



4023 – Senior Design
Spring 2017

Trot'n Trailer Senior Design

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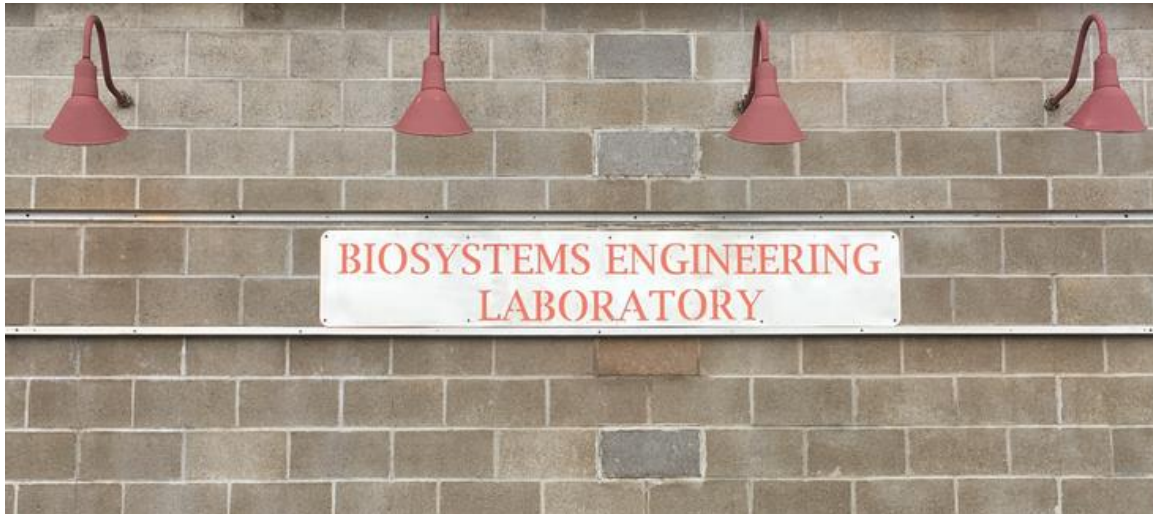
About the Client

- ▶ Charles Machine Works Inc. produce various types of equipment such as: trenchers, directional drills, skid steers, and vacuum excavators
- ▶ Charles Machine Works Inc. is headquartered in Perry, OK
- ▶ Ditch Witch is a subset of Charles Machine Works



Mission Statement

- ▶ Our goal is to instill core values throughout our design and product, such as: dependability, safety, and innovation



Problem Statement

- ▶ The client wants the team to develop a product that enables their FX-30 Vacuum Excavator to move independently and not be restricted to movement only by a vehicle.



About the FX-30

- ▶ Applications:

- ▶ 1) Exposing buried utility lines

- ▶ 2) Cleaning out storm drains

- ▶ 3) Directional drilling site cleanup

- ▶ 4) Commercial and residential debris cleanup and landscaping and pothole digging



FX30 Demo.



Project Objective

- ▶ The Design must meet the following requirements specified by Ditch Witch:
 - ▶ 1) The system is designed to operate on hard surfaces
 - ▶ 2) The design should be self-propelled
 - ▶ 3) The system must be integrated onto the existing trailer
 - ▶ 4) The system should simply be engaged and disengaged
 - ▶ 5) Controls need to be operated by a remote control
 - ▶ 6) The top speed with the system should be 1 - 1 ¼ mph





2

Choice of 500- or 800-gallon spoils tanks and 80-, 200- or 300-gallon water tanks for cleanups of any size.

3

24.8-hp (18.5-kW) Kubota[®] diesel engine powers the FX30's outstanding suction and water pressure.



5

Fully enclosed, insulated, lockable power pack protects major components from weather and vandalism while leading the industry in noise reduction.

1

Hydraulic door opens fully horizontal to maximize the efficiency of spoils removal.

4

Reusable, 2-micron vacuum filter and a blower relief valve air filter provide the industry's best filtration.

8

High-pressure water system with a 4.2-gpm (16.1-l/min). 3,000-psi (207-bar) water pump is adjustable from curbside operator's station; autoclutching feature disengages water pump when water is not in use, allowing full system power for suction.

7

Optional reverse-flow feature allows you to offload spoils quickly and easily.


6

Trailer meets federal regulations (FMVSS) and comes standard with toolbox storage in tongue.

FX-30 Trailer Dimensions

DIMENSIONS		
DIMENSIONS	U.S.	METRIC
500 Gal Spoils/80 Gal Water on T9SE6 or T9SH6		
Length	200 in	5080 mm
Width	96 in	2184 mm
Height	86 in	2337 mm
Weight, empty	5,465 lb	2479 kg
Trailer GVWR	10,000 lb	4536 kg
800 Gal Spoils/200 Gal Water on T18S		
Length	233 in	4880 mm
Width	102 in	2590 mm
Height	92 in	2337 mm
Weight, empty	8,255 lb	3744 kg
Trailer GVWR	18,000 lb	8172 kg


<http://www.ditchwitch.com/vacuum-excavators/hydro-excavators/fx30>



FX-30 Power

POWER			
POWER	U.S.		METRIC
Engine	Kubota® D1105-E3B		
Fuel	Diesel		
Cooling medium	Liquid		
Injection	Indirect		
Aspiration	Natural		
Number of cylinders	3		
Displacement	68.6 in ³		1.12 L
Bore	3.07 in		78 mm
Stroke	3.09 in		78.5 mm
Manufacturer's gross power rating (SAE J1995)	24.8 hp		18.5 kW
Rated speed	3,000 rpm		
Emissions compliance	EPA Tier 4		EU Stage IIIA
Fuel tank capacity	15 gal		57 L

<http://www.ditchwitch.com/vacuum-excavators/hydro-excavators/fx30>



FX-30 Existing Hydraulic System

FX-30 Hydraulic System

Hydraulic pump

Parameter	Value	Unit
Pressure	2500	PSI
Drive type	12	V DC
Flow rate	2	GPM



Project Scope of Work

Task Name	Task Name
<ul style="list-style-type: none"> ▣ Project Schedule 1 Statement of Work (SOW) 2 Concept Designing 3 Client Meeting 4 Work Breakdown Structure (WBS) 5 Tasks Project 6 Team meet to discuse final concept idea ▣ 7 Designing <ul style="list-style-type: none"> ▷ 7.1 Research Chosen Design ▷ 7.2 Team Meet ▷ 7.3 3D Designing ▷ 8 3D Design 'Draft' Review ▷ 9 Team/Prof Meet 10 Final Design Finished 11 (4001) Project Proposal 12 Update Client 13 Report "draft" 14 Report 'final draft' 15 Final Presentation 16 Final Report 	<ul style="list-style-type: none"> Composite team schedule ▷ List team issues Contact Client ▣ Client Meet <ul style="list-style-type: none"> Supplies & materials reviewed Final Design Reviewed Finalize design Client Meet 2 ▷ Project Materials <ul style="list-style-type: none"> Team Website Project work Fabrication Final Report rough draft Final Report second draft Testing Final Report due Presentation Preliminary Presentations Presentation revision Final Presentations



Existing Technology

▶ Haulle Trailer Tug

- ▶ 1) Towing Capacity Up To 40,000 lbs
- ▶ 2) Tongue Weight Load Up To 15,000 lbs
- ▶ 3) Radio Remote Control Drive and Steer

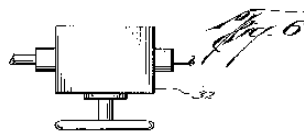
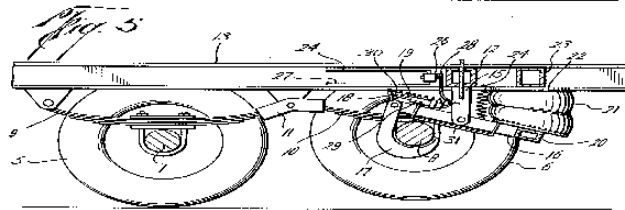
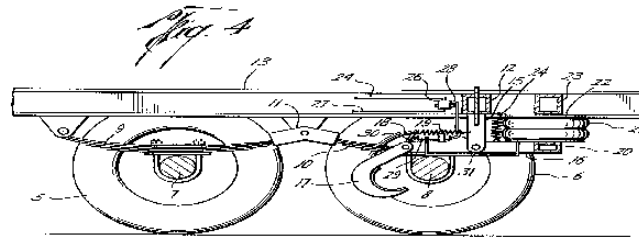


<http://www.kropfindustrial.com/conolift/trailer-tugs>



Relevant Patent

- ▶ **Axle Lift** (Patent # US 3096995 A, July 9th, 1963).
 - ▶ 1) Used to lift one axle of a tractor or trailer free of the road surface when the vehicle is traveling empty
 - ▶ 2) Used for shifting the weight distribution of the vehicle to provide less tire wear and easier steering of the vehicle



Erick G. Richardson, Jr.
INVENTOR

BY *Ronald C. Moffatt*
ATTORNEY

Trailer Standards and Regulations

- ▶ **1) Oklahoma Trailer Dimension Laws:**
 - ▶ A) Trailer length: 40 feet
 - ▶ B) Width: 102 inches
 - ▶ C) Height: 13 feet 6 inches

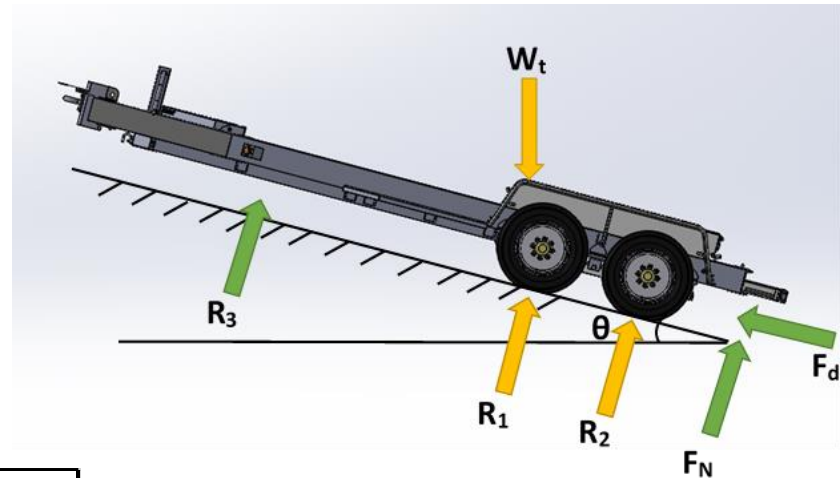
- ▶ **2) Oklahoma Trailer Towing Laws:**
 - ▶ A) Every trailer shall be equipped with a coupling device designed and constructed so that the trailer will follow in the same path as the vehicle towing it without whipping or swerving from side to side

- ▶ **3) The operator of a motor vehicle or trailer must maintain the vehicle in a condition that ensures:**
 - ▶ A) Its safe operation; and
 - ▶ B) The safety of the driver, anyone else in the vehicle and other road users



Trailer Free Body Diagram

- ❖ F_N representative of the normal force required for drive traction
- ❖ F_d representative of drive force required for motion



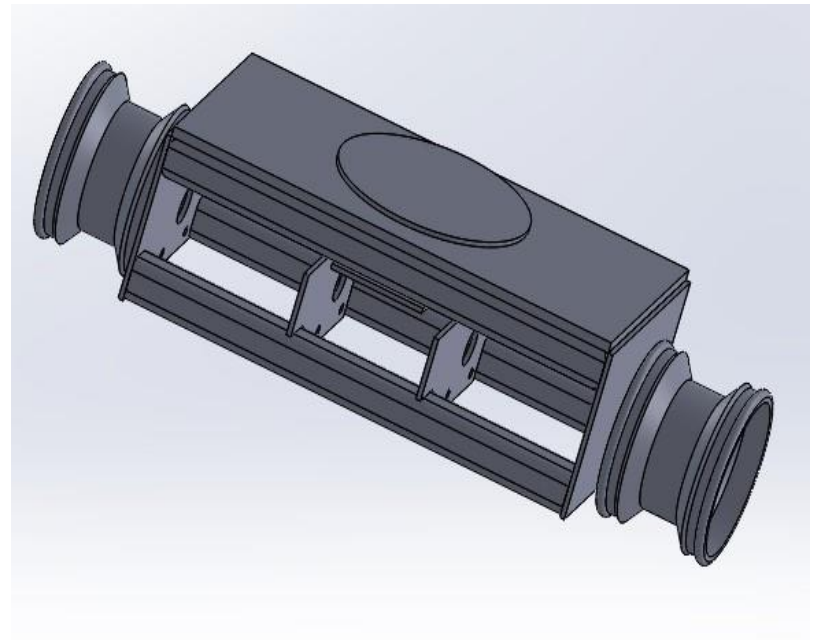
Weight Reactions		
Variable	Value	Units
Trailer gross weight (W_t)	18000.0	lbs
Trailer speed (V)	1.5	ft/s
Time required for speed (t)	4.0	s
Coefficient of friction (μ)	0.6	
Hill slope (θ)	8.0	degrees
Normal force required (F_n)	4529.1	lbs
Drive force required (F_d)	-2709.3	lbs

$$F_N = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) \left(\frac{1}{\mu} \right) + \left(\frac{W_t \sin \theta}{\mu} \right)$$

$$F_d = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) + W_t \sin \theta$$

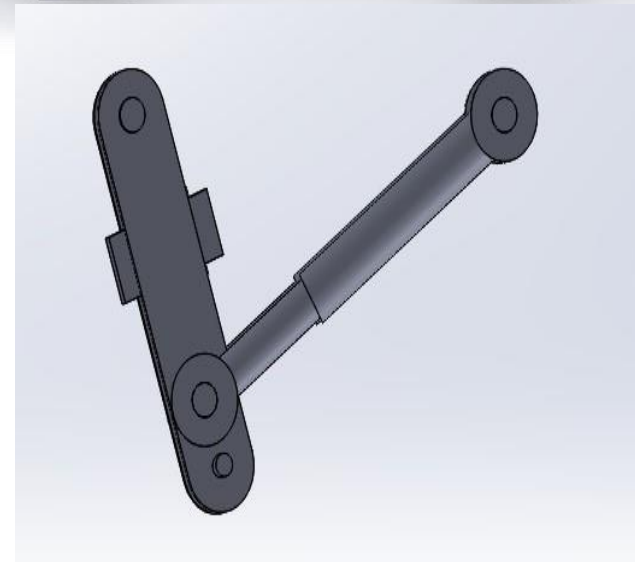
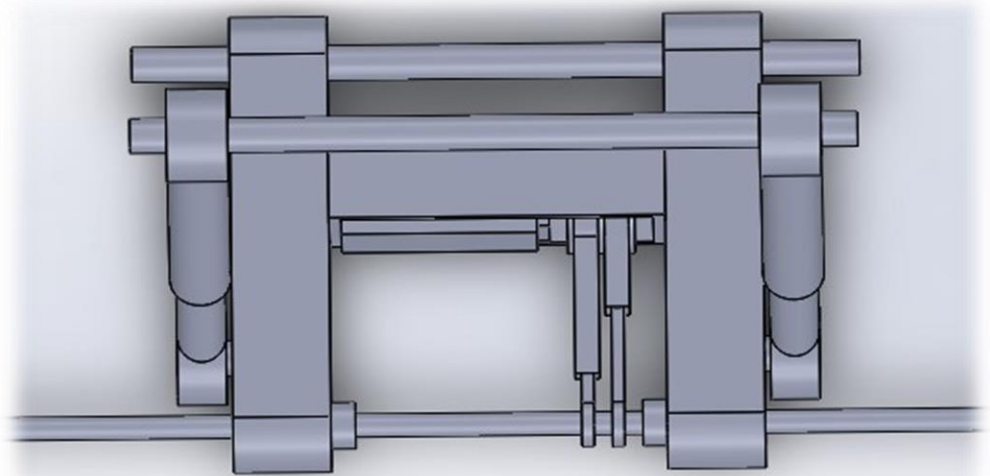
Preliminary Design Concept

- ▶ Motorized trailer tug
- ▶ Independently driven wheels for turning
- ▶ Lack of tongue weight reduces traction
- ▶ Wanted an integrated system



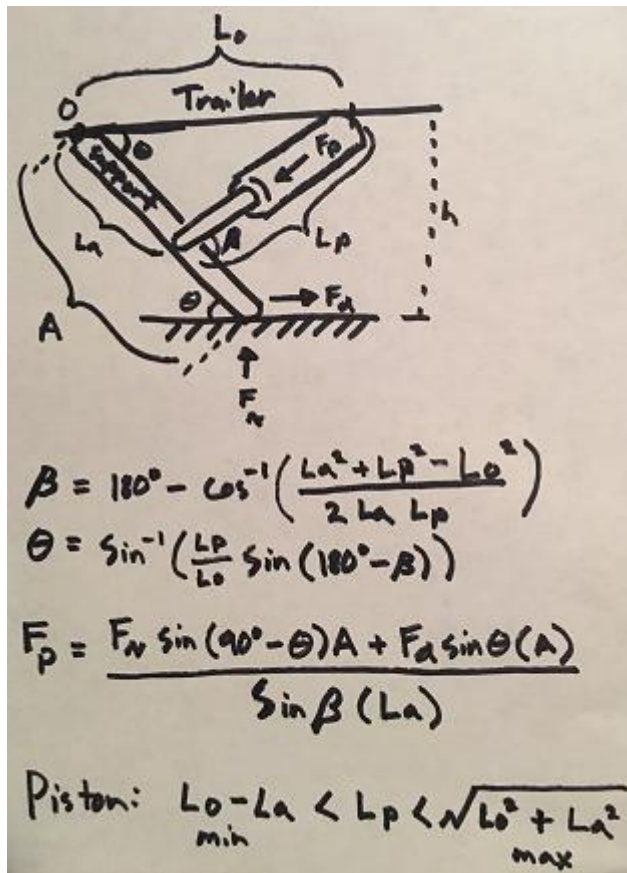
Preliminary Design Concept

- ▶ Ratcheting drop down axle
- ▶ Straight member approximations
- ▶ Telescoping ratchet mechanism for high torque



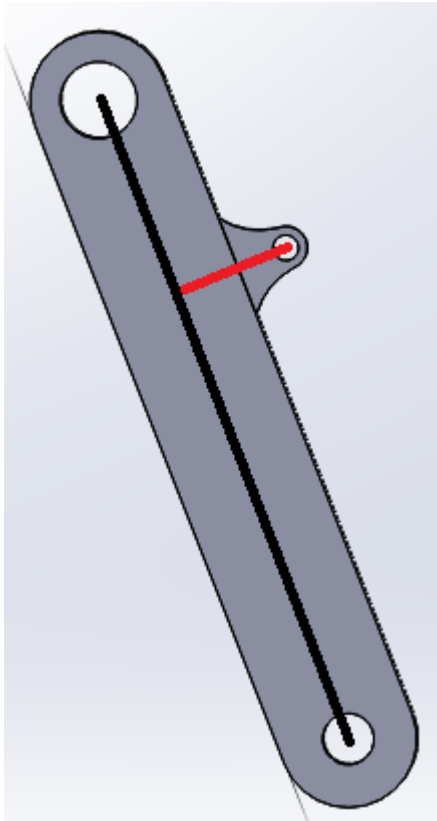
Calculations

- ❖ Piston geometry evaluation using Law of Cosines
- ❖ Geometry is approximately to scale with drawings

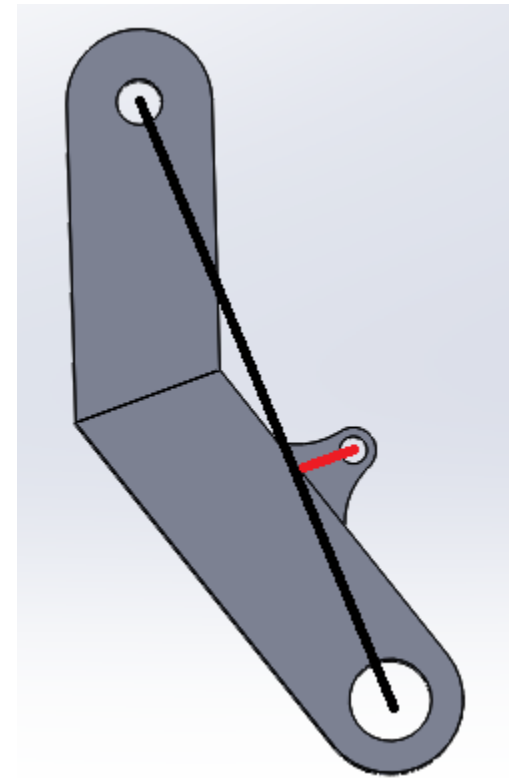


Solving for Piston Length		
Drop Down Axle Piston Reactions		
Variable	Value	Units
Number of Pistons (N)	2	
Distance between support and piston origins (Lo)	2.10	ft
Angle of support with trailer (θ) *closest to 90 degrees is best	58.02	degrees
Axle support length (A)	1.48	ft
Distance piston pinned on support (La)	0.86	ft
Distance between trailer and end of support (h)	1.26	ft
Max Piston Length	2.27	ft
Min Piston Length	1.23	ft
Piston length (Lp)	1.80	ft
Force of piston	55.26	lbs
Angle of support with trailer (θ)	1.01	rad
Lower angle between piston and support (β)	1.71	rad

Calculations

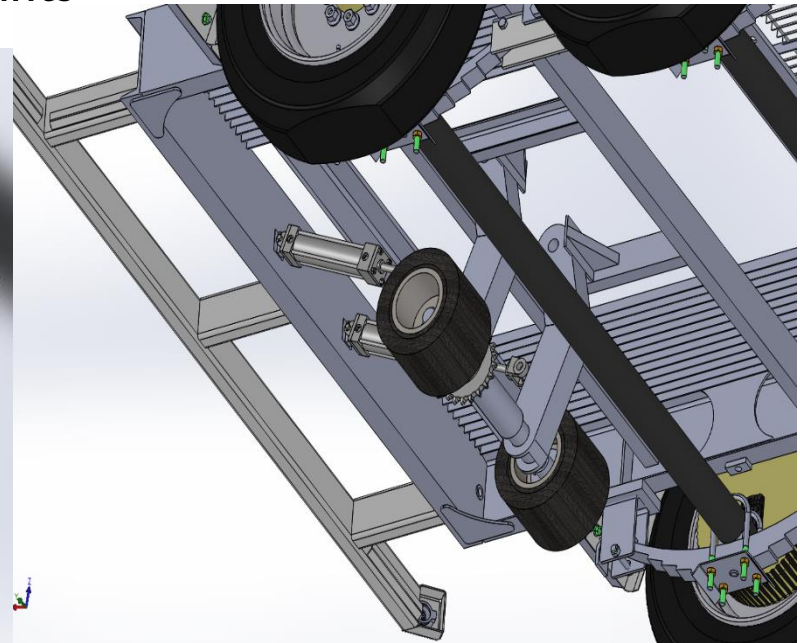
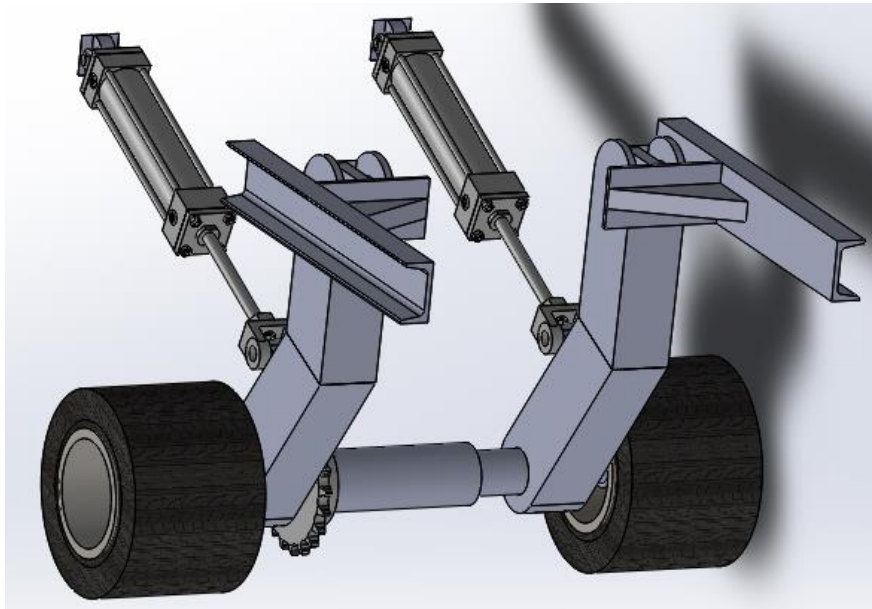


- ❖ 3x4x3/8 rectangular tubing for generous safety factor
- ❖ 2 piece orientation allows for geometric clearance
- ❖ Angle reduces error in linear approximation
- ❖ A plate welded over angle can increase strength if needed



Preliminary Design Concept – Rear Axle

- ❖ Hydraulic Lift axle mounting
- ❖ Drive system: hydraulic/Electric motor
- ❖ Drive System mounted between support arms
- ❖ Chain driven
- ❖ Solid rubber tires for weight constraints



Tires

- ❖ **Press – On Forklift Tires (Polyurethane Cushion).**
- ❖ Price: \$112 – \$180.
- ❖ Tires (10x7x6-1/4) Rated for 4800 lbs.

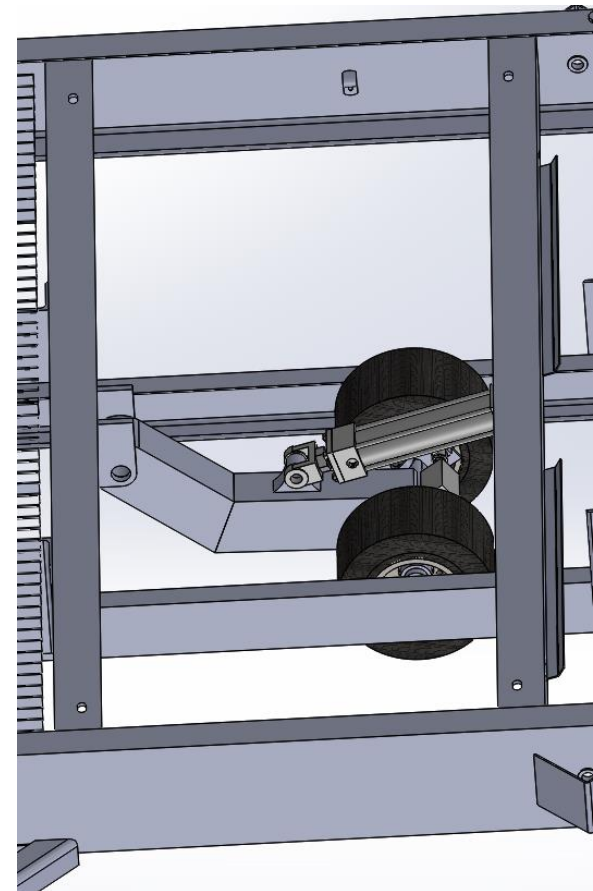
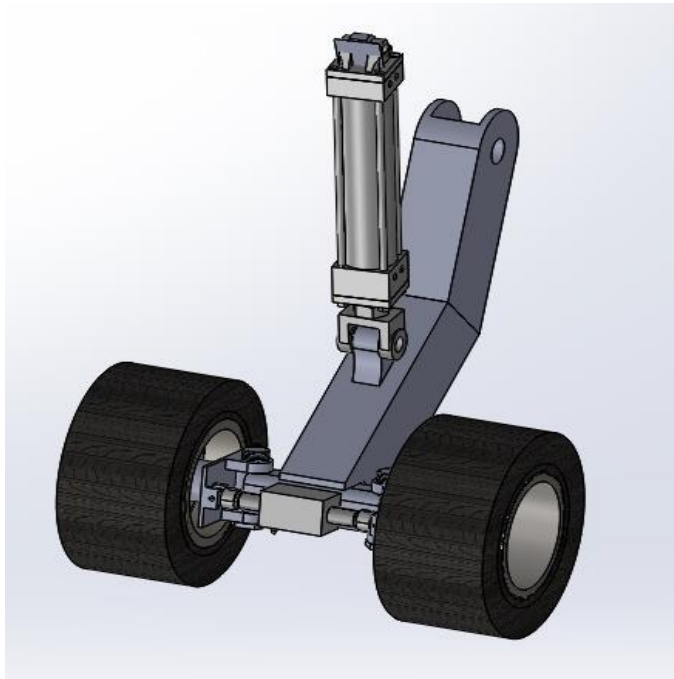


http://www.brunettetire.com/mh_cushion.cfm#specs



Preliminary Design Concept - Front Axle

- ❖ Hydraulic Steer lift Axle
- ❖ Mounted to cross members in main frame
- ❖ Double ended cylinder for steering
- ❖ Solid rubber tires for weight constraints



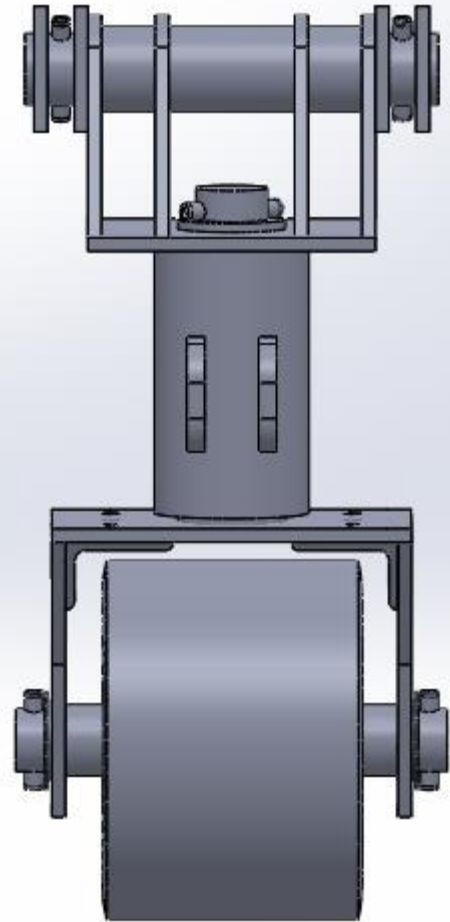
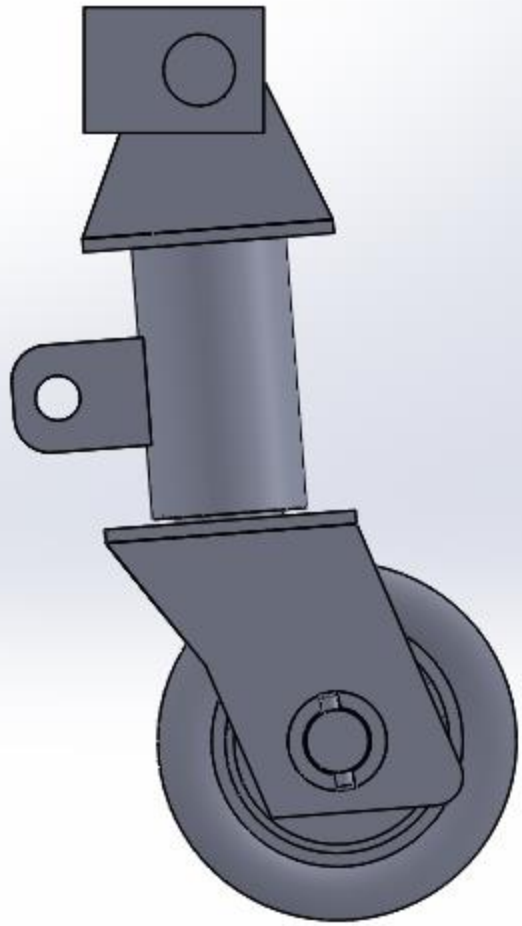
Motor Torque Requirements

Torque Requirements		
Variable	Value	Units
Number of motors (N)	2	
Diameter of tire (dt)	10.00	inches
Motor operating Pressure	2400.00	psi
Motor displacement	24.00	in ³ /rev
Torque generated	9166.58	lbs*inches
Torque required (T)	-4492.06	lbs*inches
Motor rpm	8.43	rpm
Motor Hp	-0.60	Hp

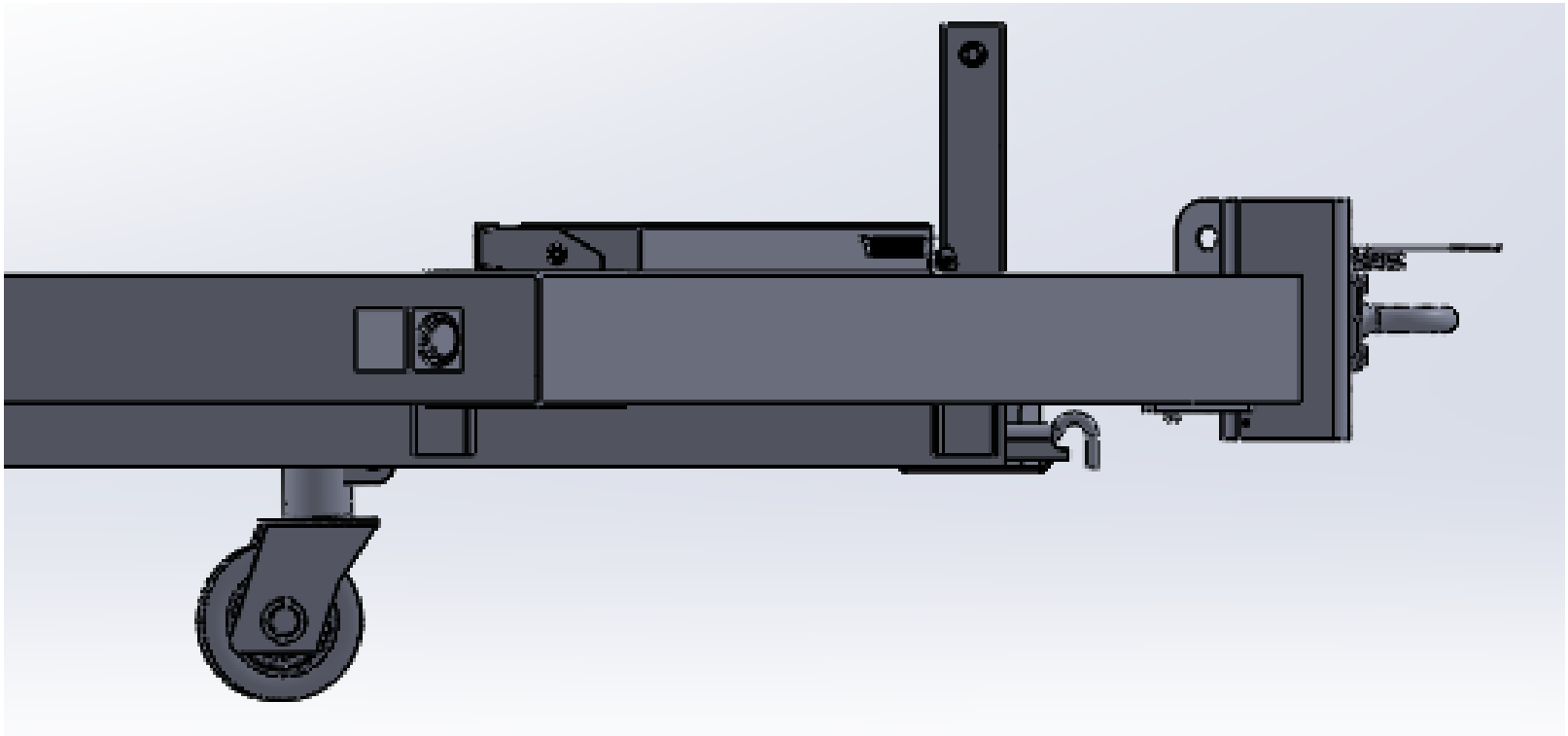
$$T = \frac{PSI * Motor Displacement}{2 * \pi}$$



Front Axle



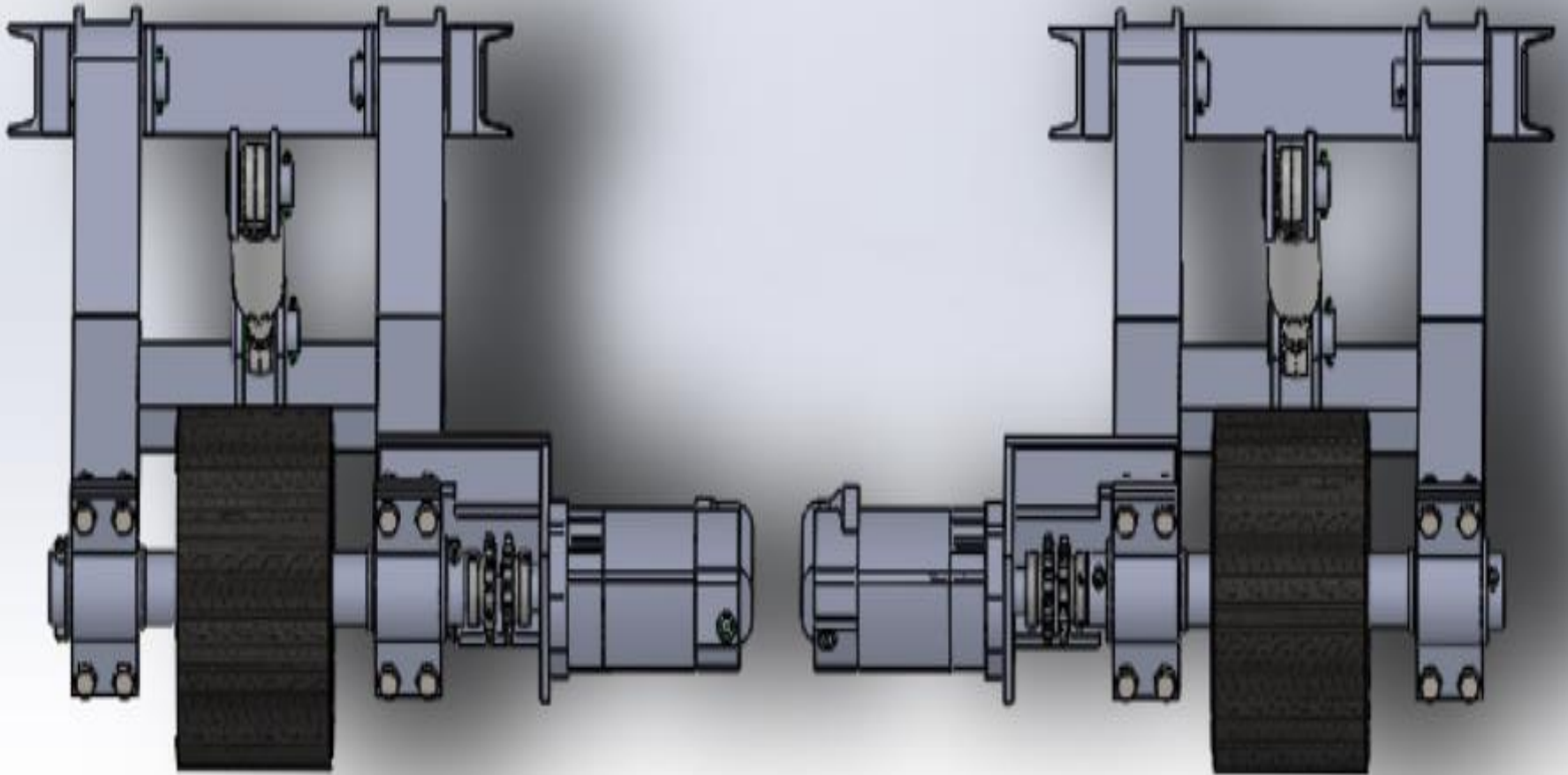
Steer wheel placed in trailer



Front Axle



Rear Axle

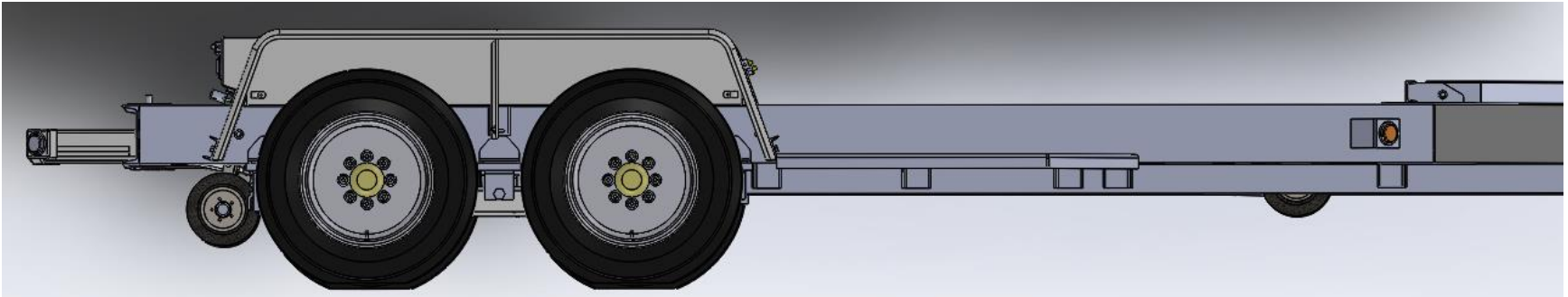


Rear Axle

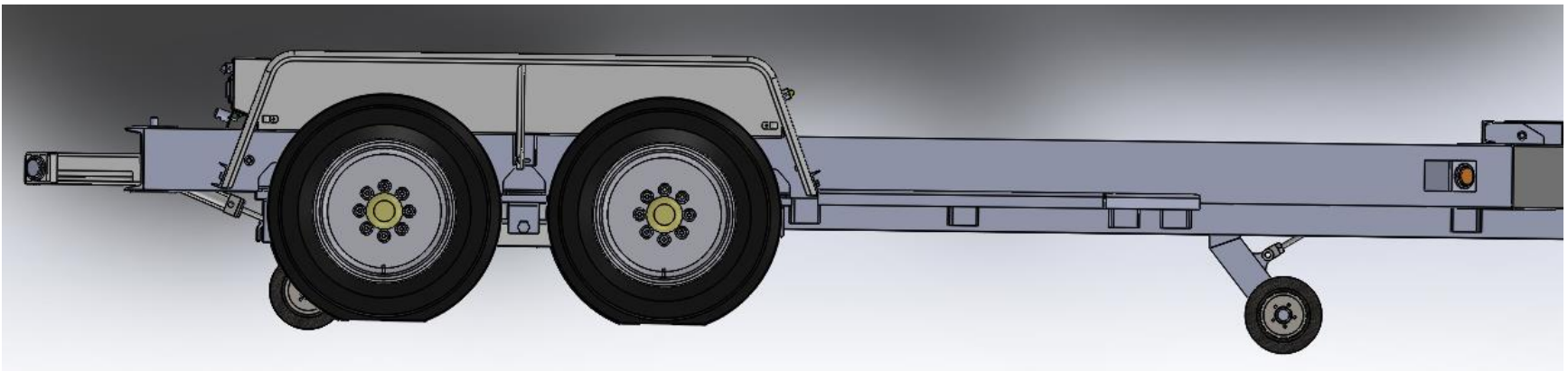


Final Design Continued

❖ Side view of lifted axles stowed away



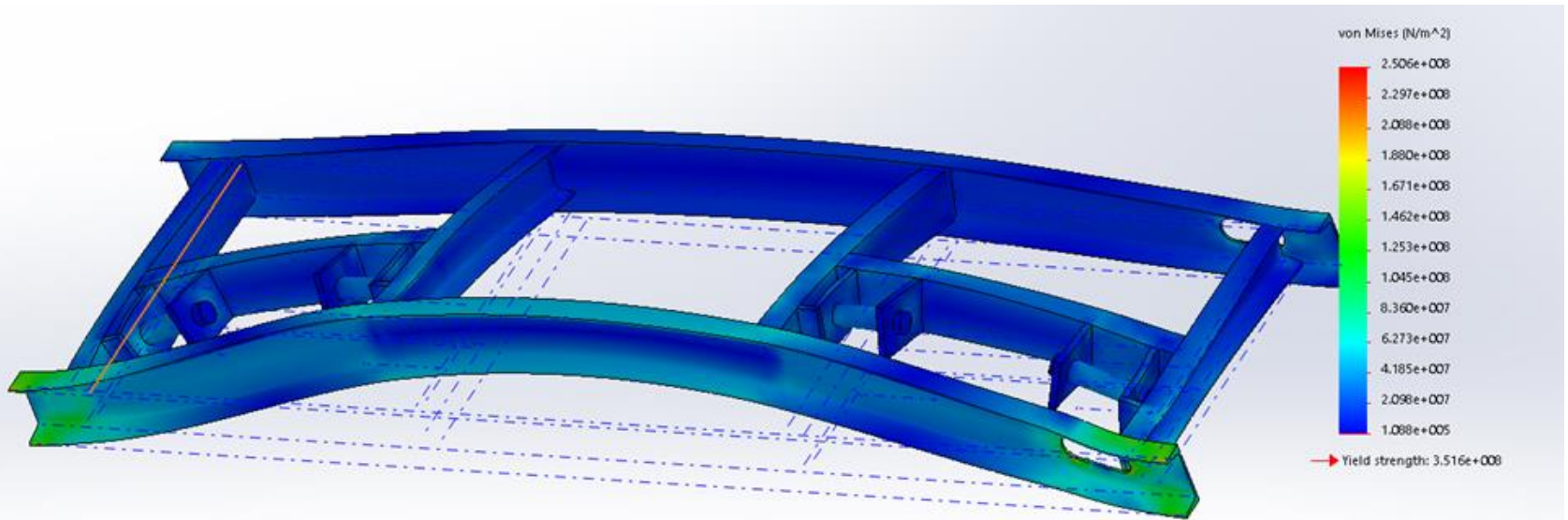
❖ Side view of engaged drive and steer axles





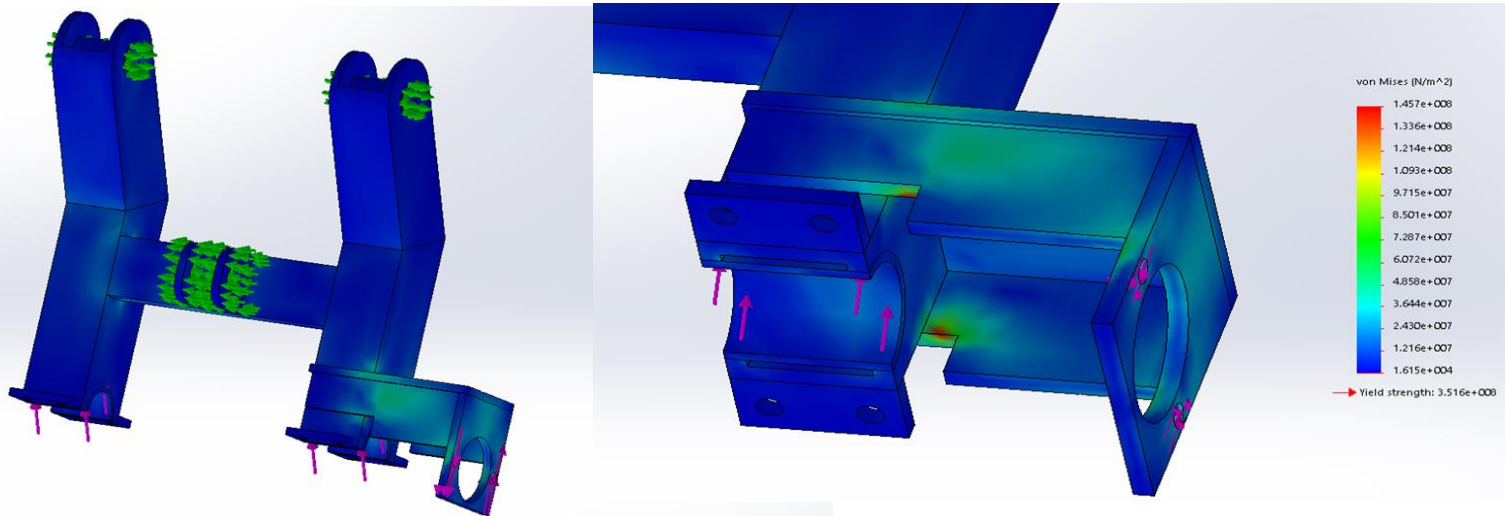
Stress Analysis

- ▶ Mount for back drop down arms
- ▶ Yield Strength 51.1 KSI
- ▶ Load of 2500 lbs per support arm pin
- ▶ Max Stress 36.4 KSI
- ▶ Factor of Safety of 1.4



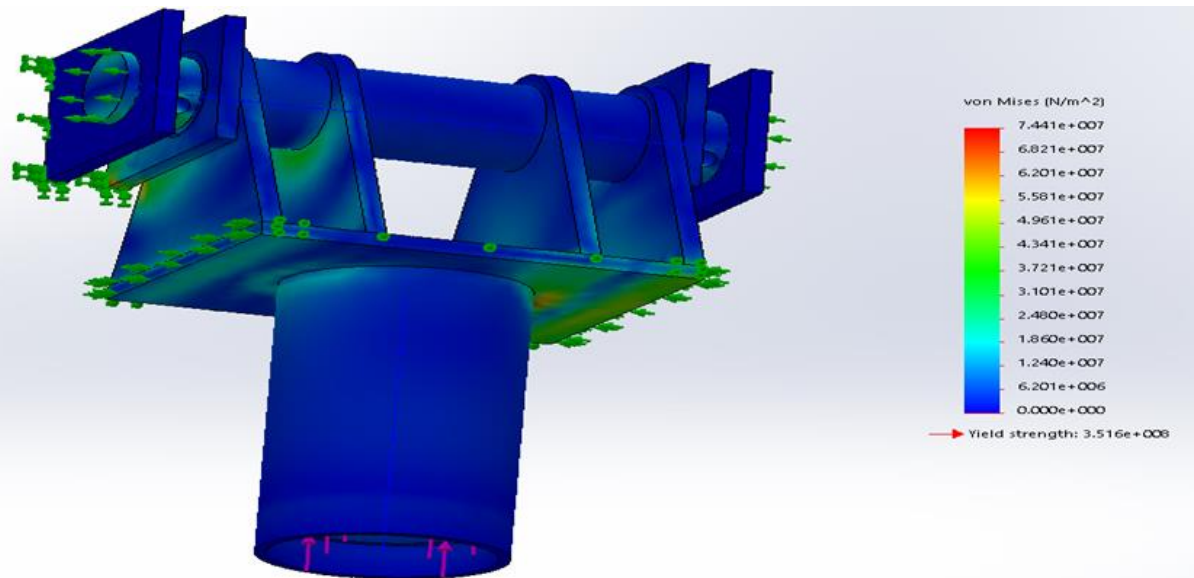
Stress Analysis

- ▶ Drop down arms and motor mount
- ▶ Yield Strength 51.1 KSI
- ▶ Load of 2500 lbs across bottom of arms and a torque of 4500 lb-in on motor mount
- ▶ Max Stress 21.2 KSI
- ▶ Factor of Safety of 2.4



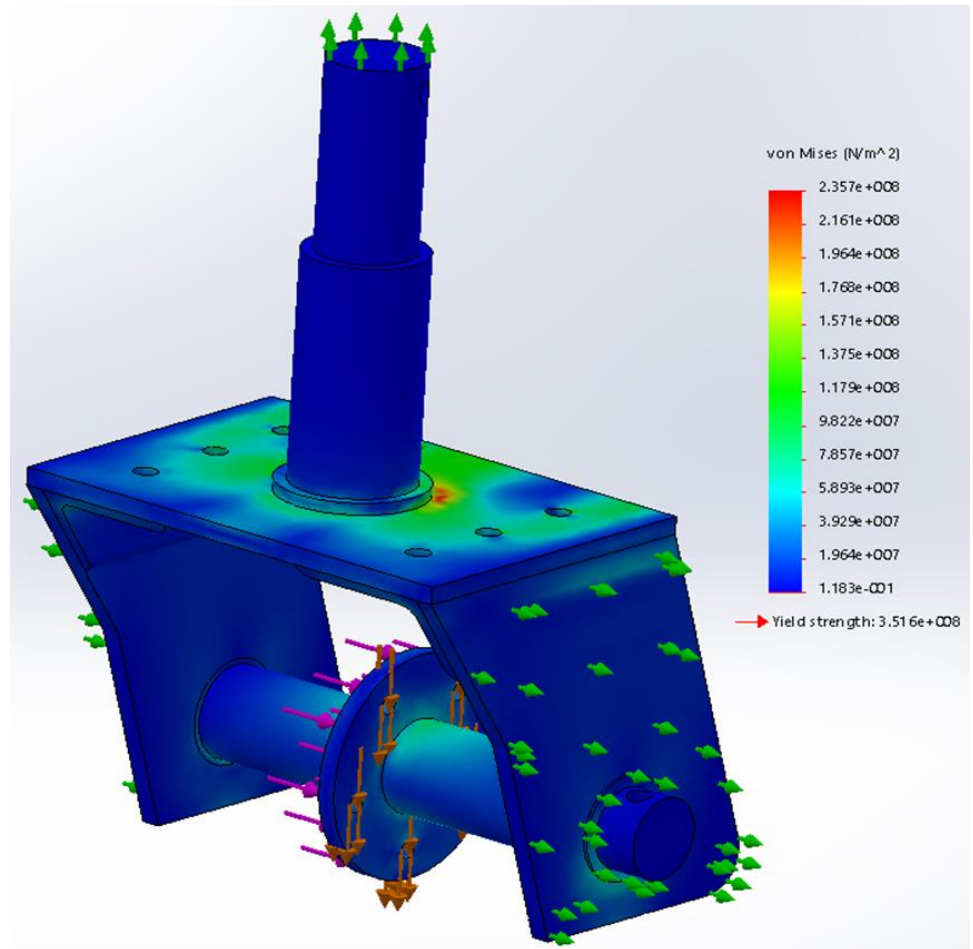
Stress Analysis

- ▶ Top half of front swivel wheel arm
- ▶ Yield Strength 51.1 KSI
- ▶ Load of 5000 lbs
- ▶ Max Stress 10.7 KSI
- ▶ Factor of Safety of 4.7
- ▶ High Factor of safety to account unforeseen loads



Stress Analysis

- ▶ Bottom half of front swivel wheel arm
- ▶ Yield Strength 51.1 KSI
- ▶ Load of 5000 lbs applied upward and a side load of 2000 lbs to simulate steering
- ▶ Max Stress 34.2 KSI
- ▶ Factor of Safety of 1.5
- ▶ A second plate was added at weakest point

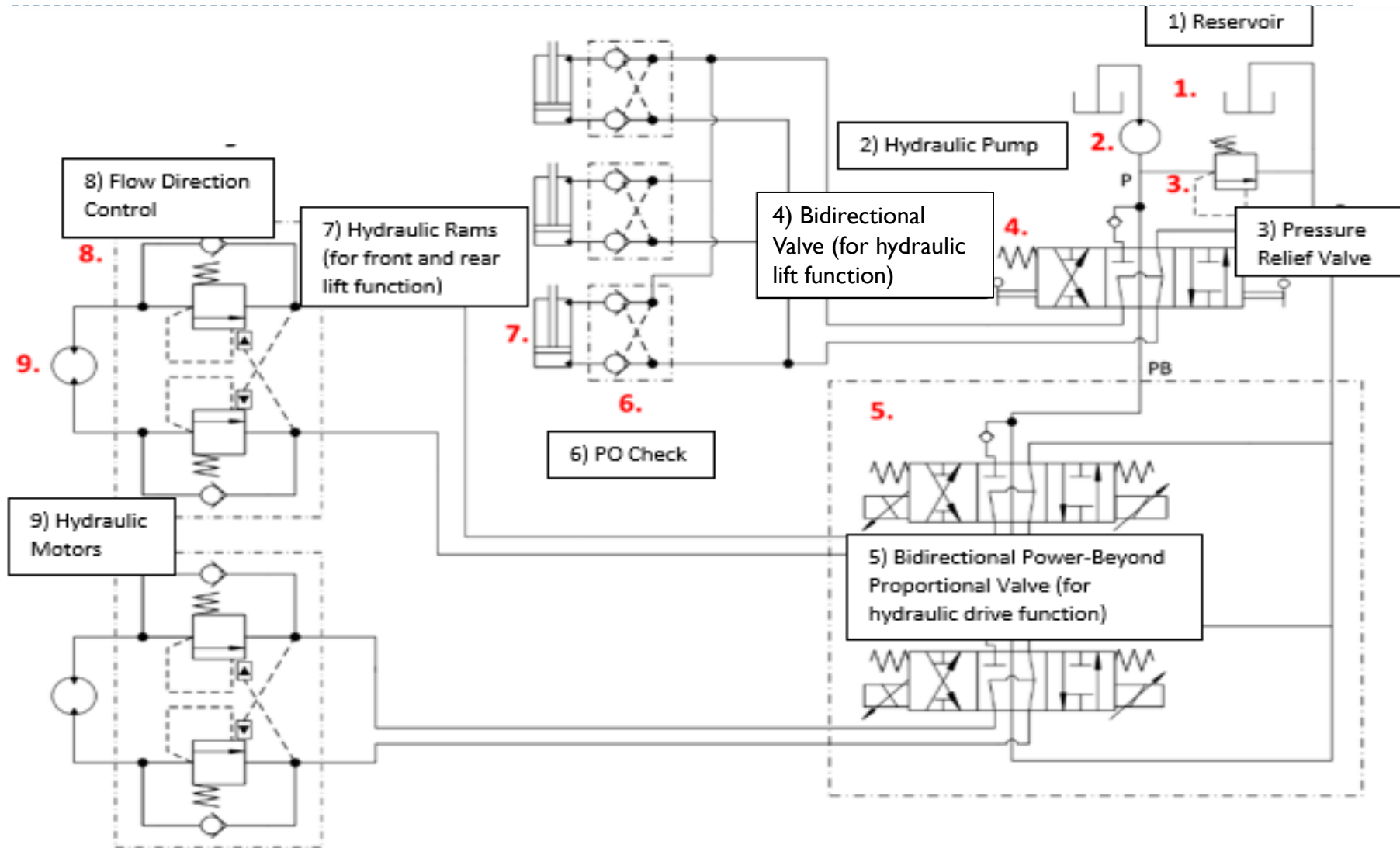


Key Components used

Components	
1	Hydraulic Motor (Eaton 2000 series, 24")
2	Hydraulic Cylinders (2" bore, 8" stroke, 1.25" rod)
3	Press-on Forklift Tires
4	Hydraulic Hoses
5	Bidirectional Valve
6	PO Check
7	Bidirectional Power-Beyond Valve
8	Axiomatic Quad Controller (receiver)
9	Trailer Remote
10	Hydraulic Fittings



Hydraulics



Hydraulic Cylinders

- ❖ Three Hydraulic Cylinders
- ❖ 2" bore x 8" stroke
- ❖ Max pressure 3000 psi
- ❖ Price \$480.75 each

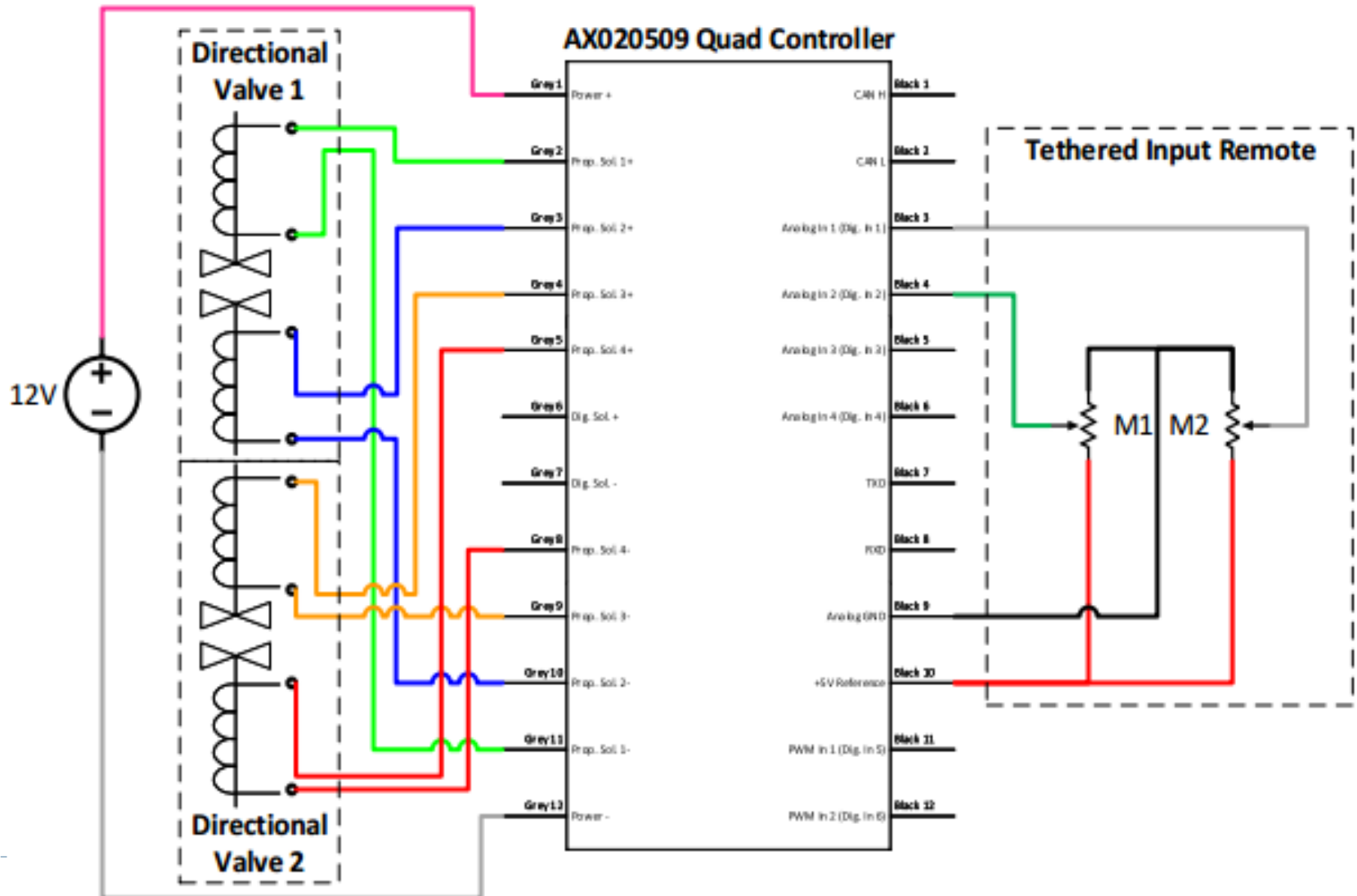


Hydraulic Motor and Proportional Valve

Proportional valve		
Parameter	Value	Unit
Operating pressure (Max)	4600	PSI
Nominal flow rate	16	GPM
Hydraulic motors		
Displacement	24	In ³ /rev
Flow rate (continuous)	20	GPM
Pressure (continuous)	2250	PSI
Torque (continuous)	6840	lb-in



Circuit Schematic



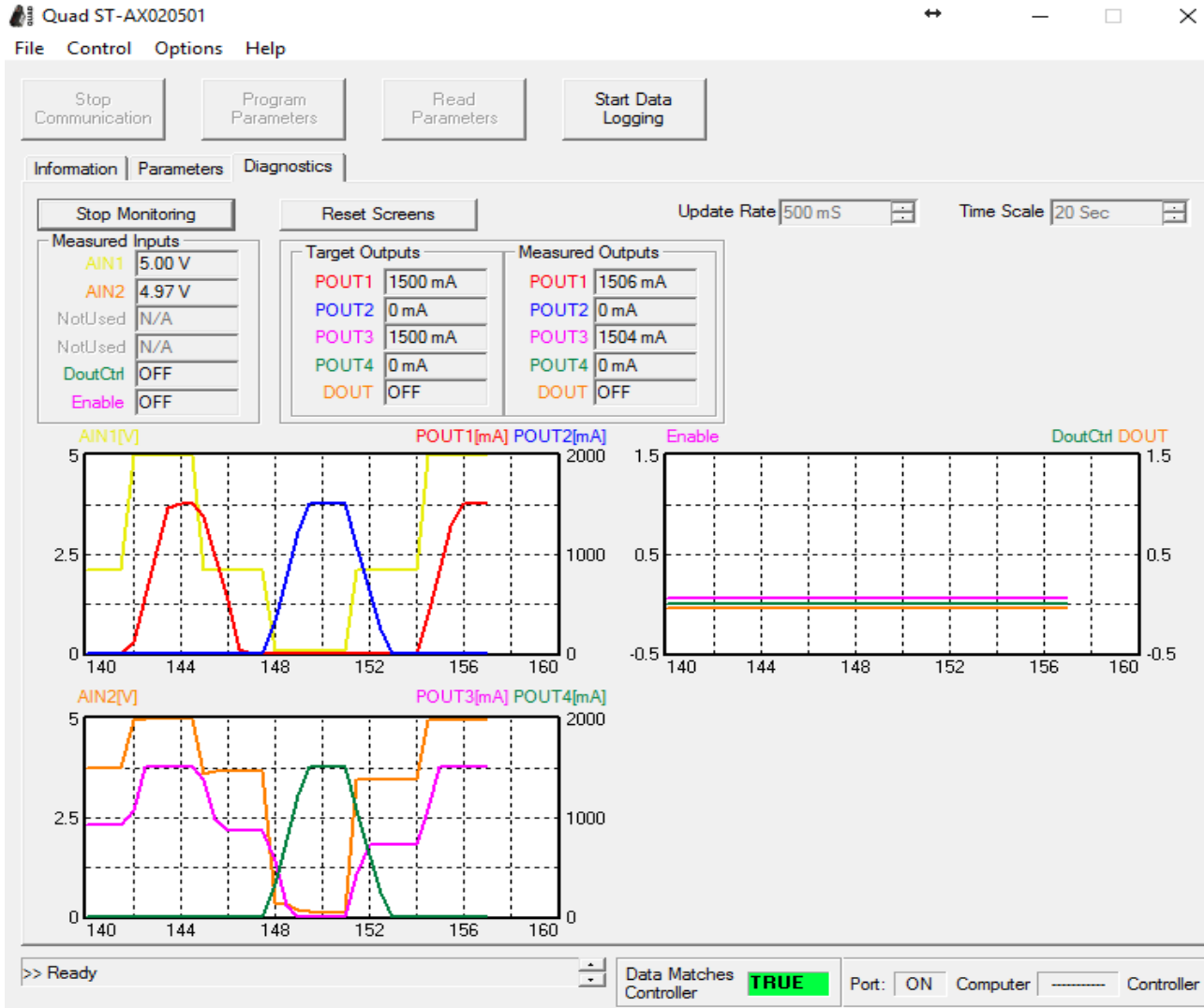
Trailer Controls



Technical Specifications:	Quad Valve Controller (RS-232 or SAE J1939 or CANopen®)
Order Codes:	P/N: AX020506 (CANopen®) - EMC Compliant P/N: AX020507 (SAEJ1939) - EMC Compliant P/N: AX020509 (RS-232) - EMC Compliant
Inputs:	Up to 6 inputs, selectable from the following. 2 PWM signal (50Hz to 10kHz), or pulse (16-bit counter inputs also available in model AX020507) 6 digital 4 analog (0-5V, 0-10V, 0-20 mA or 4-20 mA)
Outputs:	4 proportional (1.5A if all 4 used, or 2A for less than 4 used) 1 on/off (up to 5A)
Power:	8...36VDC 1 +5V, 50 mA (AX020507 has 2 +5V references)



Quad Service Program



Remote



Failure Method Analysis

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N	Actions Recommended
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How Severe is the effect to the customer?	What causes the Key Input to go wrong?	How often does cause or FM occur?	What are the existing controls and procedures that prevent either the Cause or the Failure Mode?	How well can you detect the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?
Pressed Tires	Slipping	Loss of traction	5	Poor road conditions, regularly tire check	1	checking road conditions	3	15	
Rear Drive Support Arm	Support Arm Breaking	Grounded trailer	4	Fatigue/Stress	1	Walk around check	3	12	Increased safety factor
Front Wheel Pivot Arm	Support Arm Breaking	Grounded trailer	4	Fatigue/Stress	1	Walk around check	3	12	Increased safety factor
Front Wheel Pivot bolt	Breaking	Front no longer stable	4	Fatigue/Stress	1	Walk around check	2	8	Increased safety factor
Hydraulic Cylinders	Seal Deterioration or Damaged	Loss of raising and lowering trailer	3	Cylinder misalignment or damaged	1	Walk around check	3	9	scheduled maintenance
Hydraulic Motor	Leakage	Loss of Steering and Driving	2	Fluid Deterioration	1	Scheduled Checking and changing of Fluids	4	8	Using Quality Fluids
Hydraulic Valves	Drift	Loss of Motor and Hydraulic Cylinders	2	Backpressure, Flow Forces or poor Spool control	1	Increased Safety factor of valves	2	4	
Hydraulic Lines	Leakage or cracking	Loss of motors	1	Failing to regularly check hoses	1	Walk around check	6	6	regular scheduled line check
Remote	Electrical Failure. Coding Execute Failure	Loss of Steering and Driving	1	Poor Coding/wiring or damaged	1		1	1	check before each use
Receiver	Electrical Failure	Loss of Steering and Driving	1	Poor Wiring or damaged	1		1	1	none

Testing Procedures

❖ Average Velocity – Distance over time

	Trial 1	Trial 2
Time [s]	12.32	12.57
Distance [ft]	20	20
Velocity [Ft/s]	1.623	1.591
Velocity [Mph]	1.106	1.08
Avg Velocity [Mph]	1.1	







Testing Conclusions

- ▶ Location of trailer motor results in disproportionate amount of weight over front crazy wheel
- ▶ Highly compressed tire resists turning due to large contact area of rubber
- ▶ Turning resistance on front crazy wheel is higher than the turning force generated by drive motors



Design Improvements

1) The Turning Ability

a) Solution – replacing the existing hydraulic pump would generate more pressure in the motor for higher turning torque.

b) Solution – add another wheel to the front axle to split some of the weight allowing the front end to turn more easily.

c) Solution – add another crazy wheel along with two more hydraulic motors on the front axle.

d) Solution – add a servo motor to existing steer wheel to help turn the wheel when turning.

e) Solution – add in gear reducers on motors to generate more torque.



Special Thanks

- ▶ Richard and Charles Machine Works
- ▶ Travis Peterson with Walvoil
- ▶ Wayne and BAE Lab
- ▶ Dr. Weckler, Dr. Long, and Dr. Wang



Final Design Assembly



Questions?





SUBMITTED BY

James Collingsworth | Colten Leach | Konner Kay | Skyler Sheperd | Trey Minton

Charles Machine Works - Ditch Witch

May 4th, 2017.

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Abstract

The objective of this project is the development of a system for Charles Machine Works, that will enable the FX-30 vacuum excavator to move without the use of a standard motorized vehicle. The design must meet the following parameters (as specified by Ditch Witch™): operate on hard surfaces, self-propelled, must be stowed on the trailer, operated by a remote control and the top speed achieved should be 1 – 1 ¼ mph. The design will handle hard surfaces such as, pavement, gravel, asphalt and hard ground. It is not designed for mud, or sand. The design must have its own mechanism for braking, or utilize the existing trailer brakes. In addition, it could incorporate both braking systems together as a design failsafe. The remote-control system can be tethered or wireless, it was not specified which the client preferred. The top speed achieved will be a slow walking pace.

Statement of Work

This project will consist of designing and fabricating a system that will maneuver the FX-30 Vacuum Trailer on hard pavement at a slow speed (1 - 1 ¼ mph). The FX-30 Trailer that the team are designing for will be provided to Oklahoma State University by Charles Machine Works – Ditch Witch™. The students will perform the testing of their design on the trailer at Oklahoma State University. The fabrication for the design will be done at OSU and at Ditch Witch™ as needed.

The overall objective of this project is to improve the FX-30 Vacuum Trailer by allowing it to move without a vehicle. The data collected through testing will measure the amount of HP needed to move the trailer, average velocity, max gradient the trailer can climb and the effectiveness on different surfaces.

Deliverables

- 1) Conceptual Design of the System
- 2) Fabrication and integration of the design onto the FX-30
- 3) Testing procedures and experimental data collection.
- 4) Results and Summary of completed design
- 5) Final Report

Introduction

Ditch Witch™ is an innovative company with a focus on the development of machinery that enable their customers to work more efficiently. Ditch Witch™ produces various types of equipment such as: trenchers, directional drills, skid steers, and vacuum excavators. In addition, Ditch Witch™ is always striving to further develop and improve their existing products.

The Senior Design Team was tasked to develop an innovative way to move the FX-30 excavator trailer at a slow speed of approximately (1 mph) on hard pavement, (as specified by Ditch Witch™) without the use of a standard motorized vehicle. The FX-30 excavator trailer can be seen in Figure 2.



Figure 1. FX-30 vacuum excavator in the field.

The vacuum excavators are used in many applications such as: exposing buried utility lines, cleaning out storm drains, directional drilling site cleanup, water leak repair, valve box cleanout, utility vault cleanout, commercial and residential debris cleanup and landscaping, and posthole digging. The team researched methods for towing large objects such as: airplanes, boats, trailers, etc. The most common method for moving large objects without the use of a truck is by way of a trailer tug. However, after meeting with our client, a trailer tug is not a viable solution. The client specified product must enable their trailers to move independently and not be restricted to movement only by a vehicle. The team brainstormed possible alternatives to move the trailer. The final

design will consist of adding a lift axle on the front of the trailer and another behind the rear axle. An example of a lift axle can be seen in Figure 2.



Figure 2. Hendrickson Steerable Lift Axle.

The lift axle attached on the front of the trailer will be used for steering and the back-rear axle will be the drive. By modifying the trailer and installing a drivable and steerable lift axle, the trailer can move freely without a standard motorized vehicle. Currently, the team is further developing the design to ensure exceedance of Ditch Witch™'s expectations. By implementing these modifications to Ditch Witch™'s existing products, Ditch Witch™ will generate more income, because the product is convenient for the consumers.

Technical Literature Review

The FX-30 is the trailer that the team will be utilizing for their design with Ditch Witch™. The trailer itself can be seen in Figures 3 and 4.



Figure 3. FX-30 trailer front view.



Figure 4. FX-30 back view.

The design specifications for the FX-30 were provided by Ditch Witch™ and can be seen in Tables 1-3.

Table 1. FX-30 Trailer Dimensions

Dimensions	
500 Gal Spoils/80 Gal Water on T9SE6 or T9SH6	U.S
Length	200 in
Width	96 in
Height	86 in
Weight, empty	5,465 lb
Trailer GVWR	10,000 lb
800 Gal Spoils/200 Gal Water on T18S	
Length	233 in
Width	102 in
Height	92 in
Weight, empty	8,255 lb
Trailer GVWR	18,000 lb

Table 2. Power

Power	US
Engine	Kubota D1105-E3B
Fuel	Diesel
Cooling medium	Liquid
Injection	Indirect
Aspiration	Natural
Number of cylinders	3
Displacement	68.6 in ³
Bore	3.07 in
Stroke	3.09 in
Manufacturers gross power rating (SAE J1995)	24.8 hp
Rated Speed	3,000 rpm
Emissions compliance	EPA Tier 4
Fuel Tank Capacity	15 Gal

Table 3. Hydraulic System

Hydraulic System	US
Pressure	2,500 psi
Drive type	12V DC
Tank lift cylinder size (2)	3 in
Tilt angle, max	45 degrees

Customer Requirements

The client, Charles Machine Works, had specified a few parameters that our design must achieve.

- 1) The system is designed to operate on hard surfaces.
- 2) The design should be self – propelled.
- 3) The system must be integrated onto the existing trailer.
- 4) The system should simply be engaged and disengaged.
- 5) Controls need to be operated by a remote control.
- 6) The top speed with the system should be 1 – 1 ¼ mph.
- 7) The system must have its own way to brake or utilize existing trailer brakes.

Existing Technology

As of currently, there are hundreds of trailer tugs on the market. The team chose a few that were the most relevant to their design. For example, the Haulle trailer tug (seen in Figure 5) has a similar design concept.



Figure 5. Haulle Tug

The Haulle is used for a variety of trailers ranging from: boat, yard, and highway trailers. It is rated for 40,000 lb towing capacity and it can hold up to 15,000 lb tongue weight. The tug is equipped with a wireless remote to maneuver, but it also has built in manual controls in case the remote fails. It is equipped with the following features: hydraulic lift, brakes, heavy duty steel, safety stop switches. However, some disadvantages to this product are: 24 hp gas engine, on-board hydraulic pump, 10 wheels, costly design, cannot fit onto trailer. The maintenance costs associated with this design are: hydraulic lines, tires, batteries for the remote, hydraulic rams, drive chain and belts. Similarly, to that of the Haulle, the MUV 4WD is a remote controlled electric tug (seen in Figure 6).



Figure 6. MUV 4WD Electric Tug

The MUV tug is powered by two 440W, 24V DC with two x 125A programmable motor controllers. It is equipped with a built-in battery charger, master key switch (on/off), battery gauge and safety devices such as an LED strobe and motion beeper. The disadvantage associated with this tug is its limited power capacity.

Trailer tugs are made from high grade steel in order to withstand the weight of a fully loaded trailer. The frame is durable and requires hardly any maintenance. The tires on the tug require the most maintenance. Depending on the quality of the tire and the load being applied, the tires may need replacing often. It is dependent on how often the trailer caddy is used. The cost for a tire ranges from \$20-\$40 depending on the quality. The battery life span on electrically powered tugs depends on how often the tug is used. The average life span of a battery is 2-5 years and the cost ranges from \$50-\$150. Hydraulically powered tugs have more maintenance costs and requirements due to the

hydraulic lines, fluid, and pump. Hydraulic lines can bust often if the pressure is too high or the line has a flaw. The cost of hydraulic lines on average is \$2 per foot. If a line does break, the hydraulic fluid lost needs to be replaced and costs \$5 per gallon. The hydraulic pump needs little maintenance if the pump does not run dry. The average cost of a pump is \$200. If the tug is fitted with a wireless remote control, the remote just needs to be recharged every 12 hours.

Most trailer tugs are either electrical or manually powered. A characteristic that is not used as often is hydraulic powered tugs. This is because most tugs don't have access to a hydraulic pump. If a tug is hydraulic powered, it is usually a large machine that has enough room to be fitted with a motor, pump, and hydraulic reservoir if they are to be self-sustaining. In other cases, they are ran from an existing pump on a trailer and are limited to trailers that have pumps. Another characteristic that is not used as often is being able to control the tug by a remote control. Most tugs are maneuvered manually by the operator. This is because the cost of a remote is higher and implementing it into the tug is more difficult than using handles.

The major safety concerns with trailer tugs is being able to stop the unit, particularly when moving downhill. In addition, if the product is used within a warehouse it should be equipped with a horn and siren to alert civilians that may be in the premise.

Methodology

To ensure that the trailer bears most the weight on the rear axles, the team performed force balance calculations to distribute the weight appropriately. The back axle of the trailer needs to support the weight, so the trailer has traction. Upon completing the force balance, the team calculated how much horsepower (HP) is required to pull the trailer and the max slope the trailer can climb. The horsepower methodology was calculated in Excel and can be seen in Tables 4 and 5. The results were obtained using the equations listed in Appendix pages 40-42.

Table 4. Trailer Specifications

Gross Vehicle Weight (GVW) (lb)	18,000
Weight on each Drive Wheel [WW]	3,000

(lb)	
Radius of Tire [R] (in)	8
Top Speed (V) (ft/s)	1.467
Maximum Incline (alpha) (degrees)	5
Coefficient of Traction	0.33
Desired Acceleration Time (t)(seconds)	4
Tongue Weight (lbs)	2,600

Table 5. HP Requirement per degree of Slope

Maximum Incline (alpha) (degrees)	Maximum Incline (alpha) (radians)	Total Tractive Effort (lb)	Grade Resistance	Wheel Motor Torque (lb-ft)	HP
0	0	601.015528	0	460.7785714	1.603072
1	0.017444444	914.9996027	313.9840748	701.4996954	2.440553
2	0.034888889	1228.888132	627.8726039	942.1475677	3.27778
3	0.052333333	1542.585599	941.5700708	1182.648959	4.114496
4	0.069777778	1855.996545	1254.981017	1422.930684	4.950449
5	0.087222222	2169.025599	1568.010071	1662.919626	5.785383
6	0.104666667	2481.577507	1880.561979	1902.542755	6.619044
7	0.122111111	2793.557158	2192.54163	2141.727154	7.451179
8	0.139555556	3104.869616	2503.854088	2380.400039	8.281534
9	0.157	3415.420149	2814.404621	2618.488781	9.109857
10	0.174444444	3725.114256	3124.098728	2855.92093	9.935896
11	0.191888889	4033.857697	3432.842169	3092.624235	10.7594
12	0.209333333	4341.556521	3740.540993	3328.526666	11.58012
13	0.226777778	4648.117095	4047.101567	3563.55644	12.3978
14	0.244222222	4953.446132	4352.430604	3797.642035	13.21219
15	0.261666667	5257.450721	4656.435193	4030.712219	14.02305
16	0.279111111	5560.038352	4959.022824	4262.69607	14.83014
17	0.296555556	5861.116948	5260.10142	4493.522993	15.6332
18	0.314	6160.59489	5559.579362	4723.122749	16.43199
19	0.331444444	6458.381047	5857.365519	4951.425469	17.22626
20	0.348888889	6754.384802	6153.369274	5178.361681	18.01579

After the team calculated the HP required per degree of ground slope, a 5% maximum ground slope is recommended based on the available – HP (as provided by FX-30 Trailer Specifications).

Safety Considerations

As an engineer, one of the fundamental cannons is to ensure the safety, health and welfare of the public. The primary safety concerns are within the fabrication and production of the trailer assist system, specifically. During the cutting and welding of the steel for the frame, the workers are required to wear protective gloves, eyewear, shirt,

and pants. While wiring the electrical system, the system needs to be disconnected from all electrical sources, as well as following all OSHA standards set by the Department of Labor to avoid electric shock and ground faults. During the installation of the trailer assist system, the trailer needs to be lifted and secured in a safe position to attach the system on the underside of the trailer. The trailer can also be driven over a mechanic pit if a lift is not present. A hydraulic jack needs to be used to help lift and stabilize the system while it is being attached. This system should not be attached by one person; multiple people should be present in case of an accident. While using the trailer assist system, the user must be aware of his/her surroundings. The system's top speed is 1-1 ¼ mph, but the user should never be distracted while the system is in motion. The user should always obey traffic laws and never block streets or driveways. If the system is going up or down an incline, the system is fitted with an emergency braking system that ties into the trailer brakes. If the system increases speed downhill or starts to roll downhill, the brakes can be engaged to slow the descent or completely stop the trailer. When the trailer is parked on the side of a road, the user must put out caution cones to inform the public that the trailer is stopped. By doing so, allowing the public time to slow down and reduce the risk of a vehicle hitting the trailer. When the trailer is crossing an intersection, the user needs to be extra cautious. Double check for oncoming traffic and if need be stop traffic until the trailer is safely across. During transport of the trailer, the system needs to be raised to its transport location and secured. This will keep the system off the ground and ensure that the center of gravity is centralized on the trailer. Before transportation, the user should perform regular checks of the trailer and vacuum system as specified by Ditch Witch™'s FX-30 safety manual.

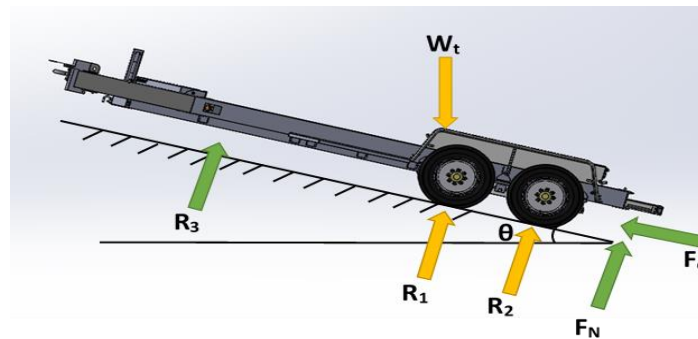
Sustainability Characteristics

Technology is continually improving and becoming more advanced. The need to further develop and improve our existing products is a must. The FX-30 trailer modifications the team will be implementing is progress towards self-driving vehicles, to an extent. Self-driving vehicles are being developed by Tesla Motors and other competitors. Tesla vehicles will allow full autonomy from the user, which with proper development, will be safer than a human driver. The FX-30 modifications will not make

the trailer self-driving, but it is a step towards that direction. Autonomous vehicles play a fundamental role in further developing transportation safety and transitioning the world to a sustainable future (Tesla). The maintenance requirements of the system are simple, moving parts must be greased every 100 hours and the tires replaced, as needed. When the trailer or the trailer assist is no longer viable, most of the components can be recycled and reused. The steel can be melted down, the tires can be recycled, and the plastic can be broken down by microbial remediation.

Engineering Specifications

Our engineering specifications were formed based on our methodology and from our Free Body Diagram of the trailer, which can be seen in Figure 7.



$$F_N = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) \left(\frac{1}{\mu} \right) + \left(\frac{W_t \sin \theta}{\mu} \right)$$

$$F_d = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) + W_t \sin \theta$$

Figure 7. Free Body Diagram of FX-30

Where

F_N = Force in the Y direction (lbs)

F_d = Force in the X direction (lbs)

W_t = Weight of the trailer (lb)

V = Velocity (ft/s)

μ = Friction

t = Time (seconds)

$\sin \theta$ = Angle

In order to calculate the size and length of pistons the design needed, the law of cosines was used. The pistons selected are 2" bore x 8" stroke and have a max push force of 3,768 lbs and max pull force of 3,396 lbs. The cost of each cylinder is \$480.75 and the team will need three cylinders.

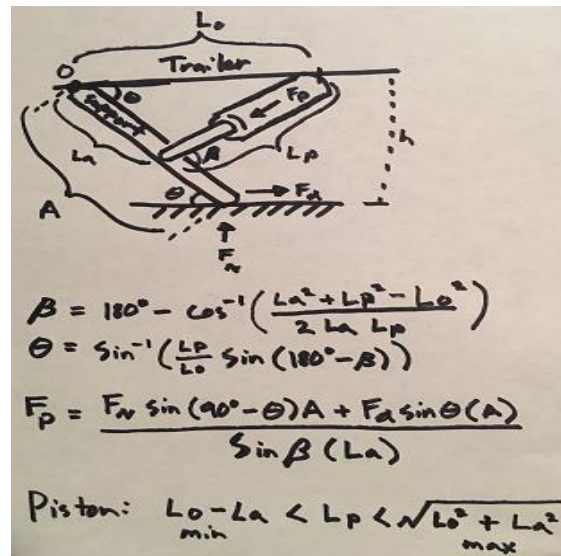


Figure 8. Law of cosines for piston

Table 6. Piston Length Data

Solving for Piston Length		
Drop Down Axel Piston Reactions		
Variable	Value	Units
Number of Pistons (N)	2	
Distance between support and piston origins (Lo)	2.097	ft
Angle of support with trailer (θ) *closest to 90 degrees is best	58.01809	degrees
Axel support length (A)	1.483	ft
Distance piston pinned on support (La)	0.864	ft
Distance between trailer and end of support (h)	1.2575	ft
Max Piston Length	2.268018	ft
Min Piston Length	1.233	ft
Piston length (Lp)	1.795292	ft
Force of piston	86.98719	lbs
Angle of support with trailer (θ)	1.012093	rad
Lower angle between piston and support (β)	1.707557	rad

The support arm sizing was calculated using the Distortion Energy Theory and the size used are 3x4x1/4 rectangular tubing with a safety factor of 3.6

Table 7. Support Arm Strength Data

Support Arms Strength		
Variable	Value	Units
Material Type	A513	\$20/ft
Modulus of Elasticity [E]	30000	ksi
Yield Tensile Strength [Sy]	72	ksi
Beam Width [b]	3	in
Beam Height [h]	4	in
Beam Wall Thickness [t]	0.25	in
Max Deflection [d]	-0.0072	in
Safety Factor [n]	3.58	

The axle diameter calculations for the front and rear steering was calculated using the Distortion Energy Theory. The axle diameter the team selected is 1.75” and a safety factor of 2.8.

Table 8. Axle Strength

Axle Strength		
Variable	Value	Units
Material Type	A513	
Yield Strength	72	ksi
Modulus of Elasticity [E]	30000	ksi
Axle Diameter [D]	1.75	in
Axle Length [L]	28	in
Wheel Distance From Support [x]	3	in
Safety Factor [n]	2.83	

Preliminary Design Concepts

Initially our team was designing a system similar to a trailer caddy for our project, but after meeting with our client we discovered that they did not want a trailer tug.

- 1) “Segway”© Tug.

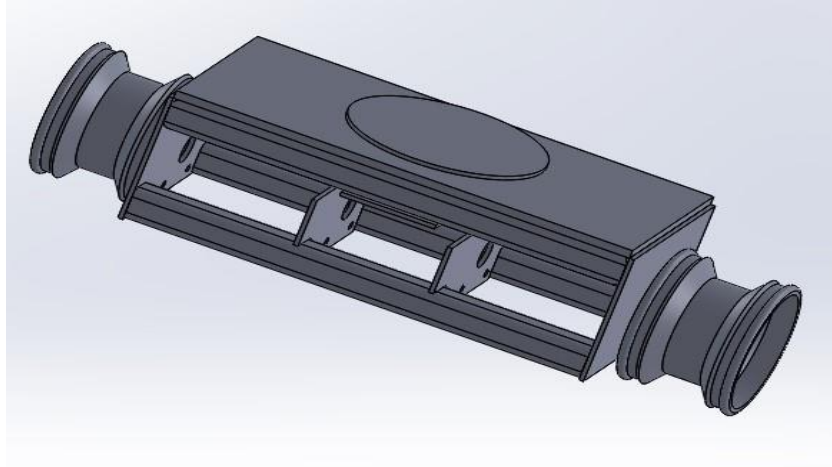


Figure 9. Segway Tug

The “Segway”© tug, seen in Figure 9, would sit under the tongue of the trailer and operate with two hydrostatic motors similar to that of a skid steer. The two hydrostatic motors would allow the unit to drive and steer. Upon further calculations, we found that the “Segway”© would not be able to pull the trailer uphill.

2) Chain and Sprocket Drive

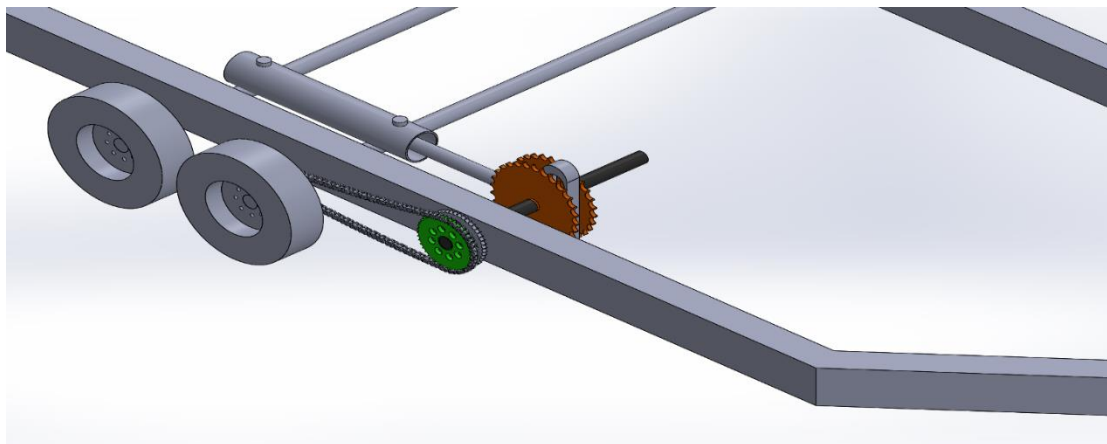


Figure 10. Chain and Sprocket Drive

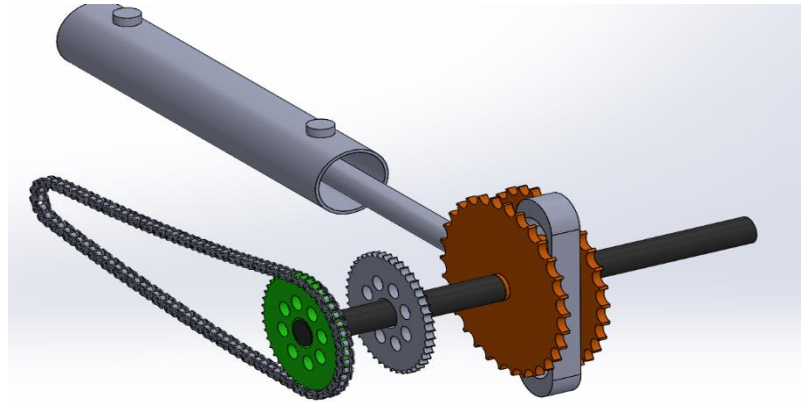


Figure 11. Chain and Sprocket Assembly

The team decided this would be an efficient way to enable the trailer to drive itself by attaching a motor to drive the sprocket and chain. However, this design was tossed out because the chain would be exposed while going down the road and it is not easy to engage and disengage.

3) Drive motor mounted to the wheel hubs.

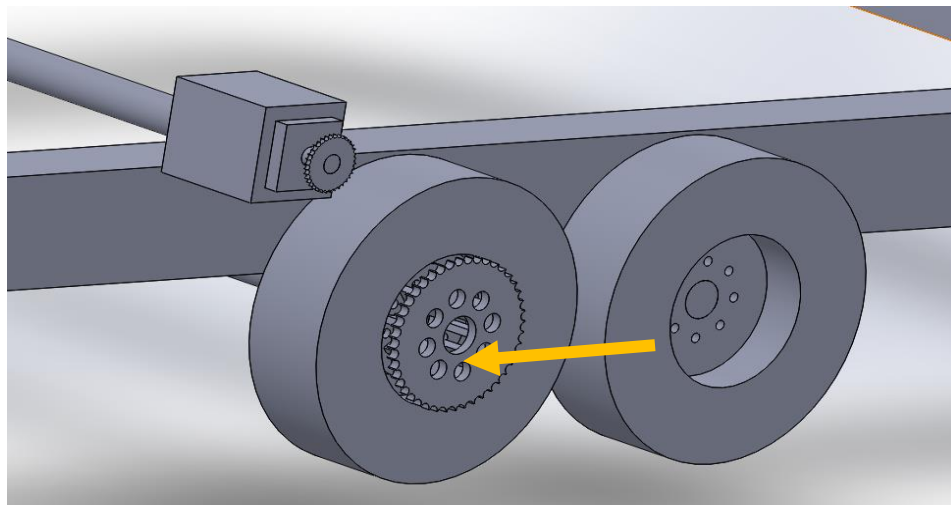


Figure 12. Drive Motor System

This design would consist of a motor mounted to the wheel hub with a chain and sprocket. It would allow the tire to rotate freely and propel the trailer. The design was not practical because the motor would be extended too far out past the

fender of the trailer. This would violate the national standard trailer laws of making the width longer than 102 inches.

4) Ratcheting axle drive

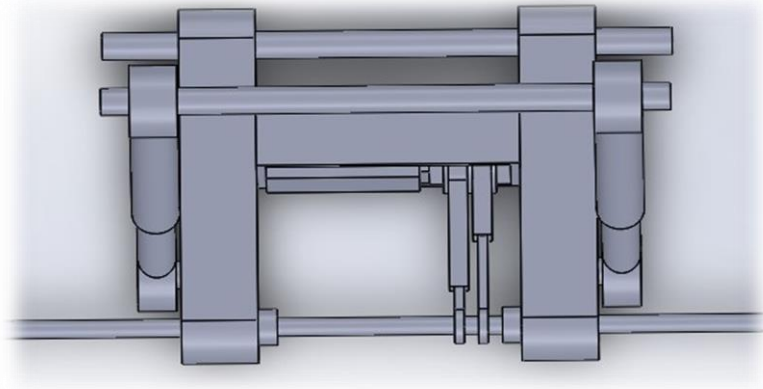


Figure 13. Ratcheting Drive Axle Top View

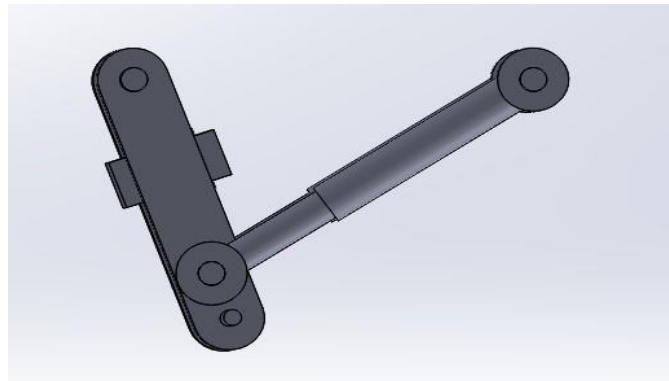


Figure 14. Ratcheting Drive Axle Side View

This was the preliminary design that led to our final design. It consisted of two ratcheting arms offset by 90 degrees, so when one arm locked forward, the other locked backward, which would allow the trailer to move forward or in reverse.

Fall Semester Design

The final design will consist of an independent drive system comprised of two lift axles. The axle in front of the trailer will be used as the steer, and the rear axle will be used for the drive.

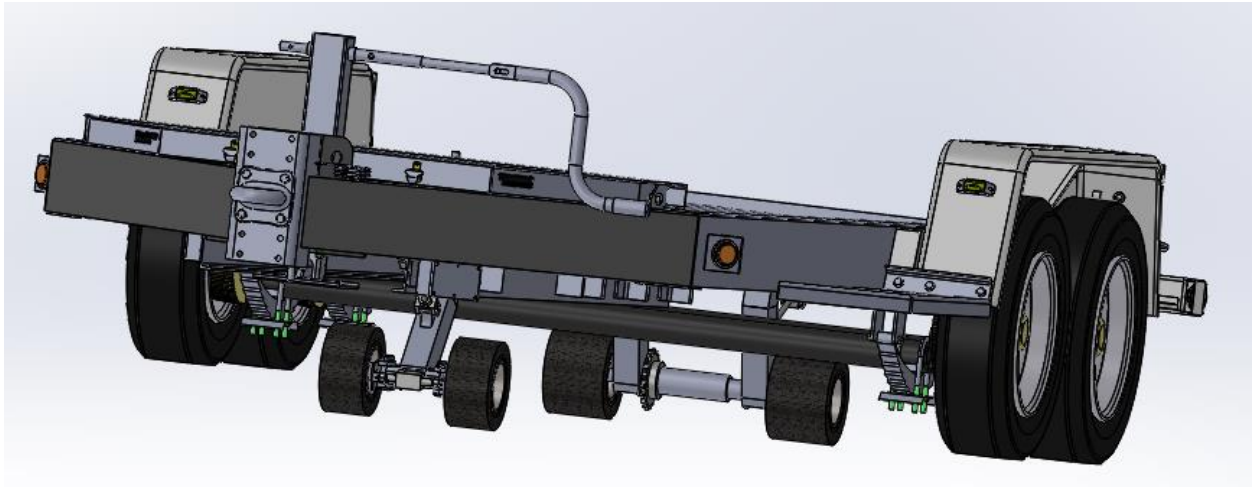


Figure 15. Trailer Front View

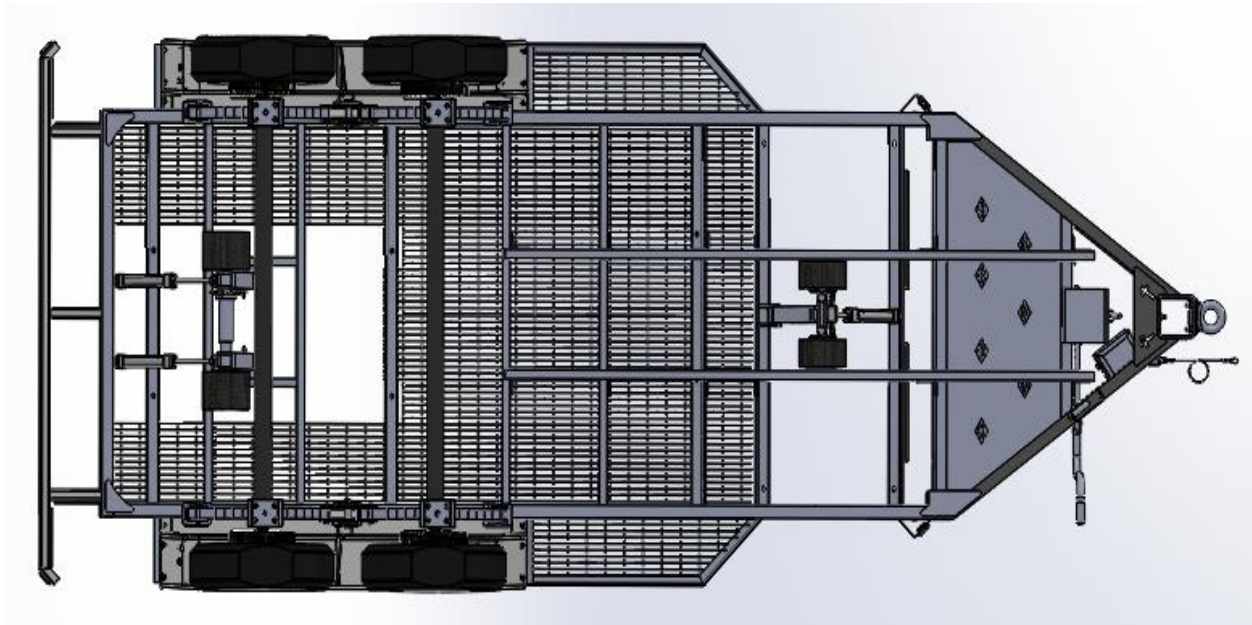


Figure 16. Trailer Top View

The drive axle will consist of a hydraulic lift axle and the motor will be hydraulic or electric (TBD). It will be a chain-driven system and the weight will be supported by two solid 10x7x6-1/4 tires. The tires are rated for 3100 lbs and cost \$116.13 per tire.

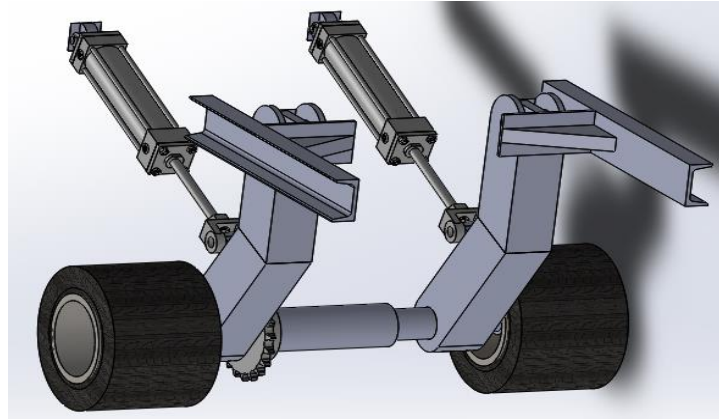


Figure 17. Drive Axle

The steer axle (seen in Figure 18) will consist of a hydraulic lift axle, and it will be mounted to the cross members of the trailer frame. The steering will be controlled by a double ended hydraulic cylinder and the system will also have two 9x5x5 solid rubber tires. The tires are rated for 1741 lbs and cost \$129.46 per tire. However, the team have not calculated any real numbers for the steer axle as of yet. The team has to account for turning forces that could cause the steering axle to shear and break. Upon entering the spring semester, the team will have performed further calculations to size the steering arm appropriately and include a factor of safety.

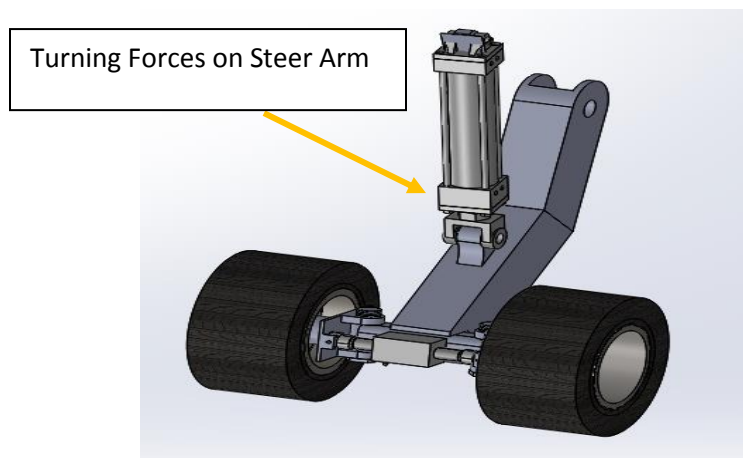


Figure 18. Steer Axle

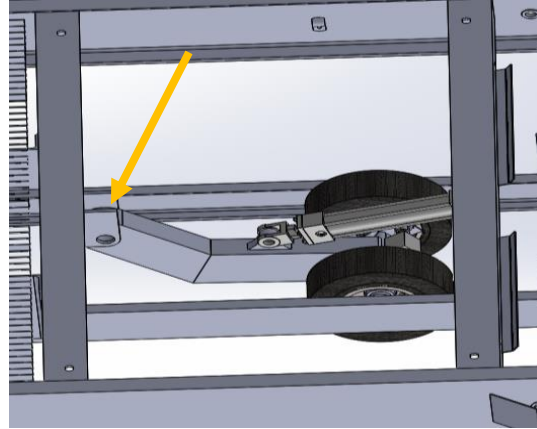


Figure 19. Steer Axle Mounting

Spring Semester (January-May 2017)

Upon finishing the fall semester design, the team met up with Charles Machine Works to discuss any design flaws and/or outstanding issues remaining. At the meeting, the client discussed a few topics the team needed to address, such as: hydraulics, stresses, electrical controls, fabricating parts and purchasing parts. In addition, the team also opted to redesign their existing system.

Spring Project Schedule

% Complete	Task Mode	Task Name	Duration	Start	Finish
100%	★	Compsite team schedule	6 days	Sun 1/15/17	Fri 1/20/17
100%	★	▾ List team issues	6 days	Sun 1/15/17	Fri 1/20/17
100%	★	create task handout	1 day	Sun 1/15/17	Sun 1/15/17
100%	★	Contact Client	1 day	Wed 1/25/17	Wed 1/25/17
100%	★	▾ Client Meet	1 day	Thu 1/26/17	Thu 1/26/17
100%	★	Supplies & materials reviewed	1 day	Thu 1/26/17	Thu 1/26/17
100%	★	Final Design Reviewed	1 day	Thu 1/26/17	Thu 1/26/17
100%	★	Finalize design	12 days	Sun 1/15/17	Mon 1/30/17
100%	★	Client Meet 2	1 day	Tue 2/7/17	Tue 2/7/17
100%	★	▾ Project Materials	13 days	Fri 1/20/17	Tue 2/7/17
100%	★	▾ order supplies & materials	7 days	Fri 1/27/17	Mon 2/6/17
100%	★	Parts List Created	1 day	Fri 1/27/17	Fri 1/27/17
100%	★	Team Website	3 days	Fri 1/27/17	Tue 1/31/17
100%	★	Project work	34 days	Wed 2/8/17	Mon 3/27/17
100%	★	Fabrication	31 days	Mon 2/13/17	Mon 3/27/17
100%	★	Final Report rough draft	10 days	Mon 3/13/17	Fri 3/24/17
100%	★	Final Report second draft	7 days	Fri 3/24/17	Mon 4/3/17
0%	★	Testing	11 days	Mon 3/27/17	Mon 4/10/17
0%	★	Final Report due	11 days	Mon 4/3/17	Mon 4/17/17
0%	★	Presentation	11 days	Mon 4/10/17	Mon 4/24/17
0%	★	Preliminary Presentations	1 day	Mon 4/24/17	Mon 4/24/17
0%	★	Presentation revision	8 days	Mon 4/24/17	Wed 5/3/17
0%	★	Final Presentations	1 day	Thu 5/4/17	Thu 5/4/17

Figure 20. Spring Project Schedule

Hydraulic System

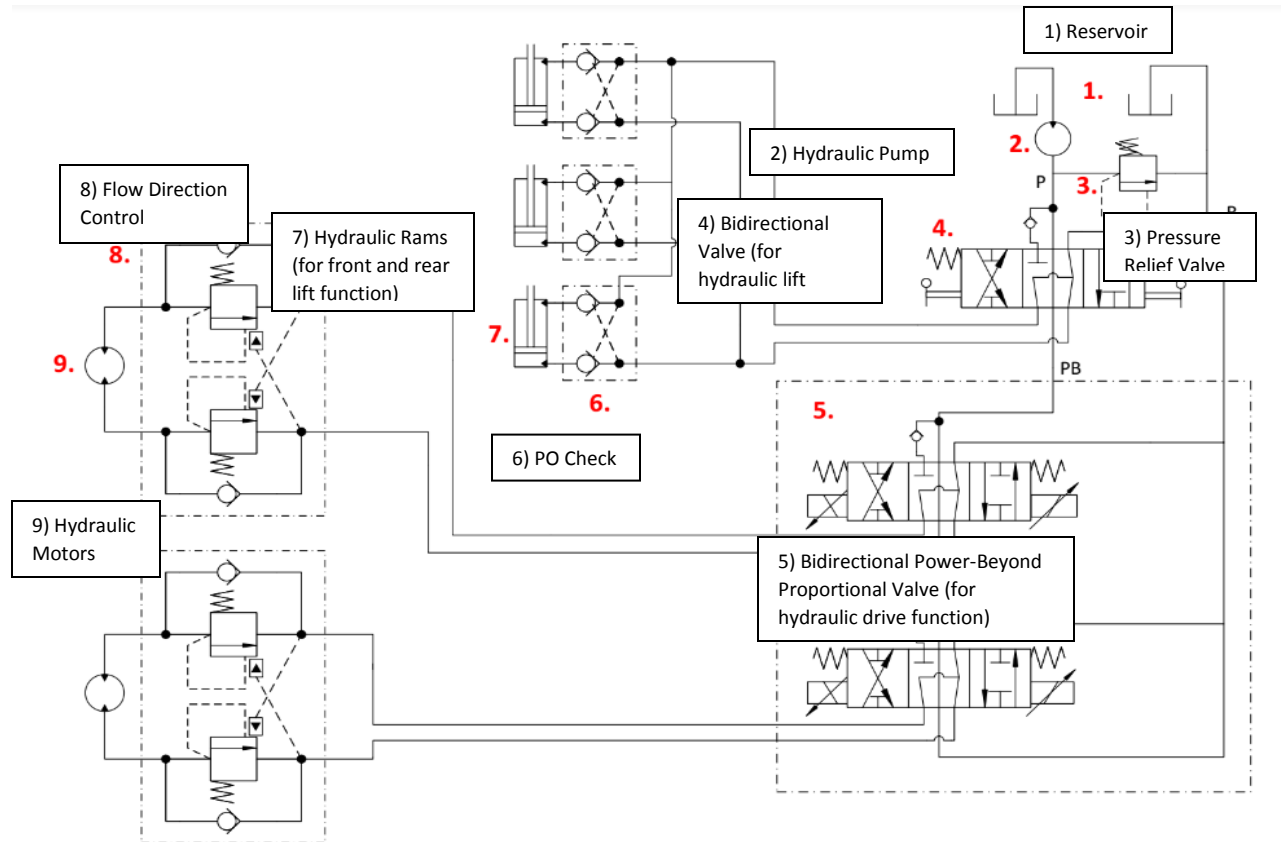


Figure 21. Hydraulic Diagram

The scope of our project is to drive and steer the FX-30 trailer via remote control. This was accomplished by restructuring the existing hydraulic pump on the trailer to only operate the drive system. The existing valves on the trailer had to be replaced as they were in a singular manifold. The two existing bi-directional levers were used to operate the hydraulic rams on the waste tank, as well as the on/off toggle for the water jet pump. The valve we used to replace the existing manifold is a singular bi-directional valve that controls the hydraulic pistons that lift and lower the drive system. We reduced the complexity of the hydraulics by connecting the pistons in parallel.

In addition, a PO check is connected to each side of the pistons. The PO checks keep the pistons from moving as the fluid is blocked in both directions unless the pump and reservoir side of the lines are pressurized. Also, connected in series with the bidirectional piston valve, is a two valve, bidirectional, power beyond, proportional

solenoid manifold. Each of these two valves is connected to a bidirectional motor on each side of the drive system. The purpose of the bidirectional and proportionally controlled valve is to control the direction and throttle of each independent motor. By doing so, it mirrors a skid steer drive system. The power beyond manifold can operate the two valves simultaneously. Two pilot operated valve manifolds are connected to each of the hydraulic motors. These manifolds ensure that unless the lines are pressurized, no fluid can escape the motor, meaning the motor cannot rotate. Pressure loss in the motors would result in the motors rotating freely without resistance. If the trailer were on an incline, the trailer could roll freely resulting in injury or death.

Stress Analysis

The stress analyses were conducted using Von Mises approximations with ANSI 1020 Steel. These are also separated such that these are largely their own part once welded together.

Top view of the front

The geometry was fixed about the 4 hinged brackets. Sliders were set on the pin and around the square part of mounting bracket to keep part from rotating. A generous axial load of 5000lbs was applied to the roller Bering contact. In the given conditions, factor of safety is approximately 4.7.

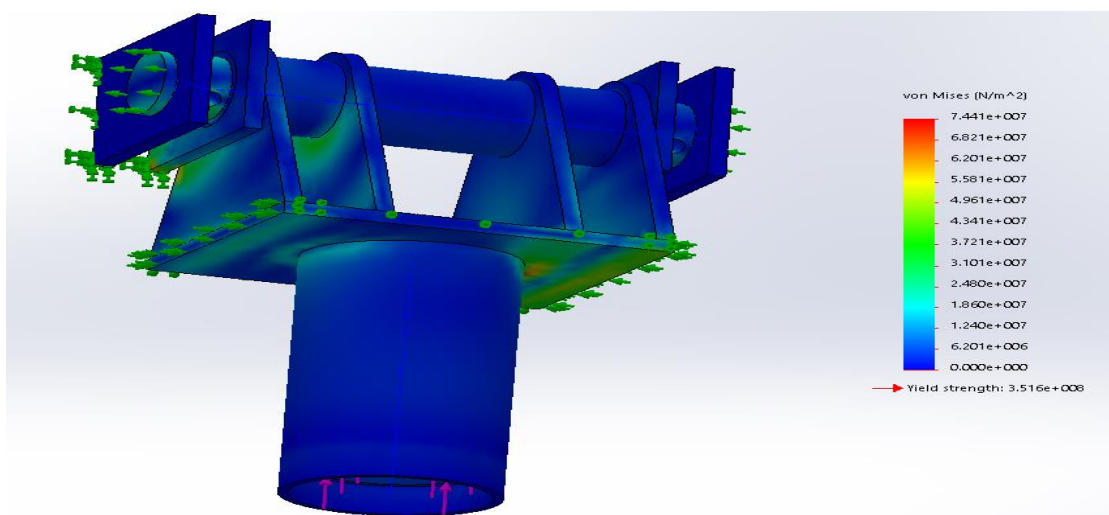


Figure 22. Top view of the front wheel assembly

Back Mount

Geometry was fixed on the 4 edges of the 2 C-channel cross members. A force of 2500lbs was applied to each of the 4 pins perpendicular to the plane that would be assumed the ground. This resulted in a factor of safety that is approximately 1.4. This is primarily because of the hole that is cut in the C-Channel for running hydraulic lines. For our purposes, we would recommend covering the hole and running the lines over/under the channel, or modifying where the shorter C- Channels are attached. It is also important to note, that 2500lbs is a very generous amount of weight.

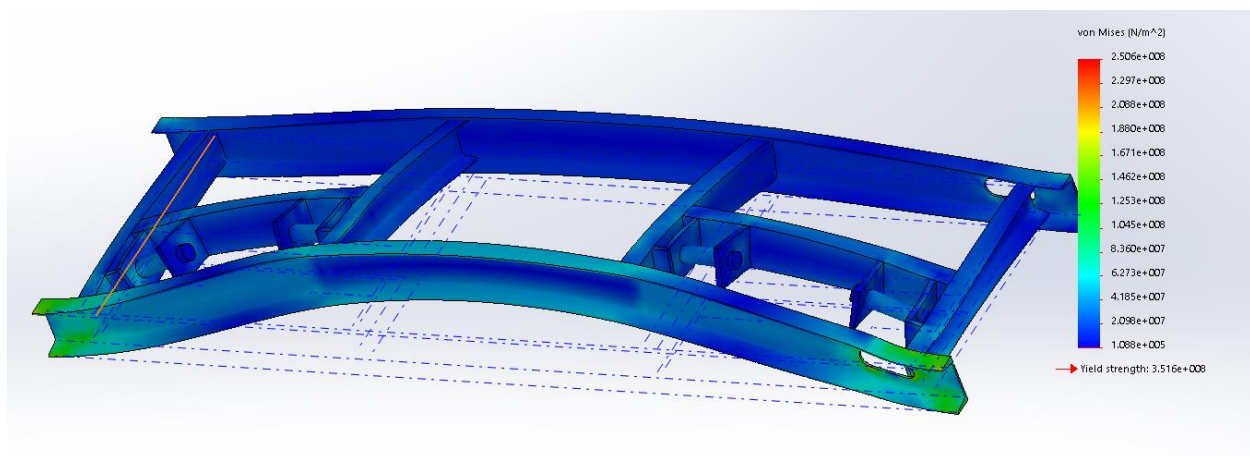


Figure 23. Back Mount

Drop Arms

Geometry was hinged about the top of the arms and about the piston mount. Sliders were set on the flat sides of the arms perpendicular to the direction of the pins, as well as on the sides of the cylinder mounts. A torque of 4500 lb-in was applied to the bolt holes where the motor would be mounted and a force of 2500lbs was applied to the bottom of the arms, perpendicular to what would be assumed the plane of the ground.

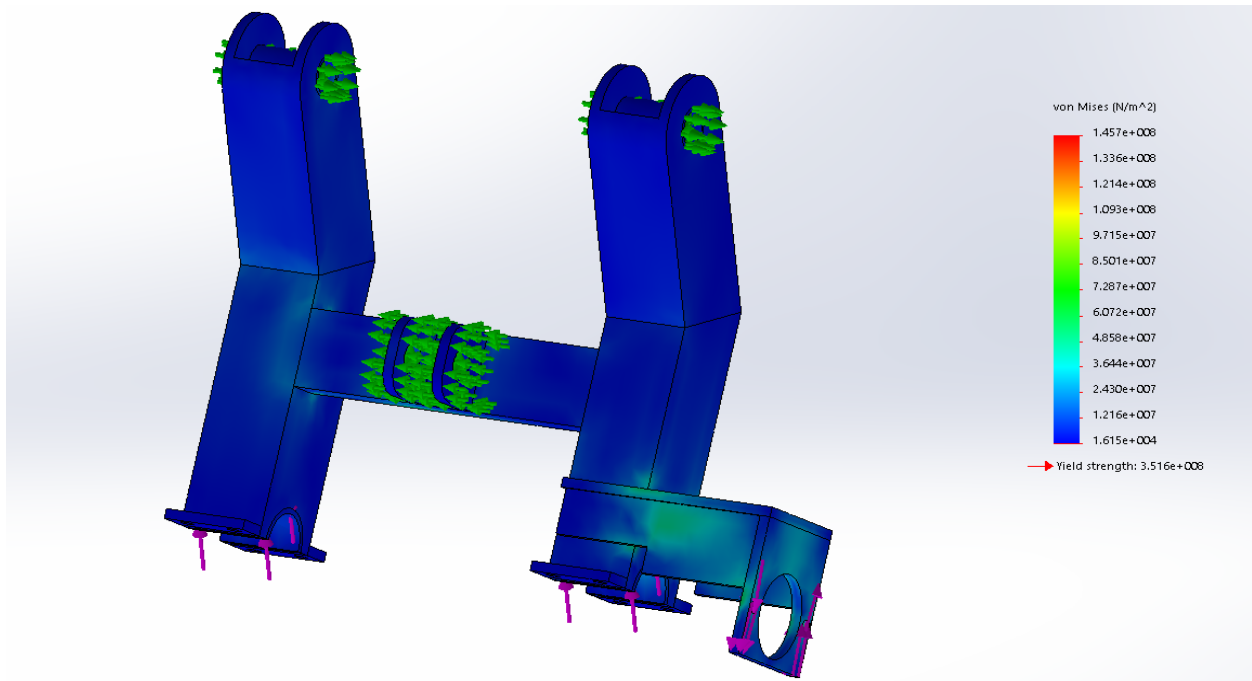


Figure 24. Side View of Drop arms

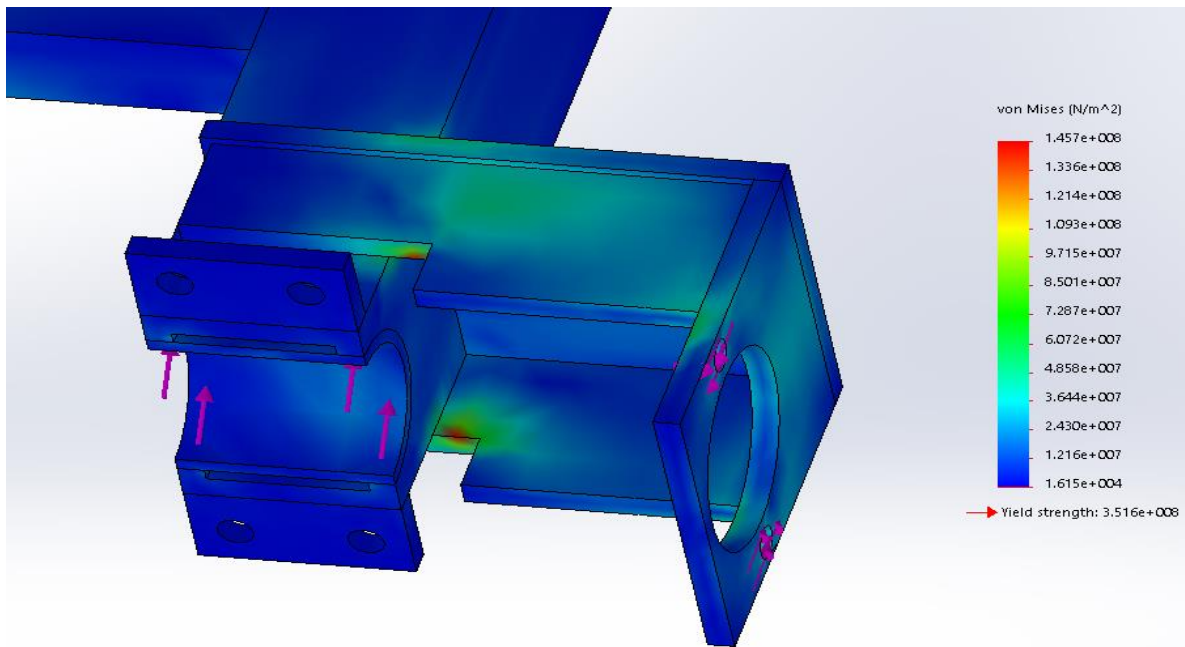


Figure 25. Bottom view of mounting brackets on side arms

Front Bottom

The Rod extended upward was treated as a hinge, and sliders were set on the top face of the rod, as well on the flat sides of the tire mount. A generous weight of 5000lbs was applied in the upward direction across the bolt holes of the tire mount. A side load of 2000lbs was applied to the wheel mount to simulate a moment that would be generated when the front is steering. These conditions gave a factor of safety of 1.49 with the weak point being the base where the swivel rod is bonded.

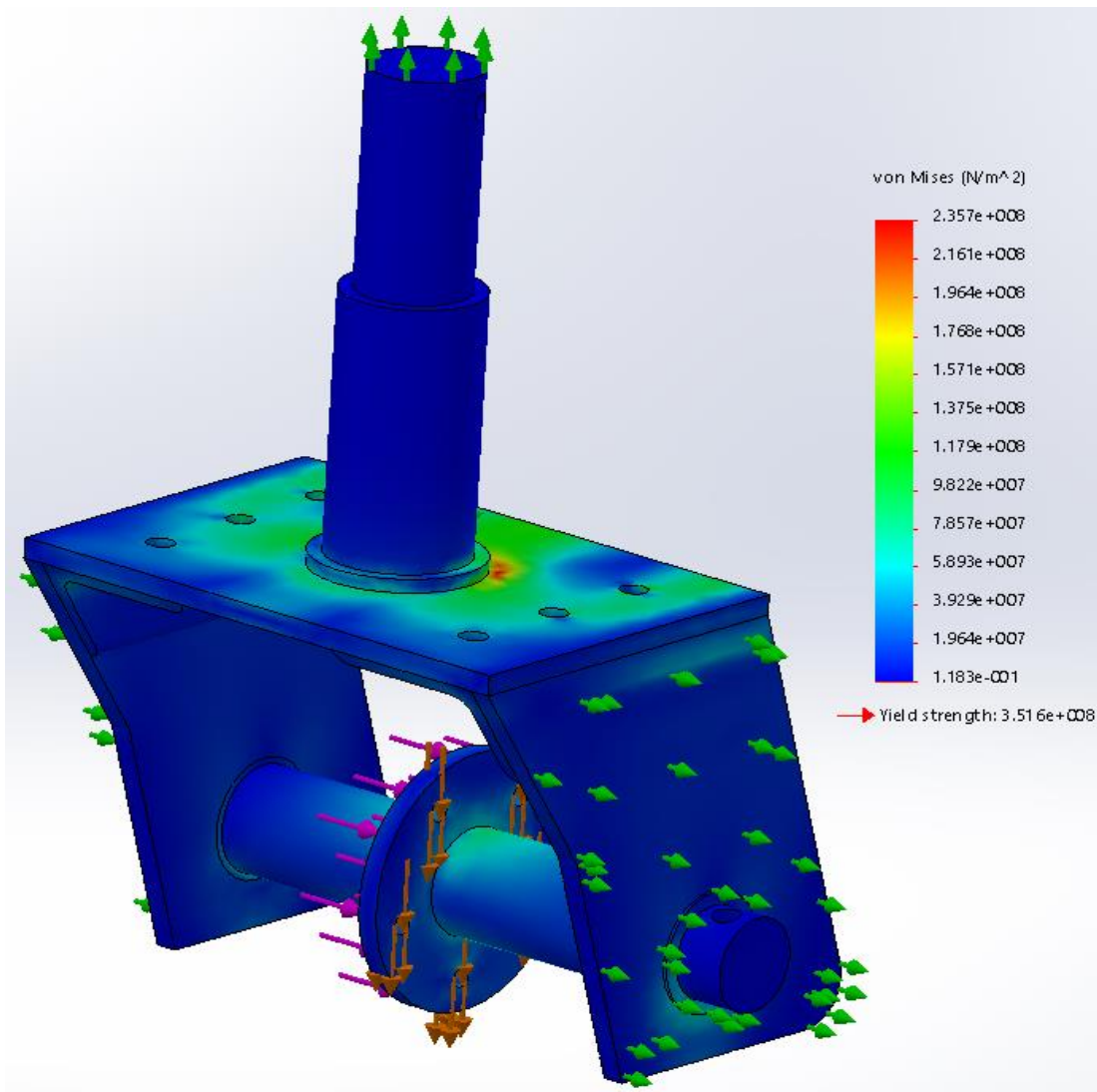


Figure 26. Front side axle view

Electrical Controls

The system controls for the trailer are operated by using the pneumatic levers existing on the trailer and an Axiomatic Quad Controller. The pneumatic levers on the trailer are used to raise and lower the front and rear lift axle. The Axiomatic Quad Controller pictured in Figure 27 is used to program the drive and steer the axles. In addition, the controller and connector pin output diagram can be seen in Figures 28-29.



Figure 27. Axiomatic Quad Controller



Figure 28. Prototype Trailer Controller

Connector Pinout

Grey Connector		Black Connector	
Pin #	Function	Pin #	Function
1	Power +	1	CANH
12	Power -	2	CANL
2	Proportional Solenoid 1 +	3	Analog Input 1/Digital Input 1 (Controls the digital output when using PWM control logic)
11	Proportional Solenoid 1 -	4	Analog Input 2/Digital Input 2 (Enable signal when using PWM control logic)
3	Proportional Solenoid 2 +	5	Analog Input 3/Digital Input 3
10	Proportional Solenoid 2 -	6	Analog Input 4/Digital Input 4
4	Proportional Solenoid 3 +	7	RS-232 Transmit
9	Proportional Solenoid 3 -	8	RS-232 Receive
5	Proportional Solenoid 4 +	9	Analog GND (could be used as RS-232 GND)
8	Proportional Solenoid 4 -	10	Analog +5V Reference
6	Digital Solenoid +	11	PWM Input 1/Digital Input 5 (Controls the digital output when using Analog Input control logic)
7	Digital Solenoid -	12	PWM Input 2/Digital Input 6 (Enable signal when using Analog Input control logic)

Note: An analog input can be configured for 0-5V, 0-10V, 0-20mA or 4-20mA input types

Connector to DB-9 Pinout (RS-232 Connection)

Black Deutsch Connector		DB-9 Female	
Pin #	Controller Function	Pin #	PC Function
7	RS-232 Transmit	2	RS-232 Receive
8	RS-232 Receive	3	RS-232 Transmit
9	GND	5	GND

Figure 29. Axiomatic Quad Controller Pins

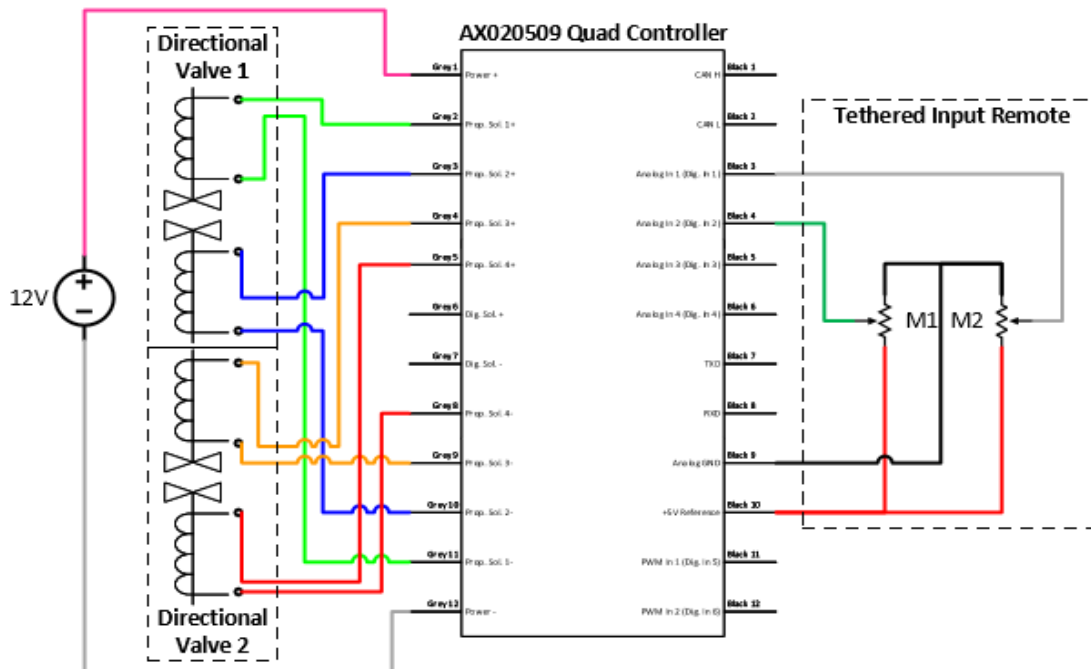


Figure 30. Circuit Diagram

Budget

The project was relatively inexpensive in terms of the BAE Departments budget. Ditch Witch supplied most of the parts from their shop. The client did not supply the team with a PO, so the parts were quoted at standard market price. As of now, the team has spent roughly \$1500. However, this does not include the hydraulic hoses or the fabrication materials such as: piping, steel, etc.

Final Design

The final design consists of two drop down lift axles. The front axle is designed with one press-on forklift tire and wheel and can be seen in Figure 31 and 33. The front axle will not have any functionality other than to help support the tongue weight. In addition, the front axle is equipped with a 2" bore 8' stroke hydraulic cylinder that can be controlled by the pneumatic levers. The hydraulic cylinder functions to engage and disengage the dropdown axle.

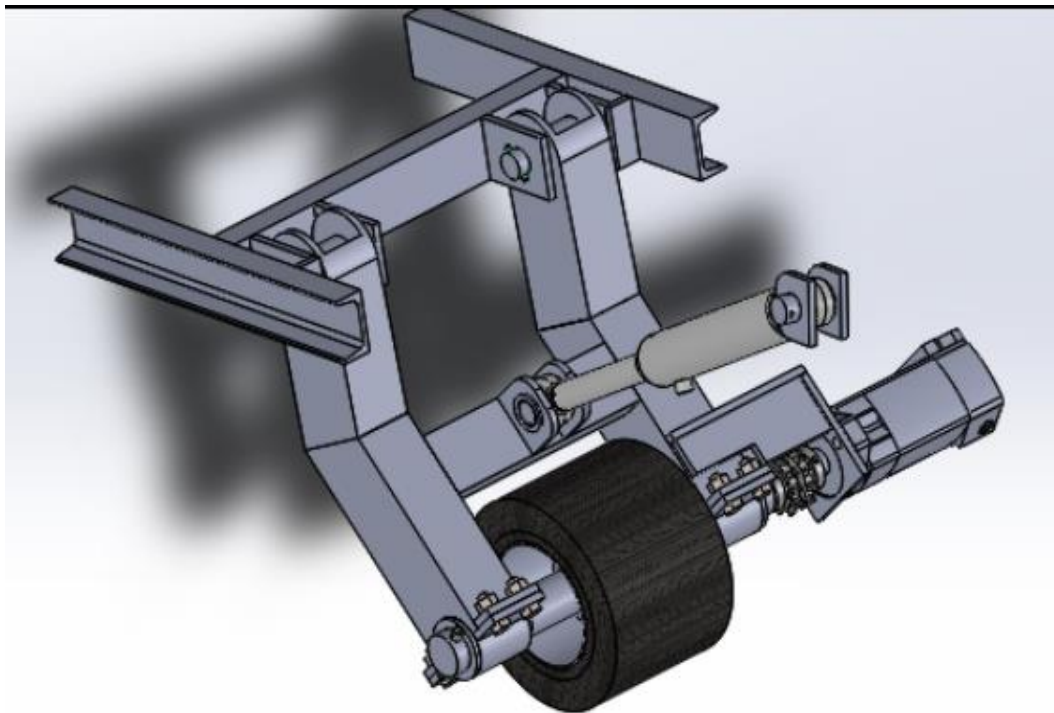


Figure 31. Front Axle



Figure 32. Front Axle Mount



Figure 33. Side View of Front Axle

The back axle consists of a split-axle with two electric motors used to drive and steer the trailer as seen in Figure 34 and 35.

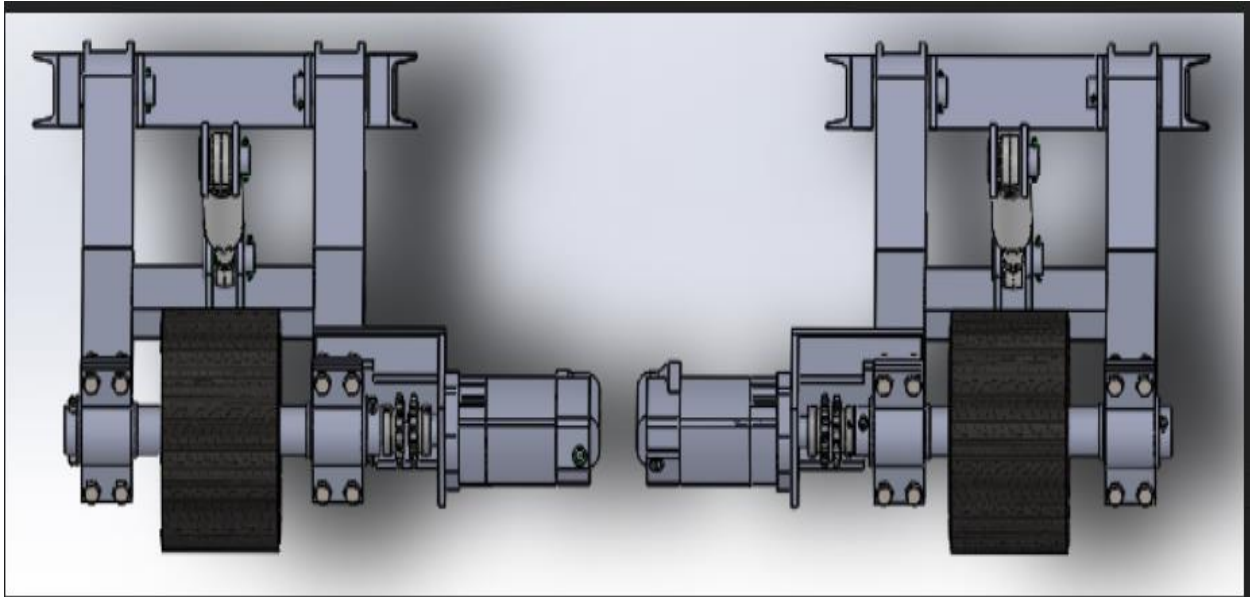


Figure 34. Back Split Axle



Figure 35. Back View of Back Axle



Figure 36. Close up of Back Axle



Figure 37. Front View of System Engaged

The rear axle is split to alleviate the friction and stresses that would come from using a solid axle. The idea of splitting the back axle and using two hydraulic motors in series was discussed in our fall design meeting with Ditch Witch. By doing so, it will enable the trailer to turn more efficiently because the motors are independent of one another and there will be less friction on the tires. In addition, the rear axle is equipped with 2 x 2" bore" 8' hydraulic cylinders that function to raise and lower the axle.

Testing/Experimentation

For our testing purposes, we looked at how fast our trailer could move, the surfaces it could operate on and collected the outputs from our Axiomatic Quad Controller when It was hooked up to the proportional valve.

Table 9. Velocity of System

Velocity		
	Trial 1	Trial 2
Time [s]	12.32	12.57
Distance [ft]	20	20
Velocity [ft/s]	1.62	1.59
Velocity [mph]	1.10	1.08
Average Velocity [mph]	1.09	

The team conducted two trials to effectively measure the average velocity. We measured out 20 feet using a tape measure and used a stop watch to measure the time taken. We conducted two trials to account for the variability within our data. Furthermore, the average velocity was 1.09 mph, which is within the range of our specified parameters by Charles Machine Works of 1 – 1 ¼ mph.

Table 10. Surfaces Tested

Surfaces Tested			
	Traction		Mobility
Asphalt	Yes		Yes
Gravel	Yes		Yes
Wet Ground	No		No

The parameters specified by Charles Machine Works only required that our system work on hard surfaces, but we tested the system on wet ground, too.

**Figure 38. System Testing on Concrete**

The system worked as intended on hard ground. The system can drive rather well backwards and forwards, but cannot make sharp turns. The system has a limited turning radius due to lack of power in the hydraulic motors and the tongue weight on the front axle.



Figure 39. System Testing on Wet Ground

As expected, the trailer did not work well on wet ground. The reason being is because the system cannot gain traction due to the solid rubber wheel. If we were to use a wheel with tread, it could possibly work.

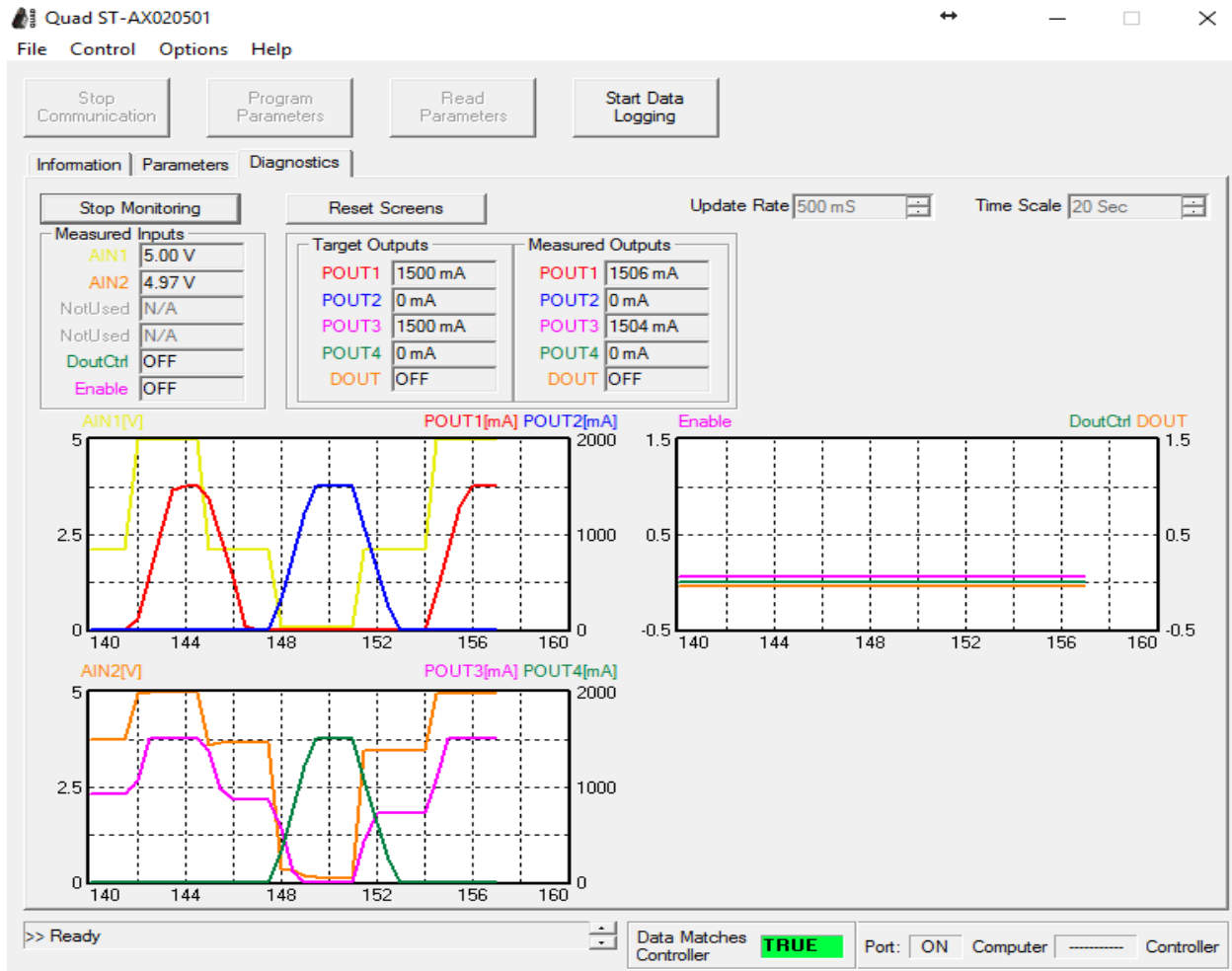


Figure 38. Axiomatic Controller Outputs

The axiomatic controller outputs were measured by hooking our controller to the proportional valve on the trailer and loading the software provided with the PLC. The yellow band is our left motor and at 2.5 volts the potentiometer is in the neutral position. When the yellow band reaches 5 volts, the potentiometer is in the full-forward position. Once the yellow band reaches 0 volts, the potentiometer is in the full-reverse position.

Alternative Design Considerations

A problem we encountered with the current design of the front of the trailer is that there is too much weight on the front tire. The front swivel wheel is structurally sound enough, but the tire compresses significantly under the weight of the trailer. This results in a very large relative contact area, which not only makes it difficult for the wheel to

swivel without forward momentum, but also generates a large moment on the swivel arm and mount. A design solution to this problem would be to build an additional swivel wheel to distribute the weight over two tires. This would require the existing swivel wheel to be relocated to the side edge of the trailer with the added wheel occupying the other side. An additional wheel may also allow the structure of the swivel wheel to be reduced, as well as the width of the tire. With less weight and width per tire, the contact area of the tire would be greatly reduced, allowing for less resistance to turning.

Summary

After conducting research over a variety of trailer tugs, it has been noted that there are advantages and disadvantages with each design. Also, the type of device used is dependent on the project at hand. As mentioned above, the objective of this project is the development of a system for Charles Machine that will enable the FX-30 vacuum excavator to move without the use of a standard motorized vehicle. The trailer the team are designing for is the FX-30 Vacuum Trailer. The final design can be its own stand-alone system or it can be integrated into the trailer's design. This system should be designed whereas when not in use, it can be stored and hauled on the vacuum trailer. Furthermore, by researching trailer caddies such as, the Haulle Tug (seen in Figure 5) and the MUV 4WD Electric Tug (seen in Figure 6). The team developed a sense of direction for their own project. Each trailer tug has its own advantages and disadvantages such as: operated via hydraulics, electric motor, multiple tires, wireless or tethered remote, etc. However, the team should consider which option will be practical and suitable for the client specifications. Some other possible alternatives for moving the trailer that were researched can be done by using hydraulic rams to move the trailer. The hydraulic rams would be mounted to the tires of the trailer like what are found on hydraulic locomotives. Also, the team would incorporate an axle lift to lighten the tongue weight, which would enable the trailer to be steered more easily. The team also conducted research over the safety parameters that must be considered throughout the design along with recommended safety checks for the FX-30 (as specified by Ditch Witch). As an engineer, one of the fundamental cannons is to ensure the well-being of the public.

Furthermore, after using the research and knowledge obtained from the project, the students developed a system to meet Ditch Witch's specifications. The final system consists of two dropdown lift axles. The front axle will not be used to steer or drive the trailer, but it will support the tongue weight. The rear axle will function as the drive and steering mechanism for the system. The rear axle is split to alleviate the friction that would come with using a solid axle. By doing so, it enables the trailer to steer and drive more efficiently.

After testing and experimenting with our design, we found the max speed the system can reach is 1.09 mph. As specified by our client, the range our system needed to be in was 1 – 1 ¼ mph. The system can effectively move and operate on hard surfaces such as: asphalt, concrete and gravel. However, it was unable to gain traction on wet ground, as expected. The system could be modified to operate on wet ground, but tires with tread would have to be used.

Furthermore, if we were to improve our design, the first thing to address would be the steering. As of now, there is too much weight on the front tire which restricts how well the trailer can turn. The front wheel can support the weight, but the tire compresses significantly under the weight of the trailer. This results in a large relative contact area, which makes it difficult for the wheel to swivel. In addition, it also generates a large moment on the swivel arm and mount. A proposed design solution would be to add an additional swivel wheel to distribute the weight over two tires. By doing so, it would enable the structure of the swivel wheel to be reduced, as well as the width of the tire. Another proposed design is to add two more hydraulic motors to the front axle. The proposed configuration would tie in the front hydraulics with the rear hydraulics essentially making it 4WD.

In conclusion, the Trot'n trailer senior design team were successful in creating a system that can be integrated onto the FX-30 Vacuum trailer. The design enables the FX-30 to drive in forward and reverse, but the steering needs a few adjustments. Nonetheless, the project was a success and it will now be further improved upon by Charles Machine Works.

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Work Breakdown Structure

WBS 1.0 Project Overview

Details the contents of the project and its purpose. Work is complete after meeting with the client and receiving the approval for the proposed solution.

WBS 1.1 – Introduction

Work with Charles Machine Works, Ditch Witch™ to develop a design that correlates to their problem statement. Task is complete once a general overview of what the client expects is completed.

WBS 1.2 – Problem Statement

Analyzing and interpreting the client's desires to ensure the project is developed to meet their needs. Task is complete once the problem statement is well defined.

WBS 1.3 – Customer Requirements

Communicate with the client to ensure that the final product produced meets their expectations. Task is complete after the client specifies what the intended product must do.

WBS 1.4 – Proposed Solution

Meet with Ditch Witch™ to discuss the design. Task is complete when the conceptual design is proposed to the client and an approval is given.

WBS 1.5 - Preliminary Design Concepts

The team developed several functional ideas that were being considered as a final solution for the problem statement.

WBS 1.6 - Fall Semester Design Concept

After testing, researching and meeting with the client, the team developed a functional solution for the problem.

WBS 2.0 Documentation and Procedures

Research relevant patents and documents that correlate to the design. Work is complete once all of the documentation and procedures have been sorted for relevance and organized accordingly in a word file.

WBS 2.1 Ditch Witch Trailer Research

Utilize Ditch Witch™'s website to find trailer specifications. Task is complete once the trailer specifications have been documented.

WBS 2.2 Patent Search

Find relevant patents that could potentially be utilized in the design. Task is complete after the patents are cited and documented.

WBS 2.3 Conceptual Drawings (Solidworks, Freehand)

Produce drawings for the trailer drive system. Task is complete when the drawings are finished.

WBS 3.0 Client Approval

Meet with the client and discuss the proposed system for the trailer. Work is complete once the client approves the design.

WBS 3.1 Client Design Review (Fall Semester)

Discuss the system with the client by way of drawings, calculations, documentation. Task is complete once the client approves of the proposed concept.

WBS 3.2 Client Design Review (Spring Semester)

After presenting the fall design concept, the team were instructed to further improve on the design and present the final functional prototype May 4th.

WBS 4.0 Fabrication of Lift Axle

Fabricate and install the Lift Axle onto the FX-30 Trailer. Work is complete once the lift axle has been fabricated and mounted to the trailer.

WBS 4.1 Materials Required for Production

Gather materials needed to begin fabricating the system. Task is complete once all the parts for the design have been collected.

WBS 4.2 Order Parts

The parts were ordered through the client, Ditch Witch, McMaster and Carr and through the BAE shop.

WBS 4.3 Fabrication

Talk with Ditch Witch™ and the BAE lab to begin fabricating parts needed to complete the system. Task is complete once all the parts needed have been produced.

WBS 4.4 Install Lift Axle

Work with Ditch Witch™ to install the lift axle onto the FX-30 Trailer. Task is complete once the lift axle is mounted to the trailer.

WBS 5.0 Integration of Remote Control (Spring Semester)

Install and mount the control modules onto the Lift Axle. Work is complete once the system is fully functional.

WBS 5.1 Install Control Modules

Install control modules onto the wheel hubs and wire in the components. Task is complete once the control modules are fully functional.

WBS 5.2 Analyze Diagnostics

Install any remaining components that may be necessary for the system to steer, drive and brake. Task is complete once the trailer is able to steer, drive and brake.

WBS 5.3 Functional Check of Controls

Perform checks on all the systems on the trailer to ensure they are working properly. Task is complete once the systems have been verified to be working.

WBS 6.0 Testing and Performance Evaluation

Test the overall performance and functionality of the final design.

WBS 6.1 Test Pneumatic Levers

Test the existing pneumatic levers on the trailer and their functionality. The levers must raise and lower the front and rear axles.

WBS 6.2 Test Axiomatic Controller

Test the Axiomatic Controller to ensure that it is able to steer, drive and engage the trailer brakes.

WBS 6.3 Testing Overall Design

The system must be able to move the trailer up to 1 mph on pavement. In addition, the trailer may be tested on our types of roads to test for functionality

Patent Searches

Compact Multipurpose Trailer Tug (Patent # US 6758291 B1, July 6, 2004).

This patent was chosen because the said device attaches to the tongue of the trailer and can pivot due to two hydrostatic motors like a skid steer.

In addition, a model of the design can be seen in Figures 8 and 9. See Appendix i. for patent claims.

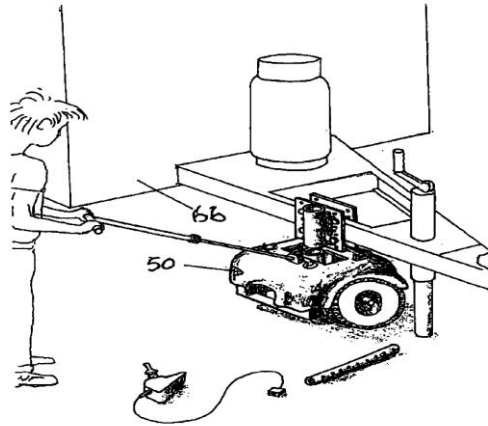


Figure 1. Trailer Tug apparatus.

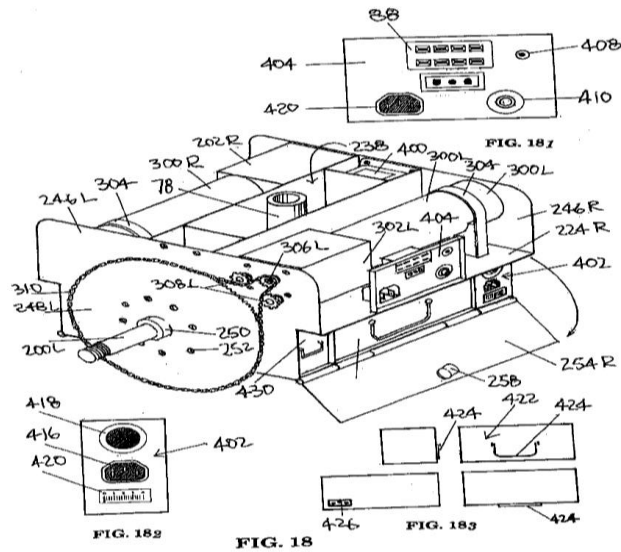


Figure 2. Tug/Remote Specifications

- i. Compact Multipurpose Trailer
 - a. At least on battery on said chassis.
 - b. At least one direct current motor.
 - c. A control device coupled with said drive train for selectively controlling rotation of said wheels whereby said tug may be positioned under said tongue.

- d. Battery powered steerable tug apparatus for carrying a cantilevered tongue of a towable vehicle and comprising.

Tugbot (Patent # US 20120215393 A1, August, 23rd, 2012).

This invention is a similar concept to that of our own, and it also utilizes a remote control for steering the device. The claims described by the patent are as described in Table 5. The design specifications for the Tugbot can be seen in Figures 10-11. See Appendix ii. for patent claims.

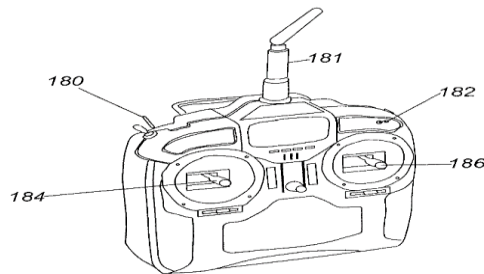


Figure 3. Tugbot Remote Control.

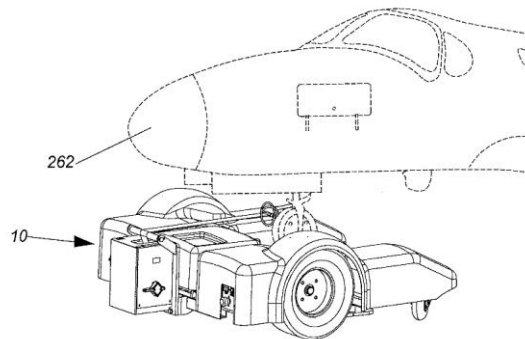


Figure 4. Tugbot Design

- ii. Tugbot
- a. A first wheel drive system assembly adapted to provide the towing device movement.
 - b. A second wheel drive system assembly to provide the towing device movement.

- c. Where in said towing device is adapted to provide a non-manned device for moving said transportation vehicle or other moving vehicle.
- d. A chassis constructed and arranged to support one or more internal and/or external components of a non-manned towing device for towing a transportation or other moving vehicle.

Drive Unit for Trailers and Caravans (Patent # US 20090308667 A1, December 17th, 2009).

This tug is operated entirely via electric power and is equipped with a remote control. In addition, the team is considering using tracks instead of tires, but this is yet to be determined. The following claims provided in Table 6 correlate to the teams' design that is under speculation and the design of the tug cited can be seen in Figures 12-13. See Appendix iii. for patent claims.

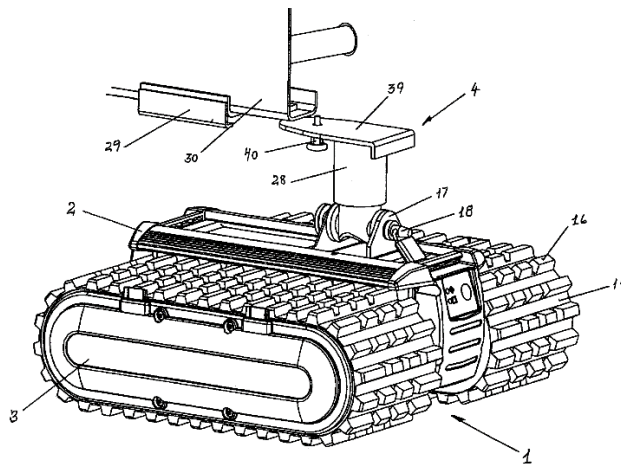


Figure 5. Drive Unit

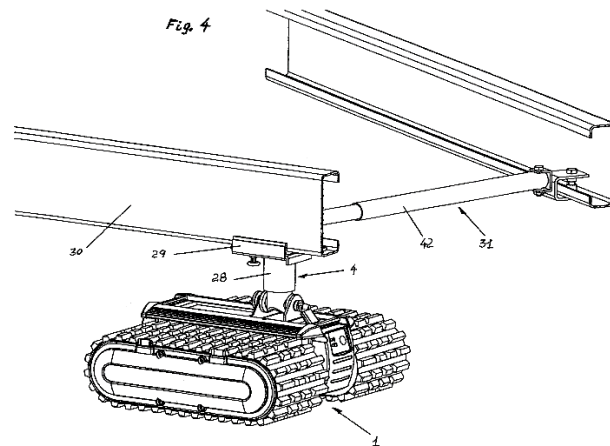


Figure 6. Drive Unit Attachment Assembly

- iii. Drive Unit for Trailers and Caravans
 - a. A motorized, maneuverable drive unit having crawler sections with crawler belts, said drive unit being adapted to be mounted on a hitch triangle of trailers.
 - b. The drive unit also comprises an energy supply and mean for steering and maneuvering the drive unit.
 - c. The steering and control means comprise a wireless as well as a non-wireless connection between the motor control system and a remote control unit.
 - d. A drive unit characterized in that the chassis additionally comprises an enclosure for a battery, a charging circuit for the battery, an electrical motor control and an electrical communications circuit for wireless control of the drive unit.
 - e. The motor control circuit is provided with a soft start function and is adapted to control at least two motors individually and to cooperate with the communications control.

Wheelchair drive system with ratchet and wheel lock (Patent # US 5743544 A, April 28th, 1998)

This invention utilizes a ratchet driven wheel that propels the wheel chair. This could be applied to a trailer by adding a hydraulic piston mounted on the trailer frame to engage the ratchet assembly mounted on either an axle or on a wheel. See Appendix iv. for patent claims.

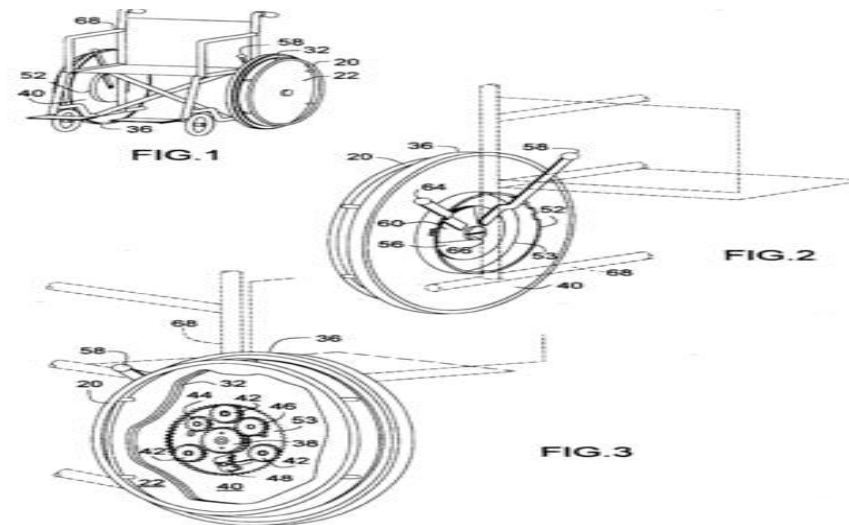


Figure 7. Wheelchair Drive System

- iv. Wheelchair Drive System
 - a. An axle, defining the axis around which the hub-and-wheel assembly rotates.
 - b. A drive wheel assembly, including a drive wheel, an internal gear, and a tire, said internal gear being supported by a plurality of circumferentially spaced supporting gears.
 - c. A driver, supported on said axle and rigidly connected to a hand ring, forming a driver assembly which is rotatable forward or rearward by manually rotating said hand ring.

- d. A drive engagement gear between said driver and said drive wheel assembly.

Axle Lift (Patent # US 3096995 A, July 9th, 1963).

Upon meeting with the client for a second time, the client specified that they would like our design to be integrated onto the trailer and do not want a trailer caddy. Therefore, the axle lift was a feasible idea because it can be engaged and disengaged as needed. See Appendix v. for patent claims.

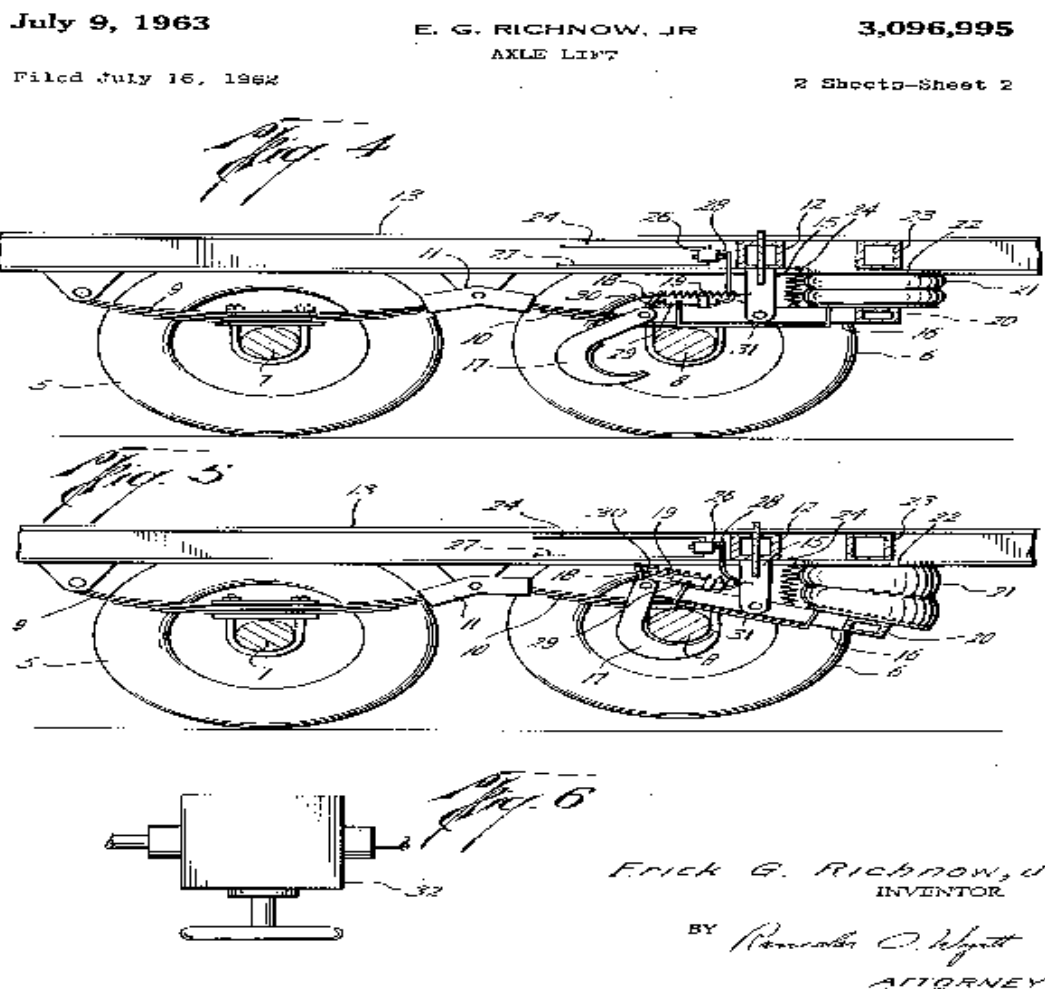


Figure 8. Axle Lift

- v. Axle Lift
- a. It is an object of this invention to provide a device for lifting one axle of a tractor or trailer free of the road surface when the vehicle is traveling empty.
 - b. It is another object of the invention to provide an axle lift having novel means for engaging an axle to be lifted and the controlled raising and lowering of the axle.
 - c. It is another object of the invention to provide means for lifting an axle on a tractor or trailer and shifting the weight distribution of the vehicle to provide less tire wear and easier steering of the vehicle.
 - d. It is another object of the invention to provide an axle lift for lifting an axle of a tandem trailer to provide less tire wear and greater traveling stability of the vehicle.

After performing a patent search, the team could get an idea of how the design could be built. The design needs to include a remote control like the tugbot. In addition, the design should also include an axle lift, which would make engaging and disengaging the design easy for the client. However, throughout the design phase, all of the relevant patents may be considered as a feasible addition to the trot'n trailers design.

Methodology

Drive Wheel Motor Torque Calculations

i. Total tractive effort

$$a.TTE [lb] = RR [lb] + GR [lb] + FA [lb] \quad (Eq. 1)$$

TTE = total tractive effort [lb]

RR = force necessary to overcome rolling resistance [lb]

GR = force required to climb a grade [lb]

FA = force required to accelerate to a final velocity [lb]

ii. Rolling Resistance

$$a. \text{RR [lb]} = \text{GVW [lb]} \times C \quad (\text{Eq. 2})$$

RR = rolling resistance [lb]

GVW = gross vehicle weight [lb]

C = surface friction

iii. Grade Resistance

$$a. \text{GR [lb]} = \text{GVW [lb]} \times \sin(\alpha)$$

GR = grade resistance [lb]

GVW = gross vehicle weight [lb]

α = maximum incline angle [degrees]

iv. Acceleration Force

$$a. \text{FA [lb]} = \text{GVW [lb]} \times V_{\max} \text{ [ft/s]} / (32.2 \text{ [ft/s}^2\text{]} \times t_a \text{ [s]})$$

FA = acceleration force [lb]

GVW = gross vehicle weight [lb]

V_{\max} = maximum speed [ft/s]

t_a = time required to achieve maximum speed [s]

v. Total Tractive Effort

$$a. \text{TTE [lb]} = \text{RR [lb]} + \text{GR [lb]} + \text{FA [lb]}$$

TTE = sum of forces in: ii+iii+iv

vi. Wheel Motor Torque

$$a. T_w \text{ [lb-in]} = TTE \text{ [lb]} \times R_w \text{ [in]} \times RF \text{ [-]}$$

T_w = wheel torque [lb-in]

TTE = total tractive effort [lb]

R_w = radius of the wheel/tire [in]

RF = resistance factor [-]

vii. Reality Check

$$a. MTT = W_w \text{ [lb]} \times \mu \text{ [-]} \times R_w$$

W_w = weight (normal load) on drive wheel [lb]

μ = friction coefficient between the wheel and the ground

R_w = radius of the drive wheel/tire [in]

Freshman Involvement

For the Charles Machine Works project, the team was assigned two freshman teams to include in the design.

Team #1 – Tires or Tracks:

- 1) Determine the pros and cons associated with tires and tracks.
- 2) Size of tires or tracks needed to carry the load.
- 3) Cost of tires or tracks.

Team #2 – Remote Control System:

- 1) Tethered Remote vs. Wireless Remote

2) Control System Parameters

- a. Engaged and Disengage dropdown lift axles.
- b. Steering and Drive.

Parts List

The parts used to fabricate the design can be seen in Tables # 9-13.

Table 1. Parts Obtained From Ditch Witch

Parts From Ditch Witch					
Quantity	Part	Supplier	Price	Total	Status
3	Hydraulic Cylinders (2" bore, 8' stroke, 1.25" rod)	Ditch Witch	\$ 56.00	\$ 112.00	Received
2	Hydraulic motor (2000 series)	Ditch Witch	\$ 440.00	\$ 880.00	Received
3	Press-on Forklift Tires	Ditch Witch	\$ 40.00	\$ 120.00	Received
3	Press on wheels	Ditch Witch	N/A		Received
1	Tapered Roller Bearing	Ditch Witch	\$ 30.00	\$ 30.00	Received
5	Bushing GGB (2" ID x 2.5" OD x 3" Length)	Traceparts.com	N/A		Received
4	Bushing GGB (2" ID x 2.5" OD x 1.5" Length)	Traceparts.com	N/A		Received
2	Bushing GGB (1.75" ID x 2.25" OD x 7/16" Length)	Traceparts.com	N/A		Received
1'	1.25" Solid Round Bar	Ditch Witch	N/A		Received
8'	2" Solid Round Bar	Ditch Witch	N/A		Received
1'	3" Solid Round Bar	Ditch Witch	N/A		Received
1'	5/16" Key Stock	Ditch Witch	N/A		Received
2' x 2'	3/8" Flat Steel	Ditch Witch	N/A		Received
			Total	\$1,142.00	

Table 2. BAE Shop Materials

BAE Shop Materials					
Quantity	Part	Supplier	Price	Total	Status
16'	3 x 5.0 Lb Channel	BAE Shop	N/A		Received
2'	1.25" Sch. 40 pipe	BAE Shop	N/A		Received
2'	2" Sch. 40 pipe	BAE Shop	N/A		Received
3'	2.5" Sch. 40 pipe	BAE Shop	N/A		Received
1'	4" Sch. 40 pipe	BAE Shop	N/A		Received
2'	3" x 2" x 1/4" Angle	BAE Shop	N/A		Received
10'	4" x 3" x 3/8" Rect. Tubing	BAE Shop	N/A		Received
1'	1/8" x 3" Flat Bar	BAE Shop	N/A		Received

Table 3. McMaster-Carr Parts

Parts From McMaster-carr					
	Part	Supplier	Price	Total	Status
8	Rollpin 1/4" Dia. X 1 3/4" Length	Mcmaster-Carr	\$ 4.00	\$ 4.00	Received
4	Rollpin 1/4" Dia. X 1 3/8" Length	Mcmaster-Carr	\$ 4.00	\$ 4.00	Received
4	Rollpin 1/2" Dia. X 2 3/4" Length	Mcmaster-Carr	\$ 4.00	\$ 4.00	Received
1	Rollpin 1/2" Dia. X 3" Length	Mcmaster-Carr	\$ 4.00	\$ 4.00	Received
4	Sprockets 1.25" Bore, 11 tooth, 3/4" Pitch	Mcmaster-Carr	\$ 19.70	\$ 78.80	Received
16	Grade 8 Hex Bolts 1/2" x 13 x 2"	Mcmaster-Carr	\$ 5.00	\$ 5.00	Received
6	Grade 8 Hex Bolts 1/2" x 13 x 1.25"	Mcmaster-Carr	\$ 5.00	\$ 5.00	Received
44	1/2" Flat Washers	Mcmaster-Carr	\$ 5.00	\$ 5.00	Received
22	1/2" Nylon locknuts	Mcmaster-Carr	\$ 5.00	\$ 5.00	Received
2'	No. 60-2 chain 3/4" pitch	Mcmaster-Carr	\$ 36.60	\$ 36.60	Received
2	NO. 60-2 chain Connecting Link	Mcmaster-Carr	\$ 3.24	\$ 3.24	Received
			Total	\$ 154.64	

Table 4. Controller Parts

Electronic Controller					
Quantity	Part	Supplier	Price	Total	Status
4	DEUTSCH DT06-2S Work Lamp hayness 11.5" 16GA Leads	Waytek	\$ 5.96	\$ 23.84	Received
2	Potentiometer	Dr. Wang	\$ 4.00	\$ 8.00	Received
1	Axiomatic Quad Controller	Ditch Witch	TBD		Received

Table 5. Hydraulic Parts

Hydraulics						
Quantity	Fittings	Supplier	Price/unit	Total	Status	
6	JIC 4M x SAE 4M SWIVEL 90 ELBOW	Surplus Center	\$ 1.95	\$ 11.70	Received	
10	JIC 8M x SAE 8M SWIVEL 90 ELBOW	Surplus Center	\$ 2.10	\$ 21.00	Received	
15	JIC 8M x SAE 8M CONNECTOR	Surplus Center	\$ 1.55	\$ 23.25	Received	
5	JIC 8M x SAE 10M 90 ELBOW	Surplus Center	\$ 4.45	\$ 22.25	Received	
5	JIC 8M x SAE 10M CONNECTOR	Surplus Center	\$ 2.35	\$ 11.75	Received	
3	JIC 6M x SAE 6M SWIVEL 90 ELBOW	Surplus Center	\$ 2.20	\$ 6.60	Received	
3	JIC 8M x SAE 10M 90 ELBOW	Surplus Center	\$ 4.45	\$ 13.35	Received	
6	JIC 8M x JIC 8M x JIC 8M UNION TEE	Surplus Center	\$ 2.65	\$ 15.90	Received	
5	SAE 10 PLUG	Surplus Center	\$ 1.30	\$ 6.50	Received	
10	SAE 8 PLUG	Surplus Center	\$ 0.95	\$ 9.50	Received	
10	SAE 6 PLUG	Surplus Center	\$ 0.75	\$ 7.50	Received	
10	SAE 4 PLUG	Surplus Center	\$ 0.55	\$ 5.50	Received	
6	JIC 6 CAP	Surplus Center	\$ 0.70	\$ 4.20	Received	
6	JIC 8 CAP	Surplus Center	\$ 0.90	\$ 5.40	Received	
				Total	\$ 164.40	
Quantity	Hose ID#	End Fittings	Length	Status		
3	1,3,13	4 JIC - 8 JIC	24"	Received		
2	2,4	4 JIC - 8 JIC	33.5"	Received		
1	14	4 JIC - 8 JIC	30"	Received		
2	15,16	6 JIC - 8 JIC	25"	Received		
4	5,6,7,8	8 JIC - 8 JIC (90 Swivel)	24"	Received		
4	21,22,23,24	8 JIC - 8 JIC	60"	Received		
4	17,18,19,20	8 JIC - 8 JIC	66"	Received		
1	PB port to porp. Valve	8 JIC - 8 JIC	24"	Received		
2	Return 1,2	8 JIC - 8 JIC	18"	Received		
1	Main Return	8 JIC - 3/4 in. Face seal Female End	84"	Received		

Rear Axle Solidworks Part Drawings

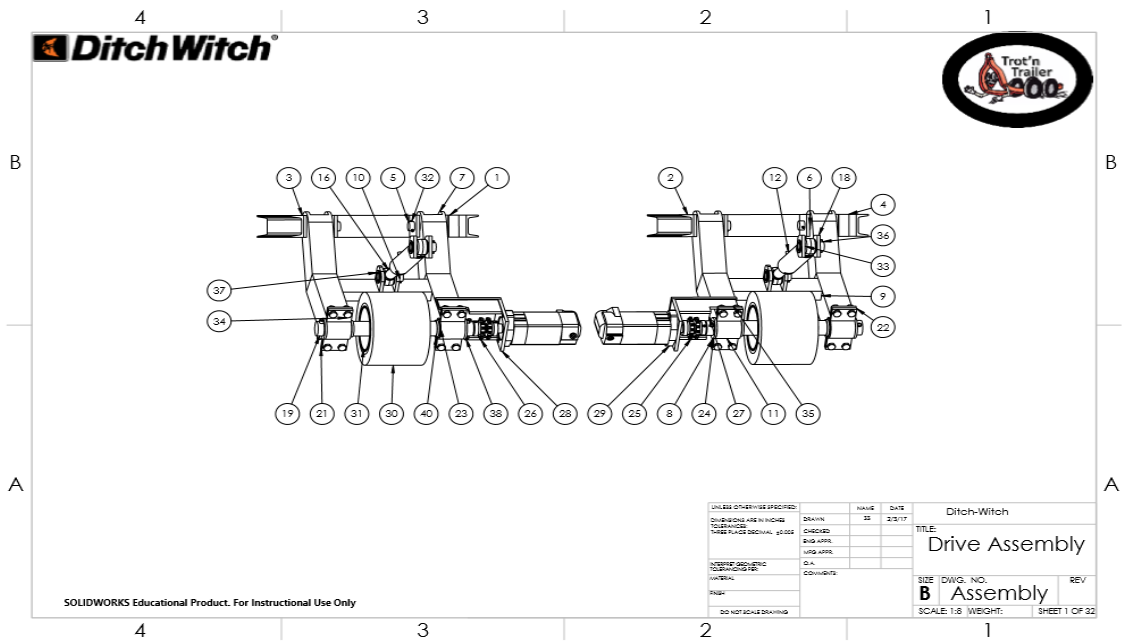


Figure 9. Rear Axle Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Part # 2 Trailer Cross member support middle (2)		2
2	Part # 1 Trailer Cross member support (Side) (4)		4
3	Part # 3 Cross member support lift Mount (8)		8
4	Part # 4 Cross member support lift Mount Brace (4)		4
5	Part # 5 lift Mount pins (4)		4
6	Part # 6 Upper Lift arm pin Support (4)		4
7	Part # 7 Upper support Lift arm (4)		4
8	Part # 8 Lower support Lift arm (4)		4
9	Part # 9 Rear lift arm Brace (2)		2
10	Part # 12 lift arm cylinder Mount (1)		4
11	Part # 16 Axle Support (8)		8
12	Store part #1 Hydraulic Cylinder 1		2
13	Store part #1 Hydraulic Cylinder 2		2
14	Store part #1 Hydraulic Cylinder 3		2
15	Store part #1 Hydraulic Cylinder 4		2
16	Store part #1 Hydraulic Cylinder 5		2
17	Store part #1 Hydraulic Cylinder 6		2
18	Part # 18 Rear Trailer Cylinder Mounting Bracket		4
19	Part # 19 Rear Drive Axle (2)		2
20	Part # 20 Wheel hub		2
21	Part # 10 Top Axle Mounting Bracket (8)		8
22	Part # 11 Bottom Axle Mounting Bracket (8)		8
23	Store Part # 2 3" Bushing		4
24	Part # 21 Axle Stay		4
25	6280K13P		4
26	Part # 13 Hydraulic Motor Mount side (4)		4
27	Part # 14 Hydraulic Motor Mount Top (2)		2
28	Part # 15 Hydraulic Motor Mount Face (2)		2
29	Store Part # 4 Hydraulic Motor		2
30	Store Part # 5 Press on Tire (3)		2
31	Part # 22 outer wheel		2
32	P237SA379		12
33	Store Part # 6 bushing for cylinder		4
34	HHSBOLT 0.5000-13X1.5X1-N		17
35	HHNUT 0.5000-13-8-N		16
36	Part # 23 cylinder pin		4
37	Part # 23 cylinder pin washer		4
38	P237SA483		4
39	Part # 24 inner wheel		2
40	Part # 25 Axle Stay inner		4

UNLESS OTHERWISE SPECIFIED:	NAME	DATE	Ditch-Witch
DIMENSIONS ARE IN INCHES	SKN	11	2/17
TOLERANCES:	CHECKED		
FRACTIONS DECIMAL .0005	ENG APPR.		
	LOG APPR.		
INTERFERING TO DIMENSIONS:	D.A.		
UNLESS OTHERWISE SPECIFIED:	DATE		
SCALE: 1:8	WEIGHT:		

TITLE:	Drive Assembly
SIZE	DWG. NO.
B	BOM Rear Drive
SCALE: 1:8	WEIGHT:
	SHEET 2 OF 32

Figure 10. Part Diagram

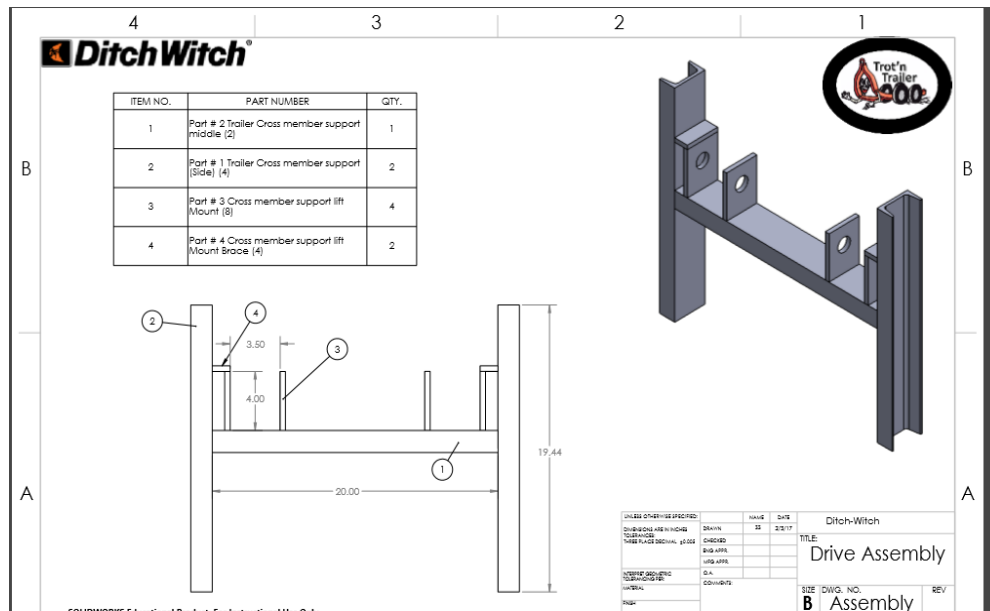


Figure 11. Crossmember

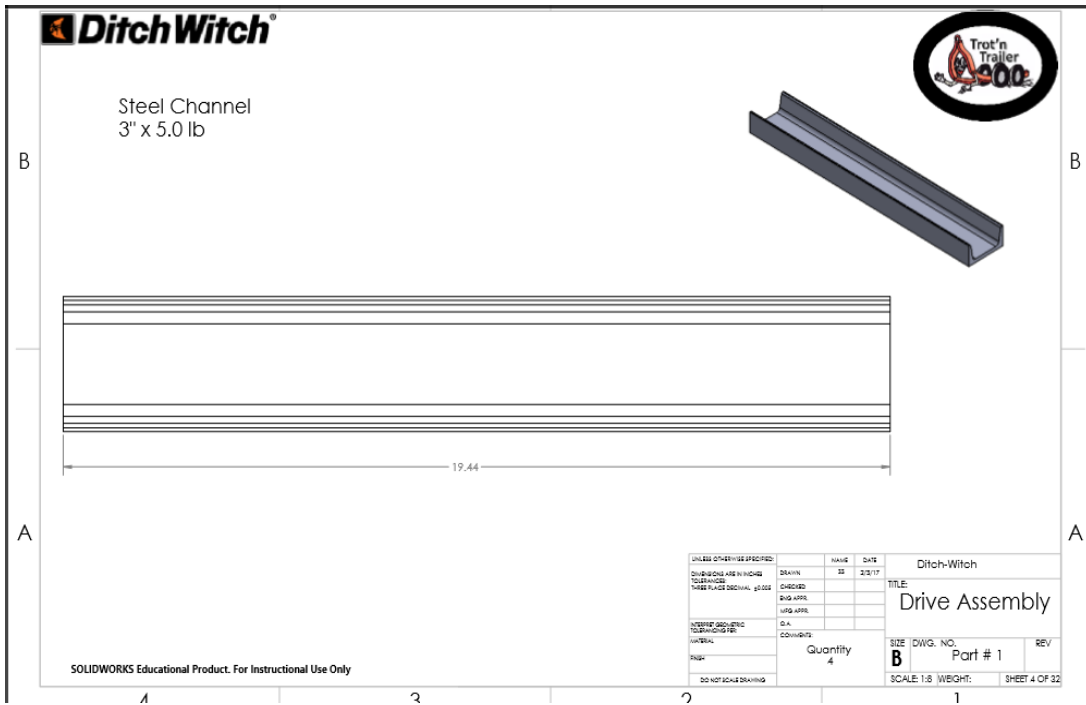


Figure 12. Part # 1

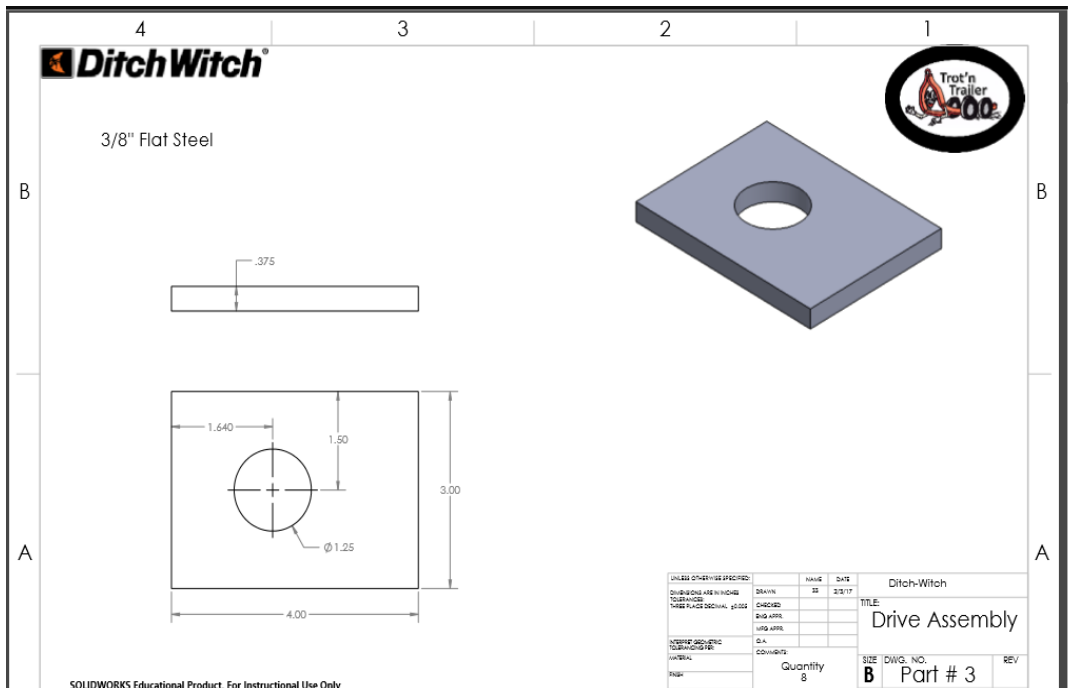


Figure 13. Part # 3

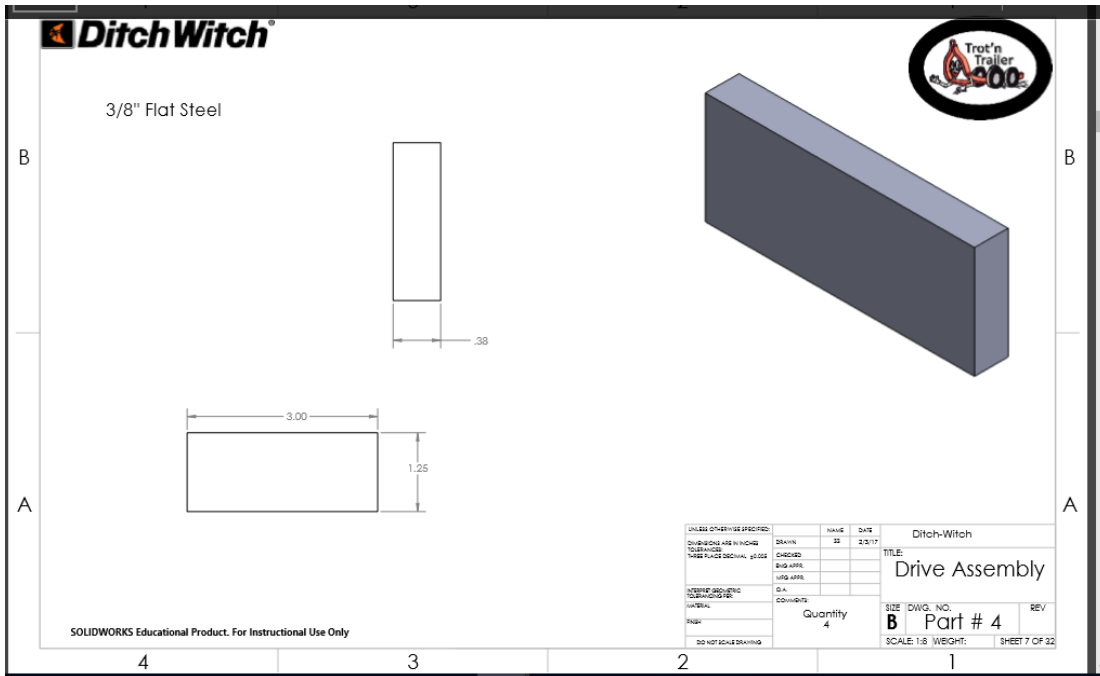


Figure 14. Part # 4

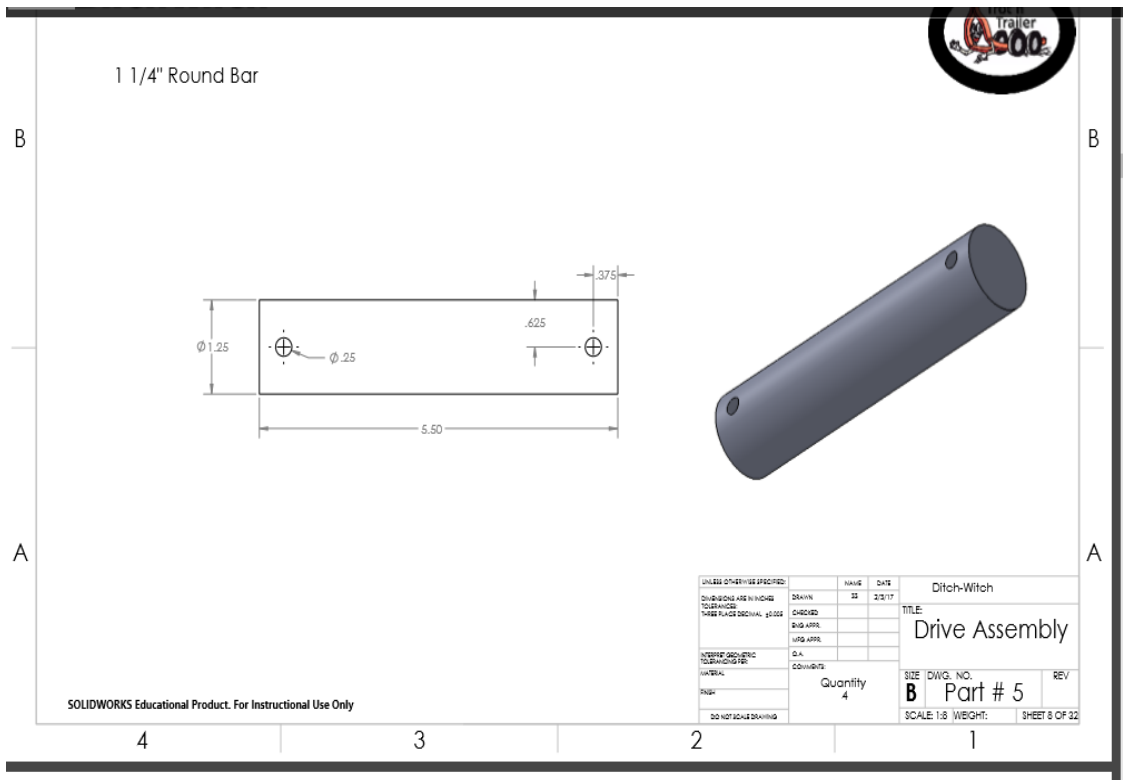
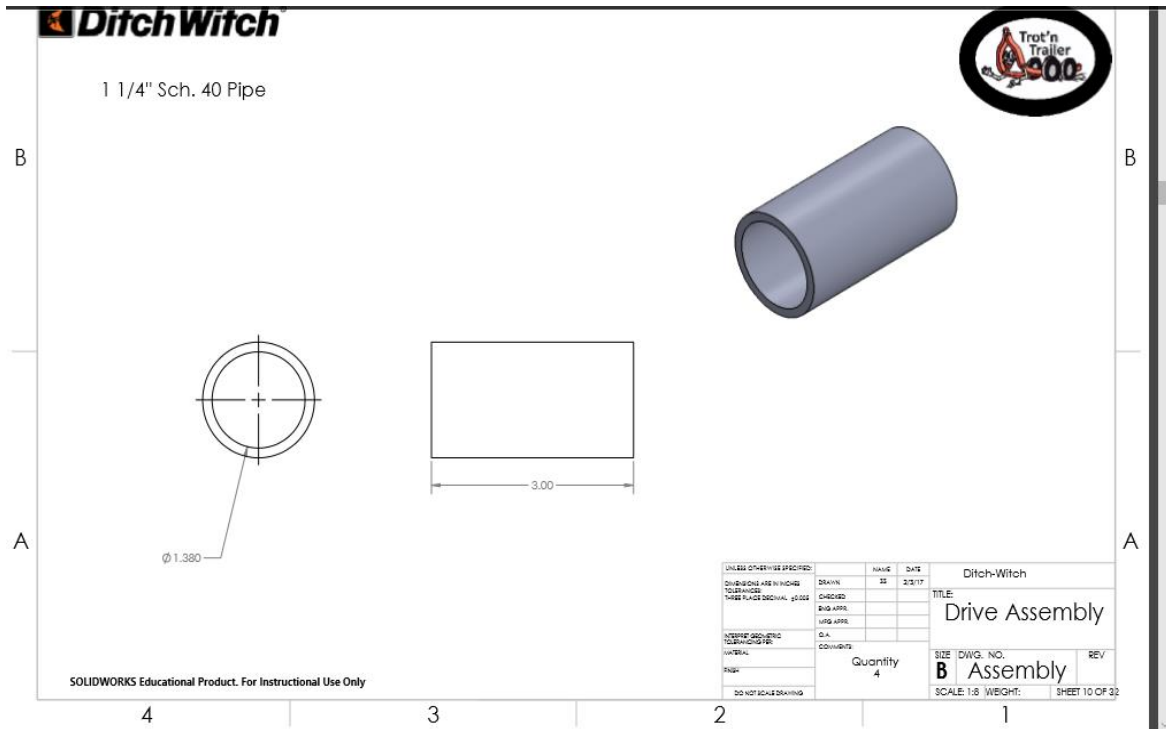
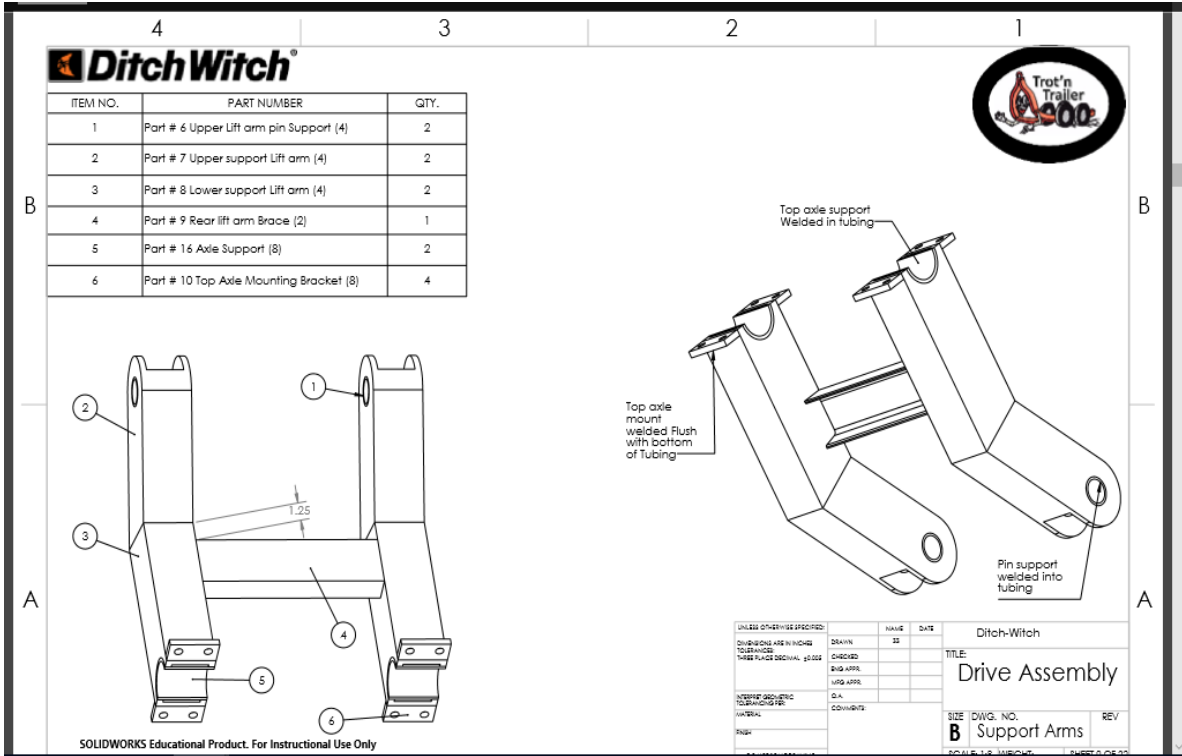


Figure 15. Part # 5



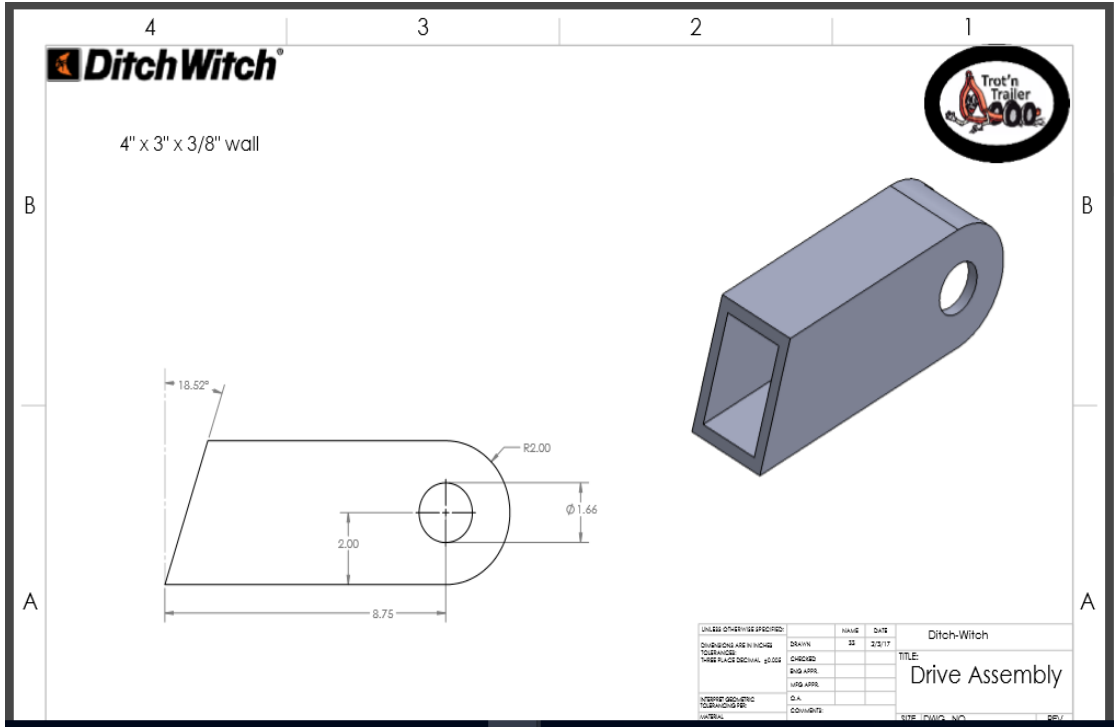


Figure 18. 4" x 3" x 3/8" Wall 1

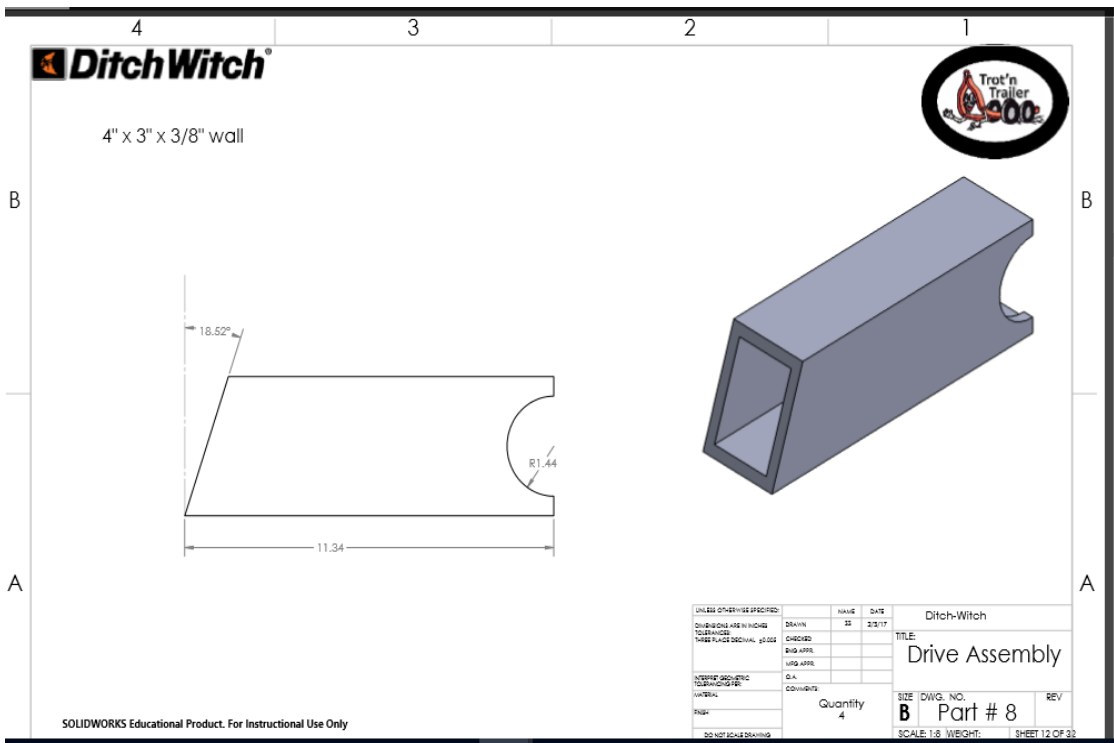


Figure 19. Part #8

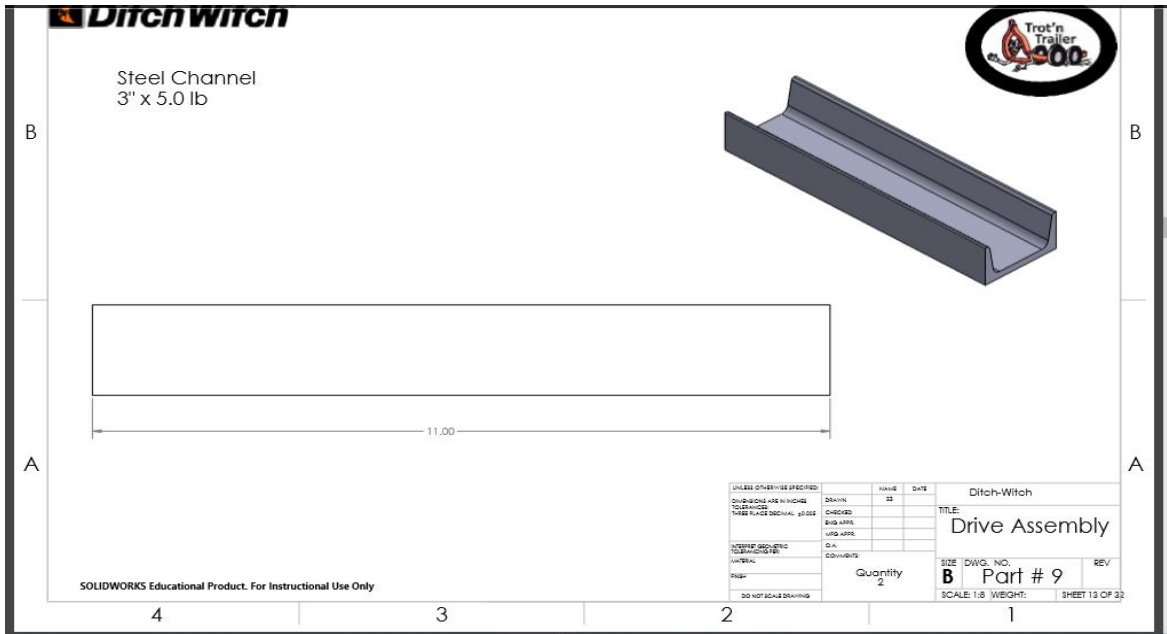


Figure 20. Part # 9

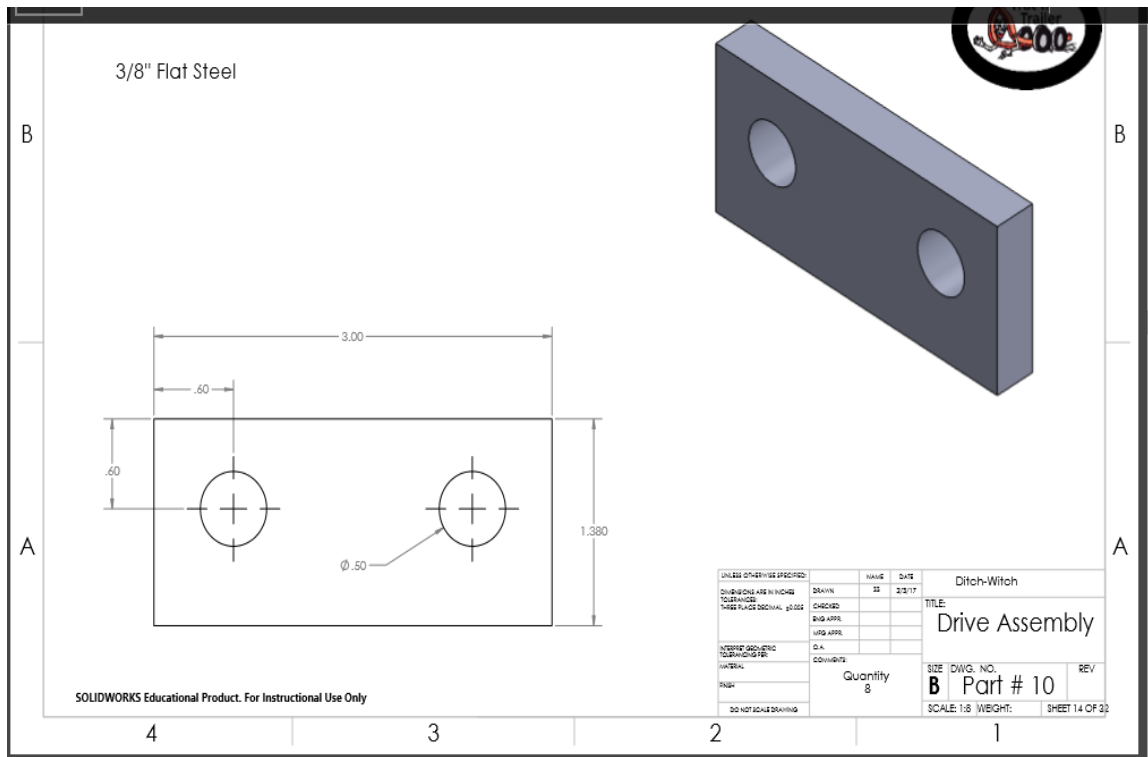


Figure 21. Part # 10

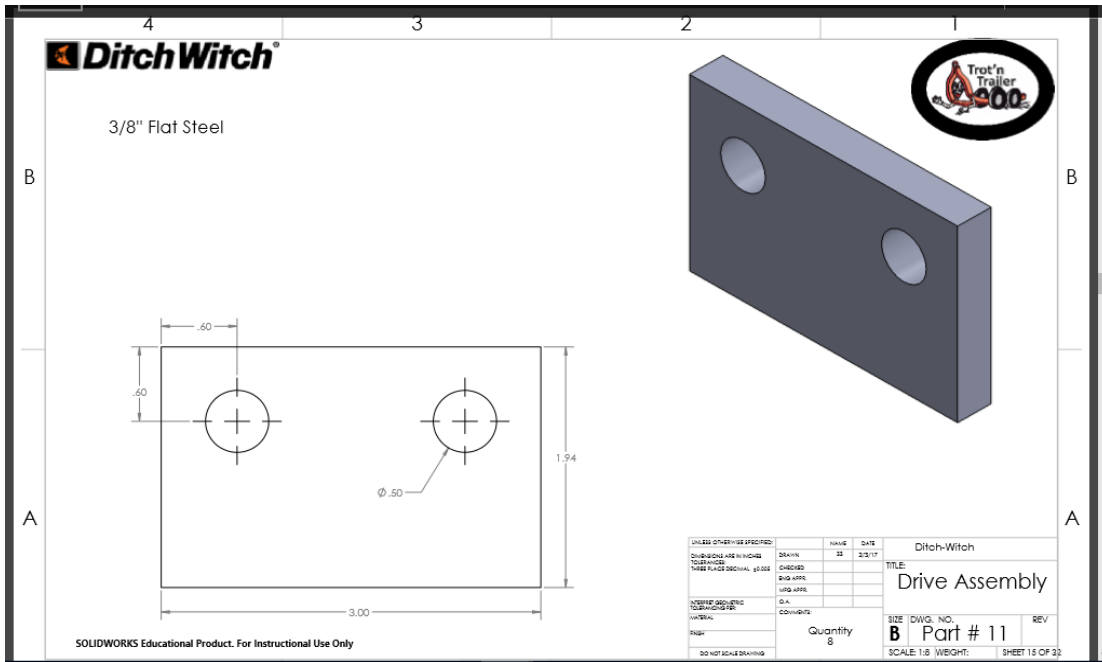


Figure 22. Part # 11

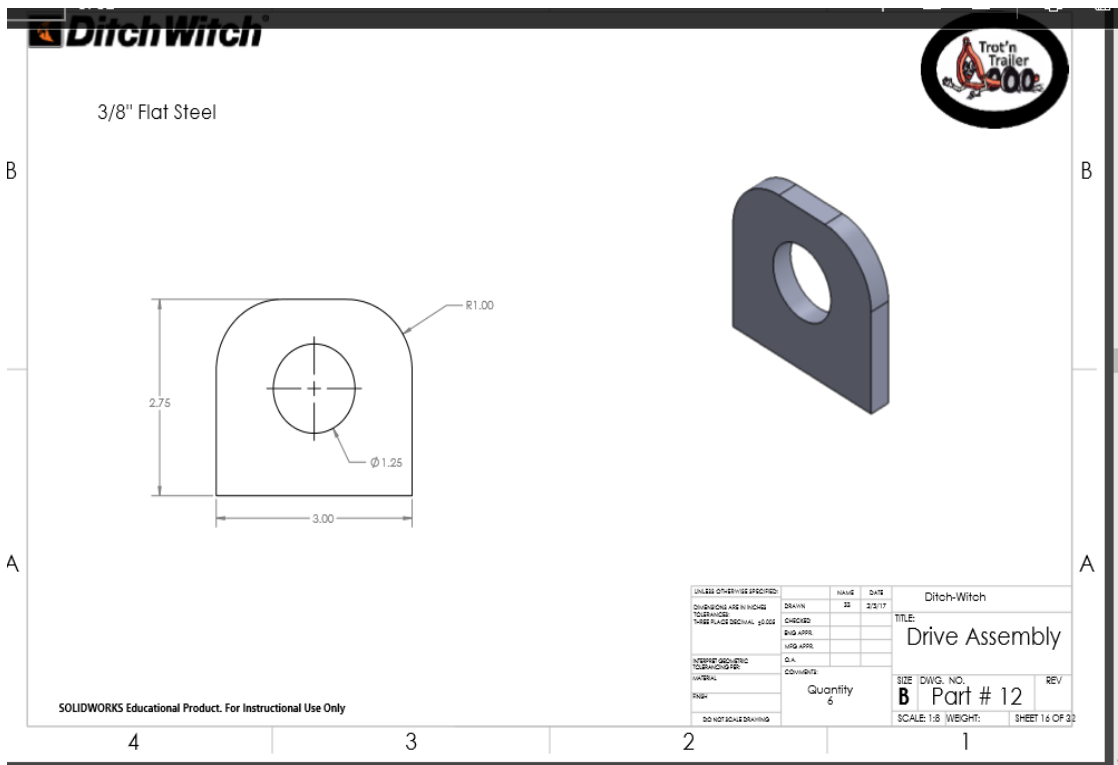


Figure 23. Part # 12

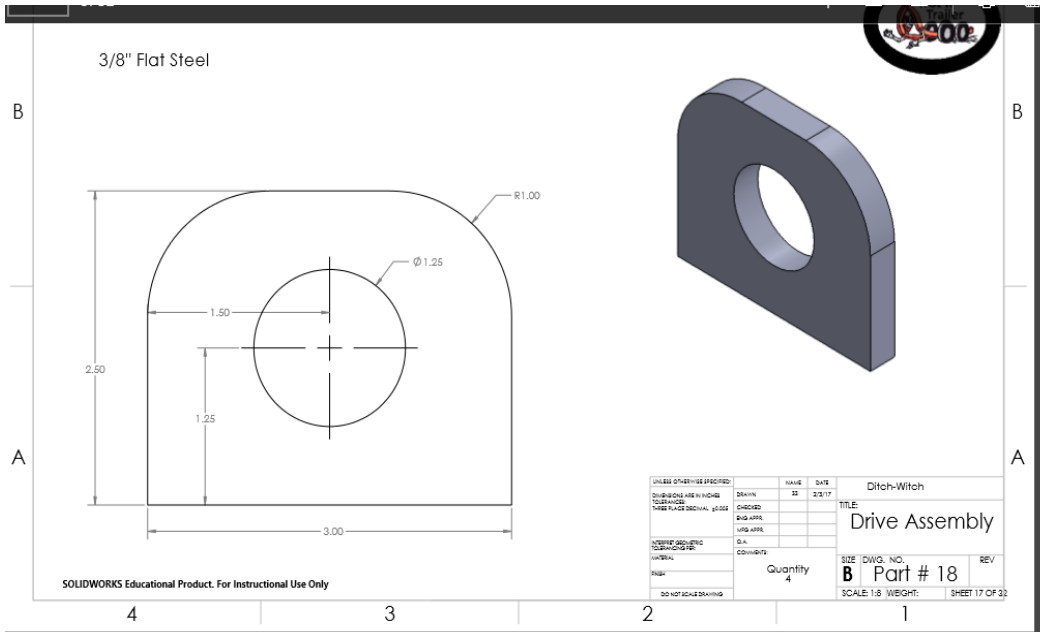


Figure 24. Part # 18

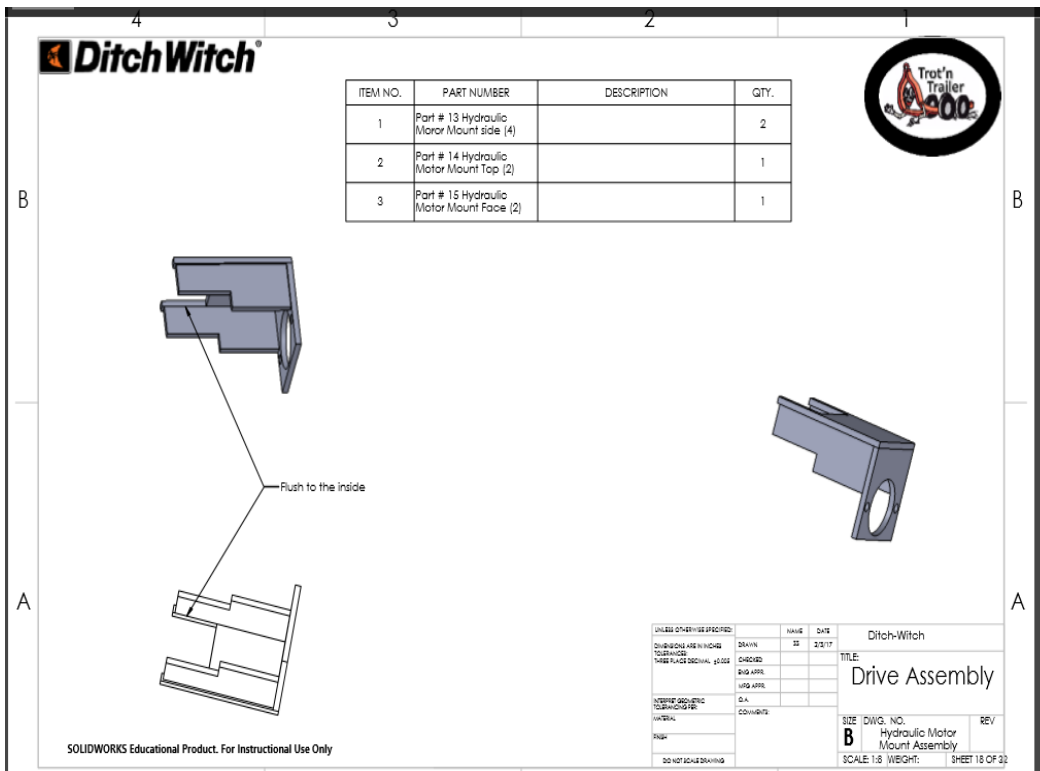


Figure 25. Hydraulic Motor Mount

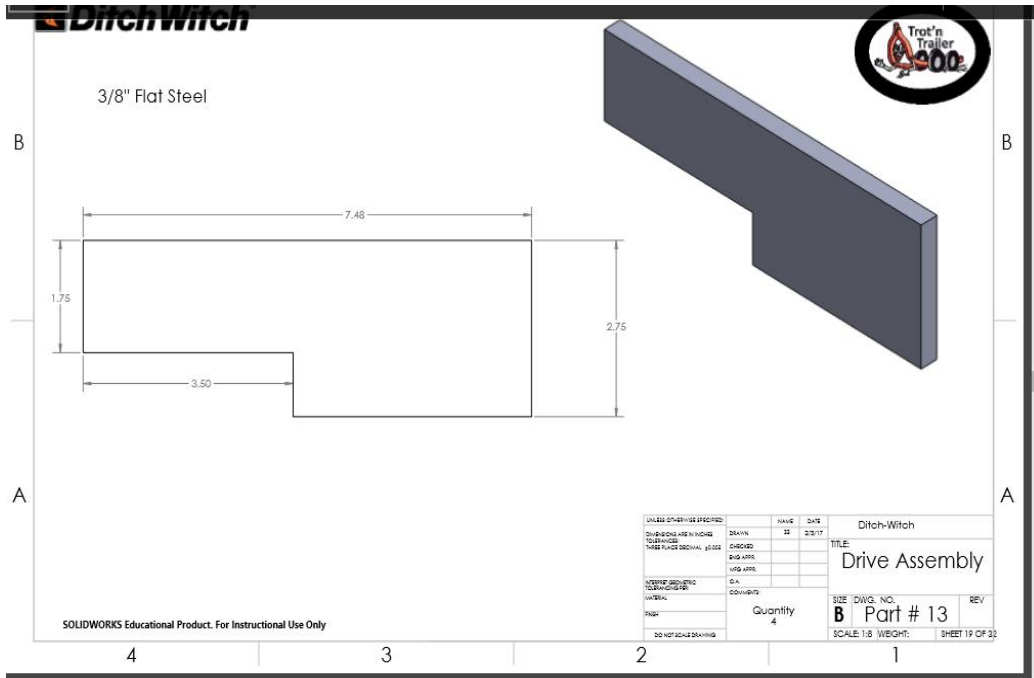


Figure 26. Part # 13

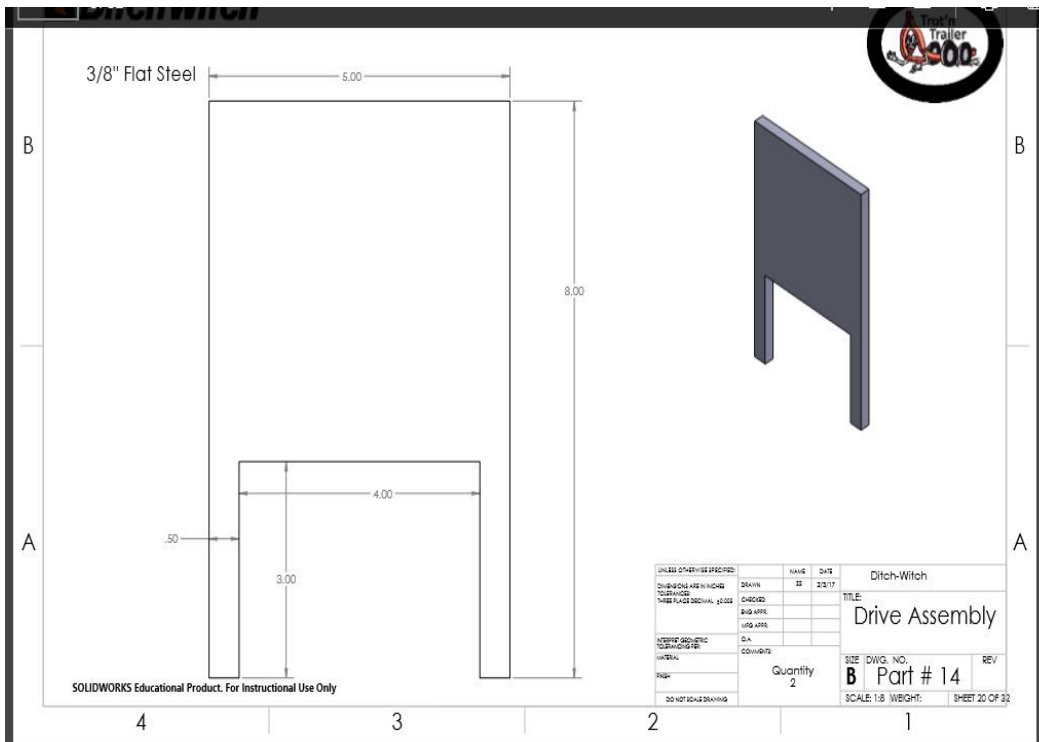


Figure 27. Part # 14

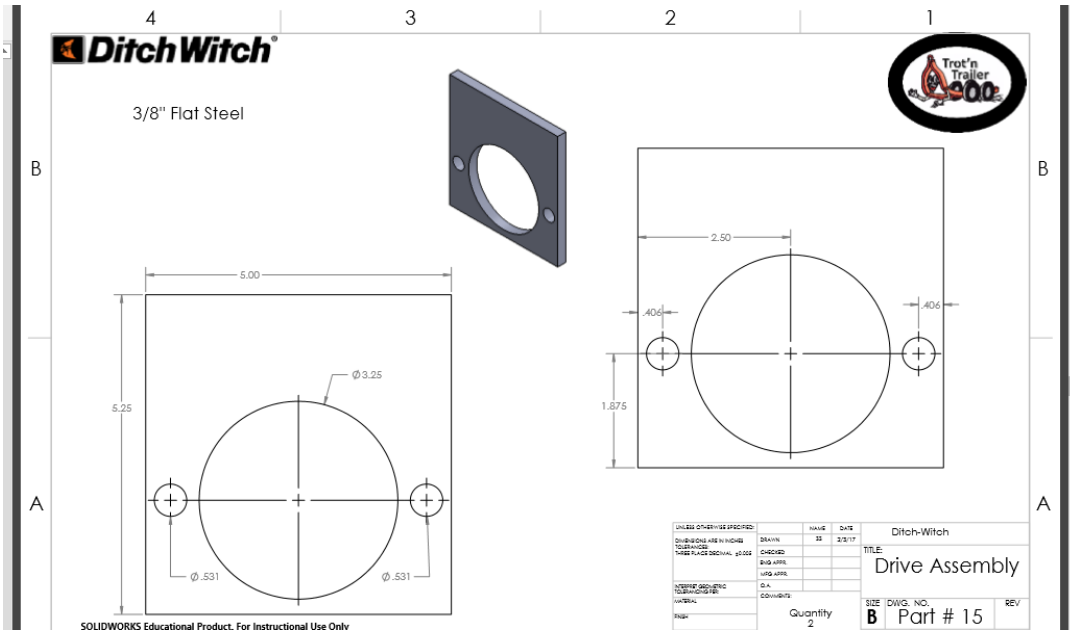


Figure 28. Part # 15

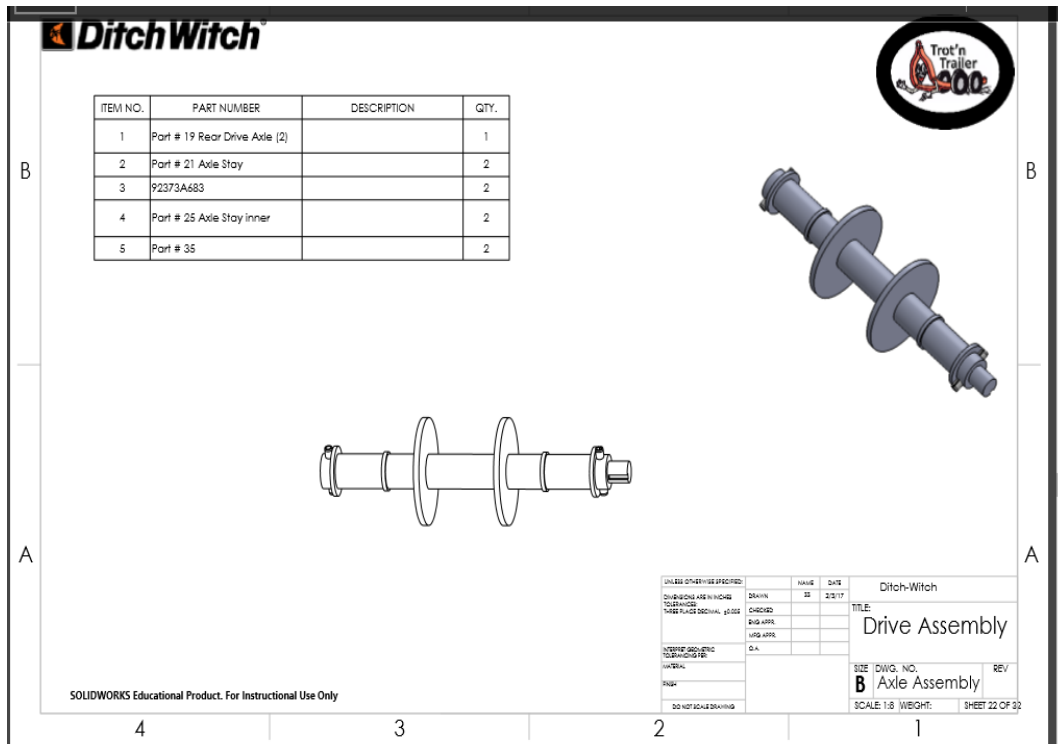


Figure 29. Drive Axle Assembly

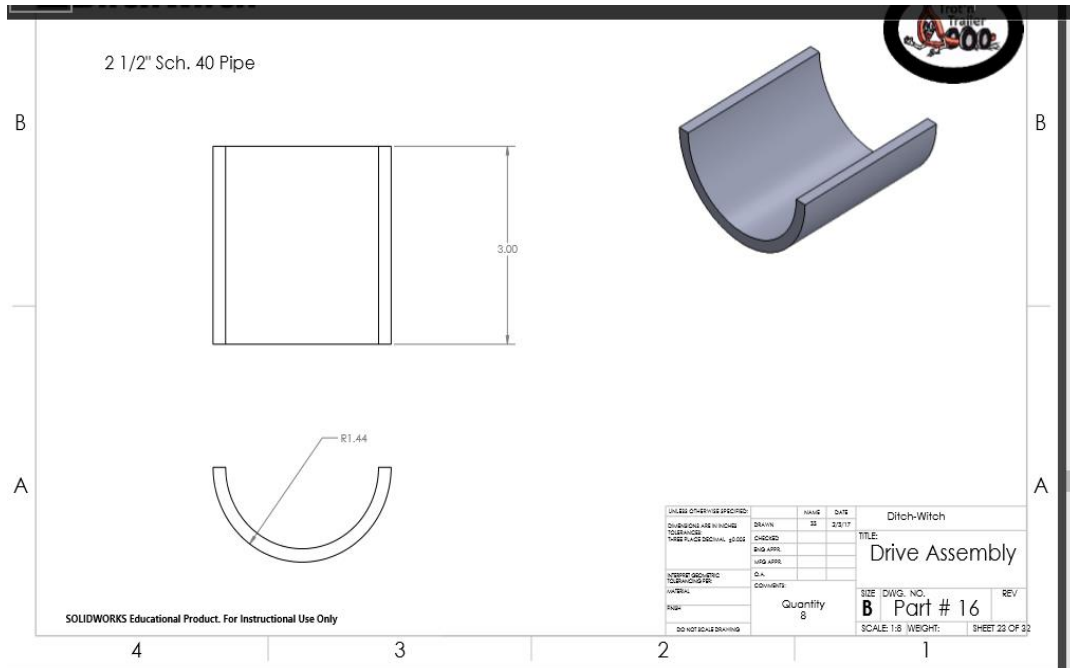


Figure 30. Part # 16

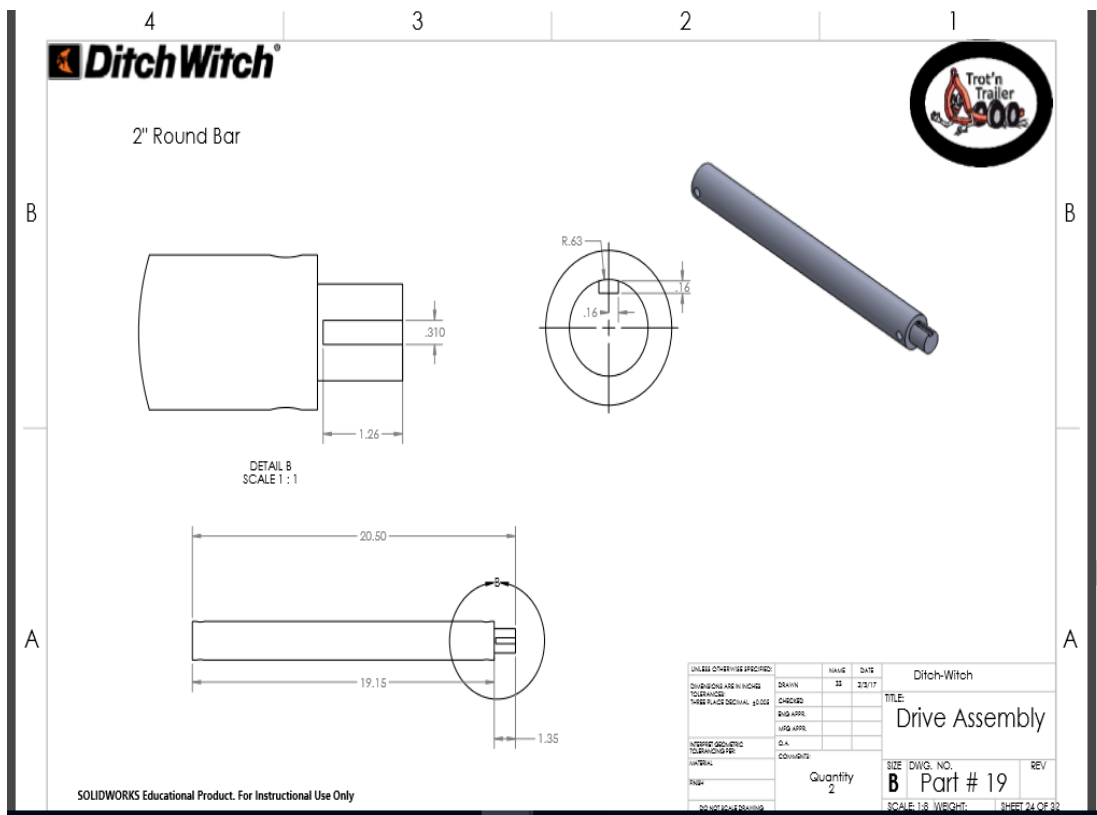


Figure 31. Part # 19

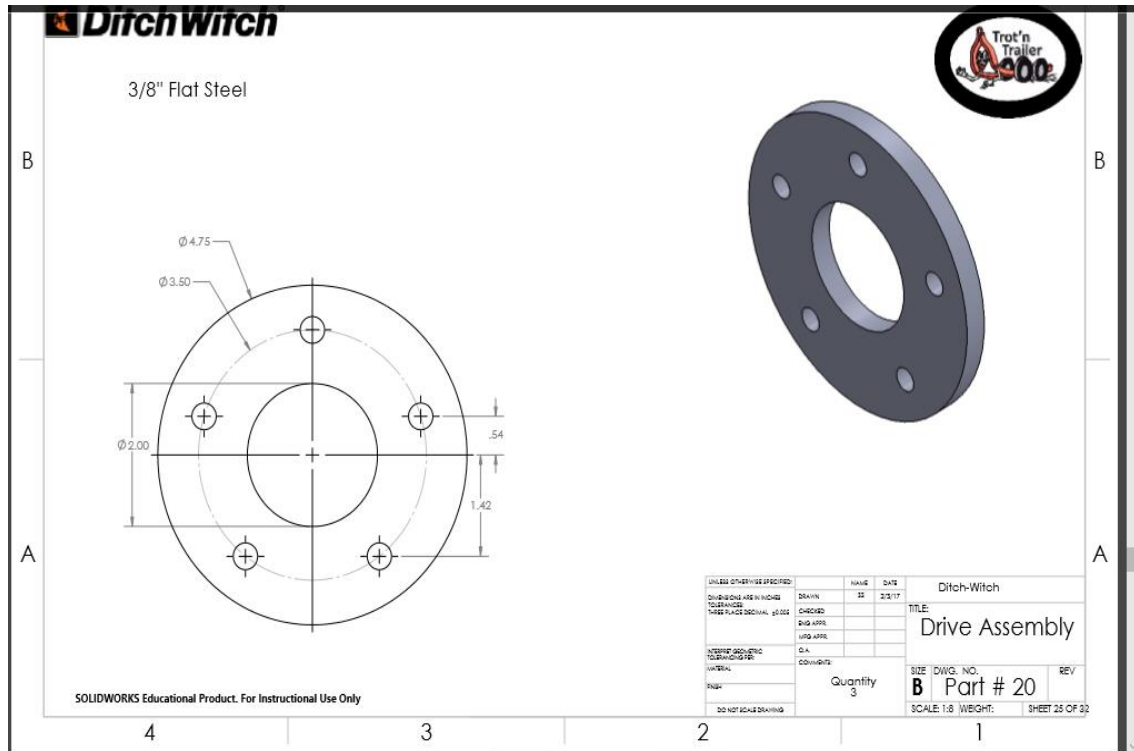


Figure 32. Part # 20

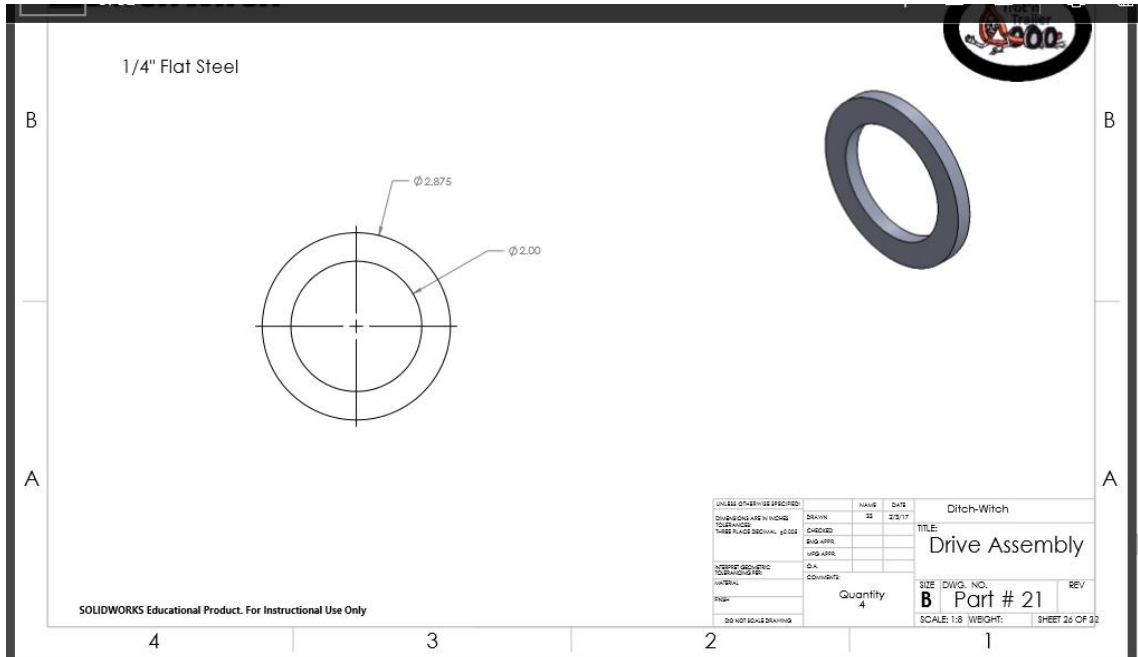


Figure 33. Part # 21

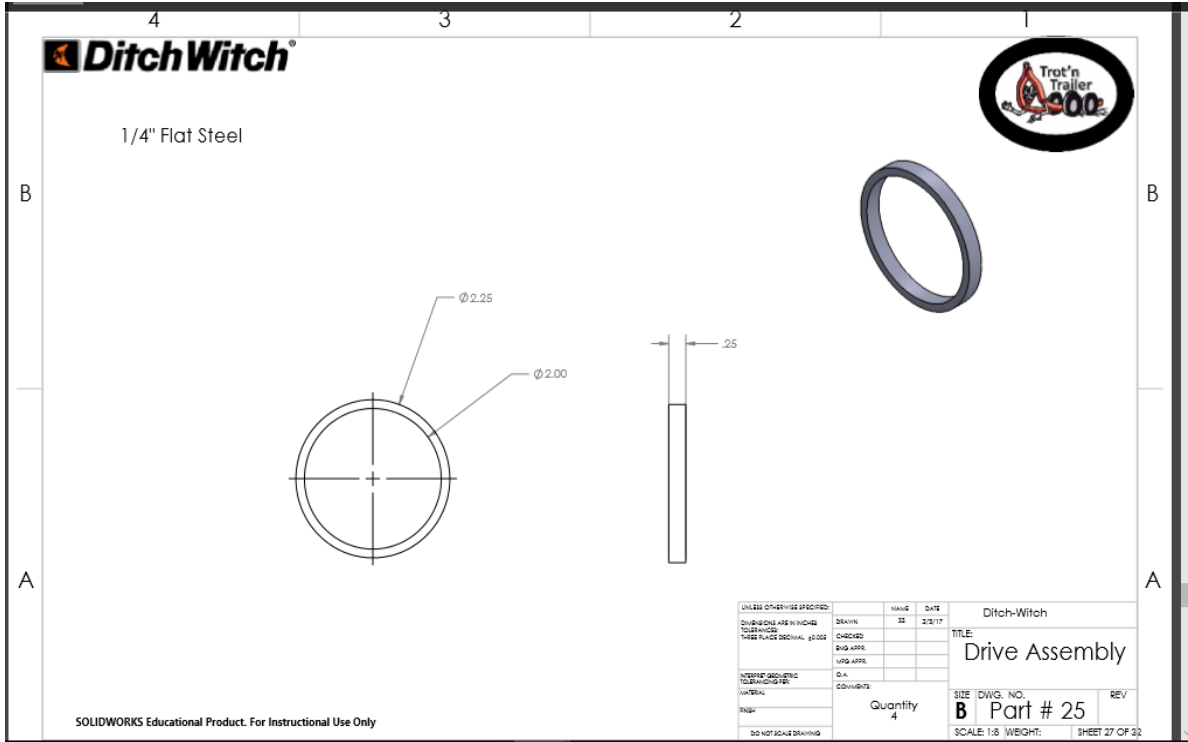


Figure 34. Part # 25

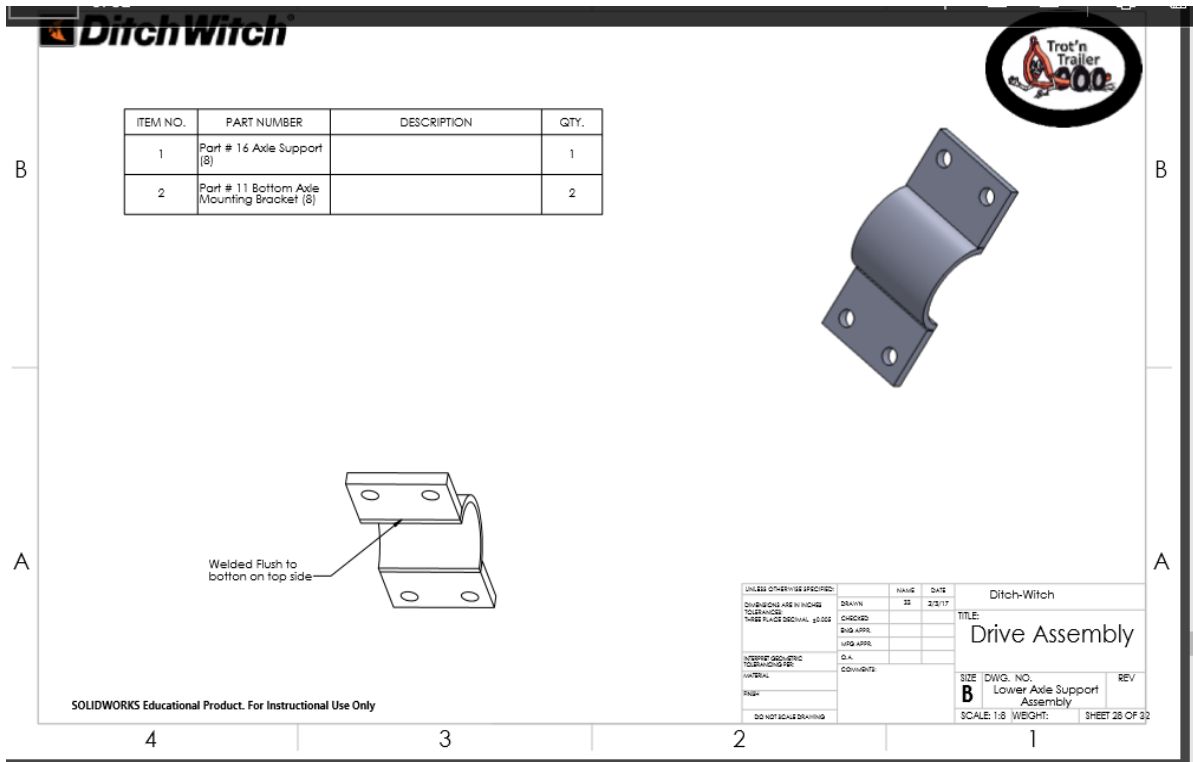


Figure 35. Lower Axle Support Assembly

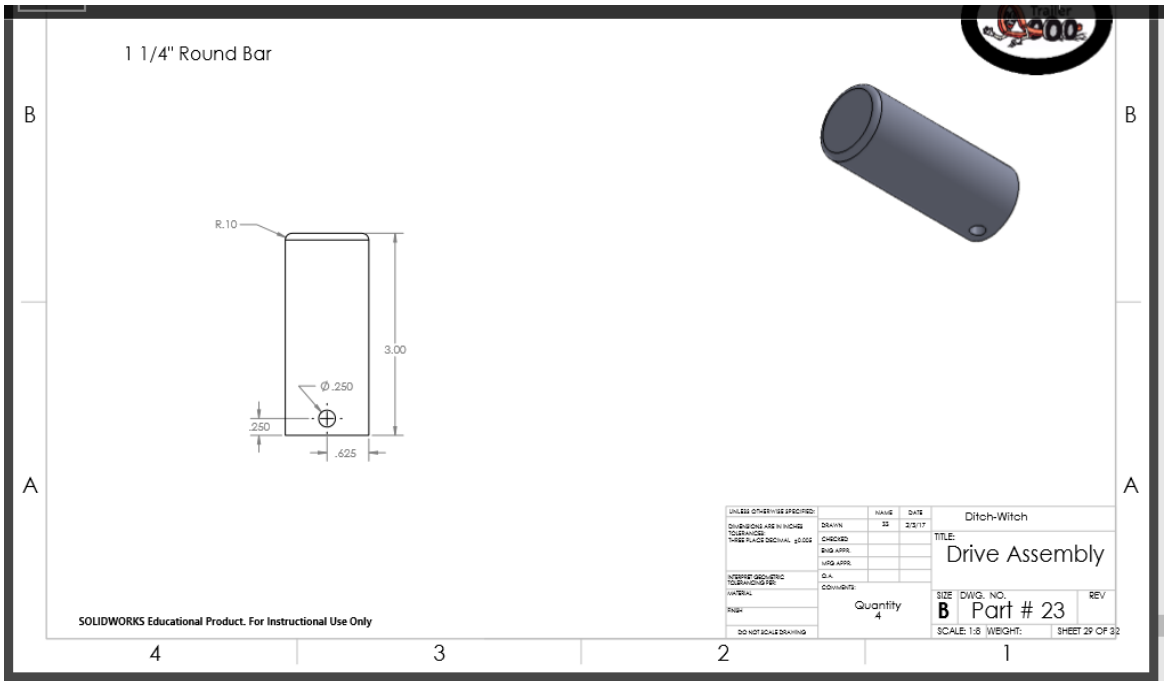


Figure 36. Part # 23

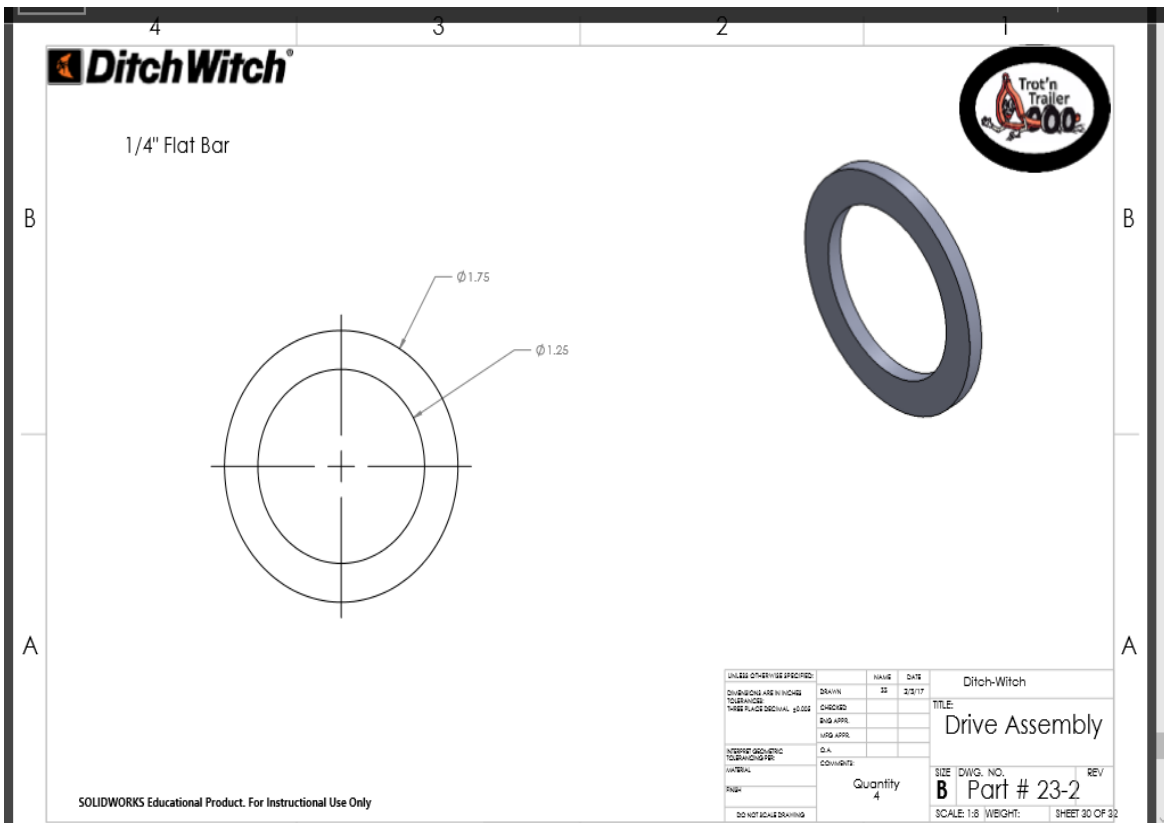


Figure 37. Part # 23-2

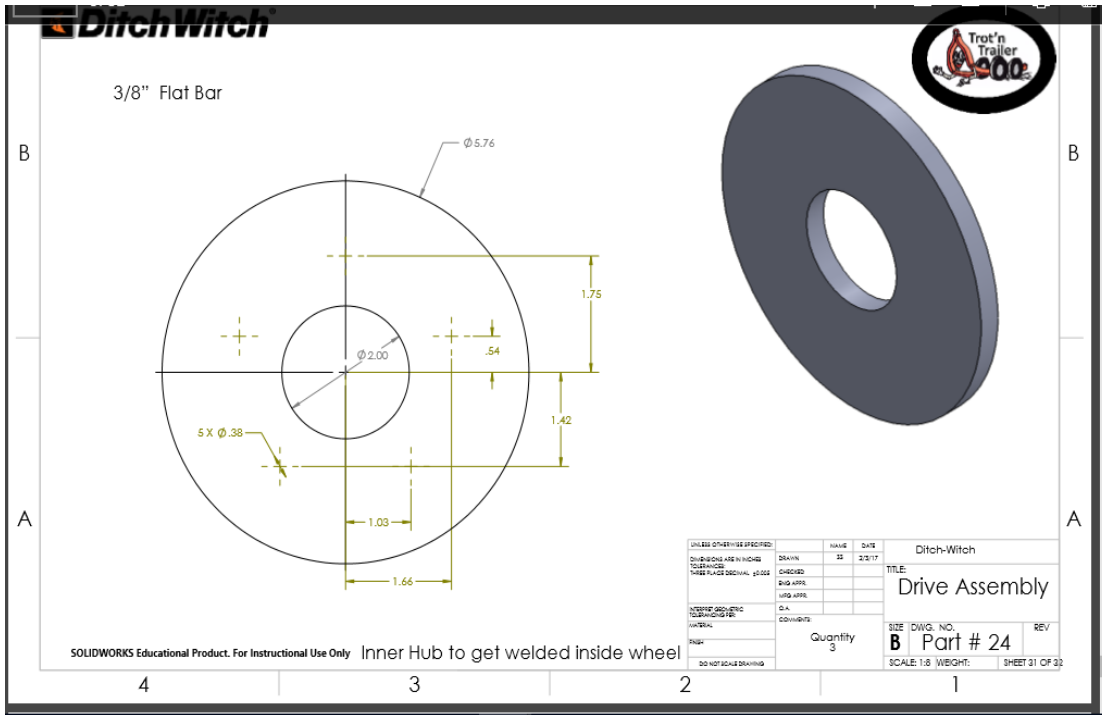


Figure 38. Part # 24

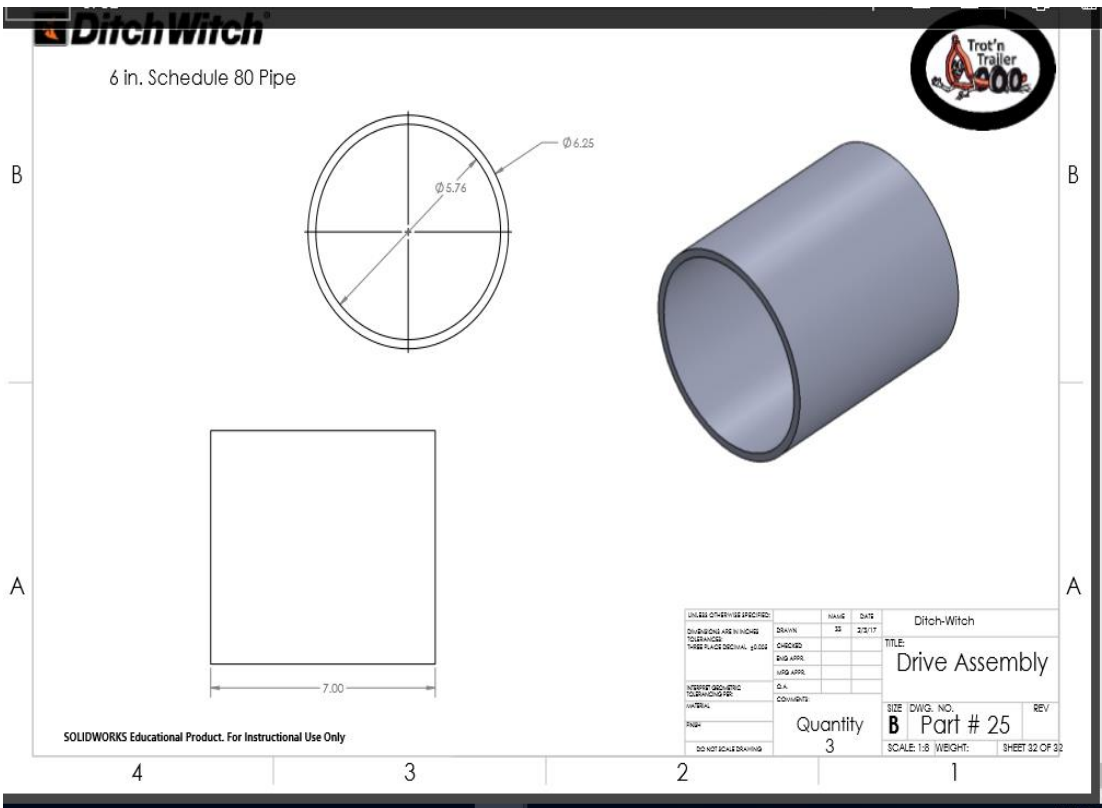


Figure 39. Part # 25

Steer Axle Solidworks Part Drawings

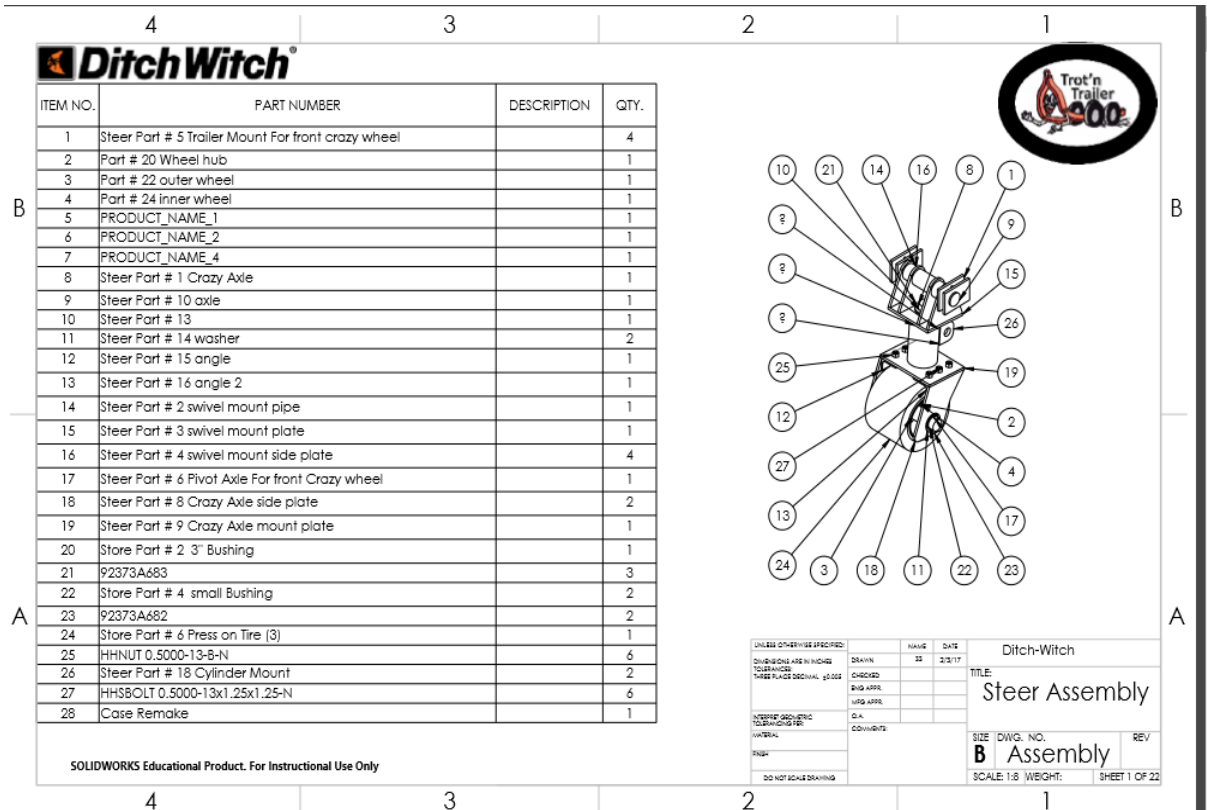


Figure 40. Steer Axle Assembly

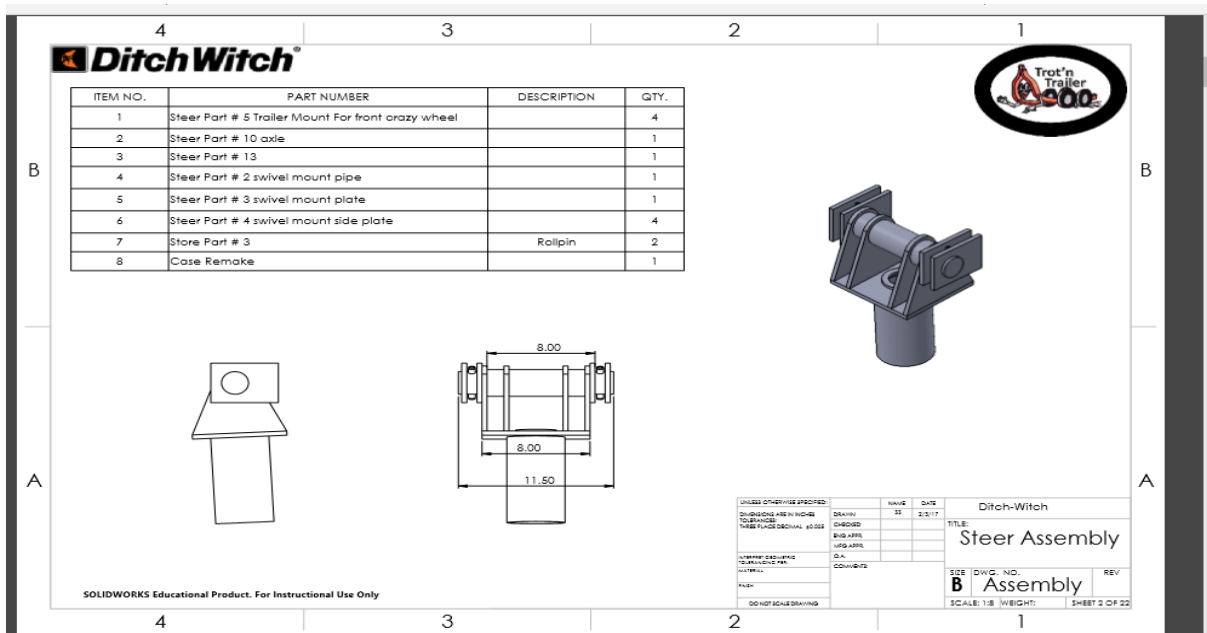


Figure 41. Assembly

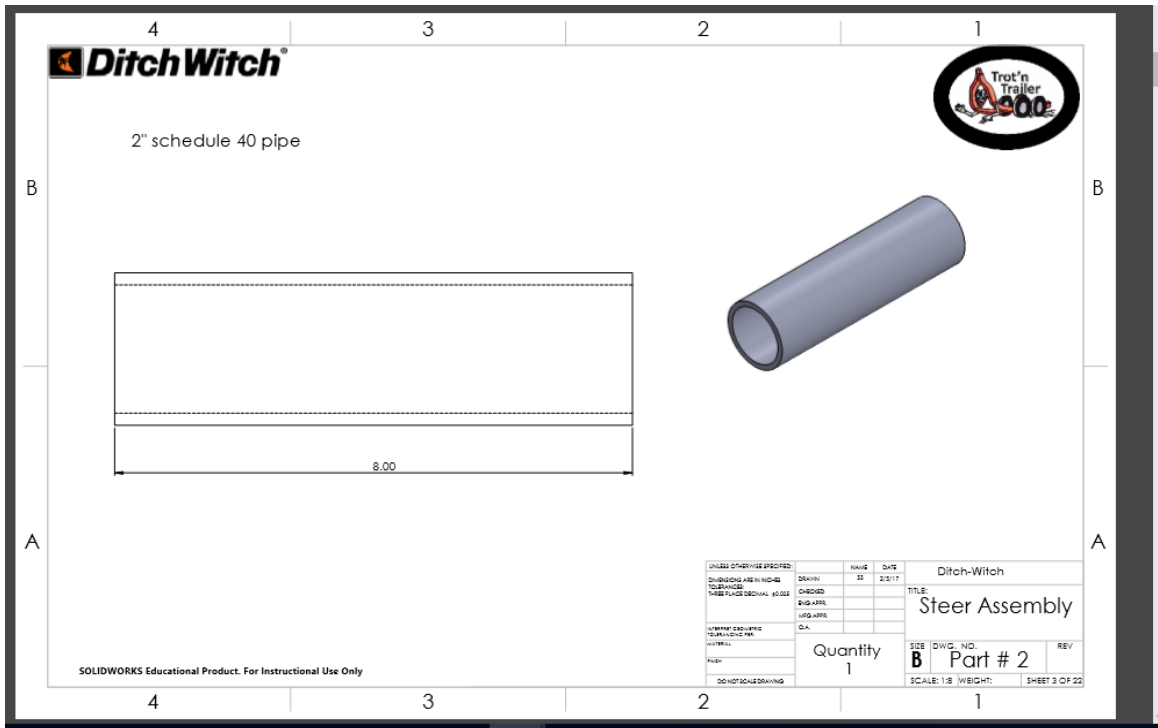


Figure 42. Part # 2

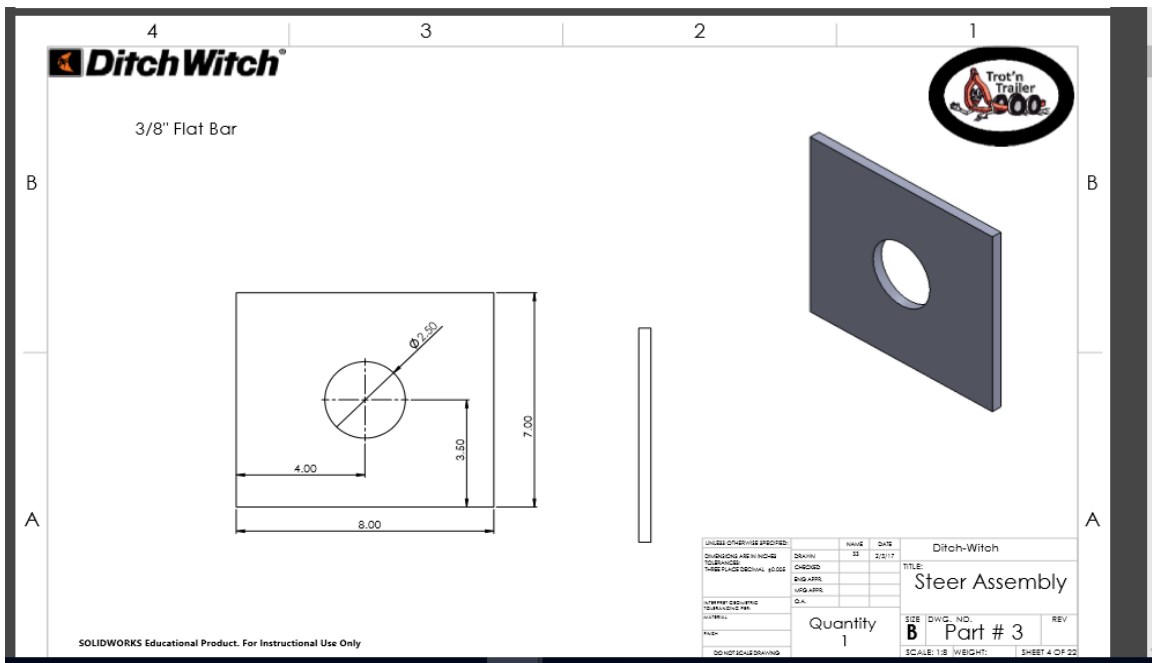


Figure 43. Part # 3

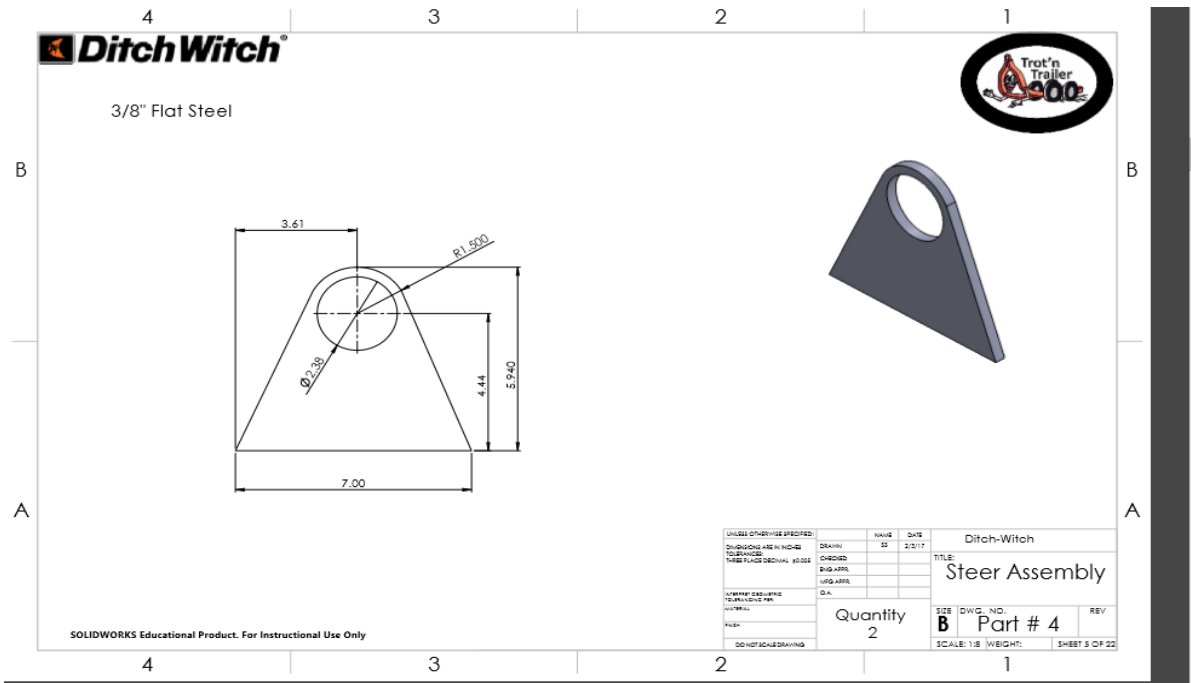


Figure 44. Part # 4

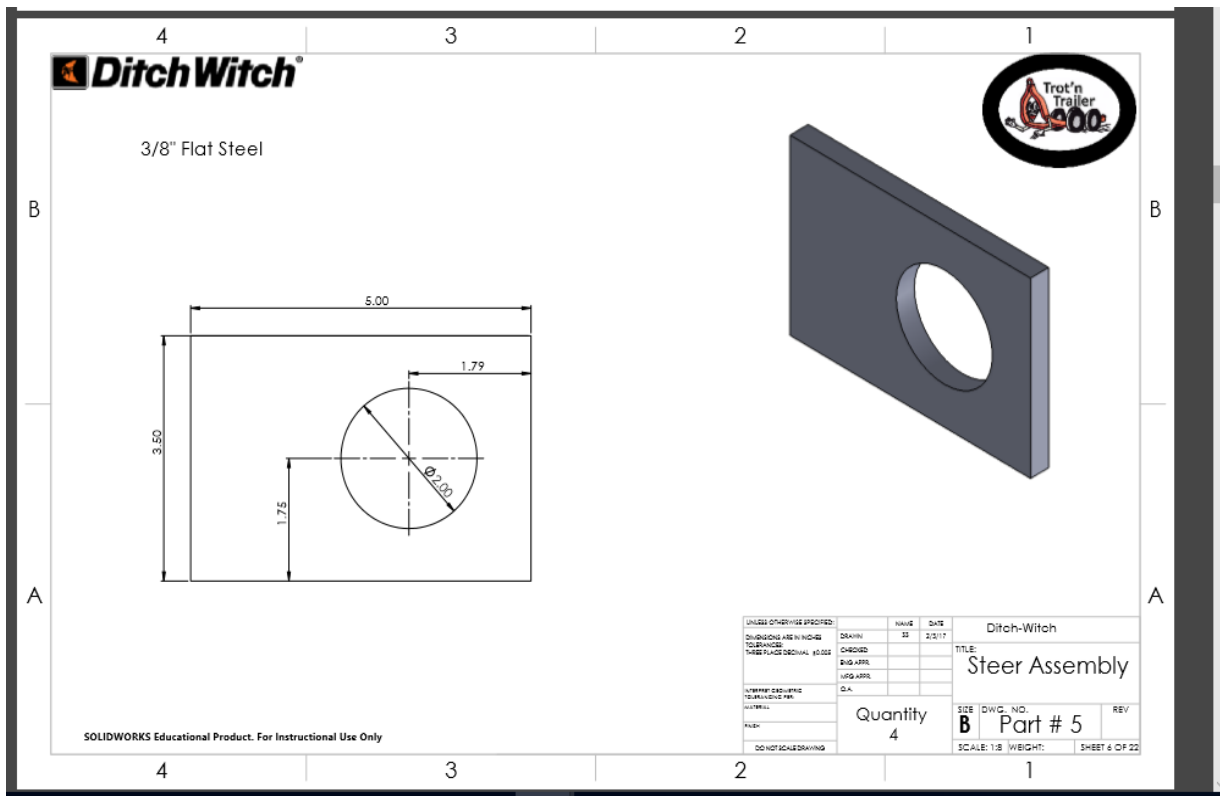


Figure 45. Part # 5

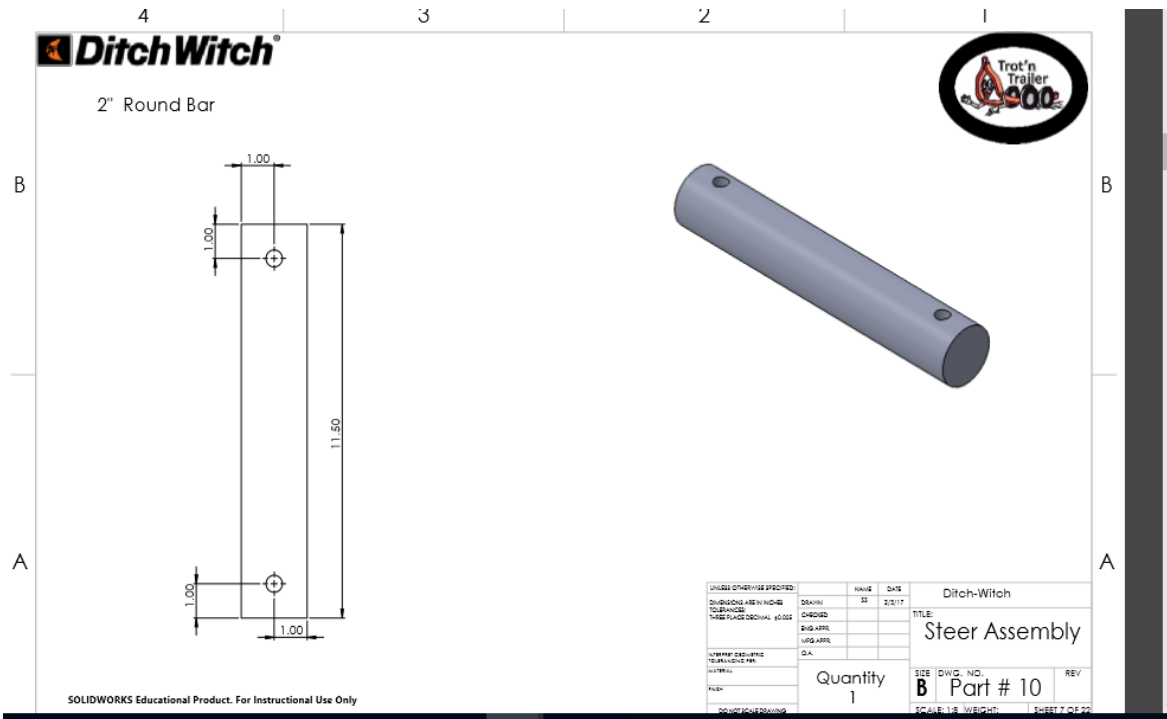


Figure 46. Part # 10

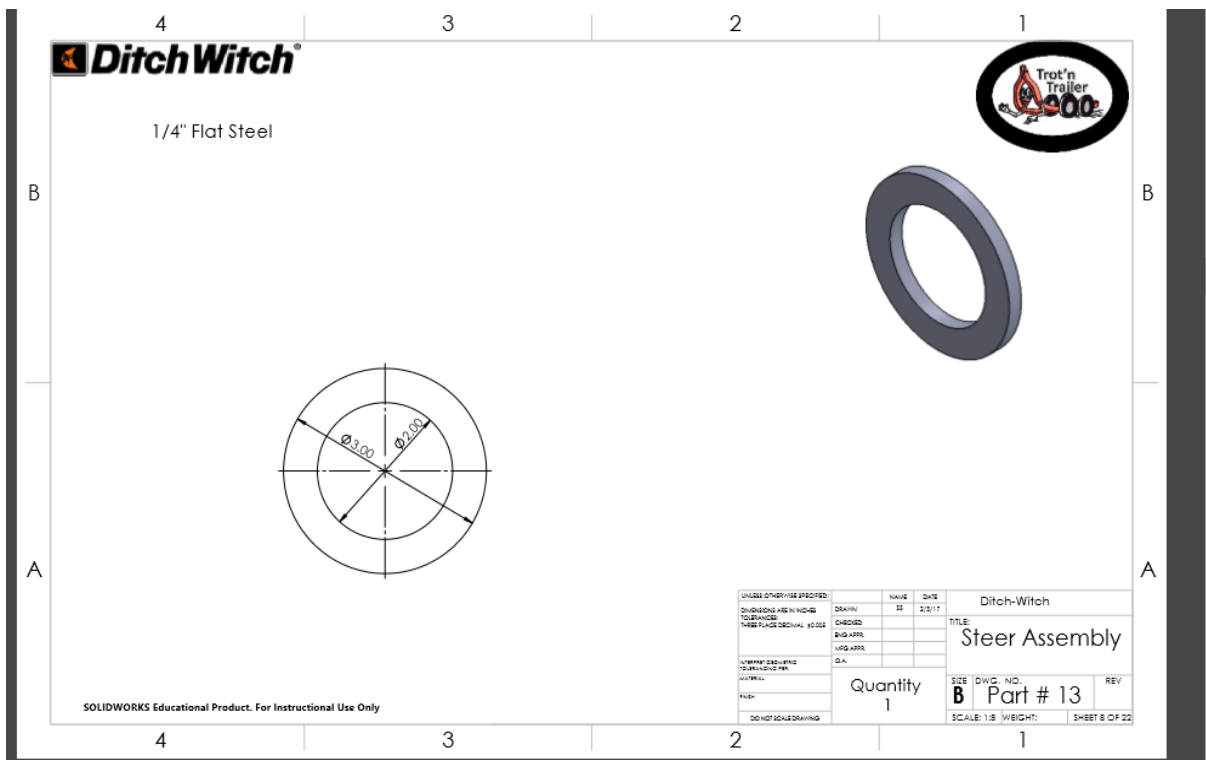


Figure 47. Part # 13

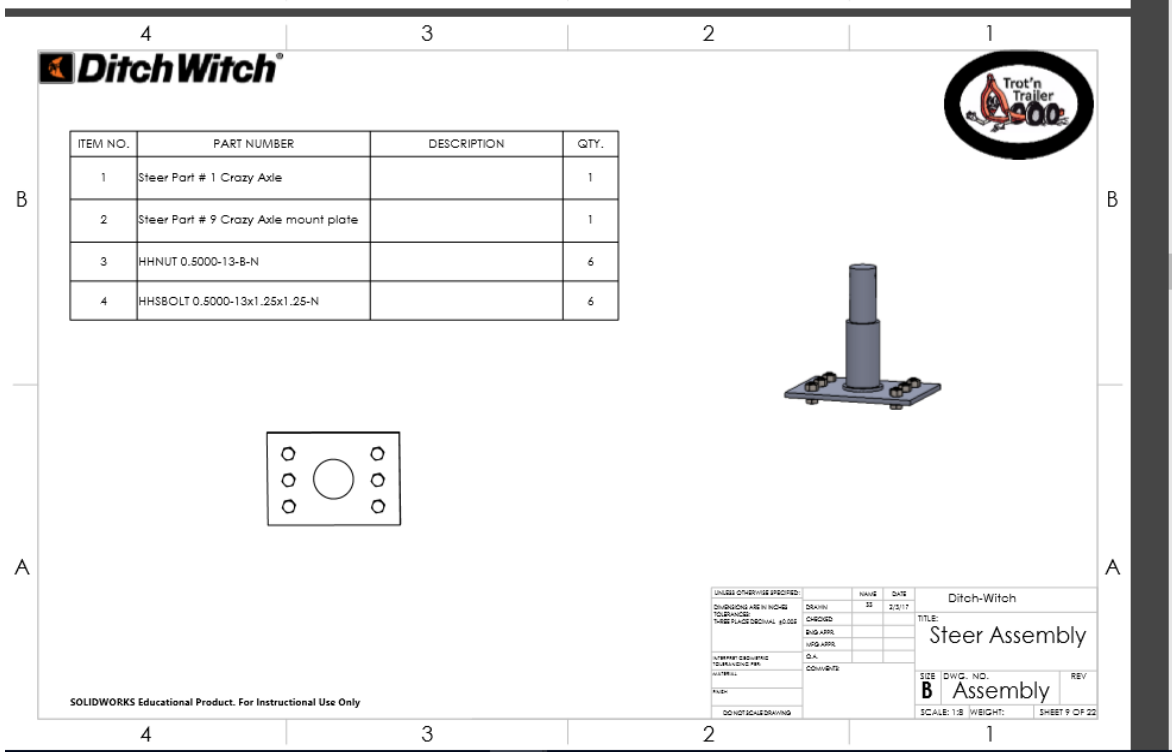


Figure 48. Wheel Mount

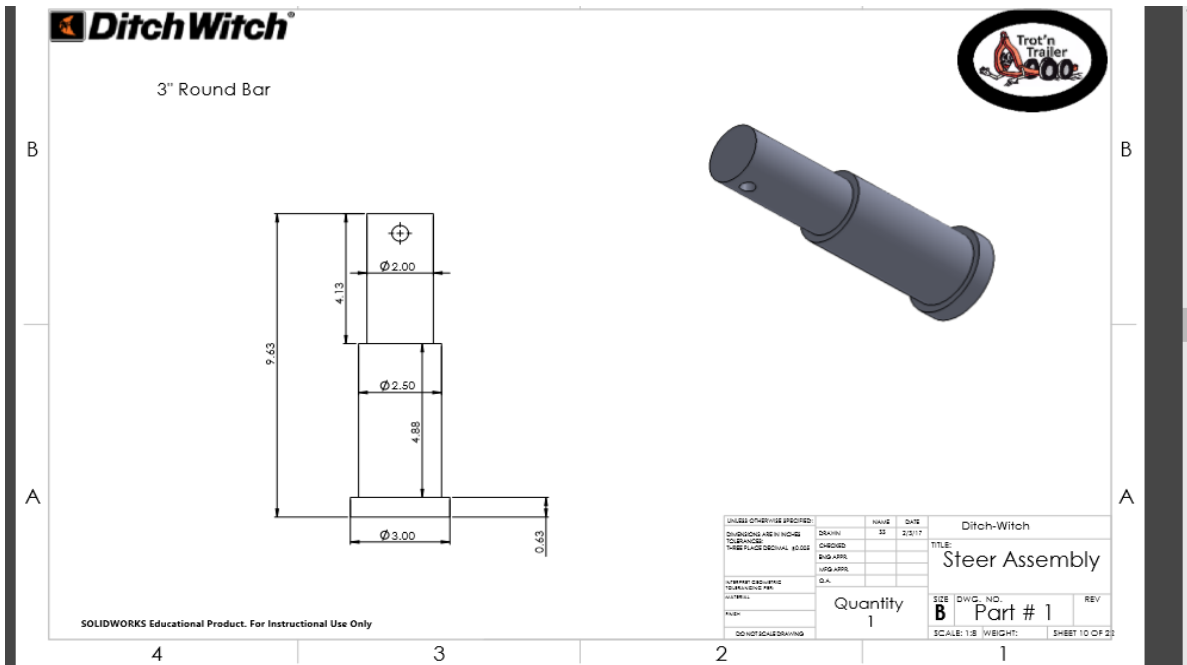


Figure 49. Part # 1

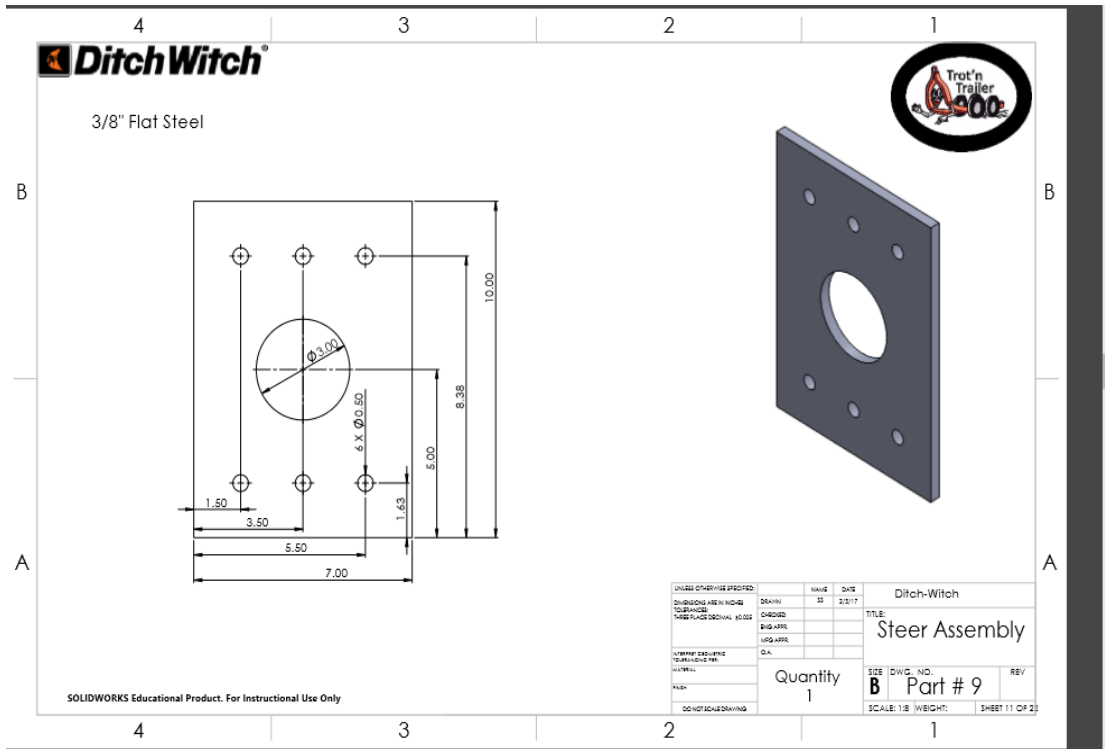


Figure 50. Part # 9

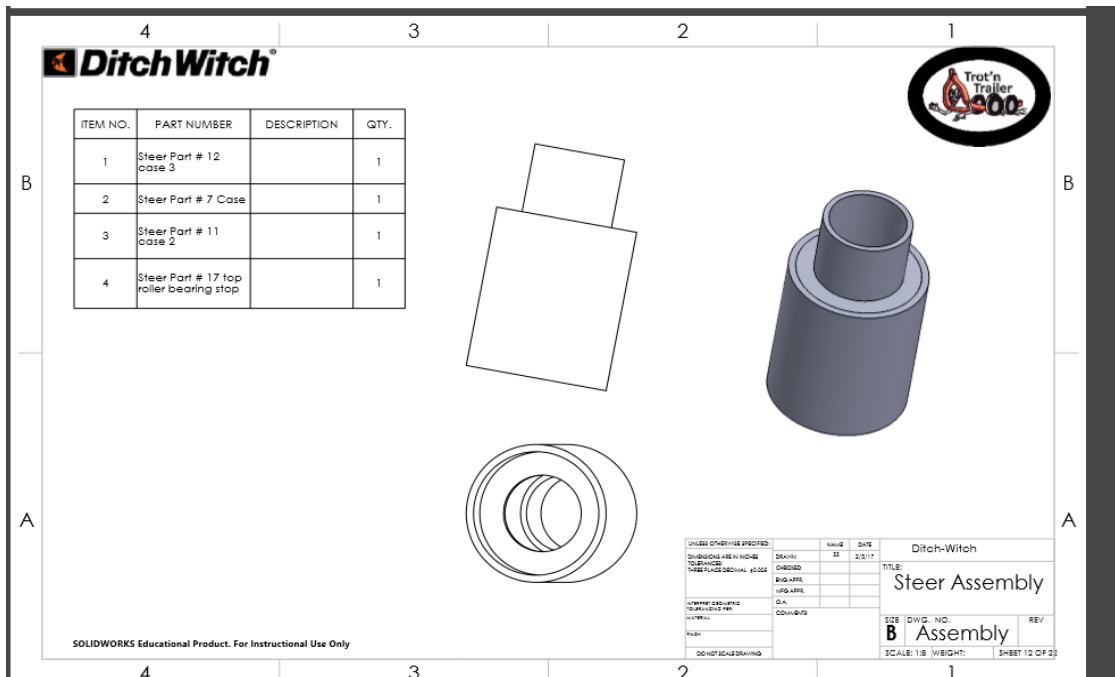


Figure 51. Steering Assembly

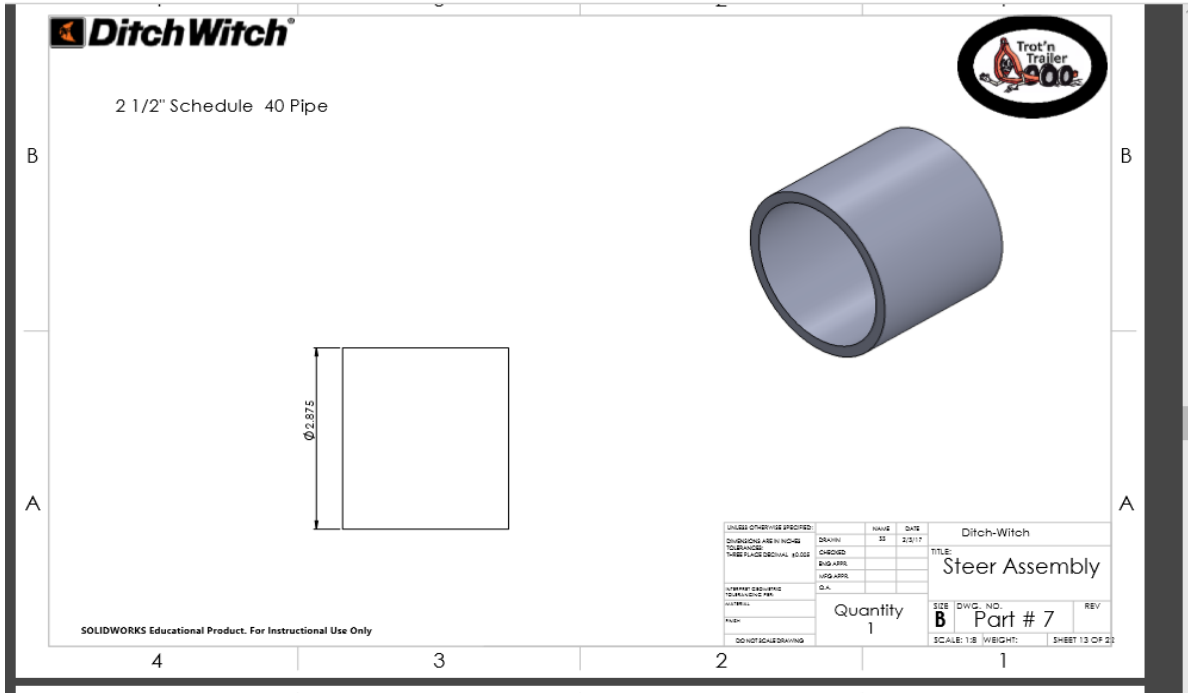


Figure 52. Part # 7

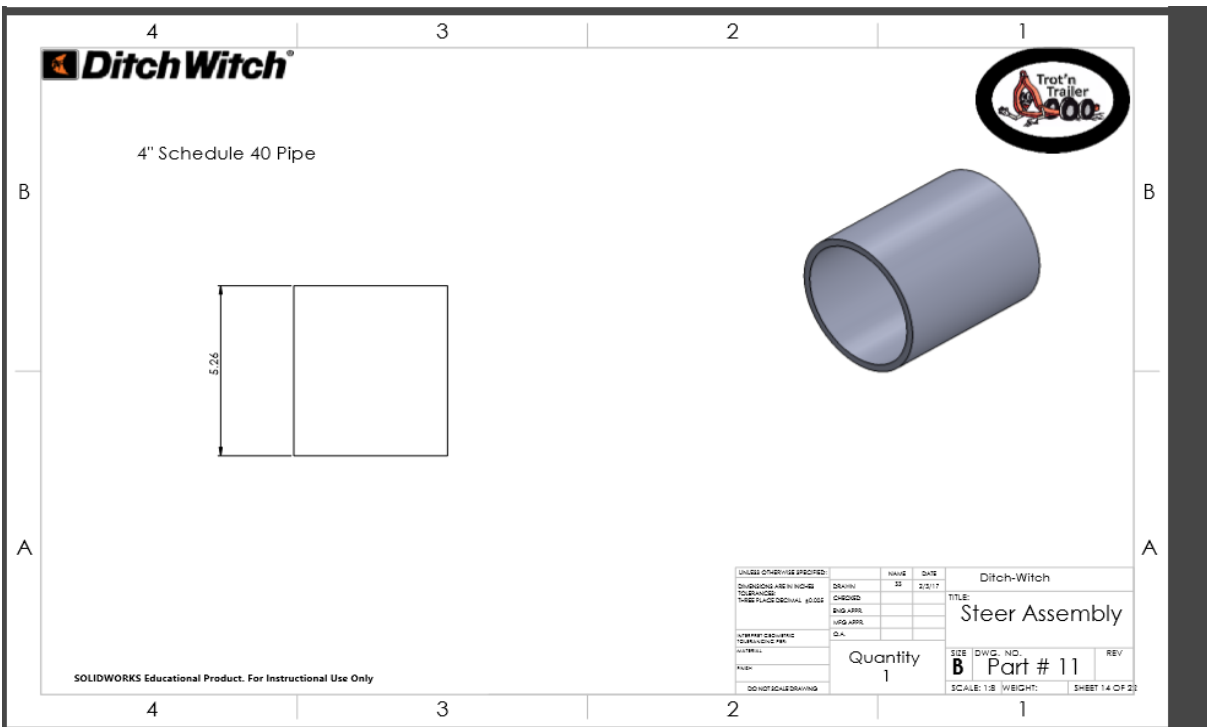


Figure 53. Part # 11

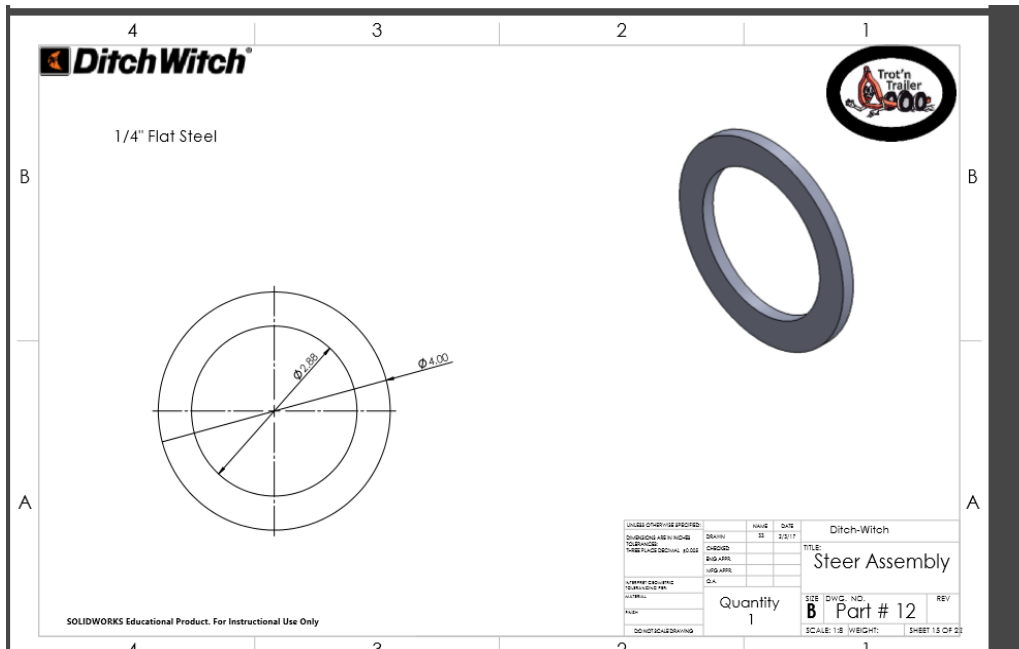


Figure 54. Part # 12

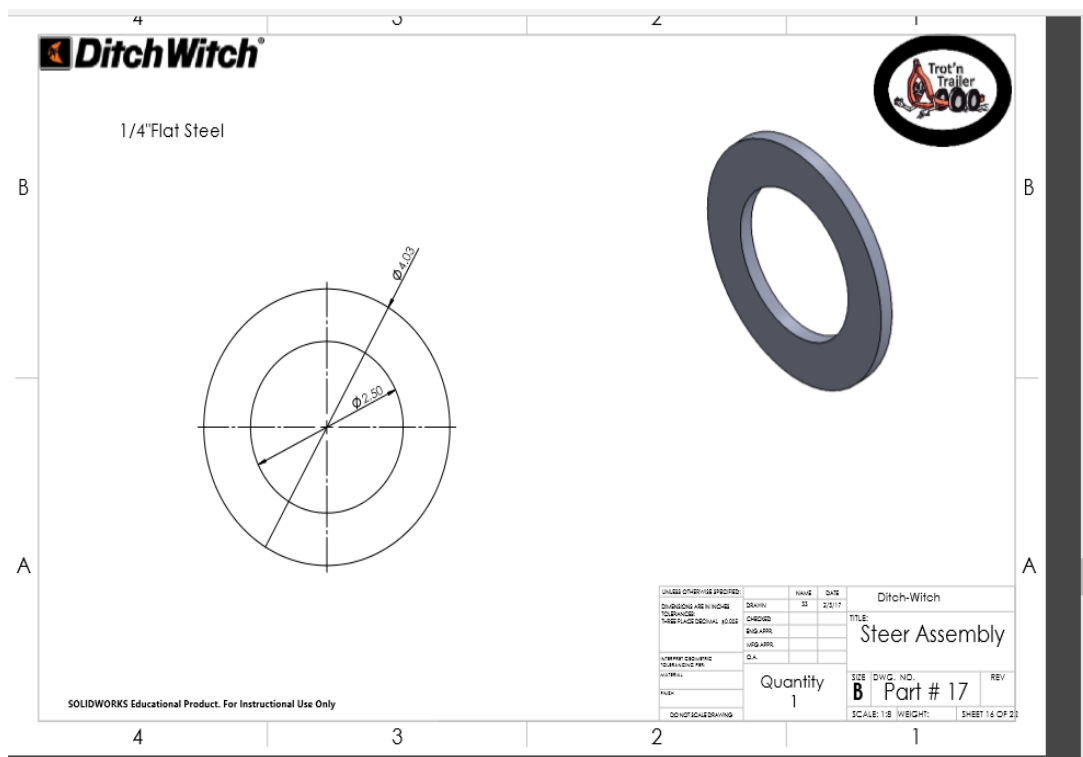


Figure 55. Part # 17

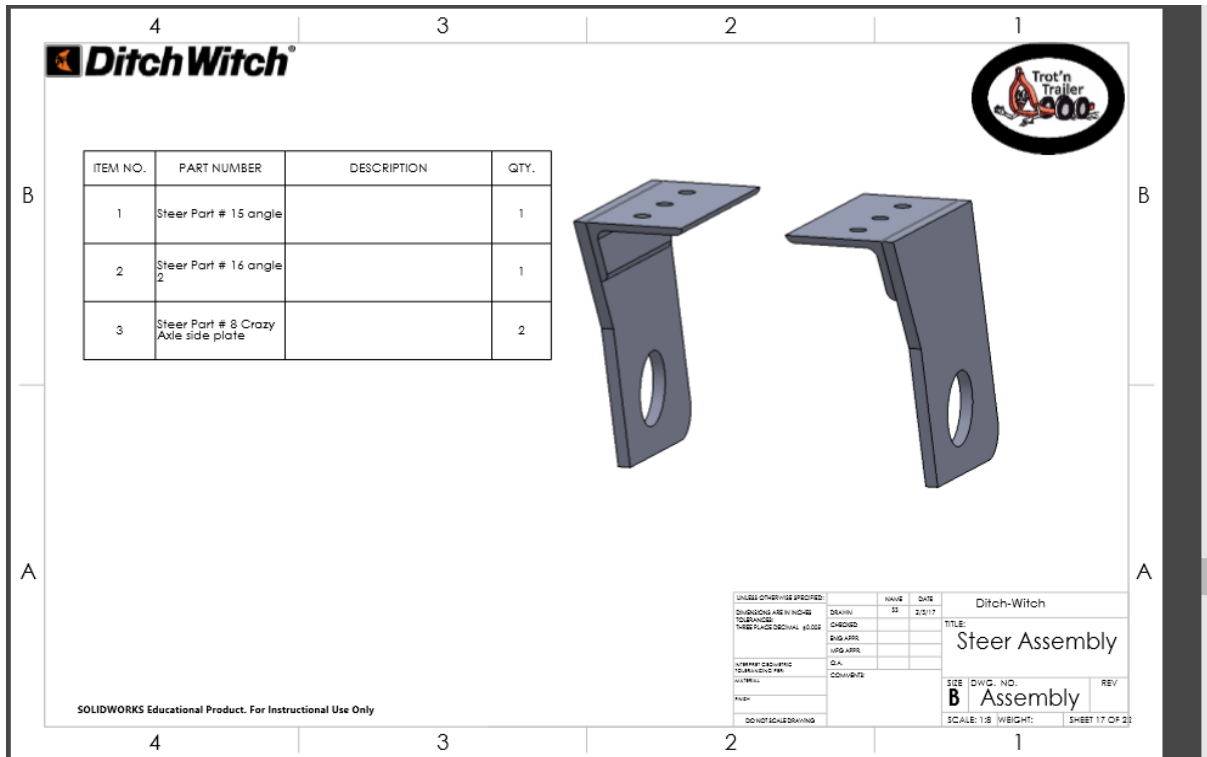


Figure 56. Steering Mount Brackets

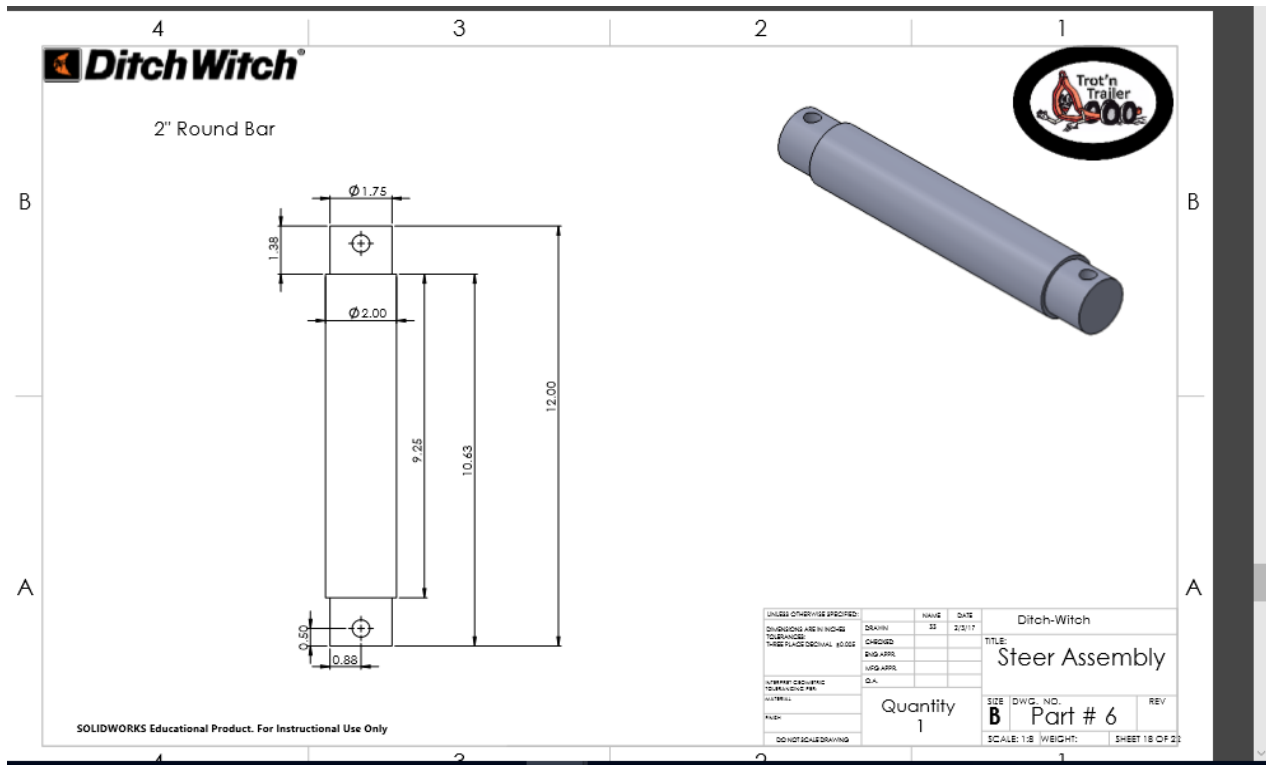


Figure 57. Part # 6

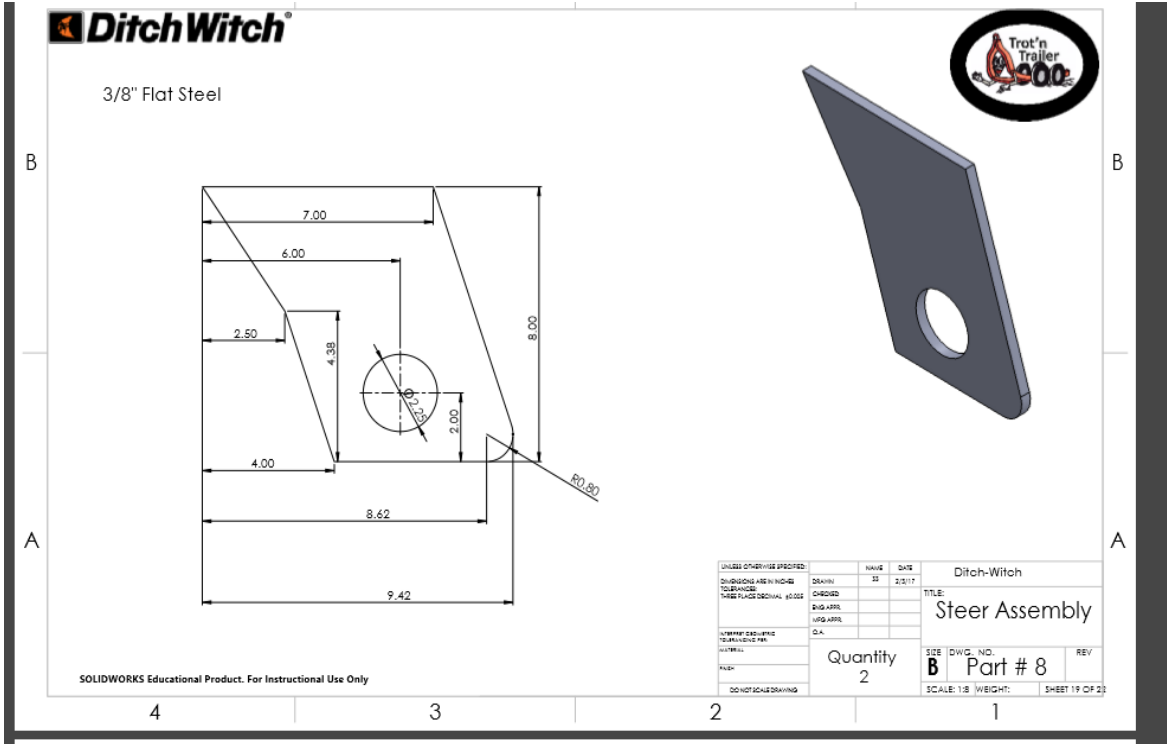


Figure 58. Part # 8

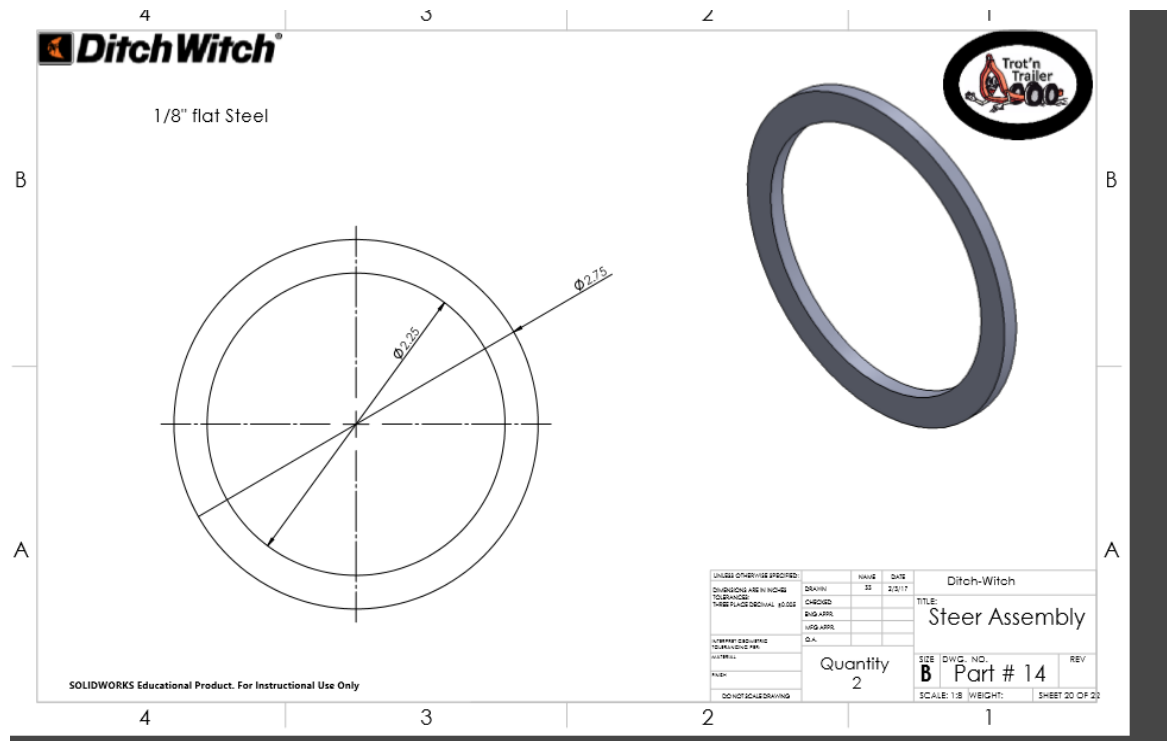


Figure 59. Part # 14

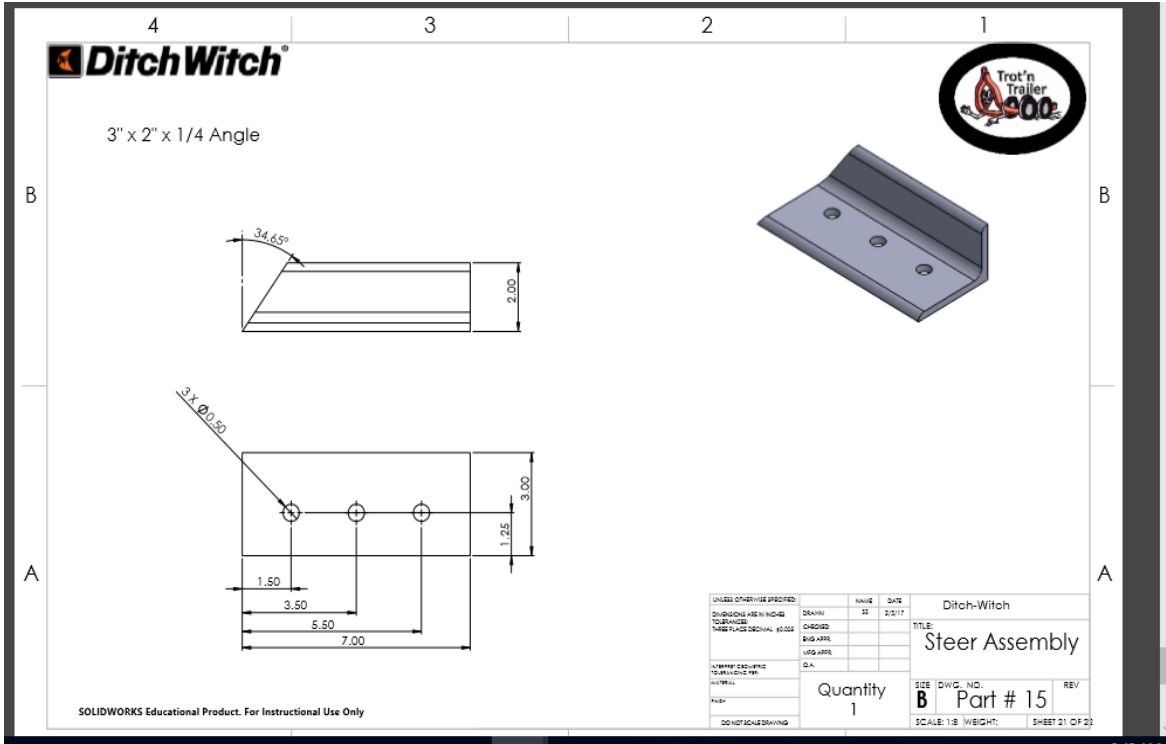


Figure 60. Part # 15

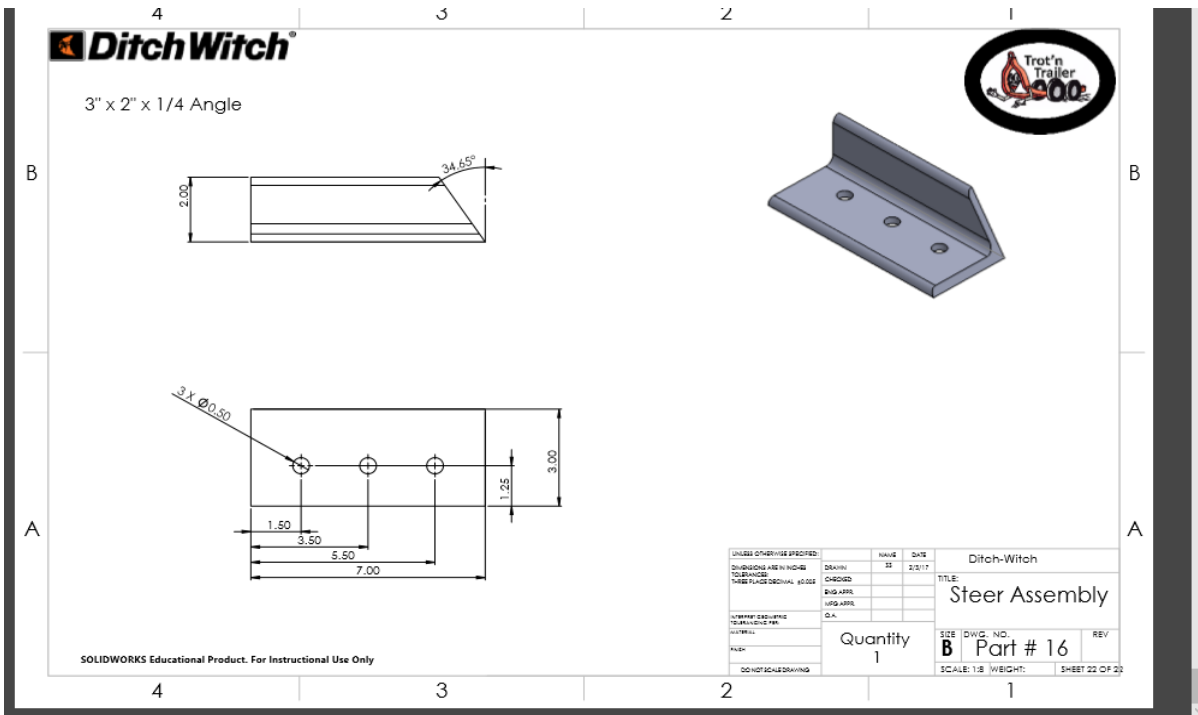


Figure 61. Part # 16

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BAE 4012 – Senior Design

Fall 2016

Trot'n Trailer Senior Design

- ▶ Konner Kay - Team Leader
- ▶ James Collingsworth
- ▶ Skyler Shepherd
- ▶ Colten Leach
- ▶ Trey Minten



Project Outline

- ▶ Introduction: (1-5)
- ▶ Problem Outlook: (6-8)
- ▶ About the FX-30: (9-12)
- ▶ Existing Technology: (14-16)
- ▶ Patent Search: (17-21)
- ▶ Trailer Standards: (22-23)
- ▶ Preliminary Designs: (24-30)
- ▶ Final Design: (31-45)
- ▶ Calculations: (33-45)
- ▶ Future plans: (46)



About the Client

- ▶ Charles Machine Works Inc. produce various types of equipment such as: trenchers, directional drills, skid steers, and vacuum excavators.
- ▶ Charles Machine Works Inc. is headquartered in Perry, OK.
- ▶ Ditch Witch is a subset of Charles Machine Works.



Mission Statement

- ▶ Our goal is to instill core values throughout our design and product, such as: dependability, safety, and innovation.



Problem Statement

- ▶ The client wants the team to develop a product that enables their FX-30 Vacuum Excavator to move independently and not be restricted to movement only by a vehicle.



About the FX-30

▶ Applications:

- ▶ 1) Exposing buried utility lines.
- ▶ 2) Cleaning out storm drains.
- ▶ 3) Directional drilling site cleanup.
- ▶ 4) Commercial and residential debris cleanup and landscaping and posthole digging.



FX30 Demo.



Project Objective

- ▶ The Design must meet the following requirements specified by Ditch Witch:
 - ▶ 1) The system is designed to operate on hard surfaces.
 - ▶ 2) The design should be self-propelled.
 - ▶ 3) The system must be integrated onto the existing trailer.
 - ▶ 4) The system should simply be engaged and disengaged.
 - ▶ 5) Controls need to be operated by a remote control.
 - ▶ 6) The top speed with the system should be 1 - 1 ¼ mph.





2

Choice of 500- or 800-gallon spoils tanks and 80-, 200- or 300-gallon water tanks for cleanups of any size.

3

24.8-hp (18.5-kW) Kubota[®] diesel engine powers the FX30's outstanding suction and water pressure.



5

Fully enclosed, insulated, lockable power pack protects major components from weather and vandalism while leading the industry in noise reduction.

1

Hydraulic door opens fully horizontal to maximize the efficiency of spoils removal.

4

Reusable, 2-micron vacuum filter and a blower relief valve air filter provide the industry's best filtration.

8

High-pressure water system with a 4.2-gpm (16.1-l/min). 3,000-psi (207-bar) water pump is adjustable from curbside operator's station; autoclutching feature disengages water pump when water is not in use, allowing full system power for suction.

7

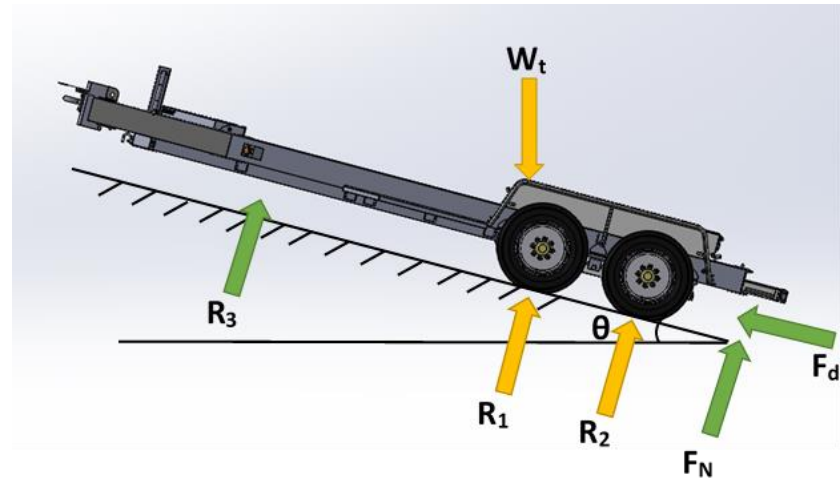
Optional reverse-flow feature allows you to offload spoils quickly and easily.

6

Trailer meets federal regulations (FMVSS) and comes standard with toolbox storage in tongue.

Trailer Free Body Diagram

- ❖ F_N representative of the normal force required for drive traction.
- ❖ F_d representative of drive force required for motion.



Weight Reactions		
Variable	Value	Units
Trailer gross weight (W_t)	18000	lbs
Trailer speed (V)	1.47	ft/s
Time required for speed (t)	4	s
Coefficient of friction (μ)	0.6	
Hill slope (θ)	8	degrees
Normal force required (F_n)	4529.058	lbs
Drive force required (F_d)	-2709.289	lbs


$$F_N = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) \left(\frac{1}{\mu} \right) + \left(\frac{W_t \sin \theta}{\mu} \right)$$

$$F_d = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) + W_t \sin \theta$$

FX-30 Trailer Dimensions

DIMENSIONS		
DIMENSIONS	U.S.	METRIC
500 Gal Spoils/80 Gal Water on T9SE6 or T9SH6		
Length	200 in	5080 mm
Width	96 in	2184 mm
Height	86 in	2337 mm
Weight, empty	5,465 lb	2479 kg
Trailer GVWR	10,000 lb	4536 kg
800 Gal Spoils/200 Gal Water on T18S		
Length	233 in	4880 mm
Width	102 in	2590 mm
Height	92 in	2337 mm
Weight, empty	8,255 lb	3744 kg
Trailer GVWR	18,000 lb	8172 kg


<http://www.ditchwitch.com/vacuum-excavators/hydro-excavators/fx30>



FX-30 Power

POWER			
POWER	U.S.		METRIC
Engine	Kubota® D1105-E3B		
Fuel	Diesel		
Cooling medium	Liquid		
Injection	Indirect		
Aspiration	Natural		
Number of cylinders	3		
Displacement	68.6 in ³		1.12 L
Bore	3.07 in		78 mm
Stroke	3.09 in		78.5 mm
Manufacturer's gross power rating (SAE J1995)	24.8 hp		18.5 kW
Rated speed	3,000 rpm		
Emissions compliance	EPA Tier 4		EU Stage IIIA
Fuel tank capacity	15 gal		57 L

<http://www.ditchwitch.com/vacuum-excavators/hydro-excavators/fx30>



FX-30 Hydraulic System

HYDRAULIC SYSTEM

HYDRAULIC SYSTEM

U.S.

METRIC

Pressure

2,500 psi

172 bar

Drive type

12V DC

Tank lift cylinder size (2)

3 in

76 mm

Tilt angle, max

45°

<http://www.ditchwitch.com/vacuum-excavators/hydro-excavators/fx30>

Flow Rate

2 GPM



Fall Semester Scope of Work

ID	Task Mode	Task Name	Duration	Start	Finish	16	Oct 16, '16	Oct 23, '16	Oct 30, '16	Nov 6, '16	Nov 13, '16	Nov 20, '16																																																																																																																																																																																																																																																																																																																																																																																																																																													
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0	✓	Project Schedule	26 days	Mon 10/17/16	Mon 11/21/16								1	✓	1 Statement of Work (SOW)	5 days	Mon 10/17/16	Fri 10/21/16								2	✓	2 Concept Designing	7 days	Mon 10/17/16	Tue 10/25/16								3	✓	3 Client Meeting	1 day	Tue 10/25/16	Tue 10/25/16								4	✓	4 Work Breakdown Structure (WBS)	1 day	Fri 10/28/16	Fri 10/28/16								5	✓	5 Tasks Project	1 day	Mon 10/31/16	Mon 10/31/16								6	✓	6 Team meet to discuss final concept idea	1 day	Tue 11/1/16	Tue 11/1/16								7	✓	7 Designing	14 days	Wed 10/26/16	Mon 11/14/16								8	✓	7.1 Research Chosen Design	14 days	Wed 10/26/16	Mon 11/14/16								9	✓	7.1.1 Find main mechanical parts	4 days	Wed 10/26/16	Mon 10/31/16								10	✓	7.1.1.1 cruch numbers	4 days	Wed 10/26/16	Mon 10/31/16								11	✓	7.1.2 Design Preliminary Concept for Remote System	13 days	Wed 10/26/16	Fri 11/11/16								12	✓	7.1.2.1 Find Remote Systems	1 day	Wed 10/26/16	Mon 10/31/16								13	✓	7.1.3 meet with Dr wong	1 day	Mon 10/31/16	Mon 10/31/16								14	✓	7.1.4 Cost Sheet 'Budget Sheet'	1 day	Fri 11/4/16	Fri 11/4/16								15	✓	7.2 Team Meet	3 days	Tue 11/1/16	Thu 11/3/16								16	✓	7.2.1 Finalize Parts	3 days	Tue 11/1/16	Thu 11/3/16								17	✓	7.2.2 crunch numbers	2 days	Wed 11/2/16	Thu 11/3/16								18	✓	7.2.3 Budget 'draft'	1 day	Thu 11/3/16	Thu 11/3/16								19	✓	7.3 3D Designing	14 days	Wed 10/26/16	Mon 11/14/16								20	✓	7.3.1 Draft 3D parts	12 days	Wed 10/26/16	Thu 11/10/16								21	✓	7.3.2 Create Mechanical Motion	12 days	Wed 10/26/16	Thu 11/10/16								22	✓	8 3D Design 'Draft' Review	13 days	Wed 10/26/16	Fri 11/11/16								23	✓	8.1 Submit Preliminary Design Concepts	12 days	Wed 10/26/16	Thu 11/10/16								24	✓	8.2 Present "draft presentation" Review	1 day	Fri 11/11/16	Fri 11/11/16								25	✓	9 Team/Prof Meet	3 days	Mon 11/14/16	Wed 11/16/16								26	✓	9.1 Budget Final	1 day	Tue 11/15/16	Tue 11/15/16								27	✓	10 Final Design Finished	1 day	Mon 10/31/16	Mon 10/31/16								28	✓	11 (4001) Project Proposal	7 days	Thu 10/27/16	Fri 11/4/16								29	✓	12 Update Client	1 day	Thu 11/10/16	Thu 11/10/16								30	✓	13 Report "draft"	1 day	Fri 11/11/16	Fri 11/11/16								31	✓	14 Report 'final draft'	1 day	Wed 11/16/16	Wed 11/16/16								32	✓	15 Final Presentation	1 day	Thu 11/17/16	Thu 11/17/16								33	✓	16 Final Report	1 day	Mon 11/21/16	Mon 11/21/16							
1	✓	1 Statement of Work (SOW)	5 days	Mon 10/17/16	Fri 10/21/16								2	✓	2 Concept Designing	7 days	Mon 10/17/16	Tue 10/25/16								3	✓	3 Client Meeting	1 day	Tue 10/25/16	Tue 10/25/16								4	✓	4 Work Breakdown Structure (WBS)	1 day	Fri 10/28/16	Fri 10/28/16								5	✓	5 Tasks Project	1 day	Mon 10/31/16	Mon 10/31/16								6	✓	6 Team meet to discuss final concept idea	1 day	Tue 11/1/16	Tue 11/1/16								7	✓	7 Designing	14 days	Wed 10/26/16	Mon 11/14/16								8	✓	7.1 Research Chosen Design	14 days	Wed 10/26/16	Mon 11/14/16								9	✓	7.1.1 Find main mechanical parts	4 days	Wed 10/26/16	Mon 10/31/16								10	✓	7.1.1.1 cruch numbers	4 days	Wed 10/26/16	Mon 10/31/16								11	✓	7.1.2 Design Preliminary Concept for Remote System	13 days	Wed 10/26/16	Fri 11/11/16								12	✓	7.1.2.1 Find Remote Systems	1 day	Wed 10/26/16	Mon 10/31/16								13	✓	7.1.3 meet with Dr wong	1 day	Mon 10/31/16	Mon 10/31/16								14	✓	7.1.4 Cost Sheet 'Budget Sheet'	1 day	Fri 11/4/16	Fri 11/4/16								15	✓	7.2 Team Meet	3 days	Tue 11/1/16	Thu 11/3/16								16	✓	7.2.1 Finalize Parts	3 days	Tue 11/1/16	Thu 11/3/16								17	✓	7.2.2 crunch numbers	2 days	Wed 11/2/16	Thu 11/3/16								18	✓	7.2.3 Budget 'draft'	1 day	Thu 11/3/16	Thu 11/3/16								19	✓	7.3 3D Designing	14 days	Wed 10/26/16	Mon 11/14/16								20	✓	7.3.1 Draft 3D parts	12 days	Wed 10/26/16	Thu 11/10/16								21	✓	7.3.2 Create Mechanical Motion	12 days	Wed 10/26/16	Thu 11/10/16								22	✓	8 3D Design 'Draft' Review	13 days	Wed 10/26/16	Fri 11/11/16								23	✓	8.1 Submit Preliminary Design Concepts	12 days	Wed 10/26/16	Thu 11/10/16								24	✓	8.2 Present "draft presentation" Review	1 day	Fri 11/11/16	Fri 11/11/16								25	✓	9 Team/Prof Meet	3 days	Mon 11/14/16	Wed 11/16/16								26	✓	9.1 Budget Final	1 day	Tue 11/15/16	Tue 11/15/16								27	✓	10 Final Design Finished	1 day	Mon 10/31/16	Mon 10/31/16								28	✓	11 (4001) Project Proposal	7 days	Thu 10/27/16	Fri 11/4/16								29	✓	12 Update Client	1 day	Thu 11/10/16	Thu 11/10/16								30	✓	13 Report "draft"	1 day	Fri 11/11/16	Fri 11/11/16								31	✓	14 Report 'final draft'	1 day	Wed 11/16/16	Wed 11/16/16								32	✓	15 Final Presentation	1 day	Thu 11/17/16	Thu 11/17/16								33	✓	16 Final Report	1 day	Mon 11/21/16	Mon 11/21/16																				
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Existing Technology #1

▶ Trailer Caddy Extreme

- ▶ 1) Capable of moving OTR/Tank Trailers up to 50,000 lbs.
- ▶ 2) Lifts Trailer Dolly Tongues up to 15,000 lbs.
- ▶ 3) 36 Volt 3 Battery System.



<http://www.teamcartcaddy.com/products/trailercaddyhextreme>



Existing Technology #2

- ▶ **Trailer Caddy HD Chain Drive**
 - ▶ 1) Pulls All Trailers Up to 50,000 lbs.
 - ▶ 2) Lifts Trailer Tongues up to 5,000 lbs.
 - ▶ 3) 36 Volt 3 Battery Powered System.



<http://www.teamcartcaddy.com/products/trailer-caddy-hd-chain-drive>



Existing Technology #3

▶ Haulle Trailer Tug

- ▶ 1) Towing Capacity Up To 40,000 lbs.
- ▶ 2) Tongue Weight Load Up To 15,000 lbs.
- ▶ 3) Radio Remote Control Drive and Steer.

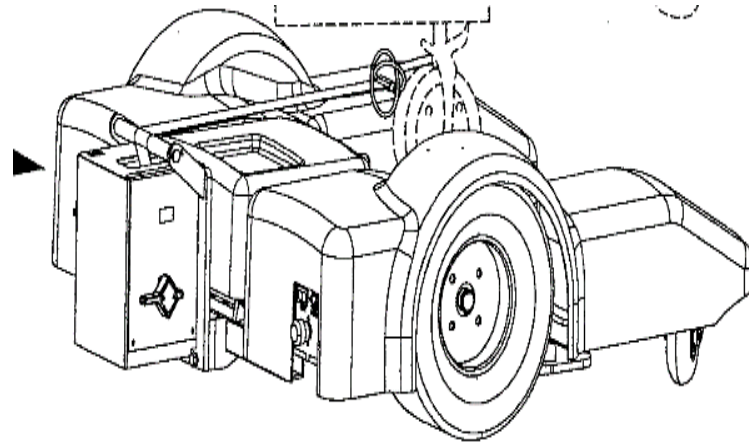


<http://www.kropfindustrial.com/conolift/trailer-tugs>



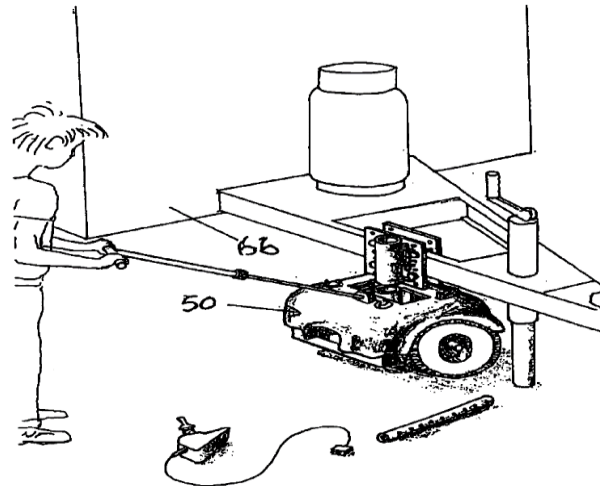
Patent Search #1

- ▶ *Tugbot* (Patent # US 20120215393 A1, August, 23rd, 2012).
 - ▶ 1) Has a first and second drive wheel system.
 - ▶ 2) A chassis constructed and arranged to support one or more internal and/or external components.
 - ▶ 3) Remote Controlled.



Patent #2

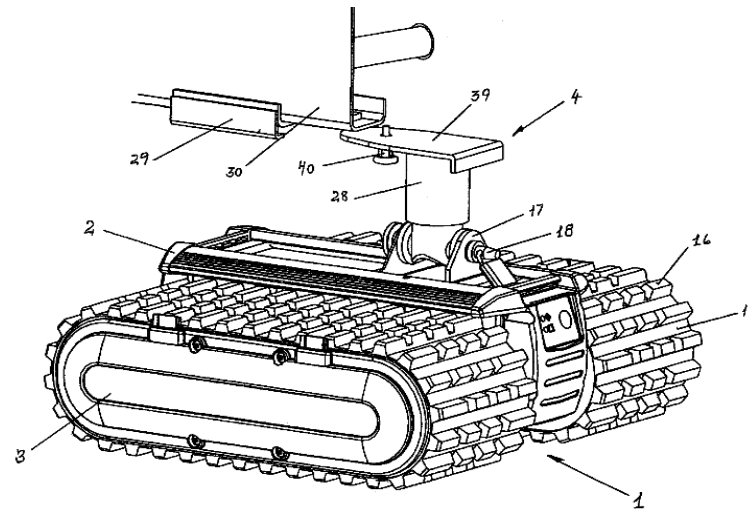
- ▶ *Compact Multipurpose Trailer Tug (Patent # US 6758291 B1, July 6, 2004).*
 - ▶ 1) Battery powered steerable tug apparatus for carrying a cantilevered tongue of a towable vehicle and comprising.
 - ▶ 2) A control device coupled with said drive train for selectively controlling rotation of said wheels whereby said tug may be positioned under said tongue.



Patent #3

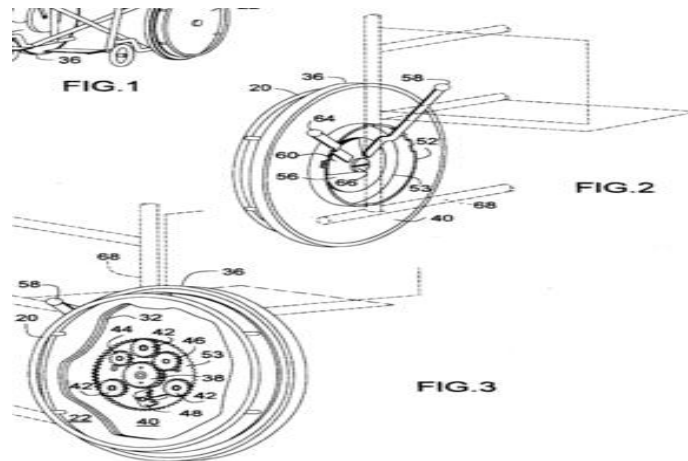
▶ *Drive Unit for Trailers and Caravans* (Patent # US 20090308667 A1, December 17th, 2009).

- ▶ 1) This tug was chosen based on the premise that it is operated entirely via electric power and is equipped with a remote control.
- ▶ 2) The team had also considered using tracks.



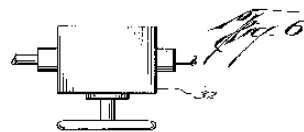
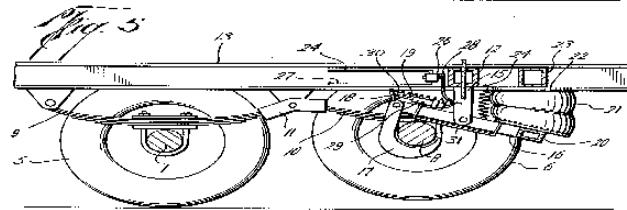
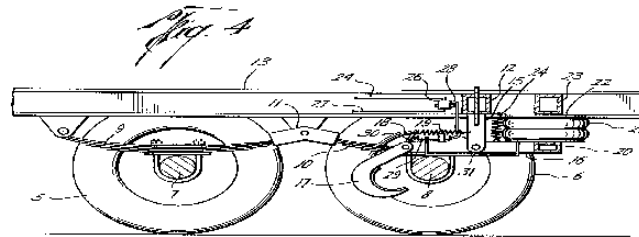
Patent #4

- ▶ *Wheelchair drive system with ratchet and wheel lock* (Patent # US 5743544 A, April 28th, 1998).
 - ▶ 1) This invention utilizes a ratchet driven wheel that propels the wheelchair forward.
 - ▶ 2) This could be applied to a trailer by adding a hydraulic piston mounted on the trailer frame to engage the ratchet assembly mounted on either an axle or on a wheel.



Patent #5

- ▶ **Axle Lift (Patent # US 3096995 A, July 9th, 1963).**
 - ▶ 1) Used to lift one axle of a tractor or trailer free of the road surface when the vehicle is traveling empty.
 - ▶ 2) Used for shifting the weight distribution of the vehicle to provide less tire wear and easier steering of the vehicle.



Erick G. Richardson, Jr.
INVENTOR

BY *Rosemarie O. Moffatt*
ATTORNEY

Trailer Standards and Regulations

▶ 1) Oklahoma Trailer Dimension Laws:

- ▶ A) Total length: 65 feet.
- ▶ B) Trailer length: 40 feet.
- ▶ C) Width: 102 inches.
- ▶ D) Height: 13 feet 6 inches.

▶ 2) Oklahoma Trailer Towing Laws:

- ▶ A) Every trailer shall be equipped with a coupling device designed and constructed so that the trailer will follow in the same path as the vehicle towing it without whipping or swerving from side to side.



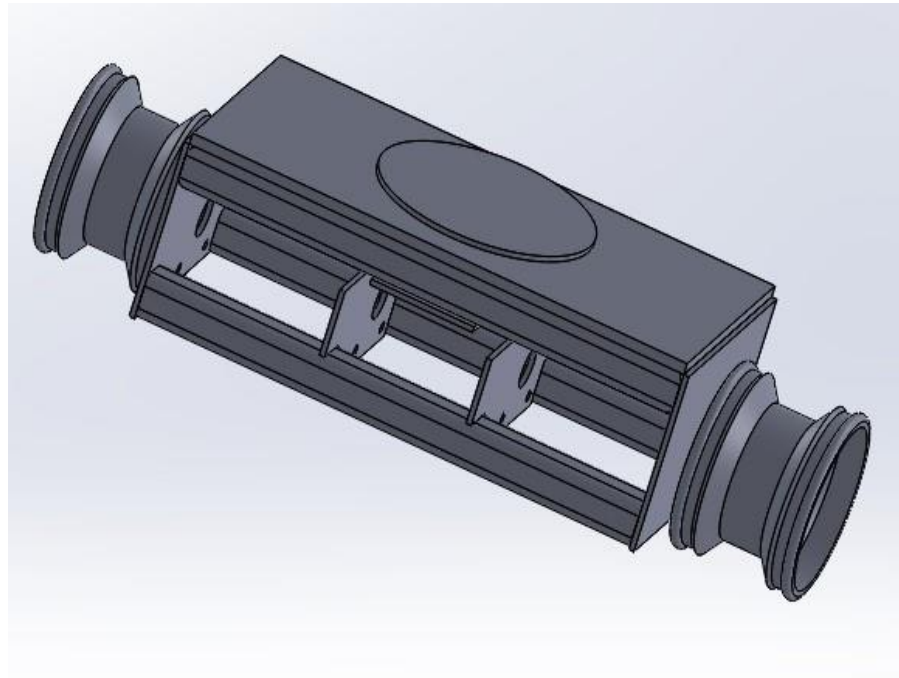
National standards

- ▶ 1) The operator of a motor vehicle or trailer must maintain the vehicle in a condition that ensures:
 - ▶ A) Its safe operation; and
 - ▶ B) The safety of the driver, anyone else in the vehicle and other road users.

- ▶ 2) The condition of the vehicle or trailer must be maintained along with the following:
 - ▶ A) its steering, brakes, suspension, wheels, tyres, towing equipment and the means of transmitting engine power to the driven wheels; and
 - ▶ B) the lights and reflectors that it is required to have under the Vehicle Standards; and
 - ▶ C) the strength of its structure; and
 - ▶ D) the driver's view of the road; and
 - ▶ E) its exhaust system; and
 - ▶ F) its fuel system.

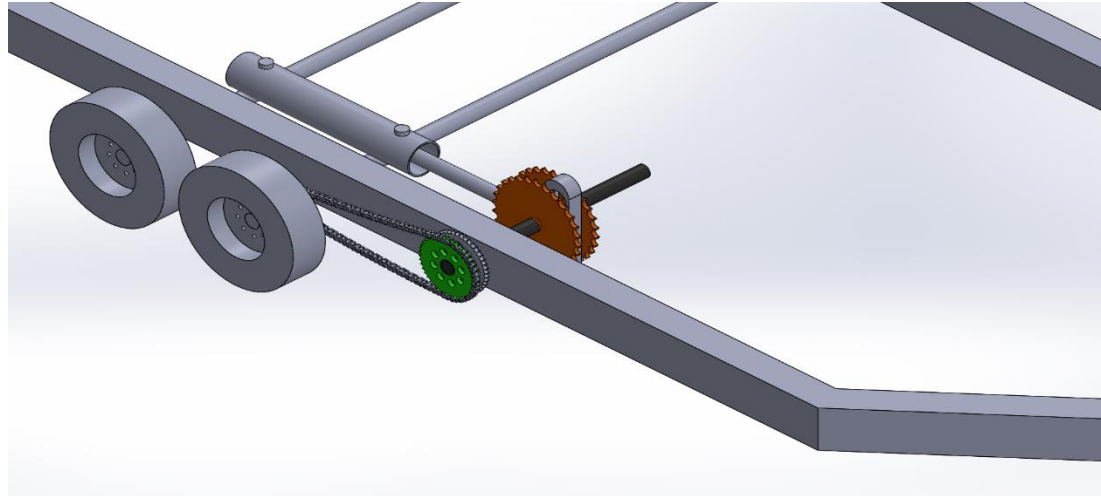
Preliminary Design Concepts

1) “Segway”© Tug

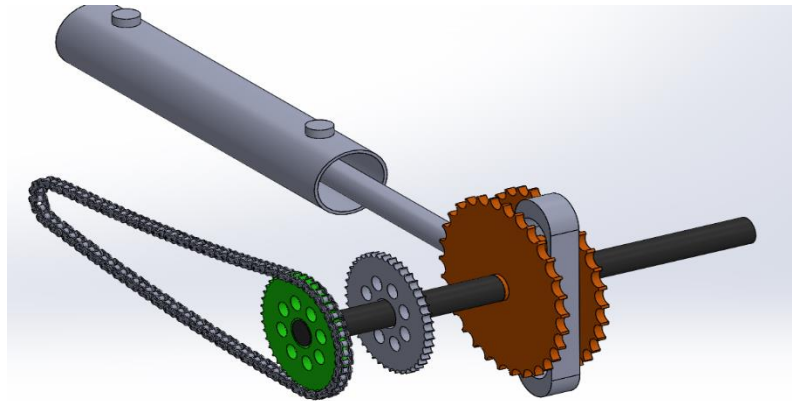


2) Chain and Sprocket

❖ Top View

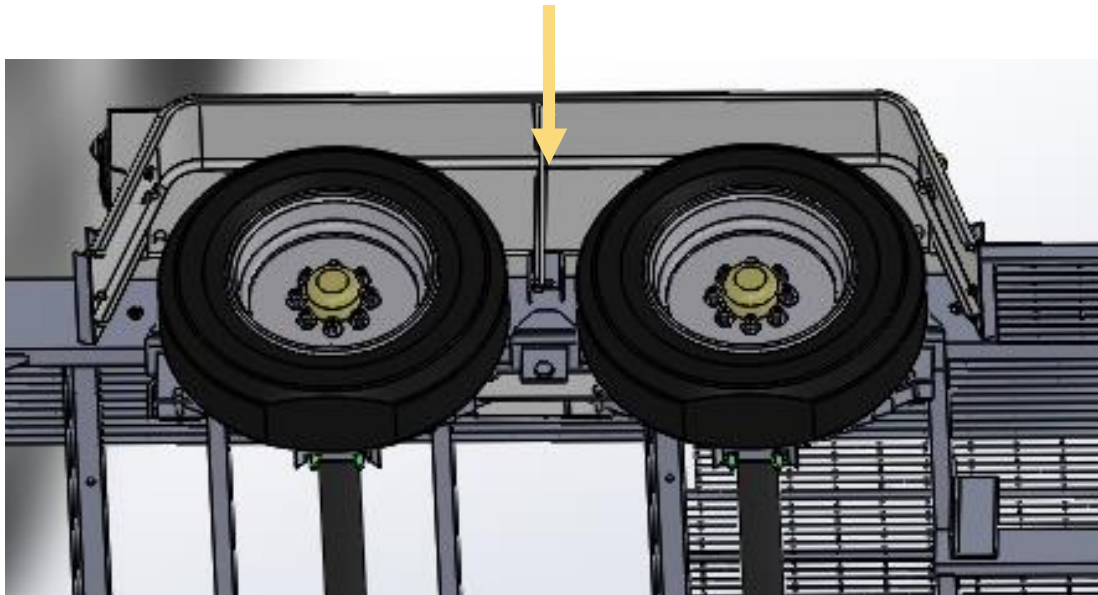


❖ Chain and Sprocket Assembly



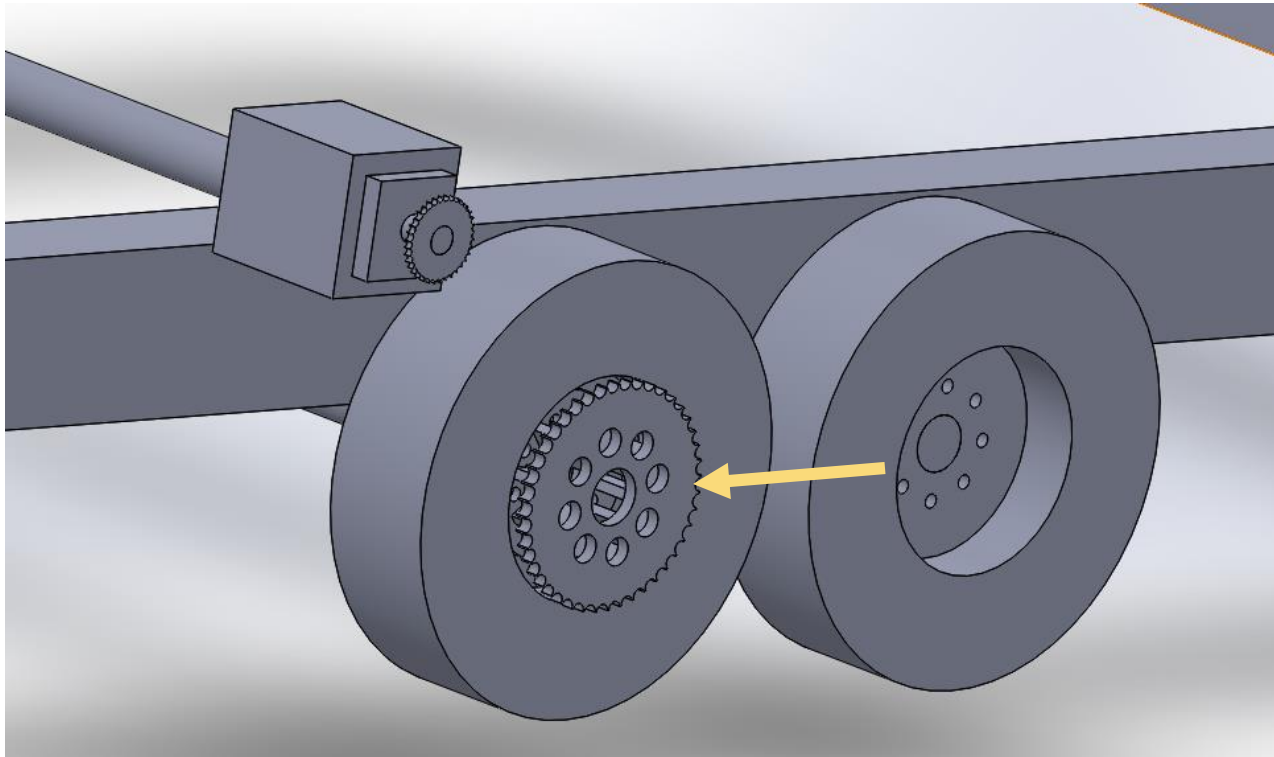
3) Attaching a drive tire onto the trailer tires.

- ❖ By rotating the attached tire, it would drive the trailer forward.



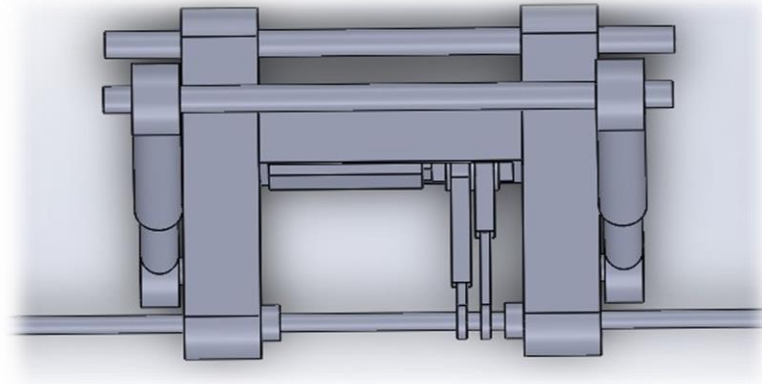
4) Fabricating a drive motor on wheel hubs.

- ❖ Powered by electric or hydraulics.

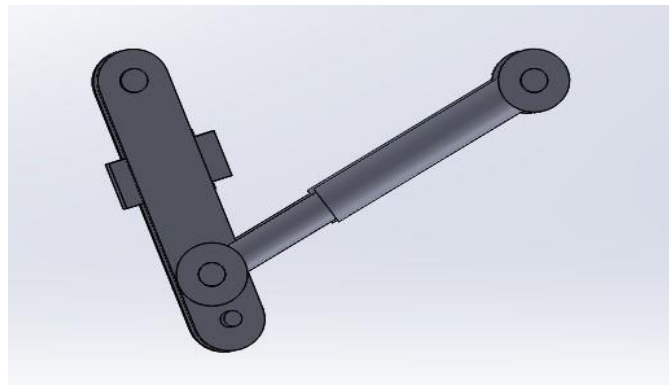


5) Ratcheting Axle Drive

❖ Top View



❖ Side View



Competitors and Similar Products

❖ Hendrickson – Steerable Truck Lift Axle

❖ SCT08 -

Model	Capacity	Suspension Weight	Hanger to Axle Spacing	Wheel Cut
SC08	UP TO 8,000 LBS	665 LBS. FOR 6-HOLE 675 LBS. FOR 8-HOLE	22.1"	31°

❖ SCT10 -

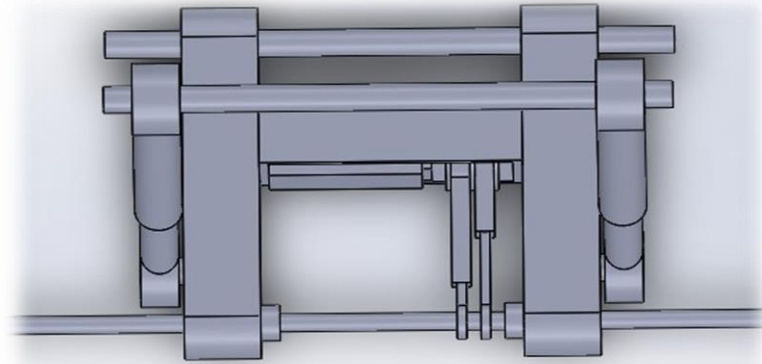
Model	Capacity	Suspension Weight	Hanger to Axle Spacing	Wheel Cut
SC10	UP TO 10,000 LBS	665 LBS. FOR 6-HOLE 675 LBS. FOR 8-HOLE	22.1"	31°



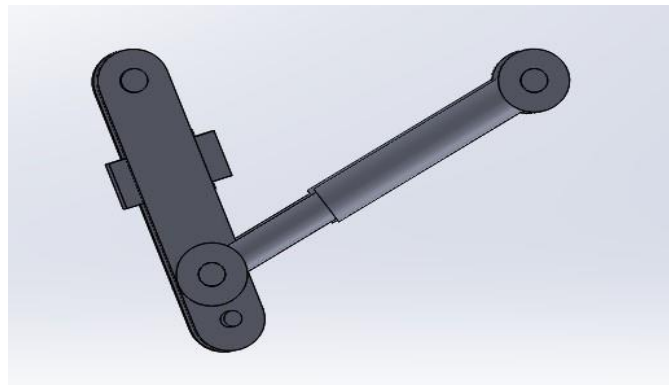
<http://www.hendrickson-intl.com/Auxiliary/Truck-Steerable-Lift-Axle/COMPOSILITE-SCT10#tabs>

❖ 5) Ratcheting Axle Drive

❖ Top View

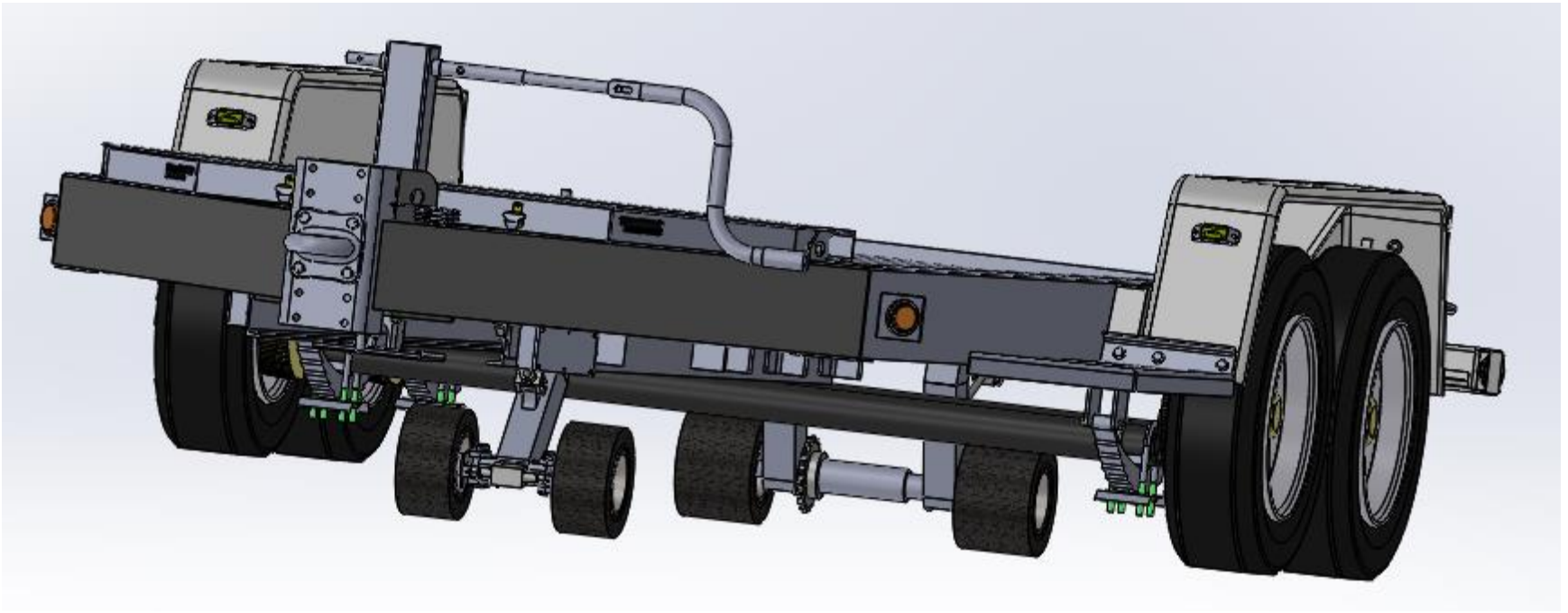


❖ Side View



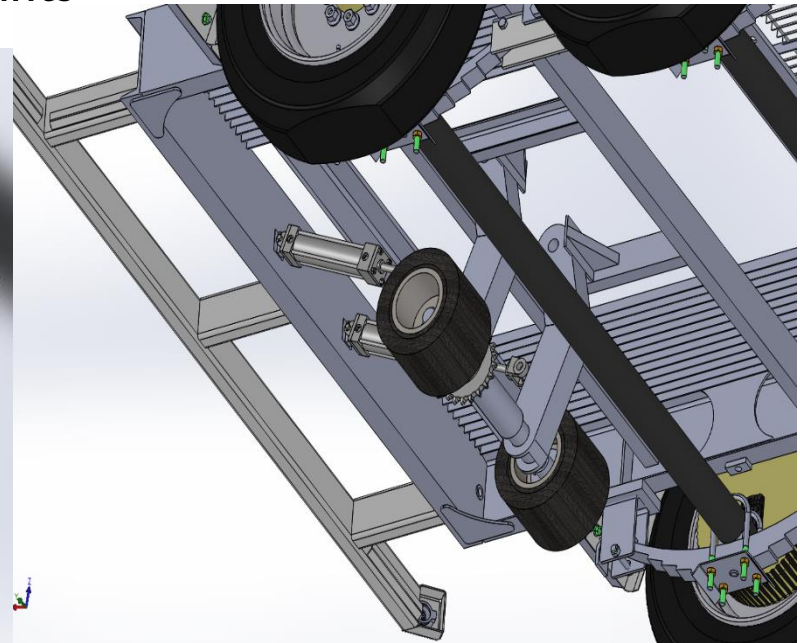
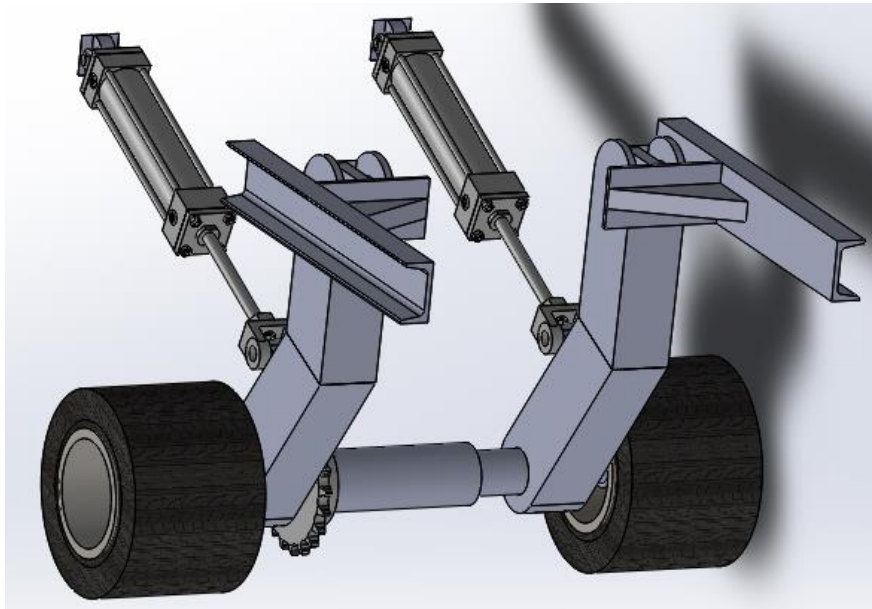
Final Design

- ❖ Independent drive System
- ❖ Rear drive axle in the back
- ❖ Steer axle located in the front



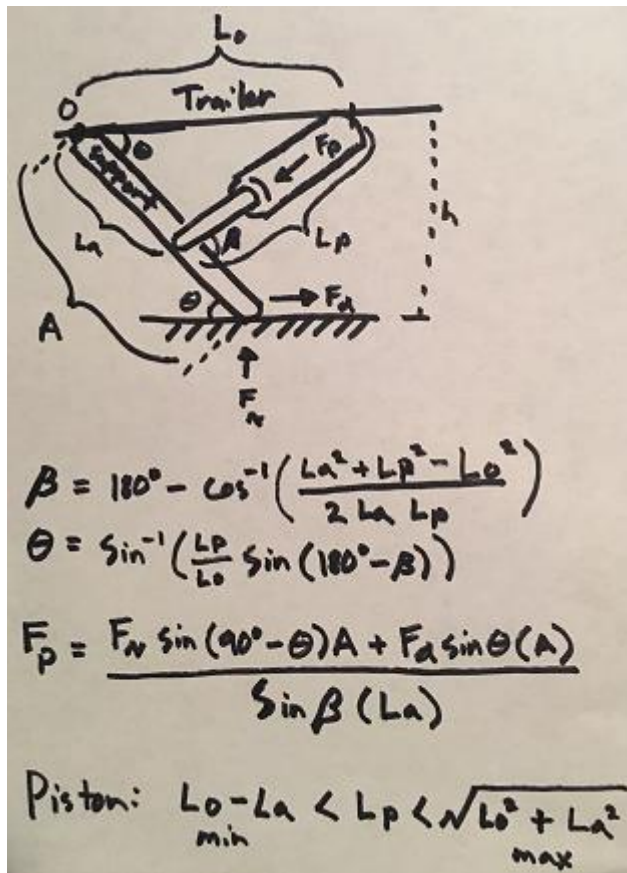
Final Design Continued

- ❖ Hydraulic Lift axle mounting
- ❖ Drive system: hydraulic/Electric motor
- ❖ Drive System mounted between support arms
- ❖ Chain driven
- ❖ Solid rubber tires for weight constraints



Calculations

- ❖ Piston geometry evaluation using Law of Cosines
- ❖ Geometry is approximately to scale with drawings

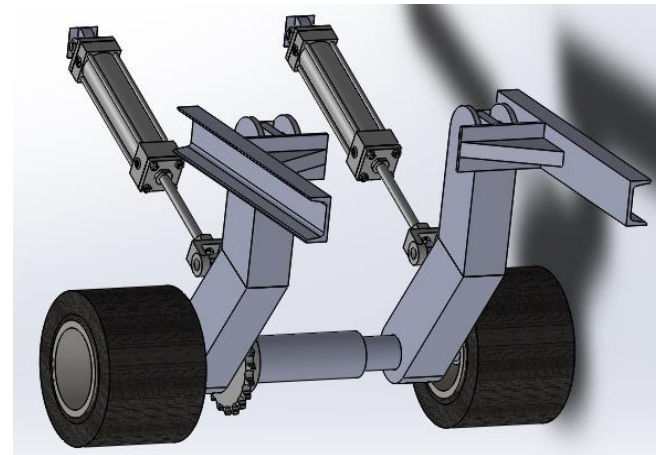


Solving for Piston Length		
Drop Down Axle Piston Reactions		
Variable	Value	Units
Number of Pistons (N)	2	
Distance between support and piston origins (L _o)	2.097	ft
Angle of support with trailer (θ) *closest to 90 degrees is best	58.01809	degrees
Axel support length (A)	1.483	ft
Distance piston pinned on support (L _a)	0.864	ft
Distance between trailer and end of support (h)	1.2575	ft
Max Piston Length	2.268018	ft
Min Piston Length	1.233	ft
Piston length (L _p)	1.795292	ft
Force of piston	86.98719	lbs
Angle of support with trailer (θ)	1.012093	rad
Lower angle between piston and support (β)	1.707557	rad

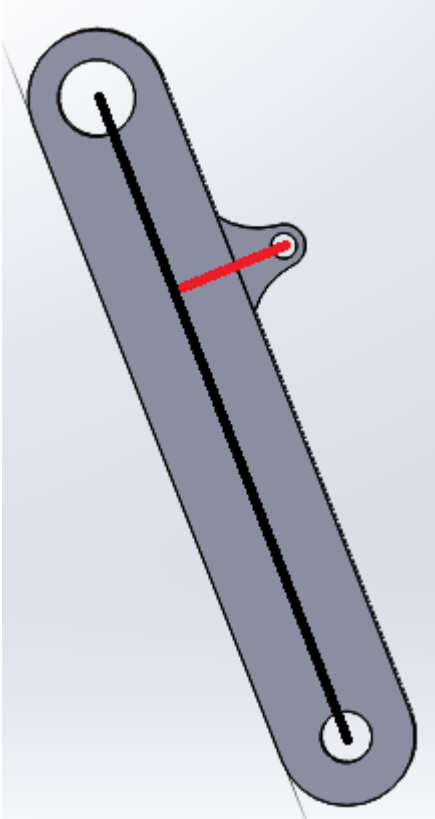
Calculations

- ❖ Support arm calculation using Distortion Energy Theory
- ❖ Orientation of the arms and piston transmits the load into the arms
- ❖ Support arm dimensions
3x4x1/4 rectangular tubing
- ❖ Yields Safety Factor of 3.6

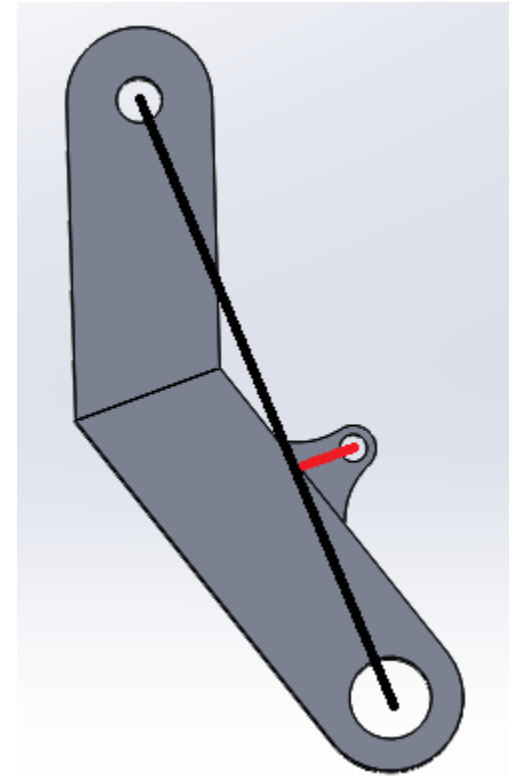
Support Arms Strength		
Variable	Value	Units
Material Type	A513	~\$20/ft
Modulus of Elasticity [E]	30000000	psi
Yield tensile Strength (Sy)	72000	psi
Beam Width (b)	3	in
Beam Height (h)	4	in
Beam Wall Thickness (t)	0.25	in
Max Deflection (d)	-0.0072475	in
Safety Factor (n) "Distortion Energy Theory"	3.57888606	



Calculations



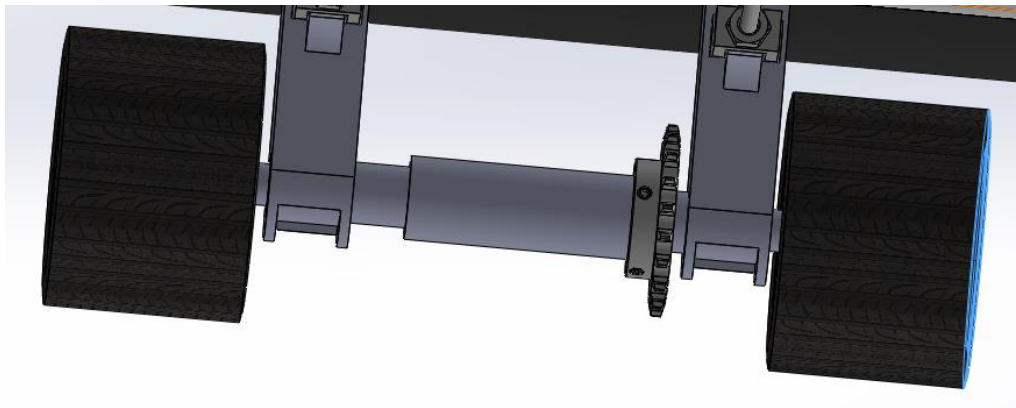
- ❖ 2 piece orientation allows for geometric clearance.
- ❖ Angle reduces error in linear approximation.
- ❖ A plate welded over angle can increase strength if needed.



Calculations

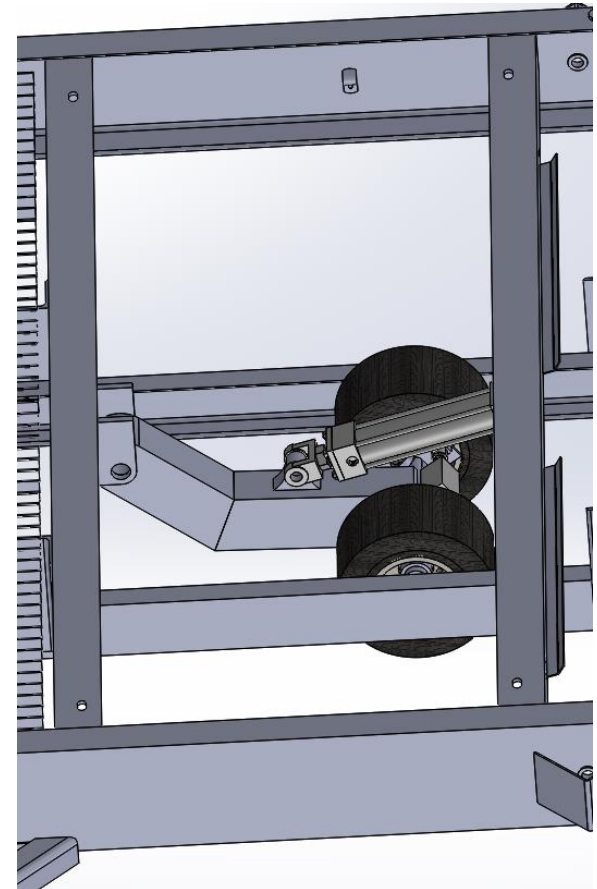
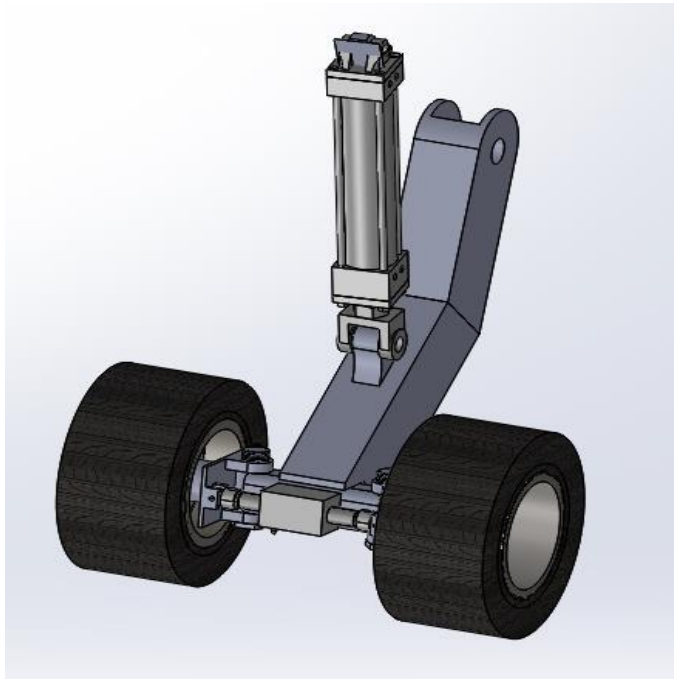
- ❖ Axle calculations evaluated using Distortion Energy Theory
- ❖ Current Axle Diameter 1.75 in.
- ❖ Yields safety factor of 2.8

Axel Strength		
Variable	Value	Units
Material Type	A513	
Yield Strength	72000	psi
Modulus of Elasticity [E]	30000000	psi
Axel Diameter (D)	1.75	in
Axel Length (L)	28	in
Wheel Distance from Support (x)	3	in
Safety Factor (n) "Distortion Energy Theory"	2.833698	



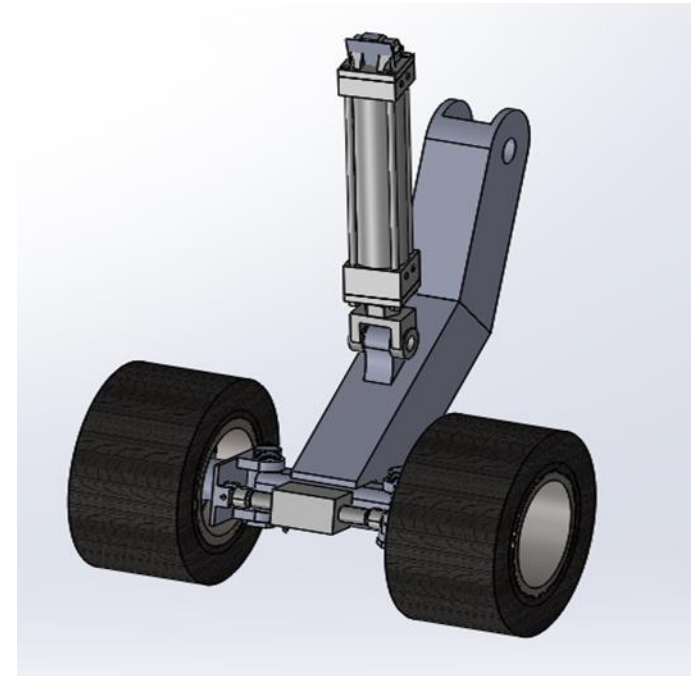
Final Design Continued

- ❖ Hydraulic Steer lift Axle
- ❖ Mounted to cross members in main frame.
- ❖ Double ended cylinder for steering
- ❖ Solid rubber tires for weight constraints



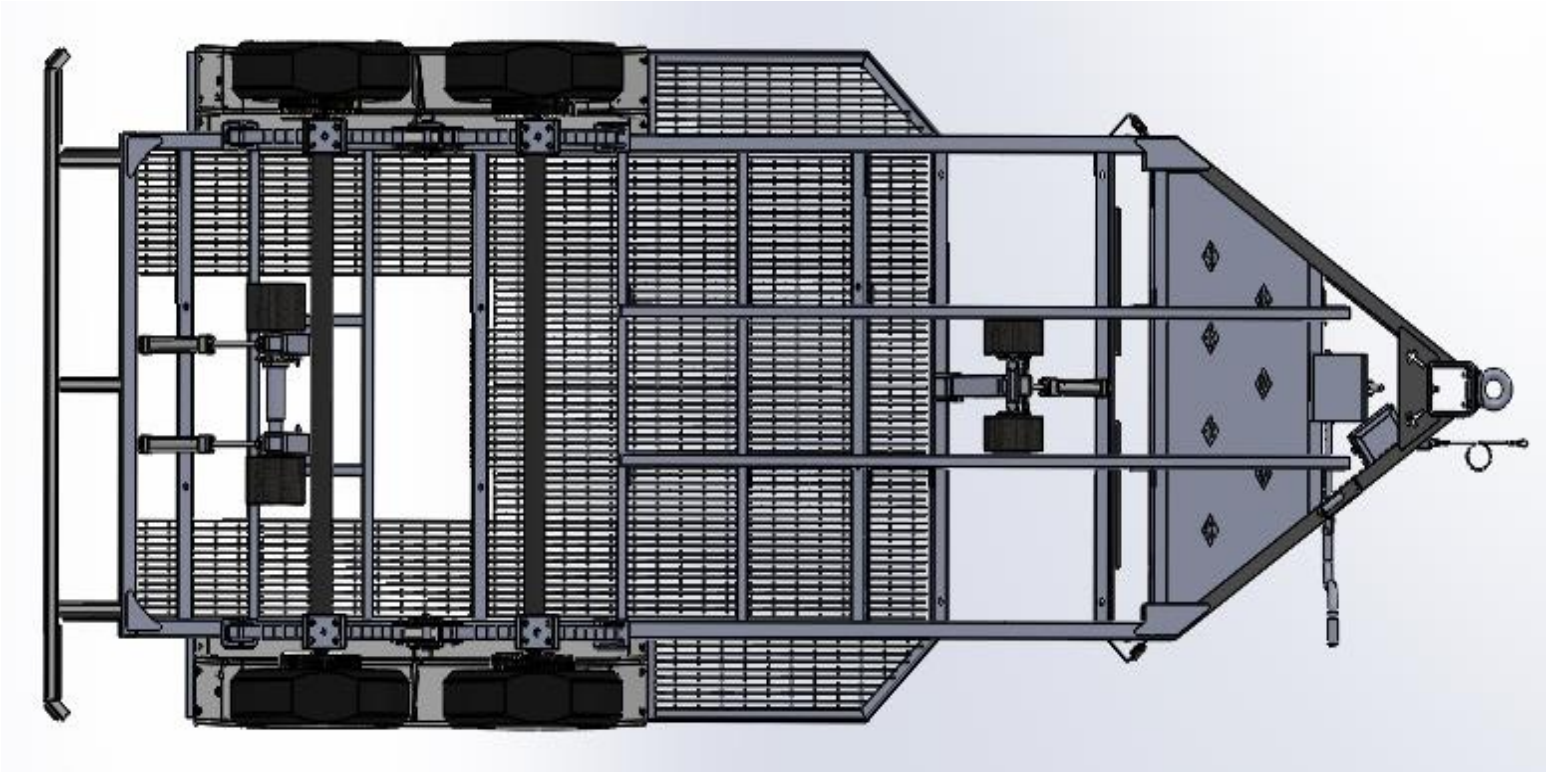
Final Design Continued

- ❖ Weight distribution testing needed for axle & support arm sizing.
- ❖ Torsional calculations needed for connection pin and support arms.



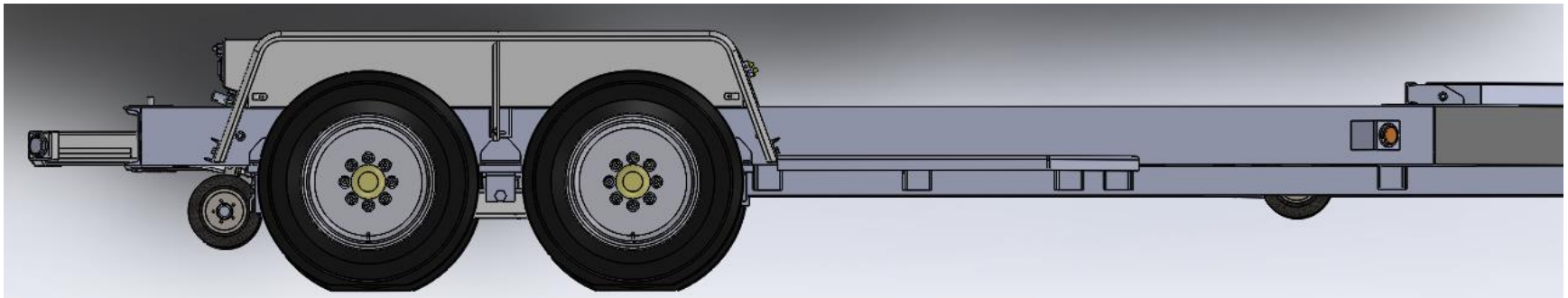
Final Design Continued

- ❖ Location of Drive axle
- ❖ Location of Steer system

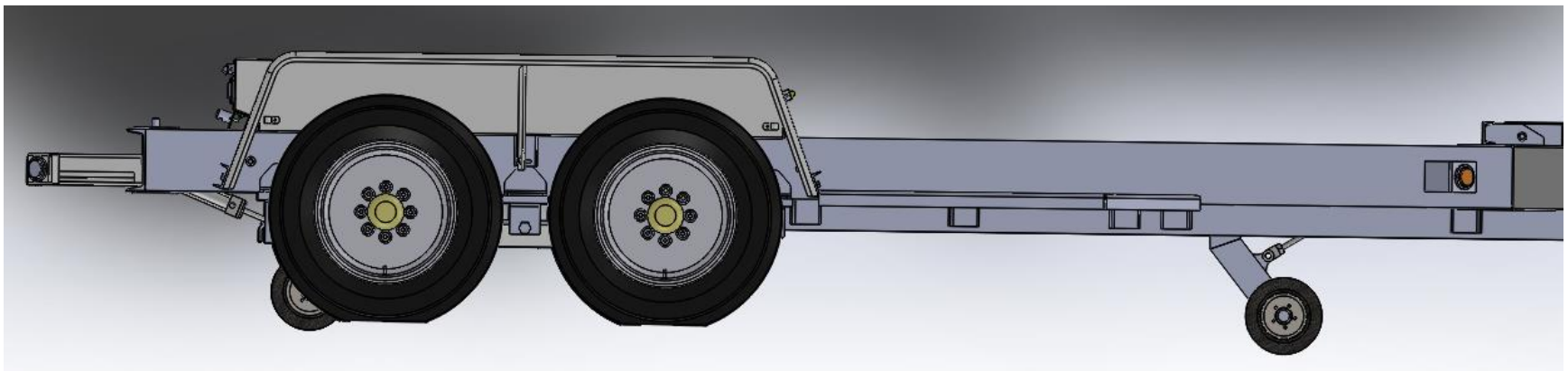


Final Design Continued

❖ Side view of lifted axles stowed away



❖ Side view of engaged drive and steer axles



BAE Freshman Involvement

- ▶ **Team #1: Tires or Tracks:**
 - ▶ 1) Pros and Cons associated
 - ▶ 2) Size of Tires or Tracks

- ▶ **Team #2 Remote Control System:**
 - ▶ 1) Tethered Remote vs Wireless Remote
 - ▶ 2) Control System Parameters
 - ▶ A) Engage and Disengage Dropdown Lift Axle
 - ▶ B) Steering and Drive



Tire #1

- ❖ **Traction SF XG Superior Press – On Rubber Tire**
 - ❖ Front Tires (9x5x5) Rated for 1741 lbs. Price: \$129.46
 - ❖ Back Tires (10x7x6-1/4) Rated for 3100 lbs. Price: \$116.13



<http://www.brunettetire.com/ProductDetail.cfm?sku=R0100070063A>



Tire #2

- ❖ **Press – On Forklift Tires (Polyurethane Cushion).**
- ❖ Price: \$112 – \$180.
- ❖ Front Tires (9x5x5) Rated for 2680 lbs.
- ❖ Back Tires (10x7x6-1/4) Rated for 4800 lbs.



http://www.brunettetire.com/mh_cushion.cfm#specs



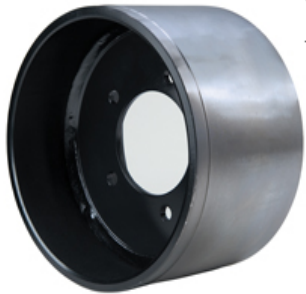
Press-On Wheels

❖ Wheels can be made up to 30”, as needed.

Press-On Wheels

Trelleborg's Press-On-Band Wheels are designed for heavy load applications and counterbalanced forklift and trailers.

Trelleborg is a leading supplier of high quality wheel assemblies for industrial applications, such as material handling equipment, industrial trailers, personnel carriers, ground support equipment, aerial lifts, construction equipment and many others. Our wheel assemblies can be designed to specific OEM requirements or can be manufactured to individual needs.



Trelleborg's Press-On-Band Wheels are designed for heavy load applications and counterbalanced forklift and trailers.

- Up to 30" Solutions
- Any size and thickness
- Optional mold on construction
- Heavy duty Press-On-Band for applications such as passenger boarding bridges with loads up to 16 tons

IMAGE PRESS-ON WHEELS



Hydraulic Cylinders

- ❖ Three Hydraulic Cylinders
- ❖ 2" bore x 8" stroke.
- ❖ Max push force – 3,768 lbs.
- ❖ Max pull force – 3,396 lbs.
- ❖ Max pressure 1,200 psi
- ❖ Price \$480.75 each



Wireless vs Tethered Remote

1) Wireless Remote

- 1) Advantages: Mobility, Convenience.
- 2) Disadvantages: Batteries, more expensive.

2) Tethered Remote

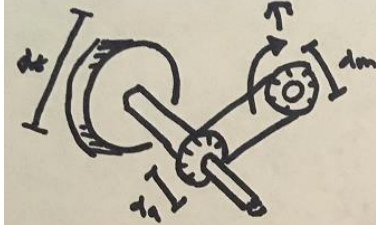
- 1) Advantages: Direct Signal, Inexpensive.
- 2) Disadvantages: Limited Range of Usage, Convenience.



Spring Semester

- ❖ Drive system requirements
- ❖ Subject to change with motor and sprocket selection
- ❖ Slip dependent on final component selection
- ❖ Hp at Maximum grade

Torque Requirements		
Variable	Value	Units
Number of motors (N)	1	
Number of roller chains (n)	1	
Diameter of tire (dt)	10	inches
Diameter of axel sprocket (da)	7.88	inches
Diameter of drive sprocket (dm)	4.98	inches
Torque required (T)	-8561.078	lbs*inches
Force per chain (Fc)	-3438.184	lbs
Motor rpm	53.335584	rpm
Motor Hp	-7.244904	Hp



Tire Circumference " C_t "
 Tire RPM = $\frac{60 \times V}{C_t}$

$$T = \frac{d_t \times F_d \times d_m}{2 \times d_a}$$

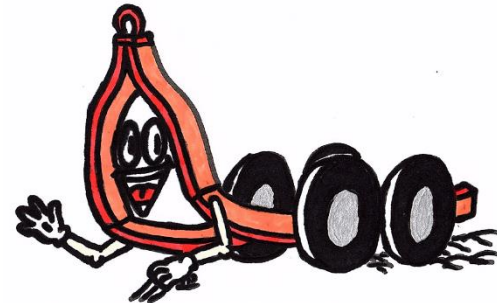
$$F_c = \frac{d_t \times d_a}{F_d}$$

$$\text{Drive RPM} = \frac{d_a \times \text{Tire RPM}}{d_m}$$

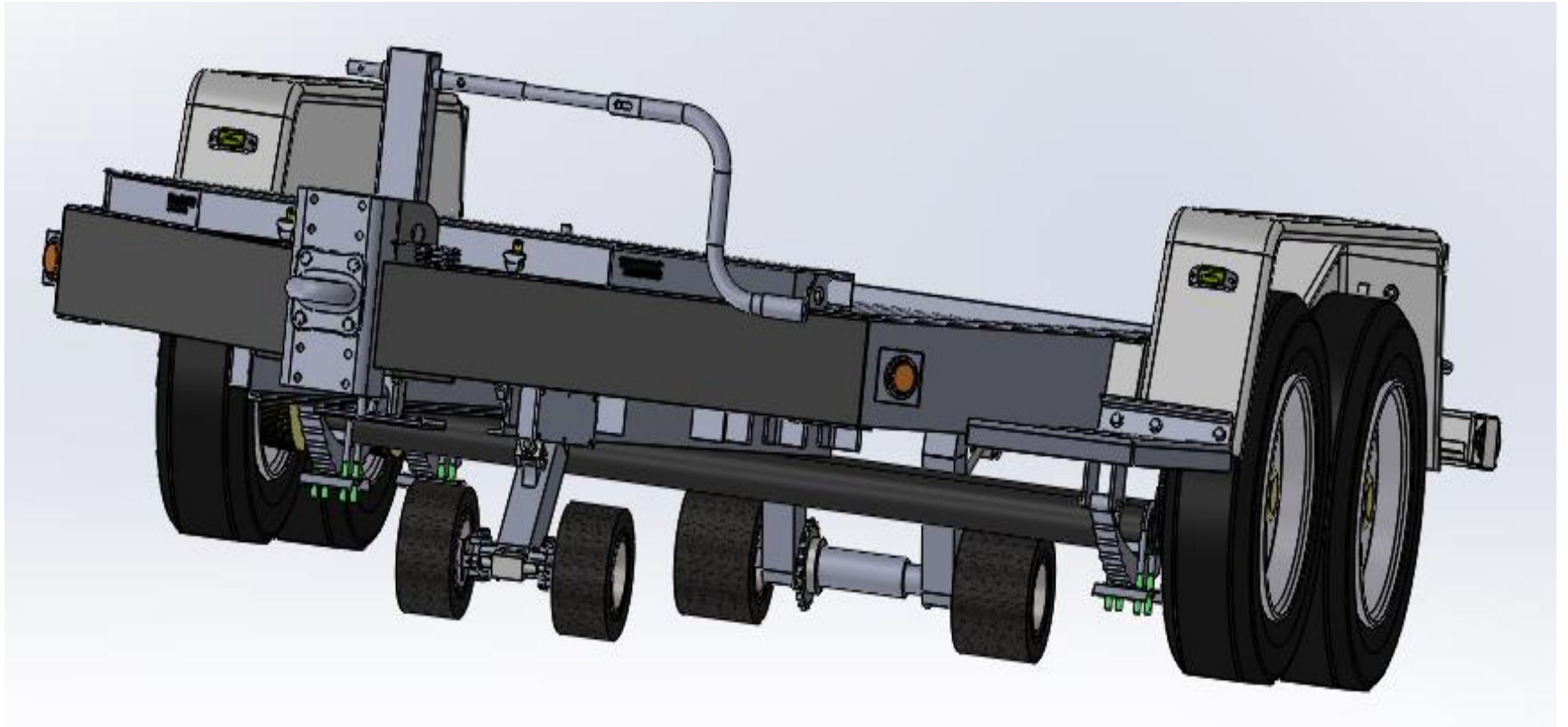
$$\text{Drive HP} = \frac{T \times \text{Drive RPM}}{63025}$$

Spring Semester

- ❖ Future Plans:
 - ❖ Calculations on steer system
 - ❖ Cost analysis
 - ❖ Specification of parts & materials
 - ❖ Fabrication of Design
 - ❖ Test the Design



Final Design Assembly



Questions?





SUBMITTED BY

James Collingsworth | Colten Leach | Konner Kay | Skyler Sheperd | Trey Minton

Charles Machine Works - Ditch Witch

December 2nd, 2016.

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Abstract

The objective of this project is the development of a system for Charles Machine Works, that will enable the FX-30 vacuum excavator to move without the use of a standard motorized vehicle. The design must meet the following parameters (as specified by Ditch Witch™): operate on hard surfaces, self-propelled, must be stowed on the trailer, operated by a remote control and the top speed achieved should be 1 – 1 ¼ mph. The design will handle hard surfaces such as, pavement, gravel, asphalt and hard ground. It is not designed for mud, or sand. The design must have its own mechanism for braking, or utilize the existing trailer brakes. In addition, it could incorporate both braking systems together as a design failsafe. The remote control system can be tethered or wireless, it was not specified which the client preferred. The top speed achieved will be a slow walking pace.

Statement of Work

This project will consist of designing and fabricating a system that will maneuver the FX-30 Vacuum Trailer on hard pavement at a slow speed (1 - 1 ¼ mph). The FX-30 Trailer that the team are designing for will be provided to Oklahoma State University by Charles Machine Works – Ditch Witch™. The students will perform the testing of their design on the trailer at Oklahoma State University. The fabrication for the design will be done at OSU and at Ditch Witch™ as needed.

The overall objective of this project is to improve the FX-30 Vacuum Trailer by allowing it to move without a vehicle. The data that will be collected through testing will measure the amount of HP needed to move the trailer, how much torque produced, max gradient the trailer can climb, effectiveness on different terrain and which design performs better (hydraulics, ratcheting, electric motor).

Deliverables

- 1) Conceptual Design of the System
- 2) Fabrication and integration of the design onto the FX-30
- 3) Testing procedures and experimental data collection.
- 4) Results and Summary of completed design

5) Final Report

Work Breakdown Structure

WBS 1.0 Project Overview

Details the contents of the project and its purpose. Work is complete after meeting with the client and receiving the approval for the proposed solution.

WBS 1.1 – Introduction

Work with Charles Machine Works, Ditch Witch™ to develop a design that correlates to their problem statement. Task is complete once a general overview of what the client expects is completed.

WBS 1.2 – Problem Statement

Analyzing and interpreting the client's desires to ensure the project is developed to meet their needs. Task is complete once the problem statement is well defined.

WBS 1.3 – Customer Requirements

Communicate with the client to ensure that the final product produced meets their expectations. Task is complete after the client specifies what the intended product must do.

WBS 1.4 – Proposed Solution

Meet with Ditch Witch™ to discuss the design. Task is complete when the conceptual design is proposed to the client and an approval is given.

WBS 2.0 Documentation and Procedures

Research relevant patents and documents that correlate to the design. Work is complete once all of the documentation and procedures have been sorted for relevance and organized accordingly in a word file.

WBS 2.1 Ditch Witch Trailer Research

Utilize Ditch Witch™'s website to find trailer specifications. Task is complete once the trailer specifications have been documented.

WBS 2.2 Patent Search

Find relevant patents that could potentially be utilized in the design. Task is complete after the patents are cited and documented.

WBS 2.3 Conceptual Drawings (Solidworks, Freehand)

Produce drawings for the trailer drive system. Task is complete when the drawings are finished.

WBS 3.0 Client Approval

Meet with the client and discuss the proposed system for the trailer. Work is complete once the client approves the design.

WBS 3.1 Client Design Review

Discuss the system with the client by way of drawings, calculations, documentation. Task is complete once the client approves of the proposed concept.

WBS 4.0 Fabrication of Lift Axle

Fabricate and install the Lift Axle onto the FX-30 Trailer. Work is complete once the lift axle has been fabricated and mounted to the trailer.

WBS 4.1 Materials Required for Production

Gather materials needed to begin fabricating the system. Task is complete once all the parts for the design have been collected.

WBS 4.2 Fabrication

Talk with Ditch Witch™ and the BAE lab to begin fabricating parts needed to complete the system. Task is complete once all the parts needed have been produced.

WBS 4.3 Install Lift Axle

Work with Ditch Witch™ to install the lift axle onto the FX-30 Trailer. Task is complete once the lift axle is mounted to the trailer.

WBS 5.0 Integration of Remote Control (Spring Semester)

Install and mount the control modules onto the Lift Axle. Work is complete once the system is fully functional.

WBS 5.1 Install Control Modules

Install control modules onto the wheel hubs and wire in the components. Task is complete once the control modules are fully functional.

WBS 5.2 Analyze Diagnostics

Install any remaining components that may be necessary for the system to steer, drive and brake. Task is complete once the trailer is able to steer, drive and brake.

WBS 5.3 Functional Check of Controls

Perform checks on all the systems on the trailer to ensure they are working properly. Task is complete once the systems have been verified to be working.

The Statement of Work and WBS can be seen collectively in Figure 1, Team Trot'n trailer's task list.

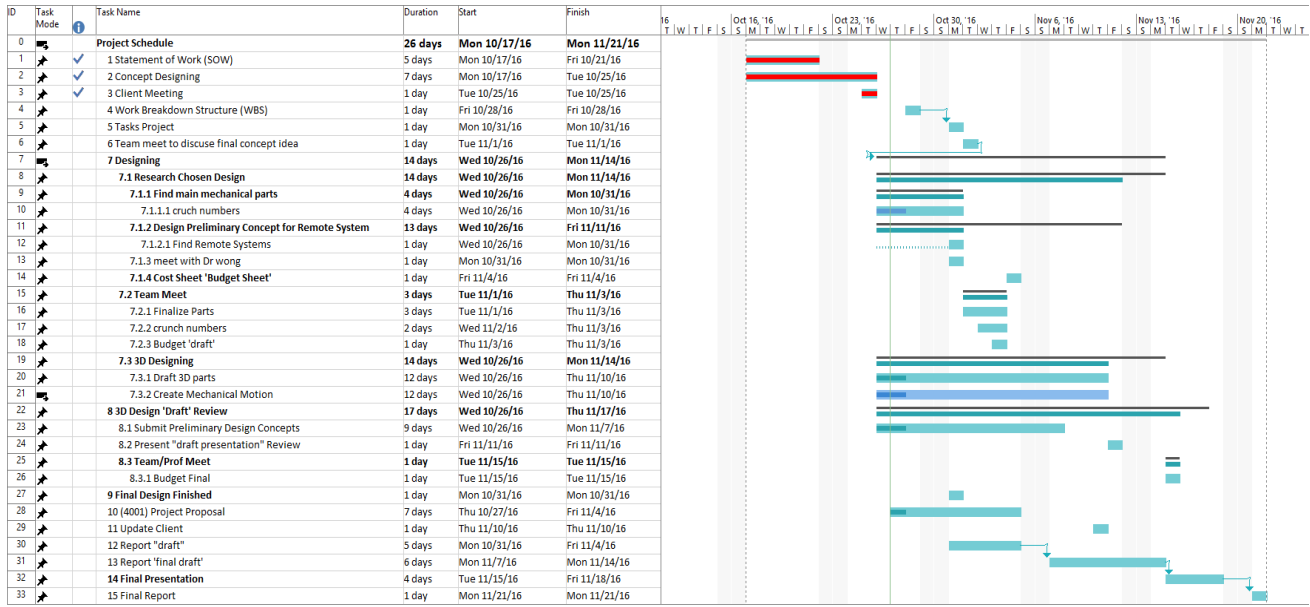


Figure 1. Task List for Fall Semester.

Introduction

Ditch Witch™ is an innovative company with a focus on the development of machinery that enable their customers to work more efficiently. Ditch Witch™ produces various types of equipment such as: trenchers, directional drills, skid steers, and vacuum excavators. In addition, Ditch Witch™ is always striving to further develop and improve their existing products.

The Senior Design Team was tasked to develop an innovative way to move the FX-30 excavator trailer at a slow speed of approximately (1 mph) on hard pavement, (as specified by Ditch Witch™) without the use of a standard motorized vehicle. The FX-30 excavator trailer can be seen in Figure 2.



Figure 2. FX-30 vacuum excavator in the field.

The vacuum excavators are used in many applications such as: exposing buried utility lines, cleaning out storm drains, directional drilling site cleanup, water leak repair, valve box cleanout, utility vault cleanout, commercial and residential debris cleanup and landscaping, and posthole digging. The team researched methods for towing large objects such as: airplanes, boats, trailers, etc. The most common method for moving large objects without the use of a truck is by way of a trailer tug. However, after meeting with our client, a trailer tug is not a viable solution. The client specified product must enable their trailers to move independently and not be restricted to movement only by a vehicle. The team brainstormed possible alternatives to move the trailer. The final design will consist of adding a lift axle on the front of the trailer and another behind the rear axle. An example of a lift axle can be seen in Figure 3.



Figure 3. Hendrickson Steerable Lift Axle.

The lift axle attached on the front of the trailer will be used for steering and the back-rear axle will be the drive. By modifying the trailer and installing a drivable and steerable lift axle, the trailer can move freely without a standard motorized vehicle. Currently, the team is further developing the design to ensure exceedance of Ditch Witch™s expectations. By implementing these modifications to Ditch Witch™s existing products, Ditch Witch™ will generate more income, because the product is convenient for the consumers.

Technical Literature Review

The FX-30 is the trailer that the team will be utilizing for their design with Ditch Witch™. The trailer itself can be seen in Figures 4 and 5.



Figure 4. FX-30 trailer front view.



Figure 5. FX-30 back view.

The design specifications for the FX-30 were provided by Ditch Witch™ and can be seen in Tables 1-3.

Table 1. FX-30 Trailer Dimensions

DIMENSIONS			
DIMENSIONS	U.S.	METRIC	
500 Gal Spoils/80 Gal Water on T9SE6 or T9SH6			
Length	200 in	5080 mm	
Width	96 in	2184 mm	
Height	86 in	2337 mm	
Weight, empty	5,465 lb	2479 kg	
Trailer GVWR	10,000 lb	4536 kg	
800 Gal Spoils/200 Gal Water on T18S			
Length	233 in	4880 mm	
Width	102 in	2590 mm	
Height	92 in	2337 mm	
Weight, empty	8,255 lb	3744 kg	
Trailer GVWR	18,000 lb	8172 kg	

Table 2. Power

POWER		
POWER	U.S.	METRIC
Engine	Kubota® D1105-E3B	
Fuel	Diesel	
Cooling medium	Liquid	
Injection	Indirect	
Aspiration	Natural	
Number of cylinders	3	
Displacement	68.6 in ³	1.12 L
Bore	3.07 in	78 mm
Stroke	3.09 in	78.5 mm
Manufacturer's gross power rating (SAE J1995)	24.8 hp	18.5 kW
Rated speed	3,000 rpm	
Emissions compliance	EPA Tier 4	EU Stage IIIA
Fuel tank capacity	15 gal	57 L

Table 3. Hydraulic System

HYDRAULIC SYSTEM		
HYDRAULIC SYSTEM	U.S.	METRIC
Pressure	2,500 psi	172 bar
Drive type	12V DC	
Tank lift cylinder size (2)	3 in	76 mm
Tilt angle, max	45°	

As of currently, there are hundreds of trailer tugs on the market. The team chose a few that were the most relevant to their design. For example, the Haulle trailer tug (seen in Figure 6) has a similar design concept.



Figure 6. Haulle Tug

The Haulle is used for a variety of trailers ranging from: boat, yard, and highway trailers. It is rated for 40,000 lb towing capacity and it can hold up to 15,000 lb tongue weight. The tug is equipped with a wireless remote to maneuver, but it also has built in manual controls in case the remote fails. It is equipped with the following features: hydraulic lift, brakes, heavy duty steel, safety stop switches. However, some disadvantages to this product are: 24 hp gas engine, on-board hydraulic pump, 10 wheels, costly design, cannot fit onto trailer. The maintenance costs associated with this design are: hydraulic lines, tires, batteries for the remote, hydraulic rams, drive chain and belts. Similarly, to that of the Haulle, the MUV 4WD is a remote controlled electric tug (seen in Figure 7).



Figure 7. MUV 4WD Electric Tug

The MUV tug is powered by two 440W, 24V DC with two x 125A programmable motor controllers. It is equipped with a built-in battery charger, master key switch (on/off), battery gauge and safety devices such as an LED strobe and motion beeper. The disadvantage associated with this tug is its limited power capacity.

Trailer tugs are made out of high grade steel in order to withstand the weight of a fully loaded trailer. The frame is durable and requires hardly any maintenance. The tires on the tug require the most maintenance. Depending on the quality of the tire and the load being applied, the tires may need replacing often. It is dependent on how often the trailer caddy is used. The cost for a tire ranges from \$20-\$40 depending on the quality. The battery life span on electrically powered tugs depends on how often the tug is used. The average life span of a battery is 2-5 years and the cost ranges from \$50-\$150. Hydraulically powered tugs have more maintenance costs and requirements due to the hydraulic lines, fluid, and pump. Hydraulic lines can bust often if the pressure is too high or the line has a flaw. The cost of hydraulic lines on average is \$2 per foot. If a line does break, the hydraulic fluid lost needs to be replaced and costs \$5 per gallon. The hydraulic pump needs little maintenance as long as the pump does not run dry. The average cost of a pump is \$200. If the tug is fitted with a wireless remote control, the remote just needs to be recharged every 12 hours.

The majority of trailer tugs are either electrical or manually powered. A characteristic that is not used as often is hydraulic powered tugs. This is because most tugs don't have access to a hydraulic pump. If a tug is hydraulic powered, it is usually a large machine that has enough room to be fitted with a motor, pump, and hydraulic reservoir if they are to be self-sustaining. In other cases, they are ran from an existing pump on a trailer and are limited to trailers that have pumps. Another characteristic that is not used as often is being able to control the tug by a remote control. Most tugs are maneuvered manually by the operator. This is because the cost of a remote is higher and implementing it into the tug is more difficult than using handles.

The major safety concerns with trailer tugs is being able to stop the unit, particularly when moving downhill. In addition, if the product is used within a warehouse it should be equipped with a horn and siren to alert civilians that may be in the premise.

Patent Searches

Compact Multipurpose Trailer Tug (Patent # US 6758291 B1, July 6, 2004).

This patent was chosen because the said device attaches to the tongue of the trailer and can pivot due to two hydrostatic motors like a skid steer.

In addition, a model of the design can be seen in Figures 8 and 9. See Appendix i. for patent claims.

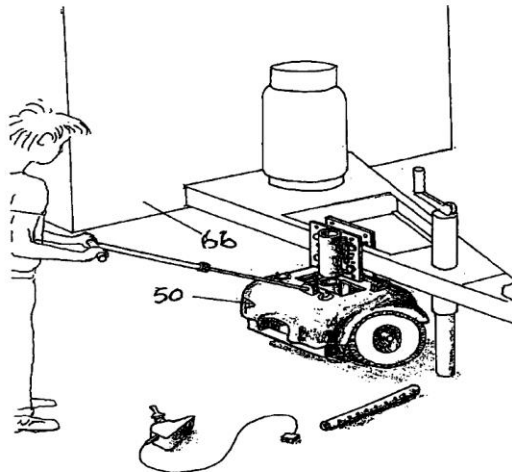


Figure 8. Trailer Tug apparatus.

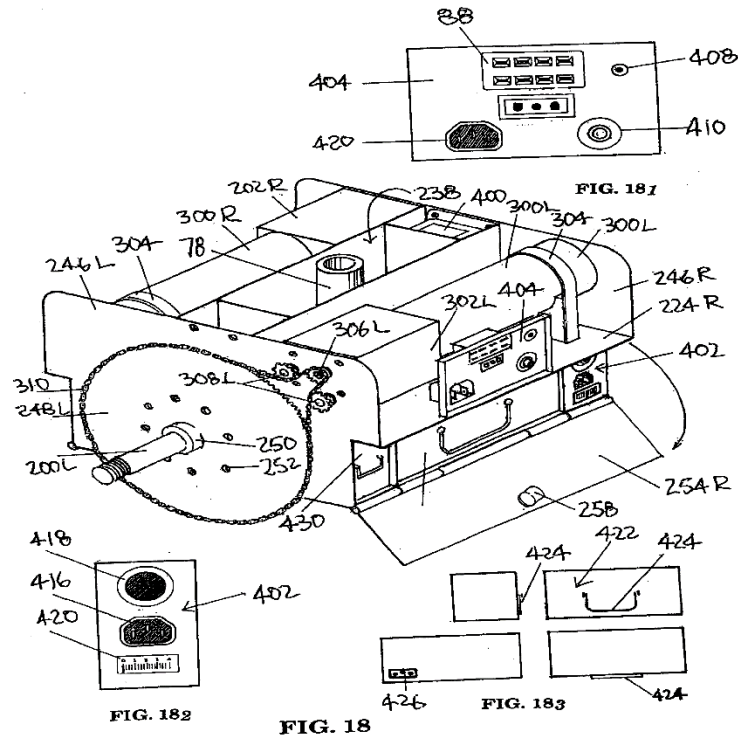


Figure 9. Tug/Remote Specifications.

Tugbot (Patent # US 20120215393 A1, August, 23rd, 2012).

This invention is a similar concept to that of our own, and it also utilizes a remote control for steering the device. The claims described by the patent are as described in Table 5. The design specifications for the Tugbot can be seen in Figures 10-11. See Appendix ii. for patent claims.

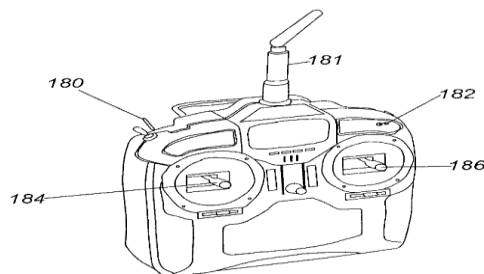


Figure 10. Tugbot Remote Control.

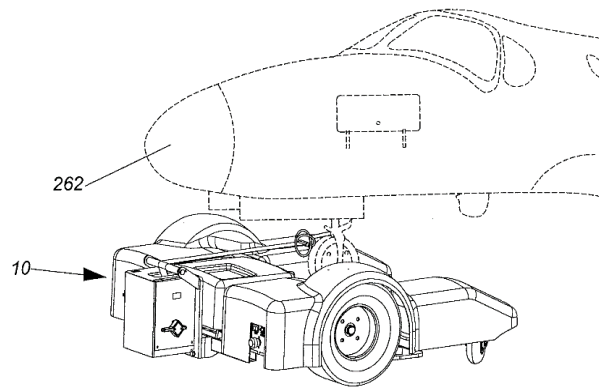


Figure 11. Tugbot Design

Drive Unit for Trailers and Caravans (Patent # US 20090308667 A1, December 17th, 2009).

This tug is operated entirely via electric power and is equipped with a remote control. In addition, the team is considering using tracks instead of tires, but this is yet to be determined. The following claims provided in Table 6 correlate to the teams' design that is under speculation and the design of the tug cited can be seen in Figures 12-13. See Appendix iii. for patent claims.

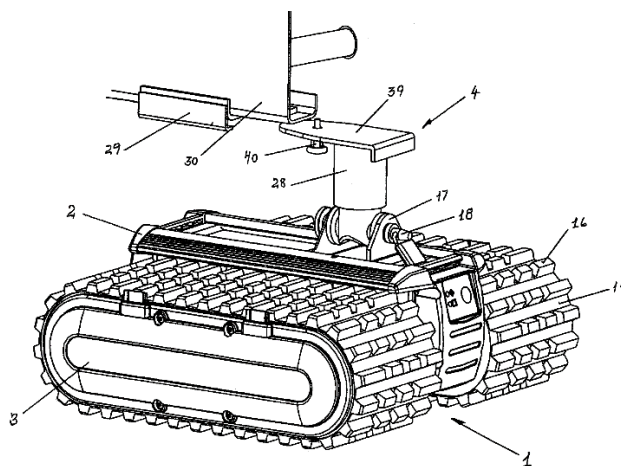


Figure 12. Drive Unit

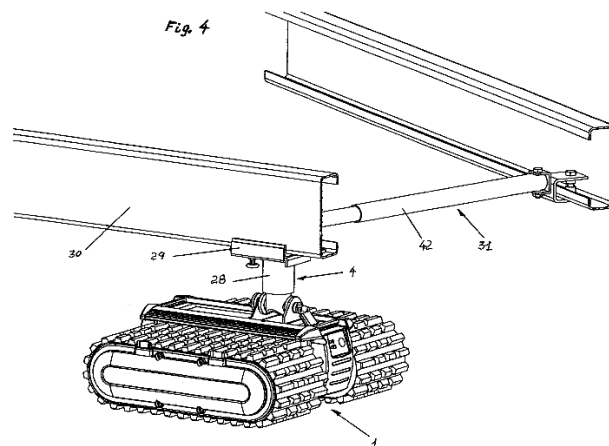


Figure 13. Drive Unit Attachment Assembly

Wheelchair drive system with ratchet and wheel lock (Patent # US 5743544 A, April 28th, 1998)

This invention utilizes a ratchet driven wheel that propels the wheel chair. This could be applied to a trailer by adding a hydraulic piston mounted on the trailer frame to engage the ratchet assembly mounted on either an axle or on a wheel. See Appendix iv. for patent claims.

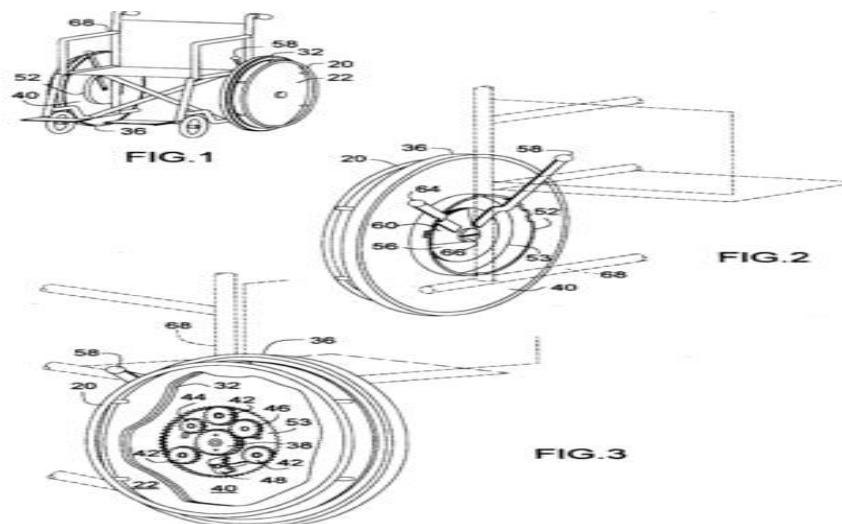


Figure 14. Wheelchair Drive System Specs

Axle Lift (Patent # US 3096995 A, July 9th, 1963).

Upon meeting with the client for a second time, the client specified that they would like our design to be integrated onto the trailer and do not want a trailer caddy. Therefore, the axle lift was a feasible idea because it can be engaged and disengaged as needed. See Appendix v. for patent claims.

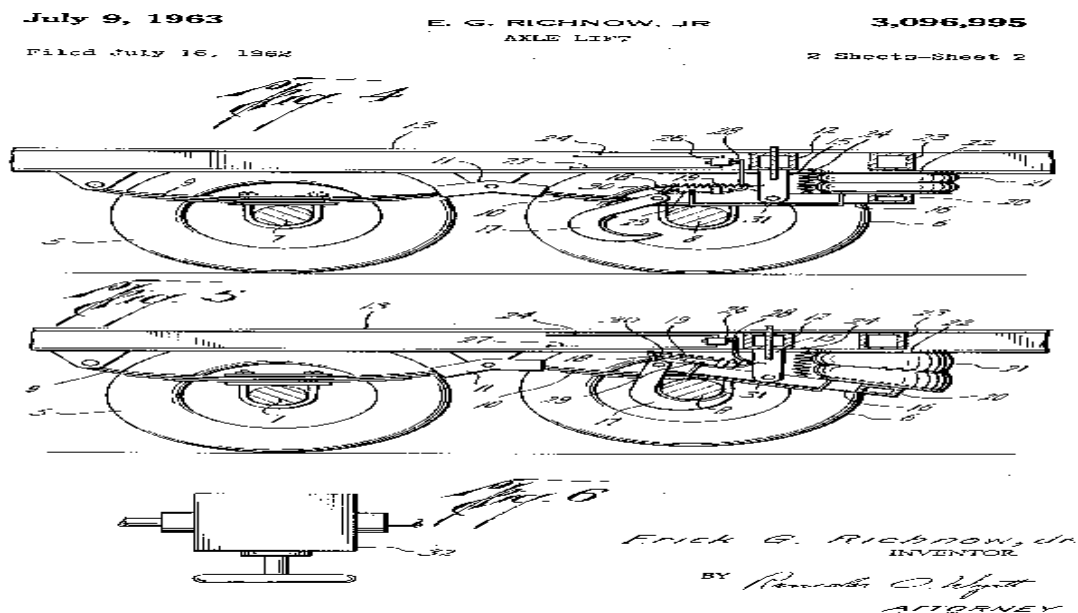


Figure 15. Axle Lift

After performing a patent search, the team were able to get an idea of how the design could be built. The design needs to include a remote control similar to how the tugbot operates. In addition, the design should also include an axle lift, which would make engaging and disengaging the design easy for the client. However, throughout the design phase, all of the relevant patents may be considered as a feasible addition to the trot'n trailers design.

Methodology

To ensure that the trailer bears the majority of the weight on the rear axles, the team performed force balance calculations to distribute the weight appropriately. The back axle of the trailer needs to support the weight, so the trailer has traction. Upon completing the force balance, the team calculated how much horsepower (HP) is required to pull the trailer and the max slope the trailer can climb. The horsepower methodology was calculated in Excel and can be seen in Tables 9 and 10. The results were obtained using the equations listed in Appendix pages 40-42.

Table 4. Trailer Specifications

Gross Vehicle Weight (GVW) (lb)	18,000
Weight on each Drive Wheel [WW] (lb)	3,000
Radius of Tire [R] (in)	8
Top Speed (V) (ft/s)	1.467
Maximum Incline (alpha) (degrees)	5
Coefficient of Traction	0.33
Desired Acceleration Time (t)(seconds)	4
Tongue Weight (lbs)	2,600

Table 5. HP Requirement per degree of Slope

Maximum Incline (alpha) (degrees)	Maximum Incline (alpha) (radians)	Total Tractive Effort (lb)	Grade Resistance	Wheel Motor Torque (lb-ft)	HP
0	0	601.015528	0	460.7785714	1.603072
1	0.017444444	914.9996027	313.9840748	701.4996954	2.440553
2	0.034888889	1228.888132	627.8726039	942.1475677	3.27778
3	0.052333333	1542.585599	941.5700708	1182.648959	4.114496
4	0.069777778	1855.996545	1254.981017	1422.930684	4.950449
5	0.087222222	2169.025599	1568.010071	1662.919626	5.785383
6	0.104666667	2481.577507	1880.561979	1902.542755	6.619044
7	0.122111111	2793.557158	2192.54163	2141.727154	7.451179
8	0.139555556	3104.869616	2503.854088	2380.400039	8.281534
9	0.157	3415.420149	2814.404621	2618.488781	9.109857
10	0.174444444	3725.114256	3124.098728	2855.92093	9.935896
11	0.191888889	4033.857697	3432.842169	3092.624235	10.7594
12	0.209333333	4341.556521	3740.540993	3328.526666	11.58012
13	0.226777778	4648.117095	4047.101567	3563.55644	12.3978
14	0.244222222	4953.446132	4352.430604	3797.642035	13.21219
15	0.261666667	5257.450721	4656.435193	4030.712219	14.02305
16	0.279111111	5560.038352	4959.022824	4262.69607	14.83014
17	0.296555556	5861.116948	5260.10142	4493.522993	15.6332
18	0.314	6160.59489	5559.579362	4723.122749	16.43199
19	0.331444444	6458.381047	5857.365519	4951.425469	17.22626
20	0.348888889	6754.384802	6153.369274	5178.361681	18.01579

After the team calculated the HP required per degree of ground slope, a 5% maximum ground slope is recommended based on the available – HP (as provided by FX-30 Trailer Specifications).

Safety Considerations

As an engineer, one of the fundamental cannons is to ensure the safety, health and welfare of the public. The primary safety concerns are within the fabrication and production of the trailer assist system, specifically. During the cutting and welding of the steel for the frame, the workers are required to wear protective gloves, eyewear, shirt, and pants. While wiring the electrical system, the system needs to be disconnected from all electrical sources, as well as following all OSHA standards set by the Department of Labor to avoid electric shock and ground faults. During the installation of

the trailer assist system, the trailer needs to be lifted and secured in a safe position to attach the system on the underside of the trailer. The trailer can also be driven over a mechanic pit if a lift is not present. A hydraulic jack needs to be used to help lift and stabilize the system while it is being attached. This system should not be attached by one person; multiple people should be present in case of an accident. While using the trailer assist system, the user must be aware of his/her surroundings. The system's top speed is 1-1 ¼ mph, but the user should never be distracted while the system is in motion. The user should always obey traffic laws and never block streets or driveways. If the system is going up or down an incline, the system is fitted with an emergency braking system that ties into the trailer brakes. If the system increases speed downhill or starts to roll downhill, the brakes can be engaged to slow the descent or completely stop the trailer. When the trailer is parked on the side of a road, the user must put out caution cones to inform the public that the trailer is stopped. By doing so, allowing the public time to slow down and reduce the risk of a vehicle hitting the trailer. When the trailer is crossing an intersection, the user needs to be extra cautious. Double check for oncoming traffic and if need be stop traffic until the trailer is safely across. During transport of the trailer, the system needs to be raised to its transport location and secured. This will keep the system off the ground and ensure that the center of gravity is centralized on the trailer. Before transportation, the user should perform regular checks of the trailer and vacuum system as specified by Ditch Witch™'s FX-30 safety manual.

Sustainability Characteristics

Technology is continually improving and becoming more advanced. The need to further develop and improve our existing products is a must. The FX-30 trailer modifications the team will be implementing is progress towards self-driving vehicles, to an extent. Self-driving vehicles are being developed by Tesla Motors and other competitors. Tesla vehicles will allow full autonomy from the user, which with proper development, will be safer than a human driver. The FX-30 modifications will not make the trailer self-driving, but it is a step towards that direction. Autonomous vehicles play a fundamental role in further developing transportation safety and transitioning the world to a sustainable future. (Tesla). The maintenance requirements of the system are

simple, moving parts must be greased every 100 hours and the tires replaced, as needed. When the trailer or the trailer assist is no longer viable, most of the components can be recycled and reused. The steel can be melted down, the tires can be recycled, and the plastic can be broken down by microbial remediation.

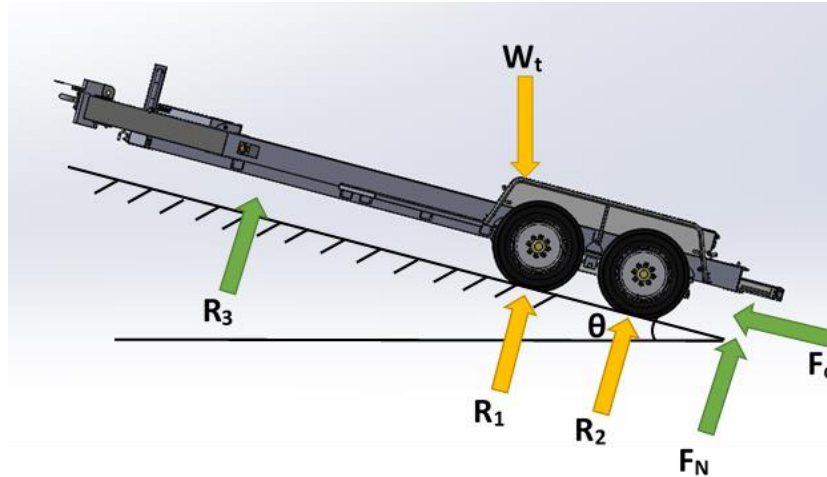
Customer Requirements

The client, Charles Machine Works, had specified a few parameters that our design must achieve.

- 1) The system is designed to operate on hard surfaces.
- 2) The design should be self – propelled.
- 3) The system must be integrated onto the existing trailer.
- 4) The system should simply be engaged and disengaged.
- 5) Controls need to be operated by a remote control.
- 6) The top speed with the system should be 1 – 1 ¼ mph.
- 7) The system must have its own way to brake or utilize existing trailer brakes.

Engineering Specifications

Our engineering specifications were formed based on our methodology and from our Free Body Diagram of the trailer, which can be seen in Figure 16.



$$F_N = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) \left(\frac{1}{\mu} \right) + \left(\frac{W_t \sin \theta}{\mu} \right)$$

$$F_d = \left(\frac{W_t}{32.2} \right) \left(\frac{V}{t} \right) + W_t \sin \theta$$

Figure 16. Free Body Diagram of FX-30

Where

F_N = Force in the Y direction.

F_d = Force in the X direction

W_t = Weight of the trailer (lb)

V = Velocity (ft/s)

μ = Friction

t = Time (seconds)

$\sin \theta$ = Angle

In order to calculate the size and length of pistons the design needed, the law of cosines was used. The pistons selected are 2" bore x 8" stroke and have a max push force of 3,768 lbs and max pull force of 3,396 lbs. The cost of each cylinder is \$480.75 and the team will need three cylinders.

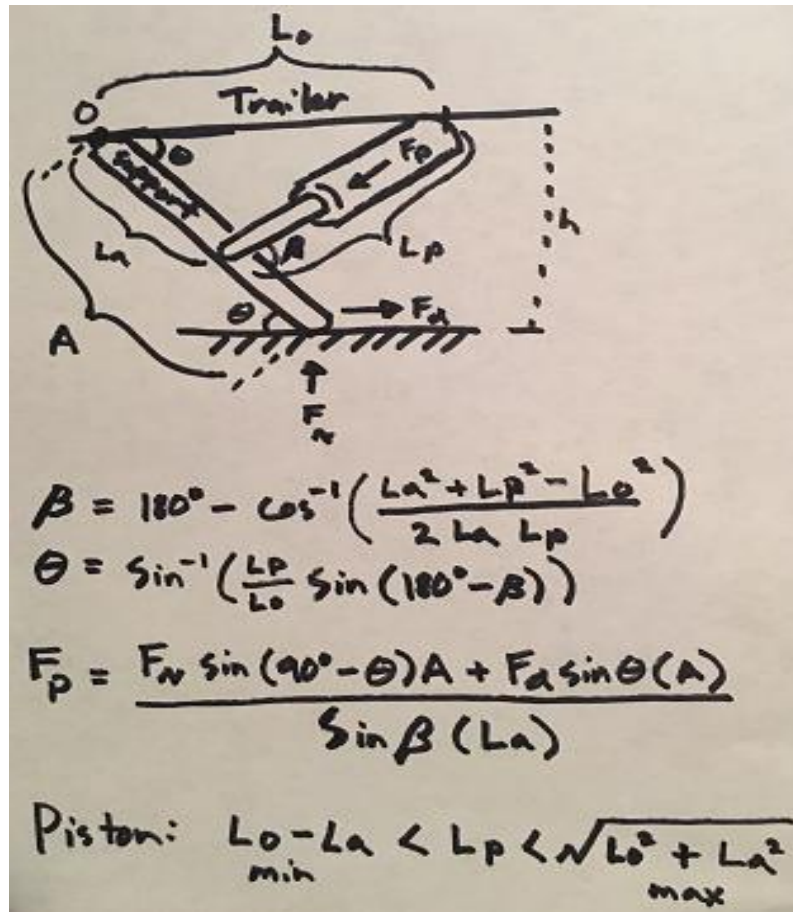


Figure 17. Law of cosines for piston

Table 6. Piston Length Data

Solving for Piston Length		
Drop Down Axle Piston Reactions		
Variable	Value	Units
Number of Pistons (N)	2	
Distance between support and piston origins (Lo)	2.097	ft
Angle of support with trailer (θ) *closest to 90 degrees is best	58.01809	degrees
Axle support length (A)	1.483	ft
Distance piston pinned on support (La)	0.864	ft
Distance between trailer and end of support (h)	1.2575	ft
Max Piston Length	2.268018	ft
Min Piston Length	1.233	ft
Piston length (Lp)	1.795292	ft
Force of piston	86.98719	lbs
Angle of support with trailer (α)	1.012093	rad
Lower angle between piston and support (β)	1.707557	rad

The support arm sizing was calculated using the Distortion Energy Theory and the size used are 3x4x1/4 rectangular tubing with a safety factor of 3.6

Table 7. Support Arm Strength Data

Support Arms Strength		
Variable	Value	Units
Material Type	A513	~\$20/ft
Modulus of Elasticity [E]	30000000	psi
Yield tensile Strength (Sy)	72000	psi
Beam Width (b)	3	in
Beam Height (h)	4	in
Beam Wall Thickness (t)	0.25	in
Max Deflection (d)	-0.0072475	in
Safety Factor (n) "Distortion Energy Theory"	3.57888606	

The axle diameter calculations for the front and rear steering was calculated using the Distortion Energy Theory. The axle diameter the team selected is 1.75" and a safety factor of 2.8.

Table 8. Axle Strength

Axle Strength		
Variable	Value	Units
Material Type	A513	
Yield Strength	72000	psi
Modulus of Elasticity [E]	30000000	psi
Axel Diameter (D)	1.75	in
Axel Length (L)	28	in
Wheel Distance from Support (x)	3	in
Safety Factor (n) "Distortion Energy Theory"	2.833698	

Preliminary Design Concepts

Initially our team was designing a system similar to a trailer caddy for our project, but after meeting with our client we discovered that they did not want a trailer tug.

- 1) "Segway"© Tug.

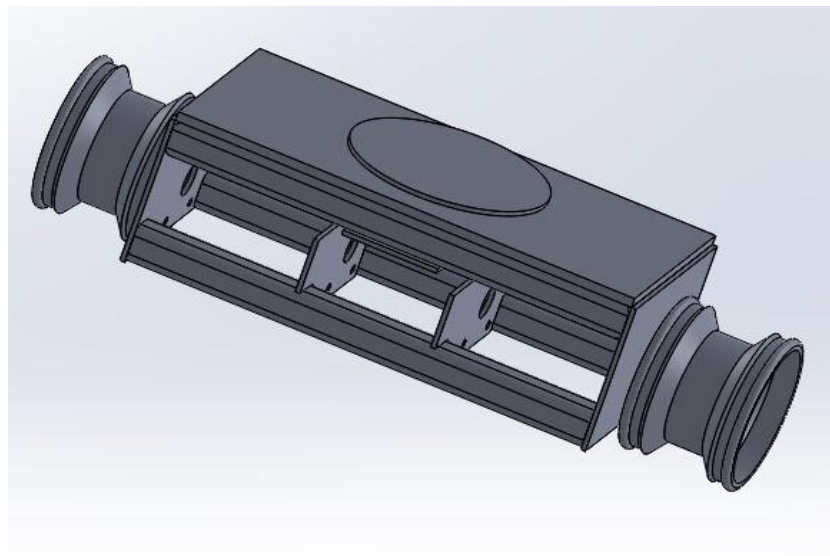


Figure 18. Segway Tug

The “Segway”© tug, seen in Figure 18, would sit under the tongue of the trailer and operate with two hydrostatic motors similar to that of a skid steer. The two hydrostatic motors would allow the unit to drive and steer. Upon further calculations, we found that the “Segway”© would not be able to pull the trailer uphill.

2) Chain and Sprocket Drive

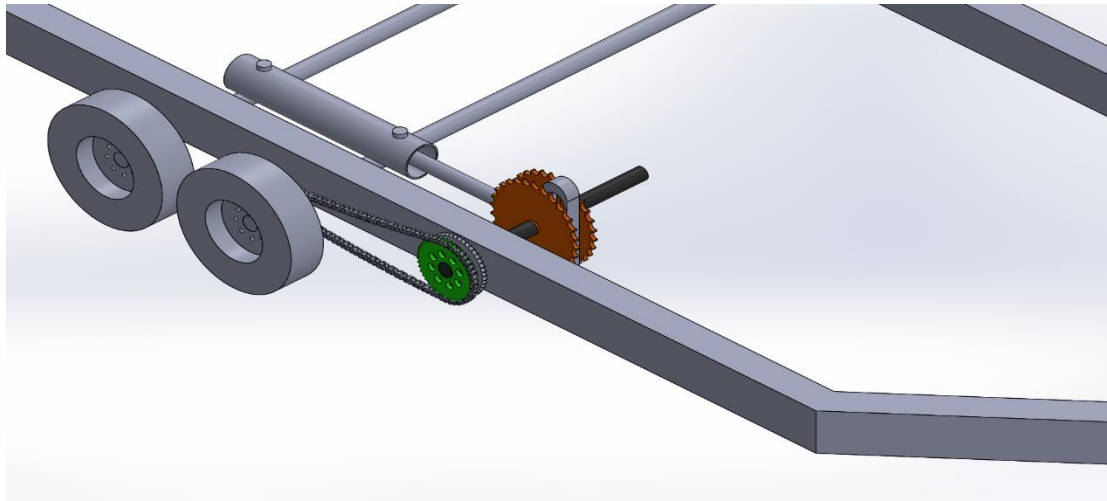


Figure 19. Chain and Sprocket Drive

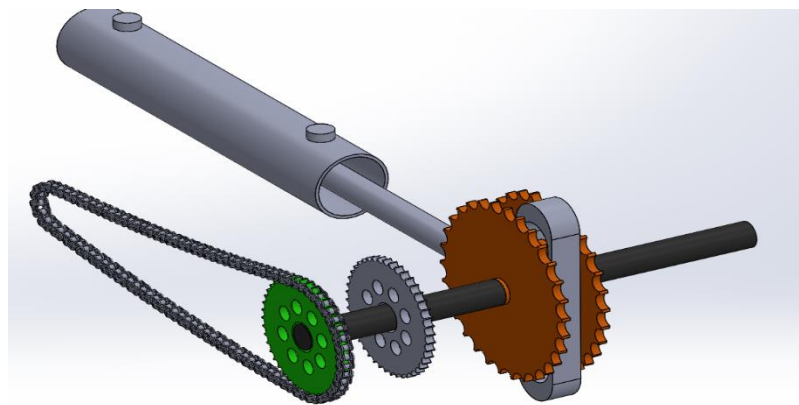


Figure 20. Chain and Sprocket Assembly

The team decided this would be an efficient way to enable the trailer to drive itself by attaching a motor to drive the sprocket and chain. However, this design

was tossed out because the chain would be exposed while going down the road and it is not easy to engage and disengage.

- 3) Drive motor mounted to the wheel hubs.

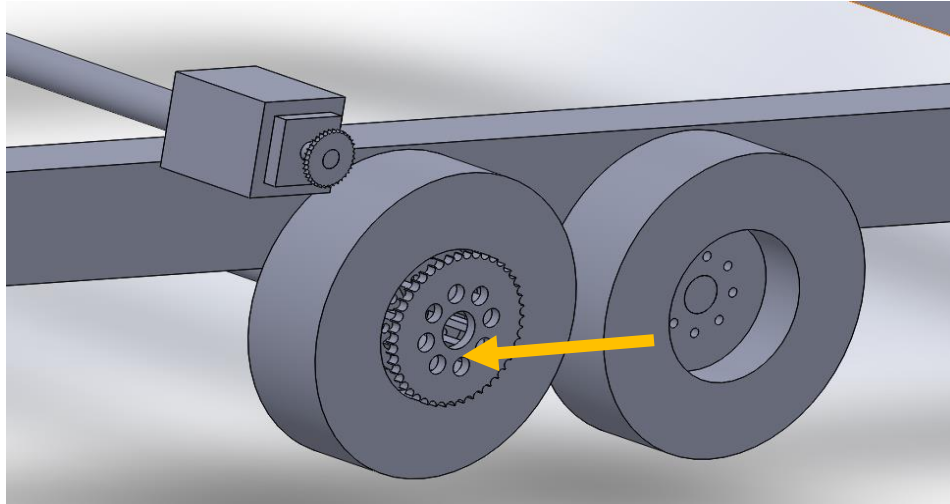


Figure 21. Drive Motor System

This design would consist of a motor mounted to the wheel hub with a chain and sprocket. It would allow the tire to rotate freely and propel the trailer. The design was not practical because the motor would be extended too far out past the fender of the trailer. This would violate the national standard trailer laws of making the width longer than 102 inches.

- 4) Ratcheting axle drive

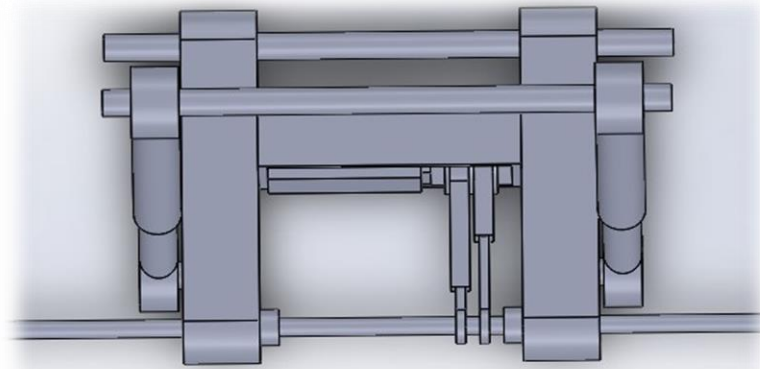


Figure 22. Ratcheting Drive Axle Top View

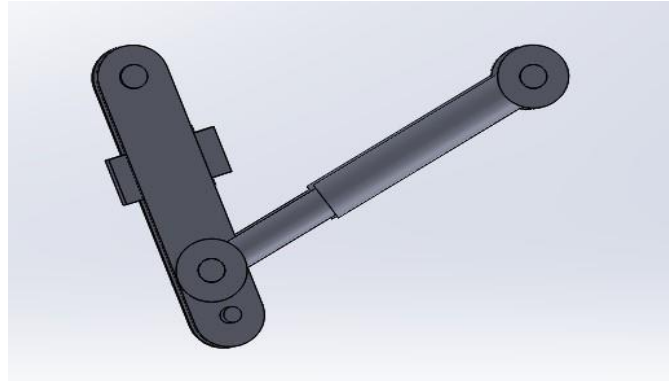


Figure 23. Ratcheting Drive Axle Side View

This was the preliminary design that led to our final design. It consisted of two ratcheting arms offset by 90 degrees, so when one arm locked forward, the other locked backward, which would allow the trailer to move forward or in reverse.

Final Design Concepts

The final design will consist of an independent drive system comprised of two lift axles. The axle in front of the trailer will be used as the steer, and the rear axle will be used for the drive.

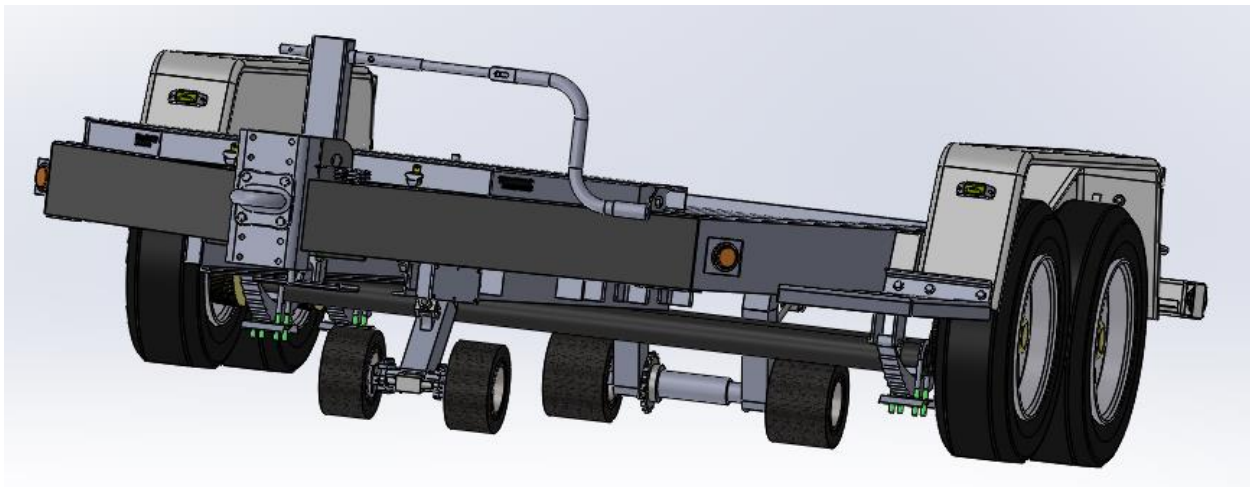


Figure 24. Trailer Front View

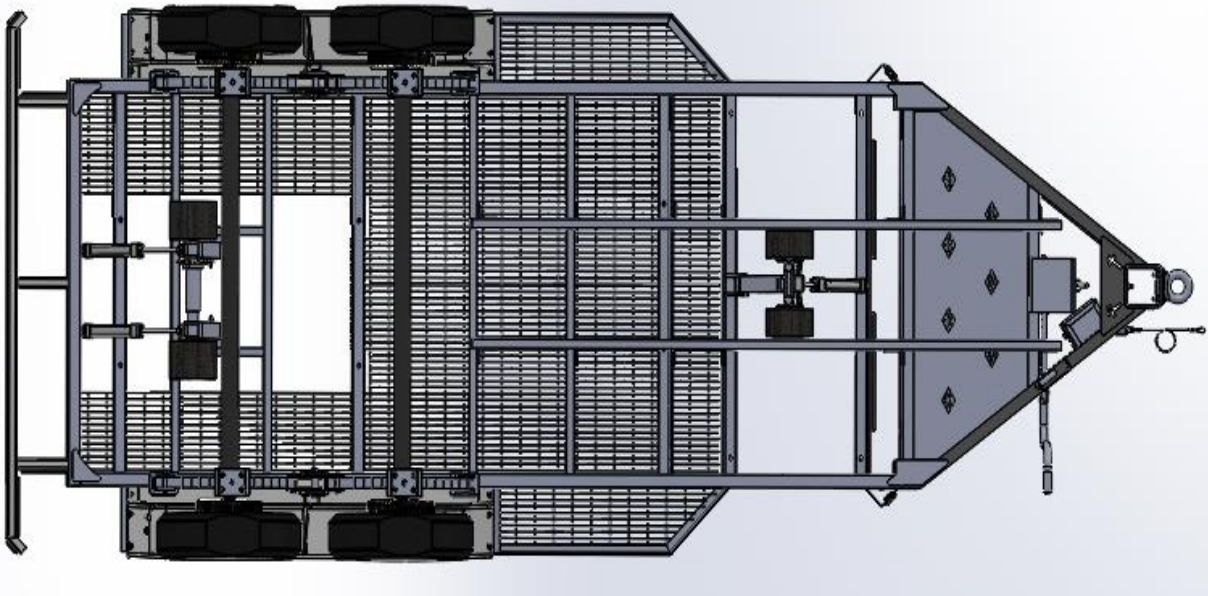


Figure 25. Trailer Top View

The drive axle will consist of a hydraulic lift axle and the motor will be hydraulic or electric (TBD). It will be a chain-driven system and the weight will be supported by two solid 10x7x6-1/4 tires. The tires are rated for 3100 lbs and cost \$116.13 per tire.

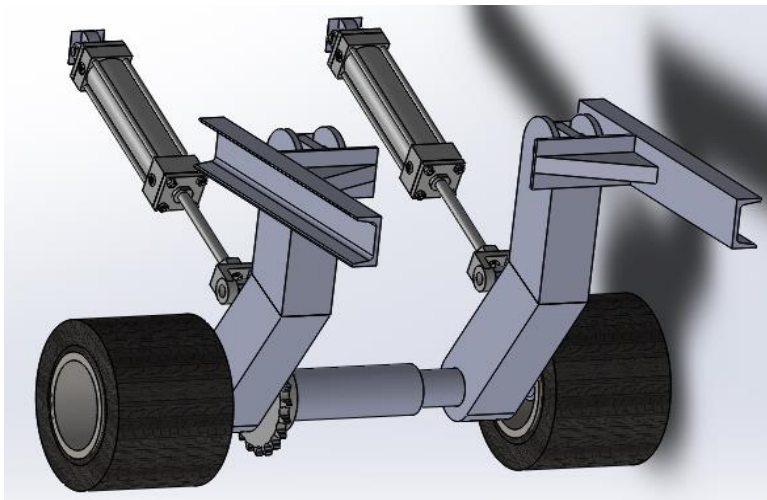


Figure 26. Drive Axle

The steer axle (seen in Figure 27) will consist of a hydraulic lift axle, and it will be mounted to the cross members of the trailer frame. The steering will be controlled by a double ended hydraulic cylinder and the system will also have two 9x5x5 solid rubber

tires. The tires are rated for 1741 lbs and cost \$129.46 per tire. However, the team have not calculated any real numbers for the steer axle as of yet. The team has to account for turning forces that could cause the steering axle to shear and break. Upon entering the spring semester, the team will have performed further calculations to size the steering arm appropriately and include a factor of safety.

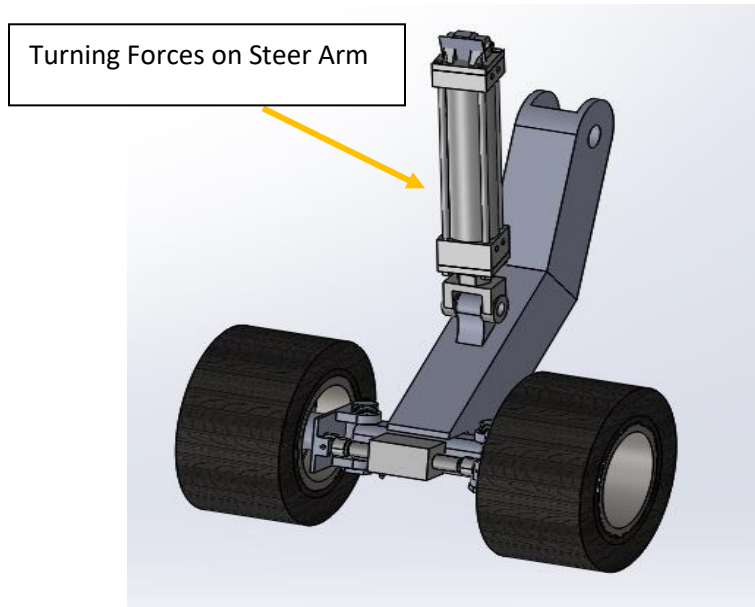


Figure 27. Steer Axle

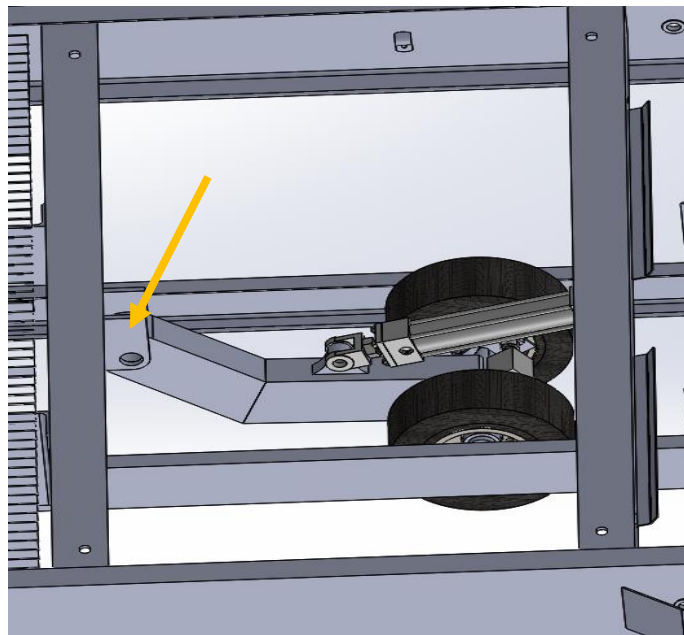


Figure 28. Steer Axle Mounting

BAE 1012 Freshman Involvement

For the Charles Machine Works project, the team was assigned two freshman teams to include in the design.

Team #1 – Tires or Tracks:

- 1) Determine the pros and cons associated with tires and tracks.
- 2) Size of tires or tracks needed to carry the load.
- 3) Cost of tires or tracks.

Team #2 – Remote Control System:

- 1) Tethered Remote vs. Wireless Remote
- 2) Control System Parameters
 - a. Engaged and Disengage dropdown lift axles.
 - b. Steering and Drive.

Summary

After conducting research over a variety of trailer tugs, it has been noted that there are advantages and disadvantages with each design. Also, the type of device used is dependent on the project at hand. As mentioned above, the objective of this project is the development of a system for Charles Machine that will enable the FX-30 vacuum excavator to move without the use of a standard motorized vehicle. The trailer the team are designing for is the FX-30 Vacuum Trailer. The final design can be its own stand-alone system or it can be integrated into the trailer's design. This system should be designed whereas when not in use, it can be stored and hauled on the vacuum trailer. Furthermore, by researching trailer caddies such as, the Haulle Tug (seen in Figure 5) and the MUV 4WD Electric Tug (seen in Figure 6). The team developed a sense of direction for their own project. Each trailer tug has its own pros and cons such as: operated via hydraulics, electric motor, multiple tires, wireless or tethered remote, etc. However, the team should consider which option will be practical and suitable for

the client specifications. Some other possible alternatives for moving the trailer that were researched can be done by using hydraulic rams to move the trailer. The hydraulic rams would be mounted to the tires of the trailer like what are found on hydraulic locomotives. Also, the team would incorporate an axle lift to lighten the tongue weight, which would enable the trailer to be steered more easily. The team also conducted research over the safety parameters that must be considered throughout the design along with recommended safety checks for the FX-30 (as specified by Ditch Witch). As an engineer, one of the fundamental cannons is to ensure the well-being of the public. Furthermore, the team plans to implement their research over patents, relevant technology and safety considerations into that of their own design.

Spring Project Schedule

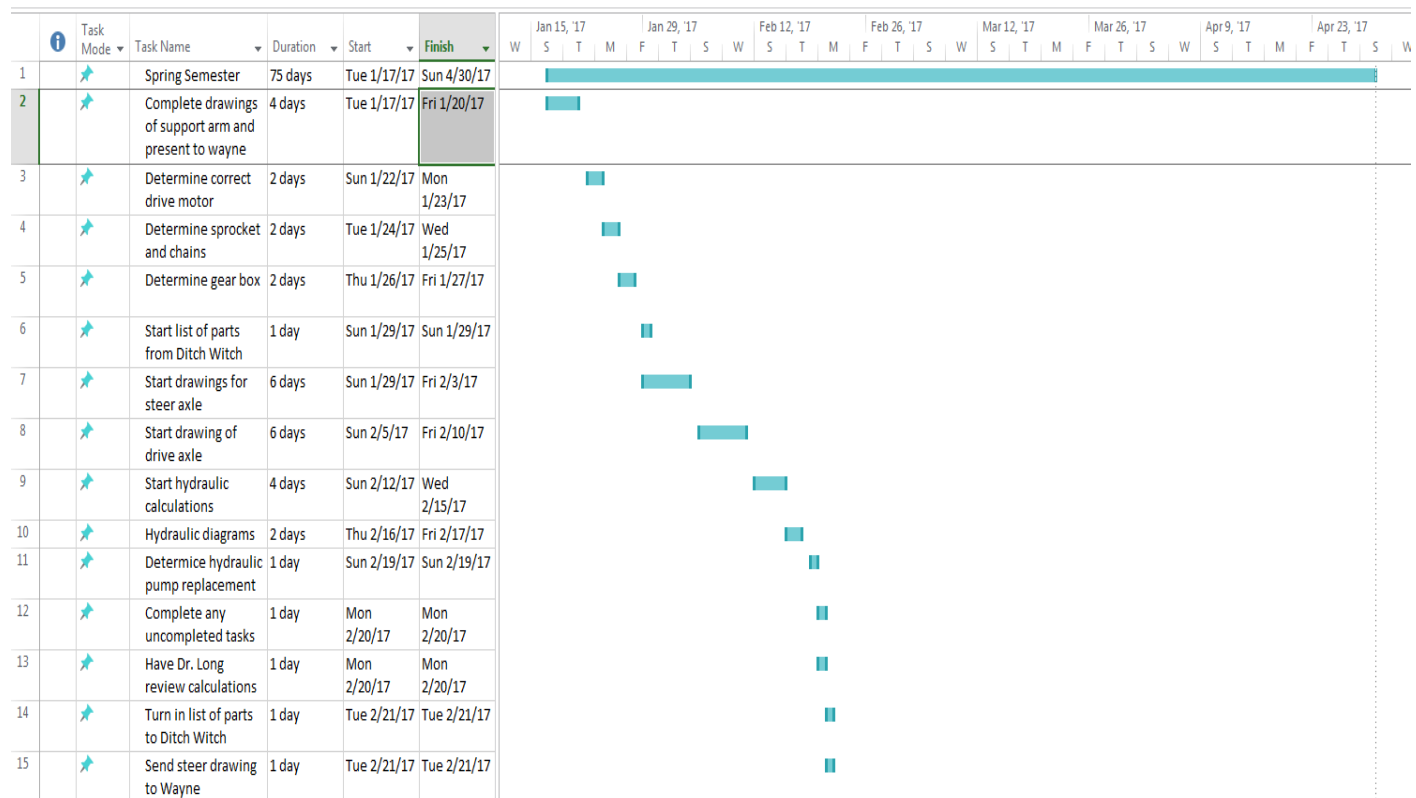


Figure 29. Project Schedule January – February

16	✦	Start circuit diagram	3 days	Wed 2/22/17	Fri 2/24/17
17	✦	Make additional parts list	1 day	Sun 2/26/17	Sun 2/26/17
18	✦	Determine how to tie into trailer brakes	2 days	Mon 2/27/17	Tue 2/28/17
19	✦	Order parts needed	1 day	Tue 2/28/17	Tue 2/28/17
20	✦	Start assembly of drive and steer axle	8 days	Wed 3/1/17	Fri 3/10/17
21	✦	Start wiring and assembling hydraulics	3 days	Wed 3/1/17	Fri 3/3/17
22	✦	Mount new pump on trailer	2 days	Sun 3/5/17	Mon 3/6/17
23	✦	Design hydraulic mounts	2 days	Tue 3/7/17	Wed 3/8/17
24	✦	Mount hydraulic valves	2 days	Thu 3/9/17	Fri 3/10/17
25	✦	Spring Break	6 days	Mon 3/13/17	Sun 3/19/17
26	✦	Start testing design	10 days	Mon 3/20/17	Fri 3/31/17
27	✦	Fix problems found during testing	6 days	Sun 4/2/17	Fri 4/7/17
28	✦	Retest design	6 days	Sun 4/9/17	Fri 4/14/17
29	✦	Work on final report	6 days	Sun 4/16/17	Fri 4/21/17
30	✦	Final presentation	1 day	Sun 4/30/17	Sun 4/30/17

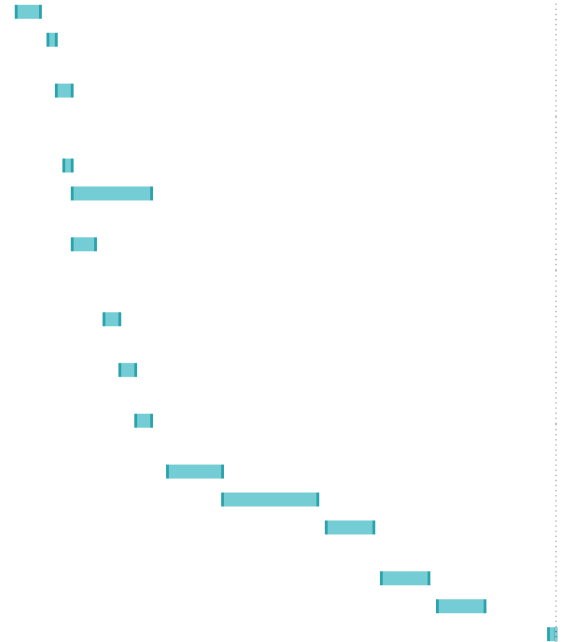


Figure 30. Project Schedule February – End of Semester

Proposed Budget

- 1) 10 feet of A513 Steel at 20\$/ft = \$200
- 2) 3, 2" bore x 8" stroke hydraulic cylinders at \$480.75 = \$1,442.25
- 3) 2, 9x5x5 solid rubber tires at \$129.46 = \$258.92
- 4) 2, 10x7x6-1/4 solid rubber tires at \$116.13 = \$232.26
- 5) Motors = TBD
- 6) Bolts and Nuts = TBD

Total = \$2,133.43

Appendix

Patent Searches

- i. Compact Multipurpose Trailer
 - a. At least on battery on said chassis.
 - b. At least one direct current motor.
 - c. A control device coupled with said drive train for selectively controlling rotation of said wheels whereby said tug may be positioned under said tongue.
 - d. Battery powered steerable tug apparatus for carrying a cantilevered tongue of a towable vehicle and comprising.
- ii. Tugbot
 - a. A first wheel drive system assembly adapted to provide the towing device movement.
 - b. A second wheel drive system assembly to provide the towing device movement.
 - c. Where in said towing device is adapted to provide a non-manned device for moving said transportation vehicle or other moving vehicle.
 - d. A chassis constructed and arranged to support one or more internal and/or external components of a non-manned towing device for towing a transportation or other moving vehicle.
- iii. Drive Unit for Trailers and Caravans
 - a. A motorized, maneuverable drive unit having crawler sections with crawler belts, said drive unit being adapted to be mounted on a hitch triangle of trailers.
 - b. The drive unit also comprises an energy supply and mean for steering and maneuvering the drive unit.
 - c. The steering and control means comprise a wireless as well as a non-wireless connection between the motor control system and a remote control unit.

- d. A drive unit characterized in that the chassis additionally comprises an enclosure for a battery, a charging circuit for the battery, an electrical motor control and an electrical communications circuit for wireless control of the drive unit.
- e. The motor control circuit is provided with a soft start function and is adapted to control at least two motors individually and to cooperate with the communications control.

iv. Wheelchair Drive System

- a. An axle, defining the axis around which the hub-and-wheel assembly rotates.
- b. A drive wheel assembly, including a drive wheel, an internal gear, and a tire, said internal gear being supported by a plurality of circumferentially spaced supporting gears.
- c. A driver, supported on said axle and rigidly connected to a hand ring, forming a driver assembly which is rotatable forward or rearward by manually rotating said hand ring.
- d. A drive engagement gear between said driver and said drive wheel assembly.

v. Axle Lift

- a. It is an object of this invention to provide a device for lifting one axle of a tractor or trailer free of the road surface when the vehicle is traveling empty.
- b. It is another object of the invention to provide an axle lift having novel means for engaging an axle to be lifted and the controlled raising and lowering of the axle.
- c. It is another object of the invention to provide means for lifting an axle on a tractor or trailer and shifting the weight distribution of the vehicle to provide less tire wear and easier steering of the vehicle.
- d. It is another object of the invention to provide an axle lift for lifting an axle of a tandem trailer to provide less tire wear and greater traveling stability of the vehicle.

Methodology

Drive Wheel Motor Torque Calculations

i. Total tractive effort

$$a. TTE \text{ [lb]} = RR \text{ [lb]} + GR \text{ [lb]} + FA \text{ [lb]} \quad (\text{Eq. 1})$$

TTE = total tractive effort [lb]

RR = force necessary to overcome rolling resistance [lb]

GR = force required to climb a grade [lb]

FA = force required to accelerate to a final velocity [lb]

ii. Rolling Resistance

$$a. RR \text{ [lb]} = GVW \text{ [lb]} \times C \quad (\text{Eq. 2})$$

RR = rolling resistance [lb]

GVW = gross vehicle weight [lb]

C = surface friction

iii. Grade Resistance

$$a. GR \text{ [lb]} = GVW \text{ [lb]} \times \sin(\alpha)$$

GR = grade resistance [lb]

GVW = gross vehicle weight [lb]

α = maximum incline angle [degrees]

iv. Acceleration Force

$$a. FA \text{ [lb]} = GVW \text{ [lb]} \times V_{\max} \text{ [ft/s]} / (32.2 \text{ [ft/s}^2\text{]} \times t_a \text{ [s]})$$

FA = acceleration force [lb]

GVW = gross vehicle weight [lb]

V_{\max} = maximum speed [ft/s]

t_a = time required to achieve maximum speed [s]

v. Total Tractive Effort

a. $TTE \text{ [lb]} = RR \text{ [lb]} + GR \text{ [lb]} + FA \text{ [lb]}$

TTE = sum of forces in: ii+iii+iv

vi. Wheel Motor Torque

a. $T_w \text{ [lb-in]} = TTE \text{ [lb]} \times R_w \text{ [in]} \times RF \text{ [-]}$

T_w = wheel torque [lb-in]

TTE = total tractive effort [lb]

R_w = radius of the wheel/tire [in]

RF = resistance factor [-]

vii. Reality Check

a. $MTT = W_w \text{ [lb]} \times \mu \text{ [-]} \times R_w$

W_w = weight (normal load) on drive wheel [lb]

μ = friction coefficient between the wheel and the ground

R_w = radius of the drive wheel/tire [in]

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