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Instrumentation and Remodeling of Truck for Maximization of Pulling Capability

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ME 487 - ME 488
Capstone Senior Design Project

Report #2

Project Title: Instrumentation and Remodeling of Truck for Maximization of Pulling Capability

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## Table of Contents

Table of Contents .......................................................................................................................................... 2

Section 1: Acknowledgements ...................................................................................................................... 3

Section 2: Abstract ........................................................................................................................................ 7

Section 3: Problem Statement ....................................................................................................................... 9

  Requirements and Specifications: ............................................................................................................... 10

  Design Parameters: .................................................................................................................................. 11

  Design Variables: ..................................................................................................................................... 12

  Limitations and Constraints: ...................................................................................................................... 13

  Additional Considerations: ....................................................................................................................... 13

Section 4: Final Designs ............................................................................................................................... 14

  Final Design – Parts .................................................................................................................................. 15

Section 5: Building Process ........................................................................................................................ 18

Section 6: Testing ......................................................................................................................................... 25

Section 7: Evaluation and Recommendations ............................................................................................. 27

Section 8: Cost Analysis ............................................................................................................................... 35

  Design Cost: ........................................................................................................................................... 36

Section 9: Conclusion ................................................................................................................................... 39

  Other Considerations: ............................................................................................................................... 40

Section 10: References ................................................................................................................................. 41

Section 11: Appendices ............................................................................................................................... 43

  Appendix 1 – 6000 lb. Stateline Pro-Street 4WD Rules ........................................................................... 44
Section 1: Acknowledgements
The Re-Patched Pulling Team would like to give a special thanks to Dr. Zhuming Bi for his guidance and knowledge in the engineering perspective. His input was a tremendous help in pointing us in the right direction.

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- Comp Cams
- CW Farms
- Danny Bee Racing
- Fort Wayne Spring Service Inc.
- Franke Plating
- Gerarodt Performance
- Hart’s Machine Shop
- IPFW
- Jesel Valvetrain Innovation
- Kickin Chicken
- Maddog Headers
- Mallory (Prestolite Performance)
- McLeod Racing
- Minnich Garage
- Olive Racing Parts
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- RacePak
- Singer Sled Rental
- Spintech
- Tastee Freeze
- Urbine Brother
Section 2: Abstract
The Re-Patched Pulling Team was created because there was a need for the design of a chassis set-up for a competition pulling truck that would be pulling a progressive weight sled in multiple sanctioned events. This progressive weight sled acts as a dead weight of 30,000 pounds when its progression reaches the end of the slide, there it will stop. The chassis set-up that was tested in an earlier competition showed weakness in performance and introduced the need of a newly designed truck set-up. The axles experienced axle wrap and wheel hop due to the truck’s original leaf springs and the distance pulled was not acceptable. In the new design, a new front suspension, rear suspension, hitch assembly, and data acquisition system will be incorporated.

The new chassis design had some requirements that were gathered from multiple locations and perspectives. The most important requirement was the rules for the class that the truck would be entered into during the competition season. This class is the 6000 lb Stateline Pro-Street 4WD which is a class in the MICHINDOH Pulling Association. If the truck did not meet the rules and regulations of the class, then the project would be a failure. Another requirement for the project is the designing of components that are durable. Any part failure that is found during competition could be catastrophic to the pull as well as the safety of all involved. While the parts must be durable, the truck must also sustain forces applied to it by the progressive weight sled and convert it to the ground evenly. That is, the front axle must exert a force to the ground that is 80% of that of the force that the rear axle exerts to the ground. Through analysis, spring rates and hitch designs will be considered towards this factor. Two requirements that will be weighed against the final design through testing is the truck’s speed going down the track and the distance that the truck accomplishes during the competition. The quantitative numbers that the team put as goals for the project were a truck speed of 24 MPH and a total distance of 93% of the full pull (300 feet) or if a full pull is not achieved by any competitor, then 93% of the farthest distance pulled by the leader. These numbers were researched as values seen by previous year’s season winners. The next requirement is the removal of any axle wrap and wheel hop. The final requirement towards the project was cost. An estimated $10,000 was placed on the project so any design would need to be able to be manufactured with a cost lower than this estimation.

The team was able to compete in all nine of the sanctioned MICHINDOH truck pulling competitions. All of the safety and measurement requirements were met according to the MICHINDOH rules. As stated previously, the goal of 93% of the Full Pull distance was achieved. The team averaged 95% of the Full Pull distance through the season. The full implementation of all designs was only implemented for the last six pulls of the season. During these six pulls the team averaged 98% of the full pull distance with three full pulls. The team was slightly below the goal to attain a truck speed of 24 MPH, averaging only 21.5 MPH. However, the team did achieve this goal in two of the last six pulls that the design was fully implemented. The designed components also did not experience any failures throughout the season, which was a major goal that was achieved for the team. Based on the results of the competition season, it was relevant that if there had been more truck pull events that the team would have continued to improve.
Section 3: Problem Statement
In order to maximize the pulling capability of a 1967 Ford truck, an integrated suspension and hitch must be designed and optimized with the use of a data acquisition system to reduce the effects of axle wrap, wheel hop, and traction loss. In order to achieve this goal, the suspension, weight distribution, and hitch of the competition truck will be analyzed, and new parts will be designed to improve the truck’s pulling capabilities. The newly optimized truck will then be tested in a pulling competition.

By analyzing the truck system, the knowledge gathered can be used on new production trucks to improve their pulling capabilities and reliability under heavy duty cycles. The system to be analyzed can be seen in Figure 1. In Figure 1, one can see the major loads which act on the system are as follows: load from the sled, weight of the frame/truck, and reaction torques which occur on the axles.

![Figure 1: System Model](image)

In the competition the truck is attached to a progressive weight sled, via the hitch, and then it pulls the sled until the pulling ability of the truck is overcome by the weight of the sled and the friction force it exerts. The progressive weight sled is started from rest with the extent of the weight resting on two frictionless axles. Then as the sled begins to move, the weight begins to progress onto a pan – flat plate of steel. The truck pulls the sled on a dirt track; thus, as the weight is completely on the pan, the amount of friction between the pan and the dirt overtakes the ability of the truck to move forward. The distance from the start to when the truck stops is measured. The truck with the farthest measured distance becomes the champion of the event and receives maximum points.

For this project, the available general-purpose truck is not optimized for the pulling competition, but rather its components are. Two aspects must be considered to develop a solution. This design project is proposed to analyze the pulling system and renovate the truck based on the system model and the collected data for the pulling competition.
To analyze the system, the following tasks will be accomplished:

- Sensors will be chosen to develop a data acquisition system to gain information about the system.
- Mathematic modeling and virtual analysis will be completed to assure that the truck components will meet specifications and not fail during competition.

To optimize the truck, the following tasks will be accomplished:

- The suspension components will be chosen based on the values determined from the system model.
- The hitch will be redesigned and manufactured based on the analysis of the forces.
- Other components will be identified, analyzed, and redesigned to ensure superior performance.

**Requirements and Specifications:**

To measure the improvement in the pulling capability of the truck, requirements and specifications must be in place to measure its success.

- **Durability** – Any designed component must not fail anytime during the season. The truck must be reliable; it should be able to withstand all the accumulated stresses applied to it throughout the season.
- **Truck Traction** – When all four tires of the truck apply the same force to the ground, the truck will be able to pull the sled a greater distance. With the weight of the sled pulling down on the rear of the truck, the rear tires will have a considerable advantage in traction over the front tires. In order for the final design to be a success, the front tires need to apply 80% of the force compared to that of the rear tires. Also, the amount of loss traction between the truck and the ground must not be less than 70%.
- **Truck Speed** – The truck must reach and maintain a speed of at least 24 MPH through the extent of the pull session. The team must obtain this speed so that the truck and sled have enough momentum to reach a Full Pull.
- **Truck Distance** – The truck must pull the sled 93% of the Full Pull mark. This specification will give the truck and the team an opportunity of being a top contender in the MICHINDOH 6000lb Stateline Pro Street 4X4 class.
**Design Parameters:**

The design parameters are the parameters that are given as characteristics to the system that cannot be changed. Many of these design parameters are specified by the MICHINDOH rules. Understanding the rules and other design parameters, the final design will be able to improve the pulling capability of the truck.

- **MICHINDOH Rules** – The truck must meet all of the rules required for the 6000lb Stateline Pro Street 4X4 class. This also includes the general club rules for MICHINDOH. The following rules are more pertinent to the design project. A complete list of the rules can be seen in the Appendix.
  - Truck needs to be safe and pass inspection
  - Truck needs to have all safety equipment and SFI blow proof components where described.
  - Truck Suspension:
    - Truck must have stock (Original Equipment Material) driveline.
    - Truck must have complete suspension with at least 1” of travel, but may be blocked during pull. There must be at least 3 leaf springs on rear axle.
    - All traction bars on rear axle must go forward of rear axle.
    - All driveline must be in stock location with a maximum wheel base of 134 inches.
    - No narrowing of front or rear axle.
  - Truck Specifications:
    - Truck must weigh 6000lb or less.
    - Truck must have full body (not gutted).
    - Truck must have working brakes on all 4 wheels.
  - Truck Hitch:
    - Hitch cannot be more than 22 inches off the ground.
    - Hook point must be a minimum of 42 inches from the rear axle.
    - Pivot point must not be forward of rear axle.
    - Pivot point must not be above truck’s frame rail.
    - No bars of hitch to reach to rear axle
    - All bars and hitch components must be mounted to frame rail only.

- **Sled Weight** – The truck will be pulling a known weight that cannot be altered.
- **Truck Layout** – The design concept must stay within the constraints of the truck’s frame and axles. The frame and axles have to remain the same and will not be changed.
- **Energy Source** – 94 or less octane fuel must be used.
Design Variables:

While meeting the requirements and specifications, it is important to identify components that can be altered to enhance the pulling capabilities of the truck. The characteristics that can be altered in the system in order to satisfy the design concept’s requirements for success are called design variables. These can be separated into two distinctive types: hardware and operating conditions.

The design variables for hardware represent the characteristics in design that are changeable in the design process; however, they are fixed after the design has been materialized. The design variables for operating conditions are characteristics that may change throughout the operation of a machine, both before and after the design phase. Both of these design variables need to be considered to develop the optimum design for the truck’s chassis set-up.

- **Hardware:**
  - Traction Devices – The length and orientation of the front and rear traction devices need to be found such that they maximize the traction and keep the axles in the desired locations. They also need to be able to transfer the combined weight of the truck and sled to the desired locations to optimize the truck’s set-up.
  - Truck Springs – The spring rate of the front and rear of the truck needs to be found to apply the load of the truck and sled weight to the tires.
  - Truck Hitch – The size and weight of the hitch needs to be found to withstand the forces found throughout the run of the pulling session. If a hitch fails during a pulling session, the truck and sled will become disconnected and devastating results could entail.
  - Truck Components – The designed components need to be sized and materialized properly to prevent failure throughout the season.
  - Data Acquisition Sensors – Sensor components will need to be selected that desired outputs (vertical displacement of axles, speed of truck/sled system, acceleration of system in all directions, and axle and wheel speed) can be measured.

- **Operating Conditions:**
  - Weight Distribution – The center of mass for the truck has to maximize the traction of the front tires compared to the back tires. This can be changed by moving weight ballast around the truck between pulling sessions to assist in any changes.
  - Truck Shocks – There will be adjustable shocks to help optimize the response of the truck’s tires to the terrain of the pulling track. They will also help keep any oscillating vibration of the suspension from occurring during the pulling session.
  - Tire Pressure – The ratio of the tire pressures (front tires versus the rear tires) will aid in the traction of the truck. This pressure can be checked and changed between pulling sessions.
  - Truck Hitch – The most desirable hitch angle and height will serve as a transfer point for the weight of the sled to pull the truck into the ground. This angle will be adjustable and will be able to change with ease.
**Limitations and Constraints:**

The limits placed on this project involve the rules as well as what is available to the Re-Patched Pulling team.

- **Low Cost** – This project has a budget of $10,000. Therefore, all the components used must have a limit on the amount of the cost. The design concept will take no shortcuts in the materials and the build; however, the thought of cost is still an issue.
- **Space Limitations** – The components of the final design concept must fit under the truck body of a 1967 Ford. This is the truck that is available for use and all the design concepts need to be able to be adapted to the truck’s frame and body.
- **Time** – The competition occurs from mid-May and lasts the summertime, thus all the modeling, data collection, building, and testing must happen in that time frame.

**Additional Considerations:**

These additional considerations involve basic goals for the Re-Patched Pulling team. The design concepts should follow these goals as if they were requirements.

- **Overall Safety** – The truck must be safe at all operating times for both the driver and any spectators within visible reach of the vehicle. It must have all the safety equipment in place with all the approved parts at all times. It must also have material that is strong enough in order to not break under normal pulling sessions.
- **Reliability** – The truck and final design concept must not break on a regular basis. It must be built strong enough not to have to worry about breaking at every pulling event.
- **Maintenance** – The truck should not need maintained on a regular basis. It should not need to be rebuilt after every pulling event.
- **Performance** – The truck should be efficient in what it was built for. It should convert most of its power to the ground and it should do this with minimal traction loss.
- **Race Environment** – There is great concern about the uncertainties of the racing environments. Weather and soil conditions are unpredictable. Because of this, the weather will have to be noted for each pulling event to take into consideration during our analysis.
- **Season Points** – The team would like to finish the season in the top 3 in points in the MICHINDOH 6000lb Stateline Pro Street 4X4 class. If this can be accomplished, the final product was designed and optimized to be a success.
Section 4: Final Designs
The process of determining the best set-up for a competition pulling truck initially started with a brainstorming event that included all the members of the Re-Patched Pulling Team. The requirements of the project were understood by each member and the brainstorming event was a time where many different ideas could be put on paper without any evaluation or criticism. Because the truck’s set-up is a complex system, the conceptual designs were split up into four distinct main categories. These categories include the hitch, the rear suspension, the front suspension, and the data acquisition.

The team then conducted an evaluation of each conceptual design. Each design was weighed against the project’s different goals and placed into a decision matrix. Then each design was given a score which showed the group members which design best suited the project’s goals. The highest scoring concepts for each category were used as the final design for the competition pulling truck’s set-up. Then the second highest scoring concepts were taken as the second best design and will be considered as our back-up design if there is a need for a different design in the future. The following figures provide a short description of the components that were chosen as the final design.

**Final Design – Parts**

**Front Suspension: Four-Bar Linkage with Front Shackle**

![AutoCAD Drawing of Front Suspension Set-up](image)

**Figure 2: AutoCAD Drawing of Front Suspension Set-up**

The final design for the front suspension set-up can be seen in Figure 2 and consists of a four-bar linkage system. The four-bar linkage is attached to the axle on a two piece bracket that is bolted and welded to the axle tube. The axle bracket has a series of three holes that the traction bar can be bolted which allows for adjustment to the bar’s orientation for different set-ups.
Rear Suspension: Four-Bar Linkage with Dual Shackles

The final design of the rear suspension set-up can be seen in Figure 3 and it consists of a four-bar linkage system. The four-bar linkage is attached to the axle by a two piece bracket that is both bolted and welded for permanent mounting to the axle. The axle bracket has a series of 5 holes for each traction bar for adjustability of the orientation of the bars.
The final design of the hitch assembly is shown in Figure 4 and Figure 5 and is a V-shaped design with one adjustable third link. Figure 4 shows the orientation of the third link. The V-shaped design was chosen for the ability for it to be made light and strong. The ends of the square tubing structure are one inch rod ends that bolt directly to the frame rail. The back two rod ends are bolted directly above the center of the rear axle to allow for a shorter lever arm lifting the front of the truck. The third link is mounted in the center of the V-shape and is adjustable for raising and lowering of the hitch compared to the ground. The third link will have one inch rod ends as well on both ends with a 4130 Chrome Moly two inch round tube connect them.
Section 5: Building Process
Part Fabrication

The chromoly and steel materials were ordered from Metal Supermakets and Century Trading, respectively. The parts were then cut to specification by the Repatched Pulling team at the Minnich Garage. Milwaukee Chop Saw 14 Amp with a 14 inch cutting wheel was used to cut the chromoly and steel parts to their respective specifications. A JET Drill Press was used to locate and drill holes in the brackets that were created. Two types of welding processed were used – MIG and TIG. The hitch was mostly TIG welded while all other parts utilized MIG welding.

Electronic Data and Programming

For electronic data collection, the Racepack G2X Data Logger was used. This electronic system came with a wide variety of information and installation manuals. These can be accessed on the Racepack website: http://www.racepak.com/downloads/.

The Racepack G2X Data Logger was mated with engine rpm, suspension travel sensors, air fuel ratio, GPS positioning and accelerometer that were attached to the vehicle. The senior design team set up the wiring to obtain the necessary data. The wiring diagram can be seen in the Appendix.

Final Truck Assembly

Using the fabricated parts, the Racepack G2X Data Logger, and other sensors, the team was able to assemble the Truck to its final state. Below are a few pictures of the Re-Patched Pulling Team working on the vehicle, and pictures of the completed assemblies.
Flow charts of the complete build process can be seen below. These charts detail the rear suspension build process, front suspension build process, and the hitch build process in Figure 6, Figure 7, Figure 8, respectively.
Figure 6: Flow Chart of Rear Suspension Build Process
Figure 7: Front Suspension Build Process

Remove OEM Suspension

1. Unbolt shocks and remove
2. Unbolt old leaf springs and remove
3. Unbolt rear drive shaft

Provides more room to work

Make Chromoly Parts

1. Cut Chromoly Tubing to length
2. Weld threaded bungs into Chromoly tubing to insert rod ends on each end
3. Assemble rod ends into tubing

Assemble 4-bar linkage brackets

1. Cut 4-link axle brackets
2. Weld 4-link axle brackets to axle
3. Line up front 4-link brackets on truck frame
4. Drill holes in truck frame
5. Bolt front 4-link brackets onto truck frame

Front Suspension Build Process Completed
Figure 8: Hitch Build Process

1. Unbolt REESE hitch
2. Remove REESE hitch

1. Cut Chromoly tubing to length
2. Tig weld hitch together

1. Line up brackets on frame
2. Drill holes to mount bracket
3. Slide both brackets into hitch maid tubing

1. Raise hitch up into position between the truck’s frame rails
2. Bolt hitch brackets to frame
3. Line up brackets on frame for 3rd links
4. Assemble purchased 3rd links with rod ends together
5. Bolt in 3rd links
6. Adjust hitch to 22”

Finish Hitch Build Process
Section 6: Testing
Testing of Prototype

Each pulling session began with the same procedure. The team had to have the Head Tech for the 6000 lb Pro Street 4X4 class come and inspect the truck out to receive the approval to pull. The tech would inspect all the safety needed for the class, which included; the kill switch, the drive shaft safety loops, the SFI approved clutch bell housing and engine balancer, and check for a fire extinguisher inside the cab. See the figures below for the pictures of these safety items. The Head Tech also would check for all the measurements of: weight, wheel base, tire size, engine size, and hitch height. If it was found that any of the safety equipment and/or measurements was out of compliance in accordance to the MICHINDOH Rules, the truck would be unable to compete until the infractions were corrected. However, the truck passed this tech inspection for each truck pull without any problems or questions.

After the truck passed the tech inspection, the admission fee was paid and a number was drawn randomly to determine the pulling order of each class. Once this was completed, the team had to determine the truck that would pull in front of them and get in numeric order according to the drawn number. If there were any last minute adjustments needed before the pull, they would be finished at this time.

Before the truck could enter the track for competition, it had to cross the scale for a final measurement to get cleared to pull. At the scale, the truck would be weighed and the hitch height would be measured again. If the truck passes this final inspection, it is then entered into the “Hot Pit” staging area where the trucks get ready to pull.

While in the Hot Pit staging area the data acquisition was turned on to allow time for GPS calibration. The driver would also prepare to pull by getting buckled in, with helmet on, and engine warming up. Finally it was at this time that the truck and prototype was put to the pulling capability test. The truck enters the track and backs to the sled where the chain on the progressive sled is attached to the truck. The driver pulls the chain tight so there is no slack to prevent a hard jerk. Then the driver waits for the flagmen to give them the green flag, designating the track is clear of all obstacles. The truck is then revved up and the clutch engaged resulting in the sled to move and the pulling competition to begin. The truck then pulls as far as possible until the progressive sled stops its momentum, and the final distance is marked as the result.
Section 7: Evaluation and Recommendations
Results of Each Pull

In order to test our prototype, we entered into the 2011 MICHINDOH Pulling season in the 6000 lb Pro Street 4X4 class. This season had 9 pulling sessions towards the class points system with each session being part of our test method. The following is a summary of each pull and the results of each:

1. Van Wert, Ohio – June 5, 2011

This pull was used for a base run without any of the conceptual designs being implemented. The tire pressures used were 35 psi for the front and 55 psi for the rear. The hitch was a REESE Class V hitch bought over-the-counter set at height 22 inches.

The result was a finish of 4th with a distance of 272 feet. The track was slimy and resulted in no traction. The truck had axle wrap and bounce. The winner was a distance of 281.50 feet, but was competitor number 291 which was found to be illegal at the end of the season. This pull gave us a result of 90.6% of the full pull mark.

2. Paulding County, Ohio – June 18, 2011

This pull was the first test of the implementation of the rear suspension design. The tire pressures used were the same, at 35 psi for the front and 55 psi for the rear. The hitch was the same REESE Class V hitch set at 22 inches.

The result was a finish of 7th with a distance of 243.10 feet. The truck bounced so badly that it barely was able to get the sled moving off the start. With just one of the portions of the conceptual design being implemented, the truck’s set-up was poor. The winner was a distance of 280.80 feet. This gave us a result of 81.0% of the full pull mark.

Figure 1: Paulding County, Ohio
3. Maria Stein, Ohio – June 26, 2011

This pull was the first test for the implementation of both the front and rear suspension designs. The tire pressures used were the same as 35 psi for the front and 55 psi for the rear. The hitch was the same REESE Class V hitch set at 22 inches.

The result was a finish of 5th with a distance of 221.11 feet. This track was a short track that was pulling up hill. The truck was able to get the sled moving with ease; but as the weight progressed onto the truck, the truck began to experience slight bounce until the engine ran out of power. The winner was a distance of 228.50 feet. The Full Pull mark was at 250 feet. This gave us a result of 88.4% from the full pull mark.


This pull was the first test for the implementation of all the design concepts. This includes the front and rear suspension as well as the hitch design. The tire pressures used were 35 psi for the front and 55 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a finish of 8th with a distance of 294.25 feet. This was after the transfer case’s output shaft twisted off and we lost power to the rear wheels. The truck was very stable and had zero bounce. The team was very optimistic after this pull to see what the truck would do when it was not broken. The winner was a distance of 320.47 feet. This gave us a result of 98.2% of the Full Pull Mark of 300 feet.

This pull was the second test for the full implementation of all the design concepts. It was the same set-up as we had at Arcola with a new output shaft in the transfer case. Since we broke at Arcola, we had a good feeling, as a team, that our set-up was adequate; however, we did not think the result at Arcola showed this as a result. This would truly be the first “legitimate” result with our fully implemented design. The tire pressures used were 35 psi for the front and 55 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a finish of 5th with a distance of 284.9 feet. The truck ran very well with zero bounce. It had good momentum until the sled’s progressive weight reached the end. This is when the truck lost all power and came to a stop. The winner was a distance of 293.11 feet. This gave us a result of 97.2% of the winner’s distance.

![Figure 4: Preble, Indiana](image)


This pull was the third test for the full implementation of all the design concepts. It also was the same set-up as the previous two pulls except the tire pressures. The tire pressures were 20 psi for the front and 65 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a finish of 5th with a distance of 311.36 feet. The winner was a distance of 320.33 feet. This gave us a result of 97.2% of the winner’s distance. This was the first time we exceeded the Full Pull mark. This pull really showed the potential that the truck’s set-up was capable of performing.

This pull was the fourth test for the full implementation of all the design concepts. It also was the same set-up as the previous three pulls except the tire pressures. The tire pressures were 15 psi for the front and 35 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a finish of 9th with a distance of 261.42 feet. The winner was a distance of 288.13 feet, but was competitor number 291 which was found to be illegal at the end of the season. This gave us a result of 87.1% from the winner’s distance. We were hoping that with a lower tire pressure that we would have more traction. However, as we found out through testing, the lower the tire pressure, the less stable the truck was. It wrinkled the tires and almost had the same type of result as axle wrap and caused the truck to hop and lunge down the track.

8. Van Wert, Ohio – September 3, 2011

This pull was the fifth test for the full implementation of all the design concepts. It was also the same set-up as the previous four pulls except the tire pressures. The tire pressures were brought back to the set-up before Bluffton. That was 20 psi for the front and 60 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a 4th with a distance of 301.09 feet. The winner was a distance of 317.05 feet, but was competitor number 291 which was found to be illegal at the end of the season. This gave us a result of 95.0% of the winner’s distance. This was the second time we exceeded the Full Pull mark of 300 feet. This pull the truck had a blown head gasket. There very minimal water getting into the cylinder; so in order to get data, we decided to run the truck with a blown head gasket. This may have hurt our horsepower and hindered our results a little.
1. Convoy, Ohio – September 24, 2011

This pull was the sixth test for the full implementation of all the design concepts. It was the same set-up as that used at Van Wert. The tire pressures were 20 psi for the front and 65 psi for the rear. The hitch was the adjustable V-Shaped design with a height of 22 inches.

The result was a 2nd with a distance of 311.42 feet. The winner was a distance of 311.87 feet. This gave us a result of 99.9% of the winner’s distance. This was the third time we exceeded the Full Pull mark of 300 feet. Even though the team lost this pull by four tenths of a foot, we were still happy to see how well our prototype performed. It steadily got better throughout the year and resulted in a 4th place finish in season points, despite the slow start of the season due to not having the prototype fully implemented until the fourth pull of the season.

A summary of the complete results can be seen in the table below.

### Table 1: Summary of 2011 MICHINDOH Pulling Season

<table>
<thead>
<tr>
<th>Location</th>
<th>Van Wert</th>
<th>Paulding</th>
<th>Maria Stein</th>
<th>Arcola</th>
<th>Preble</th>
<th>Portland</th>
<th>Bluffton</th>
<th>Van Wert 2</th>
<th>Convoy</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>max [ft]</td>
<td>277.1</td>
<td>280.8</td>
<td>228.5</td>
<td>320.5</td>
<td>293.2</td>
<td>320.3</td>
<td>287.0</td>
<td>313.0</td>
<td>311.9</td>
<td>292.5</td>
</tr>
<tr>
<td>min [ft]</td>
<td>269.0</td>
<td>228.0</td>
<td>203.9</td>
<td>275.9</td>
<td>263.1</td>
<td>238.2</td>
<td>256.3</td>
<td>5.1</td>
<td>244.9</td>
<td>220.7</td>
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<tr>
<td>μ [ft]</td>
<td>272.4</td>
<td>262.5</td>
<td>221.0</td>
<td>298.4</td>
<td>281.1</td>
<td>299.2</td>
<td>266.6</td>
<td>266.4</td>
<td>289.7</td>
<td>273.3</td>
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<tr>
<td>σ [ft]</td>
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<td>19.8</td>
<td>10.0</td>
<td>16.1</td>
<td>10.5</td>
<td>27.1</td>
<td>8.8</td>
<td>81.9</td>
<td>22.2</td>
<td>22.2</td>
</tr>
<tr>
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<td>243.1</td>
<td>221.1</td>
<td>294.3</td>
<td>284.9</td>
<td>311.4</td>
<td>261.4</td>
<td>301.1</td>
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<tr>
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<td>86.6</td>
<td>96.8</td>
<td>91.8</td>
<td>97.2</td>
<td>97.2</td>
<td>91.1</td>
<td>96.2</td>
<td>99.9</td>
<td>95.0</td>
</tr>
<tr>
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<td>-6.4</td>
<td>3.8</td>
<td>-1.2</td>
<td>4.2</td>
<td>4.2</td>
<td>-1.9</td>
<td>3.2</td>
<td>6.9</td>
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<tr>
<td>% of full pull</td>
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<td>81.0</td>
<td>88.4</td>
<td>98.1</td>
<td>95.0</td>
<td>103.8</td>
<td>87.1</td>
<td>100.4</td>
<td>103.8</td>
<td>94.3</td>
</tr>
<tr>
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<td>-12.0</td>
<td>-4.6</td>
<td>5.1</td>
<td>2.0</td>
<td>10.8</td>
<td>-5.9</td>
<td>7.4</td>
<td>10.8</td>
<td>1.3</td>
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<tr>
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<td>18.8</td>
<td>17.1</td>
<td>22.7</td>
<td>22.0</td>
<td>24.1</td>
<td>20.2</td>
<td>23.3</td>
<td>24.1</td>
<td>21.5</td>
</tr>
<tr>
<td>Slip Ratio</td>
<td>85.8</td>
<td>76.7</td>
<td>69.7</td>
<td>92.8</td>
<td>89.9</td>
<td>98.2</td>
<td>82.5</td>
<td>95.0</td>
<td>98.2</td>
<td>87.6</td>
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</table>

From Table 1, it can be concluded that our primary goal of reaching 93% of the full pull mark was met. There were only three instances where the team failed to reach the objective during the pulling season. On average, the Re-Patched Pulling Team exceeded the goal by 2%. 
Another goal for the season was to achieve a max speed of 24 MPH. The team was able to accomplish this goal two times during the pulling season. The Re-Patched Pulling Team was able to accomplish an average speed of 21.5 MPH for the season. Although this does not meet our objective, it can still be considered a success, as the team was able to “place” in many of the competitions.

Next, the team evaluated the traction loss between the ground and the truck. The goal was to maintain traction of at least 70% throughout the season. From Table 1, it can be concluded that this goal was met; the Re-Patched Pulling Team averaged a slip ratio of 87.6%. The equations to calculate the slip ratio can be seen below.

\[
\text{Theoretical MPH} = \frac{\text{Engine RPM} \times \text{Tire Diameter}}{\text{Gear Ratio} \times \text{Transfer Case} \times \text{Transmission} \times 336}
\]

\[
\text{Slip Ratio} = \frac{\text{Experimental (GPS) MPH}}{\text{Theoretical MPH}}
\]

Lastly, durability was important and the team had to ensure that none of the designed parts would fail during the pulling season. The Re-Patched Pulling Team did not experience any part failures.

**RacePAK Data**

In order to measure the success or failure of the prototype, a RacePAK G2X data acquisition system was implemented onto the truck. This data acquisition system was to measure: GPS Velocity, Lateral G Forces, Vertical G Forces, Engine RPM’s, Suspension Travel, and Time of Pull. After the second pull, the suspension travel (linear potentiometer) bottomed out during an intense wheel hop resulting in damaging the sensor beyond repair. Figure 15 shows an example of an experimental set of data obtained from the RacePAK data acquisition system.
Figure 15: RacePAK Datalink Program - Example of Experimental Data
Section 8: Cost Analysis
**Design Cost:**

To begin this project, the estimated cost had to be researched and created in order for the team members to go around and find sponsors. The projected cost for the project added up to $10,000. After the sponsorship money was added up the team actually had $12,000 pledged. This allowed for some breathing room in the project’s budget for any unforeseen costs throughout the build of the truck as well as the competition season. There is always the possibility that an issue will show up and if the budget is cut too close then the funding will be diminished.

The team separated the estimated cost of the project into separate categories. These categories are Data Acquisition, Engine, Fuel, Hitch, Image, Oil, Competition, Suspension, Tires, and Tool Costs. The expense report is shown in Table 2. The costs in this spreadsheet are the costs that incorporate the exchange of money for products. This does not include the services of the use of the shop and tools. The total cost for the project came out to be $10,227.40. This was $227.40 dollars over the expected budget. The extra cost incorporated some unforeseen expenses with fuel and tools. Our original estimate for fuel was only $104.75. We actually spent $1311.02. This was because of the higher price in fuel as well as the oversight of the fuel needed for the tow rig back and forth from the pulls. Luckily we were able to get some discounts on some other items to offset this extra amount needed for fuel. Also, we did not visualize the need to buy a Milwaukee Belt Sander. We did not put any expense in our estimated budget for electric tools.
## Table 2: Expense Report

<table>
<thead>
<tr>
<th>Category</th>
<th>Product Description</th>
<th>Part Number</th>
<th>Vender</th>
<th>Price [$]</th>
<th>Totals [$]</th>
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<td>Fuel Press Gage 0-15 psi</td>
<td>3361</td>
<td>AutoMeter</td>
<td>108.90</td>
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<td>5-205</td>
<td>Motorsports Innovations</td>
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<td>MSD Racepak GTX</td>
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<td>Ebay.com</td>
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<td>897.90</td>
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<td>Danny Bee Racing</td>
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<td>910.00</td>
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<td>Auburn Fuel Mart</td>
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<td>Speedway</td>
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<td>P&amp;G Express</td>
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<td>Fuel</td>
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<td>Image</td>
<td>Molding Clip Set, Tailgate name plate</td>
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</table>
The costs involving any service that was needed by a trained person are those that the team placed in Table 3. These costs added up to be zero dollars for the team because Minnich Garage donated its time and machinery for the project. Along with the donation of time and machinery, the use of many tools and storage of the truck during the build was also donated by Minnich Garage.

### Table 3: Service Costs

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<thead>
<tr>
<th>Service Type</th>
<th>Description</th>
<th>Quote Source</th>
<th>Price</th>
</tr>
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<tbody>
<tr>
<td>Machine Work</td>
<td>Tube Cutting - Chop Saw</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>Tap Tubing</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>Tube Fusion - Mig Weld</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>3/8&quot; Flat Stock Feature Cutting - Plasma Cut</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>3/8&quot; Flat Stock Hole Cutting - Mill</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>3/8&quot; Flat Stock Fusion - Mig Weld</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Machine Work</td>
<td>1/8&quot; Flat Stock Feature Cutting - Plasma Cut</td>
<td>Minnich Garage</td>
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</tr>
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<td>Machine Work</td>
<td>1/8&quot; Flat Stock Forming - Brake and Sheer</td>
<td>Minnich Garage</td>
<td>Donated</td>
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<tr>
<td>Machine Work</td>
<td>1/8&quot; Flat Stock Fusion - Tig Weld</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Shop Work</td>
<td>Space for Building Truck</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
<tr>
<td>Tool Useage</td>
<td>Use of Tools for Building Truck</td>
<td>Minnich Garage</td>
<td>Donated</td>
</tr>
</tbody>
</table>

**Total** $ -
Section 9: Conclusion
After looking at the results of each pull, it is evident that after exceeding the Full Pull mark of 300 feet, the prototype was deemed a success. The beginning of the season showed some low results and short distances; but as the season drew on, the results kept getting better and the distances increased. With a final count of 3 Full Pulls out of 9 pulling sessions and only the final 6 pulling sessions had the full implementations of the team’s designs, this gave a final result of 50% of the pulls with the prototype ending with a Full Pull. Also, 4 of the last 6 pulls resulted in exceeding our goal of 93%. One of these pulls that we did not exceed this goal was at Arcola where we broke the transfer case output shaft. The other pull where we did not exceed this goal was at Bluffton where we chose to drop the air pressures in both the front and rear tires. This upset the truck’s set-up and gave us a bad result.

Overall, the prototype was a success. If there were more pulling sessions during the season, we believe that we would have won a few pulls. The more pulls we had under our belt the better we got as a team and the better our results were.

**Other Considerations:**

**Safety Factors of Existing Parts**

Another requirement that was achieved was the reliability requirement. The team wanted to have a full season without having any parts failures with the designed components. This was a success for the team. The designed components never failed or plasticly deformed throughout the entire season. However, the rest of the truck’s existing components were put to the test. The output shaft of the transfer case, the component that drives both the front axle as well as the rear axle making it four wheel drive, broke in two at the Arcola pull. This hindered our performance and gave us a low result. Another instance that a component that was not designed by the Re-Patched Pulling Team broke was at the second Van Wert Pull. A blown head gasket hurt the power from the engine also putting a possible hurt to the results of this pull. But overall, the pulling season was a success. Both of these instances of failure were due to parts that were not engineered by the Re-Patched Pulling Team, but even with the failures, the truck still was able to go down the track and post a respectable result.

**Tooling**

The Re-Patched Pulling Team came up with the idea of trying to keep as many variables constant as possible. Because of this, we decided to purchase a Milwaukee Belt Sander to “shave” the tires being used on the truck. This would allow for the same possible traction from the tires at every track. After one pulling session, the tire’s tread would round off resulting in less ability to grip the dirt. This is why we did not want this to hinder our data and wanted to keep the maximum amount of traction possible constant.
Section 10: References

2. MICHINDOH Pullers Association, [www.michindohpullers.org](http://www.michindohpullers.org)
Section 11: Appendices
Appendix 1 – 6000 lb. Stateline Pro-Street 4WD Rules

6000lb. Stateline Pro-Street 4WD

General Rules:
1. Trucks must be licensed, street legal, and have proof of insurance.
2. Drivers must wear approved helmet and seatbelts.
3. No hood modifications.
4. Tires must be D.O.T. approved for highway use. 12.50 x 33 inches, or 3.75x65 metric maximum tire size. No cut tires, No boggers. No recaps.
5. Stock one ton driveline or less, OEM u-joints, driveshaft, rear end, transmission and transfer case. Trucks must have complete suspension in factory location with at least 1” of travel but may be temporally blocked to pull. All rear-end bars must be forward of rear axle.

6. No special bumpers, snowplow hook ups, or brush guards. Front bumper must be in stock location and nothing protruding beyond the bumper.
7. The decisions of the pulling officials are final.
8. Trucks must have reverse lights of some sort.
9. Points Class
10. Must have drive shaft loops and U-joint covers, scatter-proof bell housing or blanket, and a kill switch.
11. Any unsafe manner of vehicle (on or off track) will be disqualified.
12. Top 3 placing trucks may be teched after pull. Any truck in violation will forfeit placing and hook fees, Tear down and protest rules apply.

13. Fuel cell can be added but must be secured inside the bed or under the bed.
14. All drive lines in factory location, maximum wheelbase 134 inches. No narrowing of the front or rear axle, 3 rear leaf springs minimum. (No moving axles or transmission or engines).
15. Truck must have a full body. No gutting of truck. Trucks must have full bed and a solid floor made of metal or wood with rear inner fenders and all factory glass. No flatbeds.

16. Any truck that has been lightened in any way may be penalized by adding weight to the rear of the vehicle at the discretion of the tech official.
17. All vehicles must have a fire extinguisher.
18. Must have working brakes on all 4 wheels.
Weights:
1. Weights can be added, but must be secured and not visible in front of the vehicle. Weight must be secured and can be visible in the bed of the truck.

Hitches:
1. Hitch is to be no more than 22 inches off the ground, and hook point must be 42 inches minimum from rear axle. All vehicles must have easy and ample access to hitch to hook chain. Pivot point of hitch cannot be forward of center of rear axle and must be below top of frame rail. No bars or chains from hitch to axle. All bars or hitch components must fasten to the frame rail only.
2. Hitches must be tight and have no movement in any direction.

Engines:
1. Maximum 472 cubic inch. Only factory equipped trucks over this rule will be permitted. EX.496 Chevy, 488 Dodge. Engines must be in factory location.
2. Single four-barrel carburetor, maximum 4150 flange allowed. No Dominator, King Demon, or predator carburetors allowed.
3. No fuel injection unless factory equipped.
4. Cast iron block and heads must be used. No aluminum blocks or heads unless OEM to that vehicle. All blocks and heads must have OEM part number. No Merlin or Dart parts.
5. Aluminum intakes are allowed.
6. Headers are allowed. All exhausts must run through the muffler and be at least to the rear of cab.
7. No magnetos.
8. Electric water pumps are allowed.
9. 94 octane gas or less. No race alcohol, LP, Nitrous oxide, fuel additives or E-85.
10. All engines are required to have a S.F.I. approved balancer and flywheel.

For Complete Association Rules See Website:
http://www.michindohpullers.org/rules.html