SAE Baja '24 Capstone Team

Presentation 3

Abraham Plis, Evan Kamp, Bryce Fennell
Joey Barta, Lars Jensen, Seth Deluca
Cooper Williams, Gabriel Rabanal, Antonio Sagaral
Henry Van Zuyle, Donovan Parker, Ryan Fitzpatrick, Jarett Berger

Front Team

Abraham Plis, Evan Kamp, Bryce Fennell

Project Description

NAU SAE Baja 2020-2021

What is SAE Baja?

The Society of Automotive Engineers (SAE) Baja Collegiate Design Series is an engineering challenge for students to design and build a single-seat, all-terrain vehicle.

- Compete against other universities
- 13 members total, 4 sub-teams
  - Front End, Rear End, Frame, Drivetrain
- Sponsors: See Fundraising Slide!
- Successful performance puts NAU on the map, strengthens internal Baja knowledge, and grows NAU Baja industry sponsorship connections

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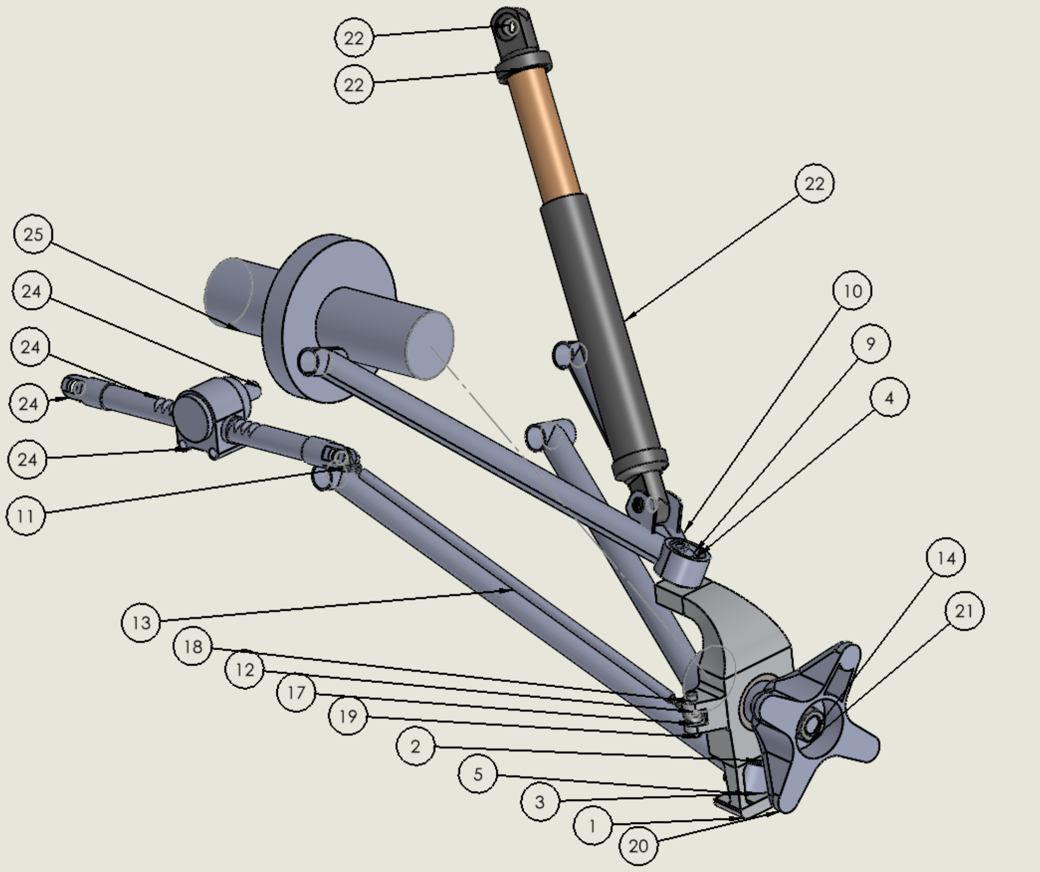
Design Description

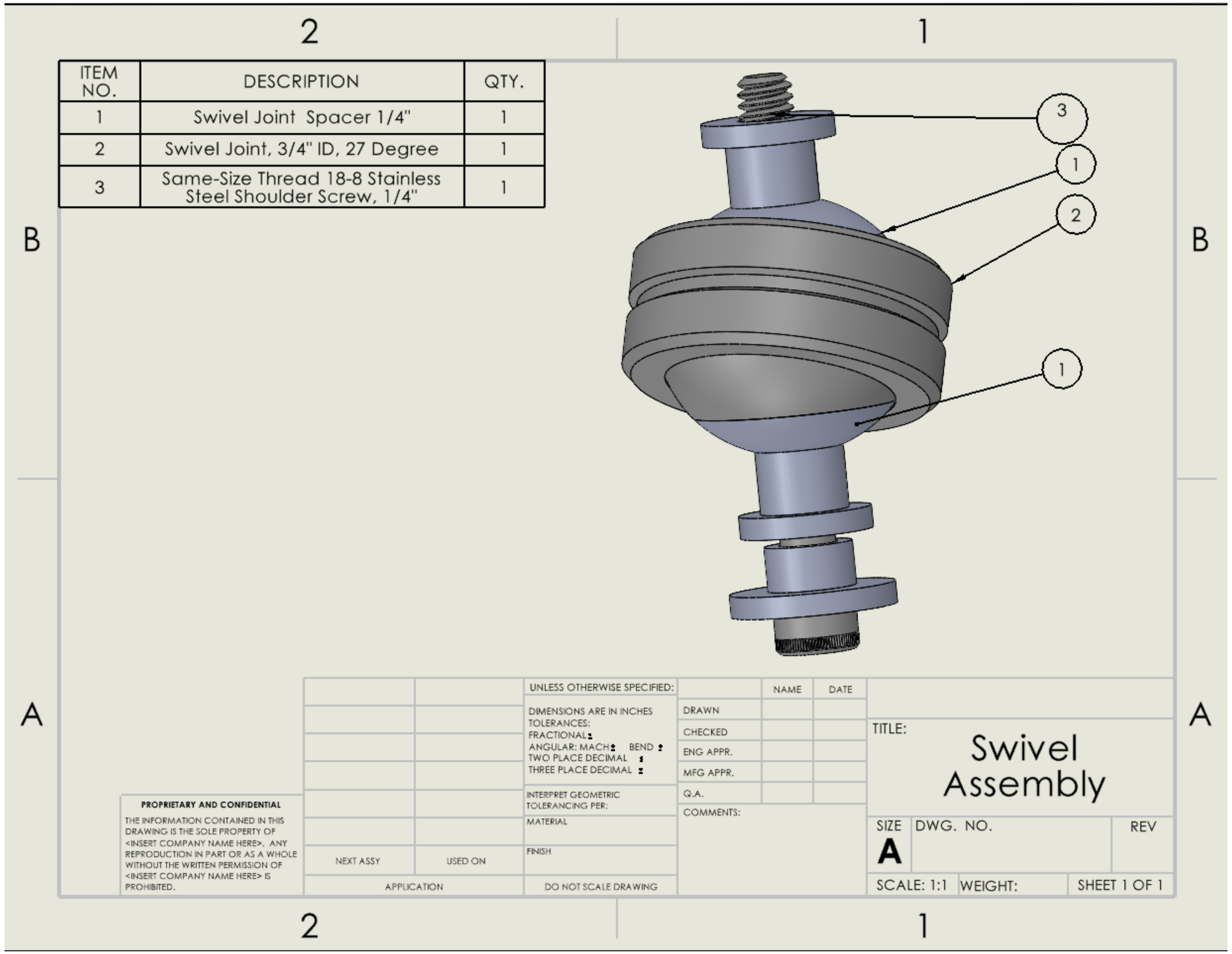
ITEM NO.	PART NUMBER	DESCRIPTION
1	Driver Knuckle 2.0	6061-T6 aluminum
2	63195K77	Swivel Joint
3	Driver_Side_LCA_Final_V4	Lower Control arm
4	63195K77	Swivel Joint, Source: MMC
5	Missalignment spacer .25in	.25"ID, .75"OD Spacer
6	Shoulder Bolt Spacer	.25"ID, .125" Length
7	91273A506	Same-Size Thread 18-8 Stainless Steel Shoulder Screw
9	Missalignment spacer .25in UCA	.25"ID, .75"OD Spacer
10	Driver_Side_UCA_Final_V2.2	Upper Control Arm
11	60645K121	Ball Joint Rod End
12	60645K121	Ball Joint Rod End
13	Tie Rod	Steering Tie Rod
14	CV Axle End	Husky 305 CV Axle End
15	CV Bearing	55mm OD, 30mm ID, 13mm Width
17	Tie Rod Ball Joint Spacer	.25"ID, .125" Height
18	90044A123	Black-Oxide Alloy Steel Socket Head Screw
19	95462A029	Medium-Strength Steel Hex Nut
20	Wheel Hub	Example hub for fittment
21	95462A538	Medium-Strength Steel Hex Nut
22	FOX Float	Shock, 18" Eye to Eye, 8" Stroke
24	Rack and Pinion	Steering rack, 18" Width, 5.5" Throw
25	CV Axle Inboard Standin	Modeled transmission for fittment



Sub Systems:

- Control arm/Knuckle interface
  - Control arm and swivel joint mounting methods
- Steering Rack
  - Rack pinion mating mechanism
- CV Axle/Knuckle interface
  - Double ball bearing compression mechanism

Design Description – Swivel Joint

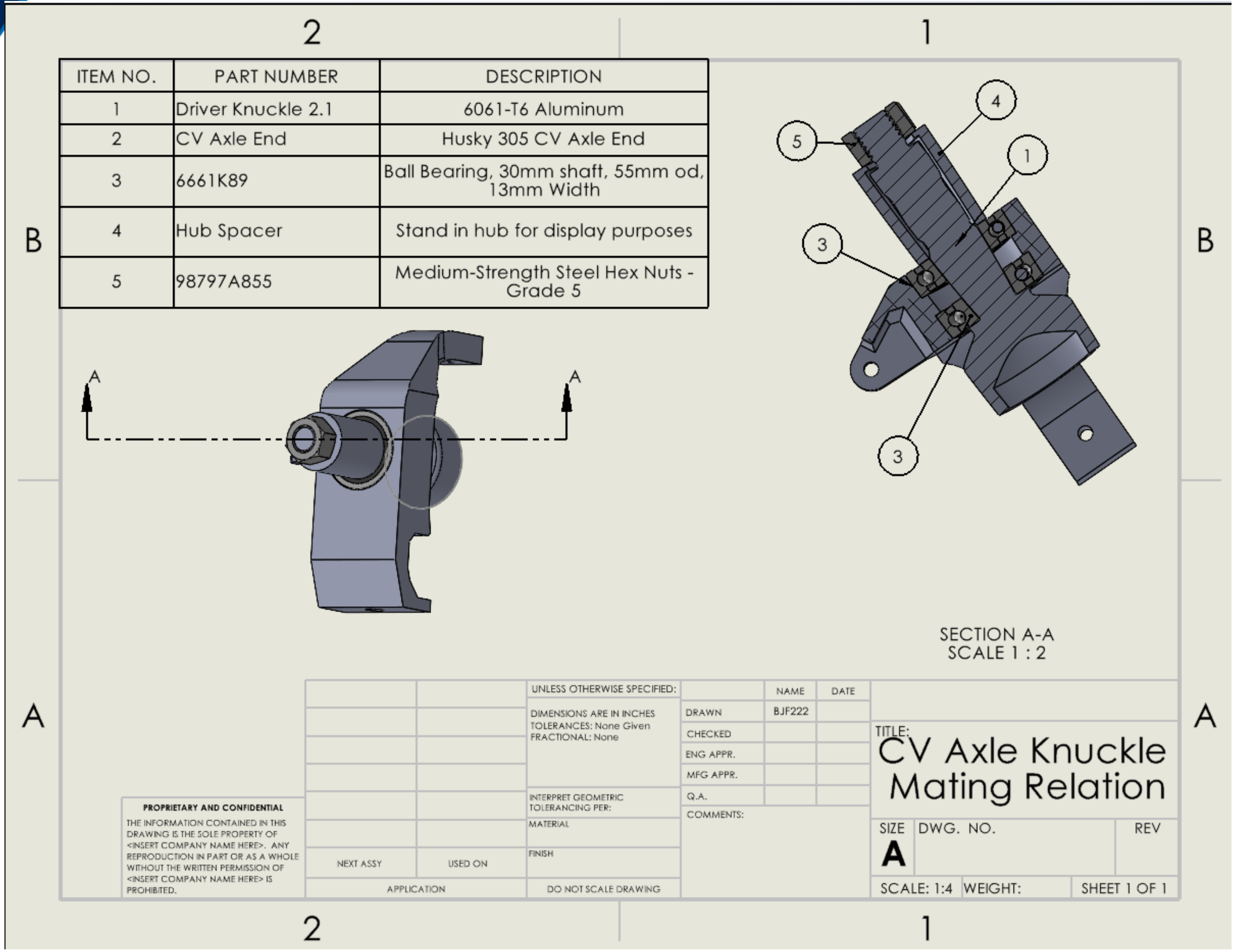


Important Features:

- Improves swivel angle from 27 degrees to 45 degrees
- Reduces bolt diameter from .75" to .25"
- Places Spacers in compression from shoulder bolt

Design Description – CV Interface

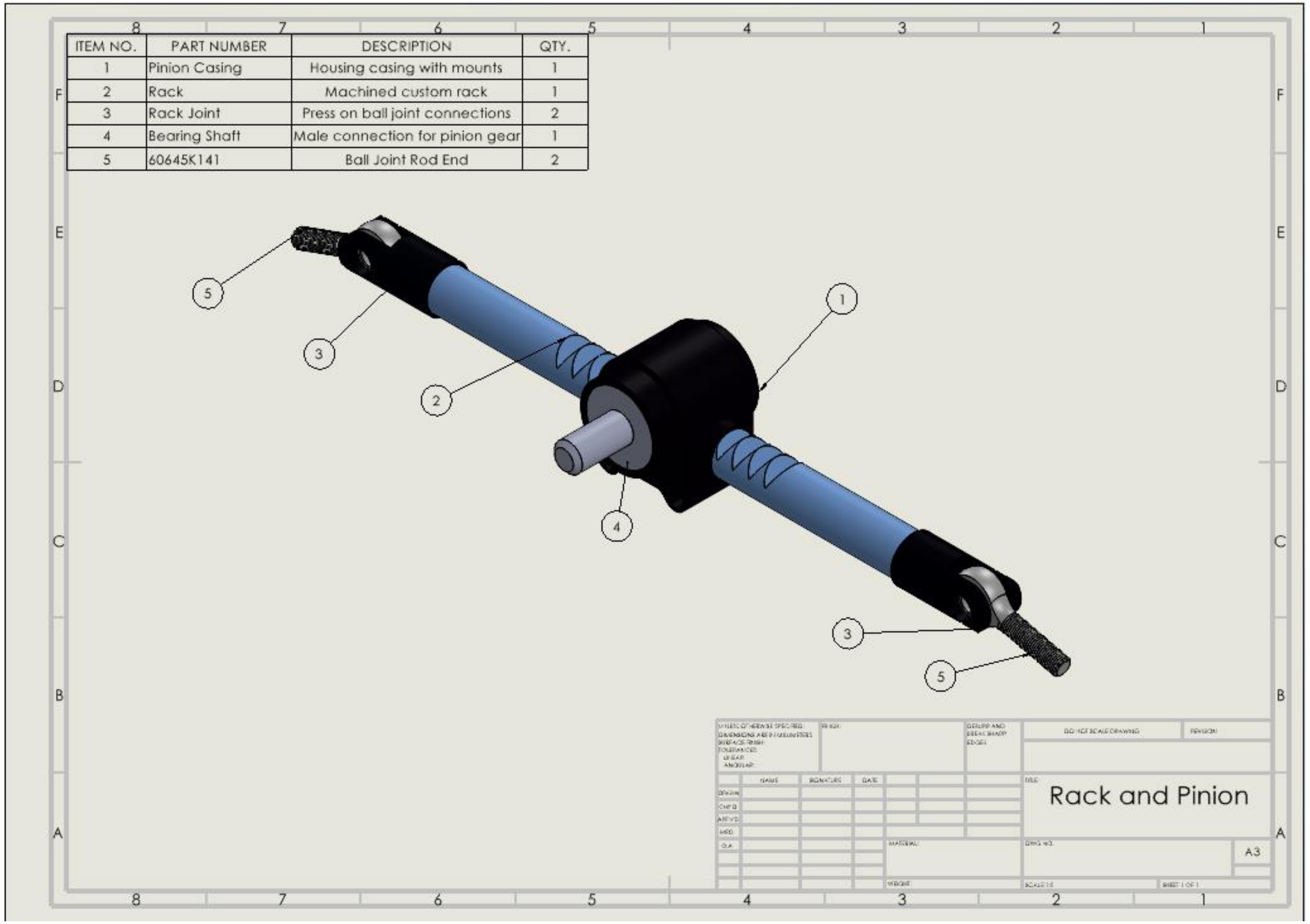
ITEM NO.	PART NUMBER	DESCRIPTION
1	Driver Knuckle 2.1	6061-T6 Aluminum
2	CV Axle End	Husky 305 CV Axle End
3	6661K89	Ball Bearing, 30mm shaft, 55mm od, 13mm Width
4	Hub Spacer	Stand in hub for display purposes
5	98797A855	Medium-Strength Steel Hex Nuts - Grade 5



Important Features:

- Reduction of bearing OD to 55mm from 72mm
- Increase separation between bearing surfaces
- Bearings retained in knuckle with single hub bolt attached to cv end

Design Description – Steering Rack



Important Features:

- Rack Length of 18” from eye to eye
- 5.5” rack travel end to end
- Rack ends pressed on to adjust angle of ball joints

Design Requirements - QFD

Engineering requirement correlations (roof)

#	Engineering Requirement	Decrease Vehicle Width	Increase Ride Height	Increase Tire Traction	Increase Capability in Rough Terrain	Increase Turn-In Angle
1	Decrease Vehicle Width					
2	Increase Ride Height					
3	Increase Tire Traction	-3				
4	Increase Capability in Rough Terrain	3	9	6		
5	Increase Turn-In Angle				3	
6	Increase Crash Durability	6	-3		6	

Legend	
A	NAU #74
B	Baja ETS
C	Cornell Racing

#	Customer Needs	Customer Weights	Decrease Vehicle Width	Increase Ride Height	Increase Tire Traction	Increase Capability in Rough Terrain	Increase Turn-In Angle	Increase Crash Durability	Customer Opinion Survey: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	Comply with track dimensions	4	9									A	BC
2	Adequate ground clearance	2		9	6	9		3			A	C	B
3	Adequate traction	3	3	3	9	6	3	3			A		BC
4	Safe operation over rough terrain	3	6	6	3	9		9				ABC	
5	Agile manuverability	4	6	3	6	3	9					A	BC
11	Robust design	3		3		3		9			BC	A	
	Technical Requirement Units		Inches	Inches	Degrees (Scrub Rad)	Inches (Wheel Travel)	Degrees	mph					
	Technical Requirement Targets		64	10	0	12	40-100	40					
	Absolute Technical Importance		87	66	72	84	45	69					
	Relative Technical Importance		1	5	3	2	6	4					

ER to ER

Positive Correlation

- Capability in rough terrain & ride height

Inverse Correlation

- Tire traction & vehicle width

CR to ER

Positive Correlation

- Comply with track dimensions & vehicle width
- Adequate ground clearance & ride height
- Agile maneuverability & turn-in angle

Design Requirements - ERs

CR	ER	Parameter	Target	Current Design	Acceptable?
Comply with Track Dimensions	Decrease Vehicle Width	Track Width	<64"	62.8”	✓
Adequate Ground Clearance	Increase Ride Height	Ride Height	>10"	10.5”	✓
Adequate Traction	Increase Tire Traction	Scrub Radius	±0”	0.34”	✓
Safe Operation Over Rough Terrain	Increase Capability in Rough Terrain	Wheel Travel	±12“	13”	✓
Agile Maneuverability	Increase Turn-In Angle	Pro-Ackerman	>40%	48%	✓
Robust Design	Increase Crash Durability	Collision Speed	20mph	N/A	N/A

Full front end assembly will be tested in FEA to verify impact performance at various speeds ASAP

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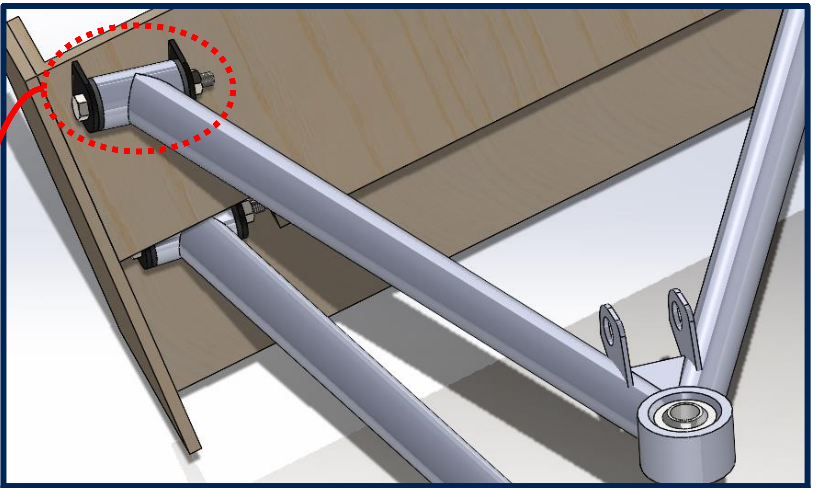
Engineering Calculations - Abe

Control Arm Pivot Shoulder Bolt Sizing



MMC - 90807A139

Problem Givens

- **Grade 8 Tensile Strength:** 150,000 psi [1]
- **Ratio of Shear/Tensile Strength:** ~0.6 [2]
- **Dynamic Load Factor for Structural Bolts:** 0.9 [3]
- **Max Impact Load:** 2160 lbf (max load from pres. 1, bolt will never see this, but better safe than sorry!)

Governing Equations

$$\boldsymbol{F_{shear,bolt}} = \mathrm{S_{tenslie}} * (0.6) * (0.9) * \mathrm{A_{bolt}}$$

$$\boldsymbol{A_{bolt}} = 2 * \frac{\pi}{4} * d_{bolt}^2 \qquad \boldsymbol{FoS} = \frac{F_{shear,bolt}}{F_{shear,impact}}$$

Diameter	A_bolt (in^2)	F_shear of Bolt (lbf)	F_shear from Impact (lbf)	FoS
1/4"	0.10	7952	2160	3.68
3/8"	0.22	17892	2160	8.28

Much better!

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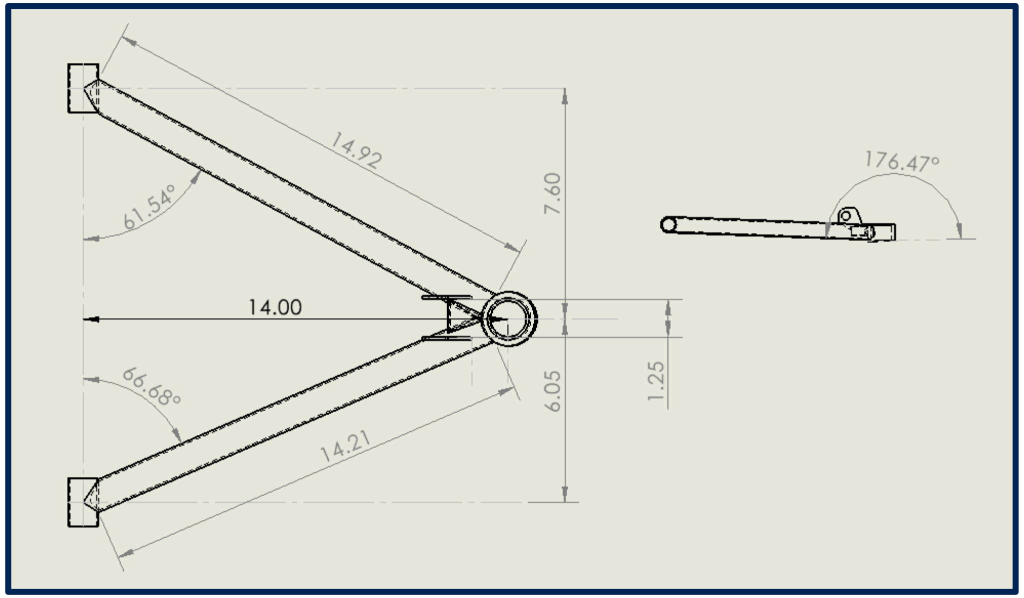
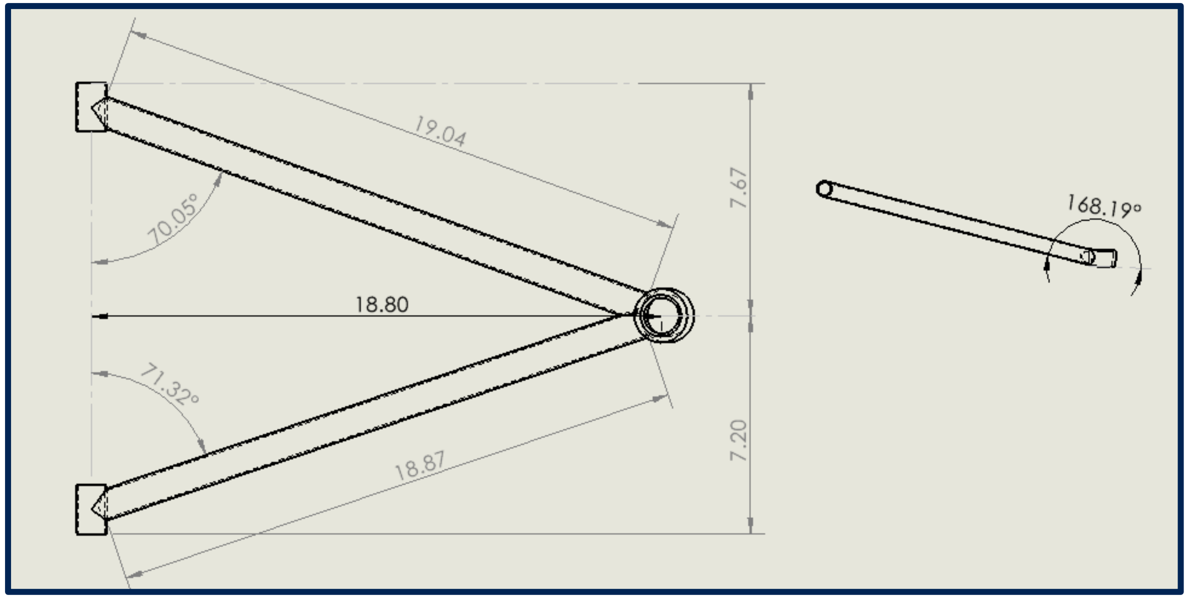
Engineering Calculations - Abe

Control Arm Construction Drawings

Upper Control Arm



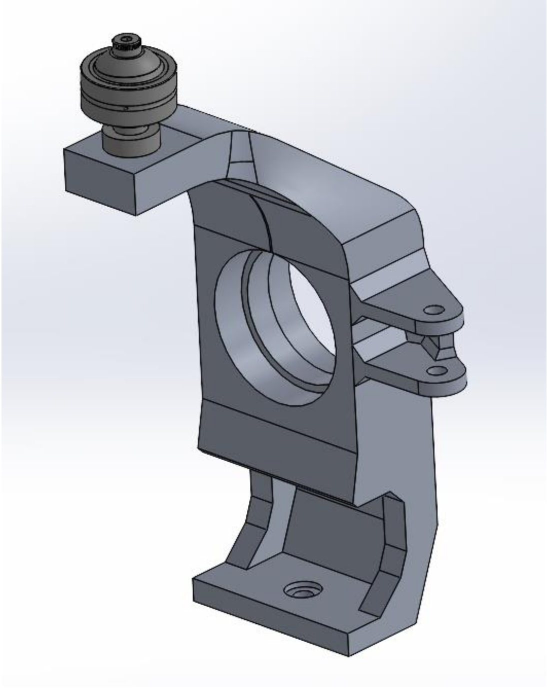
Lower Control Arm



These engineering drawings play a vital role in calculating cut angles on the pipe cutting vice and getting pipe lengths between members correct for prototyping and beyond!

Engineering Calculations - Bryce

Knuckle Upper Control Arm Mounting Interface



Problem Givens

- Material: 6061-T6 Aluminum Billet
- Maximum Impact force: 2200lbf through wheel
- Minimum cross-sectional area: 1.179 in^2
- Shear Strength: 3770ksi

Governing Equations

$$F_{shear,Aluminum} = S_{shear} * A_{Minimum\ Cross\ Section}$$

$$A_{Minimum\ Cross\ Section} = base * height \quad FoS = \frac{F_{shear,bolt}}{F_{shear,impact}}$$

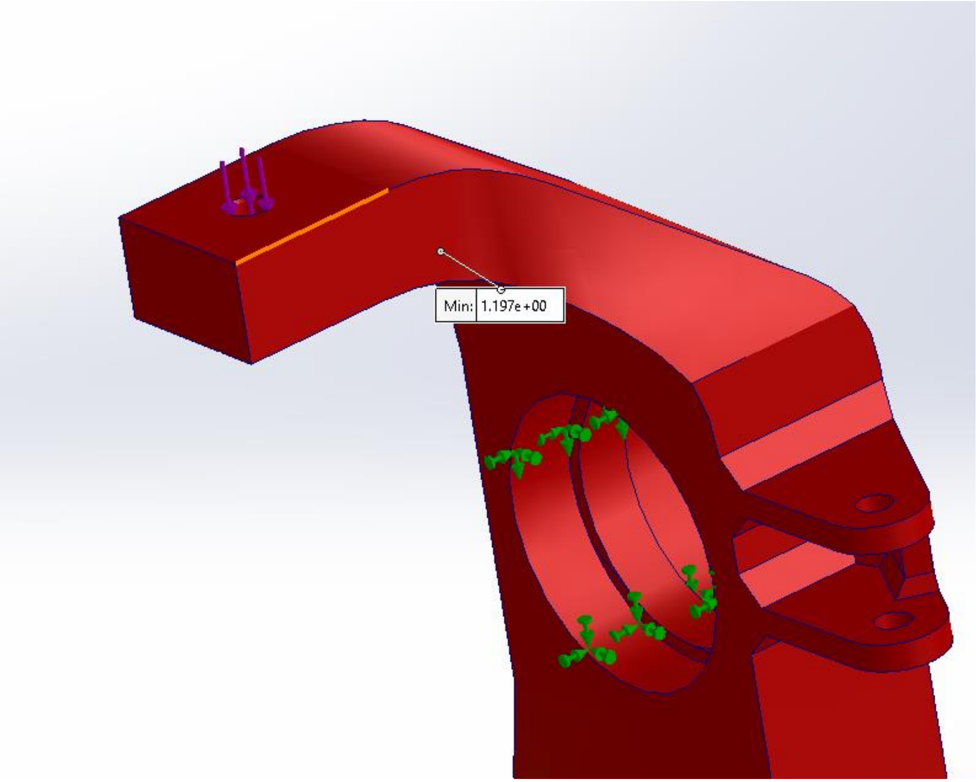
Base	Height	Area (in^2)	Impact Force (lbf)	Shear force (kpsi	Shear Strength 6061 (kpsi)	FOS
1.66	0.71	1.1786	2200	2592.92	3770	1.453959

Results

A calculated FOS of 1.45 is suitable for our applications; however, to account for unforeseen impacts, modifications will be made to accommodate a FOS of 3 for this critical feature

Engineering Calculations - Bryce

Knuckle Upper Control Arm Mounting Interface



Results generated from SolidWorks

- After performing a simple FEA simulation on the knuckle in using the SolidWorks simulation add-in, a calculated factor of safety of 1.197 was determined at the point of minimum cross-sectional area.
- Using this information, a revised design will be created aimed at increasing the factor of safety to 3

Additional notes

Due to the criticality of this feature, a higher FOS is desired to ensure the knuckle can withstand unforeseen circumstances during testing or racing.

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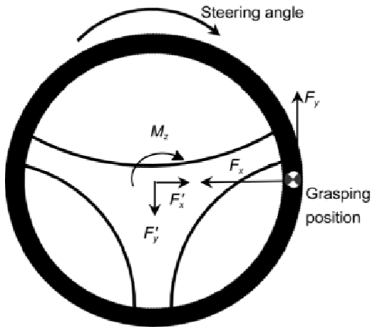
Engineering Calculations - Evan



Hypothetical Weight of Vehicle with Driver	450lbs / 205kg

½ (450lbs) = 225lbs on the front two tires

Under the Assumption that there is a perfectly centered center of gravity

Cornering Mass on One Front Wheel	112.5lbs / 51.25kg

Friction Force Calculation

$$f = \mu N$$

Friction Coefficient for Asphalt	.9
Normal Force (N)	3622.5 lb(ft/s^2)
Force of Friction on front two wheels	3260.25 lb(ft/s^2)

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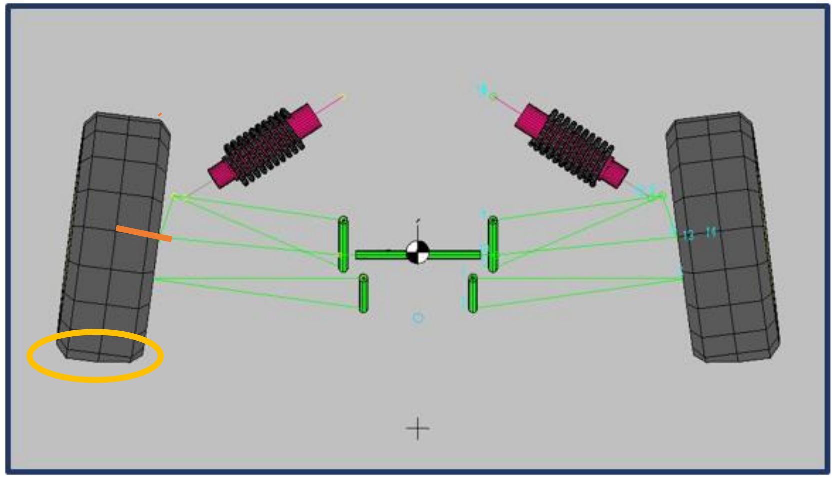
Engineering Calculations - Evan



Contact Patch (Yellow)	7.5in / 0.625ft
Torque due to friction force on Wheel	2037.5 lb(ft/s^2)ft
Lateral Push Distance (Orange)	4 in / .333ft

Torque due to Lateral Push

$$T_{lpush} = f_t * Distance\ from\ Tire\ Rod\ to\ Kingpin\ Axis$$

$$T_{lpush} = T_{friction}$$

f_t = 6117.12 lb(ft/s^2) or 85N

Design Validation – UCA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
UCA Shoulder Bolt	Impact Fatigue	Erratic Operation, Poor Appearance	Overstressing	30	Use 3/8" Shoulder Bolts
UCA Shoulder Bolt	Impact Fracture	Erratic Operation, Poor Appearance	Impact Loading	30	Use 3/8" Shoulder Bolts
UCA Pivot Tubing	Impact Fatigue	No Longer Operational, Poor Appearance	Overstressing	9	Limit Length and Check Welds
UCA Pivot Tubing	Impact Fracture	No Longer Operational, Poor Appearance	Impact Loading	9	Limit Length and Check Welds
UCA Long Member(s)	Impact Fatigue	No Longer Operational, Poor Appearance	Overstressing	18	Limit Torsion on UCA and Check Welds
UCA Long Member(s)	Impact Deformation	No Longer Operational, Poor Appearance	Impact Loading	18	Limit Torsion on UCA and Check Welds
UCA Shock Mount	Impact Fatigue	No Longer Operational, Poor Appearance	Overstressing	30	Strengthen mount with addition weld/plates
UCA Shock Mount	Impact Fracture	No Longer Operational, Poor Appearance	Impact Loading	30	Strengthen mount with addition weld/plates
UCA Ball Joint Cup	Impact Fatigue	No Longer Operational, Poor Appearance	Overstressing	30	Orient properly relative to knuckle motion
UCA Ball Joint Cup	Impact Fracture	No Longer Operational, Poor Appearance	Impact Loading	30	Orient properly relative to knuckle motion

Failures

- Shoulder Bolts
- Welded Points
  - Ball Joint
  - Joined Members
- Tubing Lengths

Mitigation

- 3/8” Shoulder Bolts
- Run FEA, Verify Welds, Brace Welded Areas
- Keep Arms Compact, Brace Long Lengths

Design Validation – LCA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
LCA Shoulder Bolt	**Impact Fatigue**	Erratic Operation, Poor Appearance	Overstressing	30	Use 3/8" Shoulder Bolts
LCA Sholder Bolt	**Impact Fracture**	Erratic Operation, Poor Appearance	Impact Loading	30	Use 3/8" Shoulder Bolts
LCA Pivot Tubing	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	8	Limit Length and Check Welds
LCA Pivot Tubing	**Impact Fracture**	No Longer Operational, Poor Appearance	Impact Loading	8	Limit Length and Check Welds
LCA Long Member(s)	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	64	Raise ride height and check welds
LCA Long Member(s)	**Impact Deformation**	No Longer Operational, Poor Appearance	Impact Loading	64	Raise ride height and check welds
LCA Ball Joint Cup	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	30	Orient properly relative to knuckle motion
LCA Ball Joint Cup	**Impact Fracture**	No Longer Operational, Poor Appearance	Impact Loading	30	Orient properly relative to knuckle motion
LCA Bracing	**Impact Fatigue**	Flying Debris, Poor Appearance	Overstressing	15	Limit length and check welds
LCA Bracing	**Impact Fracture**	Flying Debris, Poor Appearance	Impact Loading	15	Limit length and check welds

Failures

- **Shoulder Bolts**
- **Welded Points**
  - **Ball Joint**
  - **Joined Members**
- **Tubing Lengths**

Mitigation

- **3/8” Shoulder Bolts**
- **Verify Welds, Run FEA, Brace Welded Areas**
- **Keep Arms Compact, Brace Long Lengths**
- **Raise Ride Height**

Design Validation – Knuckle

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
UCA Knuckle Shoulder Bolt	**Impact Fatigue**	Knuckle detatch from Control Arm	Overstressing	30	Increase Bolt Diameter to 3/8"
UCA Knuckle Shoulder Bolt	**Impact Fracture**	Knuckle detatch from Control Arm	Impact Loading	40	Increase Bolt Diameter to 3/8"
UCA Alignment Spacer	**Impact Fatigue**	Inconsistant Operation	Overstressing	8	Change material to steel from aluminum
UCA Alignment Spacer	**Impact Fracture**	Inconsistant Operation	Impact Loading	8	Change material to steel from aluminum
LCA Knuckle Shoulder Bolt	**Impact Fatigue**	Knuckle detatch from Control Arm	Overstressing	30	Increase Bolt Diameter to 3/8"
LCA Knuckle Shoulder Bolt	**Impact Fracture**	Knuckle detatch from Control Arm	Impact Loading	40	Increase Bolt Diameter to 3/8"
LCA Alignment Spacer	**Impact Fatigue**	Lower Suspension Effectivenenss	Overstressing	8	Change material to steel from aluminum
LCA Alignment Spacer	**Impact Fracture**	Lower Suspension Effectivenenss	Impact Loading	8	Change material to steel from aluminum
Tie Rod Shoulder Bolt	**impact fracture**	Knuckle detatch from Tie Rod	Overstressing	40	Increase Bolt Diameter to 3/8"
Tie Rod Shoulder Bolt	**impact fatigue**	Knuckle detatch from Tie Rod	Impact Loading	30	Increase Bolt Diameter to 3/8"
Tie Rod Bolt Spacer	**impact fatigue**	Lower Steering Effectiveness	Overstressing	12	Change material to steel from aluminum
Knuckle LCA Lower Mount	**Impact Deformation**	Knuckle detatch from Control Arm	Impact Loading	40	Increase material thickness to .5" from .3"
Knuckle LCA Lower Mount	**impact fatigue**	Knuckle detatch from Control Arm	Overstressing	40	Increase material thickness to .5" from .3"
Knuckle LCA Bolt Thread	**impact fatigue**	LCA Shoulder Bolt detatch from knuckle	Overstressing	54	Increase bolt thread to 3/8"x20
Knuckle LCA Bolt Thread	**impact fracture**	LCA Shoulder Bolt detatch from knuckle	Impact Loading	54	Increase bolt thread to 3/8"x20
Knuckle Tie Rod Mount Tab	**impact deformation**	Tie Rod detatch from knuckle	Impact Loading	40	Increase tab thickness to .3" from .2"
Knuckle Tie Rod Mount Tab	**Impact Fatigue**	Tie Rod detatch from knuckle	Overstressing	40	Increase tab thickness to .3" from .2"
Knuckle UCA Extension	**Impact Deformation**	UCA Detach from knuckle	Impact Loading	50	Increase CX area to decrease bending moment
Knuckle Bearing Bore	**Impact Deformation**	Lower drive effectiveness	Impact Loading	3	Harden inner surface of bearing bore
Knuckle Bearing seperation	**Impact deformation**	lower drive/steering effectiveness	Impact Loading	4	Increase thickness of bearing separation

Failures

- Knuckle LCA Thread pullout
  - Thread deformation
- Knuckle UCA Mount
  - Mount deformation/fracture

Mitigation

- Increase bolt thread size
- Increase material at point of max bending moment

Design Validation – Steering

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Knuckle Connection	**Impact Fatigue**	Broken Knuckle connection to steering arm	Overstressing	20	Conduct FEA on Knuckle tab
Knuckle Connection	**Impact Fracture**	Broken Knuckle connection to steering arm	Impact Loading	40	Conduct FEA on Knuckle tab
Steering Arm Carbon Tubing	**Impact Fatigue**	Broken Steering arm hindering steering capabilities	Overstressing	16	Limit Length
Steering Arm Carbon Tubing	**Impact Fracture**	Broken Steering arm hindering steering capabilities	Impact Loading	16	Limit Length and check Clearence and skid protection
Steering Arm Tubing Insert	**Sheer Strength**	Threaded insert pulls out of carbon steering arm	Overstressing through Tension	16	Use of Epoxy to increase tensile strength
Steering Arm Tubing Insert	**Impact Deformati on**	Threaded insert damaged from impact	Impact Loading	16	Check clearance and impact protection
Steering Column	**Torsion**	Breaking carbon steering column	Overstressing through Torsion	16	Recommend using a 16mm OD x 14mm ID tube
Steering Column	**Sheer of Bolt**	Bad steering performance and broken column	Overstressing of bolt	16	Epoxy spline insert to tube in addition to using bolt
Rack and Pinion	**Contact Wear**	Poor Steering Performance	Gradual wear of the rack and pinion assembly	60	Use of brass bushings with lubrication

Failures

- Rack and Pinion Gradual Wear effecting steering performance

Mitigation

- Properly use lubricant to ensure wear is minimal within the gearbox.

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Design Validation – Testing Procedure

Testing will be completed in a variety of ways. Due to the expensive nature of the knuckle and other components within the front-end assembly, the team will use both online FEA Modeling as well as physical testing.

Control Arm Construction

- The control arms have been tested thoroughly by Ansys FEA Software
- To pass tech inspection, welds must be certified thus proving the construction of the control arm

Steering System

- The steering system will be tested once the car is constructed with digital angle gauges and the turning radius of the vehicle will be tested. Design testing was already completed thoroughly in Lotus Shark Software.
- The tensile strength of the tire arms may be tested to ensure that the threaded insert mate adequately with the carbon tubing used.

Knuckle Construction

- The knuckle has been tested thoroughly with FEA Ansys analysis.
- The knuckle will be tested with strain gauges once constructed.

Scheduling Moving Forward

Date	Deliverable
11/17/23	Prototype 1 Completed
11/20/23	Last day to register for Gorman Competition ✓
11/24/23	Report 2
	Final Cad in SolidWorks completed in addition to Bill of Materials
11/27/23	Second Prototype Demonstration
12/1/23	Second Prototype Demonstration
12/2/23	Begin Welding Frame
3/20/24	Car is functioning and drivable
4/20/24	Car Prepped for Tech Inspections
4/25-28/24	Gorman Competition

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Front End Budget

	Category	Relevant Items	Approximated Cost
1	**Vehicle Expenses**	Brake System Control Arm Materials Rod-ends/Ball Joints Shock Rebuild Knuckle Material/Manufacturing **Estimated Total**	$1,000 $120 $50 $126 $1600 **$2649**
2	**Spare Parts**	Rod-ends, Bushings, Welding supplies, Hardware	$500
3	**Competition Expenses** Front Sub-team	Registration, travel (hotel rooms, vehicle rentals, gas, etc.)	$1,125
4	**Contingency (5%)**	Unpredicted Expenses	$400
		Total	**$4,674**

No Expenses Accumulated

All **prototyping** used **existing shop materials** or was cheap enough to be **personally funded/fabricated!**

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Fundraising & Sponsors Update

VROOM Engineering & Manufacturing, Inc — Tucson, Arizona USA: Free material and laser cutting for the construction of the vehicle.

GORE: Monetary Donation

Monster: Beverage Donation

Industrial Metal Supply Company: Metal Stock for Primary Member construction Donation

NovaKinetics Aerosystems / Kinetic Defense: Carbon Construction for Components

TMS Titanium: Donation of Titanium Stock and Hardware

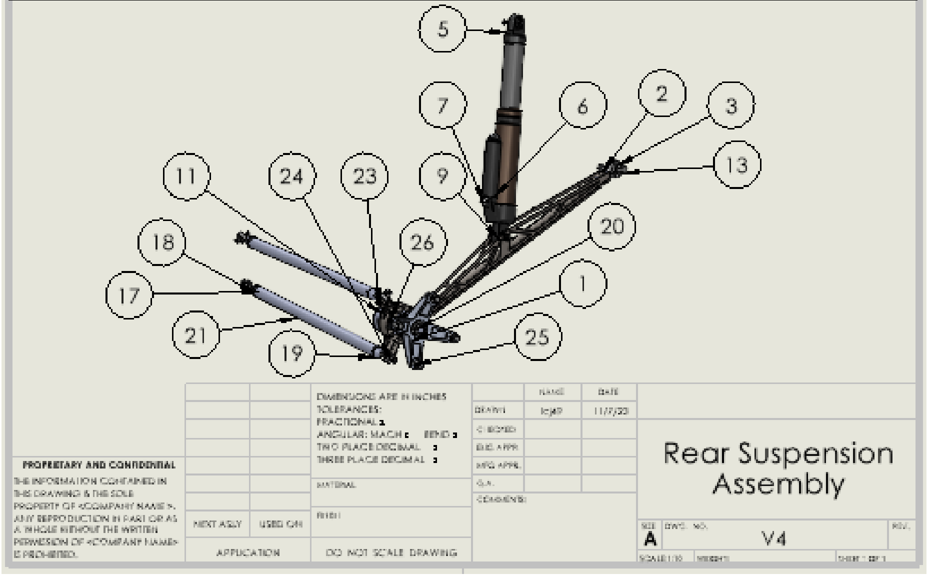
Cognito: Monetary Donation

Rear Team

Seth DeLuca, Joey Barta, Lars Jensen

Design Description – Rear Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Suspension Geometry Long Link		1
2	Trailing Link Rod End Insert		1
3	60645K171	Ball Joint Rod End	1
4	Shock Spacer Bottom		2
5	bottom cylinder		1
6	top cylinder		1
7	cap		2
8	bearing		2
9	91271A646	Alloy-Steel 12-Point Screw	2
10	92018A111	High-Strength Steel Nylon-Insert Flange Locknut	1
11	CV Axle End		1
12	wheel (1)		1
13	91271A802	Alloy-Steel 12-Point Screw	1
14	skf_bearing_6006_2_01		2
15	skf_bearing_6006_2_02		2
16	skf_bearing_6006_2_03		2
17	carbon link steel insert V1		4
18	60645K141	Ball Joint Rod End	4
19	steel pipe camber link (1Dx0.035t)		2
20	95462A538	Medium-Strength Steel Hex Nut	1
21	Part2^Rear Suspension Assemby V3		1
22	Wheel Spacer		1
23	91271A641	Alloy-Steel 12-Point Screw	4
24	90630A155	High-Strength Steel Nylon-Insert Locknut	2
25	91271A712	Alloy-Steel 12-Point Screw	4
26	HubV3		1



Sub Systems:

- Trailing link
  - Rod end and shock mount location
- Camber Links
- Hub
  - Wheels spacers
- CV Axle/Knuckle interface
  - Double ball bearing compression mechanism

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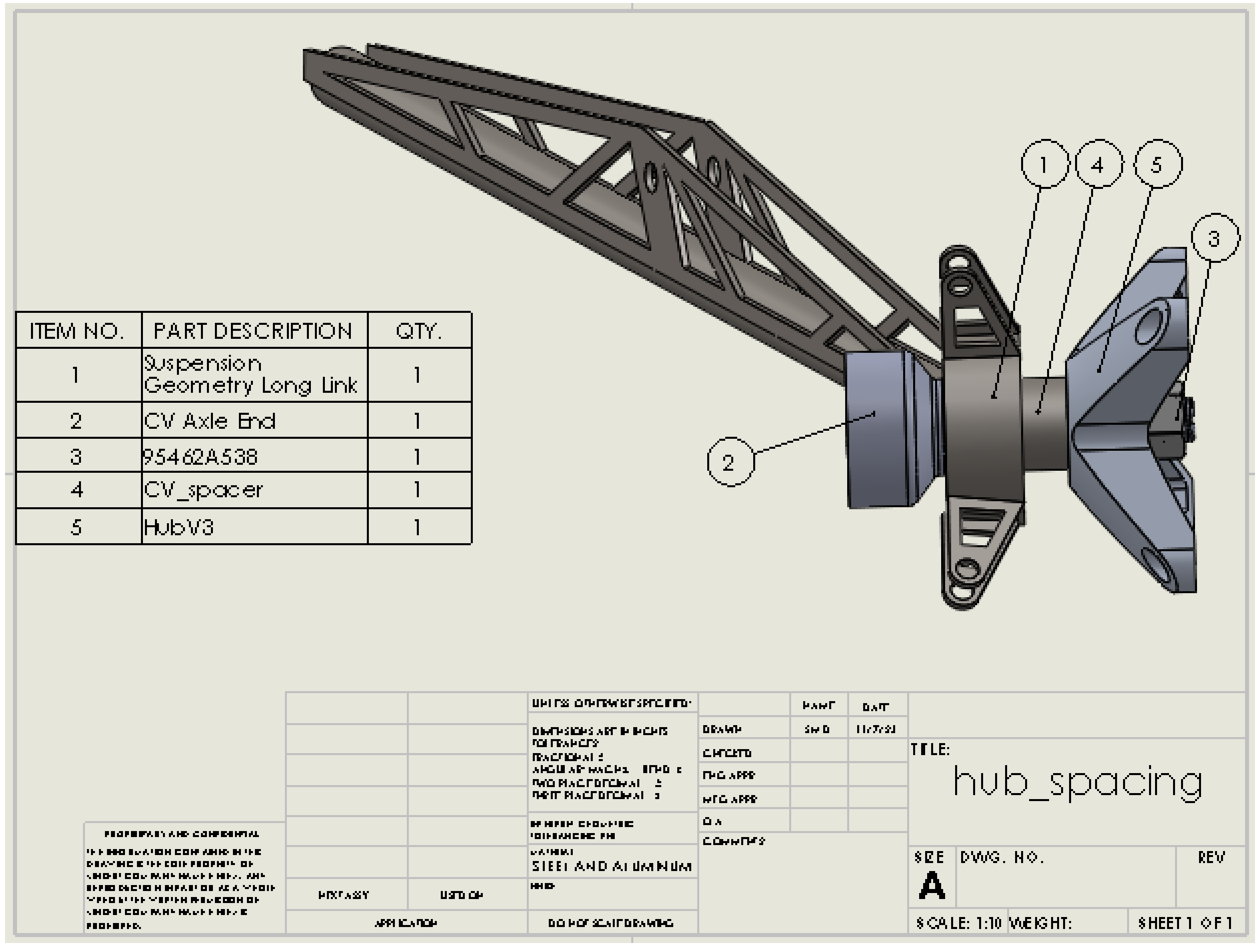
Design Description – Rear CV End Spacing

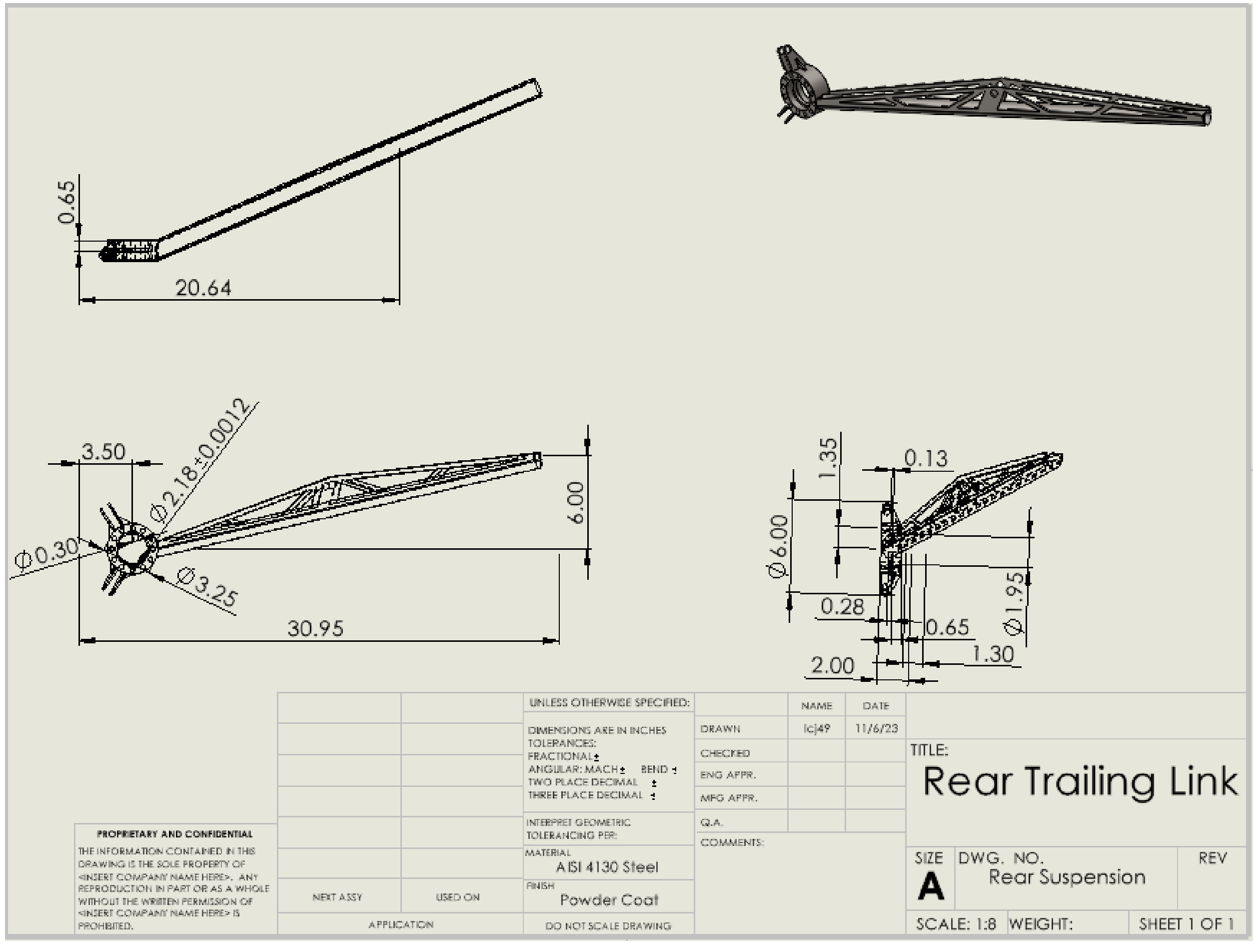


ITEM NO.	PART DESCRIPTION	QTY.
1	Suspension Geometry Long Link	1
2	CV Axle End	1
3	95462A538	1
4	CV_spacer	1
5	HubV3	1

Sub Systems:

- **Hub**
  - **Wheel mounts**
- **Knuckle**
  - **Houses two bearings for the axle end**
- **CV spacer**
  - **Allows for no slop on the axle end.**
- **-538 bolt**
  - **Tightens all parts together on axle**

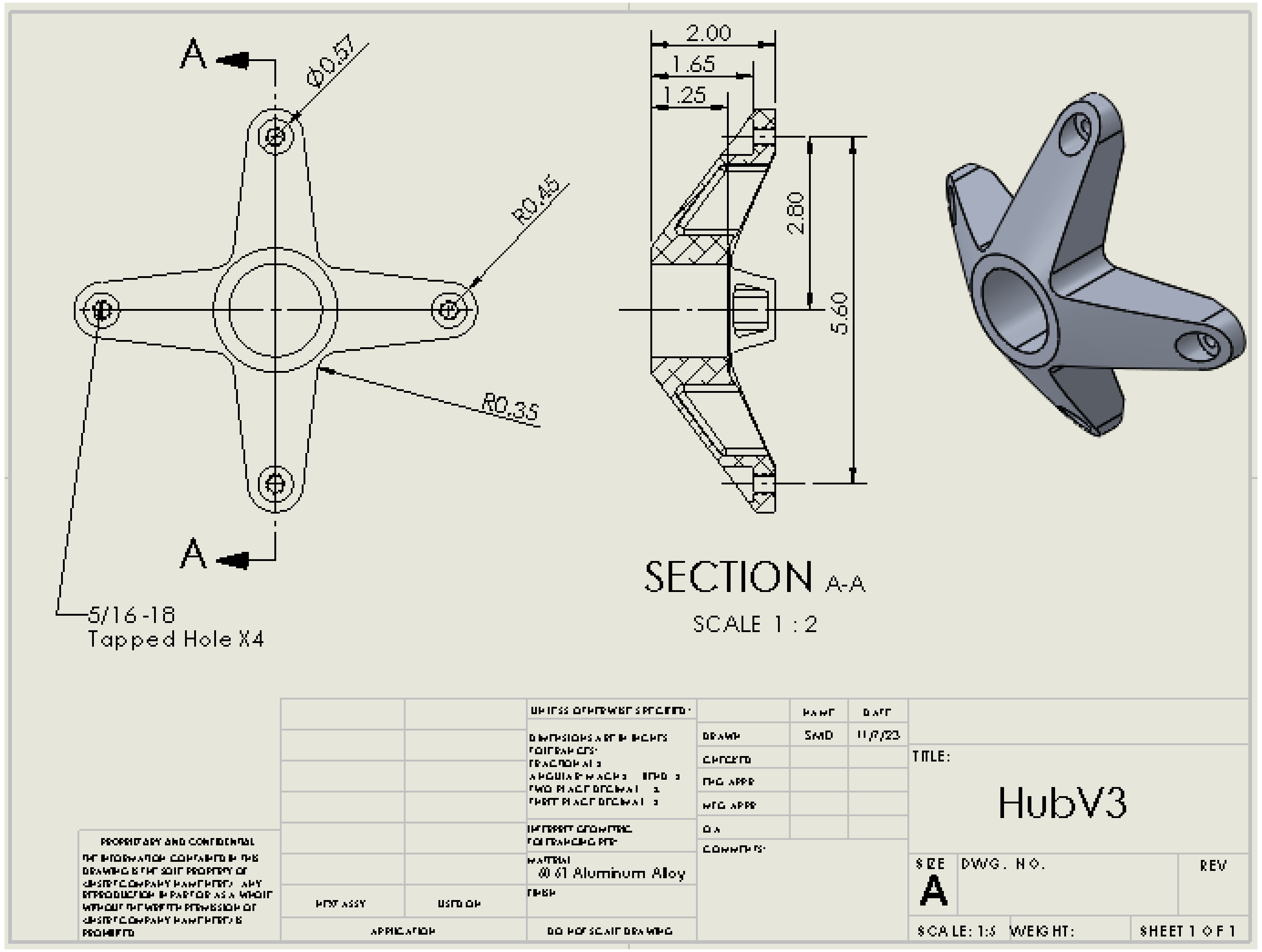
Design Description – Trailing Link



Important Features:

- Drilled out knuckle to decrease weight
- Camber links mounts reinforced with ribs
- Trailing link reinforced with laser cut steel plate

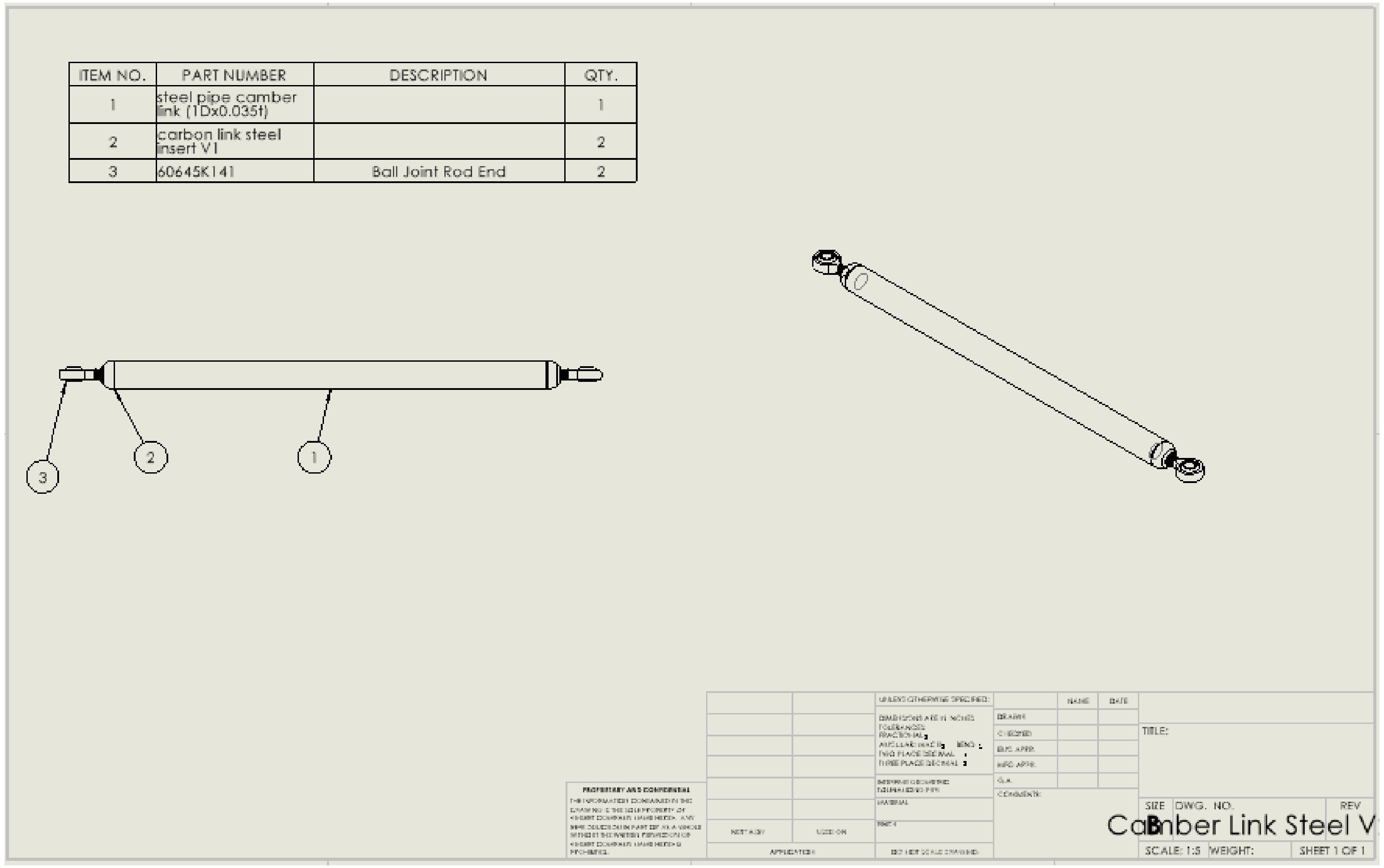
Design Description – Hub



Important Features:

- Shelled arms to eliminate unneeded material while maintaining integrity
- Threaded holes, so just have tighten the nuts
- Made of 6061 Aluminum Alloy

Design Description – Camber Links



Important Features:

- Tubing made of Carbon Fiber
- Inserts made from 6061 Aluminum
- Rod Ends made from stainless steel
- 2nd iteration of design

Design Requirements - QFD

System QFD

Project:	Lumberjack Motorsports SAE Baja
Date:	9/19/23
	Input areas are in yellow

	Decrease weight	Increase strength	Increase rearward axle path	Increase linkage radii	Increase ground clearance	Vehicle width	Decrease CV axle angle
Decrease weight							
Increase strength	-3						
Increase rearward axle path							
Increase linkage radii	-1						
Increase ground clearance	-6	3	1				
Vehicle width	1	3		6	2		
Decrease CV axle angle		3	-2	1			

Legend	
A	CWRUM
B	RIOT Baja
C	ETS BAJA

Customer Requirements	Customer Weights	Decrease weight	Increase strength	increaseward rear axle path	increase linkage radii	Increase ground clearance	Vehicle Width	decrease CV axle angle	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		Technical Requirements							**Customer Opinion Survey**				
Tunability	2	2	3	8	7	3	2	7	C	A			B
Servicability	2	2	6						A		BC		
Reliability	5	3	9	3	2			7			A	B	C
Ease of manufacturing	3	6	7	1	1		1	1		C	A		B
Low cost	5	9	9	3	3		1	3			A	C	B
Maximum Traction	2	7		8	8		3	1				B	AC
Maneuverability	4	5	1	8	6	5	7	1				AB	C
Technical Requirement Units		lb	Psi	in	in	in	in	degrees					
Target Requirements		<50	NA	<1	20	>8	<64	180					
Absolute Technical Importance		120	133	97	82	26	46	73					
Relative Technical Importance		2	1	3	4	7	6	5					

ER to ER

Positive Correlation

- Vehicle width & linkage radii

Inverse Correlation

- Increasing ground clearance & weight

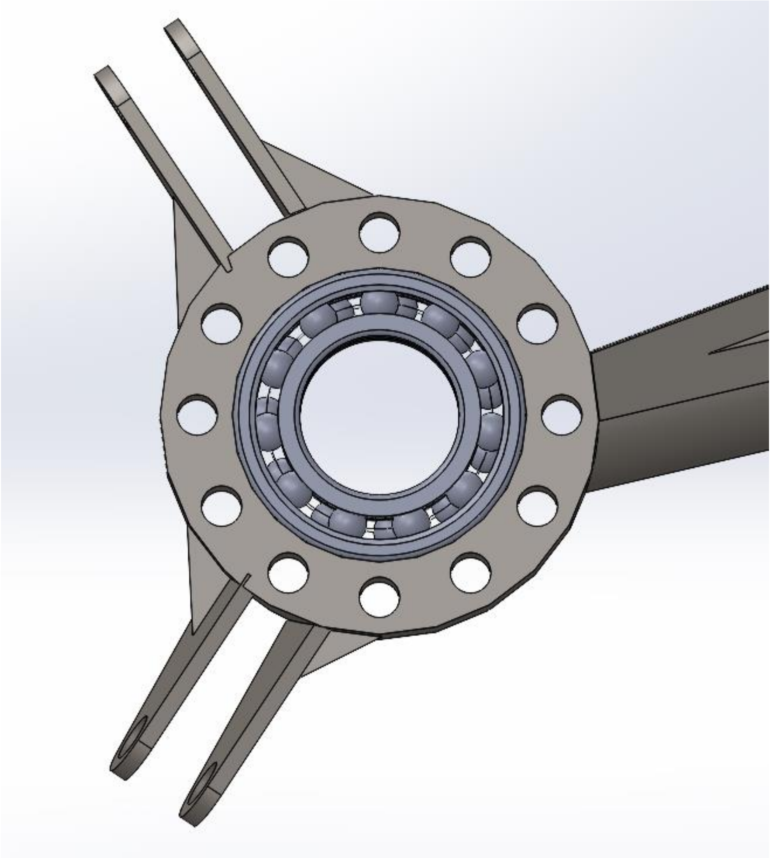
CR to ER

Strong Correlations

- Reliability & Decrease CV axle angle, Increase Strength
- Low cost & decrease weight, Increase strength

Engineering Calculations - Lars

Rear Knuckle Bearings



Two SKF 6006 Deep Groove Ball Bearings

$$Outside\ Bearing\ Diameter = D = 2.165\ in$$

Force $Fit \rightarrow H7/u6 \rightarrow IT7 \rightarrow \Delta D = 0.0012\ in$

$$D_{max} = D + \Delta D = 2.165\ in + 0.0012\ in = \mathbf{2.1662\ in}$$

$$D_{min} = D = \mathbf{2.165\ in}$$

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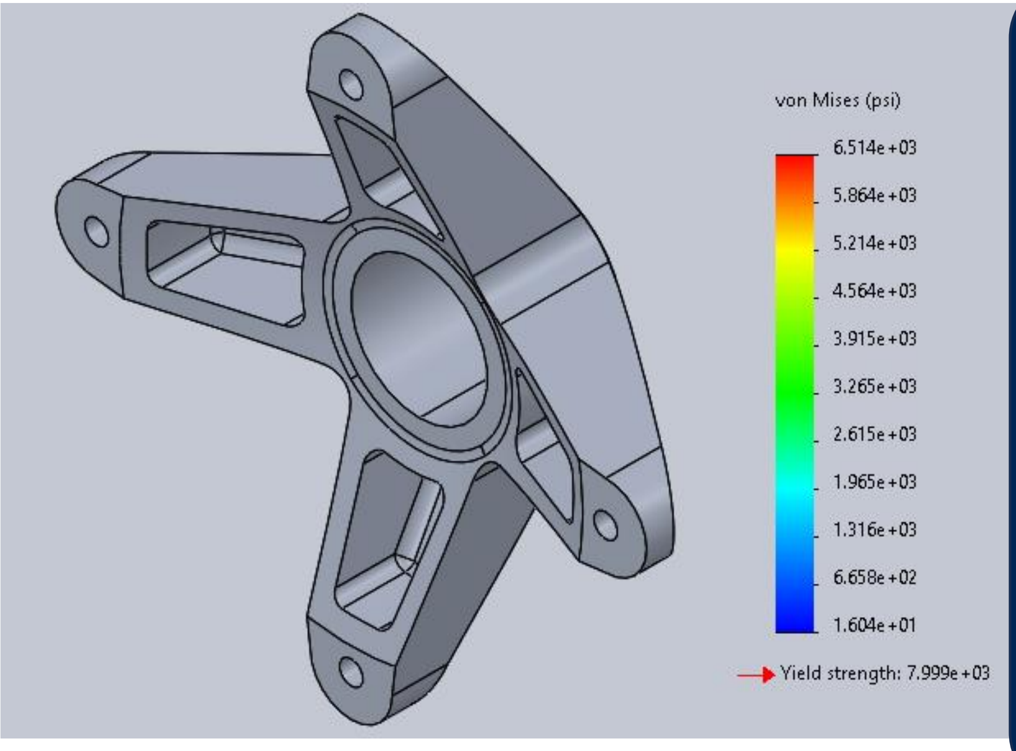
Engineering Calculations - Seth

Hub



Results generated from SolidWorks

- After performing a simple FEA simulation on the Hub using the SolidWorks simulation add-in, a calculated factor of safety of 1.228 was determined at the point highest stresses (which were where the fixtures were placed)
- This study showed there were 2 points near the fixed points that were having high stress. Another iteration can be ran eliminating more material.

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Engineering Calculations - Joey

Carbon Fiber Rod

Assumptions and B.C.

$$R_o = 0.31495in$$
$$R_i = 0.2362in$$
$$L = 16.13\ in$$
$$L_{eff} = L \times k = L$$
$$V = 2.1994\ in^3$$
$$A_{cs} = 0.136355\ in^2$$
$$I_z = \left(\frac{m}{2}\right) \times \left(R_o^2 + R_i^2\right) = 0.010191\ in^4$$
$$R = 0.27338$$

$$E = 50{,}763{,}199.98\ psi$$
$$\sigma_y = 1{,}547 - 467{,}000\ psi$$
$$\rho = 0.0614 \frac{lb}{in^3}$$
$$m = 0.131510\ lb$$
$$Pinned - Pinned \gg k = 1$$

$$If\ S < S_{crit}\ use\ Johnsons\ Formula$$

$$Johnsons\ Formula = \sigma_y \times A_{cs}\left[1 - \left(\frac{\sigma_y}{4\pi^2 E}\right)\left(\frac{LE}{R}\right)^2\right]$$

$$Eulers\ Formula = \frac{\pi^2 EI}{L_{eff}^2}$$

Results

- $\boldsymbol{F_{crit} = 1{,}547\ lbf \gg 26{,}257\ lbf}$
- With an assumed minimum σ_y of 11,600 psi, the minimum F_{crit} is 1,547 lbf. The significance of this force will be explained in the Design Validation Slide.

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Design Validation – Trailing Link

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Rod End	**Impact Fatigue**	Improper Geometry, Suspension Binding	Impact Loading	42	Use 5/8" Rod End
Rod End	**Abrasive Wear**	Improper Geometry, Suspension Binding	Poor Maintenance	42	Use 5/8" Rod End
Rod End Hardware	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	24	Use 5/8" Hardware
Rod End Hardware	**Impact Fracture**	No Longer Operational, Flying Debris	Impact Loading	24	Use 5/8" Hardware
Steel Tubing	**Impact Fatigue**	Erratic Operation, Poor Appearance	Overstressing	8	Reinforce tubing with steel plate
Steel Tubing	**Impact Deformation**	Improper Geometry, Suspension Binding	Impact Loading	8	Reinforce tubing with steel plate
Side Support Steel Plate	**Impact Fatigue**	No Longer Operational, Erratic Operation	Assembly Errors	96	Maximize welding surface and use cross members
Side Support Steel Plate	**Impact Fracture**	No Longer Operational, Flying Debris	Impact Loading	96	Maximize welding surface and use cross members
Shock Hardware	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	12	Choose higher grade hardware
Shock Hardware	**Impact Fracture**	No Longer Operational, Flying Debris	Impact Loading	12	Choose higher grade hardware

Failures

- Rod Ends
- Hardware
  - Rod Ends
  - Shock
- Weld Points

Mitigation

- 5/8” Hardware
- Maximize welding surface area
- Add cross members to welded areas

Design Validation – Hub/CV/Spacer/Wheel Mounts

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
CV Axle End	**Impact Fatigue**	Erratic operation, Poor performance	Overstressing	0	Will not happen.
CV spline	**Slipping**	Loss of power transferred to the wheel	Too high of tolerance	15	Ensure tight fit for hub and spline
Bolts from hub - wheel	**Shearing**	Flying Debris/ No longer operational	Material selection	14	Choose high quality hardware
Nuts	**Stripping**	Flying debris/ No longer operational	Assembly error	10	Choose high quality hardware
Arms to wheel	**Impact Deformation**	Flying debris/ No longer operational	Impact Loading/ Overstressing	30	Choose high quality hardware
Steel Hex Nut	**Stripping**	Flying debris/ No longer operational	Overstressing/ Assembly Error	30	Choose high quality hardware
CV Spacer	**Impact fatigue**	Moving parts on CV/ Poor performance	Overstressing	24	Use steel instead of aluminum

Failures

- **Hub spline**
- **CV Hardware**
- **Hub**
  - **Arms**
  - **Hardware**

Mitigation

- **Strong material selection**
- **Eliminating wiggle in the spacer**
- **Ensure a tight fit for hub spline**

Design Validation – Camber Links

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Carbon Fiber tube	**Impact Fracture**	Detrimental Failure of Rear Suspension	Impact Loading	45	Extensive Testing Under Different Loads
Aluminum Composite threaded Insert	**Surface Fracture**	Detrimental Failure of Rear Suspension	Overstressing	12	Extensive Testing Under Different Loads
Steel Tubing	**Impact Fatigue**	Difficult and Unpredictive Performance	Impact Loading	36	Strong Welds
Rod End	**Impact Wear**	Difficult and Unpredictive Performance	Impact Loading/Improper Maintenence	54	Proper Lubrication
Black-Oxide Screws	**Impact Fatigue**	Difficult and Unpredictive Performance	Overstressing	30	High Diameter, Small Pitch Screws
Titanium Screws	**Impact Fatigue**	Difficult and Unpredictive Performance	Overstressing	45	High Diameter, Small Pitch Screws
High Strength Glue	**Surface Fracture**	Detrimental Failure of Rear Suspension	Impact Loading	36	Extensive Testing Under Different Loads

Failures

- **Carbon Fiber Links**
  - **Carbon Fiber Tube**
  - **High Strength Glue**
- **Rod Ends**

Mitigation

- **Testing Both Steel and CF Rods under High Stress**
- **Maintenance**

Design Validation – Knuckle

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Steel Round Bar	**Impact Fatigue**	Erratic Operation, Poor Appearance	Overstressing	42	Maintain adequate amount of support material
Steel Round Bar	**Impact Fracture**	No Longer Operational, Flying Debris	Impact Loading	42	Maintain adequate amount of support material
Camber Link Mounts	**High-Cycle Fatigue**	Erratic Operation, Poor Appearance	Overstressing	8	Maximize welding surface
Camber Link Mounts	**Buckling**	No Longer Operational, Flying Debris	Overstressing	8	Maximize welding surface
Camber Link Hardware	**Impact Fatigue**	No Longer Operational, Poor Appearance	Overstressing	6	Choose high quality hardware
Camber Link Hardware	**Corrosion Fatigue**	Erratic Operation, Poor Appearance	Poor Maintenance	6	Choose high quality hardware
CV Bearings	**High-Cycle Fatigue**	No Longer Operational, Flying Debris	Impact Loading	24	Use oversized single roller bearings
CV Bearings	**Abrasive Wear**	Erratic Operation, Poor Appearance	Poor Maintenance	24	Use oversized single roller bearings
Trailing Link Weld	**Impact Fatigue**	Erratic Operation, Poor Appearance	Overstressing	18	Reinforce contact area with additional steel plate
Trailing Link Weld	**Impact Fracture**	Flying Debris, No Longer Operational	Impact Loading	18	Reinforce contact area with additional steel plate

Failures

- **Steel Round Bar**
- **Welded Points**
  - **Camber Mounts**
  - **Trailing Link**
- **Hardware**

Mitigation

- **Don’t cut away too much material**
- **Reinforce weld points**
- **Choose corrosive resistant hardware**

Design Validation – Testing Procedure

Trailing Link

- The welded trailing links will be placed in a jig with a hydraulic press applying vertical force to test for deflection and failure along the link.
- Strain gauges will be used during this testing.

CV End Spacing

- The CV spacing was tested by prototyping the system as it currently stands. This will reinforce the teams' design concept and find areas the team has not thought about entirely.

Camber Links

- A CF camber link tube will be placed in a jig with a hydraulic press applying a baseline force of 1,547 lbf.
- More realistic testing with the link installed will be carried out through 'crash testing' to mimic what the link will undergo at the track.

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Rear End Budget

	Category	Relevant Items	Approximated Cost
1	**Vehicle Expenses**	Suspension System Drive System Prototyping **Estimated Total**	$410 $850 $50 **$1310**
2	**Spare Parts**	Camber links, rode ends, cv axles, hubs	$320
3	**Competition Expenses** Front Sub-team	Registration, travel (hotel rooms, vehicle rentals, gas, etc.)	$1,125
4	**Contingency (5%)**	Unpredicted Expenses	$138
		Total	**$2893**

No Expenses Accumulated

All **prototyping** used **existing shop materials** or was cheap enough to be **personally funded/fabricated!**

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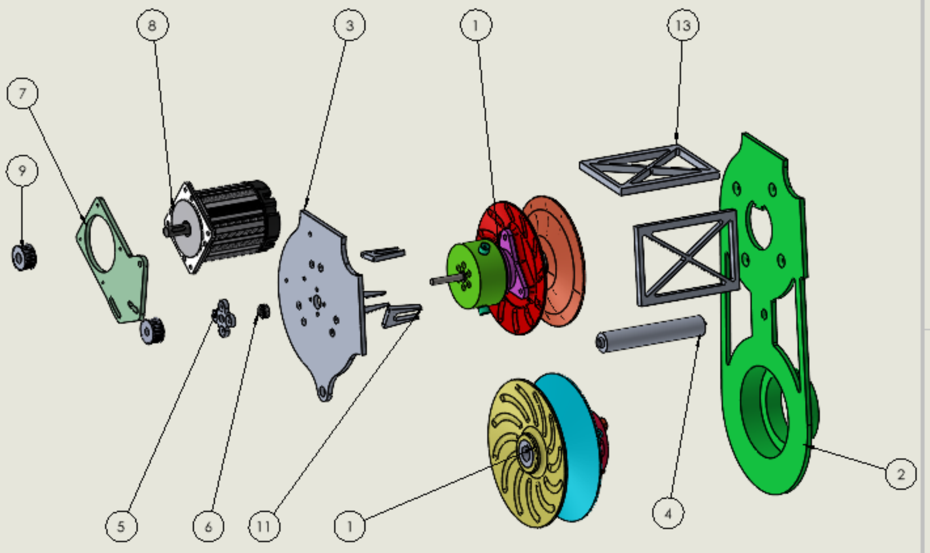
Drivetrain Team

Henry Van Zuyle, Donovan Parker, Ryan Fitzpatrick, Jarett Berger

Design Description - ECVT

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	cvt ccombined ass		1
2	20230926 cvt backplate		1
3	20231003 control motor mount plate		1
4	20231003 control motor mount standoffs		1
5	20231003 lead screw bearing mount		1
6	60715K111	One-Piece Steel Thrust Ball Bearing	1
7	20231005 motor mount plate		1
8	M-343x		1
9	20231005 ecvt control pulley	motor	1
10	20231005 ecvt control pulley		1
11	20231005 nut flange forks		3
12	1460T11	Threaded Black-Oxide Steel Track Roller, Flat	3
13	20231018 square plate standoff		2

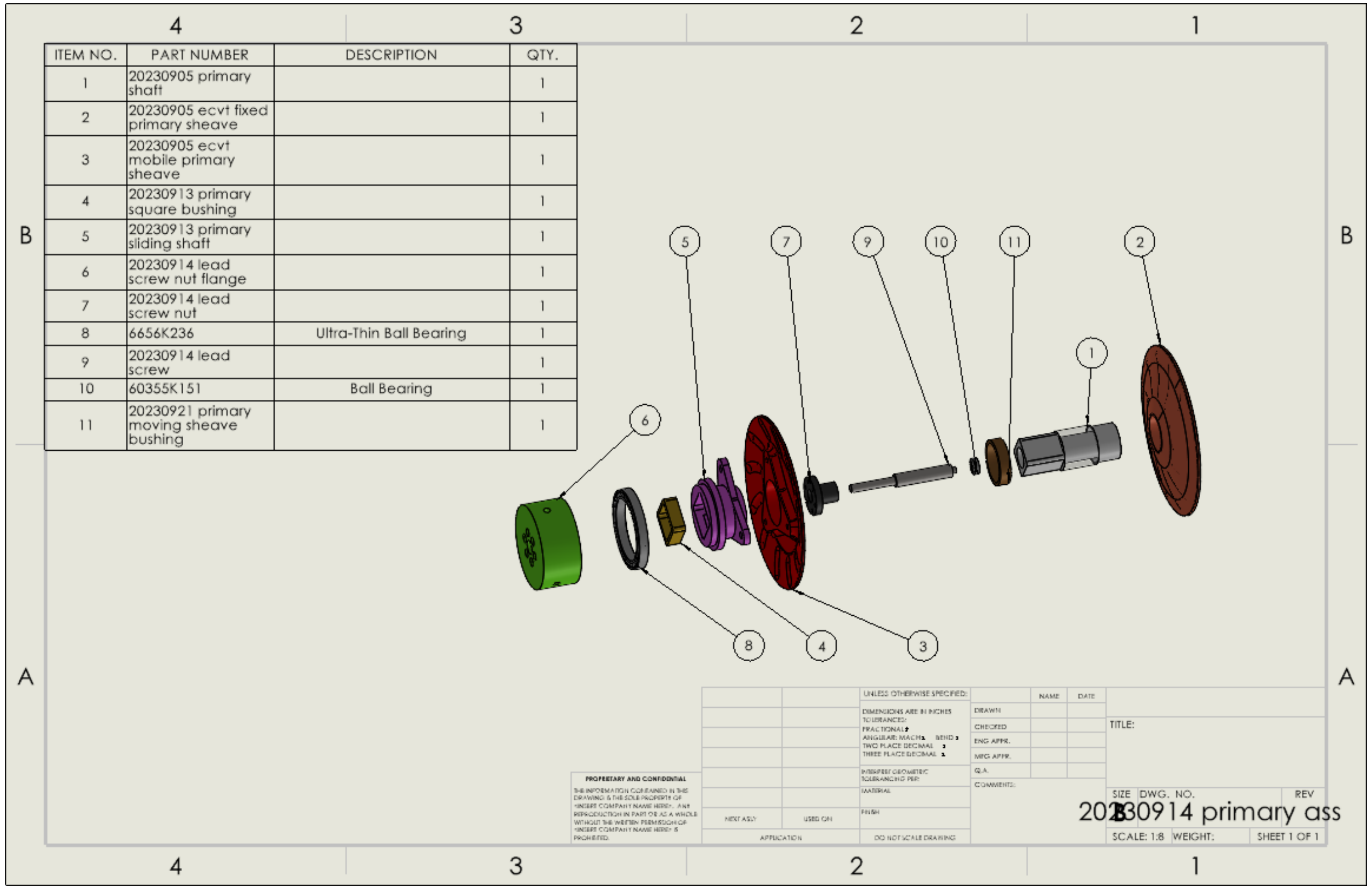


TITLE:

SIZE B DWG. NO. cvt motor ass REV

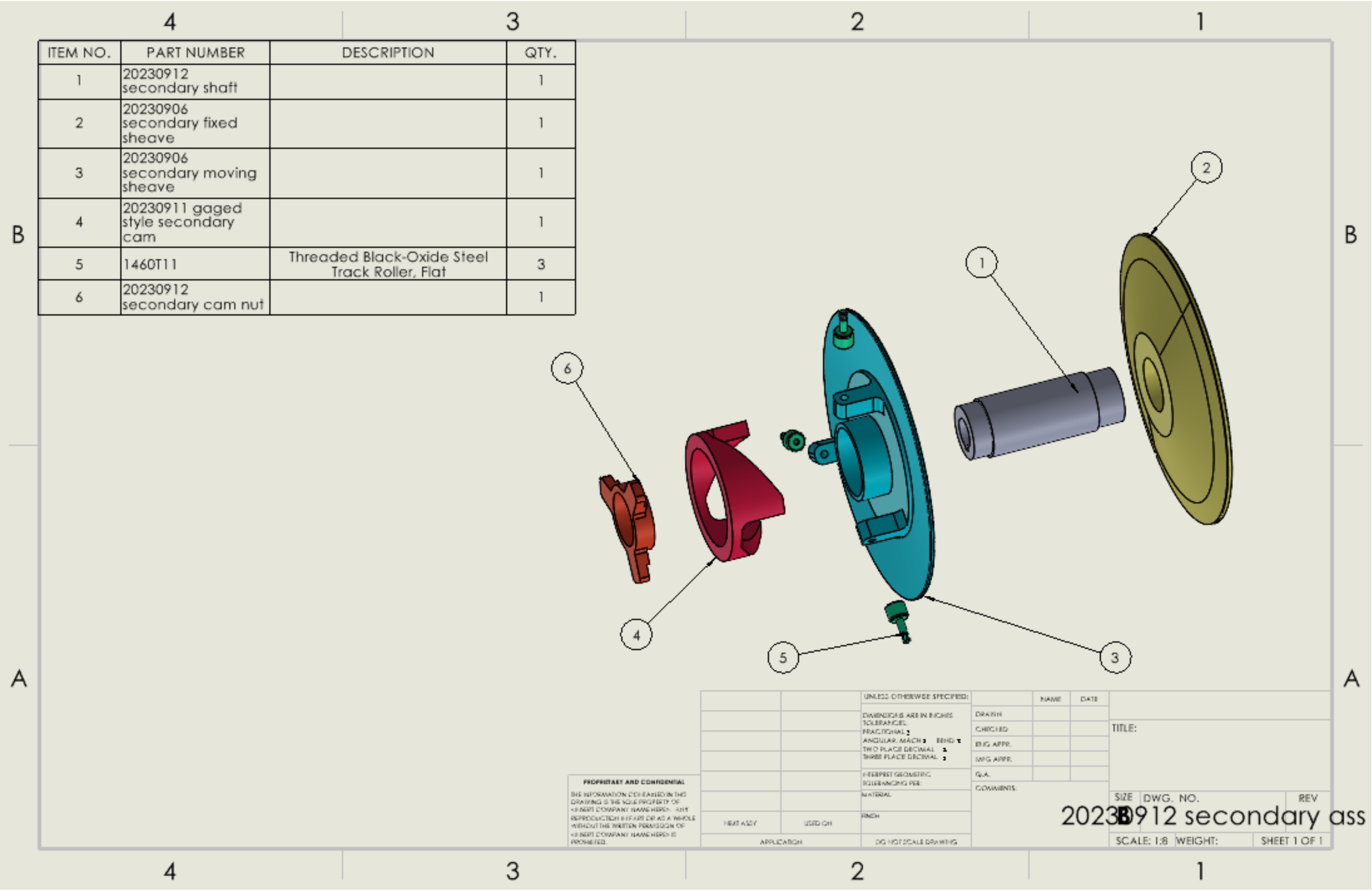
SCALE: 1:12 WEIGHT: SHEET 1 OF 1

Design Description - ECVT

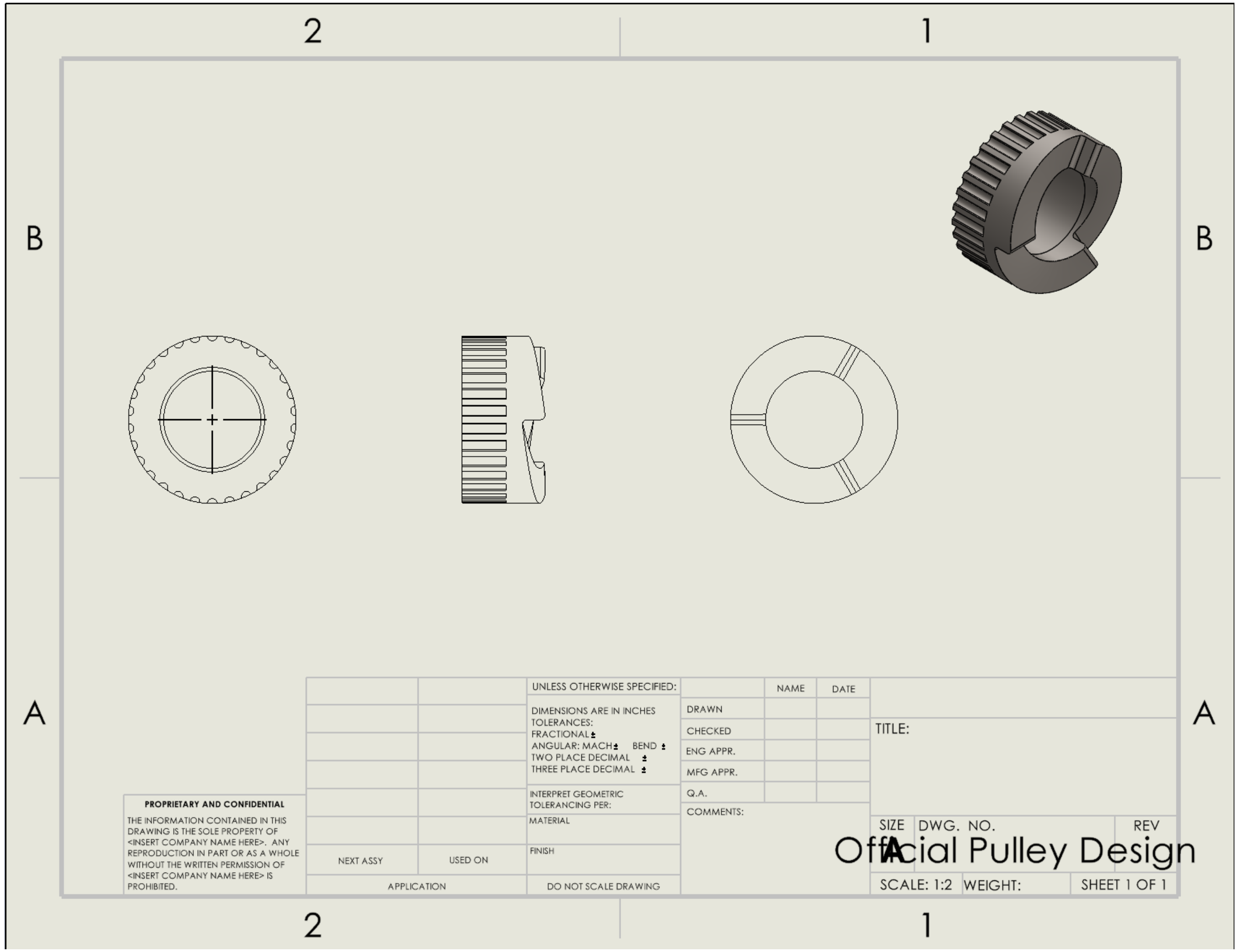


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20230905 primary shaft		1
2	20230905 ecvt fixed primary sheave		1
3	20230905 ecvt mobile primary sheave		1
4	20230913 primary square bushing		1
5	20230913 primary sliding shaft		1
6	20230914 lead screw nut flange		1
7	20230914 lead screw nut		1
8	6656K236	Ultra-Thin Ball Bearing	1
9	20230914 lead screw		1
10	60355K151	Ball Bearing	1
11	20230921 primary moving sheave bushing		1

Design Description - ECVT



Design Description



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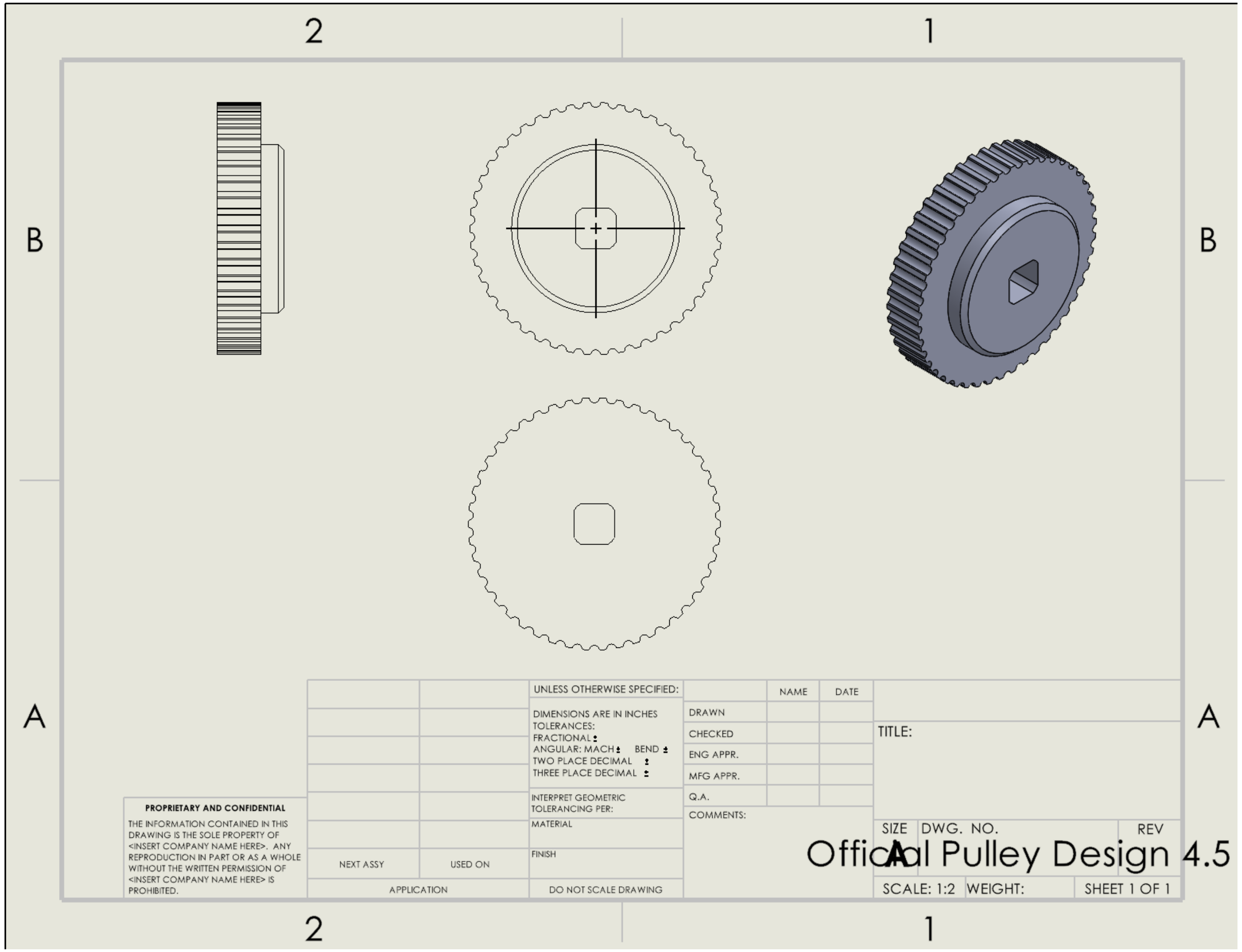

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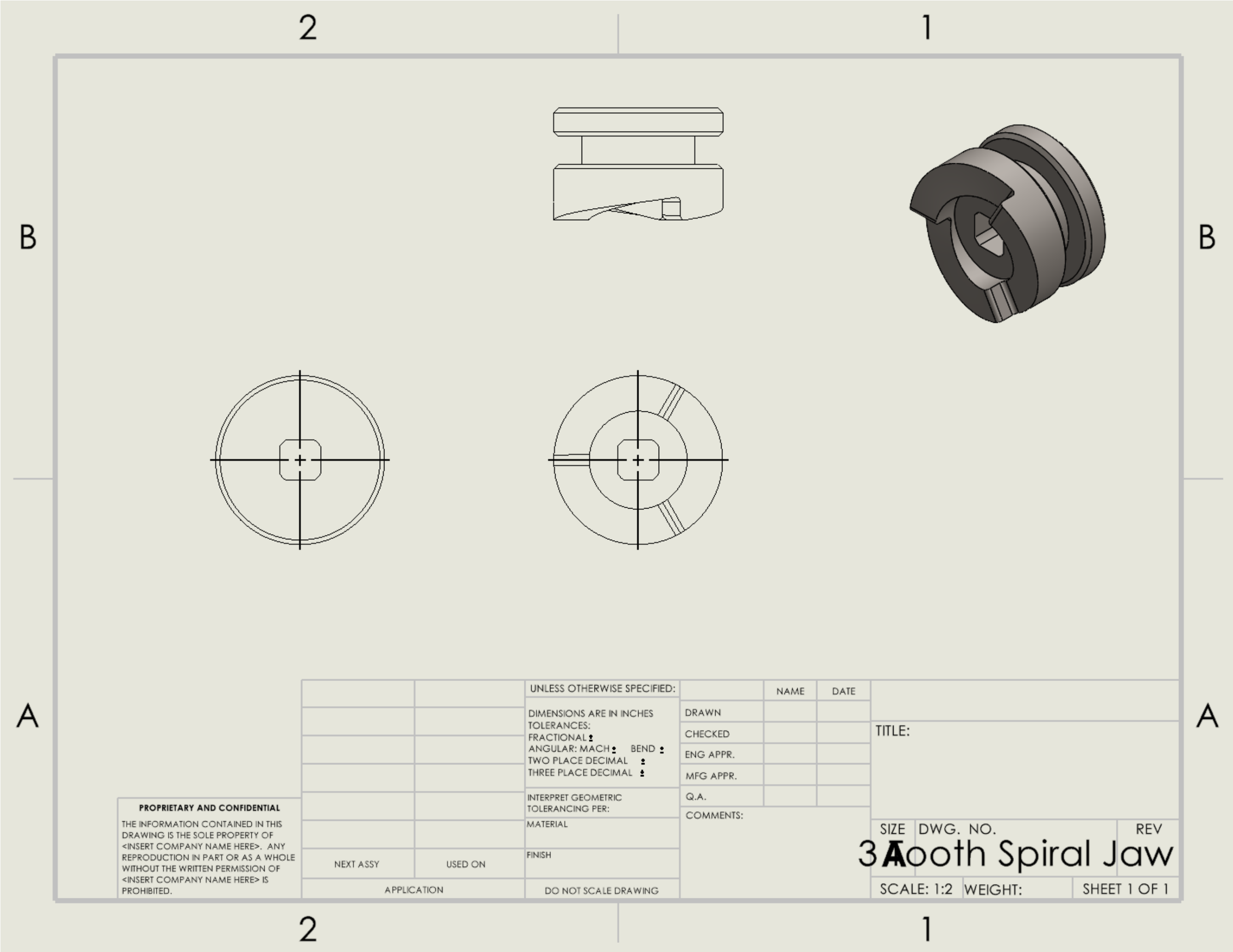
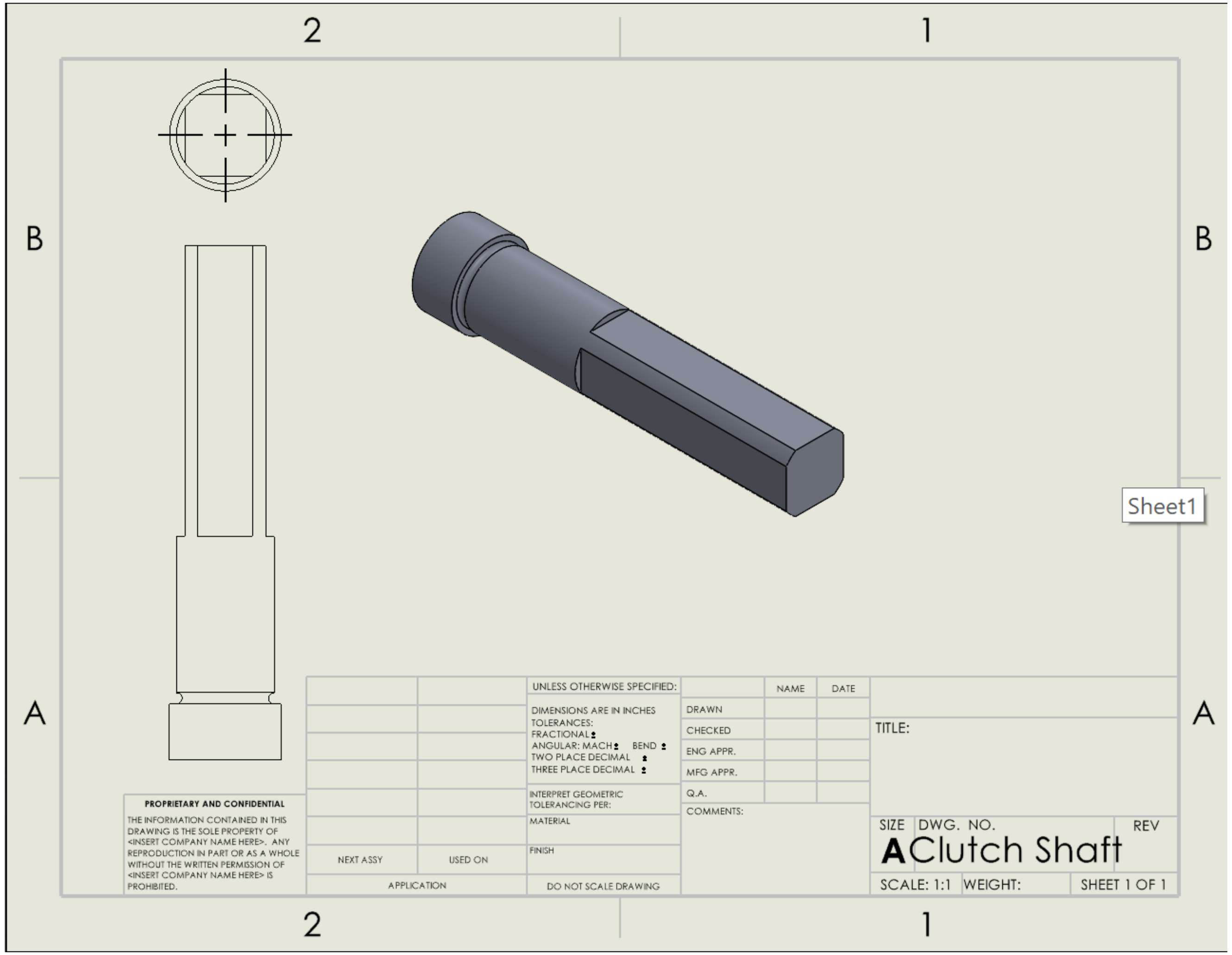
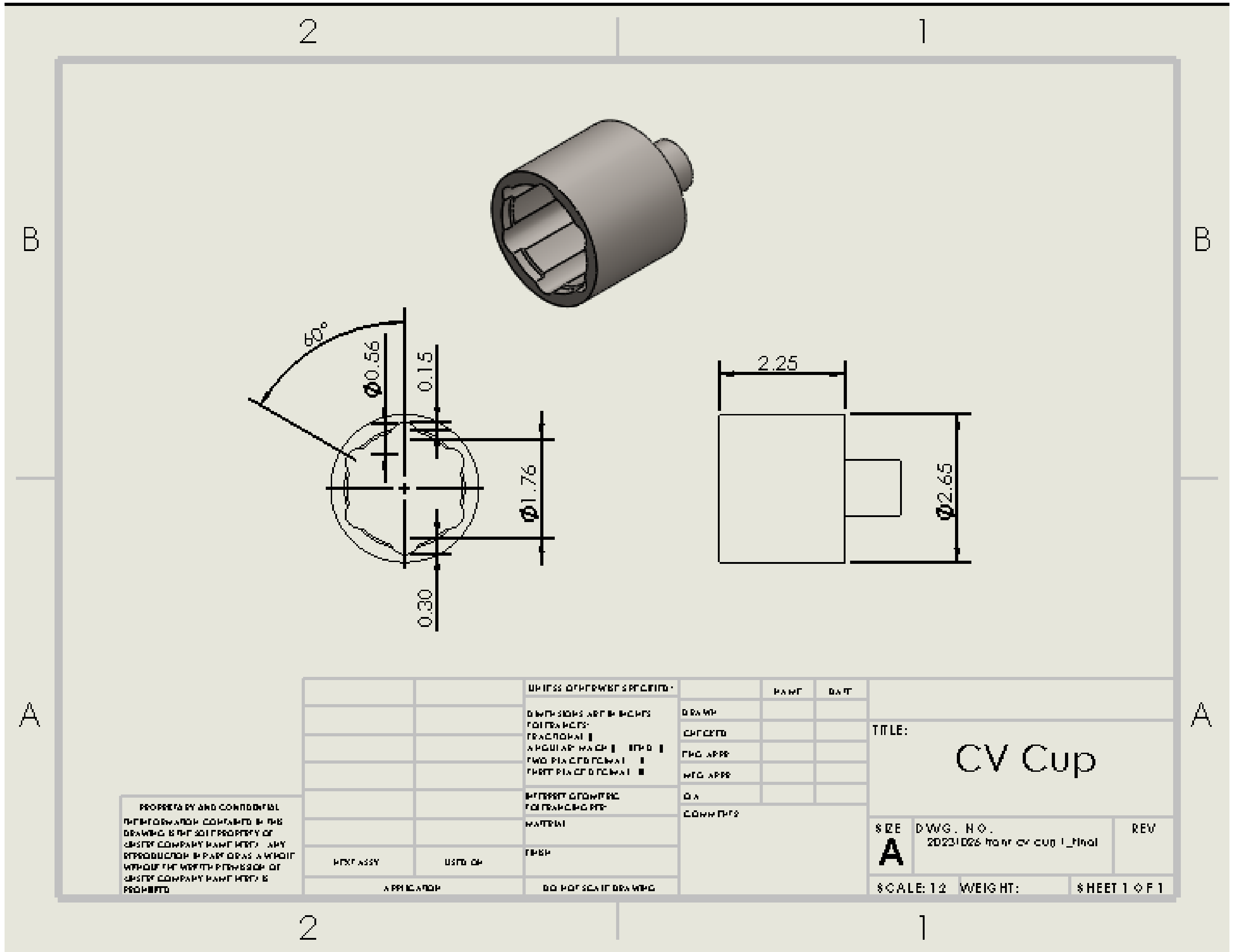


Design Description



Design Description – CV Cup



Design Requirements - QFD

Input areas are in yellow

#	Technical Requirement	1	2	3	4	5	6
1	top speed						
2	drivetrain efficiency						
3	torque to the wheels	6					
4	service life						
5	total system weight (w/out engine)		3				
6	total transmission range		6				
7	Meets HROE Guard specifications					-9	

Legend

A	Cornell 2023
B	NAU 2021 #21
C	NAU 2023 #74

#	Customer Needs	Customer Weights	top speed	drivetrain efficiency	torque to the wheels	service life	total system weight (w/out engine)	total transmission range	Meets HROE Guard specifications	1 Poor	2	3 Acceptable	4	5 Good
			Technical Requirements							Customer Opinion Survey				
1	fast	5	9	6	6	3	6	6	1	C			B	A
2	High effeciency	3	9	9	6	6	3	6	3	C		B		A
3	fast acceleration	5	3	6	9	3	9	9	1	C		B		A
4	durable	1	1	6	1	9	1	4	9			AC		B
5	can crawl and go fast	4	9	6	9	3	3	9	1	C			B	A
6	NEEDS TO BE SAFE	5	1	1	1	6	1	1	9			C	B	A
7	Aesthetically Pleasing	3	9	1	9	3	9	9	3		C		A	B
8														
9														
10														
11														
	Technical Requirement Units		MPH	Unitles	Lbf/Ft	hours	lbs	Unitless	N/A					
	Technical Requirement Targets		40	80	400	1000	60	01:04.5	N/A					
	Absolute Technical Importance		156	125	162	108	129	165	86					
	Relative Technical Importance		4	6	3	7	5	2	1					

ER to ER

Positive Correlation

- Drivetrain efficiency & Torque to the wheels

Inverse Correlation

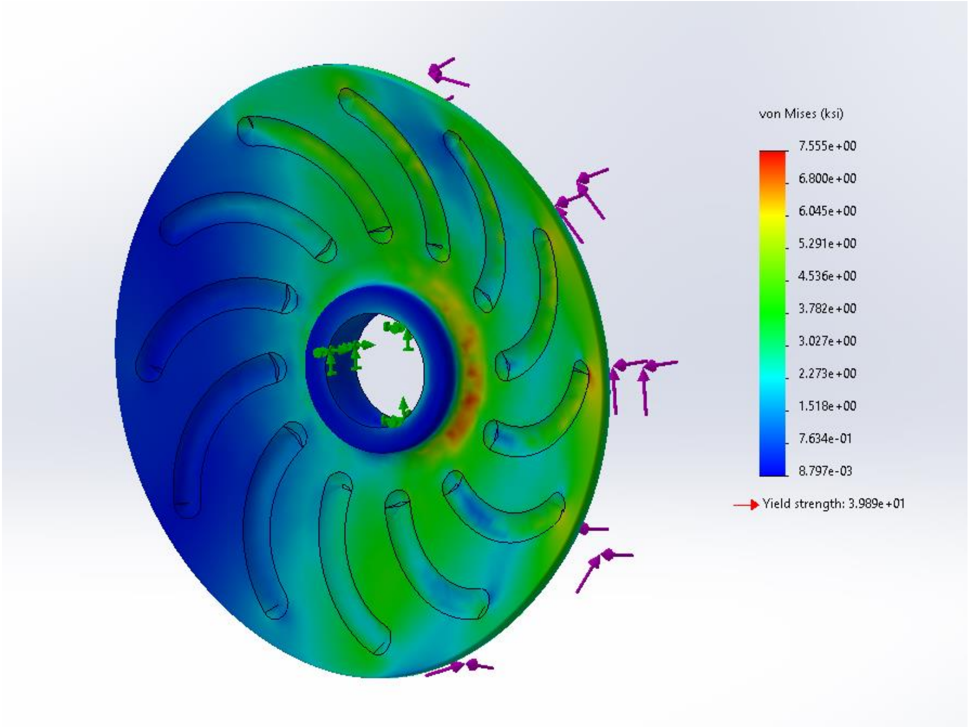
- Total system weight & service life

CR to ER

Strong Correlations

- High efficiency
- Fast acceleration
- Safety

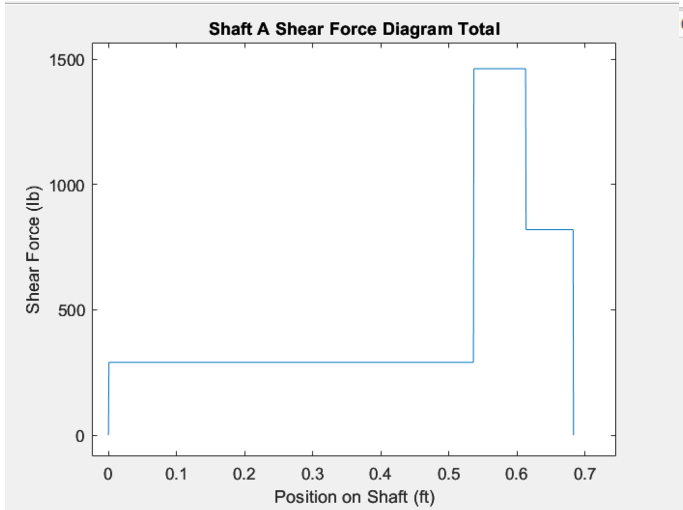
Engineering Calculations - Henry

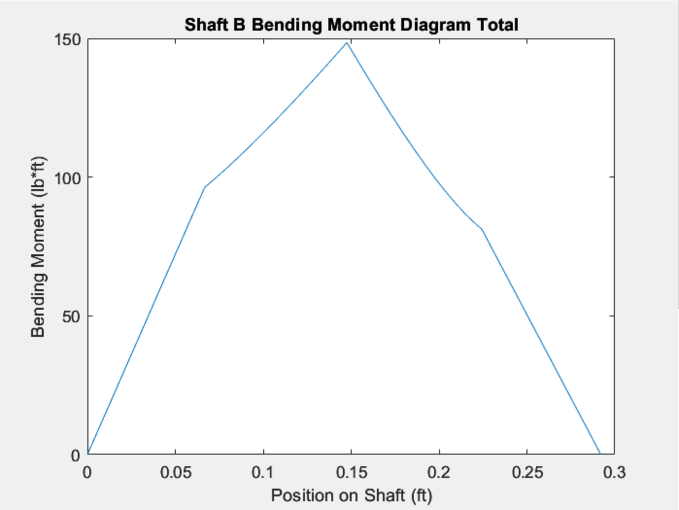


Results generated from SolidWorks

- Conducted FEA on Fixed Secondary Sheave
- Lasts 10^9 cycles at given stress

Engineering Calculations - Ryan





Command Window

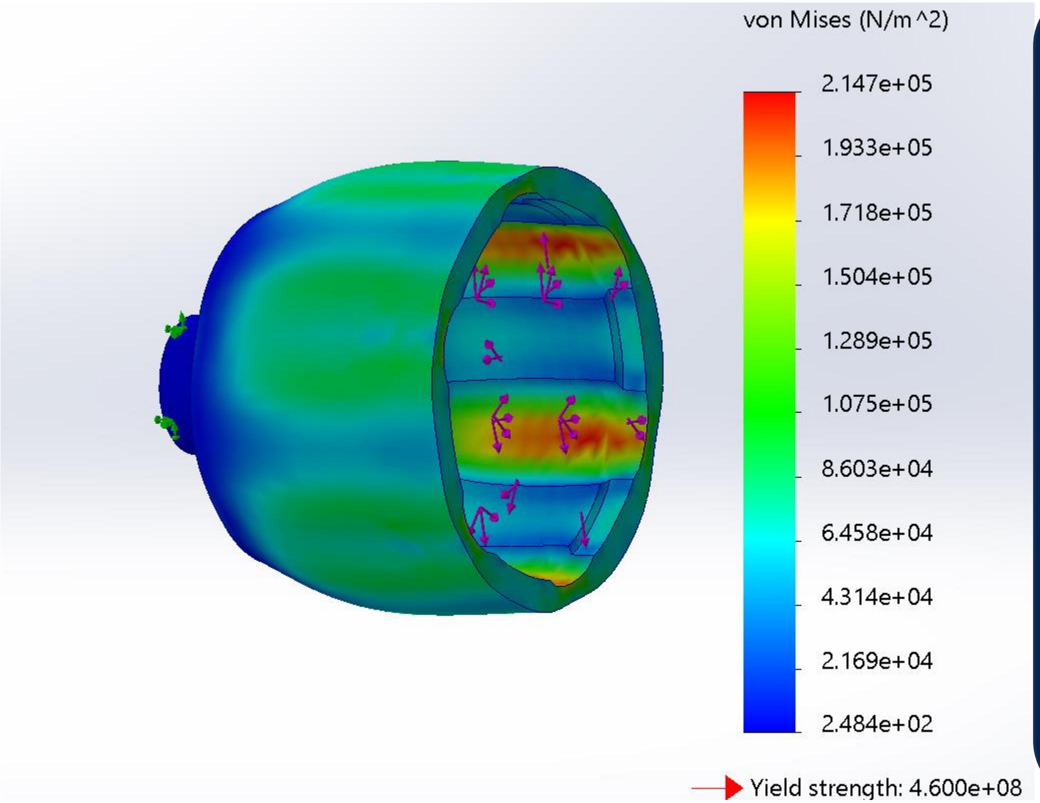
```
max_shear_shaftB =

   1.4440e+03

max_bending_shaftB =

  148.4494

max_bending_location_B =

    0.1478

Torque_shaftB =

   1.3725e+03

fos_B =

    1.0429

fx >>
```

Results generated from MATLAB

- Constructed a MATLAB script to calculate and plot shear and bending moments on each shaft.
- FOS,A = 1.0921
- FOS,B = 1.0429
- Getting the FOS for each shaft critical location as close to 1 as possible minimizes material and decreases weight.

Engineering Calculations – Jarett

CV Cup



Results generated from SolidWorks

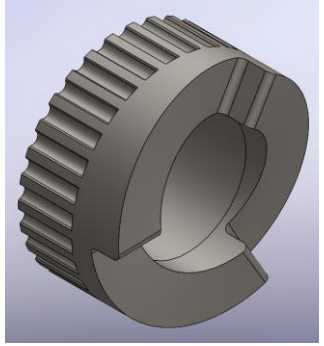
- Conducted FEA on inner groove for ball bearings
- Factor of Safety of 61.5941
- Decrease the wall thickness to save weight

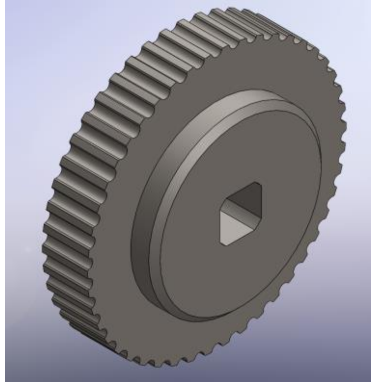
Engineering Calculations - Donovan

1	"p"	= 0.314961in	0.314961in
2	"PD"	= 3.14961in	3.149610in
3	"n"	= ("PD" * pi) / "p"	31.415927in
4	"d"	= 3in	3.000000in
5	"w"	= 0.7874in	0.787400in
6	"D1@Sketch1"	= "d"	3in
7	"D1@Boss-Extrude1"	= "w"	0.7874in
8	"D1@Sketch3"	= "d"	3in
9	"D1@Sketch7"	= "d"	3in

Design Table for: Official Pulley Design

	D1@Sketch1	D1@Boss-Extrude1	D1@Sketch2	D3@CirPattern1	D1@CirPattern1	$LIBRARY:MATERIAL@Official Pulley Design
3in Clutch Pulley	="d"	="w"	1.5	360	30	SOLIDWORKS Materials:AISI 4130 Steel, annealed at 865C
4.5 in pulley	4.5	0.7874	2.25	360	46	SOLIDWORKS Materials:AISI 4130 Steel, annealed at 865C





Results generated from SolidWorks

- Takes belt pitch to generate a pulley tooth number to match belt specifications.
- Equations and Table work in tandem to for both configuration designs.

Design Validation - ECVT

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Electronics Computation Module	Physical damage to computers	Incorrect Control Signals, damage to CVT primary sheaves due to overtravel	Debris ingress, mount failure, vibration fatigue of connections	84	ensure computation module housing is sealed to debris, mount housing with vibration dampening mounts
Electronics Motion Module	Encoder loss of position	Erratic CVT movement, damage to CVT primary sheaves due to overtravel	Extreme vibration, high electrical interference, lose cable connections	112	Ensure tight cable connections, route high amperage wires away from signal wires
Primary Sheave Assembly	Main Shaft fatigue failure	Loss of power transmission, damage to control motor, damage to belt	Lack of maintenance and inspection, higher than anticipated loads, wear from debris	30	Change main shaft to steel, properly inspect components for wear and replace within service life
Secondary Sheave Assembly	Fatigue failure of cam followers	Reduced max torque transfer, increased belt temperature leading to belt failure	Poor structural design, repeated high rpm CVT engagements from stopped	30	Inspect secondary moving sheave before use, replace within service life
Support Structure	Impact failure	catastrophic system failure, damage to all components	Massive crash, fatigue stress build over time leading to weakened structure	20	Don't crash

Failures

- Computation errors cause erratic motor movement and component damage
- Physical fatigue failure of components

Mitigation

- Thoroughly debug code and harden computation electronics against environmental factors
- Replace components before service life is reached, design components to last duration of testing and competition

Design Validation – Rear Gearbox

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Brake Components	**Fatigue Failure, Component Destruction**	Brake Failure	Brake line severed by terrain, excessive use	40	Protect brake components
Gearbox Seals	**Fatigue**	Transmission Fluid Leak	Overheating the gearbox, bearing failure	96	Use seals with a high FOS to mitigate failure risk
Shaft Bearings	**High-Cycle Failure**	Bearing Lock, Increased Friction Resistance	Cycle exceed design life	168	Use oversized ball bearings
Gears	**Contact Stresses, Fatigue Failure**	Teeth Wear/Striping, Higher Inefficiency, Failure to Transmit Torque	Material failure due to overuse, overheating, or unforeseen stress	40	Use heat treated 4140 steel for optimal strength
Input Shaft	**Fatigue Failure**	Material Yielding	Unforeseen stresses causing material failure	20	Use heat treated 4140 steel for optimal strength
Intermediate Shaft	**Fatigue Failure**	Material Yielding	Unforeseen stresses causing material failure	60	Use heat treated 4140 steel for optimal strength
Output Gear with Integrated CV Cups	**Fatigue Failure**	Material Yielding	CV cup failure or gear teeth failure due to overuse or unforeseen stresses	20	Use heat treated 4140 steel for optimal strength and employ a high FOS

Failures

- Fatigue Failure in gears, shafts, or CV cups.
- Exceeding life rating on bearings and seals.

Mitigation

- Use heat treated 4140 Steel for higher material strength.
- Use high life gearbox components.

Design Validation – Front Gearbox

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
CV Cup	**Abrasive Wear**	Erratic Operation, Poor Appearance	Impact Loading, Overstressing	75	Increase material wall thickness
Sprag	**High-Cycle Fatigue**	No Longer Operational, Flying Debris	Impact Loading, Overstressing	30	Use oversized sprag clutch
Gear Bearings	**High-Cycle Fatigue**	No Longer Operational, Flying Debris	Impact Loading, Overstressing	45	Use oversized ball bearings
Output Gear	**Contact Fatigue**	Erratic Operation, Flying Debris	Overstressing	60	Increase hardness by heat treatment
Input Gear	**Contact Fatigue**	Erratic Operation, Flying Debris	Overstressing	60	Increase hardness by heat treatment
Output Shaft	**High-Cycle Fatigue**	No Longer Operational, Flying Debris	Assembly Errors, Overstressing	30	Increase hardness by heat treatment
Input Shaft	**High-Cycle Fatigue**	No Longer Operational, Flying Debris	Assembly Errors, Overstressing	30	Increase hardness by heat treatment

Failures

- CV cup fails due to overstressing
- Fatigue failure for output/input gears

Mitigation

- Heat treatment
- Material selection
- Use oversized bearings

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Design Validation - 4 Wheel Drive

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Driving Clutch	**Material Failure**	Non-Operational	Tooth Shearing	40	Engage while off the throttle
Driven Clutch	**Material Failure**	Non-Operational	Tooth Shearing	10	Engage while off the throttle
Rear End Pulley	**High Force Failure**	Non-use of 4 Wheel Drive	Driving side clutch warps material	30	Engage while off the throttle
Front End Pulley	**Load Failure**	Non-use of 4 Wheel Drive	Belt load moves Circlip	120	Use heavy duty clip
Timing Belt	**High-Cycle Failure**	Non-use of 4 Wheel Drive	Exceed Tension Rating	24	Tension to specifications
Rear End Shaft	**Fatigue Failure**	Clutch will not be able to engage	Assembly Error	7	Lock down all non-moving parts
Shaft Bearing	**High-Cycle Failure**	Bearing Lock, Increased Friction Resistance	Cycle exceed design life	168	Use oversized ball bearings

Failures

- High Force and Load Failure
- Cease 4WD use

Mitigation

- Limit unnecessary force on clutch

Drivetrain Budget

	Category	Relevant Items	Approximated Cost
1	**Vehicle Expenses**	Motor Front Gearbox Rear Gearbox ECVT 4WD **Estimated Total**	$900 $794 $1,018.55 $2,310 $1,336.57 **$6,359.12**
2	**Spare Parts**	Gears, CV Axles, Hardware	$500
3	**Competition Expenses** Drivetrain Sub-team	Registration, travel (hotel rooms, vehicle rentals, gas, etc.)	$1,125
4	**Contingency (5%)**	Unpredicted Expenses	$300
		Total	**$8,284.12**

No Expenses Accumulated

All **prototyping** used **existing shop materials** or was cheap enough to be **personally funded/fabricated!**

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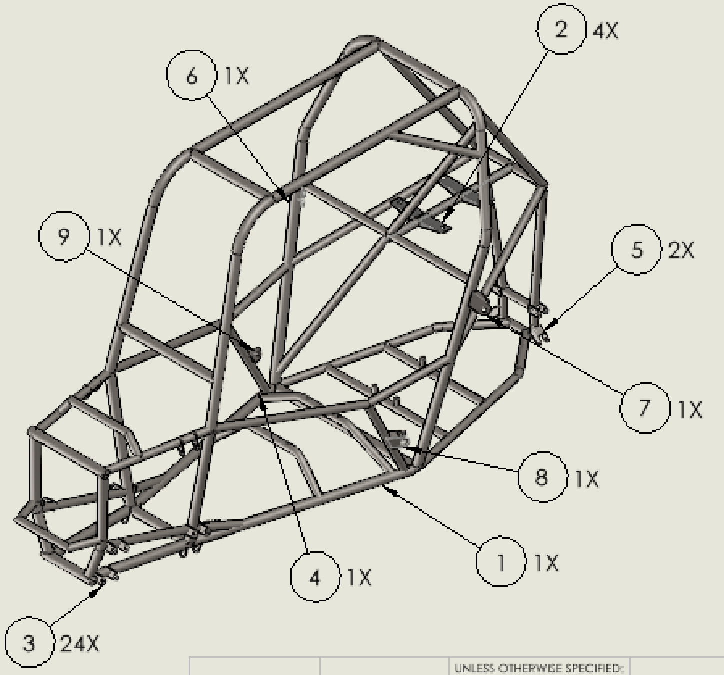
Frame Team

Cooper Williams, Gabriel Rabanal, Antonio Sagaral

Design Description



ITEM NO.	PART NUMBER	QTY.
1	Frame	1
2	Gas Bracket	4
3	Flange general	24
4	seat mount slotted	1
5	rear lower camber link tab	2
6	rear shock frame mount tab passenger	1
7	rear shock frame mount tab driver	1
8	trailing arm frame tab	1
9	trailing arm frame tab passenger	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY USED ON
APPLICATION
DO NOT SCALE DRAWING

NAME DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

TITLE:
Frame Subassembly
SIZE A DWG. NO. Assem1 Drawing REV
SCALE: 1:50 WEIGHT: SHEET 1 OF 1

Sub System Note:

- **Frame design team has different specifications for sub systems**
  - **Mounting Tabs**
  - **Side Paneling**
  - **Firewall**
  - **Driver Safety Equipment**
- **Many of these systems will be integrated later in the design stage**

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Design Requirements

System QFD

Project:	Baja 24 Frame
Date:	9/14/23

Technical Requirement Correlations

		1	2	3	4
1	Decrease weight				
2	Decrease length of body	6			
3	Decrease width of body	3			
4	Decrease Cost	-9	3	3	
5	Increase strength of frame		6	6	-3

Legend
- A ETS Baja
- B SAE Beaver racing
- C Cornell Baja Racing

	Customer Needs	Customer Weights	Technical Requirements: Decrease weight	Decrease length of body	Decrease width of body	Decrease Cost	Increase strength of frame	Customer Opinion Survey: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	Rigid	3	1	6	3	3	9				ÀBC	
2	Easy to Manufacture	3	3	3	1	3	3			B	AC	
3	Maneuverable	2	3	9	9	1	3					ABC
4	Aesthetically Pleasing	1	3	1	3	3	1			C	B	A
5	Durable	2	3	1	3	3	9			AC	B	
6	Satisfy SAE Baja Frame Guidlines	4	3	1	6	3	6					ABC
7	Stable	3	1	3	9	1	6				C	AB
8	Fast	3	6	3	3	6	3				BC	A
9	Lightweight	4	9	6	3	9	6				ABC	
10	Affordable	3	9	6	3	9	6			ABC		
	Technical Requirement Units		lbs	in	in	$	klb*in					
	Technical Requirement Targets		60	64	9	800	3.513					
	Absolute Technical Importance		123	112	120	125	154					
	Relative Technical Importance		3	5	4	2	1					

ER to ER

Positive Correlation
- Decreased Length/width & Increased Strength

Inverse Correlation
- Decreased weight & Decreased cost

CR to ER

Positive Correlation
- Decreased Width/Length & Maneuverability
- Increased Strength & Durability

Inverse Correlation
- Decreased Weight & Affordability

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Design Requirements - ERs

CR	ER	Parameter	Target	Current Design	Acceptable?
Lightweight	Decrease Weight	Roll Cage Weight	60 lbs	56 lbs	✓
Maneuverable	Decrease Body Length	Wheelbase	<64”	62.8”	✓
Stable	Decrease Body Width	Suspension Tab Width	<9”	8”	✓
Affordable	Decrease Cost	Cost	$800	$496	✓
Durable	Increase Frame Strength	Bending Strength	3.513 klb*in	4.301 klb*in	✓

Engineering Calculations-Cooper

Side Impact Member Deflection

Governing Equations:

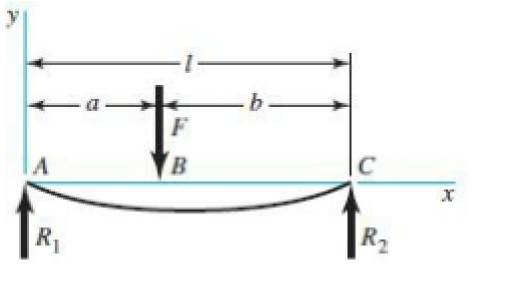
$$y_{AB} = \frac{Fbx}{6EIl}(x^2 + b^2 - l^2)$$

$$y_{BC} = \frac{Fa(l-x)}{6EIl}(x^2 + a^2 - 2lx)$$

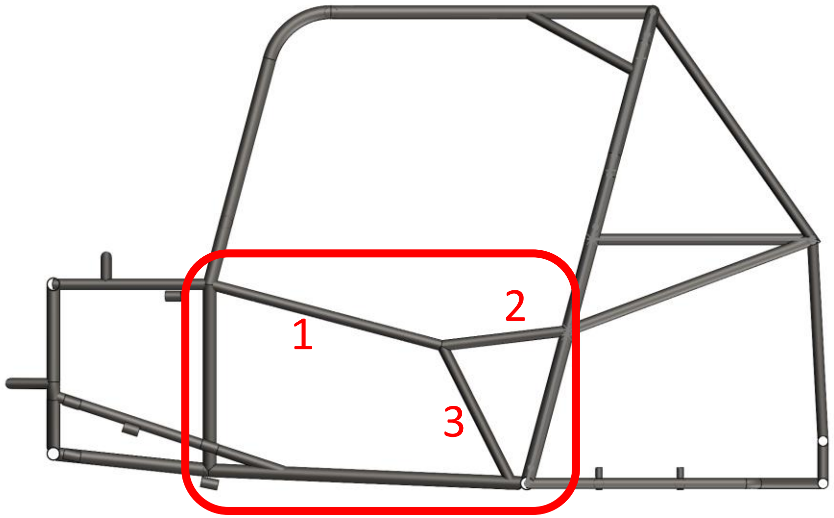
$$I_y = I_x = \frac{\pi}{64}(D^4 - d^4)$$

Assumptions:
Simply Supported Beam with an Intermediate Load
a = $\frac{1}{2}l$, b = $\frac{1}{2}l$
$x = 0.5l$
F = 300 lbf

Relevant Values:
D = 1.00 in
d = 0.93 in
L_1 = 22.977 in
L_2 = 12.049 in
L_3 = 14.501 in
E = 29000 kpsi



Maximum Deflection per Member	
δ_1	0.0212 in
δ_2	0.0030 in
δ_3	0.0053 in



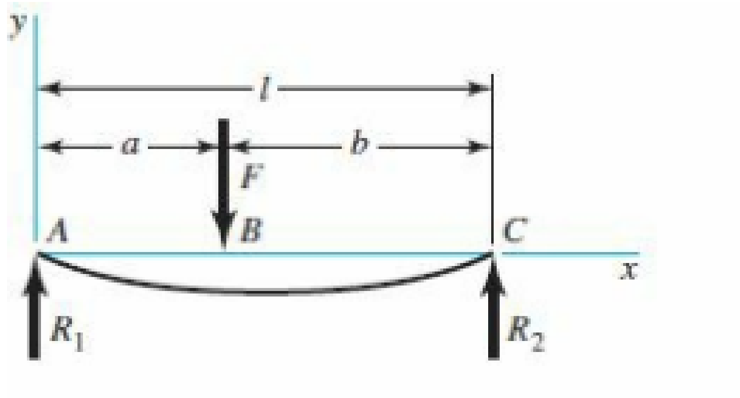
Engineering Calculations - Antonio

Front Shock Support Member

Governing Equations

$$\delta_{max} = \frac{Fb(3L^2 - 4b^2)}{48EI}$$

$$I = \frac{\pi}{64}(D^4 - d^4)$$



Results

Necessary values

F = 525 lbf

a = 11 in

b = 3 in

E = 29,000 ksi

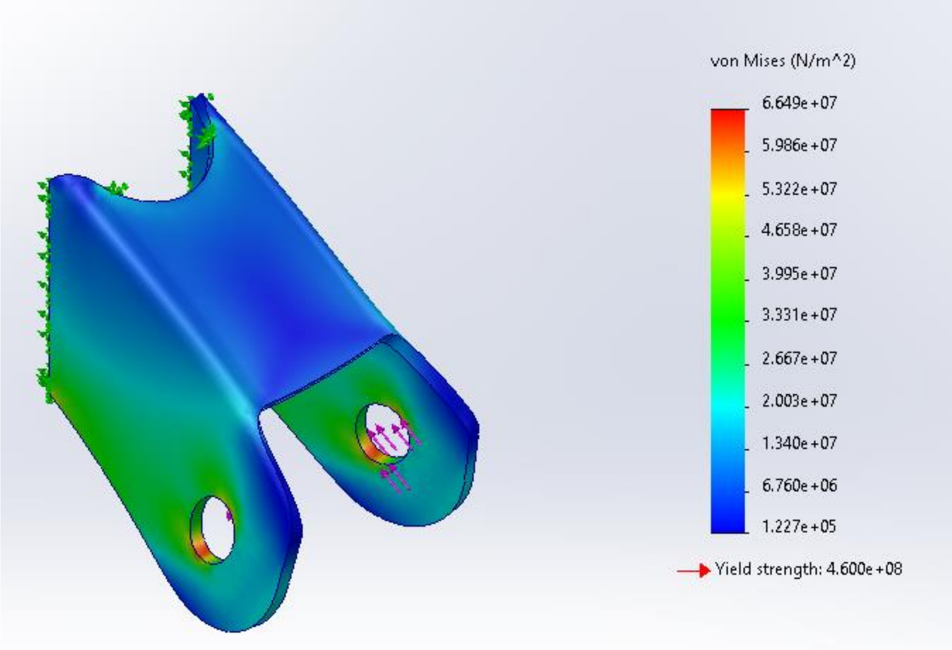
I = 0.0426

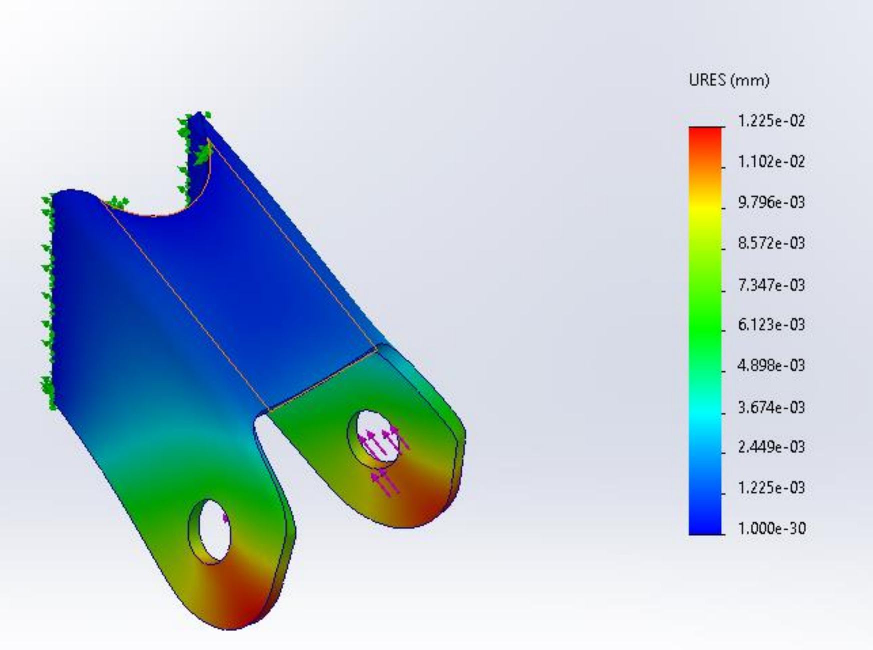
L = 13.6 in

$$\delta_{max} = 0.0236 in$$

Engineering Calculations - Gabe

Rear Shock Mount Tab





Assumptions:
F = 550 lbf applied evenly through mounting hardware

Von Mises Stress Analysis

Displacement Analysis

Results:
Minimum factor of safety in part of 18 shows extreme safety in tab design.

Assuming proper manufacturing of tab, failure would likely occur due to incorrect assembly in the welding stage.

Design Validation-Members

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Bumper	Impact Fracture, Impact Deformation, Impact Fatigue	No Longer Operational, Poor Appearance	Assembly Errors, Impact Loading, Manufacturing Defect	18	Ensure Proper Assembly
Roll Hoop Overhead Members	Impact Fracture, Impact Deformation, Impact Fatigue	No Longer Operational, Poor Appearance	Assembly Errors, Impact Loading, Manufacturing Defect	10	Ensure Proper Assembly
Side Impact Members	Impact Fracture, Impact Deformation, Impact Fatigue	No Longer Operational, Poor Appearance	Assembly Errors, Impact Loading, Manufacturing Defect	10	Ensure Proper Assembly, Optimize Supportive Geometry
Seat Mount	Impact Fracture, Impact Deformation, Impact Fatigue	No Longer Operational, Poor Appearance	Assembly Errors, Impact Loading, Manufacturing Defect	16	Ensure Proper Assembly, Limit Impact Opportunities
Steering Column Mount	Impact Deformation, Impact Fatigue	Erratic Operation	Assembly Errors, Impact Loading, Manufacturing Defect	12	Ensure Proper Assembly, Optimize Geometry
Seat	Impact Fracture, Impact Wear	Safety Hazard, No Longer Operational, Uncomfortable	Manufacturing Defect, Impact Loading	24	Thicken material, Avoid High Stress Geometry

Failures

- High Stress Geometry
- Welded Points

Mitigation

- Certify Welders
- Verify Weld integrity after installation
- Increase Material Thickness

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Design Validation-
Rear Shock Mounts

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Rear Shock Tab	Impact Fatigue, Impact Wear, Surface Fatigue Wear	Poor Handling, No Longer Operational, Poor Appearance	Incorrect Assembly, Overstressing	64	Ensure Proper Assembly, Use Thicker Material
Trailing Link Tab	Impact Fatigue, Impact Wear, Surface Fatigue Wear	Poor Handling, No Longer Operational, Poor Appearance	Incorrect Assembly, Overstressing	56	Ensure Proper Assembly, Use Thicker Material
Upper Camber Link Tab	Impact Fatigue, Impact Wear, Surface Fatigue Wear	Poor Handling, No Longer Operational, Poor Appearance	Incorrect Assembly, Overstressing	32	Ensure Proper Assembly, Use Thicker Material
Lowe Camber Link Tab	Impact Fatigue, Impact Wear, Surface Fatigue Wear	Poor Handling, No Longer Operational, Poor Appearance	Incorrect Assembly, Overstressing, Impact Loading	32	Ensure Proper Assembly, Use Thicker Material

RPN Note:
High RPN values for shock and trailing link tabs are due primarily to high values of severity and detection. Failure at this point in the vehicle is highly unlikely but could be hazardous

Failures

- Welded Points
- Tab Mount Locations
- Mounting Hardware

Mitigation

- Certify Welders
- Verify Welds after installation
- Increase Material Thickness

Design Validation- Front Shock Mounts

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Front Shock Tab	Impact Fatigue, Loop around bolt Failing, Deformation	Non-functional Vehicle, Incorrect front geometry Poor handling	Poor welds, Incorrect placement	45	Verify Welds, Ensure proper placement before final welds occur
UCA Tabs	Impact Fatigue, Loop around bolt Failing, Deformation	Non-functional Vehicle, Incorrect front geometry Poor handling	Poor welds, Incorrect placement	30	Verify Welds, Ensure proper placement before final welds occur, In line with other UCA tab
LCA Tabs	Impact Fatigue, Loop around bolt Failing, Deformation	Non-functional Vehicle, Incorrect front geometry Poor handling	Poor welds, Incorrect placement	30	Verify Welds, Ensure proper placement before final welds occur, In line with other UCA tab

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Schedule

Task	Date
Secondary Member Material Allocation* - Supplier in Phoenix	11/12/2023*
Jig Production: -Determine jigging system and effective production method	11/13/2023
Prototype Demo and Updates: -Marking SAE BAJA Rule violations, Comparing to current frame	11/17/2023
Final CAD and BOM	11/24/23
Tacked Frame - Measure members -Member lengths and angles to fit jig and match CAD model - Verify validity of frame -Tack weld primary members -Tack weld secondary members	11/30/2023

Frame Budget

	Category	Relevant Items	Approximated Cost
1	**Vehicle Expenses**	Frame Material Paneling and Carbon Layup Safety Equipment Hardware **Estimated Total**	$400 $0 $46 $50 **$496**
2	**Spare Parts**	Welding supplies, Hardware, Tab Materials, Tubing	$200
3	**Competition Expenses** Frame Sub-team	Registration, travel (hotel rooms, vehicle rentals, gas, etc.)	$1,125
4	**Contingency (5%)**	Unpredicted Expenses	$100
		Total	**$1921**

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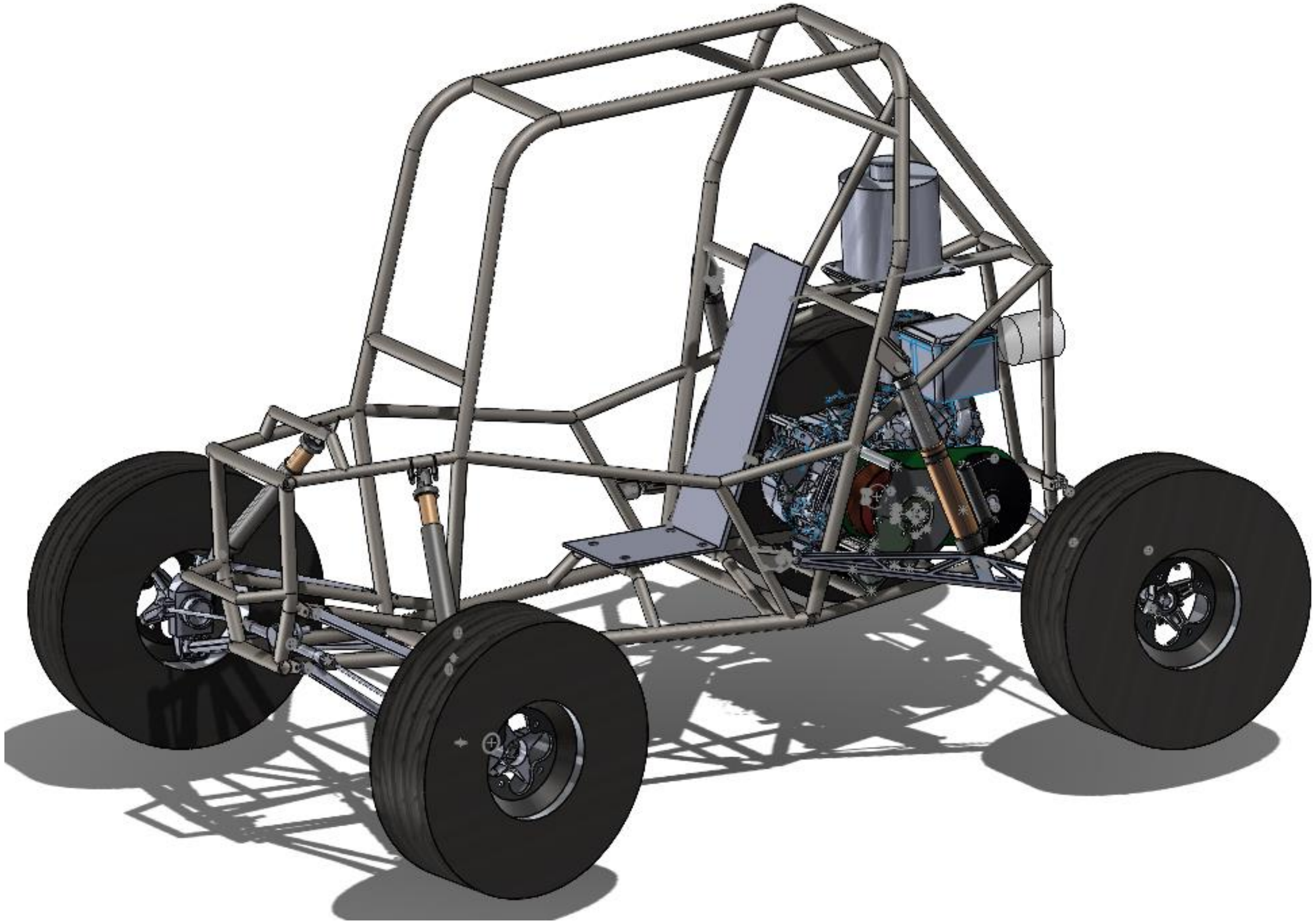
Updated CAD – Whole Car



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[2] diblazing (Mechanical) et al., “Find shear strength from tensile strength,” Engineering forums for professionals, https://www.eng-tips.com/viewthread.cfm?qid=69837#:~:text=A%20rule%20of%20thumb%20for%20engineering%20alloys%20is%20ultimate%20shear,can%20range%20up%20to%20~%200.8. (accessed Oct. 31, 2023).

[3] “Bolt shear strength - bearing, tearout, and shear load capacity calculations,” YouTube, https://www.youtube.com/watch?v=8KAEUcdyp68 (accessed Oct. 31, 2023).

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