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# University of Saskatchewan Sled Dogs $\frac{1}{4}$ Scale Tractor Team: 2023 Design Report

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## Abstract

Through ingenuity, dedication, and hard work the Sled Dogs team is beyond ecstatic to release the newest addition to the Sled Dogs ¼ scale tractor lineup. This year's new model exemplifies the latest in Sled Dogs innovation that is guaranteed to deliver the highest value to customers. Driven by a Briggs & Stratton 31 HP V-Twin engine paired with the Hawaya Racing centrifugal clutch, this tractor will undoubtedly provide the pulling performance and durability that is expected from the Sled Dogs name. Shown in Figure 1, the new 2023 model features a high-precision steering system, ergonomic operator platform, and flexible ballasting options that is guaranteed to make this one of the most impressive machines available on the market.

### Notable Highlights

- Electric steering with a 7.2 ft (2.18m) turning radius
- Dual sided tractor entry and exit with 3-points of contact
- Anti-slip floorboard design
- Ergonomic Operator Platform with seat suspension
- Electro-mechanical throttle with adjustable sensitivity
- Flexible ballasting system
- Reliable braking system
- Positive locking gear selection

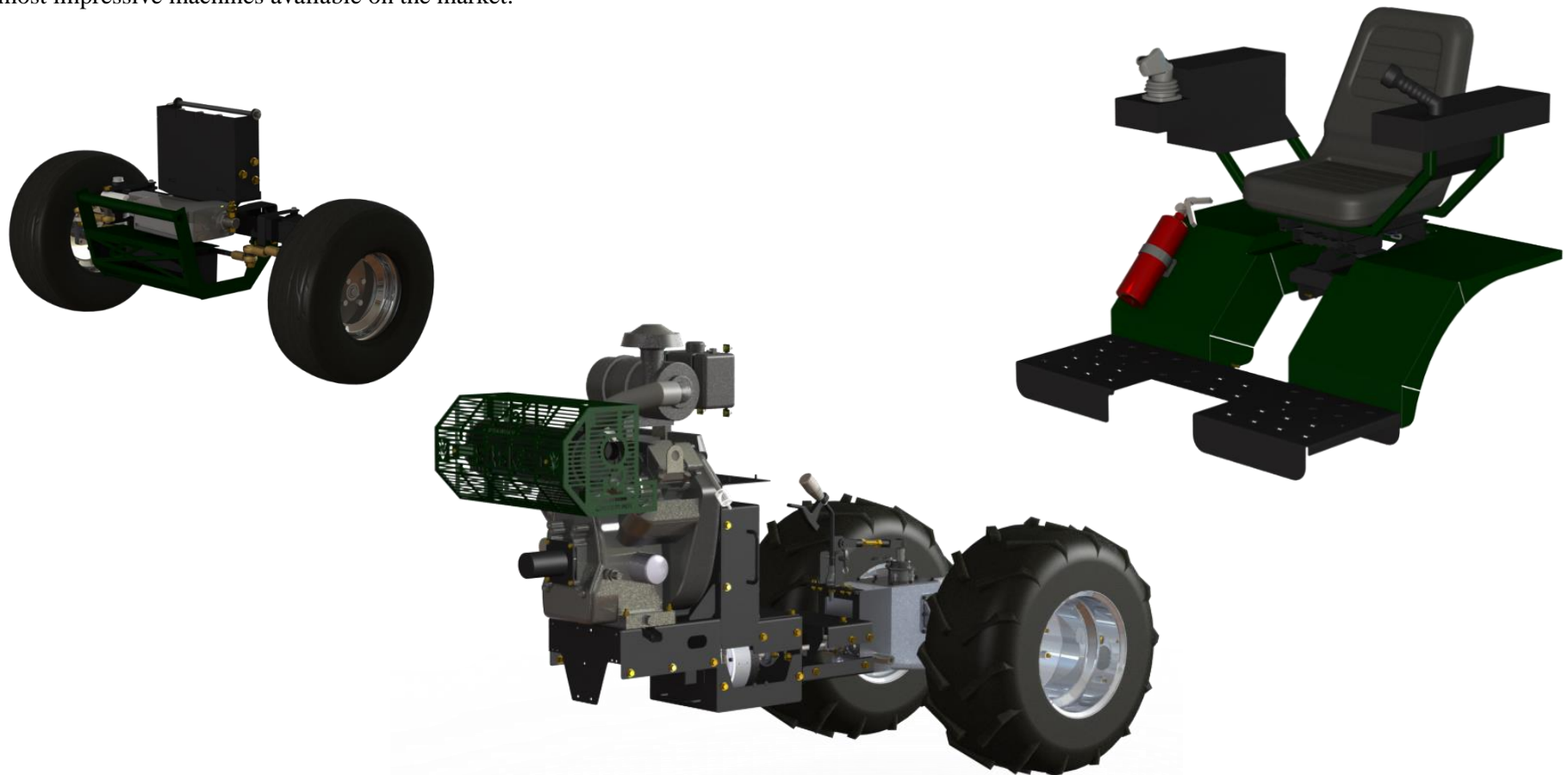


Figure 1: Front End & Steering (Top Left), Driveline & Engine (Bottom), Operator Platform (Top Right)

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## Introduction

The Sled Dogs name has become an industry leader in producing dependable and high performing ¼ scale tractors. With over twenty years of experience developing this product line, the Sled Dogs have never failed to introduce a new and innovative tractor to the market. This kind of success has by no means been easy. Every new addition to the Sled Dogs line undergoes a rigorous design process to ensure the best value and performance is delivered to the customers year after year.

## Target Market

Building upon the success of years past, the new Sled Dogs 2023 tractor has again been tailored to the needs of the ¼ Scale Tractor Alumni Group. This group consists of the ¼ Scale Tractor Alumni that still enjoy engaging in pulling competitions but no longer have the time and resources to develop their own line of pulling tractors. The Sled Dogs lineup utilizes this to deliver a high-performance pulling tractor that is competition ready from the moment of purchase.

Using the Sled Dogs' own network of alumni, last years 2022 Sled Dogs marketing team was able to solicit feedback through a survey that allowed the tested audience to rank several performance objectives of what would add value in the eyes of the consumer. These target market surveys provided a solid foundation on what the customer would need and expect from a Sled Dogs tractor. From the nine different objectives that were given for the overall tractor, pulling performance, durability, and maneuverability were listed as the top three performance values as shown in Figure 2. These surveys allowed the Sled Dogs to streamline the design process with the customer in mind at every decision.

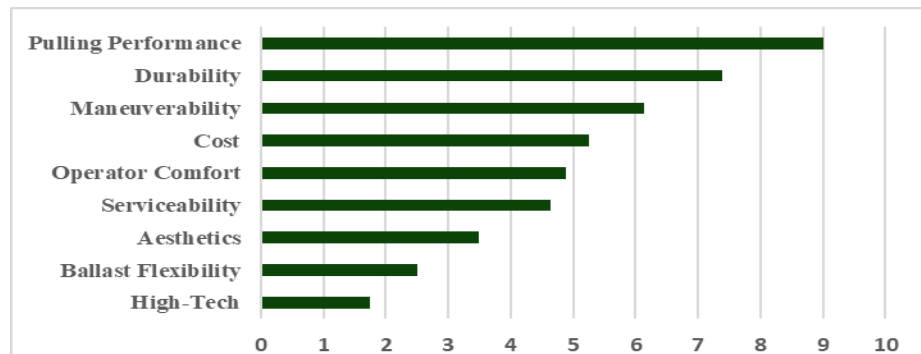


Figure 2: 2021-22 Target Market Survey Results - Overall Tractor

## The Sled Dogs Legacy



Figure 3: Previous Sled Dogs ¼ Scale Tractor Models



## Design Approach & Criteria

Continuous improvement has always been critical towards the success of the Sled Dogs brand. The new 2023 design utilized tools such as design change request forms (DCR) from the previous design year, marketing surveys, and testing results to create improvement in all areas of the tractor and further ensure the best value is continuously being delivered.

The results from testing the 2022 tractor, shown in Figure 4, highlighted several well performing components. The operator platform featured one of the most ergonomic designs to come from the Sled Dogs lineup without sacrificing performance. Additionally, drivetrain guarding and ballasting options were determined to exceed expectations. However, multiple areas for improvement were also discovered.



Figure 4: Sled Dogs 2022 Tractor

The front end showed issues in the suspension system, most notably in the overcomplication and undervalue of the spring and damper suspension. Various tests were conducted on the suspension system by simulating a durability event. These tests found that the upright suspension had negligible dampening on the force into the tractor and operator which demonstrated that the walking axle was sufficient for the tractor's purpose.

The Driveline & Engine system proved to operate well at high speeds but showed problems during low-speed situations. Creeping forward proved to be difficult as the tractor had issues with clutch engagement resulting in jolty movement affecting the overall controllability. This was a result of the clutch engaging quickly after reaching a specific RPM. With the previous design it was difficult to slow down this engagement and resulted in difficulty controlling the tractor at low speeds. Issues were also found in the overheating of the exhaust system. The exhaust guarding was located too close to the muffler and required additional material to prevent overheating of the guarding.

Furthermore, the Electrical & Instrumentation system was found to have two major failure points. First being the steering control components had the tendency to overheat during long run times. This was primarily found to be caused by poor circuit board placement and posed a potential safety hazard to the operator. Additionally, the placement of the master power switch was subject to accidental contact during operation. During durability testing it was

found that the operator often contacted the master power switch while operating on rough terrain. This resulted in the tractor being completely shut down and the operator losing all control of electrical components.

The overall design criteria for the 2023 tractor was created to satisfy the needs of the target market, and is shown below:

- Consistent pulling capability up to 200 ft (60.96m) under standard pulling conditions
- Achieve overall turning radius to less than 7.5 ft. (2.29m)
- Smooth engagement of drivetrain for low-speed maneuverability
- Total MSRP less than \$16,000 USD
- Able to complete at least 20 laps of the Sled Dogs' durability track in 20 minutes without component failure

The design criteria for each subsystem incorporated the collected data from the design change requests, testing, and subsystem specific target market surveys. This criterion is outlined as follows:

### Driveline

- Maximum weight of 450 lbs (204.12 Kg)
- Increase low speed controllability of clutch
- Increase distance of exhaust guarding from exhaust by 15%

### Frame Ballast & Brakes

- Shorten overall frame length by at least 6 inches (152.4mm)
- Improve manufacturability of hitch design

### Front End & Steering

- Improve turning radius to less than 7.5 ft. (2.29m)
- Reduce overall weight by 20%
- Reduce overall cost by 10%

### Operator Platform

- Reduce weight by 10%
- Maintain operator comfort
- Achieve seat and controls adjustability for 95<sup>th</sup> percentile of operators
- Improve switch design and placements

### Electrical & Instrumentation

- Improve steering circuit placement to allow airflow
- Decrease wire harnessing time and materials by 25%
- Reduce circuit board size by 40%
- Improve function of data acquisition system

## Project Management

### Team Organization

The Sled Dogs has always been a free and inclusive team open to all undergraduate students from the University of Saskatchewan. For the 2023 design year, the team was comprised of thirty-three members throughout the colleges of Engineering, Agriculture, Business, and Arts & Science. This diversity allowed for a wide variety of experience, skills, and perspectives to be utilized and contributed greatly to the overall success of the team.

The Sled Dogs management team consisted of five executive members and six design leads that each held specific responsibilities within the team. At the end of April 2022, the previous Sled Dogs team elected returning members to fulfill these positions for 2023. The main tractor design was led by five experienced design leads; each responsible for designing one of the five respective subsystems. A sixth lead was also elected to focus on research and development of new technologies to be used in future tractor designs. After elections, the remaining team members were assigned to subsystems based on their unique interests and skills. This organizational structure, shown in Figure 5, helped to optimize the team's performance and productivity as it utilized the unique abilities of every member.

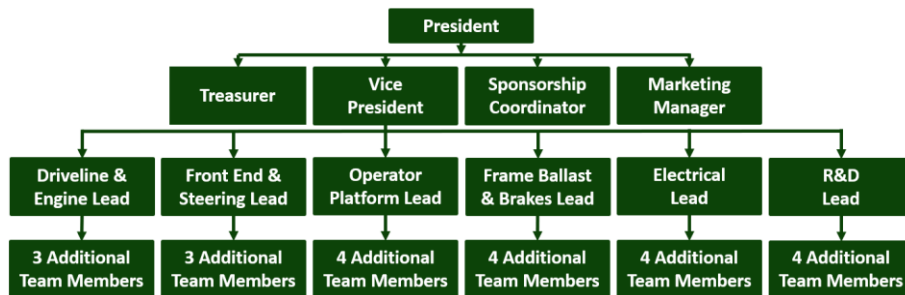


Figure 5: 2023 Sled Dogs Organization Chart

### Team Meetings

To ensure effective collaboration, communication, and overall success, the team held regular meetings and discussions on a weekly basis. This was set to a minimum one-hour session every Tuesday at 6:00 PM CST. The overall agenda of these meetings was never fixed, but was intended to present progress updates, design discussions, testing results, upcoming events/deadlines, and give time for members to work in collaboration.

### Gate Review Meetings

In addition to weekly team meetings, four formal gate reviews were utilized by the Sled Dogs for the 2023 design phase. These gate reviews primarily served as a control point to either stop or proceed with the design of each subsystem prior to advancing to the next stages of the design process. As these meetings required an in-depth presentation into the new tractor design, the Sled Dogs Alumni Group was also in attendance to validate new designs as target market representatives.

### Part Naming Convention

In 2022, the Sled Dogs team created a new part naming convention to standardize and organize part creation, editing, and classification. A similar system was again used for 2023 and identified parts as either manufactured, stock material, or purchased parts as shown in Table 1. Aside from just benefiting design, this naming scheme has also proven invaluable towards purchasing, manufacturing, and aiding in customer support when replacement parts are needed.

Table 1: Part Naming Convention

#### Manufactured Parts:

Field Name:	Model & System Abbreviation:	Main Assembly:	Subassembly:	Tractor Side: (If Needed)	Part:
Format:	##XX-	XXX-	XXX-	X-	XXX
Example:	23OP-	S-	AR-	R-	B

#### Stock Material:

Field Name:	Model & System Abbreviation:	Main Assembly:	Subassembly:	Tractor Side: (If Needed)	Part:	Material Description:
Format:	##XX-	XXX-	XXX-	X-	XXX-	TYPE, #x#x##
Example:	23OP-	S-	F-	R-	ARS-	HSS, 1x1x0.125

#### Purchased Parts:

Field Name:	Model & System Abbreviation:	Main Assembly:	Subassembly:	Tractor Side: (If Needed)	Part:	Supplier Abbreviation:	Supplier Part Number:
Format:	##XX-	XXX-	XXX-	X-	XXX-	XXX-	#####
Example:	23OP-	S-	AR-	R-	GH-	MMC-	1650A412

## Timeline

The timeline for the 2023 tractor was organized into a Gantt chart that defined project deadlines and monitored progress throughout the duration of the project. The original schedule was set using data collected from previous years in hopes to achieve the most realistic expectation for completion dates and lead times of purchased components. Overall, the project became an approximate three weeks behind schedule, but was able to hit several deadlines and only had a maximum deviation of one week during the engineering design phase and early stages of fabrication. A brief breakdown of each phase outlined within the Gantt chart from Figure 6 has been described below.

### Phase 0: Team Organization

Set timeline, recruit new members, create budgets, schedule weekly meetings and gate reviews.

### Phase 1: Engineering Design

**E1 – Preliminary Design:** Outline performance objectives, constraints, design alternatives, and recommendations.

*Gate Review 1:* Preliminary Design Review

**E2 – Detailed Design:** Justification for selected design alternative with a detailed development of system components including analysis.

*Gate Review 2:* Detailed Design Review

**E3 – Comprehensive Design:** Complete SolidWorks model, system level analysis, interference identification, and budget estimates.

*Gate Review 3:* Comprehensive Design Review

**E4 – Final Design:** Completion of entire prototype tractor design to be reviewed in detail with a finalized budget.

*Gate Review 4:* Final Design Review

**E5 – Final Design Revision:** Final check to ensure no interferences were overlooked and each design is in compliance with rule standards.

### Phase 2: Fabrication and Assembly

**F1 – Working Drawings Creation and Review:** Preparation of drawings to be sent out for fabrication.

**F2 – Mass Manufacturing Order:** Create purchase orders and order parts.

**F3 – Sub-System Fabrication:** Assemble each sub-system.

**F4 – Full Mechanical Assembly:** Assemble full tractor.

**F5 – Electrical Assembly:** Run wire and install electrical components.

### Phase 3: Testing, Validation and Revision

**T1 – Testing, Validation & Design Revision:** Comprehensive testing and validation for entire tractor; changes if necessary or beneficial.

### Phase 4: Tractor Detailing

**D1 – Tractor Disassembly:** Disassemble tractor and organize parts to be painted.

**D2 – Paint Preparation:** Preparation of parts for painting.

**D3 – Painting:** Painting of individual parts.

**D4 – Final Tractor Assembly:** Reassemble full tractor.

### Phase 5: Competition

Includes everything required for the team to compete the new 2023 tractor at the ASABE International ¼ Scale Tractor Student Design Competition.

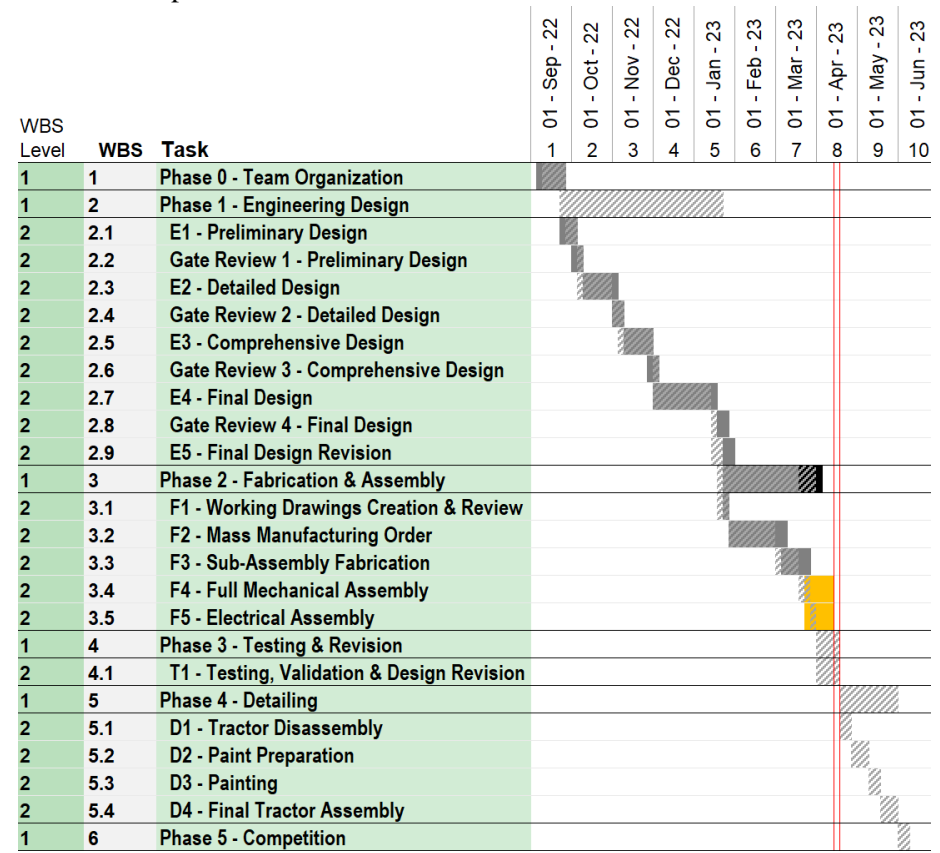


Figure 6: 2023 Timeline Gantt Chart

## General Configuration

New innovation merged with previous dependable design has allowed the Sled Dogs to produce one of the most sought-after tractors year after year. Building upon this year's predecessor, the 2022 model, the new 2023 tractor is ready to hit the market. This year's drivetrain features a 31 HP Briggs & Stratton engine paired with the proven Hawaya centrifugal clutch and three-speed Midwest Super Cub transaxle that delivers the perfect balance of pulling performance, durability, and cost. To further aid in pulling performance, this tractor includes four different ballasting options located on the tractor's front end, beneath the floorboards, under the transaxle, and fluid ballast within the 26-inch rear drive tires.

For maximum comfort the operator platform includes an off-the-shelf seat suspension and adjustment system along with a high-back seat. Further suspension has also been designed into the tractor's front end through a walking front axle with over 20° of articulation.

The Sled Dogs line of tractors is known for its simple yet effective frame design, and this year was no different. Two 3/16-inch plate steel frame rails are the base of the 2023 model. This allowed the frame rails to be laser cut for great accuracy and repeatability on the manufacturing line.

The front end steering system features a double king pin Ackermann steering geometry with electrically actuated control providing an unmatched turning radius of 7.2 ft.

A newly integrated electrical box on the right-hand armrest allowed for less clutter within the center mounted console. This provides the user with more room when servicing or performing field tests, and decreased the total amount of harnessing that was required in last year's 2022 model. With the addition of the new electrical box, the steering control components have been repositioned into the center console thus isolating the circuit from its prior heat source that created overheating issues in 2022.

The perforated anti-slip floorboard design and contact grab handles provide 3-points of contact, ensuring operator safety when entering or exiting the tractor in all conditions. Drivetrain guarding, fenders, and safety interlock systems also ensure the highest levels of safety are achieved. The operator's control panel is located on the right-side armrest and includes controls for start-up, shut-down, electrical disconnect, choke, and headlights.

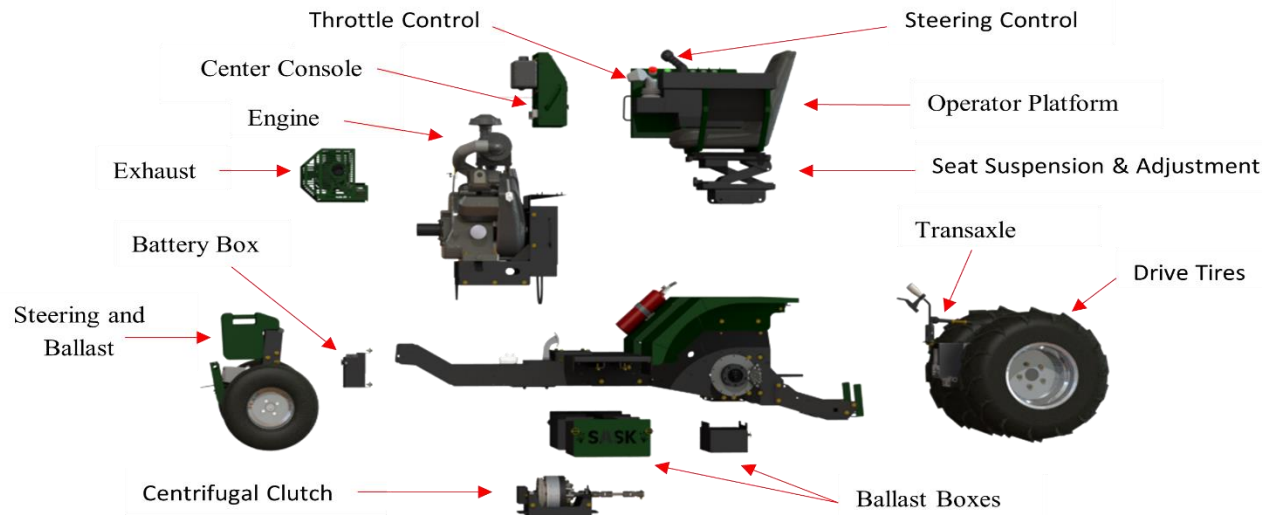


Figure 7: Exploded View of Sled Dogs 2023 Tractor



## 2023 Sled Dogs ¼ Scale Tractor Specifications

Drivetrain	
<b>Engine</b>	<ul style="list-style-type: none"> <li>896cc Briggs &amp; Stratton Vanguard V-Twin Big Block. 31 HP @ 3600RPM.</li> </ul>
<b>Driveline</b>	<ul style="list-style-type: none"> <li>Belt driven centrifugal clutch</li> <li>Midwest Super Cub aluminum transaxle.</li> <li>Three-speed gearbox with reverse</li> <li>5.0, 6.5, 7.5 mph (8.0, 10.5, 12.0 km/h) full throttle forward wheel speeds</li> </ul>
<b>Throttle</b>	<ul style="list-style-type: none"> <li>Joystick and servo</li> </ul>
<b>Choke</b>	<ul style="list-style-type: none"> <li>Toggle switch and actuator</li> </ul>
Steering & Brakes	
<b>Steering</b>	<ul style="list-style-type: none"> <li>Thompson linear electric actuator</li> <li>On-off-on rocker switch-controlled steering</li> <li>7.2 ft (2.18 m) steering radius</li> </ul>
<b>Front Axle</b>	<ul style="list-style-type: none"> <li>Solid axle with center pivot</li> <li>Front mounted ballast rack</li> </ul>
<b>Brakes</b>	<ul style="list-style-type: none"> <li>Independent rear-wheel Wilwood single-piston hydraulic calipers</li> <li>Wilwood compact master cylinders</li> <li>Billet aluminum pedals</li> </ul>
Wheels	
<b>Front Wheel</b>	<ul style="list-style-type: none"> <li>Douglas Wheel Technologies 4 x 8</li> </ul>
<b>Front Tire</b>	<ul style="list-style-type: none"> <li>Kings Tire 4 x 8</li> </ul>
<b>Rear Wheel</b>	<ul style="list-style-type: none"> <li>Douglas Wheel Technologies 12 x 12</li> </ul>
<b>Rear Tire</b>	<ul style="list-style-type: none"> <li>Titan Tru Power II 26 x 12 - 12</li> </ul>

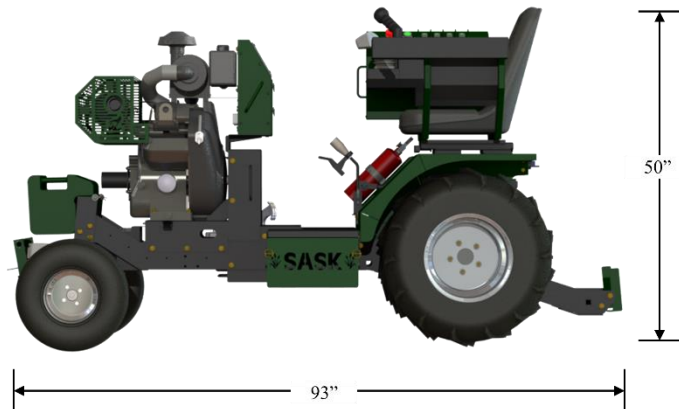


Figure 8: 2023 Tractor Side View

Electronics	
<b>Electrical Control</b>	<ul style="list-style-type: none"> <li>Arduino microcontroller</li> <li>Raspberry Pi microcomputer</li> </ul>
<b>Sensors</b>	<ul style="list-style-type: none"> <li>Ground speed radar</li> <li>Wheel speed</li> <li>Engine RPM</li> </ul>
<b>Switches</b>	<ul style="list-style-type: none"> <li>Engine kill switch</li> <li>Trailer breakaway</li> <li>Brake, neutral, and seat ignition interlocks</li> <li>Push-button start</li> </ul>
<b>Battery</b>	<ul style="list-style-type: none"> <li>Magnasport 12V battery</li> <li>270 cold cranking amps, 18 amp-hr capacity</li> </ul>
Unballasted Weight	
<b>Base Weight</b>	<ul style="list-style-type: none"> <li>860 lb (391kg)</li> </ul>
<b>Front Axle</b>	<ul style="list-style-type: none"> <li>326 lb (148kg) (38%)</li> </ul>
<b>Rear Axle</b>	<ul style="list-style-type: none"> <li>534 lb (243kg) (62%)</li> </ul>
Fluids	
<b>Fuel</b>	<ul style="list-style-type: none"> <li>2.0 qt. (1.9L) 87 octane gasoline</li> </ul>
<b>Engine Oil</b>	<ul style="list-style-type: none"> <li>2.3 qt. (2.2L) SAE 10W-30</li> </ul>
<b>Gear Oil</b>	<ul style="list-style-type: none"> <li>2.0 qt. (1.9L ) John Deere HY-GARD</li> </ul>
<b>Brake Fluid</b>	<ul style="list-style-type: none"> <li>0.25 qt. (0.24L) DOT 3</li> </ul>

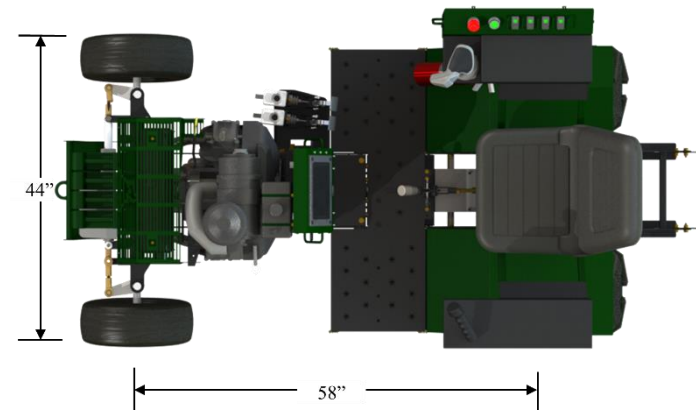


Figure 9: 2023 Tractor Top View

## Driveline & Engine

### Drivetrain Selection

To begin the design of the newest model in the Sled Dogs' line, the team revisited the drawing board and reviewed previous testing results, design change requests, and the target market surveys from 2022. These tools were used in conjunction with the team's goal of continuous improvement to select the drivetrain for this year's tractor. On a large scale, this model's drivetrain focused primarily on durability, maneuverability, and cost without impairing the pulling performance of the tractor.

To select the ideal drive configuration, the team objectively looked at different available options. Based on results of testing and prototyping in the 2019 and 2020 years, the team had invested in a fully customized CVT as it was theorized to maximize pulling performance in numerous conditions. However, at the beginning of this year, the CVT still remained largely unproven and therefore left concerns regarding reliability. While the CVT concept had been proven successful for similar machines on the market, this custom CVT also remained significantly more expensive than other alternatives. The other main option was a modified Hawaya centrifugal clutch which had been proven reliable on six previous Sled Dogs tractors. Thus, to ensure the reliability and cost of a critical drive component, the team elected to use the modified Hawaya clutch once again.

After deciding upon the drive configuration, the selection of a transaxle was considerably easier. The team had the choice between a proprietary fully custom 2-speed transaxle, designed in 2020, or the 3-speed Midwest Super Cub. However, based on results of testing this centrifugal clutch with both of these transaxles back in 2021, the custom transaxle did not provide the team with any of the pulling or durability advantages that it was originally design for. This left the Midwest Super Cub as the ideal pairing for the 2023 tractor based on cost and weight savings with very similar performance results.

### Drivetrain Layout

The 2023 Sled Dogs model follows the typical pulling tractor layout featuring a forward mounted engine, centrifugal clutch driving the rear wheels, and an operator station placed over the rear axle. This drivetrain layout provides the ideal base weight split of 60:40 while also leaving sufficient flexibility to shift the weight split using ballast as desired. The full drivetrain layout is shown in Figure 10.

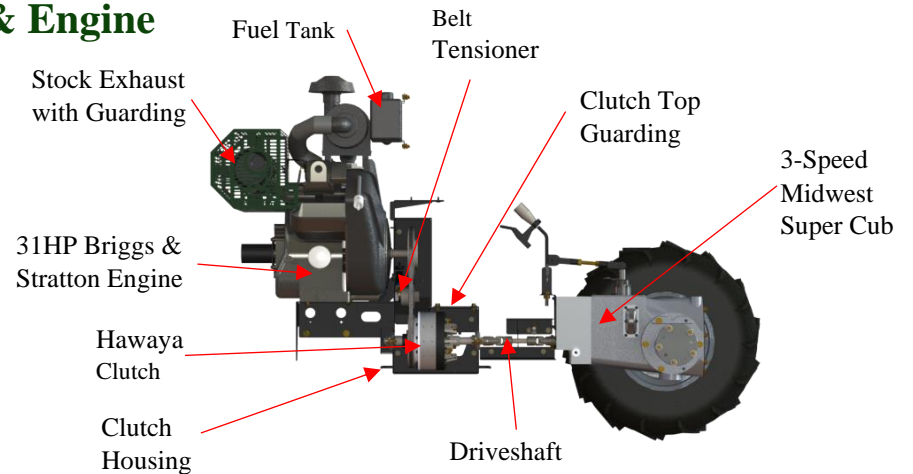


Figure 10: Drivetrain Layout

The engine on this 2023 model features the stock Briggs and Stratton exhaust with a Poly Chain belt being driven off a flywheel mounted stub shaft. This Poly Chain belt connects the engine to the modified Hawaya clutch located beneath the operator's feet and in line with the transaxle input pinion. A solid driveshaft with two universal joints connects the clutch shaft to the transaxle input pinion. The Midwest Super Cub contains gearing designed to give the operator flexibility for use in various track and maneuvering conditions.

### Driveshaft

Since the connection between the clutch and transaxle has a small effect on the pulling performance, the new design of the driveshaft focused primarily on other design objectives. These objectives resulted in the selection of a standard style driveshaft with universal joints. The NB8 universal joints provide required misalignment tolerances (up to 25°) for mounting off frame rails as well as allowing for simple removal via set screws. The shaft itself is made of 4340 HSTR providing more than sufficient strength and keeping part count low. This shaft only has two keyways making it extremely easy to manufacture. Due to the way the driveshaft interfaces with the clutch and transaxle, the driveshaft must be removed with the clutch. For this reason, the lower guarding can be removed providing full access to the driveshaft. Additionally, the entire driveshaft is a mere 9.5" long thus shortening the overall length of the tractor and improving the turning radius.

## Centrifugal Clutch

The team originally obtained the Hawaya clutch, which was designed for use in drag racing motorcycles, in 2015 and made modifications so it could be applied in the Sled Dogs line of products. The clutch engages with rotational speed based on centrifugal forces generated within the clutch. The clutch also features a multi-stage lockup which can be tuned to provide specified performance for various conditions as shown in Figure 11. This tuning can be accomplished by adding or removing weights from the engagement fingers or by adjusting the tension on the engagement springs. This allows the clutch to be tuned up or down depending on operator preference and performance requirements.

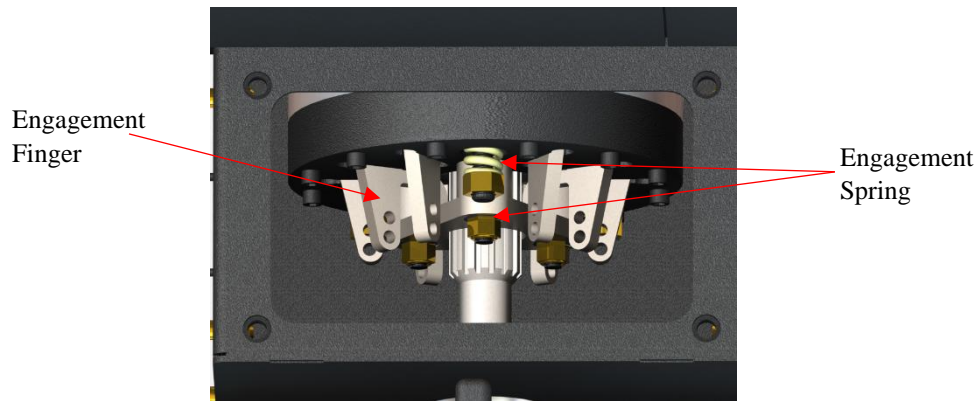


Figure 11: Overhead Access to Hawaya Clutch with Access Panel Removed

Since the versatility of the clutch is one of its main attractions, the Sled Dogs wanted to ensure it could be used to its full potential. This was achieved in two different ways. First, the clutch is mounted into a removable housing which allows the entire clutch to be removed from the tractor by disconnecting the belt drive and driveshaft and then removing the four bolts holding the housing in place. This allows the clutch to be easily tuned on a dynamometer or to perform maintenance on the clutch. Secondly, by simply removing the access panel placed above the clutch housing, the operator has full access to adjust the settings of both the engagement fingers and springs without disconnecting or removing the clutch. This allows the operator to make quick and easy adjustments to the drive of the tractor in mere seconds.

## Transaxle

As previously mentioned, this model features a 3-speed Midwest Super Cub transaxle. The transaxle is geared such that, at full throttle, it achieves ground speeds of 5, 6.5, and 7.5 mph. This provides the operator with an ideal range of operating speeds for any condition. The transaxle also features the custom, remote mounted shift lever shown in Figure 12. This shift lever has a mechanical lock to ensure the transaxle remains in gear under load. The shift lever is also designed such that the shift knob and driveshaft brake can be ergonomically used from the operator station.

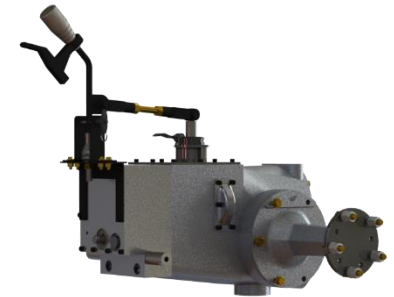


Figure 12: Midwest Super Cub Transaxle

## Belt Tensioner

The belt tensioner consists of an idler pulley on a pivoting lever arm which is kept in tension by a compression spring. This compression spring sets the tension on the belt by pulling on the lever arm. The tensioner assembly is then locked out using jam nuts to prevent rattle of the belt during operation.

## Exhaust Guarding

The Sled Dogs chose to guard their exhaust as per ISO 5395-3 Section 4.12 with a peripheral bent sheet metal guarding. This guarding is peripherally spaced two inches from the muffler using integrated spacers. The guarding also features laser cut slots to maximize airflow to the exhaust while still ensuring the structural integrity of the guarding. The final key feature of the exhaust guarding, as seen in Figure 13, is the hot surface warnings that have been laser cut into the guarding.



Figure 13: Exhaust Guarding

## Frame Ballast & Brakes

### Subsystem Overview

The complete Frame Ballast & Brakes subassembly is the framework that the entire tractor is built around. Ensuring ease of access, clearance, accuracy, and precision of all mounting points was found crucial towards the success of an operational and manufacturable design. Many hours and design iterations have gone into the development of a safe, functional, and reliable system for this years Frame Ballast & Brakes as featured in Figure 14.

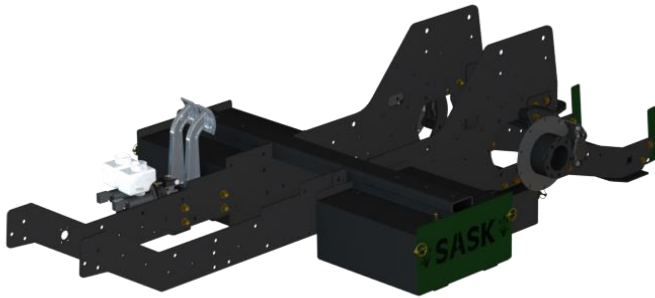


Figure 14: 2023 Frame Ballast & Brakes

### Frame

The Sled Dogs have a history of exemplifying Design for Manufacture (DFM) ideology and have placed great emphasis to continue that legacy in 2023. The new frame design, shown in Figure 15, is a great example as it features a twin frame made from 3/16-inch 44W plate that has been laser cut for precision and repeatability. Structural integrity to the frame is then provided using components from the drivetrain, front end, and operator's platform. Multiple pass-through locations have been strategically placed within the frame to assist in the routing of electrical wires and brake lines during manufacturing and servicing.



Figure 15: 2023 Frame Rail

### Ballast

Many aspects of the 2023 ballasting system have been revamped from the 2022 design, however, for further ballast flexibility two new ballasting options are now featured.

The mid-frame ballast system has received some minor advancements from the previous year's design. It was determined that although the extra mounting points did provide some stability, they were not required to safely support the max capacity of ballast nor the complete weight of the tractor. This change also helped speed the install and removal process from six bolts down to two. When not in use for ballast, these tubs have multi-purpose use as storage or toolboxes.

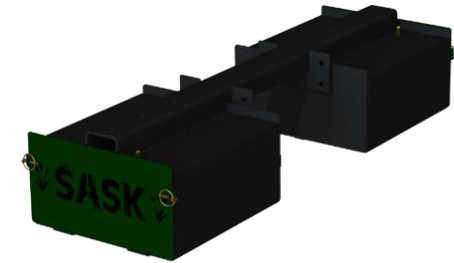


Figure 16: Mid-Frame Ballast Box

The first of the new ballast options is a suitcase weight bar mounted above the front axle. By utilizing a single retaining pin hold, ballast of up to 160lbs can be added or removed very quickly to gain optimized weight distribution. This is crucial with heavy pulls to maintain control of the tractor with steering.

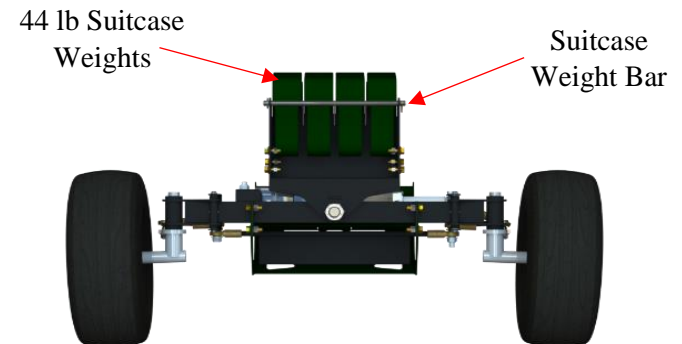


Figure 17: Front End Ballast Box



The second new ballast option is the transaxle ballast system. This allows up to 88lbs to be added directly below the rear axle centerline for optimal ballasting. With only four mounting bolts, the complete ballast box can be removed in seconds when not in use. This helps to increase ground clearance when working in soft ground conditions. As with the mid-frame ballast system, the transaxle ballast system uses a simple cover plate fastened with two lynch pins, providing quick ballast changes or storage accessibility.



Figure 18: Transaxle Ballast Box

## Hitch

The 2023 hitch assembly has undergone a redesign from recent years. Keeping with a simplistic theme, a single crossbar connects the clevis plate which has been supported by two gusset plates. Slotted holes provide 1.5 inches of quick adjustment and an additional 1.5 inches of adjustment by flipping the hitch assembly between the frame rails. As per competition rules, a 1-15/16" hole and a 0.75-inch lip were designed into the clevis plate which will easily and safely accommodate any implement that could be connected.



Figure 19: Hitch

## Brakes

Maintaining our quality braking performance, Wilwood brake calipers were once again utilized and mated to custom designed rotors. These are powered by Wilwood Master Cylinders and operated by custom designed brake arms and pedals. Keeping with two separate brake assemblies, one for each side, allows for individual wheel braking. This becomes a great steering feature when working in low traction or muddy environments as-well-as in scenarios where excessive tongue weight causes a light front end condition. The pedal mounting plate received accessibility modifications to provide better access to bolts during servicing and repair.



Figure 20: Brakes

## Wheelie Bars

Keeping safety in mind, A structurally sound, yet simplistic wheelie bar system was designed. By again using 3/16" 44W plate, strength is maintained in the vertical direction, while a single HSS crossbar maintains lateral stiffness. To save weight, bogie wheels were dropped in favour of skid plates, as these were found to have similar performance in all conditions except for hardpack.

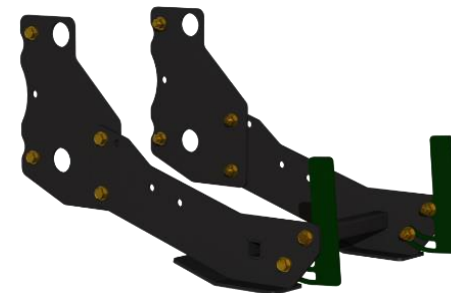


Figure 21: Wheelie Bars

## Front End & Steering

### Subsystem Overview

The 2023 front end underwent significant testing and design in order to align with the team's proven history of a manufacturable, maneuverable, and durable tractor. Keeping with the Sled Dog's reputation of producing a tractor ready for large scale production, the front end subsystem has been designed with modularity in mind and is fastened to the frame with only 6 bolts. This also significantly improves the ease of future repairs. As a result of the iterative design process, the all-new front end provides operators with a walking axle, compact and well protected steering components, a tight 7' 2" turning radius, and ballast mounting for up to 160 lbs.



Figure 22: 2023 Front End & Steering Assembly

### Suspension

As a result of the data gathered during fall testing of the Sled Dogs 2022 tractor, the 2023 model does not feature a traditional spring and damper suspension system. The tractor instead relies on a walking axle pivoting about a centrally located 1" Gr. 5 bolt. This provides  $\pm 20^\circ$  of axle articulation before contact is made with shock absorbing rubber bumper pads mounted to the axle. This provides unabated front end travel for vertical displacements of up to 22". To ensure reliable function with minimal maintenance, the front axle pivots on 1" oil embedded bronze flanged sleeve bushings. These bushings feature SAE 30 oil as lubricant, and are fit for use

in conditions between  $-35^\circ\text{F}$  and  $300^\circ\text{F}$ . In addition to the center pin, these bushings are also used to provide a maintenance free surface that lessens the rotational friction on the tractor's steering components.

To keep the front end stable and planted during heavy pulling, this year's design provides ballast storage for up to four 42lb John Deere Rear Suitcase Weights. This ballast is held on with 11Ga horizontal dividers and a ½" pinned rod to ensure safe mounting during operation over rough terrain. In addition to adequately securing the weights, the simple pinned rod system allows for quick removal or addition of weights depending on the desired configuration. The vertical mounting position of the weights ensures the operator can use a proper lifting technique when changing the ballast configuration.

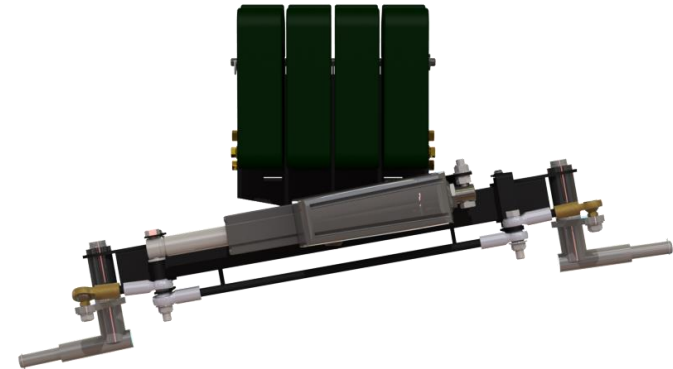


Figure 23: Axle Articulation with Ballast Installed

The primary benefit of the walking axle when compared to other suspension systems is the inability of the axle to carry a moment about the center pin. This ensures there is no torsional load applied to the frame rails until the bump stops are contacted. This in turn heavily reduces the torsional stress applied to the frame and mitigates the risk of frame failure due to uneven terrain.

## Steering

The 2023 steering system uses the Sled Dog's proven double kingpin design with Ackermann steering geometry to achieve the tight turning radius of 7' 2" (measured using ISO 7457:1997). Ackermann steering geometry was achieved by having the planes of the steering arms meet at the point where the centreline of the tractor intercepts the rear wheel axis. This specific geometry was chosen again for 2023 because it allows for the two steering tires to turn about the same turning circle center point; this ensures the inside tire has a larger steering angle and that neither tire will experience any lateral slip. Limiting the lateral slip between the operating surface and the tires provides excellent low speed maneuverability and ensures that the tractor will perform in a safe, consistent, and predictable manner over a variety of terrains. The double kingpin design allows for a steering angle of up to 47.5° without over-centering the steering arms, a common issue with single kingpin designs. A pair of female threaded ball joint ends utilized on the ends of the three tie rods allow for easy alignment of the steering tires and ensure no binding occurs through the steering arm's range of motion.

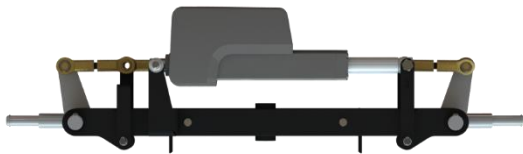


Figure 24: Ackermann Steering Geometry

Powering this steering motion is a Thomson Linear actuator rated for 382 lbf and controlled by an (on)-off-(on) momentary rocker switch. This system is intuitive to operate and can be learned quickly by new operators. In addition, the switch-controlled steering allows operator to keep both of their hands on the controls at all times. This results in a safer operator position, and better vehicle control. New for 2023 is the horizontal orientation of the actuator. This was designed to better protect the actuator behind the bumper as well as maximize walking axle travel when the optional ballast is installed.

The kingpins themselves are designed to be easily manufactured with only one welding jig. The keyed hole on the steering arm self-aligns on the CNC machined kingpin, providing a precise and repeatable steering arm angle of 13.8°. The coping on the bottom of the kingpin drives the camber angle of

+2° and is responsible for the excellent straight-line stability displayed by the tractor at high speeds. Positive camber also aids in reducing the required steering force; this results in faster actuator motion and more nimble steering in tight spaces.

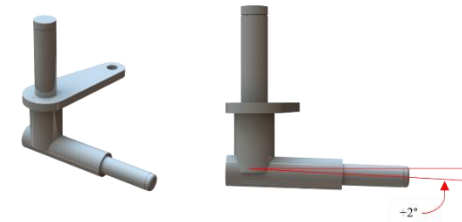


Figure 25: Ackermann Steering Geometry

## Bumper

The front bumper on the 2023 tractor features an 11 Ga sheet metal frame with robust 3/8" mounting hardware to ensure that the critical components of the front end stay well protected. Mounting the bumper directly to the axle ensures it moves with the walking motion of the axle and steering components, ensuring full protection through the entire range of motion. The tabbed and slotted symmetric frame sides eliminate the chance of using the wrong part during assembly, and aid in stiffening the weldment so that the large bottom face of the skid plate can serve as a jack point for maintenance. The large tow hook and round push bar provide easy access points for recoveries of varying severity.

## Tires

New for 2023 are 4.00-8 bias ply tires. These tires feature a stiff sidewall that allows for operation of the tractor at pressures as low as 4 psi, ensuring a smooth ride in all conditions. The common tire size used on this tractor also makes them easy to replace in the event of failure; an especially important consideration given the current industry shortages. See the "Testing and Development" section of this report for more information on the effect of tire pressure on front end impact absorption.

## Operator Platform

### *Subsystem Overview*

The 2023 Operator Platform team sought to improve the already high levels of achievements in previous years. With strong considerations placed on the results of the target market survey, the Operator Platform team was able to remain focused on a few key components, while making improvements where the potential was recognized. As well, there was a handful of design issues from previous years that had to be addressed. A brief overview of the main components in the system includes the seat and seat suspension, floorboards, and fenders, as well as the electrical joysticks and switches. The design of this subsystem is of high importance within the Sled Dogs team, as the Operator Platform interfaces with many other sub-systems.



Figure 26: 2023 Operator Platform

### *Target Market Survey*

To aid the team in making design decisions a target market survey was used, where respondents could rank each item on a scale from 1 (least important) to 5 (most important) which allows for weighted averages to be calculated and the design outcomes ranked. Ergonomics placed the highest at a weighted average of 4.17, with visibility following at 3.83, hitch visibility also follows closely. The next two most important design outcomes were seat suspension and multi-side entry ranking 3.08 and 2.83 respectively.

### *Operator Console Ergonomics*

The 2023 Sled Dogs pulling tractor maintains a similar ergonomics package as previous years, utilizing right and left joysticks mounted on the armrests of the tractor. The right joystick is a Danfoss product, which serves as a throttle for the tractor, as well as having the ability to switch between throttle modes and other auxiliary switches for addons such as headlights and an electric horn. As well, this right-hand joystick is mounted on a drop-down section of the armrest to allow for the operator to keep their arm and wrist in a comfortable position while staying secure to allow for fine throttle control. Mounted beside the right joystick is the electrical box, which contains important components for the control of the tractor. Mounted on top of this electrical box are the primary electrical controls for the 2023 tractor, such as the choke, master power, push button start, and emergency shutdown. These buttons have been located so that they are easily accessible by the operator but have enough distance from where the operators arm naturally sits to avoid incidental contact. The left-hand joystick houses a rocker switch to actuate the steering of the tires on the front axle. This steering joystick is designed in house and aims to fit a large range of hand sizes comfortably. The final control systems not yet described would be the shifter and brake pedals, which are both accessible from below the seat. The ability for a large range of operator sizes is accommodated for by the ability of the seat to slide fore and aft as well as adjusting the height up and down.

### *Operator Comfort and Visibility*

Building off the ergonomic design of the subsystem, comfort is further addressed by the choice of seat which is a high-back frame with a padded leather cover. This seat is mounted to the suspension system which also allows for the adjustability needed to reach all controls. The chosen suspension system can be tuned for operators from 80 to 300 pounds. The design of the 2023 years operator platform also ensured that the operator had a high degree of visibility in all directions. Care was taken to ensure no components protruded into necessary sight lines during operation. As well this open concept lends itself well to the ability of the tractor to be mounted by the operator from both the left- and right-hand side with relative ease.



## Electrical & Instrumentation

### Subsystem Overview

The electrical system for the 2023 tractor consists of a data acquisition system, instrument display, battery box, modular electrical console, and an electro-mechanical control for both throttle and steering. While developing these systems' reliability, manufacturability, simplicity, and safety were paramount. To achieve these objectives the following improvements were made from the systems utilized in previous model tractors:

- Refined motherboard with the introduction of direct mounted fuses on the board, fuse indicator lights, and component labels.
- Relocated motherboard and steering board for increased accessibility.
- Improved and tool-free battery box design.
- Enhanced center console design for better manufacturing.
- Switch guards to prevent unsolicited contact with the controls.

### Assembly

The main structural components of the 2023 electrical assembly include the center console, battery box, and side mounted electrical box. The center console, seen in Figure 27, contains the DAQ, screen, and several steering circuit components. Improving on rigidity, accessibility, and manufacturability was the primary focus for the new center console design. A new access panel with tool-free swell latches has replaced the previous hinged design that was featured in last year's console. This new design completely removes all required welding without sacrificing accessibility.

To reduce complexity and harnessing costs, the motherboard was moved to the electrical box located on the operator platform. This relocation allows for a self-

contained control system that optimized wiring between the motherboard and tractor controls. This electrical box, seen in Figure 28, houses the motherboard, fuses, steering and throttle microcontrollers, busbars, and several other required electrical components. The box also features a toolless access panel for efficient troubleshooting and maintenance. To allow for modular

manufacturing, the entire box has been wired independently of the tractor which allowed for electrical and operator platform assembly to be done simultaneously.

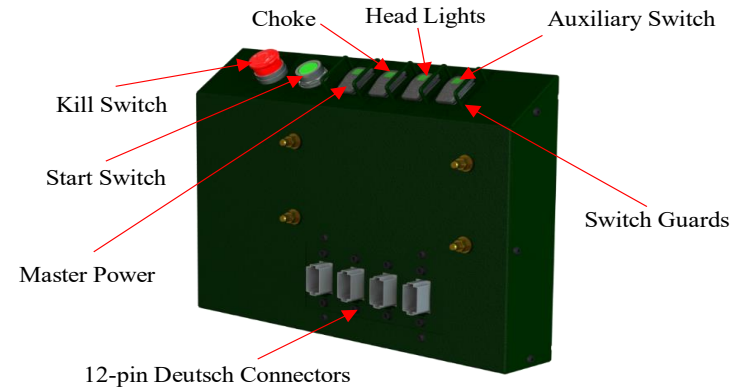


Figure 28: Electrical Box

The battery box, shown in Figure 29, is manufactured out of formed sheet steel and mounts to the front engine bracket on the tractor. Accessibility has been improved with the use of toolless thumb screws on the removable front panel for easy removal of the battery. The sides of the box were also lowered to eliminate electrical shock due to shorting to the box when connecting the battery leads.

### Harnessing and Bussing

The 2023 tractor design utilizes DEUTSCH™ connectors to reduce space taken up by wiring and allow for harness fabrication separate of the main tractor manufacturing line. This remote fabrication allows for harness creation to be outsourced or manufactured on a different line. The remote manufactured harness is then installed on the tractor efficiently and seamlessly near the end of the manufacturing process. The use of DEUTSCH™ connectors and boots creates a durable, weatherproof, and ridged connection that will result in less electrical failures and therefore improved operator safety.

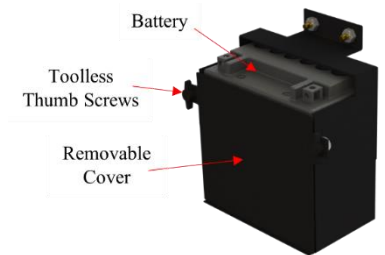


Figure 29: Battery Box

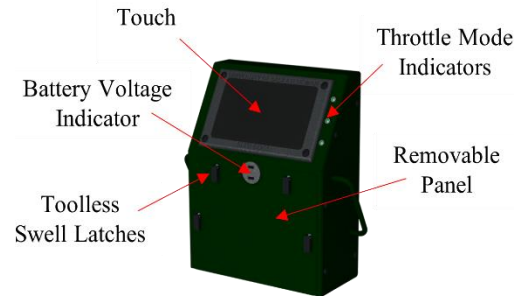


Figure 27: Center Console

## ***Motherboard Design***

For 2023, the electrical team continued to increase reliability and produce a more compact motherboard design. Overall, a 48% reduction in surface area was achieved while also integrating direct mounted fuses to the board. The 2023 motherboard, shown Figure 30, incorporates the safety control circuit, 5V protection circuit, electric steering circuit, electric throttle, and the starter circuit to one board.

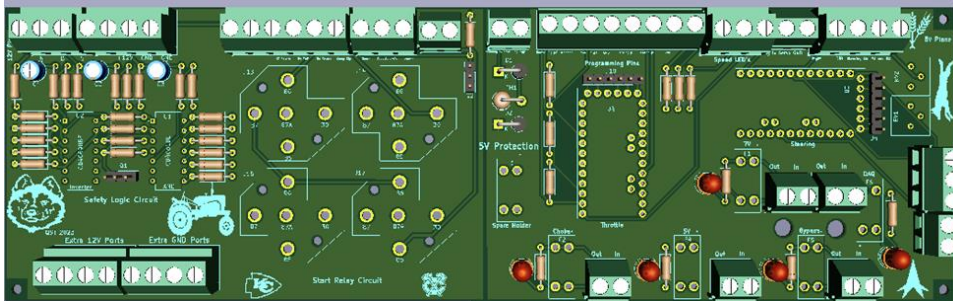


Figure 30: 2023 Mother Board

To reduce wiring and electrical component size, the direct mount fuses were added to the motherboard allowing for the bulky fuse box to be removed. To improve troubleshooting and manufacturing, all components are labelled on the PCB along with LED indication if a fuse has been blown. The team also improved and fixed the errors that were apparent in the 2022 motherboard such as removing the unnecessary diode and Positive Temperature Coefficient (PTC) fuses on the power inputs of the Arduinos. Also, switching from P-channel Metal Oxide Semiconductors (PMOS) to N-type Metal Oxide Semiconductors (NMOS) MOSFETS for better logic and tracing. Through testing the team concluded that the backup protection for the power input to the Arduinos was redundant and therefore was removed to save board space. The team was also able to do a more in-depth review on the trace widths needed on the board. It was found that the traces with the most power requirements needed to only be 0.5mm rather than 0.8mm which helped reduced the motherboard cost.

## ***Steering***

For protection of both the operator and electric actuator, a steering limit board is included within the steering control circuit. This board has been designed to disconnect the current that powers the electric actuator when it has been retracted or extended to its designed limits. If the actuator surpasses these set

limits, it has potential to damage the actuator itself and to achieve a turning radius that is hazardous to the operator.

Shown in Figure 31, the steering limit board for 2023 has undergone significant changes compared to the 2022 board. This was a result of the previous design causing the limit sensor to overcurrent when the limit setpoint was reached. The circuit for the 2023 PCB has been modified to include two NPN transistors that will allow the limit sensors to operate on a lower current loop within the circuit.

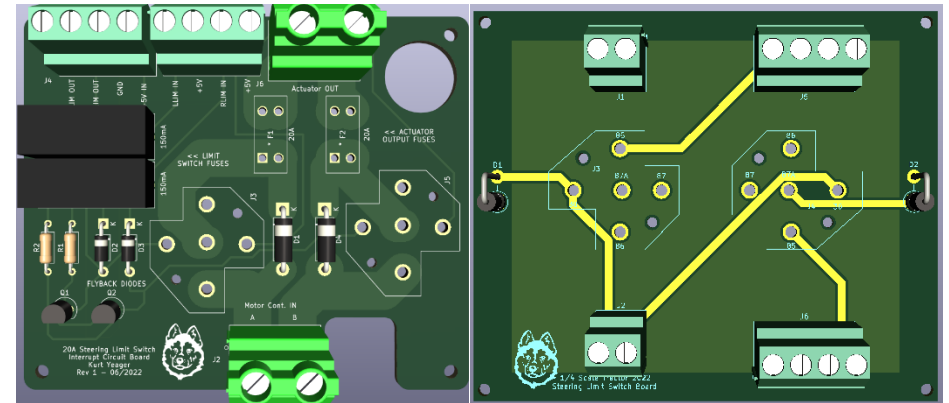


Figure 31: Steering Limit Board (2023 on Left, 2022 on Right)

## ***Engine Control System FMEA***

With the engine control system being such a critical function of an operatable and safe tractor, a Failure Modes and Effects Analysis (FMEA) was performed to identify the risks associated to the system. Shown in Table 2, this FMEA looks at everything involved with engine control such as start-up, shut-down, choke, engine speed, and throttle control. The severity for all items was relatively ranked based on the worst-case situation where the operator might be put into a hazardous situation. A mid-range severity was a general indication that would cause customer dissatisfaction and costly repairs and would become lower severity based on cost of the needed repairs. Detectability was primarily ranked depending on how quickly the operator would notice potential affects at the moment of failure. This averaged a generally moderate to high level of detectability. Items with the highest RPM were generally found to have the highest of severity such as having the inability to shut-down the tractor and therefore required action to ensure a low occurrence.

# SLED DOGS ¼ SCALE TRACTOR TEAM – 2023 DESIGN REPORT

Table 2: 2023 Engine Control System FMEA

Item	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Current Design Controls	Detectability	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
Function											Actions Taken	Sev	Occ	Det	RPN
Throttle Servo	Water/Dust Contamination	Tractor inoperable due to no throttle control.	5	Water and dust from improper storage can create corrosion on copper coils of servo.	2	ISO standards and supplier quality to ensure servo is IP67 certified.	3	30							
Throttle Servo	Overheating	Loss of throttle control or potential to seize at full throttle.	9	Close proximity to engine and exhaust as well as extended operating times.	5	Company Standard. Independent Shutdown Circuit. Spring Return Throttle.	3	135	Heat protection wrap along with field testing.	Driveline & Engine Team, January 2023	Insulated using heat wrap and tested to ensure throttle servo didn't overheat after 10, 30, and 60 minute run times.	9	2	3	54
Servo-Engine Mechanical Linkage	Structural Failure	Tractor inoperable as throttle control will be lost.	6	The fasteners could shear, tear out, or vibrate apart. Fatigue failure also possible.	2	Company Standards	4	48							
Throttle Servo Microcontroller	Input or Output Signal Interference	Loss of throttle control and/or unexpectedly increasing or decreasing of throttle.	10	Controller corruption, or improper wiring by manufacturing or vibrations in rough terrain.	4	Company Standards. Independent Shutdown Circuit.	3	120	Poka-yoke harnessing and shielded cable.	Electrical & Instrumentation Team, November 2021	Use of Deutsch connectors on harnessing and wire of SAE J1128-GPT standard implemented.	10	1	3	30
Servo DC-DC Power Module	Overcurrent and/or Electrical Surges	Fry throttle servo or blow fuse.	5	Improper voltage regulation along with supplier or manufacturing errors.	3	Company Standards & Supplier Quality. In-line Fuses.	3	45							
Printed Circuit Boards (PCB)	Solder Joint Fracture	Loss of throttle, choke, potential to start the tractor, or shut tractor down during operation.	6	Manufacturing errors or fatigue from vibrations caused by rough terrain.	1	Company Standards	3	18							
Choke	Overcurrent and/or Electrical Surges	Potential to fry the choke resulting in increased difficulty starting tractor.	2	Inrush surge when the choke is initially switched on and/or overheating during high usage.	3	Supplier Quality and In-line 3 Amp Fuse.	3	18							
Engine Governor	Faulty from Manufacturer or Altered by Vibrations	Engine could exceed the designed output speeds and potentially cause injury.	10	Improper factory setting or tampering.	1	Supplier Quality and Company Standards.	5	50							
Starter Safety Interlock	Sensor Failure	Engine will not start without safety signals engaged.	5	Sensor could break during manufacturing or from operation.	2	Company Standards. Assembly Line Testing.	5	50							
Wiring	Damage to the Wire's Jacket	Loss of function within engine control system and low voltage shock hazard.	7	Sharp corners along with wire jacket abrasion, fatigue from operation, and UV exposure.	4	Company Standards	5	140	Dynamic rated wire with rubber grommets covering sharp corners and cover exposed wires in loom.	Electrical & Instrumentation Team, February 2023	Rubber grommets, wire loom, and SAE J1128-GPT wire implemented.	7	2	5	70
Wiring	Improper Assembly	Engine will not start or will lose functionality.	5	Wires misconnected during assembly of tractor or during servicing.	7	Company Standards. Assembly Line Testing.	4	140	Assembly line testing along with Poka-yoke harnessing.	Electrical & Instrumentation Team, February 2023	Poka-yoke harnessing implemented and testing conducted after each major wiring stage.	5	2	4	40
Circuit Relays	Coil Failure, Mechanical Wear, or Contacts Sticking	Engine will not start or bypass safety interlock if stuck open.	5	Fluctuating voltages and long life spans.	3	Supplier Quality	5	75							
Kill Switch and Break-Away Switches	Sensor Switch Circuit Failure	Inability to shut off engine in emergency.	10	Mechanical failure swithes and wire fatigue.	2	Company Standards	5	100	Modify circuit to be normally open and in a shut-down state.	Electrical & Instrumentation Team, October 2022	Circuits designed to be normally open and will cause engine to shut down if fault detected.	10	1	5	50

## Designing for the Target Market

### *Pulling Performance*

Pulling performance is a vital aspect of any pulling tractor in order to have good market value. Ranked number one from the target market survey, the Sled Dogs made it a priority to improve the performance in this area. Building from previous years, time was spent researching and understanding the tuneability of the Hawaya clutch. Now able to achieve full lock-up during pulls, the team has a solid link between engine and transaxle to minimize losses and direct maximum power to the ground. Starting fresh for the 2023-year, two new ballast options allow for critical weight splits to be achieved. These new options allow up to 160 lbs directly above the front axle and 88 lbs under the rear, maximizing the ballasting flexibility.

### *Durability*

The second highest ranked objective by the targeted market was undoubtedly durability. Building a tractor that can be depended on to achieve its designed capabilities without costly repairs was no easy task. FMEA's and rigorous testing procedures highlighted where quality parts and precision manufacturing processes were required to eliminate weak links in the design. One notable design change that came from testing was the unwarranted contact to the control switches. The operator was found to either kill the electrical power or engage the choke during operation and resulted in guard switches being placed over the controls as shown in Figure 32. Other notable parts that have been included into this year's design for added durability are:

- Front bumper to prevent damage to steering system
- 20° actuating walking axle reduces shock load applied to frame rails
- Weatherproofed DEUTSCH™ connectors
- Sealed self-lubricating bushings for dusty environments
- OEM seat suspension and high-backed seat for operator comfort
- Nylock nuts to maintain fasteners at torqued spec
- Powder coated parts to prevent scratches and chipping
- Wilwood high performance brakes resist fading during extreme use
- Transaxle shaft brake to aid in gear changes
- Guarded Switching to prevent accidental contact in rough terrain
- High dimpled floorboards provide traction for operator safety



Figure 32: Guarded Switches

### *Maneuverability*

Reviewing the Sled Dog's target market survey found maneuverability to be the third most desirable feature. Despite this, many advancements are continuously implemented. Having already incorporated independent rear braking and effortless electrically actuated Ackermann steering, the team was forced to investigate other areas to improve this. The most effective route was found by shortening the entire tractor by three inches and the wheelbase by 8.5 inches. These reductions combined with double king-pin steering, resulted in a turning radius that was reduced by over 12% to 7.2 ft without over-centering the steering arms. Keeping the bumper tucked close to the front axle, a forward approach angle of 53.4°, ensuring the bumper is unlikely to contact any terrain during most operating conditions.



Figure 33: Full-lock Steering Angle



## Serviceability

The Sled Dogs have placed great emphasis on ease of service while designing the 2023 tractor. This led to a design that implements components specifically intended to improve the user's experience while servicing the tractor. Some modifications to the 2023 tractor include redesigning the exhaust guarding as an efficiently removeable, single piece for throttle and choke adjustability. Relocating the fuel tank allows for improved visibility of fuel level during operation and filling, while the elimination of the coil-over front shocks removed all required suspension service. Sealed bearings were used in the 2023 tractor to eliminate greasing requirements, and a removable plate has been installed to gain access to the clutch to make rapid adjustments. Also, the belt guarding is split offset to maximize access to the belt drive with only one half removed. Fasteners are standardized to wrench sizes of 7/16-inch and 9/16-inch where possible for easy bolt size identification and servicing adjustments with some exceptions. The 2023 tractor also implements weld nuts for single tool bolt removal in difficult to reach places. Some additional service equipment includes an easily accessible dipstick, engine oil filter, and drain plugs with fluid deflectors under the oil drain to facilitate hassle-free fluid changes. Figure 34 highlights important serviceability features.

Proper maintenance is a fundamental quality to the Sled Dog's and known to be essential to maintain optimal performance through all types of operation. An integral service schedule, service and maintenance alert system, and an hour meter within the DAQ, all being accessible through the touch-screen feature, ensures a tractor that will last for many years. The tractor service schedule as seen in Table 3, can also be found within the Operator's Manual along with all recommended fluids, the required quantities, and location illustrations.

Table 3: Tractor Service Schedule

<b>Check Engine Oil</b>	8 hrs
<b>Check Transaxle Oil</b>	8 hrs
<b>Check Brake Fluid</b>	8 hrs
<b>Clean Air Filter</b>	25 hrs
<b>Check Drive Belt</b>	25 hrs
<b>Change Engine Oil and Filter</b>	100 hrs
<b>Inspect Battery</b>	100 hrs
<b>Change Transaxle Oil</b>	200 hrs
<b>Check Brake Pads</b>	200 hrs

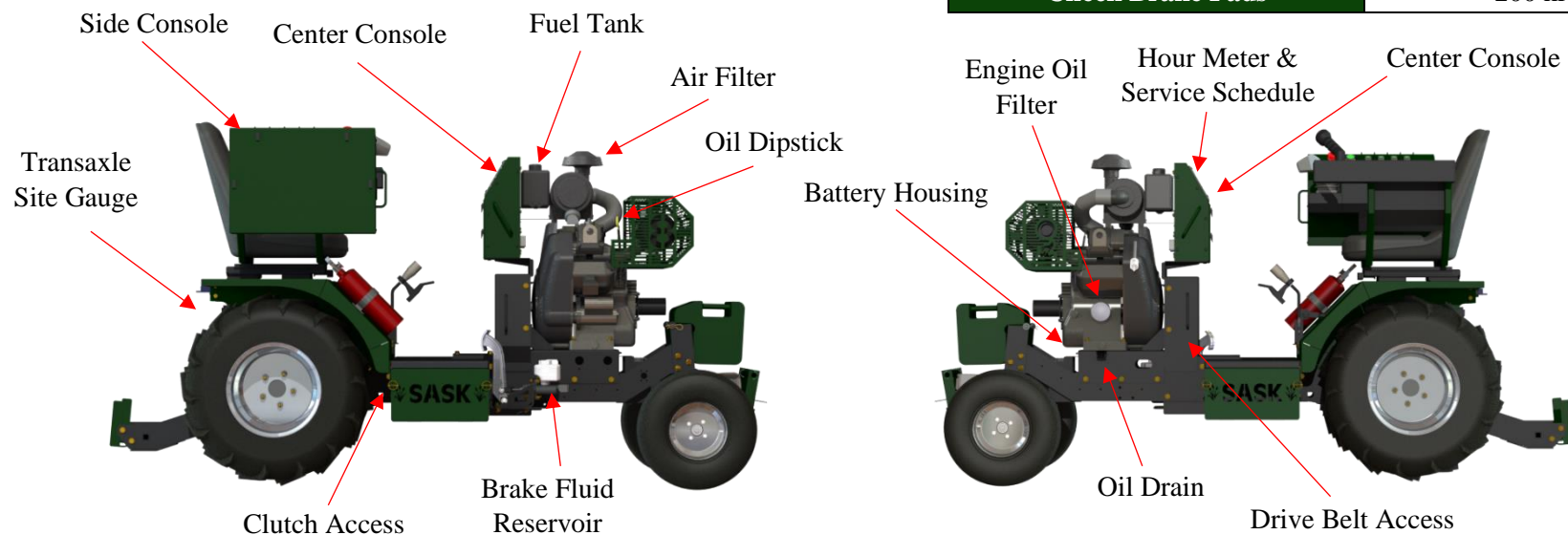


Figure 34: Service Points on 2023 Tractor

## Manufacturability

On this year's tractor, several design processes were emphasised in order to improve the tractors manufacturability. These processes include but are not limited to creating full 3D models with high detail, using uniform materials and fasteners for construction, and incorporating modular assemblies.

### Design Modeling

Through the means of high detailed 3D modeling software such as SolidWorks, the tractor was designed including high precision tolerances to ensure an accurate fit during construction. Each part of the tractor is modeled, named, and labelled using standard team conventions, which are then eventually added to their respective sub assembly. Once a sub assembly is created, it can be added to a full 3D model of the tractor to confirm the fit of the individual parts. When creating parts and sub assemblies on SolidWorks, common processes such as tab and slot and poka-yoke are used for simplicity in terms of manufacturing. After the parts and sub assemblies are created, drawings are produced based on the part type and manufacturing method. For example, a bent mounting strap such as that on the fuel tank would be drawn using a bent laser cut drawing template with manufacturing criteria such as dimensions, material, and laser filets specifications. Applying these principles in the early stages of the design process is one way the Sled Dogs emphasise manufacturability.

### Uniformity

When designing the many sheet metal parts used in sub-assemblies on the tractor, three styles are used: 11-, 14-, and 18-gauge plain carbon steel. By reducing time spent on the material selection process the team can create a design that is more efficient to manufacture. This applies to all areas of the tractor where sheet metal is used. The Sled Dogs also apply the same principle to the fasteners, where 3/8" and 1/4" bolts/nuts are standardized for assembly. Not only does this simplify material lists, but it also makes the construction of the tractor significantly easier and faster. To further simplify the manufacturing process, parts needed for both sides of the tractor are created symmetrical when possible. All parts also come laser engraved with the part number to ensure correct assembly. This eliminates confusion when assembling the tractor and makes common manufacturing practices such as machining, easier.

### Assembly

To increase simplicity in the manufacturing process, modular assemblies have been designed. Dividing the tractor into sub-assemblies that can be built and queued for the main line, is found to reduce complexity, costly rework, and missed parts. To better understand the assembly process, the order for building can be seen in Figure 35.

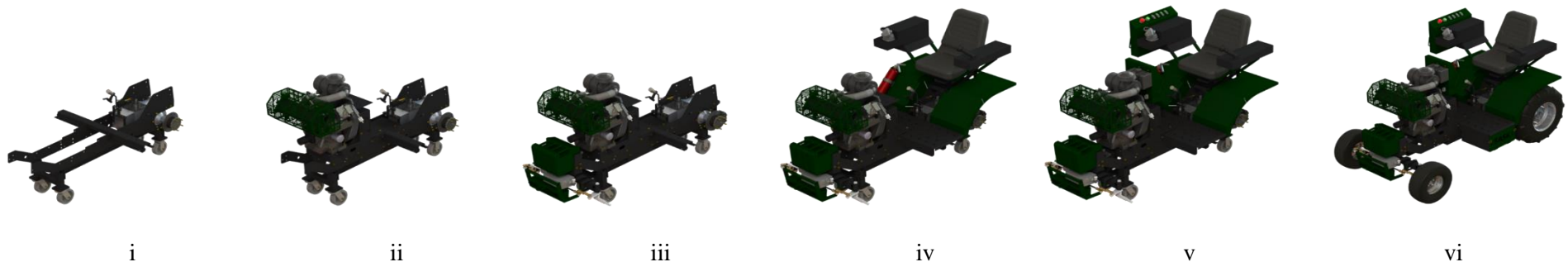


Figure 35: Order of Assembly

## **Safety**

The Sled Dogs have always held the safety of all affected by their work paramount. In the shop, this means ensuring all members are up to date and informed on all the equipment available, and holding regular training sessions to ensure all members can safely operate all equipment and tools. Regarding tractor design, the Sled Dogs design for the elimination of hazards wherever possible, however it is inevitable that despite these efforts, hazards to the operator of the tractor and bystanders still exist. The following section describes how the Sled Dogs implement engineering controls to ensure safety for any operator or bystander of the tractor.

### ***Hazard Indication***

Identifying hazards is always the first step towards prevention; thus, to minimize potential harm to the operator or bystanders, having clear warnings and indicators of hazards was a key safety consideration for the design of the tractor. The 2023 tractor comes equipped with a variety of strategically placed decals and labels, including heat warnings around the exhaust shielding, pinch point warnings near the steering and operation warnings near rotating parts. In addition to hazard-related warnings, fluid reservoirs are all clearly labelled with their respective contents, and all operational controls indicate their purpose.

### ***Entry Exit***

On either side of the tractor, there are three points of contact that can be established between the operator and the tractor to assist with safe entry and exit. On the right side, this includes two handles and the floorboards, and on the left it includes a handle, the floorboard, and the steering lever, which is rigidly secured. To further ensure the safety of the operator during entry and exit, the 2023 tractor maintained the perforated floorboard design as seen in previous years. The raised, hollow dimples ensure the floorboard does not create a falling hazard even in slippery conditions.

### ***Guarding and Shields***

Several mechanical and heat related hazards are present when operating the tractor, so the Sled Dogs use several forms of guarding to protect the operator as much as possible. As per ASAE S493 standards, all rotating parts are guarded in full compliance with 1/8" sheet steel. In the 2023 tractor, this includes guarding around the centrifugal clutch and driveshaft. In addition to guarding the operator from rotating parts, the exhaust is shielded in order to dissipate heat and reduce the hot surface area around the exhaust.

### ***Electrical***

The electrical system in the 2023 tractor utilizes multiple fail-safe switches to ensure all safety conditions are met prior to beginning operation of the tractor. Failure of any one of the following switches to be in the correct position results in the tractor not starting, as this would indicate an unsafe starting situation:

- Engine Kill Switch
- Seat Pressure Switch
- Brake Sensor Switch
- Neutral Sensor Switch
- Trailer Breakaway Switch

Once the tractor has been started, the dead-man switch on the throttle must be engaged to allow any movement of the tractor. As with previous years, the 2023 tractor also includes a complete battery disconnect which allows for servicing of the tractor without risk of electrical shock or damage to components.

### ***Fire***

Electrical fires and fires due to fluids such as gasoline are imminent safety threats when operating any sort of equipment. While the Sled Dogs take every precaution to minimize the possibility of a fire occurring, such as by strategic placement of the battery, fuel tank, and use of a complete battery disconnect, the risk of fire is always present. The 2023 tractor uses an upgraded 5.5 lb class ABC fire extinguisher, capable of extinguishing ordinary combustibles, electrical fires, and flammable liquids. Similar to the 2022 design, the fire extinguisher on the 2023 tractor is mounted on the front of the right fender, as it is easily accessible by the operator or a bystander in the event of a fire and is far away from the battery and fuel tank, two places in which the likely hood of a fire is high. Improvement on the 2022 design in 2023 is a much more secure extinguisher mount, which will ensure the fire extinguisher is not accidentally knocked off or jarred loose through normal operation, and accounts for the greater weight of the extinguisher itself.

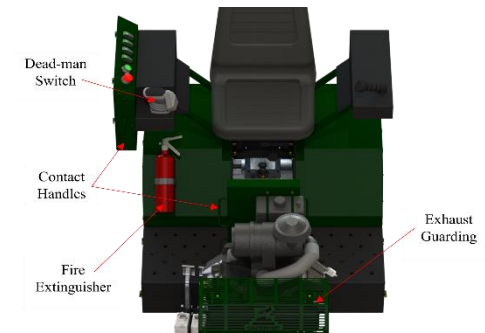


Figure 36: Fire Extinguisher and Points of Contact

## Testing & Development

### Front End Testing

The Sled Dogs' 2022 build left the front end sub-team with some unanswered questions regarding the then-new dual linear slides with twin carriages. This design was selected to reduce the binding that troubled the 2021 model; but due to weather and manpower constraints it lacked the thorough testing required to prove its adequacy in future model years. As a result, the first focus of this year's front end sub-team was to evaluate the 2022 suspension and determine what changes, if any, were required for a front end that would meet the rigorous operating conditions of the tractor. After an assessment of the current commercial manufacturer offerings and a review of the target market survey it was determined that before the team works at optimizing the coil over suspension system, the requirement for the system itself should be evaluated.

The hypothesis among the team was that a properly sized and inflated tire, coupled with the existing walking axle will provide adequate axle motion and shock absorption for use in the durability course and the rigours of general tractor operation. To evaluate the performance of the suspension, the 2022 tractor was tested with suspension as designed on a rutted gravel and dirt surface with randomly placed 4" tall rubber curbs. This was designed to replicate the durability course. This test was repeated at various speeds and suspension preloads, as well as with radial and bias ply tires at different pressures. Following the tests with the suspension functioning as designed, a length of HSS was added in parallel with the coil overs. This effectively "locked-out" the suspension and allowed the team to test the function of the 2022 front end with no coil overs. It can be observed in Figure 37 that the side wall deflection with and without suspension is nearly identical and that the displacement of the shocks is negligible. This proves that the coil overs do not provide any significant shock absorption to the system, and the tires do the bulk of the work.

As a result of this testing, the team can say with confidence that a traditional spring and damper suspension system is not necessary for optimal performance of the 2023 tractor. The walking axle proved very effective when driving over bumps effecting only one of the steering tires, or when traversing curbs at an angle to the direction of travel. In addition, the stiff sidewall of the bias ply tires helps absorb energy when hitting bumps with speed, and their ability to operate at low pressures allows for a smooth ride while on rough or rutted terrain.



Figure 37: Comparison at 6.5mph of Suspension (left) and No Suspension (Right) with Radial Tires at 8 psi.

### Clutch Spring Testing

To ensure the continued reliable performance of the modified Hawaya clutch, the team dedicated resources to testing it. The goal was to verify adequate clutch spring performance. To begin, the primary and secondary engagement springs were removed from the clutch to test if they had retained their nominal spring stiffness. After 5 years of use there was some concern that they had lost stiffness. To test the spring stiffness, the team set up a testing apparatus using a load cell and table vice. The springs were progressively compressed and measured to collect a range of data values. These compressions and load readings were then used to determine the measured spring constants. See calculated results below in Table 4.

Table 4: Result of Clutch Spring Testing

		Primary Springs			Secondary Springs		
		1	2	3	1	2	3
Spring Stiffness (kN/m)	Measured	280.0	265.7	282.4	96.2	95.3	94.4
	Nominal	288	288	288	99	99	99
Relative Error (%)		2.75	7.72	1.92	2.80	3.66	4.65



## Economics

To continue producing outstanding pulling tractors, the Sled Dogs' 2023 model was designed to keep costs low while maintaining pulling performance, maneuverability, and durability. To achieve these targeted costs, an emphasis was placed on reducing the number of fabricated parts by implementing purchased components when available. Table 5 shows a breakdown of variable costs per subsystem as well as safety equipment and miscellaneous expenses. A total manufacturing variable cost along with period manufacturing costs and research and development costs can be seen in Table 7. An MSRP of \$15,499.99 offers a profit margin of 8.5% or \$1,321.64 while the available ballast package will add an additional profit of \$106.34. This ballast package outlined in Table 6 will provide the customer with an additional 800 pounds of ballast flexibility.

Table 5: Estimated Cost Breakdown

Category	Purchased	Fabricated	Total Cost
Driveline	\$ 5,699.20	\$ 1,035.09	\$ 6,734.30
Front End & Steering	\$ 666.67	\$ 605.86	\$ 1,272.53
Operator Platform	\$ 278.32	\$ 686.53	\$ 964.85
Frame, Ballast, & Brakes	\$ 352.60	\$ 884.71	\$ 1,237.31
Electrical & Instrumentation	\$ 1,265.32	\$ 145.99	\$ 1,411.31
Safety Equipment	\$ 48.02	\$ -	\$ 48.02
Trim	\$ 8.20	\$ -	\$ 8.20
Miscellaneous	\$ 16.84	\$ -	\$ 16.84
Final Assembly	\$ -	\$ 185.00	\$ 185.00
<b>Total</b>	<b>\$ 8,335.16</b>	<b>\$ 3,543.19</b>	<b>\$ 11,878.35</b>

Table 6: Ballast Package

Options	Purchased	Fabricated	Total Cost	MSRP	Profit Margin
Ballast Package	\$ 330.93	\$ 662.72	\$ 993.65	\$ 1,099.99	9.7%

Table 7: Cost Estimate Summary

Costs & Profit	Value
Manufacturing Variable Cost	\$ 11,878.35
Period Manufacturing Cost (14%)	\$ 1,700.00
Research and Development Cost (5%)	\$ 600.00
Total Cost	\$ 14,178.35
Suggested Sales Price	\$ 15,499.99
Profit Margin	8.5%
Total Number of Parts	1561
Tractor Weight (Unballasted)	860 lb.

A low period manufacturing cost (14%) is expected due to the emphasis placed on design for manufacturing. By implementing purchased parts over fabricated, designing for common manufacturing processes, incorporating stitch welds to reduce the need of extensive welding, and introducing tab-and-slot and poka-yoke features, the Sled Dogs were able to reduce the total time spent manufacturing and keep costs low.

With the cost savings that came from a low period manufacturing cost, the Sled Dogs were able to allocate more funding to research and development. The research and development cost is estimated to be high at 5% of the manufacturing variable cost. This is an increase from previous years as a focus was set on developing new products to be used in future designs while continuing to improve upon previously validated components. A cost-savings of 5% (compared to previous year model) in the Front End and Steering system was achieved due to the emphasis on research and development.

If the design were to be mass produced, many cost saving processes could be adapted. These processes include injection molding for arm rests and fenders. An 85% reduction in cost could be achieved by implementing an automated soldering process for the steering and mother board. Additionally machining costs of the drive shaft connection could be cut by working with suppliers to implement a standard drive directly off the clutch.

## 2023 Sled Dogs Team

### *Team Members*

Position Held	Member
<b>President</b>	Max Kazuska
<b>Vice President</b>	Brandon Pomedli
<b>Treasurer</b>	Ashton Hinz
<b>Sponsorship Coordinator</b>	Eric Schill
<b>Marketing Manager</b>	Jack Grad
<b>Driveline Lead</b>	Riley Talbot
Driveline	Brett Stangeland
Driveline	Conner Majic
Driveline	Dimitri Bohach
<b>Front End &amp; Steering Lead</b>	Cole Stephens
Front End & Steering	Ben Lefebvre
Front End & Steering	Jack Li
Front End & Steering	James Campbell
<b>Operator Platform Lead</b>	Koal Sammons
Operator Platform	Andrew Cey
Operator Platform	Kenton Simonson
Operator Platform	Pranav Kapoor
Operator Platform	Warren Wourms
<b>Frame, Ballast &amp; Breaks Lead</b>	Brandon Pomedli
Frame, Ballast & Breaks	Isaac Mcphearson
Frame, Ballast & Breaks	Kyla Kiland
Frame, Ballast & Breaks	Mary Matthews
Frame, Ballast & Breaks	Vivek Rao
<b>Electrical &amp; Instrumentation Co-Lead</b>	Keenan Schmitt
<b>Electrical &amp; Instrumentation Co-Lead</b>	Nathan Harty
Electrical & Instrumentation	Cody Stathan
Electrical & Instrumentation	Roan Chretien
Electrical & Instrumentation	Sydney Sidloski
<b>R&amp;D Co-Lead</b>	Jack Grad
<b>R&amp;D Co-Lead</b>	Matthew Ratzlaff
R&D	Adam Jetski
R&D	Andrew Warwaruk
R&D	Renick Kreger
<b>Advisor</b>	Scott Noble

### *Sponsors*

Applied Industrial Technologies  
 Association of Professional Engineers and Geoscientists of Saskatchewan  
 Automated Metal Processing Ltd.  
 Bolt Supply House Ltd.  
 Bourgault Industries  
 Brandt Industries Ltd.  
 Claude Lague and Lilianne Chénard  
 Construction Fasteners  
 Engineering Shops  
 Guy Chretien  
 Igus  
 Motion Industries  
 MacDon Industries Ltd.  
 Prairie Machine and Parts  
 Ratzlaff & Associates CPAs  
 Redekop Manufacturing Company  
 Russel Metals  
 Seed Master  
 Silverdale Farms Ltd.  
 Solidworks  
 Viterra  
 Zacharie C Martin

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