# 2015 SAE Baja

## UGRADS Presentation

Ahmed Alnattar, Zane Cross, Kyle Egan, Nick Garry, Neil Gehr, Trevor Hochhaus,

Ricardo Inzunza, Brandon Janca, Matthew Legg, Ryan Worden

April 24, 2015


# Overview

- Project Description
- Customer’s Needs
- Constraints
- Goals
- Objectives
- Frame
- Suspension
- Drivetrain
- Cost Analysis
- Conclusion

# Project Description

Society of Automotive Engineers (SAE) is hosting a collegiate design competition in which students from different universities design and manufacture a Baja vehicle to compete in five dynamic events.

- Portland, Oregon
- 100 Universities
- Competition Events
  - Maneuverability
  - Suspension
  - Acceleration
  - Hill Climb
  - Endurance
  - Design


Baja Facebook

# Problem Statement

- Design and build a single-seat Baja frame that a fictitious company would want to manufacture. The vehicle will be put through a series of dynamic events that will test the structural integrity, speed, and maneuverability.

# Customer’s Needs

**Customer: Dr. John Tester**

- Weight reduction
- Weight distributions cannot exceed a 40 x 60 front to rear ratio
- Must be safe and ergonomic for driver
- Obstacle clearance
- Reverse
- Fits in 5 x 10 ft trailer

# Constraints

- All major constraints are within SAE Baja Rules
- Design drivetrain within SAE Baja rules
- Width of vehicle must not exceed 59 in
- Turning radius must be less than 12 ft
- Frame needs to be a maximum of 150 lbf
- Total vehicle weight cannot exceed 450 lbf
- Use provided engine - Briggs & Stratton 10 hp OHV Intek
- Possible to manufacture

# Goals

- Design and build a lightweight frame that will meet strength, safety, and dimension requirements for SAE Baja Competition(s) and customer needs
- Design to integrate all additional equipment into frame with mounting tabs
- Complete a 100 ft trial in 4 seconds on level dry pavement
- Able to climb an incline of greater than 60 degrees
- Incorporate packaged extras (Glove box, speakers, winch, lights, and body paneling)
- Finish within the top 10 overall

# Objectives

- Design and build a lightweight frame (under 150 lbf and a total vehicle weight under 450 lbf)
- Build within a short amount of time (time)
- Strength, via compression testing (lbf/in)
- Minimize track width of vehicle (in)

# Completed Baja Vehicle

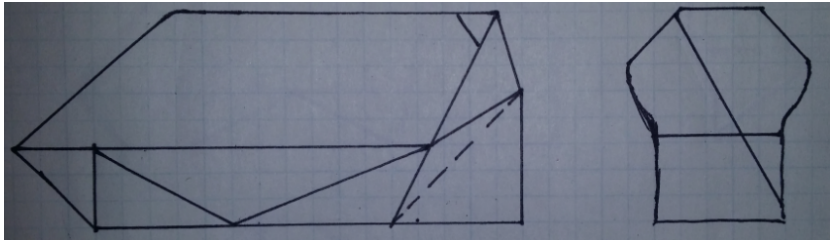
# Designing the Baja Vehicle

- Frame Team
  - Frame
  - Safety
- Suspension
  - Suspension
  - Steering
- Drivetrain
  - Transmission
  - Engine

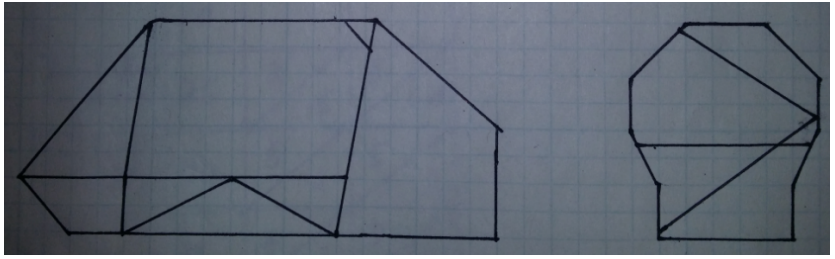
# Frame Design

# Initial Frame Concepts

Rear Bracing



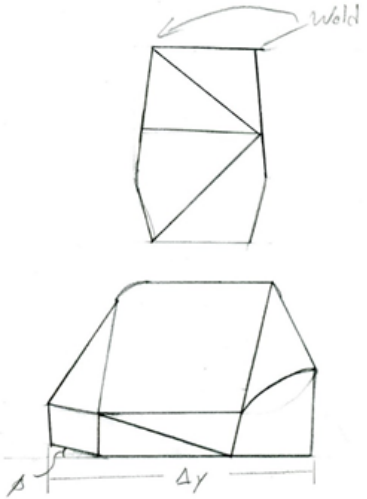
Front Bracing



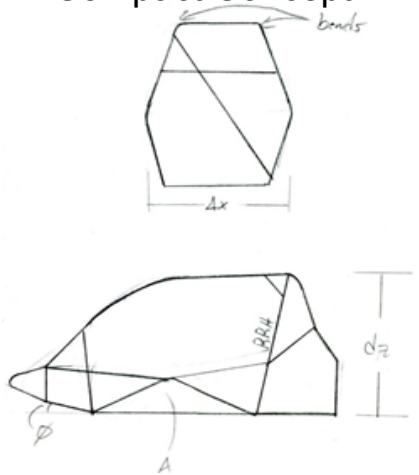
Truck Frame


Volkswagen Bug

Front Supported



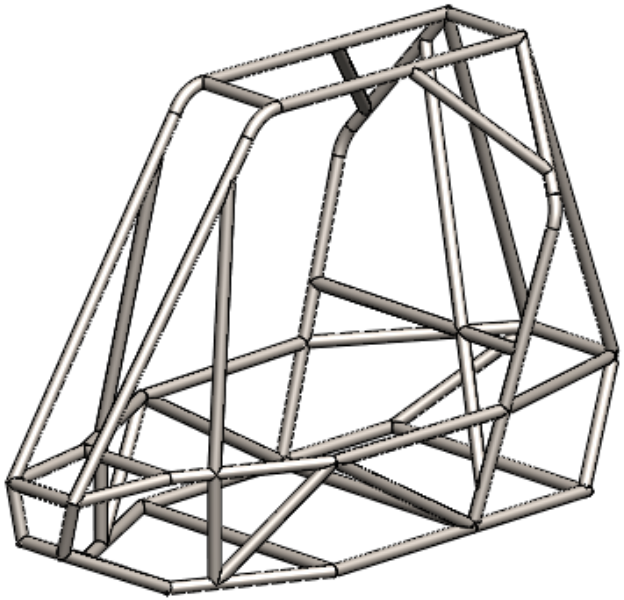

Compact Concept



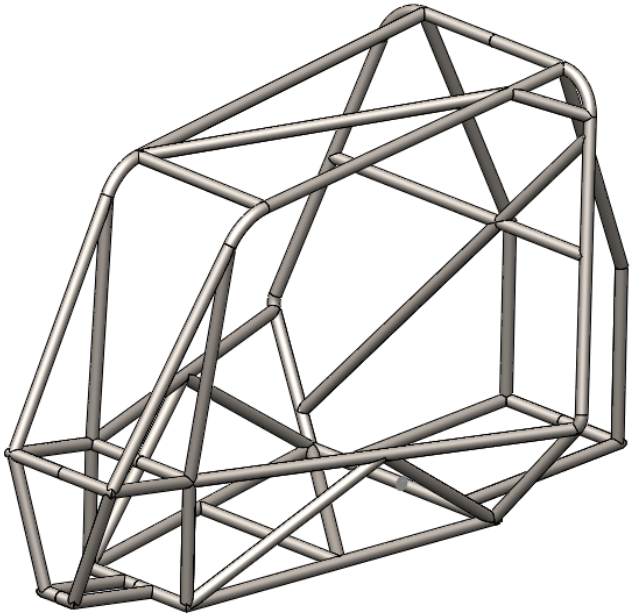

Matthew Legg

# Initial Designs

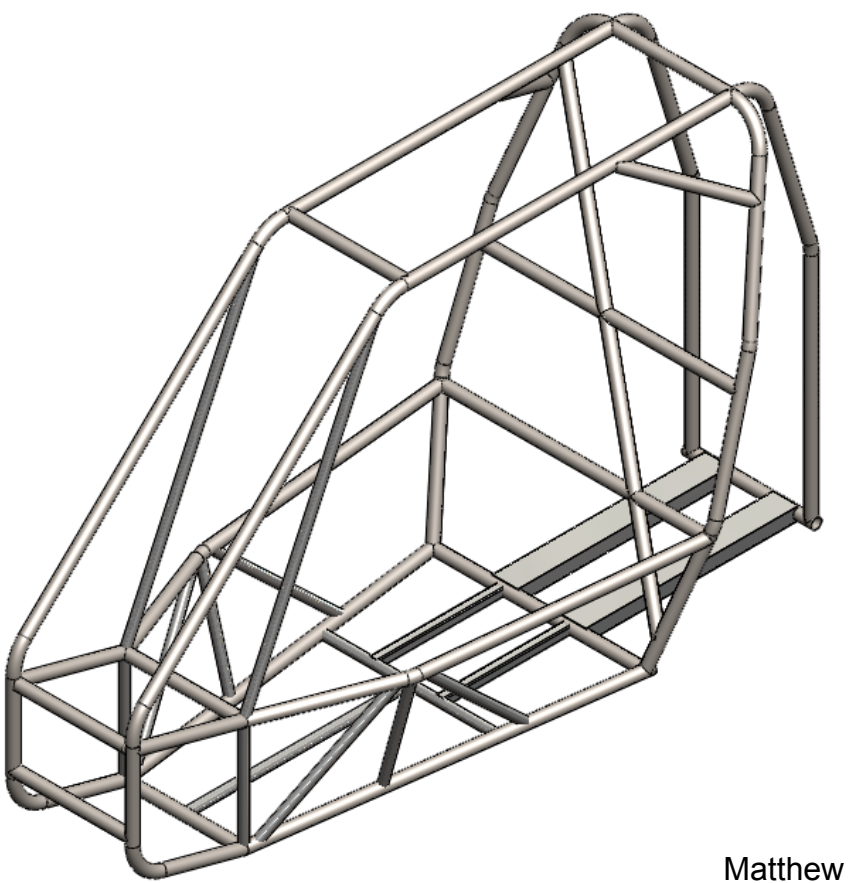
## Front Bracing Design

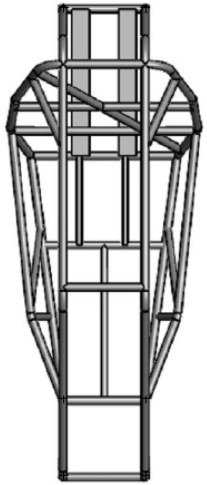


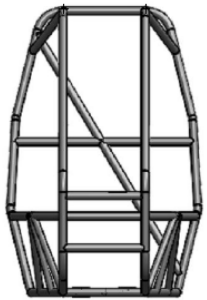
## Front Supported Design

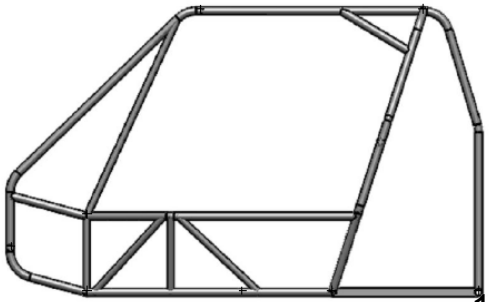


# Final Design









# Stress Analysis

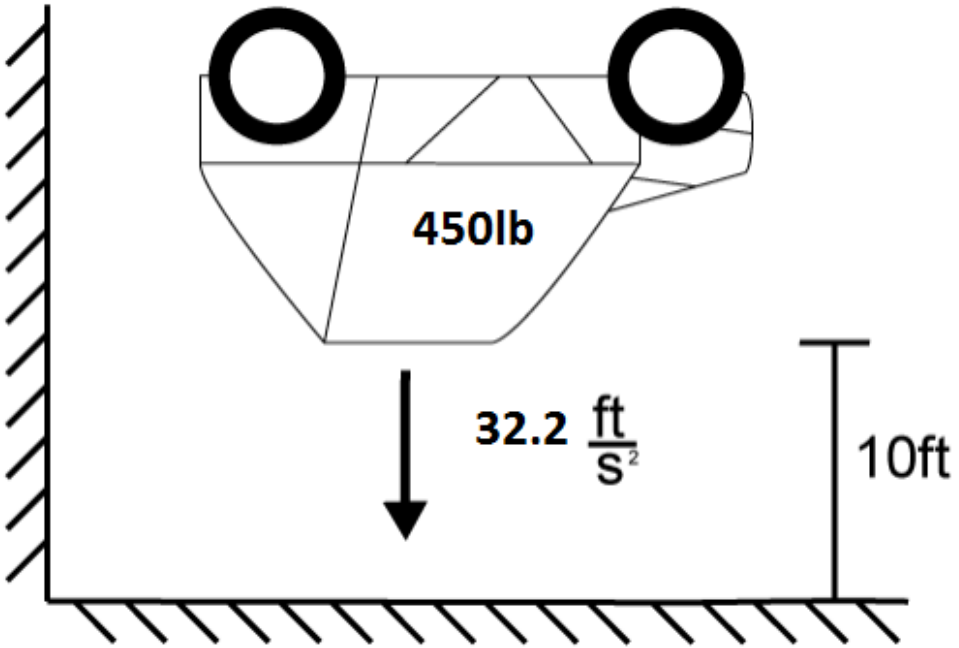
Four Simulation Studies:

1. Rollover Test
2. Front Impact
3. Rear Impact
4. Side Impact

Test Assumptions:

1. Vehicle weight of 450 lbf
2. Drop height of 10 ft
3. Impact velocity of 25 mph
4. 0.1 and 0.2 second drop and impact impulse times, respectively

# Drop Test



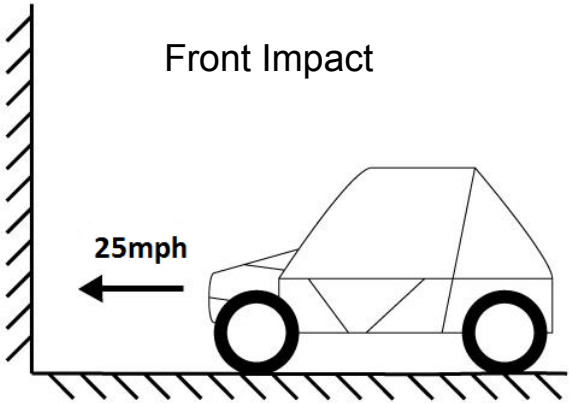

- Applied Equation:

$$F = m \cdot \frac{\sqrt{2gh}}{t} = 2507.752\ lbf$$

$$F_a = \frac{F}{l}$$

# Impact Scenarios

Front Impact

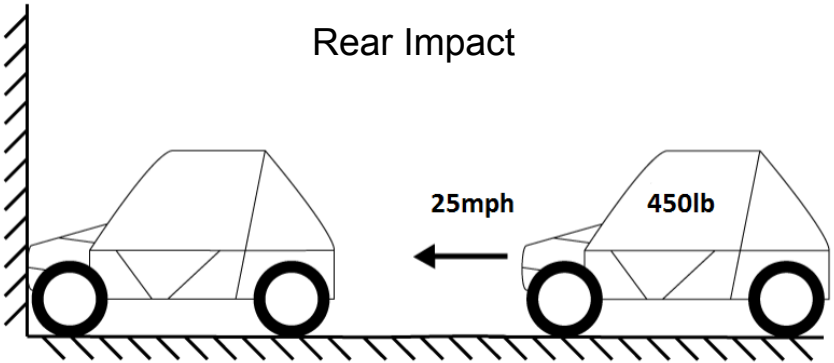



- Applied Equations:

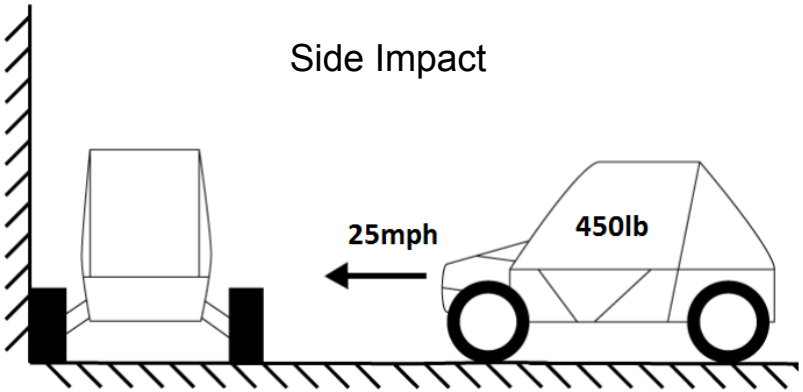
$$F = \frac{V_o}{t} m = 1192.175\ lbf$$

$$F_a = \frac{F}{l}$$

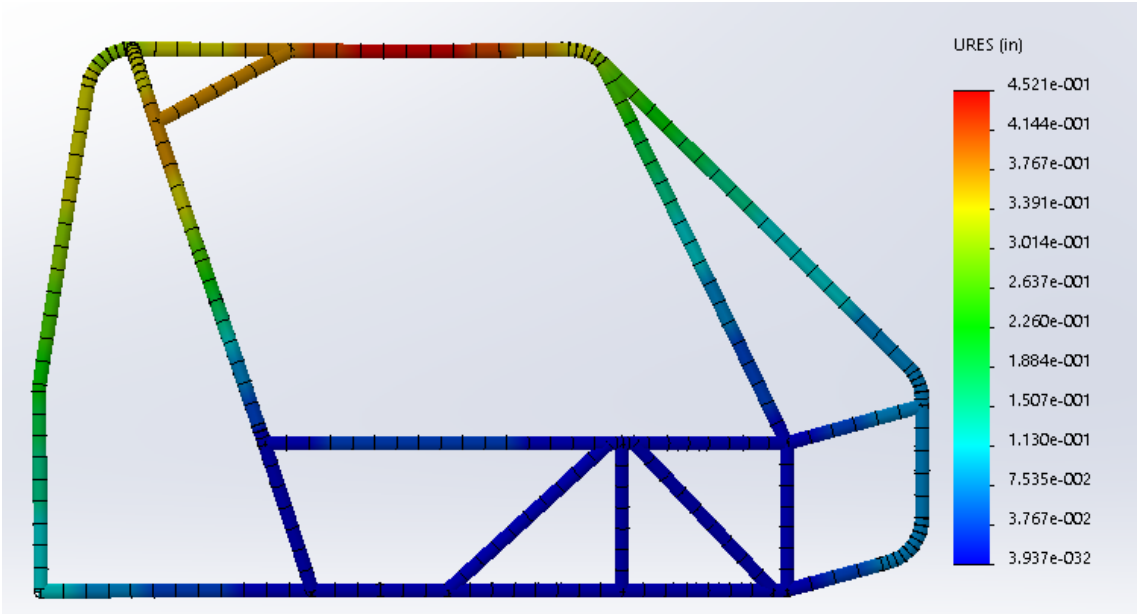
Rear Impact




Side Impact



# Drop Test

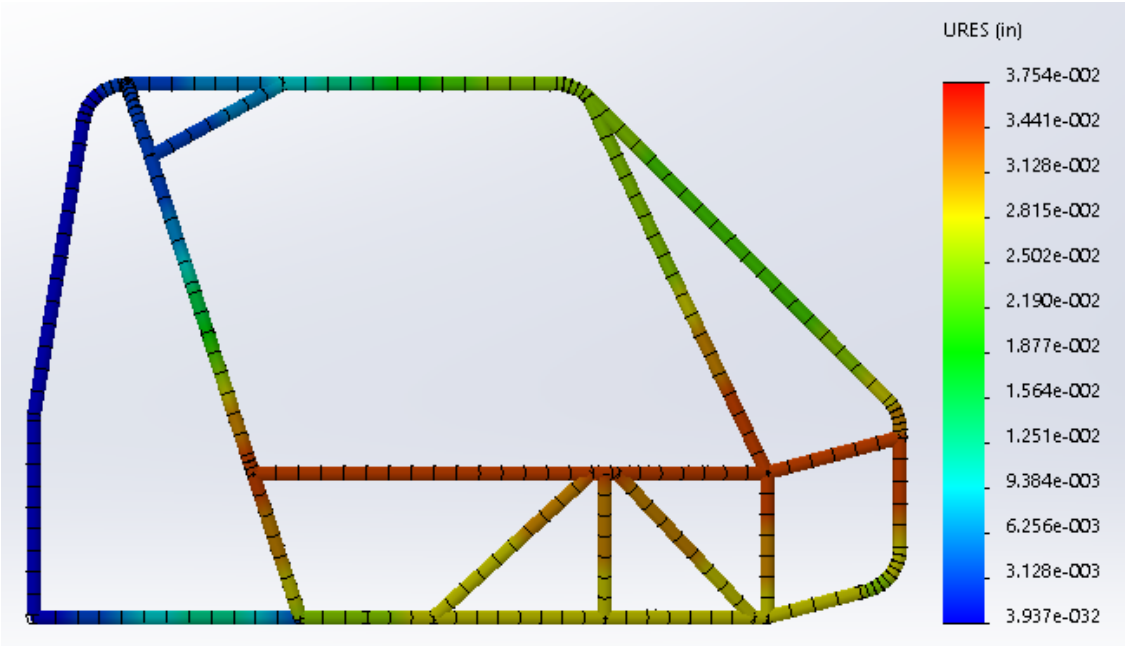



Factor of Safety (F.O.S.) = 2.2

Max Stress = 30.3 ksi

Maximum Displacement = 0.452 inches

# Front Impact Test

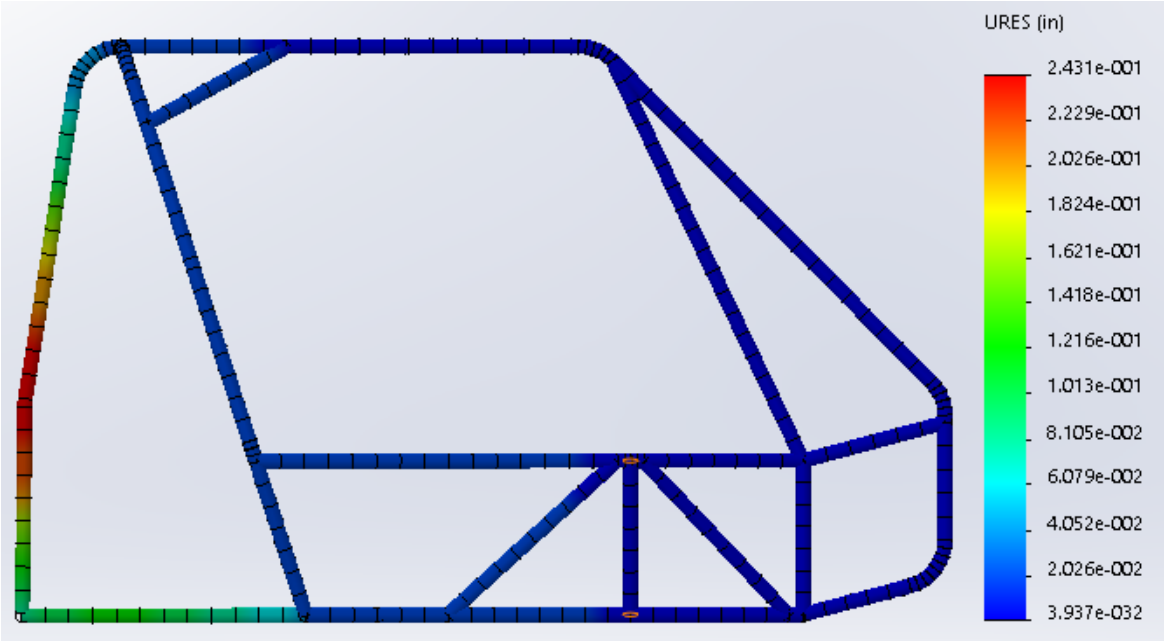



F.O.S. = 3.9

Max Stress = 17.1 ksi

Maximum Displacement = 0.038 inches

# Rear Impact Test

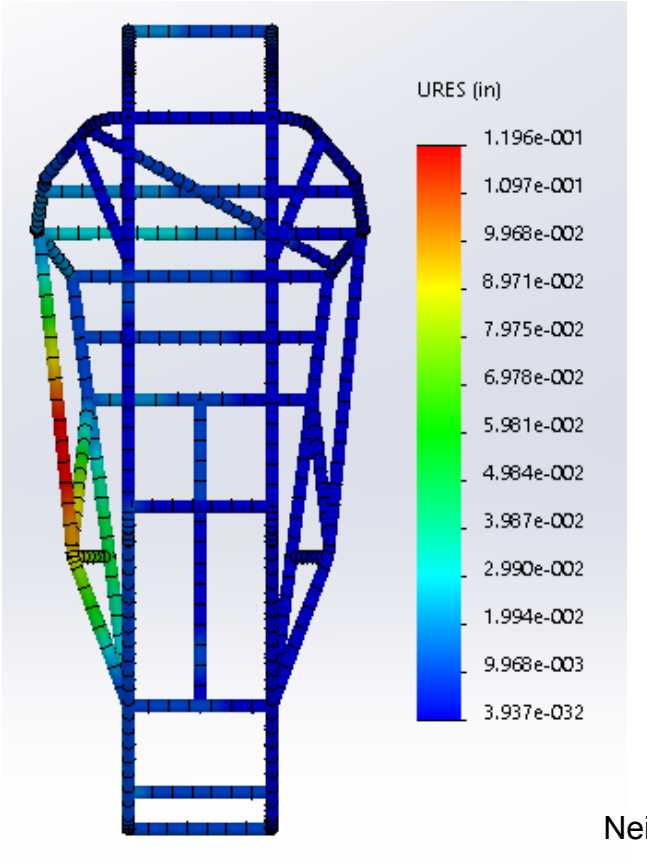



F.O.S. = 2.6

Max Stress = 25.7 ksi

Maximum Displacement = 0.243 inches

# Side Impact Test




F.O.S. = 3.7

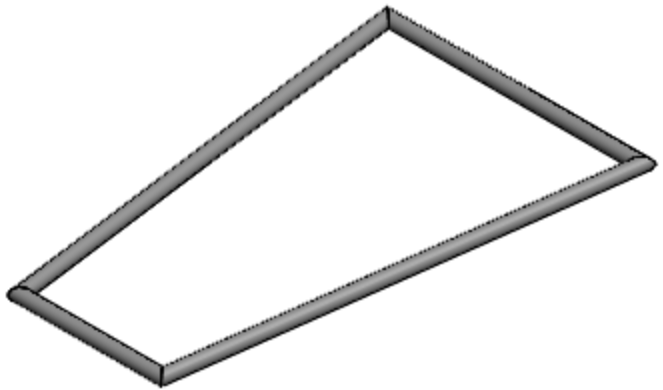
Max Stress = 18.0 ksi

Maximum Displacement = 0.120 inches

# Test Results

| Test | Max Stress (ksi) | Displacement (in) | F.O.S. |
|---|---|---|---|
| Drop Test | 30.3 | 0.4521 | 2.2 |
| Front Impact Test | 17.1 | 0.0375 | 3.9 |
| Rear Impact Test | 25.7 | 0.2431 | 2.6 |
| Side Impact Test | 18.0 | 0.1196 | 3.7 |

# Manufacturing Process



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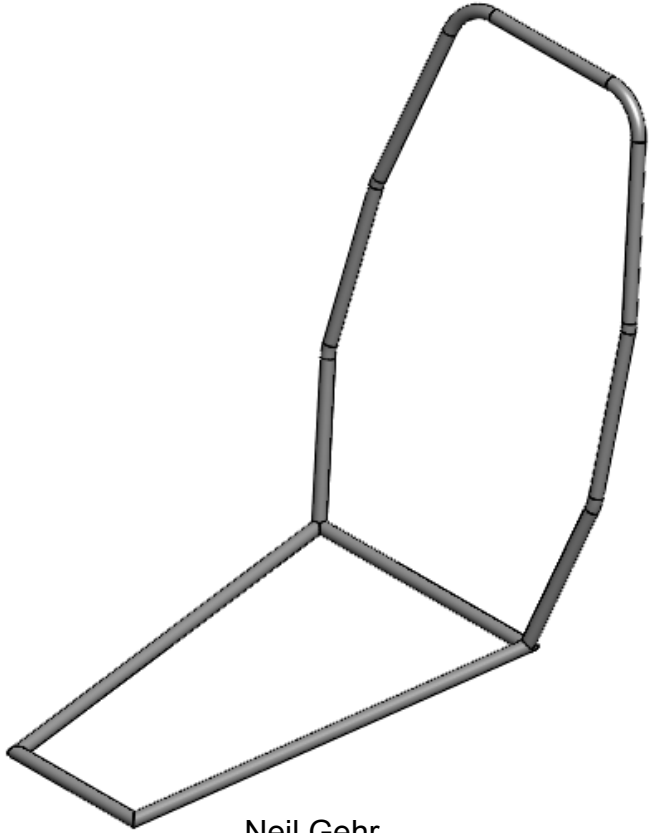

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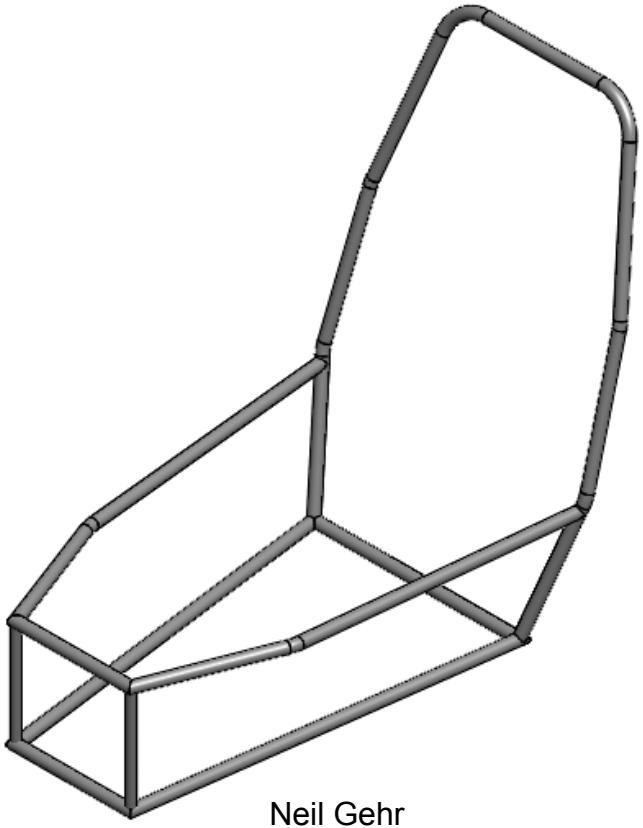
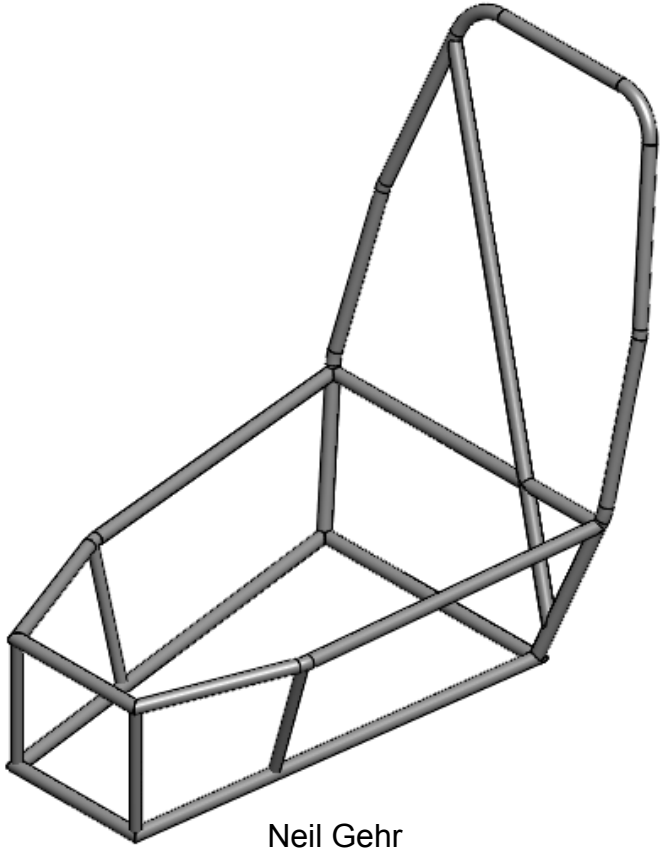


# Manufacturing Process



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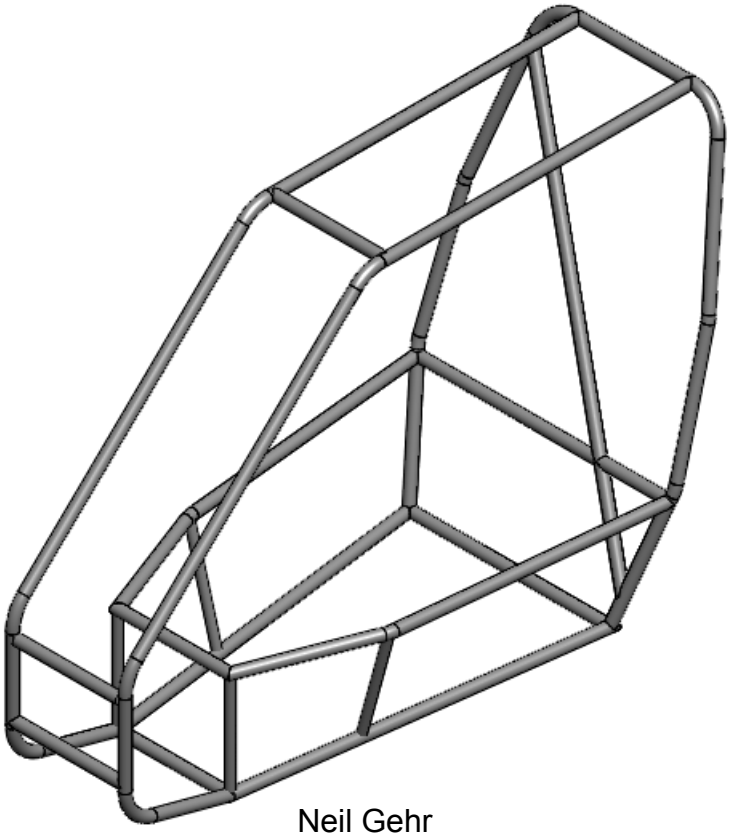
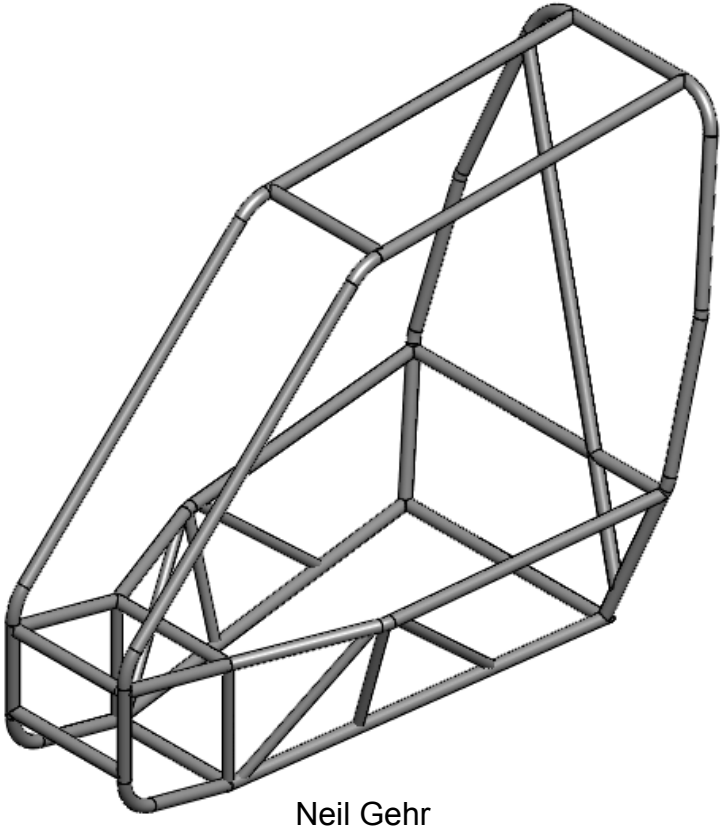


Neil Gehr

# Manufacturing Process



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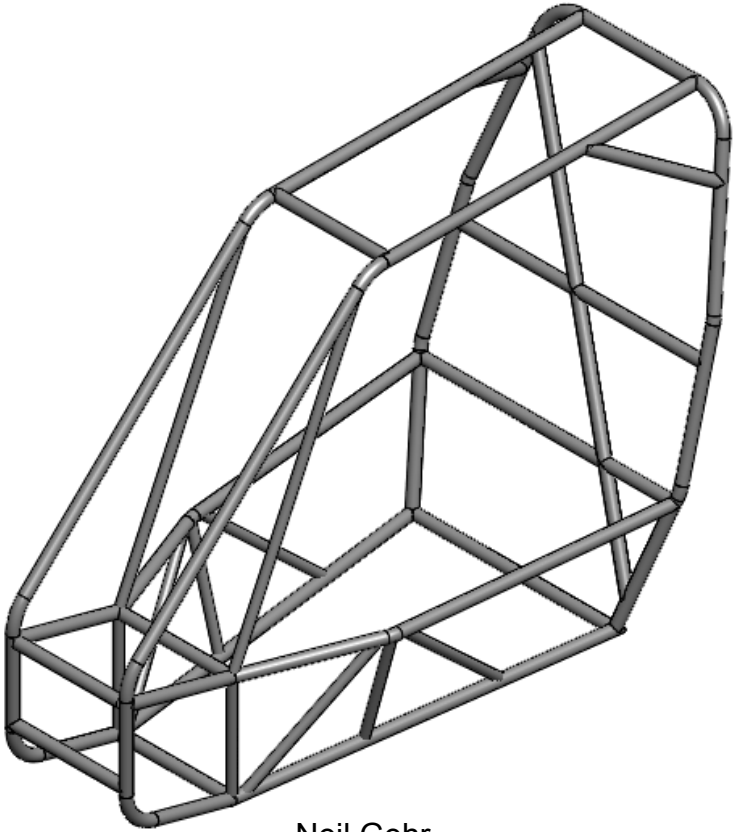

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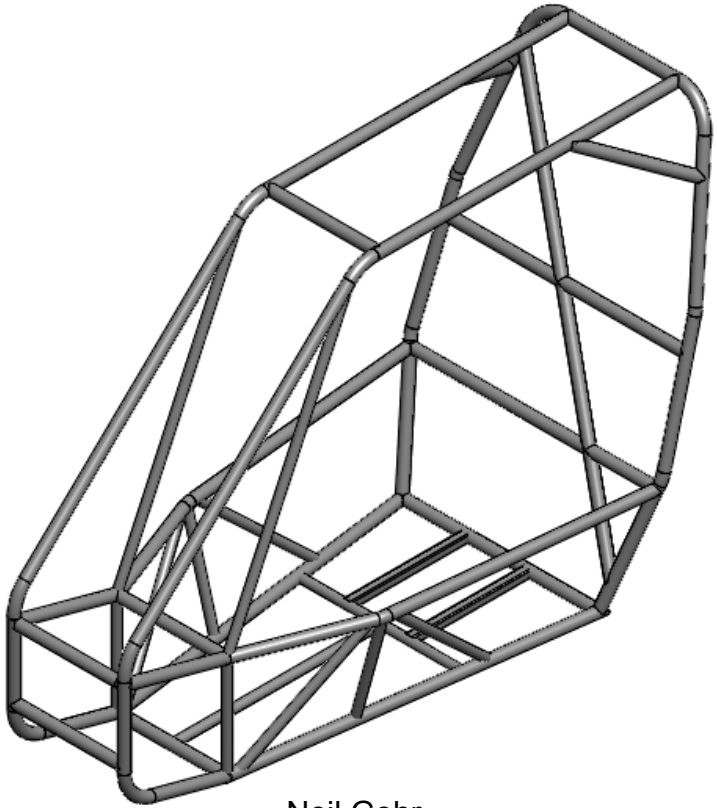
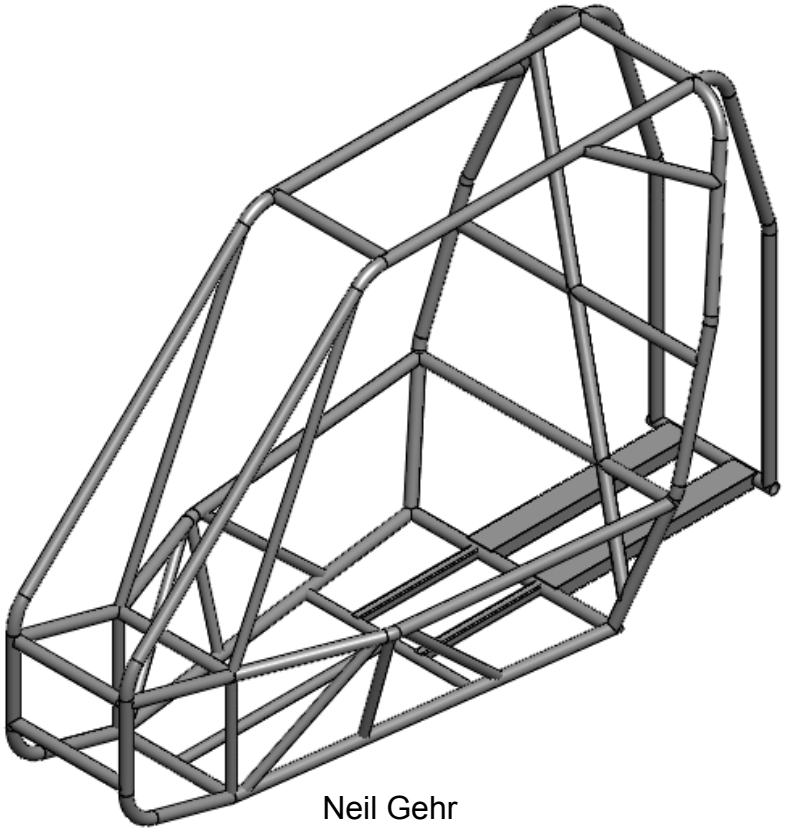
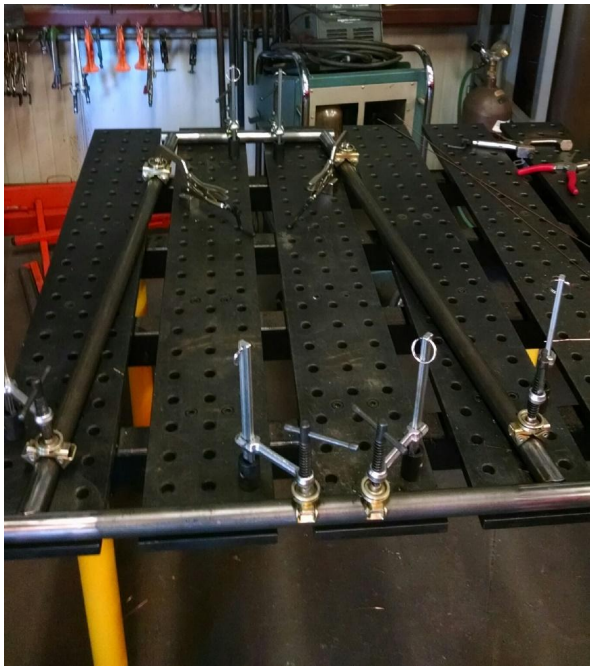


# Manufacturing Process



# Frame Progression

Feb 7th

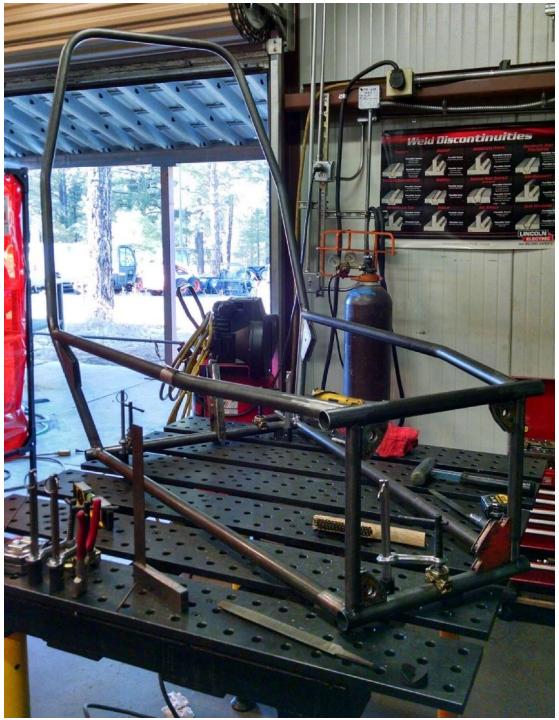


Feb 14th

Neil Gehr

# Frame Progression

Feb 14th




Feb 15th

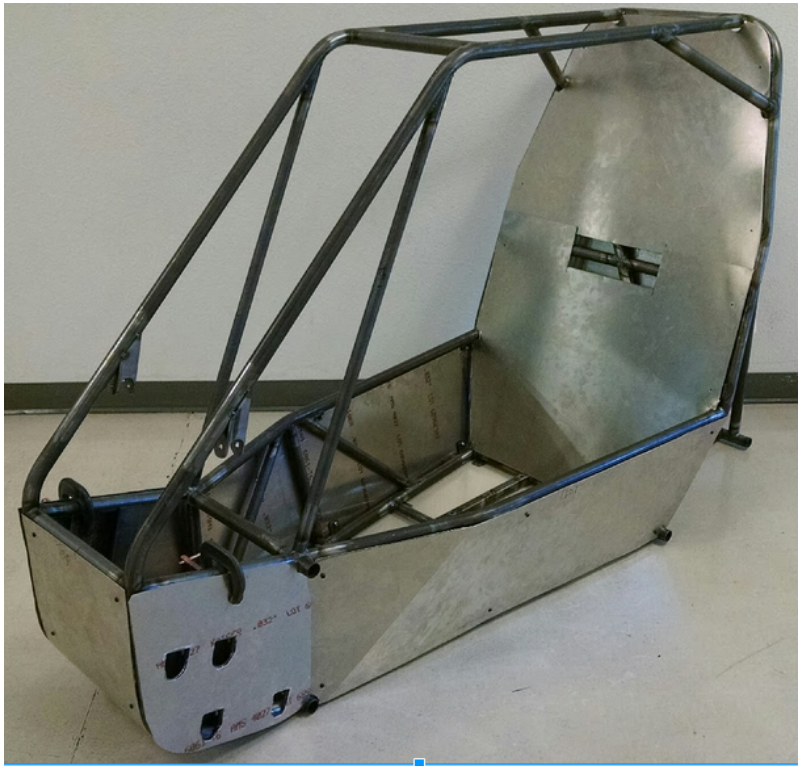

Neil Gehr

# Frame Progression

Feb. 21st – 28th

Neil Gehr

# Frame Progression



April 12th

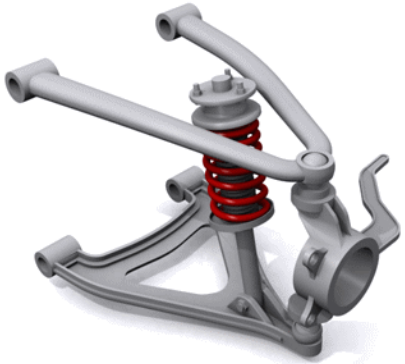
Neil Gehr

# Bill of Materials

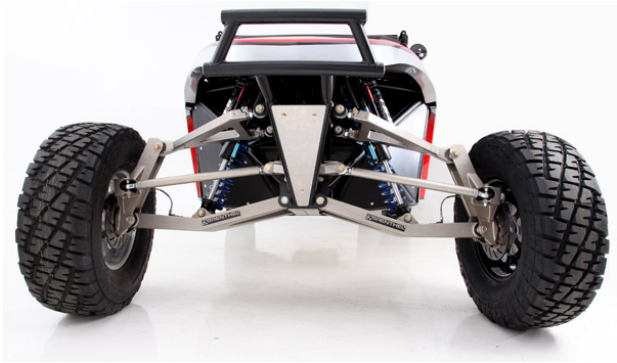
| Material | Quantity |
|---|---|
| 4130 Chromoly Steel, 1.25 x 0.065 in Primary Round Tubing | 90 ft |
| 4130 Chromoly Steel, 1 x 0.035 in Secondary Round Tubing | 30 ft |
| 1018 Steel, 1 x 1 x 0.065 in Square Tubing | 4 ft |
| 1018 Steel, 3 x 1.5 x 0.0747 in Rectangular Tubing | 50 in |
| 6061 Aluminum Sheet Metal 4 x 4 ft | 4 |
| High Density Polyethylene 3 x 4 ft | 1 |

# Suspension Design

# Front Suspension Concepts



Double A Arms

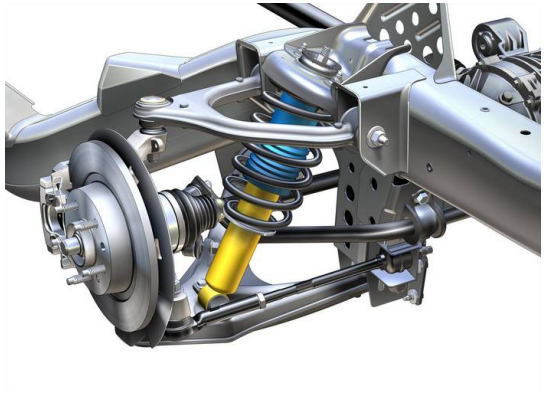


Extended A Arms

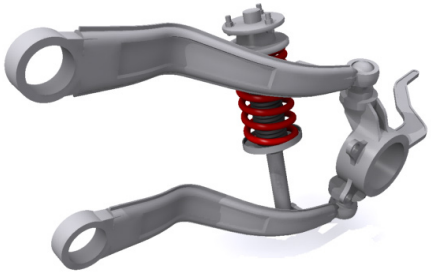
MacPherson

Torsion Bars

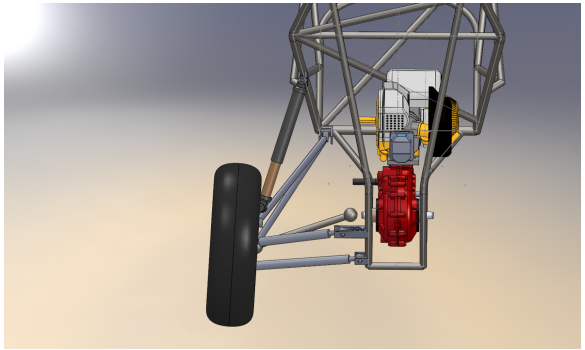
# Rear Suspension Concepts



Double A Arms

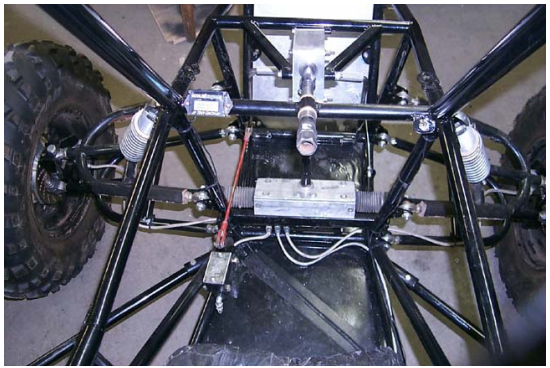


2 Link



3 Link

# Steering Concepts



Rear Mounted Steering

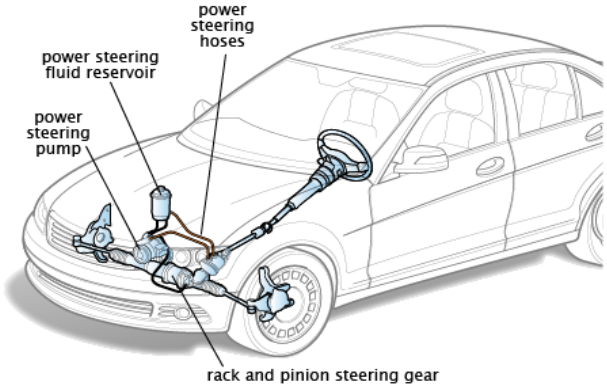
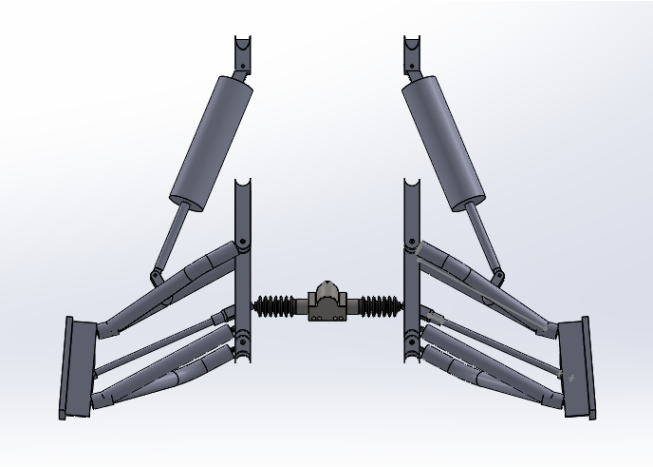



Image courtesy of ClearMechanic.com

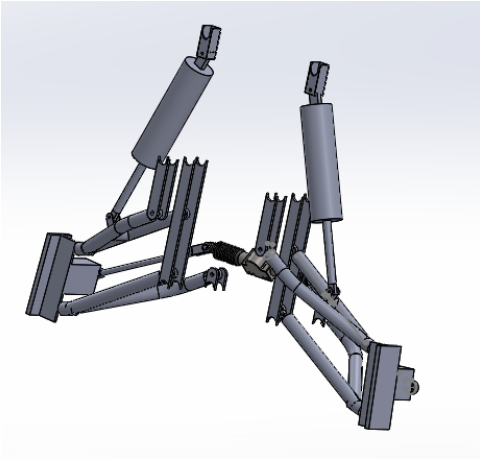
Power Steering

Front Mounted Steering

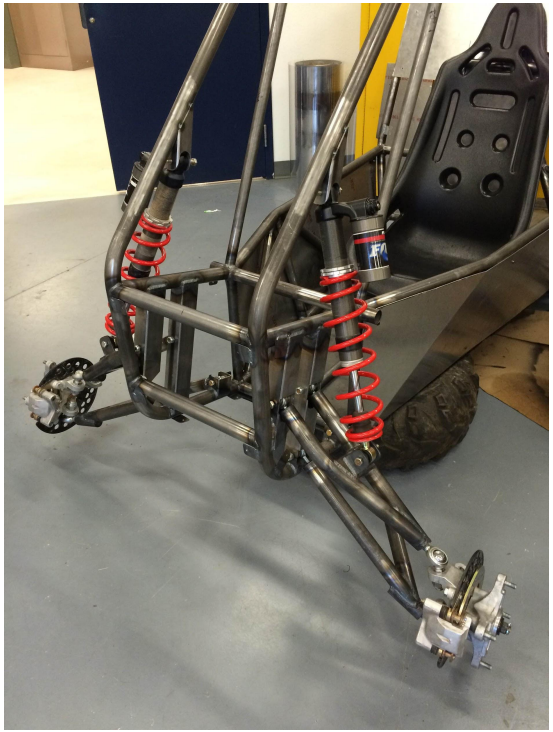
# Final Front Suspension and Steering



Front View

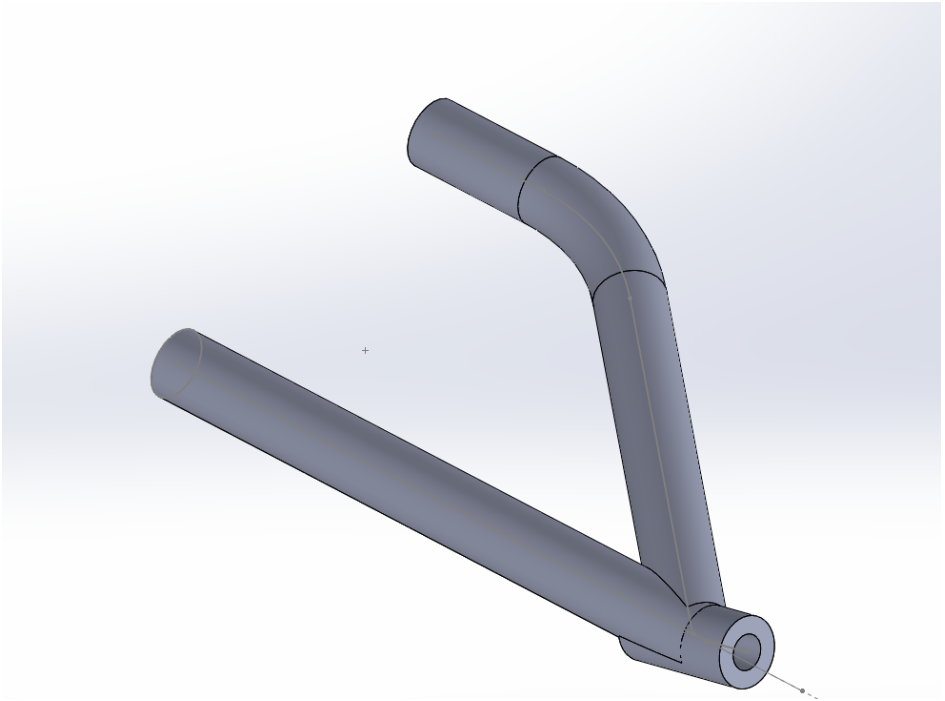


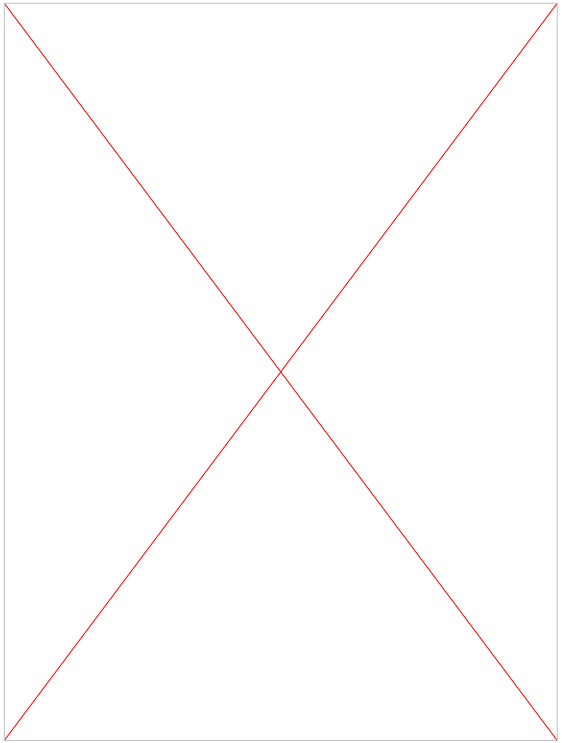
Isometric View



Manufactured Front Suspension

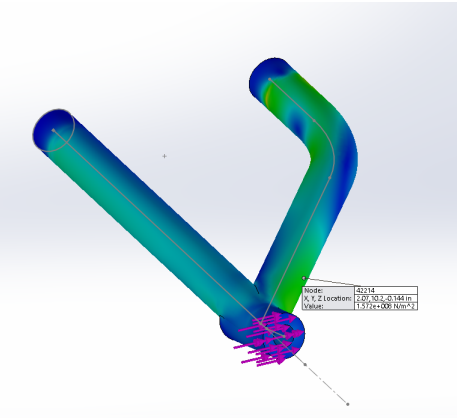
# Lower A-Arm



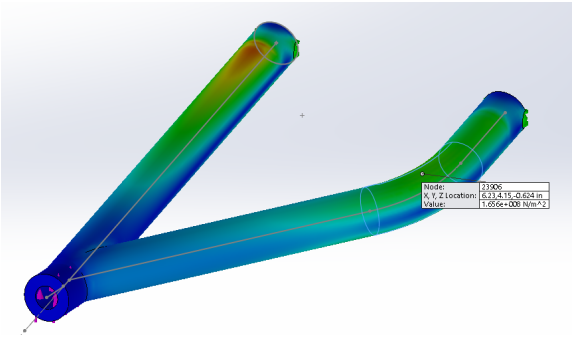


# Impact Testing in FEA

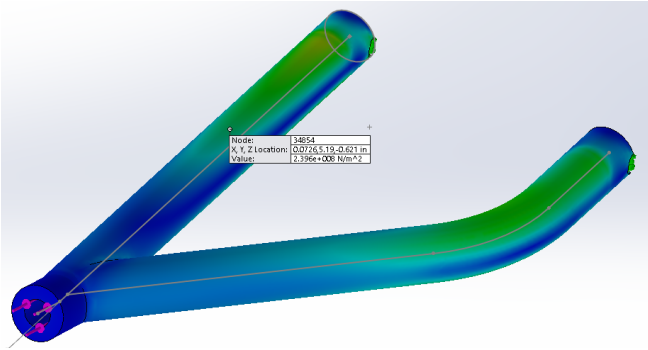
Front Impact at 10 mph. F. O.S. is 2.9.



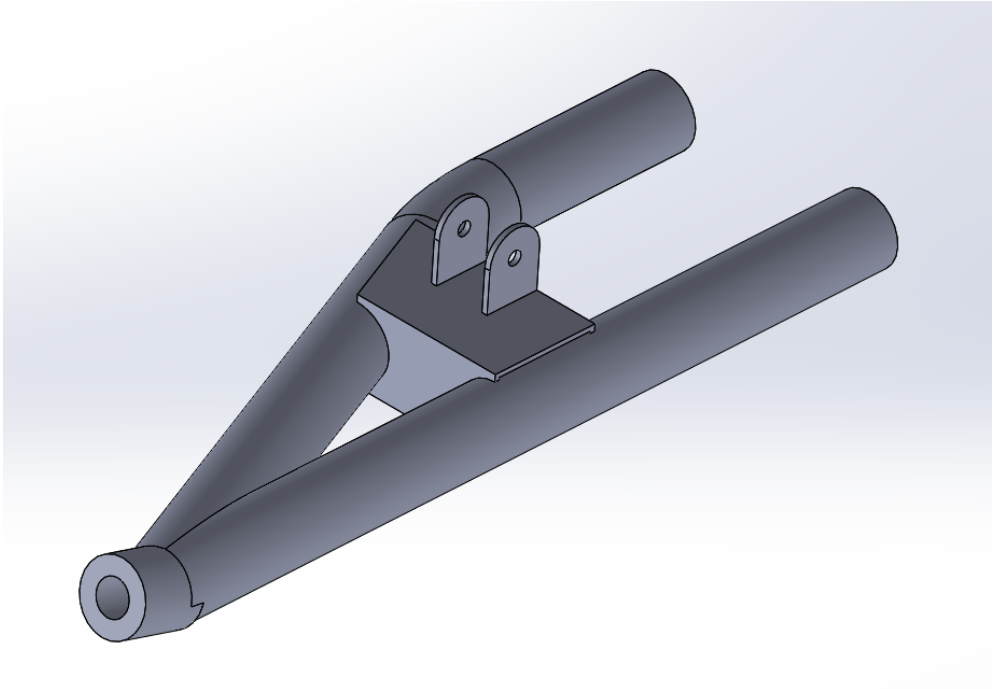
Simulates a 5 foot drop on one corner. F.O.S. of 2.8.



Simulates a side impact at 10 mph. F.O.S. of 2.0.

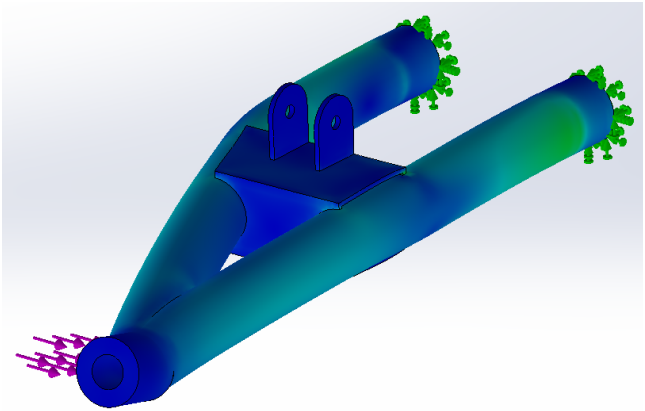


# Upper A-Arm

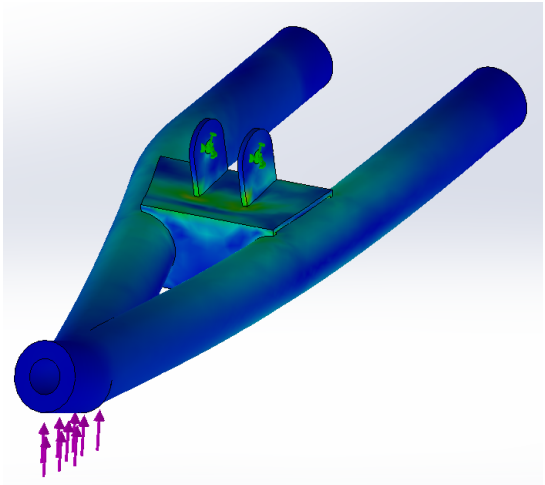


# Impact Testing in FEA

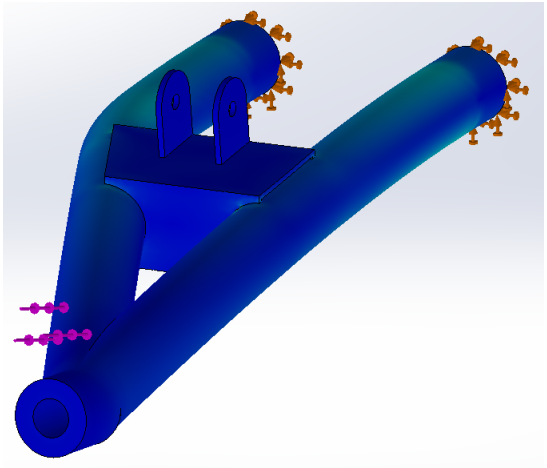
Front Impact at 10 mph. F.O.S. is 2.



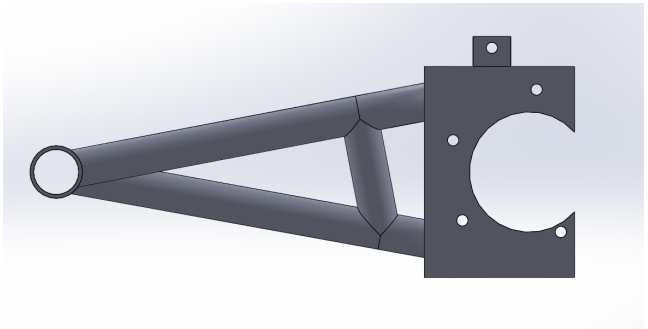
Simulates a 5 ft drop on one corner. F.O.S. of 8.



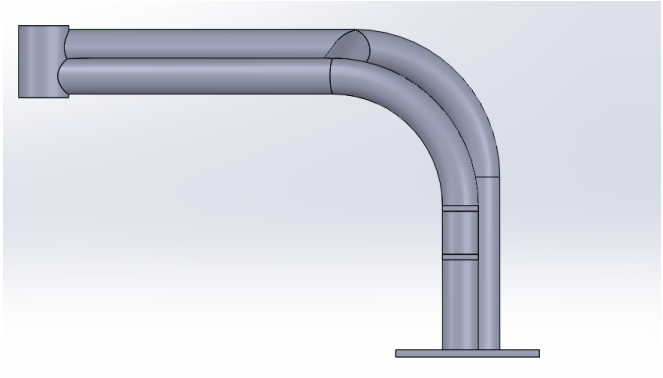
Simulates a side impact at 10 mph. F.O.S. of 2.9.



# Final Rear Suspension



Side View

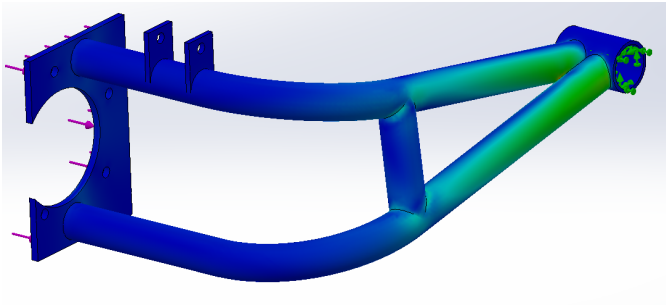


Top View

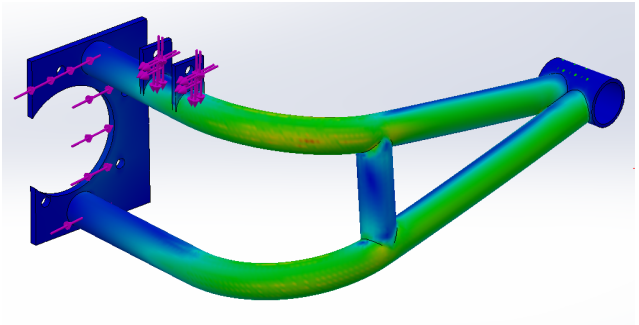
Manufactured
Trailing Arm

# Impact Testing in FEA

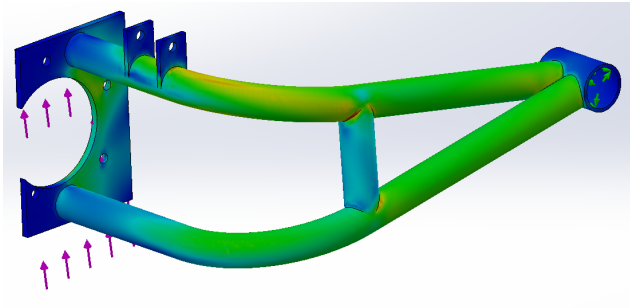
Simulates a collision at 5mph on one arm. F.O.S. of 1.7 for this simulation.



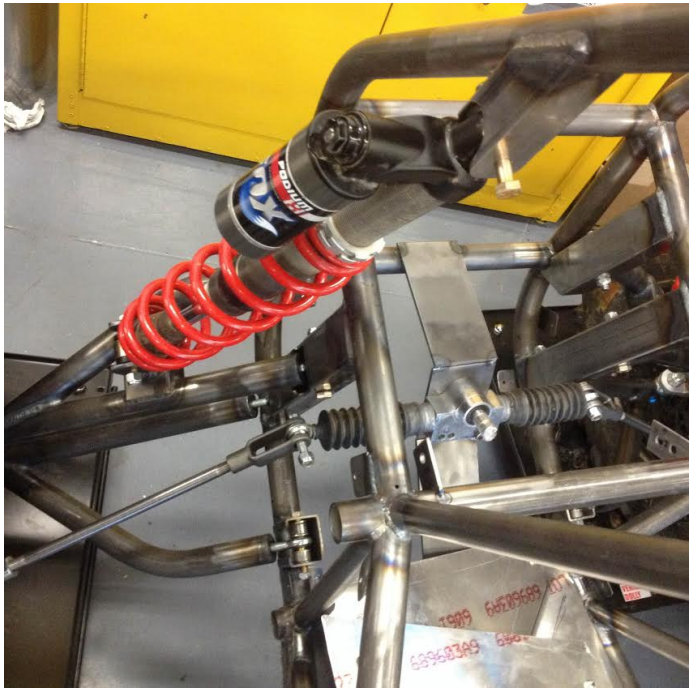
Simulates a collision with another car at 5mph. The F.O.S. for this simulation was 2.6



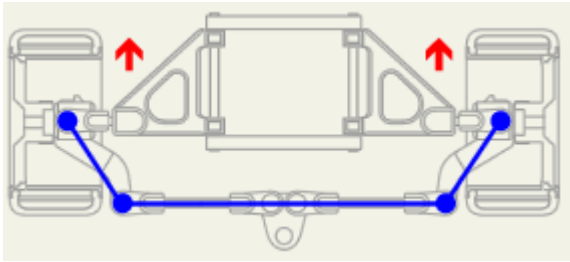
Simulates a 5 foot fall on one member. The F.O.S. for this loading is 2.4



# Steering Design



Rear Mounted Steering

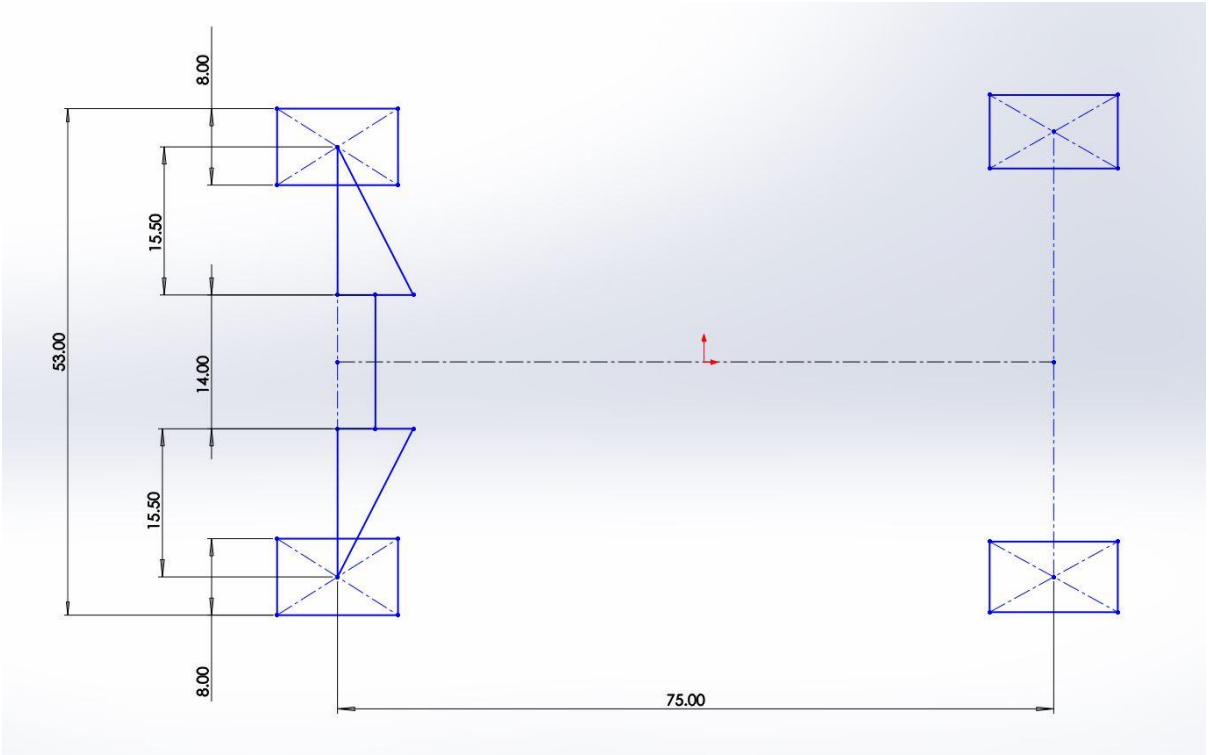


Purpose for New Hub Mount

Rack and Pinion

# Final Track Width and Wheelbase

- Track Width = 53in
- Wheelbase = 75in



# Steering Angles

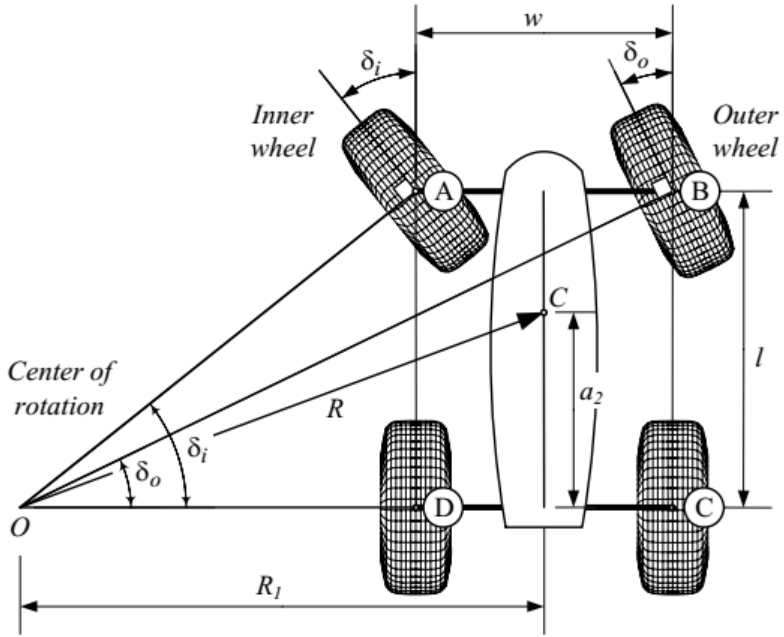
- Inside Tire Max Angle

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

- Outside Tire Max Angle

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

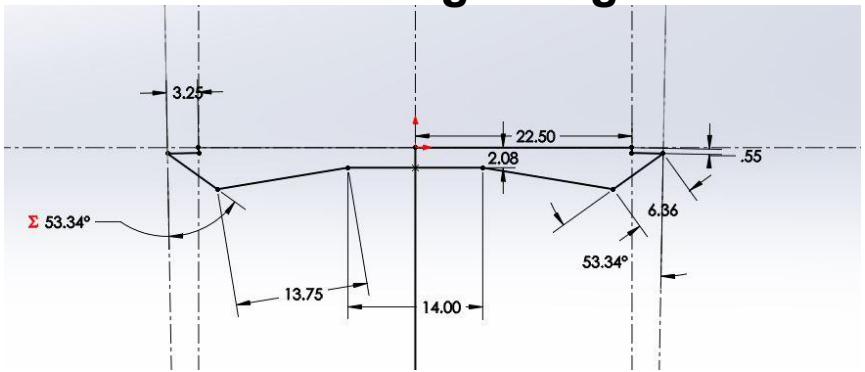
- **Inside Tire = 38.27 deg**
- **Outside Tire = 28.18 deg**



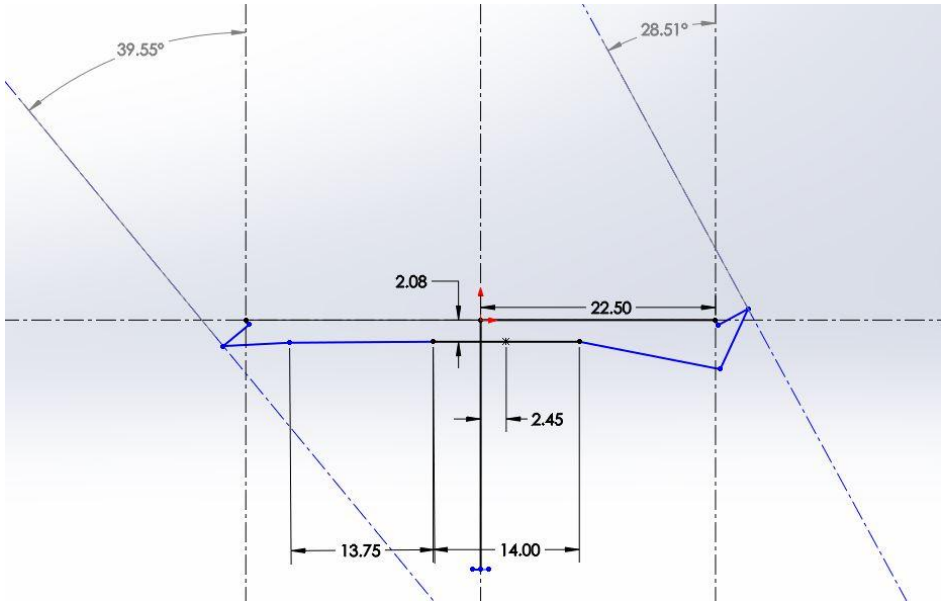
# Final Steering Dimensions

- Rack Location = 2.08 in
- Tie Rod Length = 13.75 in
- Max Rack Travel = 2.45 in
- New Tie Rod Hub Mount (Y) = 4.32 in
- New Tie Rod Hub Mount (X) = 1.93in

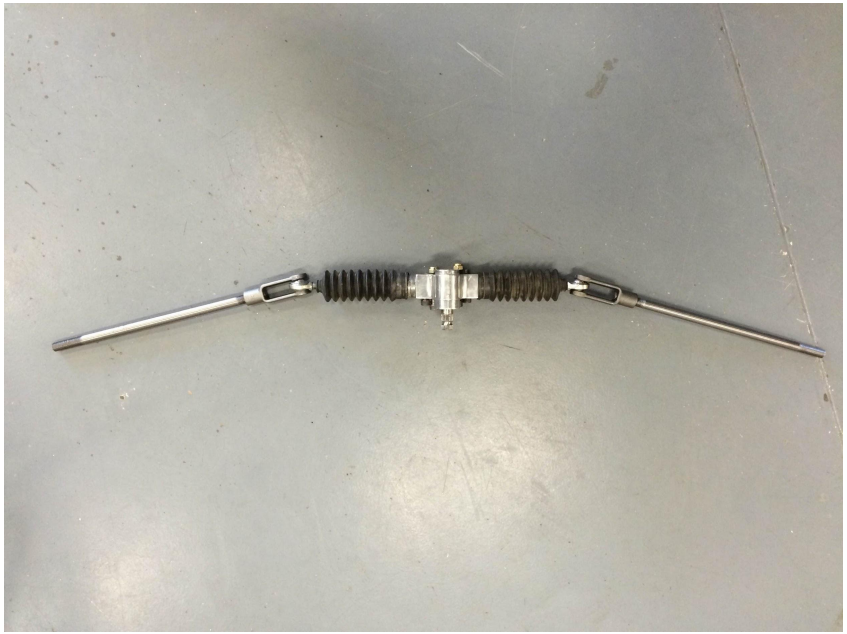
**Vehicle Going Straight**




**Vehicle at Max Turning**



# Manufacturing of Tie Rods



# Completed Suspension and Steering

# Suspension Testing

# Steering Testing

# Transmission Design

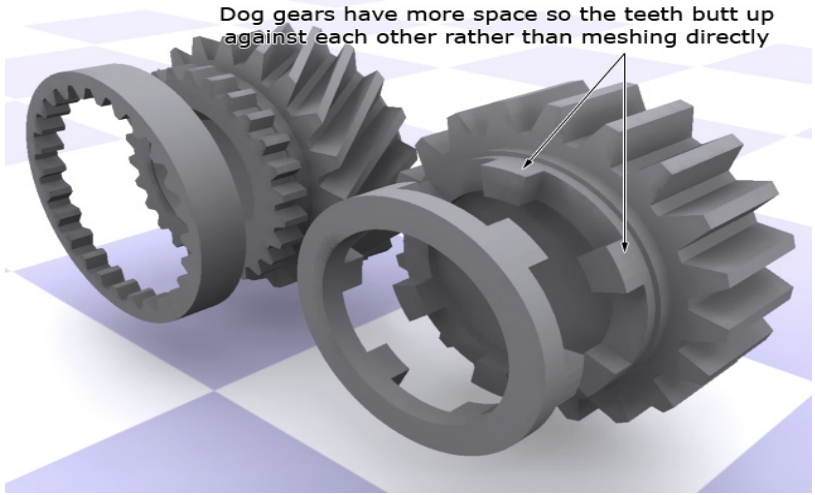
# Sequential Transmission

Typical Applications:

- Motorcycles
- ATV's
- Race Cars

Advantages:

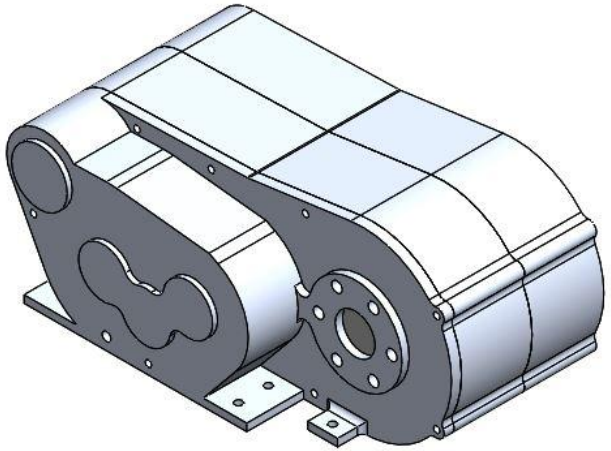
- Little loss of power
- Lightweight/Compact
- Simple to operate
- Stronger and more reliable



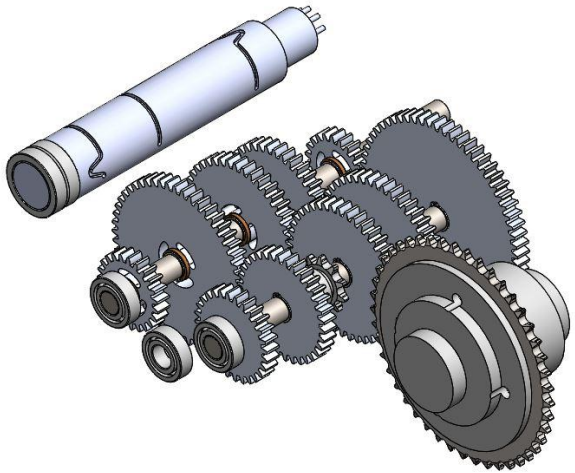

Sequential Dog ring compared to Manual Dog

# Drivetrain

Gearbox Casing



Gearbox Internals



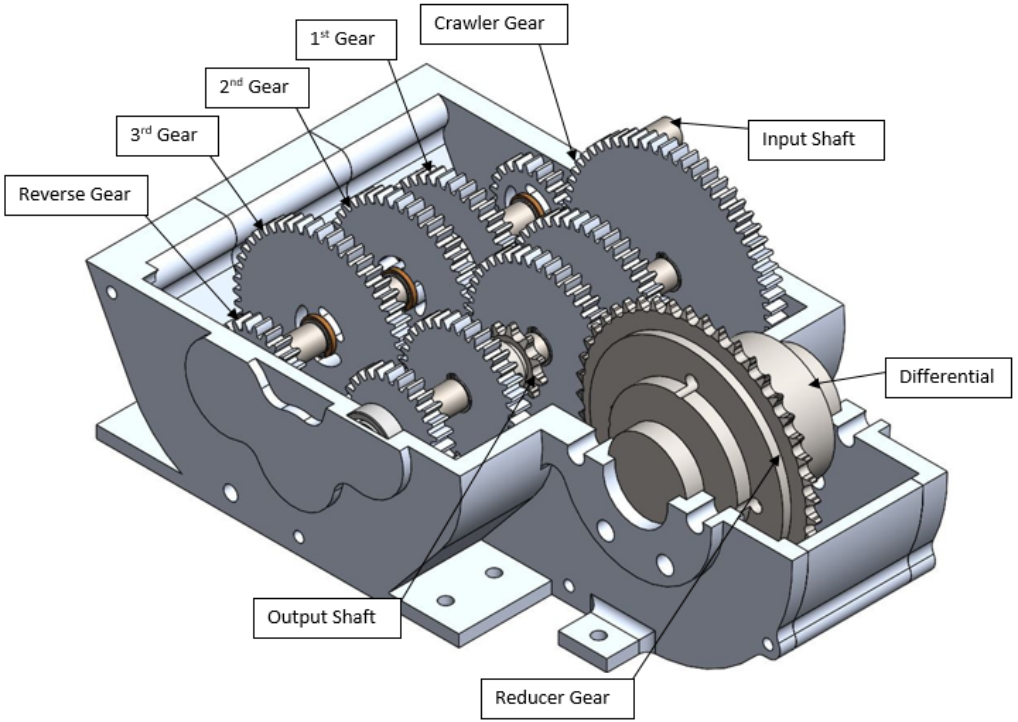
# Material Choices

- Gears
  - 7075-T6 Aluminum
- Shafts
  - 4340 Normalized Steel
- Bearings
  - Open Steel Ball Bearings
- Bushings
  - Alloy 932 Bronze Flanged Sleeve Bearings
- Dog Collars
  - 1020 Cold Rolled Steel

# Gear Ratios and Teeth Numbers

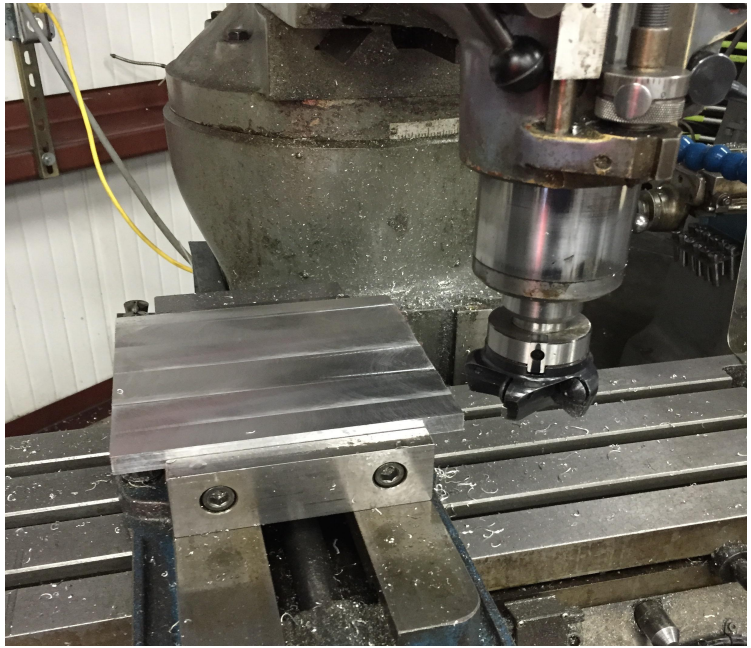
| Gear | Pinion Teeth | Gear Teeth | Idler Teeth | Overall Ratio | Transmission Ratio |
|---|---|---|---|---|---|
| **Crawler** | 23 | 63 | N/A | 25:1 | 2.71651:1 |
| **1st** | 39 | 47 | N/A | 11.219:1 | 1.21906:1 |
| **2nd** | 43 | 43 | N/A | 9.203:1 | 1:1 |
| **3rd** | 52 | 34 | N/A | 6:1 | 0.65196:1 |
| **Reverse** | 23 | 28 | 23 | 11.219:1 | 1.21906:1 |

# Gear Layout


1st Gear
Crawler Gear
2nd Gear
3rd Gear
Input Shaft
Reverse Gear
Differential
Output Shaft
Reducer Gear

# Manufacturing Gears

Planing gear plates down to 0.5 inches

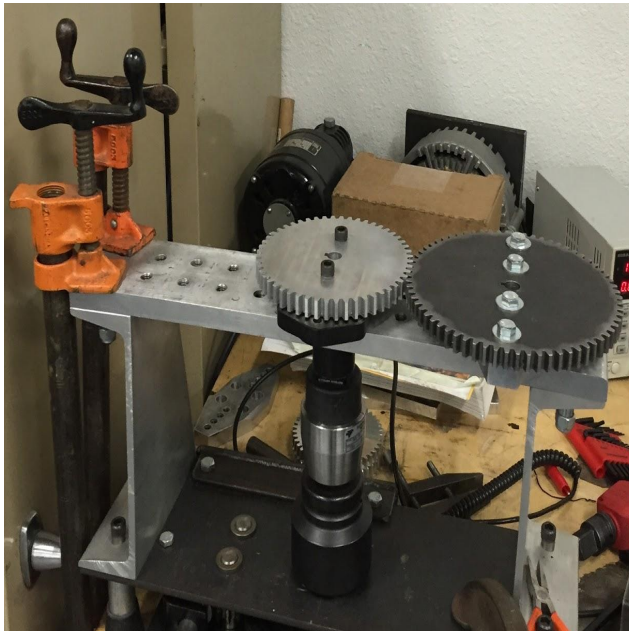


Cutting Gear Profiles on Tormach CNC Mill

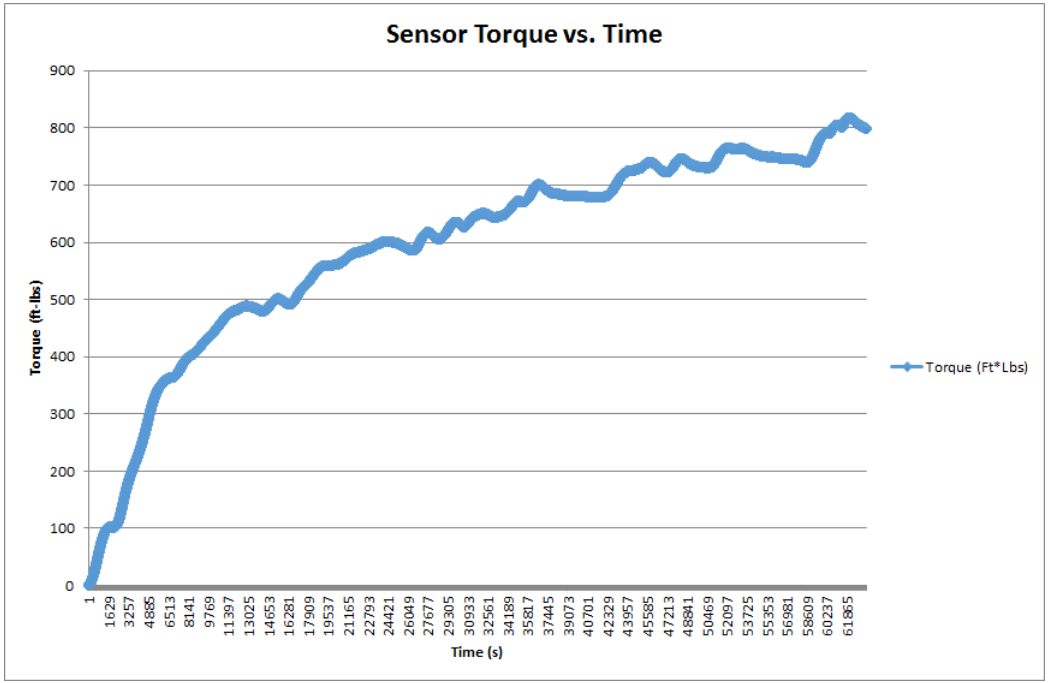
# Manufacturing Gear Teeth

(Video of 4 axis CNC machine cutting gear teeth)

# Testing



Testing Apparatus




Data from Gear Shear Testing

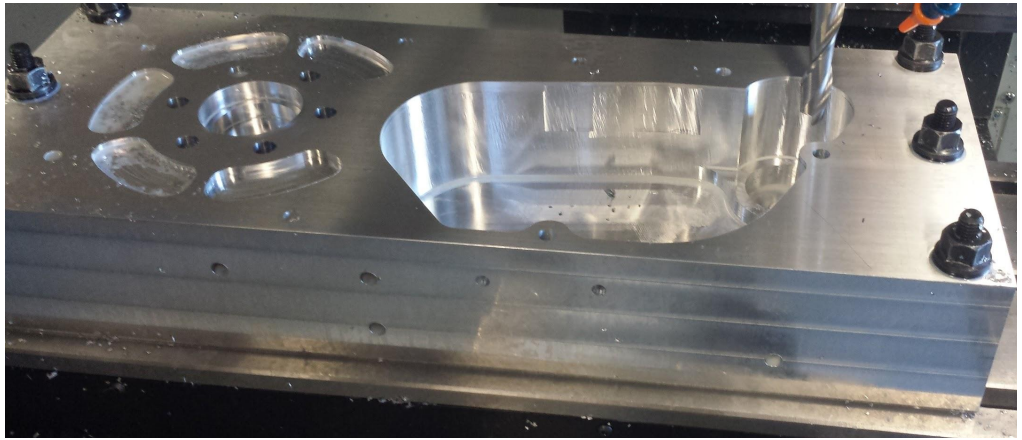
# Final Products:  Gears

Finished Aluminum Gears

- ½” thick gears
- Diametral Pitch: 10
- Pressure Angle: 14.5°
- F.O.S. = 15

Aluminum Gears

# Final Products:  Housing

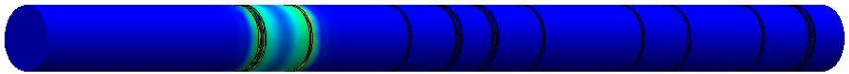


Block One of Three for Housing

# Final Products:  Shafts

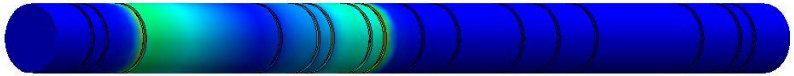

Finished 4340 steel shafts

FEA of Input Shaft



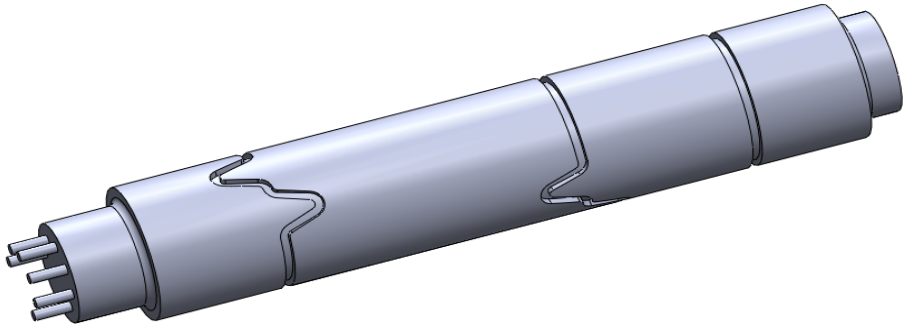
F.O.S. = 51.0

FEA of Output Shaft

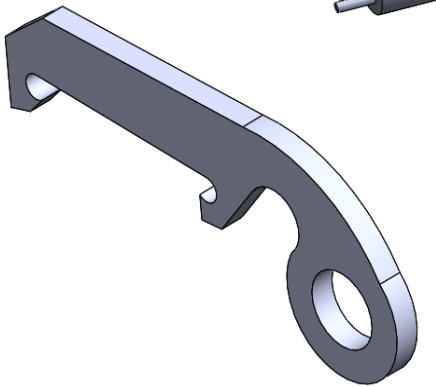


F.O.S. = 7.8

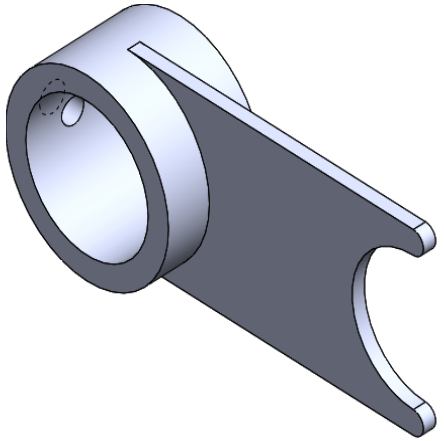
# Final Products: Shifting Mechanisms



Shifting Shaft

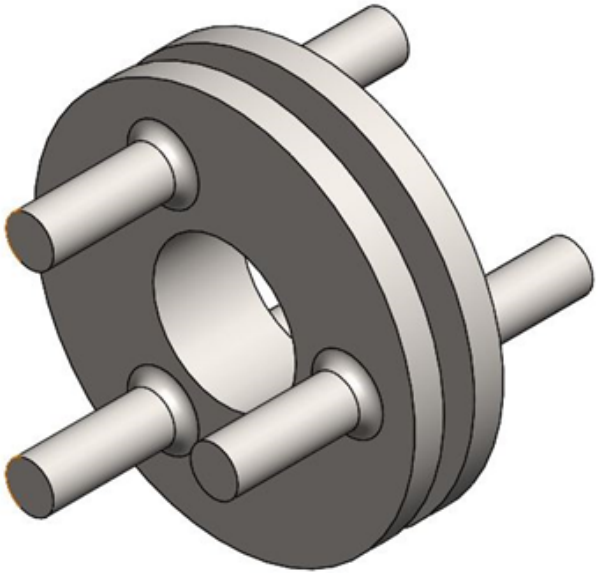


Shift Finger

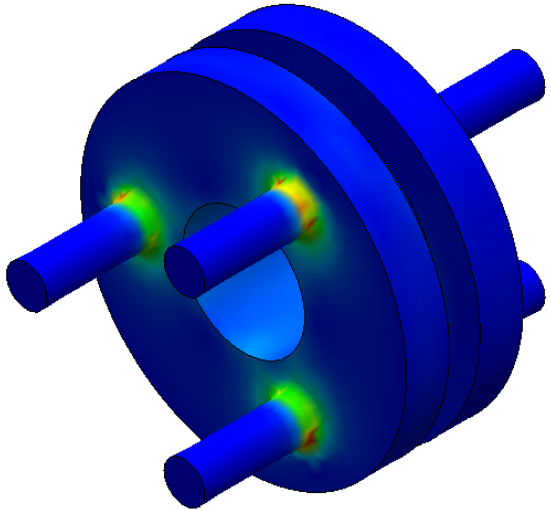


Shift Fork

# Final Products:  Dog Collars



CAD model of dog collar




FEA model of dog collar

F.O.S. = 9.25

# Current Vehicle

# Cost Analysis

***2015 Baja SAE Official Costing Sheet*** **Lumberjack Racing**

| | AUB | MAR | ORE |
|---|---|---|---|
| *Car Number* | | | *91* |
| *Total Cost* | | | *$ 11,183.35* |

| Sect # | Item | Description | Subassembly Costs Material | Subassembly Costs Labor | Vehicle Assembly Labor Time(min) | Vehicle Assembly Labor Cost | Subtotal Material | Subtotal Labor |
|---|---|---|---|---|---|---|---|---|
| 1 | Engine | | $669.52 | $1,019.70 | | $0.00 | $669.52 | $1,019.70 |
| 2 | Transmission | | $176.95 | $210.00 | | $0.00 | $176.95 | $210.00 |
| 3 | Drive Train | | $143.42 | $697.50 | | $0.00 | $143.42 | $697.50 |
| 4 | Steering | | $1,485.20 | $75.90 | | $0.00 | $1,485.20 | $75.90 |
| 5 | Suspension | | $2,133.28 | $403.80 | | $0.00 | $2,133.28 | $403.80 |
| 6 | Frame | | $154.50 | $481.40 | | | $154.50 | $481.40 |
| 7 | Body | | $128.74 | $177.80 | | $0.00 | $128.74 | $177.80 |
| 8 | Brakes | | $1,596.39 | $30.80 | | $0.00 | $1,596.39 | $30.80 |
| 9 | Safety Equipment | | $904.63 | $140.00 | | $0.00 | $904.63 | $140.00 |
| 10 | Electrical Equipment | | $292.43 | $74.80 | | $0.00 | $292.43 | $74.80 |
| 11 | Fasteners | | $85.43 | | | $0.00 | $85.43 | $0.00 |
| 12 | Miscellaneous | | $95.33 | $5.83 | | $0.00 | $95.33 | $5.83 |
| 13 | AUB Event | | $0.00 | $0.00 | | $0.00 | $0.00 | $0.00 |
| 14 | MAR Event | | $0.00 | $0.00 | | $0.00 | $0.00 | $0.00 |
| 15 | ORE Event | | $0.00 | $0.00 | | $0.00 | $0.00 | $0.00 |
| | | **AUB Total:** | $ 7,865.82 | $ 3,317.53 | | $ - | $ 7,865.82 | $ 3,317.53 |
| | | **MAR Total:** | $ 7,865.82 | $ 3,317.53 | | $ - | $ 7,865.82 | $ 3,317.53 |
| | | **ORE Total:** | $ 7,865.82 | $ 3,317.53 | 0 | $ - | $ 7,865.82 | $ 3,317.53 |

Team Captain: Ricardo Dyonga Date: 2/18/2015 Approval: Jeremy Petok Date: 2/18/2015

Level 1 Summary

Revision: 2015 Rev B

# Conclusion

- NAU SAE Baja competition team
- Frame is now at the projected weight of 150 lbf and meets SAE safety criterion
- Suspension allows for 14 inches of ground clearance and 6 inches of travel
- Turning radius of 11 ft with 12-to-1 rack ratio and 1.5 turns of the steering wheel lock-to-lock
- Drivetrain is lightweight and is optimized for the hill climb and acceleration challenges by using 4 different forward gear ratios
- Reverse is implemented into drivetrain for better versatility
- The team will participate in collegiate competition on May 30th in Portland Oregon

# References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- http://www.superatv.com/Polaris-Ranger-XP-900-6-Lift-Kit-P8182.aspx, access 2014.
- http://socalbajas.com/, access 2014.
- Introduction to Finite Element Analysis and Design
- http://www.youtube.com/watch?v=gAwVya8AfyM
- 2015 Collegiate Design Series Baja SAE® Rules
- Structural Considerations of a Baja SAE Frame
- NAU SAE Baja 2013-2014

# References


- http://www.desertkarts.com, access 2014.
- 11_0_0_Steering_Theroy.pdf
- **Introduction to Finite Element Analysis and Design** K. Nam-Ho, “Introduction to Finite Element Analysis and Design” 2008, Wiley.
- **2015 Collegiate Design Series Baja SAE® Rules** SAE International, “2015 Collegiate Design Series Baja SAE Rules” 2014, 2014.
- **Structural Considerations of a Baja SAE Frame** A. T. Owens, "Structural considerations of a baja SAE frame," 2006-12-05, 2006.
- **NAU SAE Baja 2013-2014**

# Sponsors



# Questions?