NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

SAE Mini Baja

Final Presentation

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May 2, 2014

Overview

- Project Introduction
- Need Statement
- Frame Design and Analysis
- Drivetrain Design and Analysis
- Suspension Design and Analysis
- Cost Report
- Competition Results
- Conclusion

Anthony McClinton

Project Introduction

- 2014 SAE Baja Competition
- Customer is SAE International
- Create international design standards
- Hold various collegiate design competitions
- Stakeholder is NAU SAE
- Project advisor is Dr. John Tester

Anthony McClinton

Need Statement

- NAU has not won an event at the SAE Baja competition in many years.
- Goal of the frame team is to design the lightest possible frame within the SAE Baja rules.
- Goal changes to overall vehicle safety compliance after completion of the frame.
- Build a drive-train for the Baja vehicle so that it can compete against other teams in all events
- Build a suspension system that is strong and adjustable and a steering system that has agile maneuverability.

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Frame Design Objectives

- Minimize frame weight
- Minimize cost
- Maximize safety
- Maximize manufacturability

Frame Constraints

- AISI 1018 tubing or equivalent strength
- Frame length less than 108 inches
- Frame width less than 40 inches
- Frame height less than 41 inches above seat bottom
- Frame geometry must conform to all SAE Baja Rules

Tubing Selection

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

Bending Strength and Stiffness

$$Stiffness = E \cdot I$$

$$Strength = \frac{S_y \cdot I}{c}$$

E = 29,700 ksi for all steel

I = second moment of area

S_y = yield strength

c = distance from neutral axis to extreme fiber

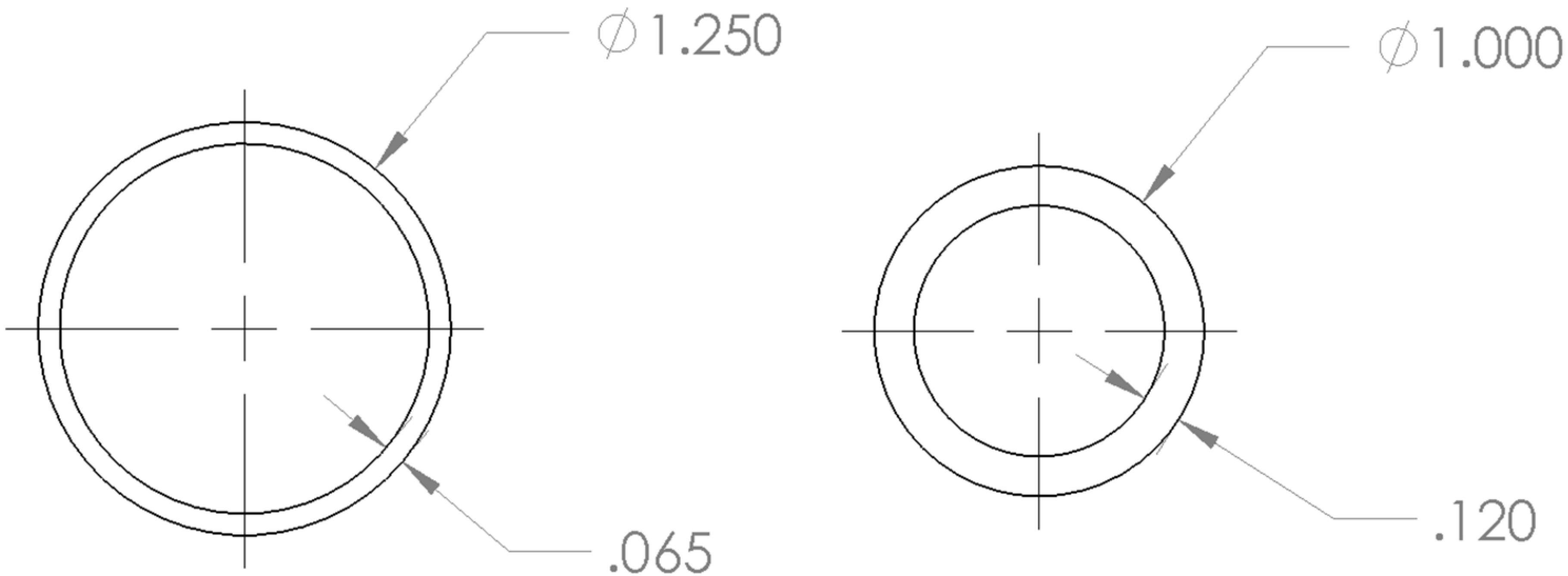
AISI 1018

Diameter [in]	Wall Thickness [in]	Stiffness [in-lb]	Strength [in^2-lb]
1.000	0.120	971.5	3.513

AISI 4130

Diameter [in]	Wall Thickness [in]	Stiffness [%]	Strength [%]	Weight [%]
1.000	0.120	100	118	100
1.125	0.083	113	119	81.9
1.125	0.095	126	131	92.7
1.250	0.065	130	122	72.9
1.375	0.065	176	150	80.6
1.500	0.065	231	181	88.3

Final Selection



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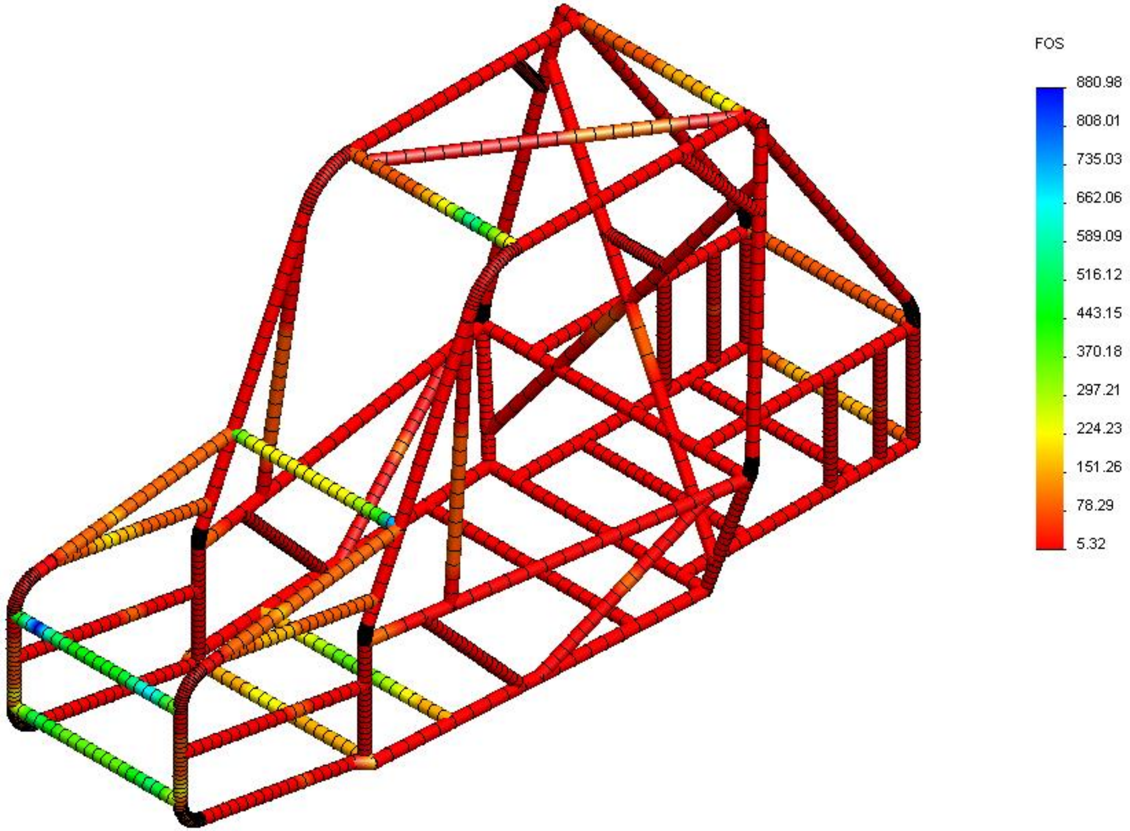
Analysis Assumptions

- Frame Weight: 100 lb
- Drivetrain Weight: 120 lb
- Suspension Weight: 50 lb per corner
- Driver Weight: 250 lb

- AISI 4130 Tubing, 1.25 in Diameter, 0.065 Thickness

Drop Test Safety Factor



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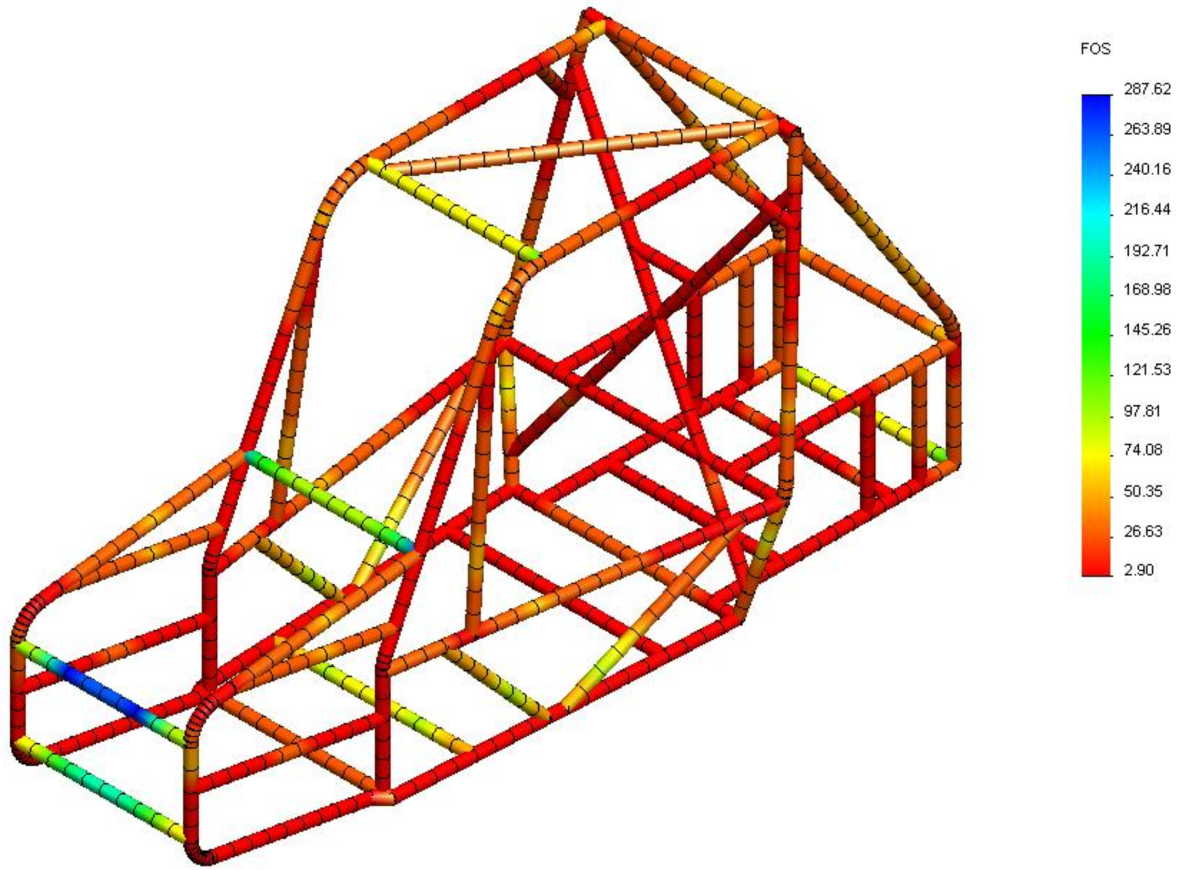
Front Collision Safety Factor



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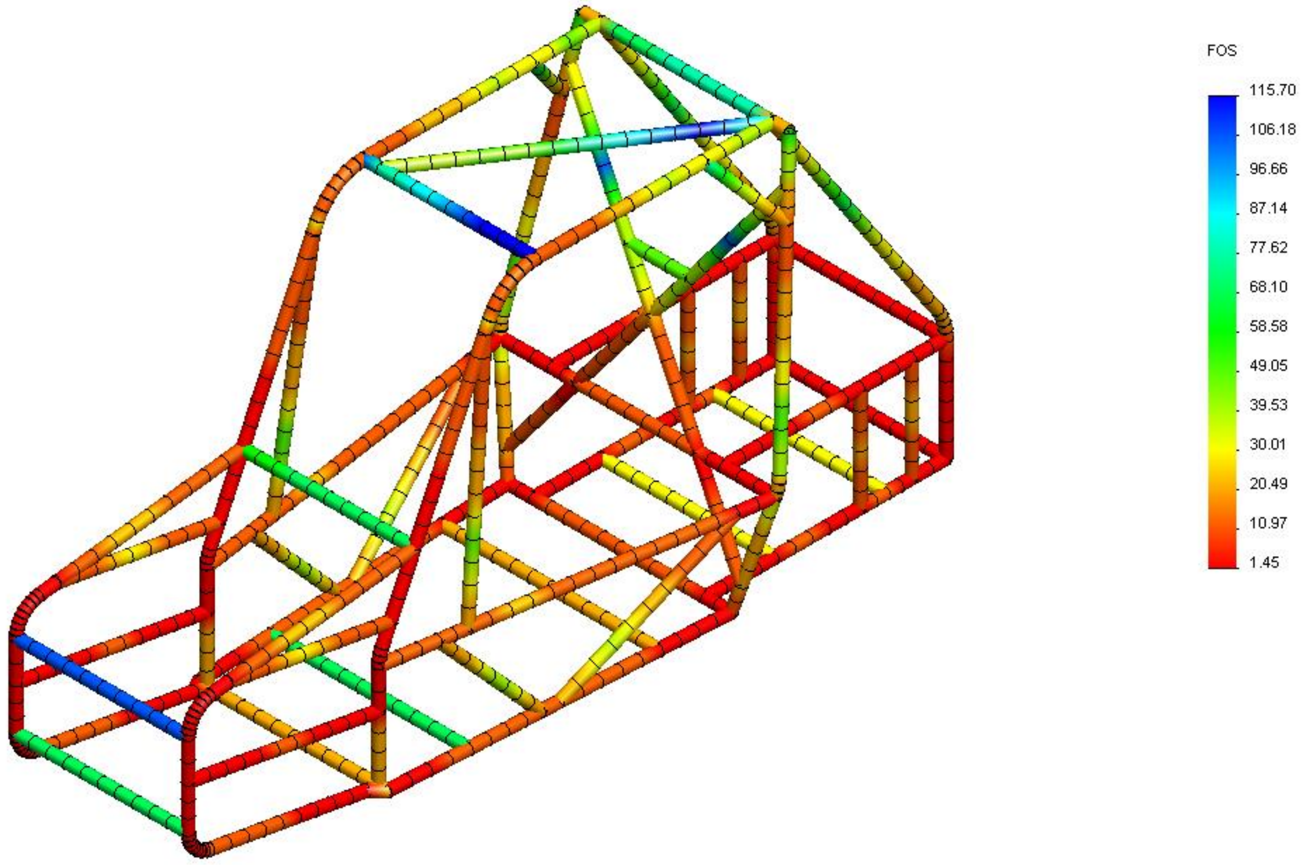
Rear Collision Safety Factor



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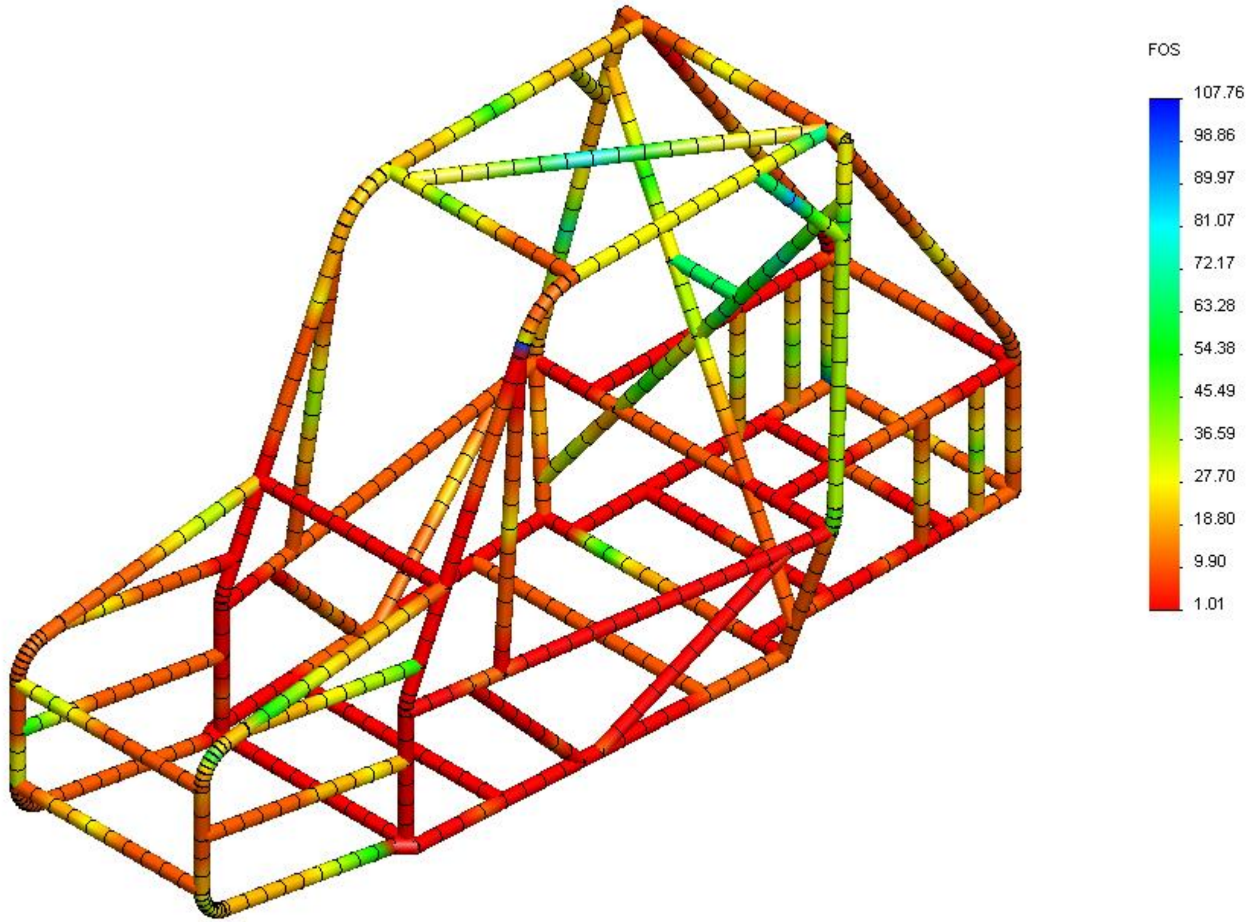
Side Impact Safety Factor



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Impact Results Summary

Test	Max Deflection [in]	Yield Safety Factor
Drop	0.089	5.32
Front Collision	0.135	2.90
Rear Collision	0.263	1.45
Side Impact	0.363	1.01

Eric Lockwood

Engineering Design Targets

Requirement	Target	Actual
Length [in]	108	88.18
Width [in]	40	32
Height [in]	41	44.68
Bending Strength [N-m]	395	486.0
Bending Stiffness [N-m^2]	2789	3631
Wall Thickness [in]	0.062	0.065
Pass Safety Rules	TRUE	TRUE

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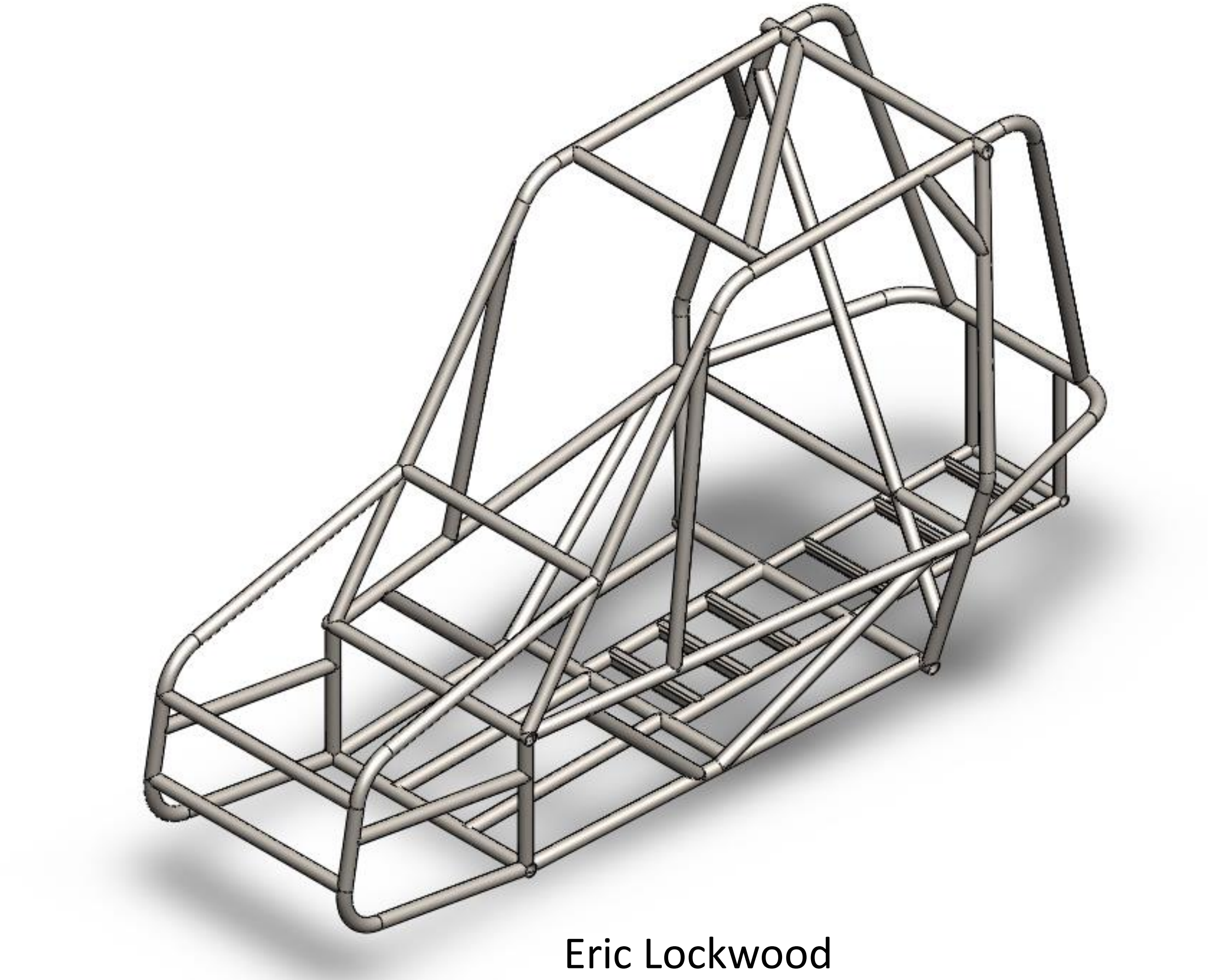
Brake Design

- Dual master cylinders
- Dual brake pedals
- Front and Rear braking

Final Frame Design



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Final Frame Built

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Drivetrain Objectives

- To build a drivetrain that will maximize speed and torque of the vehicle.
- To build a drivetrain that is reliable and durable.
- To build a drivetrain that is easy to operate

Ruoheng Pan

Drivetrain Analysis

- The top teams averaged: 4.3 sec. to finish a 100 ft course.
- Assuming constant acceleration, we can calculate the maximum velocity:

Distance = Max Velocity * time / 2

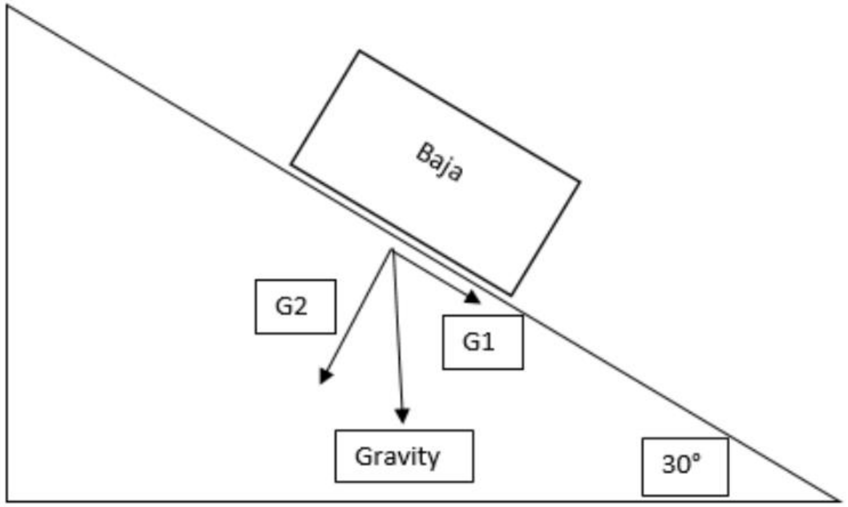
Max velocity = Distance* 2 / time = 100 ft * 2* 0.68/ 4.3s = 31.6 mph

- Max speed of 30 mph

Ruoheng Pan

Drivetrain Analysis

- G1 = G * sin ∂ = 600lb * sin 30 = 300 lb
- Force per wheel = 150 lb
- Torque per wheel = 150lb * D/2
  = 150lb * 11.5 in/12 = 143.75 $lb - ft$
- Total torque = 287.5 $lb - ft$
- Max torque 300$lb - ft$



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Speed and torque Analysis

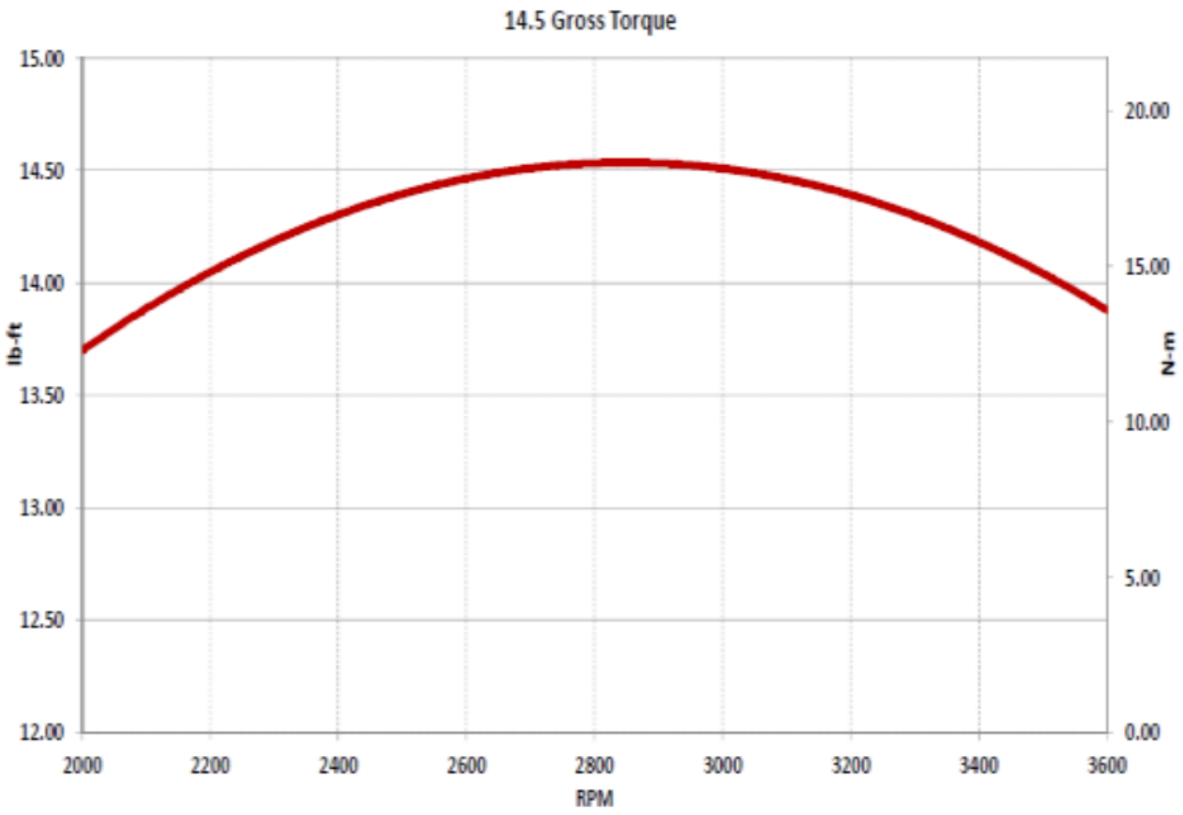
- CVT: PULLEY SERIES 0600-0021 AND DRIVEN PULLEY SERIES 5600-0171 from CVTech-AAB Inc.

  High speed ratio (r_{cvt-h}) : 0.43 Low speed ratio (r_{cvt-l}) : 3
- Differential: Dana Spicer, H-12 FNR

  Forward ratio (r_{d-f}): 13.25 Reverse ratio (r_{d-r}): 14.36
- CVT ratio = 3 - $\frac{2.57*(rpm-800)}{2800}$ for 800<rpm<3600
- Total ratio = $r_{cvt} * r_{d-f} * N_{cvt}$ = $r_{cvt} * 12$ * 0.88
- Torque on the wheel = Torque output * Total ratio * N_{cvt}
- Speed = $\frac{D * RPM * \pi}{total\ ratio * 12 * 60} * 0.68 = \frac{23\ in * RPM * \pi}{total\ ratio * 12 * 60} * 0.68$

Ruoheng Pan

Torque curve



Source: Briggs & Stratton

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Speed and Torque Calculation

Engine rpm	Torque output (lb-ft)	CVT ratio	Total ratio	Torque on wheel (lb-ft)	Speed (mph)
1800	13.20	2.082	24.278	320.467	5.06
2000	13.70	1.899	22.137	303.282	6.17
2200	14.10	1.715	19.997	281.956	7.51
2400	14.30	1.531	17.856	255.347	9.17
2600	14.45	1.348	15.716	227.096	11.29
2800	14.52	1.164	13.576	197.117	14.08
3000	14.50	0.981	11.435	165.809	17.90
3200	14.40	0.797	9.295	133.843	23.49
3400	14.20	0.614	7.154	101.590	32.43

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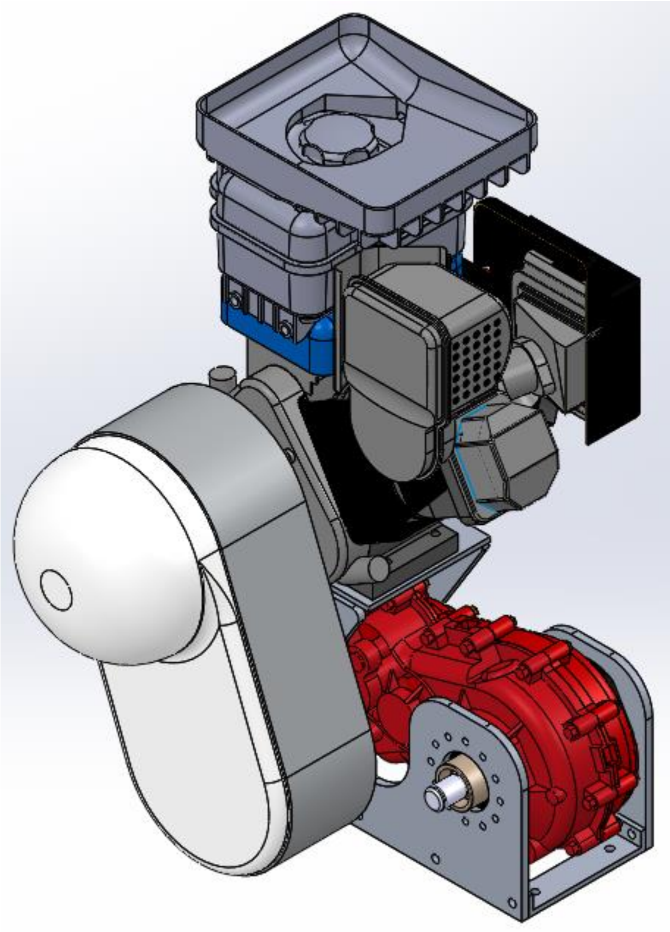
Drivetrain System



Drivetrain system CAD

Assembled Drivetrain system

Engine and Transmission Mount

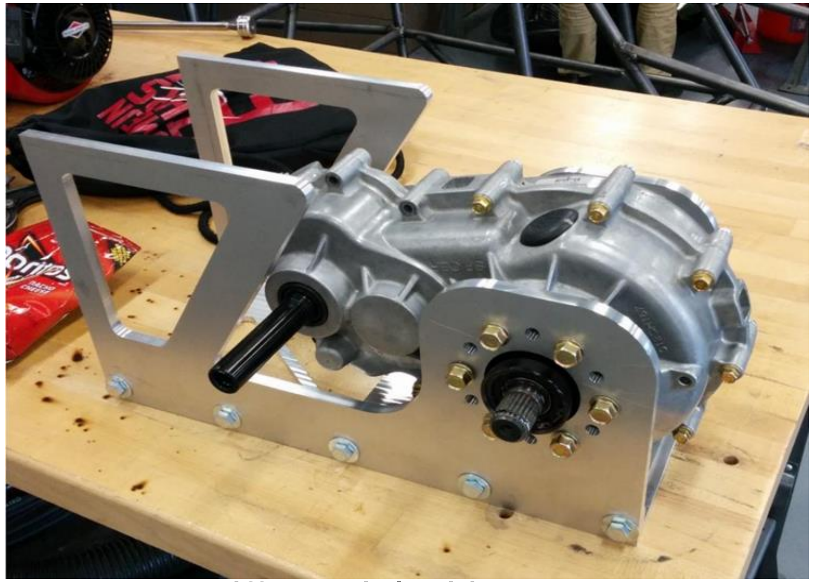
- The team designed a mount for engine and transmission.
- The mount is made by aluminum.
- The team came up with the FEA analysis for this mount.

Assume the load applied on the engine support is 200lb.

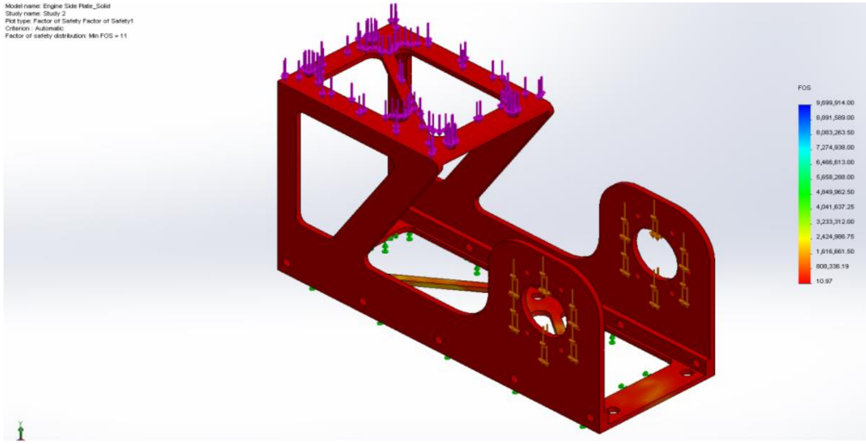
Assume the load on the differential support is 80 lb.

Safety factor: The minimum safety factor is 10.97.

Displacement: the maximum displacement on the mount is 0.228mm.

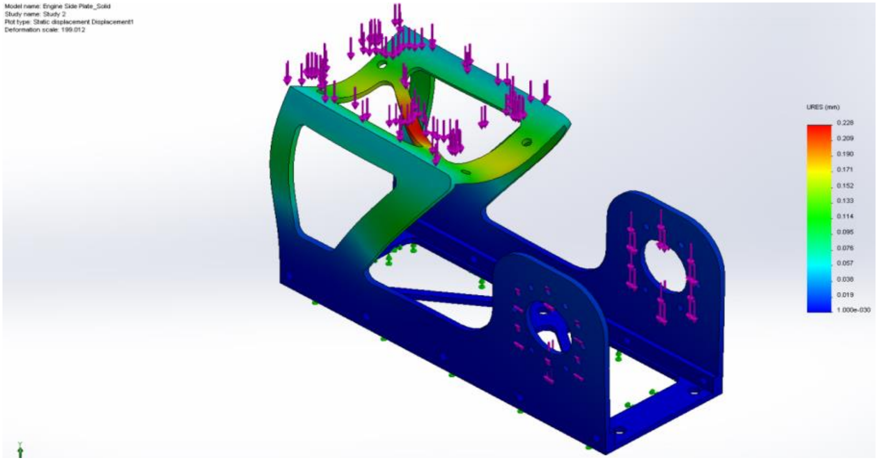


Differential with Mount



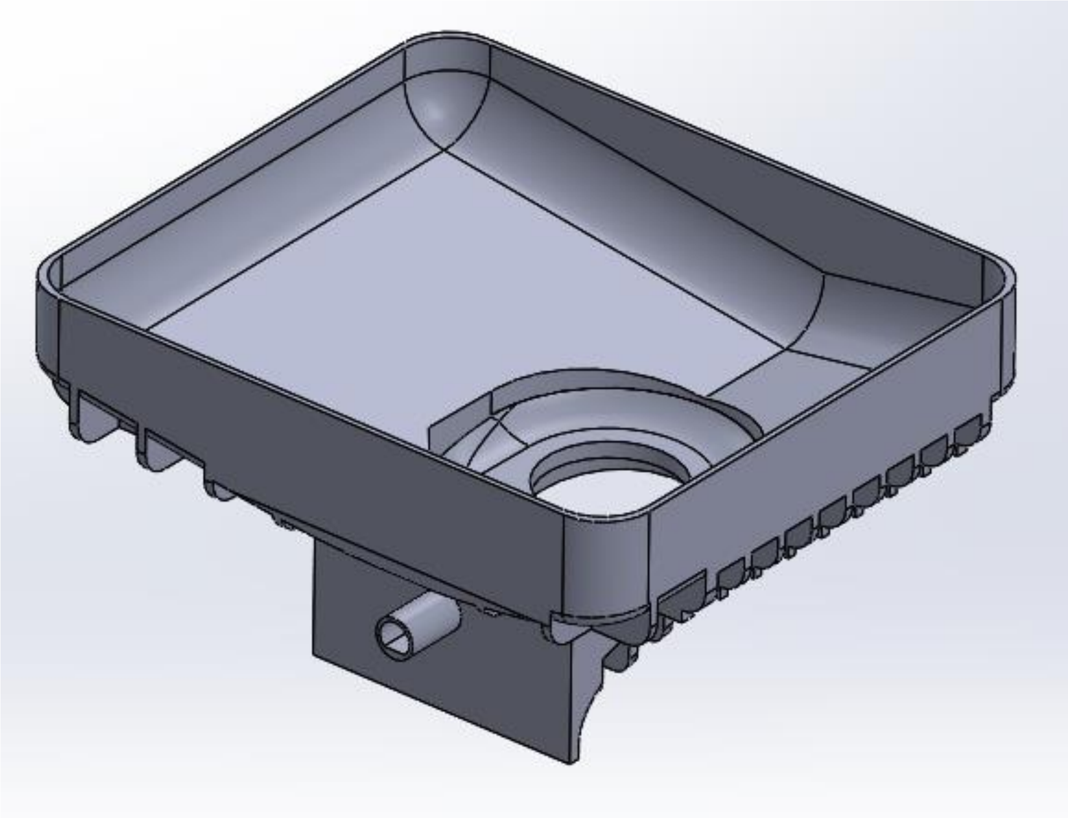
Safety Factor Analysis

Caizhi Ming



Displacement Analysis

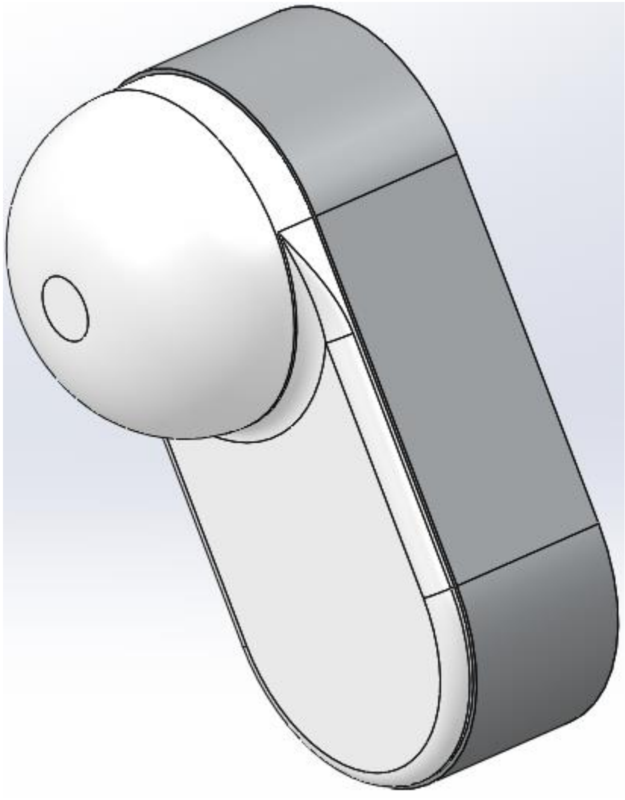
Drip Pan



Drip Pan CAD

Drip Pan

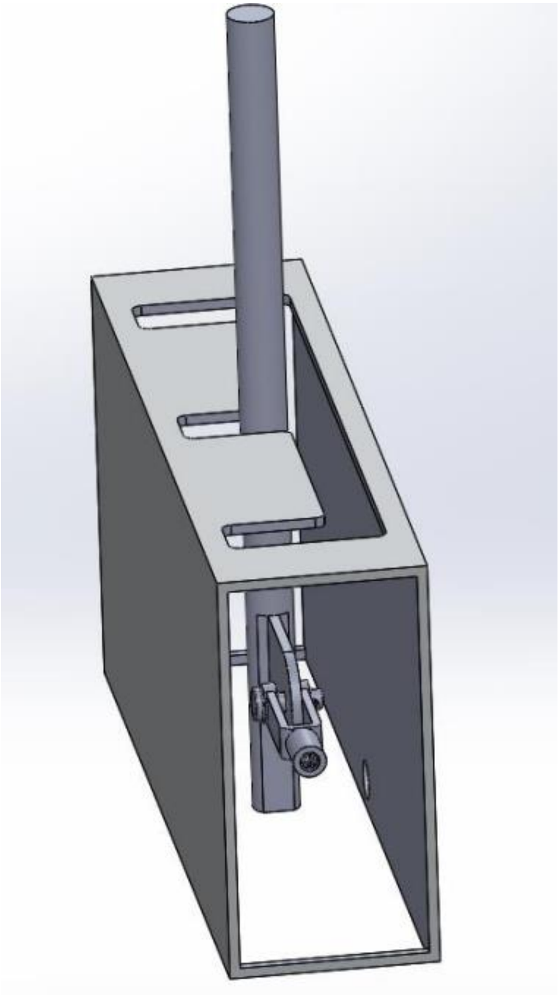
CVT Guard



CVT Guard CAD

CVT Guard

Shifting System

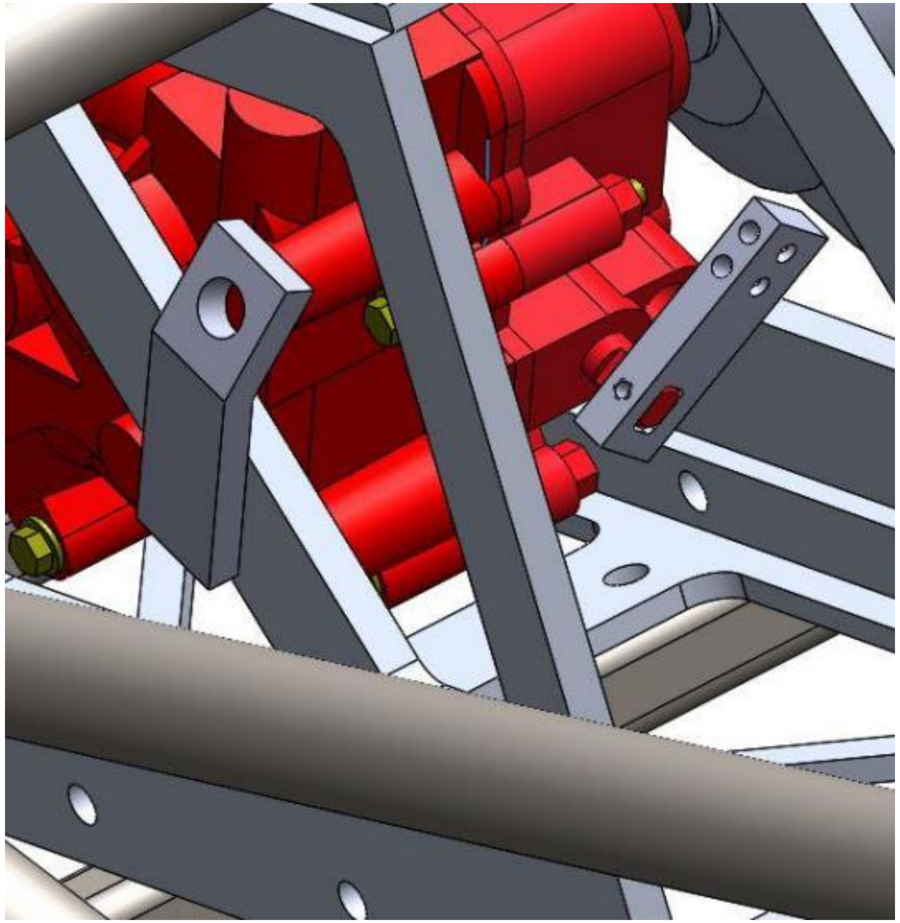


Shifting System CAD

Assembled Shifting System

Caizhi Ming

Shifting System



Shifting Cable Lock and Shifting Lever CAD

Assembled Shifting Cable Lock and Shifting Lever

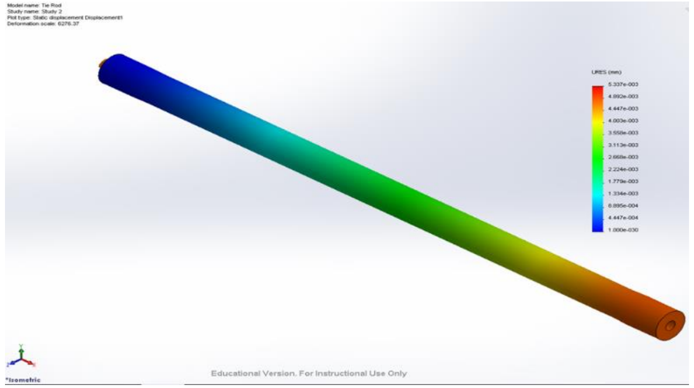
Suspension and Steering Design Objectives

- Strong suspension members
- Suspension systems that will reduce shock and fatigue to components and drivers
- Smaller turning radius than NAU's previous mini Baja vehicles

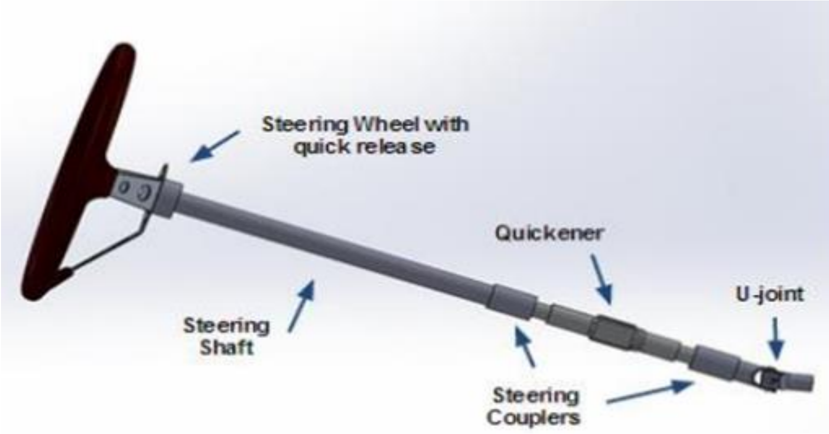
Benjamin Bastidos

Steering Components

- Final Steering Design
  - Mounted rack and pinion using ¼” plate by 6”
  - Decided on using a quickener
    - Reduces amount of steering wheel turns for full lock
  - First had tie rods connected at extensions of rack and pinion
    - Even with FEA, testing showed we needed an improved design



FEA of Tie Rod

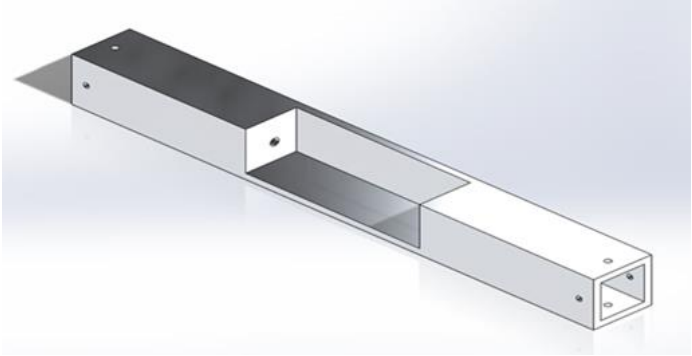


Schematic of Steering System

Benjamin Bastidos

Steering Components (Cont'd)

- Needed to strengthen extension components
  - Previous extensions = sheared, lacking support
- As well as lengthening rack length
  - Would allow tie rods and A-Arms to pivot on same plane
  - Doing so would eliminate "bump steer"
- Local company (Geiser Brothers) recommended using hollow square shaft
  - Rack would be placed at center of shaft
  - Offering support to extensions
    - Commenly used in sand rails (Geiser Brothers)



Square Shaft for Steering

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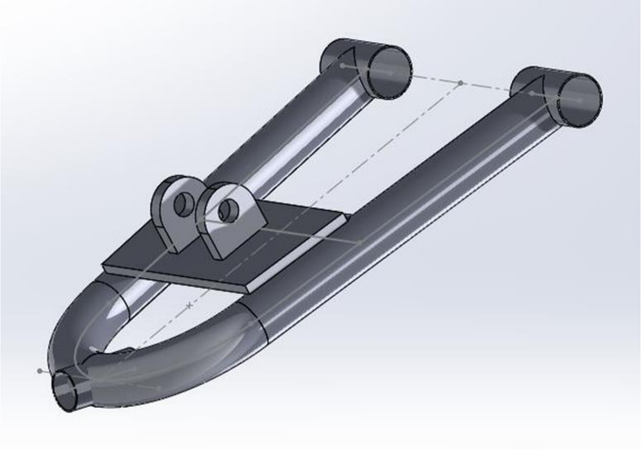
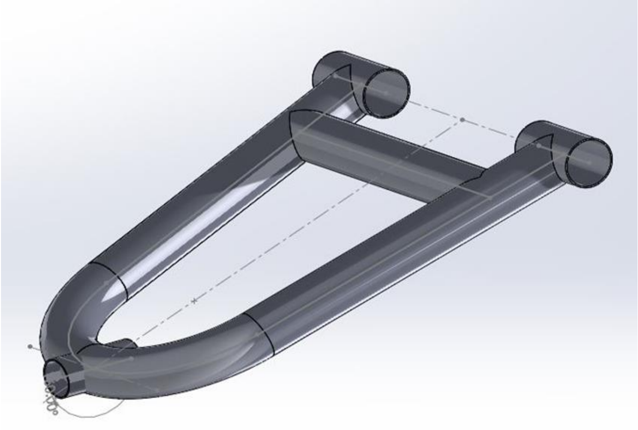
Front Suspension

- Final A-Arm Design
  - 20 degree Attachment to hub
  - To add simplicity, a bolt through bushing design is used to mount A-Arms to frame
  - Shocks previously mounted on lower A-Arm, now on upper
    - Allows clearance for steering components



Upper A-Arm



Lower A-Arm

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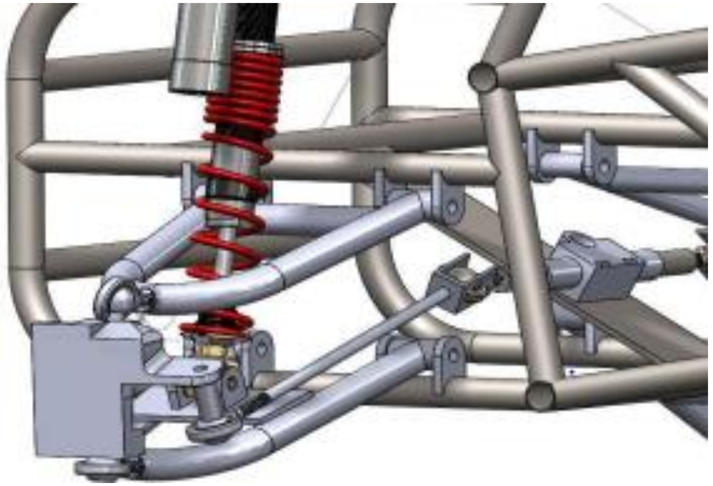
Front Suspension (Cont’d)

- Finalized A-Arm length
  - Top A-Arm: 11”
  - Bottom A-Arm: 12”

- McMaster Carr 5/8” heim joints threaded into A-Arms
  - Used for an adjustable cambe
  - Important for Endurance race



Previous A-Arms

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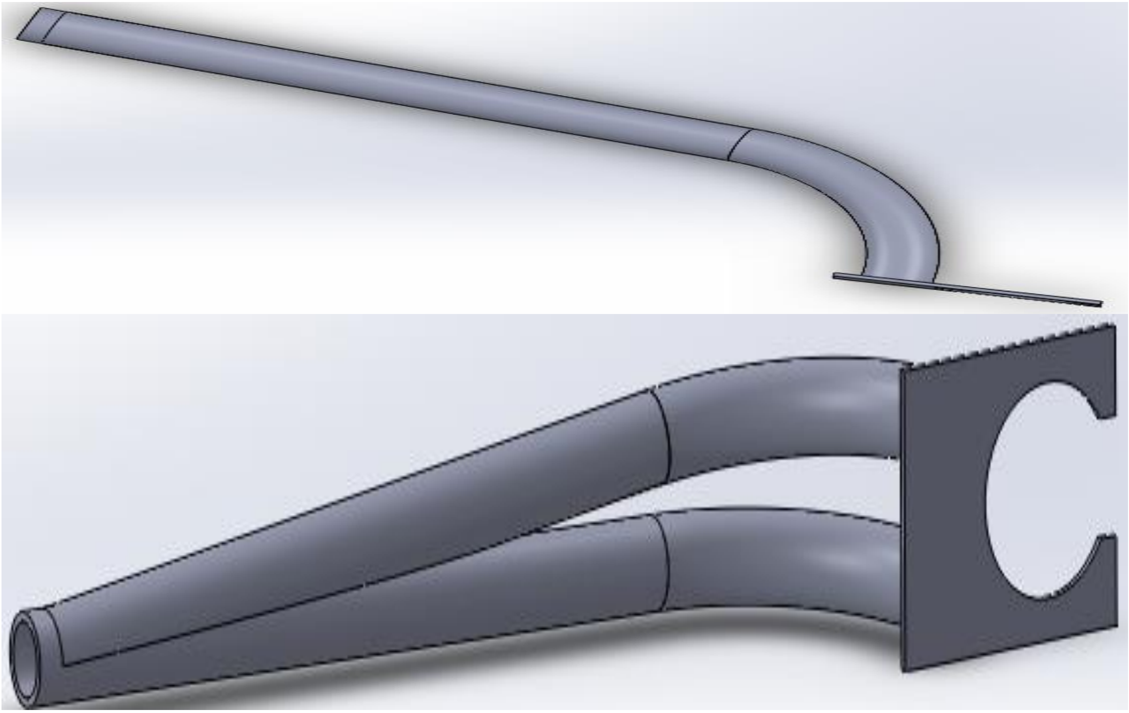
Rear Suspension

- 3-link trailing arm design
  - Simple geometry
  - Less material
  - Long travel capabilities
- Length: 17”
- 4130 chromolly steel
  - 1.25” OD
  - 0.095 wall thickness



Jeramie Goodwin

Rear Suspension Construction Photos



Jeramie Goodwin

Rear Suspension Construction Photos

Jeramie Goodwin

Final Vehicle

Jeramie Goodwin

Cost Report

2014 Baja SAE Official Costing Sheet — **NAU Lumber Jack Racing**

	ILL	TEX	KAN
Car Number		*106*	
Total Cost		*$ 13,018.30*	

Sect #	Item	Description	Subassembly Costs Material	Subassembly Costs Labor	Vehicle Assembly Labor Time(min)	Vehicle Assembly Labor Cost	Subtotal Material	Subtotal Labor
1	Engine		$1,139.93	$17.50		$0.00	$1,139.93	$17.50
2	Transmission		$1,917.60	$17.50		$0.00	$1,917.60	$17.50
3	Drive Train		$1,351.22	$70.00		$0.00	$1,351.22	$70.00
4	Steering		$1,128.01	$26.25		$0.00	$1,128.01	$26.25
5	Suspension		$3,441.65	$105.00		$0.00	$3,441.65	$105.00
6	Frame		$543.94	$353.60			$543.94	$353.60
7	Body		$261.50	$11.67		$0.00	$261.50	$11.67
8	Brakes		$1,428.36	$35.00		$0.00	$1,428.36	$35.00
9	Safety Equipment		$259.15	$17.50		$0.00	$259.15	$17.50
10	Electrical Equipment		$278.00	$35.00		$0.00	$278.00	$35.00
11	Fasteners		$0.00			$0.00	$0.00	$0.00
12	Miscellaneous		$0.00	$0.00		$0.00	$0.00	$0.00
13	ILL Event		$0.00	$0.00		$0.00	$0.00	$0.00
14	TEX Event		$579.92	$0.00		$0.00	$579.92	$0.00
15	KAN Event		$0.00	$0.00		$0.00	$0.00	$0.00
		ILL Total:	$11,749.36	$ 689.02		$ -	$ 11,749.36	$ 689.02
		TEX Total:	$12,329.28	$ 689.02	0	$ -	$ 12,329.28	$ 689.02
		KAN Total:	$11,749.36	$ 689.02		$ -	$ 11,749.36	$ 689.02

Team Captain: ______________________ Date: ________ Approval: ______________________ Date: ________

Level 1 Summary — Revision: 2014 Rev A

Jeramie Goodwin

Competition Results

- Acceleration
- Hill Climb
- Maneuverability
- Suspension and Traction
- Endurance

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Acceleration

64th out of 96 vehicles

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Hill Climb

56th out of 96 Vehicles

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Maneuverability

Placed 27th out of 96 Vehicles

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Suspension and Traction

Placed 56th out of 96 Vehicles

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Endurance

Placed 46th out of 96 Vehicles

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Overall Testing Results

- Placed 51st overall out of 96 vehicles
- Engine mount failed
- A rim cracked
- A flat tire
- Shifter cable became loose

Anthony McClinton

Conclusion

- SAE international is the client, NAU SAE is a stakeholder, and Dr. John Tester is the project advisor
- The Frame team selected AISI 4130 tubing, analyzed the factor of safety of different scenarios, and was able to successfully build the frame designed.
- The Drivetrain team selected a CVT and a differential and was able to implement the design.
- The Suspension was overbuilt but, it was sufficient for this competition.

Anthony McClinton

Conclusion

- Lumberjack Racing was able to stay within the budget given at the beginning of the semester.
- Lumberjack Racing placed 51^{st} overall in the competition due to some struggles and lack of experience.

Anthony McClinton

References

- Owens, T., Anthony, Jarmulowicz, D., Marc, Jones, Peter “Structural Considerations of a Baja SAE Frame,” SAE Technical Paper 2006-01-3626, 2006.
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- Tester, John, Northern Arizona University, personal communication, Nov. 2013.

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Bill G. Bennett

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