SAE Mini Baja: Suspension and Steering

Project Proposal

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NAU

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INTERNATIONAL

Overview

- Problem Definition and Project Plan
- Concept Generation
- Design Selection and Analysis
- Bill of Materials
- Conclusion

Problem Definition and Project Plan

Introduction

Design, build, and test suspension and steering components to compete in Mini Baja SAE competition.

Client: Dr. John Tester

SAE Mini Baja Competition Environment:

- Portland, Oregon
- Rough, natural terrain and wet weather

Nick Garry

Customer Needs

The previous car was too large, heavy, and lacked maneuverability.

Project Goals

- **Need:** Approach angle is too shallow reducing maneuverability
- **Need:** Current suspension mounts were an after thought for the frame increasing weight
- **Need:** Existing turning radius is too large limiting maneuverability

Project Goals cont.

- **Need:** Current car is too bulky in overall dimensions
- **Need:** There were too many bought components with no analytical justification
- **Need:** Most components are over engineered and too heavy

Objectives

Objective	Measurement Basis	Units
Increase Width	Track width of Mini Baja	in
Lower Weight	Weight of all steering and suspension components	lb
Increase Maneuverability	Turning radius	in
Increase Approach Angle	Ride Height	in
Increase Reliability	Repetition of suspension and steering components	reps

Constraints

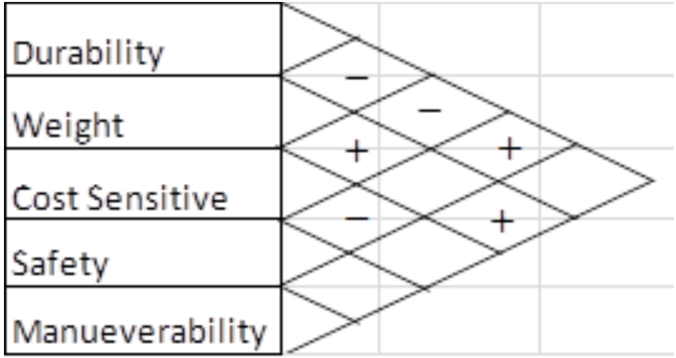
- Track width must be 59” or less
- 2 lane width turning radius
- All suspension mounts integrated into frame
- Entire Mini Baja must weigh less than 450 lbs
  - Suspension and Steering components need to weigh no more than 150 lbs
- Conform to SAE Baja competition rules

Kyle Egan

QFD

			Engineering Requirements					
		Weight	Yield Strength	Turning Radius	Ground Clearence	Suspension Travel	Weight	Cost
Customer Needs	Durability	0.2	9		3	3		
	Weight	0.3					9	3
	Cost Sensitive	0.125					3	3
	Safety	0.125	9		3	3		
	Manueverable	0.25		9	3	3		
		Units	kpsi	ft	in	in	lb	$
		Score	2.93	2.3	1.7	1.7	3.1	1
		Weighted %	23	18	14	14	24	8

House of Quality



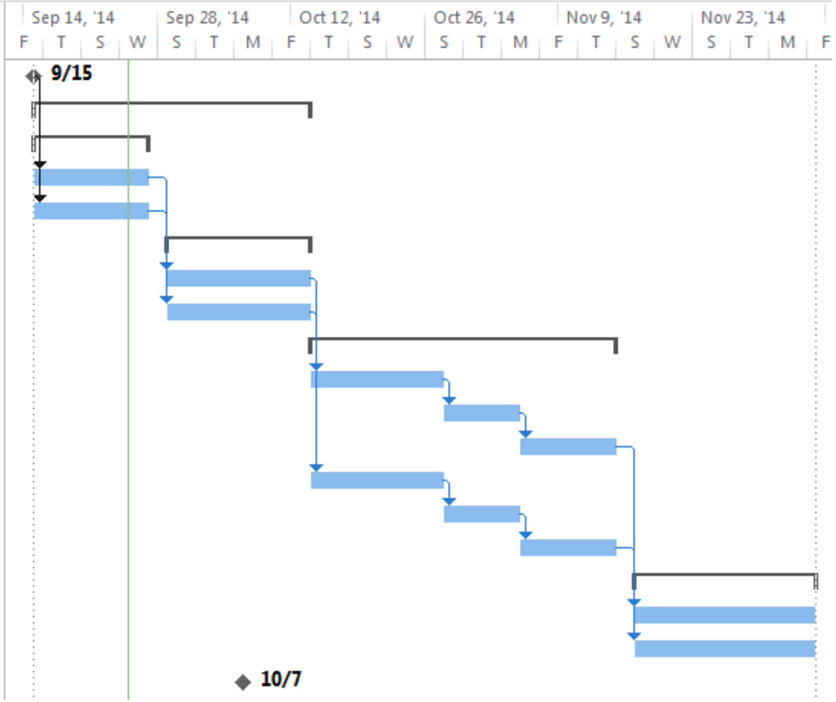
Gathering Information

- State-of-the-art Research
  - Previous NAU SAE Baja Projects
  - Previous SAE Baja Projects from other schools
  - Suspension Systems
  - Steering Systems
- Resources
  - SAE 2015 Rules and Regulations
  - Technical Suspension Books
  - Technical Steering Books
  - Previous SAE Baja Projects

Trevor Hochhaus

Project Planning

Task Name	Duration	Start	Finish	Predeces
Start	0 days	Mon 9/15/14	Mon 9/15/14	
Research	**21 days**	**Mon 9/15/14**	**Mon 10/13/14**	
Pros/Cons of Previous Design	**10 days**	**Mon 9/15/14**	**Fri 9/26/14**	
Suspension	10 days	Mon 9/15/14	Fri 9/26/14	1
Steering	10 days	Mon 9/15/14	Fri 9/26/14	1
New Research	**11 days**	**Mon 9/29/14**	**Mon 10/13/14**	
Suspension	11 days	Mon 9/29/14	Mon 10/13/14	4
Steering	11 days	Mon 9/29/14	Mon 10/13/14	5
Design	**24 days**	**Tue 10/14/14**	**Fri 11/14/14**	
Suspension	10 days	Tue 10/14/14	Mon 10/27/14	7
Suspension Solid Model	6 days	Tue 10/28/14	Tue 11/4/14	10
Suspension FEA	8 days	Wed 11/5/14	Fri 11/14/14	11
Steering	10 days	Tue 10/14/14	Mon 10/27/14	8
Steering Solid Model	6 days	Tue 10/28/14	Tue 11/4/14	13
Steering FEA	8 days	Wed 11/5/14	Fri 11/14/14	14
Build	**15 days**	**Mon 11/17/1**	**Fri 12/5/14**	
Suspension	15 days	Mon 11/17/1	Fri 12/5/14	12
Steering	15 days	Mon 11/17/1	Fri 12/5/14	15
Sign up for competition	0 days	Tue 10/7/14	Tue 10/7/14	



Trevor Hochhaus

Concept Generation

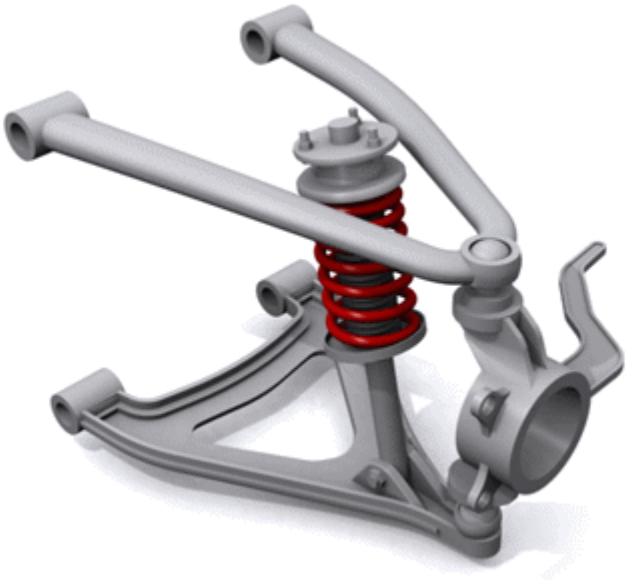
Front Suspension Concepts

- Double A Arms
- MacPherson
- Torsion Bars
- Extended A Arms

Double A Arms

- <u>Advantages:</u>
    - High strength
    - Highly adjustable
    - Good ground clearance

- <u>Disadvantages:</u>
    - Can be heavy
    - Can be difficult to analyze



www.lostjeeps.com

Nick Gary

MacPherson

- <u>Advantages:</u>
  - Lighter weight
  - Less design and machining
- <u>Disadvantages:</u>
  - Higher stresses
  - Requires wheel hub modification

www.multibody.net

Torsion Bars

- Advantages:
  - Very high strength
  - Only one member
  - Large travel

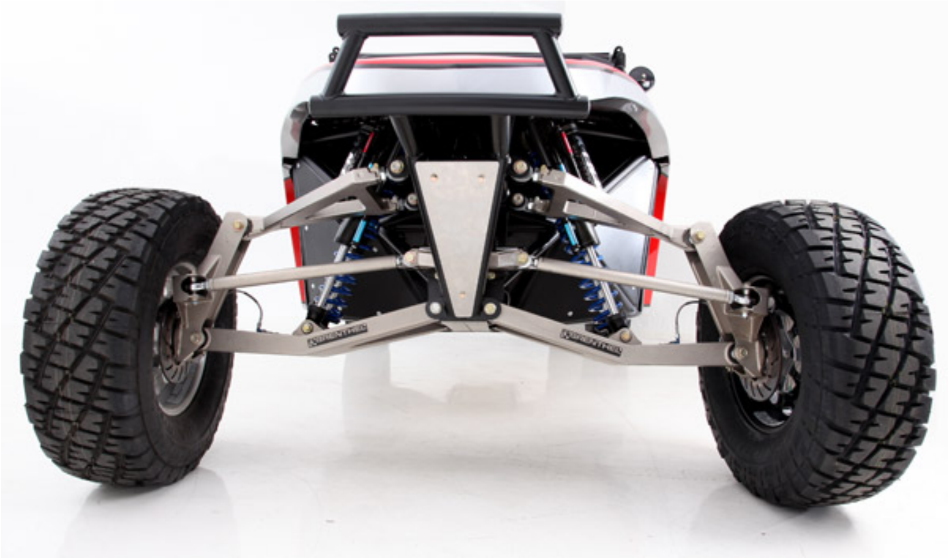
www.eurobricks.com

- Disadvantages:
  - Less ground clearance
  - Heavier design

Extended A Arms

- Advantages:
  - More travel
  - More ground clearance

- Disadvantages:
  - Heavier
  - Less impact resistance



brenthelindustries.com

Front Suspension Decision Matrix

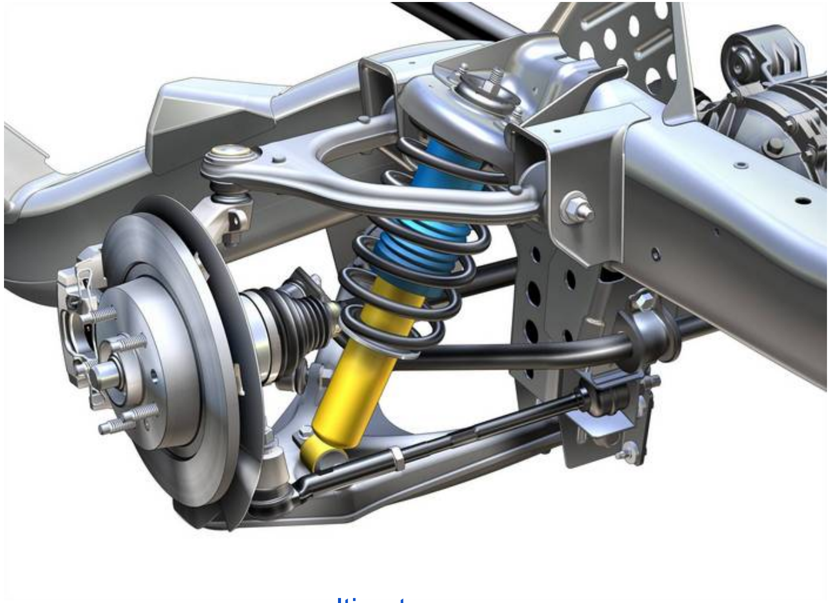
Front Suspension					
	Weight	McPherson	Double A-arms	Torsion Bars	Extended A arms
Cost	10	4	4	3	3
Weight	30	3	3	3	3
Strength	15	3	4	4	4
Ease of Machining	7.5	4	4	4	4
Ease of Design	7.5	3	5	3	3
Safety	2.5	4	4	4	4
Durability	10	3	4	4	4
Ground Clearance	10	3	3	3	4
Total Travel	7.5	3	3	3	3
Raw Total	100	30	34	31	32
Weighted		3.2	3.6	3.4	3.5

Rear Suspension Concepts

- Double A Arms
- 2 link
- 3 link

Double A Arms

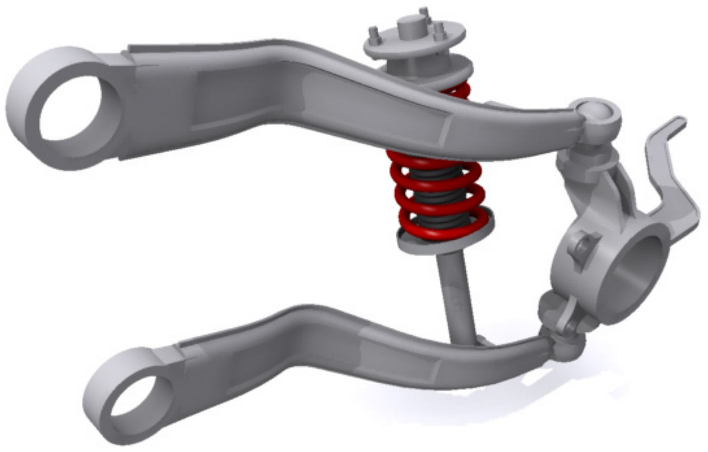
- <u>Advantages:</u>
  - Easy to analyze design
  - High strength
  - Adequate ground clearance
  - Proven design
- <u>Disadvantages:</u>
  - Difficult to machine
  - Space constraint (shock and driveshaft)



www.ultimatecarpage.com

2 Link

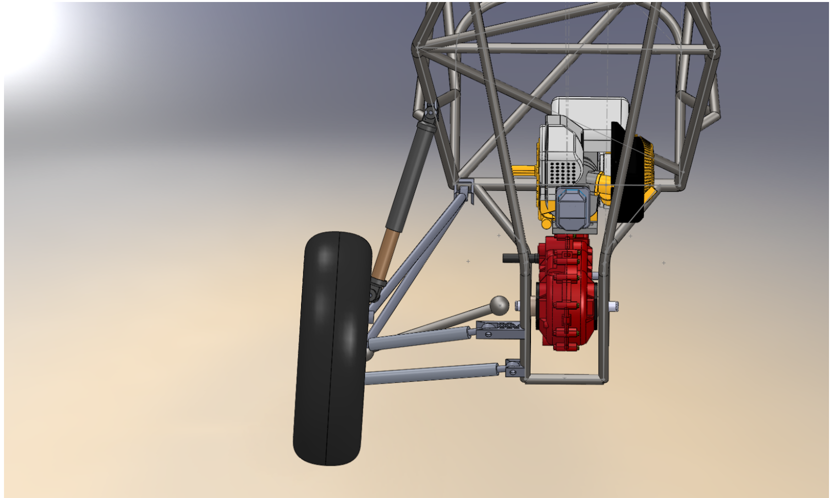
- <u>Advantages:</u>
  - Light weight
  - High strength
  - Low cost
- <u>Disadvantages:</u>
  - Difficult to design
  - Ground clearance



tortoracer.blogspot.com

3 Link

- <u>Advantages:</u>
  - High strength
  - Durable
- <u>Disadvantages:</u>
  - Difficult to analyze
  - High weight
  - High cost



ucsbracing.blogspot.com

Zane Cross

Rear Suspension Decision Matrix

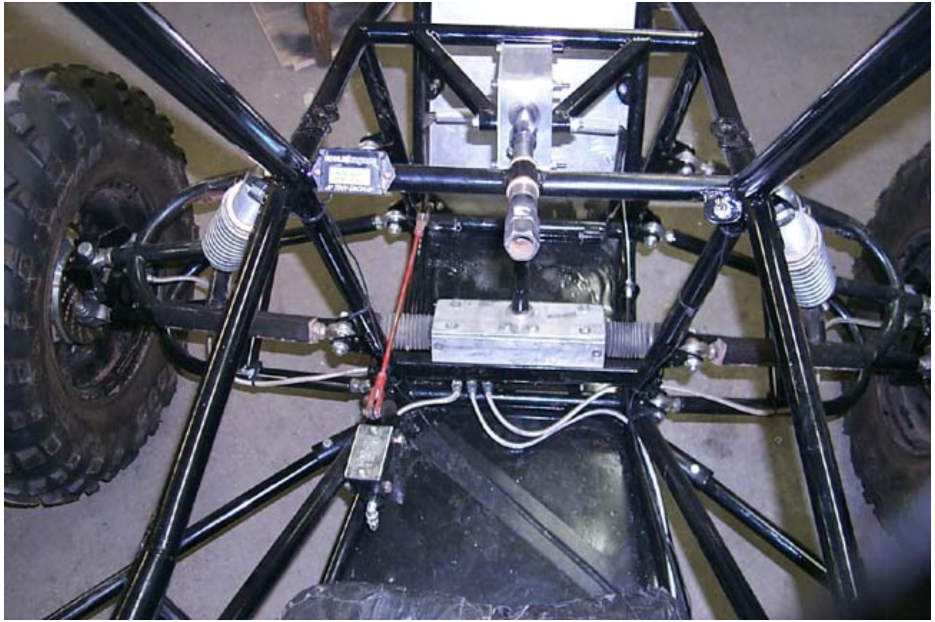
Rear Suspension				
	Weight	Double A arm	2 link	3 link
Cost	10	3	4	4
Weight	30	3	3	3
Strength	15	5	4	3
Ease of Machining	7.5	3	4	3
Ease of Design	7.5	5	3	3
Safety	2.5	5	5	5
Durability	10	5	4	4
Ground Clearance	10	5	3	3
Total Travel	7.5	4	4	4
Raw Total	100	38	34	32
Weighted		4	3.6	3.3

Trevor Hochhaus

Steering Concepts

- Back mounted
- Front mounted
- Power assist

Back Mounted



- <u>Advantages:</u>
  - Less likely to break on impact
  - More footwell room
- <u>Disadvantages:</u>
  - Less room for driver's legs
  - Possible for u-joint to bind

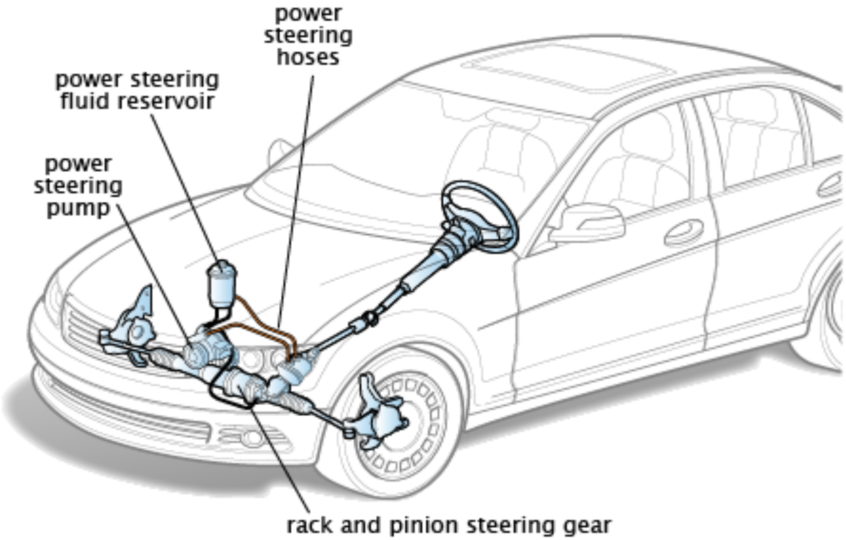
Front Mounted

- <u>Advantages:</u>
  - More room for driver's legs
  - Easier to adjust
- <u>Disadvantages:</u>
  - More weight
  - More likely to break on impact

www.cougar-racing.com

Kyle Egan

Power Assist



- <u>Advantages:</u>
  - Easier for driver
  - Adjustable
- <u>Disadvantages:</u>
  - Much heavier compared to non power assist
  - Uses much needed engine power

repairpal.com

Steering Decision Matrix

Steering				
	Weight	Back Mounted 4-1	Front Mounted 4-1	Power Steering
Cost	10	4	4	1
Weight	15	4	4	2
Strength	10	2	2	4
Ease of Machining	5	4	4	1
Ease of Design	5	5	5	1
Safety	5	4	4	4
Durability	10	5	3	4
Turning Radius	20	5	5	3
Ease of turning	15	4	4	3
Foot room	5	2	4	3
Raw Total	100	39	39	26
Weighted		4.1	4	2.7

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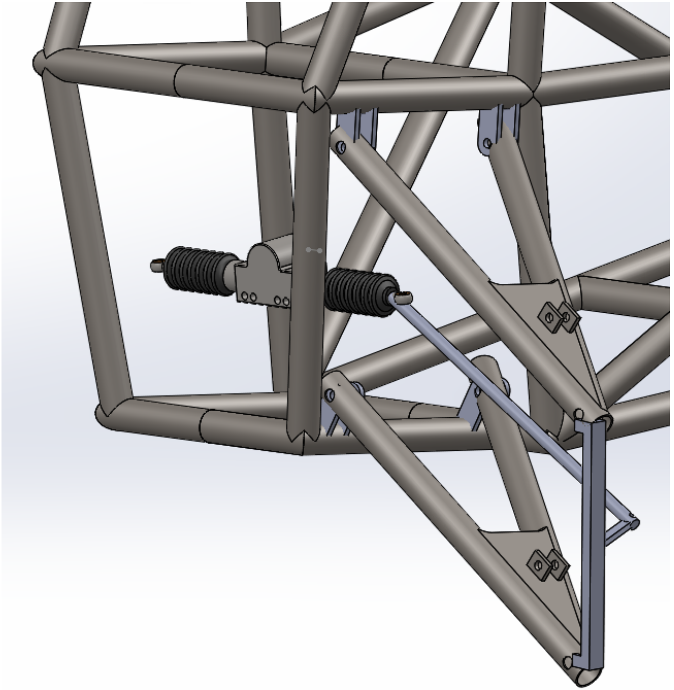
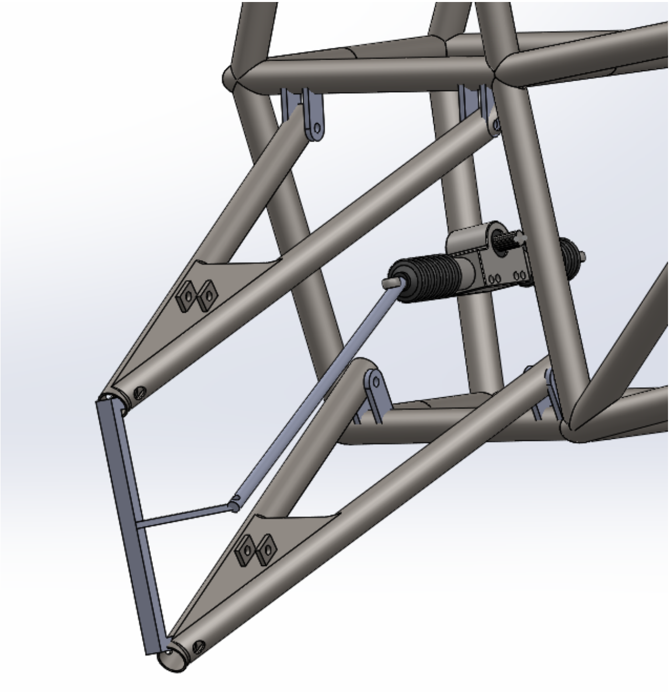
Design Selection and Analysis

Final Assembly

Front Isometric View



Back Isometric View



Suspension Analysis-Final Design

A-Shaped Members:

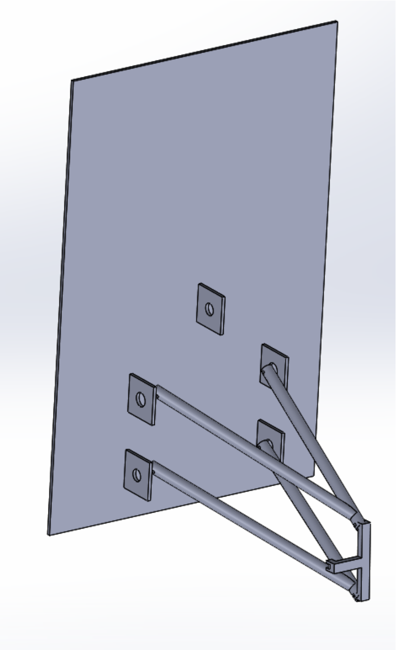
- Designed for weight reduction
- Simplistic

Pros:

- Strong against front impact
- Easy to manufacture
- Lightweight

Cons:

- Weaker in loading

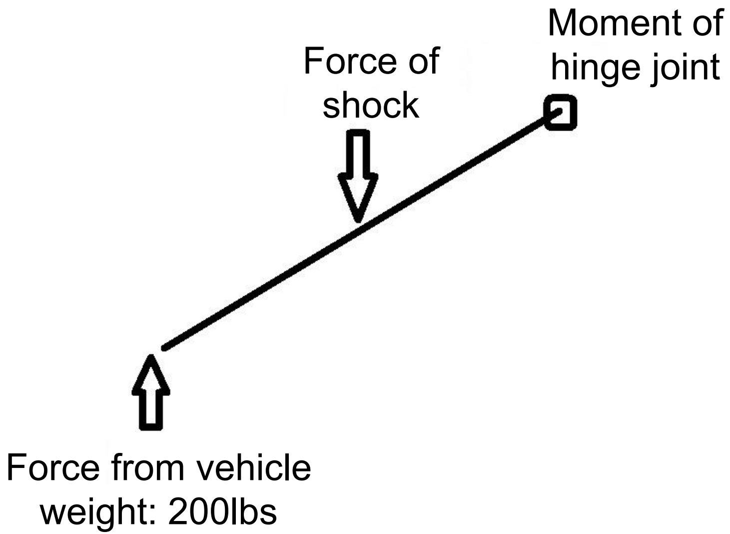


Nick Gary

Hand Calculations

Bending stress in A-arms

- Analysed half of one A-arm
- Hinge joint connecting to frame, force from vehicle weight, force of shock



Hand Calculations Cont.

Moment around hinge:

Force of shock= 325.83lbf

Sum of forces in Y direction:

Force of hinge Y dir=51.85lbf

Sum of forces in X direction:

Force of hinge X dir=124.66lbf

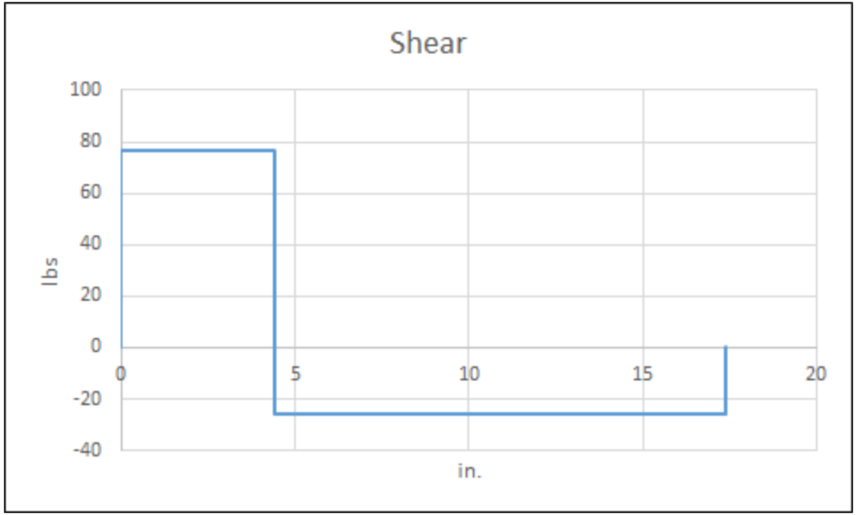
Half forces due to symmetric geometry:

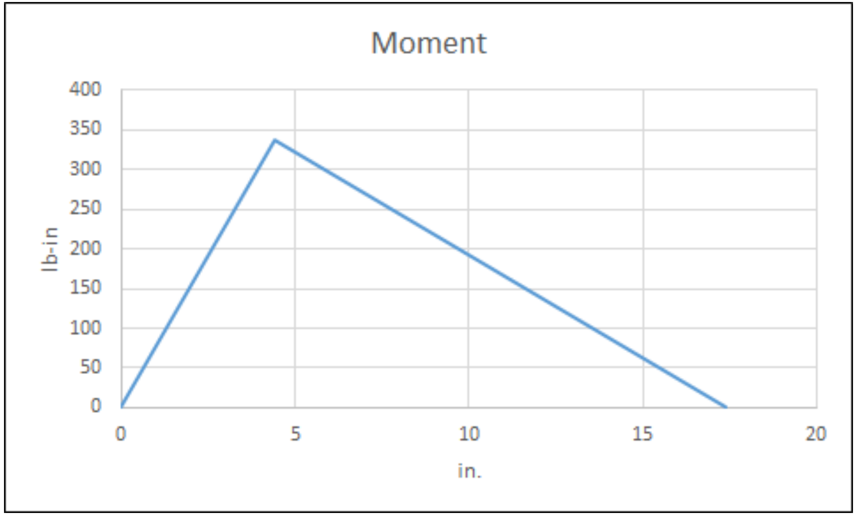
Force of shock= **162.92lbf**

Force of hinge Y dir= **25.93lbf**

Force of hinge X dir= **62.33lbf**

Hand Calculations Cont.





Max Moment = 337.04 lb-in

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Hand Calculations Cont.

$$\sigma = \frac{Mc}{I}$$

$$I = \frac{\pi}{64}(D^4 - d^4)$$

$$c = \frac{D}{2}$$

M= 337.04lb-in

σ = 36ksi for Structural A36

d=0.8D

Output:

D=**.78in**, t=**.156in**

FOS of 2:

D=**.98in**, t=**.20in**

Shock Placement

- After performing dynamic analysis on the suspension design, the forces experienced by the members can be greatly mitigated by mounting the shock as close as possible to the wheel hub.
- There are physical limitations on how close to the hub the shocks can get, such as: extended length of the shocks, desired ride height, and potential interference.

Stress Analysis

- Axial loading of the members is going to be ignored, because stresses caused by bending will far exceed them.
- The member the shock mounts to will experience the largest force in the system, so it will fail first.
- The bolts for the members will also be a mode of failure when the suspension receives a front or side impact. The shear stress on the bolts will be calculated using the axial loading on the members.

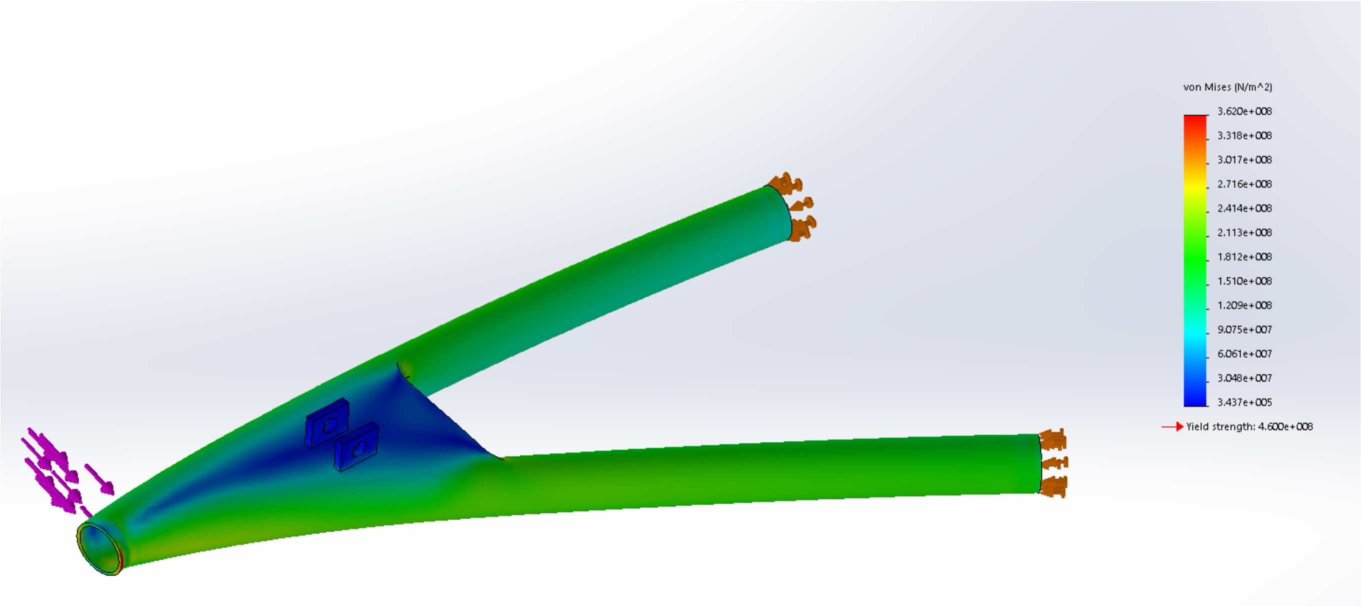
Nick Gary

Stress Analysis- Front Impact

<u>Situation:</u>

- 25 mph impact on one tire
- Simulates the car suddenly hitting an object, like a tree or rock, and coming to a full stop
- The chosen material is 4130 steel with a OD of 1.25in and an ID of 1.15in
- The load was applied to the end of one A arm, with the a arm fixed to where it would mount to the chassis

(cont.)



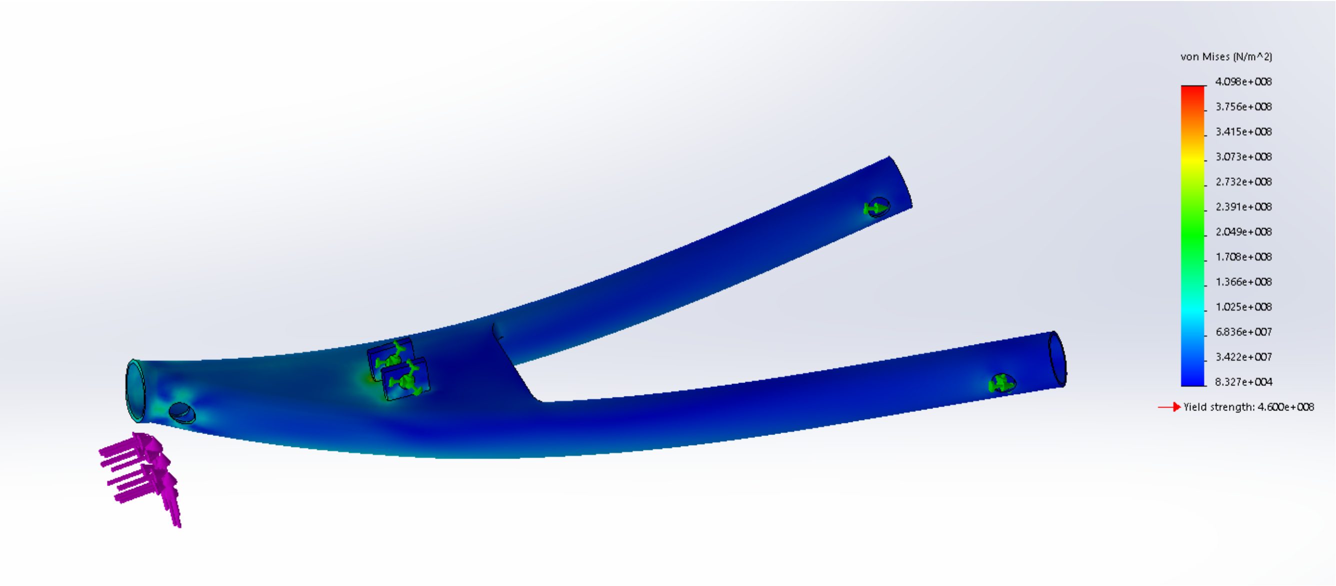
- The lowest factor of safety for this loading 2.1
- The force applied in this loading is an extreme case

Stress Analysis-Vertical Loading

Situation:

- The car jumps off a surface from 3 ft and lands crooked on only one wheel
- Same material and dimensions as the previous design scenario
- The load is applied vertically to the end of the A arm as well as axially
- The A arm is pinned at the shock mount and the chassis mount

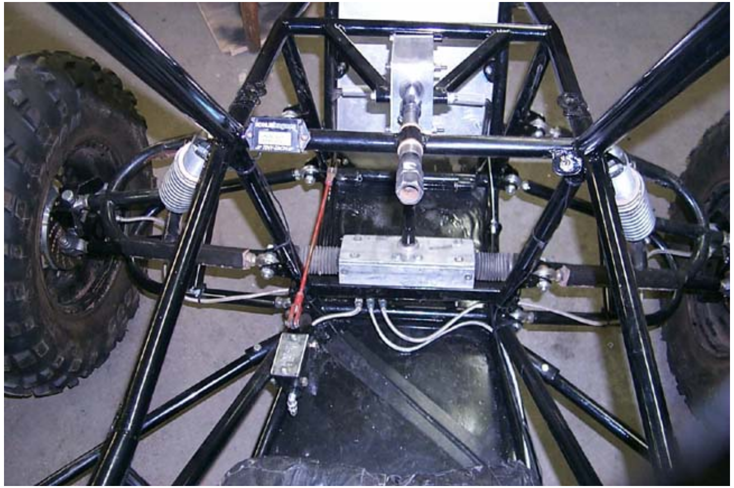
(cont.)



- The minimum factor of safety for this situation is 3.2
- This loading is an extreme case due to the suspension bottoming out before it reaches stress levels this high

Steering Design Selection

- **Back Mounted Steering**
  - Minor modification to existing hub
  - Front of frame constraints
  - Room for tie rod mounting to hub (Brake Caliper)



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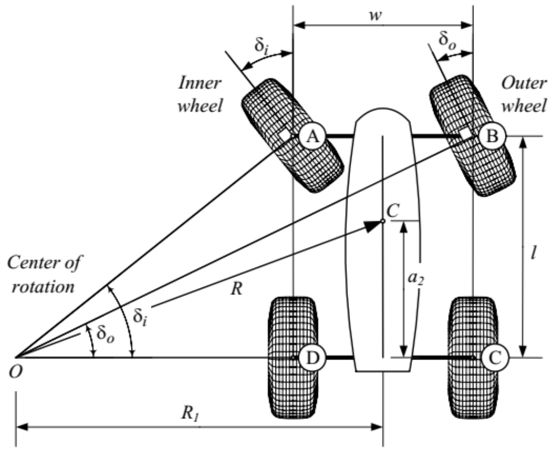
Steering Analysis - Akerman Angles

- Ackerman Steering Angles
  - Inside wheel turns at greater angle than outside wheel
  - Determine max angle of both tires such that a U-turn can be achieved within a width of 2 lanes (144 in)



Inside Tire Maximum Angle

$$\tan(\delta_i) = \frac{L}{R_1 - \frac{W}{2}}$$

Outside Tire Maximum Angle

$$\tan(\delta_o) = \frac{L}{R_1 - \frac{W}{2}}$$

Zane Cross

Ackerman Angles Calculations

- Track Width = **W** = 49 in
- Wheelbase = **L** = 65 in
- Mid-Radius = **R(1)** = 155.5 in

After inputting variables into formula and solving……

<u>Max Turning Angles</u>

- Inside Tire = **35.54 Degrees**
- Outside Tire = **24.90 Degrees**

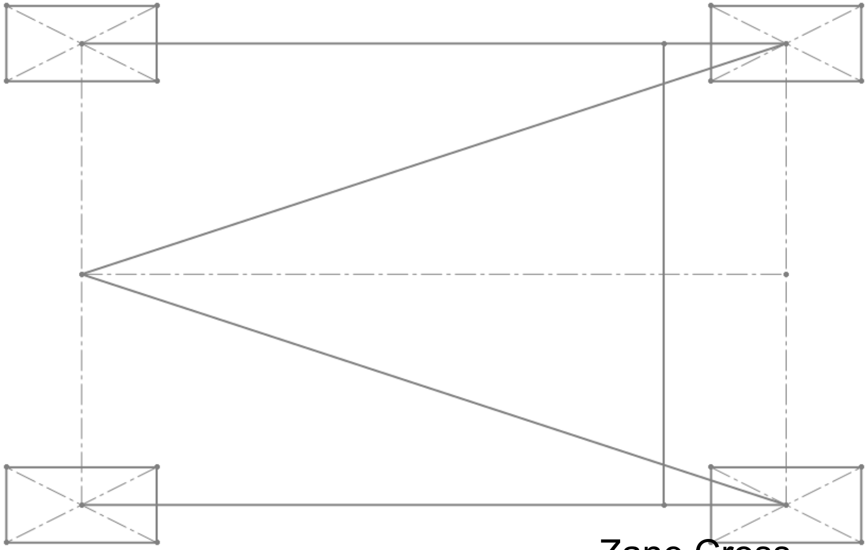
<u>Turning Radius</u>

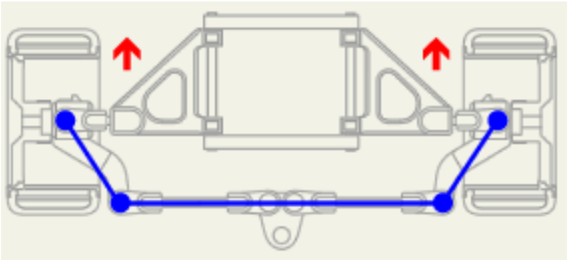
- **9.63 ft**

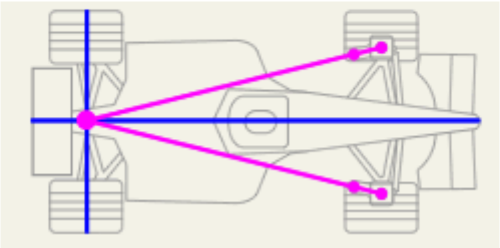
Zane Cross

Steering Analysis - Tie Rod Mount

- Determine where the tie rods are mounted to the hub of the vehicle to achieve an Akerman Angle with zero toe on turn in







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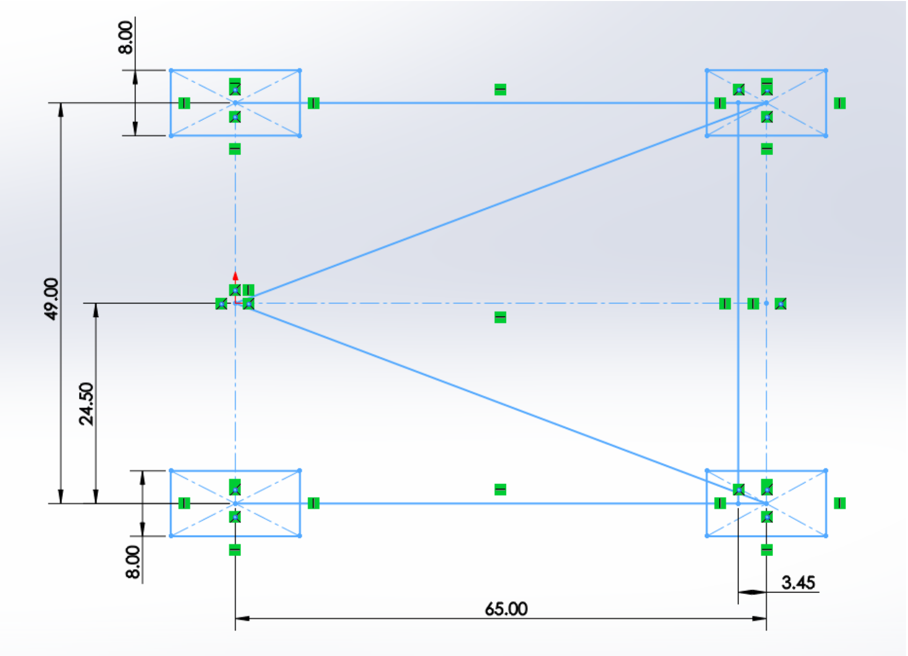
Tie Rod Mount Calculations

- Through the use of similar triangles…..

$$\frac{24.5}{65} = \frac{y}{3.45}$$

$$y = 1.43\ in$$



Steering Analysis - Steering Ratios

- Determine the ratio of the rack to pinion to give the right amount of assist in the steering system
- 1:2 Steering Quickener currently installed
- Remove steering quickener to regain 12:1 steering ratio of original steering rack

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Steering Analysis - Tie Rod Force

- Determine axial force tie rod encounters when hitting an obstacle and coming to a complete stop

$$F_{Rock} = M_V * A$$

Situation

- Velocity of Vehicle is 20 mph
- After hitting obstacle, vehicle comes to a complete stop in 0.5 sec

$$M_{Kingpin} = F_{Rock} * d_1$$

Solution

- $F_{Tie\ Rod}$ = **1,269.86 lbf**

$$F_{Tie\ Rod} = \frac{M_{Kingpin}}{d_2}$$

Steering Analysis - Tie Rod Buckling

$$F_{Tie\ Rod} = \frac{\pi^2 EI}{(KL)^2}$$

$$I_x = \frac{\pi}{64} D^4$$

- $F_{Tie\ Rod}$ = 1,269.86 lbf
- E = $(29.0 * 10^6)$ psi (A36 Steel)
- K = 1.0 (Pinned Support at both ends)
- L = 15 in

After solving for I, then solving for diameter…..

<u>Tie Rod Dimension</u>

- Safety Factor of 2
- **D = .4491 in**

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Hollow vs. Solid Tie Rod

- **Hollow**
  - Outer Diameter = .534 in
  - Wall Thickness = .159 in
  - Weight = .4845 lb
- **Solid**
  - Outer Diameter = .500 in
  - Weight = .8364 lb
- **Weight Decrease**
  - Old Tie Rod = 2 lb
  - New Tie Rod = .8364 lb
  - **58 percent decrease in weight**

Bolt Shear Analysis

- Double Shear Situation
- Assume Grade 8 Bolts
- Max Shear Force on Bolt = 5,000 lbf
- After comparing different size bolts……

- **Bolt Size Diameter = 5/16 in**
- **Bolt Dimensions = ¼ - 20**
- **Safety Factor = 3.68**

$$\tau = \frac{F}{2A}$$

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Bill of Materials

Description	Manufacture	Qty.	Price Each	Total Cost	Free/Donated
Tubing 1.25"		168"	n/a	$100.00	x
Shocks	Fox Podium X	4	$270.00	$1,080.00	x
5/16-16 Bolt		50/pack	n/a	$61.00	x
5/16-16 Nut		50/pack	n/a	$20.00	x
Female Hyme Joint		2	$27.40	$54.80	
Male Hyme Joint	Mc-Master-Carr	16	$27.40	$438.40	
Uniball		8	$15.00	$120.00	
Plate Stock 1x2'		1	$30.72	$30.72	x
Tie Rod Material 3'		1	$10.41	$10.41	x
Steering Rack	Desert Kart	1	$98.00	$98.00	x
Steering Wheel		1	$49.99	$49.99	x
Front Wheel Hub	Polaris	2	$128.00	$256.00	x
Rear Wheel Hub	Polaris	2	$32.50	$65.00	x
Front Brakes	Polaris	2	$25.50	$51.00	x
Rear Brakes	Polaris	2	$25.50	$51.00	x
Wheels/Tires		5	$100.00	$500.00	
			Total	**$2,986.32**	**$1,113.20**

Conclusion

- Problem Definition and Project Plan
- Concept Generation
- Design Selection and Analysis
- Bill of Materials

References

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