damper to the forward suspension.

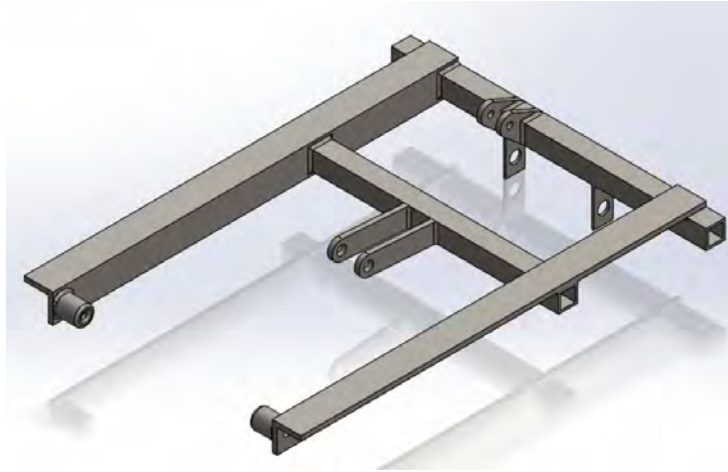


Figure 15: Forward suspension arm

The rear side of the suspension are has two spacers necessary for the mounting of the suspension arm to the runners. Due to spatial restrictions on the inner portion of the skid the suspension arm had to be designed to extend outside of the runners.

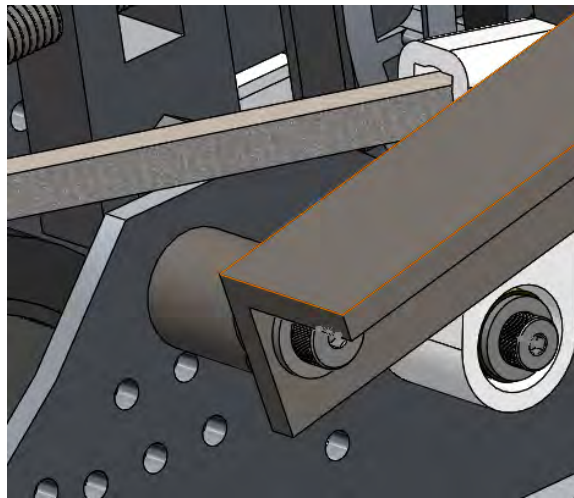


Figure 16: View of where the forward suspension arm mounts to outer side of runner

The forward shock is the same shock as used on the stock sled; however, instead of mounting the shock to a runner spacer bar a shock mount will be created to attach it to the left intermediate axle mounting plate.

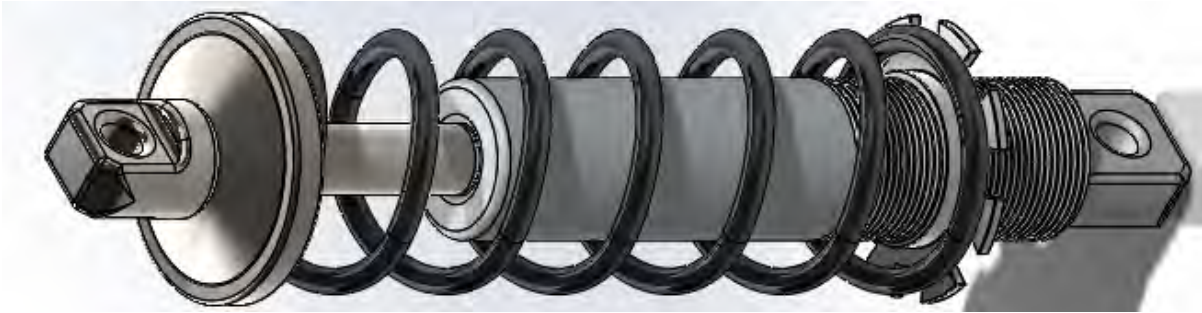


Figure 17: Forward suspension arm shock



Figure 18: View of forward suspension arm's shock mount. Mounts forward shock to left runner intermediate axle mounting plate

Intermediate Axle

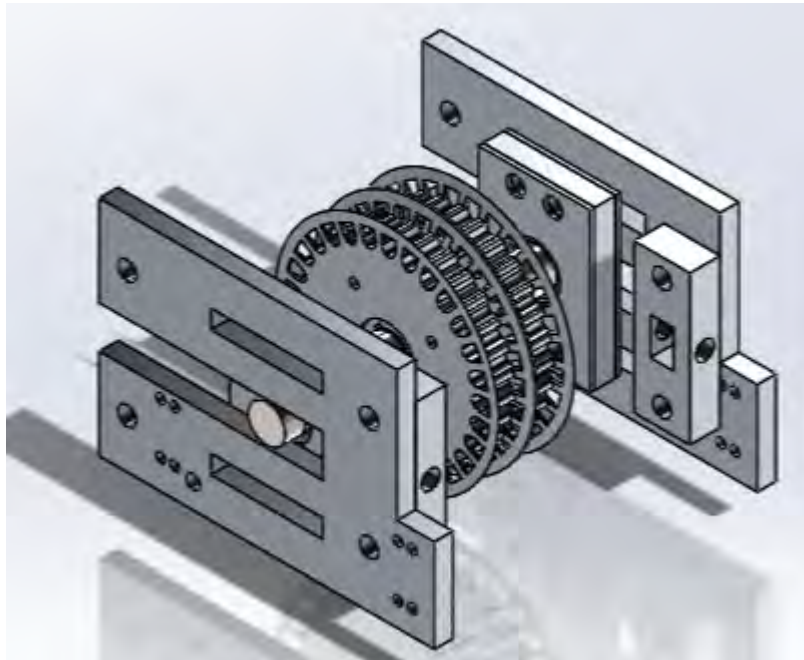


Figure 19: Intermediate axle assembly

The intermediate axle consist of:

- Two mounting plates (same ones from runner sub-assembly)
- Four bearing end plates
- Two bearing housing plates
- Two bearings (same as detailed in forward axle section)
- Two screw tensioners
- Two belt sprockets (same as detailed in forward axle section)
- One shorter axle

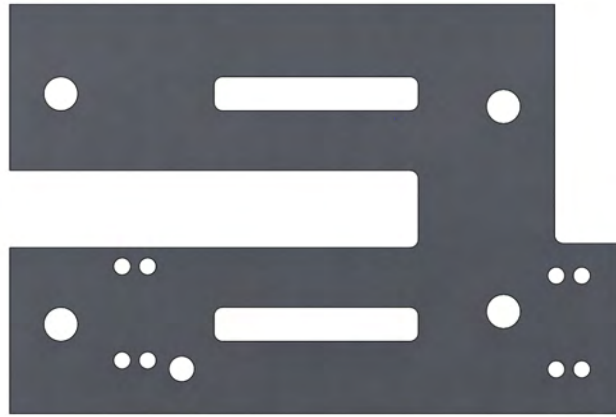


Figure 20: Intermediate axle mounting plate

The intermediate axle mounting plate, as see above, is bolted to the inner sections of the runners as detailed in the runners section. This is done via four of the 8 smaller bolt holes on the lower part of the plate as well as the two larger bolt holes that are used to mount other parts to this same section. From the picture, the large mouth is for the assembly and location placement of the axle. The axle's location is then bolted to this mounting plate by screws through the two slots that also hold the bearing end plates and bearing housing plate together. The axle's location is also fixed by a screw tensioner located to the rear of the mounting plate.

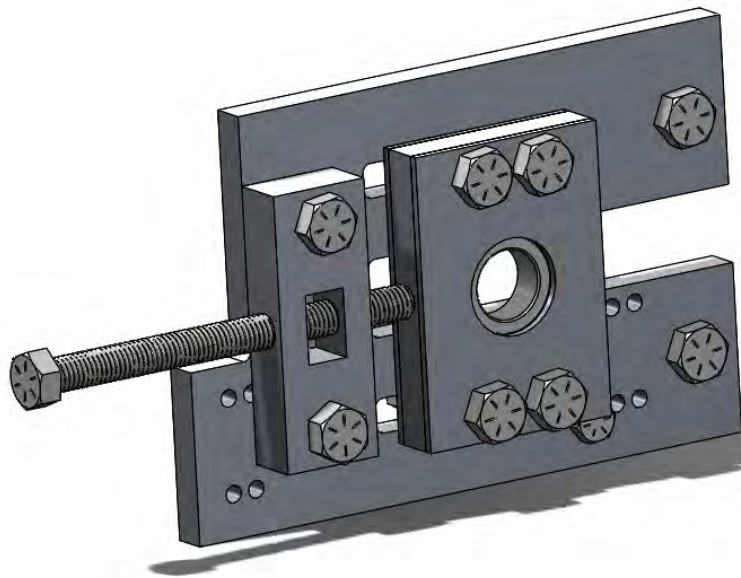


Figure 21: Intermediate axle bearing-tensioning system

Rear Suspension

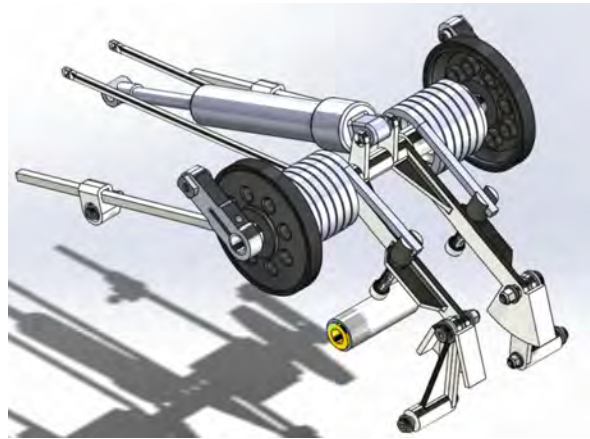


Figure 22: Rear suspension assembly

In order to replicate the stock R-motion rear suspension the team wanted to make use of the same spring mass damper system used on the stock sled, but alter the suspension arm in order to make room for the belt that would inevitably pass through the space occupied by the stock suspension arm. To do so the team decided that the upper cross-member of the stock system could be repurposed to our system. The stock suspension arm connected to the runner via a spacer bar as seen in Figure 23 (left). This space in the middle needed to be removed to make room for belt travel. In order to do so the team designed a three-part system that consists of two lower linkages as seen in Figure 23 (right) that connect to the upper portion of the arm via bronze bushings and screws.

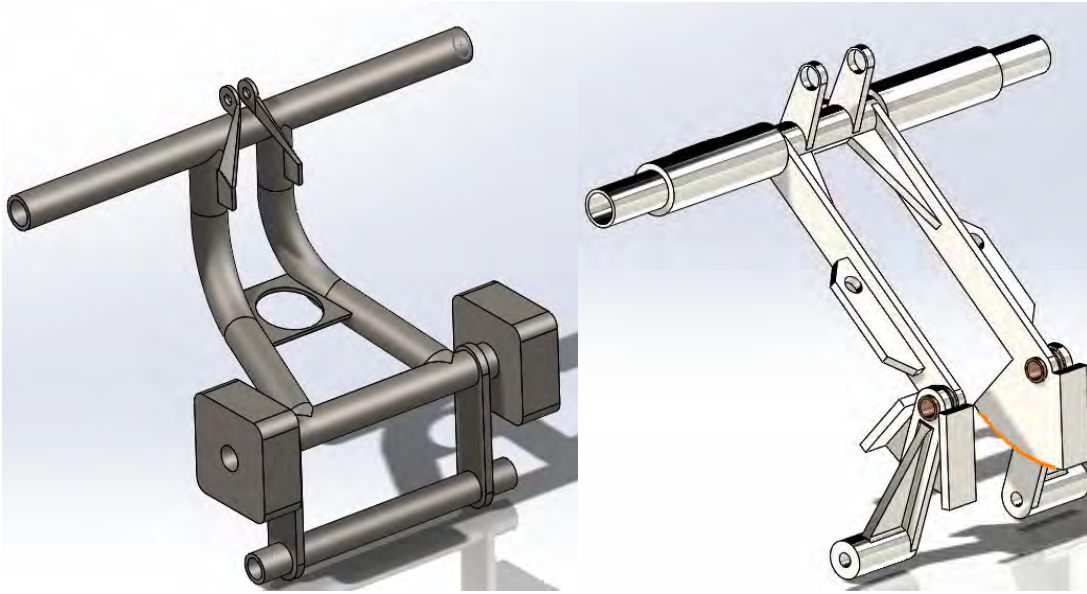


Figure 23: Stock rear suspension arm (left), new design suspension arm (right)

The team replaced the seat for the pre-tensioner with a more simple screw tension system whose tabs are located on the outsides of the upper arms member. All new pieces of the arm are plate steel.

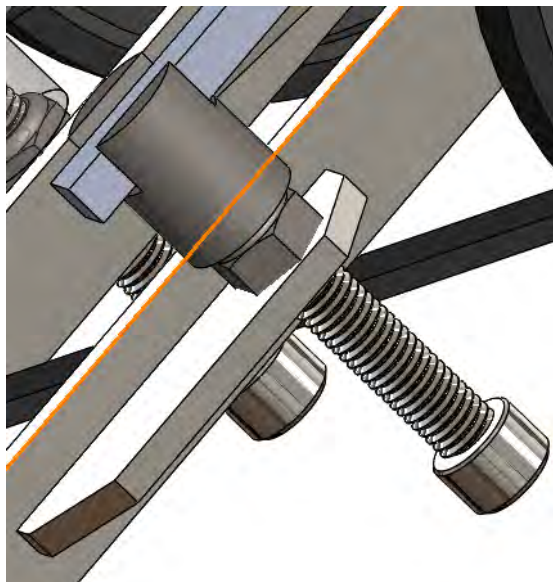


Figure 24: View of rear suspension arm pre-tension screw for torsion springs

Per competition rules the suspension must be limited to a three inch travel distance. In order to accommodate this rule the team added tabs to the upper arm of the suspension arm where the lower arm attaches to the upper arm seen in the figure below.

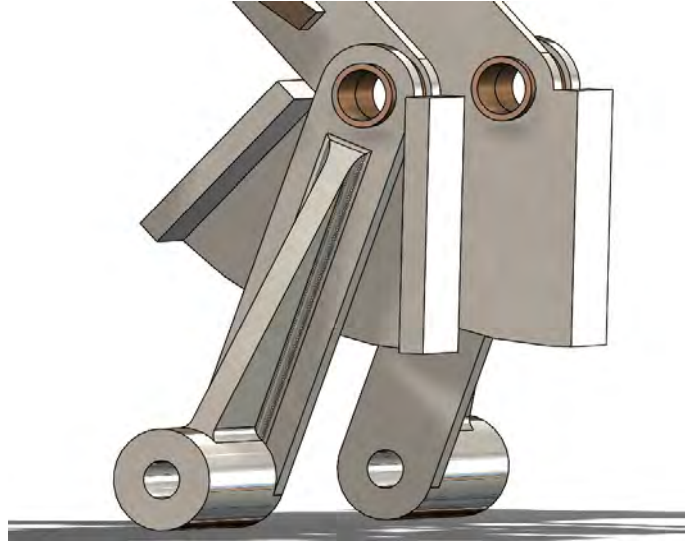


Figure 25: View of rear suspension lower-upper arm link

Belt Configuration, Tensioning, Braking

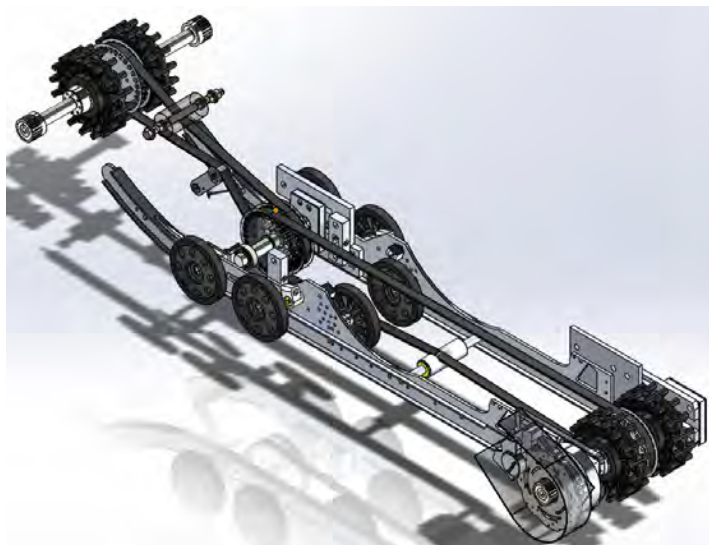


Figure 26: CAD model for belt path

The design consists of two belts purchased from Gates. These belts are polyurethane with carbon tensile chords that run along the length of the inside of the belt for strength. The forward belt is a 1400 mm length and has a 14mm pitch. The rear belt is 2450 mm length and has a 14 mm pitch.

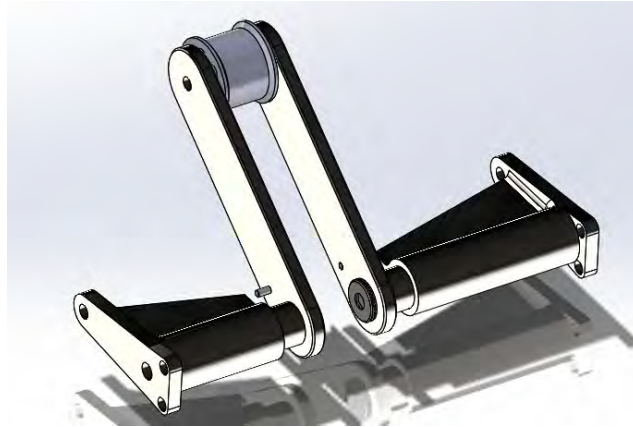


Figure 27: Forward belt tensioner

The forward belt is tensioned by springs on both sides of the roller that are wedged between the pins and the flanges of the tensioner bases. From figure 27, the left side is bolted to the right runner and the right is bolted to the left runner to line up with the belt as can be seen in figure 26 which only shows half of the tensioner.

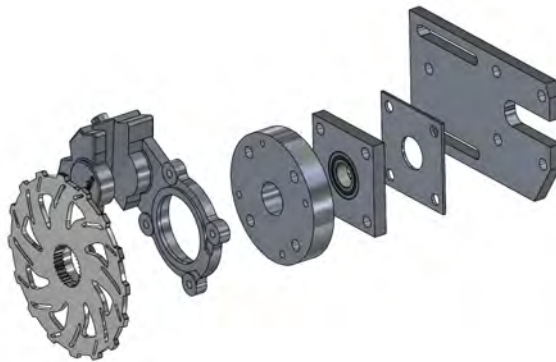


Figure 28: Rear axle brake mounting to left runners' bearing system

The brake located at the rear axle is mounted to a modified bearing end plate. This end plate has been made circular so that the brake is always in-line with the axle. Figure [XX](#) shows an exploded view of how the brake disk fits into the brake rotor, which then bolts to the modified bearing end plate, bearing housing and then another end plate. All of this is bolted to the rear axle mounting plate.

Chapter 8: Design Validation

To validate the design, a 3-part plan has been constructed, with various tests within each plan. The design of the plan is so that if a failure occurs, it occurs early. This prevents time being wasted from continued testing and allows for early evaluation of rear drive. The primary goal of rear drive is to improve the track's contact and power transfer to the snow, during high load and transient conditions. It is not likely to produce any efficiency improvements where there are low loads that would otherwise prevent the track from bunching up. Given the margin of error in fuel economy measurements there would need to be a statistical significance to the number of measurements, and a significant improvement in the value. For our purposes, our definition of significant is 10% change in fuel economy, or 2 miles per gallon whichever is first. For the design to show rear drive as a valid design, there must be at least this significant improvement in fuel economy. Alternatively, if there is a non-significant decrease in fuel economy while also a significant increase in handling characteristics (10%) then the design is valid for improved handling. If the fuel economy decreases significantly, then the design fails. Alternatively, if the fuel economy is near similar, but the handling decreases significantly, then the design also fails.

This should be an end-all validation of rear driven snowmobiles, with a the current “modern snowmobile” design.

Part 1: Justification of Testing

To justify if there is even a reason to truly test the design, two preliminary tests have been constructed. A coast-down test based on SAE J2263, and a steady state instantaneous fuel economy test.

J2263 Coast Down

The coast down test will be able to show a difference in transient states. It should be noted that since the snowmobile is coasting down, the track tension will reverse. This means that longer or shorter times and distances do not actually validate an improvement in efficiency. An on average significant change in distance or time will validate that there are some major differences in transient performance. If not, the team should decide whether to continue testing.

Measurements: Distance and Time

Tools: Measuring Tape, Marker Flags, Stopwatch

Procedure:

1. Mark a 6' wide gate, with marker flags
2. Have the snowmobile configured in a drive mode
3. Have the snowmobile a distance away from the gate, accelerate to a constant speed of 30 mph, in the direction of the gate

4. When reached the gate, start recording time (from 0) and coast until vehicle stops.
5. End recording time at the moment the vehicle stops
6. Measure distance from gate to resting position of the end of the track
7. Record the values of distance and time for each run, along with notes of snow and weather conditions.
8. Repeat steps 3-7, 4 more times (5 total tests per drive mode)
9. Start at step 2, with the snowmobile in different drive mode, and repeat steps 3-7 until all drive modes have been tested

Instantaneous Fuel Economy

The instantaneous fuel economy measurement is not likely to show change but is there to satisfy administrative curiosity. A steady state will need to be made, where the track speed is near constant and the engine speed is near constant. This would be time to make the measurements of fuel flow.

Measurements: fuel flow, track speed, engine speed

Tools: fuel flow measurement

Procedure:

1. Create 2000' straight and flat course, minimum 6 ft wide, visibly marked at the at each quarter, in the middle, and each end
2. Ride snowmobile at 35 mph, into course, keeping speed consistent through course
3. Start recording fuel flow measurement through course
4. Average all data recorded through the run into a single numerical metric
5. Turn around and go through course the opposite direction, recording as step 3
6. Repeat 3 times in each configuration

What does this tell us about our design?

Steady state fuel efficiency improvements

Part 2: Major Data Collection

The bulk of the data to be published is traditional fuel economy data. An experienced rider will need to do fuel economy runs through transient conditions. This type of riding is not a traditional type, and include keeping low throttle position, no braking, throwing weight through corners, avoiding high RPM and high RAVE positions. Typically, the peak speed is 45mph with an average speed between 25-35mph, as per the SAE CSC fuel economy course. Obviously, if there is a loss in fuel economy do not move on to the third section.

Fuel Economy

The fuel economy test is simple, do the best to keep as fast a speed as possible (while never going over 50mph) while still following the above guidelines on throttle position

Measurements: Distance and fuel consumption

Tools: Gas Cans, Scale

Procedure:

1. Weigh gas cans, record weight measurements
2. Fill gas cans, recording the filled weights and fluid volumes (from pump)
3. Fill snowmobile gas tank to a repeatable level (such as the top of the fill spout)
4. Ride snowmobile at 45 mph average (or as maintainable) for a distance (recorded by odometer) of 50 miles
 - a. Consistency is key. Having varying speeds in different turns is alright, if the speed is consistent between runs in those sections. Recommend a second rider assisting in keeping consistency.
 - b. Fuel economy riding is a skill. Reducing RAVE valve high position, throwing weight in corners, avoiding the brake, and reducing high rpm while riding is something that should be practiced before collecting data.
5. At end of ride, stop snowmobile, turn off engine, and fill gas tank to the original level
6. Record weight of gasoline required to fill tank.
7. Repeat steps 4-6 as needed for data to reach convergence. Approximately 200 miles in each configuration

Durability

As this is a testing prototype, not a full-on finished product, the durability is likely to be low. Still, it is practical to test the systems durability. To do this all one must do is ride. If an parts break during any tests, record them in the durability section. In conjunction, testing the durability during normal riding (not fuel economy), is prudent.

Measurements: If it breaks or doesn't

Tools: Secondary Snowmobile, Tow Rope

Procedure:

1. Ride Snowmobile On/Off Trail Riding
2. Regular Sled Riding cumulative 500 miles
 - a. Going over some minor jumps 2 to 3 ft. air
 - b. Going up side-walls of trails
 - c. Full speed
3. Failure?
 - a. If minor failure occurs, persist riding
 - b. If moderate failure occurs, tow back, repair, and persist riding
 - c. If complete failure occurs, design is failed, tow back and redesign

Part 3: Minor Data Collection

Assuming part 2 showed no detriment, one can proceed to the final portion, performance. Handling is not as important as fuel economy. While fuel economy makes or breaks the validity of the system, improved performance is an important facet of rear drive. This part requires an experienced rider, as acceleration pulls are an intense skill, as is proper braking.

Acceleration

Essentially drag racing on snow.

Measurements: Time

Tools: Measuring Tape, Marker Flags, Stopwatch

Procedure:

1. Mark two gates, 6' wide and 500' apart.
2. Have the snowmobile configured in a drive mode
3. Have the snowmobile with the front of the skis at start of one gate, and in the direction of the other.
4. Start Accelerating at max throttle, and start recording time (from 0)
5. Stop recording time and stop accelerating when the snowmobile reaches the second gate.
6. Record the value of time for each run, along with notes of snow and weather conditions.
7. Repeat steps 3-6, 4 more times (5 total tests per drive mode)
8. Start at step 2, with the snowmobile in different drive mode, and repeat steps 3-7 until all drive modes have been tested

Braking

The inverse of drag racing. Likely the hardest skill to do is not lock up the track while braking.

Measurements: Distance and Time

Tools: Measuring Tape, Marker Flags, Stopwatch

Procedure:

1. Mark a 6' wide gate, with marker flags
2. Have the snowmobile configured in a drive mode
3. Have the snowmobile a distance away from the gate, accelerate to a constant speed of 30 mph, in the direction of the gate
4. When reached the gate, start recording time (from 0) and apply brake until vehicle stops.
5. End recording time at the moment the vehicle stops
6. Measure distance from gate to resting position of the end of the track

7. Record the values of distance and time for each run, along with notes of snow and weather conditions.
8. Repeat steps 3-7, 4 more times(5 total tests per drive mode)
9. Start at step 2, with the snowmobile in different drive mode, and repeat steps 3-7 until all drive modes have been tested

Completion

Once the tests have all been completed, one can proceed to validate or invalidate the design. If the design is valid, then it would be prudent to create a derivative rear-drive-only system that cuts weight and complexity. Otherwise the idea should be permanently scrapped.

Chapter 9: Future Work

Future work includes finishing manufacturing, validating the design, and incorporating recommendations (if the design proves valid).

Future Manufacturing

There are two orders of business for the final product. Making the parts and assembling them. The remaining parts to be made are:

Parts Remaining:
Front Swingarm
Belt Sprockets
Tensioner Blocks
Front Belt Tensioner

Finish welds and paint
Brake Components
Front Axle
Shaft Inserts
Hyfax
Brake Rotor

The whole assembly must then be assembled, with the addition of brake line components which have yet to be purchased.

Design Validation

See section 8

Recommendations

There are 3 types of recommendations, Personal, Team-Team, and Design recommendations. Each will be presented as the members initially gave them.

Personal

Thomas

- If I could do it again, I would only worry about rear drive first, forward drive second
- Take accurate measurements and follow the design guides from the OEM. Ie: don't make a 8mm bolt a 3/8" bolt if you don't need to
- Hold off ordering bolts/hardware until everything is made, so that you don't have to waste on parts you didn't actually need
- Try a 3-D scan of stock parts you are going to use

Aref

- Team members must know how to manufacture stuff, before taking on such a manufacturing intensive project
- Do not let teammates fall behind because they arrived later. Often designs are pitched, but there are not enough people. The people that “The Capstone™” assigns to the project must be brought up to speed too.

Brannon

- Avoid welding things that are too much for the shop to handle ie: 3/8” aluminum+
- Be knowledgeable of the tools, machines, welding equipment, and tooling that is available before making design decisions
- A real understanding of the suspension, OEM design, and intent is required before even thinking about changing anything
- Use real metrology tools. Calipers, lasers, 3-D scans, CMM, ferule arms, etc. **DON'T USE TAPE MEASURES AS PRECISION INSTRUMENTS.** Anything that goes in CAD and is important needs precision dimensions down to at least 0.01”, if not 0.001”.

Team-Team

- The CAD models are never perfect. The poor metrology of the skid rails are still there from the previous team, and we still have them in our model.
- Future manufacturing: use all the shop and CSC material before buying.
- **DON'T BUY FULL SHEETS FROM FACILITIES** they will rip you off **if its not in stock already**. Get price/part/dimensionally accurate specific quotes early!
- Work together. Manage week by week, do not stretch out deadlines. CAD is best done with everyone present.
- **DON'T HAVE NON-SLED PEOPLE TACKED ON BECAUSE IT IS AN OPEN PROJECT**
- Have an open schedule, this is a lot more work than the average capstone. It requires far more attention to detail.
- **DO NOT USE PREMADE CAD FROM “PREVIOUS DEIGNS”, OTHERS OR OTHER WEBSITES IF YOU DO NOT KNOW EXACTLY WHAT THEY ARE REFERENCING.**
- Without a real sponsor, you must be self-driven and hold yourself accountable. You will need to secure sponsorship and other funding. Be bold and be ambitious. “Ask high and ye shall receive something reasonable”
- Two-part teams are dangerous. Stick to a single senior year team, if possible. Otherwise one team loses design control while the other dumps their work on to you. Especially if they do not meet the pre-assigned goals and deadlines.
- Stick to what you know! Don't look to things you have no experience with as a possible “savior design”. **ALWAYS HAVE SOMEONE ON THE TEAM WHO KNOWS ABOUT WHAT YOU ARE DESIGNING:** EX: If design a hydraulic drive, and all everyone knows is gears, it's a bad idea.
- Assign a team manager. If you have a 2-part team, have one manager who is there/present for all three semesters. Loss of consistency destroys productivity of large groups.

- Capstone hoops to jump through can helpful, or very hurtful. BUT KNOW WHAT CAPSTONE DOCUMENTS/REQUIREMENTS/DEADLINES/"WHAT YOU ARE ALLOWED TO DO". Capstone is very different from CSC management, and you will feel like it is dumb and double dipping.
- Maybe a future CSC project could be a cruise control to help for testing the rear drive
- **Future testing must be on the 2017 Skidoo TNT chassis (SPECTRE)**
- Hardware should be a separate subassembly in cad, so that design changes are not a hassle

Design

- Find a way to have the front belt center to center length be the same length as the swingarm pivot length, so as huge a dynamic tensioner is not needed.
- Find a way to machine the hubs as a solid piece, instead of welding
- Find a way to clock the key and bolt circle angles, so that they are consistently made
- Use commercial bearing retainer tech (like pillow bocks)
- Suspension is more relevant than the driveline, and that should be priority to investigate
 - Perhaps start with a C-Motion, T-Motion, Single Beam Monorail, etc. which would have more room
- Design around suspension, not around drivetrain
- Finish manufacturing according to drawing and CAD package

Appendix C – dFMEA

Runner Sub-Assembly										
Runners - Modified	Skid Structure, Holding Rear Suspension and Driver Assemblies in Position	Fracture on Impact	Loss of suspension integrity, loss of rear driving axle efficiency. i.e. catastrophic structure failure	10	Heavy Impact	2	Heat Treated Rails, Stock Manufacturing Of Rails	3	60	Heat Treatment
		Yielding		10	Significant torque bias, Side impact	2	Heat Treated Rails, Stock Manufacturing Of Rails	3	60	Heat Treatment
		Fatigue Fracture		10	Heavy Impact, Cyclic fatigue	2	Heat Treated Rails, Stock Manufacturing Of Rails	3	60	Heat Treatment
Intermediate Rail Spacers	Keeping Runners Separated at Optimal Width For Assembly	Yield	Added friction to driving axles	2	Impact	2	Size of Spacer	4	16	Propper Spacing
Rear Axle Mounting Plate	Modified Expansion Steel Plate Mended to the Runners, to fit on new rear axle position.	Fracture in slot neck	Rear axle loss of drive power, belt failure, loss of track tension	8	Excessive Loading, Impact	2	Large Slot Neck Thickness	2	32	None
		Bending/ Yielding		8	Side Impact	2	Thickness of Plate	2	32	Propper Meterial Choice and sizing Width
Rear Axle Weld Plate	Welded Mending Piece for Rear Axle Mounting Plate.	Weld Failure	Rear axle loss of drive power, belt failure, loss of track tension	8	Poor Weldment, Cyclic Fatigue	3	Larger Welds	2	48	Multiple Weld Paths Overlayed
		Yielding/ Bending		8	Side Impact	2	Thickness of Plate	2	32	Material Choice
		Bolt Hole Pull-out, tear-out		8	Excessive Loading, Impact	2	Thickness of Plate, Bolt Hole Spacing	2	32	Material Choice

Front and Rear Driving Axle Sub-Assemblies

Axles	Driving Axles for Snowmobile Track	Yielding	Loss of driving efficiency	8	Consistent irregular torsional forces	2	Diameter of axle, mounting method of axle	2	32	Proper attention to detail in lathe and tapping set up
		Fatigue Fracture	Loss of driving power	10	Irreversible plastic deformation	2		2	40	
Brake Disk	Modified Stock Brake Disk to smaller circular pattern with 7" Diameter	Fracture	Loss of breaking	9	Irregular bending moments on disk	3	Disk is mounted in-line with driving axle	3	81	Sizing Down stock diameter by lathe
Spline Cut-off Weld Insert	Spline added mounting piece to weld ends on to newly manufactured driving axle's	Weld Failure	Loss of driving power	10	Poor Weldment, Cyclic Fatigue	3	Larger welds	2	60	Weld inspection after testing
Spline Cut-off	Spline removed piece for the stock silent drivers being reused	Tooth Fracture	Loss of driving power	10	Excessive torsional forces	1	Tooth design	2	20	Mitigated by Design
Driver Internal Hub	Internally Mounted Hub within rear Newly Designed and Manufactured Plate Steel Supporting the Driving Axle's	ID yielding	Loss of drive efficiency	8	Prolonged irregular axle motion	2	Fit on axle	2	32	Inspection should irregular axle motion occur
		Bolt Hole Pull-out, tear-out	Loss of driver ability to drive track	7	Bolt hole stripping	2	Bolt Hole Spacing	2	28	Bolt sizing and use of properly sized washers
Keyed Dog	Pre fixed "slots" to fasten the radially mounted driving axle assembly members on a new driving shaft.	ID yielding	Loss of drive efficiency	8	Prolonged irregular axle motion	2	Fit on axle	2	32	Sizing
		Bolt Hole Pull-out, tear-out	Loss of driver ability to drive track	7	Bolt hole stripping	2	Bolt Hole Spacing	2	28	Bolt sizing and use of properly sized washers
Machined Key	Pre Fabricated to specified Lengths to Key in Members to the driving shaft	Fracture	Loss of driver ability to drive track	8	Irregular forces on key	1	Size of Key	2	16	
Silent Driver	BRP Specialized Snowmobile Track Drivers, optimizing frequency for less output sound	Press fit pattern wears down	Loss of driving power	10	Poor assembly	1	Press fit nature	2	20	
Bearing Block Ends	Slim Plate Steel to press inward and hold bearing in optimal position on driving shaft	Bolt Hole Pull-out, tear-out	Irregular bearing operation	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Bearing Block Center	Prefabricated Sheet Steel to hold Bearing Block in Position	Bolt Hole Pull-out, tear-out	Irregular bearing operation	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Brake Side Bearing Block End	Prefabricated Sheet Steel to hold Bearing Block in Position	Bolt Hole Pull-out, tear-out	Irregular bearing operation	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Frame End Retainer	Prefabricated Sheet Steel to hold Driving Shaft in Position	Bolt Hole Pull-out, tear-out	Loss of track tension	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Screw Tensioner	Manual Driver Pretensioning Screw "pushing track out"	Bolt Hole Pull-out, tear-out	Loss of track tension	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers

Intermediate Axle Sub-Assembly

Intermediate Axle	Transitioning Torsional Power from Front Driving Belt to Secondary/Rear Driving Belt	Yielding	Loss of driving efficiency	8	Consistent irregular torsional forces	2	Diameter of axle, mounting method of axle	2	32	
		Fatigue Fracture	Loss of driving power	10	Irreversible plastic deformation	2		2	40	
Intermediate Bearing Block End	Slim Plate Steel to press inward and hold bearing in optimal position on driving shaft	Bolt Hole Pull-out, tear-out	Irregular bearing operation	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Intermediate Bearing Block Center	Prefabricated Sheet Steel to hold Bearing Block in Position	Bolt Hole Pull-out, tear-out	Irregular bearing operation	8	Bolt hole stripping	2	Bolt Hole Spacing	2	32	Bolt sizing and use of properly sized washers
Intermediate Axle Mounting Plate	Meding Member Connecting the Intermediate Axle/Shaft Holding in the correct postioning	Fracture in slot neck	Rear axle loss of drive power, belt failure, loss of track tension	8	Excessive Loading, Impact	2	Large Slot Neck Thickness	2	32	Spacing from edges, material used
		Bolt Hole Pull-out, tear-out		7	Bolt hole stripping	2	Bolt Hole Spacing	2	28	Bolt sizing and use of properly sized washers
		Bending/ Yielding		8	Side Impact	2	Thickness of Plate	2	32	Mounted using fail-safe design

Rear Suspension Sub-Assembly

Rear Suspension Top Arm	Upper Rear Suspension Pivot Axis	Yielding/Bending/Fracturing	Total Mechanical Failure of Rear Suspension	9	Rear Arms Fracturing/Yielding Upon Compression	2	Thickness of Plates, Added Braces	2	36	Reactive Link-Arm Design between lower and upper arms
Rear Suspension Lower Link	Lower Rear Suspension Axis	Yielding/Bending/Fracturing	Total Mechanical Failure of Rear Suspension	9	Rear Arms Fracturing Upon Compression	2	Thickness of Plates, Added Braces	3	54	Static testing of adding weight
Rear Shock	Piston and Shock with Rod	Bottoming Out/Blowout	Loss of Rear Suspension Damping	4	Overloading Suspension, Suspension Failure	1	Bumpstops, Length Optimization	2	8	N/A
Push Rod(s)	Direct Rear Suspension Rotation	Yielding/Bending	Over Powering Compression Force Allowed to Shock	7	One Pushrod Bending unevenly with the other	3	Bumpstops, Length Optimization	2	42	N/A
Larger Idler Wheel(s)	Track Upper Idler Wheels	Fracture, Rubber Loss	Uneven Forces Holding Track off Inner Suspension	4	Foreign Object Impacting Wheel	2	Thickness of Wheel, Diameter of Wheel	3	24	N/A
Torsion Spring(s)	Pre Tensioning Torsional Springs for Track	Yielding, Fracture,	Loss of Rear Suspension Rebound, Loss of Track Tension	7	Fatigue, Overloading, Over-Torsion	2	Profile, Size of Wire	2	28	Static testing of adding weight
Manual Torsion Spring Tensioner	Bolt Adaptive Manual Pre Tensioner for Torsional Sp.	Falling off, Bending, Fracture	Loss of Rear Suspension Rebound, Loss of Track Tension	7	Cap Breakage	3	Pre-tension Quantity, Cap Size	2	42	Tension carefully, test different pre-tensions
Plastic Torsion Spring Skid Mount	Plastic Holding Mount for Torsional Spring Members	Yielding, Fracture,	Loss of Rear Suspension Rebound, Loss of Track Tension, Track Impalement	4	Material Strength Failure, Shock Loading, Over Pre-Tension	3	Thickness of Plastic, Elasticity	3	36	N/A

Forward Suspension Sub-Assembly

Triple Link	Actuates Rear Suspension to Forward Suspension Linkage	Yielding, Fracture	Loss of Rear Suspension Actuation	7	Bushing Failure, directional yielding, Impact, over-centering	3	Material Thickness	2	42	Static testing of suspension movement
Track Idler Bushings	Keeps Track From wearing Rear Shock	Wear, Yielding, Fracture, Stalling	Wear on triple link and rear shock	3	Friction stalling, wearing, Material properties	4	material selection	4	48	N/A
Forward Swing Arm	Forward Swing arm of Multilink Suspension	Fracture, Yielding	Catastrophic Failure	9	weld failure, shape, Load path bending	2	Material Shape, Bracing,	2	36	Consider additional bracing options
Retaining Strap	Prevents Over-Extension of swing arm	Snapping, Wear	Over extension, setup difficulty	3	wear, insufficient strength	2	material, thickness	2	12	N/A
Bump Stops	Prevents Swing arm Over Travel, Prevents System Collision	Wear, Fracture, Yielding	System collision, Belt wear/ failure, Front Shock Failure	7	wear, high impact, bolt bending, position	3	Shape, Size, Location	2	42	Static testing of suspension movement
Shock Rail Mount	Attaches/Locates Forward Coil-Over Shock	Yielding, Fracture	Impalement of track, loss of suspension performance	8	weld failure, shape, Load path bending	3	Material, Bracing, Location	2	48	Static testing of suspension movement
Roller	Prevents belt collision with forward swing arm	Wear, Yielding, Fracture, Stalling	forward Belt wear/failure	3	Friction stalling, wearing, Material properties	4	Material, Diameter	2	24	N/A
Forward Shock	Rebound force, and shock damping for forward suspension	Bottoming Out/Blowout, Spring Yield, Fracture	Loss of suspension performance,	7	Mount failure/bending, coil bind, Over Compression	2	Preload, Spring rate	3	42	N/A

Misc.

Brake Cover	Prevents Internal Combustion of Brake from hurting anyone around at time of mechanical failure	Fracture, Yielding	If Brake internally combusts, pieces wont be caught from launching, Brake Impalement	2	Impact, Falling Off, Any cause of Deformation	5	Thin Material, Fully Self Contained Assembly, Inner Drainage Holes, Light Material Choice	3	30	consider additional material on flat sections
Spiral Retaining Rings	Prevents shifting on axels of any item its butted up against	Wear, Yielding, Fracturing	Catastrophic Failure of Driving Axle Imploding	9	Material Wearing, Material Corrosion, Over Fatigued	1	Selection of type of axle retaining clip/ring/ Material Selection	3	27	purchase extras

Belt System

Forward Belt	Forward Driving Belt	Wear, Tooth removal, Stretching, Snapping	belt wear, loss of driving power	6	wear down, high tension, Material failure	4	Belt material, belt pitch, belt width	4	96	Lifted driveless testing
Rear Belt	Rear Driving Belt	Wear, Tooth removal, Stretching, Snapping	belt wear, loss of driving power	6	wear down, high tension, Material failure	4	Belt material, belt pitch, belt width	4	96	Lifted driveless testing
Track	Snowmobile Driving Belt	Wear, Tooth removal, Stretching, Snapping	Loss of braking, loss of drive system, driver damage, axle warpage, loss of traction	9	wear down, high tension, Material failure	2	Track type	2	36	N/A
Rear Idler/Rail Brace	Prevents rear belt-Track collision, Braces rear of skid	Stalling, Bending, Rubbing	Rear Belt wear, Loss of stability	4	Friction, wearing	3	diameter of idler, material	2	24	N/A
Tensioner	Tensions forward belt, takes up slack	Over/under tension, loss of component	Loss of forward belt, loss of driving power	8	improper spring strength, stalling on roller, suspension failure	4	spring, length, diameter, location	3	96	Static tensioning testing
Belt Sprockets	Transmits belt force to axle torque	wear, tooth deformation, material embedment	belt wear, loss of driving power	8	Wear down, high torque, tooth profile, material embedment	3	tooth count, sheave width, sheave profile, location in skid	3	72	N/A

Appendix D – File Structure

Name	Date modified	Type	Size
1.Problem Definition	5/7/2020 2:42 PM	File folder	
2.Project Learning	4/21/2020 4:48 PM	File folder	
3.Project Management	5/6/2020 9:38 PM	File folder	
4.Wiki Site	5/8/2020 4:33 PM	File folder	
5.Design Solution	5/14/2020 1:48 PM	File folder	
6. Implementation-Manufacturing	7/3/2019 11:04 AM	File folder	
7. Design Validation	7/15/2019 1:35 PM	File folder	
8. References	10/15/2019 10:58 AM	File folder	
CapstonePortfolio	5/15/2020 12:27 PM	File folder	
Solidworks Drawing Templates	5/14/2020 4:35 PM	File folder	
Stock Skid-CAD	12/5/2019 2:46 PM	File folder	
CapstonePortfolio	12/5/2019 3:47 PM	Microsoft OneNot...	36,022 KB