

# Portable Dirt Late Model Pull Down Machine

A Baccalaureate thesis submitted to the  
Department of Mechanical and Materials Engineering  
College of Engineering and Applied Science  
University of Cincinnati

in partial fulfillment of the  
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Dylan Rivers

April 2020

Thesis Advisor:

**Allen Arthur**

# TABLE OF CONTENTS

TABLE OF CONTENTS.....	II
LIST OF FIGURES .....	III
LIST OF TABLES .....	III
ABSTRACT.....	IV
PROBLEM DEFINITION AND RESEARCH .....	1
PROBLEM STATEMENT .....	1
BACKGROUND.....	1
RESEARCH.....	1
SCOPE OF THE PROBLEM.....	1
CURRENT STATE OF THE ART .....	2
END USER.....	2
CONCLUSIONS AND SUMMARY OF RESEARCH.....	3
CUSTOMER FEATURES .....	3
PRODUCT OBJECTIVES .....	3
QUALITY FUNCTION DEPLOYMENT .....	4
DESIGN.....	5
PROJECT MANAGEMENT .....	16
BUDGET, PROPOSED/ACTUAL.....	16
SCHEDULE, PROPOSED /ACTUAL .....	17
TESTING .....	17
SUSTAINABILITY AND MATERIAL USAGE.....	19
WORKS CITED .....	20
APPENDIX A (RESEARCH) .....	21
APPENDIX B .....	22
APPENDIX C .....	23
APPENDIX D.....	24

This project was a group project between Josh Dietz, Dylan Rivers, and Tamas Bonyhati. It was sponsored by Josh Dietz and all the components were donated to him.

## **LIST OF FIGURES**

- Fig. 1: House of Quality
- Fig. 2: Right Front Suspension
- Fig. 3: Torque Arm Suspension
- Fig. 4: Free Body Diagram of Torque Arm
- Fig. 5: Hydraulic Pump and Cylinder
  
- Fig. 6: Image of Loaded Members by Hydraulic Cylinders
- Fig. 7: FEA Analysis of Loaded Member of Frame
- Fig. 8: Completed Right Front Bracket
- Fig. 9: FEA Analysis of Right Front Bracket
- Fig. 10: Completed Lift Bar Plate
- Fig. 11: Final Assembly of Pull-Down Machine
- Fig. 12: Hydraulic Pump and Valve Pack

## **LIST OF TABLES**

- Table 1: Preliminary Budget
- Table 2: Proposed Budget
- Table 3: Final Budget
- Table 4: Proposed Schedule
- Table 5: Actual/Final Schedule
- Table 6: Test 1 - Recorded Values
- Table 7: Test 2 – Recorded Values

## **ABSTRACT**

This report is on the portable race car pull down machine. This machine is used to move a racecar into a dynamic state that it would experience while it is accelerating, decelerating, or cornering when it is on the racetrack. This machine is capable of dynamically loading a car to accurately simulate real world forces. Included in this report is the background on what the machine does and why we are addressing this problem. It also talks about the design of my section of project which was the actuation system, the budget of the project, and the testing of the project.

## PROBLEM DEFINITION AND RESEARCH

### *PROBLEM STATEMENT*

Our problem is to create a machine capable of dynamically loading a car to accurately simulate real world forces. These forces are present when the car is entering and exiting a corner at speed. Full measurements take a highly expensive fixturing system and are not available for use when most needed, at the track. Currently the only way to simulate this in a timely manner is by using shock travel data to predict the suspension geometry. This is not an accurate prediction due to chassis and suspension deflection under load as well as tire deformation.

### *BACKGROUND*

Pull down devices are used to simulate the dynamic movements of a race car when its moving around the racetrack. These devices already exist, but they are very expensive, and time consuming to setup and run. We are interested in this problem because we have been racing for 15 years combined and have been using trial-and-error to set up our car. This machine will diminish the amount of guess-and-check required. A pull-down machine works by moving the race car into a dynamic state, it achieves this through actuators that pull down on the chassis to simulate on track dynamic loading of the race car. These loading conditions can include acceleration, braking, and cornering forces. Through the dynamic change of the race car you can then measure various aspects of the race car. These measurements include:

- Wheel Loads through suspension travel
- Suspension Travel
- Dynamic Camber of front wheels
- Wheelbase movement through dynamic change of the car (Rear Axle Lead)
- Spoiler Height
- Ground Clearance

To test a setup change on the car now you have to use a “spring smasher” to get your load change at a certain ride height, but this doesn’t give you the whole picture of what this will do to the car in the corner like dynamic camber, roll steer and the travel of each corner of the race car. A “spring smasher” is a device used to determine your wheel loads at certain distances. One end of the shock is fixed, while the other end travels up and down using an electric actuator. You then move the shock up or down to known travel or load measurements, while a load cell measures the load applied to the shock at the desired distance.

## RESEARCH

### *SCOPE OF THE PROBLEM*

The problem with today’s pull down machines is that they are too expensive for the average

racer to purchase to use on an individual basis. Today, racers must take their race cars to a shop where they rent the pull-down machine for the day. Current pull down machines are all also not easy to use for the end user. The challenge for us is to design and manufacture a pull-down machine that is cheaper than the current machines available on the market today.

### ***CURRENT STATE OF THE ART***

There are many pull down rigs on the market today but most of them are either expensive or they are time consuming to setup and use. The DRP pull down system is sold in many different stages and their cost range from \$6,000 to \$46,000. These systems are sold with more and more features as the price goes up. (1) The positives about the DRP system is that it comes with multiple different features and can measure anything that you want to measure. The \$6,000 option of DRP pull down rig comes with 14 different features but does not include the scale pads that will allow you to get your wheel loads when the car is in a dynamic position. The \$46,000 option for DRP comes with 35 different features but many of these features are very useful but they come at a price. Not many local racers can afford this expensive option. The other negatives of the DRP pull down systems is that none of the different options are portable. Another pull down rig that is on the market is the Mittler Brothers pull down system. This system is mainly used for asphalt cars but it has a price tag of \$95,000. (2) The Mittler Brothers pull down system is meant for big Nascar teams that are able to pay the \$95,000 price for this machine. This machine is capable of measuring anything you want on the race car. It can also simulate the car as it is moving around the racetrack.

### **Actuation System:**

The current state the art for the actuation system of pull-down systems uses hydraulic actuators. The purpose of the actuation system within the pull-down machine is to move or “pull down” the car into dynamic state so that you are able to measure various aspects of the car as you are simulating acceleration and deceleration of the race car. These actuators cause the car to move into a dynamic position to that you can measure shock travel, ground clearance, wheel loads, and other factors when the car is at attitude on the pull-down system. The negatives about current actuation systems is that most do not come with the acceleration and deceleration packages within the system. With our pull-down device we are going to include both within the system.

### ***END USER***

The end user of this product would be low budget and entry-level racers to provide a quick and efficient, portable calibration machine. The average racer is not able to afford currently available systems or have the time and space required to set up and use existing systems. With this system there would be little time required to set up and it will be easy to move. This would allow you to quickly setup and teardown this system at any shop or even at the track.

***CONCLUSIONS AND SUMMARY OF RESEARCH***

In summary, today's pull-down systems perform necessary functions for the customer, but they are expensive and are not practical to the average local racer. Their systems also are not portable and cannot be taken to the track or to someone else's race shop to analyze how their car acts when it is in a dynamic position. Our pull-down system will be cheaper for the end user and will be easier to use and setup. You will not have to tear the system down to move it to another location.

**CUSTOMER FEATURES**

The customer features for our project are:

- Ease of Use
- Setup time
- Portability
- Initial Investment Cost

**PRODUCT OBJECTIVES**

- To create a portable system on frame and wheels so that it can be moved from track to track. (Relative Weight: 18.2)
- To create a pull-down machine with a low initial investment. (Relative Weight: 16.4)
- To design and create a pull-down machine that is easy to use and setup as well as measure all the necessary and important characteristics of a dirt late model. (Relative Weight: 14.5)

# QUALITY FUNCTION DEPLOYMENT

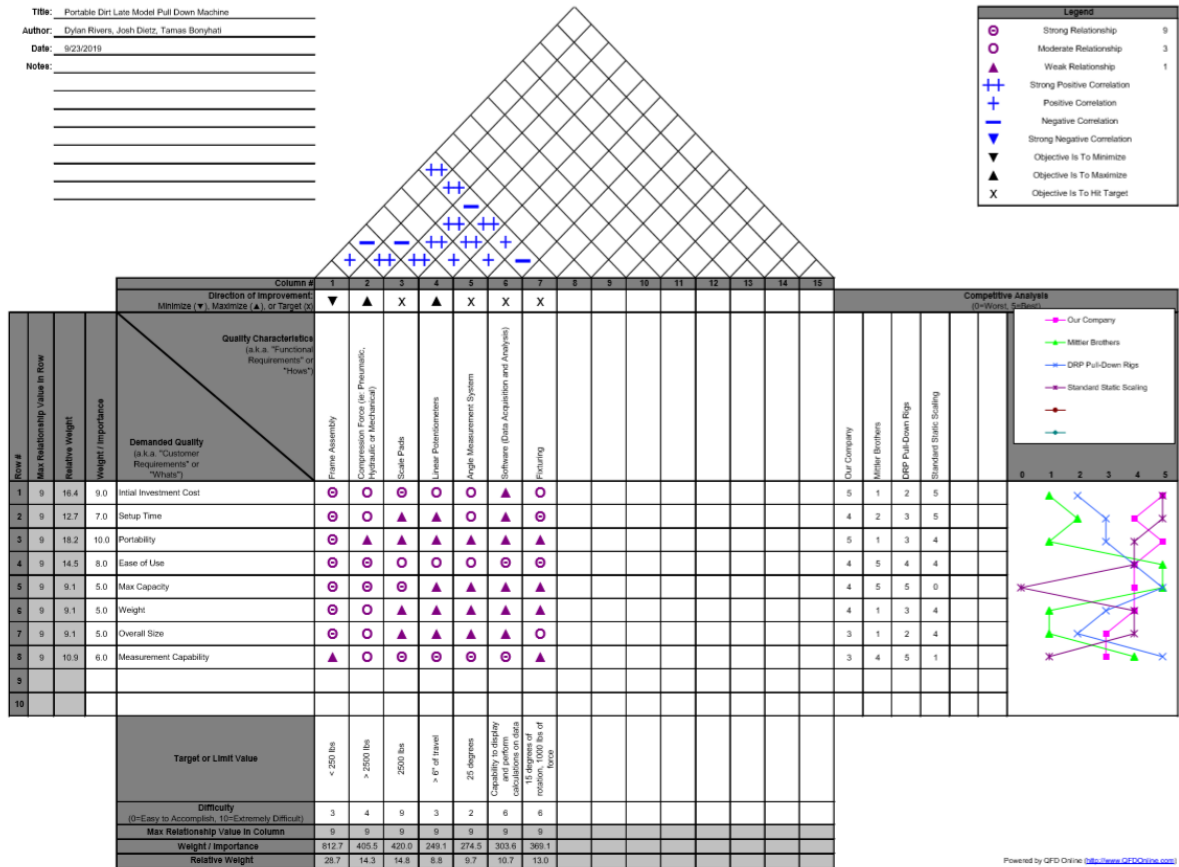


Fig. 1: House of Quality

## Customer Features

The customer features for our project are:

- Ease of Use
- Setup time
- Portability
- Initial Investment Cost

## Engineering Characteristics

The engineering characteristics to achieve the customer needs are:

- Material and Component Choice for the system (Investment cost)
- Frame Assembly (Designing a frame that can be folded up and portable)
- Software – make all measurements and loads organized and easy to understand
- Actuation system – choose actuators that are simple to setup, inexpensive and achieve moving the car into a dynamic position

## DESIGN

My section of the project was to design and build an actuation system that would actuate three points on the racecar. Those three points are as follows: pull down vertically on the right front suspension, pull horizontally on the torque arm on the rear end of the racecar, and pull vertically on the right rear suspension. With these three actuation points on a dirt racecar you can simulate all the movements that the racecar experiences during acceleration, deceleration, and cornering.

The first step was to determine the max force necessary that would need to be applied by an actuation system at these three points on the car.

### Right Front:

Below is a drawing of the right front suspension on dirt race car. In order to achieve the dynamic position of the racecar we need to compress the shock and spring setup on the right front of the car. These calculations are based on the worst-case scenario that the actuator will see when pulling vertically on the chassis. We need to be able to compress the shock and spring 4 inches from ride height. What this means is if the center to center of shock measures 18.5” at static ride height then we need to compress it to 14.5” at dynamic ride height. This the maximum distance that this shock will travel at any point on the racetrack.

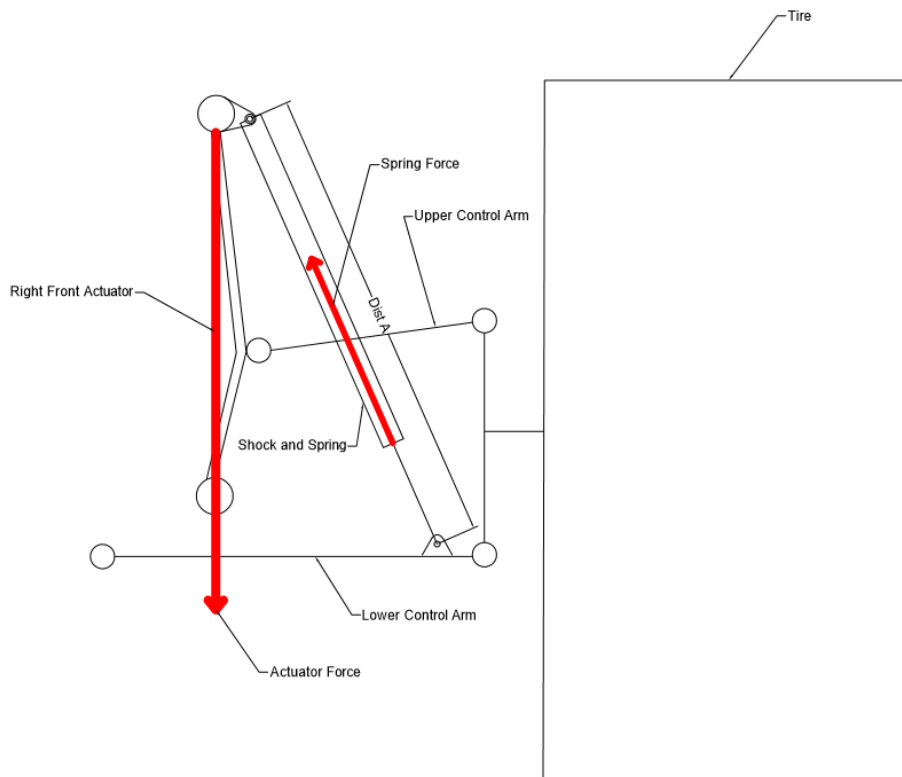


Fig. 2: Right Front Suspension

**Assumptions:**

Desired shock travel (Dist A): 4 inches down from ride height  
 Spring Load @ Ride Height: 660lb  
 Spring Load @ 4 inches down: 2000lb + 500lb(buffer) = 2500lb  
 Angle of Shock and Spring: 60 degrees

**Calculation of Force needed:**

$$\begin{aligned} \text{Actuator Force} &= \text{Spring Force @ 4in.} * \sin(\text{Angle of Shock}) \\ &= 2500\text{lb} * \sin(60 \text{ degrees}) = 2,165\text{lb} \end{aligned}$$

To achieve our dynamic ride height of 4 inches from static ride height, we need an actuator to apply a force of 2,165lb to the chassis of the racecar.

**Torque Arm:**

The torque is attached to the rear end of the race car and it has a shock and spring attached to the end of it to control the acceleration and torque of the engine when the car accelerates. To simulate acceleration with the pull-down machine we will pull horizontally from the center of the rear end and pull forward by attaching an actuator to the chassis of the racecar. This will then cause the rear-end to wrap-up or rotate like it does when the driver applies the throttle. Below is a drawing and FBD showing the forces that are needed to simulate acceleration.

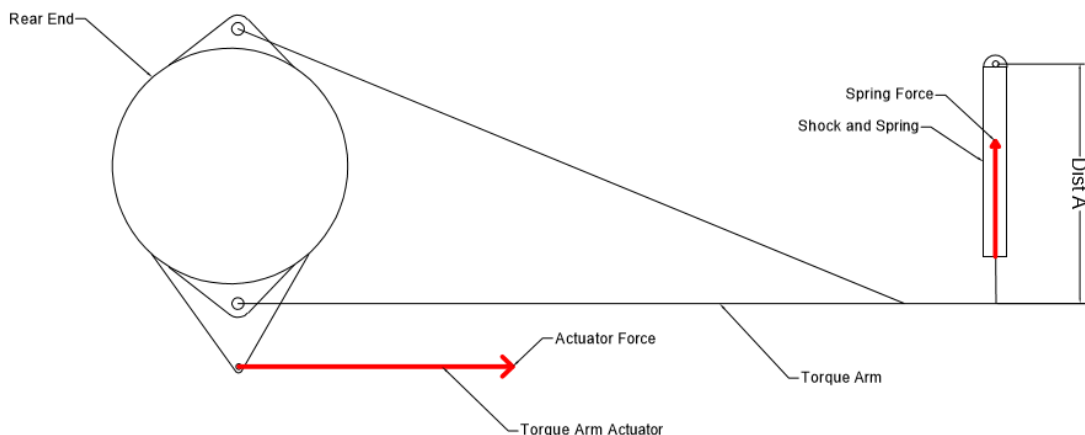


Fig. 3: Torque Arm Suspension

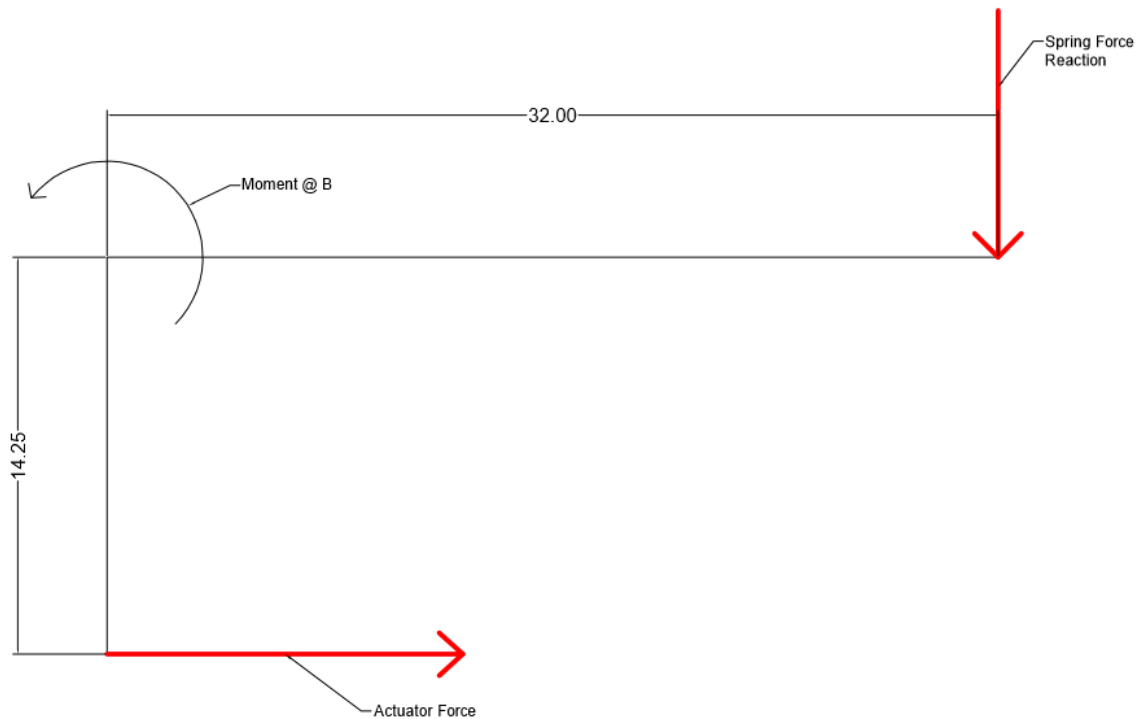


Fig. 4: Free Body Diagram of Torque Arm

The desired shock and spring travel from static ride height for the torque arm is 3 inches. If the shock measures 18.5” from center to center at static ride height, then the max dynamic travel of the shock would be 15.5”.

**Assumptions:**

- Desired shock travel: 3 inches
- Spring Load @ Ride Height: 125lb
- Spring @ 3 inches: 900lb
- Distance from Actuation Point to Shock and Spring: 32 inches

**Calculation of Force Needed:**

$$\sum MB = (-900 * 32 \text{ in}) + (AF * 14.25) = 0$$

$$AF = \text{Actuator Force} = 2021 \text{ lb}$$

To be able to reach the dynamic shock travel of 3 inches we need the actuator to apply 2021lb of force to the torque arm which will be able to simulate acceleration onto the racecar.

## **Design Alternatives**

Three systems were considered for the actuation system for our pull-down machine:

- Hydraulic Cylinders
- A system of winches
- Electric Linear Actuators

The selected system for this project is to use for this project is to use hydraulic cylinders. This system was chosen because they were inexpensive compared to the linear electric actuators and they would be able to achieve more accurate and precise movements compared to winches. Overall, I felt hydraulic cylinders would suit the needs of the project the best.

## **Component Selection**

### Hydraulic Pump Selection



Pump: Magister 12V Hydraulic Power Unit

Work Pressure = 2500 psi

Relief Valve Pressure = 3000 psi

Average Flow = 0.9 GPM

Hydraulic Cylinder Selection



Bore = 2.00in Rod Diameter = 1.25in

Area of Piston = 3.14 in<sup>2</sup> Area of Rod = 1.23in<sup>2</sup>

Pulling Area = 3.14in<sup>2</sup> - 1.23in<sup>2</sup> = 1.91 in<sup>2</sup> Pump Pressure = 2500psi

$P = F/A \rightarrow F = P \cdot A = 2500 \text{ psi} \cdot 1.91 \text{ in}^2 = 4775 \text{ lb}$

Max Force Needed by Actuator = 2,165lb

Safety Factor = 4775/2165 = 2 for the Hydraulic Cylinder

Additional Components Selected

- 3 by 5 Way Spring Return Solenoid Valve Pack
- 3000lb High Pressure Hose
- Various Fittings



Fig. 5: Hydraulic Pump and Cylinder

**Loading Conditions/Design Analysis**

The arrows below are pointing to the members that are loaded by the hydraulic cylinders when the system is activated to pull down on the race car.

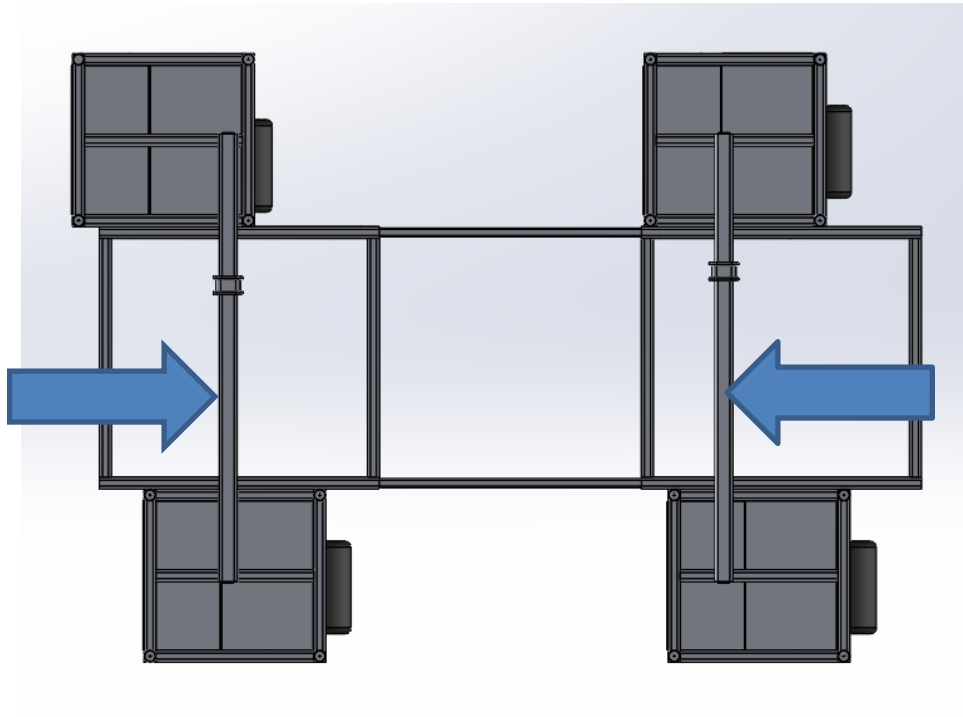


Fig. 6: Image of Loaded Members by Hydraulic Cylinders

FEA Analysis of Loaded Member:

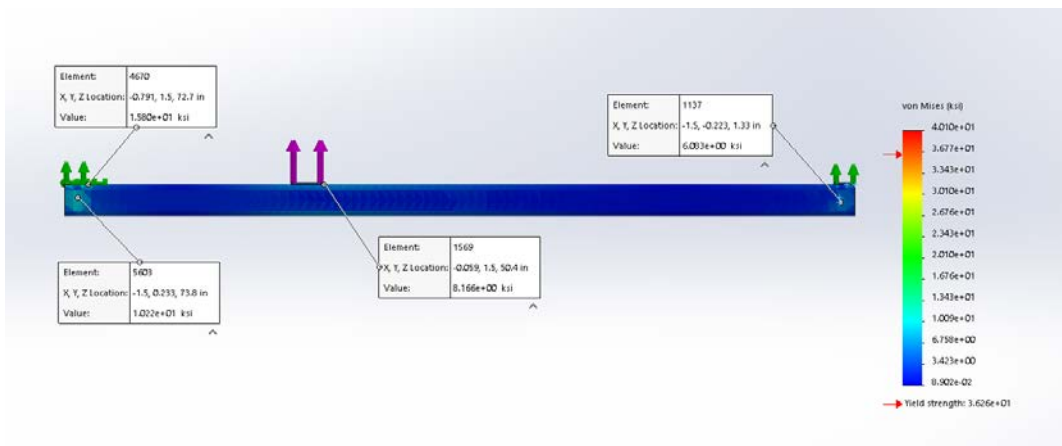


Fig. 7: FEA Analysis of Loaded Member of Frame

This member was loaded with a worst-case scenario load of 2500lb at the midpoint of the member so that I could get the worst-case scenario safety factor so that this member would not fail under max loading conditions.

Material Selection for Loaded Member:

- 3 x 3 x 0.25 A500 Grade B Square Tube
- Max Stress in Beam = 8.17ksi
- Yield Strength = 46.00ksi
- Safety Factor =  $46.00\text{ksi} / 8.17\text{ksi} = 5.63$

### Right Front Bracket Analysis

The bracket below is used to attach the hydraulic cylinder too in order to apply a force to the chassis and compress the suspension of the right front wheel. It is hooked onto the top frame of the chassis shown in the picture below and then rests against the bottom frame rail to prevent the bracket from rotating since the chassis is manufactured from round tube.



Fig. 8: Completed Right Front Bracket

FEA Analysis of Right Front Bracket:

Max Force Applied = 2500lb

- Material: A500 3/8" Plate
- Yield Strength = 36.26 ksi
- Max Stress = 2.50 ksi
- Safety Factor = 14.50

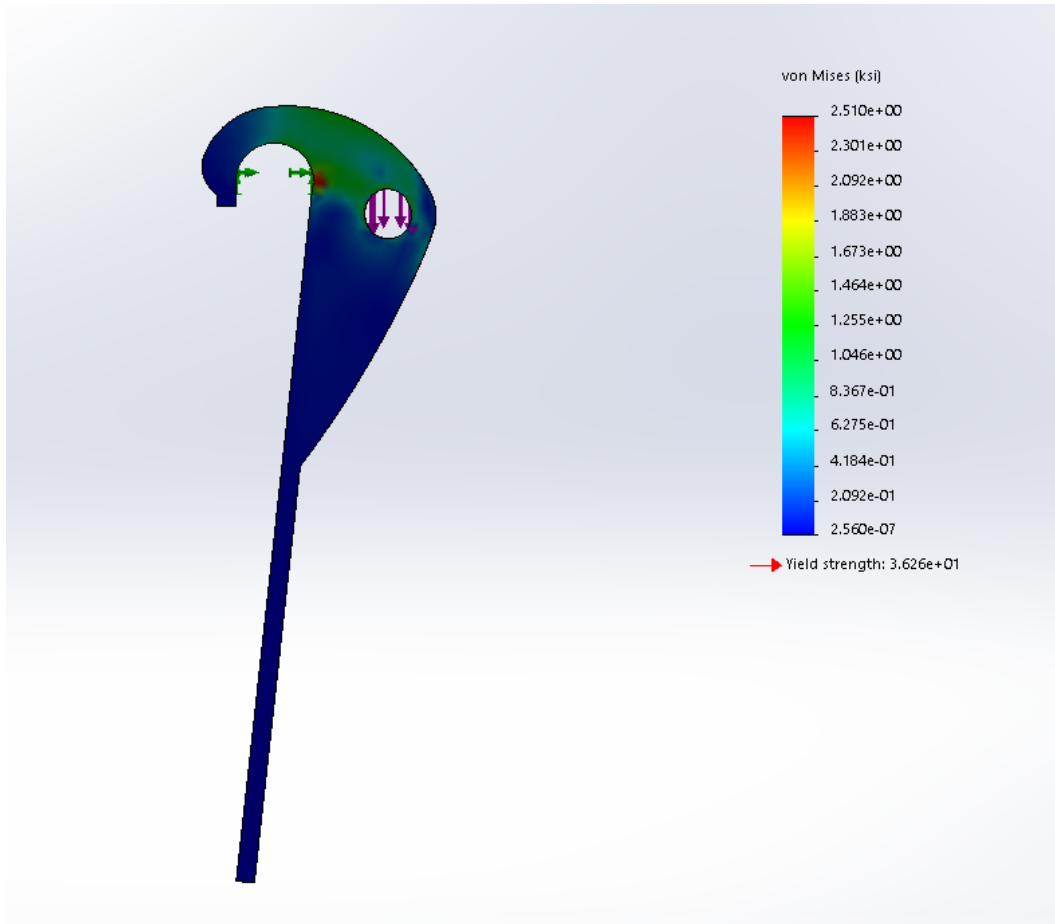


Fig. 9: FEA Analysis of Right Front Bracket

### Lift Bar Plate Analysis

This plate is attached to the center section of the rear end. Two of them are used one on the left side of center section and one on the right side of the center section. These plates are attached using the bolts that run through the center section and then the hydraulic cylinder is attached between both plates. The other end of the hydraulic cylinder is then attached to the chassis using a chain. When the hydraulic cylinder then retracts and applies a force to the torque arm.



Fig. 10: Completed Lift Bar Plate

FEA Analysis of Lift Bar Plate:

Max Force Applied to one Plate: 1250lb

- Material: A500  $\frac{3}{8}$ " Plate
- Yield Strength = 36.26 ksi
- Max Stress = 14.44 ksi
- Safety Factor = 2.57

Bill of Materials:

- 1 – 12V Hydraulic Pump (2500psi Working Pressure)
- 3 – 2in. Bore Hydraulic Cylinders
- 1 – 3 by 5 Way Spring Return Solenoid Valve Pack

- 1 – Right Front Bracket
- 2 – Lift Bar Plates
- 2 – 3in x 3in Square Tube
- 4 – 1in. Dia. Hex Bolts
- Various Fittings
- ~50ft of 3000psi Hydraulic Hose

## Final Assembly

Below is an image of the completed pull down machine with the hydraulic cylinders, pump, and valve pack. The valve pack and hydraulic pump are fixtured to the frame of the pull-down machine. The hydraulic cylinders are then attached to the frame and then to the chassis of the car. The pump and valve pack are then controlled by a plc. The solenoids are fired on the valve pack until a certain distance is reached.



Fig. 11: Final Assembly of Pull-Down Machine



Fig. 12: Hydraulic Pump and Valve Pack

**PROJECT MANAGEMENT**

*BUDGET, PROPOSED/ACTUAL*

Table 1: Preliminary Budget

Preliminary Budget	
Component	Cost
Frame/Fixturing	\$400
Actuation System	\$800
Measuring System	\$500
Total:	\$1,700

Table 2: Proposed Budget

Proposed Budget	
Component	Cost
Frame/Fixturing	\$500
Actuation System	\$1,300
Measuring System	\$700
Total:	\$2,500

Table 3: Final Budget

Actual/Final Budget	
Component	Cost
Frame/Fixturing	\$800
Actuation System	\$1,600
Measuring System	\$700
Total:	\$3,100

***SCHEDULE, PROPOSED /ACTUAL***

Table 4: Proposed Schedule

<b>Proposed Schedule</b>	
<b>Milestone</b>	<b>Date</b>
Choose Design Concept	10/18/2019
Complete Calculations	11/15/2019
Finalize Design	12/6/2019
Order Materials	1/17/2020
Complete Manufacturing	3/20/2020
Test	3/27/2020
Revisions	4/3/2020
Tech Expo	4/9/2020

Table 5: Actual/Final Schedule

<b>Actual Schedule</b>	
<b>Milestone</b>	<b>Date</b>
Choose Design Concept	10/18/2019
Complete Calculations	11/15/2019
Finalize Design	12/6/2019
Order Materials	1/17/2020
Complete Manufacturing	4/11/2020
Test	4/18/2020
Tech Expo	Cancelled

***TESTING***

We finished our project, so we were able to test it to the procedure listed below. We then performed a CPK analysis on the data. The CPK values were all greater than 1.33 therefore our process capability was high enough to be acceptable.

1. Car will be set with the standard chassis manufacturer recommended settings.
2. The machine will pull each corner down until a desired shock distance is reached. ( $\pm 1/16''$ )
3. Test will be ran 30 times with the wheel loads recorded
4. Wheel Load Error =  $\pm 2\%$  of Expected Wheel Load ( $\pm 15$  lbf)
5. RF spring is shimmed by  $1/8''$  and test is run 3 times to see if wheel weight is affected on the right front.

Table 6: Test 1 - Recorded Values

Test	Wheel Weights (lb.)				Measured Distances (in.)		
	Right Front	Left Front	Left Rear	Right Rear	Right Front	Torque Arm	Right Rear
1	1103	704	633	562	14.45	16.24	22.86
2	1109	702	630	559	14.45	16.25	22.76
3	1095	704	632	564	14.45	16.19	22.8
4	1090	710	625	557	14.45	16.21	22.8
5	1108	690	631	559	14.45	16.25	22.8
6	1116	698	644	553	14.43	16.3	22.89
7	1098	698	647	553	14.47	16.25	22.82
8	1100	692	646	551	14.45	16.24	22.83
9	1086	695	643	550	14.51	16.22	22.8
10	1096	681	645	551	14.48	16.21	22.81
11	1095	687	652	545	14.45	16.24	22.85
12	1106	701	642	546	14.45	16.25	22.86
13	1101	697	639	548	14.45	16.19	22.76
14	1097	696	649	550	14.45	16.21	22.8
15	1093	700	650	552	14.45	16.25	22.8
16	1104	703	642	559	14.43	16.3	22.8
17	1106	697	644	555	14.47	16.25	22.89
18	1108	695	651	547	14.51	16.24	22.82
19	1099	705	640	542	14.48	16.22	22.83
20	1091	699	645	555	14.45	16.21	22.8
21	1105	703	642	556	14.45	16.25	22.81
22	1103	697	651	543	14.45	16.24	22.85
23	1095	695	641	549	14.47	16.25	22.8
24	1089	685	642	554	14.45	16.19	22.8
25	1100	687	646	558	14.45	16.21	22.89
26	1105	704	649	557	14.43	16.25	22.82
27	1108	693	652	552	14.47	16.3	22.83
28	1098	700	655	545	14.45	16.25	22.89
29	1100	701	643	548	14.51	16.24	22.82
30	1101	698	651	551	14.48	16.22	22.83
AVG	1100	697	643	552	14.46	16.237	22.824
STDEV	6.803	6.526	7.308	5.586	0.021	0.029	0.035
LSL	1070	667	613	522	14.335	16.112	22.699
USL	1130	727	673	582	14.585	16.362	22.949
CPK	1.469	1.532	1.368	1.790	1.931	1.425	1.183

Table 7: Test 2 – Recorded Values

Setup Change: Adding 1/8" Packer Shim to RF shock							
Prediction of change: should increase wheel weight on the RF							
Wheel Weights (lb.)					Measured Distances (in.)		
Test	Right Front	Left Front	Left Rear	Right Rear	Right Front	Torque Arm	Right Rear
1	1170	677	660	531	14.51	16.2	22.7
2	1160	680	658	540	14.52	16.3	22.76
3	1165	686	654	542	14.52	16.25	22.81

The above table shows that when we added a shim to the RF shock, we saw the RF wheel weight increase like we knew should happen because of experience and knowledge of what adding a shim will do. This proves that we can make a change to the car and see what that change will do to the wheel weights after the change.

***SUSTAINABILITY AND MATERIAL USAGE***

Future Recommendations:

- Manufacture and construct frame out of aluminum so that it is lighter in weight
- Use a different actuation system
- Redesign locating system of pads to fit a car lift under the car to make adjustments to the car easier

## WORKS CITED

1. **DRP Pull Down Systems & Packages.** *DRP Performance Products*. [Online] [Cited: September 11, 2019.] <https://www.drpperformance.net/copy-of-pull-down-systems-1>.
2. **Ultimate Pull Down Rig.** *Mittler Brothers*. [Online] [Cited: September 11, 2019.] <https://www.mittlerbros.com/econo-pull-down-rig.html>.

## APPENDIX A (RESEARCH)

DRP Pull Down Machine:



Mittler Brother's Pull-Down Machine



## APPENDIX B

Below is a picture of the survey that we used to collect information on which features are important to the end user. The customer features that had the highest average ranking of importance were investment cost, setup time, portability, and ease of use.

### Portable Dirt Late Model Pull-Down Machine Survey

This survey will be used to prioritize various features to maximize customer satisfaction. The system in question will address issues for setting up dirt late models. This system will measure various aspects of a car through dynamic on track travel to aid in setup ability.

**How important is each feature to you?**

**Please circle the appropriate answer. 1=low importance 5=high importance**

<b>Initial Investment Cost</b>	1	2	3	4	5	N/A
<b>Setup Time</b>	1	2	3	4	5	N/A
<b>Portability</b>	1	2	3	4	5	N/A
<b>Ease of Use</b>	1	2	3	4	5	N/A
<b>Max Capacity</b>	1	2	3	4	5	N/A
<b>Weight</b>	1	2	3	4	5	N/A
<b>Overall Size</b>	1	2	3	4	5	N/A
<b>Measurement Capability</b>	1	2	3	4	5	N/A

**How satisfied are you with current setup technology?**

**Please circle the appropriate answer. 1=very unssatisfied 5=very satisfied**

<input type="checkbox"/> <b>Initial Investment Cost</b>	1	2	3	4	5	N/A
<b>Setup Time</b>	1	2	3	4	5	N/A
<b>Portability</b>	1	2	3	4	5	N/A
<b>Ease of Use</b>	1	2	3	4	5	N/A
<b>Max Capacity</b>	1	2	3	4	5	N/A
<b>Weight</b>	1	2	3	4	5	N/A
<b>Overall Size</b>	1	2	3	4	5	N/A
<b>Measurement Capability</b>	1	2	3	4	5	N/A

**How much would you be willing to invest in this setup tool?**

**\$500 - \$1000,      \$1000 - \$3000,      \$3000 - \$10000,      \$10000+**



## **APPENDIX D**

### **Product Objectives**

- To create a portable system on frame and wheels so that it can be moved from track to track. (Relative Weight: 18.2)
- To create a pull-down machine with a low initial investment. (Relative Weight: 16.4)
- To design and create a pull-down machine that is easy to use and setup as well as measure all the necessary and important characteristics of a dirt late model. (Relative Weight: 14.5)