Steering System
ARG26 Fall Technical Report
Dec 10, 2025
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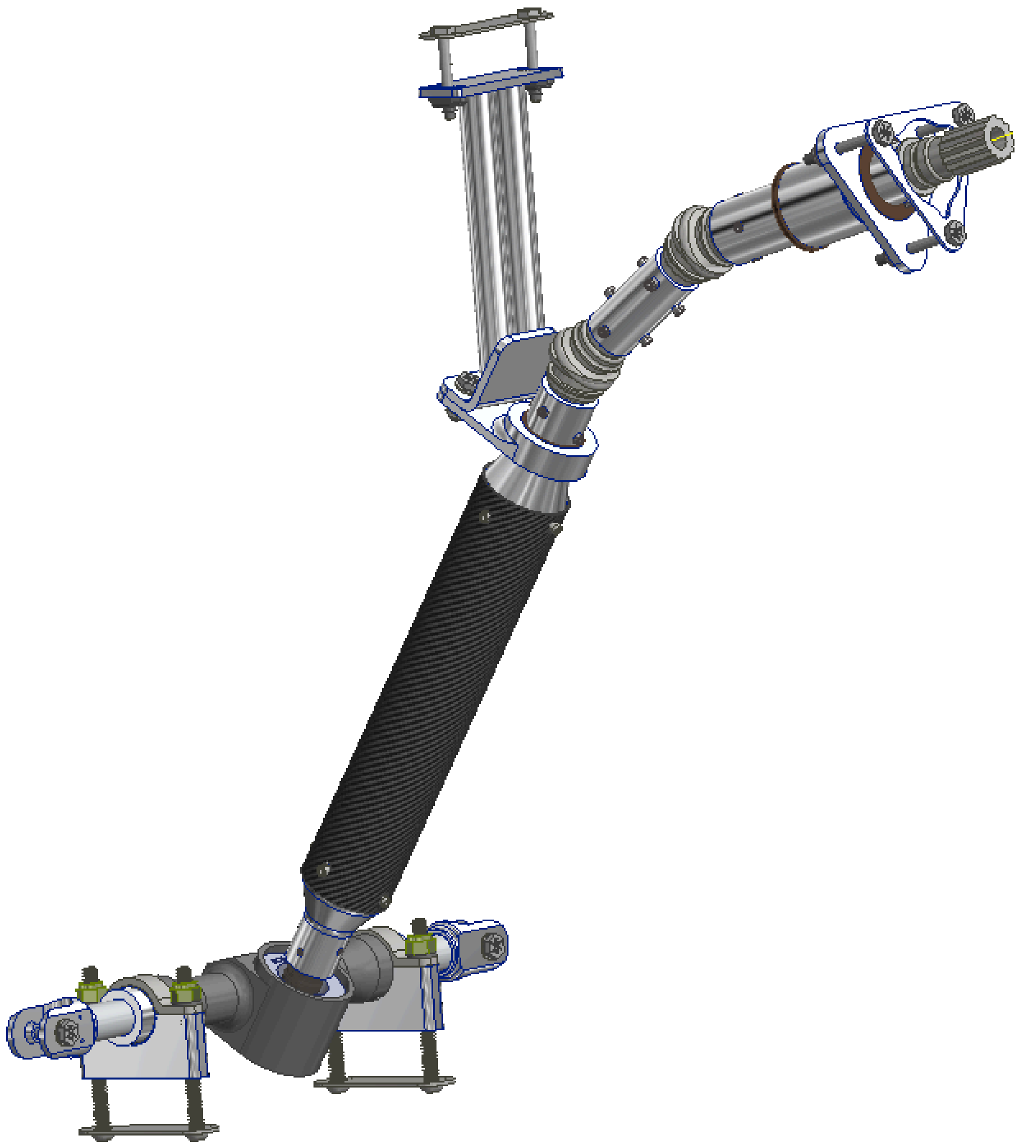


Subteam: Ergonomics
Subteam Lead: Claire McKechnie
Team: ARG26
Technical Lead : Amanda Backholm and William Baumoel

0. Introduction

Steering system is a rack and pinion system, which translates rotational motion of the steering wheel to translational motion of the rack, allowing the front wheels to turn left and right. A well designed steering system must not only enable directional control but also must remain light weight, structurally and minimize free play. As specified by the 2026 competition rules, rack and pinion steering must have no electrical integration, but should have positive stops to prevent any unwanted interfaces of other systems. Additionally steering wheel and rack must be mechanically connected/ attached and the max allowable steering free play is 7 degrees.

1. Technical Overview

The steering system geometry is largely constrained by fixed suspension points and the orientation of the monocoque dash. Establishing these boundary conditions at the start is essential, as they define the allowable shaft angles, rack placement, and overall kinematic envelope. Using these known points, the first step is to construct a steering layout sketch. This greatly simplifies the design process. An example of my layout sketch is included in Section 3 (Data).

A key thing to know when just starting is that the upper steering shaft should be oriented perpendicular to the dash face to minimize misalignment and unwanted side loads. From there, U-joint selection and placement is important. Most manufacturers specify a maximum operating angle of approximately 35°, but for reliability and reduced friction, maintaining U-joint angles below 25° is strongly recommended. Ensuring this constraint early prevents binding, non-uniform steering effort, and premature joint wear.

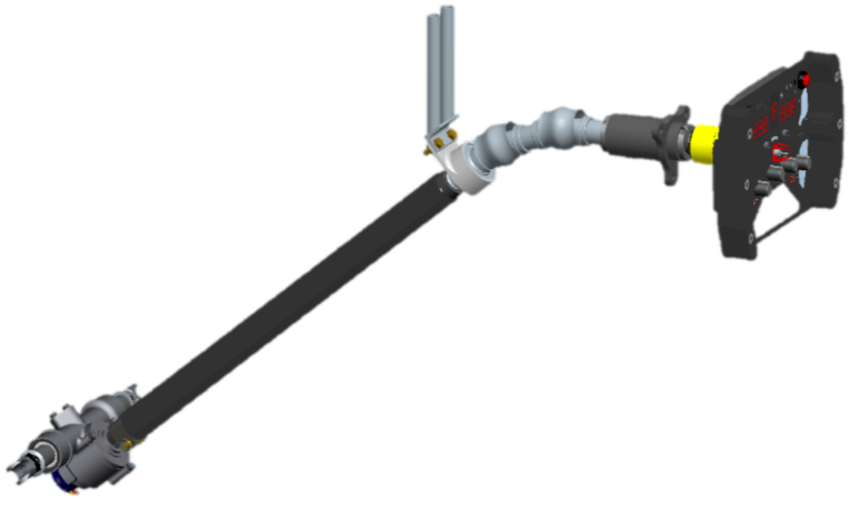
Once the steering layout is established, preliminary component design can begin. In recent years, our team has consistently ordered the same steering rack and housing, which eliminates the need to redesign or re-specify those components. With this baseline architecture defined, the next step is to integrate yearly performance objectives. For the current design cycle, my primary influences were the ARG24 and ARG25 steering systems. Their packaging, shaft routing, and structural concepts provided a foundation for refinement. Building on those designs, I modified the lower Y-constraint geometry and optimized mass across the steering column assembly to meet this year’s performance and manufacturability goals.

2. History of Past Designs

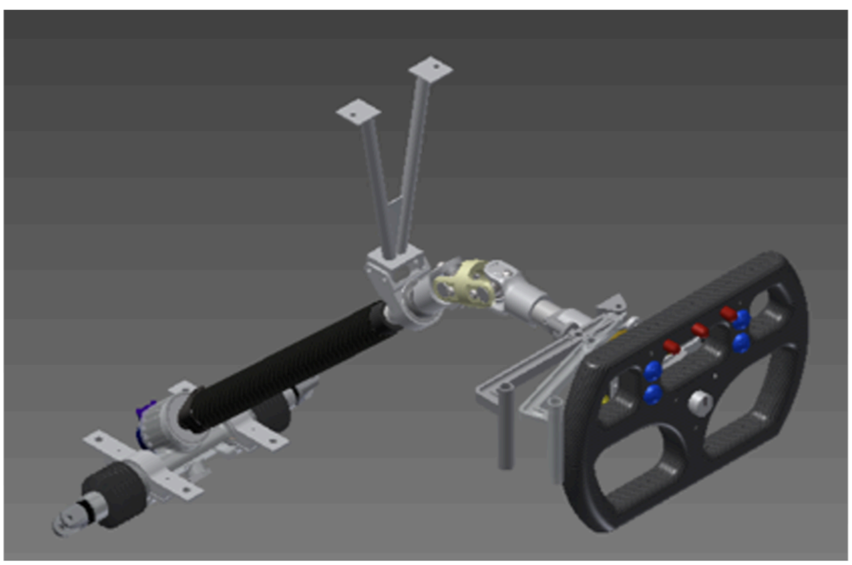
Before ARG13, our car’s geometry constraints allowed for a much simpler steering design, which used a custom rack with straight steel tubes welded directly to the pinion spline clamp. A major advantage of this straight-tube configuration was its simplicity; fewer components meant less compliance and therefore less slop in the steering system. However, the primary drawback was the lack of control over the steering wheel angle. From past driver fitments, we consistently found that drivers prefer a more vertical steering wheel for comfort and ergonomics, which the straight-shaft design could not accommodate. Additionally, the material choices—primarily steel—added unnecessary weight to the car, which could have been reduced through alternative materials.

Although the design was simple and robust, it came at the cost of driver comfort and ergonomic adjustability. Beginning with ARG13, we transitioned from the straight-shaft system to a U-joint steering column and began using carbon fiber tubes instead of steel. Prior to ARG13, using carbon fiber was considered risky because we lacked a reliable bonding method between carbon and steel, and the concept had not been thoroughly researched within the team. Over time, however, we developed and validated better bonding techniques, making carbon tubes a feasible and advantageous option.

Our team continued manufacturing custom rack-and-pinion systems through ARG17, at which point we received sponsorship from Zedaro, who began supplying our steering racks. Since then, we have outsourced both the steering rack and the carbon tube components. Meanwhile, the placement of U-joints, intermediate shafts, and upper bearing constraints has varied across teh years as packaging, driver ergonomics, and vehicle geometry evolved.



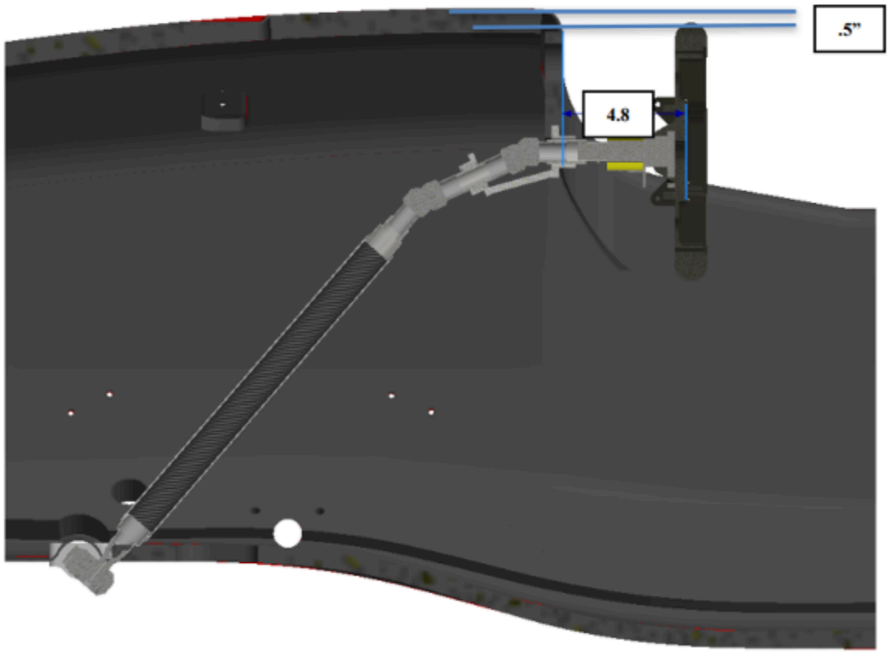
ARG13



ARG15

ARG19

ARG20



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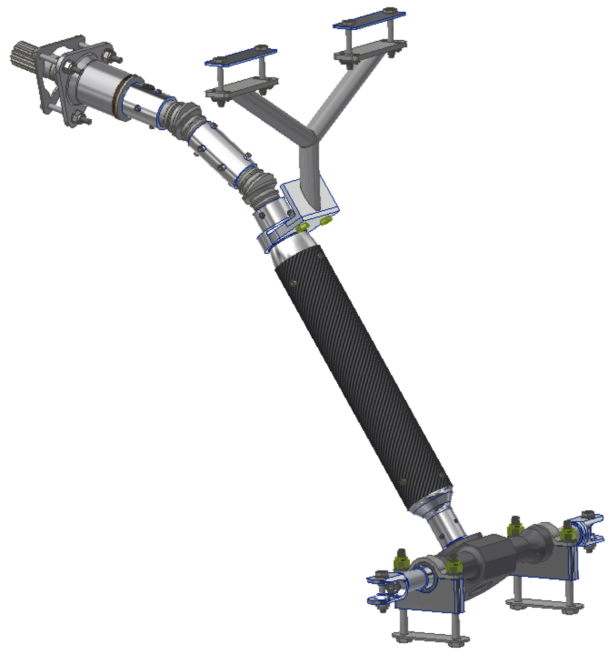
ARG24



ARG25

3. Data

First I did a driver fitment with the current driver with different steering wheel angles and steering height to have a general idea of limitations of my design based on driver comfort. I did an analysis with 18, 17.5 and 17 inch heights corresponding with 15, 20, 25 and 30 degrees of angle in the steering wheel. I didn't go below 17 as each driver stated that with 17 inch height felt already pretty cramped and overall thinking about driver egress part of the comp it will be hard to jump out of the cart easily. Additionally I couldn't also make it higher than 18 inches since that would raise the height of the dash which affects the driver's eyesight/view (specially for shorter drivers). For the chosen angles in ARG24 we have done a 30 degree angle in the steering wheel and past drivers have mentioned that it was very uncomfortable in the long run and In ARG25 with 2 U-Joints the most vertical steering angle we achieved was 15 degree. Thus my goal for my fitment was to taste between the ranges of 15-30 degrees in steering angle. Below I have included my results.

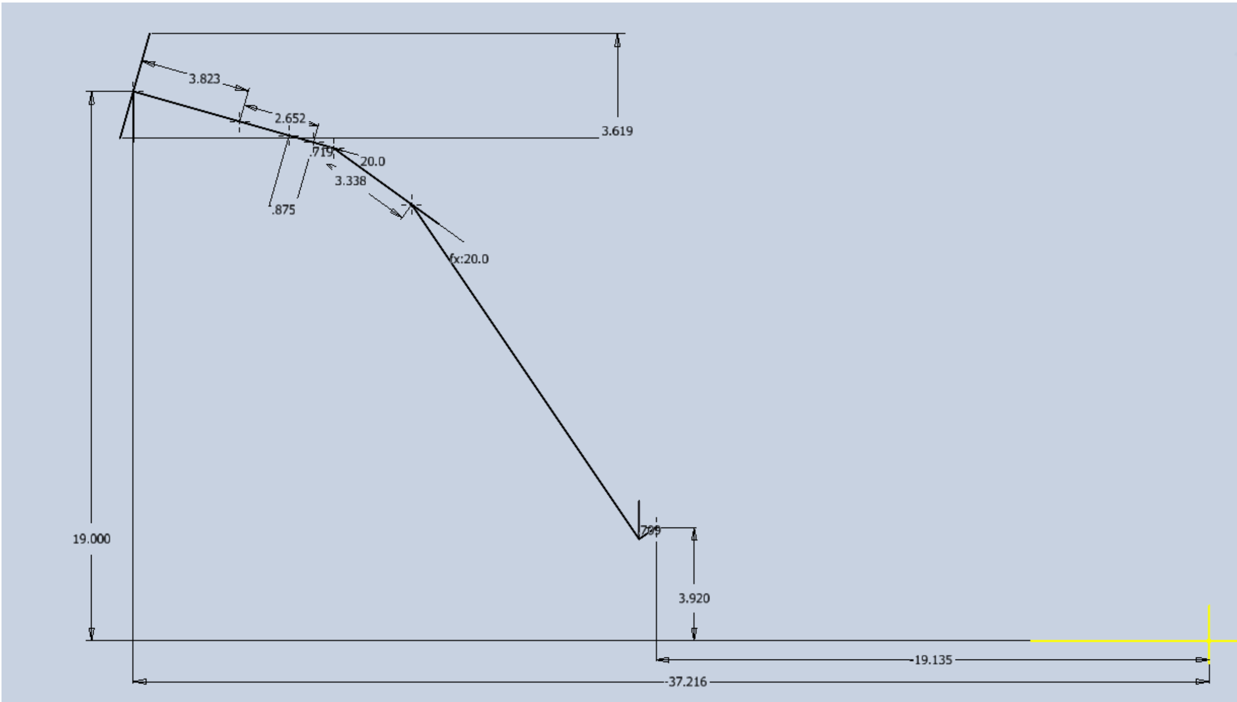
Driver Fitment:

○ Goal: Finding an optimal comfortable height and steering angle for drivers.

height/ angle	15 deg	20 deg	25 deg	30 deg

18’	**Caroline:** wrist constrained, when turned at max, had to drop one hand down **Sam:** bottom hand is rub against legs a little bit, bottom hand losing contact with steering wheel, palm loses contact from steering wheel at the bottom	**Caroline:** feels better in the wrist area, feels like the steering wheel is higher **Sam:** the bottom hand feels much better, wrist gets angled a bit too much, bottom hand hits body	**Caroline:** feels bit too far for the stretched out hand **Sam:** overall space on the top and bottom, more room by legs when turning, bottom hand more contact with wheel, top hand feels bit more stretched but not bad at all**.**	**Caroline:** top stretched out hand is too far, but the bottom arm feels nice **Sam:** top hands feels too far resting hands, feels like lifting hands up, overtime def going to get more tired.
17.5’	**Caroline:** the wheel feels lot more closer, bends wrist in -> uncomfortable **Sam:** steering wheel too close, overall feels cramped	**Caroline:** feels better in the bottom hand wrist area when turning, top hand doesn’t feel too stretched out -kinda perfect **Sam:** lowkey feels good, steering wheel is definitely closer, but in a good way, bottom hand has more grips, top arm feels great not to too stretched out not too cramped, feels inclined	**Caroline:** this is what she wants, top feels nice, bottom as well! **Sam:** feels little further back, also feels little too inclined away from hands, the bottom hands are hitting legs so bit cramped, - harder get grip on bottom hand	**Caroline:** little less comfortable, in the longer run might be more uncomfortable - During system level PDR past drivers talked about. **Sam:** feels too inclined and too far.

After getting an idea of driver comfort, height and angle, I created a layout for steering with 1 U-joint vs 2 U-Joints and did analysis on the different allowable U-joint angles we can have and how that measurement impacts the steering angle. For 2 U-joint i kept the same height as well as the same steering angle as ARGr25, however for 1 U-Joint I used a lower height and angle that is highlighted in the driver fitment test. The reasoning behind the lowering is that if we keep the same height and angle with 1 U-Joint, we’re expected to have a very large U-joint angle that is very close to the limit. A large angle in U-joint is generally not recommended since it will wear out quicker and will result in rough steering. Thus lowering overall height helped with decrease in the single U-joint angle. Below I included the results and layout for 2 U-Joint steering.



2 U-Joint angle impact on steering wheel angle:

U-Joints Angle (deg)	Steering Wheel Angle (deg)
15	20.9
20	14.3
25	7.4
30	0

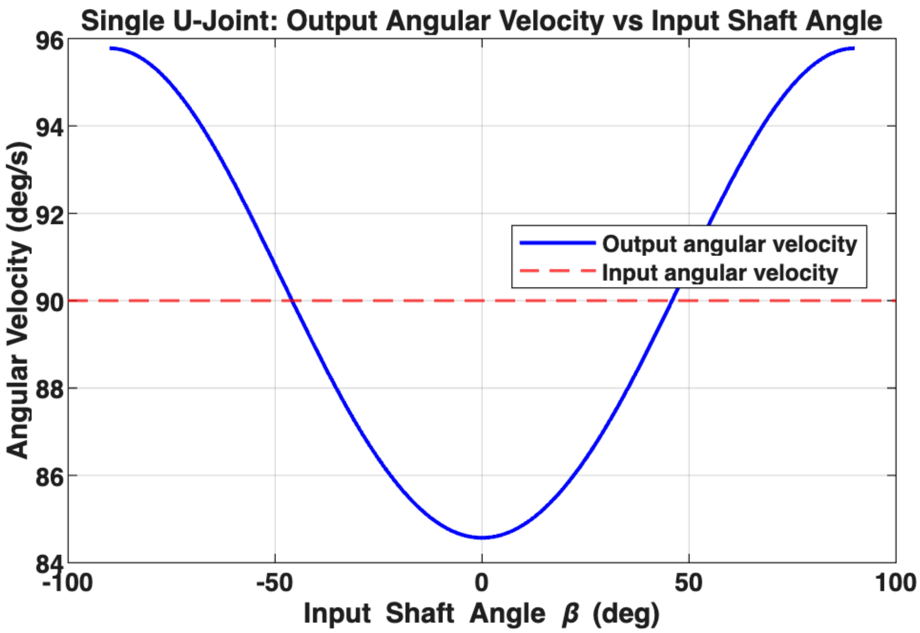
1 U-Joint angle impact on steering wheel angle

U-Joint Angle (deg)	Steering Wheel Angle (deg)
15	29
20	25.9
25	22.3
30	18.7

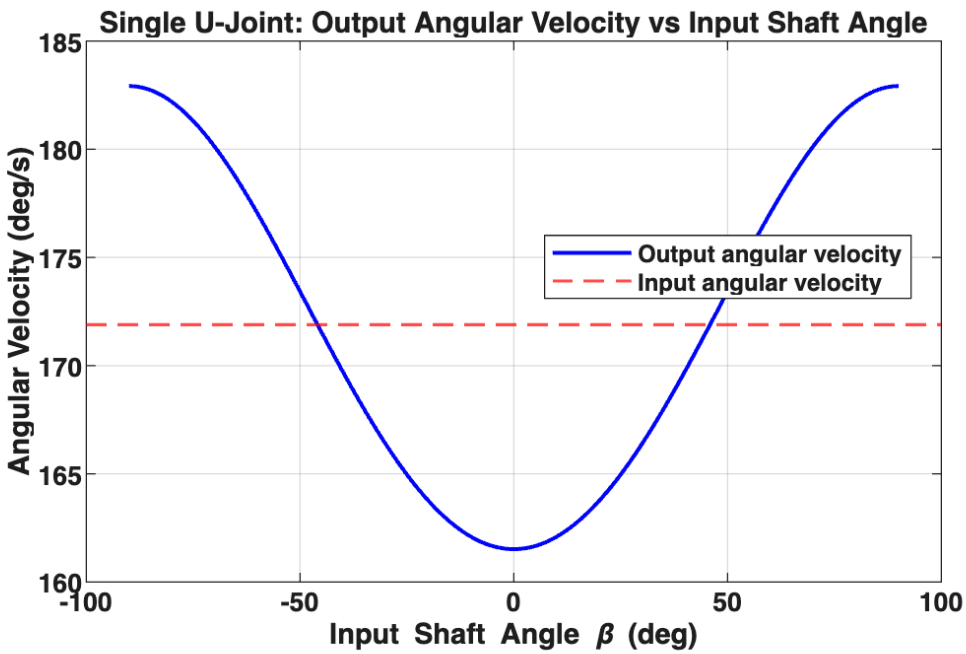
From the results if we keep 2 U-Joints, the 14.3 degree angle steering wheel with 20 degree angle in U-joints is the best option as it allows for a more vertical steering wheel as well as allowable U-Joint angle. The single U-joint, I chose to keep the U-joint angle the same which is 20 degrees with reasoning explained earlier and this corresponds with a 25 degree angled steering wheel, which is more angled but the drivers were still comfortable with it based on driver fitment.

Furthermore, If we continue with a single U-joint one big concern is the non constant velocity output it creates, Thus I conducted an analysis for non-constant velocity caused due to 1 U-joint using MATLAB. For the input angular velocity we don’t exactly know how fast the drivers turn the steering wheel and it’s also a very non constant value, i did the analysis with 3 different angular velocity inputs. With a help of google and internet I have chosen Omega = pi/2 rad/s for normal/ regular driving case, omega = 3 rad/s for medium range and omega = 2*pi rad/s for extreme cases. All graphs are included below, these show how much the output velocity varies compared to constant velocity input.

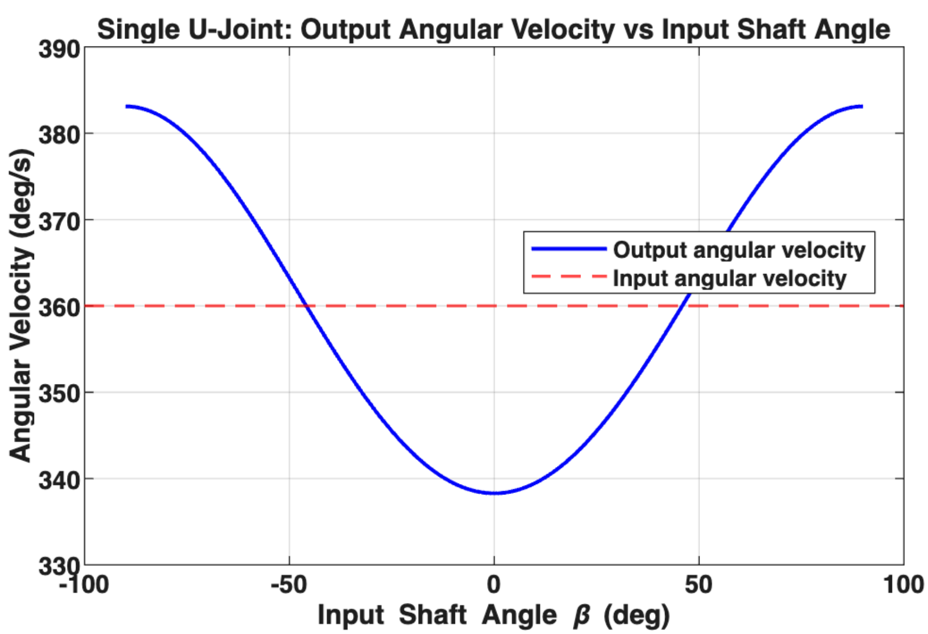
Omega = pi/2 rad/s:



Omega = 3 rad/s :



Omega = 2*pi rad/s :



Overall based on all the analysis here is the pros and cons list:

1 U-Joint :

- Pros:
  a. Saves about 0.8-1 lb
  b. Less slop in steering

- Cons:
  a. Larger steering wheel angle
     - 20° U-Joint results in 25.9° of steering wheel angle
  b. How much of non constant velocity is negligible ? (figure 1,2)
     - impacts driver performance/ more time to get used to
  c. Resulting angle change in dash of monocoque

2 U-Joint :

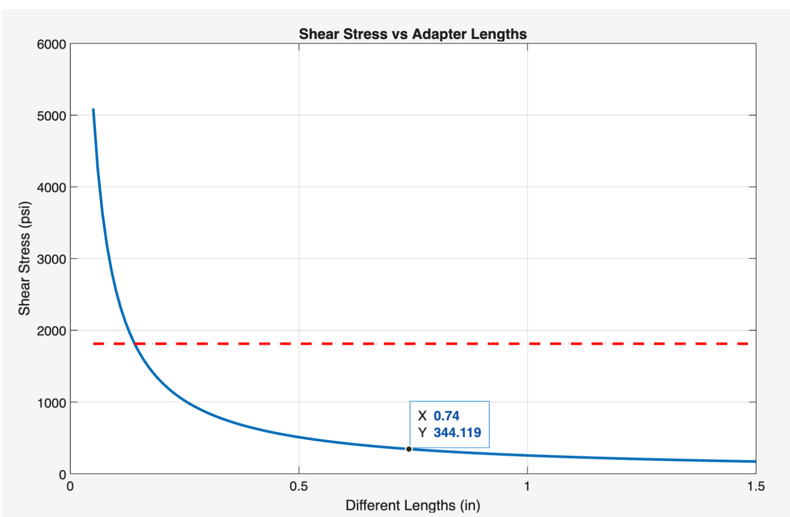
- Pros:
  a. More vertical steering wheel angle
     - 15°
  b. Keeps constant velocity throughout
  c. Doesn't effect monocoque geometry

- Cons:
  a. Heavier
  b. Might have more slop

Based on all the results and lists of pros and cons we have decided to move forward with 2 U-Joint steering designs.

Lower/Upper Adapter Bonding to Carbon Tube:

I will be using Permabond 5428 to bond the adapters to the carbon tube. The primary failure mode for this component would be the bond failing under the applied torque load of 700 N·m. To validate the design, I created a shear stress versus bonding length analysis in MATLAB. By using the shear strength of the adhesive on both aluminum and carbon fiber (as specified in the datasheet) and calculating the bonded surface area (π*(r^2)* Length), I was able to determine the minimum bonding length required to safely withstand the applied torque.



Spring Pin sizes:

Using a safety factor of 1.5 for yield and 2 for ultimate strength, I have calculated the spring pin sizes for each component, as shown below. These values are currently subject to change, as I received a notification that the quick disconnect I ordered a month ago is out of stock and unlikely to be available soon. I will be purchasing a different quick disconnect, which will alter some part dimensions and, consequently, the required spring pin sizes.

	MOSY	MOSU	Spring Pin Size
U-Joint	0.2126	0.5946428571	0.188
L Adapter (rack side)	0.6294642857	0.3895089286	0.125
L Adapter (carbon tube side)	1.433333333	1.075	0.125
Middle Shaft	2.234942857	1.758564286	0.188
U Adapter (U-Joint side)	1.859166667	1.438125	0.188
Upper Shaft (splined spigot sid	0.2591573943	0.4316447086	0.188

Carbon Tube Sizing:

As mentioned earlier, I used the Fall 2023 tube testing conducted by John Dowd to calculate the shear strength based on the resulting torques. I then analyzed various tube thicknesses and diameters to determine the stress each tube would experience under a 700 N·m torque. By comparing the calculated stress to the tube's shear strength, I identified which tubes would fail and which would not, highlighting failing dimensions in red and safe dimensions in green. Calculating carbon tube properties can be challenging since values vary depending on manufacturing and other factors, so these results are only approximate. My plan is to contact the manufacturer directly to obtain testing data for these tubes to validate the design.

ID/ t	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11
0.625	70928	56247.7	46457.7	39462.8	34215.1	30132.6	26865.9	24192.9
0.75	49539.8	39347.4	32550.7	27694.7	24051.8	21217.7	18949.9	17094.2
0.875	36544.9	29057.7	24065.2	20498.4	17822.7	15741	14075.5	12712.5
1	28064.6	22332.7	18510	15780	13732	12139	10864	9820
1.25	18036.9	14369	11923.5	10176.5	8866	7846	7030.9	6363.5
1.375	14929.2	11898	9877	8433.3	7350.37	6507	5833.9	5282.46
1.5	12560.5	10013.5	8315.43	7102.37	6192.48	5484.7	4918.4	4455

4. ARG26 Design

In the beginning of the year we were debating on switching back to 1 U-Joint vs 2 U joints. 1 U-joint allows us to save about a pound in total weight compared to last year as well as less slop as it is a simpler design. On the other hand the 2 U-joint is more ideal as this allows for constant velocity rotation output in the rack. I did an analysis on non constant velocity in U-joints which I talked about in the previous section in depth. In addition since we have decided to not have buttons or electronic components on the steering wheel, our required diameter for the QD has gone down which allows us to size down most of the parts. With 2 U-Joint designs last year, the main part that will be changing is the Y constraint and sizing parts down. Every part will be validated through either FEA, calculation tests as well as physical tests.

Most of the parts have been resized based on the smaller U-joint dimensions. Such as the middle shaft, upper adapter and upper shafts diameters have changed. All of the machined parts will be made out of 7075 Aluminum Alloy, as it is light and strong material. Moving to the carbon fiber column, it is the same size as ARG24 and ARG25 at the moment. However I did a calculation analysis to determine if we can size down the tube and save on weight. My calculations were not matching the physical tube torque testing in Fall 2023 results. During ADR, I got feedback that I should get in contact with the manufacturers and ask for testing results rather than using my approximate calculation. More about my calculations is included in the testing and analysis section.

In ARG25, the use of two U-joints required an additional constraint attached to the upper adapter and mounted to the cockpit. During the competition, judges raised concerns about how close this mounting was to the suspension components. This year, with the replacement of the z-bar with a u-bar, there is more space in the middle to work with. Consequently, I decided to redesign the Y-shaped constraint into a vertical I-shaped constraint with a single mounting tab in the middle instead of two. This new design improves mounting clearance, reduces weight, and simplifies manufacturing.

Another challenge we faced with the Y-shaped constraint last year was aligning and bolting it to the car. While manufacturing tolerances were present, the sleeve bearing that attached to the upper adapter allowed for no adjustment, making hole alignment difficult. As a result, we had to resize parts and sand them to fit properly. To address this, I initially considered switching from a sleeve bearing to a spherical bearing, which would make assembly faster and easier. However, during ADR, alumni pointed out that this might add unnecessary weight since the steering assembly does not need to be removed once installed. I agree with this assessment, so I will revert to using sleeve bearings and incorporate shims for height adjustment of the constraint.

5. Components Overview

Parts	Amount	Link/ or Machined	Material
		Rack Assembly	
Rack Mounting Bracket	2	send c...	Steel, AISI 4130
Lower Rack Mount	2	in house	Aluminum 7075-T651
Lower Mount/ upper part	2	in house	Steel, AISI 1018
Rack Stop	2	in house	Plastic Derlin
Rack Clevis	2	in house	Aluminum 6061
Rack Hat Cone	2	in house	Aluminum 7075-T651
Rack Thru Cone	2	in house	Aluminum 7075-T651
Rack	1		
		Lower Constraint	
Housing	1	in house	Aluminum 7075-T651
L bracket	1	send c...	Aluminum 7075-T651
Sleeve Bearing	1	https://www.mcmaster.com/products/6391k422/	
strut	2	https://www.mcmaster.com/9898T	Aluminum 5052
Bar Mounting	1	in house	Alumninum 5052
Strut Backing Plate	1	send c...	Steel, AISI 4130
		Column	
Lower adapter	1	in house	Aluminum 7075
Carbon Shaft	1	https://www.rockwestcomposites.com/35072-u.html?srsltid=AfmBOc	
Upper Adapter	1	in house	Aluminum 7075
Middle adapter	1	in house	Aluminum 7075
Upper shaft	1	in house	Aluminum 7075
U-Joint	2	bought	
Upper shaft shims		https://www.mcmaster.com/3088A456/ , https://www.mcmaster.com/	
		UBC	
Bronze Beasrings	2		
Housing	1	in house	Aluminum 7075
Backing Plate	1	send c...	Aluminum 7075

For our U-Jointsi have selected MS-20271-B12 version with ⅝ in bore size from Pegasus. And for our quick disconnect, I have ordered Lifeline Weld-On 3 Hole Quick Release Steering Hub, FIA.

6. References

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