Final Report

2024 Cowboy Racing Baja Senior Design Team

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Table of Contents

1 Problem Description

The objective of the 2024 Cowboy Racing Baja Senior Design Project is to design and manufacture a front suspension system for the 2023-2024 Cowboy Racing Mini Baja Car. The objectives of the designed front suspension are to maximize the strength to weight ratio, minimize unsprung weight, and obtain suitable geometry for off road vehicles. Redesigning the front suspension to these objectives will increase the handling and performance of the Baja Car.

2 Overall Solution and Subsystems

Figure 2.1 shows the designed front suspension for the 2024 Baja Car. The front suspension is composed of 3 subsystems: A-Arm and Tie Rod material, suspension geometry, and knuckle design.

Figure 2.1: Overall Front Suspension on 2024 Cowboy Racing Baja Car

2.1 A-Arm and Tie Rod Material

Materials were evaluated based on the problem description of increased strength to weight ratio and reduced unsprung weight. Through analysis of material properties, bending strength, and bending stiffness it was concluded that the most suitable material for the construction of A-Arms and Tie Rods was Webco's FinishLineST™ 4130 steel tubing. Our analysis also concluded that the most suitable size of tubing was 1" outer diameter with 0.049" wall thickness. This material satisfies our problem description by having a greater strength-to-weight ratio as well as being lighter than the current 4130 Chromoly used by the Baja Team.

2.2 Suspension and Steering Design

The suspension geometry design consisted of an upper and lower A-Arm, shock, and tie rod. The suspension and steering design satisfy the objective of a suitable off road suspension. Figures 2.2 and 2.3 show the designed upper and lower A-Arms respectively. The designs were created using a 2-D SolidWorks model and then a 3-D model in Optimum Kinematics to validate the design using simulations. We iterated through multiple 2-D models and created screening and scoring matrices with weights on the suspensions setting the team prioritized. The Optimum Kinematics simulations were run using the maximum body roll and steering angle calculations to simulate the maximum effects experienced by the Baja car.

Figure 2.2: Upper A-Arm

Figure 2.3: Lower A-Arm

2.3 Knuckle Design

The knuckle was comprised of two pieces, a base and an upright, and was CNC milled out of 6061 T6 aluminum. The material choice satisfies the objective of reducing unsprung weight. The two pieces were bolted together and secured with dowel pins and then TIG welded together. Figures 2.4-2.6 show the knuckle base, upright, and fully assembled knuckle, respectively. 6061 T6 aluminum was chosen to maximize the strength-to-weight ratio and because stock was already on hand which reduced cost and lead time. The knuckle was already constrained to specific dimensions by the suspension geometry, so manufacturing and assembly were the two main concerns. Finite Element Analysis (FEA) was done on the knuckle to ensure that it would withstand any shock loading that would occur at competition.

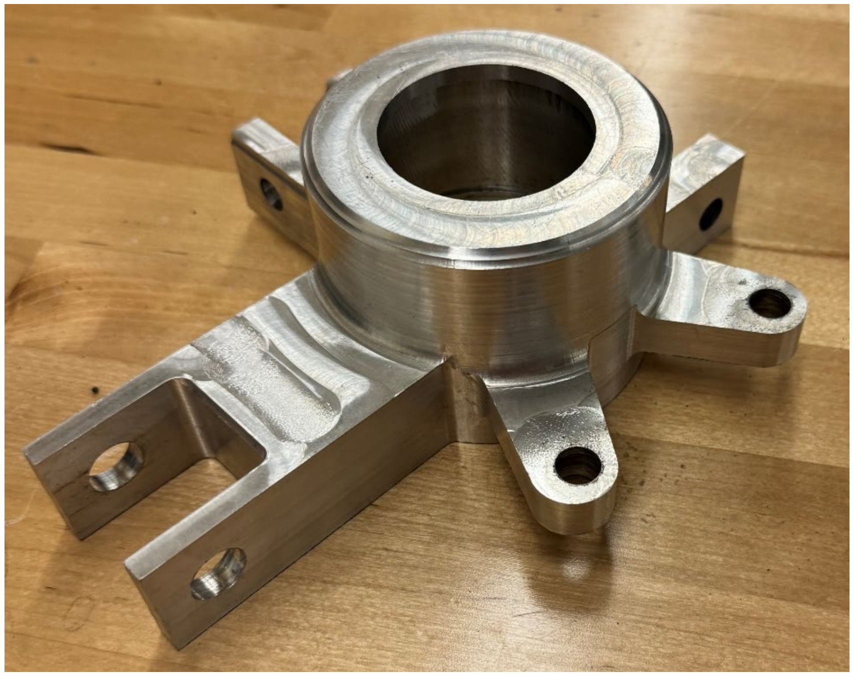


Figure 2.4: Knuckle Base

Figure 2.5: Knuckle Upright

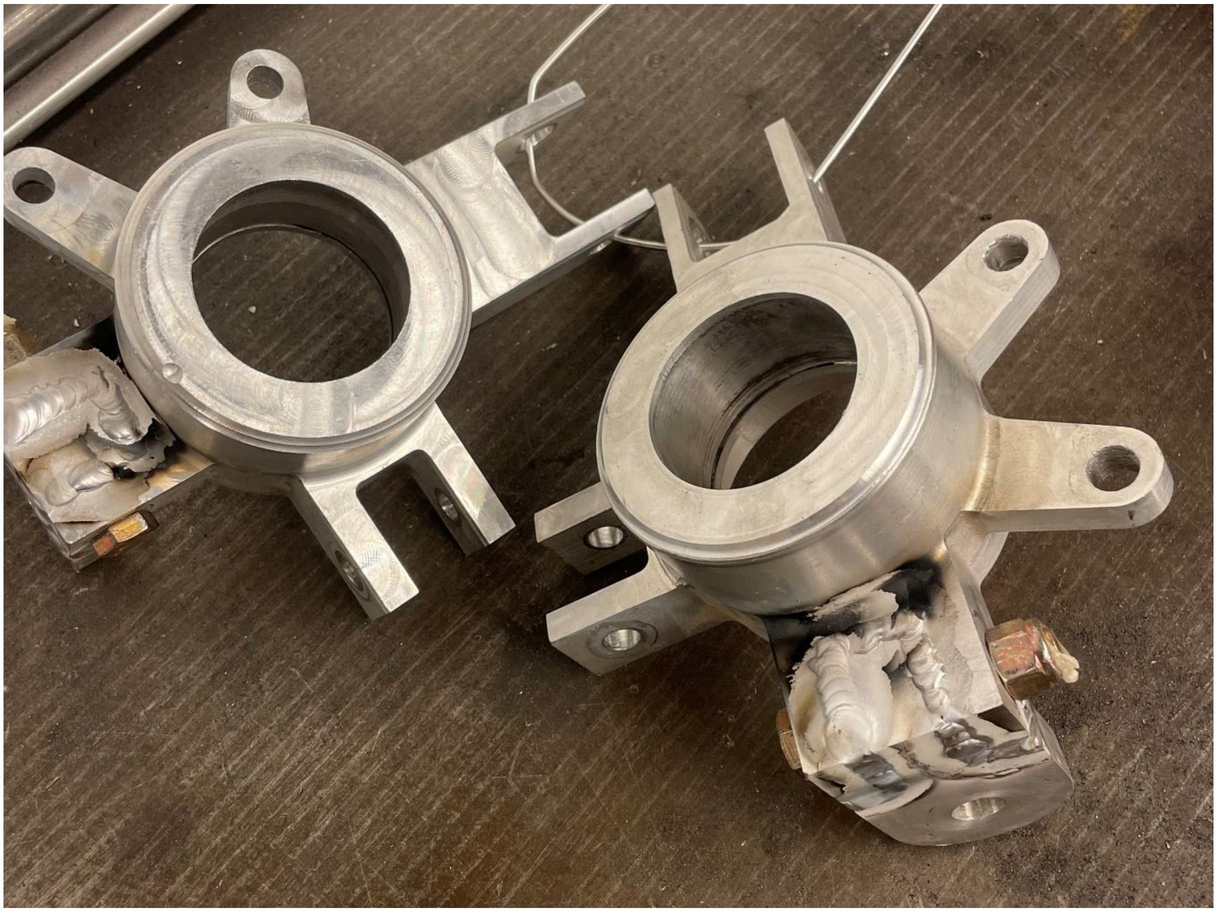


Figure 2.6: Fully Assembled Knuckle with Welded Upright

3 Engineering Principles

For this project, the team combined the 4 years of classes that the team has taken at OSU. The team utilized Strengths and Materials for the kinematics on the design of the A-arms and knuckles. Also, the team utilized this knowledge when choosing the material for the A-arm and knuckles knowing the strengths of each material. The team also used knowledge from Mechanical Design and Physics to determine the forces that the design will be under and the failure points of the materials. The team also utilized skills learned from Intro to MAE Design such as working, communicating, and scheduling with group members; as well as using Gantt charts to plan our work. Finally, we used skills learned in CAD classes to create our design in SolidWorks.

4 Environmental, Health, and Safety

Our Environment, Health, and Safety codes for this project were based on the OSU EHS Laboratory Safety Checklist. We followed these codes as all our work would be completed within the DML. The codes that were followed by all team members include wearing the correct PPE such as safety glasses, long pants, closed-toed shoes, and mask/hearing protection as needed. Also, all team members were required to have taken the correct training before operating machinery and then safely operating the machinery. The team would also follow all emergency protocols OSU or the DML gave. Next, team members will keep the workspace clean to avoid injuries and eat and drink in the correct lab locations. The team would also follow any SOPs when completing tasks. Finally, when operating the Baja car, the correct driver's PPE was worn by the drivers operating the student-made vehicle in accordance with the Baja SAE 2024 rules.

5 Engineering Codes, Standards, and Guidelines

For the project, we utilized multiple Engineering codes throughout the design process. The first code was the Baja SAE 2024 Rules. These established rules that we followed regarding suspension constraints and welding tests for our design. The rules were used to clarify what could be done with the design. We also followed SAE International codes to establish uniform engineering nomenclature for suspension systems and their components used on passenger cars, light trucks, and multipurpose vehicles. This allowed the team to have a common vocabulary for all terms discussed during the design process. Finally, we utilized ASTM A4050, the Standard Specification for General Requirements for Carbon and Low Alloy Steel Tubes. This code helped us determine the strengths of the steel tubing used in our design.

6 Knowledge Acquisition

The team acquired our knowledge from multiple sources. Our first source was textbooks. We utilized Fundamentals of Vehicle Design, Race Car Vehicle Design, Shigley's Mechanical Design Textbook, and Chassis Design: Principles and Analysis. These textbooks provided the team with knowledge of the different suspension settings and the values to hit for each setting. The team also benchmarked the top Baja teams such as Michigan, RIT, and ETS to see what suspension characteristics the teams were running so we could utilize knowledge from their designs. The team also gained knowledge from YouTube videos such as Intro to Vehicle Design to gain a better understanding of suspensions settings and Optimum Kinematics Tutorials. The tutorials helped the team run Optimum Kinematic software to complete simulations on our suspension design. Finally, we received manufacturing advice from our advisors and DML staff, Chip Palmer, Jonathon Powers, and John Gage.

7 Concept Evaluation

The team evaluated many concepts for material choice, suspension geometry, and knuckle design. The following subsections show the various concepts we considered and explain the engineering justifications for those design choices.

7.1 A-Arms and Tie Rod Material

To select a suitable material a variety of materials from Webco's catalog were initially selected as candidates. These candidates included various grades of stainless steel, nickel alloy, and FinishLineST™ tubing. Figure 7.1 shows the screening matrix of all the candidate materials evaluated based on material properties.

	Concepts									
	Control	Stainless Steel					Nickel Alloy		Specialty	
Selection Criteria	4130 Chromoly	304 Austenitic	316 Austenitic	2003 Duplex	2507 Duplex	439 Ferritic	Nickel alloy 625	Nickel alloy 825	4130 FinishLineST™	1026 FinishLineST™
Ultimate Strength	0	-	-	+	+	-	+	+	+	-
Yield Strength	0	-	-	+	+	-	-	-	-	-
Density	0	-	-	+	+	+	-	-	0	0
Modulus of Elasticity	0	-	-	-	-	+	-	-	0	+
Net		-4	-4	+2	+2	0	-2	-2	0	-1
Rank		5	4	2	1	3	2	1	1	2
Continue		No	No	No	Yes	No	No	Yes	Yes	No

Figure 7.1: Material Selection Screening Matrix A-Arms

From the screening matrix the best candidate for each type of tubing was selected to move forward with analysis. The best candidates were determined by evaluating them based on material properties such as ultimate and yield strength, density, and modulus of elasticity. Since some candidates had the same score in the screening matrix, a closer analysis of material properties was made to determine the best candidate was determined. Figure 7.2 shows the scoring matrix for the selected candidates from the screening matrix, the scoring matrix evaluated the materials based on material properties from the screening matrix as well as their bending properties and manufacturability.

		4130 Chromoly Tubing 1x0.049		2507 Duplex Stainless Steel 1x.049		AL825 Nickel Alloy 1x.049		FinishLineST 4130 1x.049	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Ultimate Strength	3	1	3	5	15	3	9	2	6
Yield Strength	3	4	12	5	15	1	3	3	9
Mass/length (g/cm)	2	3	6	5	10	1	2	3	6
Bending Stiffness	5	5	25	4	20	1	5	5	25
Bending Strength	5	4	20	5	25	1	5	3	15
Bending Strength/Mass	5	4	20	5	25	1	5	3	15
Manufacturability	4	4	16	1	4	4	16	4	16
Total		**102**		**114**		**45**		**92**	
Rank		Control		1		3		2	
Develop?		Develop		No		No		Develop	

Figure 7.2: Material Selection Scoring Matrix A-Arms

From analysis of the scoring matrix it was determined that the FinishLineST™ tubing was most suited for the scope of the project. The Duplex stainless steel was eliminated from the selection process due to an inability to heat treat and weld the material in house.

7.2 Suspension Geometry

Our suspension geometry design started with determining desirable suspension geometry parameters based on the knowledge acquisition described in Section 6. Listed below are the parameters and desired values we determined to be critical for optimizing an off-road suspension.

Critical suspension geometry parameters and values:

- Roll center axis distance to the center of gravity: minimize this parameter
  - Reasoning: Since the center of gravity of the Baja Car is fixed, the main way to reduce body roll is to minimize the distance from roll center axis to the center of gravity. Since the Baja Car is under serious body roll effects during turning, this will be a significant criterion we will be focusing on (Chassis Design).
- Scrub radius: < 0.5 inches
  - Reasoning: Having the scrub radius within this range will reduce the forces on the tie rod. In previously designed Baja Cars, the team has had issues with tie rods bending at competition; minimizing the forces on the tie rod will reduce the risk of this happening. In addition, small scrub radii track well over rough roads (Race Car Vehicle Dynamics).
- Static Camber: 0 Degrees
  - Reasoning: Having no static camber will maximize the contact patch of our tire on straightaways. Since the Baja Car this year is all-wheel drive an increased

contact patch on the front suspension increases straight line acceleration (Race Car Vehicle Dynamics).

- Static toe: toe-in .5 degrees
  - Reasoning: Having a small amount of toe-in on the front tires increases stability. This will also introduce some understeer into our car, but since we do not need the tightest steering accuracy, this is a tradeoff, we were willing to make (Chassis Design).
- KPI: 0-15 Degrees
  - Reasoning: KPI is mainly dependent on scrub radius, as long as the scrub radius goal is met within the KPI range this parameter is satisfied (Race Car Vehicle Dynamics).
- Wheelbase: ≤ 64 inches
  - Reasoning: SAE Mini Baja rules state the car can have a maximum width of 64 inches. We want to be as close to this width without going over to reduce the body roll while turning (Baja Rule Book).
- Ground clearance: ≥ 10 inches
  - Reasoning: This is a goal of the Baja Team to reduce the risk of bottoming out during rock crawling.
- Variable Camber: 5 Degrees
  - Reasoning: We had a goal of 5 Degrees because camber effects offset Body Roll; however, the body effects due to camber are not as significant. Therefore, it was more important to focus on making the distance of roll center axis to center of gravity smaller to offset body roll (Chassis Design).
- Caster: 6 Degrees
  - Reasoning: The Baja Car frame already has 6 Degrees of built-in caster. We investigated making the Caster 0 Degrees as it would improve our anti-dive percentage by 16.5% but would sacrifice handling on uneven surfaces and make steering heavy. Since the Baja Car is an off-road vehicle, we would not want to change the caster to improve our anti-dive percentage (Chassis Design).

Based on the criteria above we created different iterations of our 2-D Model within SolidWorks and picked the best versions to simulate within Optimum Kinematics. The Optimum Kinematic Simulation data then provided us with the data we needed to determine our final suspension geometry settings. Those suspension settings will be used to constrain and create the knuckle design.

7.3 Knuckle Design

The Knuckle had two major design concepts that we decided between. The first design was a single billeted aluminum knuckle with the suspension characteristics set by the suspension geometry models. The second design was a two-piece billeted aluminum knuckle that would be fastened together. Ultimately the team landed on the second design for ease of manufacturing and assembly in house.

8 Engineering and Analysis

8.1 Material Selection

8.1.1 A-Arm and Tie Rods

To analyze materials for the A-Arm construction, material properties were used to calculate bending stiffness and bending strength. There are two main reasons why we calculated bending stiffness and bending strength, the first is because bending forces are the critical forces in a double A-Arm suspension The second is because the Baja SAE rulebook (Baja Rule Book) requires bending stiffness and bending strength be calculated for structural members. The bending stiffness and bending strength calculations are shown in equations 1 and 2, respectively.

$$k_b = EI \tag{1}$$

$$S_b = \frac{S_y I}{c} \tag{2}$$

A variety of materials from Webco's catalog were initially selected as candidates. Through analysis of material properties, bending strength, and bending stiffness it was concluded that the most suitable material was Webco's FinishLineST™ 4130 steel tubing. Our analysis also concluded that the most suitable size of tubing was 1" outer diameter with 0.049" wall thickness. Material properties and analysis of selected candidates are shown in Figure B.8.1 and B.8.2.

The only deviation from the design presented in the Critical Design Report occurred during fabrication. It was determined that 1x.049" tubing could not be bent to the desired angle without yielding, to accommodate for this 1x.065" tubing was used for the bent sections of the A-Arms.

8.1.2 Knuckle

The knuckle was manufactured out of 6061-T6 Aluminum. Aluminum was chosen over steel due to a few reasons. Aluminum has more desirable material properties and is significantly lighter than steels, this reduces unsprung weight. 6061-T6 aluminum was also chosen due to availability and safety factors. The Cowboy Racing Baja Team has stock of 6061-T6 aluminum on hand, which reduces material cost and lead time to manufacture. 6061-T6 has also already been analyzed and proven to be safe for use on the Baja Car. The scoring matrix for the knuckle material is shown in Figure B.8.3

8.2 Suspension Geometry Design

8.2.1 2-D Models

The two-dimensional model, shown in Figure 8.1, aided in the iterative design process. The model allows parameters such as A-Arm lengths, shock length, knuckle length, and KPI angle to be modified. This allowed us to have many different configurations as well as easily compare the different configurations.

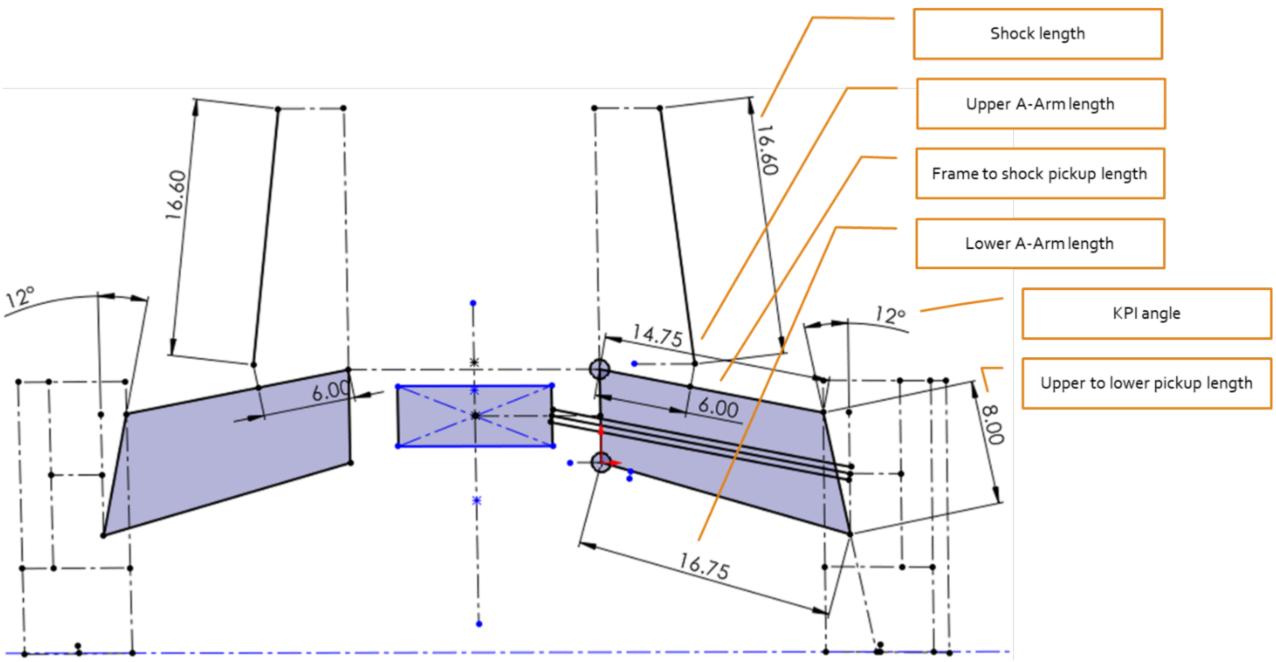


Figure 8.1: 2-D Suspension Geometry Model

From the 2-D model, 18 unique suspension geometries were created and compared based on the criteria of total width, ground clearance, distance to center of gravity, scrub radius, and static and variable camber. The screening matrix, shown in Figure 8.2, illustrates the performance of each suspension geometry variation. Analyzing the screening matrix yielded 4 versions to be analyzed in Optimum Kinematics. It should be noted that variation 3 had a greater score than the selected versions, however, it was not selected to continue development due to the scrub radius parameter being significantly outside the range of target values.

		Suspension Geometry Variations																	
Criteria	Control	1	2	3	4	5	6	7	8	18	9	10	11	12	13	14	15	16	17
Total Width	0	-	+	+	+	+	+	+	+	+	-	-	-	0	0	0	+	+	+
Ground Clearance	0	-	+	0	+	-	-	0	0	+	-	-	-	+	+	+	0	0	+
Distance to Cg	0	0	0	0	+	-	-	0	-	+	-	0	+	0	-	-	-	-	+
Scrub Radius	0	+	-	-	-	-	0	0	0	-	-	-	-	+	+	+	+	+	+
Static Camber	0	-	+	-	-	+	+	-	-	+	0	+	+	+	+	+	+	+	+
Variable Camber	0	-	+	-	-	0	0	-	0	+	0	0	-	0	0	0	+	0	-
Net		-3	3	-2	0	-1	0	-1	-1	4	-4	-2	-2	3	2	2	3	3	4
Rank		1	1	4	2	3	2	3	3	1	3	2	1	1	2	3	2	2	1
Continue		No	No	No	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	No	Yes

Figure 8.2: Suspension Geometry Screening Matrix

With the versions selected to proceed in development, a scoring matrix, shown in Figure 8.3, was created with the added criteria of wheel travel. The criteria of most significance to the scope of the project are as follows: total width, roll center distance to the center of gravity, wheel travel, and scrub radius. The weightings for the criteria were determined from the analysis of suspension components and parameters. Analysis of the scoring matrix resulted in three possible versions to be analyzed in Optimum Kinematics, preliminary analysis of the 2-D model showed the most viable suspension geometry settings to be Version 1.

		Version 1		Version 2		Version 3		Version 4	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Total Width	5	4	16	1	4	3	12	5	20
Ground Cleara	2	4	16	1	4	4	16	5	20
Distance to Cg	5	4	16	5	20	4	16	4	16
Scrub Radius	3	5	25	2	10	4	20	2	10
Static Camber	3	2	4	5	10	5	10	5	10
Variable Camb	1	3	9	2	6	5	15	2	6
Wheel Travel	4	4	16	2	8	3	12	5	20
Total		**102**		**62**		**101**		**102**	
Rank		1		3		2		1	
Develop		Develop		No		Develop		Develop	

Figure 8.3: Suspension Geometry Scoring Matrix

8.2.2 Optimum Kinematics

After completing the 2-D model iterations, we created front suspension models based on the 2-D models within Optimum Kinematics. To do this we measured from a reference point within the 2-D model that is represented in the 3-D Optimum Kinematic model. This reference point is in the center of the Baja Car, at ground level along the Baja Car front axle. The reference point is shown in Appendix B in Figure B.8.8. Taking measurements from this origin point in the 2-D model we created the 3-D model. The points that we referenced to create the suspension geometry are the pick-up points of the A-Arms on the Baja Car, A-Arm attachment points on the knuckle, tie rod attachment on the knuckle and steering rack, shock attachment points on the Baja Car and upper A-Arm tab, and wheel dimensions. The points are shown in Appendix B in Figure B.8.8 through B.8.12. We repeated this process for all three front suspension models that we would be testing within Optimum Kinematics. The front suspension models for all three versions and the 3D Points are shown in Appendix B in Figure B.8.13 through B.8.18.

After creating the three front suspension models, we needed to create a rear suspension model to run the simulations. We had to do this because you can only run simulations on a full-vehicle model within Optimum Kinematics. The rear suspension on the Cowboy Racing Baja Car is a Semi Trailing Arm setup; however, this suspension model is not available within Optimum Kinematics. To bypass this issue, we modeled the rear suspension of the Baja Car as a Double A-Arm setup and modeled the 3-D points as close to the Baja Car as possible. The Rear Suspension model and 3D Points are in Appendix B in Figures B.8.19 and B.8.20. This does put some inconsistency in our modeling process. However, since all the front suspension geometries would have the same rear suspension model, the inconsistencies would be constant and still allow for interpolation of data from the front suspension models.

We then created the three vehicle models which took each of the front suspension models and paired them with the rear suspension model. The wheelbase, center of gravity, front weight percentage, left weight percentage, and front brake bias were inserted to create the full vehicle models. The three vehicle models and Baja Car parameters are shown in Appendix B in Figure B.8.21 through B.8.24.

After creating the vehicle models, we set up the simulation parameters. The four simulation parameters that Optimum Kinematic offers are heave, roll, pitch, and steering. The main parameters we focused on were roll and pitch. We focused on these since the Baja Car endures serious body roll effects and steering angle during competition. We didn't test heave since it is more of a street racing parameter, and pitch is mainly determined by the relationship between the front and rear suspension. Since the rear suspension was not within the project's scope, pitch was not a parameter we wanted to use to test our versions. We determined the maximum and minimum body roll and steering angles from a MATHCAD file. The MATHCAD file required the inputs of distance from roll center axis to the center of gravity and other Baja Car parameters to output the maximum and minimum body roll and steering angles. For body roll we would simulate the vehicle rolling from 15 degrees to -15 degrees and steering angle within a range of 27.5 degrees to -27.5 degrees. We simulated all vehicle models with both parameters running at the same time. The Simulation Data Inputs for the Body Roll and Steering Angle Simulation are shown in Appendix B in Figures B.8.25 and B.8.26.

We received all the simulation data for the three versions and took the average values for four parameters: total width, average distance from the center of gravity to roll center in Z-axis, scrub radius, and variable camber. The simulation data from Optimum Kinematics for each version is shown in Appendix B in Figures B.8.27 through B.8.29. We created a table of these values and then compared them within a scoring matrix to determine which suspension version we would base it off. The table of values is shown in Figure 8.4 and the scoring matrix is shown in Figure 8.5. Based off the scoring matrix we determined that Version 1 was the most suitable suspension geometry since it had the best overall characteristics. It had a large total width of 60 inches, an improved distance from the center of gravity to the roll center in Z-axis at 8.29 inches, a great scrub radius of 0.23 inches, and a variable camber of 20.06 degrees. The one concerning portion of data was the very large variable camber value that was being outputted; however, we realized this was due to the spring stiffness being set at 1 N/mm and this value could not be changed since we did not have a certain paid Optimum Kinematic Add-On. This concluded the first iteration of Optimum Kinematic simulation testing.

Criteria	Version 1	Version 3	Version 4
Total Width (in)	60	58.6	61.6
Average Center of Gravity Value (in)	18.52	18.44	18.16
Average Roll Center Height in the Z-Axis (in)	10.23	10.18	10.56
Average Distance from Center of Gravity to Roll Center in Z-Axis (in)	8.29	8.26	7.6
Scrub Radius (in)	0.23	0.29	0.55
Max Camber Value (deg)	9.59	9.48	9.55
Minimum Camber Value (deg)	-10.47	-10.72	-9.98
Variable Camber (deg)	20.06	20.2	19.53

Figure 8.4: Optimum Kinematic Simulation Data Table

		Version 1		Version 3		Version 4	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Total Width	5	4	20	2	10	5	25
Average Distance from Center of Gravity to Roll Center in Z-Axis	4	4	16	4	16	5	20
Scrub Radius	4	5	20	5	20	2	8
Variable Camber	2	2	4	2	4	2	4
Total		**60**		**50**		**57**	
Rank		1		3		2	
Develop?		Develop		Discontinue		Discontinue	

Figure 8.5: Optimum Kinematic Simulation Data Scoring Matrix

After creating the initial knuckle design and full assembly design, we realized we had a clearance issue with the top ball bearing and the rim. For this, we changed the knuckle design and re-ran simulations on the suspension geometry design with the new coordinates. The Optimum Kinematic suspension model, vehicle model, and simulation data are in Appendix B in Figures B.8.30 to Figure B.8.33. The redesigned Version 1 model has a wheelbase of 60.2 inches, a distance from the center of gravity to roll center in Z-axis of 8.66 inches, a great scrub radius of 0.086 inches, and a variable camber of 20.92 degrees. For the redesigned suspension geometry, we improved the total width and scrub radius but diminished the distance from the center of gravity to the roll center and variable camber. These redesigned values are still within the acceptable range for our project. The suspension geometry values for the Redesign of Version 1 compared to the original Version 1 are shown in Figure 8.6 below.

Criteria	Version 1	Redesign of Version 1
Total Width (in)	60	60.2
Average Center of Gravity Value (in)	18.52	18.52
Average Roll Center Height in the Z-Axis (in)	10.23	9.859
Average Distance from Center of Gravity to Roll Center in Z-Axis (in)	8.29	8.661
Scrub Radius (in)	0.23	0.086
Max Camber Value (deg)	9.59	9.9
Minimum Camber Value (deg)	-10.47	-11.018
Variable Camber (deg)	20.06	20.918

Figure 8.6: Comparison of Optimum Kinematic Simulation Data for Version 1 and Redesign of Version 1

8.3 Knuckle Design

The knuckle is the connecting piece between the tie-rod, upper A-Arm, lower A-Arm, and the wheel hub, as seen in Figure 8.7 It is vital for steering and proper suspension function. Our design objectives are to maximize the strength to weight ratio, lower manufacturing costs, and ensure that in-house production is feasible.

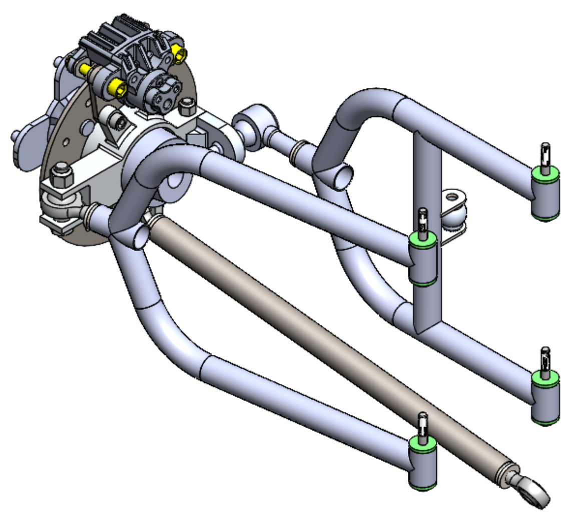


Figure 8.7: Full Suspension SolidWorks Assembly

The design freedom of the knuckle was limited by the suspension geometry selected in Section 8.2, and the hubs and cv joints previously selected by the Cowboy Racing Team. This made the design of the knuckle straightforward as the bearing housing must be a certain size and the knuckle connection points must align with the suspension geometry.

Design freedom was also limited by the capability of in-house manufacturing. Since the knuckle is intended to be CNC milled, the abstract geometry of the A-Arm connections would pose significant difficulty when manufacturing. To solve this problem the team decided to create the upper A-Arm connection upright, shown in Figure 8.9, to be CNC milled as a separate part from the base knuckle, shown in Figure 8.8. The upright was bolted onto the base knuckle and secured with dowel pins to restrict motion of the upright in both lateral directions. The connections were then TIG welded to the upright wouldn't shear the dowel pins. When the full assembly was put together and the clearance issue was discovered the upper A-Arm connection was redesigned to eliminate the clearance issue, this redesigned upper A-Arm upright is shown in Figure 8.10.

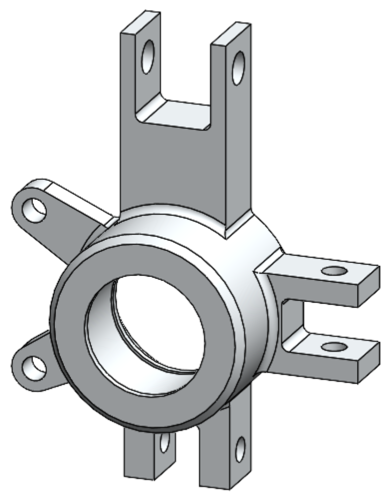


Figure 8.8: Base Knuckle SolidWorks Model

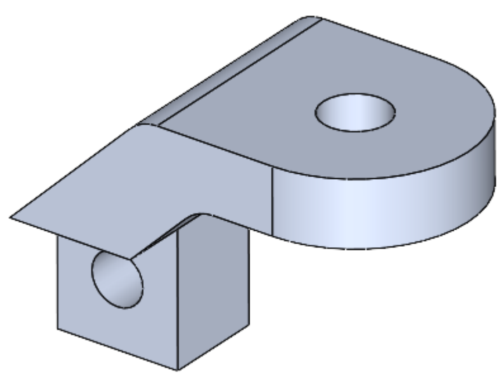


Figure 8.9: First Iteration Upper A-Arm Upright SolidWorks Model

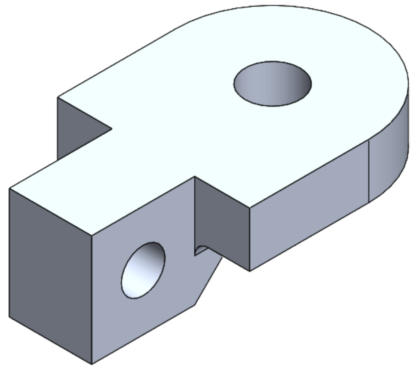


Figure 8.10: Redesigned Upper A-Arm Upright SolidWorks Model

The modeling of the knuckle was done by superimposing a SolidWorks sketch of the suspension geometry over a base template of the knuckle that was also previously modeled in SolidWorks, shown in Figure 8.11. The steering geometry sketch was also superimposed to reach 100% Ackerman steering effects on the knuckle, this is shown in Figure 8.12. The base knuckle template was then tweaked to have all connection points line up perfectly with the optimal geometry selected by the earlier simulations.

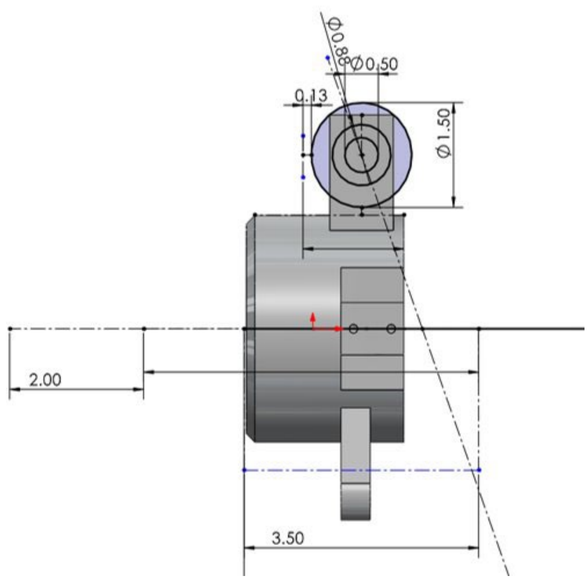


Figure 8.11: Suspension Geometry Overlayed SolidWorks Model

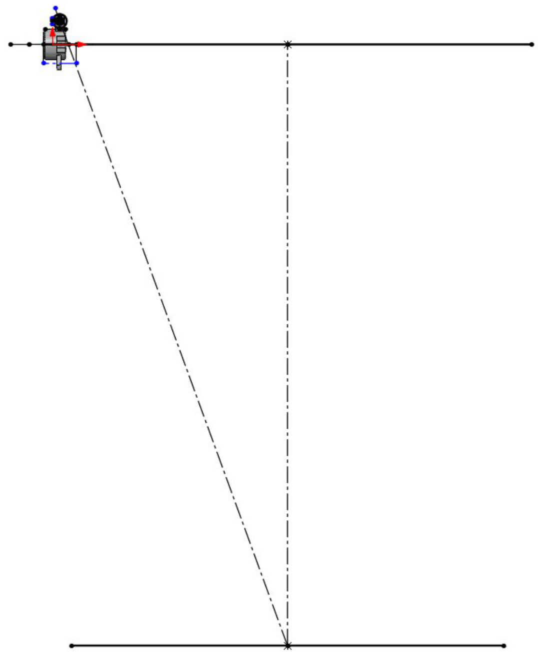


Figure 8.12: Steering Geometry Overlayed SolidWorks Model

8.3.1 Knuckle Finite Element Analysis (FEA)

To make sure that the knuckle design could withstand shock loading, that is inherent in off road vehicles, FEA simulations were done to ensure that both the base knuckle and the upright would withstand those forces. The following calculations were done to get a baseline for the FEA simulations:

$$Assumed\ Weight\ of\ Car\ with\ a\ Person = 750lbf$$

$$Shock\ Load\ Factor = 5$$

$$Force\ on\ Each\ Tire = \frac{Assumed\ Weight\ of\ Car\ with\ a\ Person}{4}$$

$$Force\ on\ Each\ Knuckle\ Half = \frac{Force\ on\ Each\ Tire}{2}$$

$$FEA\ Baseline = Force\ on\ Each\ Knuckle\ Half \times Shock\ Load\ Factor$$

$$\therefore FEA\ Baseline = 468.75lbf$$

Restraining the base knuckle and the upright, with fixed hinges and roller sliders, and applying the FEA Baseline force, both the base knuckle and the upright reached a factor of safety above 3 as shown in both figure 8.13 and figure 8.14. Overall weight for the car was recorded, after these calculations and FEA procedures were completed, as 585lbs. Adding an assumed 200lbs to the car for a driver is as total of 785lbs which is just 35lbs over the assumed weight used.

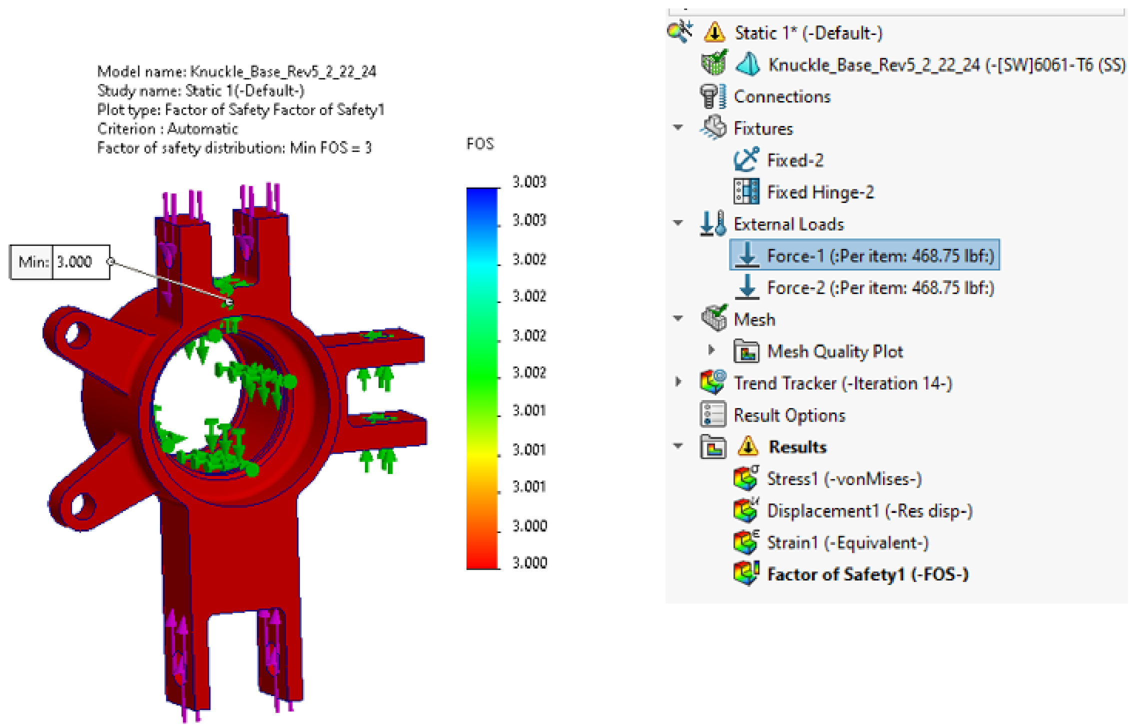


Figure 8.13: Base Knuckle FEA

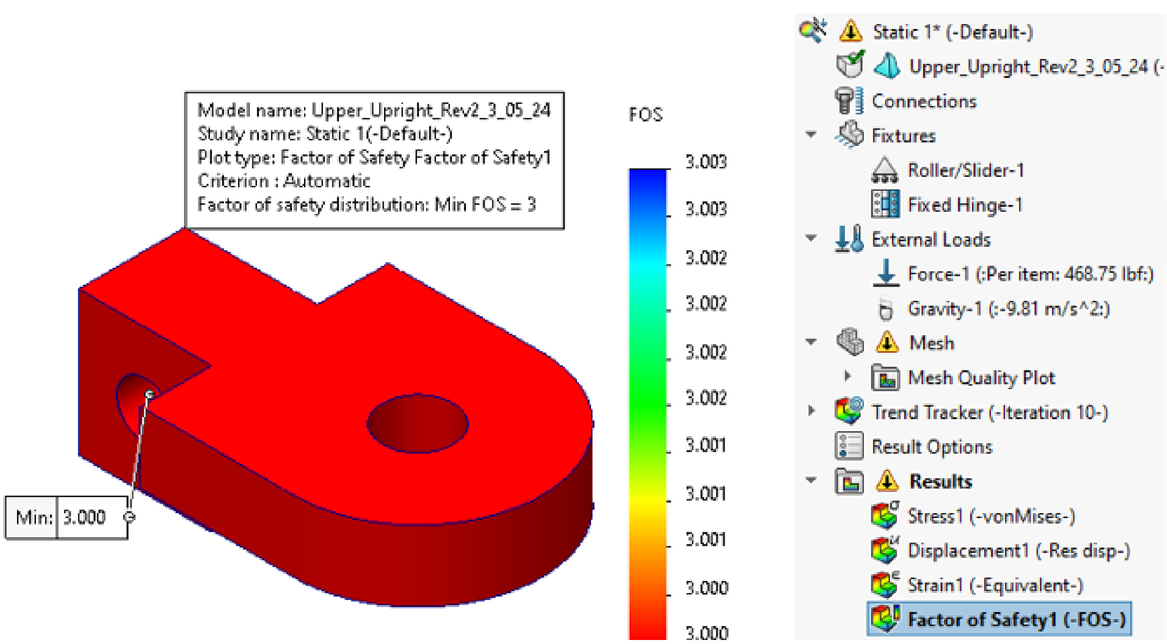


Figure 8.14: Upper A-Arm Upright

9 Testing and Quality

Testing procedures remained less quantitative and more qualitative in nature. This was due to the recognition of scope creep of the project. The team vehemently recommends that a full data acquisition package should be done of the suspension systems used on the current Baja car. The qualitative results we got from the team were great. Each member of the Cowboy Racing team tested the handling characteristics of the vehicle and they were very satisfied with the results. The front suspension system was also able to withstand all shock loading that occurred over the course of the Baja SAE California competition. There were a few issues that the team discovered over the course of the competition. The main two being ride height and attack angle of the wheels relative to the frame. Both issues could not have been mitigated by the senior design team however, because both the shocks and the frame pick-up points were pre-determined by the Cowboy Racing team. Other than these issues the suspension system overall functioned just as designed with great handling, bump, and jounce characteristics. During testing there were a few repairs that needed to be done due to driver error. In the first instance, the driver ran over a rock with the A-Arms rather than the tire and in the second instance another team drove over our entire suspension system breaking a shock and disfiguring the A-Arms. These instances are shown below in figure 9.1.

Figure 9.1: Risk Management Matrix

10 Costs

The overall cost of the project was $4,260 which is well within the budget of $10,000.

All expenditures were necessary and approved and they include materials, fasteners, joints, and tooling for manufacturing. Specifics are included in Figure B.10.1 located in the appendix.

The expenses had a few changes throughout the manufacturing process. Webco graciously donated all the chromoly tubing, saving the team approximately $750. The team also had to order a reaming tool for the CNC machine that was overlooked in the initial cost estimate, adding a $70 expense.

To save cost in the future less expensive materials and fasteners could be selected but that comes with an added risk of design failure.

11 Risk Management

The team created a risk management matrix that we utilized throughout the semester to mitigate possible risks during the design process. The risks were brainstormed through the team deciding what risks we could face and how we could change our design to not have these risks. The chart is shown in Figure 11.1 below.

		Severity			
		Negligible	Minor	Moderate	Significant
Likelihood	Probable	Time conflicts	Parts/tools break	Knuckle does not fit geometry	Welding Stainless Steel due to TIG requirements
	Possible		Sensor integration issues	Data acquisition issues	Insufficient budget
	Unlikely		Manufacturing defects	Supply chain issues	Baja car not finished
	Very Unlikely		Spindle Speeds for machining are incorrect	Cam for CNC is incorrect	Not meeting qualification Injury

Figure 11.1: Risk Management Matrix

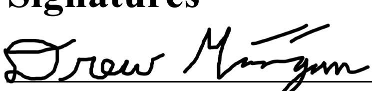
12 Project Plan

The project plan is a document that outlines the project’s tasks, goals, deadlines, and dependencies. The preliminary design phase of the project plan contains high level descriptions of tasks and goals which include material analysis, suspension geometry research, and knuckle manufacturing process research. The critical design phase of the project is more detailed with tasks and goals that include a creation of bill of materials, 2-D and Optimum Kinematic analysis of suspension geometry, and CAD design of knuckle. The Fabrication phase of the project plan contains all fabrication steps, dependencies, and deadlines. The first step of the fabrication phase is to order and receive all the items on the bill of materials. Fabrication of the knuckle, tie rod, and A-Arms was conducted concurrently. Fabrication of the A-Arms included verifying geometry and bend angles with the A-Arm drawings. The tubing was bent and notched, placed in a jig, and welded together. Fabrication of the knuckle began with creating and implementing the CNC milling procedures for the base knuckle and upper A-Arm upright. The cutouts were then machined, and the parts were dimensioned to confirm tolerances. Tie rods were cut to length and had their inserts pressed and welded in. Once all the suspension components were fabricated, they were painted. The fabricated suspension components were then assembled for testing. The testing and validation phase of the project is described in section 9. The project plan is shown in appendix Figures B.12.1-B.12.5

13 Work Breakdown Overview

Group Member	Work Performed
Drew Milligan	Knuckle and A-Arm Design; selection of fasteners, 2-D and 3-D suspension geometry models, Manufacturing of A-Arms via welding, Testing of overall design
Mason Hagelberg	Knuckle material selection and design for overall solution, concept evaluation, and engineering and analysis; cost reports; purchasing; bill of materials; risk management
Craig Mularkey	A-Arm Design, 2-D and 3-D Modeling of suspension components, steering geometry design, CNC of knuckle, manufacturing of inserts and A-Arms, EHS, Hazard Analysis,
Spencer Swanson	Knuckle, A-Arm, and Tie Rod Design, Manufacturing of A-Arms and Inserts, CAD Modeling for Jig
Joshua Davies	Material selection for overall solution, concept evaluation, and engineering and analysis; 2-D suspension geometry; project plan; document setup; formatting; proofreading

Signatures



Drew Milligan

Mason Hagelberg

Craig Mularkey

Spencer Swanson

Joshua Davies

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Appendix A

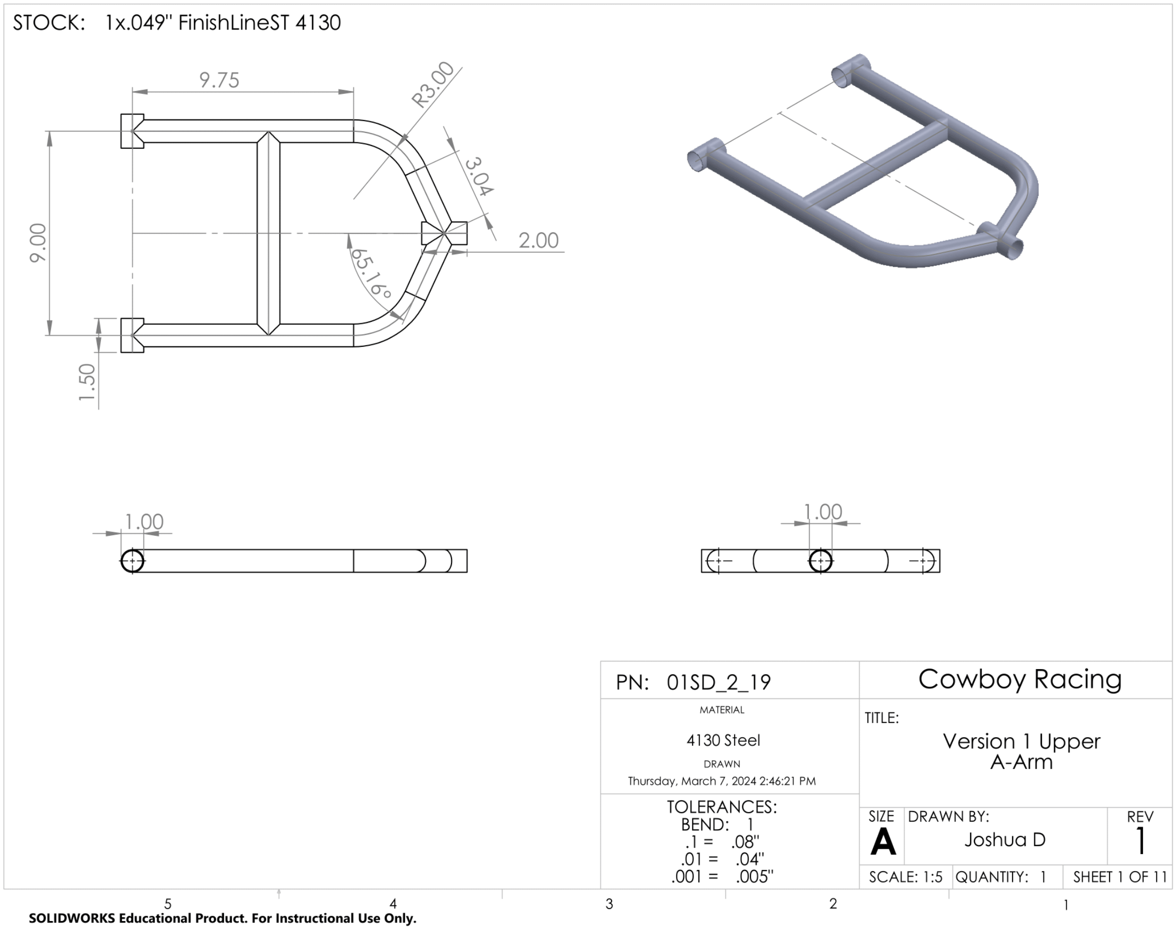


Figure A.1: Upper A-Arm

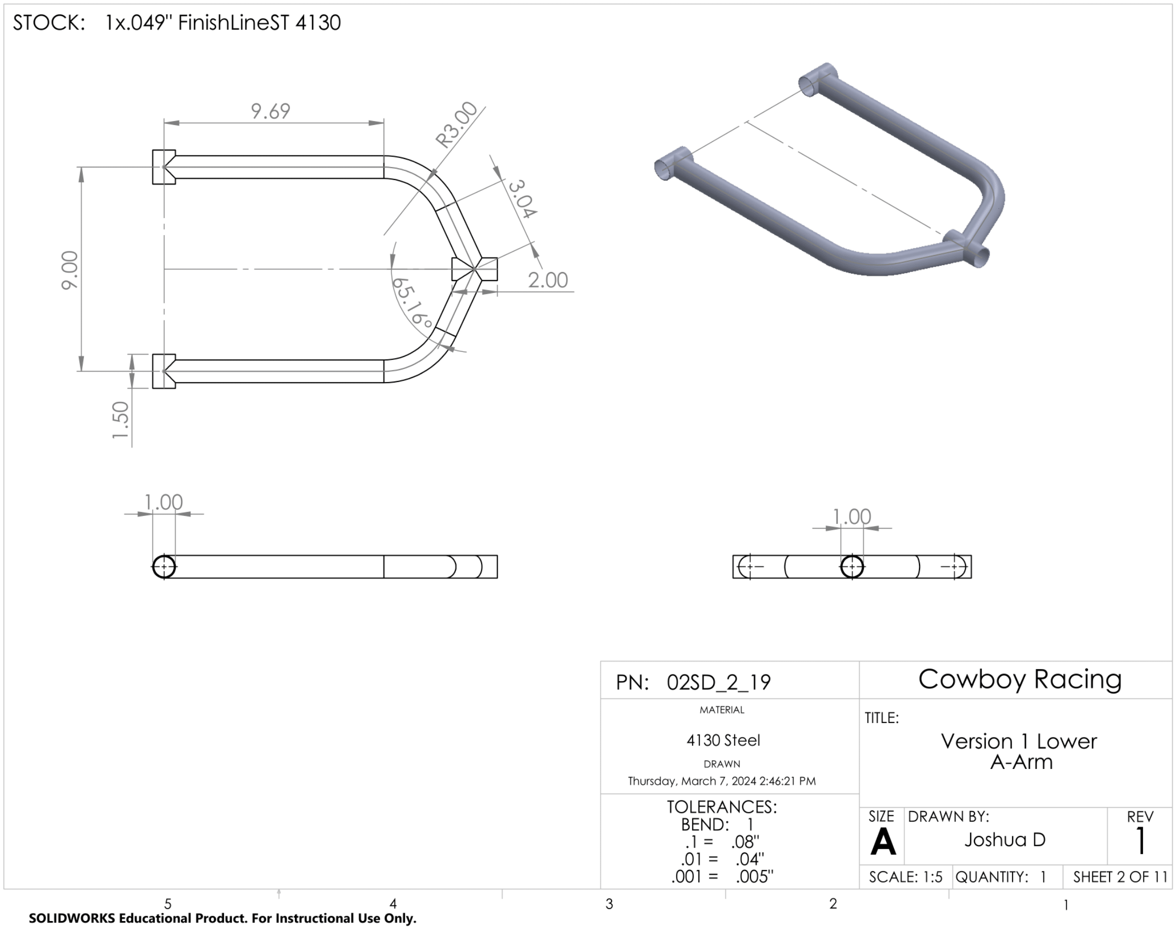


Figure A.2: Lower A-Arm

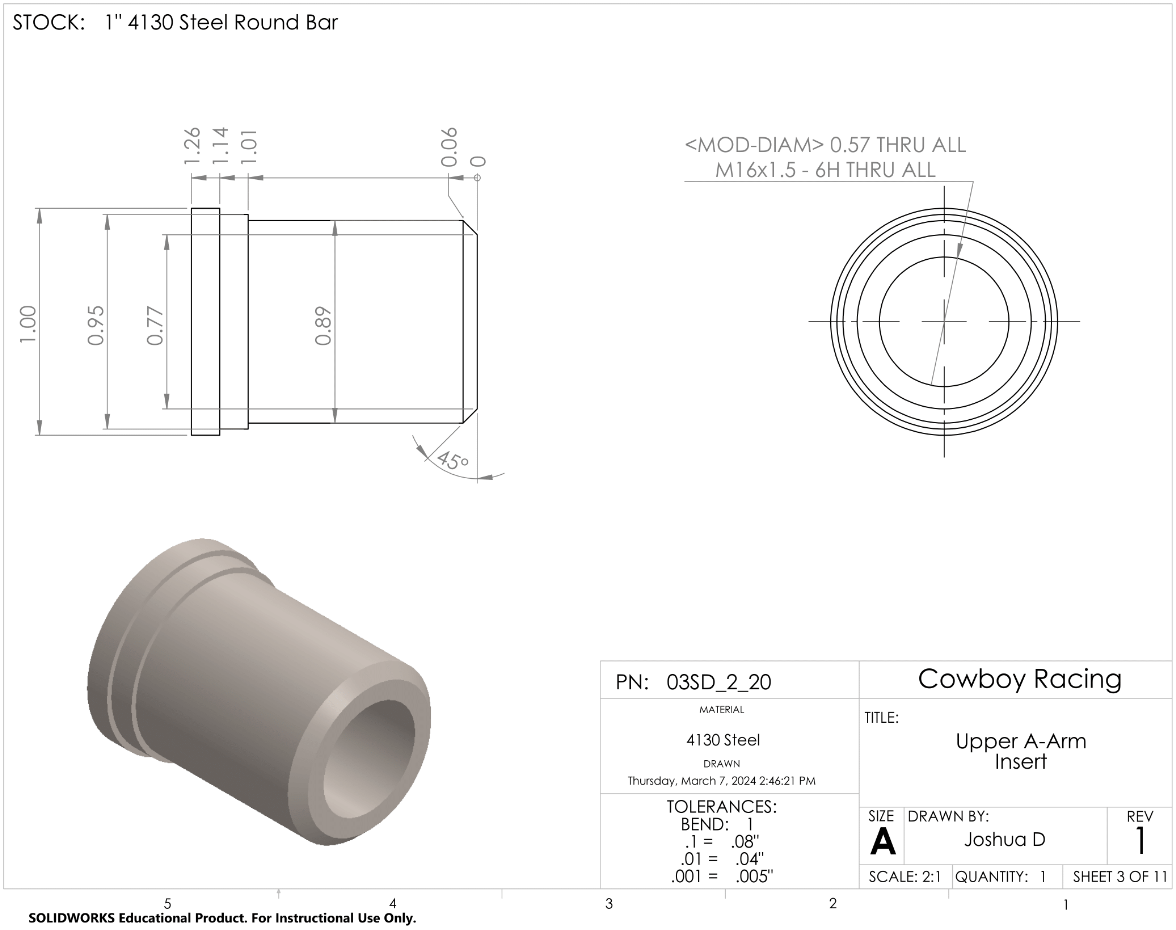


Figure A.3: Upper A-Arm Insert

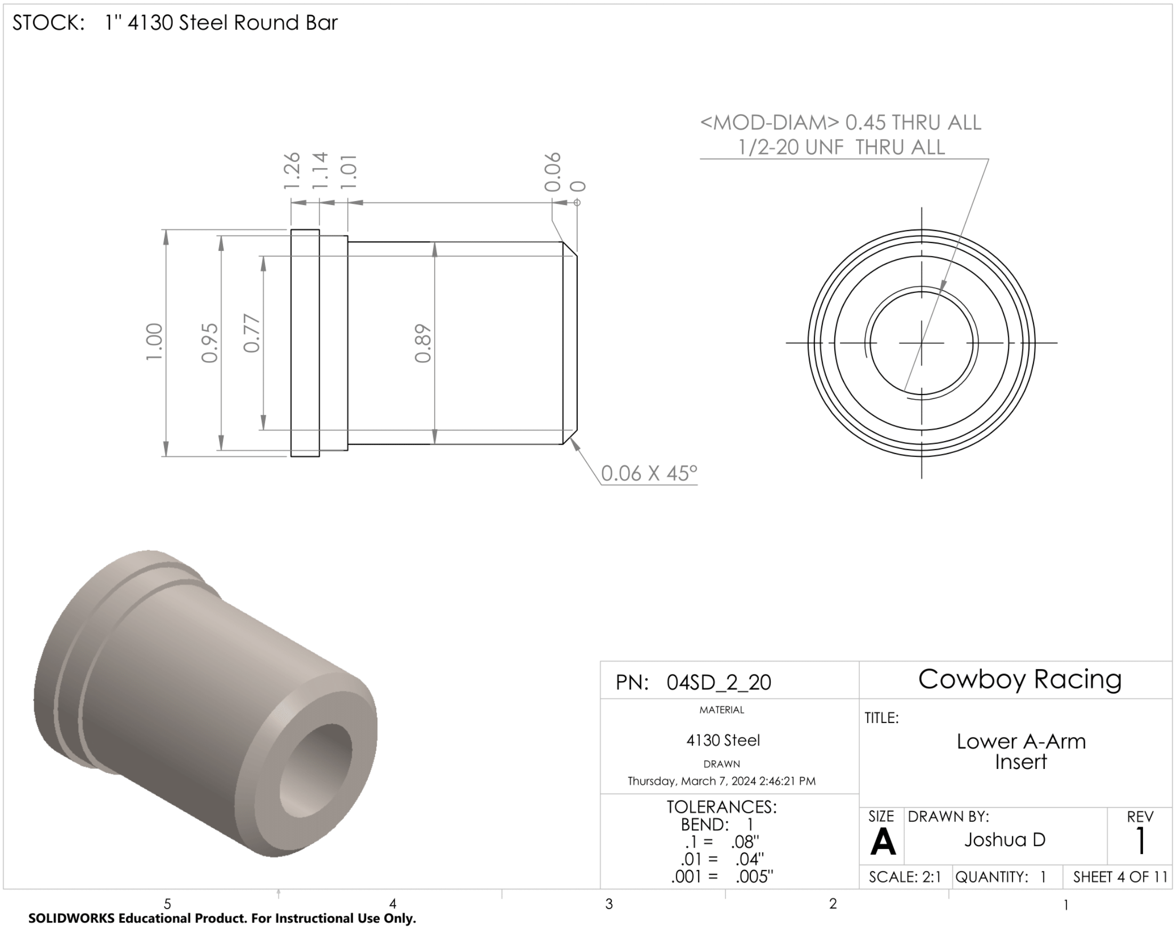


Figure A.4: Lower A-Arm Insert

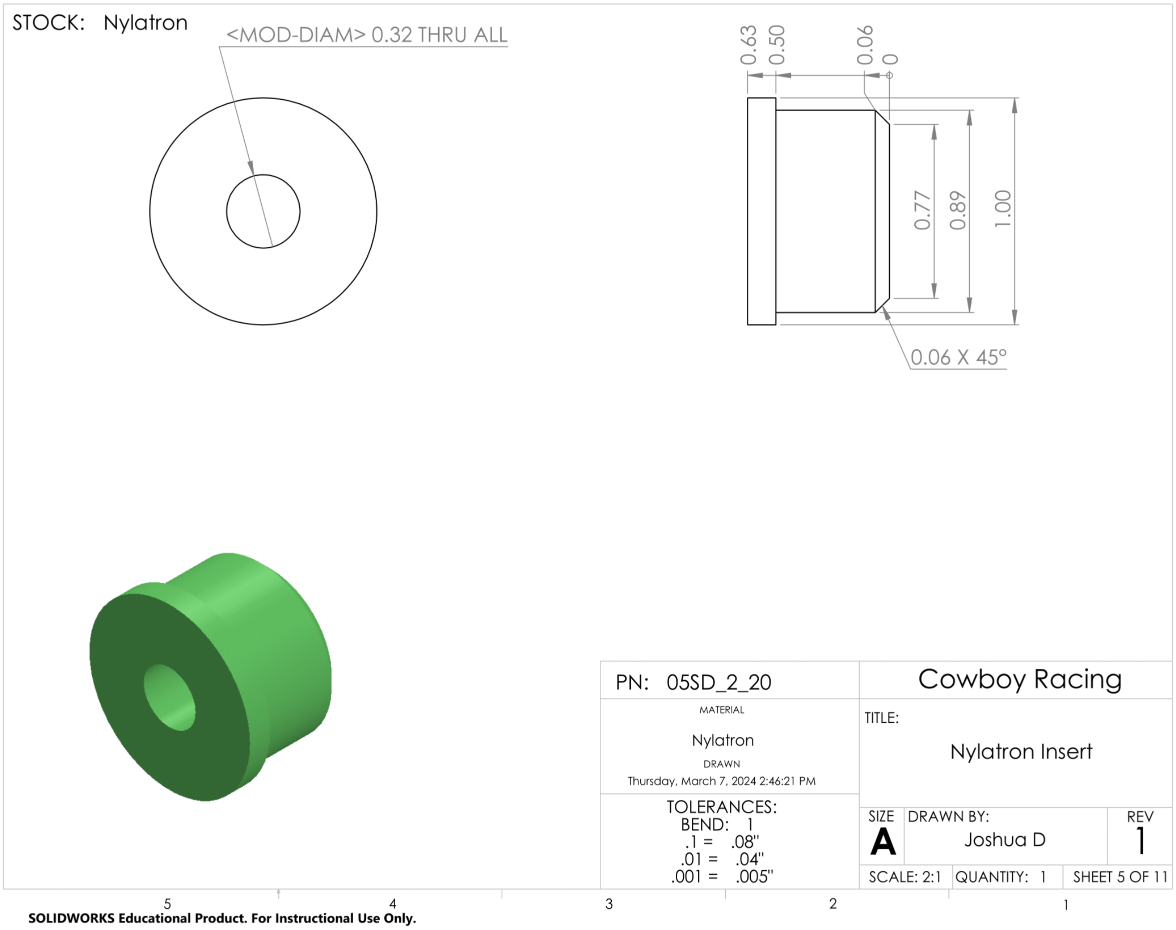


Figure A.5: Nylatron Insert

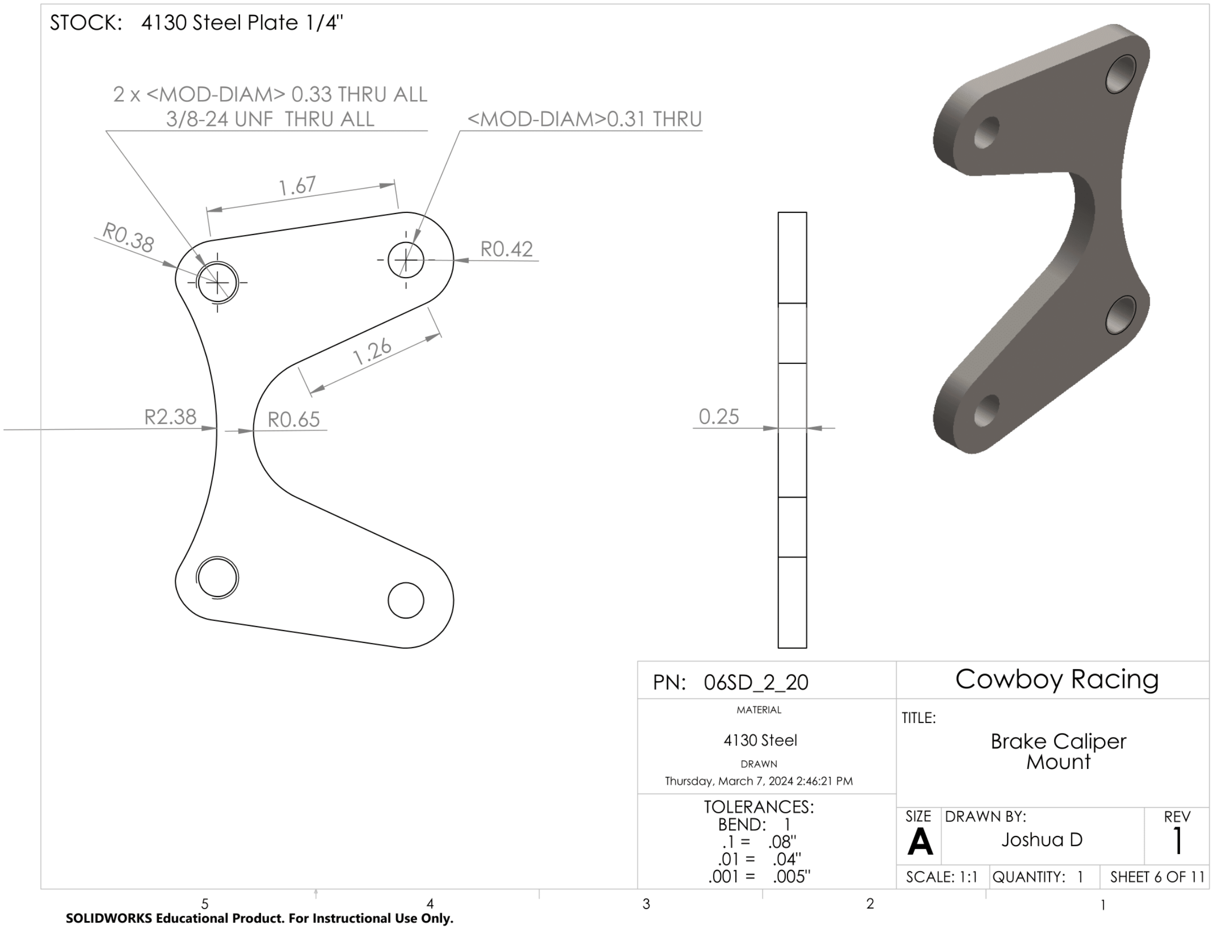


Figure A.6: Brake Caliper Mount

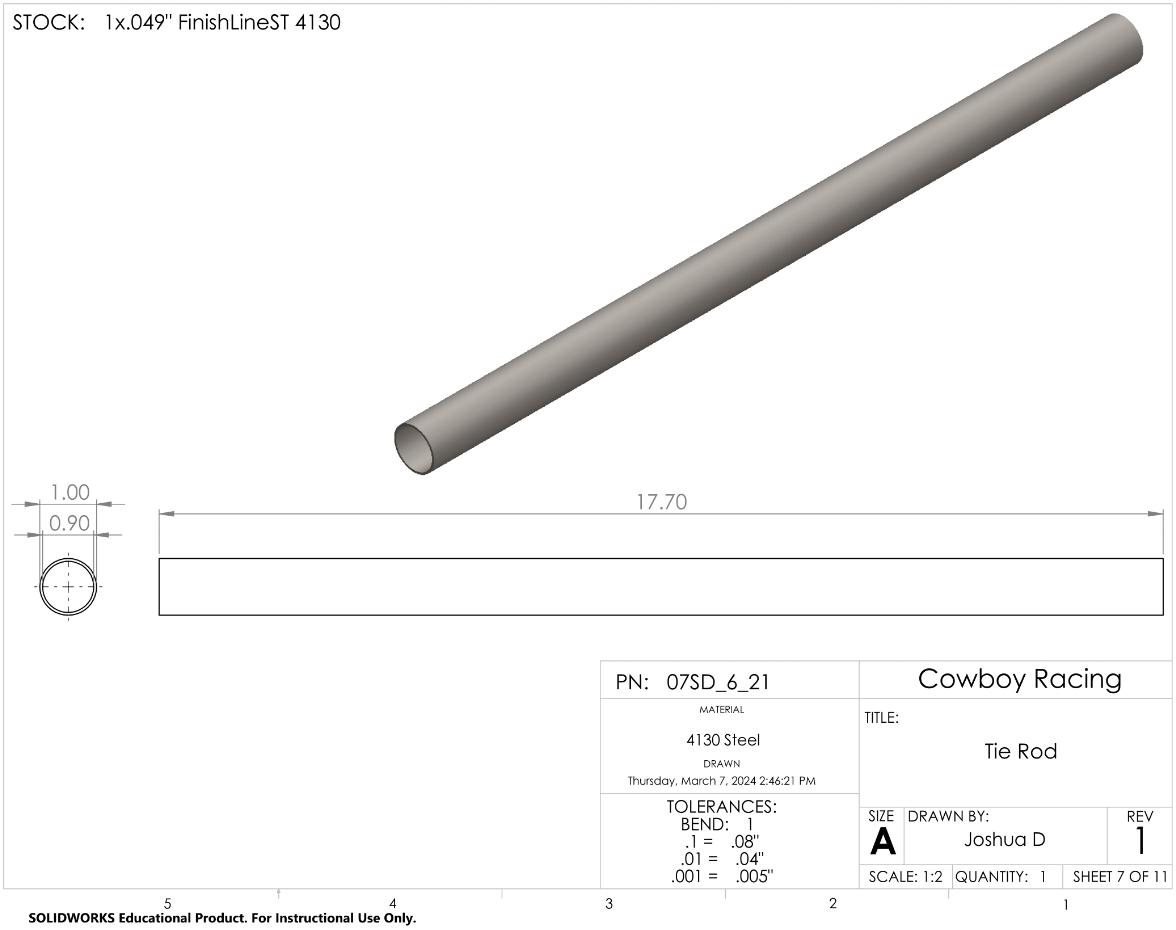


Figure A.7: Tie Rod

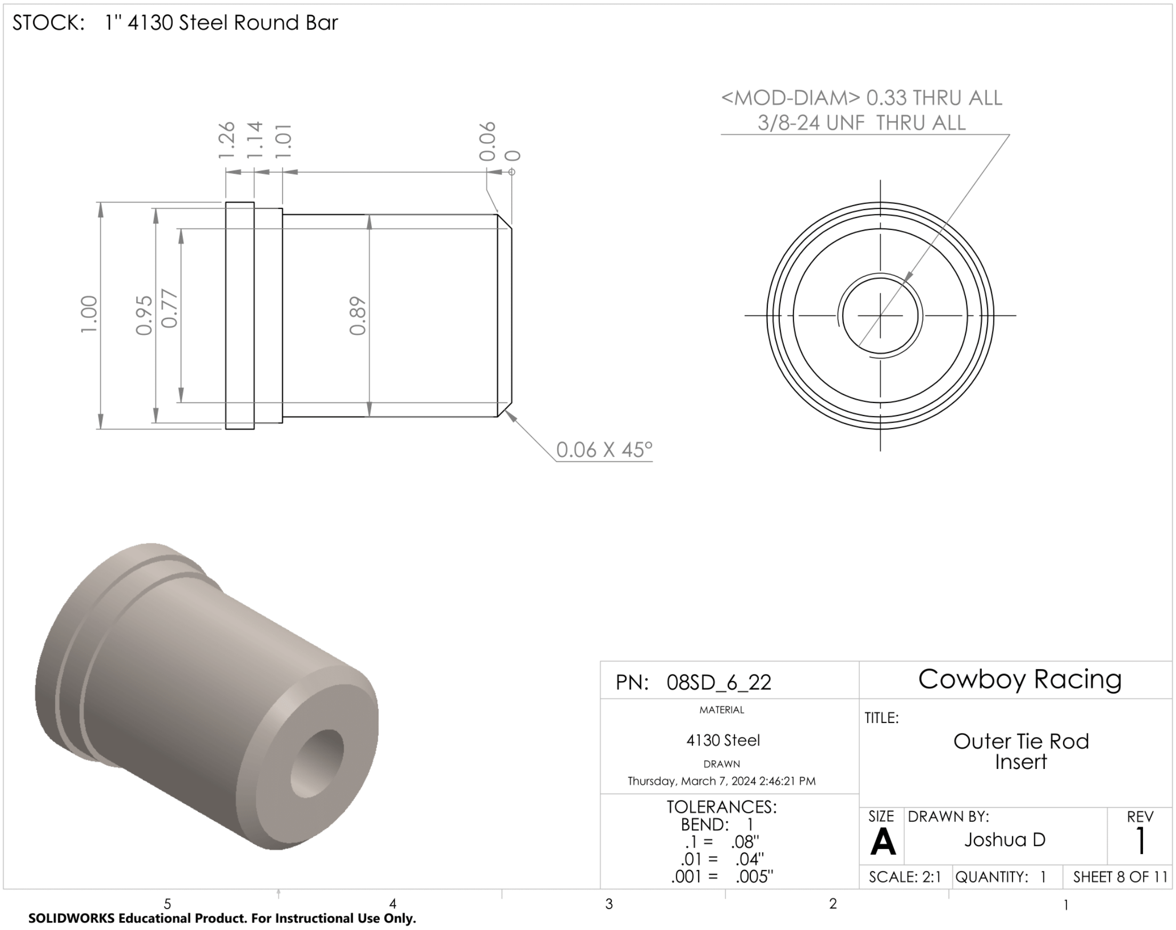


Figure A.8: Outer Tie Rod Insert

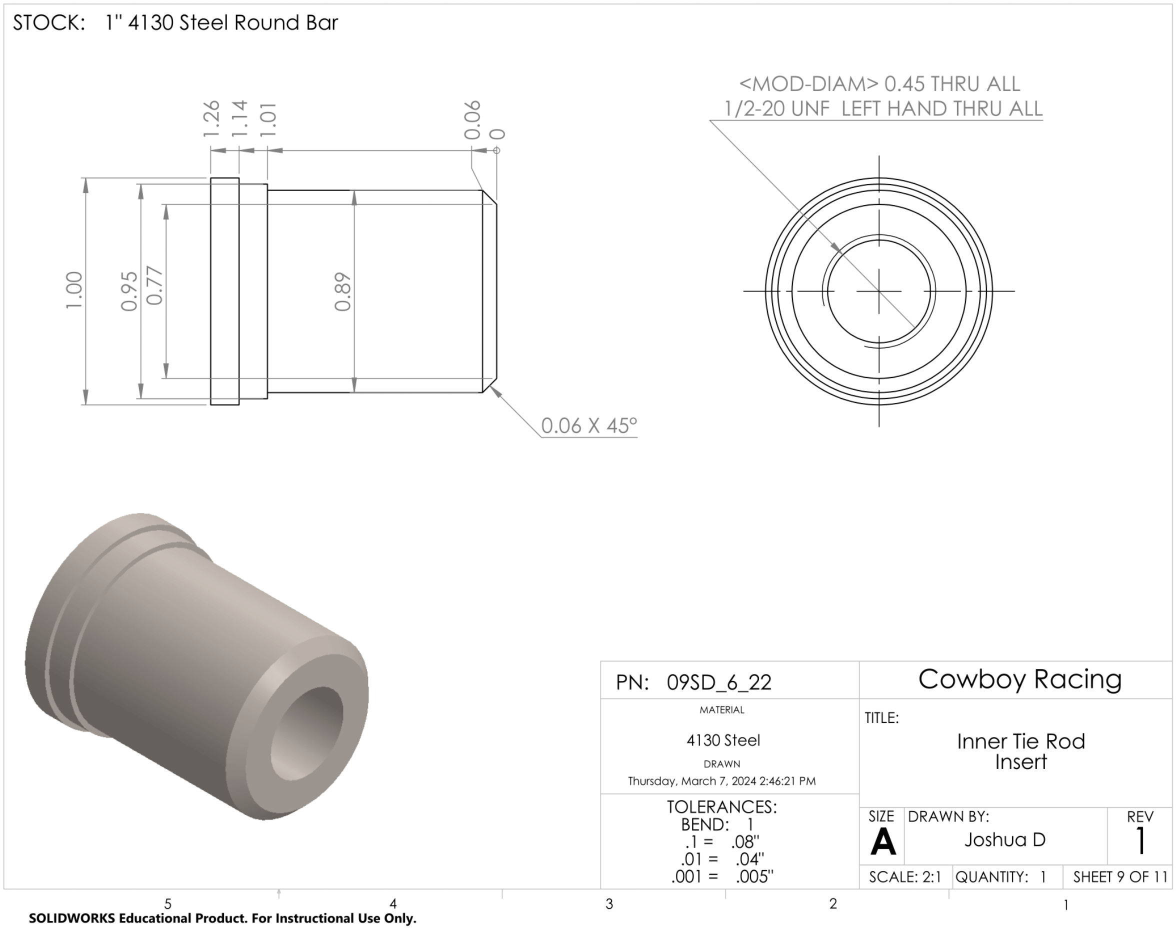


Figure A.9: Inner Tie Rod Insert

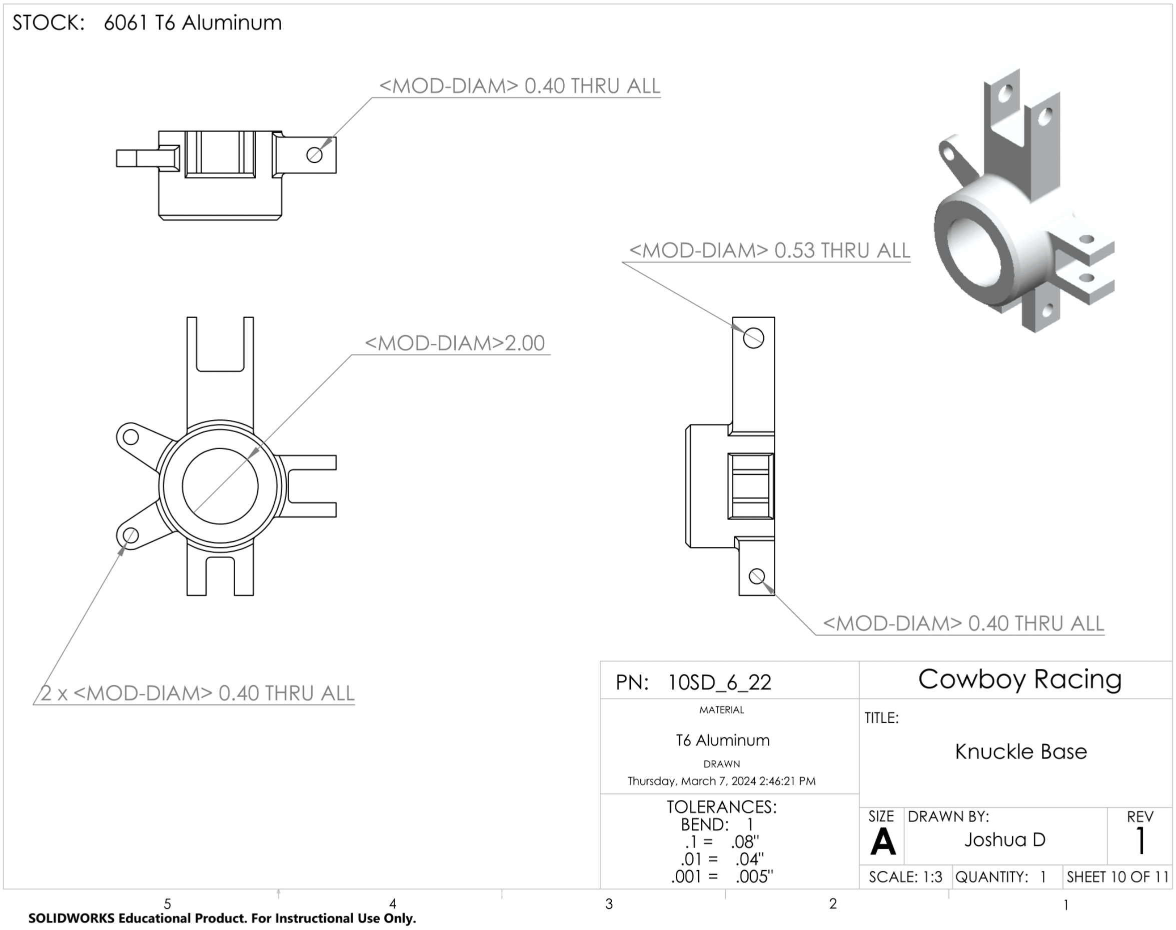


Figure A.10: Knuckle Base

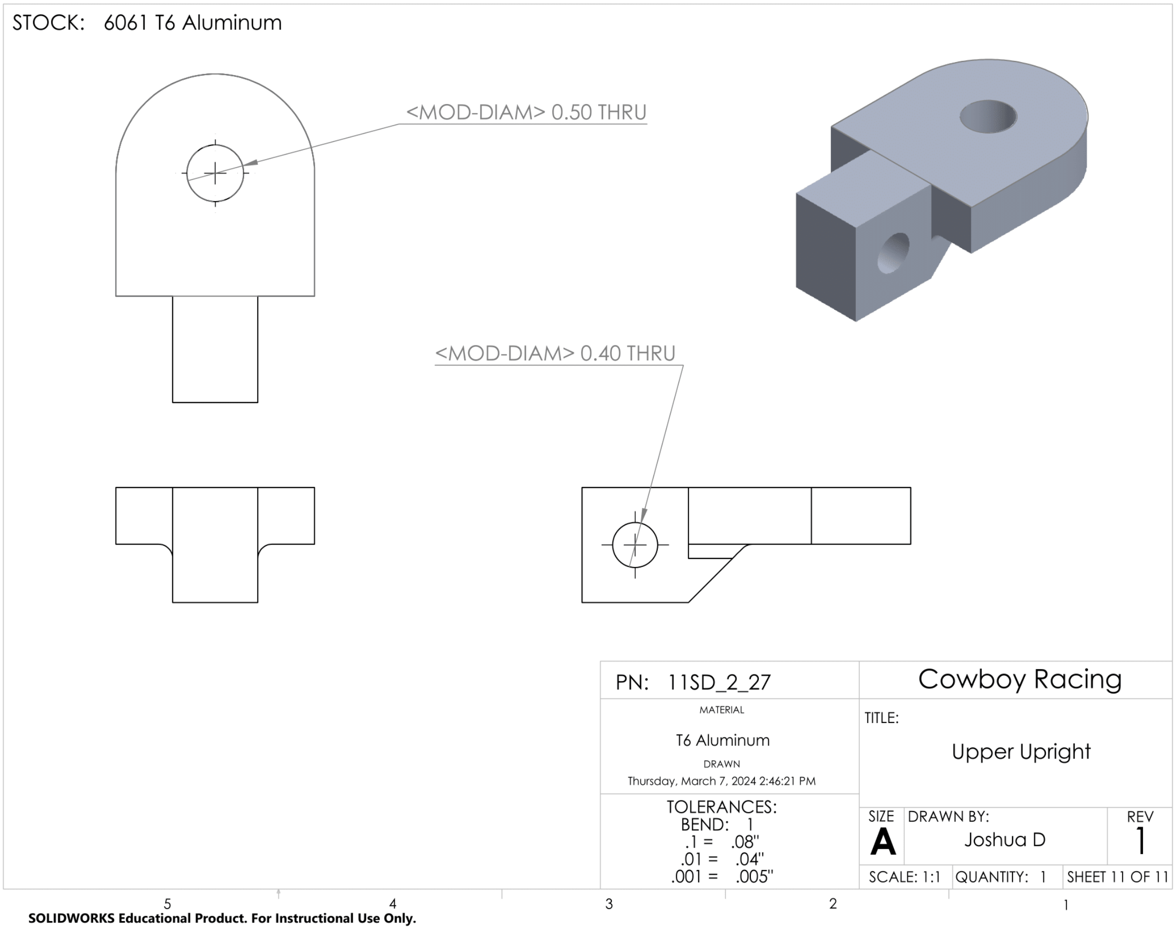


Figure A.11: Knuckle Upper Upright

Appendix B

Variable	Description	4130 Chromoly Tubing 1x0.049	2507 Duplex Stainless Steel 1x.049	AL825 Nickel Alloy 1x.049	FinishLineST 4130 1x.049	Units
OD	Outside Diameter	1	1	1	1	inches
ID	Inside Diameter	0.902	0.902	0.902	0.902	inches
E	Modulus of Elasticity	205	200	196	205	GPa
Su	Ultimate Strength	560	900	690	690	Mpa
Sy	Yield Strength	460	550	310	655	Mpa
rho	Density	7.85	7.8	8.14	7.85	g/cm^3
OD	Outside Diameter	0.0254	0.0254	0.0254	0.0254	meters
ID	Inside Diameter	0.0229	0.0229	0.0229	0.0229	meters
c	Greater Radius	0.0127	0.0127	0.0127	0.0127	meters
I	2nd moment of area	6.907E-09	6.907E-09	6.907E-09	6.907E-09	m^4
A	Cross Sectional Area	0.9445	0.9445	0.9445	0.9445	cm^2
B_stf	Bending Stiffness	1415.92	1381.38	1353.75	1415.92	Nm^2
B_str	Bending Strength	250.17	299.12	168.59	356.22	Nm
M	Mass/length	7.4142	7.3670	7.6881	7.4142	g/cm
B/M	Bending Strength/Mass (1 cm)	33.7423	40.6026	21.9292	48.0461	Nm/g

Figure B.8.1: Material Selection Scoring Matrix Values

Variable	Description	FinishLineST 4130 1x.049	Units
D_O	Outside Diameter	1.00	inches
D_I	Inside Diameter	0.902	inches
E	Modulus of Elasticity	205	GPa
Su	Ultimate Strength	690	Mpa
Sy	Yield Strength	655	Mpa
rho	Density	7.85	g/cm^3
D_O	Outside Diameter	0.0254	meters
D_I	Inside Diameter	0.0229	meters
c	Greater Radius	0.0127	meters
I	2nd moment of area	6.91E-09	m^4
k_b	Bending Stiffness	1415.92	Nm^2
S_b	Bending Strength	356.22	Nm

Figure B.8.2: 4130 FinishLineST Properties

		Steel		Aluminium	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating
Density	5	2	10	5	25
Manufacturability	4	4	16	3	12
Modulus of Elasticity	4	2	8	3	12
Ultimate Strength	3	4	12	3	9
Yield Strength	3	4	12	3	9
Total		**58**		**67**	
Rank		2		1	
Develop?		No		Develop	

Figure B.8.3: Material Selection Scoring Matrix Knuckle

Design #	Top A-Arm Length	Lower A-Arm Length	Ratio	Shock Distance	Knuckle Size	KPI	Total Width	Ground Clearance	Distance to Cg	Scrub Radius	Static Camber -16.6 in	Max Camber	Min Camber	Variable Camber	Wheel Travel
1	12.5	14.5	0.86206897	7	8	11	56.3	10.94	8.91	0.35	-1.04	1.3	-7.78	9.08	
2	16.25	17.5	0.92857143	7	8	6.25	61.83	11.83	8.91	0.97	-0.16	3.09	-7.21	5.43	
3	16.25	17.5	0.92857143	7	8	6.25	61.8	11.21	8.898	1	0.89	2.84	-7.46	10.3	8.44
4	16.25	17.5	0.92857143	6	8	6.25	61.8	11.94	8.48	1	0.51	3.9	-8.37	12.27	10.035
5	16.25	17.5	0.92857143	8	8	7.125	61.8	10.5	9.3	0.88	0.24	2.83	-6.15	8.98	7.31
6	15.75	17.5	0.9	8	8	10.75	62.24	10.42	9.54	0.39	-0.06	2.38	-6.07	8.45	7.71
7	15.75	17.5	0.9	6	8	10.75	61.94	11.8	8.835	0.39	1.1	4.02	-7.41	11.43	9.74
8	15.75	17.5	0.9	7	8	10.75	62.15	11.3	9.21	0.39	0.56	3.13	-6.51	9.64	
9	13.5	15.25	0.8852459	8	8	10	57.9	10.84	9.24	0.49	-0.59	1.7	-6.65	8.35	
10	13.5	15.25	0.8852459	7	8	10	57.9	10.84	8.9	0.495	-0.1	2.46	-7.08	9.54	
11	13.5	15.25	0.8852459	6	8	9.5	57	10.84	8.52	0.564	-0.06	2.84	-8.47	11.31	
12	14	16	0.875	6	8	11.5	58.6	12.1	8.81	0.29	-0.1	2.53	-8.31	10.84	
13	14	16	0.875	7	8	12	59.04	12.1	9.18	0.21	-0.1	2.25	-6.92	9.17	
14	14	16	0.875	8	8	12	59.31	12.1	9.53	0.144	-0.07	2.07	-6	8.07	
15	14.75	16.75	0.88059702	8	8	12.25	60.88	10.93	9.6	0.18	-0.35	1.8	-6.3	8.1	
16	14.75	16.75	0.88059702	7	8	12.25	60.47	11.55	9.29	0.18	-0.12	2.48	-6.73	9.21	
17	14.75	16.75	0.88059702	6	8	12	60.04	12.23	8.89	0.22	-0.38	3.01	-7.88	10.89	
18	15.75	17.5	0.9	6	8	9.5	61.6	12.46	8.77	0.56	-0.15	2.77	-8.66	8.66	

Figure B.8.4: 2-D Suspension Geometry Values for Screening Matrix

		Suspension Geometry Variations																	
Criteria	**Control**	1	2	3	4	5	6	7	8	18	9	10	11	12	13	14	15	16	17
Total Width	0	-	+	+	+	+	+	+	+	+	-	-	-	0	0	0	+	+	+
Ground Clearance	0	-	+	0	+	-	-	0	0	+	-	-	-	+	+	+	0	0	+
Distance to Cg	0	0	0	0	+	-	-	0	-	+	-	0	+	0	-	-	-	-	+
Scrub Radius	0	+	-	-	-	-	0	0	0	-	-	-	-	+	+	+	+	+	+
Static Camber	0	-	+	-	-	+	+	-	-	+	0	+	+	+	+	+	+	+	+
Variable Camber	0	-	+	-	-	0	0	-	0	+	0	0	-	0	0	0	+	0	-
Net		**-3**	**3**	-2	**0**	**-1**	**0**	**-1**	**-1**	**4**	**-4**	**-2**	**-2**	**3**	**2**	**2**	**3**	**3**	**4**
Rank		**1**	**1**	**4**	**2**	**3**	**2**	**3**	**3**	**1**	**3**	**2**	**1**	**1**	**2**	**3**	**2**	**2**	**1**
Continue		No	No	No	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	No	Yes

Figure B.8.5: 2-D Suspension Geometry Screening Matrix

Version	Top A-Arm Length	Lower A-Arm Length	Ratio	Shock Distance	Knuckle Size	KPI	Total Width	Ground Clearance	Distance to Cg	Scrub Radius	Static Camber -16.6 in	Max Camber	Min Camber	Variable Camber	Wheel Travel
1 17	14.75	16.75	0.88059702	6	8	12	60.04	12.23	8.89	0.22	-0.38	3.01	-7.88	10.89	9.16
2 11	13.5	15.25	0.8852459	6	8	9.5	57	10.84	8.52	0.564	-0.06	2.84	-8.47	11.31	8.38
3 12	14	16	0.875	6	8	11.5	58.6	12.1	8.81	0.29	-0.1	2.53	-8.31	10.84	8.71
4 18	15.75	17.5	0.9	6	8	9.5	61.6	12.46	8.77	0.56	-0.15	2.77	-8.66	11.43	9.78

Figure B.8.6: 2-D Suspension Geometry Values for Scoring Matrix

		Version 1		Version 2		Version 3		Version 4	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Total Width	5	4	16	1	4	3	12	5	20
Ground Cleara	2	4	16	1	4	4	16	5	20
Distance to Cg	5	4	16	5	20	4	16	4	16
Scrub Radius	3	5	25	2	10	4	20	2	10
Static Camber	3	2	4	5	10	5	10	5	10
Variable Camb	1	3	9	2	6	5	15	2	6
Wheel Travel	4	4	16	2	8	3	12	5	20
Total		**102**		**62**		**101**		**102**	
Rank		1		3		2		1	
Develop		Develop		No		Develop		Develop	

Figure B.8.7: 2-D Suspension Geometry Scoring Matrix

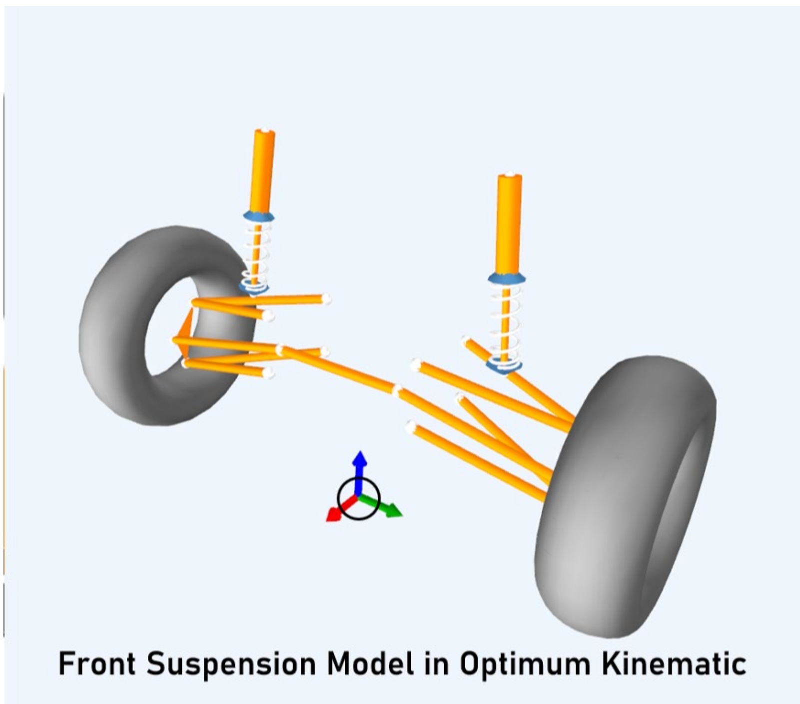


Figure B.8.8: Origin

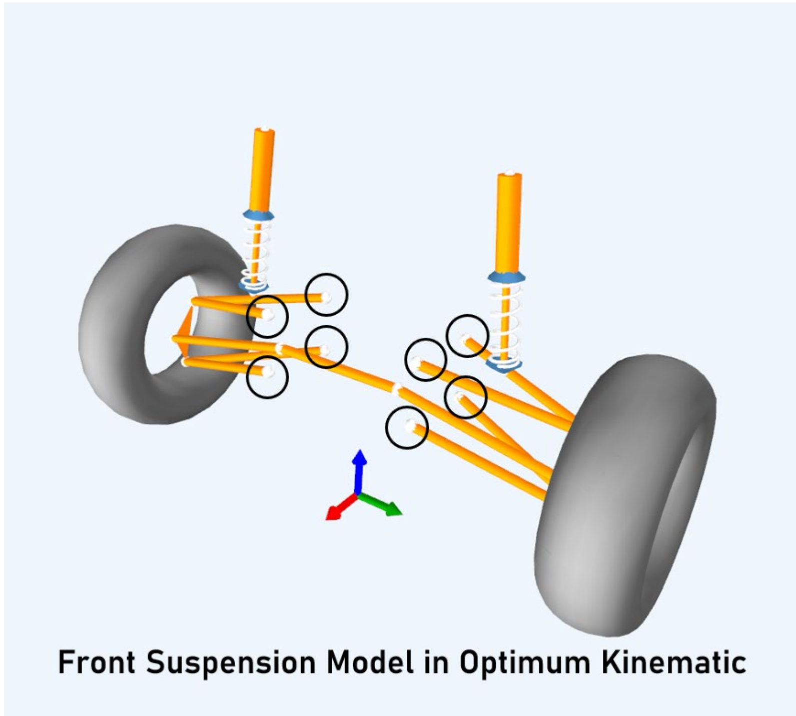


Figure B.8.9: Pickup Points of A-Arms onto the Baja Car

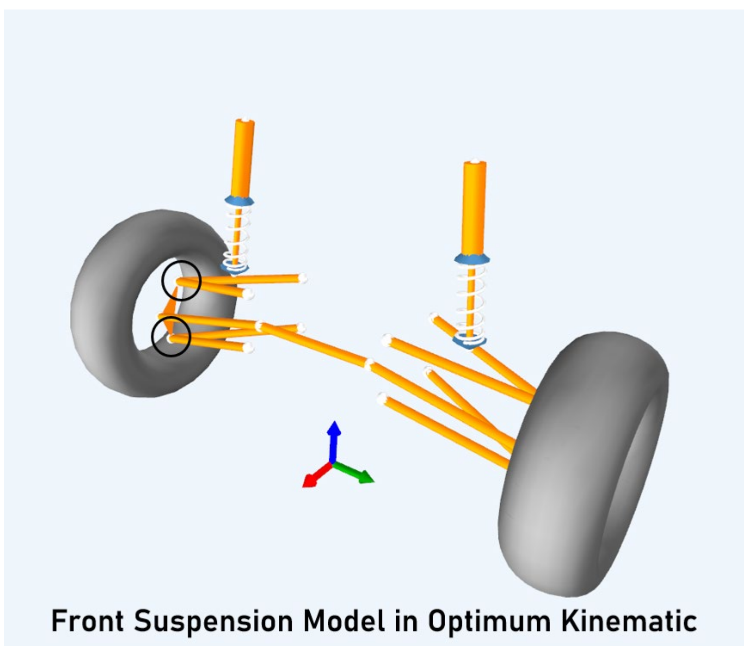


Figure B.8.10: A-Arm Attachment Points to the Knuckle

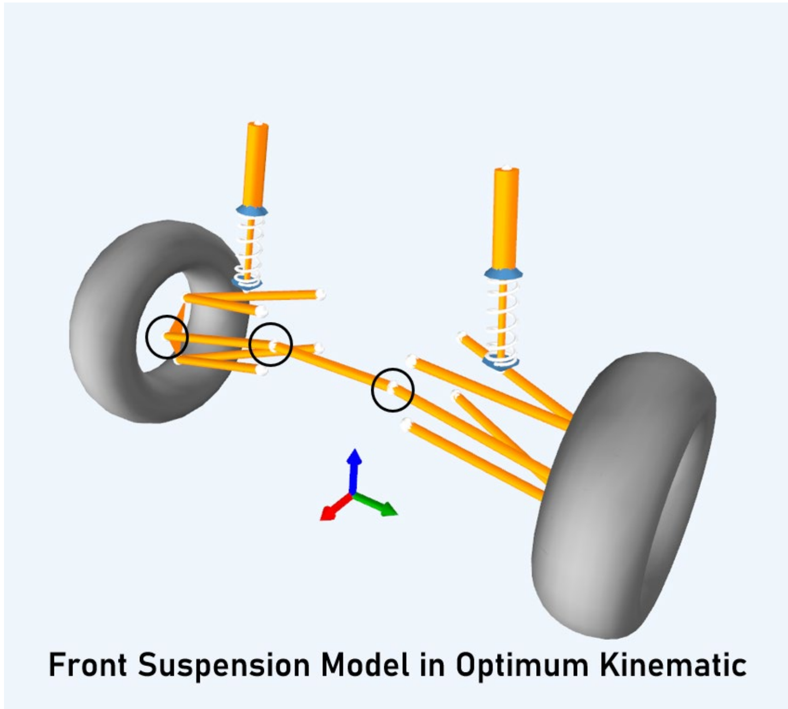


Figure B.8.11: Tie Rod Attachment to the Knuckle and Steering Rack

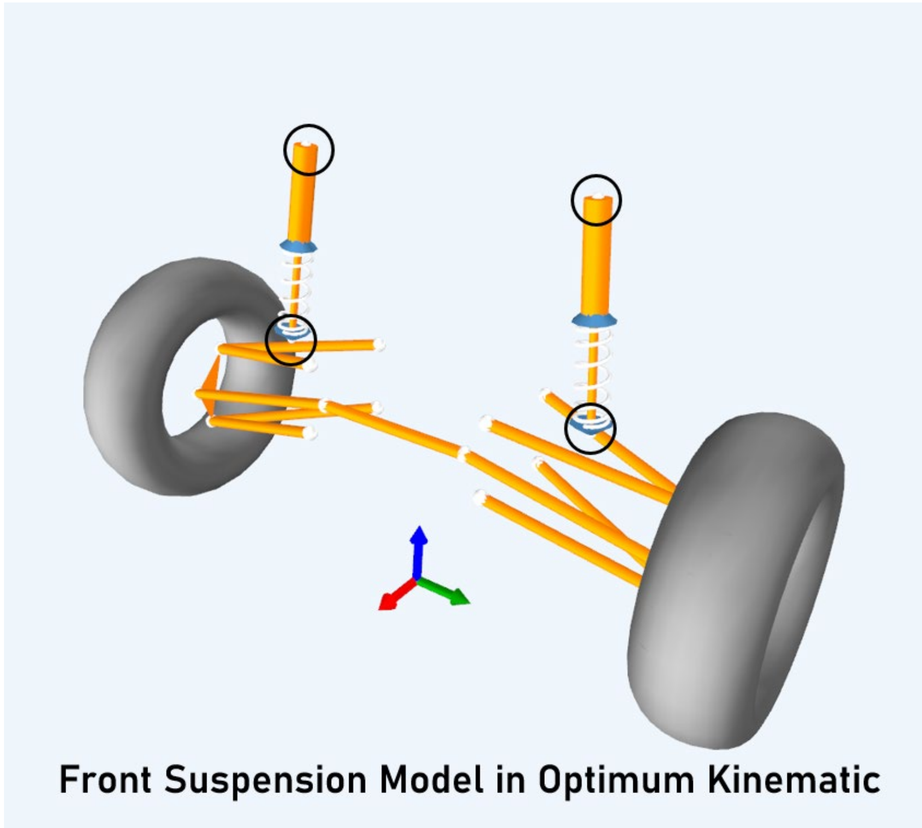


Figure B.8.12: Shock Pickup Points to Baja Car and Upper A-Arm Tab

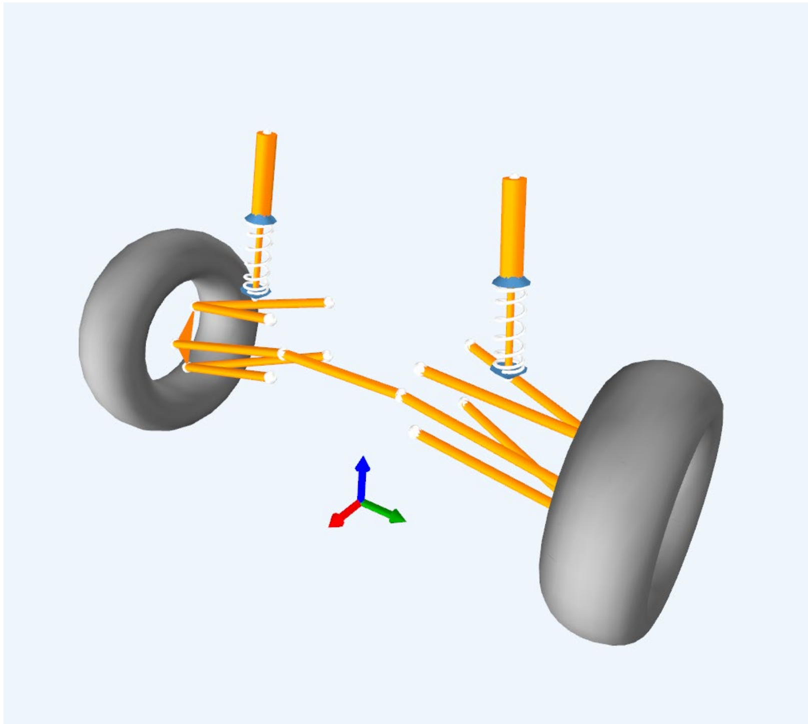


Figure B.8.13: Version 1 Front Suspension Model in Optimum Kinematics

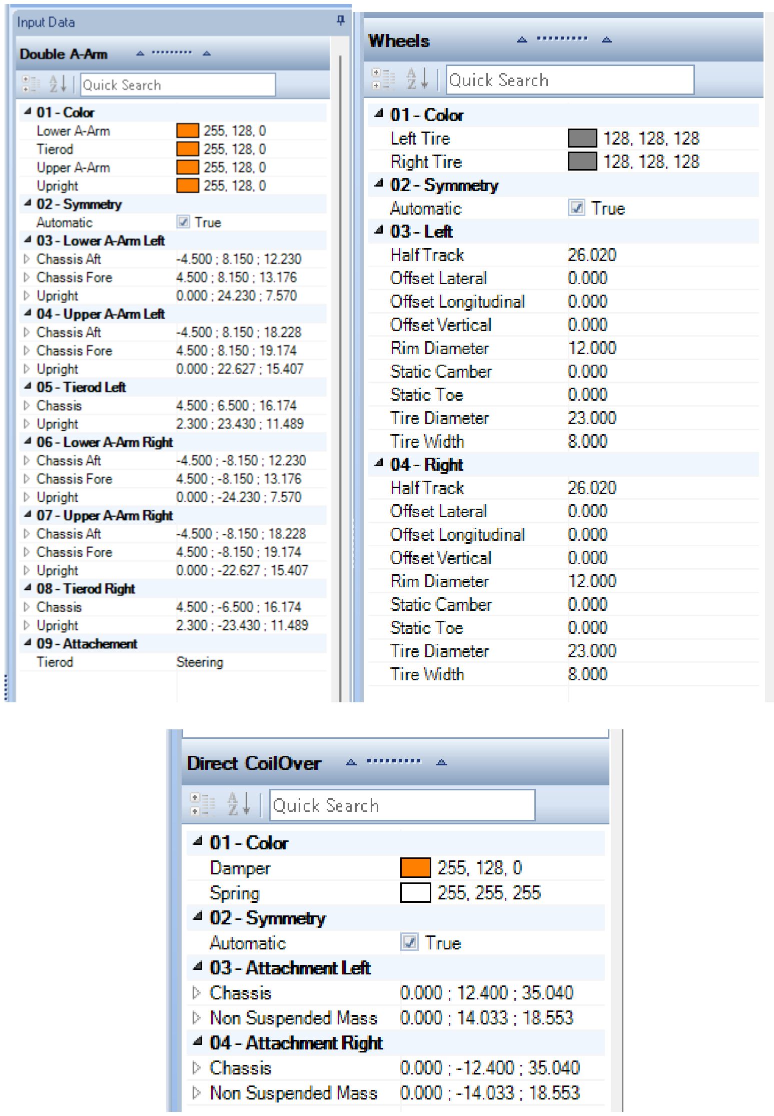


Figure B.8.14: Version 1 Front Suspension Model 3D Points in Optimum Kinematics

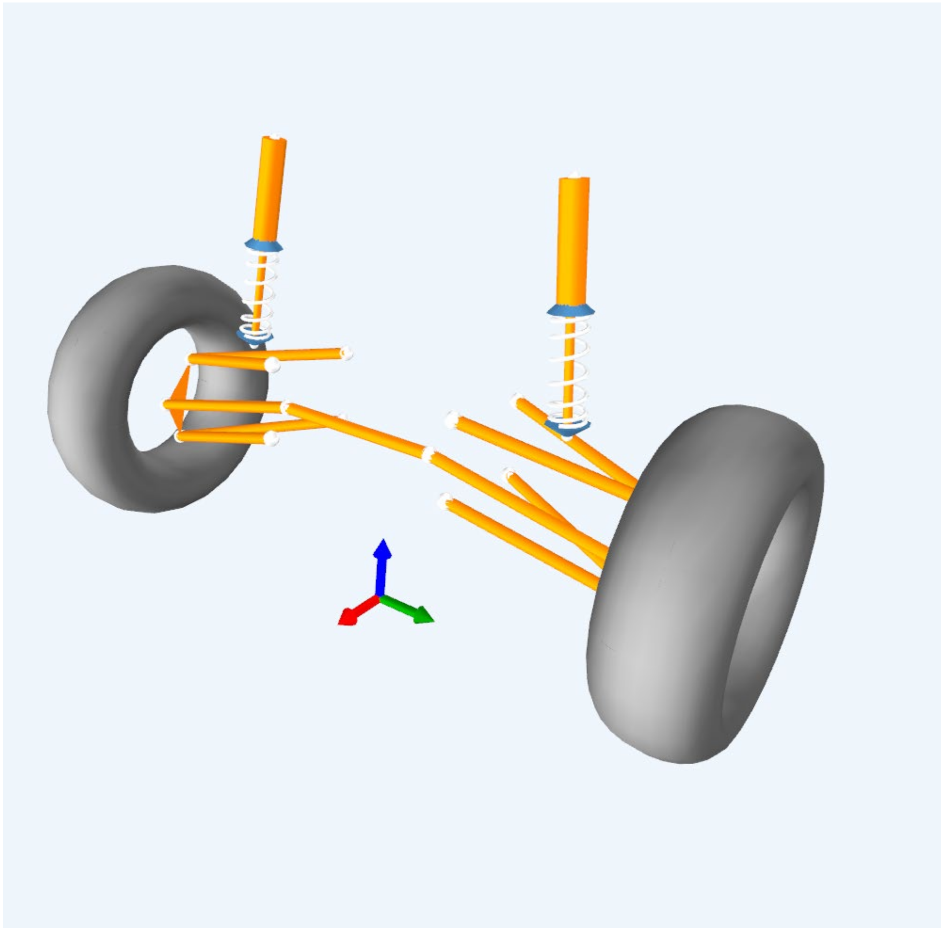


Figure B.8.15: Version 3 Front Suspension Model in Optimum Kinematics

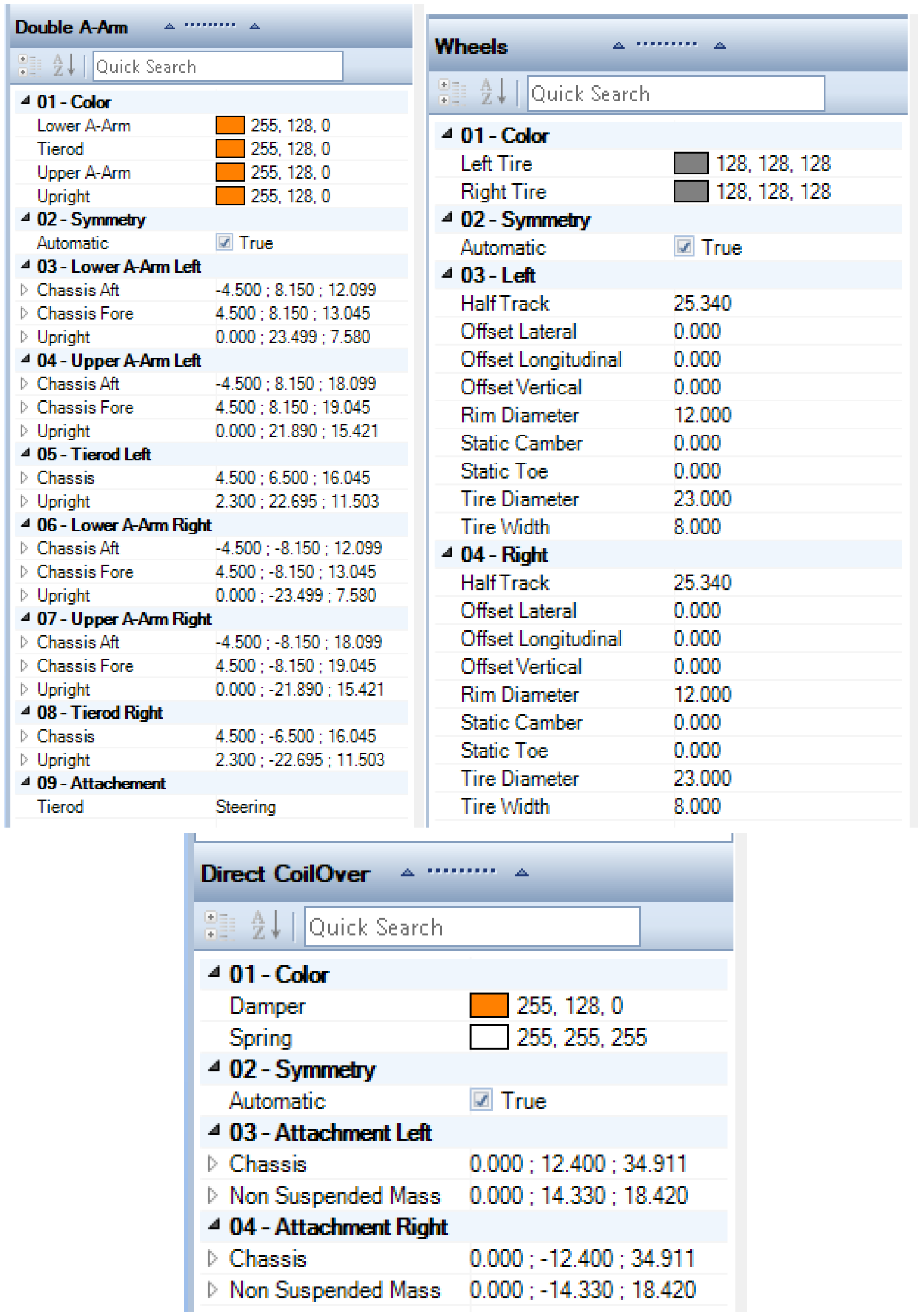


Figure B.8.16: Version 3 Front Suspension Model 3D Points in Optimum Kinematics

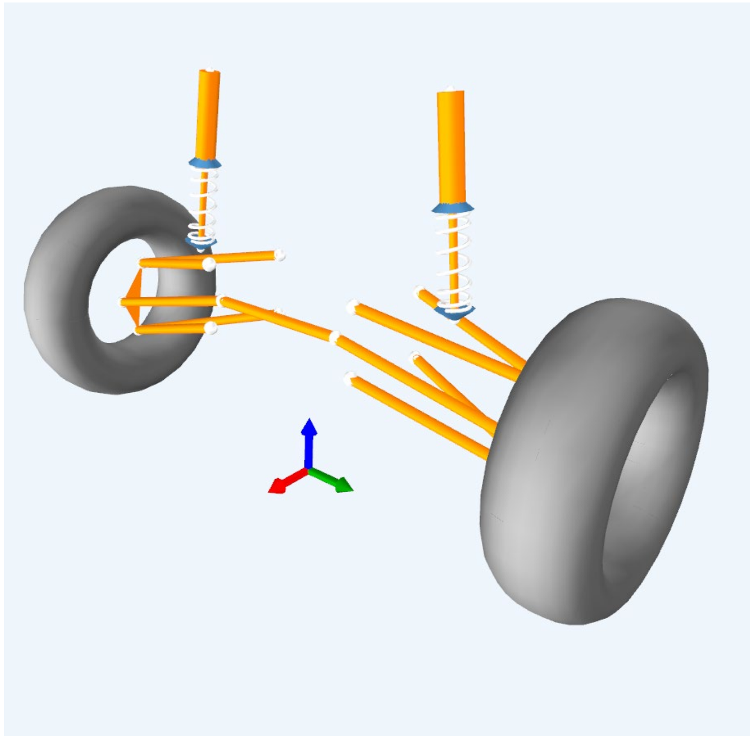


Figure B.8.17: Version 4 Front Suspension Model in Optimum Kinematics

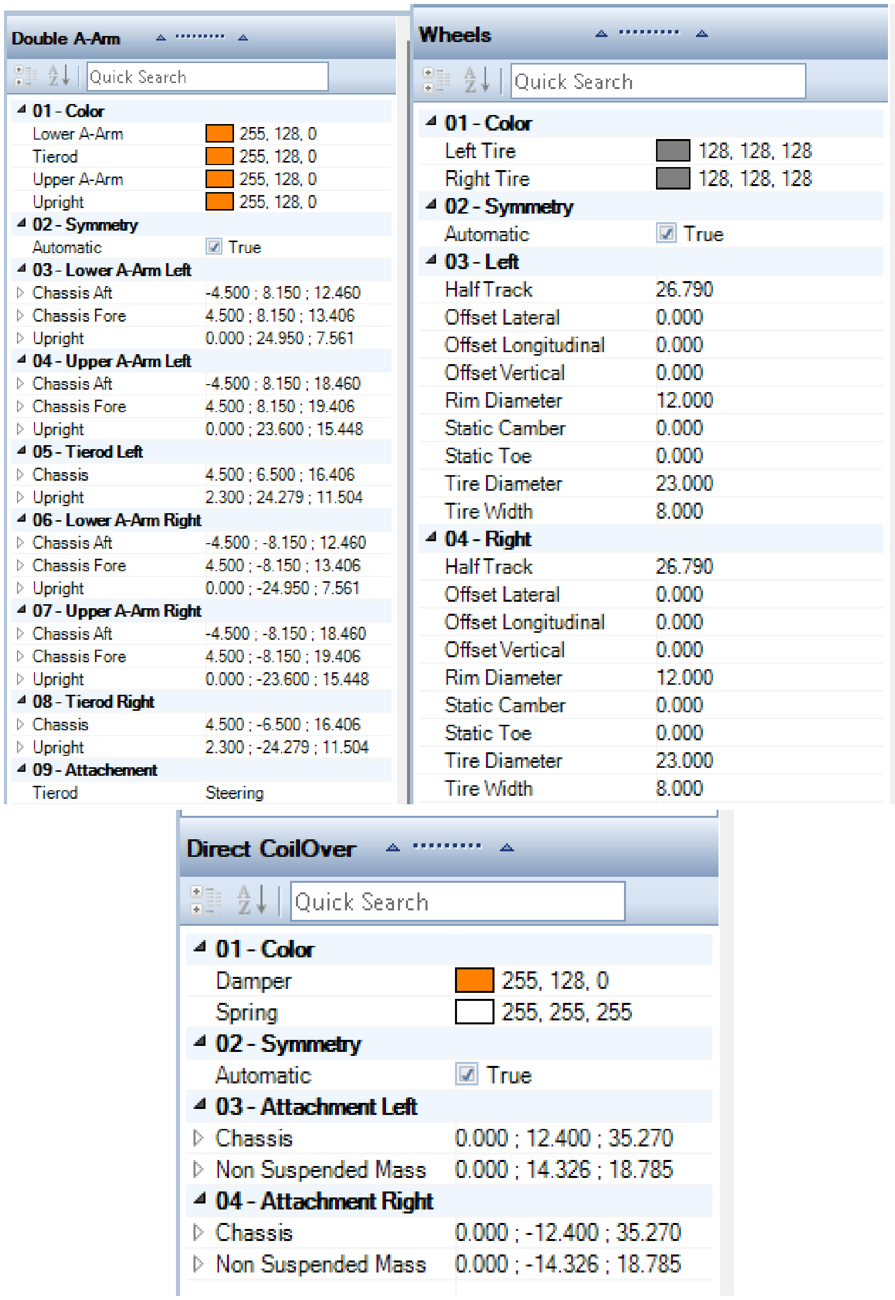


Figure B.8.18: Version 4 Front Suspension Model 3D Points in Optimum Kinematics

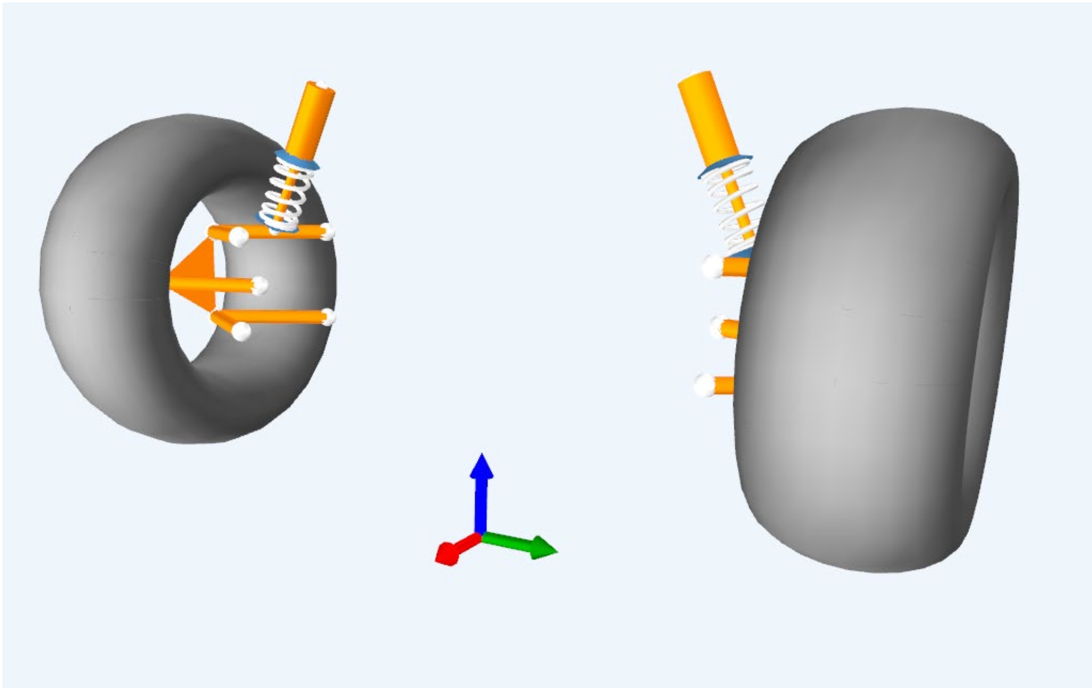


Figure B.8.19: Rear Suspension Model in Optimum Kinematics

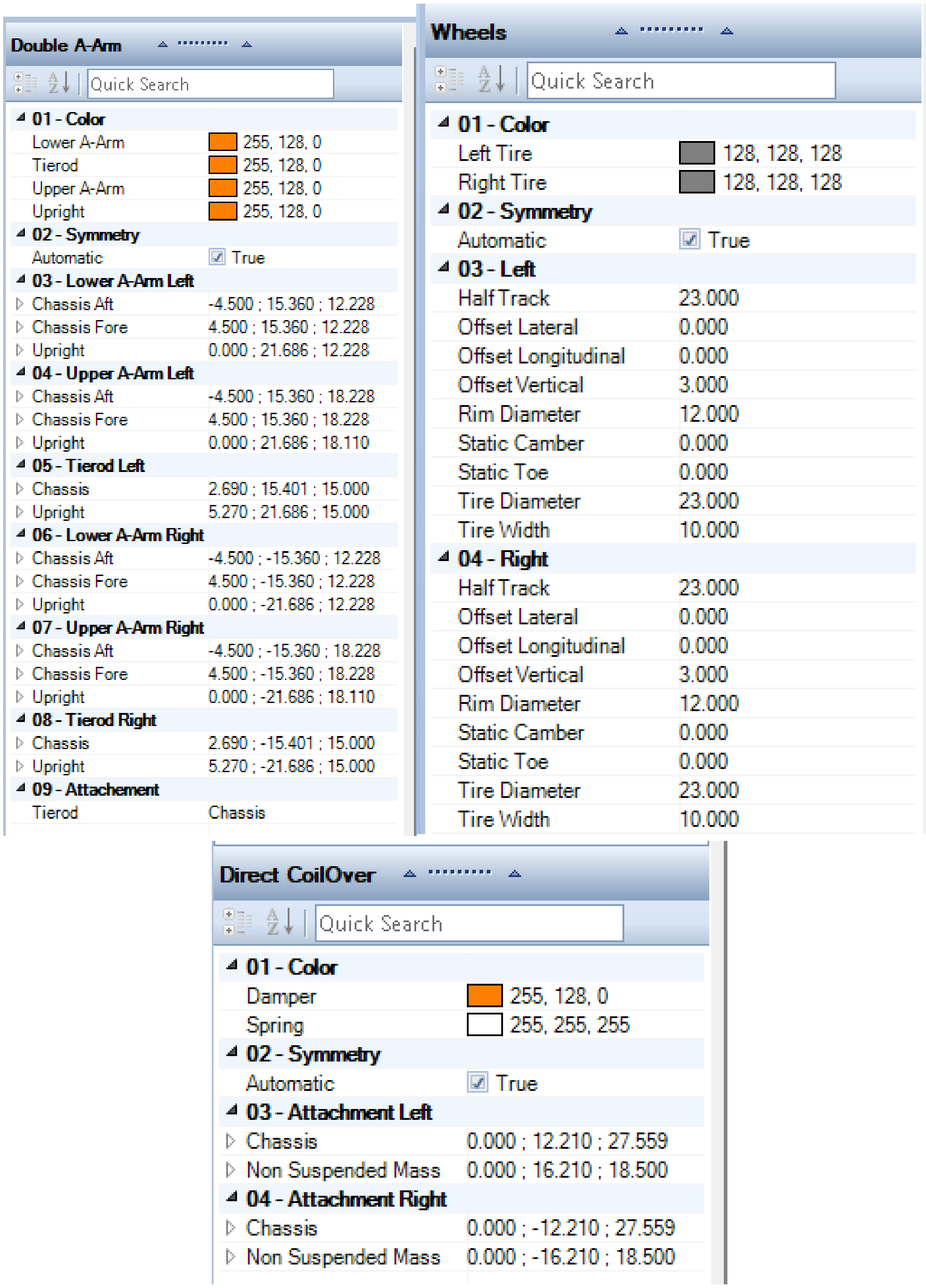


Figure B.8.20: Rear Suspension Model 3D Points in Optimum Kinematics

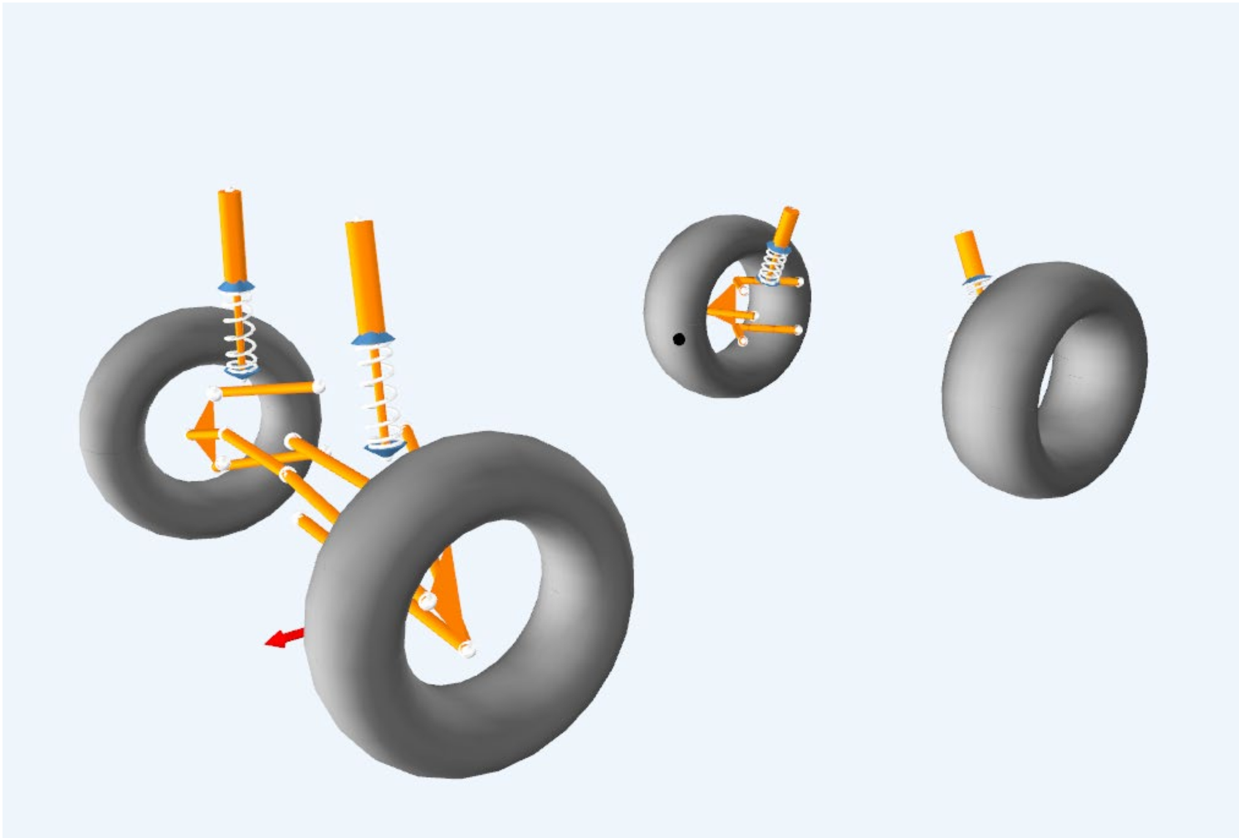


Figure B.8.21: Version 1 Full Vehicle Model with Baja Car Parameters

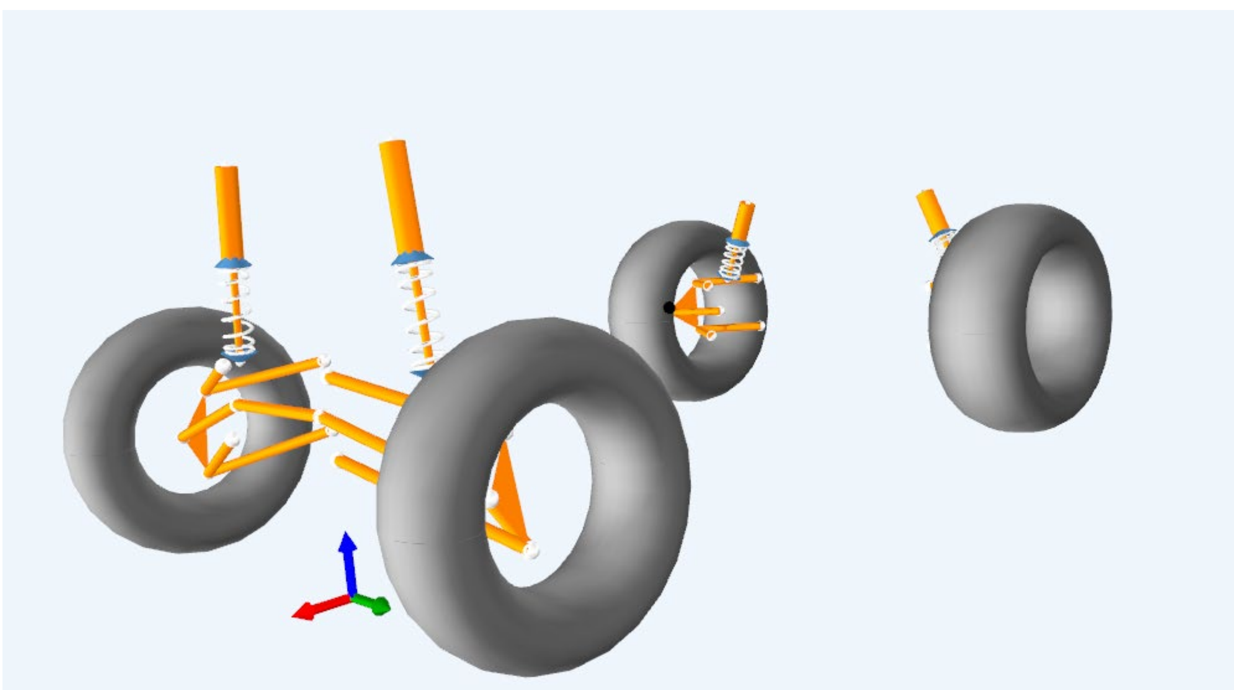


Figure B.8.22: Version 3 Full Vehicle Model with Baja Car Parameters

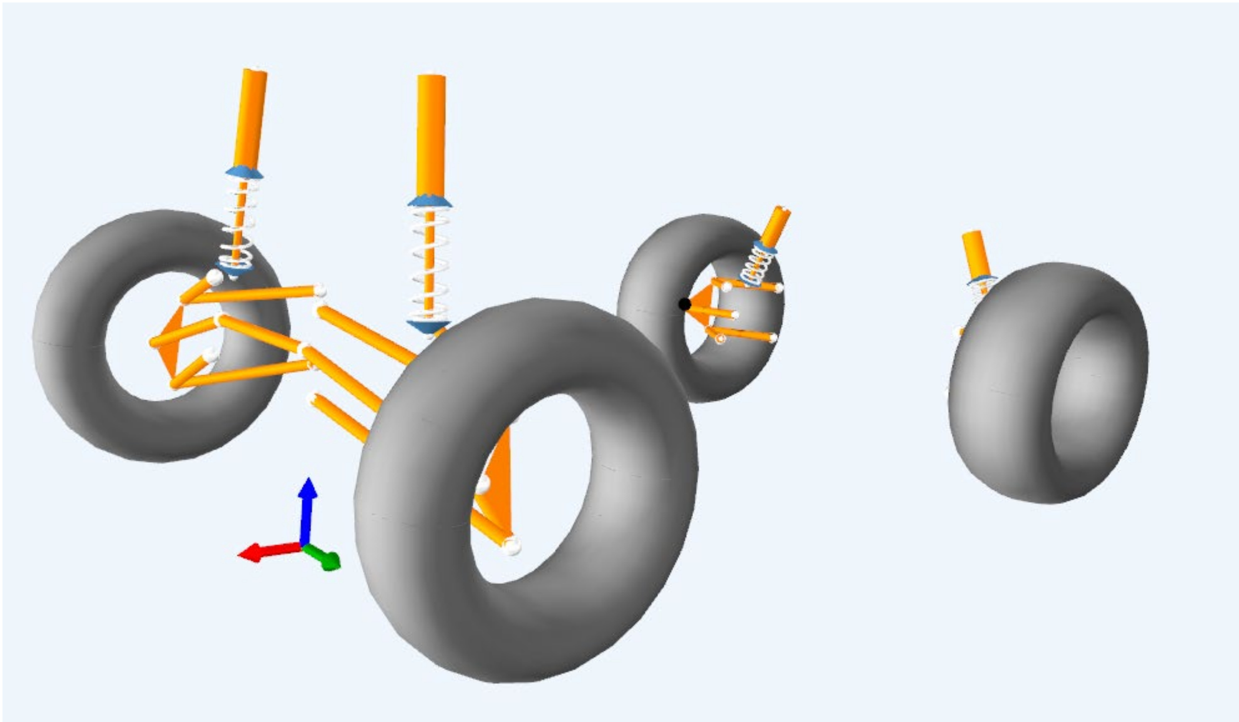


Figure B.8.23: Version 4 Full Vehicle Model with Baja Car Parameters

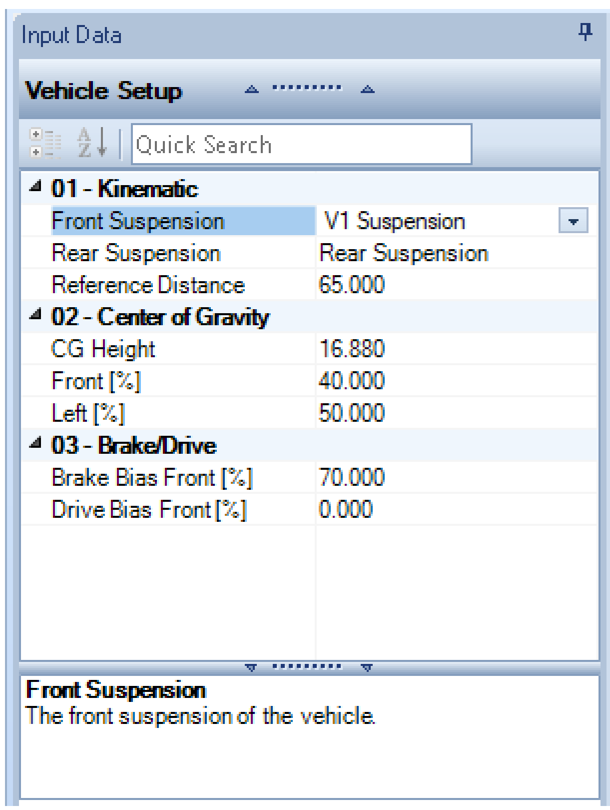


Figure B.8.24: Baja Car Vehicle Parameters

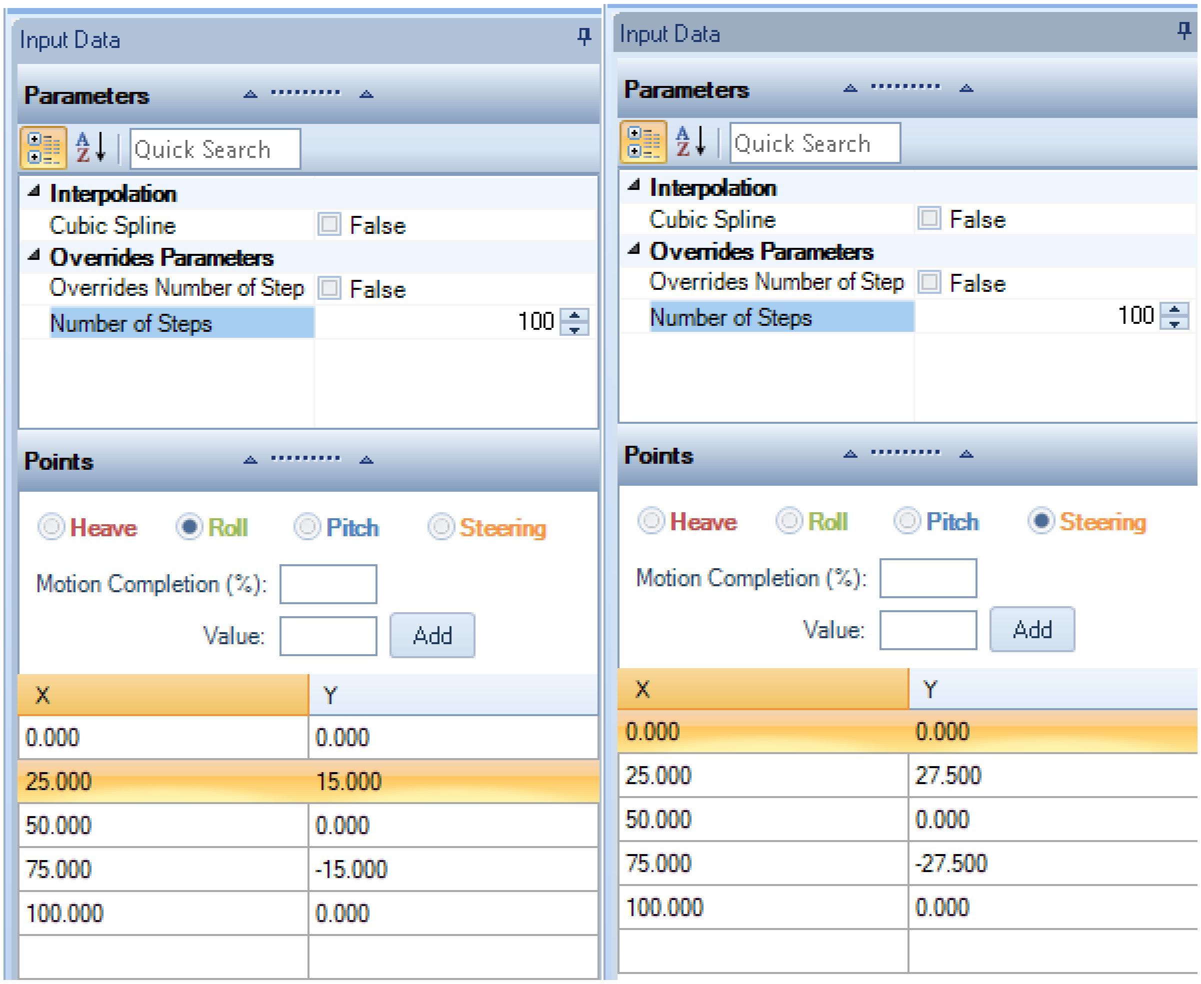


Figure B.8.25: Simulation Data Table Inputs for Body Roll and Steering Angle Simulations

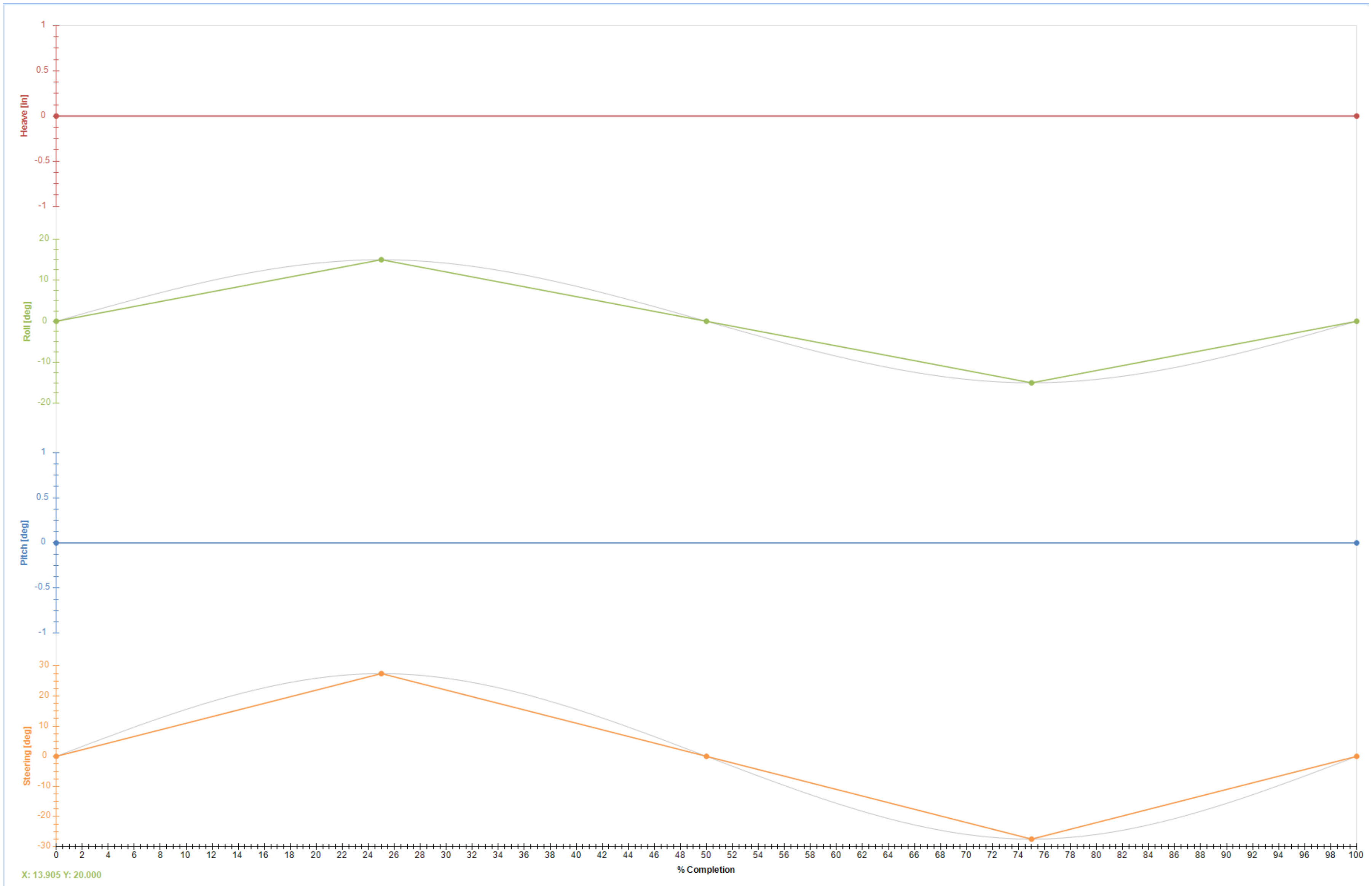


Figure B.8.26: Body Roll and Steering Angle Input Data Graph for Simulations

V4 Baja Vehicle - Body + Steering | V3 Baja Vehicle - Body + Steering | **V1 Baja Vehicle - Body + Steering** | Body + Steering * | V1 Suspension

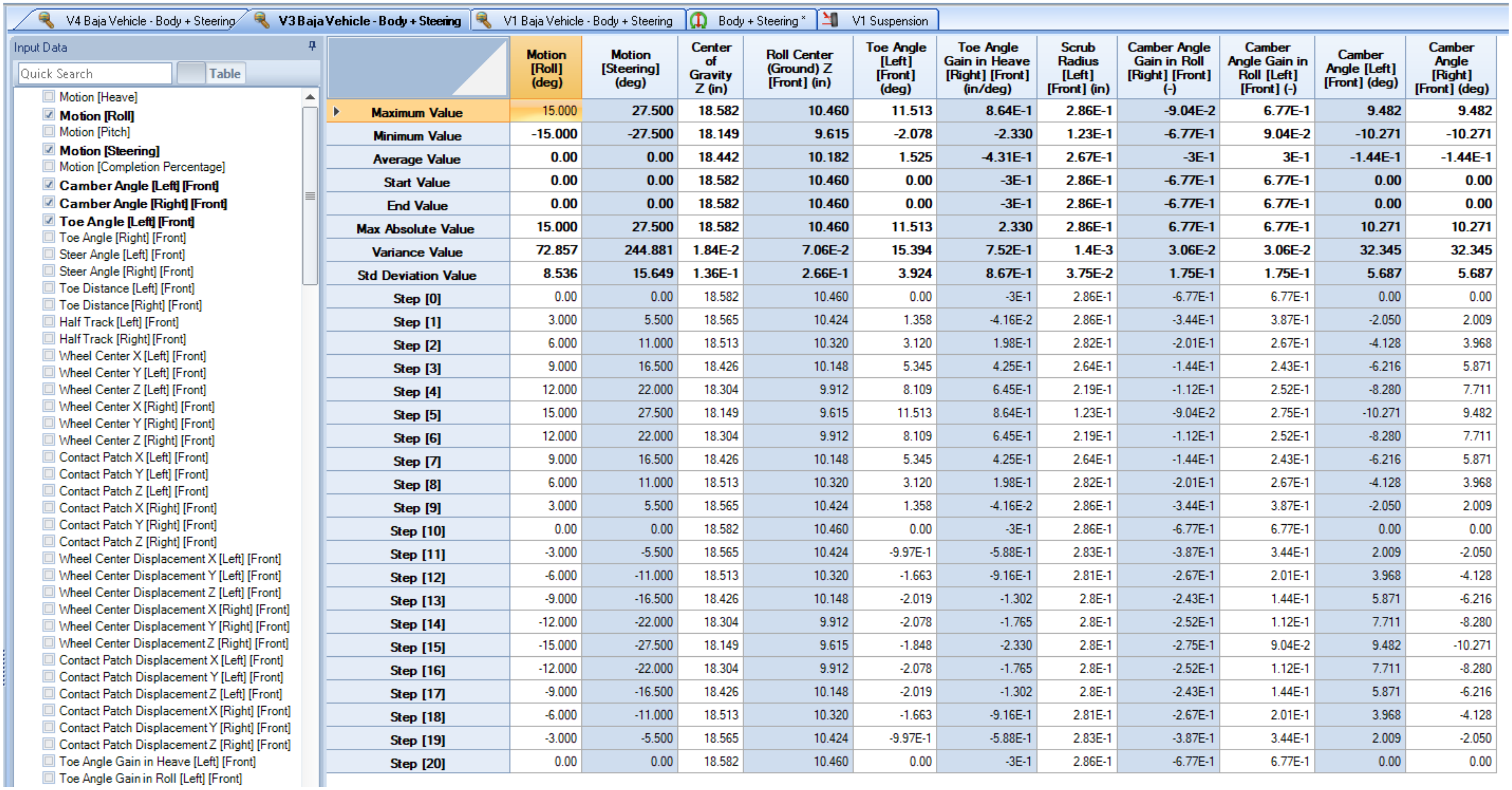
Input Data

Quick Search | Table

- Motion [Heave]
- **Motion [Roll]**
- Motion [Pitch]
- **Motion [Steering]**
- Motion [Completion Percentage]
- **Camber Angle [Left] [Front]**
- **Camber Angle [Right] [Front]**
- **Toe Angle [Left] [Front]**
- Toe Angle [Right] [Front]
- Steer Angle [Left] [Front]
- Steer Angle [Right] [Front]
- Toe Distance [Left] [Front]
- Toe Distance [Right] [Front]
- Half Track [Left] [Front]
- Half Track [Right] [Front]
- Wheel Center X [Left] [Front]
- Wheel Center Y [Left] [Front]
- Wheel Center Z [Left] [Front]
- Wheel Center X [Right] [Front]
- Wheel Center Y [Right] [Front]
- Wheel Center Z [Right] [Front]
- Contact Patch X [Left] [Front]
- Contact Patch Y [Left] [Front]
- Contact Patch Z [Left] [Front]
- Contact Patch X [Right] [Front]
- Contact Patch Y [Right] [Front]
- Contact Patch Z [Right] [Front]
- Wheel Center Displacement X [Left] [Front]
- Wheel Center Displacement Y [Left] [Front]
- Wheel Center Displacement Z [Left] [Front]
- Wheel Center Displacement X [Right] [Front]
- Wheel Center Displacement Y [Right] [Front]
- Wheel Center Displacement Z [Right] [Front]
- Contact Patch Displacement X [Left] [Front]
- Contact Patch Displacement Y [Left] [Front]
- Contact Patch Displacement Z [Left] [Front]
- Contact Patch Displacement X [Right] [Front]
- Contact Patch Displacement Y [Right] [Front]
- Contact Patch Displacement Z [Right] [Front]
- Toe Angle Gain in Heave [Left] [Front]
- Toe Angle Gain in Roll [Left] [Front]

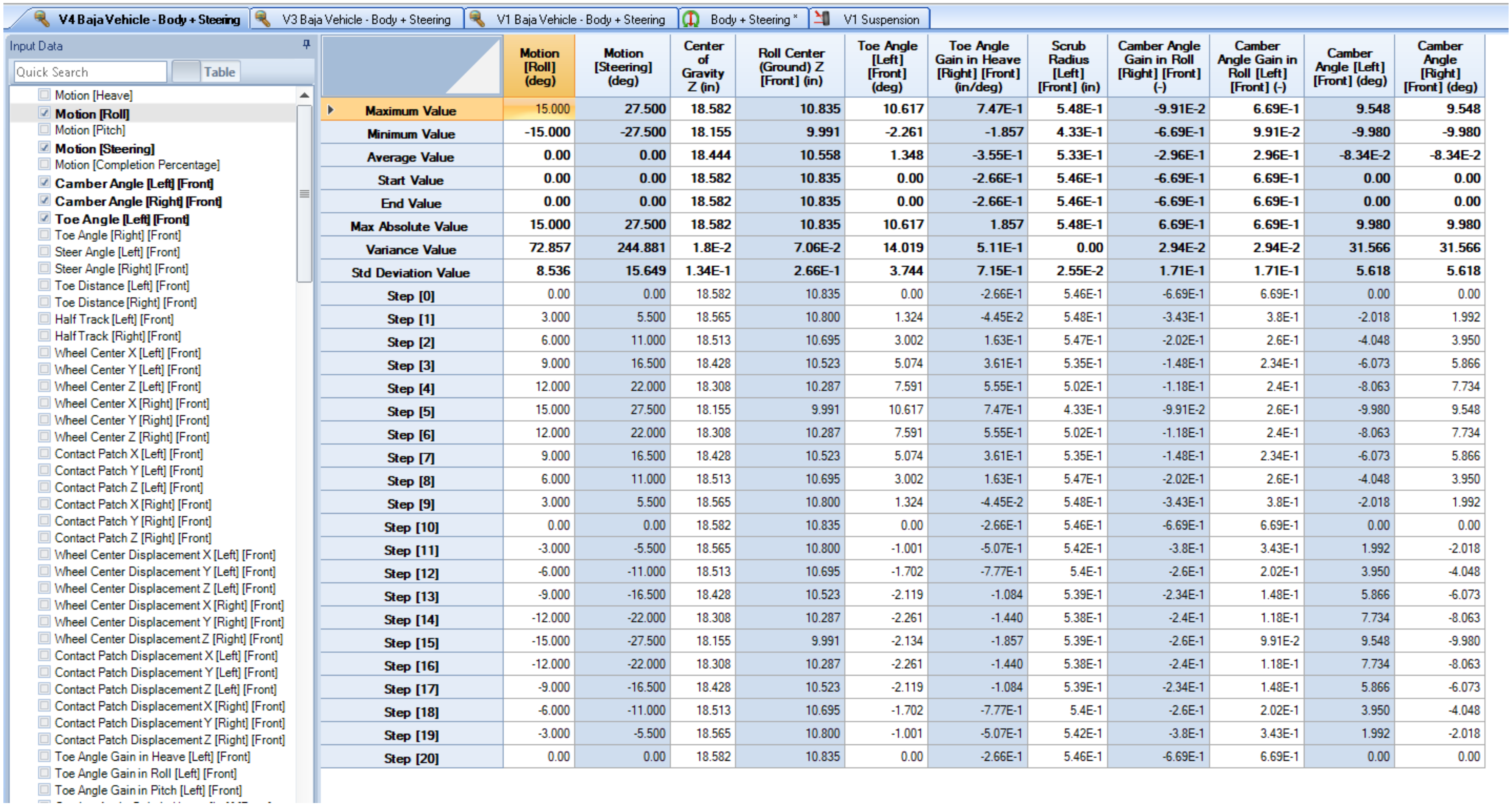
	Motion [Roll] (deg)	Motion [Steering] (deg)	Center of Gravity Z (in)	Roll Center (Ground) Z [Front] (in)	Toe Angle [Left] [Front] (deg)	Toe Angle Gain in Heave [Right] [Front] (in/deg)	Scrub Radius [Left] [Front] (in)	Camber Angle Gain in Roll [Right] [Front] (-)	Camber Angle Gain in Roll [Left] [Front] (-)	Camber Angle [Left] [Front] (deg)	Camber Angle [Right] [Front] (deg)
Maximum Value	15.000	27.500	18.662	10.492	9.190	7.84E-1	2.43E-1	-7.25E-2	6.82E-1	9.593	9.593
Minimum Value	-15.000	-27.500	18.227	9.681	-9.03E-1	-2.150	1.44E-1	-6.82E-1	7.25E-2	-10.469	-10.469
Average Value	0.00	0.00	18.521	10.225	1.434	-4.02E-1	2.31E-1	-2.89E-1	2.89E-1	-1.53E-1	-1.53E-1
Start Value	0.00	0.00	18.662	10.492	0.00	-2.79E-1	2.42E-1	-6.82E-1	6.82E-1	0.00	0.00
End Value	0.00	0.00	18.662	10.492	0.00	-2.79E-1	2.42E-1	-6.82E-1	6.82E-1	0.00	0.00
Max Absolute Value	15.000	27.500	18.662	10.492	9.190	2.150	2.43E-1	6.82E-1	6.82E-1	10.469	10.469
Variance Value	72.857	244.881	1.86E-2	6.53E-2	8.107	6.38E-1	0.00	3.33E-2	3.33E-2	33.155	33.155
Std Deviation Value	8.536	15.649	1.36E-1	2.55E-1	2.847	7.99E-1	2.19E-2	1.82E-1	1.82E-1	5.758	5.758
Step [0]	0.00	0.00	18.662	10.492	0.00	-2.79E-1	2.42E-1	-6.82E-1	6.82E-1	0.00	0.00
Step [1]	3.000	5.500	18.645	10.458	9.44E-1	-4.05E-2	2.43E-1	-3.42E-1	3.84E-1	-2.066	2.025
Step [2]	6.000	11.000	18.592	10.357	2.269	1.79E-1	2.42E-1	-1.92E-1	2.55E-1	-4.165	4.002
Step [3]	9.000	16.500	18.505	10.191	4.032	3.87E-1	2.33E-1	-1.3E-1	2.24E-1	-6.283	5.926
Step [4]	12.000	22.000	18.383	9.965	6.307	5.87E-1	2.06E-1	-9.5E-2	2.28E-1	-8.397	7.792
Step [5]	15.000	27.500	18.227	9.681	9.190	7.84E-1	1.44E-1	-7.25E-2	2.49E-1	-10.469	9.593
Step [6]	12.000	22.000	18.383	9.965	6.307	5.87E-1	2.06E-1	-9.5E-2	2.28E-1	-8.397	7.792
Step [7]	9.000	16.500	18.505	10.191	4.032	3.87E-1	2.33E-1	-1.3E-1	2.24E-1	-6.283	5.926
Step [8]	6.000	11.000	18.592	10.357	2.269	1.79E-1	2.42E-1	-1.92E-1	2.55E-1	-4.165	4.002
Step [9]	3.000	5.500	18.645	10.458	9.44E-1	-4.05E-2	2.43E-1	-3.42E-1	3.84E-1	-2.066	2.025
Step [10]	0.00	0.00	18.662	10.492	0.00	-2.79E-1	2.42E-1	-6.82E-1	6.82E-1	0.00	0.00
Step [11]	-3.000	-5.500	18.645	10.458	-6.03E-1	-5.45E-1	2.4E-1	-3.84E-1	3.42E-1	2.025	-2.066
Step [12]	-6.000	-11.000	18.592	10.357	-8.97E-1	-8.49E-1	2.39E-1	-2.55E-1	1.92E-1	4.002	-4.165
Step [13]	-9.000	-16.500	18.505	10.191	-9.03E-1	-1.205	2.38E-1	-2.24E-1	1.3E-1	5.926	-6.283
Step [14]	-12.000	-22.000	18.383	9.965	-6.36E-1	-1.631	2.37E-1	-2.28E-1	9.5E-2	7.792	-8.397
Step [15]	-15.000	-27.500	18.227	9.681	-1.07E-1	-2.150	2.37E-1	-2.49E-1	7.25E-2	9.593	-10.469
Step [16]	-12.000	-22.000	18.383	9.965	-6.36E-1	-1.631	2.37E-1	-2.28E-1	9.5E-2	7.792	-8.397
Step [17]	-9.000	-16.500	18.505	10.191	-9.03E-1	-1.205	2.38E-1	-2.24E-1	1.3E-1	5.926	-6.283
Step [18]	-6.000	-11.000	18.592	10.357	-8.97E-1	-8.49E-1	2.39E-1	-2.55E-1	1.92E-1	4.002	-4.165
Step [19]	-3.000	-5.500	18.645	10.458	-6.03E-1	-5.45E-1	2.4E-1	-3.84E-1	3.42E-1	2.025	-2.066
Step [20]	0.00	0.00	18.662	10.492	0.00	-2.79E-1	2.42E-1	-6.82E-1	6.82E-1	0.00	0.00

Figure B.8.27: Simulation Results for Vehicle 1



	Motion [Roll] (deg)	Motion [Steering] (deg)	Center of Gravity Z (in)	Roll Center (Ground) Z [Front] (in)	Toe Angle [Left] [Front] (deg)	Toe Angle Gain in Heave [Right] [Front] (in/deg)	Scrub Radius [Left] [Front] (in)	Camber Angle Gain in Roll [Right] [Front] (-)	Camber Angle Gain in Roll [Left] [Front] (-)	Camber Angle [Left] [Front] (deg)	Camber Angle [Right] [Front] (deg)
Maximum Value	15.000	27.500	18.582	10.460	11.513	8.64E-1	2.86E-1	-9.04E-2	6.77E-1	9.482	9.482
Minimum Value	-15.000	-27.500	18.149	9.615	-2.078	-2.330	1.23E-1	-6.77E-1	9.04E-2	-10.271	-10.271
Average Value	0.00	0.00	18.442	10.182	1.525	-4.31E-1	2.67E-1	-3E-1	3E-1	-1.44E-1	-1.44E-1
Start Value	0.00	0.00	18.582	10.460	0.00	-3E-1	2.86E-1	-6.77E-1	6.77E-1	0.00	0.00
End Value	0.00	0.00	18.582	10.460	0.00	-3E-1	2.86E-1	-6.77E-1	6.77E-1	0.00	0.00
Max Absolute Value	15.000	27.500	18.582	10.460	11.513	2.330	2.86E-1	6.77E-1	6.77E-1	10.271	10.271
Variance Value	72.857	244.881	1.84E-2	7.06E-2	15.394	7.52E-1	1.4E-3	3.06E-2	3.06E-2	32.345	32.345
Std Deviation Value	8.536	15.649	1.36E-1	2.66E-1	3.924	8.67E-1	3.75E-2	1.75E-1	1.75E-1	5.687	5.687
Step [0]	0.00	0.00	18.582	10.460	0.00	-3E-1	2.86E-1	-6.77E-1	6.77E-1	0.00	0.00
Step [1]	3.000	5.500	18.565	10.424	1.358	-4.16E-2	2.86E-1	-3.44E-1	3.87E-1	-2.050	2.009
Step [2]	6.000	11.000	18.513	10.320	3.120	1.98E-1	2.82E-1	-2.01E-1	2.67E-1	-4.128	3.968
Step [3]	9.000	16.500	18.426	10.148	5.345	4.25E-1	2.64E-1	-1.44E-1	2.43E-1	-6.216	5.871
Step [4]	12.000	22.000	18.304	9.912	8.109	6.45E-1	2.19E-1	-1.12E-1	2.52E-1	-8.280	7.711
Step [5]	15.000	27.500	18.149	9.615	11.513	8.64E-1	1.23E-1	-9.04E-2	2.75E-1	-10.271	9.482
Step [6]	12.000	22.000	18.304	9.912	8.109	6.45E-1	2.19E-1	-1.12E-1	2.52E-1	-8.280	7.711
Step [7]	9.000	16.500	18.426	10.148	5.345	4.25E-1	2.64E-1	-1.44E-1	2.43E-1	-6.216	5.871
Step [8]	6.000	11.000	18.513	10.320	3.120	1.98E-1	2.82E-1	-2.01E-1	2.67E-1	-4.128	3.968
Step [9]	3.000	5.500	18.565	10.424	1.358	-4.16E-2	2.86E-1	-3.44E-1	3.87E-1	-2.050	2.009
Step [10]	0.00	0.00	18.582	10.460	0.00	-3E-1	2.86E-1	-6.77E-1	6.77E-1	0.00	0.00
Step [11]	-3.000	-5.500	18.565	10.424	-9.97E-1	-5.88E-1	2.83E-1	-3.87E-1	3.44E-1	2.009	-2.050
Step [12]	-6.000	-11.000	18.513	10.320	-1.663	-9.16E-1	2.81E-1	-2.67E-1	2.01E-1	3.968	-4.128
Step [13]	-9.000	-16.500	18.426	10.148	-2.019	-1.302	2.8E-1	-2.43E-1	1.44E-1	5.871	-6.216
Step [14]	-12.000	-22.000	18.304	9.912	-2.078	-1.765	2.8E-1	-2.52E-1	1.12E-1	7.711	-8.280
Step [15]	-15.000	-27.500	18.149	9.615	-1.848	-2.330	2.8E-1	-2.75E-1	9.04E-2	9.482	-10.271
Step [16]	-12.000	-22.000	18.304	9.912	-2.078	-1.765	2.8E-1	-2.52E-1	1.12E-1	7.711	-8.280
Step [17]	-9.000	-16.500	18.426	10.148	-2.019	-1.302	2.8E-1	-2.43E-1	1.44E-1	5.871	-6.216
Step [18]	-6.000	-11.000	18.513	10.320	-1.663	-9.16E-1	2.81E-1	-2.67E-1	2.01E-1	3.968	-4.128
Step [19]	-3.000	-5.500	18.565	10.424	-9.97E-1	-5.88E-1	2.83E-1	-3.87E-1	3.44E-1	2.009	-2.050
Step [20]	0.00	0.00	18.582	10.460	0.00	-3E-1	2.86E-1	-6.77E-1	6.77E-1	0.00	0.00

Figure B.8.28: Simulation Results for Vehicle 3



	Motion [Roll] (deg)	Motion [Steering] (deg)	Center of Gravity Z (in)	Roll Center (Ground) Z [Front] (in)	Toe Angle [Left] [Front] (deg)	Toe Angle Gain in Heave [Right] [Front] (in/deg)	Scrub Radius [Left] [Front] (in)	Camber Angle Gain in Roll [Right] [Front] (-)	Camber Angle Gain in Roll [Left] [Front] (-)	Camber Angle [Left] [Front] (deg)	Camber Angle [Right] [Front] (deg)
Maximum Value	15.000	27.500	18.582	10.835	10.617	7.47E-1	5.48E-1	-9.91E-2	6.69E-1	9.548	9.548
Minimum Value	-15.000	-27.500	18.155	9.991	-2.261	-1.857	4.33E-1	-6.69E-1	9.91E-2	-9.980	-9.980
Average Value	0.00	0.00	18.444	10.558	1.348	-3.55E-1	5.33E-1	-2.96E-1	2.96E-1	-8.34E-2	-8.34E-2
Start Value	0.00	0.00	18.582	10.835	0.00	-2.66E-1	5.46E-1	-6.69E-1	6.69E-1	0.00	0.00
End Value	0.00	0.00	18.582	10.835	0.00	-2.66E-1	5.46E-1	-6.69E-1	6.69E-1	0.00	0.00
Max Absolute Value	15.000	27.500	18.582	10.835	10.617	1.857	5.48E-1	6.69E-1	6.69E-1	9.980	9.980
Variance Value	72.857	244.881	1.8E-2	7.06E-2	14.019	5.11E-1	0.00	2.94E-2	2.94E-2	31.566	31.566
Std Deviation Value	8.536	15.649	1.34E-1	2.66E-1	3.744	7.15E-1	2.55E-2	1.71E-1	1.71E-1	5.618	5.618
Step [0]	0.00	0.00	18.582	10.835	0.00	-2.66E-1	5.46E-1	-6.69E-1	6.69E-1	0.00	0.00
Step [1]	3.000	5.500	18.565	10.800	1.324	-4.45E-2	5.48E-1	-3.43E-1	3.8E-1	-2.018	1.992
Step [2]	6.000	11.000	18.513	10.695	3.002	1.63E-1	5.47E-1	-2.02E-1	2.6E-1	-4.048	3.950
Step [3]	9.000	16.500	18.428	10.523	5.074	3.61E-1	5.35E-1	-1.48E-1	2.34E-1	-6.073	5.866
Step [4]	12.000	22.000	18.308	10.287	7.591	5.55E-1	5.02E-1	-1.18E-1	2.4E-1	-8.063	7.734
Step [5]	15.000	27.500	18.155	9.991	10.617	7.47E-1	4.33E-1	-9.91E-2	2.6E-1	-9.980	9.548
Step [6]	12.000	22.000	18.308	10.287	7.591	5.55E-1	5.02E-1	-1.18E-1	2.4E-1	-8.063	7.734
Step [7]	9.000	16.500	18.428	10.523	5.074	3.61E-1	5.35E-1	-1.48E-1	2.34E-1	-6.073	5.866
Step [8]	6.000	11.000	18.513	10.695	3.002	1.63E-1	5.47E-1	-2.02E-1	2.6E-1	-4.048	3.950
Step [9]	3.000	5.500	18.565	10.800	1.324	-4.45E-2	5.48E-1	-3.43E-1	3.8E-1	-2.018	1.992
Step [10]	0.00	0.00	18.582	10.835	0.00	-2.66E-1	5.46E-1	-6.69E-1	6.69E-1	0.00	0.00
Step [11]	-3.000	-5.500	18.565	10.800	-1.001	-5.07E-1	5.42E-1	-3.8E-1	3.43E-1	1.992	-2.018
Step [12]	-6.000	-11.000	18.513	10.695	-1.702	-7.77E-1	5.4E-1	-2.6E-1	2.02E-1	3.950	-4.048
Step [13]	-9.000	-16.500	18.428	10.523	-2.119	-1.084	5.39E-1	-2.34E-1	1.48E-1	5.866	-6.073
Step [14]	-12.000	-22.000	18.308	10.287	-2.261	-1.440	5.38E-1	-2.4E-1	1.18E-1	7.734	-8.063
Step [15]	-15.000	-27.500	18.155	9.991	-2.134	-1.857	5.39E-1	-2.6E-1	9.91E-2	9.548	-9.980
Step [16]	-12.000	-22.000	18.308	10.287	-2.261	-1.440	5.38E-1	-2.4E-1	1.18E-1	7.734	-8.063
Step [17]	-9.000	-16.500	18.428	10.523	-2.119	-1.084	5.39E-1	-2.34E-1	1.48E-1	5.866	-6.073
Step [18]	-6.000	-11.000	18.513	10.695	-1.702	-7.77E-1	5.4E-1	-2.6E-1	2.02E-1	3.950	-4.048
Step [19]	-3.000	-5.500	18.565	10.800	-1.001	-5.07E-1	5.42E-1	-3.8E-1	3.43E-1	1.992	-2.018
Step [20]	0.00	0.00	18.582	10.835	0.00	-2.66E-1	5.46E-1	-6.69E-1	6.69E-1	0.00	0.00

Figure B.8.29: Simulation Results for Vehicle 4

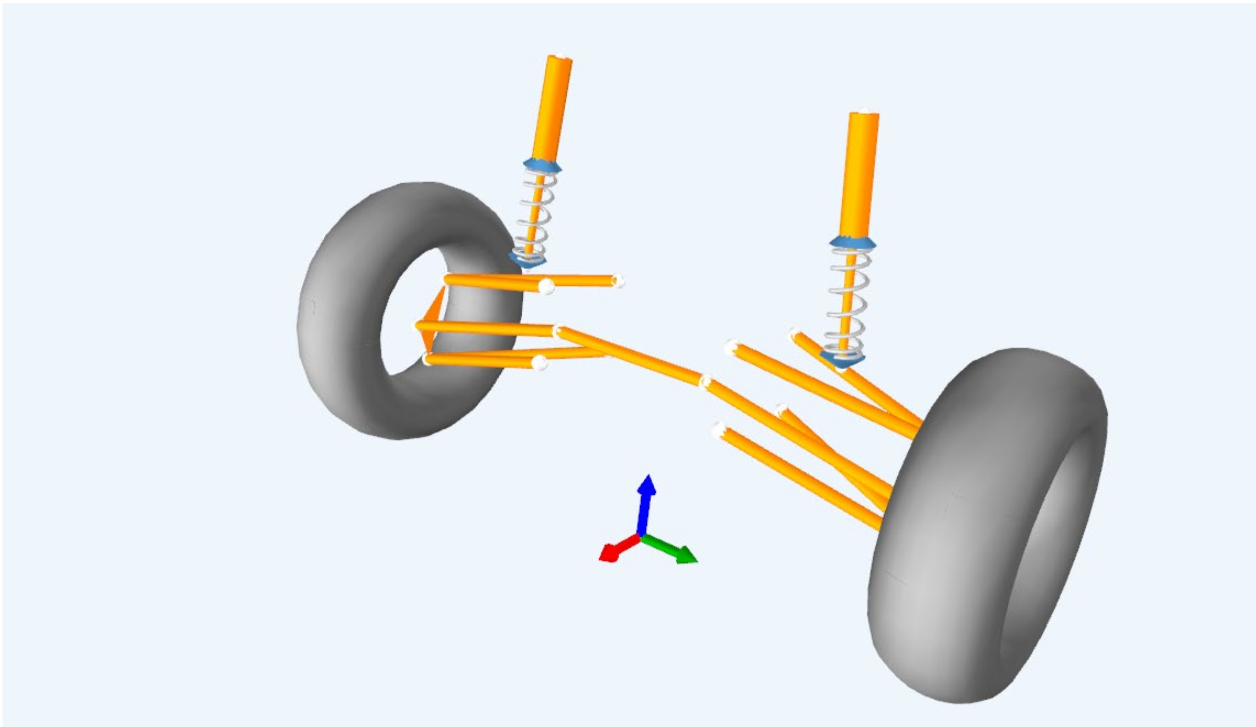


Figure B.8.30: Version 1 Redesign Front Suspension Model in Optimum Kinematics

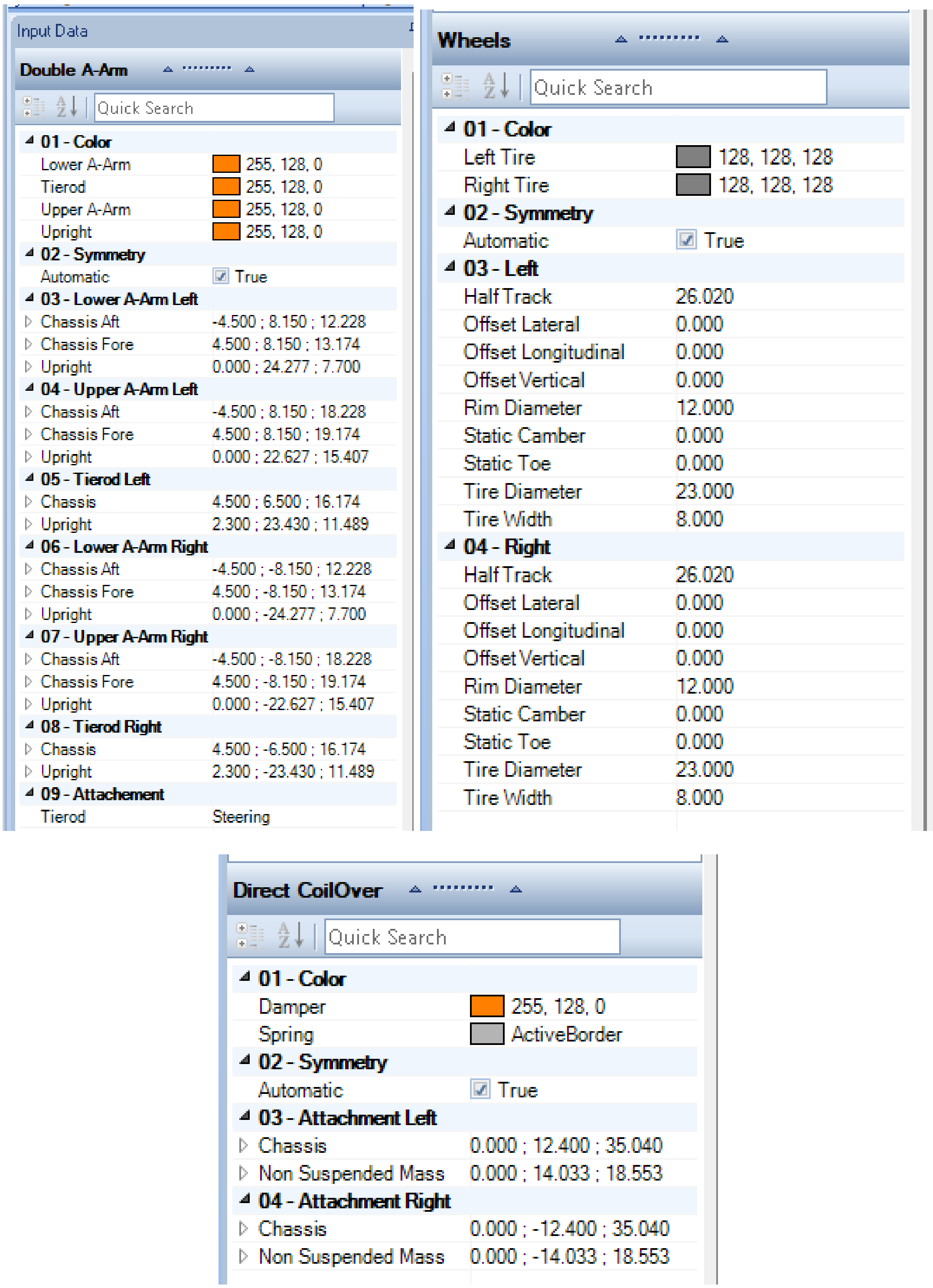


Figure B.8.31: Version 1 Redesign Front Suspension Model 3D Points in Optimum Kinematics

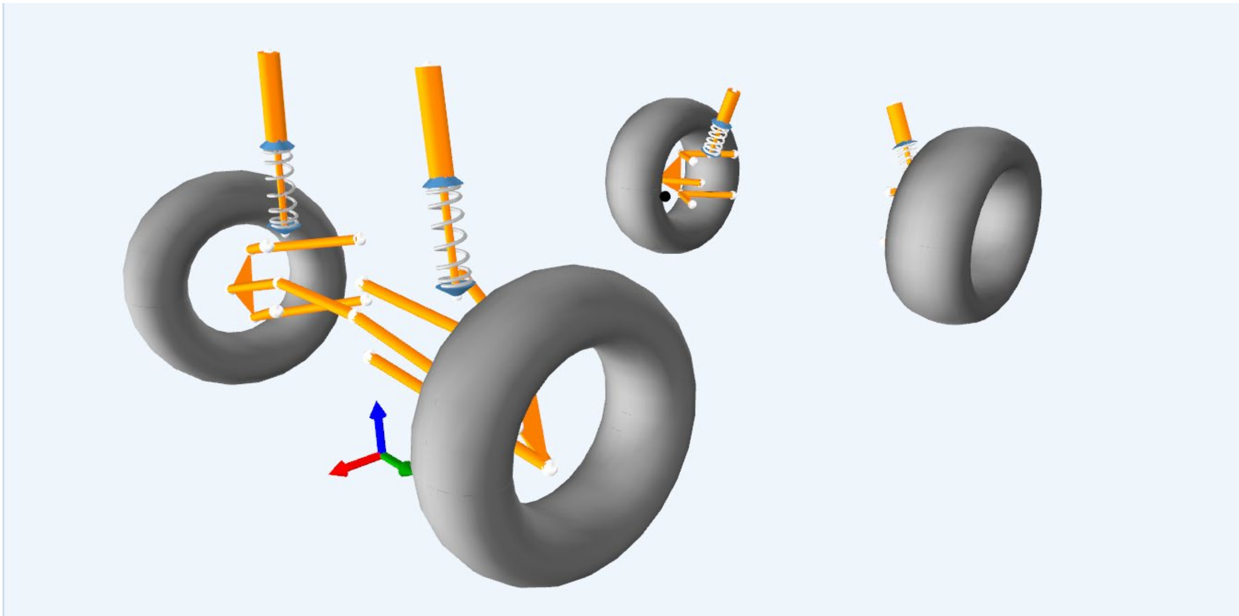
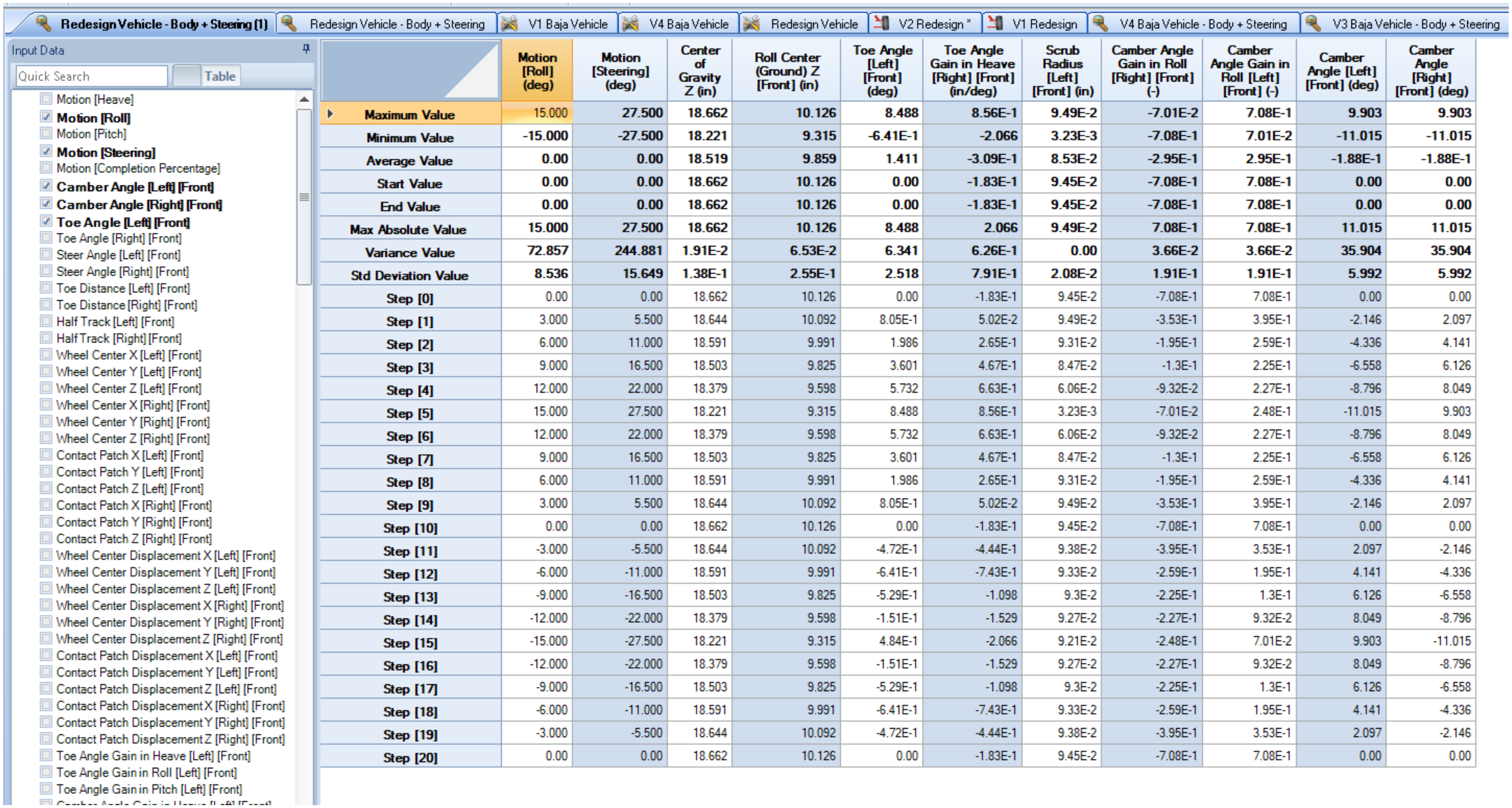


Figure B.8.32: Version 1 Redesign Full Vehicle Model in Optimum Kinematics



	Motion [Roll] (deg)	Motion [Steering] (deg)	Center of Gravity Z (in)	Roll Center (Ground) Z [Front] (in)	Toe Angle [Left] [Front] (deg)	Toe Angle Gain in Heave [Right] [Front] (in/deg)	Scrub Radius [Left] [Front] (in)	Camber Angle Gain in Roll [Right] [Front] (-)	Camber Angle Gain in Roll [Left] [Front] (-)	Camber Angle [Left] [Front] (deg)	Camber Angle [Right] [Front] (deg)
Maximum Value	15.000	27.500	18.662	10.126	8.488	8.56E-1	9.49E-2	-7.01E-2	7.08E-1	9.903	9.903
Minimum Value	-15.000	-27.500	18.221	9.315	-6.41E-1	-2.066	3.23E-3	-7.08E-1	7.01E-2	-11.015	-11.015
Average Value	0.00	0.00	18.519	9.859	1.411	-3.09E-1	8.53E-2	-2.95E-1	2.95E-1	-1.88E-1	-1.88E-1
Start Value	0.00	0.00	18.662	10.126	0.00	-1.83E-1	9.45E-2	-7.08E-1	7.08E-1	0.00	0.00
End Value	0.00	0.00	18.662	10.126	0.00	-1.83E-1	9.45E-2	-7.08E-1	7.08E-1	0.00	0.00
Max Absolute Value	15.000	27.500	18.662	10.126	8.488	2.066	9.49E-2	7.08E-1	7.08E-1	11.015	11.015
Variance Value	72.857	244.881	1.91E-2	6.53E-2	6.341	6.26E-1	0.00	3.66E-2	3.66E-2	35.904	35.904
Std Deviation Value	8.536	15.649	1.38E-1	2.55E-1	2.518	7.91E-1	2.08E-2	1.91E-1	1.91E-1	5.992	5.992
Step [0]	0.00	0.00	18.662	10.126	0.00	-1.83E-1	9.45E-2	-7.08E-1	7.08E-1	0.00	0.00
Step [1]	3.000	5.500	18.644	10.092	8.05E-1	5.02E-2	9.49E-2	-3.53E-1	3.95E-1	-2.146	2.097
Step [2]	6.000	11.000	18.591	9.991	1.986	2.65E-1	9.31E-2	-1.95E-1	2.59E-1	-4.336	4.141
Step [3]	9.000	16.500	18.503	9.825	3.601	4.67E-1	8.47E-2	-1.3E-1	2.25E-1	-6.558	6.126
Step [4]	12.000	22.000	18.379	9.598	5.732	6.63E-1	6.06E-2	-9.32E-2	2.27E-1	-8.796	8.049
Step [5]	15.000	27.500	18.221	9.315	8.488	8.56E-1	3.23E-3	-7.01E-2	2.48E-1	-11.015	9.903
Step [6]	12.000	22.000	18.379	9.598	5.732	6.63E-1	6.06E-2	-9.32E-2	2.27E-1	-8.796	8.049
Step [7]	9.000	16.500	18.503	9.825	3.601	4.67E-1	8.47E-2	-1.3E-1	2.25E-1	-6.558	6.126
Step [8]	6.000	11.000	18.591	9.991	1.986	2.65E-1	9.31E-2	-1.95E-1	2.59E-1	-4.336	4.141
Step [9]	3.000	5.500	18.644	10.092	8.05E-1	5.02E-2	9.49E-2	-3.53E-1	3.95E-1	-2.146	2.097
Step [10]	0.00	0.00	18.662	10.126	0.00	-1.83E-1	9.45E-2	-7.08E-1	7.08E-1	0.00	0.00
Step [11]	-3.000	-5.500	18.644	10.092	-4.72E-1	-4.44E-1	9.38E-2	-3.95E-1	3.53E-1	2.097	-2.146
Step [12]	-6.000	-11.000	18.591	9.991	-6.41E-1	-7.43E-1	9.33E-2	-2.59E-1	1.95E-1	4.141	-4.336
Step [13]	-9.000	-16.500	18.503	9.825	-5.29E-1	-1.098	9.3E-2	-2.25E-1	1.3E-1	6.126	-6.558
Step [14]	-12.000	-22.000	18.379	9.598	-1.51E-1	-1.529	9.27E-2	-2.27E-1	9.32E-2	8.049	-8.796
Step [15]	-15.000	-27.500	18.221	9.315	4.84E-1	-2.066	9.21E-2	-2.48E-1	7.01E-2	9.903	-11.015
Step [16]	-12.000	-22.000	18.379	9.598	-1.51E-1	-1.529	9.27E-2	-2.27E-1	9.32E-2	8.049	-8.796
Step [17]	-9.000	-16.500	18.503	9.825	-5.29E-1	-1.098	9.3E-2	-2.25E-1	1.3E-1	6.126	-6.558
Step [18]	-6.000	-11.000	18.591	9.991	-6.41E-1	-7.43E-1	9.33E-2	-2.59E-1	1.95E-1	4.141	-4.336
Step [19]	-3.000	-5.500	18.644	10.092	-4.72E-1	-4.44E-1	9.38E-2	-3.95E-1	3.53E-1	2.097	-2.146
Step [20]	0.00	0.00	18.662	10.126	0.00	-1.83E-1	9.45E-2	-7.08E-1	7.08E-1	0.00	0.00

Figure B.8.33: Simulation Results for Vehicle 1 Redesign

Criteria	Version 1	Version 3	Version 4
Total Width (in)	60	58.6	61.6
Average Center of Gravity Value (in)	18.52	18.44	18.16
Average Roll Center Height in the Z-Axis (in)	10.23	10.18	10.56
Average Distance from Center of Gravity to Roll Center in Z-Axis (in)	8.29	8.26	7.6
Scrub Radius (in)	0.23	0.29	0.55
Max Camber Value (deg)	9.59	9.48	9.55
Minimum Camber Value (deg)	-10.47	-10.72	-9.98
Variable Camber (deg)	20.06	20.2	19.53

Figure B.3.34: Optimum Kinematic Simulation Data Table

		Version 1		Version 3		Version 4	
Criteria	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Total Width	5	4	20	2	10	5	25
Average Distance from Center of Gravity to Roll Center in Z-Axis	4	4	16	4	16	5	20
Scrub Radius	4	5	20	5	20	2	8
Variable Camber	2	2	4	2	4	2	4
Total		**60**		**50**		**57**	
Rank		1		3		2	
Develop?		Develop		Discontinue		Discontinue	

Figure B.8.35: Optimum Kinematic Simulation Data Scoring Matrix

Criteria	Version 1	Redesign of Version 1
Total Width (in)	60	60.2
Average Center of Gravity Value (in)	18.52	18.52
Average Roll Center Height in the Z-Axis (in)	10.23	9.859
Average Distance from Center of Gravity to Roll Center in Z-Axis (in)	8.29	8.661
Scrub Radius (in)	0.23	0.086
Max Camber Value (deg)	9.59	9.9
Minimum Camber Value (deg)	-10.47	-11.018
Variable Camber (deg)	20.06	20.918

Figure B.8.36: Version 1 and Redesign of Version 1 Optimum Kinematic Simulation Data Comparison

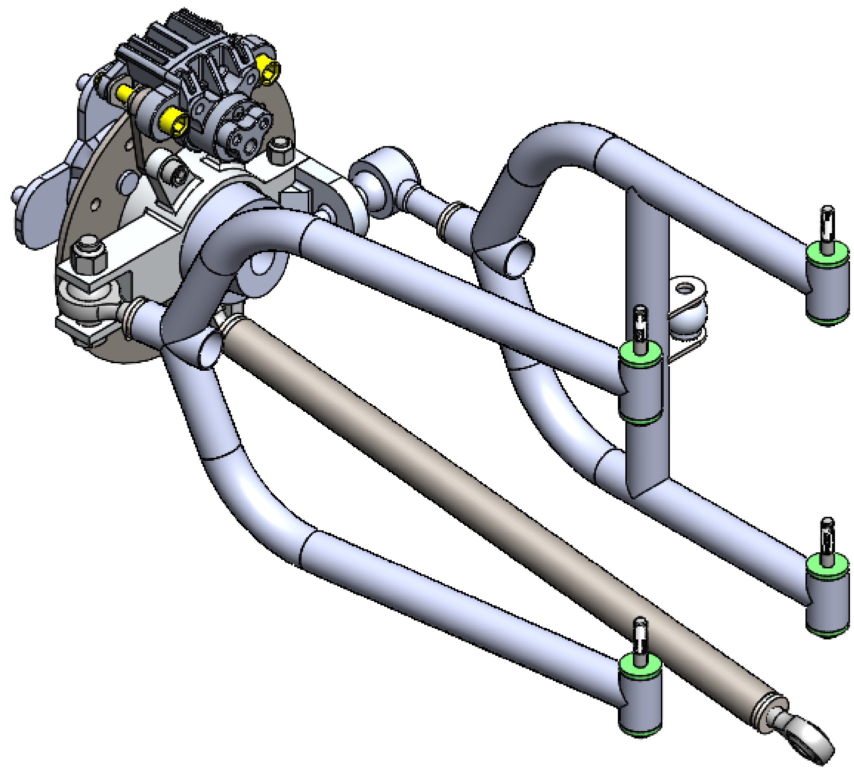


Figure B.8.37: Full Suspension SolidWorks Assembly

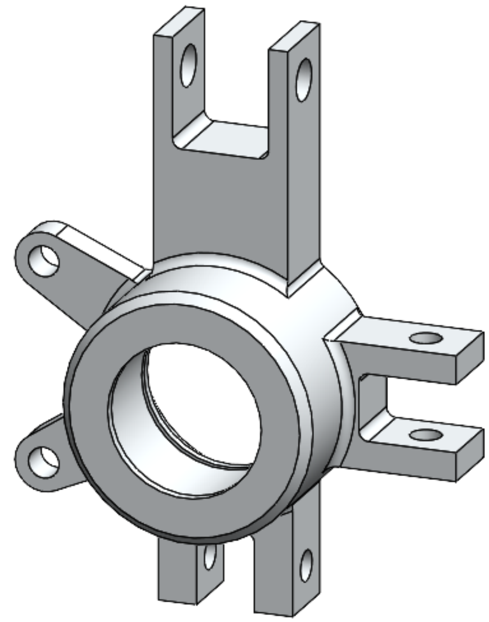


Figure B.8.38: Base Knuckle SolidWorks Model

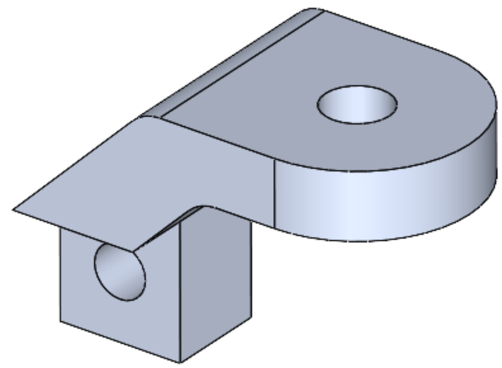


Figure B.8.39: First Iteration Upper A-Arm Upright SolidWorks Model

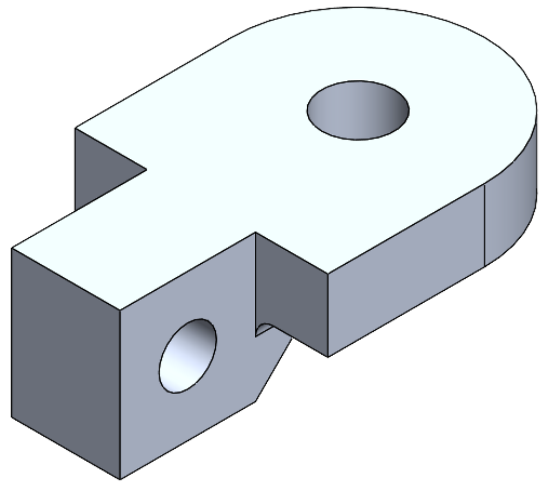


Figure 8.40: Redesigned Upper A-Arm Upright SolidWorks Model

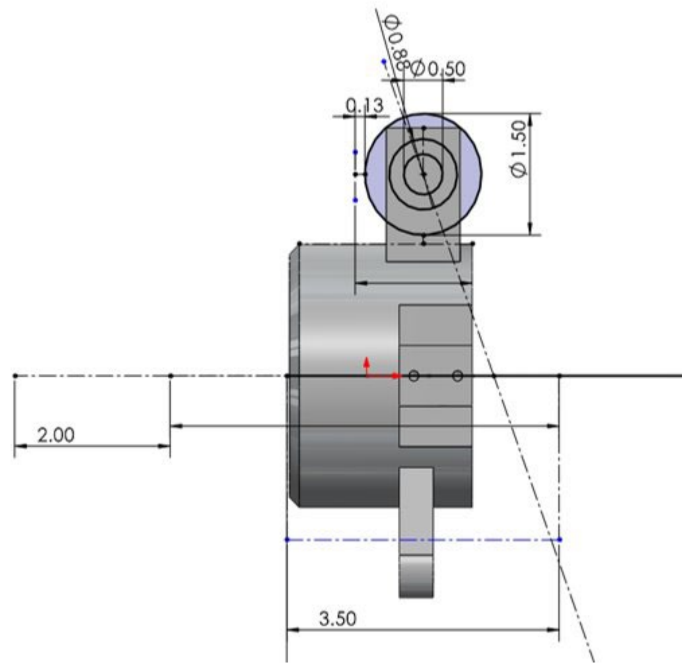


Figure B.8.41: Suspension Geometry Overlayed SolidWorks Model

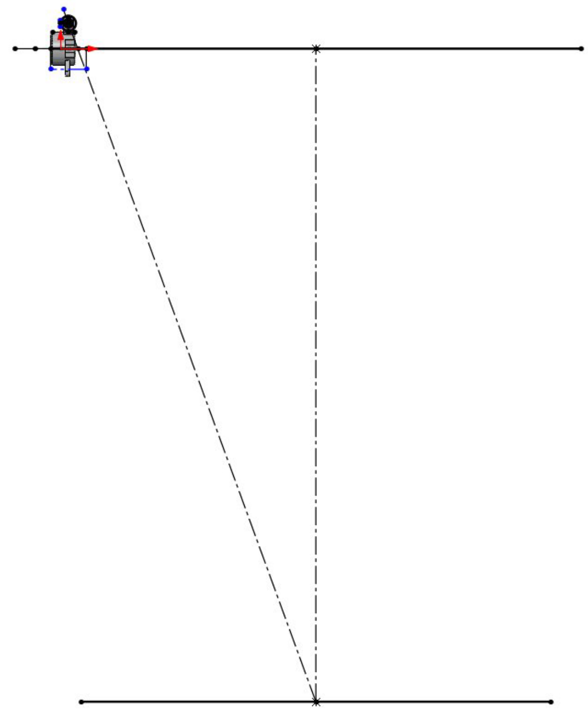
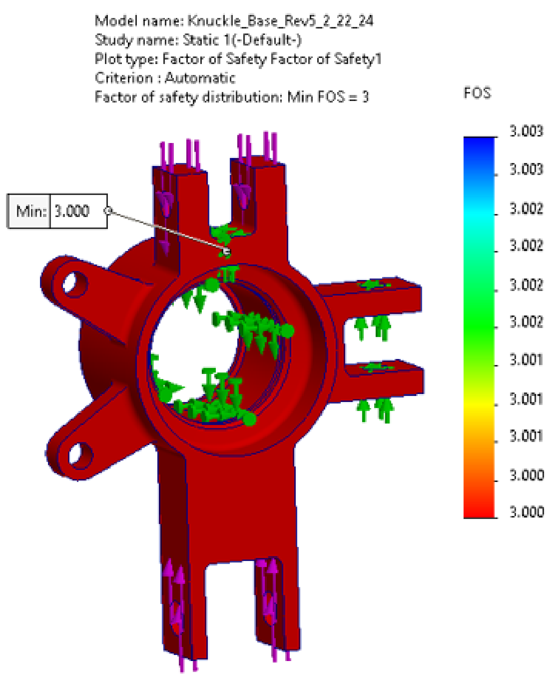


Figure B.8.42: Steering Geometry Overlayed SolidWorks Model



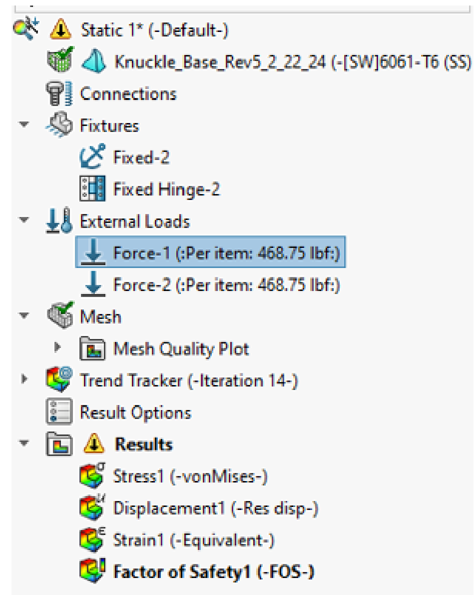


Figure B.8.43: Base Knuckle FEA

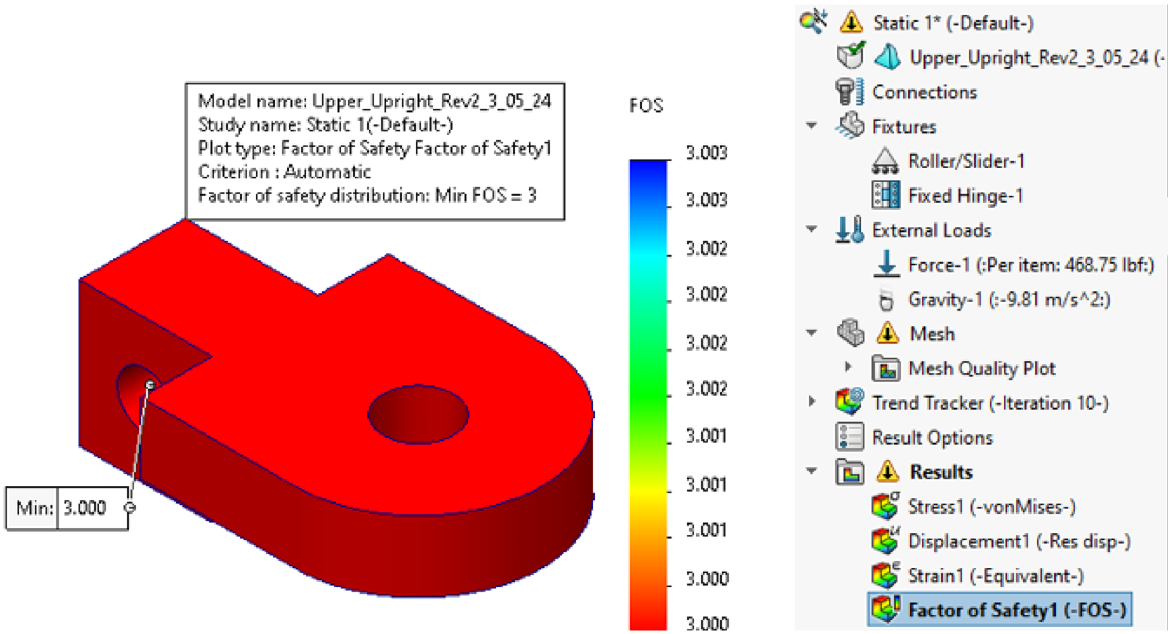


Figure B.8.44: Upper A-Arm Upright

Figure B.9.1: Risk Management Matrix

Date Requested	Supplier Name	Part #	Link to part	Description	Comments/Additional Instructions	Quantity	Cost/Unit, Excluding Shipping	Cost for all Units
	Wilson Powersports	RS3003		Upper A-Arm Ball Joint	8 Joints Discounted (Sponsor)	1	305.36	305.36
	Niche Industries	MK1000994	here	Front CV Axle Set		2	128.95	257.9
	Powdercoat Stores	N/A	here	Black Gloss Paint		1	15.99	15.99
	Online Metals	7368	here	Inserts Material	36" total	1	70.88	70.88
	Online Metals	20902	here	4130 Steel Plate	0.125"x72"x36"	1	703.54	703.54
	Online Metals	14971	here	4130 Steel Plate	0.25"x12"x24"	1	181.77	181.77
	Partzilla	90109-08087-00	here	Brake Disc Bolts		16	6.16	98.56
	Wilwood Racing		here	Brake Pads		4	62.02	248.08
	Webco			FinishLine Tubing	Donated	1	0	0
	McMaster-Carr	91257a660	here	Upright/Tie Rod Bolt		2	12.36	24.72
	McMaster-Carr	98381a471	here	Dowel Pins		1	12.33	12.33
	McMaster-Carr	97135A235	here	Upright/Tie Rod Nuts		1	5.8	5.8
	McMaster-Carr	91257A750	here	Lower Heim Bolt		1	21	21
	McMaster-Carr	97135A255	here	Lower Heim Nut		1	6.36	6.36
	McMaster-Carr	91257A613	here	Mounting Bolt		3	9.74	29.22
	McMaster-Carr	97135A225	here	Mounting Nut		2	5.64	11.28
	McMaster-Carr	90128a362	here	Caliper Mounting Bolts		1	14.48	14.48
	McMaster-Carr	6960t231	here	Outer Tie Rod Heim		6	13.74	82.44
	McMaster-Carr	60645k162	here	Inner Tie Rod Heim		6	10.2	61.2
	McMaster-Carr	6960t251	here	Lower A-Arm Heim		6	21.55	129.3
	McMaster-Carr	94409A126	here	Upper A-Arm Jam Nut		1	7.3	7.3
	McMaster-Carr	94895A815	here	Outer Tie Rod Jam Nut		1	10.92	10.92
	McMaster-Carr	94895A825	here	Lower A-Arm Jam Nut		1	12.38	12.38
	McMaster-Carr	99891A145	here	Inner Tie Rod Jam Nut		1	8.4	8.4
	McMaster-Carr	93760A233	here	Upper A-Arm Castle Nut		2	6.87	13.74
	Miller Welds	1880272	here	MIG Welding Consumables		1	52.21	52.21
	Airgas	HARE70S612	here	Welding Wire		3	24.04	72.12
	DWT		here	Rims	Order Through Wilson Powersports	6	244.29	1465.7
	McMaster-Carr	99142a595	here	Snaprings		2	6.37	12.74
	Harvey Tool	23528-C3	here	Keyseat Cutter		1	98	98
	Lowes	405419	here	Dewalt Angle Grinder		1	99	99
	Grainger	4F963	here	Tap Magic		2	18.21	36.42
	Grainger		here	Weilding Gloves	L/9	1	16.74	16.74
	Iron Rock Offroad	81083	here	Reamer		1	75.23	75.23
								4261.2

Figure B.10.1: Full Bill of Materials

Task Name	% Complete	Duration	Start	Finish	Owner	Predece
Preliminary Design Presentation	**100%**	**17.38 days?**	**Tue 1/16/24**	**Fri 2/2/24**		
Material Selection	**100%**	**6.38 days?**	**Fri 1/19/24**	**Thu 1/25/24**	**Joshua**	
Material Analysis	100%	5.91 days	Fri 1/19/24	Thu 1/25/24		
Suspension Geometry	**100%**	**6.38 days?**	**Fri 1/19/24**	**Thu 1/25/24**	**Drew and**	
Geometry Research	100%	6.38 days	Fri 1/19/24	Thu 1/25/24		
Knuckle Design	**100%**	**6.38 days?**	**Fri 1/19/24**	**Thu 1/25/24**	**Mason an**	
Material and manufacturing Process	100%	6.38 days	Fri 1/19/24	Thu 1/25/24		
Mock Presentation	100%	0 days	Tue 1/30/24	Tue 1/30/24	Group	

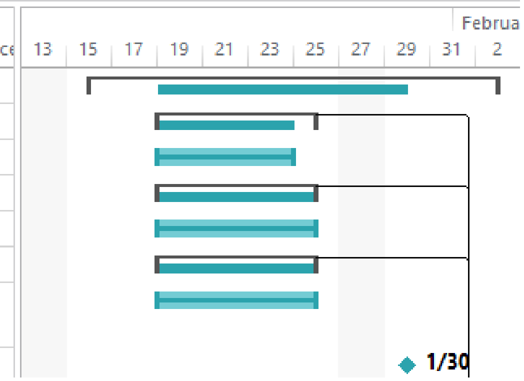


Figure B.12.1: Project Plan PDR

Task Name	% Complete	Duration	Start	Finish	Owner	Predece
Critical Design Presentation	**100%**	**28.38 days?**	**Fri 2/2/24**	**Fri 3/1/24**		
Material	**100%**	**21.38 days?**	**Fri 2/2/24**	**Fri 2/23/24**	**Joshua**	**32**
Material Quote	100%	11.38 days	Mon 2/12/24	Fri 2/23/24		
Bill of Materials	100%	11.38 days	Mon 2/12/24	Fri 2/23/24		
Suspension Geometry	**100%**	**21.38 days?**	**Fri 2/2/24**	**Fri 2/23/24**	**Drew and**	**34**
2D Analysis	100%	7.38 days	Mon 2/5/24	Mon 2/12/24		
3D Analysis	100%	4.38 days	Mon 2/12/24	Fri 2/16/24		
Optimum Kinematics Analysis	100%	4.38 days	Mon 2/19/24	Fri 2/23/24		
Knuckle Design	**100%**	**21.38 days?**	**Fri 2/2/24**	**Fri 2/23/24**	**Mason an**	**36**
Cad Design	100%	21.38 days	Fri 2/2/24	Fri 2/23/24		
Critical Design Report	100%	30.38 days	Mon 2/5/24	Wed 3/6/24	Group	

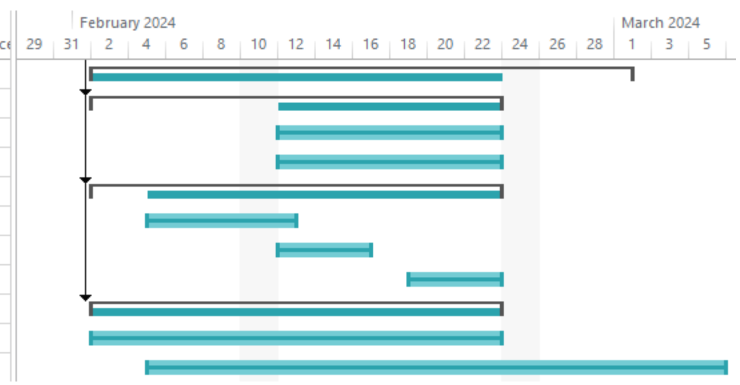


Figure B.12.2: Project Plan CDR

Task Name	% Complete	Duration	Start	Finish	Owner	Predecessors
Fabrication	**100%**	**35 days**	**Fri 3/1/24**	**Fri 4/5/24**		
Material Procurement	**100%**	**7 days**	**Fri 3/1/24**	**Fri 3/8/24**	**Joshua**	
FinishLineST 1x.049" Tubing	100%	7 days	Fri 3/1/24	Fri 3/8/24		
4130 1" round bar	100%	7 days	Fri 3/1/24	Fri 3/8/24		
1/8" Steel plate	100%	7 days	Fri 3/1/24	Fri 3/8/24		
1/4" Steel plate	100%	7 days	Fri 3/1/24	Fri 3/8/24		
Fasteners	100%	7 days	Fri 3/1/24	Fri 3/8/24		
CV Axle set	100%	7 days	Fri 3/1/24	Fri 3/8/24		
~~Testing Jig~~	~~0%~~	~~18 days~~	~~Mon 3/11/24~~	~~Fri 3/29/24~~	~~Spencer~~	~~51~~
Knuckle	**100%**	**18 days**	**Mon 3/11/24**	**Fri 3/29/24**	**Drew**	**51**
Develop CAM for knuckle/upright	100%	5 days	Mon 3/11/24	Sat 3/16/24		
CNC base knuckle and uprights	100%	5 days	Sat 3/16/24	Thu 3/21/24		63
Machine cutouts	100%	2 days	Thu 3/21/24	Sat 3/23/24		64
Check dimensions	100%	2 days	Sat 3/23/24	Mon 3/25/24		65
Install uprights	100%	2 days	Mon 3/25/24	Wed 3/27/24		66
Press fit bearings	100%	2 days	Mon 3/25/24	Wed 3/27/24		66
Insert retaining ring	100%	2 days	Mon 3/25/24	Wed 3/27/24		66
Tie Rod	**100%**	**18 days**	**Mon 3/11/24**	**Fri 3/29/24**	**Craig**	**51**
Cut rods to correct length	100%	2 days	Mon 3/11/24	Wed 3/13/24		
Press and weld inserts	100%	3 days	Wed 3/13/24	Sat 3/16/24		71
Send for sand blasting and powder coating- out of house	100%	10 days	Sat 3/16/24	Tue 3/26/24		72
Attach Heim joints with jam nut	100%	2 days	Tue 3/26/24	Thu 3/28/24		73

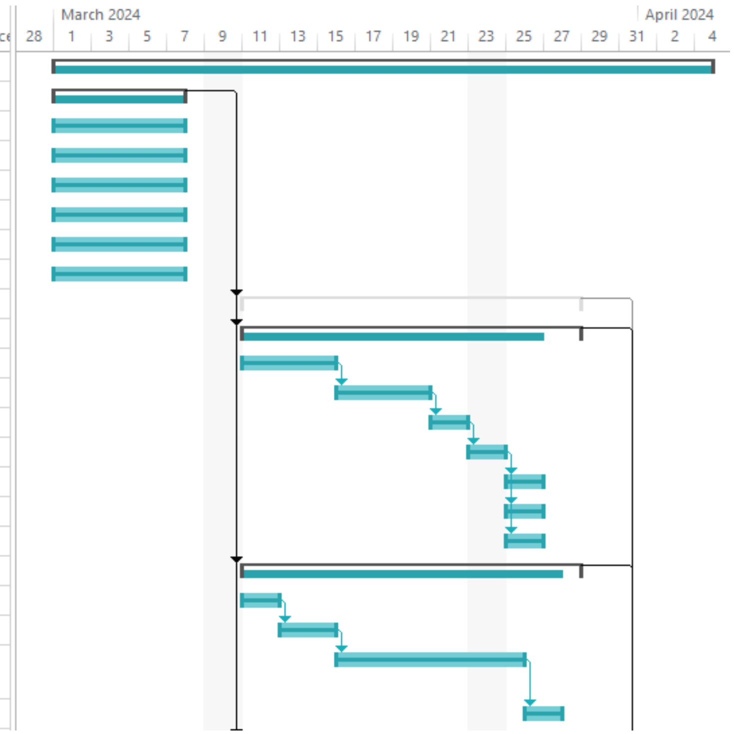


Figure B.12.3: Project Plan Fabrication Part 1

Task Name	% Complete	Duration	Start	Finish	Owner	Predece
A-Arms	**100%**	**18 days**	**Mon 3/11/24**	**Fri 3/29/24**	**Mason**	**51**
Confirm beng angles and notch geometry	100%	0.5 days	Mon 3/11/24	Mon 3/11/24		
Create and 3D print jigs	100%	2 days	Mon 3/11/24	Wed 3/13/24		76
Bend and notch tubing	100%	3 days	Mon 3/11/24	Thu 3/14/24		76
Place tubing in primary and secondary jig	100%	0.5 days	Thu 3/14/24	Fri 3/15/24		78
Weld A-Arms, tabs and inserts	100%	5 days	Fri 3/15/24	Wed 3/20/24		79
Send for sand blasting and powder coating- out of house	100%	8 days	Wed 3/20/24	Thu 3/28/24		80
Attach Heim and Super Swivel joints	100%	1 day	Thu 3/28/24	Fri 3/29/24		81
Assembly	**100%**	**3 days**	**Mon 4/1/24**	**Thu 4/4/24**	**Group**	**62,75,5**
Connect A-Arms to testing jig or Baja car via tabs	100%	0.5 days	Mon 4/1/24	Mon 4/1/24		
Bolt tie rod to testing jig or steering rack	100%	0.5 days	Mon 4/1/24	Mon 4/1/24		
Attach knuckle to A-arms and tie rod	100%	0.5 days	Mon 4/1/24	Tue 4/2/24		84,85
Attach wheel to knuckle	100%	1 day	Tue 4/2/24	Wed 4/3/24		86
Safety Inspection	100%	1 day	Thu 4/4/24	Fri 4/5/24		83

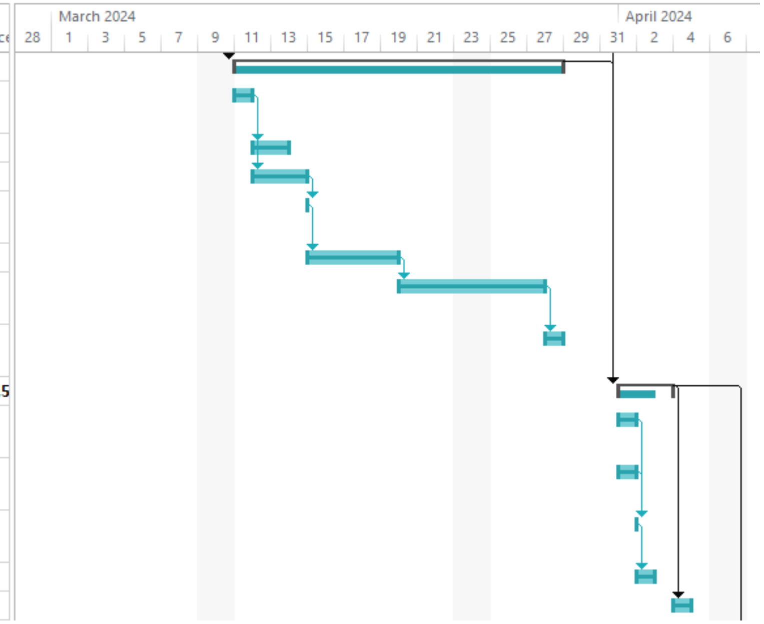


Figure B.12.4: Project Plan Fabrication Part 2

Task Name	% Complete	Duration	Start	Finish	Owner	Predece
Testing and Validation	**100%**	**18 days**	**Mon 4/8/24**	**Fri 4/26/24**		
~~Strain Gagues~~	~~0%~~	~~4 days~~	~~Mon 4/8/24~~	~~Fri 4/12/24~~	~~Group~~	~~83~~
~~Testing on jig~~	~~0%~~	~~4 days~~	~~Mon 4/15/24~~	~~Fri 4/19/24~~	~~Group~~	~~90~~
Test Track	**100%**	**4 days**	**Mon 4/22/24**	**Fri 4/26/24**	**Group**	**93**
Validate assembly of suspension parts on Baja car	100%	1 day	Mon 4/22/24	Tue 4/23/24		
Test suspension parts on test track	100%	3 days	Tue 4/23/24	Fri 4/26/24		97

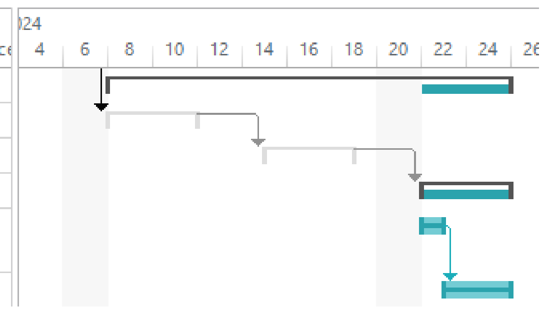


Figure B.12.5: Project Plan Testing