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: Get sponsorships
- Race and compete against other universities at the end of the year

NAU SAE Baja Car 2020-2021

Brennan

Background

Cornell SAE Baja Car 2023-2024

(1st Overall for California Competition)

End of the year competition:

- Static events: Tech inspection, Design evaluation, Cost evaluation, Business presentation
- Dynamic events: Acceleration, Traction, Maneuverability, Endurance
- Overall winners are announced, as well as specific award winners (Business presentation, overall dynamic, overall static, design, suspension, hill climb, etc.)

Ethan

Budget

	Category	Description	Approximate Cost
1	Vehicle Expenses	Materials, Hardware, Tooling, Safety Equipment, Components that are already made, Labor (if out of house)	$16,000
2	Spare Parts	Materials, Hardware, Labor	$4,000
3	Competition Expenses	Registration, Travel (Hotel/Airbnb, Gas, food)	$4,000
4	Contingencies	Unexpected Expenses Estimate 5% of 1, 2, and 3 combined	$1,200
		Total Cost:	$25,200

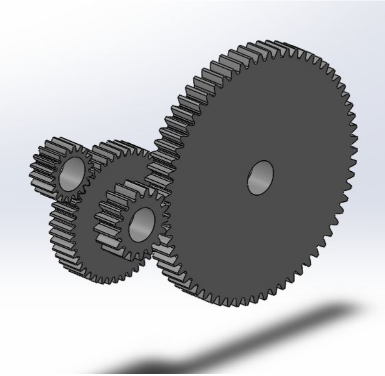
Potential Sponsors:

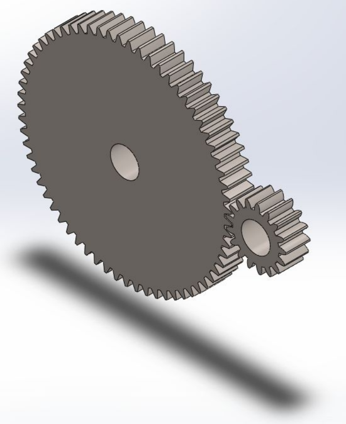
Gore, Copper State, Mother Road, HASS, Babbitt Ford.

Sponsor Methodology:

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

Dylan C.

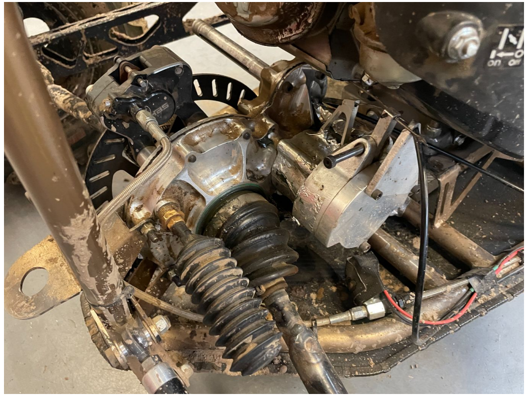




Drivetrain

Dylan Carley **Matthew Dale** **Ethan Niemeyer**	Reduction Box, Axles, and Hubs
Rowan Jones **Nolan Stomp**	4WD System
Brennan Pongratz **Seth Scheiwiller**	CVT

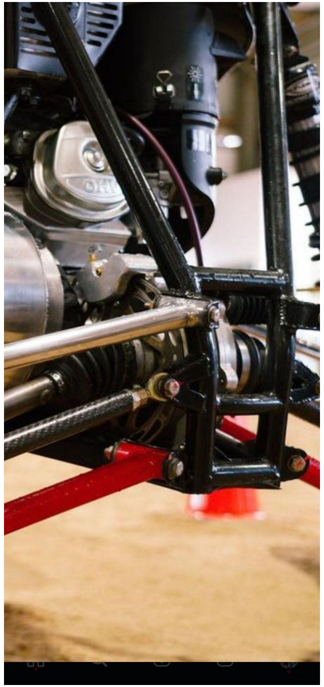
Benchmarking #1 - Reduction Box



NAU - 2024 - Reduction box - Placed 33rd overall

Reduction Box:
Making the reduction box as light as possible.
Running fluid: need expansion chamber

RIT - 2024 - Reduction Box - 3rd place overall



Cornell - 2024 - Reduction Box - 1st place overall

Dylan C.

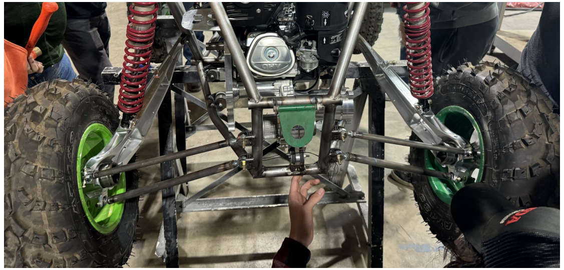
Benchmarking #2 - Axles and Hubs

Univ. of Michigan - 2024 - U-joints - Placed 4th overall

Case Western Reserve University - 2020 - U-joints - Placed 9th overall

Rochester Institute of Technology - 2022 - CV axles - Placed 3rd overall

Virginia Tech - 2024 - Hubs - Placed 2nd overall

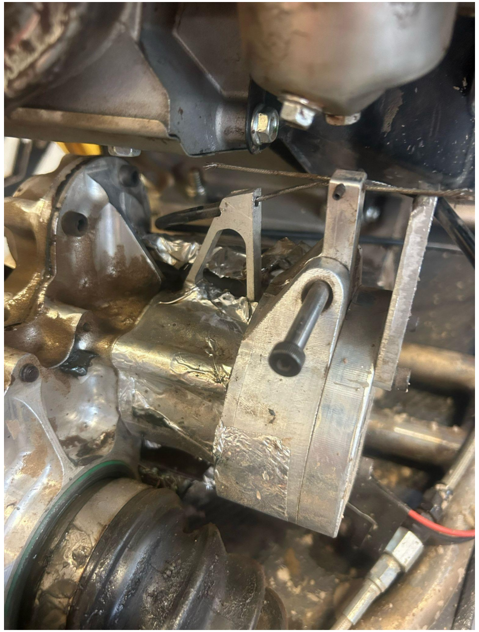


Cal Poly - 2024 - Hubs - Placed 3th overall

Previous NAU Hubs

Ethan N. & Matthew D.

Benchmarking #3 - 4WD System



Dog Clutch from NAU Car #44

Chain Drive from NAU Car #74

Cal Poly - 2024 - Front Gear Box - Placed 3rd overall

Nolan

Benchmarking #4 - CVT

Gaged CVT - Mechanical
Ramp/Roller Assembly

Cornell CVT - Mechanical
Cam/Roller Assembly

Cal Poly CVT - ECVT
Pivoting Arms w/ Lead Screws

Brennan

Customer and Engineering Requirements

Customer Requirements

- High acceleration
- Efficient
- Lightweight
- Safety
- Durability
- Affordable
- Pass Techs

Engineering Requirements

- 35+mph top speed
- Ease of manufacturing and assembly
- Total weight <50lbs (without motor)
- Delivers >415 lbf-ft of torque to the wheels
- ~4:1 transmission range

Matthew

QFD - Body

			Engineering Requirements																							Customer Competitive Assesment				
Relative Weight (%)	Customer Weights	Customer Requirments	Primary Flyweight	Primary Spring	Seconday Spring	Max Weight	Max Torque	High Top Speed	Moving Powertrain parts must be guarded on all sides	Competitive Transmission Range	Ratio-Rear	Ratio-Front	4WD	Moving Powertrain parts must be guarded on all sides	Gearbox vent system 100mm away from exhaust	4WD driveshaft surrounded and seperate from cockpit	Minimum life cycles of gears	Torque output	Length	Angle	CV Joints	Thickness on CV axle	Weight	Max Diameter	Max Thickness	1 Poor	2 Ok	3 Acceptable	4 Good	5 Excellent
11	4	Efficiency	9	9	9	9	9	1	1	9	9	9	9	1	1	1	9	9	9	9	9	3	9	3	3			A	B	C
22	5	Safety	1	1	1	1	1	3	9	1	1	1	1	9	3	9	1	1	3	3	3	9	1	3	3					ABC
10	3	Durability	3	3	3	3	1	3	1	3	1	1	1	1	1	1	9	3	9	9	9	9	1	9	9		A			BC
10	3	Affordable	9	1	1	9	1	1	1	3	1	1	1	1	1	1	1	1	3	1	3	9	1	3	3	BC			A	
5	2	Ease of Manufacturing	9	1	1	3	1	1	1	3	3	3	3	1	1	1	3	1	9	9	9	9	1	3	3		BC		A	
5	1	Aesthetics	1	1	1	3	1	1	1	1	1	1	3	3	3	1	1	1	1	1	3	3	3	3	3		A		B	C
22	5	Pass Techs	1	1	1	1	1	1	9	1	1	1	9	9	9	9	1	1	1	1	1	9	1	1	1					ABC
5	2	Acceleration	3	3	3	1	9	9	1	9	9	9	9	1	1	1	1	9	1	1	1	1	9	3	3			A	C	B
10	3	Lightweight	3	1	1	9	1	9	3	1	9	9	9	3	3	3	1	1	9	1	1	9	9	3	3			A		BC
Technical Requirement Units			grams	grams	grams	lbs	lbf-ft	mph	N/A	N/A	N/A	N/A	Yes/No	N/A	mm	N/A	Cycles	ft*lbs	inches	degrees	N/A	inches	grams	mm	mm					
Technical Requirement Targets			70	35	35	15	415	35	N/A	5	9.56:1	3.82:1	Yes	N/A	100	N/A	10^9	226	16	40	N/A	1.2	75	70	40					
Relative Technical Importance			5	8	7	6	1	2	3	4	3	4	5	6	8	7	1	2	3	4	2	1	3	1	2					

Sub-Section	Color Code
CVT	
Gears	
Axels	
Hubs	

Relationship	
Strong	9
Moderate	3
Weak	1

C.C.A. Legend	
A	NAU 2024 #44
B	Cornell 2024 #73
C	ETS 2024 #27

Ethan

QFD - House

	Primary Flyweight	Primary Spring	Seconday Spring	Max Weight	Max Torque	High Top Speed	Moving Powertrain parts must be guarded on all sides	Competitive Transmission Range	Ratio-Rear	Ratio-Front	4WD	Moving Powertrain parts must be guarded on all sides	Gearbox vent system 100mm away from exhaust	4WD driveshaft surrounded and seperate from cockpit	Minimum life cycles of gears	Torque output	Length	Angle	CV Joints	Thickness on CV axle	Weight	Max Diameter	Max Thickness
Primary Flyweight																							
Primary Spring	pos																						
Seconday Spring																							
Max Weight	neg	pos	pos																				
Max Torque	pos	pos	pos																				
High Top Speed	pos			neg	neg																		
Moving Powertrain parts must be guarded on all sides																							
Competitive Transmission Range	pos				pos																		
Ratio-Rear					pos	neg		pos															
Ratio-Front					pos	neg		pos	pos														
4WD								pos	pos	pos													
Moving Powertrain parts must be guarded on all sides						neg	pos				pos												
Gearbox vent system 100mm away from exhaust																							
4WD driveshaft surrounded and seperate from cockpit							pos				pos	pos											
Minimum life cycles of gears					neg	neg																	
Torque output	pos	pos	pos	neg	pos	neg		pos	pos	pos	neg												
Length																							
Angle																	neg						
CV Joints																		pos					
Thickness on CV axle				neg	neg											neg	neg		neg				
Weight				pos	pos											pos							
Max Diameter																					neg		
Max Thickness																					neg	pos	

Engineering Requirements

Sub-Section	Color Code
CVT	
Gears	
Axels	
Hubs	

Dylan

Literature Review
-Dylan Carley-

Books/Chapters

- Shigley's Mechanical Engineering Design [1]
  - Chapters 13 and 14 (Spur Gears)
- Machinery's Handbook [2]
  - Chapter 12, Gearing

Papers

- Design, Analysis, and Simulation of a Four Wheel-Drive Transmission for an All-Terrain Vehicle – SAE [3]
  - Gear analysis with equations
- Numerical analysis of the heat transfer of gears under oil dip lubrication [4]
  - Heat transfer of the gears between the oil
- KHK Stock Gears: Lubrication of Gears [5]
  - How to properly lubricate gears.

Online

- AZO Materials: AISI 4340 Alloy Steel [6]
  - Has all the material properties for 4340 steel
- MatWeb material property data: Aluminum 6061-T6 [7]
  - Has all the material properties for 6061-T6 aluminum
- Standard: AGMA

Literature Review
-Matthew Dale-

Books/Chapters

- Ball & Roller Bearing Design: Theory, Design, and Application [8]
    - Bearing design and fit
- Non-Destructive Material Testing [9]
    - How to stress test to determine fatigue

Papers

- Design And Analysis Of Wheel Hub Of Baja ATV In Ansys. [10]
    - Determination of hub shape
- Design and Weight optimization of wheel assembly components using FEA for BAJA [11]
    - Hub development and stress testing
- Simulation and Optimization of Wheel Hub and Upright of Vehicle: A Review [12]
    - Force Calculations and part development

Online

- Ansys Innovation Space [12]
    - Hub analysis and force visualization
- Design and Analysis of Wheel Hub for Weight Optimization by using Various Material [13]
    - Material selection and hub analysis

Standard

- Validation of Complex Wheel/Hub Subassemblies by Multiaxial Laboratory Tests Using Standardized Load Files [13]
    - Part development to make sure it makes sense

Literature Review
-Ethan Niemeyer-

Books/Chapters

- Shigley's Mechanical Engineering Design
  - Chapters 13 and 14 (Spur Gears) [1]
- Machinery's Handbook
  - Gears and Gearing [2]

Papers

- A Review on Constant Velocity Joint [14]
  - CV joint information
- SAE Baja 25' Rule Book [15]
  - Drivetrain outlines and safety parameters
- Universal (U) Joints - Axle and Driveshaft [16]
  - Article about U-joints and comparison to CV joints

Online Sources

- Gear generator [17]
  - Used to build basic gear train
- Rush gears [18]
  - Input gear parameters, outputs gear geometry
- Basic Gear Mechanisms [19]
  - Website that describes basic gear function and parameters

Standard

- American Gear Manufacturers Association (AGMA)

Literature Review - 4WD
-Rowan Jones-

Books/Chapters

Shigley's Mechanical Engineering Design [1]

- Chapters 13 and 14 (Spur Gears)

Machinery's Handbook [2]

- Chapter 12 (Gearing)

Papers

Cal Poly Gearbox Report [20]

- Establishes benchmarking

A Review of Recent Advances in Design Optimization of Gearbox [21]

- Gearbox optimization

Design analysis and fabrication of automotive transmission gearbox using hollow gears for weight reduction [22]

- Gear Weight Reduction

Online Sources

The Basics of Gear Theory [23]

- Basic understanding of gear ratios

AZO Materials: AISI 4340 Steel [6]

- Values for desired gear material

An Advanced Approach to Optimal Gear Design [24]

- More gearbox optimization

Standard

Machinery Handbook [2]

- ISO TC/600 for allowable contact stress

Literature Review - 4WD

-Nolan Stomp-

Online Sources

What is a dog clutch? [25]

Introduces the dog clutch, along with its uses, purposes, pros and cons

Dog Transmission Explained [26]

Discusses the differences in strengths and weaknesses between the dog clutch and synchromesh

Chain Drive vs Belt Drive: Difference and Comparison [27]

Provides pros and cons of using a belt drive and chain drive, along with a table highlighting the main parameters of each

Books

Shigley's Mechanical Engineering Design [1]

Chapter 16-17

Discusses in length miscellaneous options for clutch design, along with characteristics for each

2025 SAE Baja Rulebook [15]

The rulebook has regulations for how 4WD/AWD is required to function

Standard

AGMA

Papers

Machinery's Handbook [2]

Ideal turning speed and feed rates for manufacturing parts

Kinematics of roller chain drives- Exact and approximate analysis [28]

Gives approximate examples to how a chain drive should act, which pertains to design and implementation

The Effect of the tooth chamfer angle on the dog clutch shiftability [99]

Analyzes the relationship between chamfering and successful engagement of the dog teeth

Literature Review - CVT

-Seth Scheiwiller-

Textbooks

Shigley's Mechanical Engineering Design [1]

- Chapter 17, Flexible Mechanical Elements, V-Belts

Machinery's Handbook [2]

- Machine Elements, Flexible Belts and Sheaves

Papers

Olav Aaen's Clutch Tuning Handbook [35]

- Tuning Tips

Modeling and Tuning of CVT Systems for SAE Baja Vehicles [30]

- CVT force calculations

Design and Manufacturing of Continuously Variable Transmission (CVT) [31]

- CVT Ratio and Belt Calculations

Online Resources

Virtual training on How CVT works and How to Design CVT in solidworks [32]

- CAD model of CVT transmission

Modeling of a Continuously Variable Transmission [33]

- MATLab model of CVT transmission

Standard

Machinery's Handbook [2]

- Dimensioning, Gaging, and Measuring, standards for interference and clearance fits, and keyway standards

Literature Review - CVT

-Brennan Pongratz-

Textbooks

Shigley's Mechanical Engineering Design [1]

- Chapter 17, Flexible Mechanical Elements, V-Belts

Machinery's Handbook [2]

- Flame Hardening steel for cams

Papers

Design and Manufacturing of Continuously Variable Transmission (CVT) [34]

- CVT ratio and belt calculations

Collegiate Design Series Baja SAE Rules [15]

- CVT regulations and guard specifications

Olav Aaen's Clutch Tuning Handbook [35]

- Tuning parameter clarification

Online Resources

Modeling of a Continuously Variable Transmission [36]

- MATLab model of CVT transmission

Fatigue Design Curves and Analysis for Aluminum [37]

- Designing aluminum sheaves

Standard

Machinery's Handbook [2]

- Press fit standards and thread standards

Mathematical Modeling: Rear Gears

Rear Gearbox Design

Torque Required:

T= (d/2)(Fs(w/4))

d=1.833ft ; Fs = .9 (Highest car will experience)

w=550lb (Approximate weight w/driver)

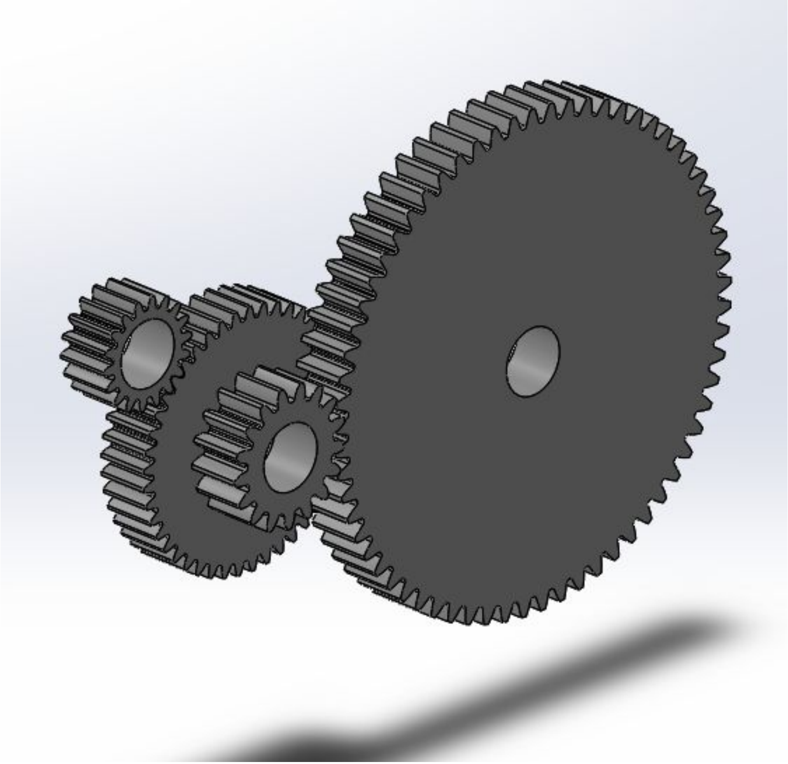
226.83 ft-lb of torque required to break rear wheels loose.

Our Reduction box will be within 85%-95% efficient with the given parameters

We will use a two-stage compound spur gear train with four total gears as shown on the right

Final drive ratio is 9.56:1 through the rear gear box (Subject to change)

We will run oil in the rear gearbox with an expansion chamber



Preliminary Gear train Design

Ethan.

Mathematical Modeling: Rear Gears Cont.

Allowable Bending Stress:

We will be using 4340 HT steel for the gears (Brinell Hardness = 217) [7]

Grade 1: St=77.3Hb + 12800psi (Gear bending strength)

σall = (St*Yn)/(Sf*Kt*Kr)

Yn = Stress Cycle Factor ; Kt = Temp. Factor ; Kr = Reliability Factor ; Sf = AGMA factor of safety

St = 29,574.1 psi ; Yn = 1.6831N^(-0.0323) = 1 ; Kt = 1 ; Kr = 1 ; Sf=1.5

σall = 19,716.07 psi

Diametral Pitch : P = N/d -->

Train Value : e = (Product of driving tooth numbers) / (Product of driven tooth numbers) ; e = 1/9.56

If output RPM from CVT = 2400 (CVT engagement)

Reduction box output RPM = 241.05

Gear	Pitch diameter (in)	# of teeth	Diametral Pitch
1	1.125	18	16
2	2.8125	45	16
3	1.417	17	12
4	5.417	65	12

-Pressure Angle = 20° for all
-Face Width = 0.625 in for all

Dylan C.

Mathematical Modeling: Rear Gears Cont.

Fatigue life on Gears:

Sut: 108 kpsi

F = 1.06 - 2.8(10^-3)Sut + 6.9(10^-6)Sut^2 [70 < Sut < 200 kpsi]

- F = .838

S'e = 0.5Sut [Sut < 200 kpsi]

- S'e = 54 kpsi

a = (F*Sut)^2 / (S'e)

- a = 151.7

b = -⅓*log(F*Sut/S'e)

- b = -0.0748

N = (σar/a)^(1/b)

- N = 7.032 X 10^11 Cycles

F: Fatigue line in the high-cycle

S'e: Endurance limit

a & b: Constants that are the ordinate intercept and the slope of the line in log-log coordinates.

N: Number of Cycles

σar: Completely reversed stress equal to σall from slide earlier.

Dylan C.

Mathematical Modeling: Chain Drive

Speed Variation of Chain Drive

V=Npn/12

Vmax= πDn/12=πnp/12sin(γ/2)

Vmin= πdn/12=πnp/12*(cos(γ/2)/sin(γ/2))

ΔV/V= (Vmax-Vmin)/V

V= **106.25 ft/min**

Vmax= **106.84 ft/min**

Vmin= **105.02 ft/min**

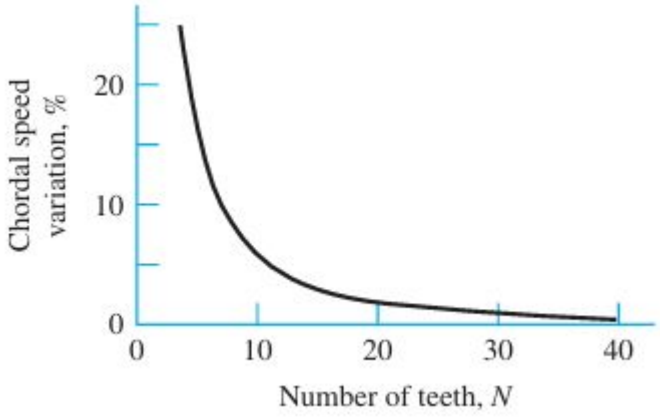
ΔV/V= **1.7%**

N= number of teeth on sprocket=**17**

p= chain pitch (in)= **0.625 in** (ANSI 50)

n= sprocket speed (rev/min)=**120 rpm**

γ= pitch angle= 360/N=**21.18 degrees**



Nolan S.

Mathematical Modeling: Chain Drive Cont.

$H_1 = 0.004N^{1.08}n^{0.9}p^{(3-0.07p)}$
$H_2 = 1000K_RN^{1.5}p^{0.8}/n^{1.5}$

$H_1 = 1.58$ hp
$H_2 = 622.4$ hp

$H = \min(H_1, H_2) =$ **1.58 hp**

H_1 = link-plate limited power
H_2 = roller-limited power
K_R=17 for chain number 50

Table 17–20 Rated Horsepower Capacity of Single-Strand Single-Pitch Roller Chain for a 17-Tooth Sprocket

Sprocket Speed, rev/min	ANSI Chain Number					
	25	35	40	41	50	60
50	0.05	0.16	0.37	0.20	0.72	1.24
100	0.09	0.29	0.69	0.38	1.34	2.31
150	0.13*	0.41*	0.99*	0.55*	1.92*	3.32
200	0.16*	0.54*	1.29	0.71	2.50	4.30

Nolan S.

Mathematical Modeling: Front Gears

Front Gear Box

4340 HT steel for the gears (Brinell Hardness = 217) [7].

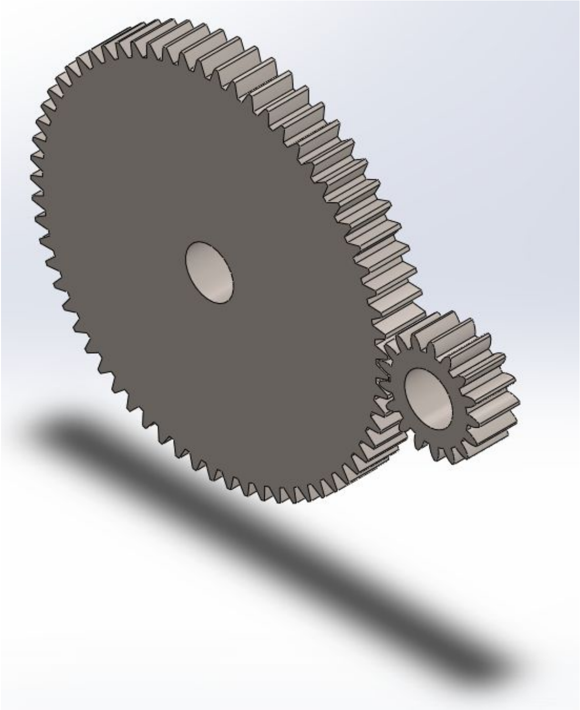
Oil will be run in the front gearbox as a lubricant, and an expansion chamber will be included as specified in rule B.9.4 in the 2025 SAE BAJA rulebook [61].

Gear ratio is subject to change based on further research regarding underdriving the front.

Estimated fatigue life will be the same as rear gears.

Finite Element Analysis (FEA) will be in the future to determine stresses based off known input forces.

Gear	Pitch Diameter (in)	No. of Teeth	Diametral Pitch
1	5.417	65	12
2	1.417	17	12



-Face Width = 0.625 in for both
-Pressure Angle = 20° for both

Rowan

Mathematical Modeling: Front Gears Cont.

Allowable Bending Stress

Grade 1: St = 77.3 Hb + 12800 psi

Hb = 217

(Gear bending strength)

St = 29,574.1 psi

σall = (St*Yn)/(Sf*Kt*Kr)

Yn = Stress Cycle Factor
Kt = Temp. Factor
Kr = Reliability Factor
Sf = AGMA factor of safety
St = 29,574.1 psi
Yn = 1.6831*N^(-0.0323) = 1
Kt = 1, Kr = 1, Sf=1.5

σall = 19,716.07 psi

Allowable Contact Stress

Grade 1: Sc = 322 Hb + 29100 psi

Hb = 217

(Contact-fatigue Strength)

Sc = 98,974 psi

σc,all = (Sc*Zn*Ch)/(Sh*Kt*Kr)

Zn = stress-cycle factor
Ch = hardness ratio factors for pitting resistance
Kt = are the temperature factors
Kr = reliability factor
Sh = AGMA factor of safety
Sc = 98,974 psi
Zn = 1.4488*N^(-0.023) = 1
Ch = 1, Kt = 1, Kr = 1, Sh = 1.5

σc,all = 65,982 psi

Rowan

Mathematical Modeling: Hubs

$$\text{Cantilever Beam Max Deflection} = \frac{(Force)(Length)^3}{3(Elasticity)(Inertia)}$$

Max Impact Force = 1348 N (as calculated by suspension team)

Youngs Modulus for 6061-T6 Aluminum = 69 GPa

$$\text{Inertia}= \frac{(0.17145m)^4}{12} = 7.2(10^{-5})$$

$$0.005mm = \frac{(1348N)(Length)^3}{3(69{,}000MPa)(7.2*10^{-5})} = 0.381m = 1.5 \text{ in}$$

Matthew D.

Mathematical Modeling - CVT

CVT diameters, angles, and forces

- Iterated through MATLab based on selectable parameters
- Ensure geometry complies with ratios needed and can be integrated into the vehicle

If $\beta \geq \pi$

$$T_0(lbf) = \frac{2\sin\left(\frac{\beta}{2}\right) * \left[2F_{Clamp}\tan\left(\frac{\phi}{2}\right) + \frac{1}{12}M_{Belt} * R^2 * \omega^2\right]}{cos\left(\frac{1}{2}(\beta - \pi)\right) * \left(e^{\mu_e \beta} + 1\right)}$$

Equation 33: Slack Side Tension if $\beta \geq \pi$.

If $\beta \leq \pi$

$$T_0(lbf) = \frac{2\sin\left(\frac{\beta}{2}\right) * \left[2F_{Clamp}\tan\left(\frac{\phi}{2}\right) + \frac{1}{12}M_{Belt} * R^2 * \omega^2\right]}{cos\left(\frac{1}{2}(\pi - \beta)\right) * \left(e^{\mu_e \beta} + 1\right)}$$

Equation 34: Slack Side Tension if $\beta \leq \pi$.

…and more!

CVT Force Equations used in MATLab Code

```
camCurveEquation1 = 0.5*sin((L+0.85)^1.2)-0.07;
camCurveEquationDerivative1 = diff(camCurveEquation1);
initialRollerOffset1 = 0.85

StartingcamMass1 = 0.1 % The cam mass you want to start the iteration with
MaxcamMass1 = 0.3;  % The cam mass you want to end the iteration with
camMassInterval1 = 0.02; % The mass step for the next iteration
numrows1 = (MaxcamMass1-StartingcamMass1)/camMassInterval1 % Calculates the number of iterations
numrows1 = ceil(numrows1)

StartingCMRadius1 = 0.9 % The CM radius you want to start the iteration with
MaxCMRadius1 = 1.1 % The CM radius you want to end the iteration with
CMRadiusInterval1 = 0.02 % The CM radius step for the next iteration
nummatrix1 = (MaxCMRadius1-StartingCMRadius1)/CMRadiusInterval1 % Defines the number of matrices

shiftRPM1 = zeros(numrows1, vectorSize);
camMass1 = StartingcamMass1
camCMRadius1 = StartingCMRadius1

for k=1:1:nummatrix1
for j=1:1:numrows1
for i=1:1:vectorSize
```

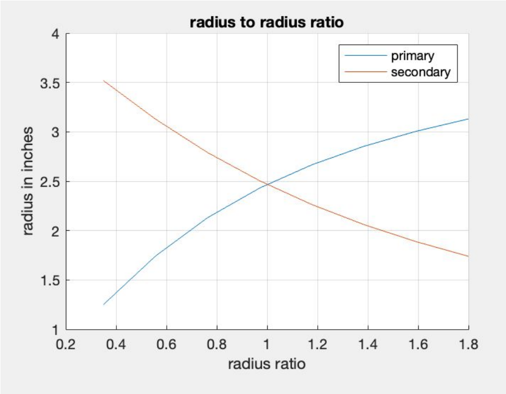
Iterative MATLab code for Shift RPM

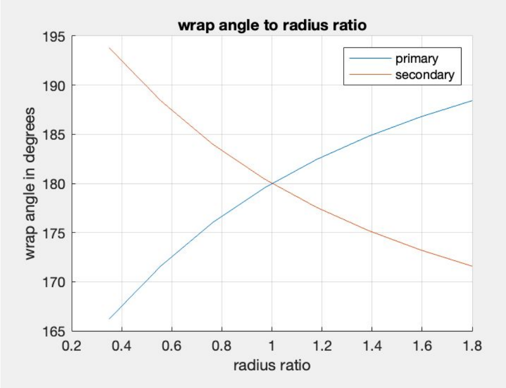
Ideal Shift RPM

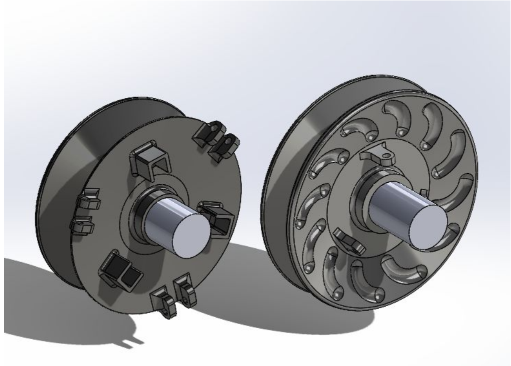
- MATLab code iterates through multiple different cam profiles based on mass, center of mass profiles, spring pretension, and more
- Yields ~500 different results each time code is ran

Seth

Mathematical Modeling - CVT







Results

- Ratio range of 5.14
- Primary radius range 0.818in to 3.31in
- Secondary radius range 1.323in to 3.706in
- Sheave angle ~13 degrees
- Primary travel 0.86in
- Secondary travel 0.809in

Desired ratio range —> Check!

Fits within geometry of vehicle and motor —> Check!

Belt has been selected —> Check!

Ideal shift RPM —> Work in progress!

Time to start CAD!

Seth

Mathematical Modeling - CVT

CVT Spider Simplified Bending Calculation

$$v = 556\,N$$
$$A = 9.025X10^{-5}\,m^2$$

-Known Values

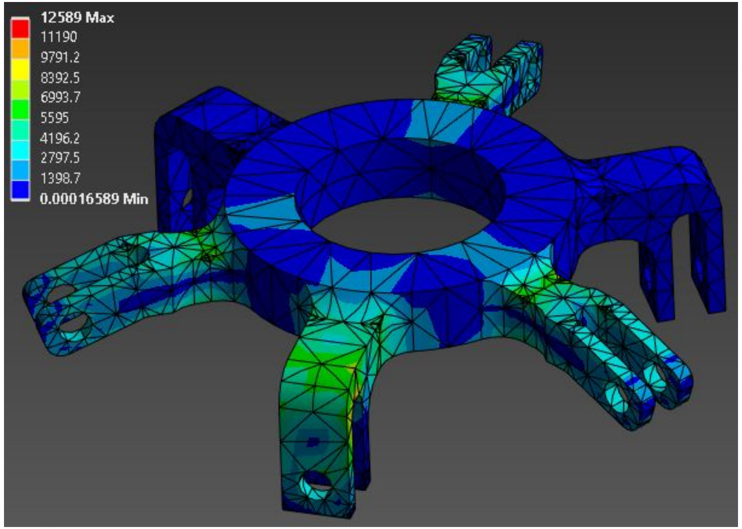
$$\tau = \frac{4v}{3A} = 8.2\,MPa$$

-Calculating Shear Stress

$$\sigma' = \sqrt{(3\tau^2)} = 14.2\,MPa = 2.1\,kpsi$$

$$\sigma\,(10^8\,cycles) = 10kpsi$$

-Comparing calculated stress to allowable stress for 6061-T6 Aluminum

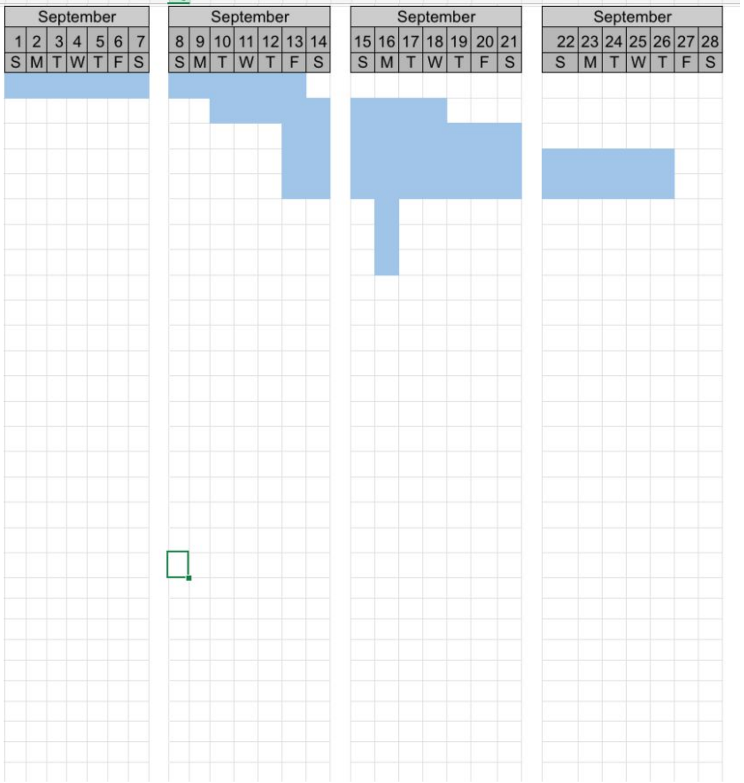


Ansys FEA of initial spider design

Brennan P.

Schedule

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

Benchmarking

ETS 2024 #27

- Front Bracing Member Suspension Mount
- Wider Front Bracing Members
- Overall shorter track length

Cornell 2024 #73

- Front Bracing Member Suspension Mount
- Wider Front Bracing Members
- Taller Toe Box
- Lower Seating Position

NAU 2024 #44

- Cockpit Width is to narrow
- 4130 Chromoly Steel
- Toe Box is to cramped

Ryan

Customer and Engineering Requirements

Customer Requirements

- Performance
- Safety
- Durability
- Affordable
- Comfort
- Ease of Fabrication
- Aesthetics
- Pass Tech. Inspection
- Balanced Weight Distribution

Engineering Requirements

- Increased Strength
- Lightweight
- Low Cost
- Driver Egress
- Rulebook/Tech. Inspection Requirements*

Wyatt

QFD

		Technical Requirements																														
Customer Weights	Customer Requirments	Increase Strength	Light Weight	Low Cost	Driver Egress	B.3.2.17 Roll Cage Spec sheet filled out	B.3.2.16 Primary members steel OD, ID requirements	B.3.2.16 Alternate Material requirements	B.3.2.3 Secondary members OD, ID requirements	B.3.2.15 Welding samples requirements	B.3.2.1 Straight (40in) and bent members (33in unsupported, <30deg length	B.3.2.5 Lateral cross member and CLC <=8in requirements	B.3.2.6 RRH Continuis vertical members & +/- 20 degree verticality	B.3.2.7 LDB max 5in from top & bottom of roll cage	B.3.2.12 FBM max 45 deg. from vertical, FBMup & FBMlow joints	B.3.2.9 LFS must extend from RRH to past driver's heels	B.3.2.12.1 Gussets required if RHO and FBMup are not continuous	B.4.2.4.3 Safety harness tubes are in RRH plane from one side to the other	B.3.2.13.2 Rear bracing structual triangle connecting points A & B (within 2in)	B.3.2.8 RHO & RRH dimension and placement guidlines	B.3.2.10 SIMs run 8in-14in above lowest point of the seat	B.3.2.11 UST connect to LFS members securely below the seat	B.3.3.1 Roll cage clearance for the largest driver (6in helmet) (3in torso & limbs)	B.4.2 Min. 5 point harness with 3in webbing with single metal buckle	B.4.2.4.2 Shoulder webbing laterally placed 6in-9in	B.12.2 Lap and anti-sub mounting tabs (double shear) >=0.09in thick & >=1.3125in of weld length	B.4.5 Must have a conventional seat (65-90deg back angle) with back & bottom plane	B.4.5.3.2 Seat has 4 mounting points on the bottom and 2 on the back plane	B.12.2 Seat tabs >=0.125in thick, fastener of 0.25in dia. spacers <=0.5in thick	B.4.2.6.2 Anti-Sub belt angle 0-20deg aft of the chest line	B.4.2.4.1 Mount shoulder belts at or below driver's shoulders =<4in	B.10.3.3.1 Cockpit kill switch is within easy reach of a restrained driver
2	Performance	9	9	-3	9		9	3	9					1	3	3	9		3	1	1	1		1								3
3	Safety	9	-3	-3	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	3	9	9	9	9
5	Durability	9	-3	-1	1		9	9	9	9	9	9	3	9	9	9	9	3	3	9	9	3				3	1	1	3			
4	Affordable	-3	3	9	1		9	9	9		3		1	3	1	3	1	1	1	3	1	1		1		1	3	3	1	1		
8	Comfort	1	1	-3	9								9			3		9		9	9	9	9	9	9		9		1	9	9	
7	Ease of Fabrication	-3	3	-1	-3		3	3	3	9	3	3	3	3	3	3	-3	-1	-3	-3	1	-3	-3	1	1	-1	-3	-3	-3		-3	-1
9	Aesthetics	1	1	-3	-1					3	3	3	9	3	9	3	9		3	9	9		9	3			3				1	
1	Pass Techs	9	-1	-1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
6	Balanced Weight	-3	-1	-3	1		3	3	3		3	3	3		3	1	1		9	3	1	3	3									
Technical Requirement Units		psi	lbs	$	Seconds	N/A	Inches	N/A	Inches	N/A	Inches	Inches	N/A	Inches	N/A	N/A	N/A	N/A	N/A	N/A	Inches	N/A	Inches	Inches	Inches	Inches	N/A	N/A	Inches	N/A	Inches	N/A
Technical Requirement Targets			100	2500	5		1, 0.065, 0.118		1, 0.035		40,33	8		5							8,14		6,3	3	6,9	0.09, 1.3125			0.125, 0.25,0.5		4	

Wyatt

QFD

Baja 25' Frame	
Date: 9/9/24	

Relationship	
Strong	9
Moderate	3
Weak	1
N/A	0

Legend	
A	NAU 2024 #44
B	Cornell 2024 #73
C	ETS 2024 #27

Correlation	
Positive	+
Negative	-

	1	2	3	4	5	6	7	8	9	10
Increase Strength										
Light Weight	-									
Low Cost	-	+								
Driver Egress										
B.3.2.17 Roll Cage Spec sheet filled out	+			+						
B.3.2.16 Primary members steel OD, ID requirements	+		-	+	+					
B.3.2.16 Alternate Material requirements		+	+	+	+	+				
B.3.2.3 Secondary members OD, ID requirements	+		-	+	+		+			
B.3.2.15 Welding samples requirements	+		-	+	+		+			
B.3.2.1 Straight (40in) and bent members (33in unsupported, <30deg length	+	-		+	+					
B.3.2.5 Lateral cross member and CLC <=8in requirements	+				+					
B.3.2.6 RRH Continuis vertical members & +/- 20 degree verticality	+			+	+					
B.3.2.7 LDB max 5in from top & bottom of roll cage	+	-			+					+
B.3.2.12 FBM max 45 deg. from vertical, FBMup & FBMlow joints	+				+					
B.3.2.9 LFS must extend from RRH to past driver's heels			-	+	+					-
B.3.2.12.1 Gussets required if RHO and FBMup are not continuous	+	-	-	+	+					-
B.4.2.4.3 Safety harness tubes are in RRH plane from one side to the other				+						
B.3.2.13.2 Rear bracing structual triangle connecting points A & B (within 2in)	+				+					
B.3.2.8 RHO & RRH dimension and placement guidlines				+	+					
B.3.2.10 SIMs run 8in-14in above lowest point of the seat			-	+	+					
B.3.2.11 UST connect to LFS members securely below the seat				+	+					
B.3.3.1 Roll cage clearance for the largest driver (6in helmet) (3in torso & limbs)				+	+					
B.4.2 Min. 5 point harness with 3in webbing with single metal buckle				+						
B.4.2.4.2 Shoulder webbing laterally placed 6in-9in				+						
B.12.2 Lap and anti-sub mounting tabs (double shear) >=0.09in thick & >=1.3125in of weld length	+			+						
B.4.5 Must have a conventional seat (65-90deg back angle) with back & bottom plane				+						
B.4.5.3.2 Seat has 4 mounting points on the bottom and 2 on the back plane				+						
B.12.2 Seat tabs >=0.125in thick, fastener of 0.25in dia. spacers <=0.5in thick	+			+						
B.4.2.6.2 Anti-Sub belt angle 0-20deg aft of the chest line				+						
B.4.2.4.1 Mount shoulder belts at or below driver's shoulders =<4in				+						
B.10.3.3.1 Cockpit kill switch is within easy reach of a restrained driver	+			+						

Technical Requirements

Increase Strength
Light Weight
Low Cost
Driver Egress
Roll Cage Spec sheet filled out
ry members steel OD, ID requirements
Alternate Material requirements
ndary members OD, ID requirements
5 Welding samples requirements
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l seat (65-90deg back angle) with back & bottom plane
ating points on the bottom and 2 on the back plane
 thick, fastener of 0.25in dia. spacers <=0.5in thick
ub belt angle 0-20deg aft of the chest line
lder belts at or below driver's shoulders =<4in
switch is within easy reach of a restrained driver

Customer Opinion Survey

	1 Poor	2 OK	3 Acceptable	4 Good	5 Excellent
Performance		A		C	B
Safety					ABC
Durability			A		BC
Affordable	C	B	A		
Comfort	A			B	C
Ease of Fabrication		AC	B		
Aesthetics			A	B	C
Pass Techs				A	BC
Balanced Weight			A	B	C

Ryan

Literature Review

Charles Anderson

Books:

The Procedure Handbook of Arc Welding [38]

- Chapter 2 Designing for Arc Welding

Material Science and Engineering [39]

- Chapter 11 Applications and Processing of metal alloys

Papers

Effect of Preheating Temperatures On Impact Properties [40]

SAE Baja Final Proposal Report [41]

Stress analysis of a roll cage[42]

Online

Designing a Roll Cage in Solidworks [43]

Static Structural Analysis in Ansys [44]

Standard

ASTM- AISI 4130 Steel [45]

Literature Review

Ryan Carley

Books

Engineering Analysis with ANSYS Software (Ch.3) [46]

- Two dimensional & three dimensional stress analysis using ANSYS

The Automotive Chassis (Second Edition) (Ch. 6) [47]

- Center of Gravity calculations for a frame

Standard

ASTM A500/A500M-23 [48]

- Inspection and Welding Standards for tubing

Papers

Analysis of Roll Cage and Various Design Parameters of an All Terrain Vehicle (Baja) [49]

- Calculations and static analysis of a baja frame

Design, analysis and optimization of all terrain vehicle chassis ensuring structural rigidity (5. Calculations) [50]

- Impact calculations

Static and Modal Analysis of All Terrain Vehicle Roll-Cage [51]

- Simulating various impacts on a baja frame for FEA in SolidWorks

Online Resources

Introduction to Simulations (FEA) [52]

- Using FEA simulations in SolidWorks

Bentley Garner Shares Tips for Successfully Welding Chromoly Tube [53]

- Instructions on preparing Chromoly tubing and necessary steps in tacking and welding
- Different welding wires that should be used

Literature Review

Wyatt Walker

Books

Shigley's Mechanical Engineering Design [1]

Chapter 2 section 2-1 Material Strength and Stiffness

- Material Calculations resource

Standard

Machinery's Handbook [2]

Bending Sheet Metal pg.1346-1353

- Tube bending calculations and tables.

Papers

Design and Optimization of Mini Baja Chassis [54]

- Impact Simulations of Baja Frame

Design, analysis and optimization of all terrain vehicle chassis ensuring structural rigidity (6 Finite Element Analysis) [55]

- ANSYS Impact simulation

Plastic Deformation Analysis in Tube Bending [56]

- Prediction of tube bending outcomes

Online Resources

2024 Baja SAE Roll Cage Doc. Package. Pg. 8 [57]

- Official Baja SAE Equivalency calculations

Techniques to improve weld penetration in TIG welding [58]

- Suggestions on how to improve welding quality

Mathematical Modeling #1

Arc Length Calculations

Ex: 75° bend & 5” Centerline Radius

- 75*(Π/180) ≅ 1.31 rad
- 1.31*5 = 6.55”

∑ Straight + Bent= Total

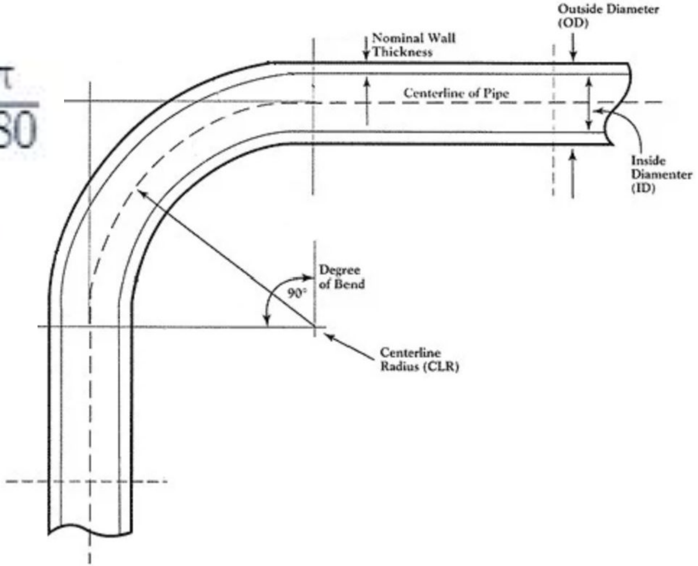
- ≅ 83’ feet of tube

∑ Pm + Sm= Total

- ≅ 48’ PM, 35’ SM

$$rad = \theta \cdot \frac{\pi}{180}$$

$$L = \theta \cdot clr$$



Charles

Mathematical Modeling #1

Cost Of Tubing

(Assuming 1 ¼” OD and 0.065” WT for PM and 1” OD and 0.035” for SM)

4130 Chromoly

- Via: Online Metals
- PM= $29.68/ft
- SM= $14.76/ft

Total costs
PM : 29.68 * 48= $1424.64
SM: 14.76 * 35= $516.60

Total= $1941.24

316 Stainless

- Via: Grainger
- PM= $26.43/ft
- SM= $13.87/ft

Total Costs
PM: 26.43 * 48= $1268.64
SM: 13.87* 35= $485.45

Total= $1754.09

1020 DOM

- Via: Stock Car Steel
- PM= $4.38/ft
- SM= $4.10/ft

Total Costs
PM: 4.38 * 48= $210.24
SM: 4.10 * 35= $143.50

Total= $353.74

Charles

Mathematical Modeling #2

1018 Steel [62]

OD = 25mm = 0.984in
Wall Thickness = 3mm = 0.118in
ID = 19mm = 0.748in
E = 205 GPa = 29733200 psi (Modulus of Elasticity for all steels)
Sy = 365 MPa = 52939.6 psi
C = OD/2 = 12.5mm = 0.492in (Distance to neutral axis)

Bending Stiffness (Kbreq)

I = Second moment of area for the structural cross section
I = pi/64*(OD^4-ID^4)
I = pi/64*(0.984^4-0.748^4)
I = 0.0308in^4

Kbreq = E*I
Kbreq = 29733200psi * 0.0308in^4
Kbreq = 915,782.56 lbf*in^2

Bending Strength (Sbreq)

Sbreq = (Sy*I)/C
Sbreq = (52939.6 psi*0.0308in^4)/0.492in
Sbreq = 3,314.11 lbf*in

4130 Chromoly Steel

OD = 1.25in
Wall Thickness = 0.065in
ID = 1.12in
E = 205 GPa = 29733200 psi (Modulus of Elasticity for all steels)
Sy = 63100 psi [2]
C = OD/2 = 0.625in (Distance to neutral axis)

Bending Stiffness (Kbreq)

I = Second moment of area for the structural cross section
I = pi/64*(OD^4-ID^4)
I = pi/64*(1.25^4-1.12^4)
I = 0.0426in^4

Kbreq = E*I
Kbreq = 29733200psi * 0.0426in^4
Kbreq = 1,266,634.32 lbf*in^2

Bending Strength (Sbreq)

Sbreq = (Sy*I)/C
Sbreq = (63100 psi*0.0426in^4)/0.625in
Sbreq = 4,300.9 lbf*in

Wyatt

Mathematical Modeling #3

Estimated Weight of the Frame:

$$Weight = Density \times Volume \qquad V_{tube} = V_{outer} - V_{inner}$$

Primary Members:

$$OD = 1.25\ in$$

$$Wall\ Thickness = .065in$$

$$Density = .284\ \frac{lbs}{in^3}$$

$$Lenght \approx 49ft$$

$$\left(\pi \times \left(\frac{1.25in}{2}\right)^2 \times (49ft \times 12in)\right) - \left(\pi \times (.56in)^2 \times (49ft \times 12in)\right) = 143.28\ in^3$$

$$143.28\ in^3 \times .284\frac{lbs}{in^3} = 40.73\ lbs$$

Secondary Members:

$$OD = 1\ in$$

$$Wall\ Thickness = .035in$$

$$Density = .284\ \frac{lbs}{in^3}$$

$$Lenght \approx 36ft$$

$$\left(\pi \times \left(\frac{1in}{2}\right)^2 \times (36ft \times 12in)\right) - \left(\pi \times (.465in)^2 \times (36ft \times 12in)\right) = 43.53\ in^3$$

$$43.53\ in^3 \times .284\frac{lbs}{in^3} = 12.35\ lbs$$

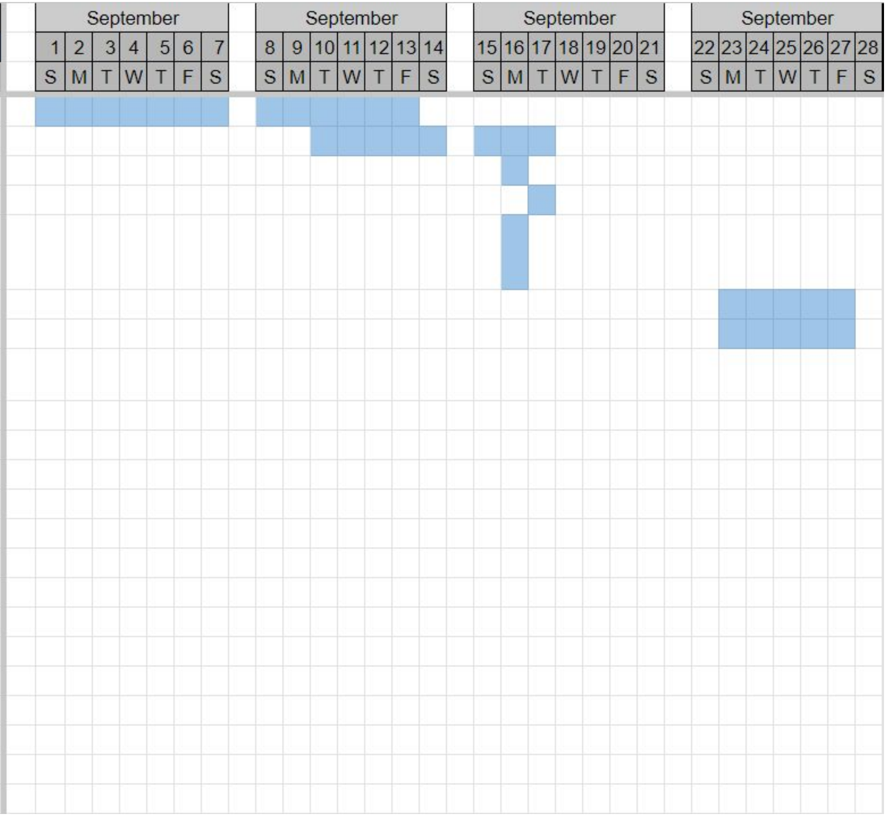
$$Total\ Weight \approx 54\ lbs$$

Not including weight of welds

Ryan

Schedule

		Number code	Color
		1	
Task	**Assigned To**	**Start**	**End**
Organizing Teams	Chassis Team	9/1/24	9/13/24
Working on Presentation One	Chassis Team	9/10/24	9/16/24
Measure Drivers (reach out and meet)	Chasssis Team	9/16/24	9/16/24
Presentation #1	All		9/17/24
Welders Certifications	Charles, Taylor, Maddox, Matalina	9/16/24	Working
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	Working	
Begin Prototyping #1	Chassis Team	Working	
Begin Prototyping #2	Chassis Team	Working	
Registration for Competition opens	All	10/2/24	
Presentation #2	All		10/9/24
Report #1	All		10/18/24
Website Check #1	Charles		10/25/24
Final CAD of the frame	Chassis Team		10/30/24
Begin Fabrication	Chassis Team	10/31/24	
Analysis Memo	Chassis Team		11/1/24
Presentation #3	All		11/6/24
1st Prototype Demo	All		11/13/24
Report #2	All		11/27/24
Final CAD and Final BOM	All		12/3/24
Project Management	All		12/6/24



Charles

Steering, Brakes, and Suspension

David Polkabla Jr.
Taylor Hewitt
— Steering, Brakes

Ryan Key
Ryan Latulippe
Oliver Husmann
— Suspension

Benchmarking

NAU 2024 #44

Cal Poly 2024 #36

Cornell 2024 #73

Benchmarking

2024 Cornell #73	2024 SDSU #43	2024 NAU #44
		
1st in suspension (2024)	2nd in suspension (2024)	25th in suspension (2024)

Suspension: Ryan K.

Customer and Engineering Requirements

Customer Requirements

- High Performing
- Affordable
- Comfortable
- Easy Operation
- Passes SAE Inspection

Engineering Requirements

- Reduce Turning Radius
- Reduce Steering Slop
- Increased stability
- Ideal Wheel Angles
- Ideal Steering Ratio

Steering: David

QFD

		Technical Requirements									
Customer Weights	Customer Requirements	Reduce Turning Radius	Reduce Steering Slop	Increased stability	Proper toe	Ideal Castor Angle	Ideal Camber Angle	Ideal Steering Ratio			
9	Safety	3	9	9	1	1	1	3			
3	Affordable	3	3	9	1	1	1	9			
4	Performance	9	9	3	9	9	9	9			
7	Easy Operation	3	9	9	1	1	1	9			
4	Reliable	1	9	9	3	3	3	9			
3	Comfortable	3	9	3	3	3	3	9			
8	Lightweight	1		3							
3	Easy to Mount	3	3	3	3	3	3	0			
2	Pass Inspection	1	1	1	1	1	1	1			
Technical Requirement Units		ft.	Degrees	N/A	in.	Degrees	in.	N/A			
Technical Requirement Targets		12	0		.0.0625	10	0.25				

Steering: David

QFD

	Reduce Turning Radius	Reduce Steering Slop	Increased stability	Proper toe	Ideal Castor Angle	Ideal Camber Angle	Ideal Steering Ratio
Reduce Turning Radius							
Reduce Steering Slop							
Increased stability	+	+					
Proper toe	+		+				
Ideal Castor Angle	+		+				
Ideal Camber Angle	+		+				
Ideal Steering Ratio	+		+				

Customer Weights	Customer Requirements	Technical Requirements						
		Reduce Turning Radius	Reduce Steering Slop	Increased stability	Proper toe	Ideal Castor Angle	Ideal Camber Angle	Ideal Steering Ratio

		Baja 2025 Steering	
Relationship		Date: 9/15/2024	
Strong	9	Legend	
Moderate	3	A	NAU 2024 #44
Weak	1	B	Cal Poly 2024 #36
N/A	0	C	Cornell Univ. #73

Customer Opinion Survey				
1 Poor	2 OK	3 Acceptable	4 Good	5 Excellent
			A	BC
	A		BC	
A				BC
		A	B	C
A			B	C
		A		BC
			ABC	
			A	BC
				ABC

Steering: David

Customer and Engineering Requirements

Customer Requirements

- Safe to use
- Affordable
- No Hydraulic Issues
- Doesn’t Overheat
- Passes SAE Inspection

Engineering Requirements

- Maximize braking force
- Pedal Must be made from aluminum or steel
- Maximize Safety
- Minimize pedal force needed to apply brakes

QFD

		Technical Requirements										
Customer Weights	Customer Requirements	Reduce Braking Distance	Minimize Pedal Force	Maximize Safety	Easily Serviceable	Must Stop All Four Tires At Once	Maximize Braking Force	Pedal Components must be made from aluminum or steel	Brake System must have sufficient force to hold vehicle while engine is runni	Brake Pedal Shall Be Designed for Unobstructed Travel	Brake Systems Must Have Two Independent Hydraulic Resevoirs	Maximize Clamping Force
9	Safety	9	9	9	3	9	9	3	9	9	9	9
3	Affordable	-1	-1	-1	1	-3	3	9	-3	-3		3
2	Performance	1	3	3	1	3	3	1	3	9	1	9
7	Easy Operation	9	3	9		1	3		9	9	3	9
4	Hydraulic	1	9	3			1	-1	3	1	9	9
3	No Overheating	9	-1	9	-1	3	9		3		1	
8	Long Pad Life	9	3	9	-1	3	3		9	3	3	1
3	Easy to Mount	-3		3	3		2		1		3	1
2	Pass Inspection	-3	3	9	3	9	9	9	9	9	9	9
Technical Requirement Units		ft	lbf	N/A	N/A	N/A	psi	lbf	ft-lbf/s	N/A	N/A	psi
Technical Requirement Targets		60	450				500	450	7700			90

Brakes: Taylor

QFD

Correlation	
Positive	+
Negative	-
N/A	

Relationship	
Strong	9
Moderate	3
Weak	1
N/A	

Baja 2025 Brakes	
Date: 9/12/2024	
Legend	
A	NAU 2024 #44
B	Cal Poly 2024 #36
C	Cornell Univ. #73

	Reduce Braking Distance	Minimize Pedal Force	Maximize Safety	Easily Serviceable	Must Stop All Four Tires At Once	Maximize Braking Force	Pedal Components must be made from aluminum or steel	Brake System must have sufficient force to hold vehicle while engine is running	Brake Pedal Shall Be Designed for Unobstructed Travel	Brake Systems Must Have Two Independent Hydraulic Resevoirs	Maximize Clamping Force
Reduce Braking Distance											
Minimize Pedal Force											
Maximize Safety	+										
Maximize Safety	+	+									
Must Stop All Four Tires At Once		-	+	+							
Maximize Braking Force	+	+	+	+							
Pedal Components must be made from aluminum or steel	+	+	+	+	+						
Brake System must have sufficient force to hold vehicle while engine is running	-	-	+	+	+	+	+				
Brake Pedal Shall Be Designed for Unobstructed Travel	+	+	+	-	+	+	-	+			
Brake Systems Must Have Two Independent Hydraulic Resevoirs	+	+	+	-	+	+	+	+			
Maximize Clamping Force			+	-	+	+			+	+	

Technical Requirements

Customer Weights	Customer Requirements	Reduce Braking Distance	Minimize Pedal Force	Maximize Safety	Easily Serviceable	Must Stop All Four Tires At Once	Maximize Braking Force	Pedal Components must be made from aluminum or steel	Brake System must have sufficient force to hold vehicle while engine is runni	Brake Pedal Shall Be Designed for Unobstructed Travel	Brake Systems Must Have Two Independent Hydraulic Resevoirs	Maximize Clamping Force

Customer Opinion Survey

1 Poor	2 OK	3 Acceptable	4 Good	5 Excellent
			A	BC
				ABC
			A	BC
			AB	C
			AB	C
			A	BC
			ABC	
				ABC
				ABC

Brakes: Taylor

Customer and Engineering Requirements

Customer Requirements

- Performance/comfort
- Serviceability/tunability
- Durability
- Affordable
- Ease of fabrication
- Aesthetics
- Pass tech

Engineering Requirements

- Light weight
- B.8.7 - cockpit shielding for steering/suspension links
- Optimal ride height/ground clearance
- B.1.6 - Vehicle width
- Vehicle length/approach angle
- Singular known replaceable failure point (bolt)
- Efficiently designed knuckle
- Optimize maximum suspension travel

Suspension: Ryan L

QFD

Suspension QFD	
Team Members	
Oliver Husmann	
Ryan Key	
Ryan Latulippe	

Baja 25' Suspension	
Date: 9/12/24	

Relationship	
Strong	9
Moderate	3
Weak	1
N/A	0

Legend	
A	2024 Cornell #73
B	2024 SDSU #43
C	2024 NAU #44

		Technical Requirements										Customer Opinion Survey				
Customer Weights	Customer Requirments	Light weight	B.8.7 - all steering or suspension links exposed in the cockpit shall be shielded with a sturdy, robust, metal cover.	Optimal ride height/ground clearance	B.1.6 - Limitations - Vehicle width	Vehicle length/approach angle	Singular known replaceable failure point (bolt)	Efficiently designed knuckle	Optimal camber angles	Optimal caster angle	Optimize maximum suspension travel	1 Poor	2 OK	3 Acceptable	4 Good	5 Excellent
2	Performance/comfort	3	3	9	9	9	9	9	9	9	9		C			AB
3	Servicability/tunability	1	-1		3	9	9	9	3	3	9		C	B	A	
4	Durability	-3	3	3	3	9	9	9			3		C	B		A
6	Affordable	3	-1				3	9				C		B	A	
5	Ease of Fabrication	1	1				3	9	1	1	1		C	AB		
7	Aesthetics		3	9	9	3	1	9	3	3	9				BC	A
1	Pass Tech		9		9											ABC
Technical Requirement Units		lbs	mm	In.	In.	In.	Psi.	lbs, Psi, in., hrs.	Degrees	Degrees	In.					
Technical Requirement Targets		<50	<6.35	12-16	64	48-60					12-16					

	Light weight	B.8.7 - all steering or suspension links exposed in the cockpit shall be shielded with a sturdy, robust, metal cover.	Optimal ride height/ground clearance	B.1.6 - Limitations - Vehicle width	Vehicle length/approach angle	Singular known replaceable failure point (bolt)	Efficiently designed knuckle	Optimal camber angle	Optimal caster angle	Optimize maximum suspension travel
Light weight										
B.8.7 - all steering or suspension links exposed in the cockpit shall be shielded with a sturdy, robust, metal cover.	+									
Optimal ride height/ground clearnace										
B.1.6 - Limitations - Vehicle width	-		+							
Vehicle length/approach angle			+							
Singular known replaceable failure point (bolt)	+									
Efficiently designed knuckle	+					+				
Optimal camber angle			+							
Optimal caster angle			+							
Optimize maximum suspension travel			+		+			+	+	

Technical Requirements

Correlation	
Positive	+
Negative	-
N/A	0

Literature Review

David Polkabla

Books/Chapters

Suspension Analysis & Geometry [59]
- Chapters 1 & 5

Shigley's Mechanical Engineering Design [1]
- Chapter 14

Papers

-Experimental Rig Study on Resistance Forces in Car Steering System with Rack and Pinion. [60]
-Design and comparative analysis of Ackermann and Anti-Ackermann steering system [61]
-Design of a Low Alloy Steel Vehicle Tie Rod to Determine the Maximum Load That Can Resist Failure [62]

Online Resources

- Ackermann Steering Geometry Explained [61]
- Caster & Camber [63]

Standard

- ANSI/AGMA 1006-A97 [64]

Literature Review

Taylor Hewitt

Books/Chapters

Brake Design and Safety Third Ed. Rudolf Limpert Chapters 1 & 2 [65]

Shigley's Mechanical Engineering Design Chapter 16 (Brakes) [1]

Papers

Design and Analysis of Double Piston Brake Caliper for SAE Baja [66]

Design and Analysis of Inboard Braking System for Vehicle [67]

Modeling and Simulation of Disc Brake to Analyse Temperature Distribution using FEA [68]

Online Resources

Calculating the Braking Force of a Car [69]

Modeling to Understand and Improve Your Braking system [70]

Standard

U.S. Department of Transportation

5.1.1 Brake systems [71]

Literature Review

Ryan Latulippe

Books/Chapters

- **Dixon Suspension Geometry and Computation (Ch. 12) [72]**
  - Explains various forms of double wishbone suspension and details (front application)
- **Fundamentals of Vehicle Dynamics [73]**
  - General overview of different types of suspension and respective applications with equation and calculation information.
- **Baja 2025 Rule Book [15]**
  - Holds standards for all teams to follow.

Papers

- **Optimization of Suspension Systems of Offroad Vehicles for Vehicle Performance Improvement [74]**
  - Double wishbone suspension vs Macpherson suspension.
- **Design Review of Suspension Assembly of a BAJA ATV [75]**
  - Analyzes the process of creating/designing a suspension assembly for a Baja ATV, along with info on some software that aligns with what we are learning.

Online Resources

- **Understanding Caster and Camber Angles [76]**
  - Explains various angles and respective applications for both camber and caster.
- **Bump Steer [77]**
  - Defines bump steer along with real world ways to mitigate/eliminate it.
- **Lotus Shark Suspension Tutorial [78]**
  - Tutorial video for Lotus Shark suspension software.

Literature Review

Ryan Key

Books/Chapters

- Tune to Win - Carroll Smith [79]
  - Ch. 3, 4 - weight , mass load, load transfer, suspension geometry
- Suspension Geometry and computation - John C. Dixon [72]
  - Ch. 4, 7, 11 - ride geo., camber & scrub, single arm suspensions

Papers

- 2019 University of Cincinnati SAE Baja Rear Suspension [80]
- Design, Analysis and Optimization of Trailing Arm with Two Link Suspension System [81]
- Optimization of suspension system of off road vehicle for vehicle performance improvement [82]

Online Resources

- Guide To Suspension Design For Going Fast In Comfort [83]
- Design of Three and Four Link Suspensions for Off Road Use [84]
- Custom Link Suspension Rules - General guidelines for custom suspension setup [85]

Literature Review

Oliver Husmann

Books/Chapters

- **Performance Vehicle Dynamics: engineering and applications (7 and 8) [86]**
  - Ch. 7: an introduction to suspension kinematics and configurations
  - Ch. 8:modeling vehicle suspension dynamically.
- **Race Car Vehicle Dynamics (6) [87]**
  - Ch. 6: Advanced suspension systems and tuning

Papers

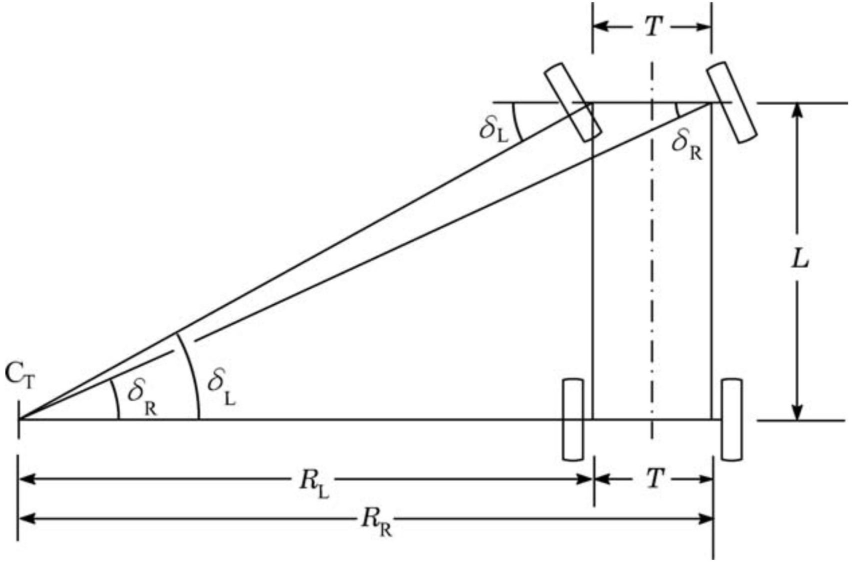
- **Design cycle implementation on a customized steering knuckle for a competition ATV [88]**
  - Design methodologies and iterative improvements for steering knuckles
- **Optimization of suspension system of off road vehicle for vehicle performance improvement [89]**
  - Techniques for enhancing suspension performance and vehicle handling
- **Structural Optimization of a Knuckle with Consideration of Stiffness and Durability Requirements [90]**
  - Methods for balancing strength, stiffness, and durability in knuckle design

Online

- **Design and analysis of suspension system for an All-Terrain vehicle [91]**
  - Design principles and analysis techniques for all-terrain vehicle suspensions
- **Suspension Videos: XF Motorsports [92]**
  - Practical demonstrations and visual insights into suspension systems
- **Off Road Suspension 101: An Inside Look [93]**
  - Basic overview and design considerations for off-road suspension systems

Mathematical Model

$$\cot\delta_R - \cot\delta_L = \frac{T}{L}$$



$$\delta_R = \cot^{-1}\left(\cot(50^o) + \frac{56}{64}\right) \Rightarrow \delta_R = 30.26^o \ or \ 30^o$$

$$R = L \tan\delta_L \Rightarrow 64 tan60^o \Rightarrow R = 120in$$

δ_R = Outside turning angle

R = Turning Radius

Mathematical Modeling

$$a = \frac{v - v_0}{t - t_0} \quad => \quad a = \frac{58.7}{4} = 14.7 ft/s^2$$

$$d = vt - \frac{1}{2}at^2 \quad => \quad d = 58.7(4) - \frac{1}{2}(14.7)(4)^2 = 117.2\, ft$$

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

$$F_{brake} = \frac{W}{d} \quad => \quad F_{brake} = \frac{29460}{117.2} = 251.4\, psi$$

$$F_{clamp} = \frac{F_{brake}}{2} * \mu \quad => \quad \frac{251.4}{2} * 0.7 = 88\, psi$$

Weight of vehicle (with driver) = 550 lbs
Mass of vehicle (m) = 550/32.2 = 17.1 lbm
Velocity of vehicle = 40 mph = 58.7ft/s
a = acceleration (ft/s^2)
v = velocity (ft/s)
t = time (s)
d = distance (ft)
W = work done (lb*ft/s^2)
F_{brake} = Brake Force (psi)
F_{clamp} = Clamping Force (psi)
Coefficient of Friction (μ) = 0.7

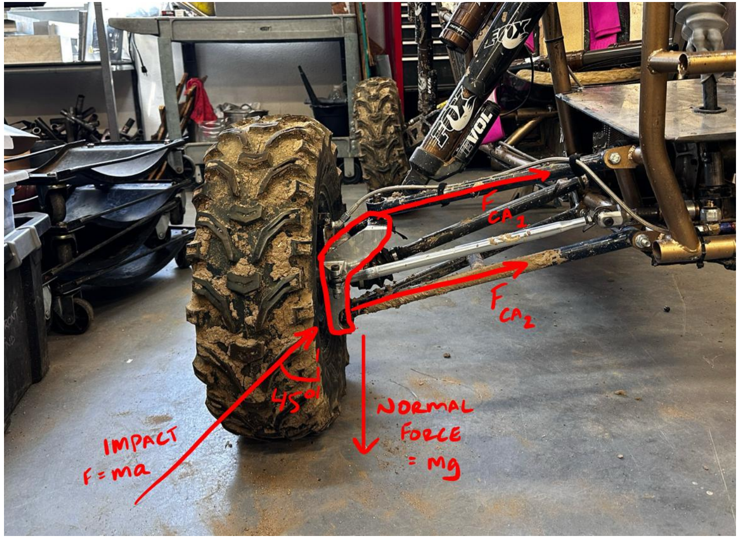
Brakes: Taylor

Mathematical Modeling: Impact Force

Max Impact Force Based on Car Nose Diving Off a Jump on One Corner

Given Info:

- Car + driver weight: ~600lbs → 272kg
- 1 meter tall jump
- Velocity off jump (at impact)



$$v_{horiz.} = \frac{14.13m}{s} \, (previously\ calculated)$$

$$\Sigma F = 0 \rightarrow 0 = Normal\ force - Impact\ force + F_{Control\ arm}$$

$$\Sigma F = 0 \rightarrow 0 = -272(9.81) - [272(14.13)\sin(45)] + F_{CA}$$

$$F_{CA} = 5391.8\ N$$

$$2\ Control\ Arms\ (upper\ and\ lower) \rightarrow 2\frac{members}{arm}(A\ arm\ geometry)$$

$$\frac{F_{CA}}{2} = Force\ per\ arm$$

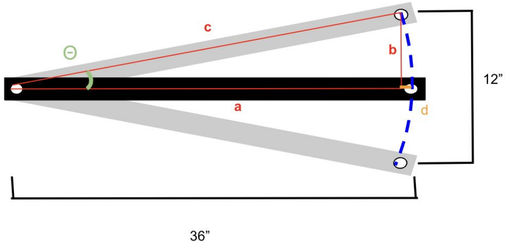
$$\frac{F_{CA}}{4} = Force\ per\ member \rightarrow \frac{5391.9}{4} = 1348\frac{N}{member}$$

$$1348N \rightarrow \frac{303lbs}{member}$$

Suspension: Ryan L.

Mathematical Modeling: Trailing Arms

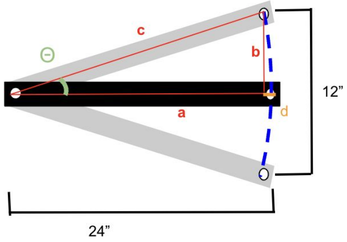
- Total wheel travel: 12”
- Lateral movement: 0.51” vs 0.77”
- Arm angle (deg) at full tuck/bump: 9.59 vs 14.48



$$a^2 + b^2 = c^2$$
$$a = \sqrt{c^2 - b^2}$$
$$a = \sqrt{(36)^2 - (6)^2}$$
$$a = 35.49$$

$$d = 36 - 35.49$$
$$d = 0.51in$$

$$sin\Theta = \frac{b}{c}$$
$$\Theta = sin^{-1}(\frac{b}{c})$$
$$\Theta = sin^{-1}(\frac{(6)}{(36)})$$
$$\Theta = 9.59deg$$



$$a^2 + b^2 = c^2$$
$$a = \sqrt{c^2 - b^2}$$
$$a = \sqrt{(24)^2 - (6)^2}$$
$$a = 23.23$$

$$d = 24 - 23.23$$
$$d = 0.77in$$

$$sin\Theta = \frac{b}{c}$$
$$\Theta = sin^{-1}(\frac{b}{c})$$
$$\Theta = sin^{-1}(\frac{(6)}{(24)})$$
$$\Theta = 14.48deg$$

Suspension: Ryan K.

Mathematical Modeling: Knuckle Forces

What is the bending moment and bending stress on the knuckle?

Force applied: 1348 N

Moment arm: 0.5 m

$$M = F * d = 1348N * 0.5m = 674N$$

Section Modulus (S): $3.04 * 10^{-4} m^3$

$$\sigma = \frac{M}{S} = \frac{(674\ N)}{(3.04 * 10^{-4} m^3)} = 2.2175\ MPa = 322.96\ psi$$

Suspension: Oliver

Schedule

SAE Baja 2025

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

Gannt Chart for Suspension, Steering & Brakes Weeks 1-8

Project Start 8/26/2024

Managers: Seth Scheiwiller & Brennan Pongratz

8/26/2024 9/2/2024 9/9/2024 9/16/2024 9/23/2024 9/30/2024 10/7/2024 10/14/2024

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 13 14 15 16 17 18 19 20

Task	Assigned To	Start	Days	End	Progress
Week 1					
HW-00	All	8/26/2024	4	8/29/2024	100.00%
HW-01	All	8/27/2024	4	8/30/2024	100.00%
Timecard Week 1	All	8/26/2024	7	9/1/2024	100.00%
Week 2					
Team Meeting 1	All	9/3/2024	1	9/3/2024	100.00%
Staff Meeting 1	All	9/3/2024	1	9/3/2024	100.00%
Team Charter	All	9/2/2024	5	9/6/2024	100.00%
Start Research	All	9/2/2024	6	9/7/2024	100.00%
Week 3					
Team Meeting 2	All	9/10/2024	1	9/10/2024	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%
Staff Meeting 2	All	9/10/2024	1	9/10/2024	100.00%
Team Meeting 3	All	9/13/2024	1	9/13/2024	100.00%
Week 4					
Team Meeting 4	All	9/17/2024	1	9/17/2024	
Presentation 1	All	9/17/2024	1	9/17/2024	
Peer Eval 1	All	9/18/2024	2	9/19/2024	
Week 5					
Team Meeting 5	All	9/24/2024	1	9/24/2024	
Staff Meeting 3	All	9/24/2024	1	9/24/2024	
Week 6					
Team Meeting 6	All	10/1/2024	1	10/1/2024	
Staff Meeting 4	All	10/1/2024	1	10/1/2024	
Week 7					
Team Meeting 7	All	10/8/2024	1	10/8/2024	
Presentation 2	All	10/7/2024	1	10/7/2024	
Presentation 2 Submission	Taylor	10/8/2024	1	10/8/2024	
Peer Eval 2	All	10/9/2024	1	10/9/2024	
Week 8					
Team Meeting 8	All	10/15/2024	1	10/15/2024	
Report 1	All	10/14/2024	5	10/18/2024	
Staff Meeting 5	All	10/15/2024	1	10/15/2024	
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	

Brakes: Taylor

Schedule

SAE Baja 2025

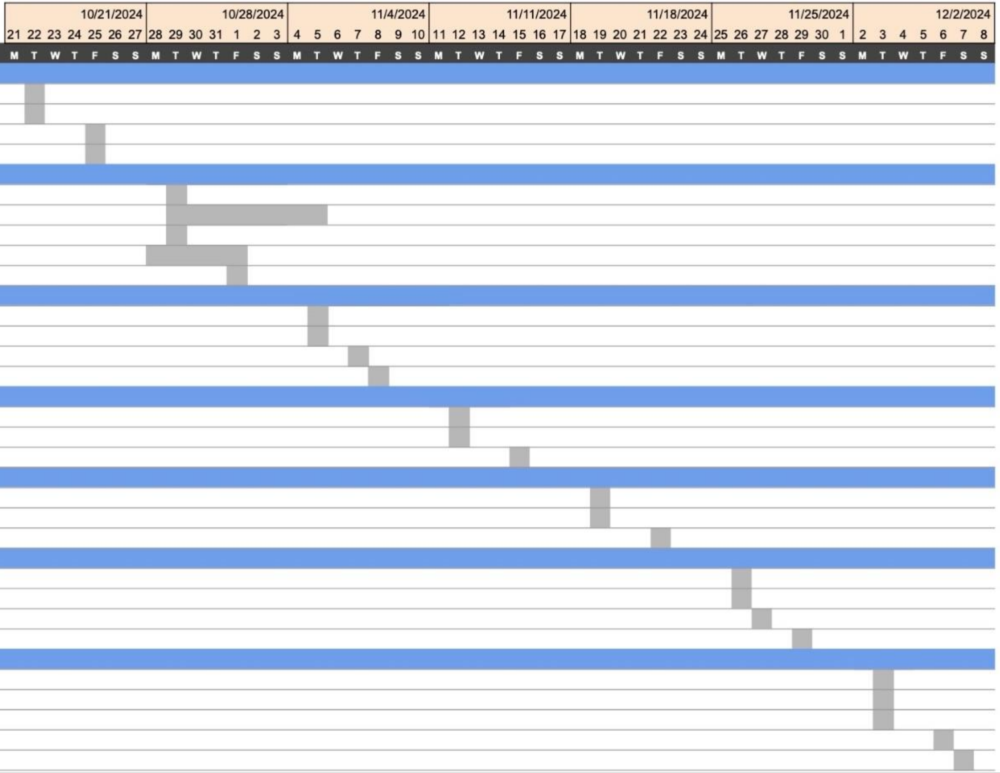
Gantt Chart for Suspension, Steering & Brakes Weeks 9-15

Project Start 10/21/2024

Managers: Seth Scheiwiller & Brennan Pongratz

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

Task	Assigned To	Start	Days	End	Progress
Week 9					
Team Meeting 9	All	10/22/2024	1	10/22/2024	
Staff Meeting 6	All	10/22/2024	1	10/22/2024	
Website Check #1	All	10/25/2024	1	10/25/2024	
Team Meeting 10	All	10/25/2024	1	10/25/2024	
Week 10					
Team Meeting 11	All	10/29/2024	1	10/29/2024	
Start Presentation 3	All	10/29/2024	8	11/5/2024	
Staff Meeting 7	All	10/29/2024	1	10/29/2024	
Analysis Memo	All	10/28/2024	5	11/1/2024	
Team Meeting 12	All	11/1/2024	1	11/1/2024	
Week 11					
Team Meeting 13	All	11/5/2024	1	11/5/2024	
Presentation 3	All	11/5/2024	1	11/5/2024	
Peer Eval	All	11/7/2024	1	11/7/2024	
Team Meeting 14	All	11/8/2024	1	11/8/2024	
Week 12					
Team Meeting 15	All	11/12/2024	1	11/12/2024	
Prototype #1 Demo	All	11/12/2024	1	11/12/2024	
Team Meeting 16	All	11/15/2024	1	11/15/2024	
Week 13					
Team Meeting 17	All	11/19/2024	1	11/19/2024	
Staff Meeting 8	All	11/19/2024	1	11/19/2024	
Team Meeting 18	All	11/22/2024	1	11/22/2024	
Week 14					
Team Meeting 19	All	11/26/2024	1	11/26/2024	
Staff Meeting 9	All	11/26/2024	1	11/26/2024	
Report # 2	All	11/27/2024	1	11/27/2024	
Team Meeting 20	All	11/29/2024	1	11/29/2024	
Week 15					
Team Meeting 21	All	12/3/2024	1	12/3/2024	
Final CAD & BOM	All	12/3/2024	1	12/3/2024	
2nd Prototype Demo	All	12/3/2024	1	12/3/2024	
Team Meeting 22	All	12/6/2024	1	12/6/2024	
Website Check #2	All	12/7/2024	1	12/7/2024	



Brakes: Taylor

Thank You

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[2] E. Oberg, F. Jones, H. Horton, and H. Ryffel, Machinerys Handbook.

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[14] S. Jadhav, S. Jadhav, S. Pokharkar, and V. Ladda, “A Review on Constant Velocity Joint”.

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