Baja SAE: Four Wheel Drive Integration

April 25, 2021

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Group Members: Aaron Corona
Chris Escobar
Ezechiel Lucien
Maung Thu
Brian Torres
Britney Tran
Rafael Zamarron-Brito

Agenda

I. Introduction/Background
II. Project Requirements
III. Technical Progress
   - Chain Drive
   - Differential
   - Wheel Hub
   - Brakes
   - Front Suspension
   - Shocks
   - Driver Ergonomics
IV. Summary

Project Background

Team Objective: To design a 4-wheel drive Baja vehicle

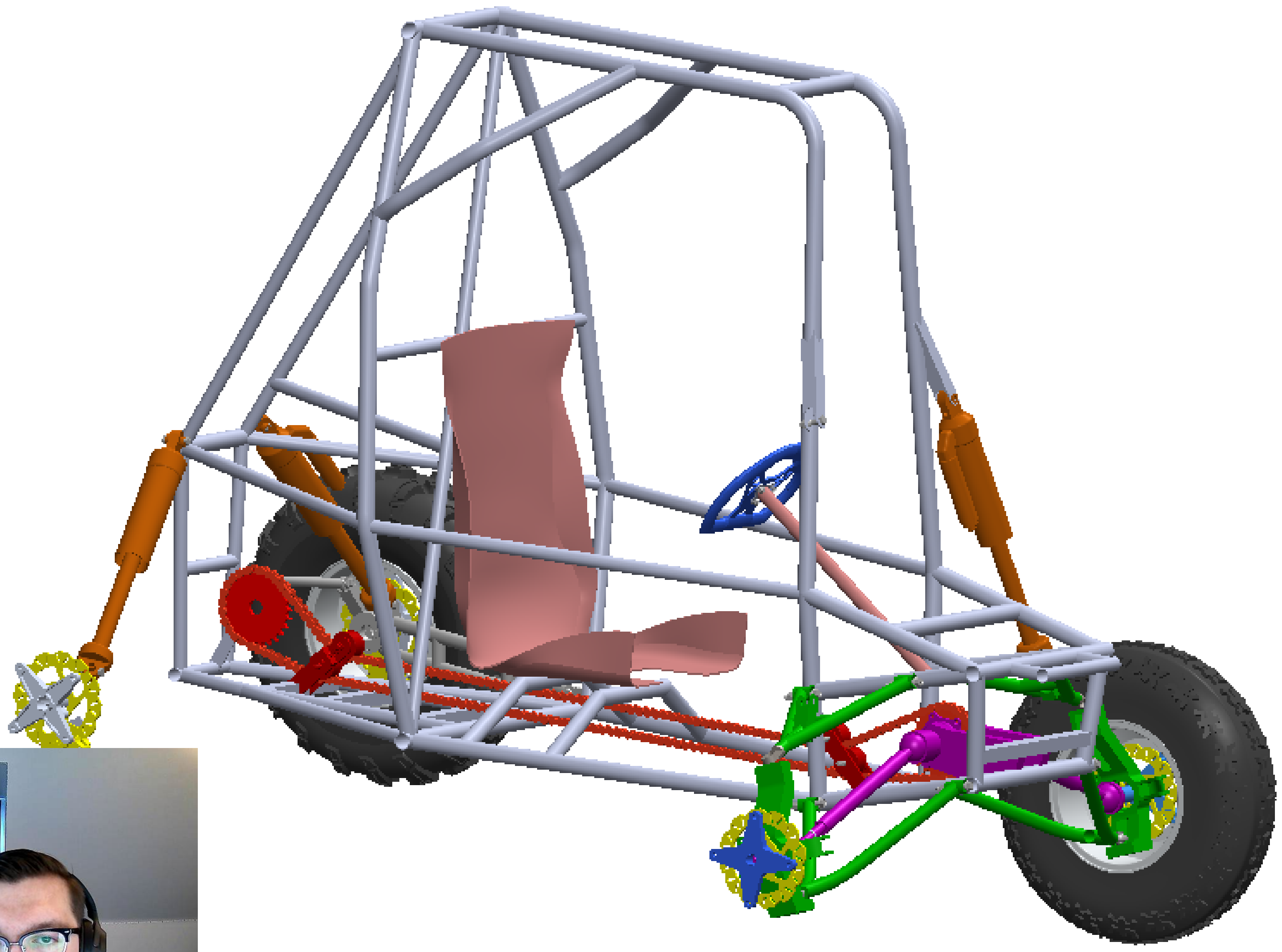
Background: Baja SAE is a collegiate design competition where students must design and manufacture a single seat off road vehicle. Competition rules now require all cars to be 4-wheel drive

2021 Eagle Talon IV GT

Vehicle Requirements

Section 1.1	Requirement	Parent Requirement	Verification Method
1.1-1	All 4 wheels shall be powered by engine	Competition Requirements	Inspection
1.1-2	Shall comply with all rules established by Baja SAE competition	Competition Rules	Inspection
1.1-3	Shall have no failures over a 6-hour endurance run.	Competition Running Time	Stress analysis on components
1.1-4	Shall have acceleration times within 5% of two-wheel drive vehicle	Team Goals	Timed acceleration runs
1.1-5	Vehicle shall place higher in competition in dynamic events (hill climb, maneuverability)	Team Goals	Competition placement/timed tests

Project Organization



Aaron – Front Suspension
- Geometry/Kinematic Analysis
- CAD Design and Analysis

Britney – Front Differential
- Differential Placement
- Mounting CAD & Analysis

Chris – Shock Analysis
- Shock selection & tuning
- Quarter & half car model

Rafael – Steering Wheel & Hubs
- CAD Designs
- Analysis & Fatigue

Maung – Chain Drive
- Sprocket and Chain selection
- Tensioner design & analysis

Brian – Driver Ergonomics
- Seat & steering wheel position
- Seat CAD

Ezechiel – Brakes System
- Pedal design
- Master cylinder & caliper selection

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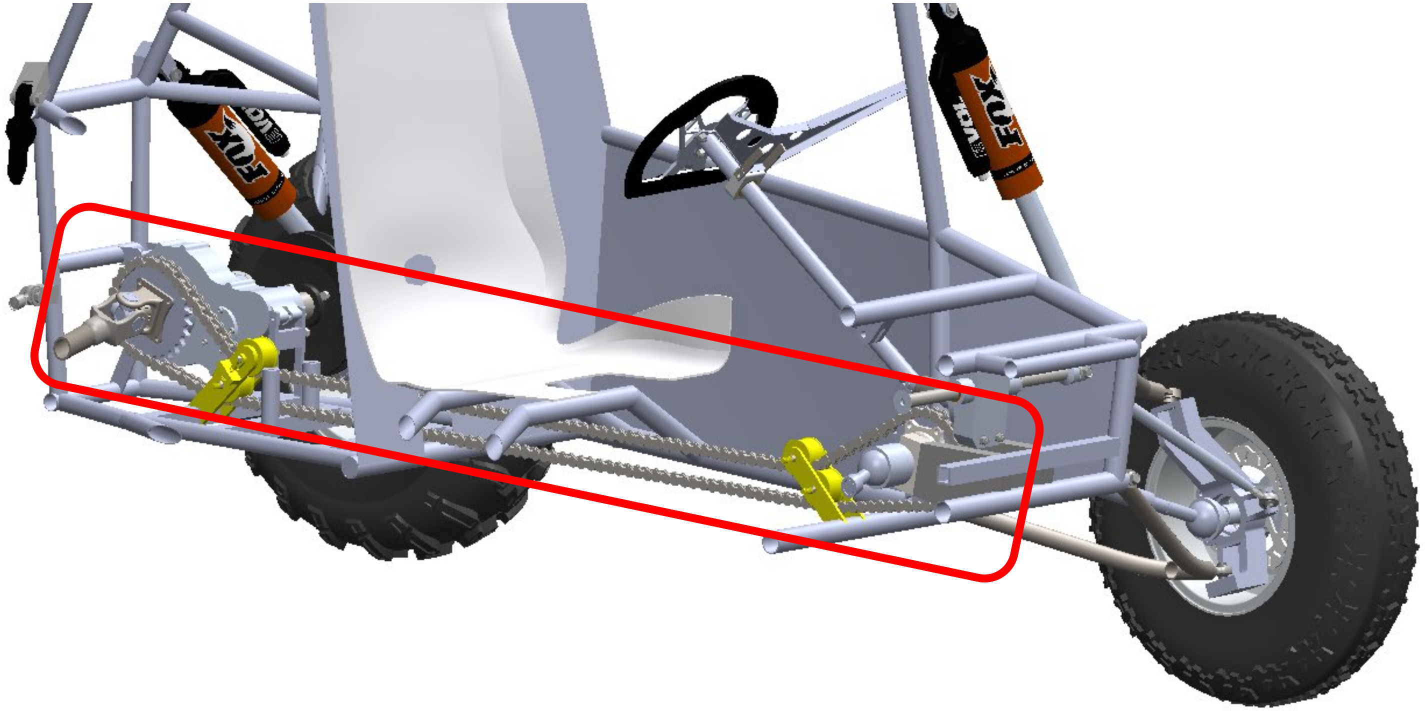
IV. Questions?

Placement of Chain Drive



Sectioned View of Full Assembly Baja Vehicle

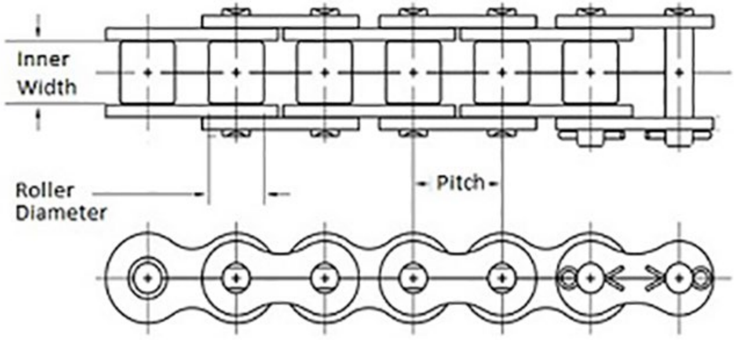
Engine Horsepower: 9 HP
Engine RPM: 3600
Total Gear Ratio: 32-1
Chain Gear Ratio: 1.03 – 1
Sprocket RPM: 117

Selection of Sprocket and Chain

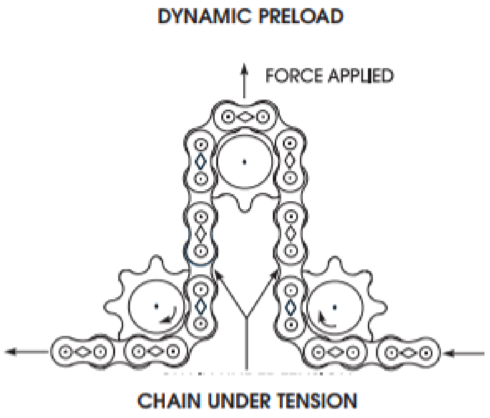
Table 1	Chain 80
Sprocket Ratio	26/25
Working Load (lbf)	**1216.58**
Allowable Working Load (lbf)	**3300**
Ult.Tensile Strength (psi)	12500
Weight (lbs/ft)	1.86
Front Sprocket Diameter (in.)	7.97

Table 2	Chain 60
Sprocket Ratio	22/21
Working Load (lbf)	**1913.60**
Allowable Working Load (lbf)	**1950**
Ult.Tensile Strength (psi)	7030
Weight (lbs/ft)	0.99
Front Sprocket Diameter (in.)	5.03

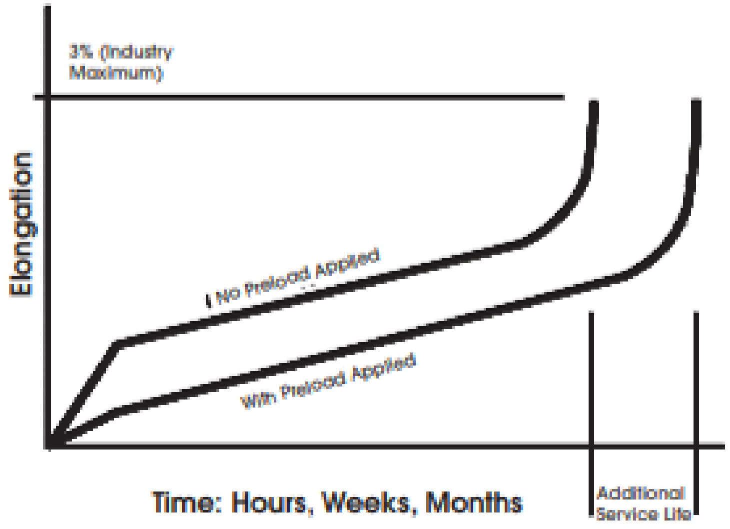
Table 3	Chain 50
Sprocket Ratio	27/26
Working Load (lbf)	**1874.57**
Allowable Working Load (lbf)	**1400**
Ult.Tensile Strength (psi)	4880
Weight (lbs/ft)	0.67
Front Sprocket Diameter (in.)	5.18



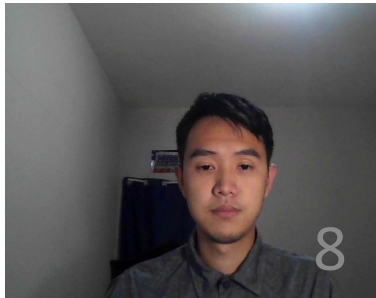
Roller Chain



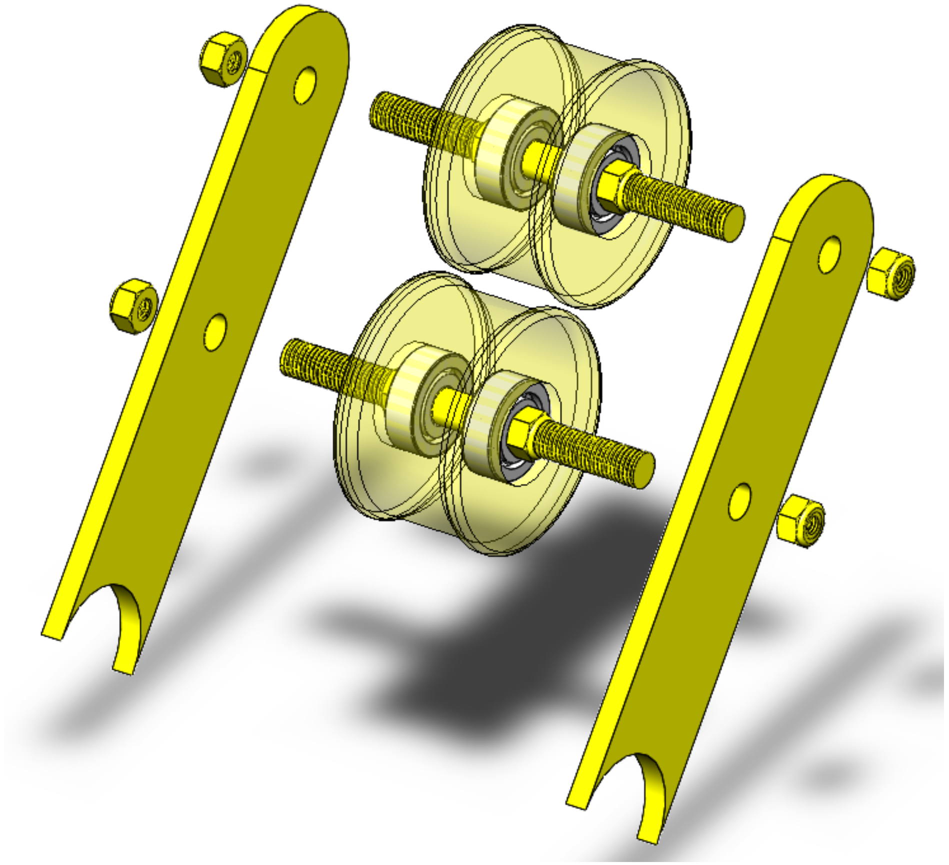
Preloading



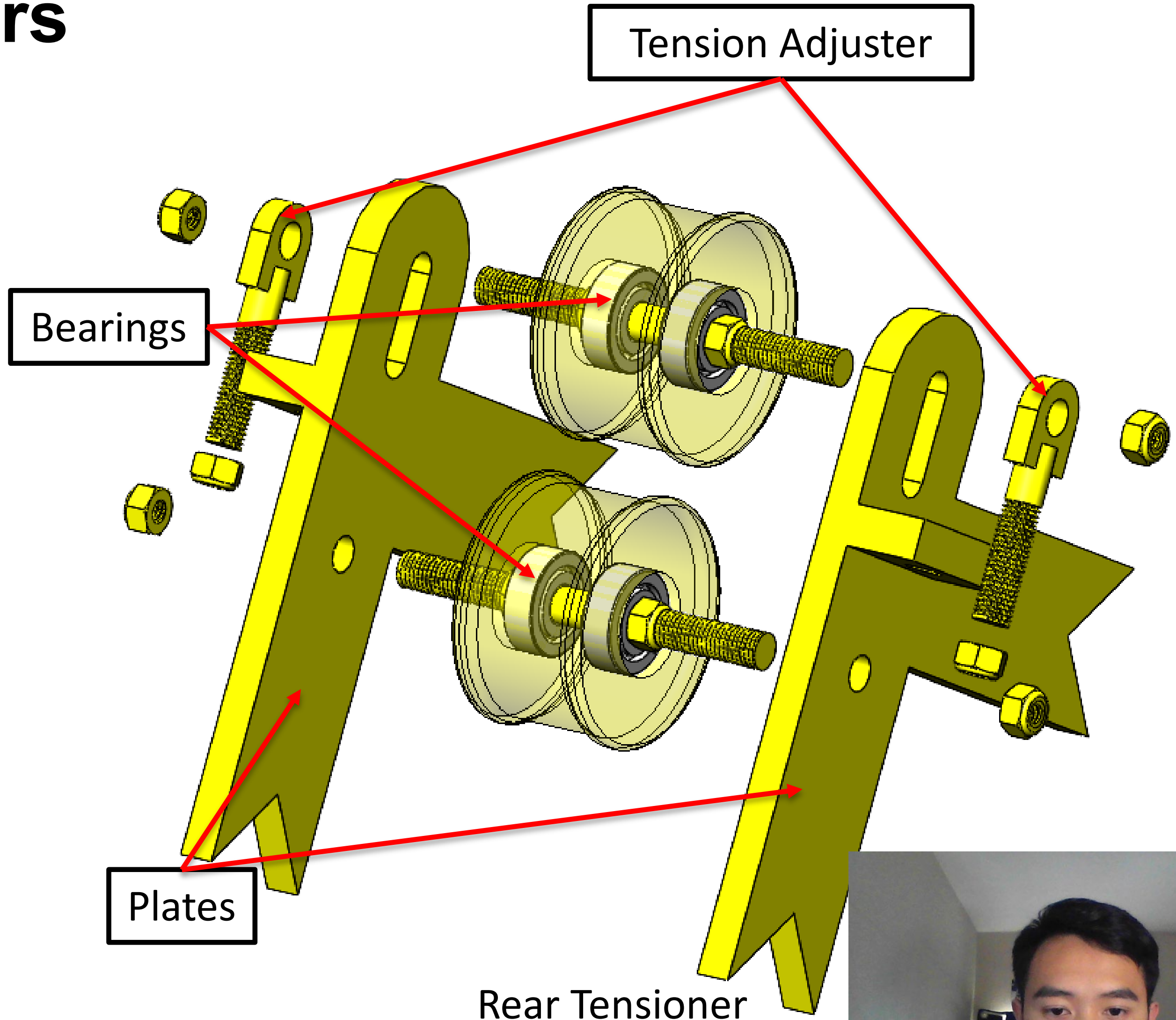
Benefits of preloading



Exploded View of Tensioners

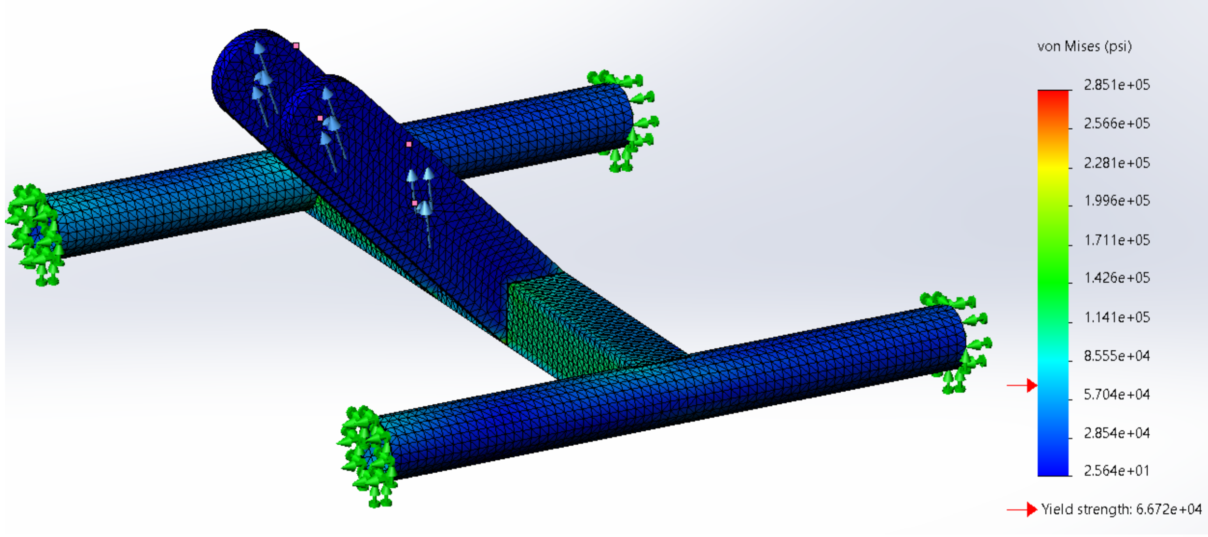


Front Tensioner

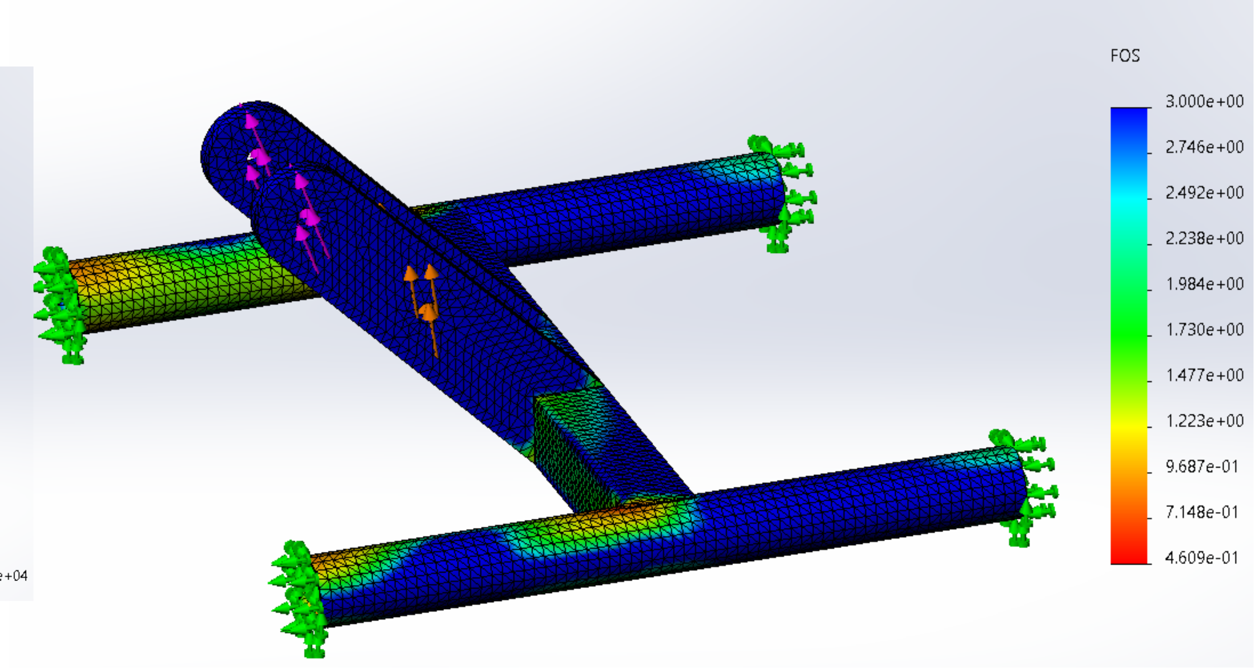


Rear Tensioner

Tensioners



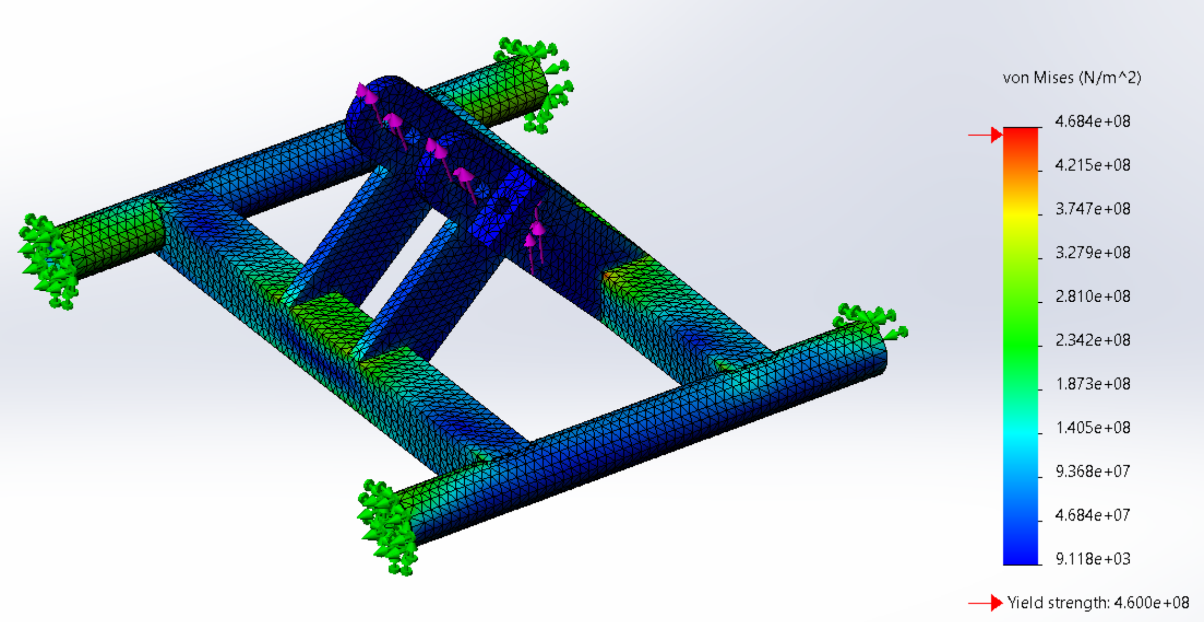
FEA Analysis of Rear Tensioner – Von Mises



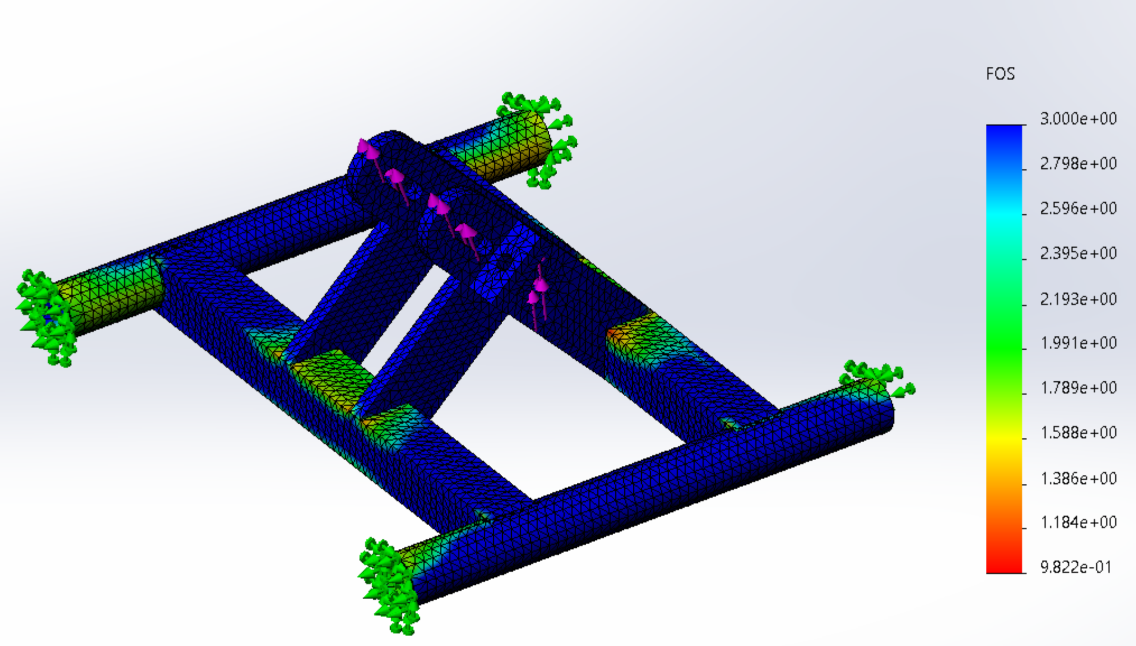
FEA Analysis of Rear Tensioner - FOS

	Rear Tensioner	Front Tensioner
Top Load (lbf)	641.1	485.51
Bottom Load (lbf)	244.63	163.09
Plate Thickness (in)	0.30	0.30
Rect. Tube Thickness (in)	0.039	0.039
Circular Tube Thickness (in)	0.039	0.039

Tensioners



FEA Analysis of Rear Tensioner – Von Mises Stress



FEA Analysis of Rear Tensioner -FOS

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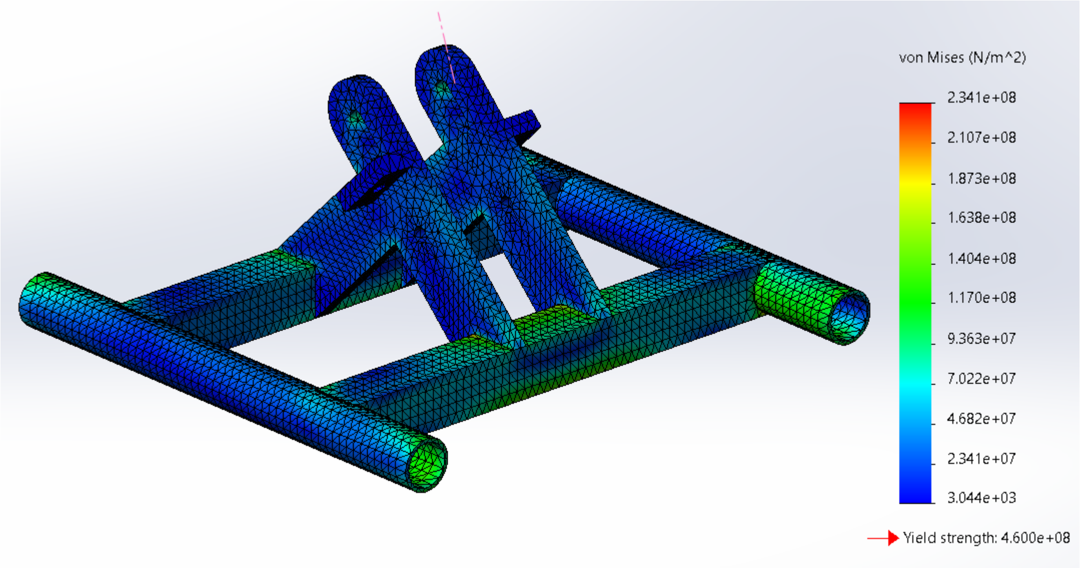
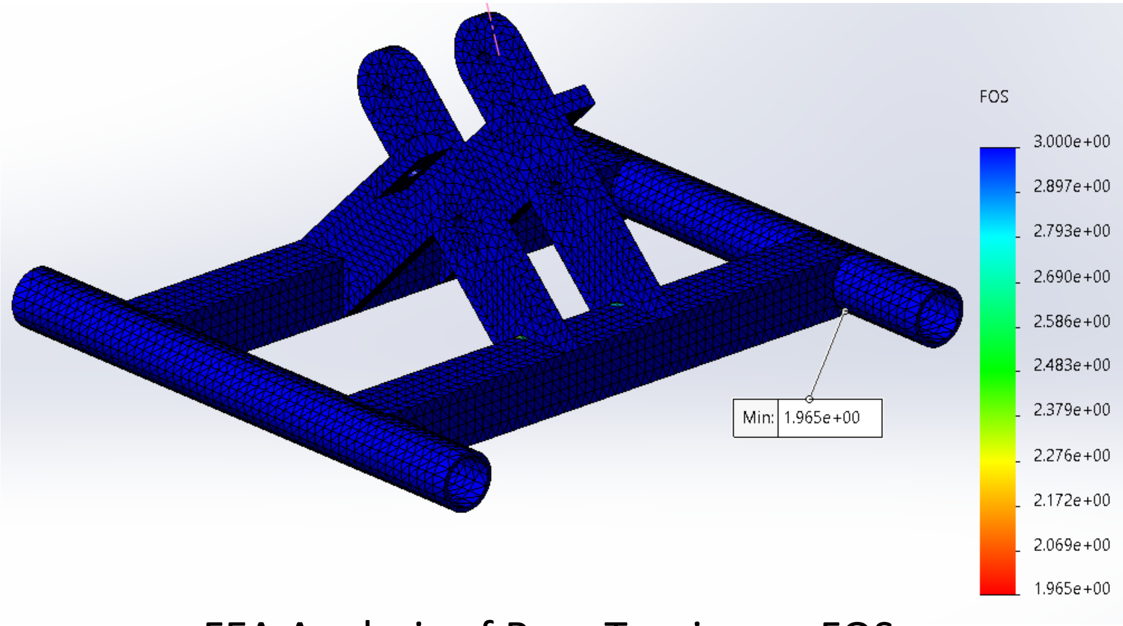
Tensioners



FEA Analysis of Rear Tensioner – Von Mises Stress



FEA Analysis of Rear Tensioner -FOS

	Rear Tensioner	Front Tensioner
Top Load (lbf)	641.1	485.51
Bottom Load (lbf)	244.63	163.09
Plate Thickness (in)	0.30	0.30
Rect. Tube Thickness (in)	0.15	0.15
Circular Tube Thickness (in)	0.15	0.15

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   - Differential- Britney
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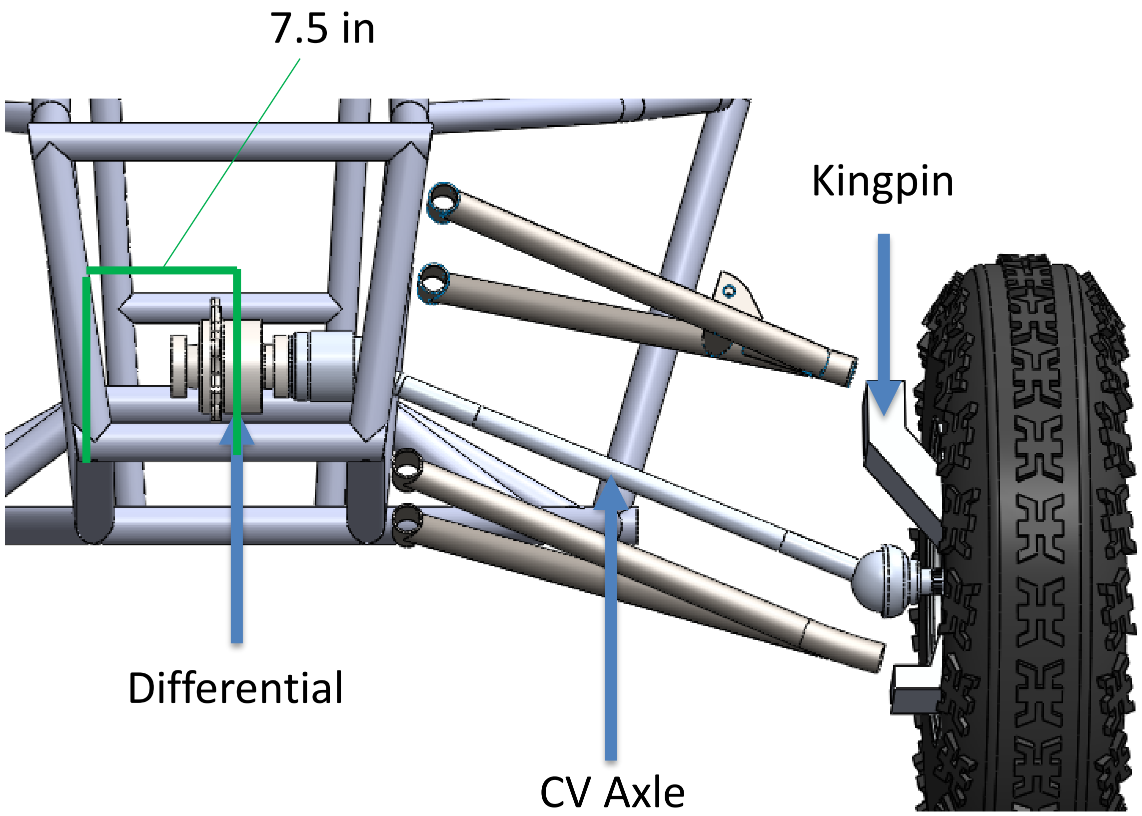
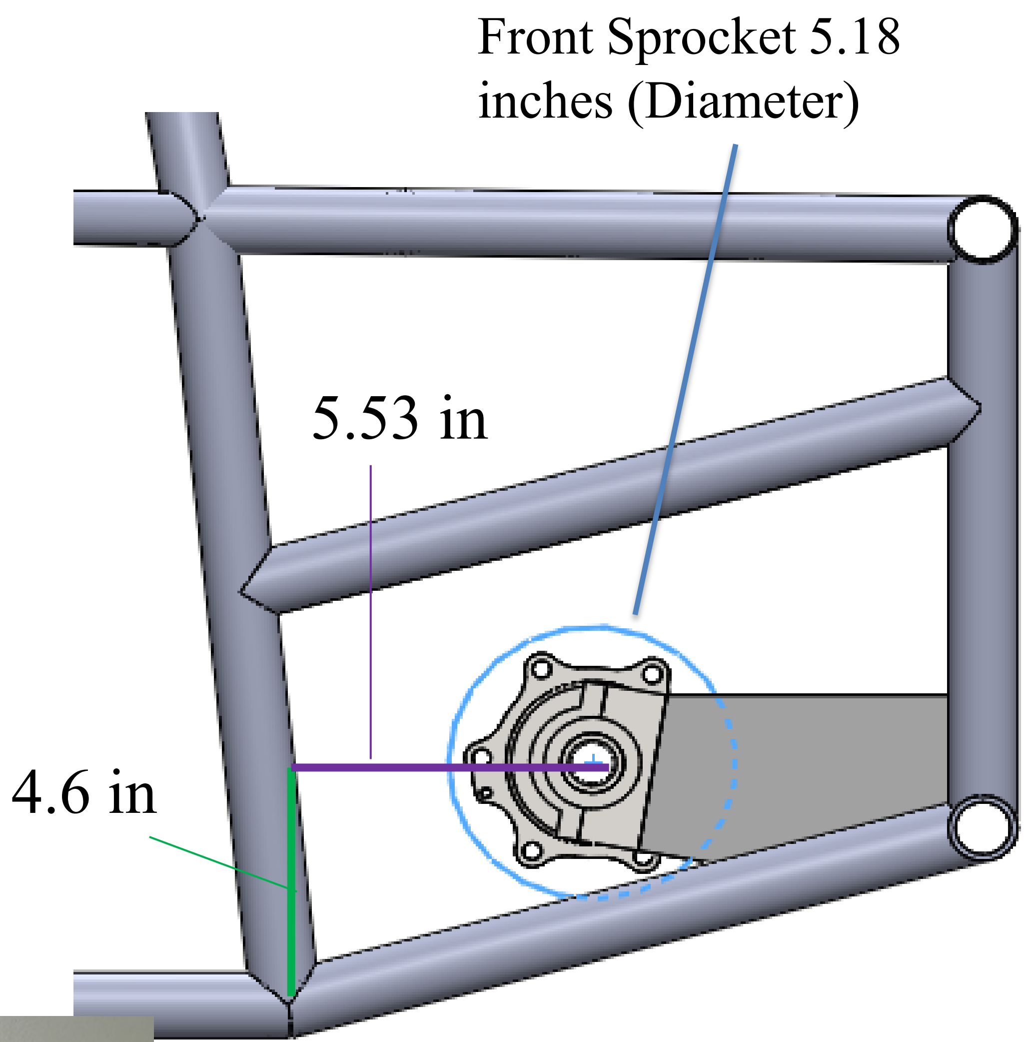
IV. Questions?

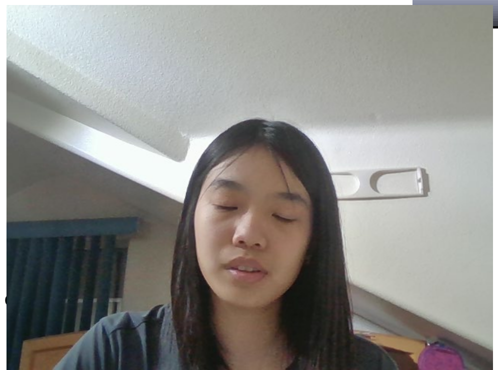
Differential Placement



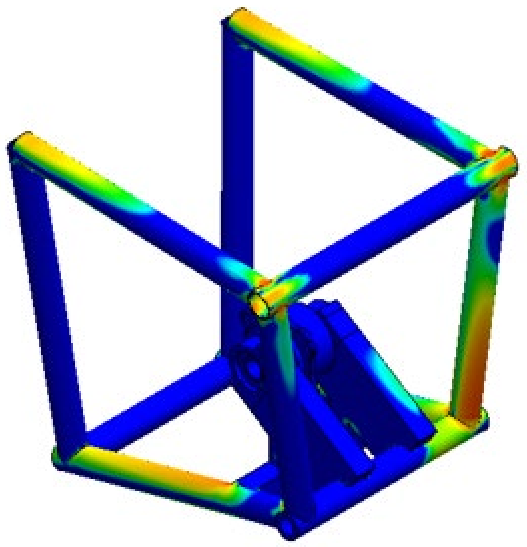
Schematic of Front Drivetrain



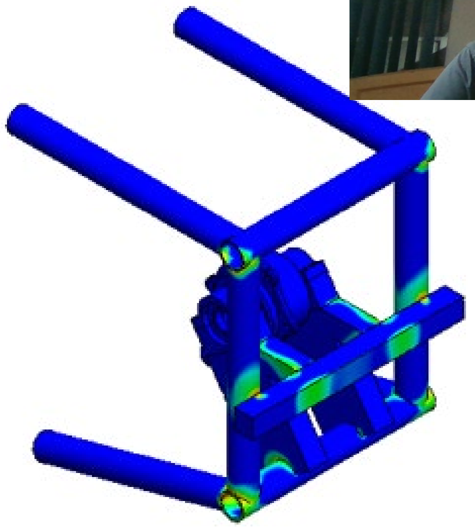
Location of Front Differential



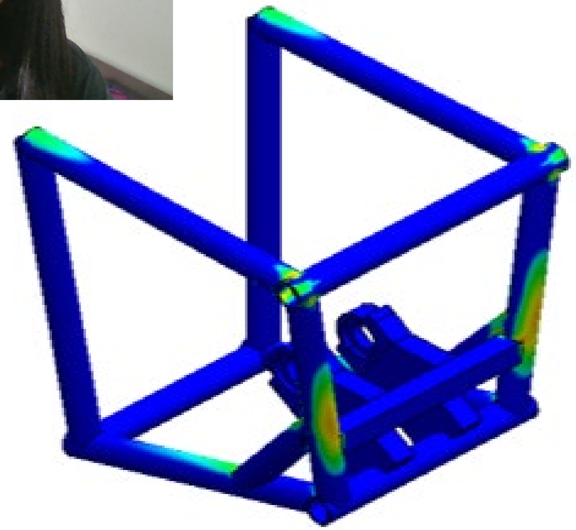
Results of FEA



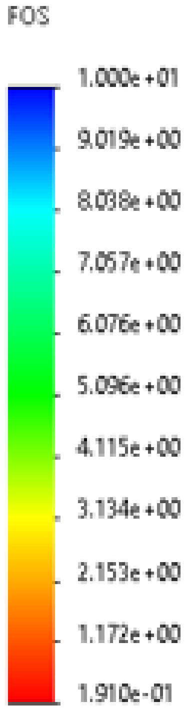
Design 3



Design 4



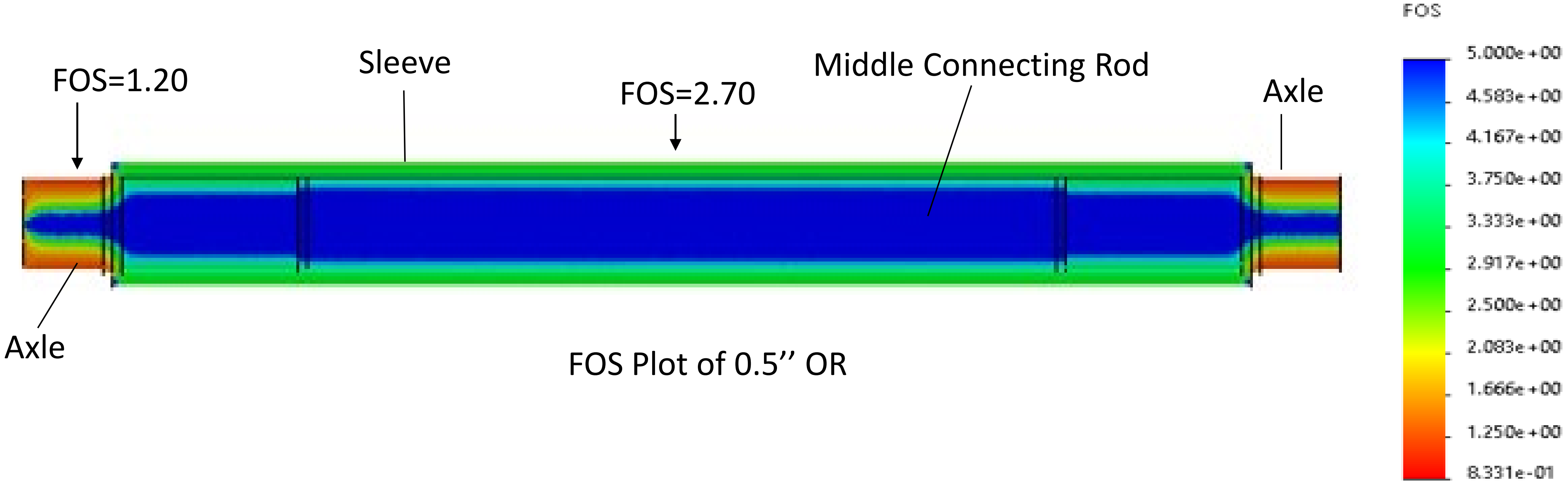
Design 5



Design #	3	4	5
FOS – 1300 lbf 83 Deg	0.19	0.65	1.8
Corrected FOS – 1884 lbf 85 Deg	0.84	3.72	3.17

Criterion	Weight	Design 3 (Baseline)	Design 4	Design 5
FOS	3	0	+3	+3
Integration Support	2	0	-2	+2
Material Usage	1	0	0	-1
	Total (Non Weighted)	0	0	2
	Total (Weighted)	0	1	4

CV Axles – 0.5” OR



FOS Plot of 0.5’’ OR

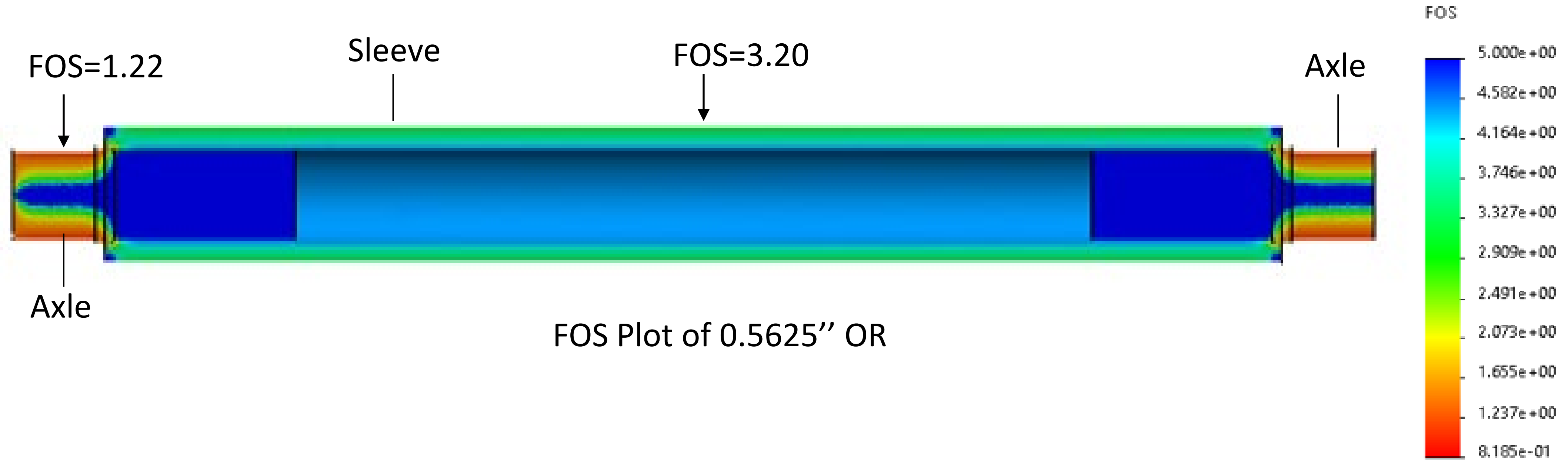
Axle Hand Calculations vs. SOLIDWORKS

Axle	Hand Calcs	SOLIDWORKS
τ (psi)	3.17e4	3.16e4
FOS	1.27	1.20

Sleeve Hand Calculations vs. SOLIDWORKS

Sleeve	Hand Calcs	SOLIDWORKS
τ (psi)	1.33e4	1.47e4
FOS	3.02	2.70

CV Axles – 0.5625" OR



FOS Plot of 0.5625'' OR

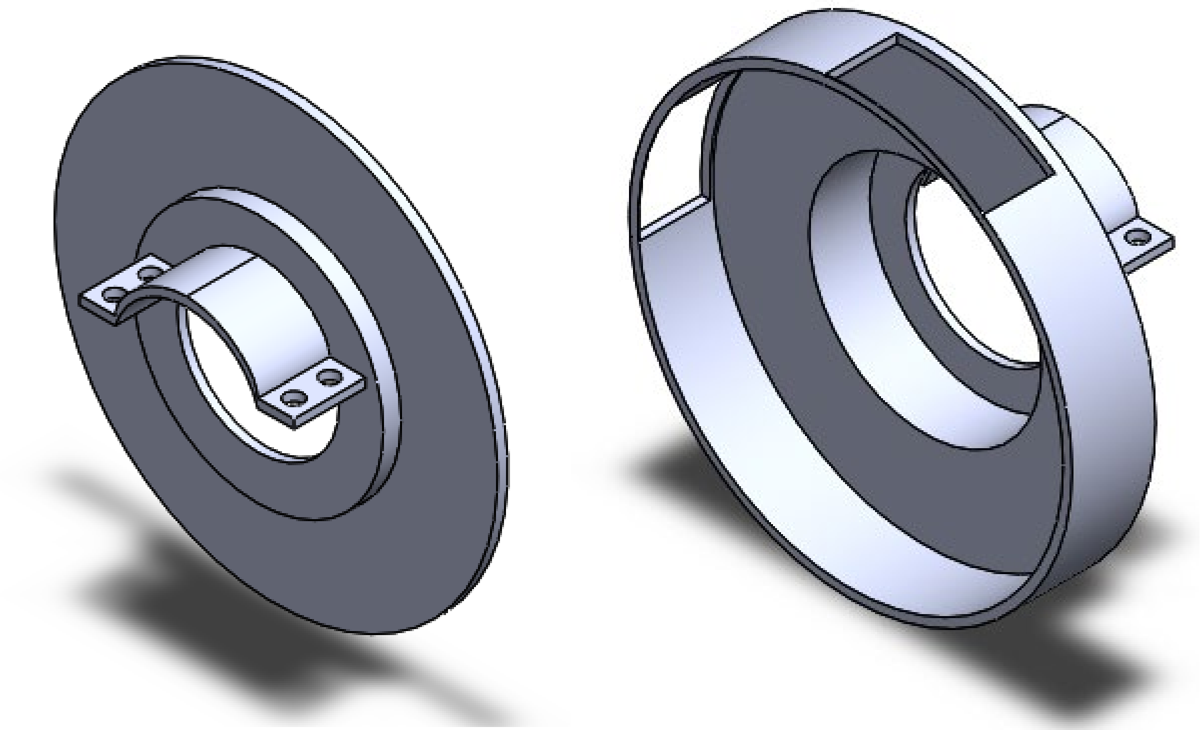
Axle Hand Calculations vs. SOLIDWORKS

Axle	Hand Calcs	SOLIDWORKS
τ (psi)	3.17e4	3.17e4
FOS	1.27	1.22

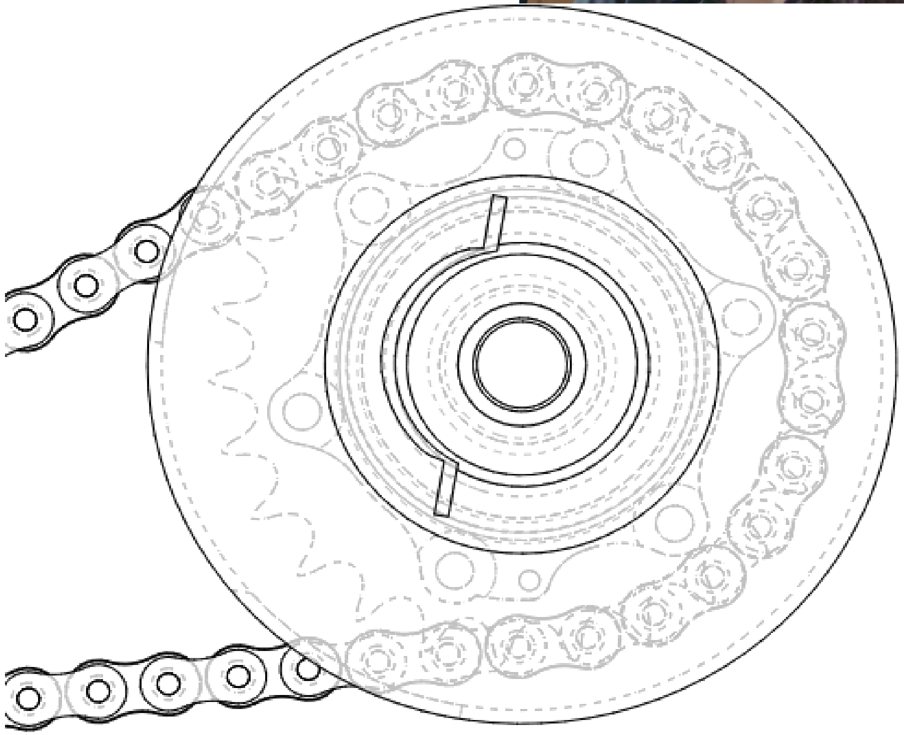
Sleeve Hand Calculations vs. SOLIDWORKS

Sleeve	Hand Calcs	SOLIDWORKS
τ (psi)	1.26e4	1.26e4
FOS	3.20	3.20

Housing



Isometric View of Housing



Side View of Housing

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- Wheel Hub – Rafael
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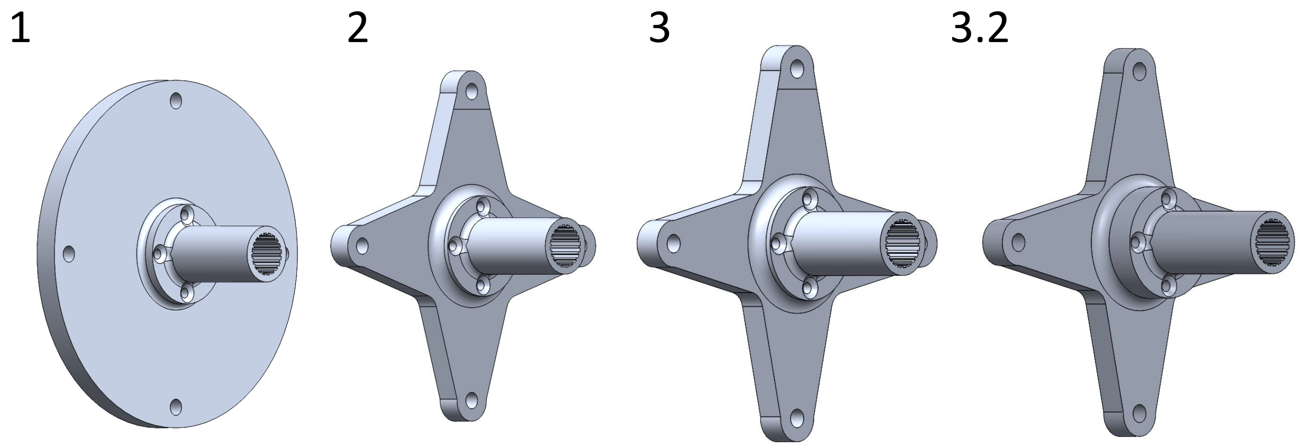
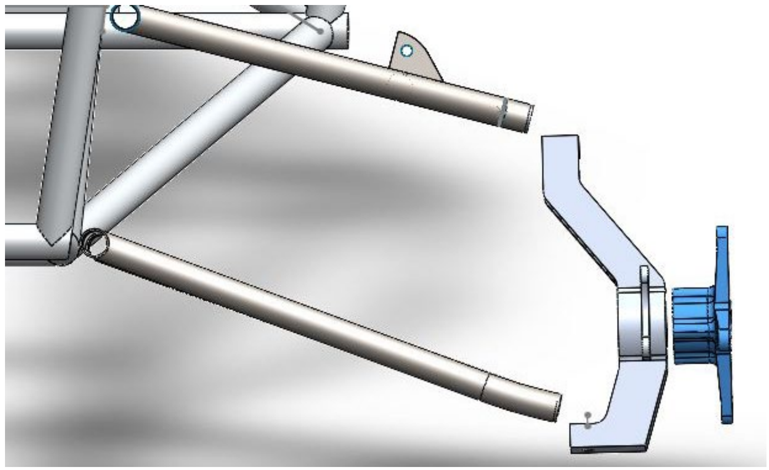
IV. Questions?

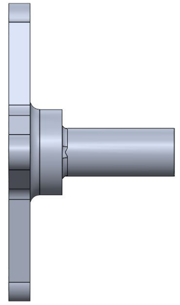
Initial Concepts

Design Concepts Parameters

- To properly utilize 4WD the front hub needs to accommodate the CV boot and half shaft.



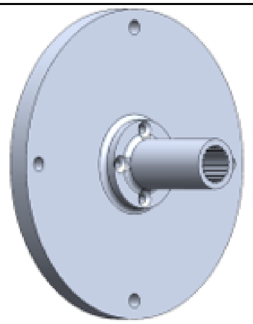
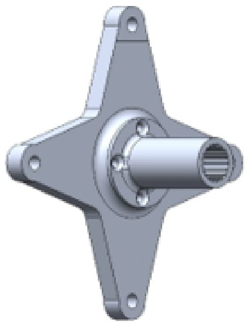
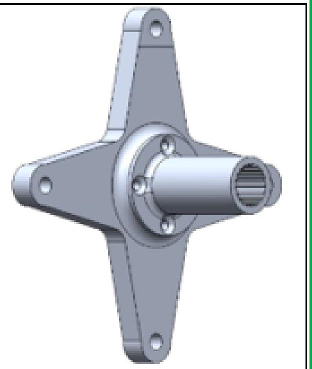


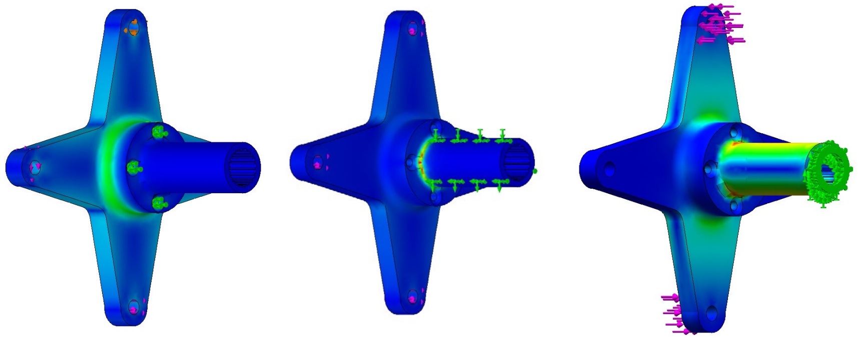


CONCEPT SELECTIONS

Hub design version 3 properties

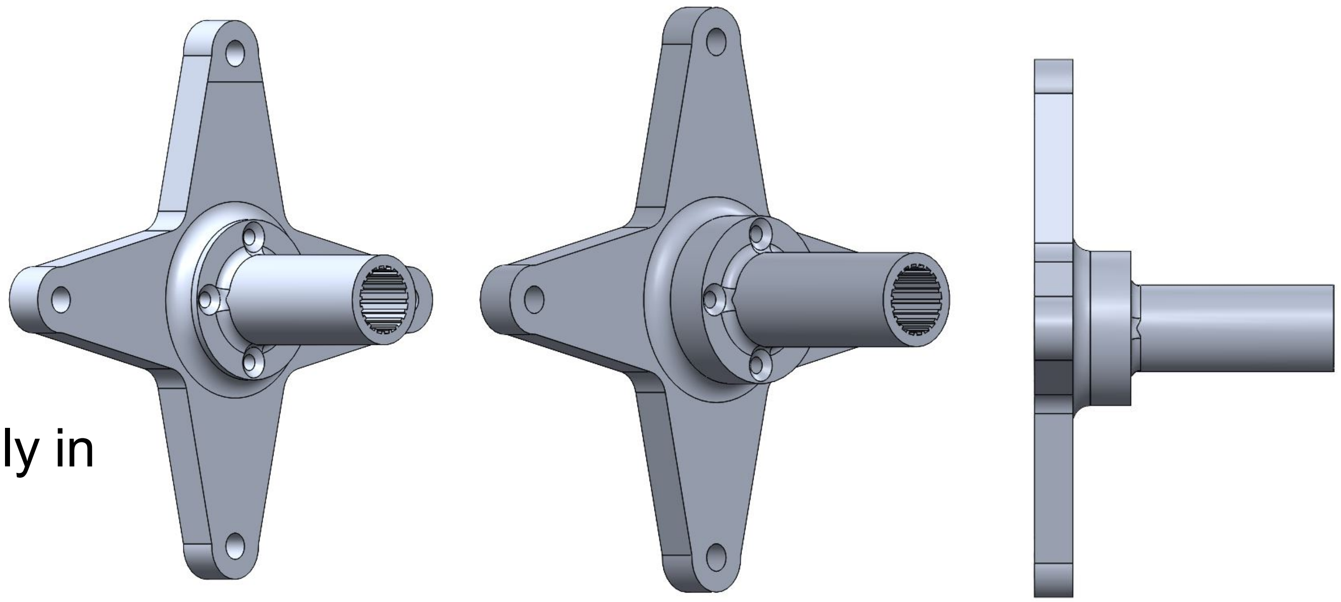
- Material: 6061-T6
- Total mass: 1.0 lb
- Meets FEA Requirement and has minimum FOS above 5.

Front Hub Scale 1-5; 5= Best			
Manufacturing (20%)	4	3	3
FOS (40%)	2	3	5
Weight (30 %)	1	3	4
Cost (10 %)	4	3	3
Total	2.3	3	4.1



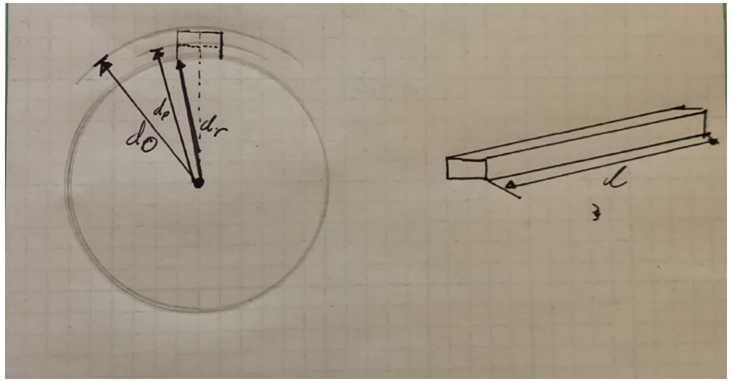
Front Hub Update

- After integrating Hub to vehicle CAD interference with steering measurements.
- Increased wheel offset to fit thoroughly in vehicle cad with no interference.



Expected Forces	Force(N) (X4)	FOS
Braking	137.6	35
Impact	147.5	15
Cornering	258.7	9.2

Hand Calculations & Fatigue analysis



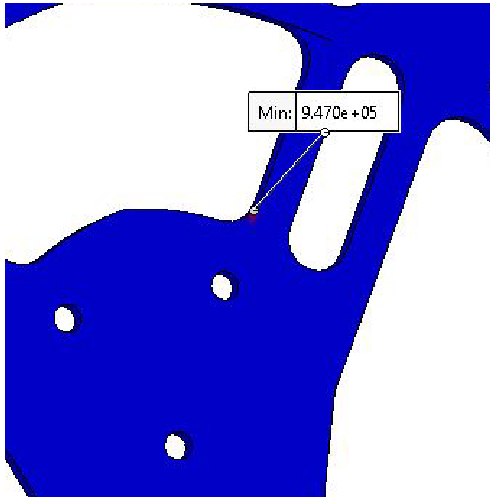
Hand Calculations

- Conducted torque analysis of broached splines on the hub spindle.
- Loads applied are the max torque of the gearbox if CVT has not shifted.

T (IN-LB)	t (Psi)	ksi	FOS
5040	41400.82	41.4	1.01

Fatigue analysis

- Conducted fatigue simulations through Solid Works on the steering wheel.



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Concepts

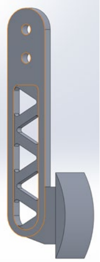
Brake requirements

- All the wheels will lock

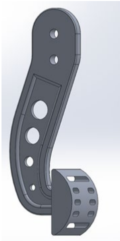
Design Concepts

- There are 3 major parts worked on in braking system, brake pedal, master cylinder and caliper.

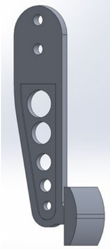
Brake Pedals



Version 1



Version 2



Version 3

Rear Brake Caliper Choices

GP200 Caliper Caliper

Choice 1

Billet Go-Kart Caliper

Choice 2

PS-1 Caliper

Choice 3

Master cylinder Choices

GS Compact Remote Master Cylinder

Choice 1

Tandem Master Cylinder (TM1)

Choice 2

Kart Master Cylinder (RM1)

Choice 3

Front Brake Caliper Choices

Dynalite Single IIIA Caliper

Choice 1

Dynapro Single Caliper

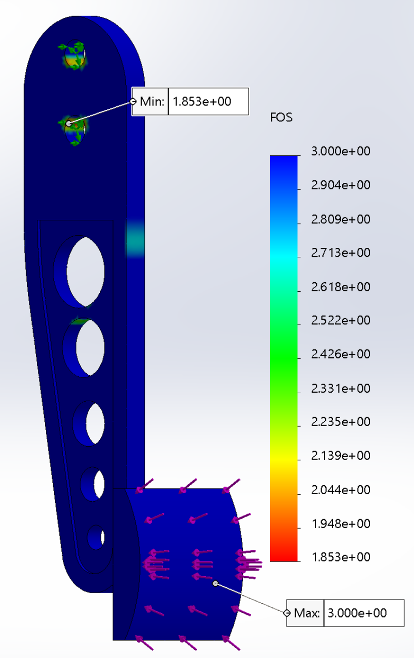
Choice 2

Dynapro Single Caliper

Choice 3

Concepts

Brake Pedals



- A load of 450lb applied
- Factor of safety higher than 1.7
- Version 3 was selected
- Martial: Aluminum 6061-T6

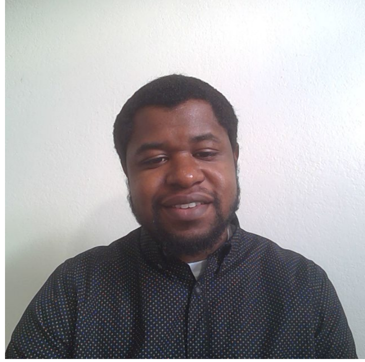
Criteria	Weight	Version 1(.55lbs)	Version 2(.66lbs)	Version 3(.51lb)
Price	10%	4	3	5
Mass	40%	5	4	5
Ability to Manufacture	30%	3	2	4
Factor of Safety	20%	3	4	5
Total	100%	3.9	3.3	4.7

Master Cylinder - 2

GS Compact Remote Master Cylinder

- All are tested to 1200Psi
- They all are designed for 1400Psi
- ½ in bore size

Criteria	Weight %	GS Compact Remote	Tandem Master Cylinder (TM1)	Kart Master Cylinder (RM1)
Price	15	2	4	5
Bore Size	40	5	3	5
Stroke	30	4	5	2
Overall Length	10	3	1	5
Reliability	5	4	5	2
Total	100	4	3.65	3.95



Concepts

Rear Brake Calipers - 2

PS-1 Caliper

- Bore size is 1in
- Inlet thread is 1/8-27 NPT
- Want small Bore

Criteria	Weight%	GP200 Caliper	Billet Go-Kart	PS1 Caliper
Price	20%	3	1	5
Mass	10%	5	3	4
Piston Bore	30%	1	5	5
Mount Side	10%	5	5	3
Size	30%	5	3	5
Total	100%	3.4	3.4	4.7

Front Brake Calipers - 2

GP200 Caliper Caliper

- Bore size is 1.25in
- Inlet thread is 1/8-27 NPT
- Want big bore

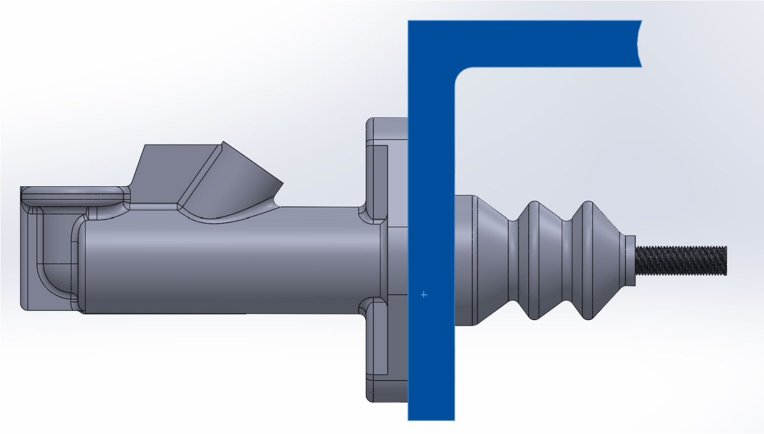
Criteria	Weight%	GP200 Caliper	Dynalite Single IIIA	Dynapro Single Caliper
Price	20%	3	1	5
Mass	10%	5	3	4
Piston Bore	30%	4	5	5
Mount Side	10%	5	5	3
Size	30%	5	1	1
Total	100%	4.3	2.8	3.5

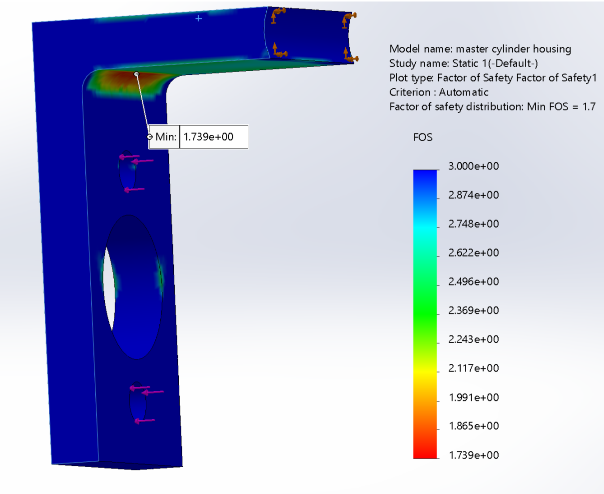
- 100 lbs. applied
- A proportional value can be used to optimize performance

Front Braking Efficiency	2.55
Rear Braking Efficiency	2.29
Ratio (70 is Normal)	53

Concepts

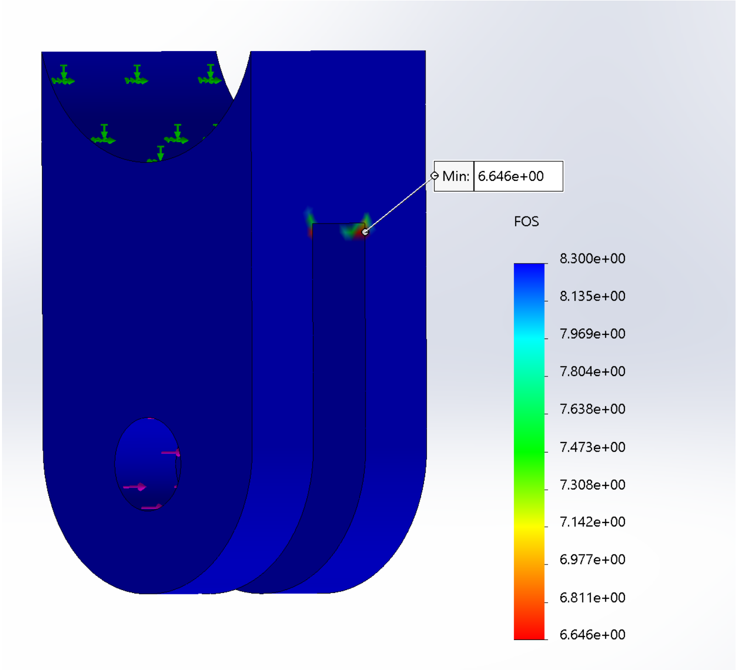
Master Cylinder Housing - 2



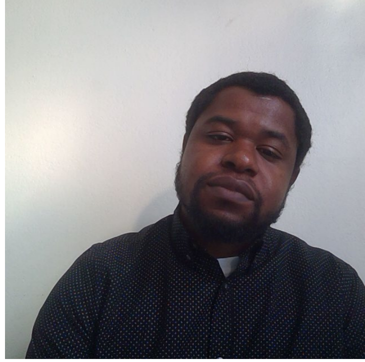


- FOS of 1.7
- Withstand full load from the pedal
- Martial: Steel

Pedal Housing



- Designed with forces at 90deg
- FOS is 6.6
- Martial: Steel



Other Achievements

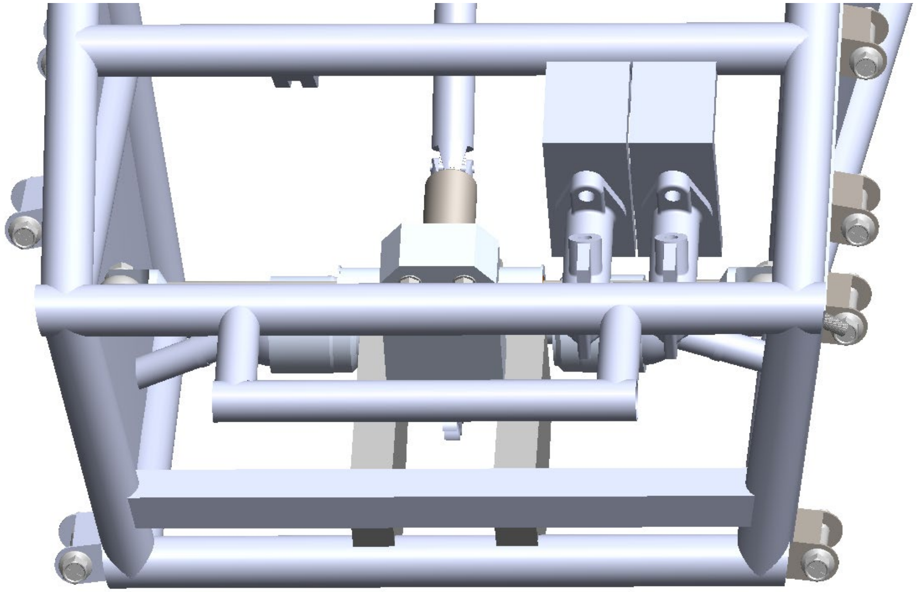
Improved excel brake sheet

- More accurate data
- Better understanding of the forces and pressures at each point
- Add data for front and rear braking
- Energy requirement calculations
- Braking ratio value

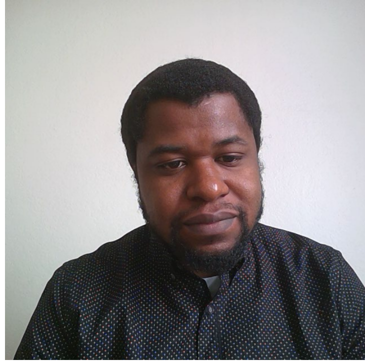
Nose model

- In progress

$$n = \frac{T_{rot}}{T_{tire}} = \frac{F_{pedal}}{\frac{W}{2 * wB}(c + \mu hcg)} * \frac{L_p}{L_{mc}} * \frac{A_{cal}}{A_{mc}} * \frac{r_{pad}}{r_{tire}} * \frac{\mu_{pad}}{\mu_{tire}}$$



Agenda

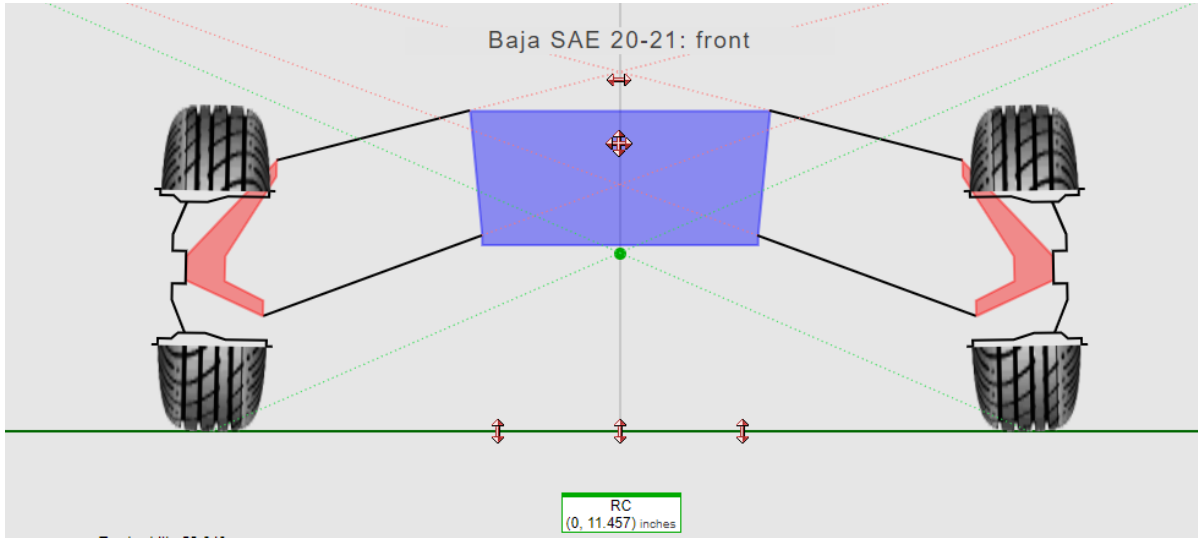


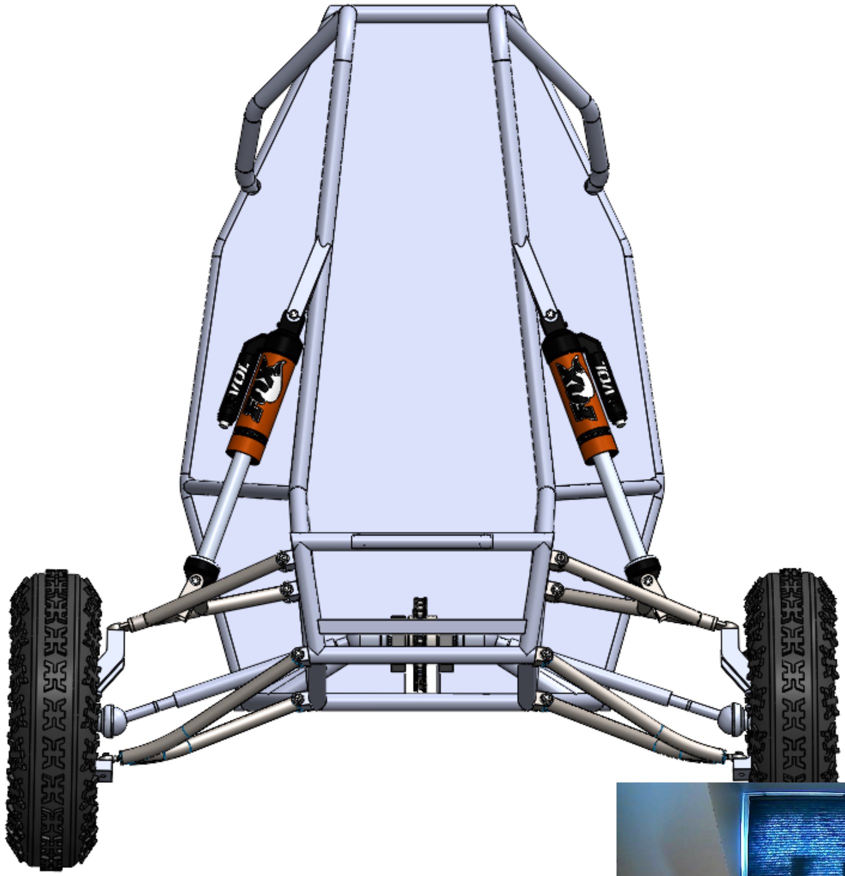
I. Introduction/Background
II. Project Requirements
III. Technical Progress
   - Chain Drive
   - Differential
   - Wheel Hub
   - Brakes
   - Front Suspension - Aaron
   - Shocks
   - Driver Ergonomics
IV. Questions?

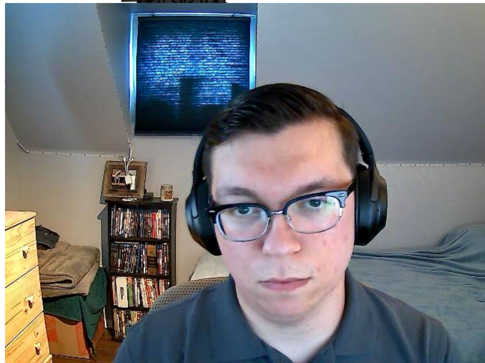
Front Suspension

Geometry & Kinematics

- Due to packaging constraints, suspension geometry needed to change to accommodate a wider nose, while maintaining optimal kinematics and trackwidth.





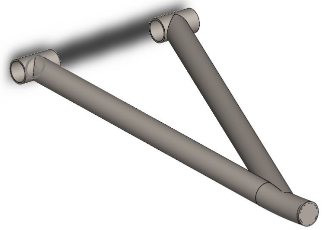


Concept Selection

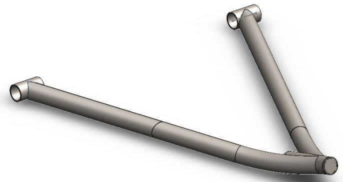
Design Concepts

- Front suspension is composed of 3 major components, the kingpin, lower control arm (also known as A-arm), and upper control arm.

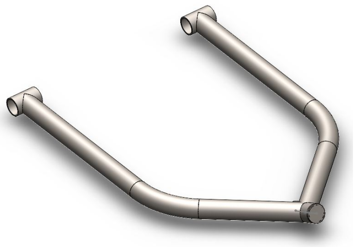
Bottom Arm Concepts
All made from 1”x.049” 4130 steel round tubing



Iteration 1

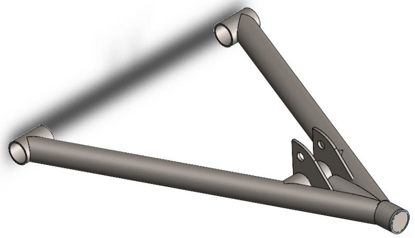


Iteration 2

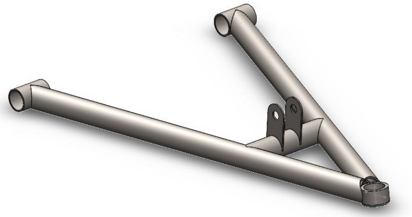


Iteration 3

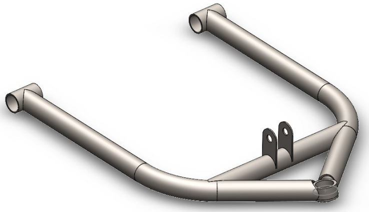
Top Arm Concepts
All made from 1”x.065” 4130 steel round tubing



Iteration 1

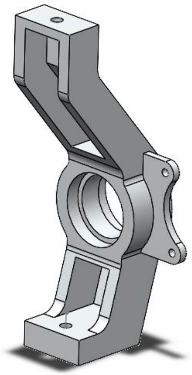


Iteration 2

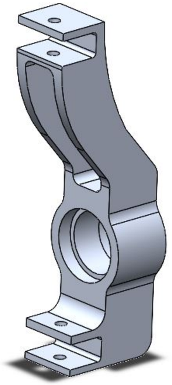


Iteration 3

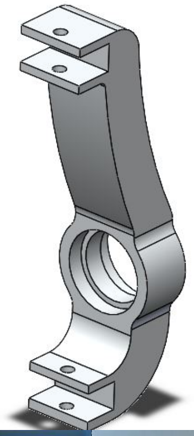
Kingpin Concepts
All machined out of 6061-T6 aluminum



Iteration 1

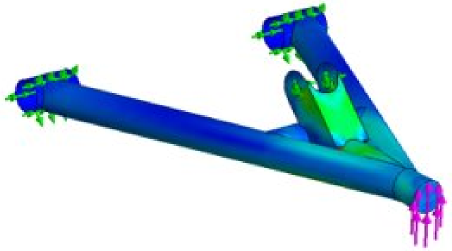


Iteration 2



Concept Selection

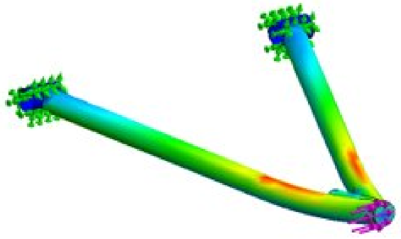
Top A-Arm



Load Case: 850 lbf vertical
Mesh type: Shell Mesh
Fixture: Fixed Hinge at frame and shock tab
FOS: 1.4

Top A-Arm	Model 1	Model 2	Model 3
Scale 1-5, 5 = best			
Manufacturing (20%)	5	5	3
FOS (40%)	4	2	3
Cost (10%)	3	3	3
Weight(30%)	5	5	5
Total	4.4	3.6	3.6

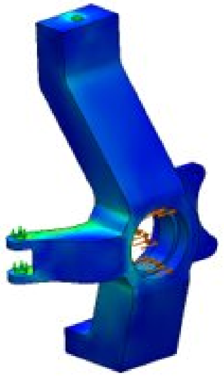
Bottom A-Arm



Load Case: 500 lbf longitudinal
Mesh type: Shell Mesh
Fixture: Fixed Hinge at frame
FOS: 5.7

Bottom A-Arm	Model 1	Model 2	Model 3
Scale 1-5, 5 = best			
Manufacturing (20%)	5	4	5
FOS (40%)	2	5	4
Cost (10%)	3	3	3
Weight(30%)	5	4	4
Total	3.6	4.3	4.1

Kingpin



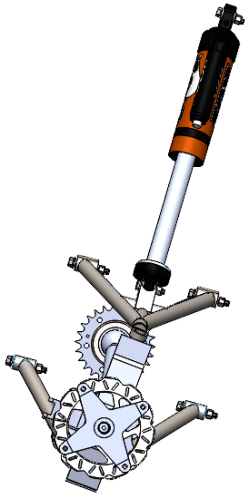
Load Case: 500 lbf longitudinal
Mesh type: Solid Mesh
Fixture: Fixed Hinge and Rigid Contact
FOS: 4.1

Kingpin	Model 1	Model 2	Model 3
Scale 1-5, 5 = best			
Manufacturing (20%)	4	4	4
FOS (40%)	5	3	3
Weight(40%)	5	4	3
Total	4.8	3.6	3.2

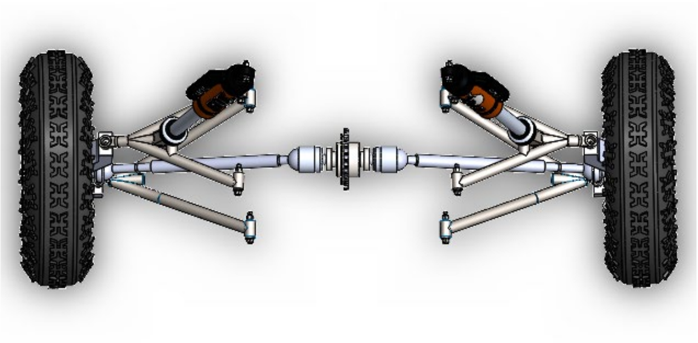
Final Design-Front Suspension

Suspension CAD - Front View

Front Suspension CAD - Side View



Front Suspension - Top View



Front Suspension - Isometric View

Agenda

I. Introduction/Background
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- Chain Drive
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- Shocks - Chris
- Driver Ergonomics

IV. Questions?

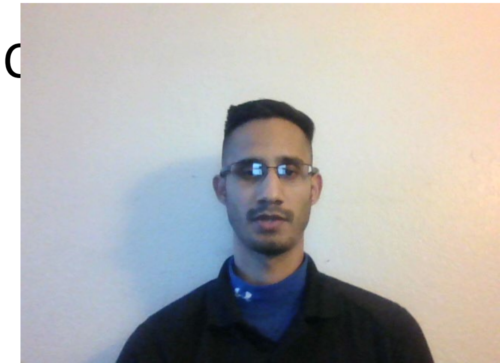
Shock Packaging

Air Shock
(Progressive)

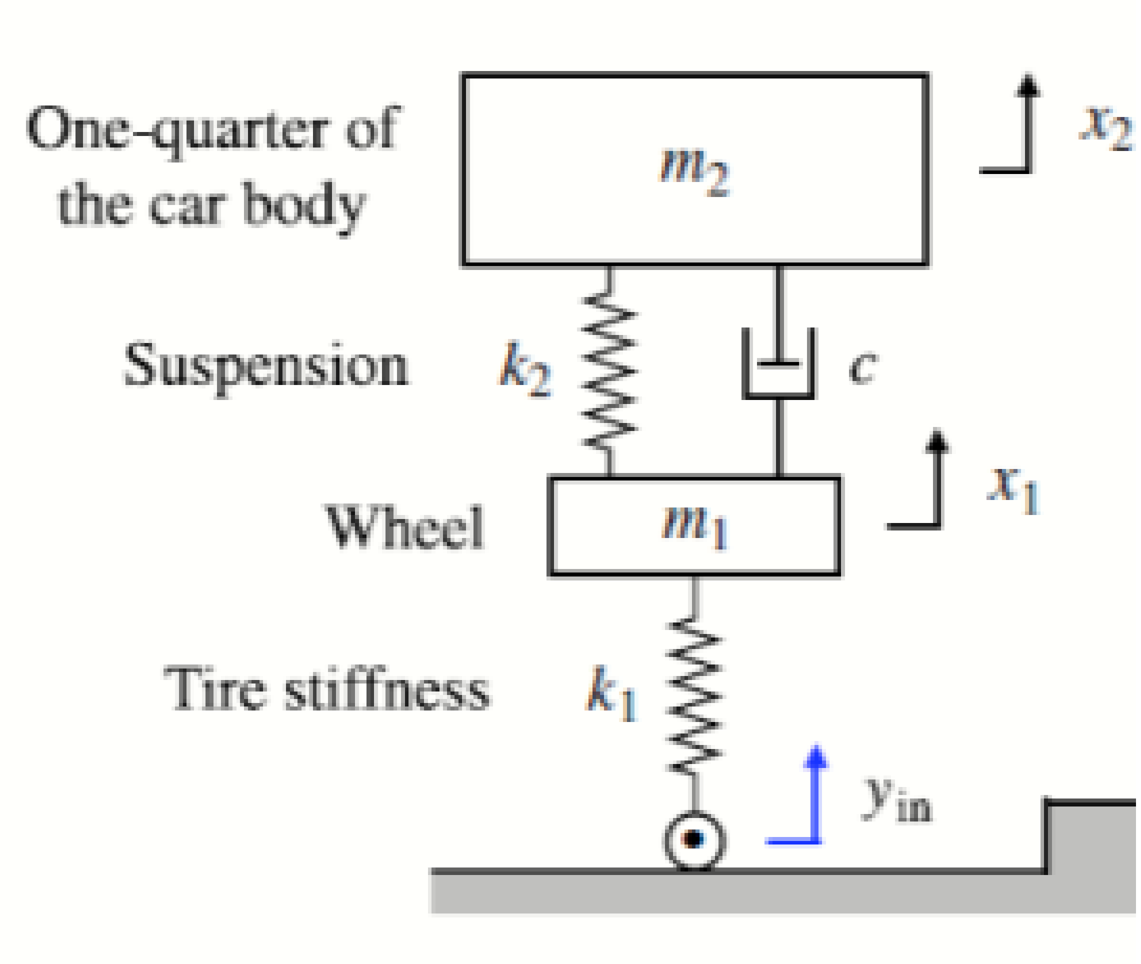
Coil over shock single
spring (linear)

Coil over shock dual spring
(Progressive)

- Importance:
  - appropriate shocks are required to settle car to optimum ride condition
  - The faster & smoother this is done the faster the car can go
- How its done:
  - Limits the amount of chassis movement
  - Provides Stable and C ride for the driver

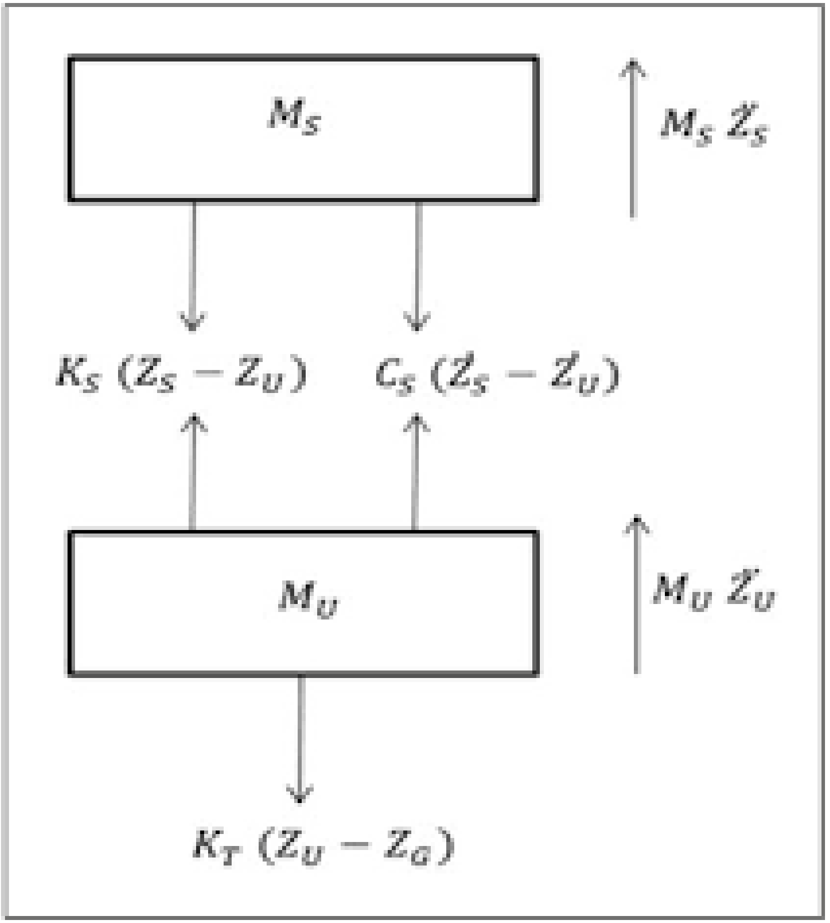


Quarter Car Suspension Model



- m_2: Sprung corner mass
- m_1: Unsprung corner mass,
  - Tire/wheel assembaly
  - Calipers
  - Hub
  - Axle
  - Etc.
- k_2: Shock spring rate
- k_1: Tire spring rate
- c : Shock damping rate

Quarter Car Model Free Body Diagram



- Shock spring force : $F_s = K_s(z_s - z_u)$
- Shock damping force: $F_{sd} = C_s(\dot{z}_s - \dot{z}_u)$
- Tire spring force: $F_t = K_t(z_u - z_g)$

- Applying newtons second law of motion (F = ma) to both sprung and unsprung masses
- Equations of motion

- $\sum F = m_s\ddot{z}_s = -F_s - F_{sd}$

  1) $m_s\ddot{z}_s = -K_s(z_s - z_u) - C_s(\dot{z}_s - \dot{z}_u)$

- $\sum F = m_u\ddot{z}_u = F_s + F_{sd} - F_t$

  2) $m_u\ddot{z}_u = K_s(z_s - z_u) + C_s(\dot{z}_s - \dot{z}_u)$

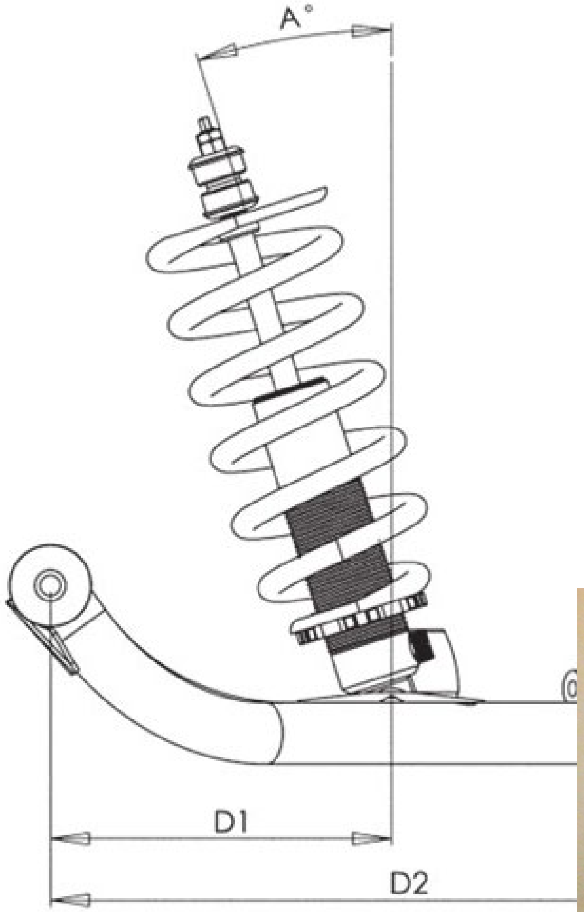
Important Parameters Considered

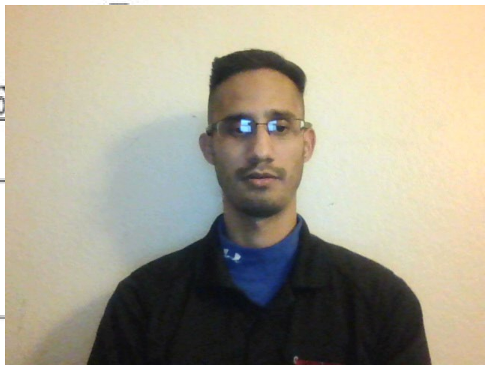
	Front	Rear
Arm Length [in]	13	23.19
Length to Shock Mount [in]	9	21.65
Angle Placement α [degrees]	35	4.62

- Motion Ratio:
  - the ratio of the shock displacement to the wheel displacement

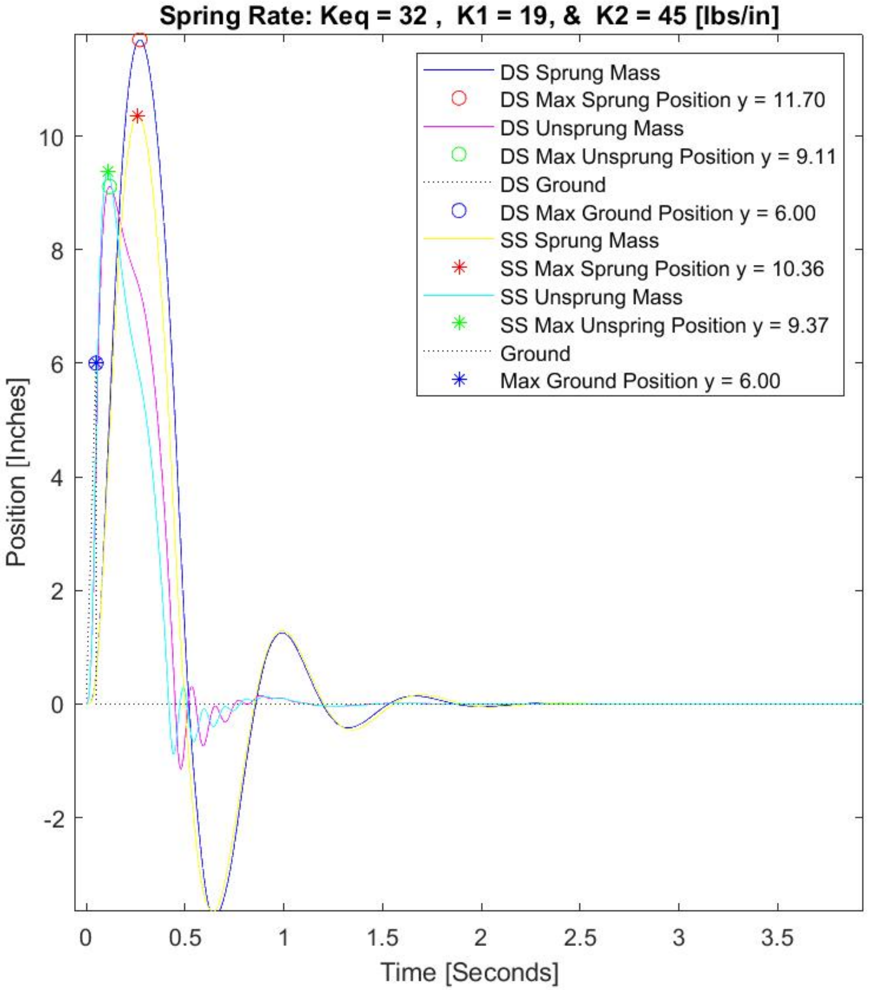
$$3)\quad MR = \frac{\Delta B}{\Delta C}\cos\alpha = \frac{L_{AB}}{L_{AC}}\cos\alpha$$

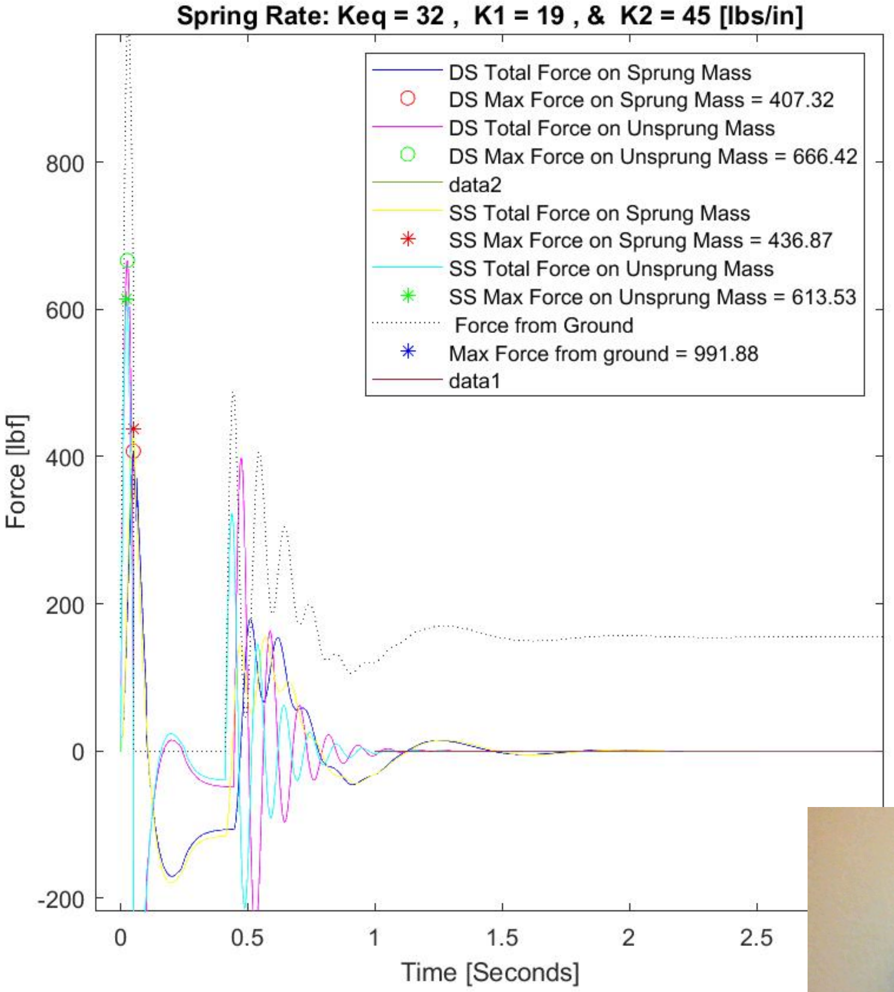
- Shock extended length:
  - Must be larger than the distance between the shock mounting points on the chassis and arm tabs at ride height
- Droop:
  - Roughly 40% of the shock travel compressed at ride height



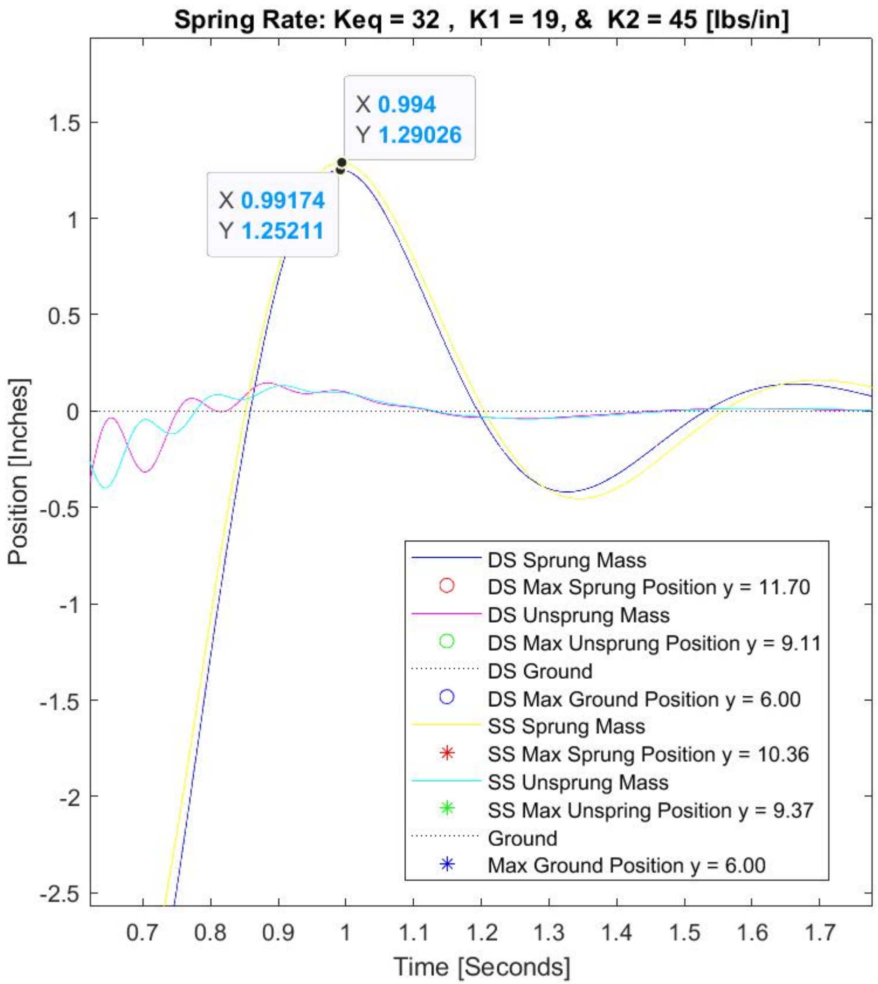


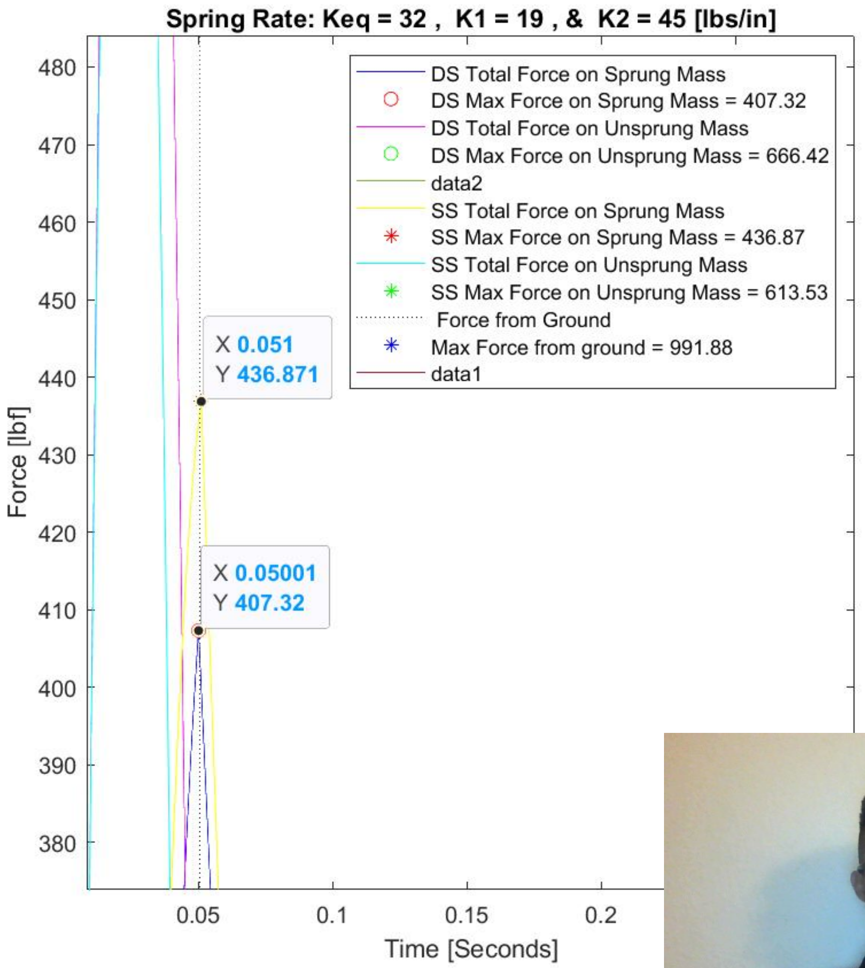
Example of MATLAB Dual & Single spring rate Quarter Car model results

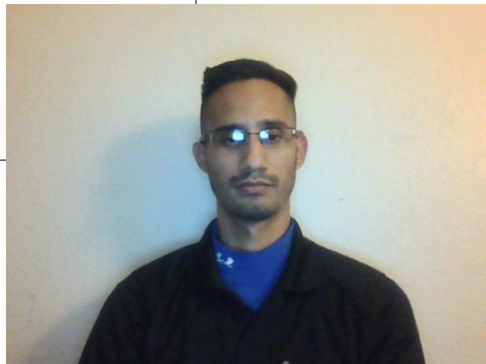




Analyzing Results







Dual Rate vs Single rate simulation results

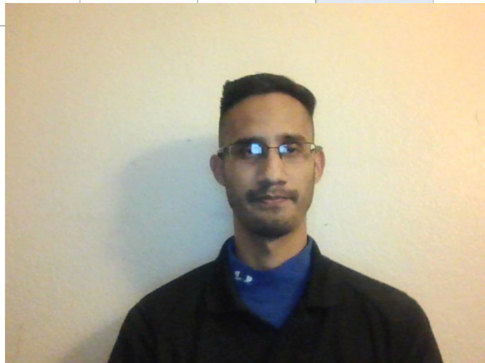
Table 1

REAR	Whoops		Ramp w/ Drop off		Tabletop w/ slope		Small Bumps	
	Dual Spring	linear spring	Dual Spring	linear spring	Dual Spring	linear spring	Dual Spring	linear spring
max Force Ms [lbf]	239.62	253.39	407.32	436.87	199.33	216.3	26.65	29.66
max Force Mus [lbf]	555.43	596.92	666.42	613.53	671.42	663.36	361.85	360.96
max Position Ms [in]	4.47	4.64	11.7	10.36	3.27	3.28	0.37	0.37
max Position Mus [in]	4.91	5.41	9.11	9.37	3.51	3.6	0.37	0.37
	Lowest Result		Lowest Result		Lowest Result		Lowest Result	
	Dual Spring		Dual Spring		Dual Spring		Dual Spring	
	Dual Spring		linear spring		linear spring		linear spring	
	Dual Spring		linear spring		Dual Spring		FALSE	
	Dual Spring		Dual Spring		Dual Spring		FALSE	

Table 2

FRONT	Whoops		Ramp w/ Drop off		Tabletop w/ slope		Small Bumps	
	Dual Spring	linear spring	Dual Spring	linear spring	Dual Spring	linear spring	Dual Spring	linear spring
max Force Ms [lbf]	91.33	99.01	135.92	141.42	227.74	245.32	32.43	35
max Force Mus [lbf]	212.71	218.97	296.04	297.13	507.11	504.54	358.8	358.8
max Position Ms [in]	4.92	4.77	6.59	6.5	10.25	9.9	0.56	0.53
max Position Mus [in]	4.13	4.13	6.2	6.22	8.86	9.11	0.7	0.71
	Lowest Result		Lowest Result		Lowest Result		Lowest Result	
	Dual Spring		Dual Spring		Dual Spring		Dual Spring	
	Dual Spring		Dual Spring		linear spring		FALSE	
	linear spring		linear spring		linear spring		linear spring	
	FALSE		Dual Spring		Dual Spring		Dual Spring	

	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	
CRITERIA DESCRIPTION	Price	Weight	Travel Length	Adjustability	Extended Length	
	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	WEIGHTED SCORE
WEIGHT	2	3	5	1	4	15
	13%	20%	33%	7%	27%	100%
OPTIONS	Criteria 1 SCORES	Criteria 2 SCORES	Criteria 3 SCORES	Criteria 4 SCORES	Criteria 5 SCORES	
AFCO 3895 Eliminator	4	2	5	1	5	4.00
QA1 Proma Star Single	5	4	4	1	3	3.67
Gensis G6	3	5	5	0	4	4.13
Elka	2	3	5	0	3	3.33



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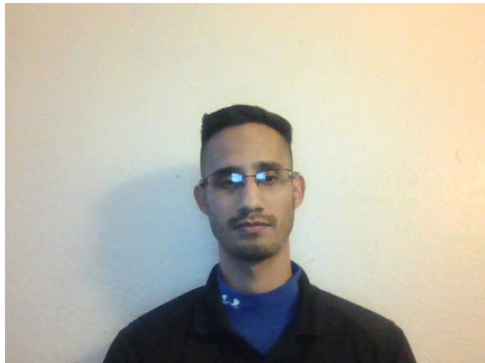
- Front Suspension
- Shocks
- Driver Ergonomics – Brian

IV. Questions?



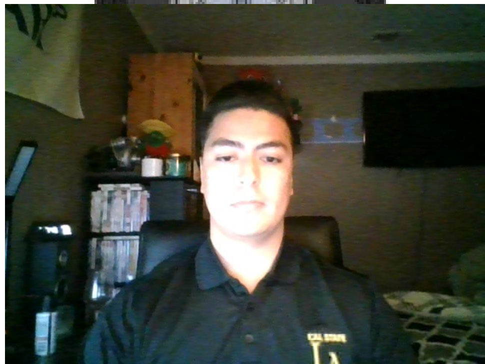
Cockpit Ergonomics

Factors Considered

- Safety
- System Integration
- Design based upon quantitative data

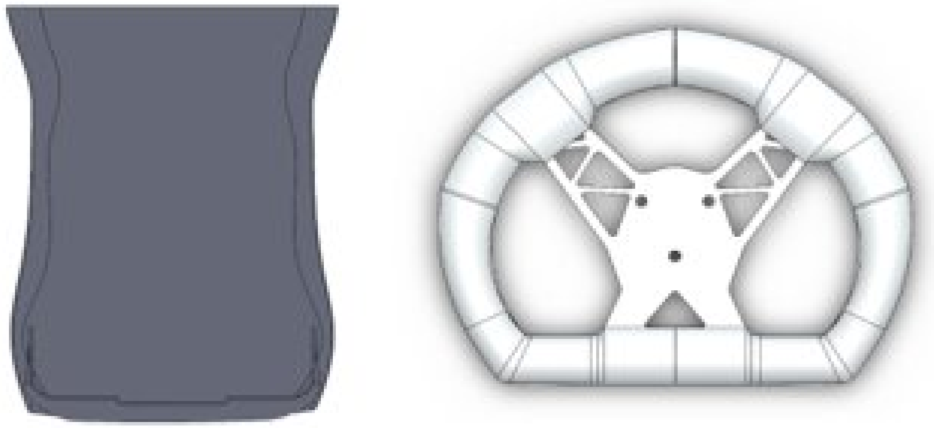
Manufacturing Methods

- 3D print mold, lay over with fiberglass.
- Vaccuum resin infusion carbon fiber on fiberglass mold



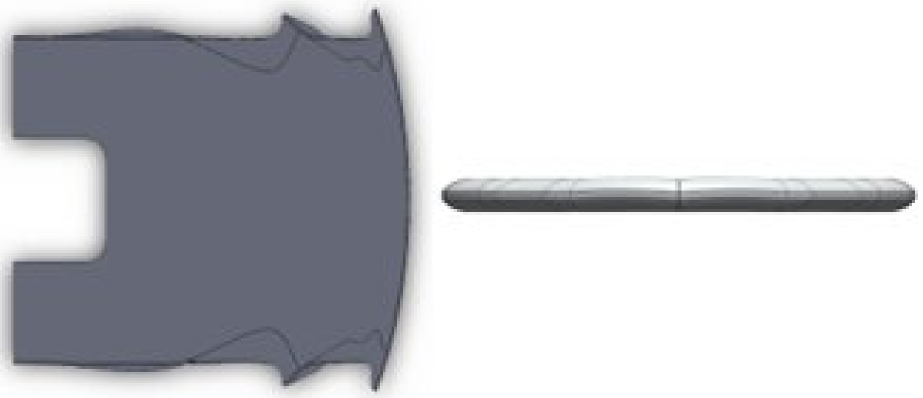
Cockpit Ergonomics

Ergonomics CAD – Front View

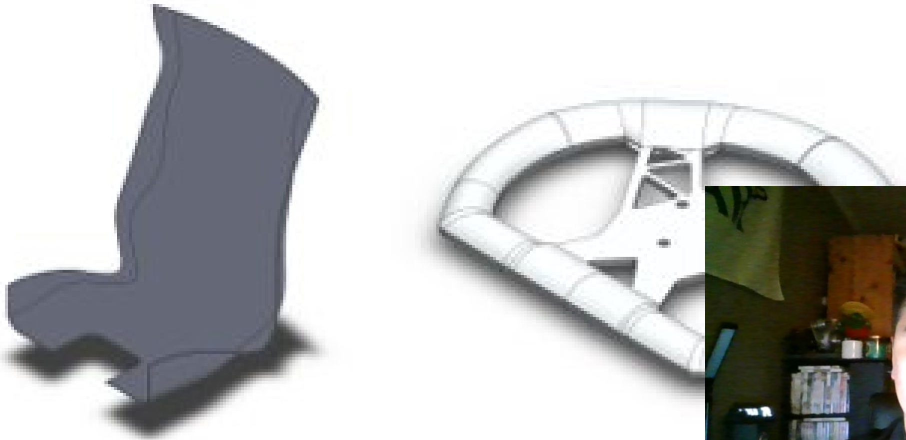


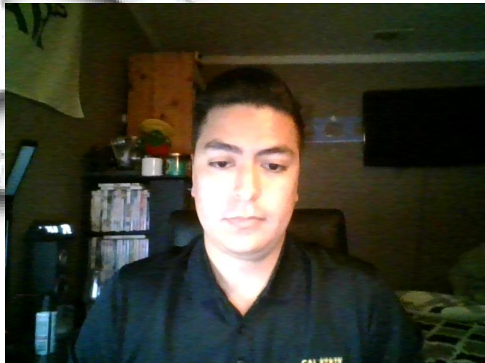
Ergonomics CAD – Left Side View

Ergonomics CAD – Top View



Ergonomics CAD – Isometric View





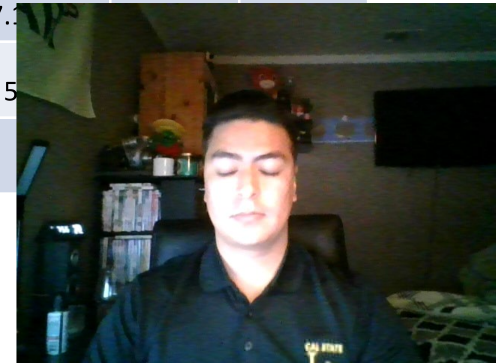
Cockpit Ergonomics

Data Collection

- A questionnaire asking for prospective driver body dimensions
- Use measurements to determine Center of Mass

Analysis Summary

	Segment	Weight %	CM %	Weight lbs.	CM location	CM X (in)	CM Y (in)
1	Head/ Neck	8.26	0.55	14.042	5.225	-3.84	40.57
2	Trunk	46.84	0.63	79.628	12.6	-1.28	22.95
3	Upper Arm	3.25	0.436	11.05	5.232	2.07	31.78
4	Forearm	1.87	0.43	6.358	5.0525	13.33	32.32
5	Hand	0.65	0.468	2.21	0.936	20.76	35.75
6	Thigh	10.5	0.433	35.7	8.227	8.1	17.09
7	Lower Leg	4.75	0.434	16.15	[illegible]	[illegible]	[illegible]
8	Foot	1.43	0.5	4.862	[illegible]	[illegible]	[illegible]



Cockpit Ergonomics

Analysis Summary

Rapid Upper Limb Assessment

•Grand score: 6

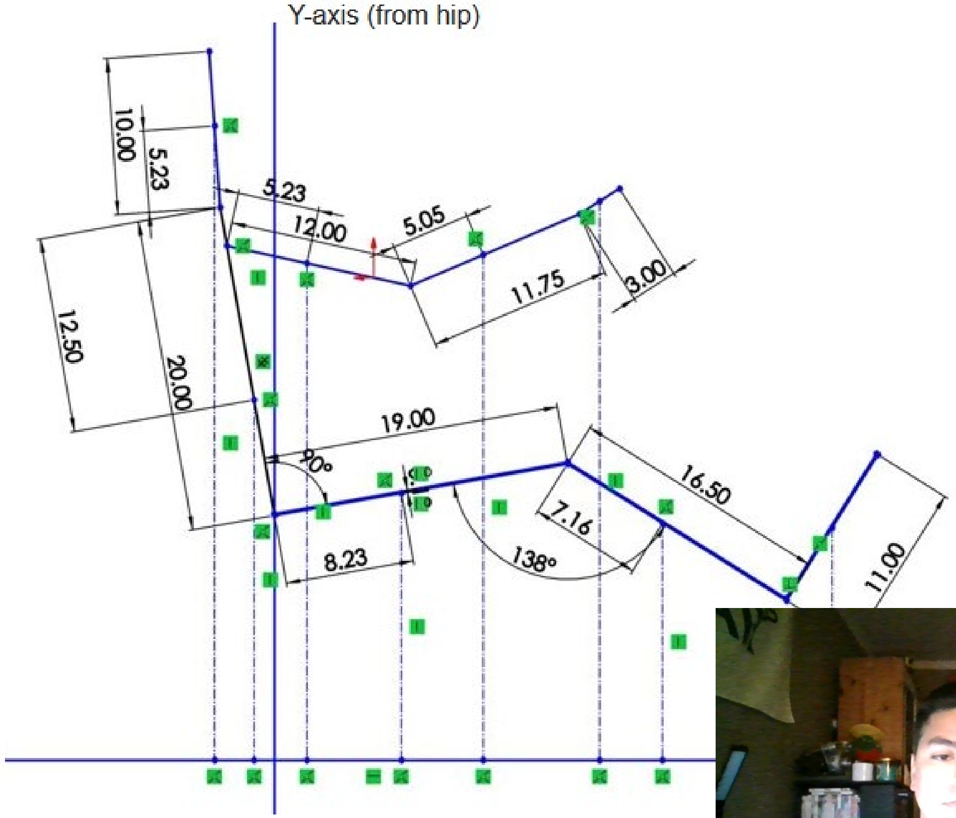
•Meets requirements

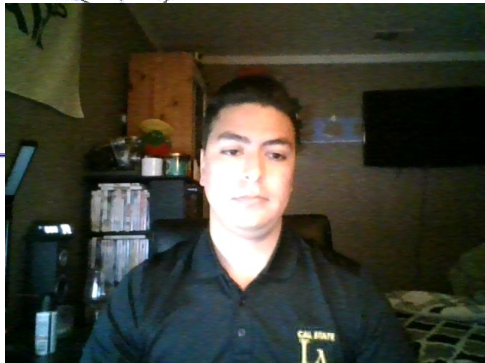
•Center of driver mass on a 2D plane

•Driver: 5'9" - 170lbs

•Coordinates (5.06", 23.31")

Analysis Summary





Cockpit Ergonomics

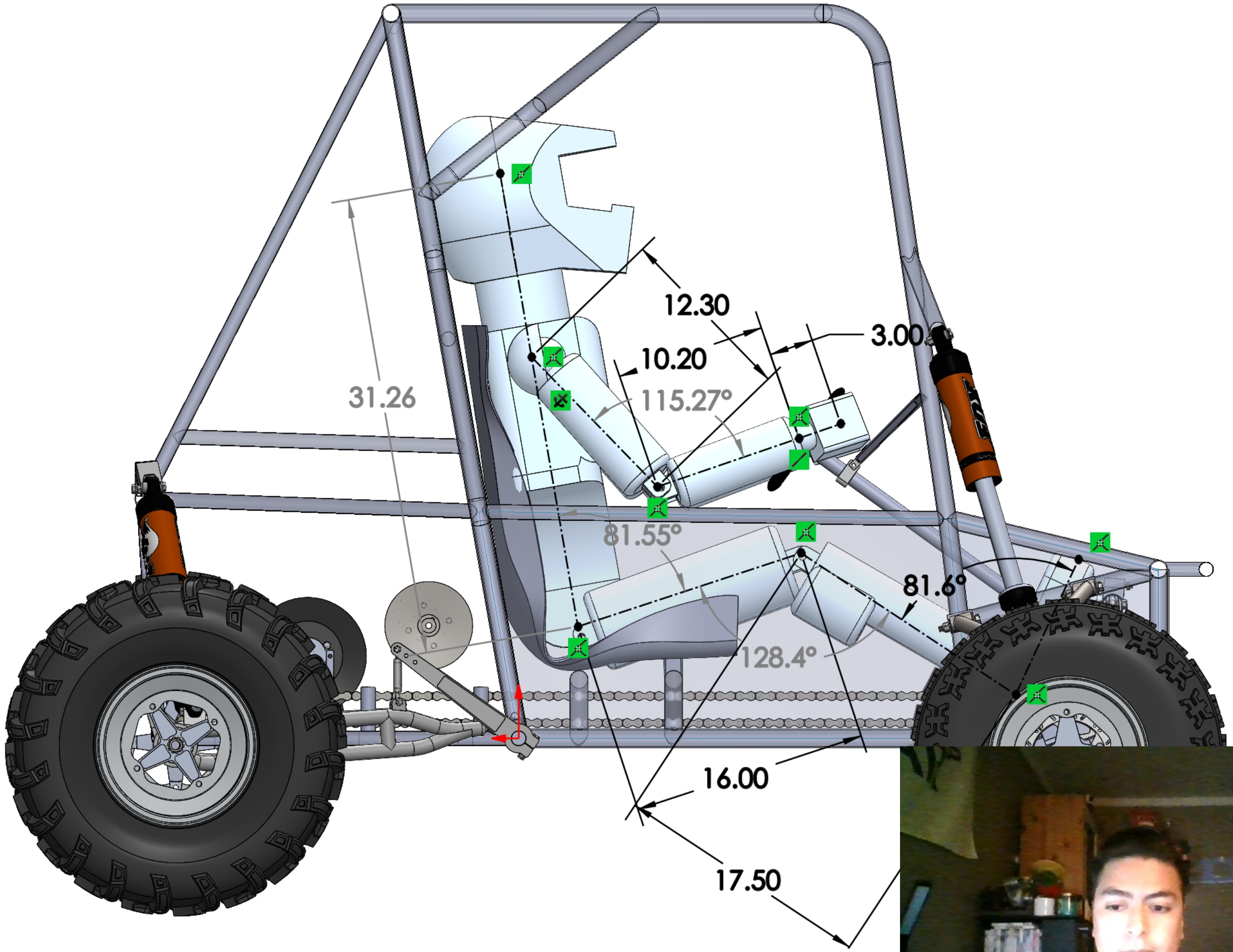
Analysis Summary

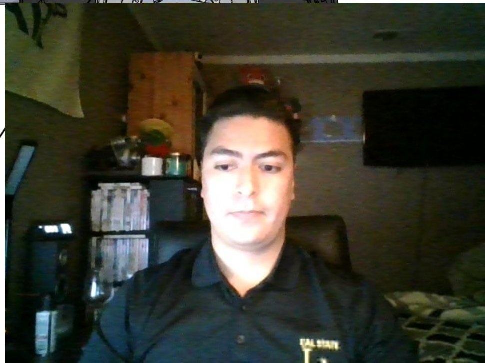
Targeted body angles

- Elbow [90-170 deg]
- Hip [80-120 deg]
- Knee [100-150 deg]
- Ankle [80-120 deg]

Measured results

- Elbow **115 deg**
- Hip **81 deg**
- Knee **128 deg**
- Ankle **81 deg**





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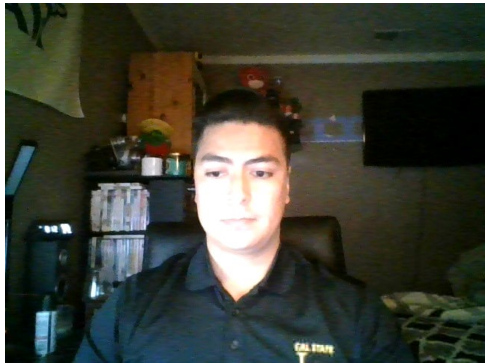
IV. Summary

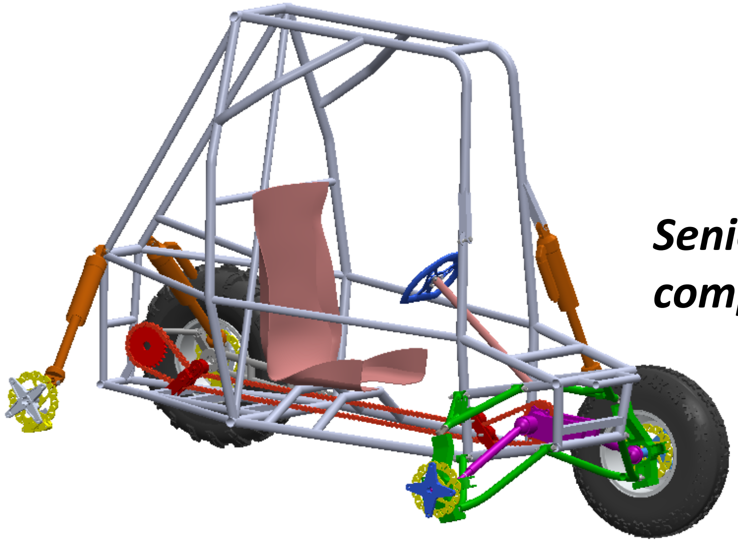


Summary

Initial Goals
- Design, build and test a four-wheel drive Baja style vehicle

Issues along the way
- Lack of lab access did not allow for manufacturing
- Packaging constraints within the nose of vehicle prompted redesigns for various members

Final Results
- Finalized designs for all subsections of the vehicle are completed with thorough analysis, and are ready to be manufactured



Senior Design components

2021 Baja SAE Vehicle