SAE Baja: Project Proposal Suspension and Steering

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Overview

- Introduction
- Concept Generation & Selection
- Engineering Analysis
  - Structural: Tie Rod, Front A-Arms, Rear Trailing Arms
- Cost Analysis
- Conclusion

Project Introduction

- 2014 SAE Baja Competition
- Customer is SAE International
- Stakeholder is NAU SAE
- Project advisor is Dr. John Tester

Need Statement

- NAU has not won an event at the SAE Baja Competition in many years
- Goal of the suspension team is to design the most durable, and versatile front and rear suspension systems
- Goal of the steering team is to design an efficient steering mechanism that will meet the needs of off-road racing

Design Objectives

- Minimize cost
- Maximize suspension member strength
- Minimize suspension member weight
- Minimize turning radius

Constraints

- AISI 1018 tubing or equivalent strength
- Funding
- Must Follow SAE International Collegiate Design Series, Baja SAE Series Rules

QFD Matrix: Steering

Customer Needs	Customer Weights	Y.S.	Caster Angle	Ackerman Angle	Turning Radius	Cost	Bolt Shear Stress	Width
1. Lightweight	10					3	1	
2. Maneuverability	10		9	9	9			9
3. Relatively inexpensive	6	9				9	3	
4. Stable/safe	9		9	9	3			9
5. Must be durable	8	9				9	3	
6. Transportable	8				3			3
	Raw score	126	171	171	141	156	52	195
	Relative Weight	12%	17%	17%	14%	15%	5%	19%
	Unit of Measure	psi	degrees	degrees	ft	$	psi	lb

Victor 6

QFD Matrix: Suspension

Customer Needs	Customer Weights	Ground Clearance	Suspension Travel	Y.S.	Stiffness	Spring Rate	Cost	Weight
1. Lightweight	10					3	3	9
2. Maneuverability	10	9	9		3	9	3	9
3.Relatively inexpensive	6		1				9	
4. Must be safe	7	3	1	9	3		1	
5. Must be durable	8			9	9		3	
6. Transportable	8	3	3					3
	Raw Score	135	127	135	123	120	145	204
	Relative Weight	14%	13%	14%	12%	12%	15%	21%
	Unit of Measure	in	in	in	lb	lb/in	$	ft

Operating Environment

- Cinders OHV Area
- El Paso Gas Pipeline Service Road
- NAU Building 98C
- NAU Parking Lot 64

Figure1: Operating Environment Example
Image Credit: Stu Olsen's Jeep Site

Concept Generation & Selection

- Steering
  - Rack and Pinion
  - Pitman Arms
- Suspension
  - Double A-Arms
  - Twin I-Beam
  - Semi-Trailing Arm
  - Solid axle
- Tubing Selection

Steering Design 1

- Pitman Arm Steering Assembly
- Advantages
  - Easily repaired
  - Robust
  - Strictly Mechanical Components
- Disadvantage
  - “Dead Spot”
    - Response time

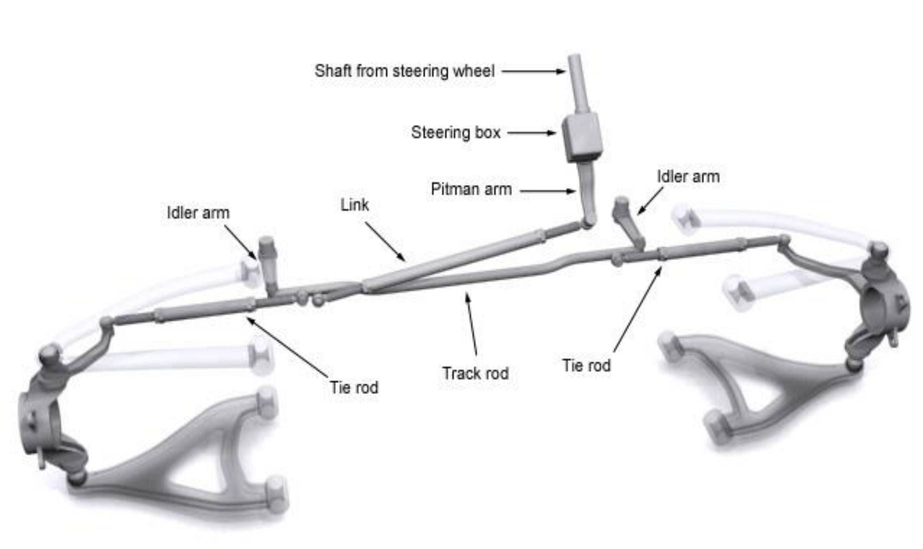

Figure 2: Pitman Arm
Source: Car Bibles

Steering Design 2

- Rack and Pinion
- Advantages
  - Smooth gear Meshing
  - Simple mechanical design
- Disadvantage
  - Not as durable than pitman arm style

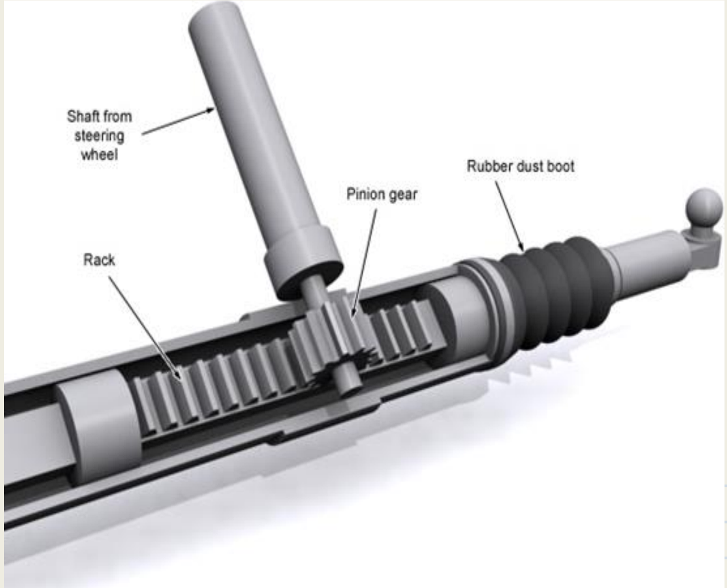

Figure 3: Rack/Pinion
Source: Car Bibles

Suspension Design 1 (Front & Rear)

- Independent Suspension
- Advantages
  - Lightest weight
  - Good range of travel
- Disadvantages
  - Not as strong as other considered designs

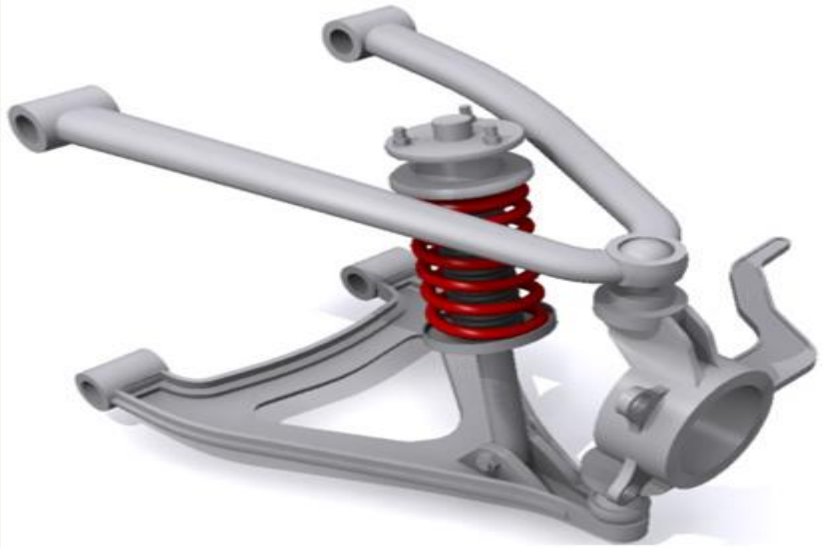

Figure 4: A Arm
Source: CarBibles

Suspension Design 2 (Front)

- Equal I Beams
- Advantages
    - Allows for maximum travel
    - Best articulation
- Disadvantage
    - Susceptible to bumpsteer
    - Radical camber & caster change

Figure 5: I-Beams
Source: HM Racing Design

Suspension Design 3 (Rear)

- Trailing Arm
- Advantages
  - Lots of travel
  - Truly independent
  - Strong
  - Simple
- Disadvantages
  - Camber is static
  - Handling suffers at limit

Figure 6: Trailing Arm
Source: SAEBaja.net

Suspension Design 4 (Rear)

- Live Axle/Solid Rear Axle
- Advantages
  - Tough
  - Simple design
  - Good articulation
  - Reliable
- Disadvantage
  - Large unsprung weight
  - Wheels are not independent

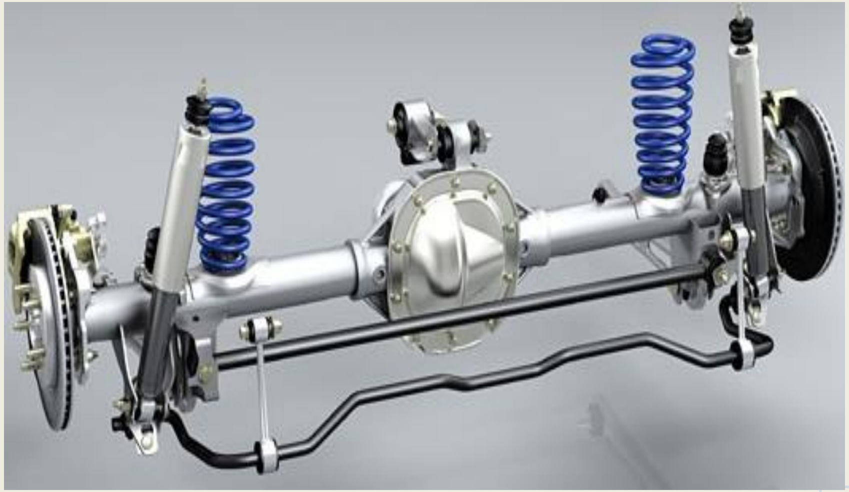

Figure 7: Solid Axle
Source: Motor Trend

Suspension Decision Matrix (Front)

Table 3: Front Suspension Decision Matrix

Requirements	A Arm	Equal I Beam
Simplicity (0.20)	4	4
Reliability (0.30)	4	4
Weight (0.30)	3	2
Cost (0.20)	4	3
Totals	3.7	3.2

Suspension Decision Matrix (Rear)

Table 4: Rear Suspension Decision Matrix

Requirements	A Arm	Solid Axle	Trailing Arms
Simplicity (0.20)	3	4	4
Reliability (0.30)	3	5	3
Weight (0.30)	4	1	4
Cost (0.20)	4	2	4
Totals	3.5	3.3	3.7

Decision Matrix Steering

Table 5: Steering Decision Matrix

Requirements	Rack & Pinion	Pitman Arm
Simplicity (0.20)	5	4
Reliability (0.30)	4	5
Weight (0.30)	4	3
Cost (0.20)	4	3
Totals	4.2	3.8

Tubing Selection

- SAE Specification:
  - AISI 1018 Steel
  - 1” Diameter
  - 0.120” Wall Thickness
- Other Sizes Allowed
  - Equivalent Bending Strength
  - Equivalent Bending Stiffness
  - 0.062” Minimum Wall Thickness

AISI 4130 Steel

- Equivalent Strength With Smaller Diameter Than AISI 1018 Steel
- Heavily Used In The SAE Mini Baja Competition And Other Racing Applications
- Welding of AISI 4130 Steel Can Be Performed By All Commercial Methods
- Motivated by choice of frame team to use the same material

Front Geometry

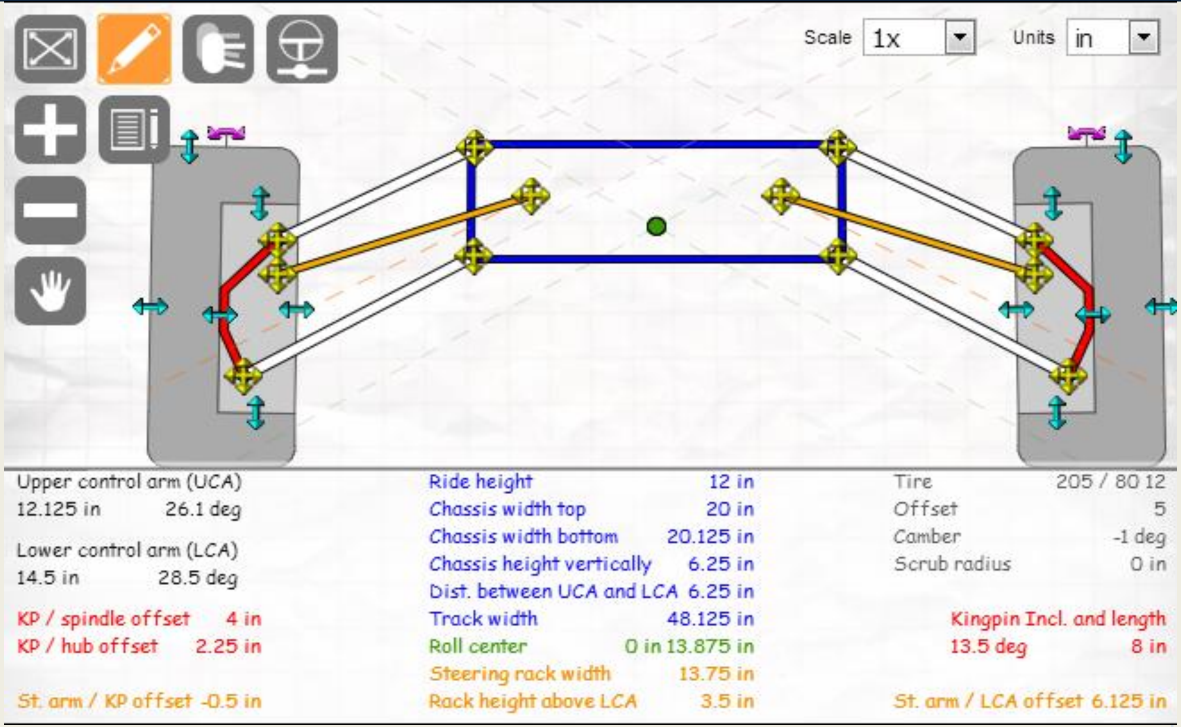

Figure 8: Front Suspension Geometry

Full Compression

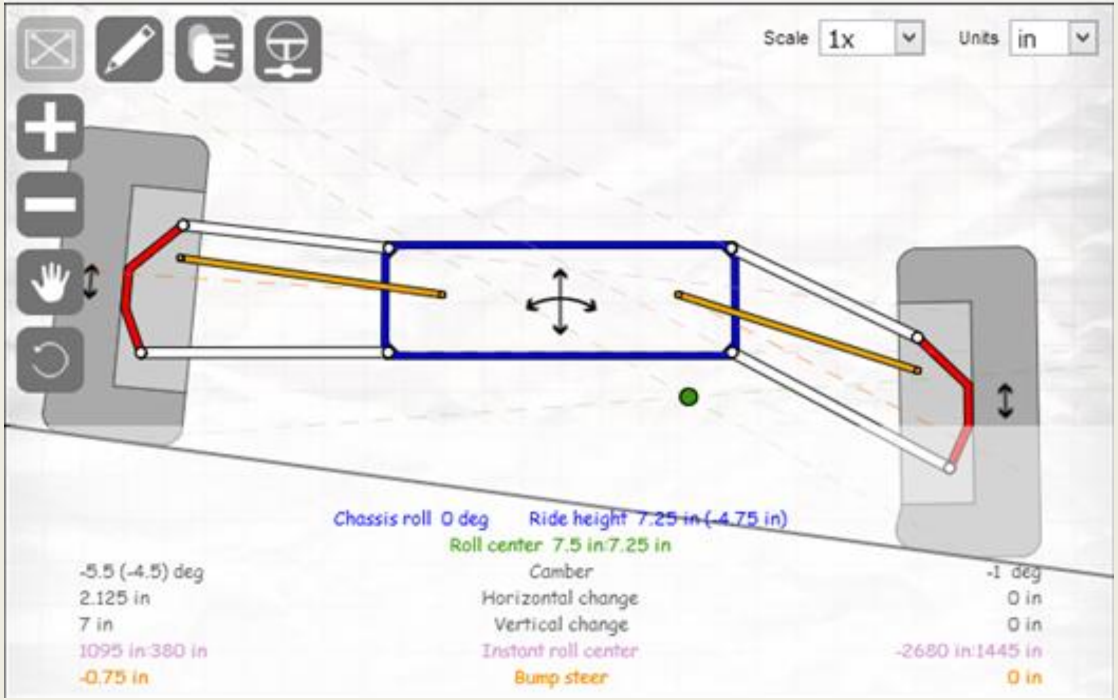

Figure 9: Full Compression

Full Droop

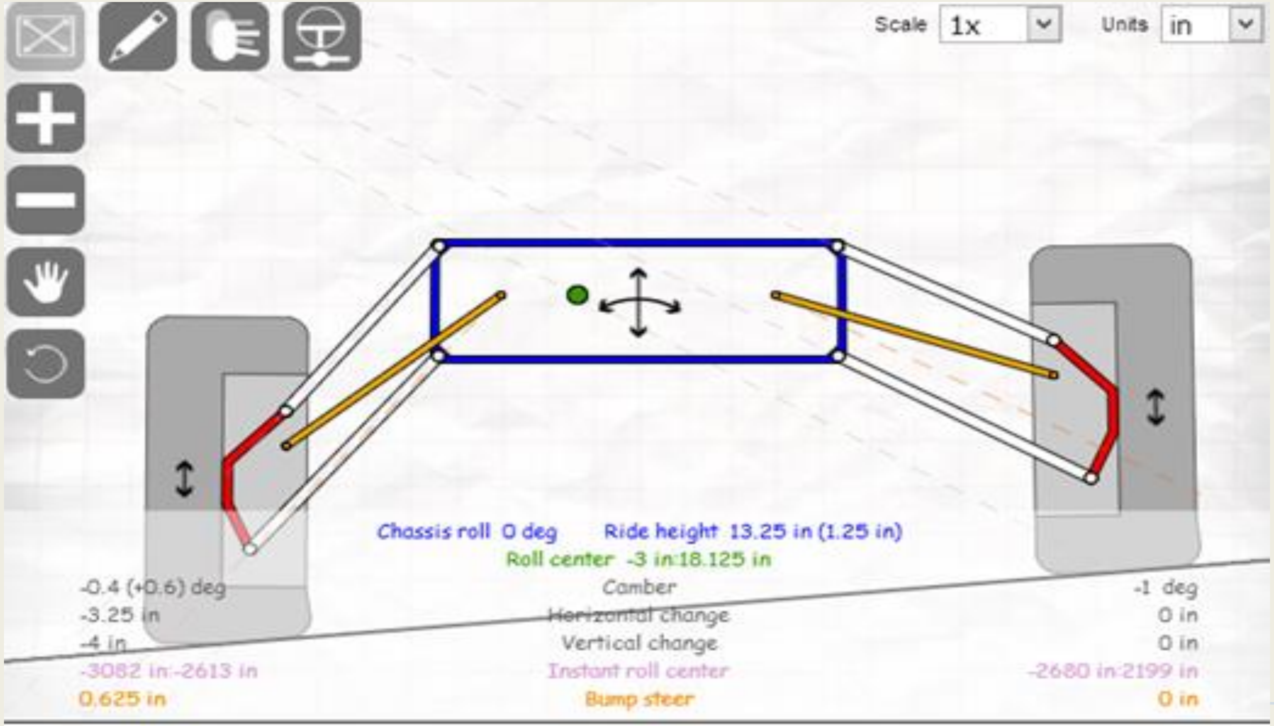

Figure 10: Full Droop Analysis

Front Suspension Geometry

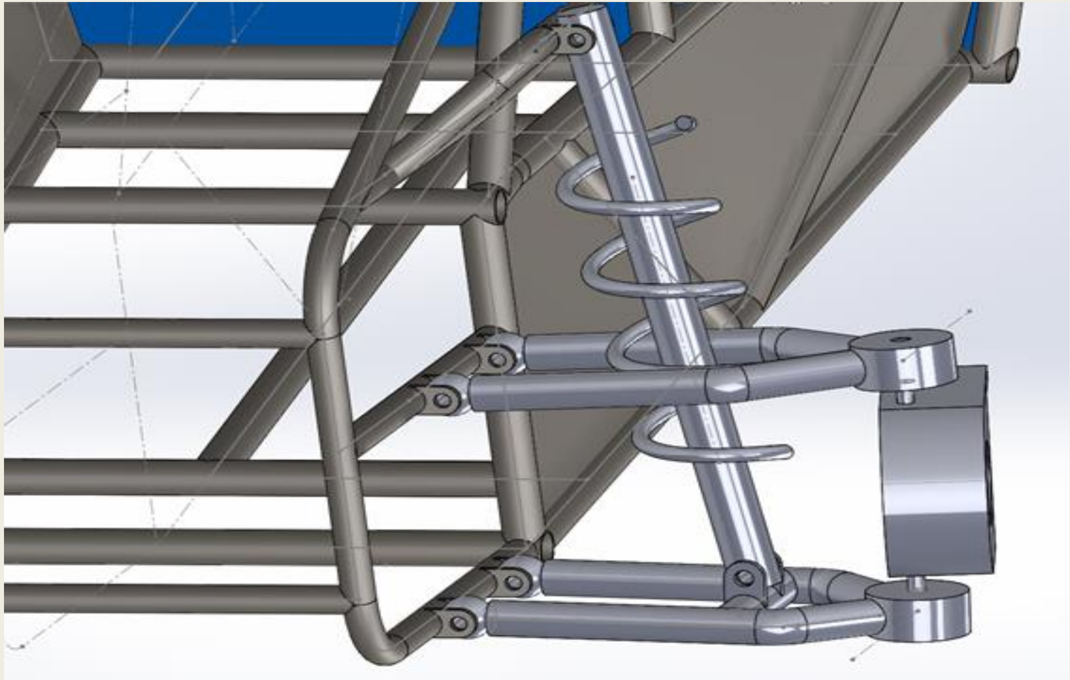

Figure 11: Front Suspension Geometry (Front-view)

Front Suspension Geometry

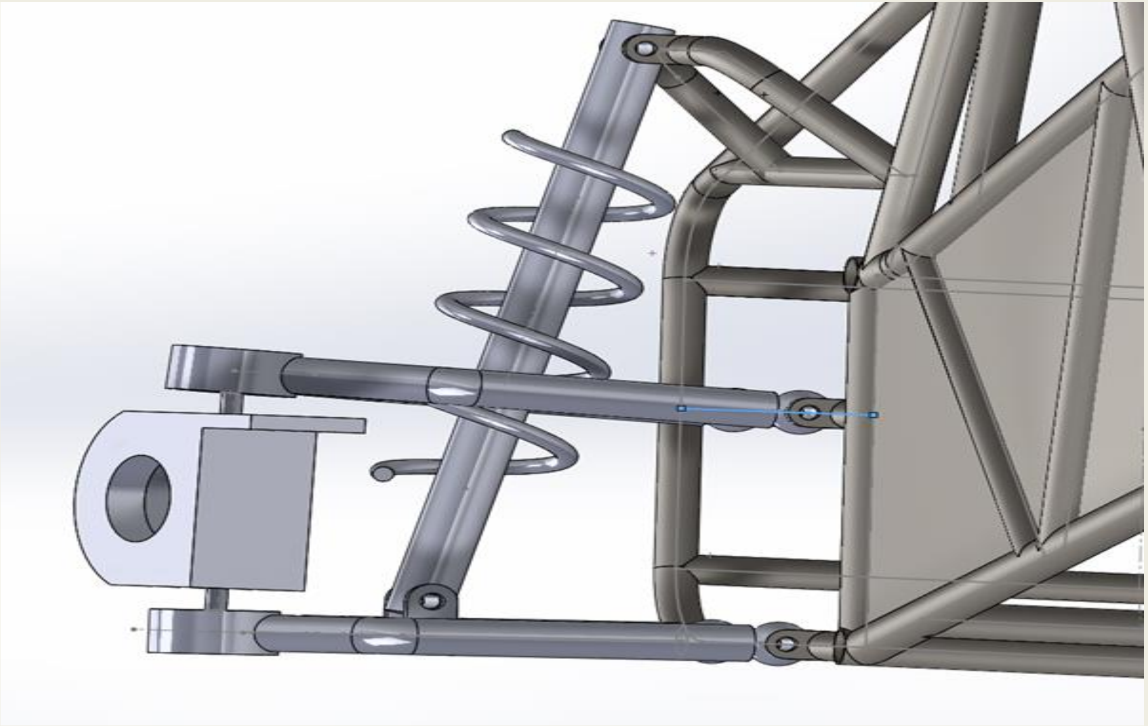

Figure 12: Front Suspension Geometry (Back-view)

Front Suspension Geometry

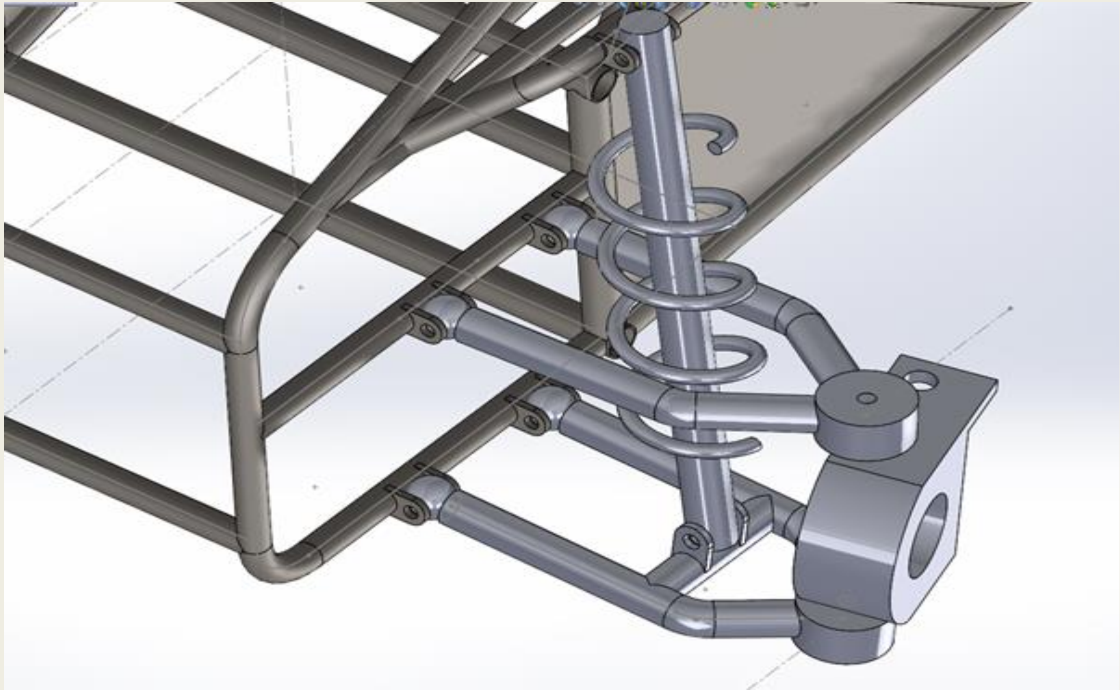

Figure 13: Front Suspension Geometry (Iso-view)

Expected Drop Forces

Drop Test Assumptions:

- Fi = Force of impact
- Fs=500 lb Weight
- h= 6 ft Drop Height
- K= 160 lbin Spring rate constant (using shocks from Polaris RZR 570)
- Force assuming worst case landing on one wheel

- $Fi = Fs + ((Fs)^2 + 2 \times K \times 12 \times Fs \times h)^{1/2}$ (Source SAE Brasil)
- Fi=1022.53 lb

Upper Arm from bottom

- Upper arm
- loaded at 700 lbf from bottom
- FS=1.05

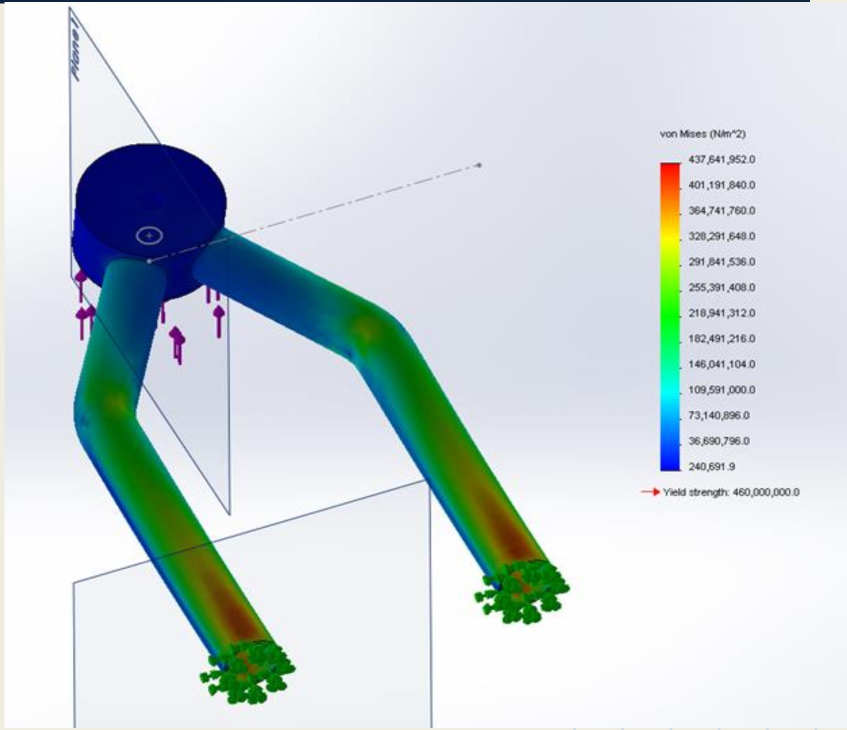

Figure 13: FEA of Upper A Arm (Bottom)

Lower Arm from bottom

- Lower arm
- loaded at 700 lbf from bottom
- FS =1.07

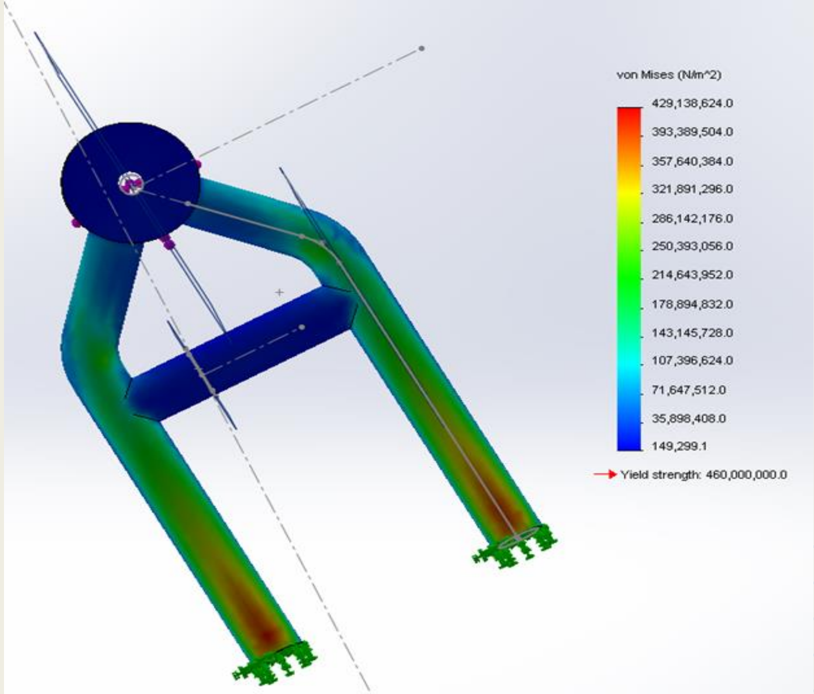

Figure 14: FEA of Lower A Arm (Bottom)

Expected Impact Forces

Max speed is ~ 35MPH=51.33Ft/s

M=500lb/32.2=15.53slug

T=.2s

$F_{impact}=M(V/T_{impact})$

$F_{impact}=15.53(51.33/.2)=3985.77lbf$

Upper Arm from front

- Upper arm
- loaded At 1000 lbf front front
- FS=1.56

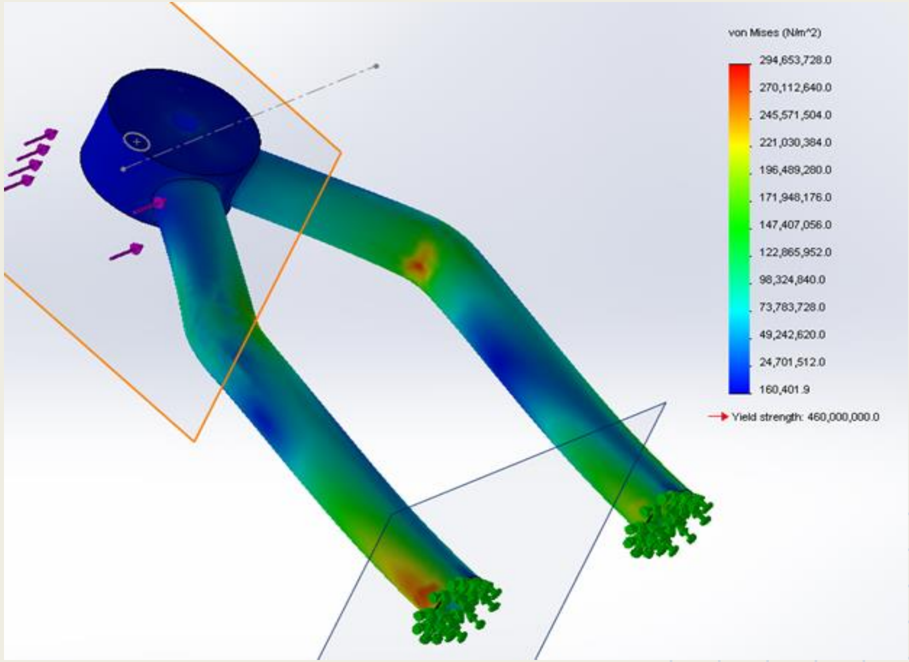

Figure 15: FEA of Upper A Arm (front)

Lower Arm from Front

- Lower arm
- Loaded at 1000 lbf from front
- FS=1.82

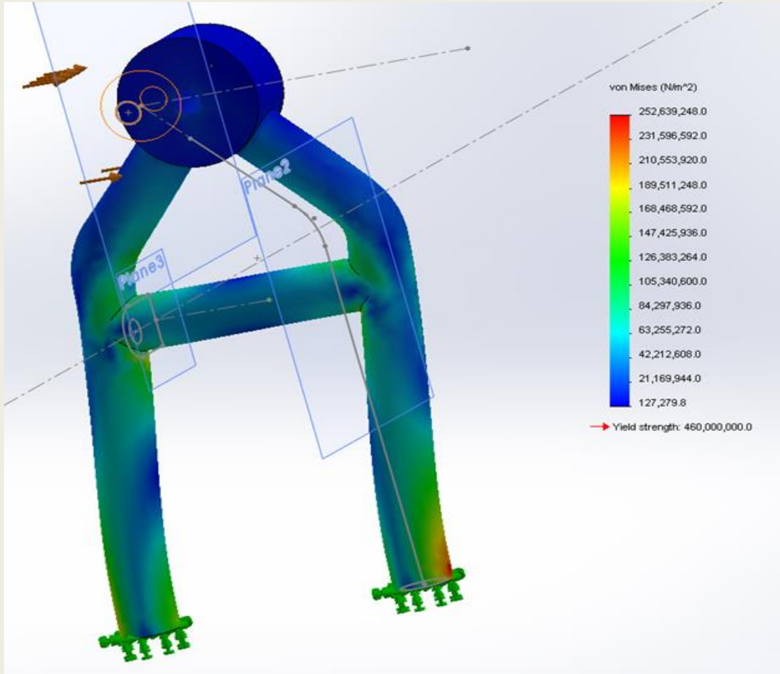

Figure 16: FEA of Lower A Arm (Front)

Analysis: Tie Rod

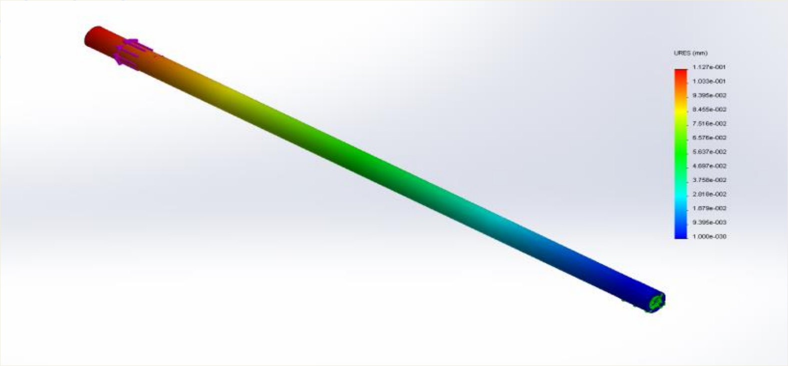

Figure 17: FEA of Tie Rod

Figure 18: CAD Tie Rod

- AISI 4130 (Chromoly)
- Diameter = 0.7”
- Maximum Axial Deformation @ 3000 lbf = 0.13mm

Rack and Pinion Geometry

- Rack and Pinion with Casing and steering shaft

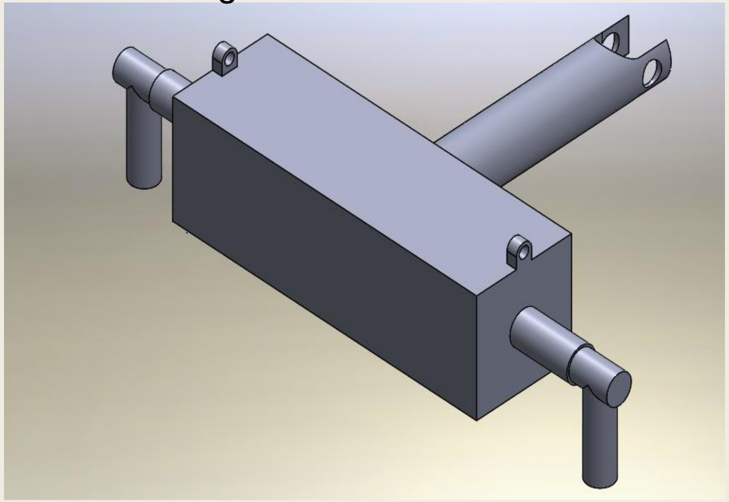

Figure 19: Rack and Pinion (Enclosed)

- Bare Rack and Pinion

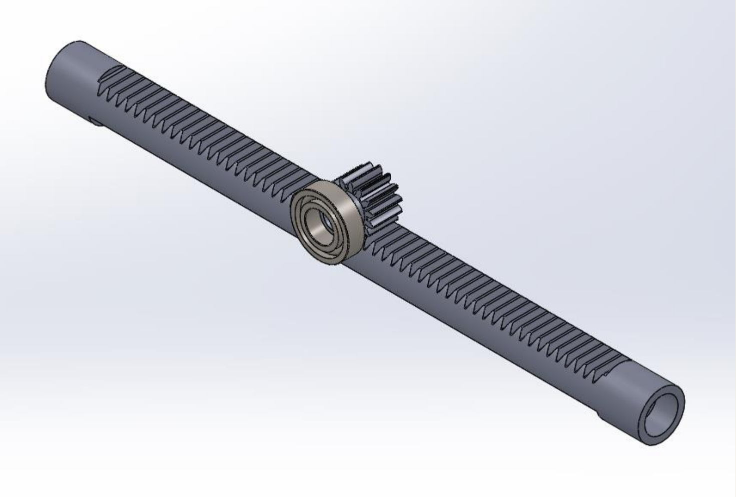

Figure 20: Rack and Pinion (Inside)

Rack and Pinion Geometry

- Rack and Pinion
  - Designed but most likely buy
  - Assumptions: No crown, Hardened, Not operating at high temp’s, Range for force applied
  - Force by Driver: 0.1-10 lbf
  - Rack teeth => pinion turns 360 degrees max, both sides
    - if circumference of pinion=4.64in, rack ~ 9in

Rack and Pinion Geometry

Table 6: Dimensions of Pinion and Rack

	Teeth Number	Face Width (in.)	Bending Stress (kpsi)	Radii for Pitch Circle (in)	Radii for Base Circle (in)	Adden. (in.)	Dedden (in)
pinion	20	0.74	0.04 - 3.9	0.787	.739	0.078	0.098
rack	40	0.74	-	inf	inf	0.078	0.098

Rack and Pinion Geometry

- Rack: approx. 9 inches

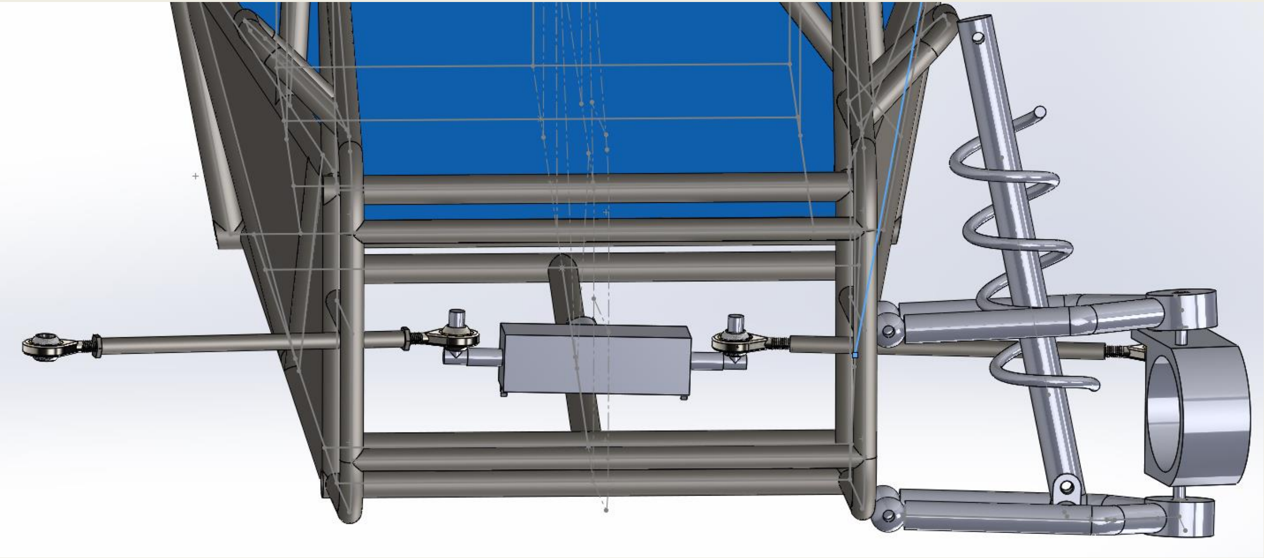

Figure 21: CAD Front Assembly

Cost of Front Suspension

- Fox Podium X Shocks
- Wheel hubs
- Bearing Carrier
- Heim joints
- Uniball Joints
- Brake Caliper and master cylinder
- 10 Ft of 1.25” .065” thick 4130 steel tubing

Table 7: Front Suspension Cost

	Full Retail	Sponsorship Rate
Prices:	$2529.33	$1440.33

Cost of Rear Suspension

- Fox Podium X shocks
- Bearing Carrier
- Wheel hub
- Heim Joints
- 1.5” diameter
- .0625” thick 4130 Steel tubing

Table 8: Rear Suspension Cost

	Full Retail	Sponsorship Rate
Prices:	$1868.14	$1067.67

Cost Steering

- Rack and Pinion
- Tie Rods
- Heim Joints

Table 9: Steering Cost

	Full Retail	Sponsorship Rate
Prices:	$649.20	$324.60

Total Cost Analysis

- We estimate that the total cost of the suspension, brakes, and steering to be
  - $2832.60 at sponsorship rates
  - $5046.67 at full retail

Rear Suspension Geometry

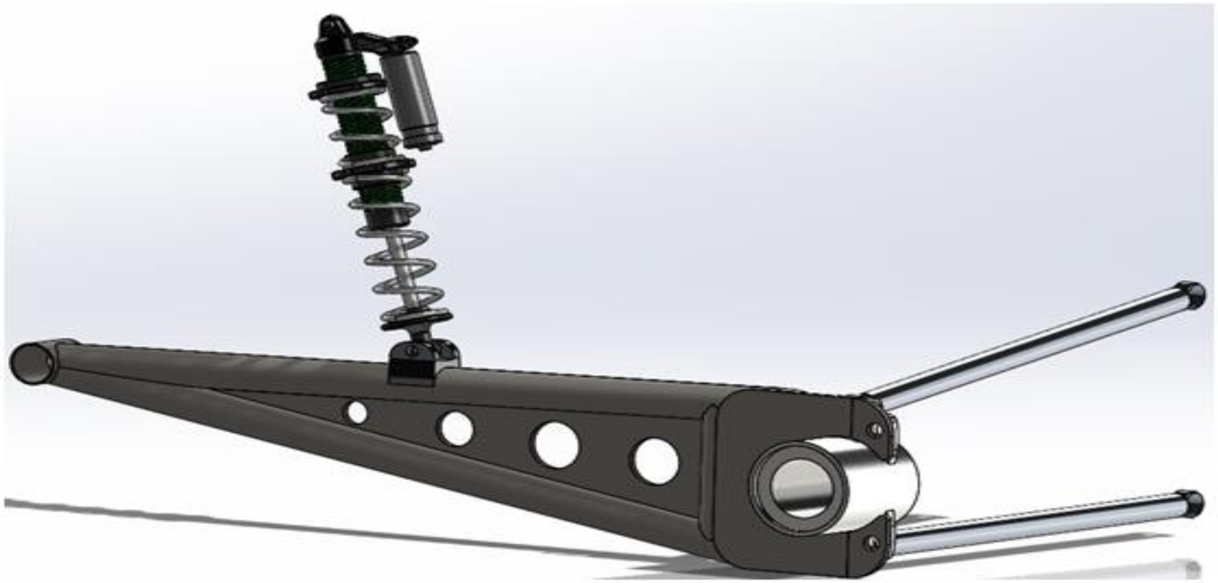

Figure 22: Rear Suspension Geometry

Rear Suspension Geometry

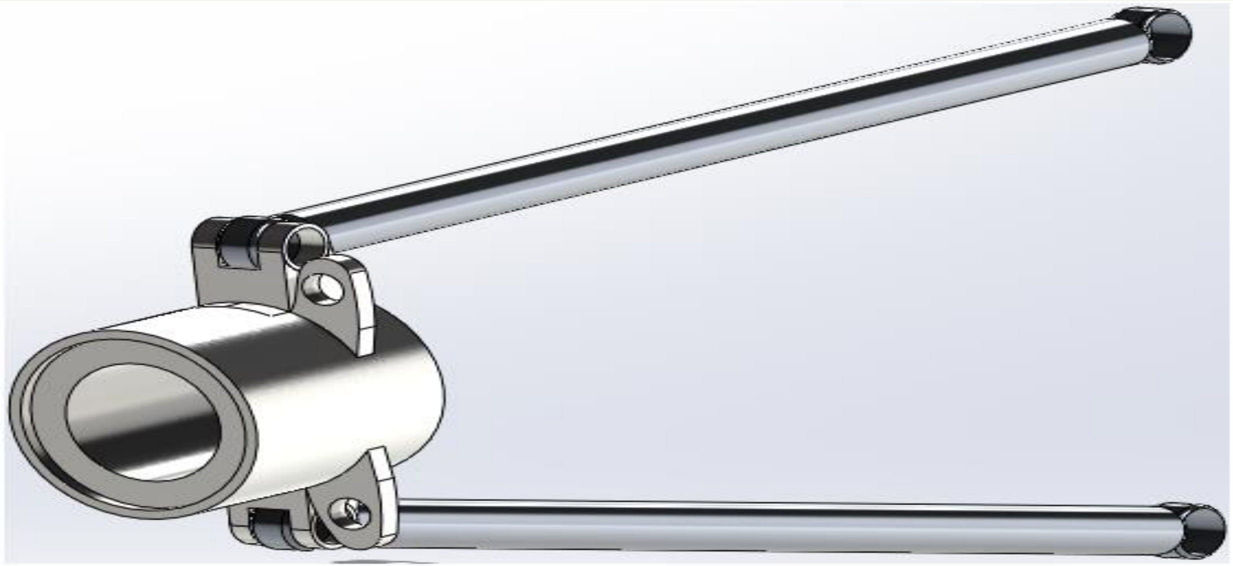

Figure 23: Rear Suspension Geometry

Final Rear Suspension

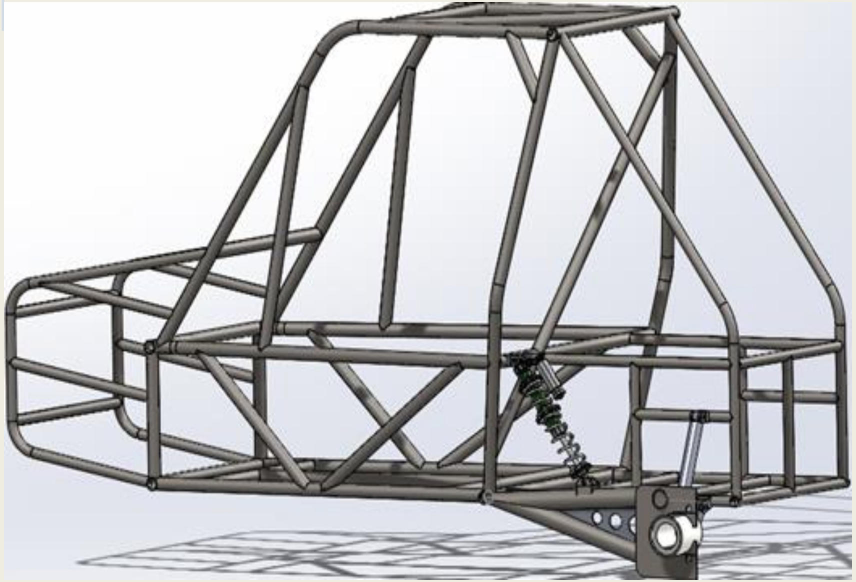

Figure 24: Rear Suspension

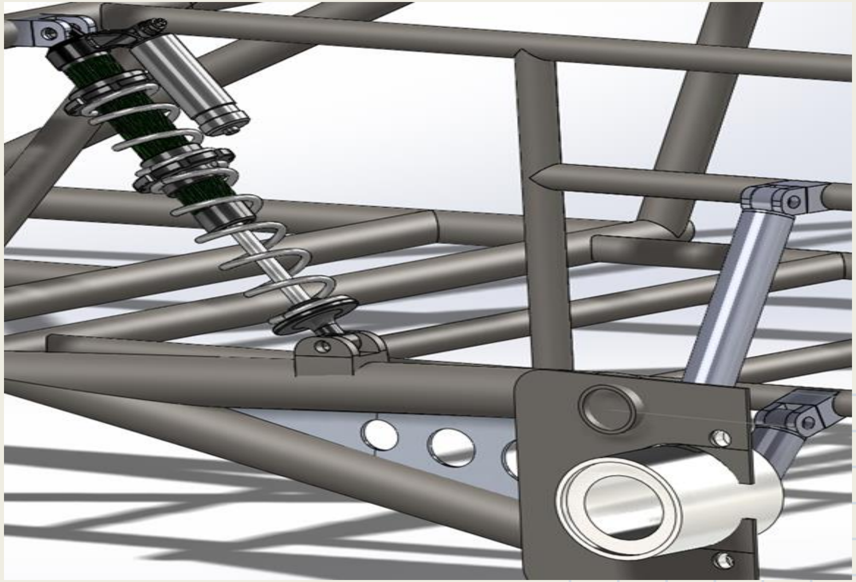

Figure 25: Rear Suspension

Gantt Chart

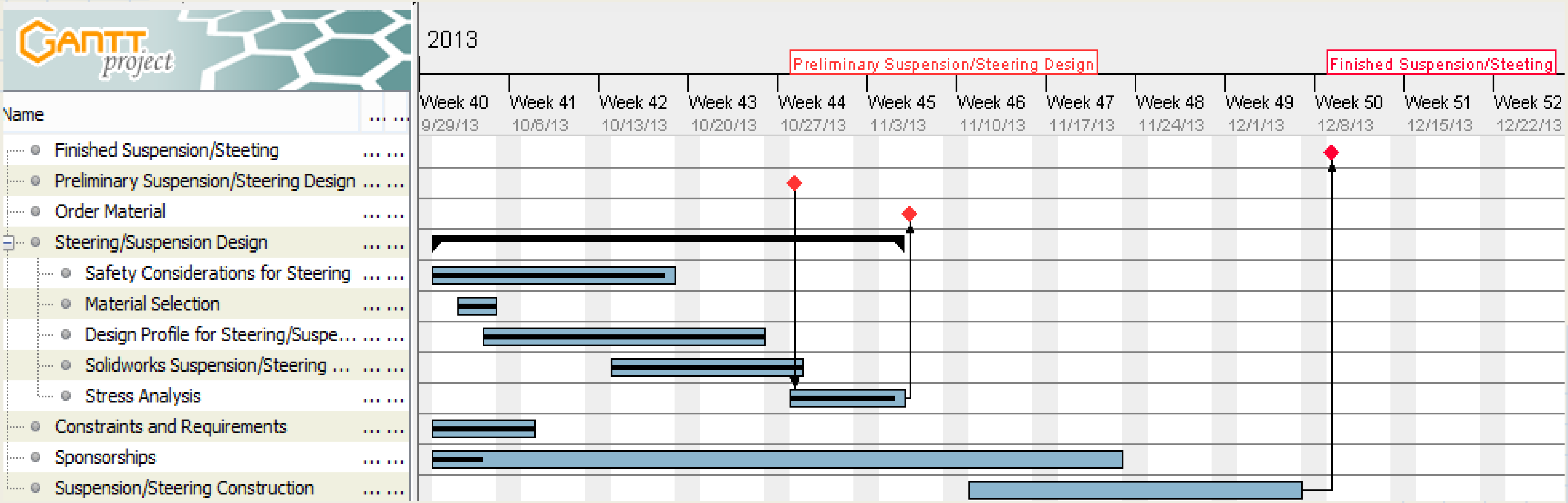

Figure 26: Gantt Chart

Spring 2014 Project Plan

- Finish Shock Calculations
- Further Design Refinement
- Completed Frame by January 31
- Completed Suspension Members by February 24
- SAE Cost Report by March 3
- SAE Design Report by March 20
- Competition on April 24

Conclusion

- SAE International is the client, NAU SAE is a stakeholder, and Dr.John Tester is the project advisor.
- Material Selection - AISI 4130 steel tubing for suspension members 1.25” - 1.50” O.D. and 0.065” - 0.083” wall thickness.
- Create a Baja design with an adequate weight and steering radius
- Front Suspension: Double A-Arms
- Rear Suspension: Trailing Arms
- Steering System: Rack and Pinion
- Analysis Results for optimization of design
- Cost analysis for economics of design

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