NAU
NORTHERN ARIZONA UNIVERSITY

SAE Baja

2024-2025

Project Description

Design, Fabricate, and Race a 4WD, off-road Vehicle

- 3 Subteams (Chassis, Drivetrain, Suspension, Steering, and Brakes)
- Everything is standardized in correspondence with the Society of Automotive Engineers (SAE)
- Outreach: Continue getting sponsorships
- Race and compete against other universities at the end of the year

NAU SAE Baja Number 57

Brennan

Budget

	Category	Description	Approximate Cost
1	Chassis	Cost from Bill of Materials	$1641.72
2	Drivetrain	Cost from Bill of Materials	$5169.63
3	Steering, Suspension, and Brakes	Cost from Bill of Materials	$3515.19
4	Travel and Contingencies	Estimated Cost from First Presentation	$5,200
		Total Cost :	$15,526.54

Potential Sponsors:

Gore, Copper State, Mother Road, NAPA HAAS, Harsh Co., Poba Medical, Discount Tire, H&S Field Services, Dylan and Ryan’s Dad, Novakinetics

Sponsor Methodology:

Reach out to all of the team’s personal connections, and any local businesses to raise money.

Dylan C.

Team Finance

Income:

Put Sponsors on this list that have committed to donating			Contact Info	
Sponsor Names	Package option	$ Amount	Phone #	Email
Gore	Rock Hopper	$5,000	n/a	n/a
H&S Field Services	Rock Hopper	$5,000	need	need
Poba Medical	Mud Buggy	$1,500	n/a	mindyd@pobamedical.com
Harsh Co	Rock Hopper	Services	(928) 303-4586	robbyglass@harshco.com
Dylan and Ryan's Dad	TBD	$ unknown at the moment	(480) 586-5754	dcarley69@gmail.com
Disocunt Tire (Store Manager on east side of town)	TBD	$ unknown at the moment	(623) 330-8961	n/a

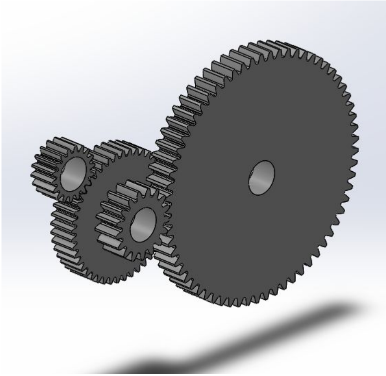
Package Options	
Mud Buggy	$50-$1000
Rock Hopper	$1000-$5000
Hill Climber	$5000+

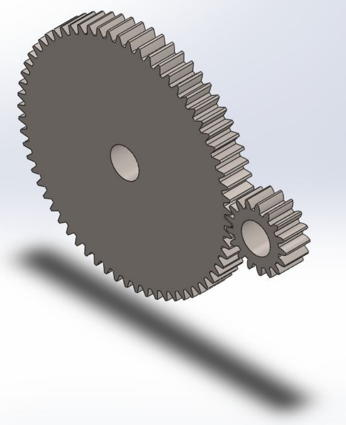
Expenses:

Finances for SAE Baja 2025							
Vender Name/Sponsor	Weblink to Item	Description	Item or Catalog #	Size/Color	Qty	Discount Code	Total Cost
Online Metals		Aluminum Bar stock	12864		1	Free from Mystery Donor	1291.68
Online Metals		Aluminum Round stock	1110		1		339.65
Online Metals		Aluminum Plate stock	27600		1		307.16
Online Metals		Secondary Tube for Chassis	10751	12 Feet	5		571.24
IMS		Primary Tube for Chassis	Quote	8 Feet	6		620.48
SpeedyMetals		4140 steel	Quote		1		289.71
MotoSport		Wheels for Vehicle	DVT A5 wheels	polished	4		314.27
Grainger		Corded Milwaukee 3 jaw hammer drill	3du39	red	1		201.78
Registraion for Comp		Companition Requirement to Compete			1		$1,800
Home Depot		1 in. x 10 ft. PVC Schedule 40 Tubing DW	Milwaukee1-1/4 in. H	10 feet	6		55.55
Home Depot		Oatey16 oz. Regular Clear PVC Cement	310143	16 oz	1		11.99
Home Depot		Oatey16 oz. Regular Clear PVC Cement	9-56-9609	1 in	2		26.14
Home Depot		Milwaukee1-1/4 in. Hole Dozer Bi-Metal H	49-56-961	1 1/4 in	2		27.97

Total Cost	121.65

Dylan





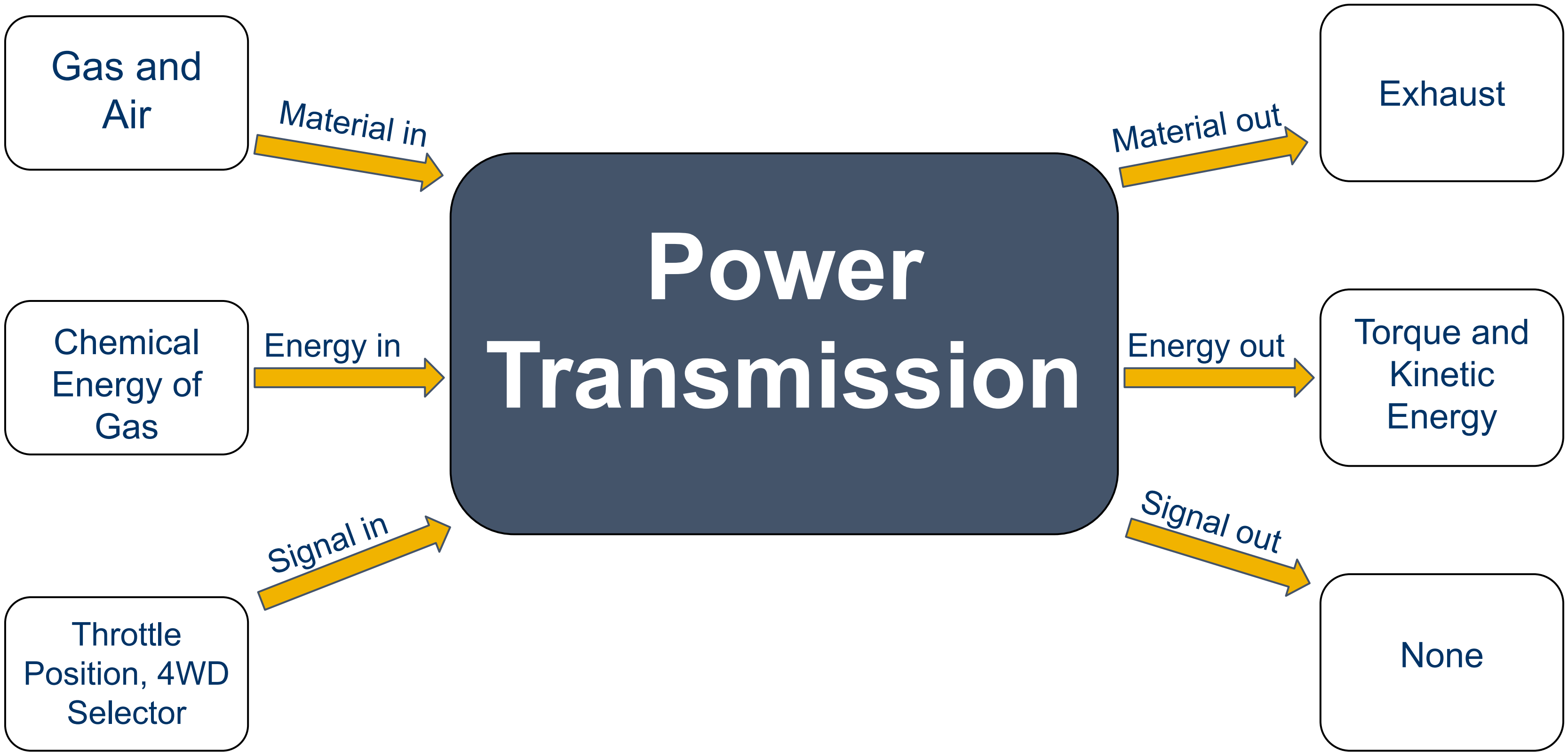
Drivetrain

Dylan Carley
Matthew Dale
Ethan Niemeyer
} Reduction Box, Axles, and Hubs

Rowan Jones
Nolan Stomp
} 4WD System

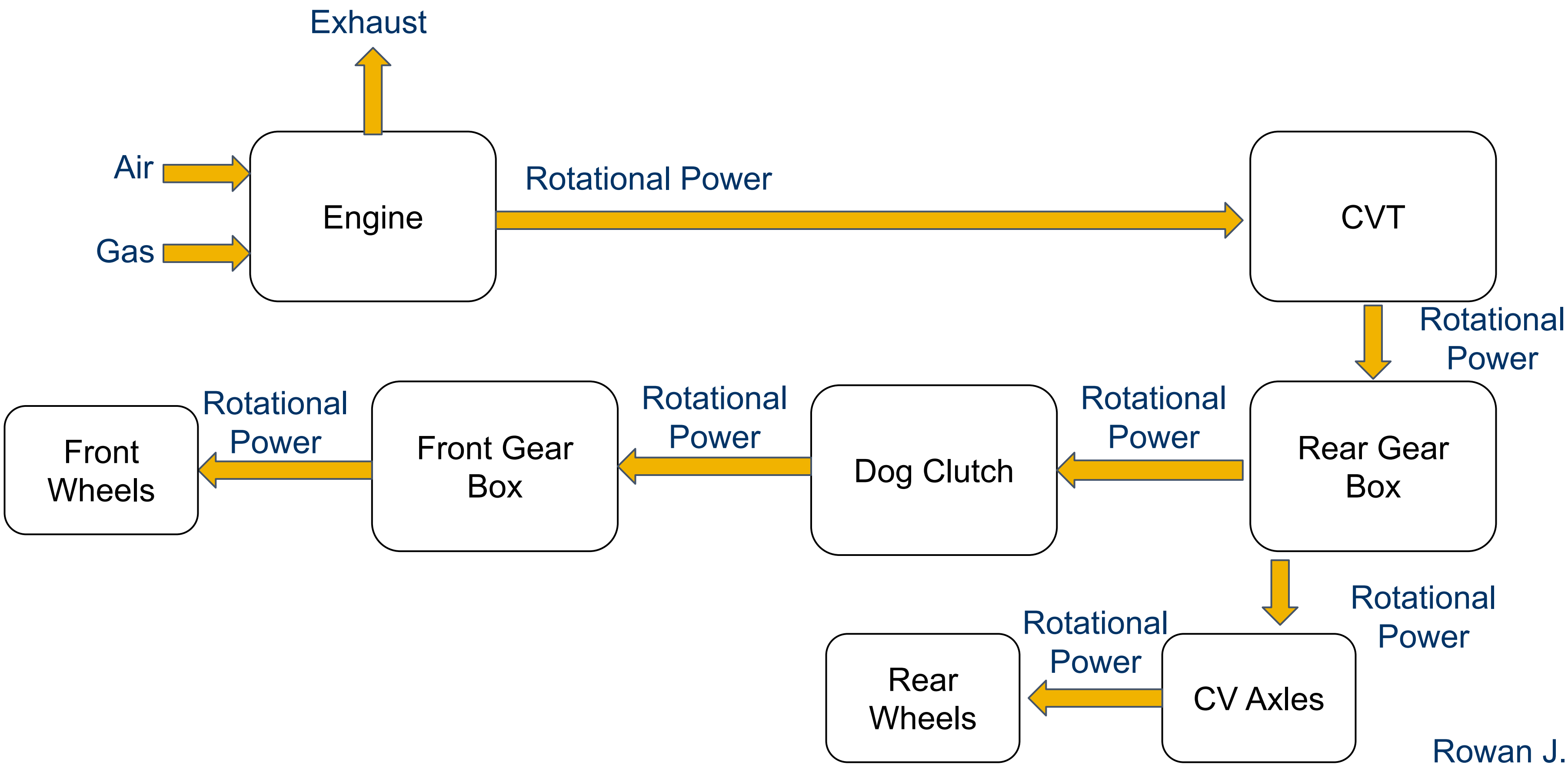
Brennan Pongratz
Seth Scheiwiller
} CVT

Black Box Model - Drivetrain



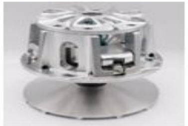
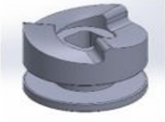
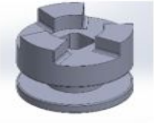
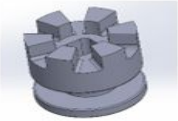
Ethan N.

Functional Flow Diagram - Drivetrain



Rowan J.

Concept Generation

Concept	Design Variants		
CVT Actuating Mechanism	 Cams + Rollers	 Ramps + Rollers	 Electronic
Axles	 CV (Cup alone)	 CV (Cup-Shaft-Cup)	 U-Joints
Gears	 Spur Gears	 Helical Gears	 Bevel Gears
Hubs	 Spline	 Hex	 Press Fit
Dog Clutch	 3-tooth Curvic	 3-tooth Square	 6-tooth Square

All

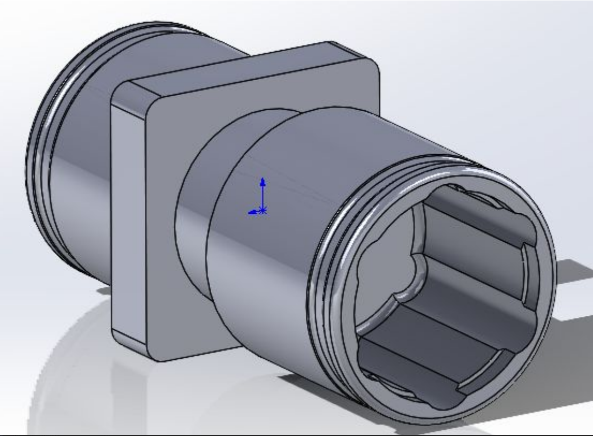
Engineering Calculations - Axles

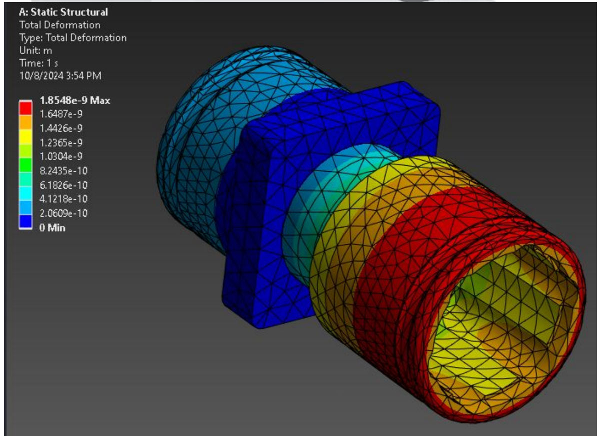
Shaft Diameter

Minimum Diameter of a 4130 steel tube that can withstand 20 hp (Safety of factor of 2) at post reduction box 300 rpm:

P = (T*w)/5252
P=Power in (HP)
T= Torque in (Ft-Lb)
w=Rotational Speed in (RPM)
5252 is a unit conversion factor
Solve for T
T=(π/16)*τ*d^3
Solve for d

d=0.73 inches





CV Cup Thickness

Minimum wall thickness for 4140 HT Steel CV cup with assumed OD of 2.5” that experiences 20 hp (Safety factor of 2) at post reduction box 300 rpm

P=(T*w)/5252
P = (T*w)/5252
P=Power in (HP)
T= Torque in (Ft-Lb)
w=Rotational Speed in (RPM)
Solve for T
T=(π/16)*τ*((d(outer)^4-d(inner)^4)/d(outer))
τ=allowable shear stress in (Psi); 54150 for 4140 HT steel
Solve for d(inner)
t=(d(outer)-d(inner))/2

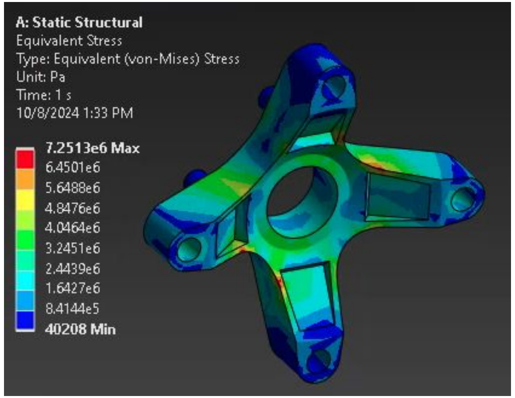
t=0.125 inches

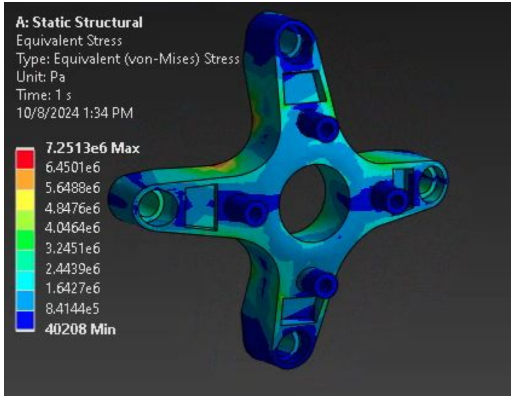
Ethan N.

Engineering Calculations - Hub

Ansys Static Structural Analysis

- 6061 T6 Aluminum
- Fixed at center hole
- Max impact force = 1348 N
- Max braking force = 312 lb-ft
- Stress and deformation results shown

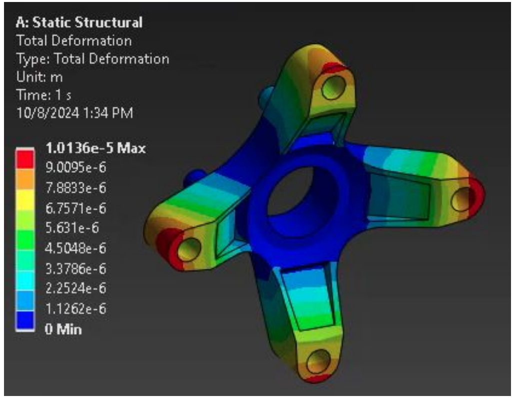


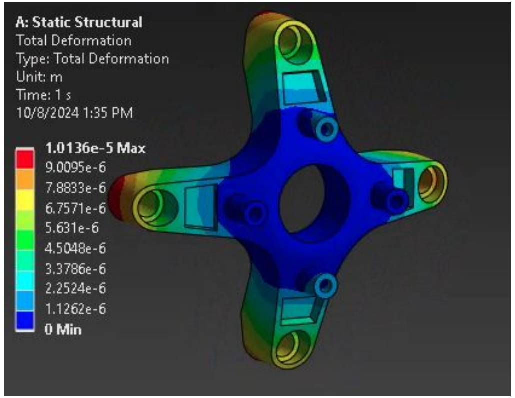


Results

With thickness of 1.5 inches from initial calculation, much of the part is experiencing minimal stress.

Part can be made smaller to reduce weight while still being strong enough for competition.





Matthew D.

Engineering Calculations - Rear Gear Bearings

Desired Life (ld) = 1000 hours

Desired Speed (nd) = 1300 rpm

Application factor (af) = 1

Reliability (Rd) = .9

Rating life (revelations L10) = 10^6

Input torque = 600 in*lbf
F = T/dist.
Input shaft dist. ~= 8in
Bearing 1: takes both axial and radial load (6in from torque application)
Bearing 2 takes on radial load (8 in from torque application)

Bearing 1: Radial load = T/dist = 600/6 = 100 lbf
Bearing 1: Axial Load = 50 lbf (from secondary on CVT)
Bearing 2: Axial Load = 600/8 = 75 lbf
Xd = Ld/L10 = (60*1000*1300)/(10^6) = 78 (Rating Life Multiple)
Weibull Parameters for L10 = 10^6:
X0 = 0.02
Theta = 4.459
b = 1.483
a = 3 (for roller bearings)

$$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)[\ln(1/R_D)]^{1/b}} \right]^{1/a}$$

$$(1)(8.33)\left(\frac{78}{(.02) + (4.459 - .02)\left(\ln\left(\frac{1}{.9}\right)\right)^{\frac{1}{1.483}}} \right)^{\frac{1}{3}}$$

$$= 35.6705143769$$

C10 = 35.67 lbf = .1587 kN -> For size of bearing we need this catalog rating is ~= 80 times underrated

Dylan

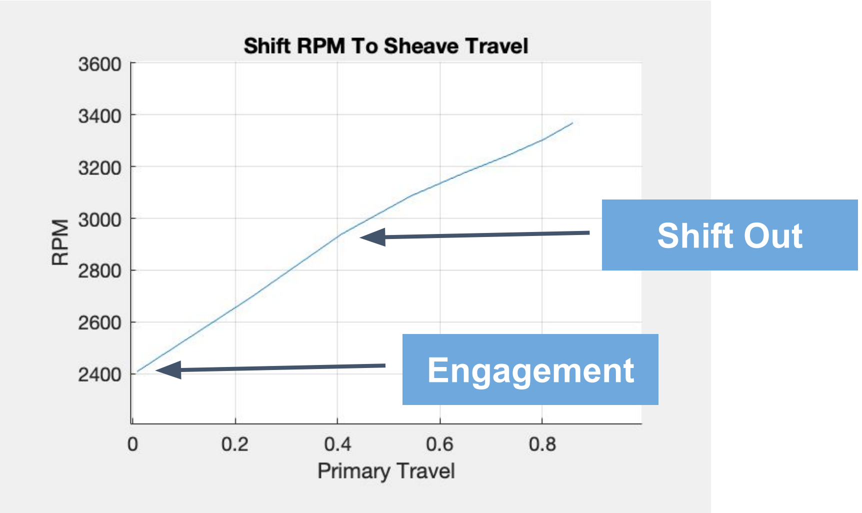
Engineering Calculations - Shift RPM

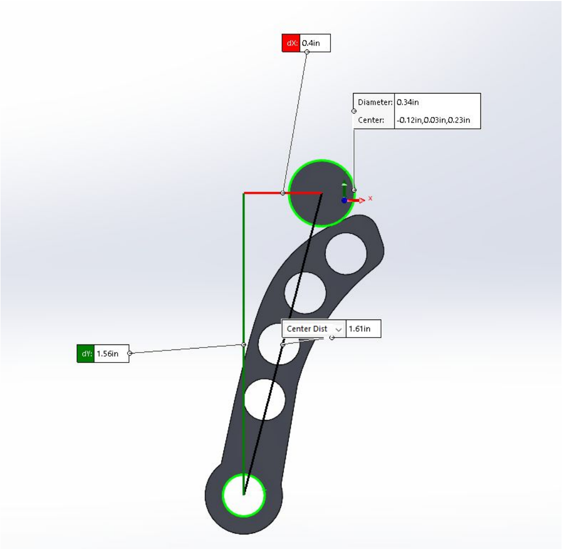
After iterating in MATLab, potential cam curve reveals:

Engagement is at peak torque rpm of ~2400 RPM

Shift out is at peak HP rpm of ~3000 to ~3300 RPM

***May continue iterating to find more ideal cam curve**





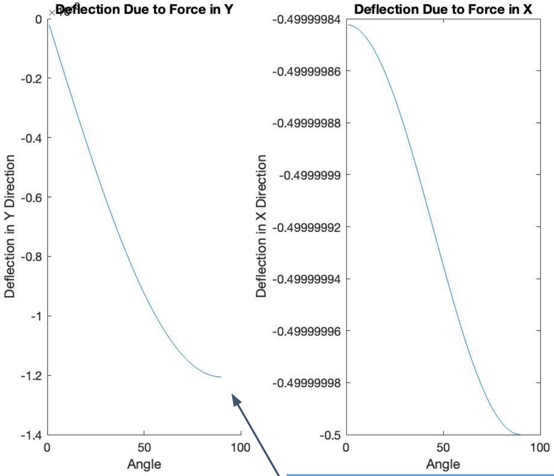
After visualising in CAD:

- **Cam length satisfies required sheave travel**
- **Confirms direction of forces throughout engagement. Provides basis for beam deflection calculations of cam spider**

Seth S.

Engineering Calculations - Beam Deflection of Spider Legs


```
camForce = flyweightShiftForce/3 % Divides
ForceMagnitude = camForce/2 % determines m

x1 = 1.1
x2 = 1.7

y1 = 0
y2 = 0.5

theta2 = 20
theta3 = 90-theta2

h = 0.375
b = 0.25
I = b*h^3/12

E = 10000

deltaX1X2 = zeros(1,90)
deltaY1Y2 = zeros(1,90)

deltaTotalY=zeros(1,90)
deltaTotalX=zeros(1,90)

for i=1:1:90
    ForceX = cosd(i)
    ForceY = sind(i)
```



Max deflection of ~.0012 inches

Assumptions:

- Flyweight force is split evenly between all 6 spider legs
- Uniform cross section and no fillets
- Cam exerts force only between 0 and 90 degrees

Results

- MATLab iterates beam deflection through different angles of cam contact
- Confirms that deflection in x direction is negligible
- Max deflection occurs when cam force is at 90 degrees
- Will perform future iterative FEA with the assumption that cam contact will always be 90 degrees as worst case scenario
- Will use code to optimize geometry and reduce weight

Seth S.

Engineering Calculations

Secondary Max Clamping Force = 380 lbf

With Design Factor of 1.2 = 450 lbf

Acting on ⅓ Roller Mounts = 150 lbf

With 40° Helix Angle = (96, 115) lbf

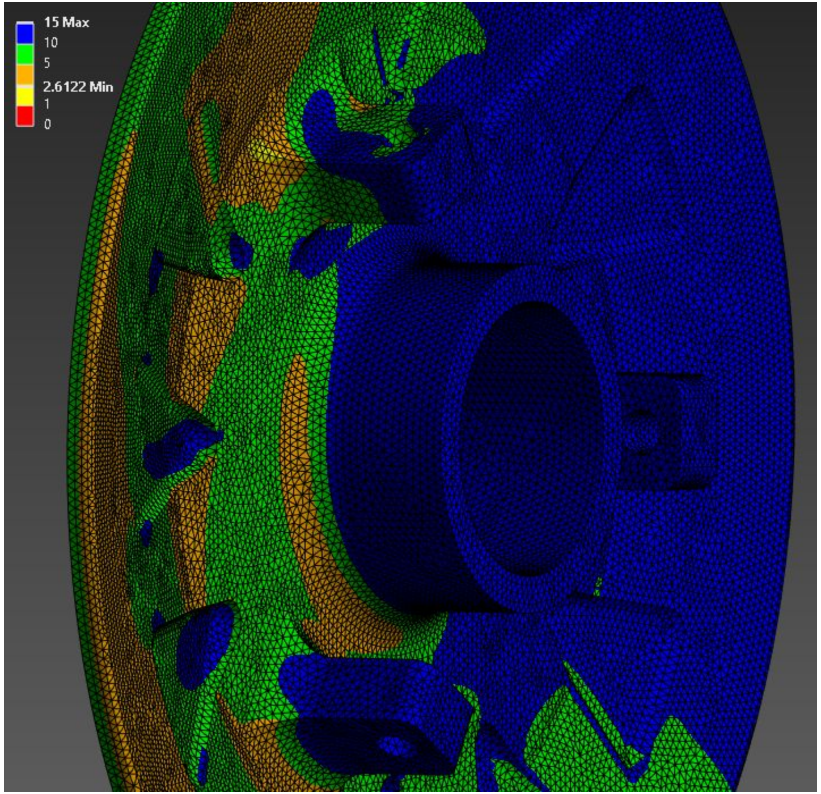
6061 Al UTS = 45 kpsi

Results:

Max Deformation = 0.015 in

Safety Factor = 2.6

Life Cycle = 10^8



Brennan

Engineering Calculations - Front Gear Bearings

The front gear box is connected to the chain drive which allows power transmission from the rear gearbox to the front. The front will be slightly underdriven (about a 1:1.1 ratio) to allow for better handling and maneuverability of the vehicle.

Input Torque ~ 6000 lbs-in = 500 lbs-ft

Bearing Reactions

Axial: 600 lbs-ft (from gear reduction)

Radial: 100 lbs-ft

Using Weibull Parameters:

X0 = 0.02; theta = 4.459; b = 1.483;

a = 3; af = 1; Rd = 0.9; Lr = 10^6; Ld = 1000*300*60

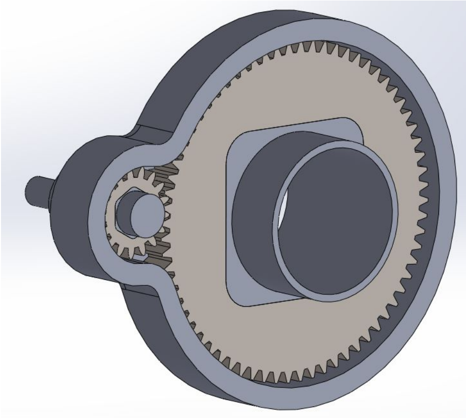
XD = Ld/Lr = 18; FD =~ 600 lbf

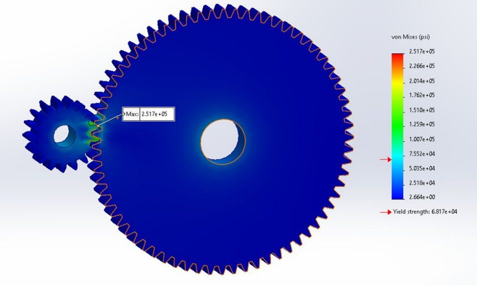
C10 =~ 2000 ft-lbs

$$C_{10} \approx a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{1/b}} \right]^{1/a} \qquad R \geq 0.90$$

For the SAE BAJA vehicle, the needed life out of these bearings will be low due to the length of the competition, so the bearing selection will be based majoritively on the load experienced by the adjoining shafts. The bearings that will be selected and purchased will be satisfactory for this use-case. See BoM for specific bearings.

Bore Diameters (subject to change):
Input Gear = 0.75in
Output Gear = 2.75in





Rowan J.

Engineering Calculations- Dog Clutch

3-tooth Curvic Teeth

d_o= 2 in.

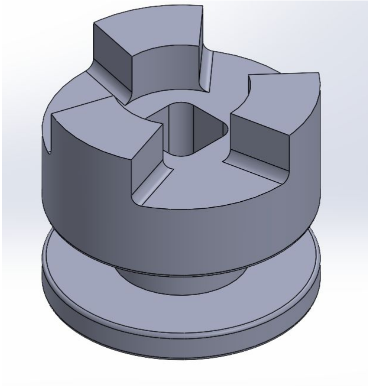
d_i = 1 in.

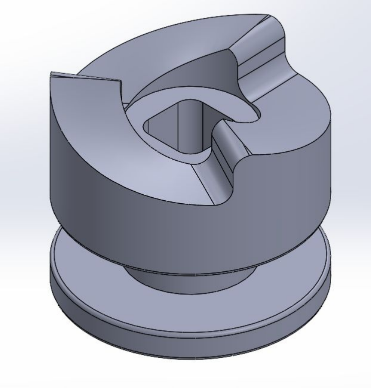
Δd= d_o-d_i = 1 in.

F= T/(r_i/12)

=125 lbf*ft/(0.5/12)= 3000 lbf

σ=F/A= 3000 lbf/0.20 in^2= **15000 psi**





3-tooth Curvic Teeth

d_o= 2 in.

d_i = 1 in.

Δd= d_o-d_i = 1 in.

F= T/(r_i/12)

=125 lbf*ft/(0.5/12)= 3000 lbf

σ=F/A= 3000 lbf/0.26 in^2= **11538.46 psi**

4130 Annealed Steel

Nolan S.

Concept Evaluation

	Variants					
Subsystem	1	Results	2	Results	3	Results
Axle Types	CV (Cup-Shaft-Cup)	✓	CV (Cup alone)	X	Universal -Joint	X
Gear Types	Bevel Gear	X	Helical Gear	X	Spur Gear	✓
Clutches	3-Tooth Square	X	3-Tooth Curvic	✓	6-Tooth Square	X
CVT	Cams	✓	Ramps	X	ECVT	X
Hub	Spline	✓	Hex	X	Press Fit	X

Bill of Materials - Drivetrain

CVT		
Part	Quantity	Total Cost ($)
Sec. Fix Sheave	1	60
Sec. Move Sheave	1	90
Sec. Helix	1	15
Sec. Spring Cap	1	10
Sec. Shaft	1	50
Sec. Torsion Spring	1	0
8-32 Bolts	6	61.38
Sec. Cam Rollers	3	84.99
Cam Roller Nuts	3	19.05
Pri. Fixed Sheave	1	60
Pri. Move Sheave	1	100
Pri. Spider	1	70
Pri. Spring Cap	1	10
Pri. Shaft	1	50
Pri. Cams	3	45
Pri. Roller Bearings	3	39.84
Ti Dowel Rods	3	58.29
Shoulder Bolts	3	80.76
Nuts	3	11.37
Pri. Compression Spring	3	36
Pri. & Sec. Spacers	3	15
V-Belt	2	200
Pri. & Sec Shaft Key	2	0
Pri. & Sec. Bushings	4	59.72

Rear Gear Box		
Part	Quantity	Total Cost ($)
SKF 210-ZNR	2	160
SKF 6206	2	70
SKF 6208	1	80
SKF 6212	1	175
Gear 1 (4340 HT)	1	30
Gear 2 (4340 HT)	1	100
Gear 3 (4340HT)	2	150
Gear 4 (4340 HT)	2	80
Casing (6061-T6)	2	200
Shaft 1 (4140)	1	30
Shaft 2 (4140)	1	50
Shaft 3 (4140)	1	100

Front Gear Box		
Part	Quantity	Total Cost ($)
1654-2RS	4	200
FZ 6207	2	400
Pinion (Gear 1) (4340 HT)	1	30
Gear (Gear 2) (4340 HT)	1	100
Casing (6061-T6)	2	150
Shaft (4140)	2	80
#10-24 Shoulder Screw	10	40
1/4 - 20 Head Cap Screw	4	20

CV Axles		
Part	Quantity	Total Cost ($)
Caltric CV Axles	2 (+2 at shop already)	116
4130 Steel round tube (1"OD, 0.834"ID)	2 x 36" pieces	122.34

Hub		
Part	Quantity	Total Cost ($)
Front Hub	2 (+1 Spare)	510
Rear Hub	2	340
Sleave	1	25
Lugnut	16 (+4 Spare)	200
Stud	16 (+4 Spare)	160

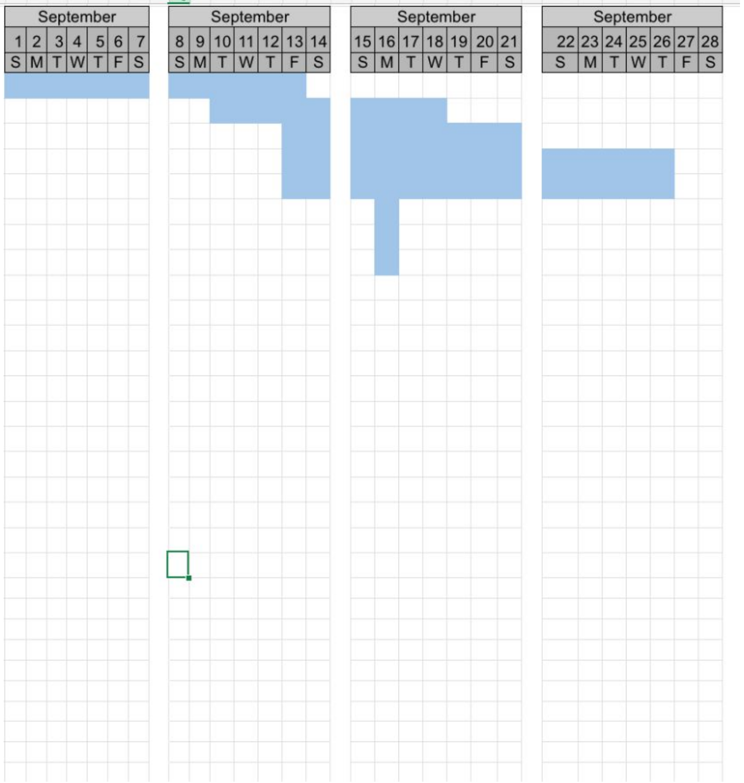
4WD System/ Dog Clutch		
Part	Quantity	Totla Cost ($)
4130 Steel Round Bar (1ft length, 2.5" OD)	1	30
ANSI 40 Roller Chain (10ft)	1	38.95
40A17 Sprocket	6	155.94

Summary	
Subteam	Total Cost ($)
CVT	1226.4
4WD	224.89
CV Axles	238.34
RGB	1225
FGB	1020
Hub	1235
Total	5169.63

Rowan J.

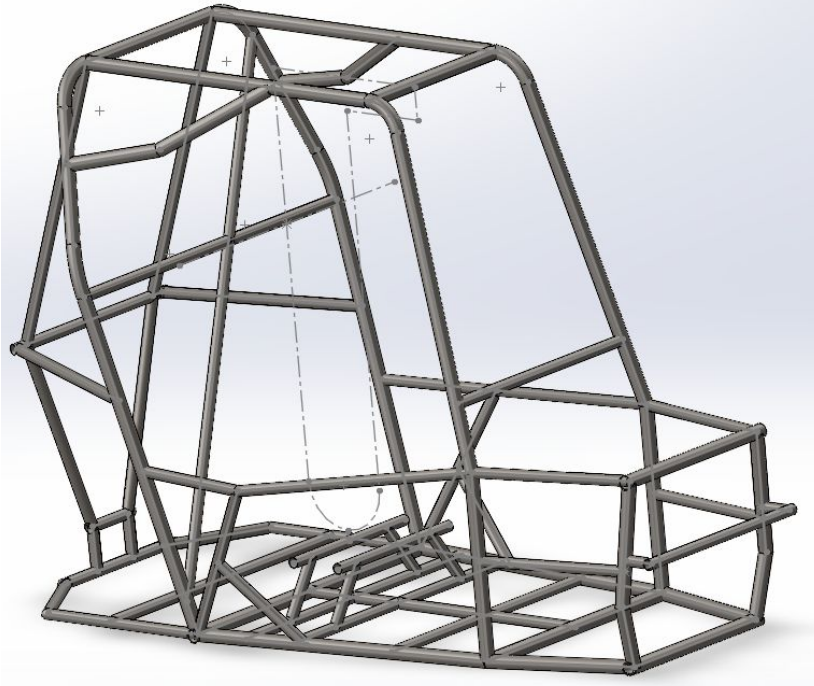
Schedule

	Color	Task	Assigned To	Start	End
5		Organizing Teams and getting resources together for the semester	Team	9/1/24	9/13/24
6		Presentation 1	Team	9/10/24	9/18/24
7		Finalize Sub-system Decisions	Drivetrain Team	9/13/24	9/21/24
8		Rear Drivetrain Points	Drivetrain Team	9/13/24	9/26/24
9		Front Drivetrain Points	Drivetrain Team	9/13/24	9/26/24
10		Begin Refined CVT CAD	Brennan and Seth	9/16/24	Pending
11		Conduct stress analysis on CVT components	Brennan and Seth	9/16/24	Pending
12		Find ideal cam curve and geometry	Brennan and Seth	9/16/24	Pending
13		Finilize calculations for front gear box	Rowan	9/16/24	10/18/2024
14		Begin CAD for front gear box casing	Rowan	9/16/24	10/18/2024
15		Finalize calculations for rear reduction box gear train	Ethan and Dylan	9/16/24	Pending
16		Finalize calculations for clutch system	Nolan	9/16/24	Pending
17		Begin CAD for chain drive sprockets	Nolan	9/16/24	Pending
18		Finalize calculations for hubs	Matthew	9/16/24	Pending
19		Design/FEA rear gearbox hosuing and shafts	Ethan and Dylan	9/18/24	Pending
20		Registration for competition	Team	10/2/2024	Pending
21		Presentation #2	Team	Pending	10/9/2024
22		Report #1	Team	Pending	10/18/2024
23		Website check #1	Team	Pending	10/25/2024
24		Rough CAD Assembly for Drivetrain	Drivetrain Team	Pending	11/1/24
25		Begin Manufcaturing CVT	Brennan and Seth	11/1/2024	1/20/25
26		Start assembling first Prototype	Drivetrain Team	Pending	11/13/24
27		Analysis Memo	Team	Pending	11/1/24
28		Presentation #3	Team	Pending	11/6/24
29		1st Prototype Demo	Team	11/13/2024	11/13/24
30		Individual Analysis	Individual	Pending	11/22/24
31		Report #2	Team	Pending	11/27/24
32		Final CAD and Final BOM	Team	Pending	12/3/24
33		2nd Prototype Demo	Team	Pending	12/4/2024
34		Website Check #2	Team	Pending	12/7/2024



Seth

Chassis & Frame

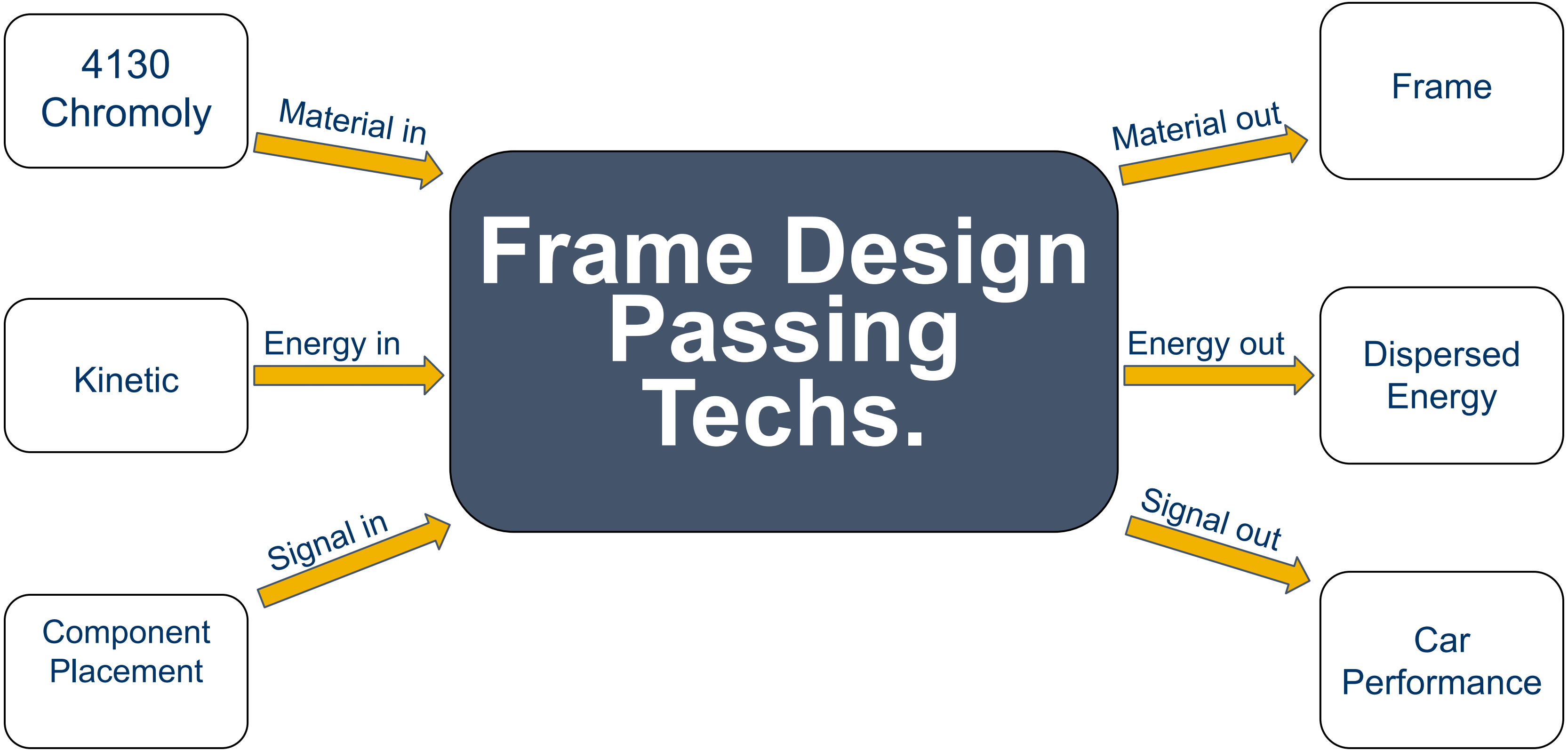


Ryan Carley - Front End, Team Lead

Wyatt Walker - Cockpit, CAD Manager

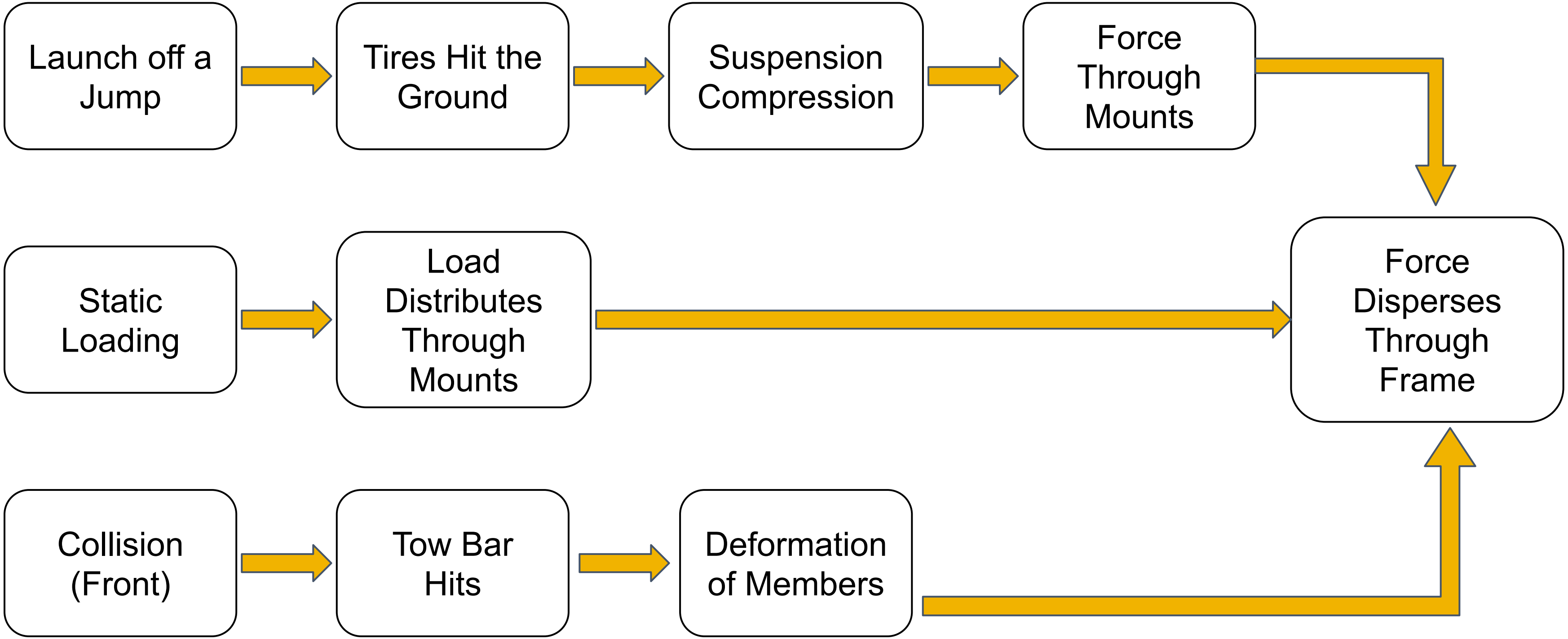
Charles Anderson- Rear End, Fabrication & Web Design

Black Box Model - Chassis



Charles

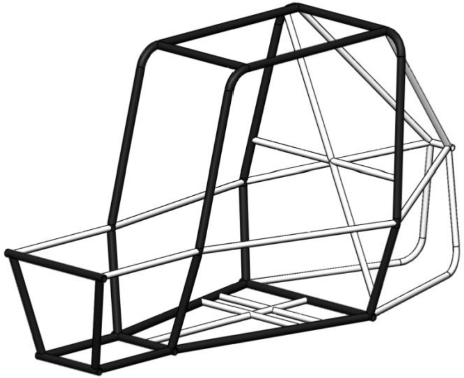
Functional Model



Wyatt

Concept Generation

Rear Braced VS Front Braced Frame

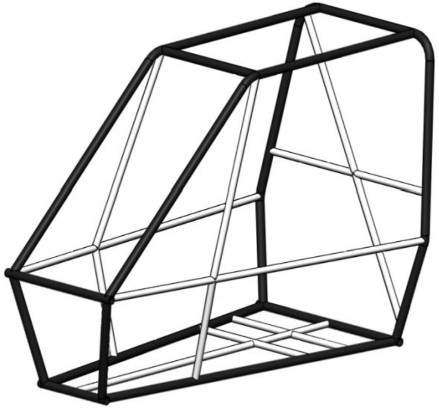


Per SAE Rule Book-2 Choices

Front Braced- Better Weight Distribution

Rear Braced- Ease of Benchmarking

Rear Braced- More Opened Cockpit

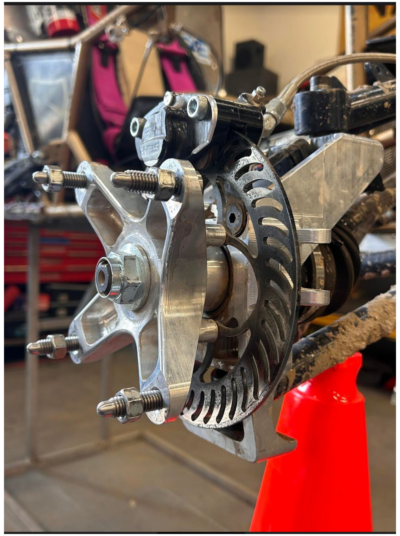


Concept Generations

Inboard vs Outboard Brake.

Inboard Brake- Creates crowding in the front toe box.

Outboard brakes- Creates a lower center of gravity



Ryan

Concept Generation

Hanging Floor Pedals VS Floor Mounted Pedals

Hanging- Requires additional member, Allows for ease of full depression of pedal

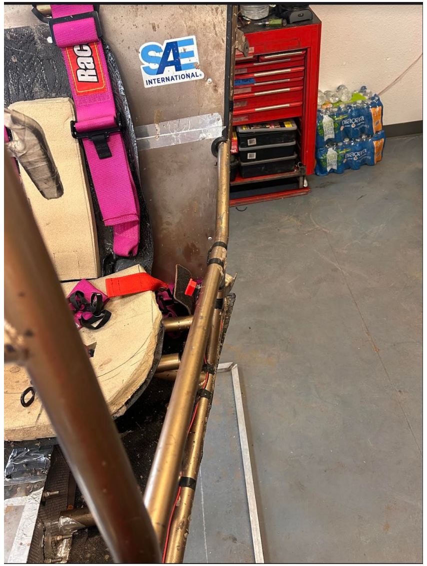
Floor- Requires more space in the front end, Harder for the driver to fully depress pedal

Concept Generation

SIM Supports: Inward Vs Outward

Outward facing- allows larger clearances for suspension mounting.

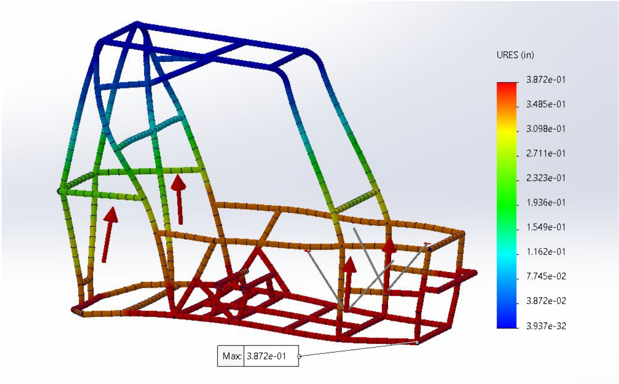
Inward facing- Creates a tighter cockpit



Engineering Calculations

Suspension Fully Compressed

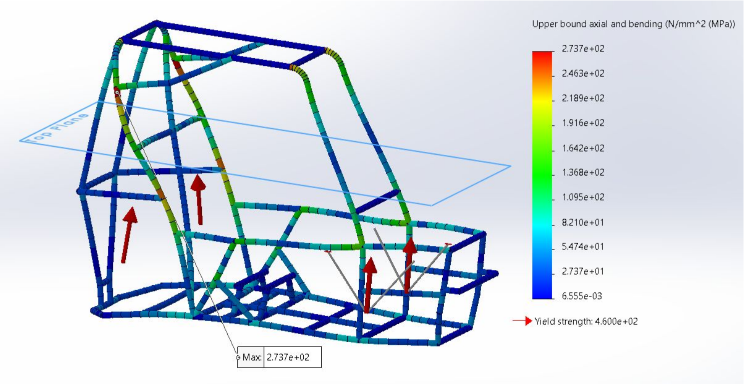
Car is falling from 10 ft and suspension bottoms out on impact



F = 5000 N

Max Deformation: .387in

Max Stress: 2.7x10^2 MPa

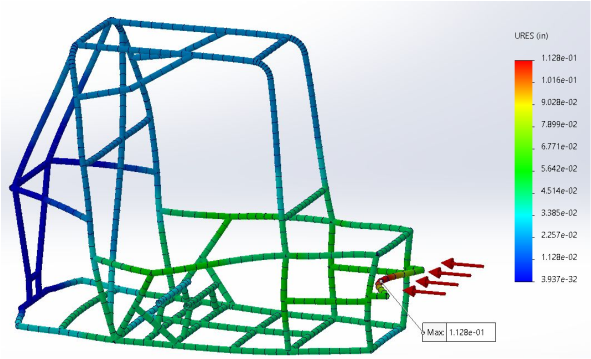


Ryan

Engineering Calculations

Head on Collision

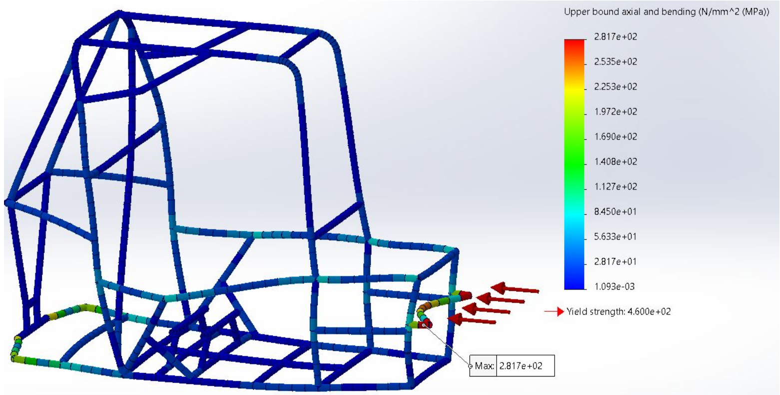
Car is moving 30 mph our car hits the rear of another competitor



F = 3350 N

Max Deformation: .112 in

Max Stress: 2.82x10^2 MPa

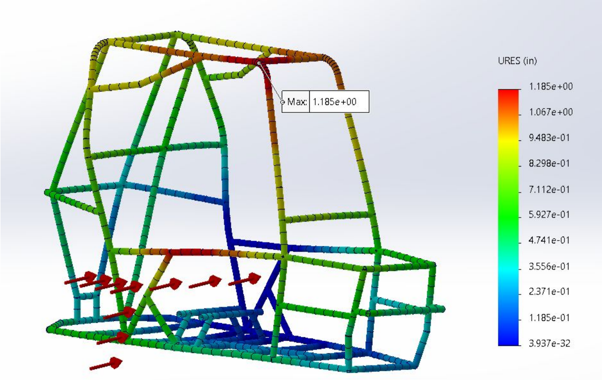


Wyatt

Engineering Calculations

Side Impact

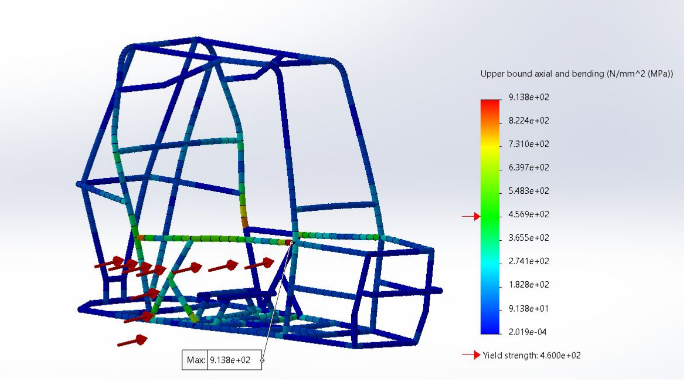
Car is T-Boned by another car which is moving at 30 mph, and hits our side impact member



F = 3350 N

Max Deformation: 1.185 in

Max Stress: 9.13x10^2 Mpa

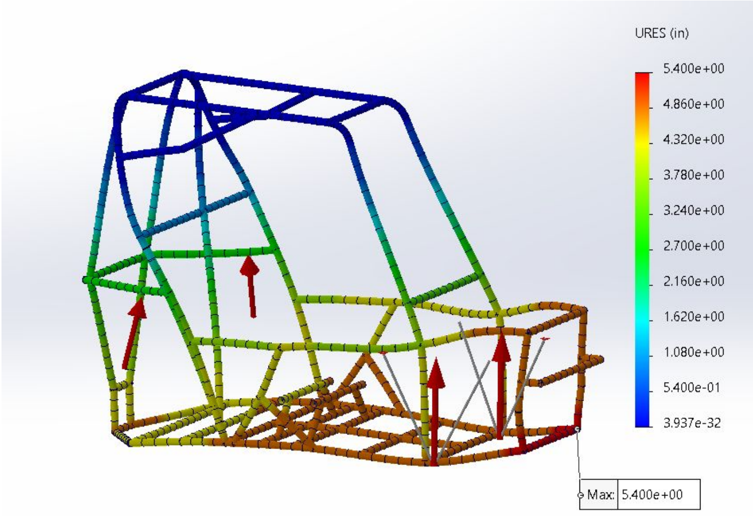


Charles

Concept Evaluation

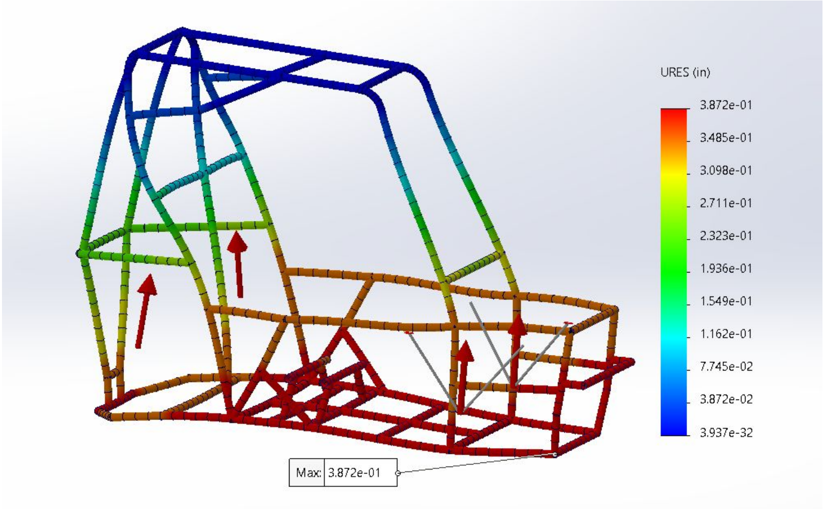
Deformation Evaluation

Max: 5.4 in



Without Upper Control Arm Support

Max: .387 in



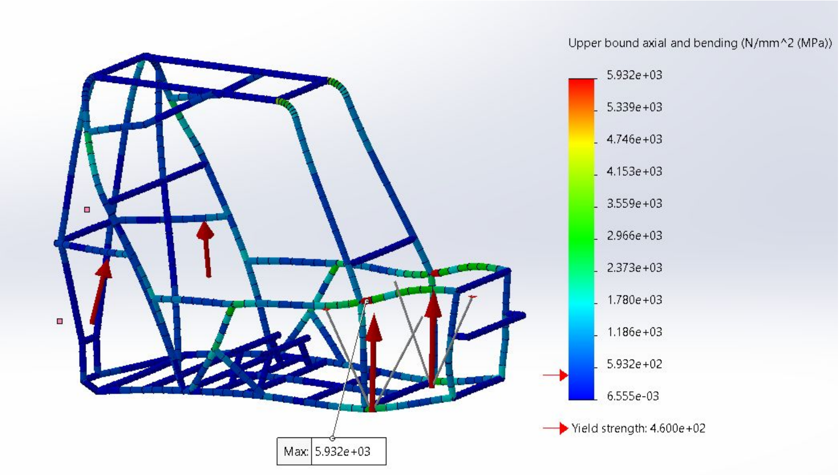
With Upper Control Arm Support

Ryan

Concept Evaluation

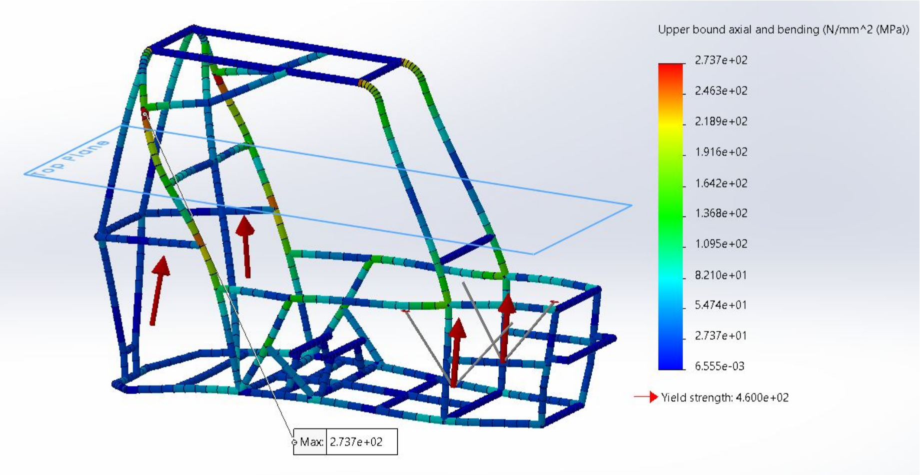
Stress Evaluation

Max: 5.93x10^3 MPa



Without Upper Control Arm Support

Max: 2.7x10^2 MPa



With Upper Control Arm Support

Ryan

Bill of Materials/Budget

Item	Quantity	Estimated Cost	Actual Cost
4130 Chromoly Steel Round Tubing 1.25OD x 0.065Wall	60 ft	620.48	0
4130 Chromoly Steel Round Tubing 1.00OD x 0.035Wall	48 ft	571.24	0
Carbon Fiber	TBD	200	TBD
Seat Belts	5	100	TBD
Fasteners & Tabs	~50	150	TBD
Total		1641.72	0

Wyatt

Schedule

		Number code	Color
		1	
Task	**Assigned To**	**Start**	**End**
Order PVC & Glue	Chassis Team	9/23/24	9/27/24
Order tubing	Chassis Team	9/23/24	9/27/24
Coordinate With other sub teams On Mounting Points	Chassis Team & Suspension	9/23/24	Working
Presentation #2	All	9/30/24	10/9/24
Registration for Competition	All	10/2/24	10/2/24
Begin Prototyping #1 (PVC Roll Cage and Jigs)	Chassis Team	10/10/24	10/13/24
Begin Fabrication	Chassis Team	10/14/24	10/14/24
Report #1	All		10/18/24
Begin Prototyping #2	Chassis Team	Working	
Website Check #1	Charles		10/25/24
Final CAD of the frame	Chassis Team		10/30/24
Analysis Memo	Chassis Team		11/1/24
Presentation #3	All		11/6/24
1st Prototype Demo	All		11/13/24
Finish Frame Fabrication	Chassis Team		11/26/24
Report #2	All		11/27/24
Final CAD and Final BOM	All		12/3/24
Project Management	All		12/6/24

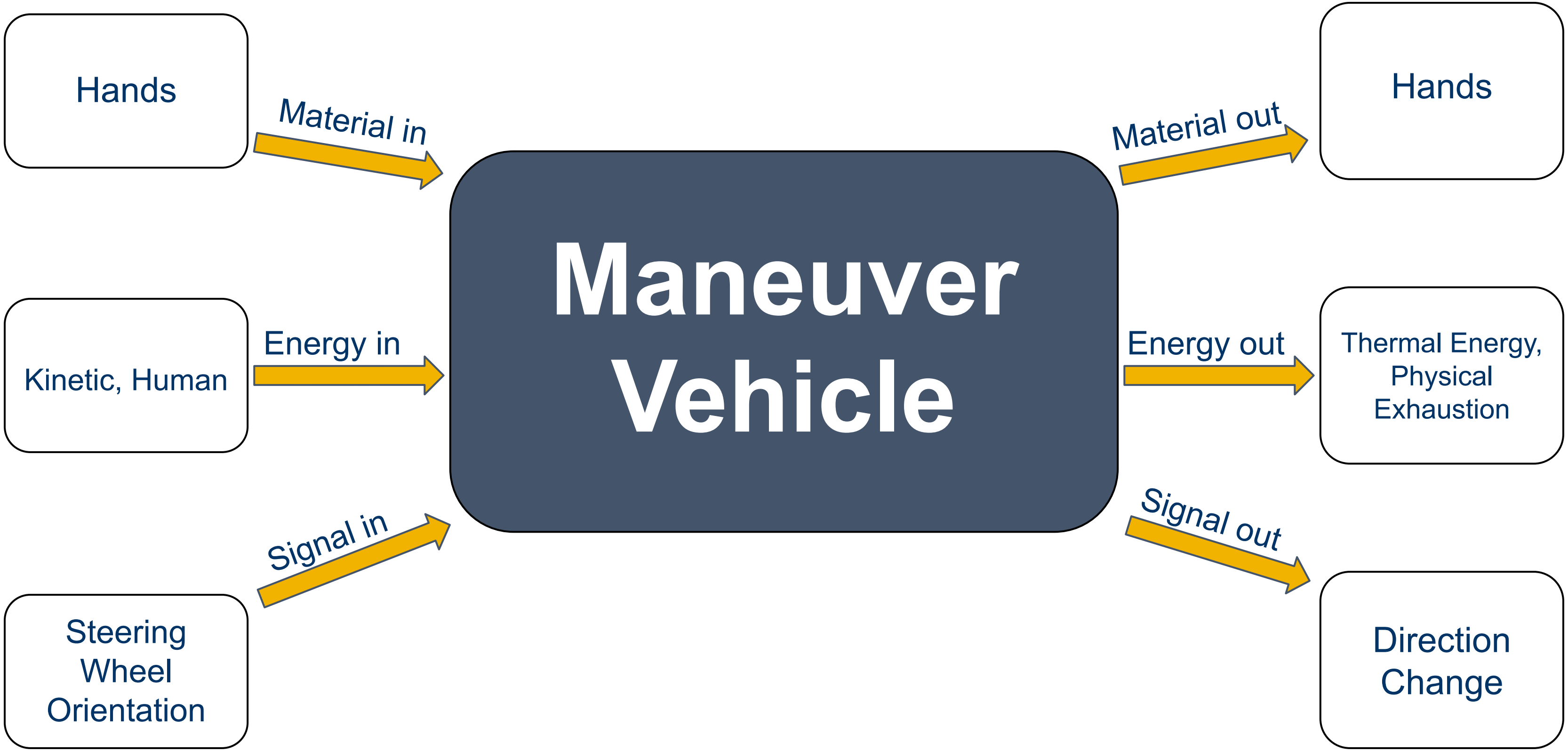
September							Sep.-Oct.							October							October						
22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S

Charles

Steering, Brakes, and Suspension

David Polkabla Jr. **Taylor Hewitt**	Steering, Brakes
Ryan Key **Ryan Latulippe** **Oliver Husmann**	Suspension

Black Box Model - Steering



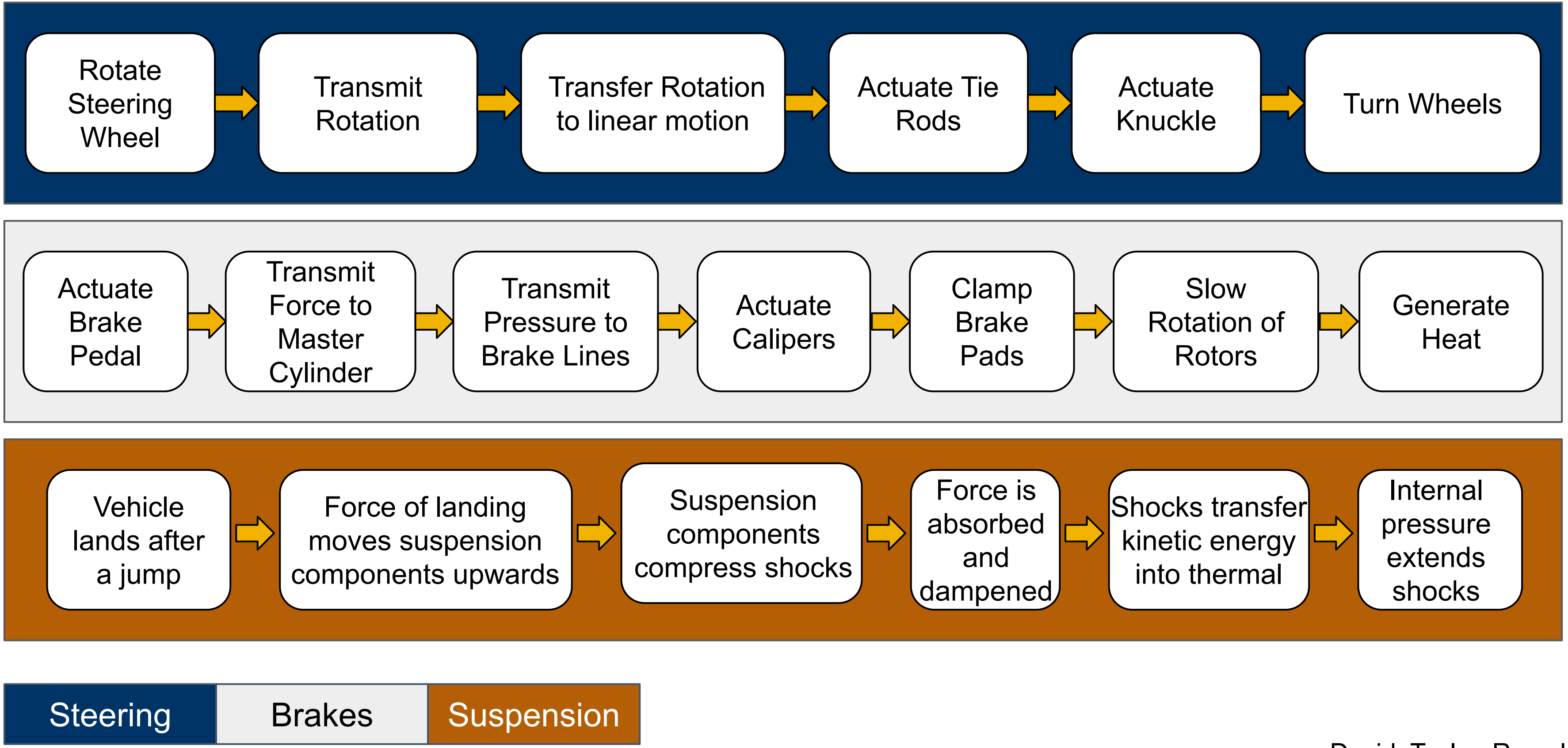
David

Black Box Model - Brakes

Black Box Model - Suspension

Oliver

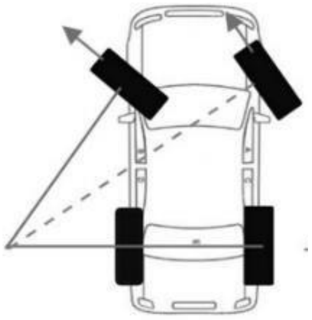
Functional Model



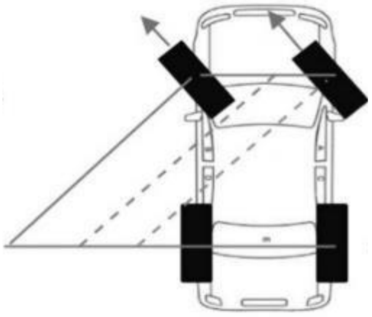
David, Taylor, Ryan K.

Concept Generation - Steering

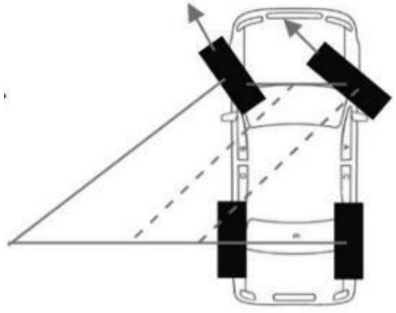
- Pro-Ackerman Provides a tighter turn radius with minimal tire scrub.
- Parallel steering allows for a even tire rotation, with the drawback of tire scrub.
- Anti-Ackerman maximizes tire scrub and minimizes turn radius.



Pro-Ackerman



Parallel



Anti-Ackerman

David

Concept Generation - Brakes

Master Cylinder Bore Diameter

- **⅞ in. Diameter**
  - Less effort to brake
  - Pushes more brake fluid to the calipers
- **⅝ in. Diameter**
  - Pushes less brake fluid to calipers
  - Requires more effort to Brake

Brake Pedal Ratio

- **5:1 Ratio**
  - Saves Space in packaging
  - Shorter pedal travel
- **6:1 Ratio**
  - Reduces brake pedal force
  - Longer pedal travel

Taylor

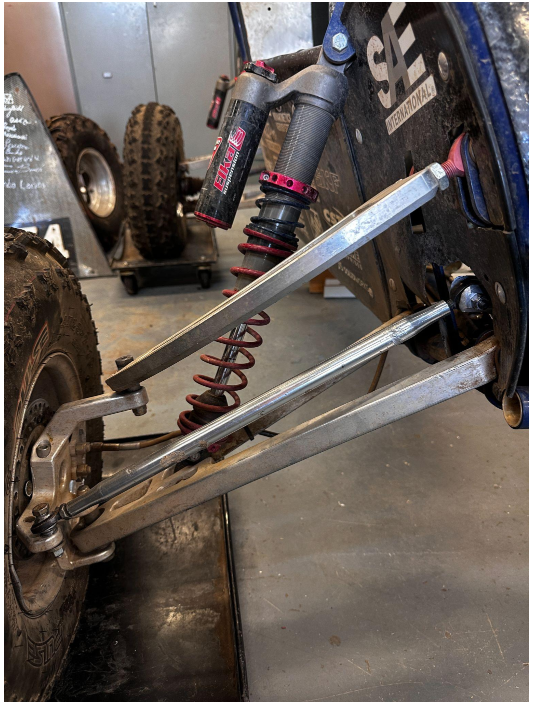
Concept Generation - Shock Mounting on Control Arms

Upper Control Arm

- More optimized/greater suspension travel
- Not as traditional of a mounting location

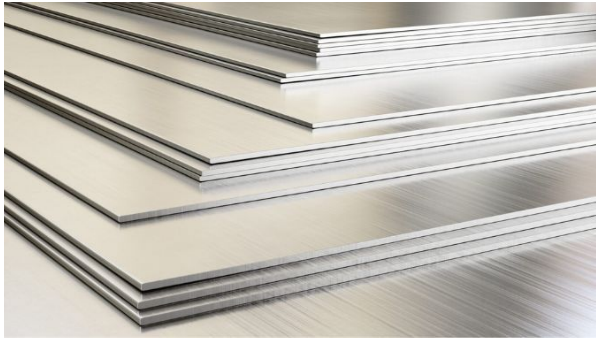
Lower Control Arm

- More traditional mounting location
- Clearancing/packaging with axles and various other components



Ryan L.

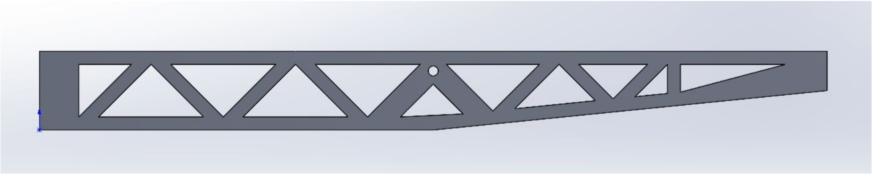
Concept Generation - Trailing Link Construction



Titanium vs. Steel for Rear Links

Titanium

- Expensive
- Less Dense (4.51 g/cm3)
- Tensile strength - 140 mPa
- Welds can be compromised by heat/oxygen

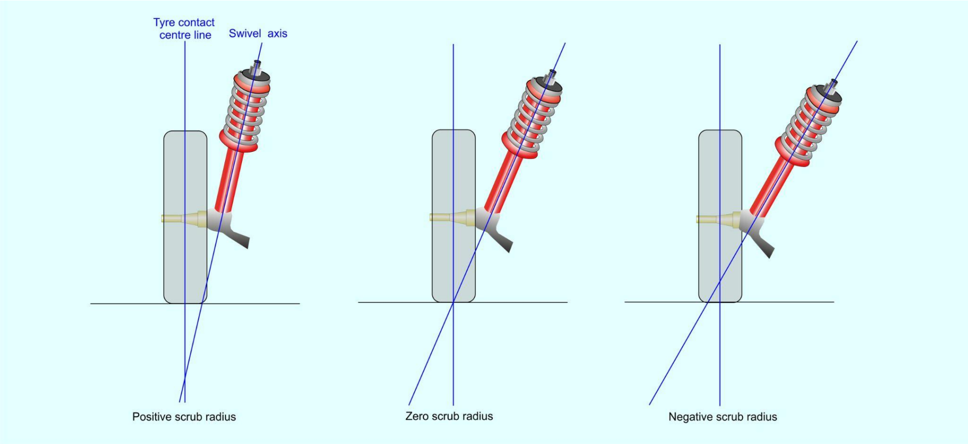


Steel

- Less expensive
- More dense (7.88 g/cm3)
- Tensile strength - 350 mPa
- Susceptible to corrosion

Ryan K.

Concept Generation- Scrub Radius



Positive Scrub Radius:

- Occurs when the intersection point of the steering axis is inside the tire contact patch.
- Provides more road feedback to the driver.
- Can increase steering effort
- Helps stabilize the vehicle when braking.

Zero Scrub Radius:

- The intersection point of the steering axis is aligned with the center of the tire contact patch.
- Neutral steering feel.
- Balances road feedback and steering effort.
- Often used for vehicles aiming for balanced handling.

Negative Scrub Radius:

- Occurs when the intersection point of the steering axis is outside the tire contact patch.
- Reduces steering effort, making it lighter.
- Improves stability in front-wheel-drive vehicles.
- Can reduce torque steer in powerful vehicles.

Oliver

Engineering Calculations-Steering

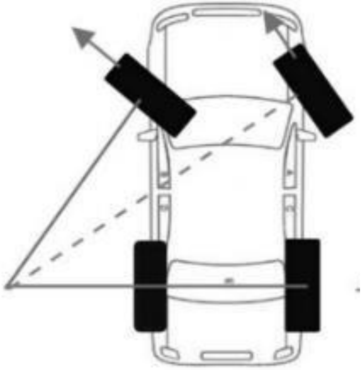
Wheelbase L = 60in

Track Width = 62in

Inner Steering Angle θ_{in} = 50°

Outer Steering Angle θ_{out} = 28.11°

Estimated Turn Radius R = 81.3in or 6.78ft



$$R_{in} = \frac{L}{\tan(\theta_{in})}$$

$$R = R_{in} + \frac{Track\ width}{2}$$

$$R_{out} = R + \frac{Track\ width}{2}$$

$$\theta_{out} = \tan^{-1}\left(\frac{L}{R_{out}}\right)$$

David

Engineering Calculations-Brakes

$$a = \frac{v - v_0}{t - t_0} \quad => \quad \frac{58.7}{3} = 19.6 ft/s^2$$

$$d = vt - \frac{1}{2}at^2 \quad => \quad 58.7(3) - \frac{(19.6)(3^2)}{2} = 88\ ft$$

$$W = \frac{1}{2}mv^2 \quad => \quad \frac{(17.1)(58.7)^2}{2} = 29460\ lb * ft/s^2$$

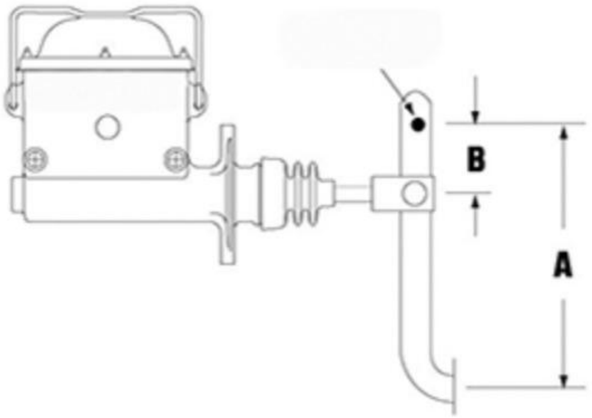
$$F_{brake} = \frac{W}{d} \quad => \quad \frac{29460}{88} = 335\ lb$$

$$F_{clamp} = \frac{F_{brake}}{2} * \mu \quad => \quad \frac{335}{2} * 0.7 = 117.25\ lb$$

$$BPR = Brake\ Pedal\ Ratio = 6:1 = 6$$

$$F_{BPF} = \frac{F_{brake}}{BPR} \quad => \quad \frac{335}{6} = 55.8\ lb$$

Brake Pedal Ratio



A/B = Pedal Ratio

Engineering Calculations-Brakes

Front Brake Calcs

$r = 3.5\ in \qquad \theta_1 = 36^\circ \qquad \theta_2 = 144^\circ$

$\theta_2 - \theta_1 \ => \ (144 - 36)\frac{\pi}{180} = 1.885\ rad$

$d = 0.875\ in \qquad A_p = \frac{\pi d^2}{4} = 0.601\ in^2$

$r_o = r - 0.0625 \ => \ 3.4375\ in \qquad r_i = r_o - 0.75 \ => \ 2.6875\ in$

$f_r = 0.37 \qquad r_e = \frac{r_o + r_i}{2} \ => \ \frac{3.4375+2.6875}{2} = 3.0625\ in$

$$\bar{r} = \frac{\cos(\theta_1) - \cos(\theta_2)(r_e)}{(\theta_2 - \theta_2)} => \frac{(\cos(36) - \cos(144))(3.0625)}{(1.885)} = 2.63\ in$$

$$T = \bar{r} * F_{Clamp} => \frac{(2.63)(117.3)}{12} = 25.6\ ft - lb$$

$$p_a = \frac{T}{(\theta_2 - \theta_1) f r_i (r_o^2 - r_i^2)} => \frac{12(25.6)}{(1.885)(0.37)(2.6875)(3.4375^2 - 2.6875^2)} = 36\ psi$$

$$F_{Actuating} = (\theta_2 - \theta_1) p_a r_i (r_o - r_i) => 1.885(36)(2.6875)(3.4375 - 2.6875) = 136\ lbf$$

$$p_{hydraulic} = \frac{F_{actuating}}{A_p} => \frac{136}{0.601} = 226\ psi$$

Rear Brake Calcs

$r = 4.5\ in \qquad \theta_1 = 36^\circ \qquad \theta_2 = 144^\circ$

$\theta_2 - \theta_1 \ => \ (144 - 36)\frac{\pi}{180} = 1.885\ rad$

$d = 7/8\ in \qquad A_p = \frac{\pi d^2}{4} = 0.601\ in^2$

$r_o = r - 0.0625 \ => \ 4.4375\ in \qquad r_i = r_o - 1.125 \ => \ 3.3125\ in$

$f_r = 0.37 \qquad r_e = \frac{r_o + r_i}{2} \ => \ \frac{4.4375+3.3125}{2} = 3.875\ in$

$$\bar{r} = \frac{\cos(\theta_1) - \cos(\theta_2)(r_e)}{(\theta_2 - \theta_2)} => \frac{(\cos(36) - \cos(144))(3.875)}{(1.885)} = 3.326\ in$$

$$T = \bar{r} * F_{Clamp} => \frac{(3.326)(117.3)}{12} = 32.5\ ft - lb$$

$$p_a = \frac{2T}{(\theta_2 - \theta_1) f r_i (r_o^2 - r_i^2)} => \frac{12(32.5)}{(1.885)(0.37)(3.3125)(4.4375^2 - 3.3125^2)} = 19\ psi$$

$$F_{Actuating} = (\theta_2 - \theta_1) p_a r_i (r_o - r_i) => 1.885(19)(3.3125)(4.4375 - 3.3125) = 136\ lbf$$

$$p_{hydraulic} = \frac{F_{Actuating}}{A_p} => \frac{136}{0.601} = 226\ psi$$

Taylor

Engineering Calculations-Brakes

Master Cylinder Bore Size (d_{mc})

Max caliper pressure p_c = 226 psi

Assume $p_m = p_c$ = 226 psi

Master Cylinder Area $(A_{mc}) = \frac{F_{clamp}}{p_c} => \frac{117.25\ lb}{226\ psi} = 0.52\ in^2$

$$d_{mc} = 2\sqrt{\frac{A_{mc}}{\pi}} \quad => \quad 2\sqrt{\frac{0.52}{\pi}} = 0.813\ in$$

$$Master\ Cylinder\ Bore\ Diameter = \frac{7}{8} in$$

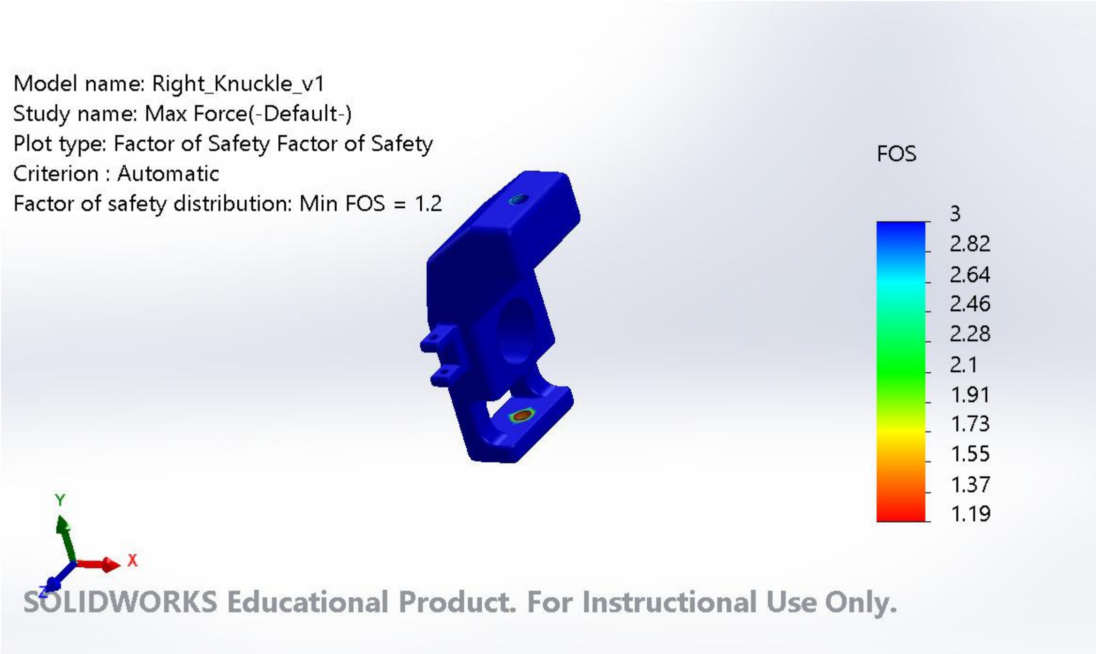
Taylor

Engineering Calculations- Front Knuckle

Simulated impact from a 1-meter jump, with all force on one front wheel, causing max stress on the knuckle due to fully compressed suspension.

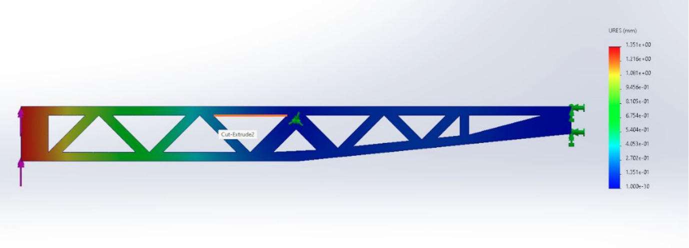
Material: 6061-T6 Aluminum

Factor of Safety (FOS): The minimum factor of safety is 1.2

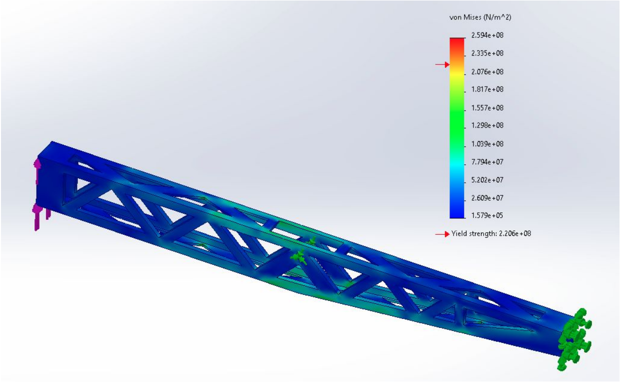


Engineering Calculations

Rear Suspension (Trailing Link) Bottoms Out



Car is dropped from 1 meter onto one rear wheel and the suspension bottoms out



Carbon Steel

F:5400 N

Max Deformation: 5.32x10^-2 inches

Max Stress: 9.59x10^2 MPa

Ryan K.

Engineering Calculations - Approx. Control Arm Member Length

Front most CA member = member A

Rear most CA member = member B

Track width = 62”

Member ELC Length = 8”

Member FLC Length = 13.5”

Tire width = 7”

Approx. Knuckle Width = 4.5”

Approximate control arm length A

= Track width – (Tire width * 2) – (Knuckle width * 2) – Member ELC length

= Length/2 → CA member A length per side

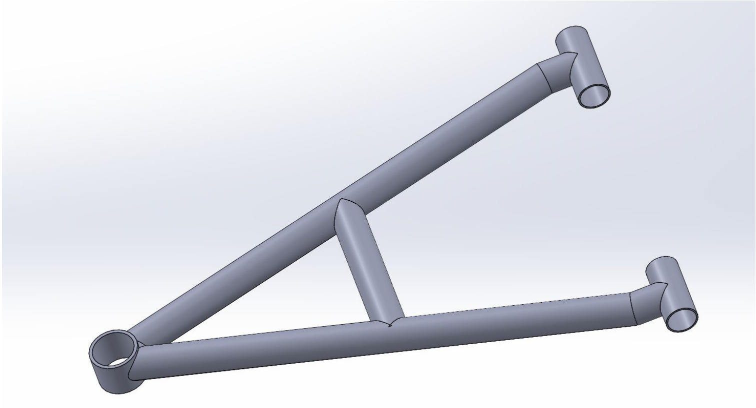
= 62” – (7” * 2) – (4.5” * 2) – 8” = 31”/2 = 15.5” per side (member A)

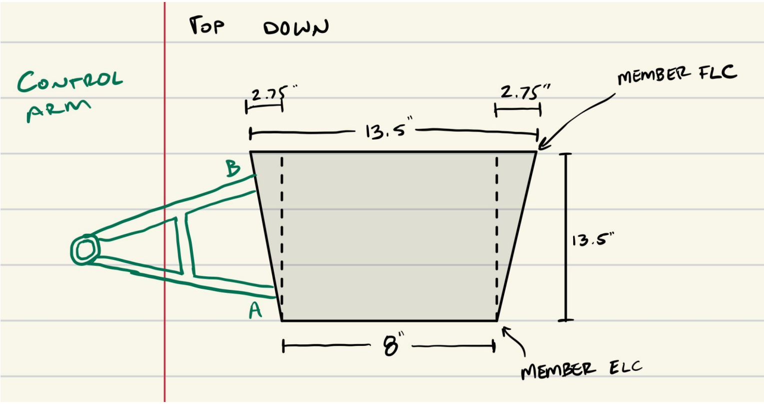
Approximate control arm length B

= Track width – (Tire width * 2) – (Knuckle width * 2) – Member FLC length

= Length/2 → CA member B length per side

= 62” – (7” * 2) – (4.5” * 2) – 13.5” = 25.5”/2 = 12.75” per side (member B)





Ryan L.

Concept Evaluation

	Variants			
Subsystem	1	2	3	**Result**
Steering	Pro-Ackerman	Anti-Ackerman	Parallel	**Pro-Ackerman**
Master Cylinder	5/8 in.	7/8 in.	N/A	**7/8 in.**
Pedal Ratio	5:1	6:1	N/A	**6:1**
Shock Mounting	UCA Mount	LCA Mount	N/A	**UCA Mount**
Scrub Radius	Zero Scrub	Negative Scrub	Positive Scrub	**Zero Scrub**
T.L. Material	Steel	Titanium	N/A	**Steel**

Ryan L.

Bill of Materials - Steering

Steering

Item	Quantity	Estimated Cost	Total Cost
1" Aluminum Round Stock for Tie Rods	4 ft	33	33
1" Carbon Steel	2 ft	17	17
1/4 - 20 Bolts	10	18	18
Universal Joints	2	30	60
Pinion	1	61	61
Pinion Housing	1	100	100
Aluminum Tubing	6 ft	40	40
1/4-20 Nuts	10	8	16
2" Aluminum Round Stock	1 ft	35	35
Aluminum Plate	6x12 in	31	31
		Total	411

David

Bill of Materials - Brakes

Brakes

Item	Quantity	Estimated Cost	Total Cost
Tilton Master Cylinder 7/8" Bore	2	122	244
Hyper EZ Brake Calipers	3	104	312
1/4-20" Button Head Socket Cap screws, Alloy Steel with Black Oxide	10	0.30	3
10-32 Socket Cap Screws	6	6	34
3/8" Stainless Steel Plate	1x3 ft	275	275
Steel Braided Brake Line Kit	25 ft	47	47
		Total	915

Taylor

Bill of Materials - Suspension

Suspension

Item	Quantity	Estimated Cost	Total Cost
3/8"-16 Supension Mount Bolts	18	8 (5 bolts per pack)	32
Ball Joints*	4	25	100
4130 Steel	20'	140	140
1/4" steel plate	3"x6'	90	180
1/8" steel plate	1.5"x12'	14	28
Shocks	4	Owned	N/A
Control Arm Bushings*	8	3	24
3/8" washers	18	7	7
3/8" Nylon Nuts	18	6	6
Carbon fiber tube	10'	140 (6ft per qty)	280
Suspension tabs	14	N/A	N/A
Camber Link Ends	8	25	200
Aluminum Stock (6061-T6)	6" x 6" x 48"	1400	1400
		Total	2397

Ryan K.

Schedule

SAE Baja 2025

Gannt Chart for Suspension, Steering & Brakes Weeks 1-15 — Project Start 8/26/2024

Managers: Seth Scheiwiller & Brennan Pongratz

Contact Info: twh63@nau.edu ohh6@nau.edu dp892@nau.edu ral425@nau.edu rwk47@nau.edu

8/26/2024 | 9/2/2024 | 9/9/2024 | 9/16/2024 | 9/23/2024 | 9/30/2024 | 10/7/2024

26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12

Task	Assigned To	Start	Days	End	Progress
Team Charter	All	9/2/2024	5	9/6/2024	100.00%
Start Research	All	9/2/2024	6	9/7/2024	100.00%
Start Calculations	All	9/10/2024	6	9/15/2024	100.00%
Start Presentation 1	All	9/10/2024	6	9/15/2024	100.00%
Front Suspension -Knuckle	Oliver	9/10/2024	6	9/15/2024	100.00%
Rear Suspension - Trailing Arms	Ryan K.	9/10/2024	6	9/15/2024	100.00%
Front Suspension - A-Arms	Ryan L.	9/10/2024	6	9/15/2024	100.00%
Steering	David	9/10/2024	6	9/15/2024	100.00%
Brakes	Taylor	9/10/2024	6	9/15/2024	100.00%
Presentation 1	All	9/17/2024	1	9/17/2024	100.00%
Presentation 2	All	9/28/2024	11	10/8/2024	
Present Presentation 2	All	10/8/2024	1	10/8/2024	
Report 1	All	10/14/2024	5	10/18/2024	
Suspension CAD Drawings	Ryan L., Oliver, Ryan K.	10/14/2024	7	10/20/2024	
Steering CAD Drawings	David	10/14/2024	7	10/20/2024	
Brakes CAD Drawings	Taylor	10/14/2024	7	10/20/2024	
Website Check #1	All	10/25/2024	1	10/25/2024	
Start Presentation 3	All	10/29/2024	8	11/5/2024	
Analysis Memo	All	10/28/2024	5	11/1/2024	
Presentation 3	All	11/5/2024	1	11/5/2024	
Prototype #1 Demo	All	11/12/2024	1	11/12/2024	
Report # 2	All	11/27/2024	1	11/27/2024	
Final CAD & BOM	All	12/3/2024	1	12/3/2024	
2nd Prototype Demo	All	12/3/2024	1	12/3/2024	
Website Check #2	All	12/7/2024	1	12/7/2024	

Taylor

Thank You

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