CHEVROLET UPPER
CONTROL ARM RE-DESIGN
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Abstract

The purpose of this project is to design and manufacture an improved upper control arm for a 1988-1998 Chevrolet K2500 truck. This component controls the suspension of a vehicle and will be redesigned to improve the many shortcomings of the current design. The objectives of this project were met by redesigning the stock upper control arm, designing and manufacturing a weld fixture, manufacturing a prototype component, and performing a cost analysis. This component was designed to improve performance, reliability, serviceability and strength while maximizing manufacturability. The fixture and upper control arm were manufactured using computer aided design, CNC methods and welding. Successful prototype fabrication has resulted in the evaluation of small, medium, and large production volumes. Recommendations have been made for the future direction of this component.
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Introduction

This report will describe the design and manufacture of 1988-1998 Chevrolet 2500 4x4 upper control arms. These upgraded components will replace the stock components that are prone to failure, lack performance, and difficult/expensive to service. There is a large demand for this type of product and there are many similar products on the market, but none have been designed for this make and model. By redesigning and manufacturing new upper control arms for this vehicle, many of the problems found in the stock components will be eliminated. The objectives of this project are as follows:

- Redesign upper control arms
- Design weld fixture
- Manufacture weld fixture
- Manufacture prototype component
- Perform cost analysis

In order to achieve these objectives, the improved component was completely and carefully redesigned. First the stock component was reverse engineered and modeled in Pro-Engineer computer-aided design software. Next, the component was redesigned and assembled in Pro-Engineer around the improved joints and plate steel structure. Using this assembly, a weld fixture was designed around critical dimensions. Both the component and fixture were designed using design for manufacture/assembly guidelines. Using the fixture and component CAD drawings, steel plate was CNC laser cut. Upon return of the plate, component was assembled in fixture and finish welded. Finally, a cost analysis was performed for small, medium, and large production volumes. This prototype will not be installed on any vehicle nor physically tested by any means.

Following in this report are background, literature review, design, methods, results, and conclusion which will further explain the purpose and scope of this project.
In 1988, Chevrolet introduced the fourth generation K2500 Pickup/Suburban. There were many changes made to these vehicles compared to the prior generation. One of the major changes was the front suspension design. Previously, Chevrolet used a live axle with leaf springs to suspend the front end. This design lacked steering and handling performance, but provided a very stout design. With the introduction of the fourth generation K2500, Chevrolet opted to replace the live axle with independent front suspension. Although handling is improved, this new design is lacking some key characteristics needed for a heavy duty truck.

There are a number of shortcomings with this suspension design that result in a flawed component. With weaker suspension joints and the larger wheel/tire combinations offered for these ¾ ton trucks, much more stress is applied to the suspension joints, causing premature failure. Other shortcomings include lack of performance and difficult /expensive to service components. There are multiple options to address these problems: the stock suspension components can be replaced often when failure occurs or the components can be upgraded with replacements that can withstand heavy duty use. The temporary solution of replacing failed components is not viable option; but replacement with an upgraded component will provide many benefits and address the root cause.

Aftermarket fabricated control arms are very popular in the off road community and have been around for many years. There are many different styles of control arms manufactured by a few companies. Some companies that specialize with this type of off-road suspension components are: Blitzkrieg Motorsports, Camburg Racing, Total Chaos Fabrication, and Icon Vehicle Dynamics. These components are made for most light and medium duty trucks manufactured in the last two decades. The complexity of fabricated control arms ranges from mild to extravagant and there are three main categories of aftermarket suspension control arms: bolt-in replacement upper control arms, bolt-in full suspension systems, and race suspension systems that require custom fabrication.
The first category of bolt-in replacement upper control arms is the least expensive and the most popular upgrade of the three options (figure 1). This upgrade can usually be used with the stock shock absorbers and springs or upgraded to a high performance shock/strut. One of the biggest advantages to this category is the ease of installation. These components can be installed with minimal standard tools and can be aligned easily. The most common material for these components is 1020 DOM steel tube or 1018 steel plate, but 4130 cromoly alloy can be used as well. The cost of an aftermarket fabricated control arm will range from $600-$1250. The performance is significantly improved compared to the stock component, but can be increased with a higher performance kit. Following are the specifications for Camburg Racing Performance 1.50” Uniball Upper Arms:

- Tubular chromoly upper a-arms
- High Angle Misalignment Spacers to increase wheel travel over stock
- Increase in positive caster geometry for better handling
- Energy Suspension polyurethane bushings with thick inner sleeves and zerk fittings
- Uses Made in the USA FK Uniballs
- Includes all necessary hardware
- ABS line clamps
- Powder coated gray finish

For enthusiasts looking to further improve off-road performance while keeping a vehicle street-able, a bolt-in suspension system is often the solution (figure 2). This system will usually include upper and lower fabricated control arms. The benefits of these types of kits are significant strength and performance improvements, but a replacement shock and steering are required. These suspension systems are usually built with 1020 DOM steel tube, 1018 steel plate, or 4130 cromoly tube or plate. The cost of a bolt-in suspension kit has a large price tag of about $5,000, but this is a popular upgrade for enthusiasts.

For thrill seekers looking for much more performance, a custom installed fully fabricated race kit is an option (figure 3). These kits are built from 4130 steel and include a fully fabricated spindle and upper and lower control arms. There is significant experience and fabrication
required to install this type of suspension system and the street-ability of a vehicle is reduced/eliminated. The cost of this type of suspension system is upwards of $10,000. Due to this significant price tag and off-road only design, this type of suspension system is usually only seen on race vehicles.

Although there are many aftermarket suspension control arms and kits available, there has been no upgraded control arms designed for the fourth generation Chevrolet K2500. Companies such as Total Chaos Fabrication and Camburg Racing have been around for years, specialize in the Toyota and Ford vehicles. It wasn’t until recently that Blitzkrieg Motorsports began developing aftermarket suspension solutions for newer Chevrolet trucks. Therefore, the aftermarket for 1988-1998 K2500 suspension is untapped and has the potential to thrive.

![Figure 1- Replacement Upper Control Arm](image-url)
Figure 2-Bolt-In Suspension System

Figure 3-Fabricated Race Kit
Literature Review

In order to properly and effectively design and fabricate a chassis component, one must be familiar with the related subjects. For this project, literature has been reviewed for ground vehicle dynamics, design for manufacture/assembly, material selection, metalworking, and welding. These topics all play an integral role in the creation of a chassis component like an upper control arm.

Ground Vehicle Dynamics

When designing an automotive suspension component, ground vehicle dynamics cannot be overlooked. Ground vehicle dynamics relates to the ride, handling and optimization of a vehicle in relation to the road. There are three main categories associated with ground vehicle dynamics: dynamics, kinematics, and vibrations. Dynamics is considered to be the motion of a rigid body with respect to a fixed global coordinate frame. Kinematics focuses on position, velocity and acceleration. Vibration is an avoidable phenomenon in vehicle dynamics (Jazar, 2008). These vibrations can be reduced or eliminated with the proper application of dynamics and kinematics.

A vehicle's suspension system connects the vehicle chassis to the wheels and ground. These systems are designed to isolate the vehicle from the road while providing sufficient acceleration, braking, handling, and support. Vehicle suspension systems are broken into two main categories: the live axle (dependent) and independent suspension systems.

Live axle suspension systems usually utilize a leaf spring or linkage with a coil spring to suspend and isolate the vehicle. This is called a dependent system since the front or rear wheels are directly attached to each other. Live axle suspension is commonly found on heavy duty trucks and equipment as well as 4x4 vehicles. It is preferred for these applications because of the superior strength compared to independent suspension systems.

Although independent suspension may not be as strong as the alternative, it provides many benefits over the live axle. As implied by the title, independent suspension systems isolate each individual wheel and allow it to move through the travel without affecting the
others. This provides many advantages over the alternative; most notably reducing steering vibrations, control of roll center, ability to control tread change, larger suspension deflections, and greater roll stiffness (Gillespie, 1989). There are many different types of independent suspension, but the double a-arm suspension and McPherson strut suspensions are the most common. Both of these types of suspension designs are commonly used for the front and rear of most passenger cars and the double a-arm suspension is often found on the front of light and medium duty trucks. The McPherson type suspension uses a lower control arm connected to the bottom of the spindle while a strut is rigidly attached to the upper portion.

This system works well for small, lightweight passenger and sports cars. The double a-arm type suspension attaches to the bottom of the spindle in the same manner, but uses an upper control arm to control the top of the spindle. A coil spring or torsion bar and a shock must then be fixed to either the upper or lower control arms. Either of these systems is ideal for front engine vehicles with rear wheel drive since it allows for maximum room around the engine, but both systems can be altered to work with front drivetrain components. Much caution must be taken when designing the geometry for an independent suspension system since the moving parts must work together in order to achieve the desired ride and handling characteristics. The most desirable of these characteristics is the camber compensation of the outside tire when cornering. But, this camber change must be carefully designed to minimize excessive tire wear (Car Bibles, 2011).
In the past the biggest disadvantage to independent front suspension has been the lack of strength in the drivetrain components as well as the complexity of the suspension parts. With many apparent advantages to independent front suspension, there has been a push in industry for stronger and more durable parts and many companies have been developing drivetrain and suspension components for this market like the ones used on Shannon Campbell’s off road race car.

Figure 6-Shannon Campbell’s 4wd Independent Front Suspension Race Car
Design for Manufacture/Assembly

This concept refers to the design of any product, part or assembly with the goal of maximizing efficiency and minimizing the cost to produce it. Although this is an intuitive process for many, it plays a critical role in the design of a component and can be the difference between the design of a profitable product or wasted resources. DFM/A is often the responsibility of a manufacturing engineer in which they will perform a design review for an existing concept/part. There are many guidelines for DFM/A, some of the guidelines specified by Engineers Edge are:

- Design using “off the shelf” standard or OEM components
- Design for ease of fabrication and assembly
- Avoid special tooling and equipment
- Avoid small and intricate features
- When designing steel fixtures or tooling…specify material low carbon hot rolled
- Always specify the largest radius possible
- Always specify the largest unilateral tolerances possible
- Design tolerances must be within manufacturing capabilities
- Simplify design and assembly so assembly is unambiguous
- Components should be designed to only be assembled one way
- Design parts to orient themselves
- Design for efficient joining and fastening
- Reduce the number and complexity of parts

Different DFM/A guidelines must be taken into account for each component and manufacturing process in order to maximize profits and efficiency (Engineers Edge, 2011).

Material Selection

Material selection plays a major role in every aspect of manufacturing. For the design and manufacture of a control arm, material will need to be selected for the fixture and component being fabricated. Although composites are gaining popularity, metals and their alloys are the most common for these types of critical components. Not only are metals
commonly used for chassis components, but they are used in the manufacture of many structural components. There are many different options of metals and alloys that can be used; the most common structural metals are steel and aluminum due to their strength, cost, and material properties, but titanium and stainless steel can be found in high-end structural components as well.

Steel has been the most common material used in the automotive industry since its birth, but with new processes and the push for efficiency, aluminum has been slowly gaining popularity in the industry. These metals have relatively similar properties, but some major differences exist that will aid the decision of material selection. The cost difference between these two materials is large. The price of aluminum is about 3 times the price of steel. This cost is considerable when considering that the automotive industry uses 16 million tons of steel per year. Steel has many superior characteristics when it comes to metal forming: improved elastic modulus, superior strain rate sensitivity, as well as increased fatigue performance, formability, hardness, damping, magnetic properties, and galvanic potential. Despite the previously stated advantages of steel, aluminum is also easily formed and machined and significantly lighter. In order to build the desired part, joining between multiple parts must take place. This can be done with welding, fastening, or bonding. There are many options for welding processes that need to be considered for this project and they will be discussed in depth. There are multiple ways of fastening and bonding for steel and aluminum, but since the designed part is a critical suspension component, all joining will be done with welding. Finishing processes are necessary for aluminum and steel parts in order to reduce oxidation and rust. There are commercial finishing processes for both steel and aluminum, but the aluminum processes tend to be more expensive. “Steel has always played a significant role in automotive production, from the inception of the automobile at the turn of the century, to the advanced ultra-high strength grades proposed for the cars of tomorrow. This is for good reason; steel combines the best attributes from every avenue that can be applied to an optimally designed automotive body. Its inherent mechanical properties provide ideal conditions for optimal crashworthiness, superior formability, and weldability.” (Steel vs. Aluminum: Introduction, 2008)
There are many different steel alloys that need to be considered based on the application of the part being manufactured. One of the most common and inexpensive alloys is general purpose low carbon mild steel alloy A36. This alloy is often used in industry because it is easy to form, bend, machine, weld, and most importantly, inexpensive. This is due to fact that this alloy is initially formed by hot working. The yield strength of A36 is significantly less than other steel alloys at 36,300 psi, but the cost is significantly lower as well. The most common cold worked low carbon mild steel alloy is 1018. This alloy shares many of the same properties as A36, but has a higher yield strength of 53,700 PSI and is easier to machine. But, the increased energy required to cold work this alloy results in an increased yield strength and price compared to A36. Finally, the most widely used steel alloy for high end applications is 4130 chromium-molybdenum alloy steel. This alloy shares many of the same properties of the previous alloys, but has increased yield strength of 63,100 PSI when heat-treated (normalized). This alloy is also the most expensive of these three common steel alloys (Online Metals, 2011).

With the drive for high strength and lightweight components in many industries, like automotive racing, aerospace and golf club manufacturing, titanium is desirable for many high end components. Some alloys of this metal have yield strength of more than double that of heat treated cromoly steel, but this improved strength comes with a price. The cost of raw titanium is almost 20 times that of mid-grade steel and is significantly more difficult to join, form, and machine (Aircraft Spruce, 2011).

Stainless steel is commonly found in marine, aerospace, food processing, architecture and automotive industries due to its high corrosion resistance and yield strength. Although significantly lower that titanium, stainless steel has a range of yield strength similar to that of regular steel. The cost of this type of metal is roughly four times the cost of mid-grade steel, but maintains good formability and weldability (Aircraft Spruce, 2011).

**Metalworking**

When metals are machined and worked, their characteristics and properties are greatly affected. Some of these changes can benefit the metals properties and other changes can hurt the properties. Since machining and metal forming are necessary for creating a fabricated
control arm, the effects of these processes will be studied. There are three main categories of metalworking; primary, secondary, and final parts production processes (Stout, 1993).

Primary and secondary refer mainly to metal working/additive processes while the final process is often a metal removal process. Hot rolling, hot extrusion, and ingot formation are examples of primary processes. These are often followed by the secondary processes of cold rolling, cold extrusion and drawing. When heat is used to decrease the amount of force needed to form metal, it is referred to as hot working. Adversely, metal forming processes done without heat are referred to as cold working processes. Cold working processes often add strength and benefit the properties of the worked metals. Many physical and metallurgical changes occur when working a material. These changes include stress, strains, distortion of metal grains, recrystallization and phase changes. These changes may potentially benefit the material, but caution must be taken as adverse affects may be an issue if not handled correctly. For example, surface stresses can harden a material and also make it brittle if not relieved by a heat treatment (Stout, 1993). Cold rolling or drawing can also improve strength and hardness, but will decrease ductility by distorting grains. This grain distortion results in recrystallization if thermal activation is available. Often lubricants are used in metalworking in order to prolong die life, increase forming speeds and decrease temperature effects.

For the final parts production processes, material removal operations are often necessary. The final parts production includes milling, turning, grinding, drilling, tapping, etc... There are often residual effects of the final production process that can be removed with polishing. Surface finish is an important aspect of final parts production. A good surface finish can minimize future finishing costs. Surface finish/roughness is commonly measured with a profilometer, but optical techniques have become popular for measuring moving parts. Metalworking and machining are often necessary operations for manufacturing, but, the need to add material is just as important as the need to remove it.

Welding

There are many welding processes that must be considered when designing a component for fabrication. These processes include SMAW, GMAW, and GTAW. All processes
have some advantages and disadvantages, but each must be carefully analyzed for individual applications.

Shielded metal arc welding (SMAW) is classified as a fusion welding process where electricity passes (arcs) between the electrode and the work piece. This arc results in enough heat to melt the electrode and work piece, causing them to join in a weld puddle. Arc welding uses a flux covered electrode in order to shield the weld puddle which minimizes porosity, inclusions, and other defects. The advantages of arc welding include speed and versatility, but this process requires significant final processing (Spitler, 1993).

Gas metal arc welding (GMAW) is similar to arc welding, but uses gas to shield the weld puddle instead of flux. The electrode in GMAW is a thin wire that is fed continuously. This is very beneficial for automated welding, which is why GMAW is the primary form of welding in the automotive industry (Spitler, 1993).

Gas tungsten arc welding (GTAW), uses a non-consumable electrode, shielding gas, and a filler metal (optional). If the filler metal is used, it is fed into the weld puddle from an independent source. This process, also known as TIG welding, is a very versatile form of welding because it can be used on a wide range of thickness materials and on many different metals and their alloys. The main disadvantage of GTAW is a relatively slow welding process, therefore costly in comparison (Spitler, 1993).

There are many other types of welding including oxy-fuel, flash, upset, percussion, high frequency resistance, resistance projection, resistance seam, resistance spot, carbon arc, and stud welding. But the welding processes discussed are the most commonly used processes and the only available options for this project.
Design

There are two major components for this project that needed to be designed, the upper control arm and the fixture. The redesign of the upper control arm had to be completed first, followed by fixture design around the component. The design for the control arm needed to incorporate many key factors, including increased performance, reliability, strength, and serviceability at a decreased cost. The fixture is designed to maximize welding efficiency while
providing sufficient rigidity. These designs also needed to incorporate design for manufacture and assembly (DFM/A).

**Component**

*Design for Manufacture/Assembly*

In order to design this suspension component for a K2500 Chevrolet truck many critical steps had to be taken. Since this project focuses on the redesign of an existing component, the first step was to obtain a stock component from a 4th generation K2500. It was important that this was the correct component and that it was in good condition. Therefore, many measurements were taken to ensure the component was appropriate and undamaged. After the component passed initial inspection, the reverse engineering process began. There are three critical locations that need to be measured for this component. Two of these locations are the bushings which have a fixed location and pivot on an axis, allowing for 1 degree of freedom. The third location is that of the ball joint or pivot. For design purposes, this joint was analyzed with 3 degrees of freedom - two degrees for location and one for radial movement.

These critical locations were reverse engineered using metrology equipment and techniques. The width and separation of bushings was measured using a micrometer and dial calipers. Next, the ball joint was disassembled in order to find the pivot point and a height gage was used to find the distance from the pivot point to the flat mounting surface for the ball joint. Then the distance and location of the bushing axis to the pivot center point was measured using calipers and checked on a coordinate measurement machine. Finally the angle of the ball joint was measured using a precision angle gauge.

After obtaining measurements, the critical measurements were calculated and input into Pro-Engineer. Using these measurements and selected parts, the computer aided design process was initiated. This process was based upon upgraded suspension joints which play a critical role in this project. These parts were chosen for their improved performance, reliability, strength, and serviceability.
The bushing that was chosen for this component needed to provide improved reliability, serviceability and offer the required dimensional constraints. It was critical that this joint utilized standard tubing for inner and outer sleeves and that the inner sleeve have 9/16” inner diameter to utilize the factory alignment cams. It was also important that this bushing provided improved durability compared to the factory rubber bushings. Also, this bushing needed to be easily serviceable with standard hand tools. After much research, an off-the-shelf polyurethane bushing was chosen for this application. This molded polyurethane bushing has increased durability properties and will not crack and dry rot like a rubber bushing. This bushing contains two halves and an inner sleeve that can easily be serviced with standard hand tools. The inner and outer diameters are acceptable, but the length of the bushing does need trimming. Overall, these components are well suited for this application. If high volumes of this product were to be made, it may be worthwhile to design a mold for a bushing that would not need modification.

The suspension joint used to replace the stock ball joint needed to provide improved performance, reliability, serviceability and strength. Since the ball joint articulates almost 30 degrees, the options for replacement joints were limited. Most suspension joints with this much misalignment are large and/or expensive. After much research, a compact, high misalignment spherical rod end was chosen. This joint (also known as a uniball) can reach up to 32 degrees of misalignment which allows for more wheel travel and improved performance. Since the uniball uses a wear resistant Teflon liner instead of a plastic liner to lubricate the joint, reliability is increased. Serviceability is also improved through the use of standard hand tools for replacement. This joint increases strength by using a significantly larger diameter ball joint at 1.875” instead of the stock 1.18” diameter. Also, this suspension joint is often housed in an off the shelf machined steel uniball cup which can be easily welded to. There are many advantages to using this joint to replace the stock ball joint, but there is one disadvantage. A conversion pin will need to be purchased in order to adapt ¾” shank needed for the uniball spacers to the stock ball joint taper. These pins can be purchased from Blitzkrieg Motorsports.
It was decided that the structure of the arm would be constructed out of steel plate due to welding considerations, strength, and design for manufacture/assembly. The steel plate construction replaced the stock construction of hot formed and stamped steel rod. The steel plate construction allows for maximized weld area around the critical suspension joints. The material choice was 1/8” cold rolled 1018 mild steel compared to the 7/8” round bar A36 hot worked stock control arm (Figure 12). Although there is significantly less material in the new design, the boxed plate construction, fully welded design and increased material strength provide a stronger, lighter and more rigid control arm. Design for manufacture of this component was taken into consideration to increase manufacturability and decrease cost. Some of the DFM guidelines emphasized were minimal number and complexity of parts and design for efficient joining (welding) (Figures 10 & 11). The part was designed using tooth and slot construction to orient and locate parts. Each control arm is made up 10 individual components:

- Top Plate (Figure 31)
- Bottom Plate (Figure 32)
- Front Inner Plate (Figure 24)
- Front Outer Plate (Figure 25)
- Rear Inner Plate (Figure 29)
- Rear Outer Plate (figure 30)
- Gusset Plate (Figure 26)
- Bushing Sleeve x2 (Figure 28)
- Uniball Cup (Purchase Part)

The purpose of the design was to minimize the amount of resources needed for a shop to produce this product. Since this product is most likely a low volume aftermarket part, the component was designed to be manufactured with only a welder, the fixture, and some basic hand tools. The plate construction of the control arm was designed to be outsourced to a shop with CNC laser/water jet cutting and CNC bending capabilities. Although this may increase cost, it will allow this part to be manufactured with limited tools and space.
Figure 10- Steel Plate Construction

Figure 11- DFM

Figure 12- Stock Component
Fixtures

Design for Manufacture

As discussed earlier, there are 3 critical locations for this component. When designing the fixture, these locations were designed in order to maximize rigidity (Figure 33) and locate the bushing sleeves and uniball cup. The heat input from welding will cause material to deform and warp unless held in place by a rigid structure. Since the main concern for this fixture is to locate components during welding, a tubular steel frame was constructed out of 1.5" A-513 steel square tube with ¼" A36 steel tabs to hold critical components in place as suggested in DFM/A guidelines. There is also significant gusseting on the tabs to prevent the fixture from flexing when component is being welded. The bushings are held in place using 9/16" grade 5 hardware with double shear tabs, therefore eliminating all six degrees of freedom. This is done using the cylindrical hardware, which acts like a pin, to constrain 4 degrees of freedom: two degrees of freedom for axes and two degrees of freedom for location. The last two degrees of freedom are constrained by the clamping force for the bolt and tabs which constrain movement along the axis and rotation about the axis. The uniball cup uses a ¾" hardware mounted to the 1.5" steel tubular frame. This component is fixed in space similarly to the bushings. Four degrees of freedom are constrained by the bolt (pin) and the last two are constrained by the clamping force of the bolt (movement along Z axis and rotation about Z axis). For all three of these components, the clamping force provided by the bolts and weld slugs precision are the key to accurately and firmly locating the parts.

The precision of the weld slugs is a critical aspect of the fixture design. These machined fixture components need to be machined so that the outer bushing sleeves and uniball cup can be easily and accurately located for welding. The tolerances for these parts were carefully designed to provide a minimal clearance fit for all sleeves and cups that are within tolerance (figure 40 & 41). To achieve these tolerances, a HAAS TL-1 CNC Lathe was used and the dimensions were verified with a vernier micrometer (accurate to ±.0001). The clearance fit is designed to aid the operator in installing and removing these fixture components from the final weld assembly quickly and easily. Also, the material chosen for the slugs was aluminum to
prevent damage to the critical machined inner surfaces. Although these slugs will wear over time, the decreased surface hardness will not damage critical surfaces.

Although, a tooth and slot design (Figure 10) was used to align and orient parts, there are still significant forces applied to the fixture during welding, but the thick material and significant reinforcement used for the fixture design will retain component integrity. The tooth and slot design used for the component allows the component to be pieced together outside of the fixture. When positioned between the uniball cup and bushing sleeves, the plate components fit snugly and no supports or locators are needed. The weld fixture is constructed of 11 critical components, six of these components were welded together to form the rigid structure and five components were machined to locate/prevent warpage of components. The components that make up the rigid structure are:

- Fixture Base (Figure 34)
- Tabs (Figures 35-38)
- Tab Gusset (Figure 39)

The components which are used to locate/prevent warpage are:

- Uniball Slug (Figure 41)
- Bushing Slugs (Figure 40)
Methods

In order to test the design, multiple methods were used to ensure that proper fit and function were achieved. Although the prototype will not be installed and tested on a vehicle for this project, a mock-up component and a prototype have been manufactured to test the design and functionality of this component.

As explained in design, a CAD model was created using identical geometry to the stock component, but with upgraded suspension joints. In order to test that this geometry was ideal for the new suspension joints, a mock-up suspension arm was built. This mock-up component was constructed with the new suspension joints and tack welded using scrap metal to connect them. A carefully measured fixture was tack welded to a welding table to achieve the desired geometry. This mock-up arm was installed on a vehicle and the suspension was cycled (see Figures 14 &15). The purpose of this is to check camber and caster change, as well as ensure that no components are binding. When the suspension was cycled, the uniball would reach the maximum angle of 32 degrees of misalignment before the suspension would fully compress, but there was extra angularity available in the joint when the suspension was uncompressed. This meant that the suspension joint was limiting up travel and must be reoriented. To address this problem, I measured the difference between the angles and adjusted the fixture to account for half of the difference, about 3.5 degrees. The fixture was modified accordingly and the mock-up arm was then disassembled, re-fixtured, and tack welded to account for the change in angle. Next, it was reinstalled on the vehicle and inspected. This time the mock-up component cycled well and all adjustments were documented in order to make the necessary changes in the solid model. The purpose of the mock-up control arm was to check geometry; once acceptable geometry was achieved and documented, the mock-up component was scrapped.

The updated CAD model (Figure 16) was then used to create the individual components for both the fixture and the prototype upper control arm. The individual components were used to create 1:1 drawings and exported as a 2D AutoCad “.dxf” file. These files were sent to a
laser cutter to get cut out of 1/8” cold rolled 1018 mild steel plate and ¼” A36 hot rolled steel plate. When these parts returned (Figure 16), the fixture plates were assembled and welded (Figure 18) and the plates that needed a bending operation were taken to the Aero Hangar and bent. A large box/pan Brake was used to bend the 2 lower plates 21.33 degrees. This method was chosen over CNC bending because the asymmetrical shape of the part may cause unpredictable bends on a CNC press brake. With the current time frame, it was not economical to risk the possibility of scrapping these parts; hence the manual brake was used. Once the plates were bent and the fixture welded, component assembly took place. The weld slugs were assembled with the uniball cup and bushing sleeves. They were then installed in the fixture using standard hardware. Next, the individual plates were assembled and tack welded in the fixture (Figure 19 & 20). Final alignment was checked and plates were strategically welded.

Since most of the joints require 2 or 3 start/stops, welding would alternate locations on the component in order to reduce heat concentration and warp age (Figure 21 & 22). The welding was done using a Miller 180 220v wire feed welder with 75/25 Argon & CO₂ shielding gas. This combination provides clean and predictable weld. In a manufacturing setting, welding of this part is estimated to take approximately two hours. This estimate is based on the manufacturer suggested wire speed for this material, inches of weld needed for the component and the ideal volume of weld needed. After welding was completed, the prototype upper control arm was removed from the fixture and suspension joints installed.
Figure 14 - Mock-Up Arm Uncompressed

Figure 15 - Mock-Up Arm Compressed

Figure 16 - Updated CAD Model
Figure 17 - Laser Cut and Bent Parts

Figure 18 - Fixture Assembled and Welded
Figure 19- Prototype Assembly

Figure 20- Assembly w/ Top Plate

Figure 21- Prototype Final Welding
The results of this project are consistent with initial expectations. The benefits provided by this component are similar to those of competitors and are approaching the maximum capabilities for this type of upgrade. All objectives outlined in the introduction have been met: the stock upper control arms have been redesigned, a weld fixture was designed and manufactured, a prototype component has been manufactured and a cost analysis has been performed for multiple production volumes (following).

As mentioned in the background section, there are no similar products on the market for this vehicle, but there are many available for other makes and models. For this project, it is important that this component can be profitable when priced at or below the average price of
similar products. The price range of similar products from companies like Blitzkrieg Motorsports, Camburg Racing, and Total Chaos Fabrication ranges from $600-$900 with the exception of the $1250 control arm manufactured by Icon Vehicle Dynamics. To produce a potentially competitive product, a cost analysis must be performed. A cost analysis was done for this component for small (~10 units), medium (~100 units), and large (~1000 units) production volumes (Tables 1 & 2). These values were calculated based on monthly production with dedicated shop space for production of this single component.

According to calculations, the total cost to produce this component for a small production volume is of 10 units is about $616 per pair of control arms. When compared to the average price of about $700 for steel fabricated control arms, the difference is $84 dollars. This would result in a 12% mark-up if sold for average market price. If only 10 parts per month were manufactured, it would be difficult to justify this risk.

Using dealer costs and bulk order prices, a total cost was calculated for medium sized production volume of 100 units. The total cost to produce for this level of production is about $323. If this product was priced at average market value, there would be a markup of about $377 or 54%. With this amount of monthly production, this product has the potential to be very profitable.

This product is designed for a limited aftermarket and there is little possibility that a high level of production will be in demand. But, the possibility will be analyzed for large production volumes of 1000 units. If this level of production were achieved, the cost would be less than $323. There are limited resources for sourcing pricing for this level of volume, but, it is assumed that part and hardware cost would decrease slightly due to bulk purchasing from the supplier. Improved methods of sheet metal cutting would be used. This could be CNC laser or water jet plate cutting in house or designing custom dies for sheet metal punching/stamping. Calculations for return on investment would be performed for machining conversion pins and uniball cups in-house. Another process that could be improved is welding. Alternate welding processes would be analyzed and standard MIG welding could be replaced with spray or pulse MIG process for faster welding cycle time and possibly automated.
The design developed for this project was a good overall design, but there are some improvements that could be made. The plate construction for this component provides many benefits, but some changes would significantly improve the manufacture of this product. The first change I would make would be to alter the plate design to have the bottom plate mimic the top plate with tooth and slot construction or including more bends in the design to minimize welding. This was not done for the prototype because I assumed that the vertical plates would be located well enough using the top two slots and contact with the sleeve and uni-ball cup. Since this was not the case, the setup time was greater than estimated. Also, it may be beneficial to put a bend into the inner vertical plates. Although this contradicts DFM guidelines, the weld joint would be improved and this joint could have been welded in the fixture. The final design change I would make is to improve the weld joint between the uni-ball cup and top plate. This weld was very difficult and would need final machining if not executed properly. For prototype fabrication a threaded rod was used to secure the bushings and bushing weld slugs. Since the nuts had to be threaded off the entire rod, this was not a very efficient way to secure these components. If this part were put into production, a wing style bolt would be used with a welded nut to allow for hand tightening and reduced cycle time. Using these observations, I would suggest that the design be revised while keeping a very similar steel plate construction.

Implementation of this design has the possibility for success. There are currently many companies profiting off very similar products for different vehicles. If the preceding minor design changes were made and some testing were done, I feel that this product would be fit for sale and have the potential to be profitable for medium volumes or small volumes for an already equipped job shop. Also, the plate construction design used for this project could be used for developing control arms for many other types of vehicles. As shown by the innovators in industry, design using plate construction is the direction of high end manufacturing in off-road. Therefore, the limitation of what can be designed and built is limited only by one’s imagination.
Conclusions

There are many shortcomings with the stock suspension components for 1988-1998 Chevrolet K2500 trucks. The objective of this project is to address these issues and improve the stock upper control arm through a full redesign of this component. As mentioned in the background, there are many similar products available for other makes and models of vehicles, but none have been manufactured for this vehicle. The objectives of this project were met by redesigning the stock upper control arm, designing and manufacturing a weld fixture, manufacturing a prototype component, and performing a cost analysis. The redesign began by reverse engineering the stock component, modeling it in CAD around improved suspension joints, testing and modifying the design, and finally fabricating a prototype using precision cut steel plate components.

This project provided me with an opportunity to apply much of the knowledge learned in IME classes at Cal Poly. Many concepts, techniques, and projects from MFGE classes played an integral role in the successful completion of this project. This project gave me an opportunity to learn more about manufacturing a product from inception to production. This process took much more time than expected, but this will allow for a more accurate estimate for future projects. Going into this project I felt comfortable doing design work with Pro-Engineer CAD software, but had no experience with sheet metal design in Pro-Engineer. The basics of it were easy to learn, but there were many revisions that took place over the course of this project and problems with Pro-Engineer were prevalent. This resulted in much more design time than expected. Overall, I feel that the scope of this project encompassed many areas of manufacturing and it was a great opportunity to apply the knowledge learned at Cal Poly.

The final prototype manufactured for this project turned out very well, but there are some small changes that could be made. The only thing that I would change for this project would have been to schedule for time to create another prototype. As reiterated by this
project, there is little possibility that the first prototype will be ideal and another prototype would have given me the opportunity to make all desired changes.

In the future, I plan on making the proposed changes to this component as well as working to develop a suspension system (as described in Background) for this vehicle. As with this component, aftermarket suspension systems for this vehicle are nonexistent and there is potential to make significant improvements. I believe that further research and development for this vehicle would be worthwhile.
## Appendices

### Table 1

<table>
<thead>
<tr>
<th>Part</th>
<th>Qty</th>
<th>Qty 1-10</th>
<th>Qty 11-100</th>
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<tr>
<td></td>
<td></td>
<td>Price</td>
<td>Total</td>
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<tr>
<td>1&quot; Uni-Ball Cup</td>
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| **Total**                 |           | **$2,826.99** | **$615.99** | **$323.44** | < $322.54 |          |
Figure 25

Cal Poly SLO

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SCALE 1:2
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<td>Chris McLean</td>
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<tr>
<td>Date</td>
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**Cal Poly SLO**

Figure 29

![Diagram with dimensions](image)
Figure 30
References


