SAE Mini Baja: Suspension and Steering

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Progress Report

Document

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Abstract

The suspension and steering systems of the SAE Baja vehicle needs to be adaptive, durable, efficient, and relatively inexpensive. The vehicle must be able to withstand the harsh environment of off-road competition and recreational driving. The vehicle needs to traverse over large rocks, downed logs, mud holes, steep inclines, jumps, and off camber turns. In order to meet the demands of the race course, the steering and suspension systems were designed and redesigned for a more effective turning radii and efficient use of suspension travel. The rear suspension geometry, profile, and material has gone through a few different iterations, and the final design is near completion. Construction has begun on the other vehicular components, i.e. frame and drivetrain, and the team is on schedule.

Chapter 1. Introduction

1.1 Project Overview

The Society of Automotive Engineers International (SAE) has contracted the Northern Arizona University (NAU) chapter to design and build a Mini Baja vehicle for competition use. The stakeholders for the project are Dr. John Tester and SAE NAU. SAE is a United States based organization that sets international standards for the automotive, aerospace, and commercial vehicle industries. The Mini Baja competition is one of many collegiate competitions sponsored by SAE, it is designed to challenge each team in the design, planning, and manufacturing process involved in the production of small, consumer based off-road vehicles. The competition itself consists of several different disciplines to test speed and maneuverability as well as endurance racing. The suspension and steering team has been assigned to design effective and efficient systems to support and maneuver the vehicle during competition.

1.2 Project Need Statement

The Northern Arizona University chapter has not won an event at the SAE Mini Baja competition in years. The competition consists of several events that the vehicle must be able to handle each one effectively. These events include the Presentation, Hill Climb, Endurance, and Acceleration tests. The team must make a sales presentation to a panel of judges on the marketability of the vehicle and therefore must be aesthetically pleasing.

1.3 Project Goals

The goal of the suspension and steering team is to design efficient, strong, and easily manufactured systems of each system. Having a vehicle that is both maneuverable and capable of handling rough terrain is key for victory at the 2014 SAE Mini Baja competition. To achieve this goal the team will design suspension members with the strongest materials that are easily machineable while still maintaining relative low weight and adhering to all safety regulations. The steering system will be designed with an adequate turning radius to stay competitive in the maneuverability event. Once the frame is completed, construction on the front suspension, rear suspension, and steering systems will be built and installed.

Chapter 2. Design Modifications

2.1 Front Suspension

The front suspension is still comprised of two pairs of control arms allowing for maximum traction, good articulation and light weight. The bulk of the design is the same and only changed to maintain good geometry with the newest version of the frame of the vehicle. The main design change to the front suspension is replacing the control arms with a simplified design that cuts down on weight and fabrication time while still maintaining strength requirements. Mounting to the frame is a cheaper, and very simple bolt through bushing design, cutting out the use of expensive heim joints for the majority of the front suspension. Heim joints, however, are still retained for mounting to the off-the shelf hub, upper joint also retains the ability to adjust for tune-ability. Shocks will be downgraded to a less expensive but still adequate model but will sacrifice some adjustment. Choices for shocks are most likely going to be the stock units off of a similar sized vehicle, potentially using used shocks to fit in the cost constraints.

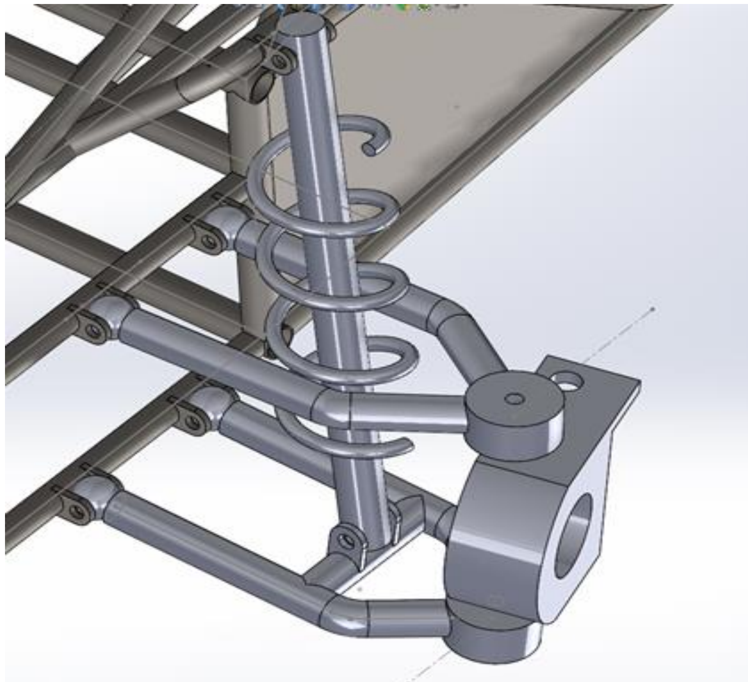

Figure 1 - Original design for Control Arms

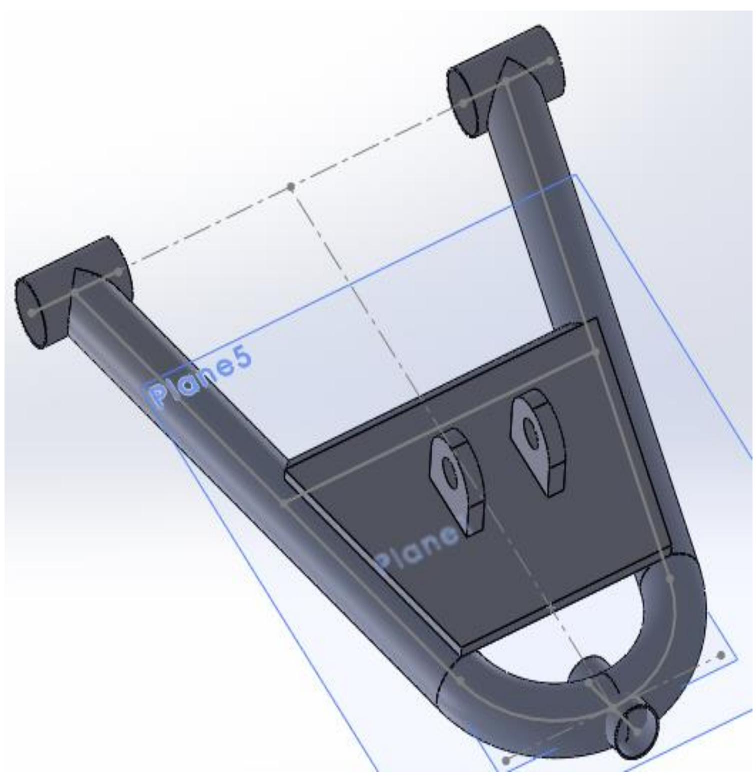

Figure 2 - Updated Control Arm Design

2.2 Rear Suspension

The rear suspension has gone through many iterations during the design process. The rear suspension system will use a three-link trailing arm design made of 4130 Chromolly Steel for sufficient travel, rigidity, and high strength. The original iterations were too heavy for this particular vehicle, and would not work with the current frame and drivetrain designs. *Figure 3* and *Figure 4* show the original trailing arm designs from different views.

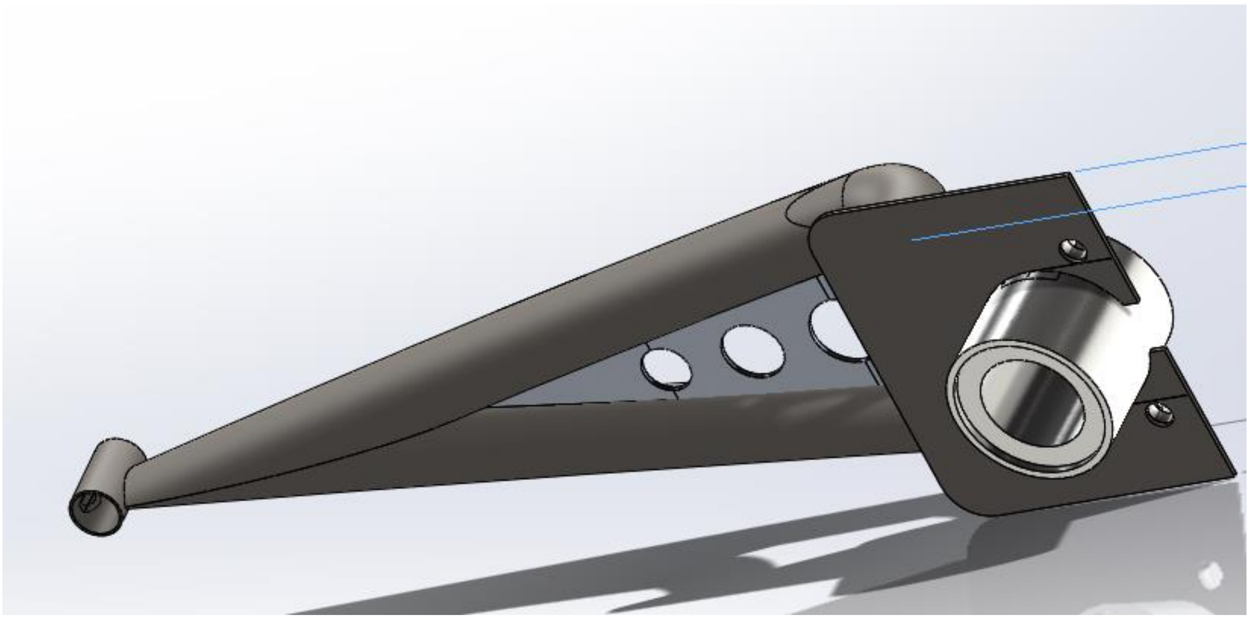

Figure 3 – Original Trailing Arm Design (Isometric)

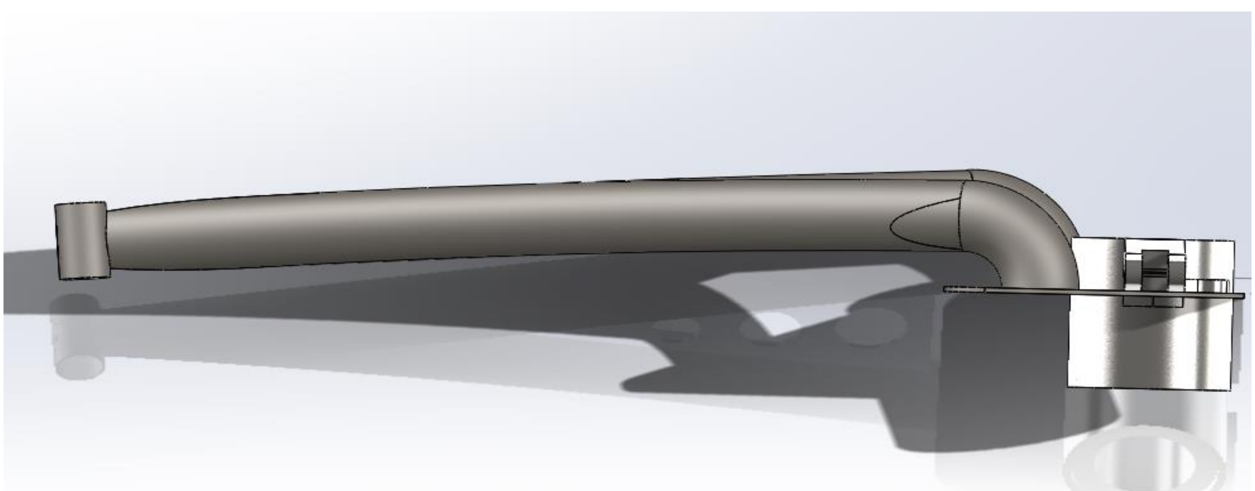

Figure 4 - Original Trailing Arm Design (Top)

The trailing arm tubing selection changed for the second suspension member design. The team did analysis on both square and rectangular tubing for the new 3-link design. This design choice was based on the new Polaris RZR XP 1000 rear suspension shown; the main body of the member is rectangular tubing. This design would simplify and drastically lighten the rear suspension, a primitive design is shown in *Figure 5*.

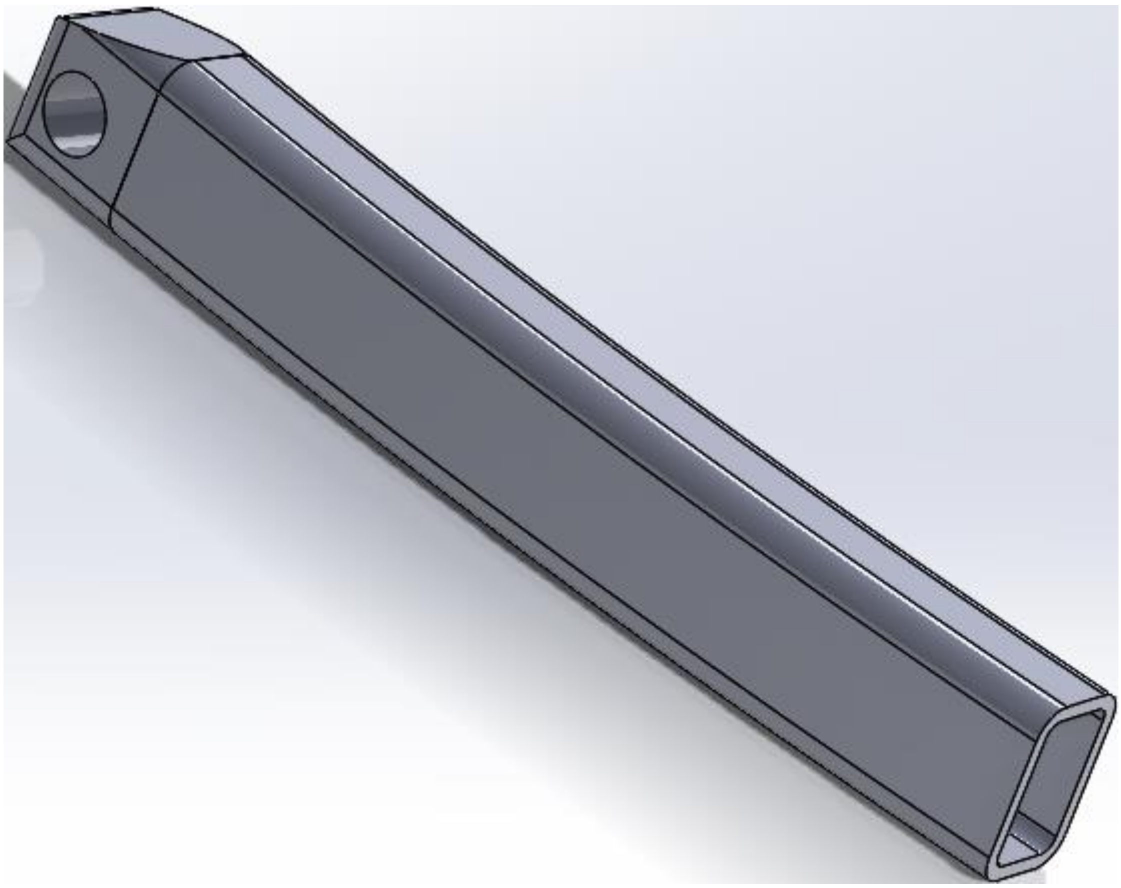

Figure 5 – Rectangular Trailing Arm Design

For the final design the team decided to go back to the original design with a few modifications for lengthening the track width and give enough clearance for the CV axle to operate its full range of motion. A rough draft of the rear trailing arm attached to the frame is shown in *Figure 6*. The rear suspension design will be finalized and construction will be begin within the next few weeks.

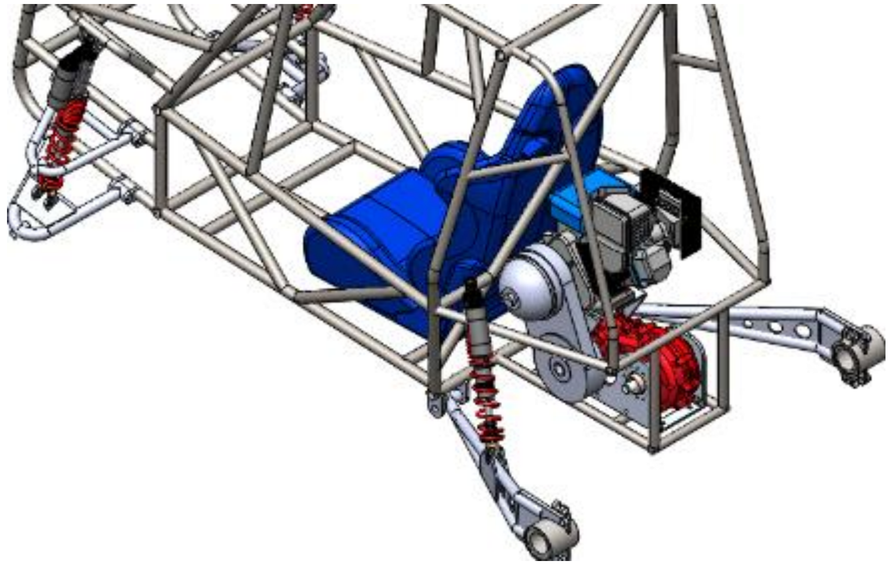

Figure 6 – Suspension and Frame Assembly

2.3 Steering

Previously, our team decided to choose a 9in rack and pinion for the steering system but ended up with a turning radius of 12ft and diameter of 24ft. This turning radius was not ideal and did not meet our previous goal of being within 66% of the previous Mini Baja turning radius (radius = 15ft). Now, we will use a 14in rack and pinion for the steering system in order to decrease the turning radius of our current Mini Baja design. Currently, our theoretical turning radius is 6.56ft with the 14in rack and pinion which meets the previously stated goal for our turning radius. *Figure 7* shows the rack and pinion our team is planning on ordering and using for the Mini Baja:

Figure 7 - Rack and Pinion

In addition, the new rack and pinion has a higher gear ratio (12:1) then the previously designed rack and pinion which will make it easier for the driver to turn the steering wheel. Another note, a 12:1 ratio means that the driver would have to turn the steering wheel well over 360 degrees which is not ideal to do in the small space where the driver is placed. One suggestion is to place a quickener between the rack and pinion and the steering column in order to reduce the ratio up to 0.5in order to have a faster turning response. The one drawback to this suggestion is the price of quickeners ranging from $200 - $400. This suggestion will be implemented into the design once more sponsors are collected and more money becomes available.

Steering Radius Calculation

$R = turn\ Radius$

$L = Wheelbase$

$\delta_0 = outer\ steering\ angle$

$\delta_i = inner\ steering\ angle$

$\delta = Average\ steering\ angle$

$N = Distance\ from\ tie\ rod\ mount\ to\ kingpin$

$\tau = rack\ travel$

$$\delta = 2sin^{-1}\left(\frac{0.5\tau}{N}\right) \qquad (1)$$

$$\delta = \frac{\delta_i + \delta_0}{2} \qquad (2)$$

$$\delta = \frac{L}{R} \Rightarrow R = \frac{L}{\delta} \qquad (3)$$

- Assumptions:
  - Inner and outer steering angles are equal at this point (use equation (1) above, otherwise take the average of the two shown in equation (2))
  - Kingpin directly on pivot point of tire
  - 0 degrees of castor
  - System takes advantage of all 4.25 inches of rack travel
  - The distance from the tie rod to the mount point assumed 4 inches
- In the equation (3) above, δ should be in radians and the turn radius should come out in the units that the wheelbase is in.
- These equations hold true for low speeds where turning is static and all wheels make complete rotations without skidding on the ground.

While calculating the new steering radius theoretically with the new rack and pinion and knuckle dimensions, the new turning radius is down to 6.56ft, which makes a steering diameter of 13.13ft at low speeds. The theoretical steering radius of 6.65ft is somewhat of an unrealistic number and this is most likely because there were many assumptions made about the design. The assumptions made were that the hubs would have the kingpin mounted directly in the center of where the wheel pivots, the steering system would take advantage of 100% of the rack and

pinion travel of 4.25 inches, there is no castor, and the distance from the kingpin to the tie rod mount point is 4 inches. This theoretical calculation will vary with changes to the front suspension components and changes to the tie rod mount point on the hubs that will also vary with changing measurements in designing the suspension.
Suspension components that will optimally change the steering design will be the kingpin inclination and length, king pin spindle offset and the difference in length between the top and bottom A-arms.

Another factor to take into account when calculate the steering radius is slipping of the wheels while cornering. So when calculating the steering radius and factoring in the cornering stiffness and slip angle, the turning radius will decrease significantly because of the slip of the tires in the dirt at higher speeds. This gives somewhat of a dynamic example as opposed to the static steering explained with assumptions in the previous paragraph above.

Chapter 3. Current Progress

3.1 Design Finalization

3.1a Front Suspension

The front suspension remains largely unchanged from the original version. The control arms are designed for the nearly completed frame and are meant to cut down on fabrication time and purchasing of exotic joints. The heim joints are replacing uniball joints for mounting of the wheel hubs and still allow for high adjustability and durability. The frame mounts have been changed from heim joints to a standard, bolt through bushing design, the bolt will mount through tabs welded to the frame and allow the suspension to articulate without any unwanted lateral movement.

3.1b Rear Suspension

The rear suspension has gone through many design changes, most of which revolve around the weight of each suspension member. The current design is very similar to the original, with modifications for a longer vehicle track and accommodations for CV axles. Seeing that the original members were over designed, another main focus of the current design is to decrease weight as much as possible while keeping the required member strength.

3.1c Steering System

The steering system went through a refinement phase where the team chose a new steering rack and started to calculate the theoretical turning radius. The steering rack chosen has a ratio of 12:1, meaning that nearly a full 360 degree turn of the steering wheel is needed for full lock. In order to remain maneuverable, the addition of a steering quickener may be added for quicker reaction time in the potential maneuverability challenge.

Chapter 4. Conclusion

The suspension and steering systems have to mesh well with both designs for the frame and drivetrain, as well as both steering and suspension have to handle complex motion. Due to the nature of both systems there have been multiple iterations of every piece that the team has to fabricate. The designs have now been finalized and the team is looking to start fabrication on suspension members and continue with in-depth turning radius and steering calculations. As construction begins, any changes in design will be documented and checked to make sure all members meet the needs of the design requirements.

References

Gillespie, T., The Fundamentals of Vehicle Dynamics, Society of Automotive Engineers, Warrendale, PA, 1992.

Milliken, W.F. and Milliken, D.L., Chassis Design Principles and Analysis, Society of Automotive Engineers, Warrendale, PA, 2002.

Hunt, D., farm Power and Machinery Management, Iowa State University Press, Ames, IA, 2001.

Appendix

A. Front Suspension Parts/Cost List

2010 Polaris Outlaw 525

6		1823341	Asm., Knuckle, Steering, RH	1	
6		1823340	Asm., Knuckle, Steering, LH		
1		7547336	Nut, Castle	2	
2		7661401	Pin, Cotter	2	
3		7555721	Washer	2	
4		5133342	Spacer, Spindle, Outer	2	
5		3610090	Seal, Lip	2	
6		3514650	Bearing, Ball	2	

7		5135268	Hub, Wheel, Front	2	
8		7515513	Stud	8	
9		5335231	Spacer, Tapered	2	
10		3514649	Bearing, Ball	2	
11		3610093	Seal, Lip	2	
12		5247752	Disc, Brake	2	
13		5133341	Spacer, Spindle, Inner	2	
14		7518643	Bolt	8	
-		1911187	Asm., Caliper, Brake, Dual Bore, RH	1	
-		1911186	Asm., Caliper, Brake, Dual Bore, LH		

B. Rear Suspension Parts/Cost List

Part Number	Part Description	University Discount Price	Retail Price
5136543	Rear Bearing Carrier - Left	$28.00	$68.81
5136544	Rear Bearing Carrier - right	$28.00	$68.81
5135113	Rear Hub (Black)	$19.00	$46.01
3514635	Rear Hub Bearing	$14.00	$34.32
7710440	Rear Hub Bearing Retaining Ring	$4.00	$7.85
7518903	Rotor Bolt	$0.58	$0.58
7547337	Castle Nut	$1.00	$1.32
1332947	Drive Shaft		

C. Steering Parts/Cost List

Part	Description	Source	Cost
Rack & Pinion	36 spline shaft input, 14" Mini Dune Buggy	desertkarts.com	$98.00
Tie Rods (Part C42-425) (x2)	16" tie rods, threaded ¾" tubes	secure.chassisshop.net	$64.95
Quick Release	3 Bolt Hex Head Quick Release adapter	kartek.com	$34.99
Steering Column	Fabricate?		

Steering Wheel	Standard VW three bolt pattern. 14" Dia. x 3-1/2" Dish Foam Wheel, 3 Bolt	Kartek.com	$63.99
Heim Joints	Donation?		