1967 Mustang Rear Suspension Redesign

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

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April 2016

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ABSTRACT

The original leaf spring rear suspension designed for the 1967 Ford Mustang underperforms in comparison to modern suspension designs. Anti-squat and axle wrap in addition to poor ride quality limit the 1967 Mustang to a lower standard of performance. A redesign of the rear suspension was completed and tested to meet the standards of car enthusiasts wanting a car for both drag racing and drive comfort.

The majority of potential customers rated their top features in the redesign of the rear leaf spring suspension as having adjustability, improved ride quality, reduced weight, low complexity of installation, ease of serviceability, and appropriately selected material. Modern improvements to the rear suspension of the 1967 Mustang are available; however, do not provide the adjustability and features desired by car enthusiasts wanting a car for both the performance of a race car and the comfort of an everyday road car.

The design was divided among three individuals to create a 4-link rear suspension, which is suspended by coilovers. Upper and lower aluminum links were designed by Alex Snyder to locate and center the axle and maintain a proper pinion angle. The lengths of links are designed to allow adjustability in the angles and positioning of the axle. Torsion in the axle is transferred to the links to control squat and axle wrap. Aluminum 7075-t6 was chosen to reduce the weight while also providing the necessary strength for tensile and compressive forces.

Lower coilover mounts were designed by Nicholas Crall to fasten the lower links to the axle and also provide a lower mounting location for the coilovers. The design of the mounts allow for the ability to position the coilovers at 90 degree angles for improved launching and performance on a drag racing track. The mounts also allow for the ability to mount the coilovers closer to the tires for improved ride quality on the streets.

The sub-frame and upper coilover mounts were designed by Jared Niehauser. The design uses a rectangular hollow tube for added rigidity to the chassis of the car and for mounting the top of the coilovers. The hole locations for the top of the coilovers allow the coilovers to be adjusted within the 20 degree angle range. All hardware was selected to meet strength requirements without the need for special tooling during installation.
INTRODUCTION - PROBLEM STATEMENT AND INTERVIEW

PROBLEM STATEMENT
The Ford Mustang has been one of the most iconic vehicles in American automotive history. Being introduced in the year 1964 ½, the Mustang is still in full stride and has sold over 8 million vehicles. The 1967 Ford Mustang saw different overall dimensions and more powerful engines than its predecessors. This helped to spark the “muscle car” revolution. Today, the cars are sought after by car enthusiasts and collectors alike. Being built in 1967, this mustang is missing a lot of modern technology which effects performance.

The 1967 Mustang currently utilizes a leaf spring and shock absorber suspension system. The current suspension system causes issues in handling and ride quality of the vehicle. The leaf spring and shock absorber suspension systems also lacks in versatility. This design project will focus on improving handling and ride quality by applying modern technology and components while redesigning a new rear suspension system. This is a team project that will be divided three ways. Nick Crall will focus his time on suspending the vehicle, as well as managing the team. Alex Snyder’s role is to locate the axle in the correct position. My task will be designing a sufficient sub-frame that will support the suspension system.

INTERVIEW
Justin Miller is a current car enthusiast who has personally designed and hand built his own vehicle from scratch. He is knowledgeable in suspension systems from his experience of designing his own. According to Justin, he expressed that the car handling and the adjustability of the suspension system should be our main focuses. This is critical information for designing a sufficient suspension system.
ORIGINAL DESIGN

The 1967 Ford Mustang utilizes a leaf spring and shock absorber suspension. At that time this was a great design; however, as time progressed it became out-of-date and various suspension systems were designed for many different purposes. Figure 1 illustrates the components that were used in 1967 for the rear suspension.

![Figure 1 – Current Suspension System – Courtesy of AutoZone](image)

One of the many disadvantages of leaf springs is that leaf springs are heavier than most other suspension systems. In every application it is beneficial for weight reduction. Another downfall of leaf springs is that the leaf springs themselves locate the axle. Because a spring locates the axle this allows the axle to move slightly left, right, forward, and aft. Modern suspension systems locate the axle more precisely.
RESEARCH CONCLUSION

The conducted research reviewed many styles of rear suspension systems along with their components. The research looked into the improvement of the original suspension system. Improving the existing components includes upgrading the bushings, shock absorbers, and spring leaves. Improvement of the original design also includes installing traction bars and a Panhard bar or Watt’s link. These modifications would improve overall handling, but from a marginal standpoint. Improving the original design requires a lower cost investment and involves an easier installation. However, enhancing the original suspension system lacks in versatility, adjustability, and other key customer features.

The research directed itself into the technology of air ride suspension systems. While this type of suspension system provides many benefits towards handling and adjustability, the components that would have to be implemented are not only very expensive but also involve a complex installation process. The benefits that this system could supply would be the reduction of body roll while cornering and automatic body leveling while under various loads. These features would greatly improve the overall performance, but a compromise had to be made with installation time and budget.

Through further research it was concluded that a triangulated 4-link and coilover suspension meets the desired customer features. The triangulated 4-link and coilover suspension offers a lower cost alternative to the air ride suspension, while also providing adjustability, greater performance, lower unsprung mass due to not needing a panhard bar, and greater overall ride quality than the original design. The design of the suspension will be separated into three major categories. The first category will include the selection of the coilover shock absorber and the design of the multi-positioning mounting brackets. The second category will include the selection of bushings and the design of the links and corresponding mounting brackets. The final category will include the design of the sub-frame to properly support the system.

For further detailed research, see Appendix A.
CUSTOMER FEATURES AND OBJECTIVES

PRODUCT FEATURES AND OBJECTIVES

The product features were obtained from the customer features listed on the survey. According to the survey the product features are listed in descending order from most important to least important. The product objectives are the measurable goals established to meet the customer features.

1. Adjustability (18%)
   a. The coilovers used will provide features that will allow for altering of the preload and valve adjustment.
   b. Multi-position mounting brackets to set desired preload, anti-squat, and roll center for performance needs.

2. Ride Quality (17%)
   a. Spring factor of a suitable nature.
   b. Performance bushings.
   c. Mono-tube coilovers to maximize sensitivity in minimal movement of the suspension.

3. Weight (16%)
   a. Measurement will be performed to compare the mass of the current suspension to the new design
   b. The goal is to have the new suspension system lighter than the current system.

4. Complexity of Installation (14%)
   a. Usage of standard sizes for hardware and components.
   b. Ability to complete installation with use of standard tooling.

5. Initial Investment Cost (13%)
   a. Based on customer survey results the investment cost shall not exceed $2,000.

6. Serviceability (13%)
   a. Inspectional parts will be visible and easily accessible without removing any components.

7. Material Used (9%)
   a. Material used will meet desired weight and factors of safety.
   b. Material used will withstand environmental conditions.
CONCEPT GENERATION

**Upper Coilover Mount**

The upper coilover mount and the sub-frame were combined into a single part to reduce the complexity and weight of the system. The sub-frame was included in the new suspension design for multiple reasons. The first purpose is to provide sufficient support for the suspension system. Loading from the coilovers will be transferred into the sub-frame and ultimately into the rear chassis of the car. Secondly, the sub-frame adds rigidity and support to the chassis of the car. When the car is traveling at high speeds and launching with a large acceleration, twisting of the car will be reduced with the addition of the sub-frame. Each upper coilover mount hole is located in the middle of the sub-frame, with one on each end. Each mounting hole will be drilled to match the 5/8” diameter bolt. This mount provides one mounting location for the top of each coilover. To meet the adjustability objective, the coilovers will be adjustable on the lower coilover mounts to change the angles and positions. The holes will be used to set the coilover at 90 degrees. When the lower coilover mount is adjusted to move closer to the tire, the coilover angle should be within a 70 degree to 90 degree range. This hole location will maintain the set ride height and position the coilover at a 73 degree angle. See the figure below for an isometric view of the part.

![Figure 2 – Upper Coilover Mount](image)
**SUB-FRAME ASSEMBLY**  
The sub-frame assembly (Figure 3) will consist of three total parts: two sub-frame mounting plates and one rectangular hollow structural section beam. Each part will be made from low carbon steel. The sub-frame mounting plates will be used to mount the sub-frame to the rear chassis of the car. A total of two holes will be drilled into each 0.125" thick mounting plate and the car’s chassis. The hole sizes are 0.5" in diameter, and will be fastened with 0.5” diameter grade 8 bolts. As mentioned previously, the rectangular HSS beam provides support for the rear chassis as well for the suspension system. A standard 2” x 1” x 0.120” rectangular HSS beam will provide the support needed to withstand the bending stress applied by the coilovers. Both ends of the beam will be joined to the sub-frame mounting plates by means of welding.

![Figure 3 – Sub-frame Assembly](image-url)
CALCULATIONS

**Calculation of Forces in Sub-frame**

The calculation of the forces on the sub-frame began with the measure of the sprung and unsprung weight. The sprung weight is defined as the weight supported by the suspension. The unsprung weight is defined as the weight below the suspension. The front sprung and unsprung weight were measured to be 1702 lbs and 120 lbs. The rear sprung and unsprung weight were measured to be 944 lbs and 320 lbs. As a result, each rear wheel support a static load of 472 lbs. The sub-frame will experience an impact loading; therefore, the design factor was set at 12.

It was determined that a standard 2” x 1” x 0.120” rectangular hollow structural section would be used for the sub-frame.

\[
\text{Maximum Bending Stress} = \sigma_{\text{max}} = \frac{Mc}{I} = \frac{M}{S}
\]

\[
\sigma_{\text{max}} = \frac{826 \text{ in} \cdot \text{lbf}}{0.18 \text{ in}^3} = 4589 \text{ psi}
\]

Setting the maximum bending stress calculated above equal to the design bending stress, the minimum yield strength needed was computed.

\[
\text{Design Bending Stress} = \sigma_d = \sigma_{\text{max}} = 4589 \text{ psi}
\]

\[
\sigma_d = \frac{S_y}{12}
\]

\[
S_y = 12 \times \sigma_d
\]

\[
S_y = 12 \times 4589 \text{ psi} = 55068 \text{ psi} \rightarrow \text{Minimum yield strength required}
\]

ASTM A513 carbon steel will be used for the sub-frame. This material has a yield strength of 72,000 psi, which meets the minimum requirement of 55,068 psi.

**Calculation of Forces in Coilover Bolt**

This calculation was used to select a suitable bolt to connect the top of the coilover to the sub-frame. The coilover will use a half inch bolt to fasten the top to the sub-frame. Using the static load of 472 lbs and the cross-sectional area of the bolt, the single shear stress in the bolt was computed.

\[
\text{Shear Stress} = \tau = \frac{F}{A}
\]

\[
\tau_{\text{max}} = \frac{472 \text{ lbs}}{\pi(0.25 \text{ in})^2} = 2404 \text{ psi}
\]

With the shear stress computed, the minimum yield strength required for the bolt
material was determined. The maximum shear stress computed above is equal to the design shear stress. The bolt will be subject to an impact/shock load. The design factor for impact/shock loading is N=6.

\[ \text{Design Shear Stress} = \tau_d = \tau_{max} = 2404 \text{ psi} \]

\[ \tau_d = \frac{S_y}{2N} \]

\[ S_y = \tau_d \times 2N \]

\[ S_y = 2404 \text{ psi} \times 2(6) \]

\[ S_y = 28848 \text{ psi} \rightarrow \text{Minimum yield strength required} \]

Due to the manner of loading on the bolt and researched suggestions, a grade 8 bolt will be used. Grade 8 bolts have a yield strength of 130,000 psi which meets the minimum yield strength requirement of 28,848 psi.
SHEAR FORCE AND MOMENT DIAGRAMS

Figure 4 – Shear Force & Moment Diagrams
FINITE ELEMENT ANALYSIS

STRESS PLOT

A Solidworks simulation study was performed to measure the stress in the components. The sub-frame mounting brackets were fixed at each bolt location. An upward applied load of 472 lbs on each coilover mounting location was set to simulate the static load. The results were then plotted, with red coloring signifying the highest stress and blue the lowest. The highest stress recorded from the simulation was 3.748 ksi.

Figure 5 – FEA Stress Graph – Position 1

Figure 6 – FEA Stress Graph – Position 2
A factor of safety plot was also created to validate the sub-frame’s ability to meet the design requirements. Because the manner of loading for this sub-frame is impact/shock, a design factor of 12 was selected. The results of the simulation indicate that the sub-frame illustrate that the minimum factor of safety of 12 was achieved. Therefore, the design meets the minimum factor of safety requirement without failure.
FABRICATION AND ASSEMBLY

MACHINING PROCESS

The first task in the fabrication of the sub-frame was the cut-down to length of the rectangular hollow tubing. A measurement of the distance between the frames in the rear of the car was taken to ensure the correct length. Using a band saw (Figure 9 - Cut-down of Sub-frame), the sub-frame was cut down to 36.75 inches. Because the chassis in the rear of the car angles outward toward as it moves toward the rear of the car, the ends of the sub-frame needed to be angled for a proper fit. Using an angle grinder, the ends were ground down to meet the correct length and angles.

With the sub-frame frame cut down to the proper length, the holes for the upper coilovers were able to be located on the sub-frame. The diameter of the holes for the upper coilover mounts needed to be precise to limit movement of the bolt inside the hole. The hole was drilled 1/64” undersized and reamed to meet the 5/8” diameter hole size.

The four holes in the sub-frame end plates were designed for 1/2” bolts. Using a drill press, the holes were drilled 1/32” oversize to allow bolt clearance.
ASSEMBLY PROCESS
The assembly process began with joining the sub-frame with the two end plates. The end plates were aligned to match the form of the rear chassis, and MIG welded on to the sub-frame. With the sub-frame assembled, a coating of primer along with three coatings of corrosion resistant paint were applied to the parts to protect the part from extensive wear underneath the car. Finally, the clearance holes for fastening the sub-frame to the car were drilled into the rear chassis. The figure below shows the sub-frame assembled and fastened to the rear chassis of the car.

Figure 10 - Assembled Sub-frame
TESTING

**TESTING PROCEDURE: SUSPENSION SYSTEM ANTI-SQUAT**

Testing the system will be determined by the amount of squat recorded by our testing apparatus. A marker will be attached to the rear of the car, and will draw a black line on the white testing apparatus. Because the car has an automatic transmission, we will be able to accurately repeat this test. This will allow us to hold the brake and reach a specified RPM and release the brake, resulting in an almost identical launch of the car. The testing will consist of three RPM levels for launching: 1500, 2000, and 2500. The test will first be completed with the leaf spring suspension, and conclude with the testing of our new suspension system. Upon completion, measurements of the squat distance will be recorded for comparison between the leaf springs and the 4-link coilover suspension. Figure 11 shows the testing apparatus, which is 4’ x 4’ sheet of plywood attached to 2”x4” for bracing. The car will mark the flat side which is shown in the figure.

![Figure 11 – Model of Testing Apparatus](image-url)
**TESTING RESULTS**

The results of the testing indicated that the 4-link coilover suspension outperformed the original leaf spring suspension at every level of RPM. Table 1 - Test Results shows the collected data for the squating distance at each RPM level in inches.

<table>
<thead>
<tr>
<th></th>
<th>Squat at 1500 RPM (in.)</th>
<th>Squat at 2000 RPM (in.)</th>
<th>Squat at 2500 RPM (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf Spring</td>
<td>0.625</td>
<td>1.000</td>
<td>1.500</td>
</tr>
<tr>
<td>Coilover/4-Link</td>
<td>0.500</td>
<td>0.500</td>
<td>0.625</td>
</tr>
<tr>
<td>Percent Difference</td>
<td>25%</td>
<td>100%</td>
<td>140%</td>
</tr>
</tbody>
</table>

The graphical results of the test data are shown below. The blue line represents the leaf spring data, while the red line represents the 4-link coilover data. It is clearly visible in this graph that the 4-link coilover suspension is consistent, and experiences slight variation in the distance that the car squats. The leaf spring data shows an inconsistent and significant increase in the squat distance of the car.

The addition of the links allowed for the torsion built up in the axle to be transferred via torsion and compression into the links, instead of the leaf springs. As a result, there was a reduction in axle wrap, which is seen in the amount the car ascended while increasing the RPMs. The rear of the car ascended nearly three inches with the leaf spring suspension, while the 4-link suspension held the rear of the car to zero ascent. Once the brake was released, the leaf spring suspension system allowed the tires to spin due to the reduction of down force from axle wrap. This can be seen on the leaf spring testing board, which shows twenty four inches of acceleration before the car gains traction and squats an inch and a half at 2500 rpm. The 4-link suspension allowed for almost immediate traction which allowed for the car to only squat five-eighth inches at 2500 RPM. Because the car is accelerating much
more consistent, the 4-link board is much more difficult to read. The figures below are pictures of the testing boards.

Figure 13 - Leaf Spring Test Board

Figure 14 - 4-Link Coilover Test Board
**Weight Comparison**

Each of the components were weighed and recorded to meet the objective of weight reduction. The tables below show the difference in weight of the leaf spring suspension compared to the 4-link coilover suspension. The 4-link coilover suspension weighs approximately 20 pounds lighter than the leaf spring suspension.

### Table 2 - Leaf Spring Weight

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Weight (lbs.)</th>
<th>Total (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf Spring Suspension</td>
<td>2</td>
<td>26.50</td>
<td>53.00</td>
</tr>
<tr>
<td>Shock Absorber Mount</td>
<td>2</td>
<td>13.00</td>
<td>26.00</td>
</tr>
<tr>
<td>Shock Absorber</td>
<td>2</td>
<td>3.00</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>Overall Total:</strong></td>
<td></td>
<td><strong>85.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3 - 4-link Coilover Weight

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Weight (lbs.)</th>
<th>Total (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Links</td>
<td>2</td>
<td>4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Upper Links</td>
<td>2</td>
<td>2.90</td>
<td>5.80</td>
</tr>
<tr>
<td>Upper Links-Brackets</td>
<td>2</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Lower Coilover Brackets</td>
<td>2</td>
<td>10.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Coilover</td>
<td>2</td>
<td>9.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Coilover Spacer</td>
<td>2</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Chassisworks Offset Bracket</td>
<td>2</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>Subframe</td>
<td>1</td>
<td>7.75</td>
<td>7.75</td>
</tr>
<tr>
<td>Additional Hardware</td>
<td>1</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td><strong>Overall Total:</strong></td>
<td></td>
<td><strong>65.55</strong></td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSION

The design of the rear 4-link coilover suspension accomplished all seven objectives defined by the customer surveys. From the testing results, the anti-squat was reduced up to 140% with the 4-link coilover suspension. The results also demonstrate that axle wrap was greatly reduced by transferring the load into the 4 links as opposed to the leaf springs. Although all objectives were achieved, testing could be improved with additional funds and resources. While 4-link rear suspensions are not uncommon, this unique design separates itself from existing kits with the use of adjustable light weight aluminum links along with the versatility of adjusting the coilovers' mounting locations for desired performance.
WORKS CITED

APPENDIX A – RESEARCH

LEAF SPRING RESEARCH

The 1967 Ford Mustang was equipped with a Hotchkis-type rear leaf spring suspension. This type of spring was made up of 4 layers of arc-shaped metal leafs bound together to form a single spring. The leaf springs were attached directly to the solid rear axle using U-bolts and spring plates. The front mounting eye included a rubber bushing to reduce shock and noise and to allow for slight horizontal movement. The rear end of the spring was held in a rubber-bushed compression shackle to allow flexing on lighter impacts and resistance on greater impacts. The overall suspension unit also included angle mounted shock absorbers that were attached to the spring plates. The shock absorbers were filled with viscous fluid to help reduce side sway and oscillation in the springs. (1)

The leaf spring suspensions have their disadvantages. The leaf spring suspension is heavier than most alternatives, which can be an issue for racing enthusiasts. Leaf spring suspensions tend to require a significant amount of space and offer little to no adjustability. Adding horsepower to the 1967 Ford Mustang can greatly affect the performance of the stock leaf spring suspension. Increased acceleration with stock leaf springs can cause the rear axle to wrap and alter the pinion angle. Also, when cornering hard, the leaf springs can cause lateral movement and negatively affect the handling of the car. (2)

Modified leaf springs do offer advantages over other suspension upgrades. Because the leaf springs are already installed on the car, modifying the existing springs requires a lower cost of investment and involves easier installation. Some of the most popular upgrades to a stock leaf spring rear suspension include but are not limited to: adding a Panhard rod or Watt's link, swapping out the bushings, and adding traction bars. The Panhard rod and Watt's link (see Figure 17) are both axle centering devices that reduce the amount of lateral
movement of the axle when cornering. Both devices can lower the car’s rear roll center to improve the overall handling. Unlike the Watt’s link; however, the Panhard rod can be adjusted to change the height of the roll center. (3) With a significant amount of acceleration or extreme braking, the rear axle tends to wind-up and twist the leaf springs into an “S” shape, which causes wheel hop. Traction bars (see Figure 16) can be installed to "locate" the rear axle and sure the axle to the car. As a result, the axle wind-up can be reduced in extreme situations. However, the traction bars reduce the overall ride quality by adding extra weight and increasing the roll stiffness when cornering. (4)

![Figure 16 – Traction Bar – Courtesy of cartechbooks.com](image)

![Figure 17 – Panhard Rod and Watts Link – Courtesy of ve-blog.local-motors.com](image)
**Air Suspension**

Air suspension on a vehicle can be described as a shock absorber that is filled with compressed air that is supplied by an onboard compressor. The compressor pumps air into each individual shock. This replaces the conventional spring, which absorbs the energy transferred from the road. Because each shock is individually filled with air, sensors can be placed so that the suspension can self-adjust in various situations allowing for maximum adaptability. (5) Whether the vehicle is cornering or traveling at high speed, air suspension has the capability to adjust for maximum performance.

Figure 18 – Air Suspension System – Courtesy of Discoweb.org

Figure 18 illustrates the basic air suspension setup for a rear axle. One of the benefits that this system offers is the ability to change the ride quality of the vehicle, even while the car is in motion. (5) Adjusting the air suspension for ride quality can allow the car to ride smoothly or roughly. Sporting and racing applications desire a stiff suspension. With more advanced air systems the air springs can adjust for cornering, and also keeps the car more level with the road than conventional springs. Thus, in some situations the anti-roll bar can be deleted.

A contributing factor in high speed performance and fuel economy is wind resistance, also known as drag. To minimize drag, the air suspension system utilizes its adaptability by varying the ride height of the vehicle. In most cases, the underside of the vehicle is the
location in which the vehicle is least aerodynamic. Lowering the car allows for less air to pass underneath the vehicle, thus reducing the less drag on the vehicle. The air suspension lowers the vehicle at higher speeds when the vehicle encounters fewer large inconsistencies in the road. In our application for the 1967 Ford Mustang, the front suspension will also need to be converted to an air suspension for this particular feature to be utilized. (5)

Another benefit that air suspension has to offer is the ability to adapt to heavier loads in the vehicle without negatively affecting the handling of the vehicle. This feature is known as self-leveling, where the suspension increases the volume of air within a suitable camber range. Self-leveling, with the proper sensors, can also adapt to uneven roads where one side of the road is higher than the other. (5)

A drawback of the air suspension system is the overall weight compared to conventional coil-over suspensions. Air suspensions are also very complex, requiring wiring of the compressor and running air lines throughout the vehicle. Because the vehicle is suspended by air pressure, if there is a leak in the system, the car becomes useless from the lack of suspension. (5)

**COILOVERS**

**Coil Spring Over Shock**

A coilover is a suspension component short for coil spring over shock absorber. They consist of a shock absorber with a coil spring encircling it. The weight of the vehicle is supported by the coilover. More accurately by the coil spring itself. The coil spring will react to energy by extending and releasing the energy. If there wasn’t a shock absorber present the spring would simply oscillate until it reaches equilibrium or until another force was applied. This would result in very unsatisfactory conditions and an uncontrollable vehicle. This is where the shock absorber is used for damping.

There are three kinds of coilovers; OEM-style spring-over-shock assemblies, slip-fit coilovers and full-bodied coilovers. OEM-style spring-over-shock assemblies are based off of a conventional strut assembly surrounded by a coil spring. These are non-adjustable and are made of a fixed-length (depending on the model). Slip-fit coilovers consist of a hollow, threaded cylinder that sits on an existing shock perch shown below. (6)

![Figure 19 – Adjustable Coilover – Courtesy of Super Street Online](image)

These are able to be adjusted by compressing or decompressing the spring, thus directly affecting the ride height of a vehicle. The two types mentioned earlier use existing parts on a vehicle. A full-bodied coilover is an entire system. The full-bodied coilover will be the focus due to not using any existing components.
**Shock Body**

The shock is in the center of the coil spring. The upper mount of the coilover will mount to the chassis or sub-frame while the bottom mounts to the rear axle. The shock controls unwanted spring oscillation and reduces vibrations caused by the chassis and also the environment that the tire is on. As a vehicle hits a bump the springs will compress and then decompress. The energy is then transferred to the shock from their upper mounts and the piston inside of the shock absorbs the load. Hydraulic fluid is inside of the shock tube where the piston is located. The piston will exert a force to push the hydraulic fluid through the shocks valves. The kinetic energy released by the suspension system is transmitted to the shock which turns into heat energy. This heat will conclusively dissipate within the hydraulic fluid. This process can be changed or altered by variations in shocks internal components. Softer shocks will result in more spring movement while stiffer shocks will reduce spring movement.

There are two configurations of shocks offered in coilovers, Mono-tube and Twin-tube. The mono-tube structure consists of a rod and piston assembly housed within the shock tube where both compression and rebound service occurs. Twin-tube shocks consist of two cylinders. The inner cylinder is where the piston and rod move up and down. The outer cylinder is where the hydraulic fluid is held. A benefit of twin-tube over mono-tube, is the increased piston stroke capabilities. On the contrary the mono-tube style generally has a larger diameter which is beneficial in dissipating heat and displacing more fluid. This results in increased sensitivity of the shock in minimal suspension movements. (7)

![Coilover Assembly](image)

**Figure 20 – Coilover Assembly – Courtesy of Super Street Online**

**Shock Travel**

Shock travel is the distance the shock is able to act before “bottoming out.” Bottoming out is when the shock runs out of travel before emitting all of the acting energy to heat. (6) A combination of shock travel and spring choice can prevent bottoming out.
**Preload**

Preload is the amount of force applied to the springs. This can be determined by how much the spring is compressed during static conditions. Adjusting the shock can allow more load onto the spring. Adding preload can be beneficial in increasing tire contact while cornering for example. Ride height is directly dependent on preload. (7) That is only the case if the lower mounts for the coilover are non-adjustable. Adjustable lower mounts will allow for preload adjustment while maintaining a consistent ride height (if that’s what you want).

**Conclusion**

Coilovers can be dialed in to best fit a specific application by a combination of position, spring constant of the coil spring, and the shock absorber used. A correct combination of the various styles can help create a sufficient suspension system.

**THE WATT’S LINK**

When using a leaf spring style rear suspension the rear axle is able to move side to side. The Watt’s link absorbs much of the lateral stress that the leaves were once receiving. This allows the leaf springs to perform better by keeping the axle centered under the vehicle. With the axle being centered it will not work against the front suspension. The Watt’s link has the same response when cornering left or right. (2) It’s also easily adjustable. The Watt’s link is fairly complex, and due to its complexity it is the least common devise used in centering a rear axle.

**PANHARD**

A Panhard rod, or also commonly referred as a track bar, is another method of centering the rear axle. This is more prevalent when compared to the Watt’s Link. A Panhard rod is a lateral bar that runs from a frame of a vehicle to the axle. The goal is to have the rod as close to horizontal as possible. (2) This allows the axle to stay more centered under lateral load compared an angled Panhard bar. An angled Panhard bar may be necessary depending on its application.

**FOUR-LINK**

The overall main function of a four-link system is to maintain the proper location of a rear axle under the vehicle. When a vehicle accelerates, makes a turn, or hits a bump the rear axle will constantly want to move. There are two links, one on each side of the vehicle, two upper links and two lower links. The lower links are used to keep the axle in place front to back. The upper links keep the axle from rotating and keep the pinion angle as constant as possible. Bret Voelkle of Air Ride Technologies was quoted saying “In a leaf-spring suspension, the leaves perform two functions. First, they hold the rear axle in the car. Secondly, while they are doing this, they also support the load of the vehicle. With a four-link suspension, the functions of locating the rear axle and supporting the vehicle have been separated. We like the four-link rear suspension because of its ability to properly locate the rear axle no matter how soft we want to make the spring. With a leaf-spring rear suspension, softening the spring rate can cause other problems such as side-to-side flex or axle wrap, which is when the axle tries to twist the leaves out of the vehicle.” (2)
**TRAINGULATED FOUR LINK**

A triangulated four-link uses the upper links to keep the rear axle centered under the vehicle. This eliminates the need for a Panhard Bar or Watt’s Linkages. The upper links are placed at angle compared to the lower links. Without the need for a Panhard Bar or Watt’s Linkage, the area under the rear of the car becomes more open. This allows for other modifications for example; re-routing exhaust, fuel cells, and batteries. When contemplating a triangulated four-link one must consider “roll blind.” Roll blind is a non-linear resistance to body roll. Body roll is the load transfer of a vehicle towards the outside of a turn. When a vehicle is cornering the pivot points of all four links are resisting body roll. During this resistance a side load is placed on the pivot points. Roll blind can cause snap oversteer or an unanticipated transition from understeer to oversteer. (2) Methods to combat roll blind is by using urethane bushings and or heim joints.

![Tri-link from top.](image)

Figure 21 – Triangular 4-Link – Courtesy of Ridetech

**PARALLEL FOUR-LINK**

A parallel four link functions very similarly. The upper and lower links are parallel to another. The main difference of a parallel four-link compared to a triangulated is that a Panhard bar or Watt’s link must be used. With the upper linkages being in parallel they are unable to keep the rear axle centered under the vehicle. (8)

![Parallel 4 link from the rear.](image)

Figure 22 – Parallel 4-Link Utilizing Panhard – Courtesy of Ridetech
APPENDIX B – COMPILED CUSTOMER SURVEY

CUSTOMER SURVEY

Redesign of a 1967 Ford Mustang Rear Suspension

The Ford Mustang has been a popular choice for car enthusiasts and collectors alike throughout the car's history. This design will be focused on implementing modern technology on a classic vehicle. The rear suspension of a 1967 Mustang uses leaf springs and shock absorbers. This design entails the usage of coil-overs and a 4-link suspension system to enhance overall driving characteristics and performance.

How important is each feature of the proposed rear suspension design?

Please circle the appropriate answer.

<table>
<thead>
<tr>
<th>Importance</th>
<th>1=Low Importance</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5=High</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Investment Cost</td>
<td>1</td>
<td>2(1)</td>
<td>3(1)</td>
<td>4</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Complexity of Installation</td>
<td>1</td>
<td>2</td>
<td>3(1)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>2</td>
<td>3(1)</td>
<td>4(1)</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Serviceability</td>
<td>1</td>
<td>2</td>
<td>3(2)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Adjustability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Ride Quality</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(2)</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Material</td>
<td>1</td>
<td>2(2)</td>
<td>3(1)</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

How adequate is the current leaf spring and shock absorber suspension system?

Please circle the appropriate answer.

<table>
<thead>
<tr>
<th>Importance</th>
<th>1=Very Unsatisfied</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5=Very Satisfied</th>
<th>N/A</th>
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</thead>
<tbody>
<tr>
<td>Initial Investment Cost</td>
<td>1</td>
<td>2(2)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A(1)</td>
</tr>
<tr>
<td>Complexity of Installation</td>
<td>1</td>
<td>2(1)</td>
<td>3</td>
<td>4(1)</td>
<td>5</td>
<td>N/A(1)</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>2(1)</td>
<td>3(1)</td>
<td>4</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Serviceability</td>
<td>1</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Adjustability</td>
<td>1(1)</td>
<td>2(1)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A(1)</td>
</tr>
<tr>
<td>Ride Quality</td>
<td>1(1)</td>
<td>2(1)</td>
<td>3</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Material</td>
<td>1</td>
<td>2(2)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A(1)</td>
</tr>
</tbody>
</table>

How much would you be willing to spend on this technology?

$1,000-$1,500 $1,500-$2,000 $2,000-$2,500 $2,500-$3,000 $3,000+ (1)
### APPENDIX C – QUALITY FUNCTION DEPLOYMENT (QFD)

#### Table 4 - QFD

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>Importance Weight</th>
<th>Adjustable linkages</th>
<th>Multi-Position Mounts</th>
<th>Invasive Installation</th>
<th>High Grade Hardware</th>
<th>Spring Constant</th>
<th>Dampening</th>
<th>Lightweight materials</th>
<th>Standard Size Equip.</th>
<th>Rounded Surfaces</th>
<th>Customer Satisfaction Rating (0.00 - 1.00)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Investment Cost</td>
<td>13%</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>0.40</td>
<td></td>
<td></td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Complexity of Install</td>
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<td>1</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.60</td>
<td></td>
<td></td>
<td>0.60</td>
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<tr>
<td>Weight</td>
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<td>3</td>
<td>1</td>
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<td>9</td>
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<td>1</td>
<td>0.67</td>
<td></td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Serviceability</td>
<td>13%</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td>0.53</td>
<td></td>
<td></td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Adjustability</td>
<td>18%</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td></td>
<td>0.30</td>
<td></td>
<td></td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Ride Quality</td>
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<td>3</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td></td>
<td>0.47</td>
<td></td>
<td></td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>9%</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>1</td>
<td></td>
<td>0.40</td>
<td></td>
<td></td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

|                  |                  | 2.27                | 3.09                  | 1.80                  | 2.64                | 2.35          | 2.76      | 4.06                 | 0.80              | 0.55           |

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APPENDIX D – TIMELINE

Figure 23 – Timeline of Project
### APPENDIX E – BUDGET

Table 5 - Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Supplier/Vendor</th>
<th>Estimated Cost</th>
<th>Actual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x Coilovers</td>
<td>Ridetech</td>
<td>$850.00</td>
<td>$665.00</td>
</tr>
<tr>
<td>Coilover Dropdown</td>
<td>Ridetech</td>
<td>$50.00</td>
<td>$60.00</td>
</tr>
<tr>
<td>2x Lower Coilover Offset Mount</td>
<td>Chassisworks</td>
<td>$120.00</td>
<td>$93.00</td>
</tr>
<tr>
<td>Material</td>
<td>Raw Material</td>
<td>$400.00</td>
<td>$236.50</td>
</tr>
<tr>
<td>Hardware</td>
<td>McMaster Carr</td>
<td>$280.00</td>
<td>$291.76</td>
</tr>
<tr>
<td>Machining</td>
<td>In-House</td>
<td>$20.00</td>
<td>$-</td>
</tr>
<tr>
<td>Welding</td>
<td>In-House</td>
<td>$20.00</td>
<td>$-</td>
</tr>
<tr>
<td>Bending</td>
<td>In-House</td>
<td>$-</td>
<td>$-</td>
</tr>
<tr>
<td>Painting</td>
<td>In-House</td>
<td>$50.00</td>
<td>$26.90</td>
</tr>
<tr>
<td>Car Transport</td>
<td>U-Haul</td>
<td>$80.00</td>
<td>$67.36</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$1,850.00</strong></td>
<td><strong>$1,440.52</strong></td>
</tr>
</tbody>
</table>
Figure 24 – Mounting Plate – Sub-frame
Figure 25 – Sub-frame Rectangular Beam
SUB-FRAME ASSEMBLY

Figure 26 – Sub-frame Assembly Drawing