

Vette-Kart (Suspension)

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Bachelor of Science
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by

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ABSTRACT

The problem with older sports car is that they are no longer in their prime. Modern sports cars are light weight, quicker, and more agile in the corners, but cost a lot of money. Older sports cars are heavy, slow and not so great in corners. This project aims to improve on a cheaper 1985 C4 Corvette. This project will address improving the over all handling by introducing a light weight replacement to the upper control arm, which in combination of removing around 317.5 kg from the car, will help bring some life back into this old car. Because so much weight is being taken out of the car, the normal shims that are used to adjust camber will no longer suffice. An adjustable upper control arm will be needed to adjust the camber of the wheels.

The areas in which to improve the car come from customer surveys as well as areas of improvement identified by the team working on this project. All existing projects that aim to solve this problem do so for outrages cost, and we aim to show that this project can be done safely and affordable, with a small amount of welding and machining experience. All of which can be learned in a few short weeks.

After all the design work was done, we where able to have a light weight, sports car that is safer than some modern cars. We feel into some issues along the way, including an electrical issue that has put the car down for now. But once that is addressed the car will be up and running better than ever.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Our proposal is to take an existing Vette, which is running and driving, and make it lighter and nimbler in corners. This will require: a custom full tube roll cage to be mounted to the frame, due to the one of the team members being be 6' 8. Standard roll cages are not designed for humans that are that tall, and we need 3" of clearance. As well as a redesign of the front and rear suspension, due to the lightening of the vehicle, modification of exhaust, and fuel tank and fuel pump, and addition of safety equipment. The tube-frame chassis that will meet FIA, SCCA, and DOT requirements. This combination of "adding lightness", stiffening the chassis, and improving overall safety will make this car a cheap, road-capable, track car. This project will be in combination with Jiahua Zhu and Josh Doerbaum's projects.

RESEARCH

BACKGROUND OF THE PROBLEM

The C4 Corvette is a common and cheap Corvette, "Vette." Over 350,000 of these Vettes where manufactured form 1983-1996 (1). These Vettes where low on power but boasted a V8. Many of these are starting to fall into disarray.

With the introduction of the C4, General Motors, GM, completely redesigned the Corvette's body. GM introduced the first ever uni-body construction (2). With this uni-body the front suspension was bolted to the frame rails providing engine mount points. While the rear suspension borrowed a lot from earlier Vettes. The entire suspension system was designed to support 3500lbs, which is the entire weight of the Vette (3).

SCOPE OF THE PROBLEM

With the current weight of the vehicle and being down of power, where the 1985 Vette makes 230 HP, with 330 lb-ft of torque (3). This makes the car slower around a track. To improve on the overall handling and performance of any car, one can take out a lot of weight from the vehicle. In order to achieve this one can, take out most the of the interior of the car; leaving only the driver seat, and most of the dashboard. This will take out considerable

amount of the weight for the car. To take this a step further, one can begin to remove a lot of the body panels. This will make the car even lighter, but in doing this it is necessary to make changes to the suspension of the car. The reason for the suspension adjustment is because when weight is taken out of the car, the car starts to rise due to there be less weight pressing down on the shocks. This will begin to introduce positive camber of the wheels.

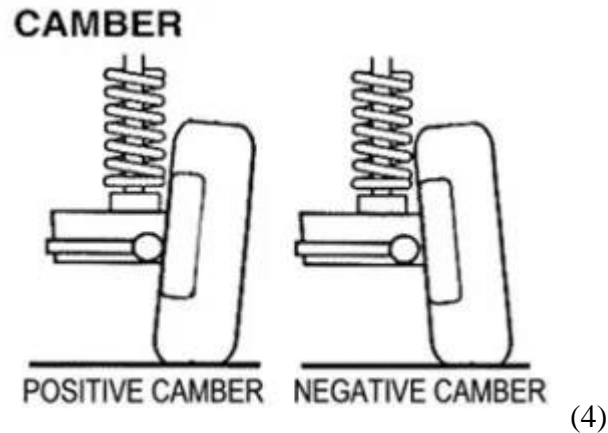


Figure 1: Examples of Camber

Positive camber is known for causing poor handling in vehicles. In order to prevent positive camber from forming, it is necessary to introduce negative camber back into the car.

Negative camber, to a point, is known for improving the handling in vehicles. Another issue with taking weight out the vehicle, is that it will raise the car. Because of this, the center of gravity will rise, causing the car to be less stable in corners. To prevent this, it will be necessary to lower the car back to stock ride height, to bring back the stability of the car. It would also be more beneficial to lower the car even more to lower the center of gravity even more.

STATE OF THE ART

Currently the state of the art for suspension components are aftermarket components that are designed for a stock Vette. These components are mainly aftermarket shocks, and other wear components, like rubber bushings. Companies like Bilstein® (Bilstein® is the OE manufacture of the shocks for the C4 Vette), QA1®, RideTech®, and many other

aftermarket shock manufacturers don't design shocks specifically for the C4 Vette, but design shocks to fit a wide range of vehicles. This is done to ensure that they can have their shocks on as many different cars as possible. This design will not involve the replacement of the shocks, only if they are still in working order.

Currently there the aftermarket control arms are just standard OE parts. No aftermarket manufacturer tries to design performance focused control arms. The only major upgrade that is currently on market is upgrading the rubber bushings on the control arm to polyurethane bushings. These polyurethane bushings are more robust and will last a lot longer than the OEM Rubber bushings.

When it comes to autocrossing a car most people do adjust their suspensions. These adjustments range from replacing the shocks or struts to decrease the wheel travel. This will allow for the tire to remain on the track when the tire goes over bumps (5). Along with this upgrade, another recommendation is to replace control arms and upgrade it the stock rubber bushings to polyurethane bushing set (6). This will help "tighten things up considerably giving you more control and quicker response" (6). This can be done to help improve all cars built for autocross.

END USER

This project will be designed for anyone wanting to transform their C4 Vette into a lightweight autocross capable car. Most C4 Vette owners will most likely not transform their car into this. This is more designed for hobbyist looking to do something different with their car.

CONCLUSIONS AND SUMMARY OF RESEARCH

In conclusion, due to the loss of weight in the Vette the suspension system will have to be reconfigured as well as some modifications will have to be made. The current dampers in the vehicle will be sufficient, but work will have to be done in order to add negative camber back into the wheels in order to maintain the current handling performance. But to improve upon

the current level of performance the Vette will have to be lowered and more negative camber will have to be added to the wheels. Adding negative camber into the wheels will allow for the tires to gain more grip and improve the overall handling in the car. Also in lowering the car, it will bring the overall center of gravity down which will improve the stability of the car in corners.

In doing both, adding a small amount of negative camber, and lowering the car, will help improve the overall times around the track. This will greatly increase the confidence of any driver knowing that car will have better performance around the track.

CUSTOMER FEATURES

PRODUCT OBJECTIVES

1. Tire Contact Surface (in²) - 4.35
2. Head Room (in) – 3.15
3. Strength of Roll Cage (lbf) - 3.15
4. Weight (lb) - 2700
5. Angle of Camber (°) – 2.70
6. Wheel Travel (in) – 2.65

From the house of quality, we found that is it necessary to focus a lot of our time, onto the contact area that the tire has with the road. This is done to improve overall grip of the car, this will help the tires have more grip in the corner allowing for corners to be taken at a higher speed. Headroom is very important for the safety of the drivers. In the event of a roll over any extra amount of headroom will allow the roll cage to take as much of the impact as possible before the head is anywhere near the coming into contact with anything. That is also why we need to focus our time on the roll cage. Roll cages are a necessary safety equipment to ensure that the force of the impact is not going to come through to the driver. They also protect all passenger, if there is one.

QUALITY FUNCTION DEPLOYMENT

CUSTOMER FEATURES

- Turns easily - .15
- Protects the people in the car - .35
- Corners easily at speed -.25
- Stiffen Ride - .25

ENGINEERING CHARACTERISTICS

- Tire contact (in²)
- Angle of Camber (Degrees)
- Weight of car (lbs)
- Head Room (in)
- Wheel travel (in)
- Strength of Roll cage (lbs)

HOUSE OF QUALITY

		Engineering Requirements (units)														Customer Satisfaction Rating (0.00 - 1.00)					
		Importance wt.	Tire Contact Surface (in ²)	Angle of Camber (°)	Weight (lb)	Head Room (in)	Wheel Travel (in)	Strength of Roll Cage (lbf)									CP	A	B	C	
Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14						
1	Turns Easily	0.15	9	3	1		1												0.7	0.7	0.8
2	Protects the Passenger	0.35			3	9		9											0.5	0.5	0.6
3	Corners Easily at Speed	0.25	9	9	3		1												0.4	0.4	0.7
4	Stiffen Ride	0.25	3		3		9												0.4	0.4	0.3
5																					
6																					
7																					
8																					
9																					
10																					
Total Importance		1.00																			
Engineering requirement importance			4.35	2.70	2.70	3.15	2.65	3.15													
Performance																					
	Current Product		7	0	3239	-3	5	5000													
	competitor A		7	0	3239	-3	5	5000													
	competitor B		6	-2.8	2317	-3	5	5000													
	competitor C																				
	New Product Targets		8	-2.8	2700	-3	4	6000													

		Interaction Matrix														
		Engineering Requirements	Tire Contact Surface (in ²)	Angle of Camber (°)	Weight (lb)	Head Room (in)	Wheel Travel (in)	Strength of Roll Cage (lbf)	0	0	0	0	0	0	0	0
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Tire Contact Surface (in ²)	1		9	3		1										
Angle of Camber (°)	2			9												
Weight (lb)	3					1										
Head Room (in)	4															
Wheel Travel (in)	5															
Strength of Roll Cage (lbf)	6															
	0 7															
	0 8															
	0 9															
	0 10															
	0 11															
	0 12															
	0 13															
	0 14															

Figure 2: House of Quality

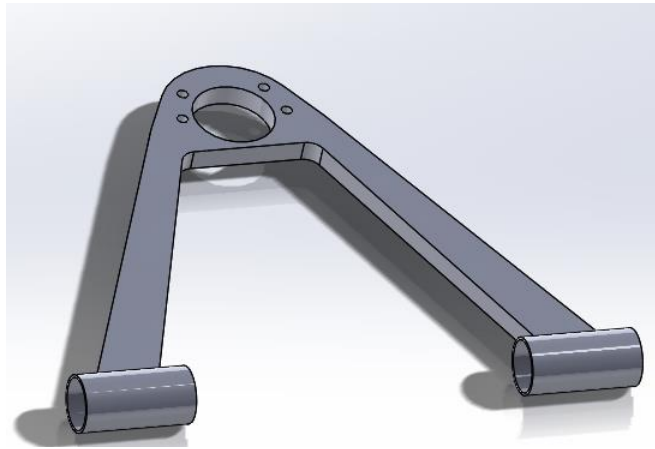
DESIGN*CONCEPT 1*

Figure 3: Concept 1

Concept one is the simplest and cheapest of the three. This one a simple but light weight control arm that will add a small amount of camber to the Vette.

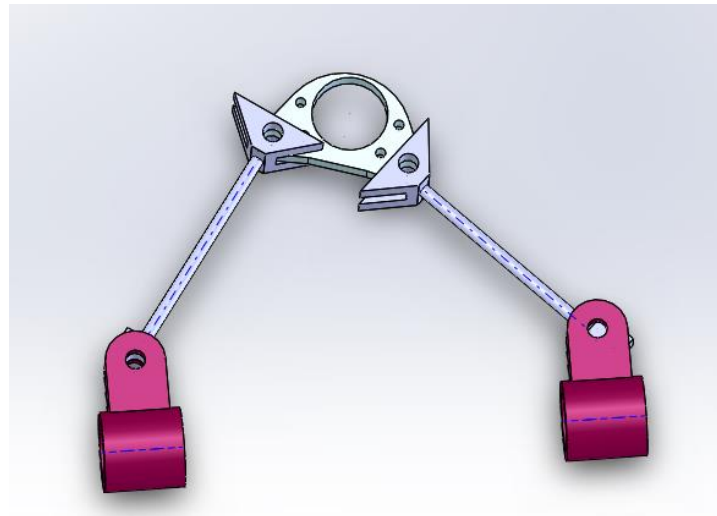
CONCEPT 2

Figure 4: Concept 2

Concept 2 is more detailed; this will a more complex control arm that allows for parts to be changed out to adjust the camber of the wheels, while being light weight.

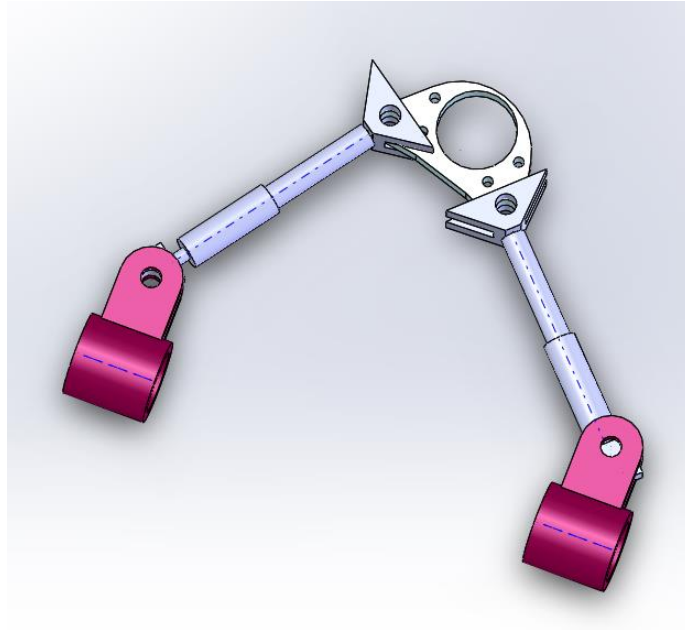
CONCEPT 3

Figure 5: Concept 3

Concept 3 is the most complex of the three. The control arms will be fully adjustable allowing for changes to the camber of the wheels to be made on the fly.

CONCEPT SELECTION

Table 1: Concept Selection

Criteria	Importance Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Light Weight	50%	3	1.50	3	1.50	3	1.50
Complexity	10%	4	0.40	3	0.30	0	0.00
Strength of Part	20%	4	0.80	3	0.60	2	0.40
Number of Parts	5%	3	0.15	3	0.15	2	0.10
Adjustability	15%	0	0.00	4	0.60	4	0.60
	100%	14	2.85	16	3.15	11	2.60
Rating					Value		
Unsatisfactory					0		
Just tolerable					1		
Adequate					2		
Good					3		
Very Good					4		

I have chosen to go with concept 2, which is shown to the left. Concept 2 has the potential for the most adjustability, without sacrificing, too much strength.

WEIGHT REDUCTION

As well as improving the adjustability of the Upper Control Arm a large amount of mass will be removed from the car. The plan is for 10%-15% of the total weight will be removed from the Vette. Here is all the weight that will be removed from the car. All weights were taken once the parts were removed from the car.

- Glass Weight – 68 kg
- Hood and Front Clip – 50 kg
- Both Doors with Glass – 75 kg
- Rear Clip and Fuel Tank – 45 kg
- Exhaust – 18 kg
- Seats – 36 kg
- Fiber glass – 23 kg
- Total Weight Savings of about 315kg
- Plus Additional weight of 138 kg
- New Weight of – 2900 lbs or 1315 kg
 - Weight Savings of 15.5%

FINAL SOLUTION

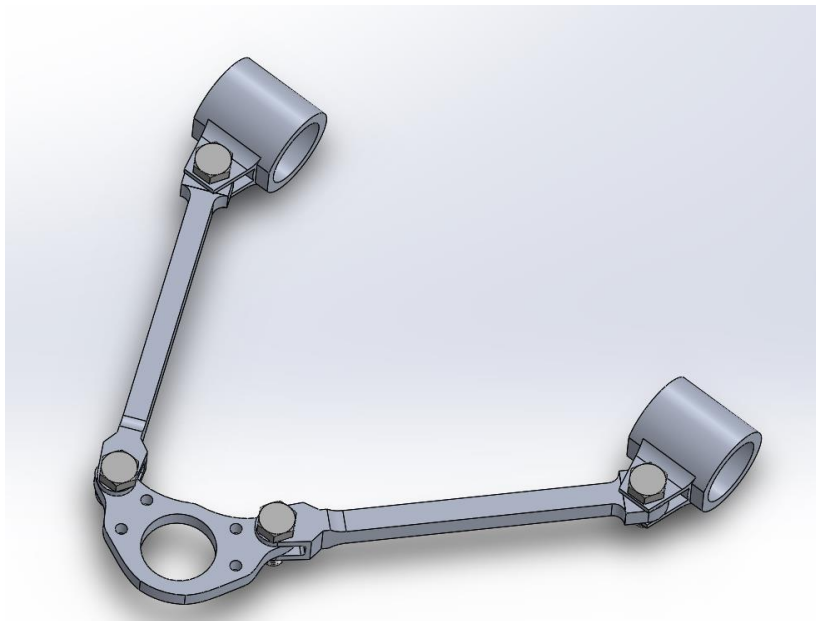
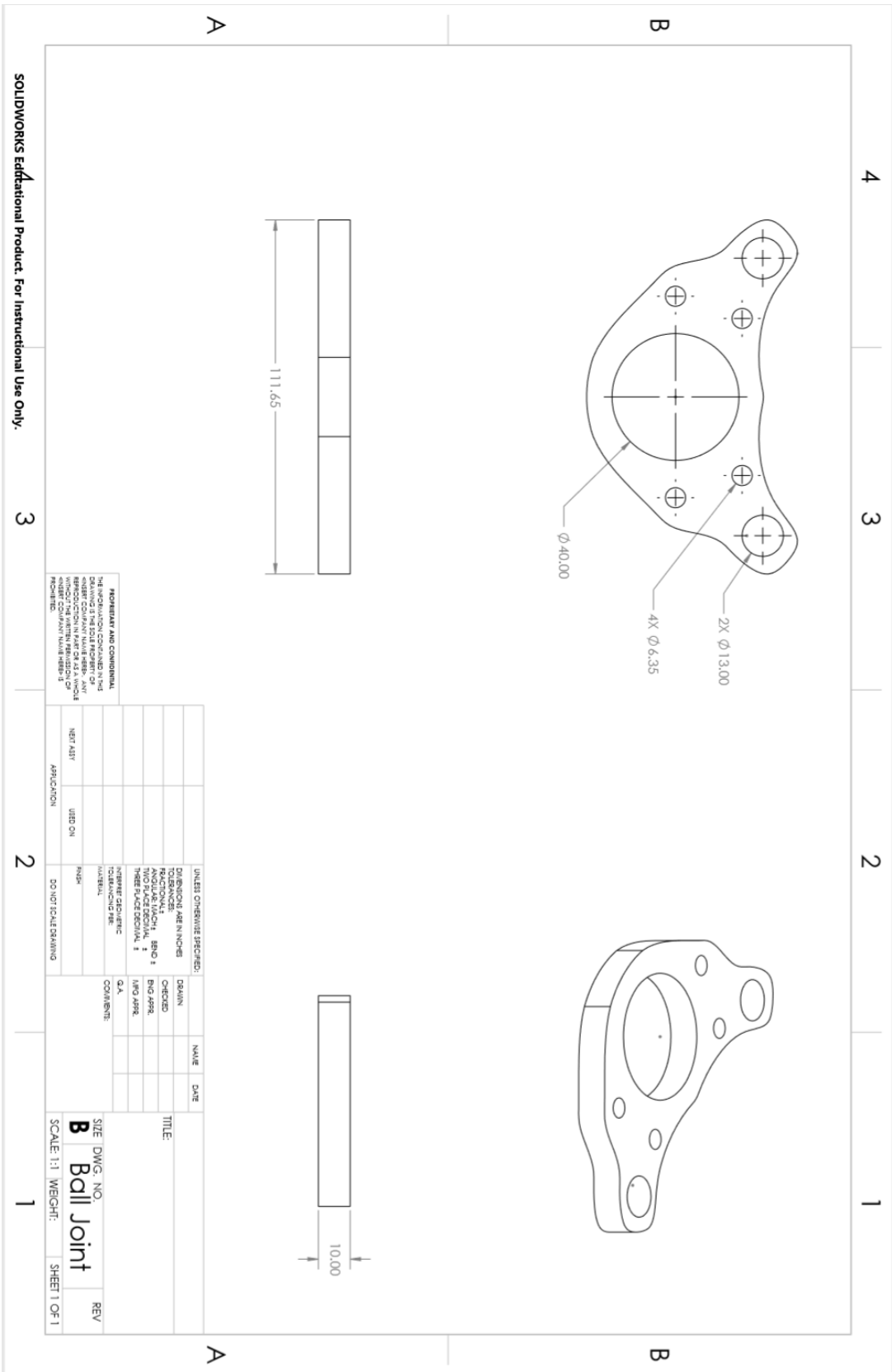


Figure 6: Final Solution

Concept 2 was modified in order to be able to withstand the forces that are calculated. The overall function was not changed. This product will help with the ability to adjust the camber

of the front wheels. Adjusting the camber will help improve handling for any situation. As well as lower the car a small amount helping to bring the car's center of gravity down, to help keep the car planted when going around corners.



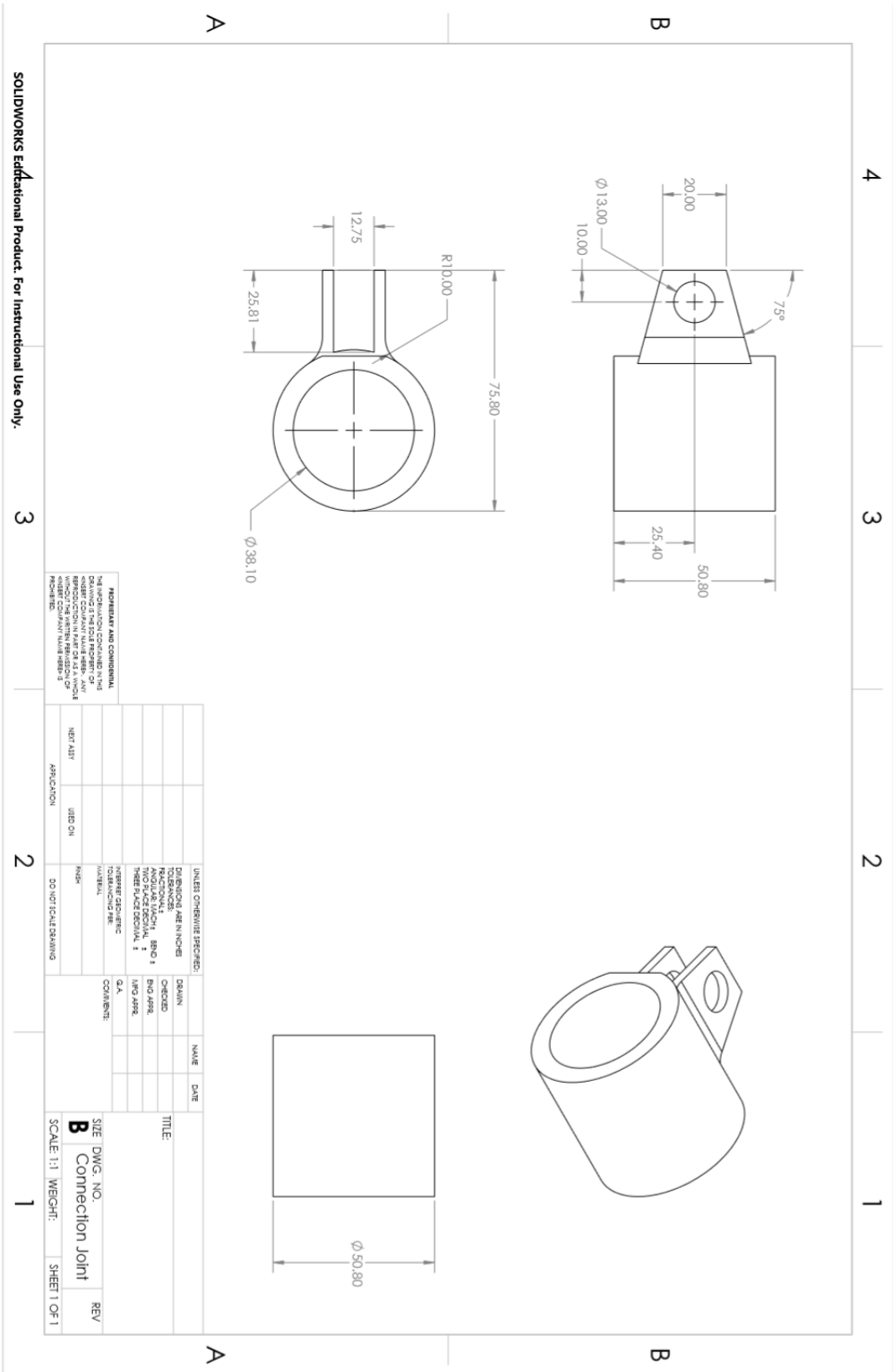
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LOAD CONDITIONS

Assumption made for the calculations. It was assumed that the made are done in order to ensure that the calculations are done correctly and allow for adequate safety precautions that are needed to make sure the Upper Control will be safe to use in the world. Some of the assumptions are the final mass of the Vette-Kart (1315.42 kg), the stopping distance when the breaks are locked up (52.73m), and the highest force comes during hard breaking. As well as a simplified drawing of the front wishbone suspension was used to simplify the calculations.

To begin the calculations, I first needed to find how much work is being done in order to stop the Vette in the 52.73m.

$$E_k = \frac{1}{2}mv^2$$
$$E_k = \frac{1}{2}(1315.42kg)(31)^2$$

From that I found the work needed to bring the car to a complete stop is $6.32 * 10^5 J$. From this I then have to calculate the force from each wheel to bring the car to rest.

$$W = Fd$$
$$6.32 * 10^5 J = F(52.73m)$$
$$F = \frac{6.32 * 10^5 J}{52.73m}$$

I was able to find that the total force applied to all 4 wheels would be 11.98 kN. The total force that would be applied through each wheel is 2995N.

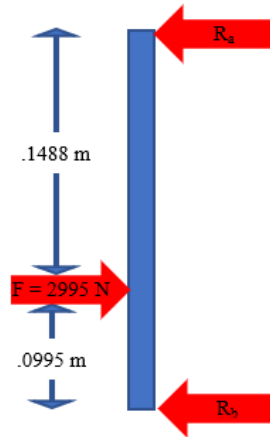


Figure 7: Free Body Diagram of Front Wishbone Suspension

It was then possible to calculate the reaction force, or the force applied at each the upper and lower control arms.

$$\Sigma F_y = 0 = R_{ay} + R_{by} = 0$$

$$R_{ay} = R_{by} = 0$$

$$+\circlearrowleft M_a = 0 = -2995N(.1488m) + R_{bx}(.1488 + .0995) = 0$$

I was able to calculate the reaction force that is applied trough the lower control arm, which is $1794.83 N$. And using this information it is possible to find the force applied through the upper control arm.

$$\Sigma F_x = R_{ax} - 2995N + 1794.83N = 0$$

$$R_{ax} = 1200.17 N$$

The upper control arm is expected to see a force of $1200.17N$ of force during hard breaking. In order to ensure that the driver is safe, a Factor of Safety of 4 is applied (7). This is done to ensure that the Control Arm can withstand a larger force than is expected.

$$S_d = F * f_s$$

$$S_d = 1200.17 N * 4$$

$$S_d = 4800.68 N$$

This $4800N$ of force will be used to preform a Finite Element Analysis in Soildworks to test the strength of the parts.

PROJECT MANAGEMENT

PROJECT BUDGET

Current budget is each of us willing to put in \$1000 toward our own part of the project. As well as selling body panels and parts we don't need in order to get more money for the project.

Table 2: Proposed Budget

PN	Description	QYT	Cost Per	Total cost
93306A722	1/2"-13 Thread Size, 2-1/2" Long	4	\$3.89	\$15.56
95856A275	Aluminum Nylon-Insert Locknut 1/2"-13 Thread Size (Pack of 5)	1	\$4.58	\$4.58
	Dayton WaterJet (Upper Control Arm)	3	\$140.00	\$420.00
827-94001	EARLY GM METRIC B/JOINT	1	\$36.99	\$36.99
355-3-3142R	CONTRL ARM BUSH SET F GM	1	\$27.22	\$27.22
	Total	10		\$504.35

An extra \$750 dollars was spent in order to help pay for the full roll cage for the car. As well as an extra \$200 was spent on miscellaneous supplies. Causing me to go over budget.

Table 3: Final Budget

PN	Description	QYT	Cost Per	Total cost
93306A722	1/2"-13 Thread Size, 2-1/2" Long	4	\$3.89	\$15.56
95856A275	Aluminum Nylon-Insert Locknut 1/2"-13 Thread Size (Pack of 5)	1	\$4.58	\$4.58
	Dayton WaterJet (Upper Control Arm)	1	\$140.00	\$140.00
827-94001	EARLY GM METRIC B/JOINT	1	\$36.99	\$36.99
355-3-3142R	CONTROL ARM BUSH SET F GM	1	\$27.22	\$27.22
	Roll Cage	1	\$750.00	\$750.00
	Miscellaneous Supplies			\$200.00
	Total	8		\$1,174.35

Because of this I was only able to afford one upper control due to all the expenses, roll cage and the miscellaneous supplies occurred prior the Upper control Arm being quoted. This caused me to only be able to afford one Control Arm. Only ordering one control arm would still allow for me to do my planned testing.

KEY MILESTONES

We plan on beginning the tear down of the car over Fall break. In doing this we will get a better understanding of a timeline for our project. The car suspension for the car will be completed and ready to go for the Tech Expo on April 18th. During this the week of April 15th, we will be working on finalizing the presentation. We will have the presentation done are ready to go for the week of April 22nd.

TESTING

For the testing of my parts I choose to go with a Finite Element Analysis. This will allow me to see how the forces will affect my part. I had originally planned on placing the part on to the Vette-Kart and performing break test starting at a slow speed and increasing the speed with at which I was hard breaking. But due to an unforeseen electrical issue I was unable to attach my parts to the car and test it in this fashion. A FEA was deemed satisfactory for testing.

FINITE ELEMENT ANALYSIS (FEA)

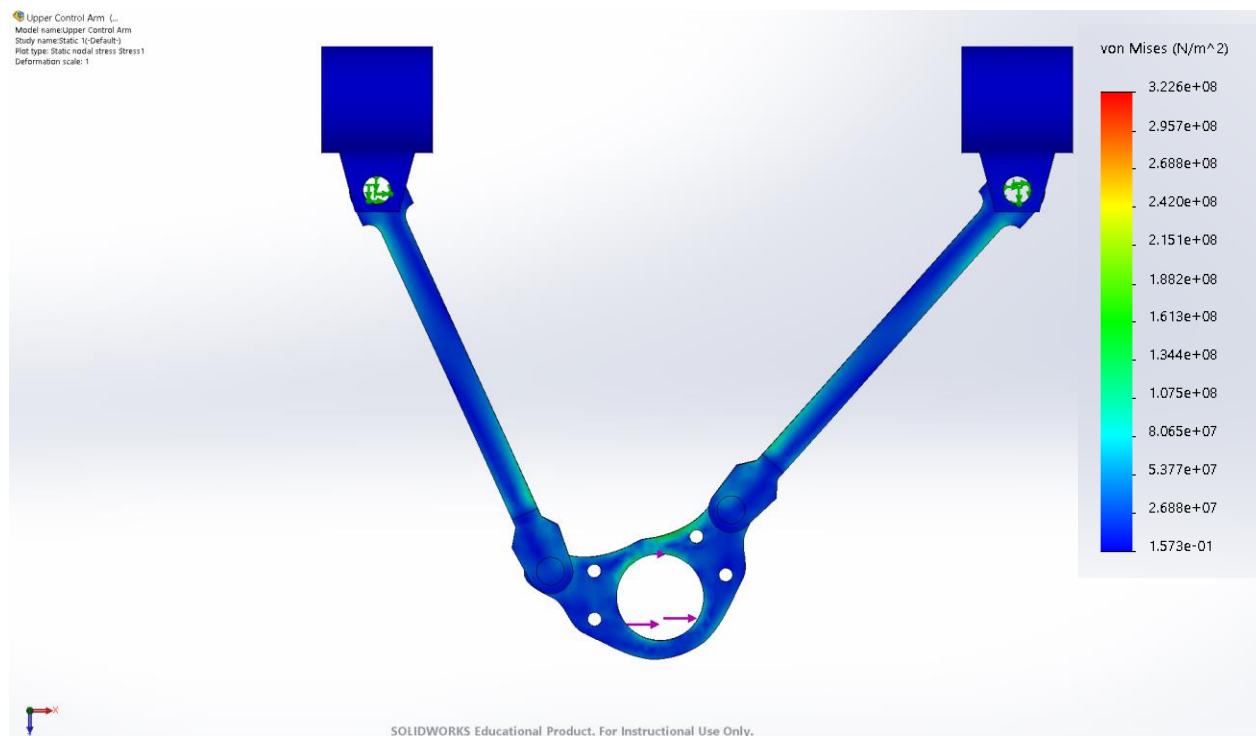


Figure 8: FEA of the Upper Control Arm Assembly

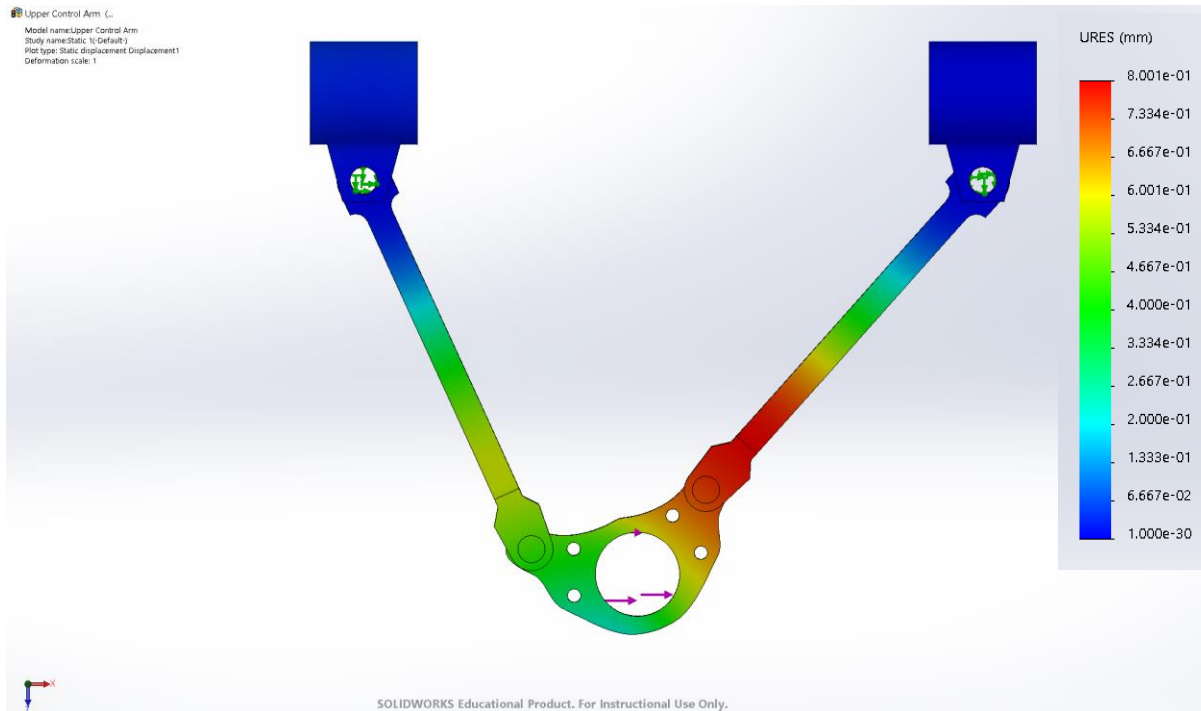


Figure 9: Displacement Calculated from the FEA

From the forces applied to the Upper Control arm, the FEA shows that I should expect a displacement of about .8mm of deflection. This is a small amount of deflection, that does not pose a risk to the part failing. As well ensuring that the part will still be useable after hard breaking.

MATERIAL SELECTION

In order to ensure that this part will last, I need a strong, light weight, and corrosion resistant metal. This metal also needs to be easily machined, so that the parts can be made safely and efficiently. I choose to go with Aluminum 6061 T6, this is a strong aluminum alloy that is readily available, that offers good corrosion resistance and is easily machined.

Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	<u>310 MPa</u>	45000 psi	AA; Typical
Tensile Yield Strength	<u>276 MPa</u>	40000 psi	AA; Typical
Elongation at Break	<u>12 %</u>	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	<u>17 %</u>	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	<u>68.9 GPa</u>	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	<u>324 MPa</u>	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, $K_t = 17$.
Ultimate Bearing Strength	<u>607 MPa</u>	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	<u>386 MPa</u>	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	<u>96.5 MPa</u>	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	<u>29 MPa-m^{1/2}</u>	26.4 ksi-in ^{1/2}	K_{Ic} ; TL orientation.
Machinability	<u>50 %</u>	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	<u>26 GPa</u>	3770 ksi	Estimated from similar Al alloys.
Shear Strength	<u>207 MPa</u>	30000 psi	AA; Typical

(7)

Figure 10: Material Property of Aluminum 6061 T6

FABERCATION AND ASSEMBLY

In order to have my parts fabricated I sent them out to be water cut. This was done in order to save time. I was able to find a place that had the materials on hand and was able to have the parts done same day. I used Dayton Waterjet to have my parts cut out. I had originally planned to water cut them myself at 1819 Innovation hub, but was unable to do so, due to the water jet being down.

The parts I received where slightly under sized due to the shop only having in Imperial sized stock. I had originally designed my parts to be made from Metric stock. In doing this there was no significate change in the part’s overall functions, and the parts would still be able to withstand the calculated forces.



Figure 11: Machining of the A-arm

In order to achieve the desired taper, a $\frac{1}{2}$ " end mill with a tapered edge was used. The tapered edge on the end mill allowed me to machine in the $\frac{1}{2}$ " fillet I needed to reduce the stress concentration, that would have been present if it had been a flat corner cut.



Figure 12: Slot Being Cut into the A-Arm

In order to cut the slot into the A-arms I used a 3/8" slot end mill. This was just slightly oversized which was perfect for cutting out. This was done unintentionally, but was a pleasant surprise, which cut down on the total fabrication time.

ASSEMBLY



Figure 13: Assembled Upper Control Arm

Once the parts were finished with machining all parts were bolted together with corrosion resistant bolts, and lock washers. Polyurethane bushings are to be pressed into the Connecting Joint. The stock support bar is to be reinstalled in between each connecting joint. The replacement ball joint is to be installed onto the ball joint mount. Then the Upper Control is to be mounted back onto the car in the reverse order of taking the stock upper control arm. But due to the bushing being on back order I was unable to get them in time for this project. They are projected to get in sometime in early May. At that time I will be able to make another control arm as well as fit both to the Vette.

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APPENDIX A – SURVEY & SURVEY RESULTS

C4 Corvette Survey

This survey will be used to help us gain a better understanding of necessary changes need to be done on a C4 Corvette to improve its handling, safety, speed. This is for our senior design project, any feedback will helpful with our project.

How important is each feature to you in a Corvette?

Please circle the appropriate answer. 1=Low importance 5=high importance

Safety	1	2	3	4	5
Handling	1	2	3	4	5
Speed	1	2	3	4	5
Appearance	1	2	3	4	5
Ride comfort	1	2	3	4	5
Sound	1	2	3	4	5
Maintenance	1	2	3	4	5
Ability to Modify	1	2	3	4	5
Fuel Consumption	1	2	3	4	5

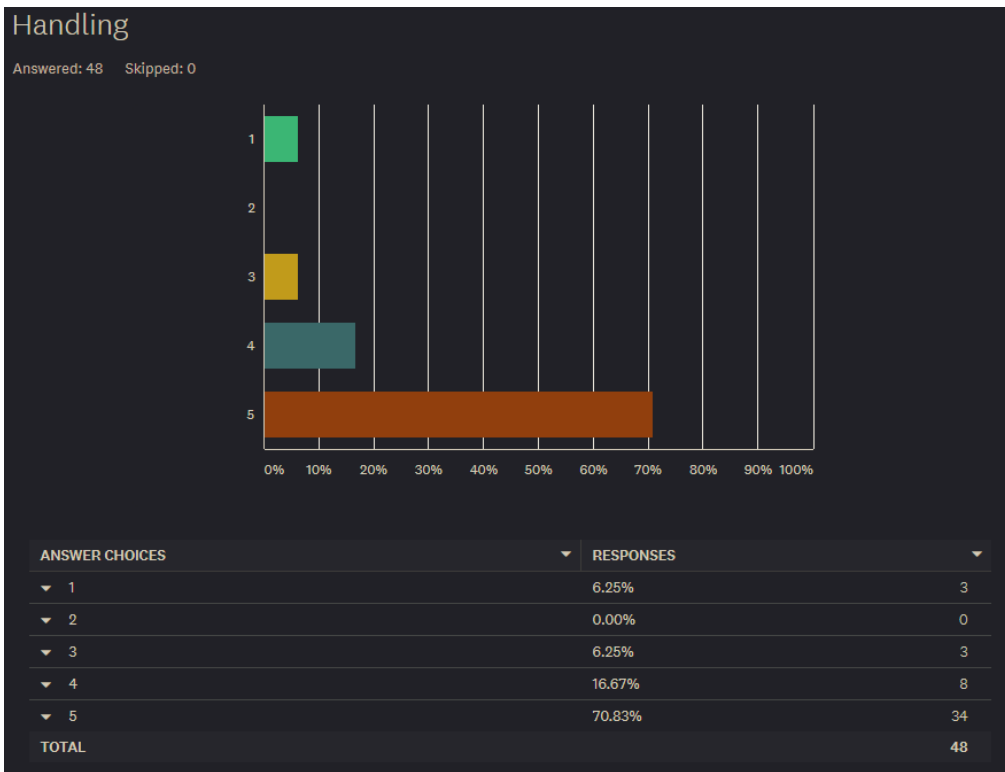
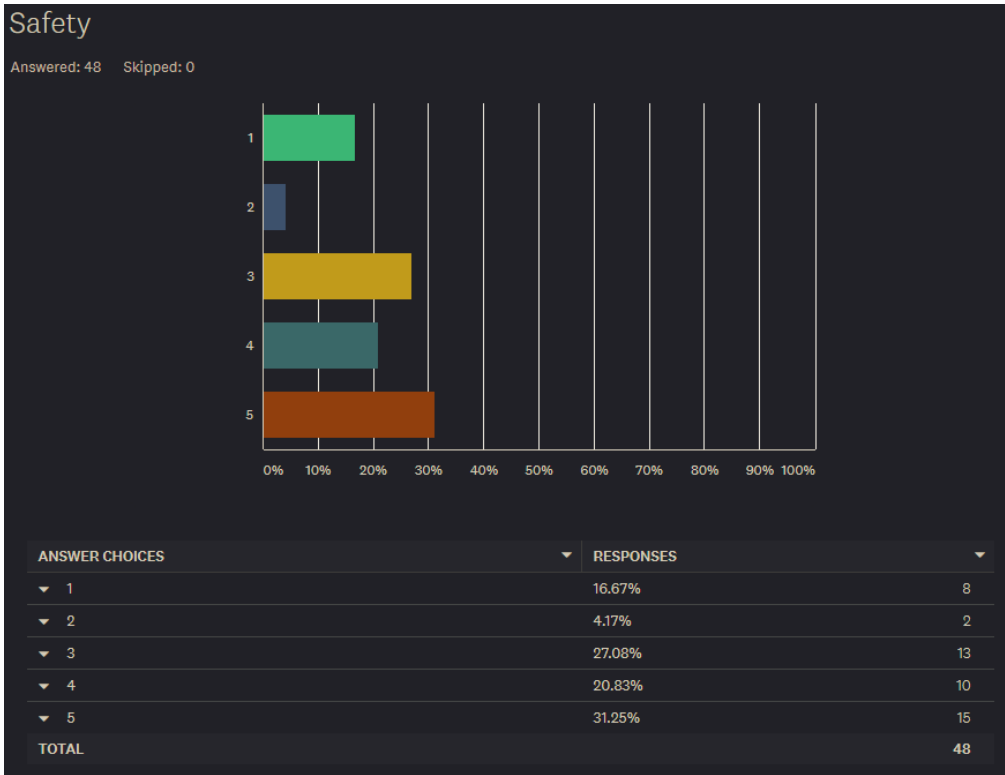
Overall satisfaction with the C4 Corvette

Please circle the appropriate answer. 1=very Unsatisfied 5=very satisfied

1 **2** **3** **4** **5**

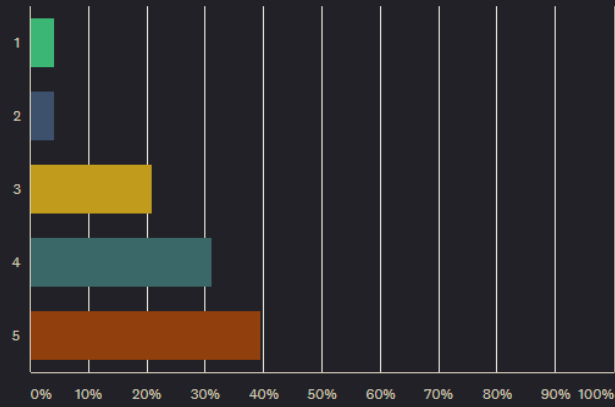
Any other feedback on the C4 Corvette.

SURVEY RESULTS



Speed

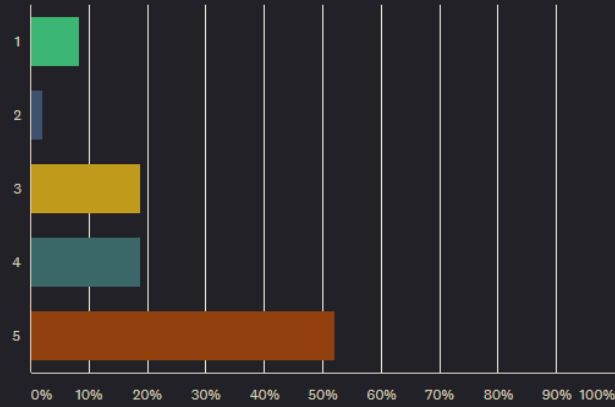
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ANSWER CHOICES	RESPONSES
▼ 1	4.17% 2
▼ 2	4.17% 2
▼ 3	20.83% 10
▼ 4	31.25% 15
▼ 5	39.58% 19
TOTAL	48

Appearance

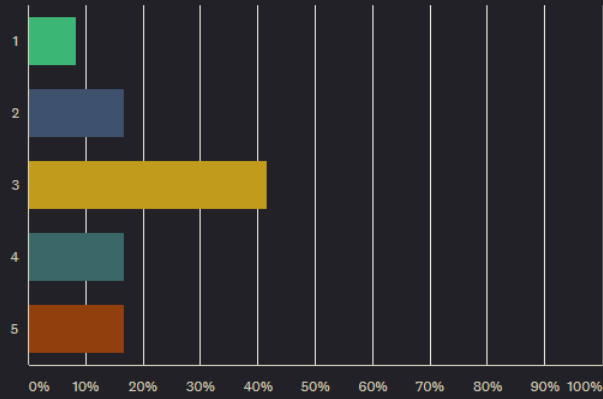
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ANSWER CHOICES	RESPONSES
▼ 1	8.33% 4
▼ 2	2.08% 1
▼ 3	18.75% 9
▼ 4	18.75% 9
▼ 5	52.08% 25
TOTAL	48

Ride comfort

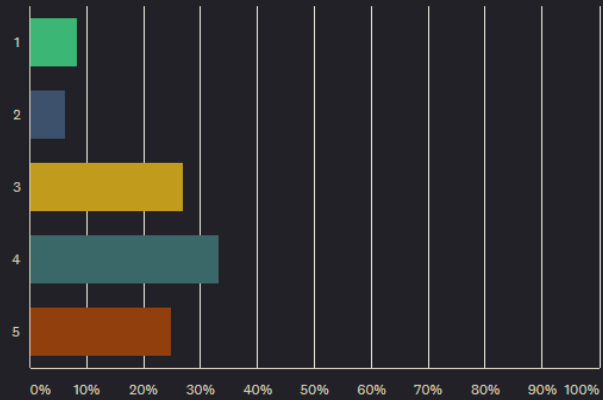
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ANSWER CHOICES	RESPONSES
▼ 1	8.33% 4
▼ 2	16.67% 8
▼ 3	41.67% 20
▼ 4	16.67% 8
▼ 5	16.67% 8
TOTAL	48

Sound

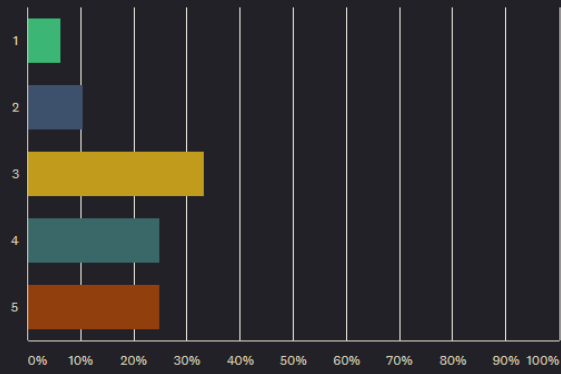
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ANSWER CHOICES	RESPONSES
▼ 1	8.33% 4
▼ 2	6.25% 3
▼ 3	27.08% 13
▼ 4	33.33% 16
▼ 5	25.00% 12
TOTAL	48

Maintenance

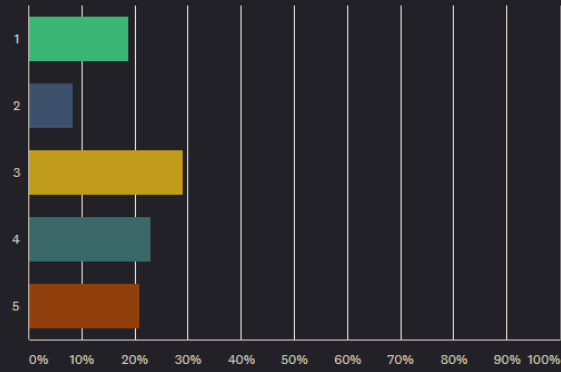
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ANSWER CHOICES	RESPONSES
1	6.25% 3
2	10.42% 5
3	33.33% 16
4	25.00% 12
5	25.00% 12
TOTAL	48

Ability to Modify

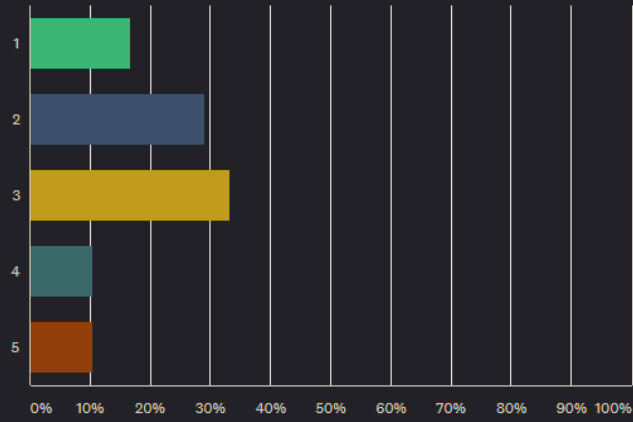
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ANSWER CHOICES	RESPONSES
1	18.75% 9
2	8.33% 4
3	29.17% 14
4	22.92% 11
5	20.83% 10
TOTAL	48

Fuel Consumption

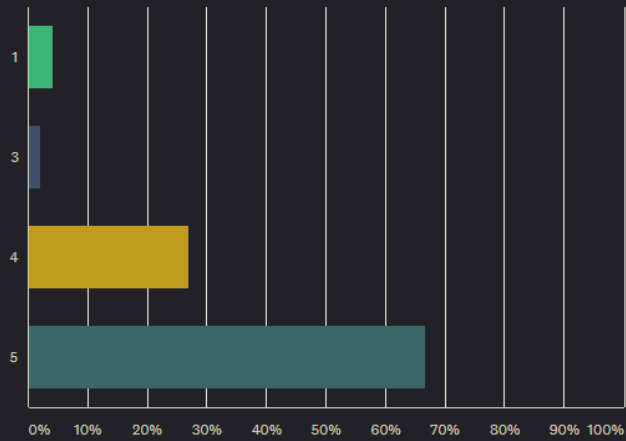
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ANSWER CHOICES	RESPONSES
▼ 1	16.67% 8
▼ 2	29.17% 14
▼ 3	33.33% 16
▼ 4	10.42% 5
▼ 5	10.42% 5
TOTAL	48

Overall satisfaction

Answered: 48 Skipped: 0



ANSWER CHOICES	RESPONSES
▼ 1	4.17% 2
▼ 3	2.08% 1
▼ 4	27.08% 13
▼ 5	66.67% 32
TOTAL	48