

# 1970-1981 Camaro Suspension Redesign

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by

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## **ABSTRACT**

The problem with the 1970-1981 Camaro front suspension is the lack of compatibility with new radial tires. This suspension was designed for old bias ply tires and does not utilize the proper geometry to allow for proper tire wear and handling when using radial tires. A redesigned upper a-arm that offers improved handling and tire wear characteristics was designed, constructed, and tested to meet the desires of potential customers.

The main customer needs, determined by survey results, included increased performance, increased tire wear, and street use application. Existing products on the market are all aimed toward performance without considerations to tire wear or optimizing for street driving. To achieve this goal new upper a-arms were manufactured which allowed for an increase in caster and a decrease in camber. The caster increase resulted in better vehicle handling and performance. The camber decrease resulted in better tire wear. These upper a-arms were designed to target the customer who wanted some handling improvements without sacrificing tire wear.

After design and assembly was completed testing was conducted. A simple force vs displacement test proved structural integrity and safety. Before and after caster/camber measurement proved an increase in performance. Tire heat analysis proved a better tire wear pattern resulted from using this product. The resulting product is one that the average car enthusiast can install on their Camaro to achieve a better driving experience and increase the life of their tires.

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## PROBLEM DEFINITION AND RESEARCH

### *PROBLEM STATEMENT*

The suspension of the second-generation Camaro (1970 – 1981) was designed in 1969 and it uses concepts from mid-1960's vehicles. The system is outdated and does not work as well as it could with newer tires. I will redesign the front suspension on the second-generation Camaro to fully utilize modern radial tires.

### *BACKGROUND*

The second-generation Camaro is quickly becoming popular with car enthusiasts. This car is one of the iconic American muscle cars of the 70's. The increased popularity has caused owners to fix these cars up to drive them once again. One issue with these older Camaros is their lack of modern suspension. The suspension in these cars were designed to be used with bias ply tires. Modern radial tires handle better, last longer, are more fuel efficient, and are safer (1). It was not until 1982 that radial tires became standard equipment and car manufactures began to design suspension specifically for radial tires (1).

## RESEARCH

### *SCOPE OF THE PROBLEM*

Most owners of second-generation Camaros simply install new radial tires on their car. Just switching tires can improve ride and handling characteristics but it can cause some underlying alignment problems. Manufactures tune suspension systems at the factory to the specific type of tire that the car came with (2). By changing to radial tires without updating the suspension geometry owners will not receive the full benefits of improved handling and longer tire wear. Owners may also experience pulling or drifting out of the lane (2). Some of the later second-generation Camaros came from the factory with radial tires but still sported the older suspension design.

In-order to fully utilize modern radial tires on the second-generation Camaro I will address the geometry of the front suspension. Suspension geometry is broken down into caster, camber, and toe. The geometry measurements are in degrees. Caster indicates the forward or backwards slope of a line drawn through the upper and lower ball joint when viewed from the side (3). Camber indicates how far the tires slant in or out when viewed from the front (3). Toe is the direction the tires are pointed when the steering wheel is straight (3). Different tire types behave differently when cornering and will need different suspension set ups. The figures below show how bias ply and radial tires behave around corners.

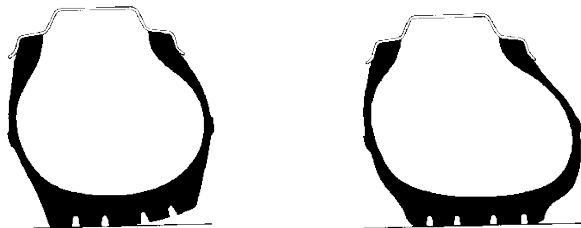


Figure 1: Bias Ply Vs Radial Tire (3)

Older bias ply tires lose contact from the road when taking a corner due to the stiff side wall of the tire (4). These tires require high negative camber and low caster to help compensate for this issue (4). Newer radial tires have flex in the side wall so the tire stays in contact with the road as you corner (4). Radial tires no longer need the high negative camber (improves tire wear) and can use more caster to improve handling and add safety due to increased control (4). The stock geometry of the second-generation called for 1 degree of caster and 1 degree of negative camber (5). The optimum street geometry of the second-generation Camaro is 3-4 degrees of caster and 0.5 degrees of negative camber when using radial tires (6). Any less than 3-4 degrees of caster and the full handling and performance benefits of the radial tires will not be seen. Any more than 0.5 degrees of negative camber and increased tire wear will occur (6). Usually the more caster you have the more negative camber that goes along with it. This means it is not possible to run 6-8 degrees of caster with only 0.5 degrees of negative camber though this would be ideal.

By tuning the suspension geometry characteristics with new upper a-arms for radial tires, I hope to create a front suspension system that handles better and produces longer tire life than the stock suspension using radial tires. A-arms are "A" shaped members that control the up and down motion of the wheel. See the figure below.

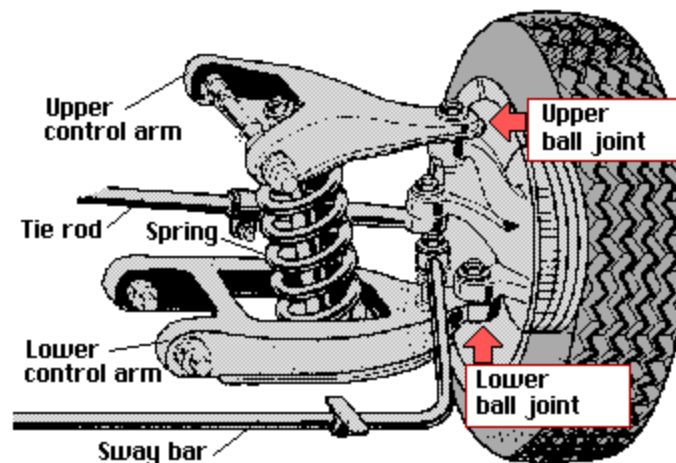


Figure 2: Suspension Example (10)

The base of the a-arms are attached to the frame and allow for swivel motion. The tip on the a-arms are attached to the wheel hub with ball joints. By changing the upper ball joint location in relation to the lower ball joint the suspension geometry is changed (3).

### ***CURRENT STATE OF THE ART***

Hotchkis Sport Suspension is one of the top producers of tubular upper a-arms for the second-generation Camaro. Their geometry corrected control arms offers increased caster and camber of 5.2 degrees and -1.1 degrees. The pros of this set would be the corrected geometry, high quality bushings, added strength over stock, and negatable effects on steering (7) (8). Another pro is only needing to purchase upper a-arms. The cons of this set would be slightly too large geometry for normal street usage, and this set is also one of the highest costing a-arm set on the market (8).

Q1A Suspension, Driveshaft and Rod End Experts also produce a-arms for the second-generation Camaro. These control arms offer 3-4 degrees of caster and 0.5 to 1 degree of negative camber when used with Q1A lower control arms. The pros of this set would be optimum geometry for street use, added strength over stock, options for upgraded ball joints (9). The cons of this set are you must purchase both upper and lower a-arms.

Global West Suspension Components produces upper a-arms for the second-generation Camaro. These control arms offer 6.5 to 7 degrees of caster and 1.25 to 1.75 degrees of negative camber. The pros of this set would be high quality bushings, added strength over stock, updated geometry (8). The main con is the geometry is too great for street applications.

The final major manufacture of upper a-arms for the second-generation Camaro is Detroit Speed. These control arms claim improved geometry over stock but do not list caster and camber measurements. The pros of this set would be high quality bushings, added strength over stock, updated geometry, and caster adjustment bushings (8). The cons of this set would be no listed caster and camber measurements and higher cost.

All the products on the market have upgraded strength, higher quality bushings, and an updated suspension geometry for better performance. Manufactures like Hotchkis and Global West have geometry's that are too great for most street applications. These products are marketed towards all out performance and road racing. Detroit Speed brings a good concept to the table with the adjustable caster bushings, but they fail to specify geometry specifications. Q1A Suspension offers optimum geometry, but it requires the use of both lower and upper a-arms which cost more.

### ***END USER***

The end user of my product will most likely be an owner of a second-generation Camaro. Owning and working on their car is a hobby. Most owners use their car for street purposes while going to an occasional auto cross or road race event. All of survey participants are running newer radial tires. The end user is looking for a product that will make their car perform better and increase tire wear while being at a hobby level price. The product must be upper a-arms only and have street level geometry. An a-arm system that is designed to utilize street geometry while only using upper a-arms to achieve this is missing from the market. There are made to order manufactures out there, but these options are usually costlier in nature.

### ***CONCLUSIONS AND SUMMARY OF RESEARCH***

In conclusion, due to the way bias ply and radial tires behave there is room for improvement on second-generation Camaros that are using radial tires but have suspension systems designed for bias ply tires. New tubular upper arms will increase the performance, safety, and tire wear. Common themes on the market is geometry that was too great for street use. This geometry is great for all out performance for racing, but tire wear starts to suffer greatly due to the high negative camber. One manufacture produces a-arms that fit the street level geometry category but requires the purchase and installation of both upper and lower a-arms. My solution is going to be use upper a-arms only to save on cost and allow for easier

installation. My solution is also going to use street geometry of 3-4 degrees of caster and 0.5 degrees of negative camber. This design will allow for increased performance without tire wear issues.

## **CUSTOMER FEATURES**

Along with the above research surveys where posted to nasty28.com which is a popular forum and message board for second generation Camaro owners. The survey consisted of the following questions: what is the main use of your Camaro, what geometry best suits you, do you want upper a-arms only or uppers and lowers, what size tires are you running, how often do you adjust you tire alignment, how important is tire wear to you, how much are you willing to spend on new tubular a-arms. See appendix for survey and survey results. Using the above research and the survey responses the following customer features were determined to be: safe operation, added performance, street use a-arms, low cost, low tire wear, easy adjustment, and ease of initial install.

## **PRODUCT OBJECTIVES**

The following product objectives have been determined to satisfy the customer features. Added performance over the current product will be accomplished increasing caster geometry and adding proper camber geometry into the a-arms during manufacturing. The stipulation of street use a-arms will be achieved by using a geometry of 3-4 degrees of caster and 0.5 degrees of negative camber. Anything past this will hurt street-ability which is exactly what most other products have done. Producing a low-cost product will be done by only using upper a-arms to reduce material and labor cost and using of original ball joints and bushings to reduce material costs. Low tire wear will be achieved by keeping camber as close to -0.5 degrees as possible. Easy adjustment will be made possible by including adjustment shims or possibly built in adjustment bushings. Easy initial install will be made possible by only needing to install upper a-arms. This will cut install time and difficulty level of installation. In summary, the product objectives are: Increased caster geometry, proper camber geometry, street geometry of 3-4 degrees of caster and 0.5 degrees of negative camber built into a-arm, only using uppers to cut cost, allowing for use of original ball joints and bushings, keeping camber as close to -0.5 degrees as possible, only using upper a-arms to allow for an easier install.

QUALITY FUNCTION DEPLOYMENT

Table 1: QFD

| Customer Requirements              |                         | Importance wt. | Engineering Requirements (units) |     |       |     |     |     |      |     |     |    |    |    |    |    | Customer Satisfaction Rating (0.00 - 1.00) |   |     |     |     |     |     |
|------------------------------------|-------------------------|----------------|----------------------------------|-----|-------|-----|-----|-----|------|-----|-----|----|----|----|----|----|--|---|-----|-----|-----|-----|-----|
|                                    |                         |                | 1                                | 2   | 3     | 4   | 5   | 6   | 7    | 8   | 9   | 10 | 11 | 12 | 13 | 14 | CP   | A | B   | C   | D   |     |     |
| 1                                  | Added Performance       | 0.20           |                                  | 3   | 9     | 9   |     |     |      |     |     |    |    |    |    |    |  |   | 0.3 | 0.9 | 0.7 | 0.9 | 0.8 |
| 2                                  | Street use A-arms       | 0.20           |                                  |     | 9     | 9   |     |     |      |     |     |    |    |    |    |    |  |   | 0.7 | 0.4 | 1.0 | 0.3 | 0.4 |
| 3                                  | Low Cost                | 0.15           |                                  |     |       |     |     |     | 9    |     |     |    | 9  |    |    |    |  |   | 1.0 | 0.4 | 0.4 | 0.7 | 0.6 |
| 4                                  | Low Tire Wear           | 0.10           |                                  | 9   | 1     | 9   |     |     |      | 9   |     |    |    |    |    |    |  |   | 0.6 | 0.6 | 1.0 | 0.3 | 0.5 |
| 5                                  | Easy Adjustment         | 0.05           |                                  |     |       |     | 9   |     |      |     |     |    |    |    |    |    | 3  |   | 0.7 | 0.7 | 0.7 | 0.7 | 1.0 |
| 6                                  | Ease of Initial Install | 0.05           |                                  |     |       |     |     | 9   |      |     |     |    |    |    |    |    | 9  |   | 0.9 | 0.9 | 0.9 | 0.5 | 0.9 |
| 7                                  | Safety                  | 0.25           | 9                                |     |       |     |     |     |      |     |     |    |    |    |    |    |  |   | 0.8 | 9.0 | 0.9 | 1.0 | 1.0 |
| 8                                  |                         |                |                                  |     |       |     |     |     |      |     |     |    |    |    |    |    |  |   |     |     |     |     |     |
| 9                                  |                         |                |                                  |     |       |     |     |     |      |     |     |    |    |    |    |    |  |   |     |     |     |     |     |
| 10                                 |                         |                |                                  |     |       |     |     |     |      |     |     |    |    |    |    |    |  |   |     |     |     |     |     |
| Total Importance                   |                         | 1.00           |                                  |     |       |     |     |     |      |     |     |    |    |    |    |    |  |   |     |     |     |     |     |
| Engineering requirement importance |                         |                | 2.25                             | 1.5 | 3.7   | 4.5 | 0.5 | 0.5 | 1.35 | 1.5 | 0.6 | 2  |    |    |    |    |  |   |     |     |     |     |     |
| Performance                        | Current Product         | 0.009          | 150                              | 1   | -1.5  | 60  | 240 | Y   | N    | N   | 2   |    |    |    |    |    |  |   |     |     |     |     |     |
|                                    | Hotchkis                | 0.005          | 155                              | 5.2 | -1.1  | 60  | 240 | N   | N    | Y   | 2   |    |    |    |    |    |  |   |     |     |     |     |     |
|                                    | Q1A                     | 0.005          | 140                              | 3.5 | -0.05 | 60  | 360 | N   | Y    | Y   | 4   |    |    |    |    |    |  |   |     |     |     |     |     |
|                                    | Gobal West              | 0.003          | 158                              | 7   | -1.5  | 60  | 240 | N   | N    | Y   | 2   |    |    |    |    |    |  |   |     |     |     |     |     |
|                                    | Detroit Speed           | 0.003          | 155                              | 5   | -1.25 | 40  | 240 | N   | N    | Y   | 2   |    |    |    |    |    |  |   |     |     |     |     |     |
|                                    | New Product Targets     | 0.003          | 140                              | 3.5 | -0.05 | 40  | 240 | Y   | Y    | Y   | 2   |    |    |    |    |    |  |   |     |     |     |     |     |

| Interaction Matrix                            |      |   |   |    |    |   |   |    |   |    |    |    |    |    |
|---|------|---|---|----|----|---|---|----|---|----|----|----|----|----|
| Engineering Requirements                      | 1    | 2 | 3 | 4  | 5  | 6 | 7 | 8  | 9 | 10 | 11 | 12 | 13 | 14 |
| Displacement under load (in)                  | 1    |   |   |    |    |   |   | -3 |   |    |    |    |    |    |
| Average tire heat after prolonged driving (F) | 2    |   |   | -1 | -9 |   |   |    |   |    |    |    |    |    |
| Caster (degrees)                              | 3    |   |   |    | -3 |   |   |    | 9 |    |    |    |    |    |
| Camber (degrees)                              | 4    |   |   |    |    |   |   | -9 |   |    |    |    |    |    |
| Adjustment time (min)                         | 5    |   |   |    |    |   |   |    |   | -3 |    |    |    |    |
| Install time (min)                            | 6    |   |   |    |    |   | 1 |    |   | -9 |    |    |    |    |
| Use of original replacement parts (y/n)       | 7    |   |   |    |    |   |   |    |   |    |    |    |    |    |
| Tire heat even (y/n)                          | 8    |   |   |    |    |   |   |    |   |    |    |    |    |    |
| Steering returns quick (y/n)                  | 9    |   |   |    |    |   |   |    |   | 1  |    |    |    |    |
| No. of needed a-arms                          | 10   |   |   |    |    |   |   |    |   |    |    |    |    |    |
|   | 0 11 |   |   |    |    |   |   |    |   |    |    |    |    |    |
|   | 0 12 |   |   |    |    |   |   |    |   |    |    |    |    |    |
|   | 0 13 |   |   |    |    |   |   |    |   |    |    |    |    |    |
|   | 0 14 |   |   |    |    |   |   |    |   |    |    |    |    |    |

**DESIGN**

***DESIGN ALTERNATIVES AND SELECTION***

The function of the product is to maintain suspension geometry during all driving conditions while also allowing for suspension travel. The following table shows concept alternatives and selection.

Table 2: Concept Selection

| Criteria          | Wt. | Round Tube |      | Square Tube |      | Stamped |      |
|-------------------|-----|------------|------|-------------|------|---------|------|
| Low Cost          | 30  | 4          | 1.2  | 3           | 0.9  | 2       | 0.6  |
| Strength          | 20  | 3          | 0.6  | 4           | 0.8  | 2       | 0.4  |
| Manufacturability | 35  | 3          | 1.05 | 2           | 0.7  | 4       | 1.4  |
| Light Weight      | 15  | 4          | 0.6  | 3           | 0.45 | 3       | 0.45 |
| Total:            |     | 3.45       |      | 2.85        |      | 2.85    |      |

**Selection: Round Tube**

Round tubing was chosen due to its overall ability to perform well in all four criteria categories'. Round tubing really excels in low cost and light weight making it the perfect material to construct frame members from. Below are product configurations derived from the chosen concept.

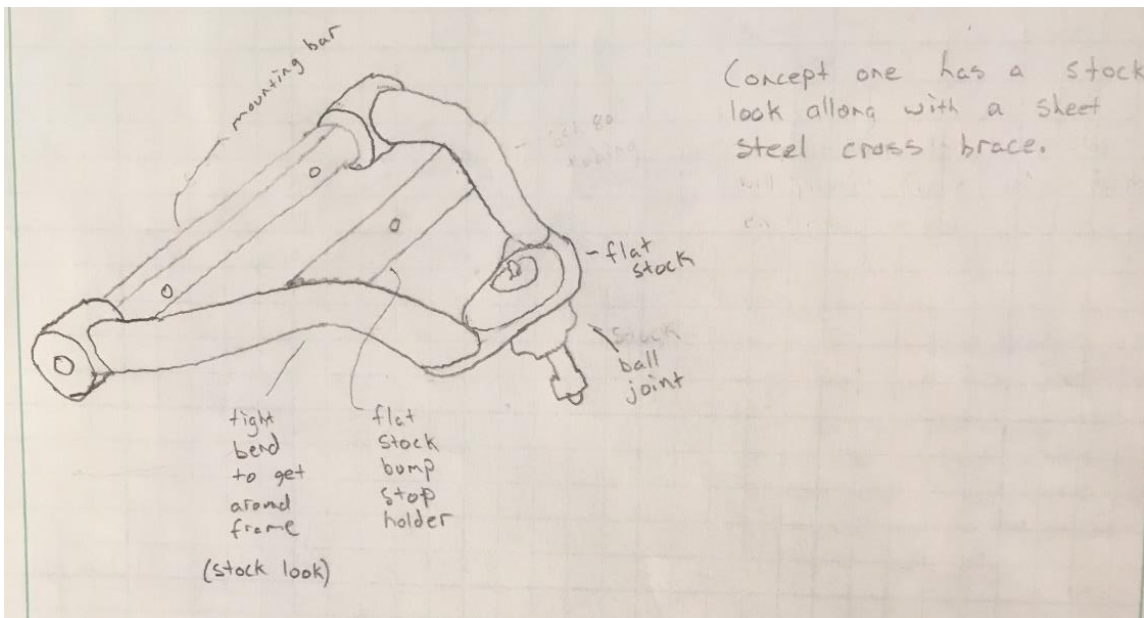


Figure 3: Product Configuration 1

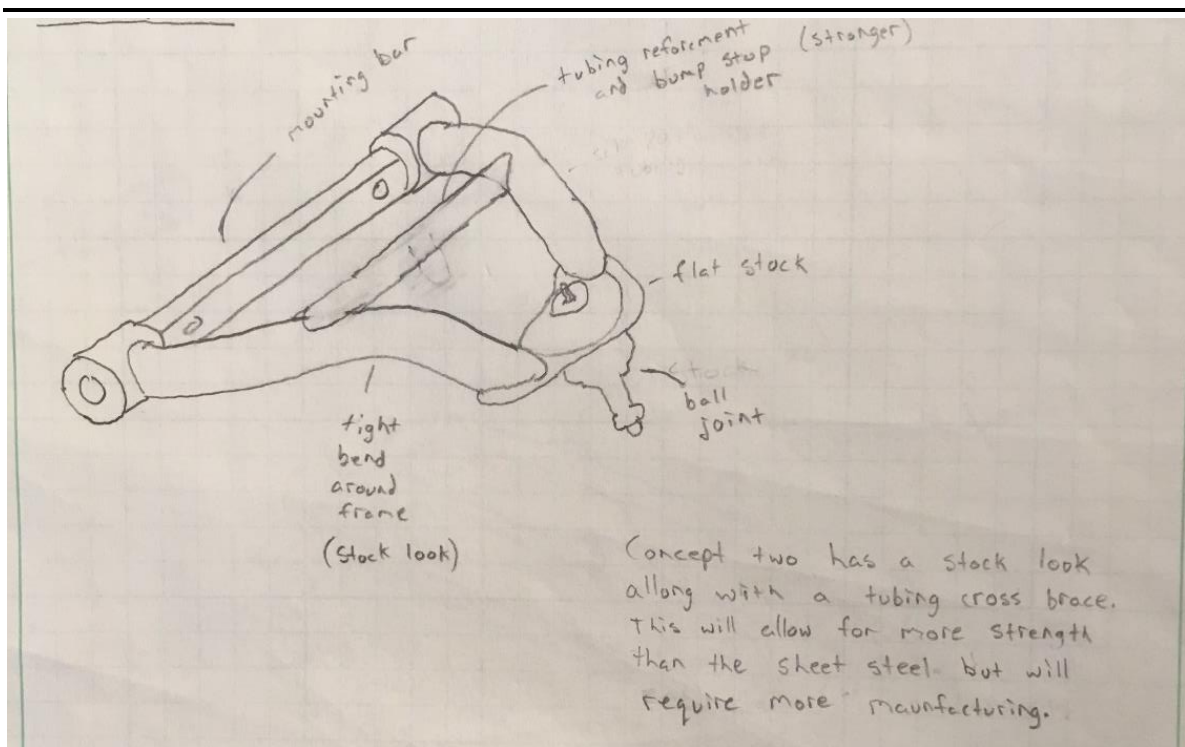


Figure 4: Product Configuration 2

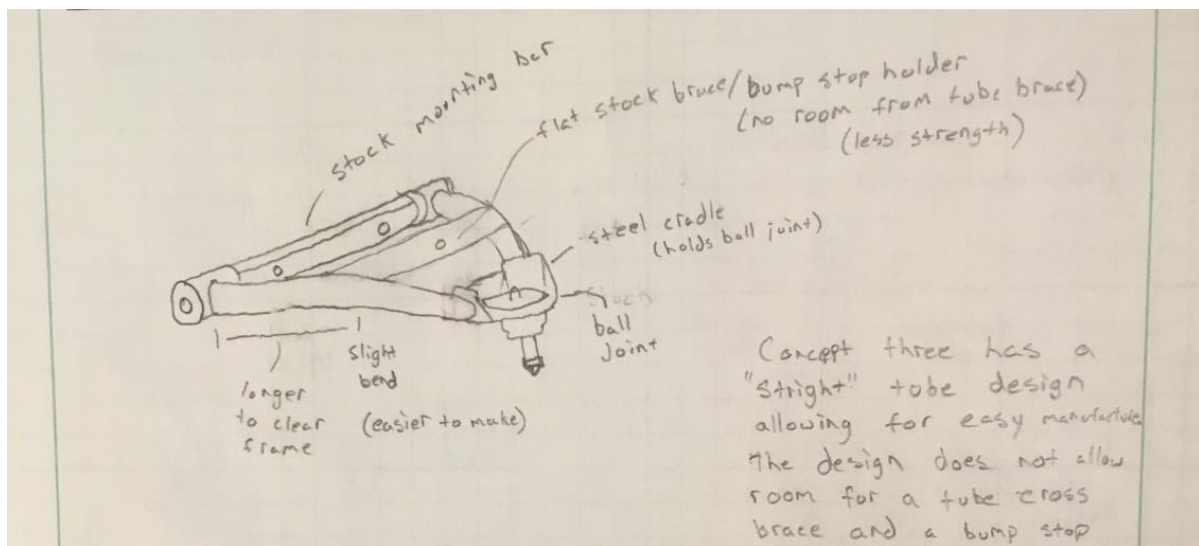


Figure 5: Product Configuration 3

Table 3: Configuration Selection

| Criteria          | Wt. | Configuration 1 |     | Configuration 2 |     | Configuration 3 |      |
|-------------------|-----|-----------------|-----|-----------------|-----|-----------------|------|
| Function          |     |                 |     |                 |     |                 |      |
| Correct Geometry  | 20  | 4               | 0.8 | 4               | 0.8 | 4               | 0.8  |
| Free Articulation | 25  | 4               | 1   | 4               | 1   | 1               | 0.25 |
| Stock Look        | 5   | 4               | 0.2 | 4               | 0.2 | 2               | 0.1  |
| High Strength     | 20  | 2               | 0.4 | 3               | 0.6 | 4               | 0.8  |
| Manufacture       |     |                 |     |                 |     |                 |      |
| Cost/material use | 10  | 3               | 0.3 | 4               | 0.4 | 3               | 0.3  |
| Bend Radius       | 10  | 3               | 0.3 | 3               | 0.3 | 4               | 0.4  |
| Assembly          |     |                 |     |                 |     |                 |      |
| # of Parts        | 5   | 4               | 0.2 | 4               | 0.2 | 3               | 0.15 |
| # of Tube Notches | 5   | 4               | 0.2 | 2               | 0.1 | 4               | 0.2  |
| Total:            |     |                 | 3.4 |                 | 3.6 |                 | 3    |

**Selection: Configuration 2**

Configuration 2 was chosen over configuration 1 due to the added strength of using the middle tube instead of sheet steel. Configuration 2 was chosen over configuration 3 due to the added articulation (frame clearance) and nicer look. Below are part configurations derived from the chosen configuration.

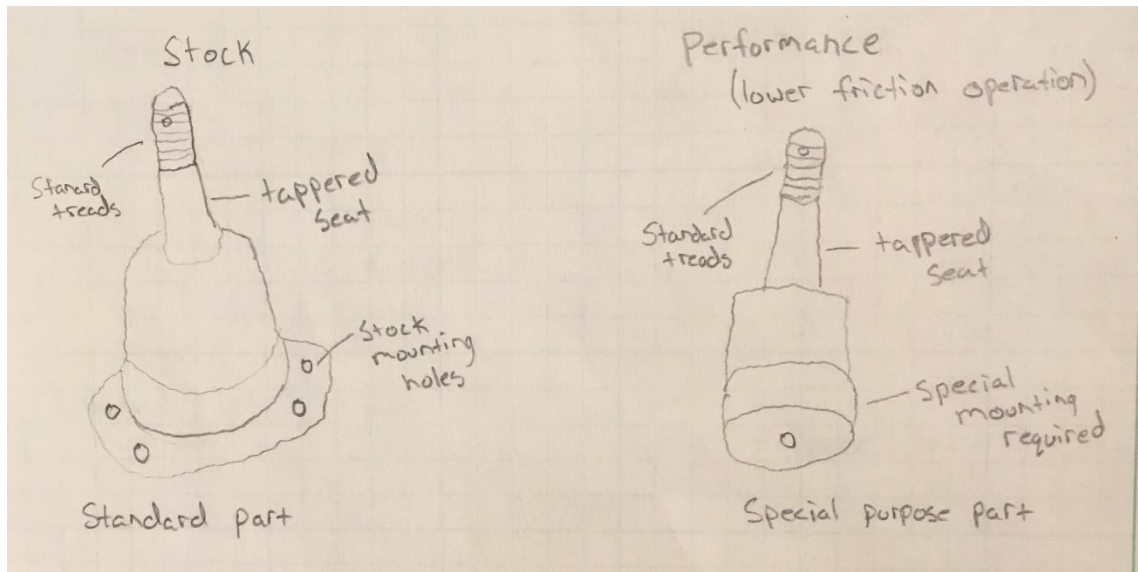


Figure 6: Ball Joint Configuration

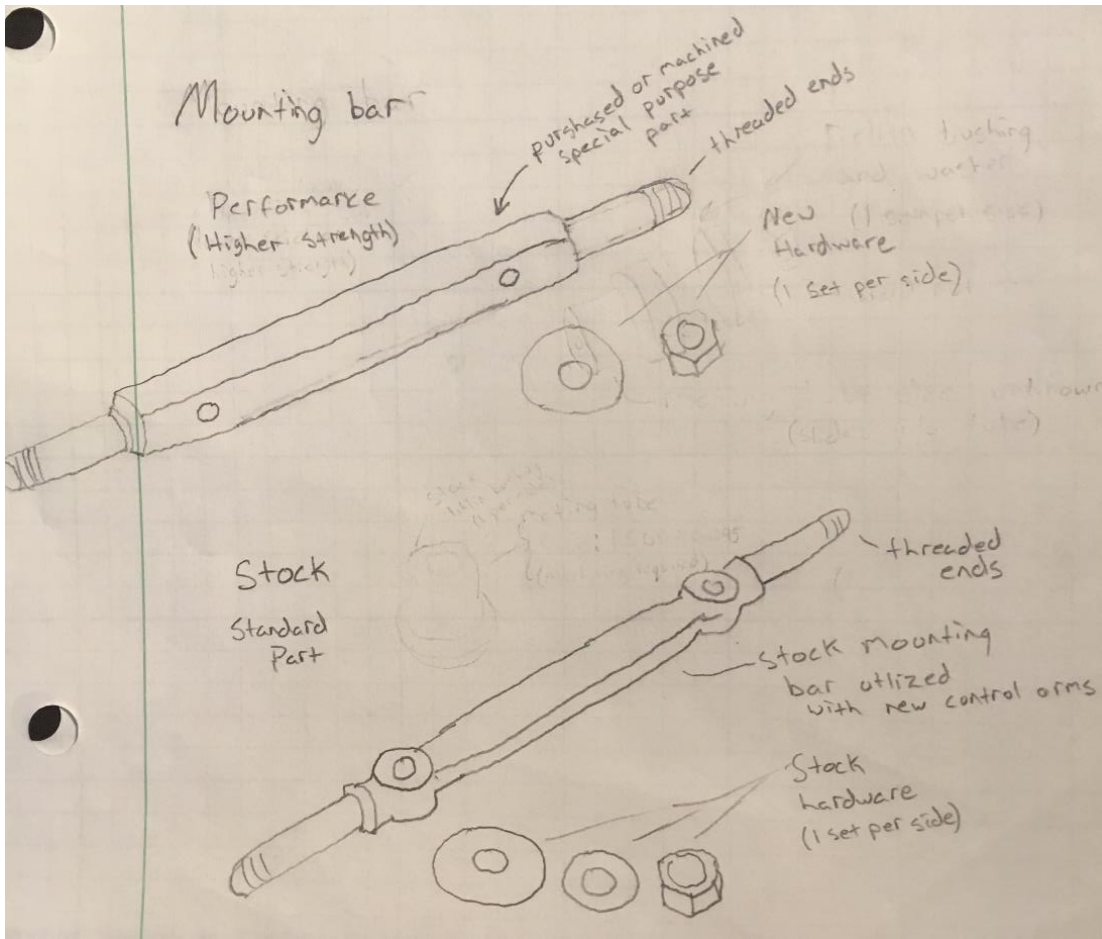


Figure 7: Mounting Bar Configuration

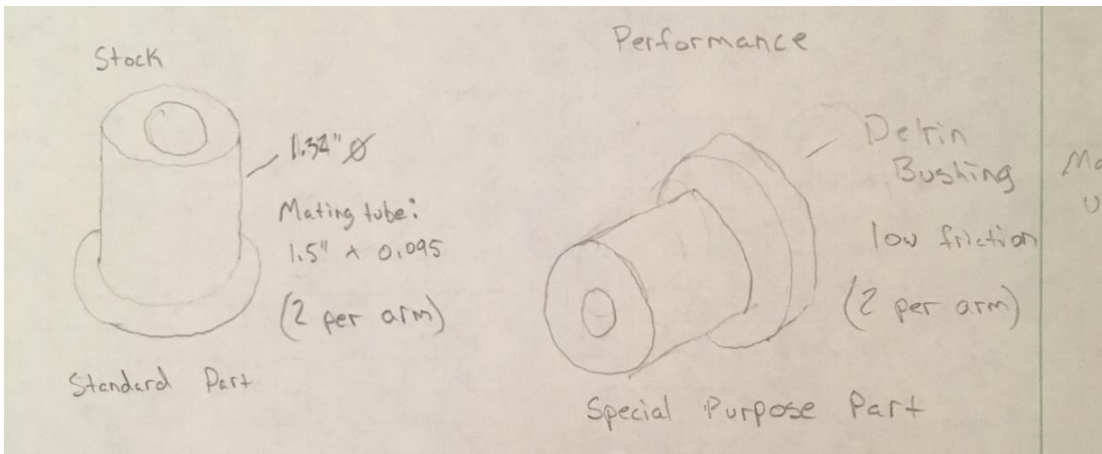


Figure 8: Bushing Configuration

Table 4: Ball Joint Part Selection

| Criteria     | Wt. | Stock |     | Performance |      |
|--------------|-----|-------|-----|-------------|------|
| Performance  | 25  | 2     | 0.5 | 4           | 1    |
| Cost         | 25  | 4     | 1   | 3           | 0.75 |
| Availability | 30  | 4     | 1.2 | 3           | 0.9  |
| Reliability  | 20  | 4     | 0.8 | 3           | 0.6  |
| Total:       |     | 3.5   |     | 3.25        |      |

Selection: Stock

Table 5: Mounting Bar Part Selection

| Criteria     | Wt. | Stock |      | Performance |     |
|--------------|-----|-------|------|-------------|-----|
| Performance  | 25  | 3     | 0.75 | 4           | 1   |
| Cost         | 25  | 3     | 0.75 | 2           | 0.5 |
| Availability | 30  | 0     | 0    | 3           | 0.9 |
| Reliability  | 20  | 3     | 0.6  | 4           | 0.8 |
| Total:       |     | 2.1   |      | 3.2         |     |

Selection: Performance

Table 6: Bushing Part Selection

| Criteria     | Wt. | Stock |     | Performance |      |
|--------------|-----|-------|-----|-------------|------|
| Performance  | 25  | 2     | 0.5 | 4           | 1    |
| Cost         | 25  | 4     | 1   | 1           | 0.25 |
| Availability | 30  | 4     | 1.2 | 4           | 1.2  |
| Reliability  | 20  | 4     | 0.8 | 3           | 0.6  |
| Total:       |     | 3.5   |     | 3.05        |      |

Selection: Stock

In conclusion, concept number two was chosen because of the utilization of the center bar for strengthening. This concept will use stock ball joints and bushing whiling using a performance mounting bar (aftermarket mounting bar). The image below shows the solid models for both driver and passenger side for the chosen concept.

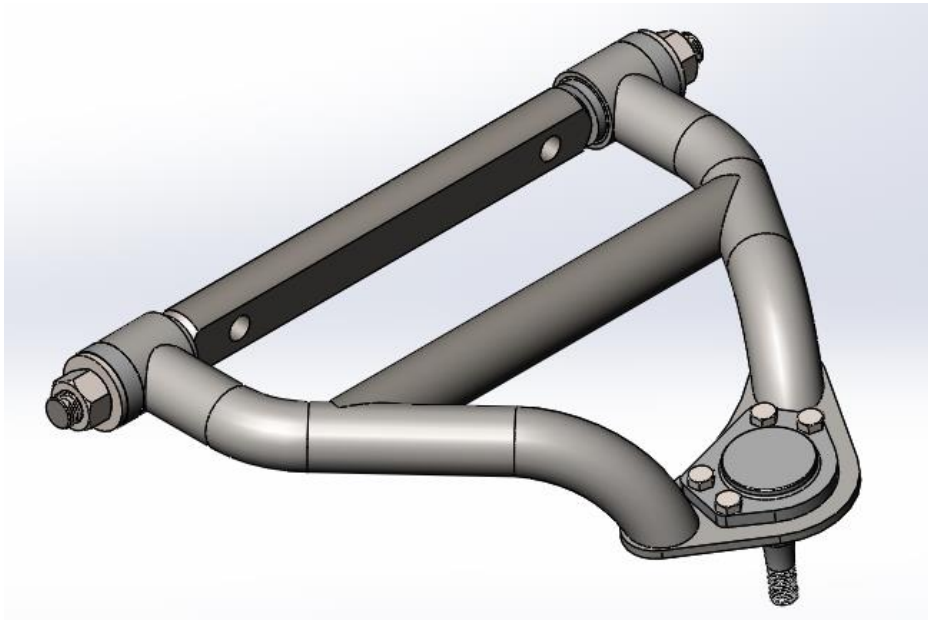


Figure 9: Drivers Assembly

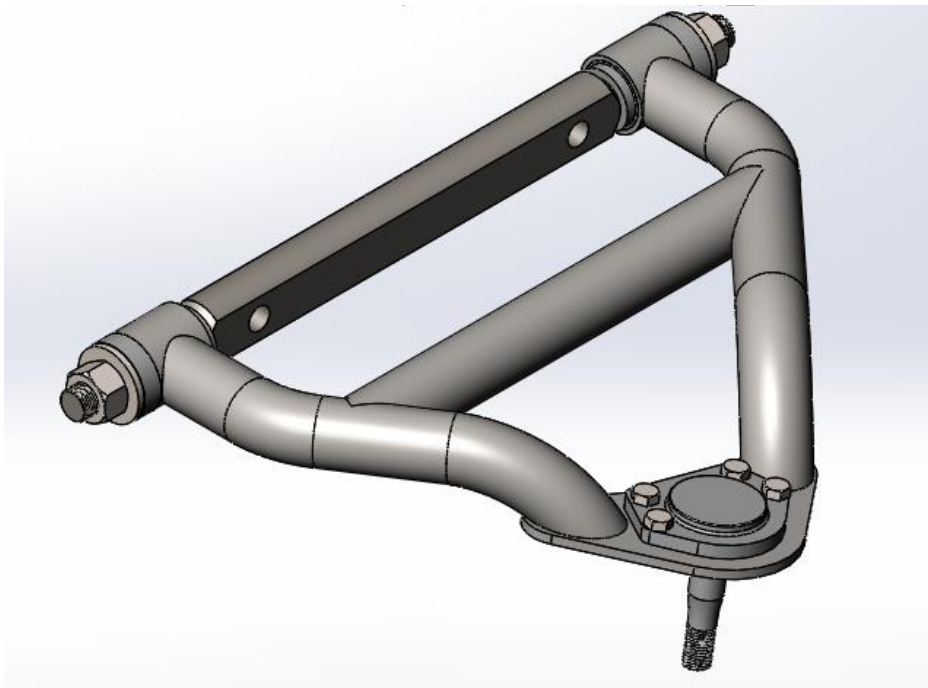
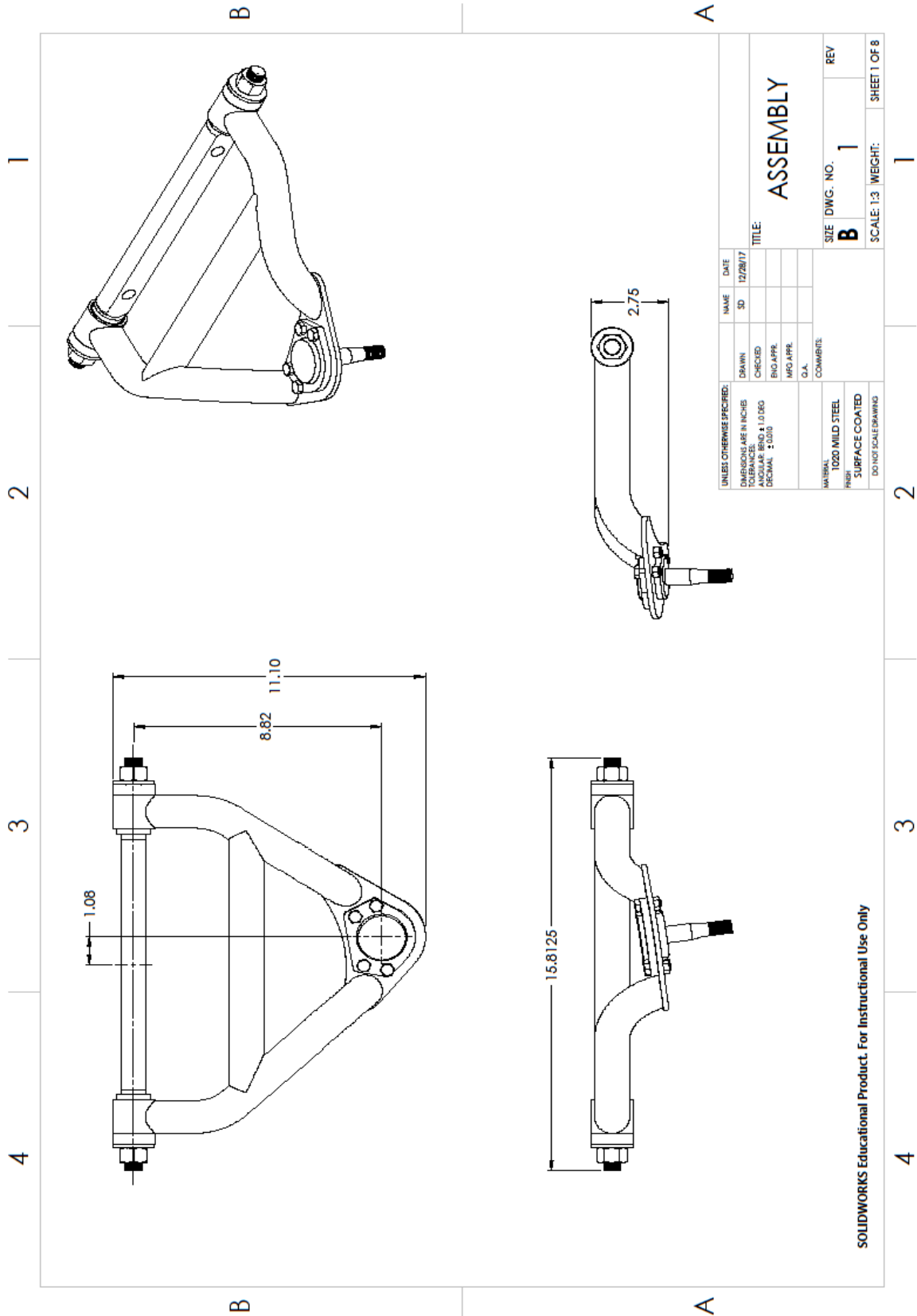


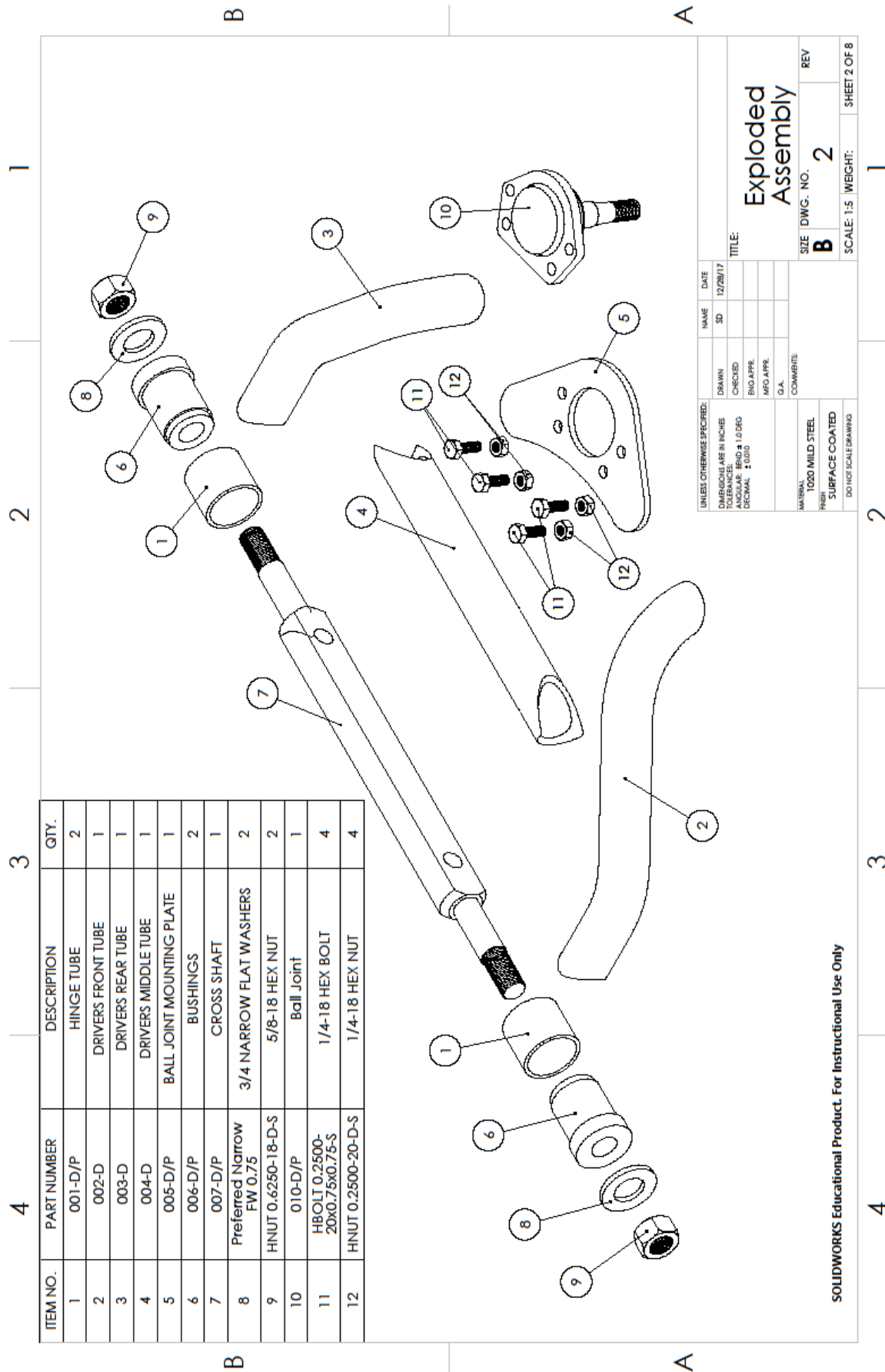
Figure 10: Passenger Assembly

**DRAWINGS**

**Drivers**



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| ITEM NO. | PART NUMBER                 | DESCRIPTION               | QTY. |
|----------|-----------------------------|---------------------------|------|
| 1        | 001-D/P                     | HINGE TUBE                | 2    |
| 2        | 002-D                       | DRIVERS FRONT TUBE        | 1    |
| 3        | 003-D                       | DRIVERS REAR TUBE         | 1    |
| 4        | 004-D                       | DRIVERS MIDDLE TUBE       | 1    |
| 5        | 005-D/P                     | BALL JOINT MOUNTING PLATE | 1    |
| 6        | 006-D/P                     | BUSHINGS                  | 2    |
| 7        | 007-D/P                     | CROSS SHAFT               | 1    |
| 8        | Preferred Narrow FW 0.75    | 3/4 NARROW FLAT WASHERS   | 2    |
| 9        | HNUT 0.6250-18-D-S          | 5/8-18 HEX NUT            | 2    |
| 10       | 010-D/P                     | Ball Joint                | 1    |
| 11       | HBOLT 0.2500-20x0.75x0.75-S | 1/4-18 HEX BOLT           | 4    |
| 12       | HNUT 0.2500-20-D-S          | 1/4-18 HEX NUT            | 4    |

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 ANGULAR DIMS IN DEGREES  
 DECIMAL 2/1000

|      |          |
|------|----------|
| NAME | DATE     |
| SD   | 12/28/17 |

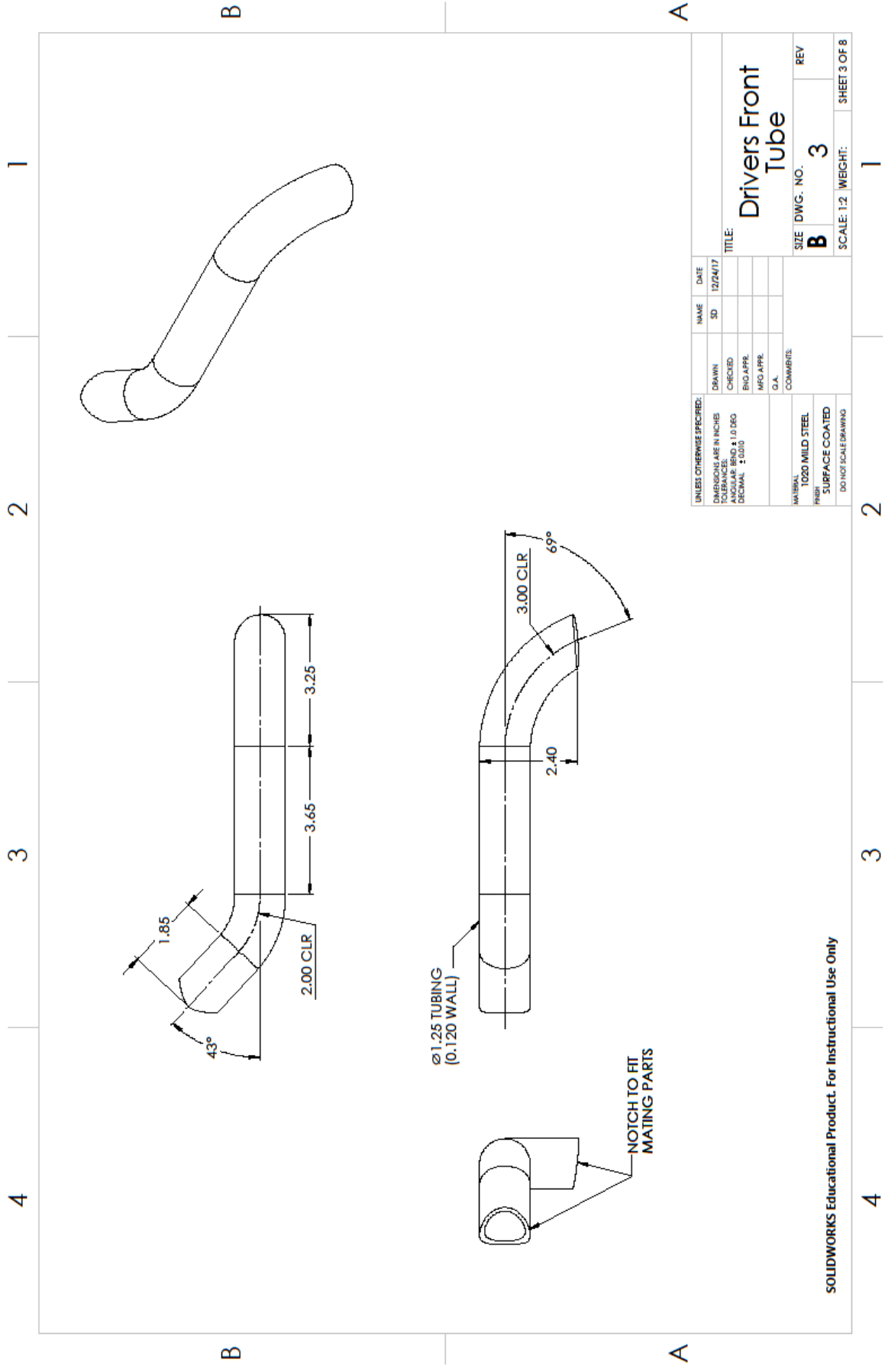
TITLE:  
**Exploded Assembly**

SIZE DWG. NO. **B** 2 REV

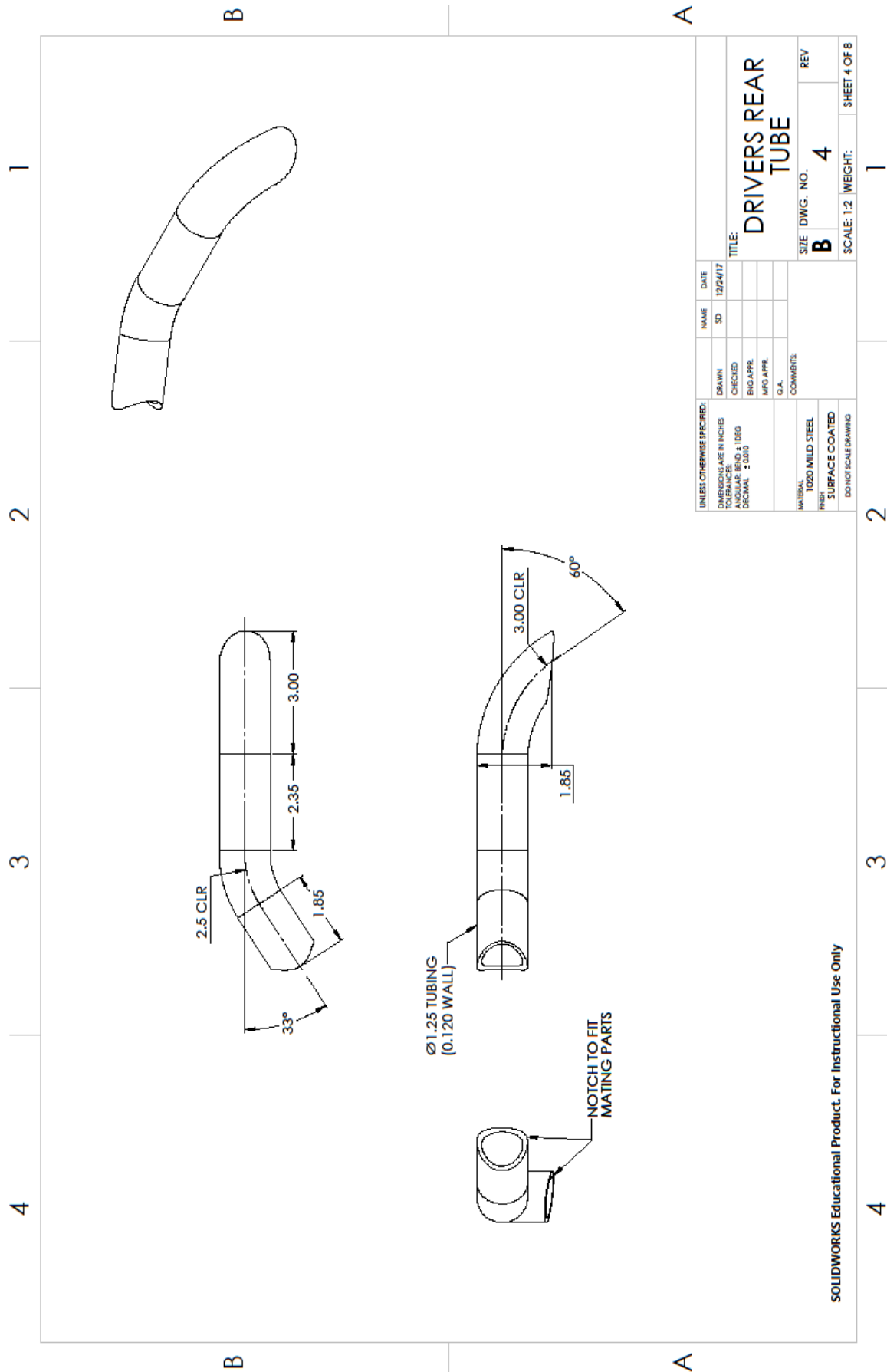
SCALE: 1:5 WEIGHT: SHEET 2 OF 8

COMMENTS:  
 MATERIAL 1020 MILD STEEL  
 FINISH SURFACE COATED  
 DO NOT SCALE DRAWING

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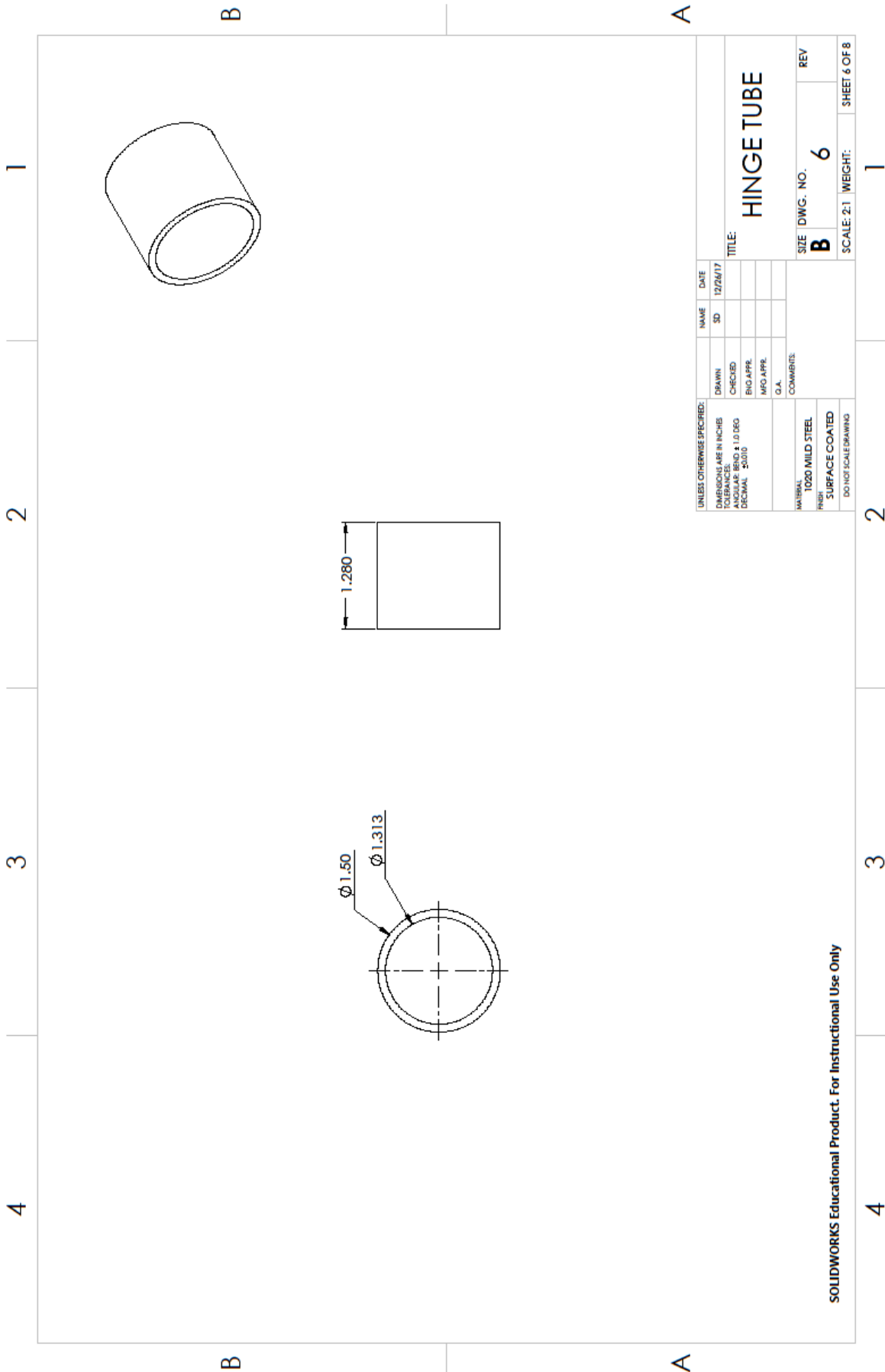
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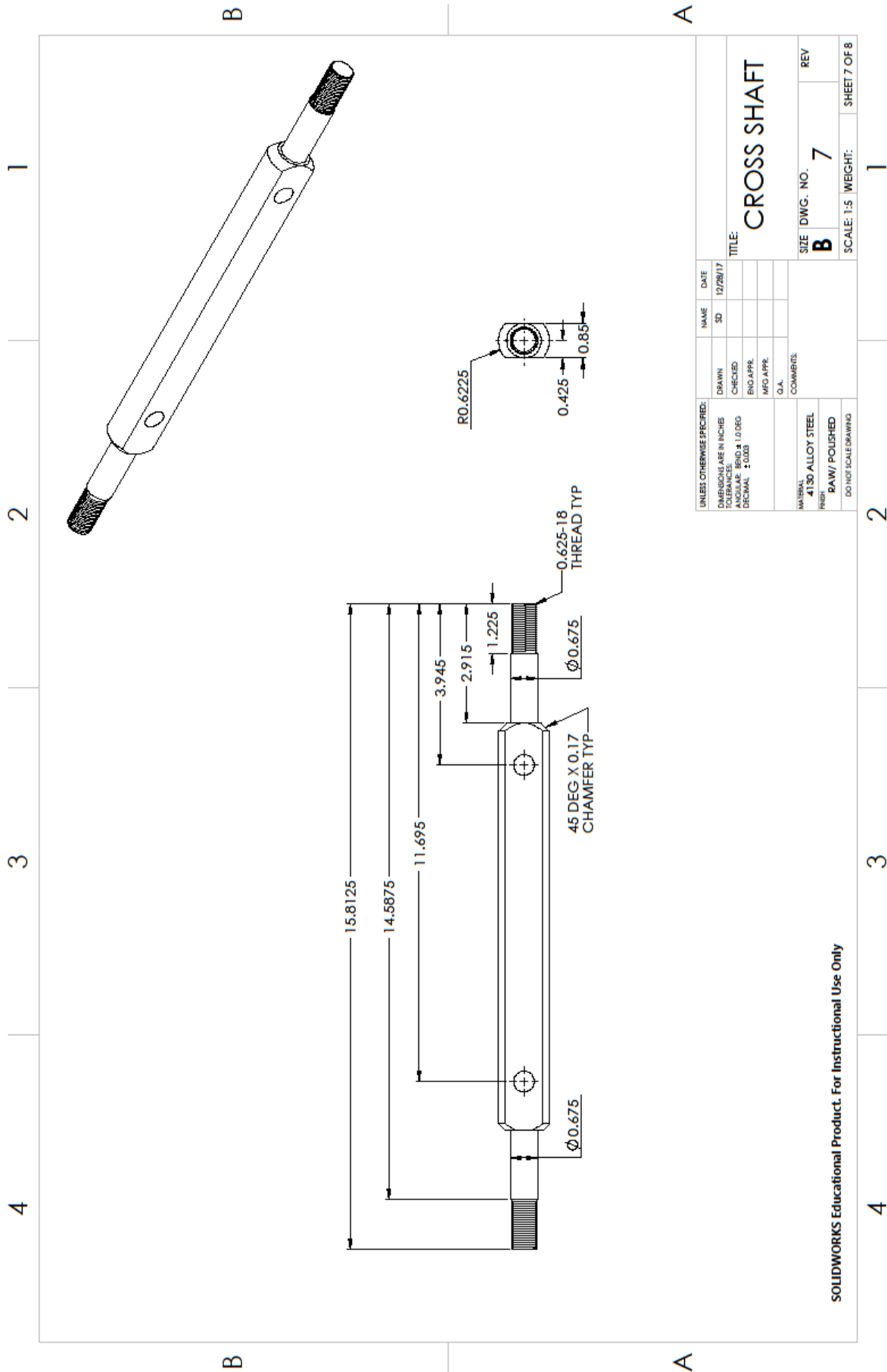


|  |  |                   |              |
|--|--|-------------------|--------------|
| UNLESS OTHERWISE SPECIFIED:            |  | NAME              | DATE         |
| DIMENSIONS ARE IN INCHES               |  | SD                | 12/24/17     |
| FRACTIONS TO BE IN 16ths               |  |                   |              |
| DECIMALS TO BE TO 2 DECIMALS           |  |                   |              |
| TOLERANCES UNLESS OTHERWISE SPECIFIED: |  |                   |              |
| FRACTIONS TO BE ± 0.005                |  |                   |              |
| DECIMALS TO BE ± 0.010                 |  |                   |              |
| SURFACE COATING:                       |  |                   |              |
| MATERIAL:                              |  |                   |              |
| FINISH:                                |  |                   |              |
| DO NOT SCALE DRAWING                   |  |                   |              |
| DRAWN                                  |  |                   |              |
| CHECKED                                |  |                   |              |
| ENG APPR                               |  |                   |              |
| MFG APPR                               |  |                   |              |
| G.A.                                   |  |                   |              |
| COMMENTS:                              |  |                   |              |
| TITLE:                                 |  | DRIVERS REAR TUBE |              |
| SIZE                                   |  | DWG. NO.          | REV          |
|  |  | B                 | 4            |
| SCALE: 1:2                             |  | WEIGHT:           | SHEET 4 OF 8 |

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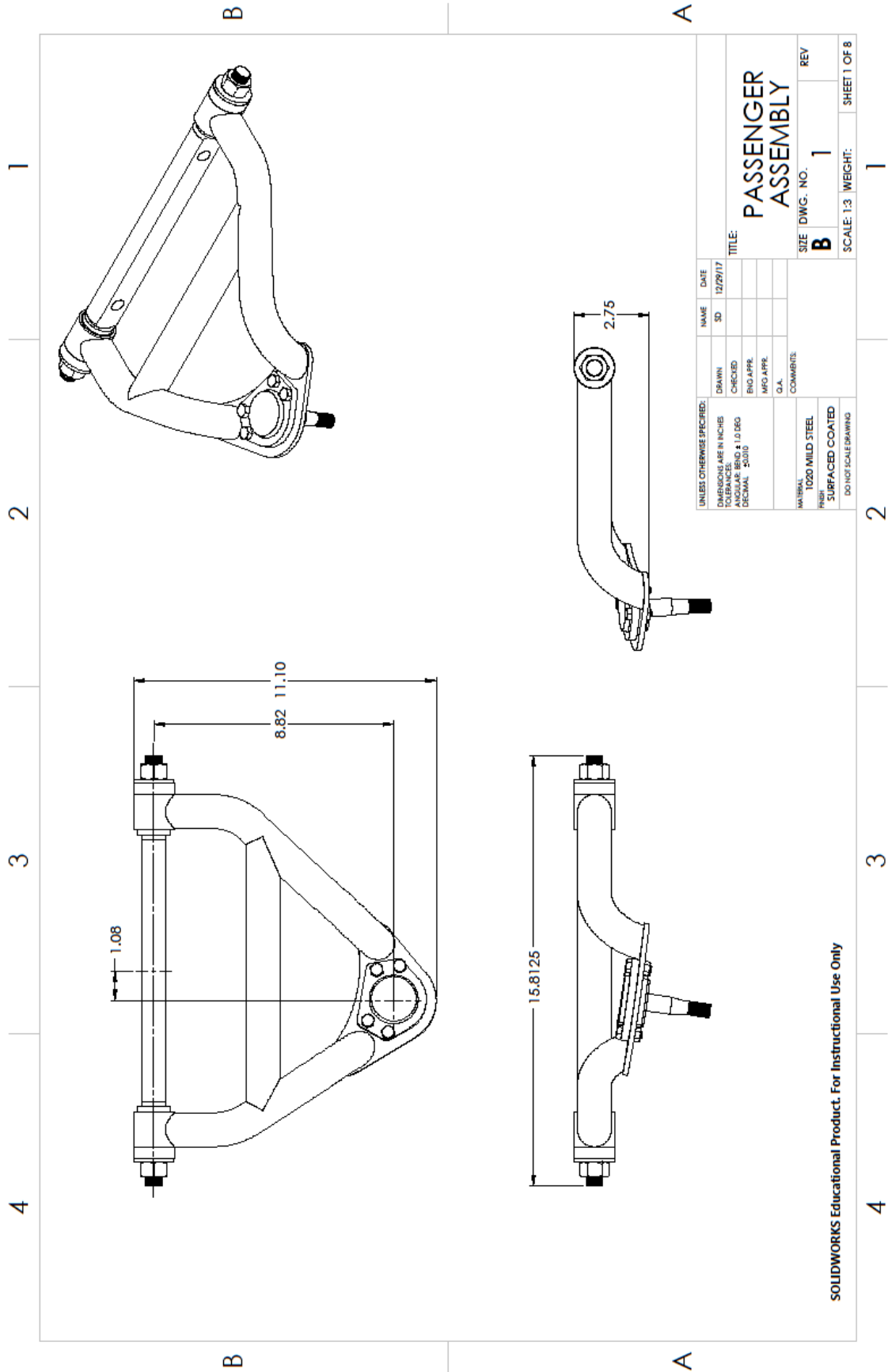




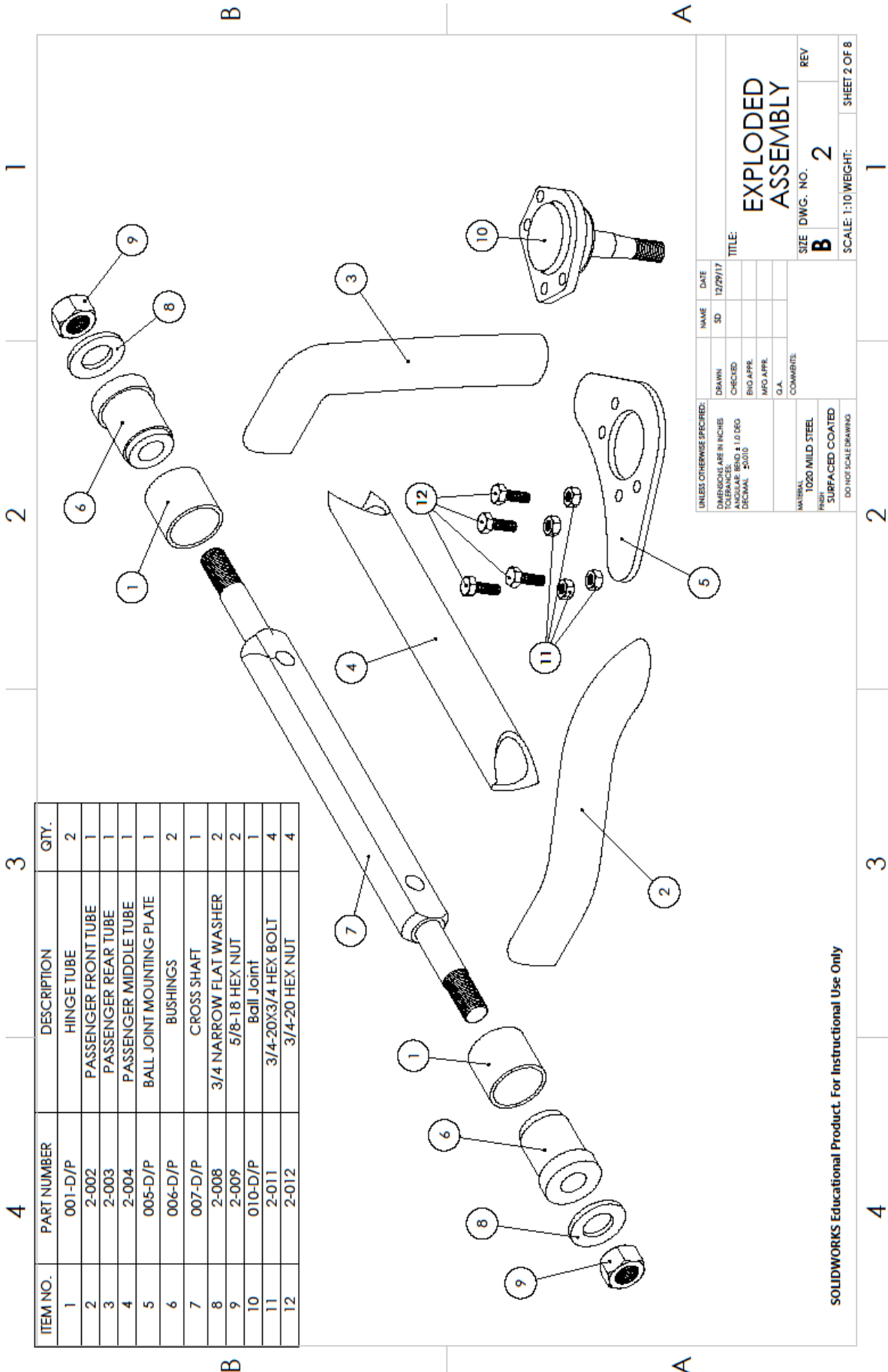
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Passengers



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| ITEM NO. | PART NUMBER | DESCRIPTION               | QTY. |
|----------|-------------|---------------------------|------|
| 1        | 001-D/P     | HINGE TUBE                | 2    |
| 2        | 2-002       | PASSENGER FRONT TUBE      | 1    |
| 3        | 2-003       | PASSENGER REAR TUBE       | 1    |
| 4        | 2-004       | PASSENGER MIDDLE TUBE     | 1    |
| 5        | 005-D/P     | BALL JOINT MOUNTING PLATE | 1    |
| 6        | 006-D/P     | BUSHINGS                  | 2    |
| 7        | 007-D/P     | CROSS SHAFT               | 1    |
| 8        | 2-008       | 3/4 NARROW FLAT WASHER    | 2    |
| 9        | 2-009       | 5/8-18 HEX NUT            | 2    |
| 10       | 010-D/P     | Ball Joint                | 1    |
| 11       | 2-011       | 3/4-20X3/4 HEX BOLT       | 4    |
| 12       | 2-012       | 3/4-20 HEX NUT            | 4    |

UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN INCHES  
 TOLERANCES ARE:  
 FINISHES:  
 SURFACED COATED  
 DO NOT SCALE DRAWING

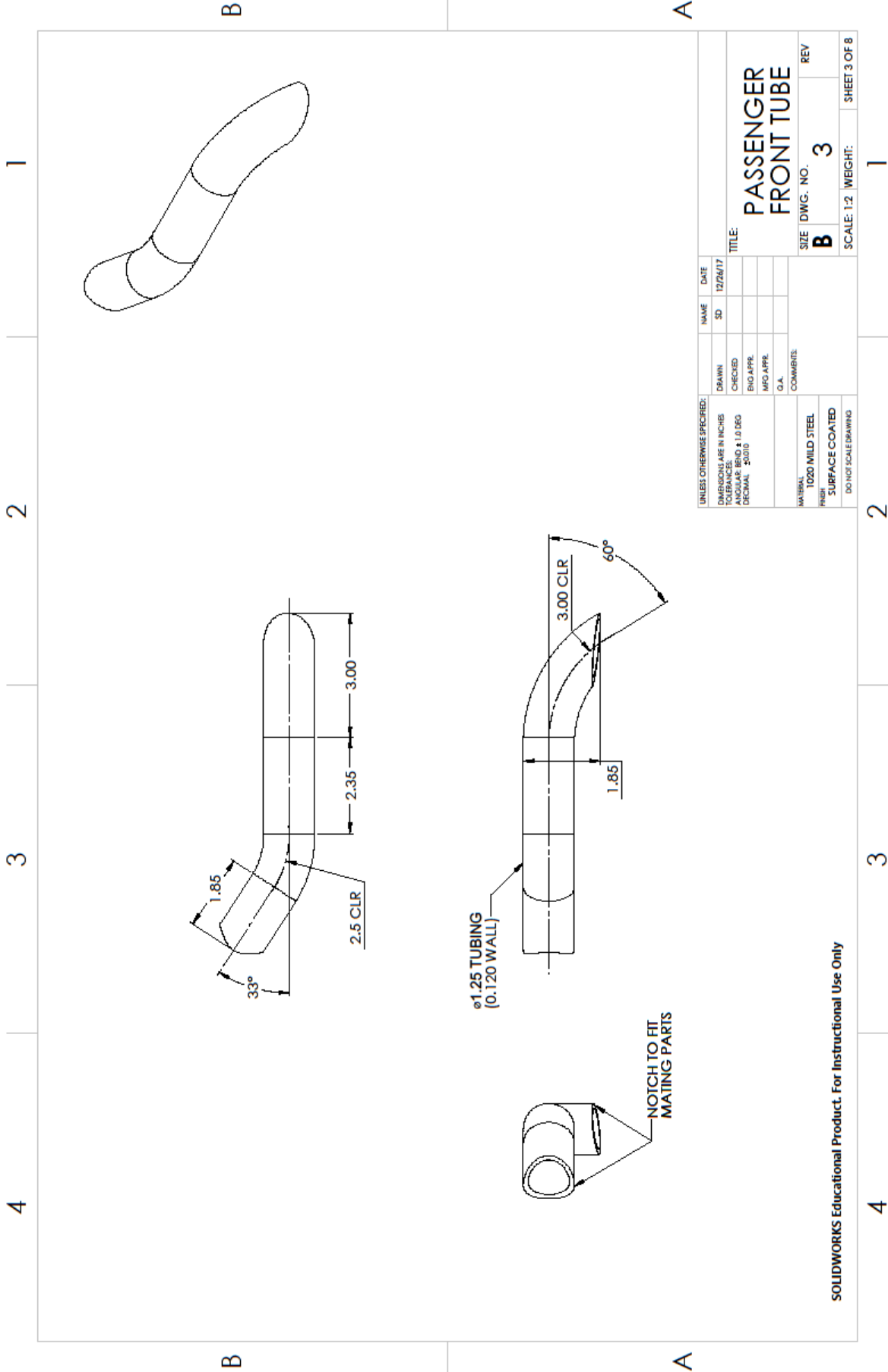
|            |    |            |          |
|------------|----|------------|----------|
| NAME       | SD | DATE       | 12/29/17 |
| DRAWN      |    | CHECKED    |          |
| ENG. APPL. |    | MFG. APPL. |          |
| G.A.       |    | COMMENTS:  |          |

TITLE: **EXPLODED ASSEMBLY**

SIZE: DWG. NO. **B** REV **2**

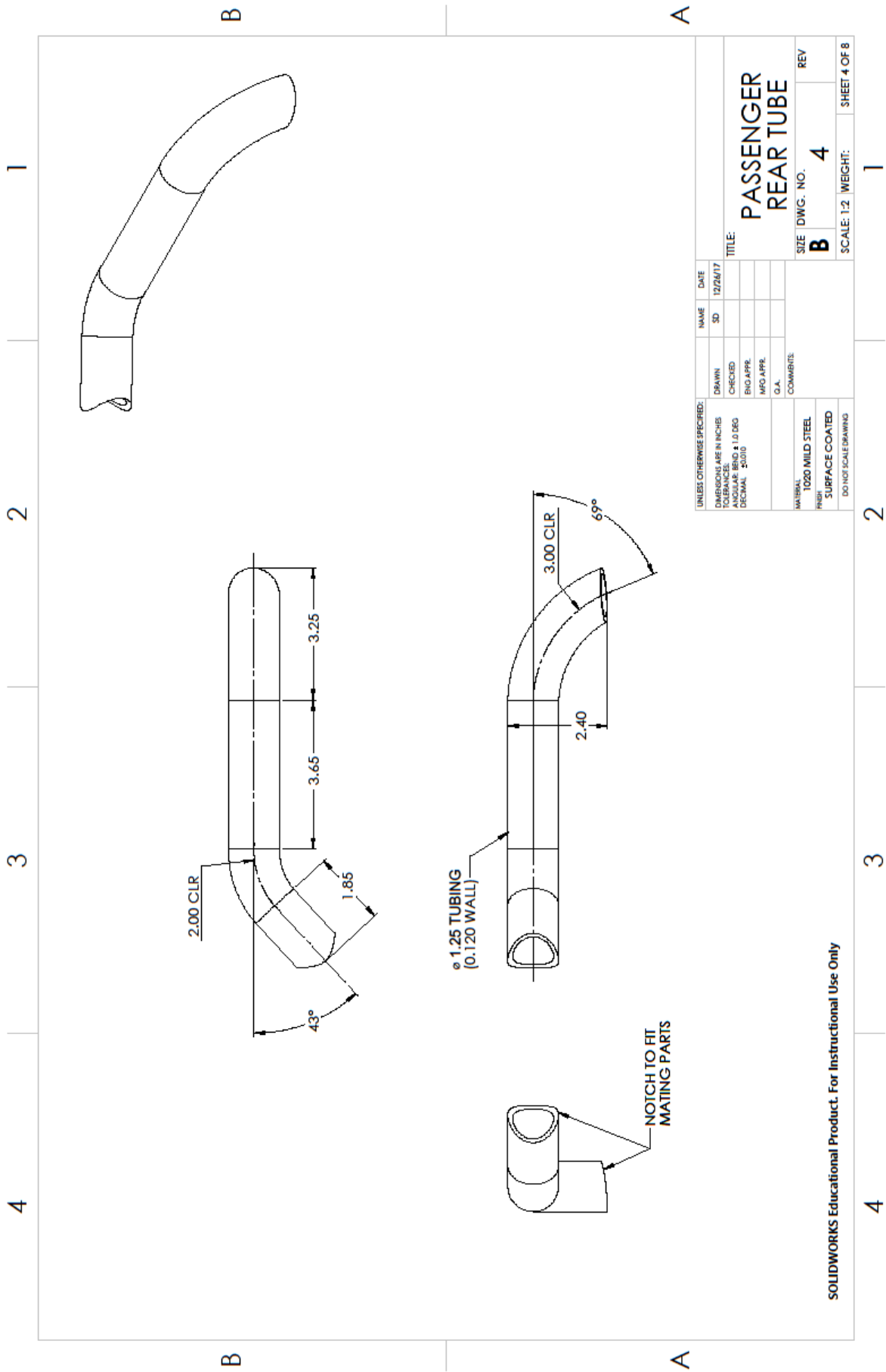
SCALE: 1:10 WEIGHT: SHEET 2 OF 8

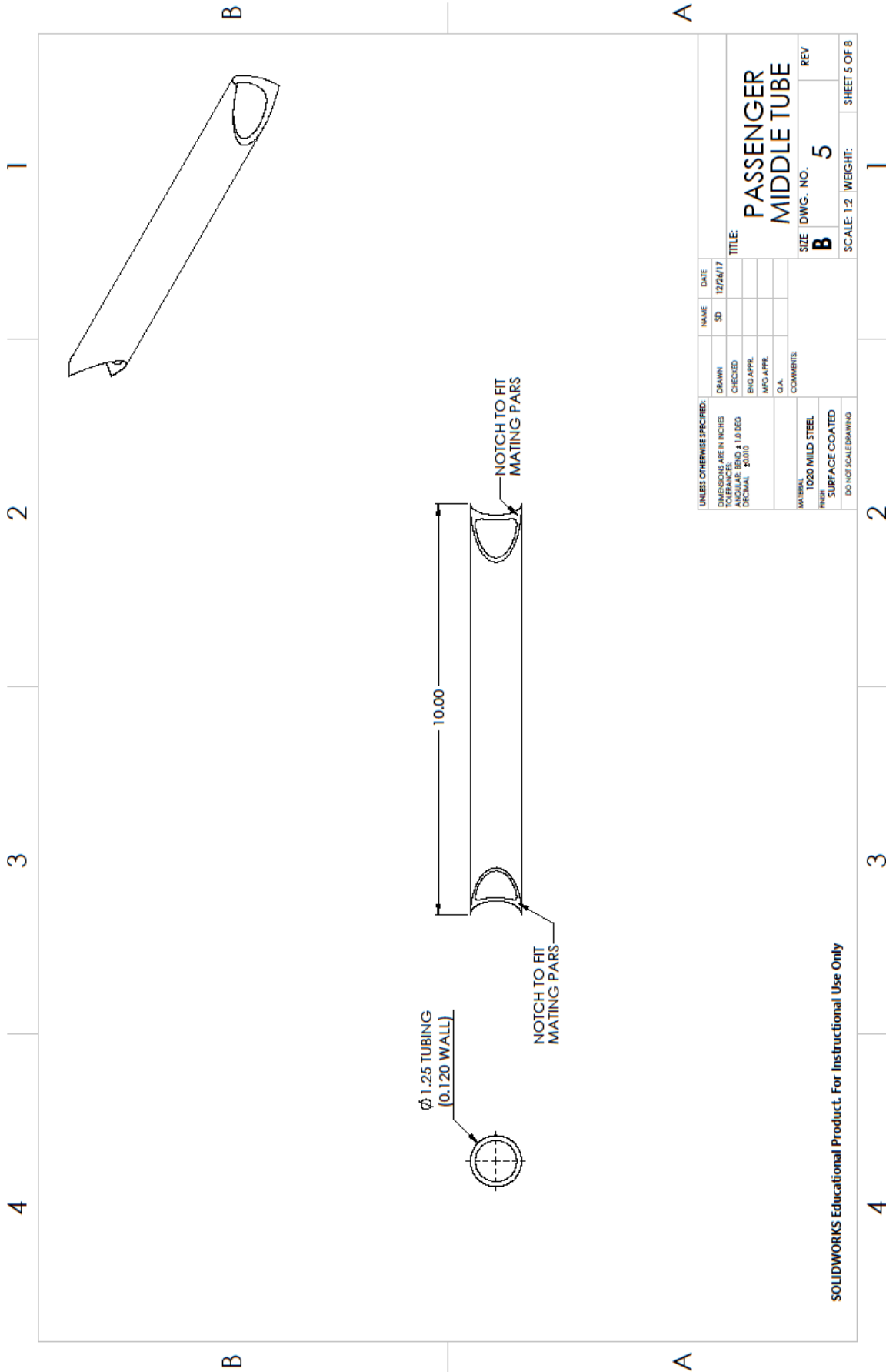
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|                             |  |            |              |
|-----------------------------|--|------------|--------------|
| UNLESS OTHERWISE SPECIFIED: |  | NAME       | DATE         |
| DIMENSIONS ARE IN INCHES    |  | SD         | 12/24/17     |
| TOLERANCES:                 |  | DRAWN      |              |
| FRACTIONS ± .015            |  | CHECKED    |              |
| DECIMALS ± .010             |  | ENG APPR.  |              |
| ANGLES ± .5000              |  | MFG APPR.  |              |
|                             |  | G.A.       |              |
|                             |  | COMMENTS:  |              |
| MATERIAL:                   |  | SIZE       | DWG. NO.     |
| 1020 MILD STEEL             |  | B          | 3            |
| FINISH:                     |  | REV        |              |
| SURFACE COATED              |  |            |              |
| DO NOT SCALE DRAWING        |  | SCALE: 1:2 | WEIGHT:      |
|                             |  |            | SHEET 3 OF 8 |

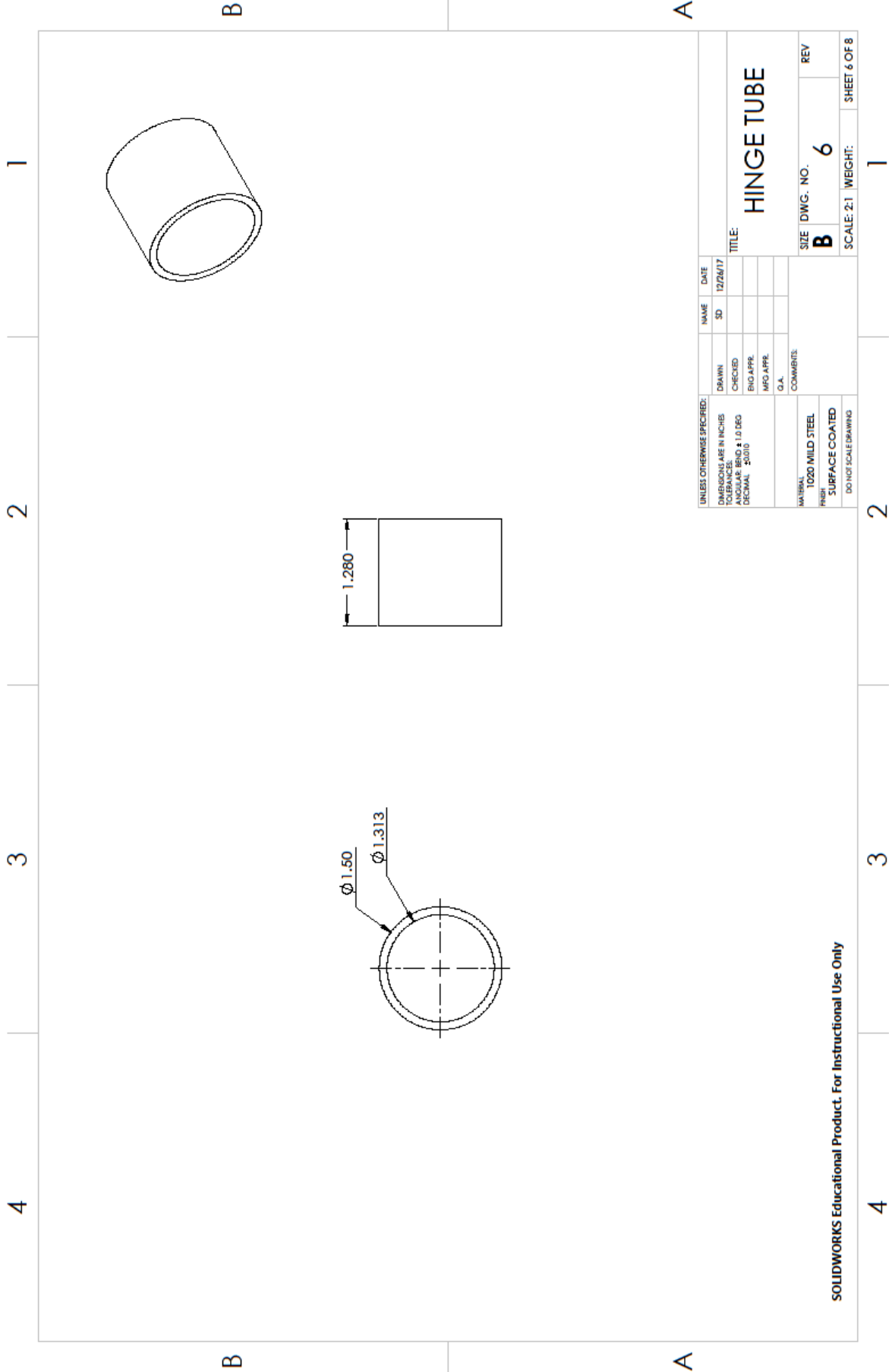
SOLIDWORKS Educational Product. For Instructional Use Only



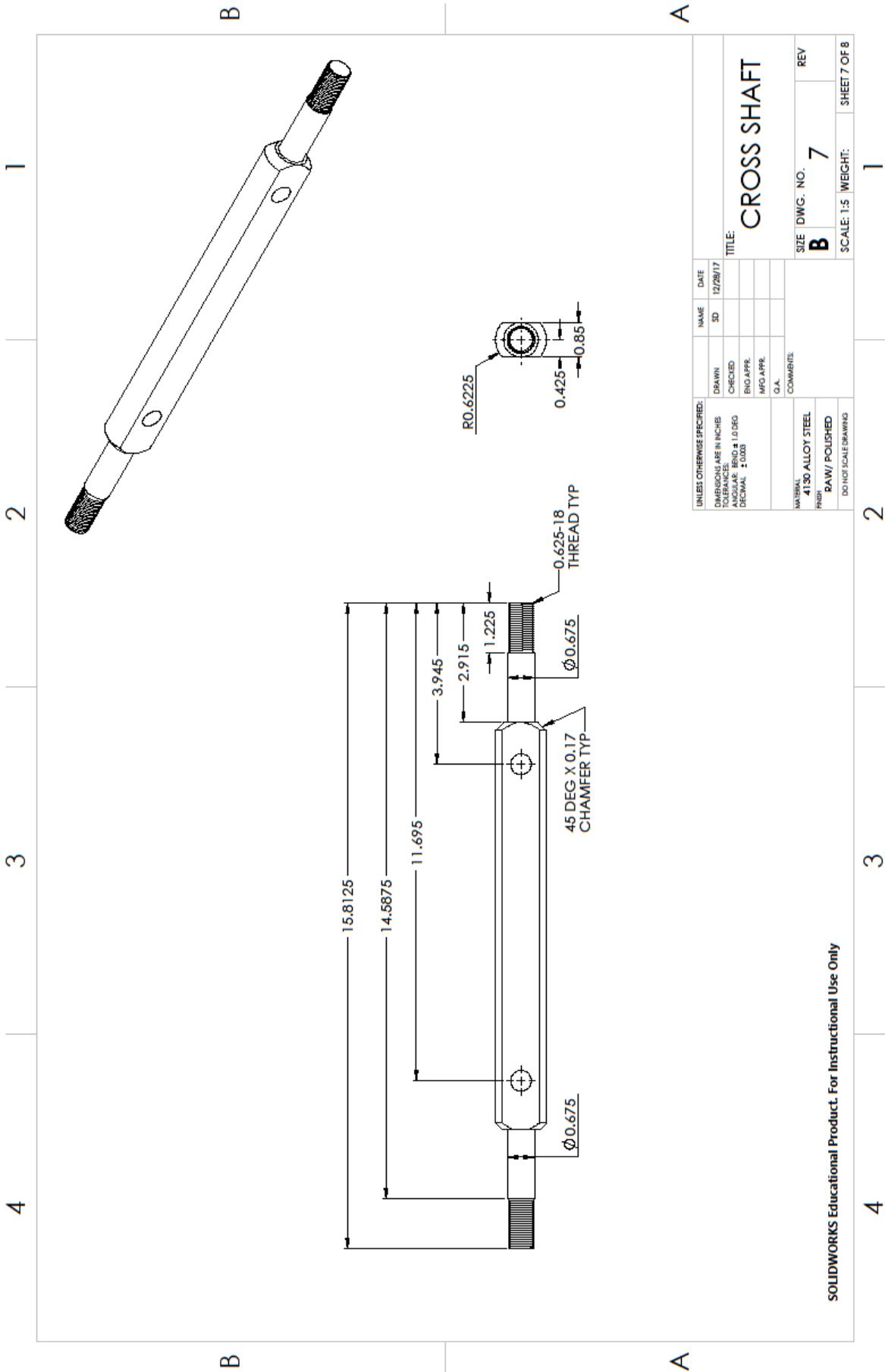


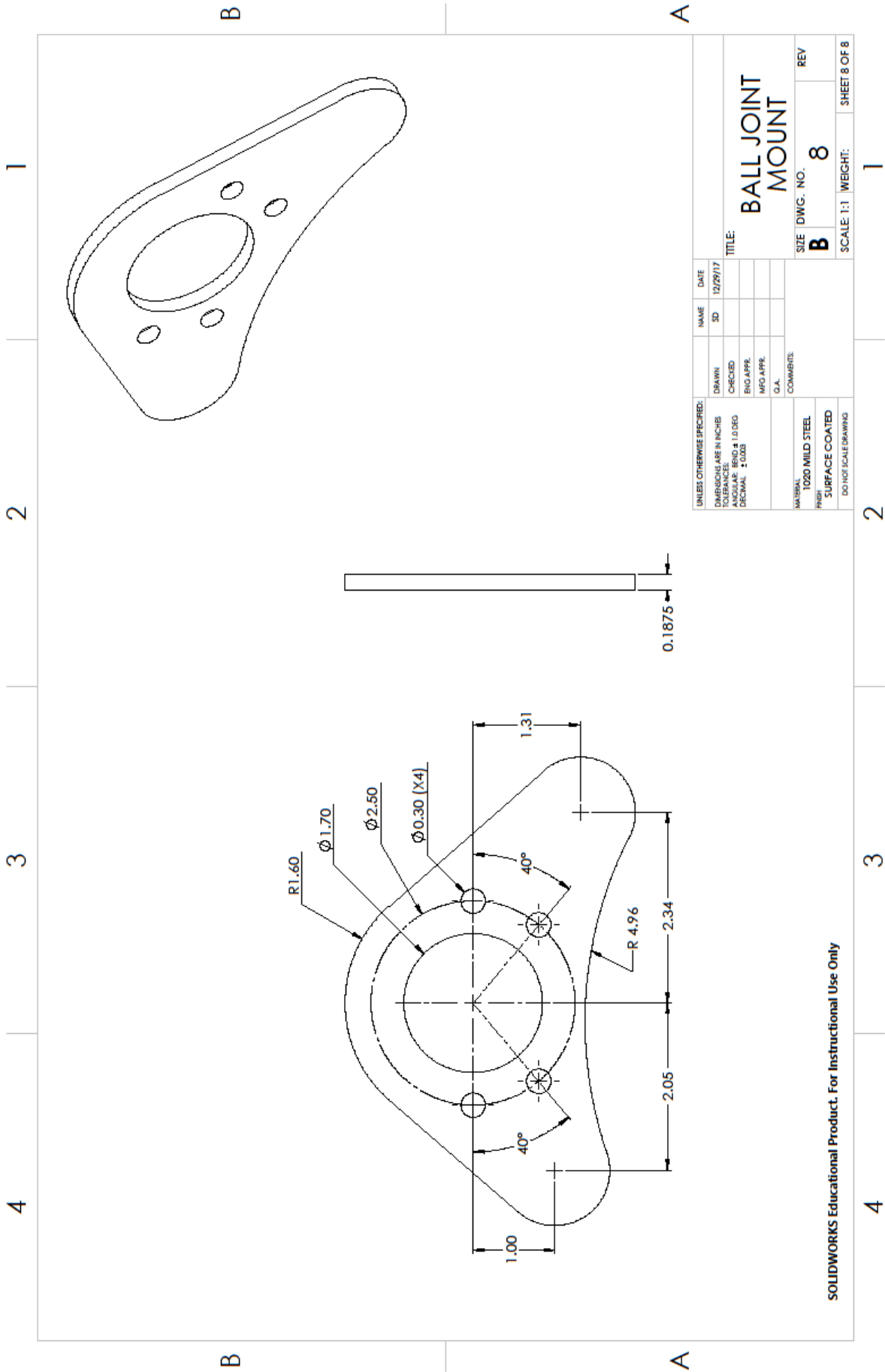
| UNLESS OTHERWISE SPECIFIED:            |    | NAME     | DATE         |
|--|----|----------|--------------|
| DRAWN                                  | SD | 12/26/17 |              |
| CHECKED                                |    |          |              |
| ENG. APPL.                             |    |          |              |
| MFG. APPL.                             |    |          |              |
| G.A.                                   |    |          |              |
| COMMENTS:                              |    |          |              |
| DIMENSIONS ARE IN INCHES               |    |          |              |
| TOLERANCES UNLESS OTHERWISE SPECIFIED: |    |          |              |
| FRACTIONS ± 0.005                      |    |          |              |
| DECIMAL ± 0.010                        |    |          |              |
| HOLE POSITION ± 0.010                  |    |          |              |
| MATERIAL: 1020 MILD STEEL              |    |          |              |
| FINISH: SURFACE COATED                 |    |          |              |
| DO NOT SCALE DRAWING                   |    |          |              |
| TITLE:                                 |    | SIZE     | REV          |
| PASSENGER MIDDLE TUBE                  |    | B        | 5            |
| SCALE: 1:2                             |    | WEIGHT:  | SHEET 5 OF 8 |

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### LOADING CONDITIONS

Forces on the a-arms are caused by the frictional force of the tire. The maximum friction force will occur on dry pavement while using a sport tire. This friction force is static friction because the tire is rolling (12). This static friction is at a maximum when the brakes are depressed to the point right before tire lock up occurs (12). Once tire lock up occurs the frictional force acting on the car becomes kinetic friction which is less than static friction (12). The coefficient of friction for such tire is around 0.9 ( $\mu_s=0.9$ ). The normal force on the tire is due to the weight of the car. Each front tire has 1000lbs of vehicle weight it must support. Therefore, the frictional force acting on the tire during max braking before lock-up would be  $\gamma = \mu_s * N = 0.9 * 1000 = 900lbs$ . Half of this force would be directed to the lower a-arm and the other half would be directed to the upper a-arm. Therefore, the max force the upper a-arm will see is 450 lbs. This load is a static load because it is applied gradually as the break pedal is pressed by the driver. This force would be directed into the a-arm differently depending on the angle at which the tires are turned during braking. Each a-arm can be broken into two members. Member A (rear tube) and member B (front tube). For the rough hand calculations, the maximum force on member A or B can be assumed to occur when the wheels are turned so the forces are in line with the member. For the solid model FEA there will be three loading conditions considered. In line with the front member (hard cornering), in line with the rear member (hard cornering), and straight back (tires straight). The force is directed through the ball joint which is attach to the a-arm using four bolt holes. The tube joints are constrained using a fixed hinge. This allows rotation only. The ball joint mounting plate is constrained using a roller/slide. This allows movement in the x and z but not the y axis. The images below show the three loading conditions used in the FEA analysis.

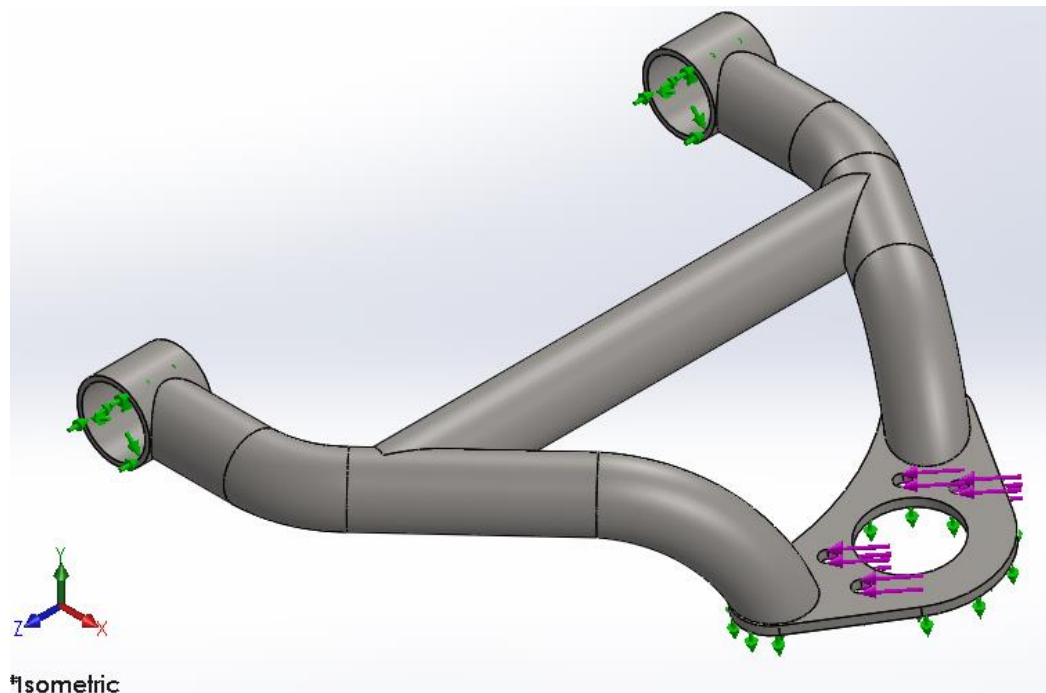
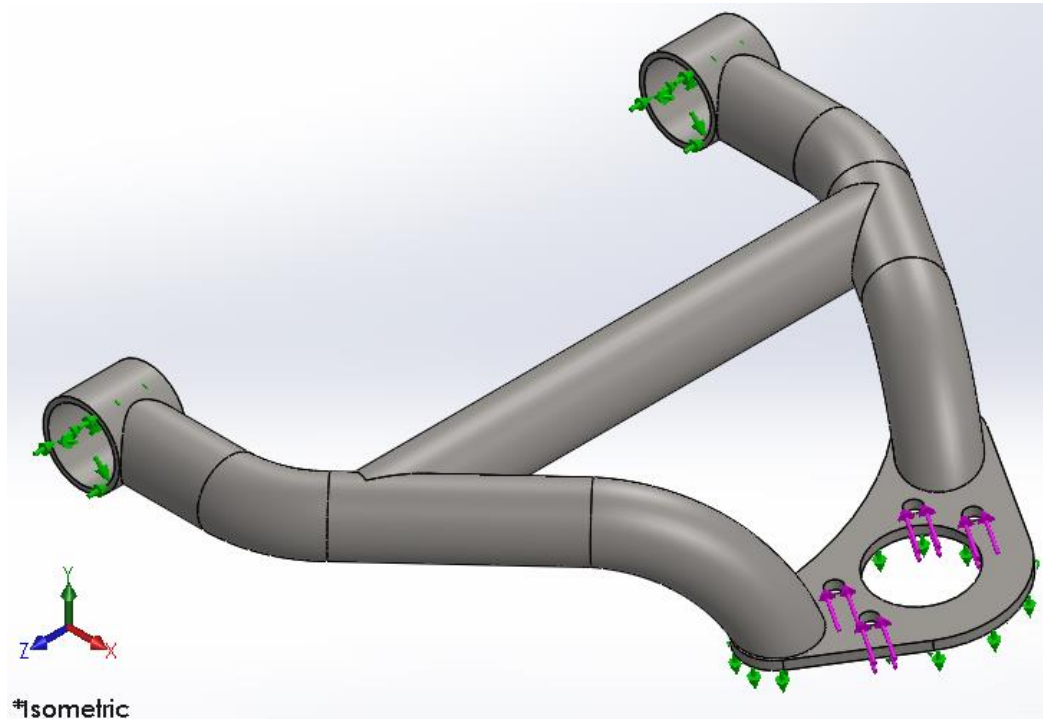
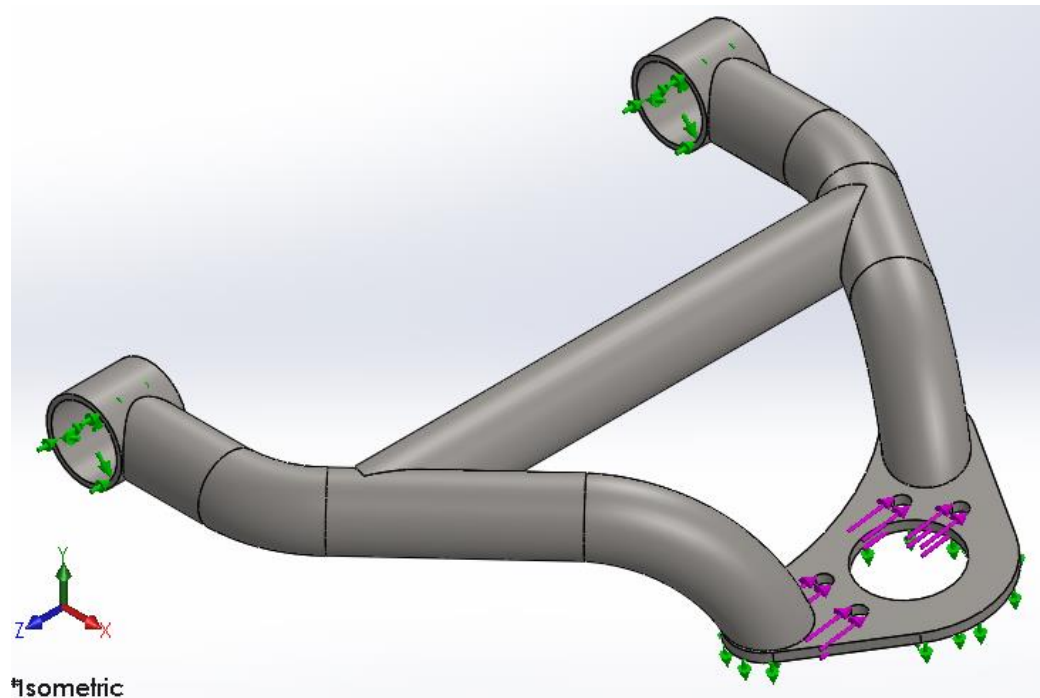


Figure 11: Load Conditions (in line with front member)



\*Isometric

Figure 12: Loading Conditions (in line with rear member)



\*Isometric

Figure 13: Loading Conditions (straight back)

**DESIGN ANALYSIS**

**Member B: Front Drivers/ Rear Passenger**

Material size: 1.25 tubing (0.120 wall)

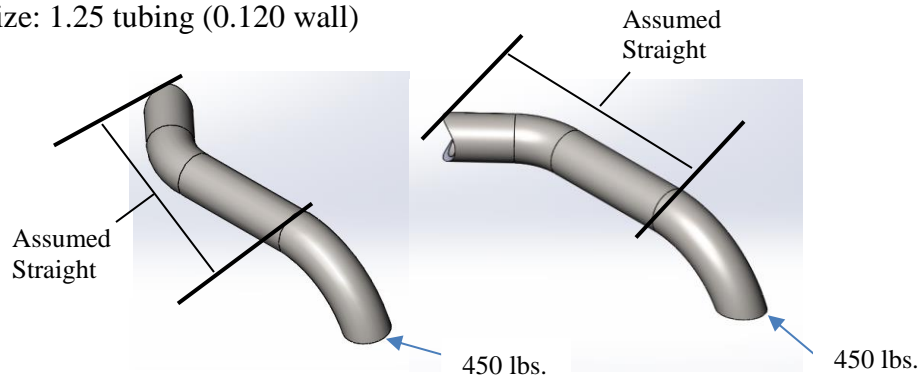


Figure 14: Drivers Tubes

Straight portion:

$$\sigma = \frac{F}{A} \quad A = \pi R^2 - \pi r^2$$

$$\sigma = \frac{450}{1.704} \quad A = \pi 1.25^2 - \pi 1.01^2$$

$$\sigma = 264.08 \text{ psi} \quad A = 1.704 \text{ in}^2$$

Curved portion:

$$\sigma_{inside} = \left( \frac{M}{eA} * \frac{C_i}{r_i} \right) + \frac{F}{A}$$

$$\sigma_{outside} = \left( \frac{-M}{eA} * \frac{C_o}{r_o} \right) + \frac{F}{A}$$

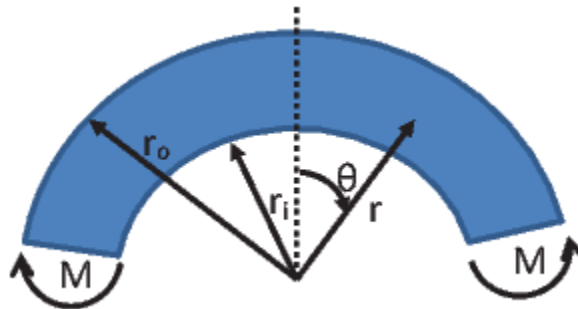


Figure 15: Bending Example

$r_n$  = neutral axis       $e$  = neutral axis shift distance       $R$  = radius of tubing  
 $C_i$  = distance from neutral axis to inside       $C_o$  = distance from neutral axis to outside

$$r_n = \frac{R^2}{2(r - \sqrt{r^2 - R^2})} = \frac{0.625^2}{2(3 - \sqrt{3^2 - 0.625^2})} = 2.967 \text{ in}$$

$$M = F * r = 450 * 3 = 1350 \text{ in} * \text{lb}$$

$$e = r - r_n = 3 - 2.967 = 0.033 \text{ in}$$

$$C_i = R - e = 0.625 - 0.033 = 0.592 \text{ in}$$

$$C_i = R + e = 0.625 + 0.033 = 0.658 \text{ in}$$

$$r_i = r - R = 3 - 0.625 = 2.375 \text{ in}$$

$$r_o = r + R = 3 + 0.625 = 3.625 \text{ in}$$

$$\sigma_{inside} = \left( \frac{M}{eA} * \frac{C_i}{r_i} \right) + \frac{F}{A}$$

$$\sigma_i = \left( \frac{1350}{0.033 * 1.704} * \frac{0.592}{2.375} \right) + 264.7$$

$$\sigma_i = 6248.31 \text{ psi}$$

$$\sigma_{outside} = \left( \frac{-M}{eA} * \frac{C_o}{r_o} \right) + \frac{F}{A}$$

$$\sigma_o = \left( \frac{-1350}{0.033 * 1.704} * \frac{0.658}{3.625} \right) + 264.7$$

$$\sigma_o = -4093.73 \text{ psi}$$

**Member A: Rear Drivers/ Front Passenger**

Material size: 1.25 tubing (0.120 wall)

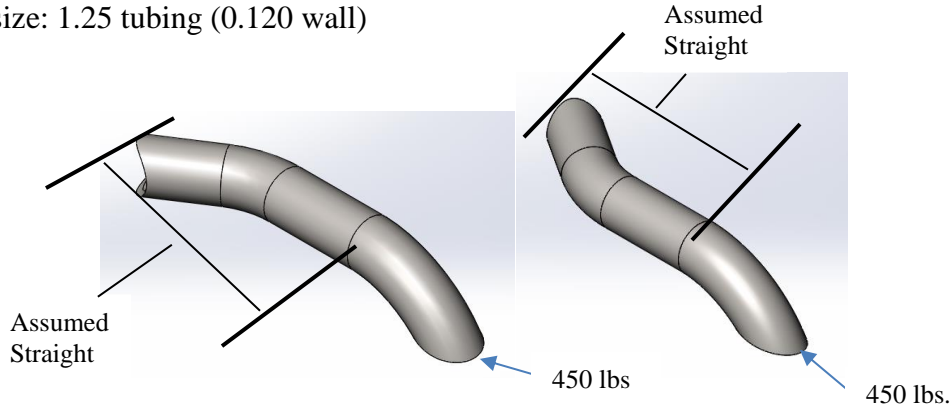


Figure 16: Passenger Tubes

Straight portion:

$$\sigma = \frac{F}{A}$$

$$A = \pi R^2 - \pi r^2$$

$$A = \pi 1.25^2 - \pi 1.01^2$$

$$\sigma = \frac{450}{1.704}$$

$$A = 1.704 \text{ in}^2$$

$$\sigma = 264.08 \text{ psi}$$

Curved portion:

$$\sigma_{inside} = \left( \frac{M}{eA} * \frac{C_i}{r_i} \right) + \frac{F}{A}$$

$$\sigma_{outside} = \left( \frac{-M}{eA} * \frac{C_o}{r_o} \right) + \frac{F}{A}$$

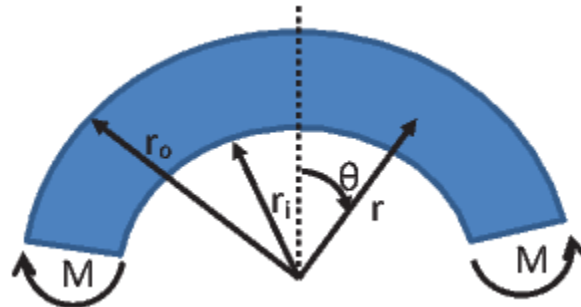


Figure 17: Bending Example

$r_n$  = neutral axis       $e$  = neutral axis shift distance       $R$  = radius of tubing  
 $C_i$  = distance from neutral axis to inside       $C_o$  = distance from neutral axis to outside

Actual CLR=3

CLR=2.7 (compensates for less than 90deg curve use)

$$r_n = \frac{R^2}{2(r - \sqrt{r^2 - R^2})} = \frac{0.625^2}{2(2.7 - \sqrt{2.7^2 - 0.625^2})} = 2.663in$$

$$M = F * r = 450 * 2.7 = 1215 in * lb$$

$$e = r - r_n = 2.7 - 2.663 = 0.0367in$$

$$C_i = R - e = 0.625 - 0.0367 = 0.588in$$

$$C_o = R + e = 0.625 + 0.0367 = 0.6617in$$

$$r_i = r - R = 2.7 - 0.625 = 2.075in$$

$$r_o = r + R = 2.7 + 0.625 = 3.325in$$

$$\sigma_{inside} = \left( \frac{M}{eA} * \frac{C_i}{r_i} \right) + \frac{F}{A}$$

$$\sigma_i = \left( \frac{1215}{0.0367 * 1.704} * \frac{0.588}{2.075} \right) + 264.7$$

$$\sigma_i = 5769.62 psi$$

$$\sigma_{outside} = \left( \frac{-M}{eA} * \frac{C_o}{r_o} \right) + \frac{F}{A}$$

$$\sigma_o = \left( \frac{-1215}{0.0367 * 1.704} * \frac{0.6617}{3.325} \right) + 264.7$$

$$\sigma_o = -3602.35 psi$$

### Ball Joint Mount

Force: 450lb

Area of one hole: 0.1767 in<sup>2</sup>

Maximum part distortion is assumed to occur during a straight back force

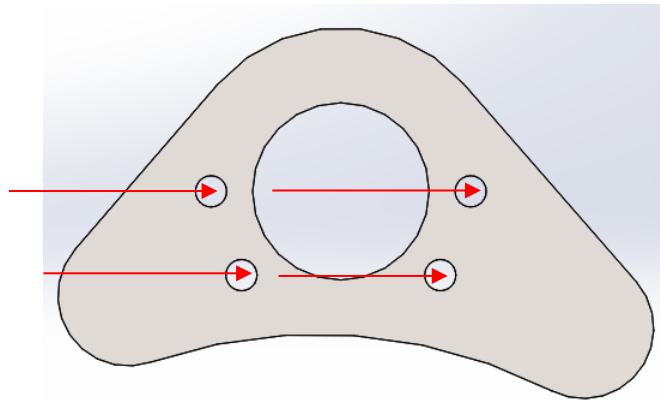


Figure 18: Ball Joint Mount

$$Area = \left( \frac{0.1767 * 4}{2} \right) * \frac{3}{16} = 0.3534 * \frac{3}{16} = 0.0663 in^2$$

$$\sigma = \frac{F}{A} = \frac{450}{0.0663} = 6791.17 psi$$

## FINITE ELEMENT ANALYSIS

### Driver

The front member loading condition for the driver side is shown in the image below. The maximum stress occurred in member B (front member) at 5,862 psi. Maximum displacement at this load is just under 2 thousandths.



Figure 19: FEA Driver Front Member

The rear member loading condition for the driver side is shown in the image below. The maximum stress occurred in member A (rear member) at 5,208 psi. Maximum displacement at this load is just over 1 thousandths.

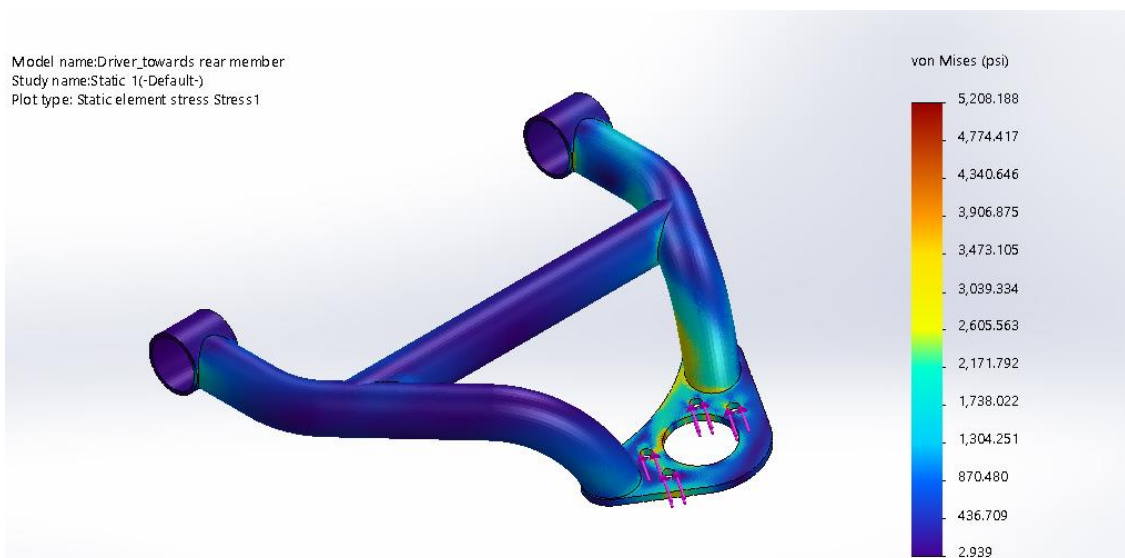


Figure 20: FEA Driver Rear Member

The straight back loading condition for the driver side is shown in the image below. The maximum stress occurred in ball joint mount at 7,005 psi. Both member A and B had stress approaching 7,000 psi at the tube hinge connections. Maximum displacement at this load is 2 thousandths.

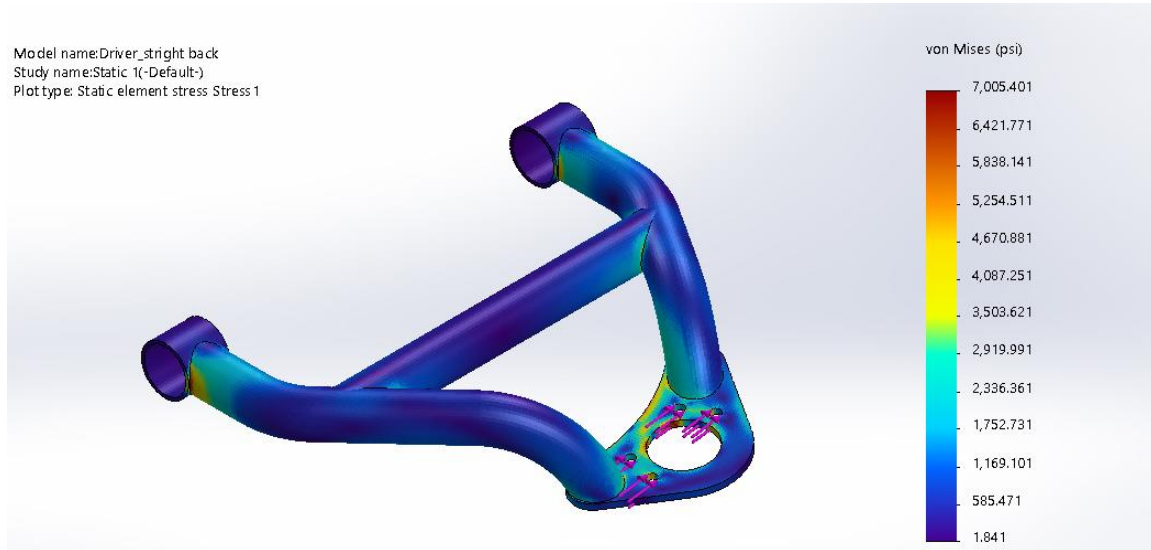


Figure 21: FEA Driver Straight Back

**Passenger**

The front member loading condition for the driver side is shown in the image below. The maximum stress occurred in member B (front member) at 5,901 psi. Maximum displacement at this load is 2 thousandths.

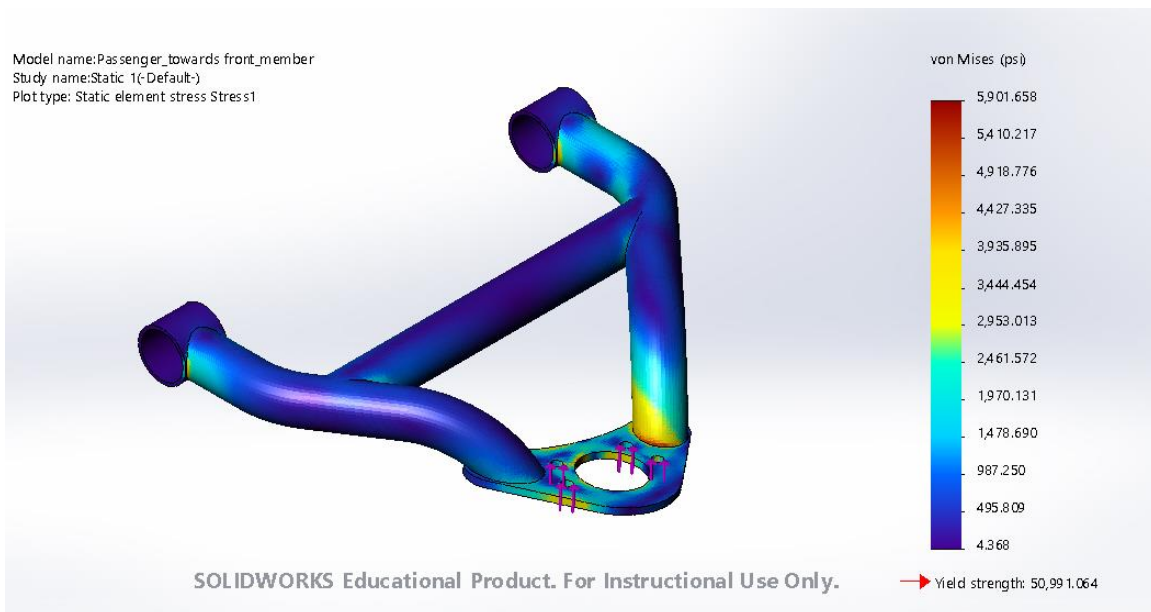


Figure 22: FEA Passenger Front Member

The front member loading condition for the driver side is shown in the image below. The maximum stress occurred in member B (front member) at 4,944 psi. Maximum displacement at this load is 1 thousandths.

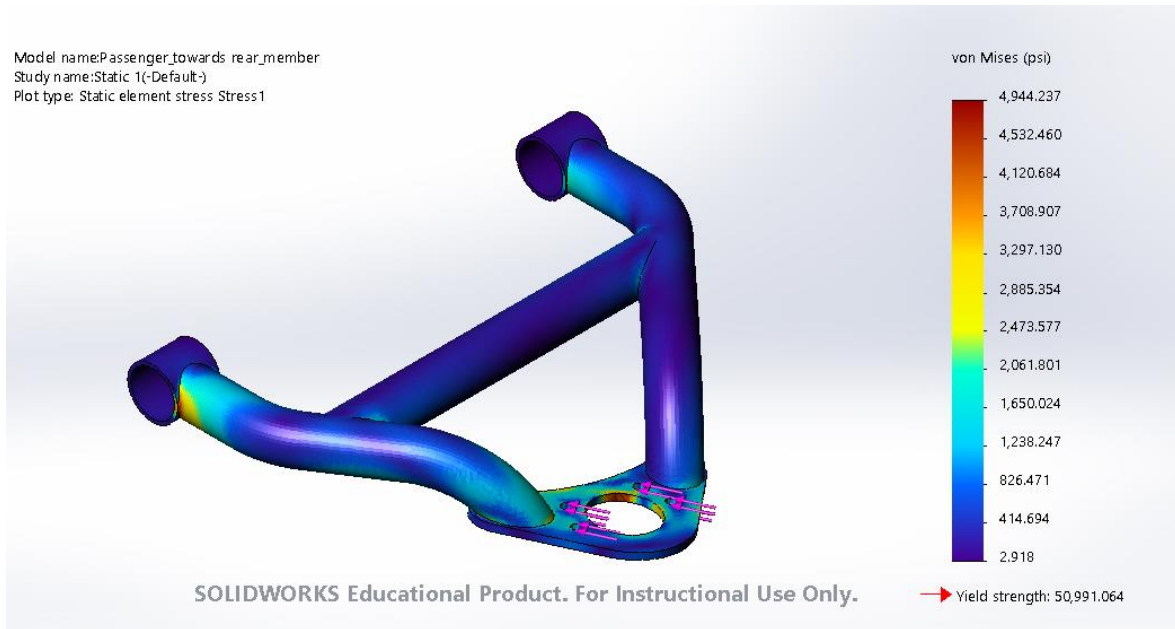


Figure 23: FEA Passenger Rear Member

The straight back loading condition for the driver side is shown in the image below. The maximum stress occurred in ball joint mount at 6,926 psi. Both member A and B had stress approaching 6,900 psi at the tube hinge connections. Maximum displacement at this load is 2 thousandths.

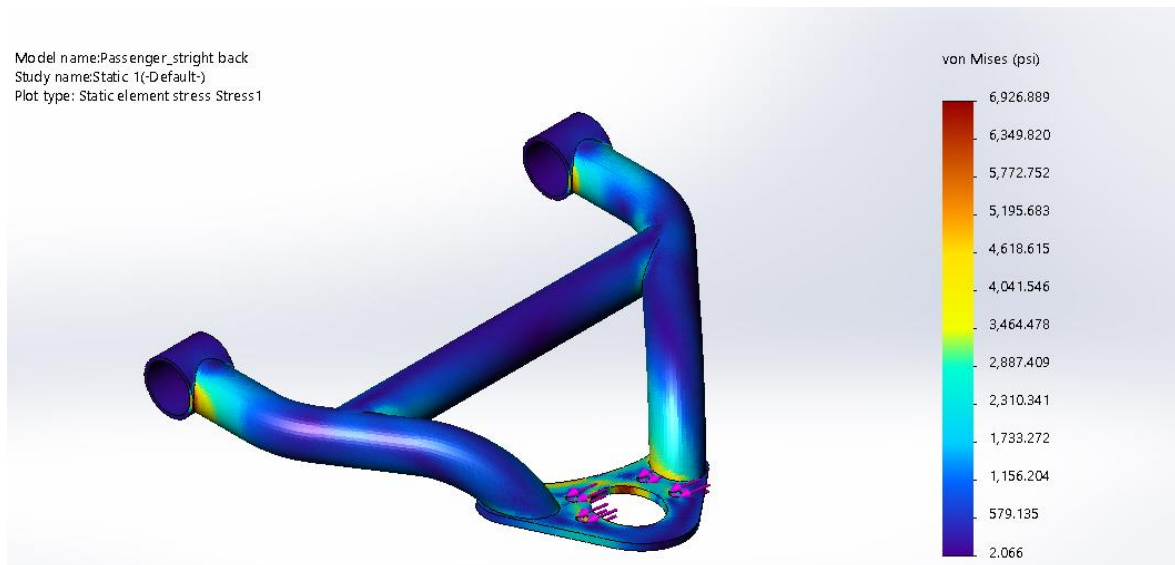


Figure 24: FEA Passenger Straight Back

The about design section shows a max stress of 6248psi in the tubing members and 6,791 in the ball joint mount. A max stress of around 7,000 psi in the tubing members and 7,005 psi in the ball joint mount was determine using an FEA software. The rough hand calculations match the finite element analysis well. These calculations where used as a rough starting point for material selection and proof of concept.

### ***FACTORS OF SAFETY OF CONCERN***

There a-arms are a crucial part to the cars suspension a frame structure. A failure would most certainly cause loss of control of the vehicle resulting in a wreck. For a static load application like this case a design factor of safety of three is called for (11). The system needs to be at least three times stronger than it needs to be to account for any errors in the FEA model or hand calculations. The factor of safety is also accounts for any unattended loads like hitting a large pot hole in the road. The largest stress seen in the a-arms is 7,005 psi. The design stress would then be as follows:  $S_d = f_s * S_m = 3 * 7,005 = 21,015 \text{ psi}$ .

### ***MATERIAL SELECTION***

Common material for this application includes 4130 alloy steel and 1020 cold rolled steel. A majority of the current state of the art products use 4130 while the rest used 1020. The tubing (both 4130 and 1020) is produced by cold drawing it over a mandrel to produce a strong seamless tube. Other material grades and manufacturing options are available but are uncommon for this application. The table below shows material selection process.

Table 7: Material Selection

| Criteria             | Wt. | 4130 |      | 1020 |      |
|----------------------|-----|------|------|------|------|
| Strength             | 20  | 4    | 0.8  | 3    | 0.6  |
| Elastic Strength     | 20  | 4    | 0.8  | 4    | 0.8  |
| Stiffness            | 15  | 4    | 0.6  | 3    | 0.45 |
| Corrosion Resistance | 10  | 4    | 0.4  | 2    | 0.2  |
| Cost                 | 25  | 1    | 0.25 | 3    | 0.75 |
| Weldability          | 10  | 2    | .2   | 4    | .4   |
| Total:               |     | 3.05 |      | 3.2  |      |

Selection: 1020 Cold Rolled

1020 cold rolled steel was chosen due to its lower cost and excellent weldability. The chosen material was a yield strength of 61740 psi and a tensile strength of 74988 psi. Chosen material size is listed above in the drawing/ design section. The high yield strength of the material gives an actual factor of safety of 8.8, which is well over the design factor of safety of 3 and the design yield strength of 21,015 psi. Smaller sized material or material with less strength could have been used to closely match the design stress but the product would look under designed when compared to the current state of the art products.

***BILL OF MATERIALS***

Table 8: Drivers BOM

| <b>Item NO.</b> | <b>Part NO.</b> | <b>Description</b>                | <b>QTY.</b> |
|-----------------|-----------------|-----------------------------------|-------------|
| 1               | 001-D/P         | Hinge Tube                        | 2           |
| 2               | 002-D           | Drivers Front Tube                | 1           |
| 3               | 003-D           | Drivers Rear Tube                 | 1           |
| 4               | 004-D           | Drivers Middle Tube               | 1           |
| 5               | 005-D/P         | Ball Joint Mounting Plate         | 1           |
| 6               | 006-D/P         | Bushings                          | 2           |
| 7               | 007-D/P         | Cross Shaft                       | 1           |
| 8               | 008-D/P         | $\frac{3}{4}$ Narrow Flat Washers | 2           |
| 9               | 009-D/P         | 5/8-18 Hex Nut                    | 2           |
| 10              | 010-D/P         | Ball Joint                        | 1           |
| 11              | 011-D/P         | $\frac{1}{4}$ -18 Hex Bolt        | 4           |
| 12              | 012-D/P         | $\frac{1}{4}$ -18 Hex Nut         | 4           |

Table 9: Passengers BOM

| <b>Item NO.</b> | <b>Part NO.</b> | <b>Description</b>                | <b>QTY.</b> |
|-----------------|-----------------|-----------------------------------|-------------|
| 1               | 001-D/P         | Hinge Tube                        | 2           |
| 2               | 002-P           | Passengers Front Tube             | 1           |
| 3               | 003-P           | Passengers Rear Tube              | 1           |
| 4               | 004-P           | Passengers Middle Tube            | 1           |
| 5               | 005-D/P         | Ball Joint Mounting Plate         | 1           |
| 6               | 006-D/P         | Bushings                          | 2           |
| 7               | 007-D/P         | Cross Shaft                       | 1           |
| 8               | 008-D/P         | $\frac{3}{4}$ Narrow Flat Washers | 2           |
| 9               | 009-D/P         | 5/8-18 Hex Nut                    | 2           |
| 10              | 010-D/P         | Ball Joint                        | 1           |
| 11              | 011-D/P         | $\frac{1}{4}$ -18 Hex Bolt        | 4           |
| 12              | 012-D/P         | $\frac{1}{4}$ -18 Hex Nut         | 4           |

**PROJECT MANAGEMENT***BUDGET, PROPOSED/ACTUAL*

Table 10: Material Budget

| Material           | Proposed (\$) | Actual (\$) |
|--------------------|---------------|-------------|
| Tubing/ Flat Stock | 150           | 75          |
| Ball Joints        | 50            | 30          |
| Bushings           | 40            | 16          |
| Cross Shaft        | 45            | 150         |
| Hardware           | 30            | 0           |
| <b>Total:</b>      | <b>315</b>    | <b>271</b>  |

Table 11: One Time Tooling Cost Budget

| Tooling       | Proposed (\$) | Actual (\$) |
|---------------|---------------|-------------|
| Tubing Bender | 400           | 550         |
| Tig Welder    | 1200          | 1500        |
| Fixture       | 400           | 300         |
| <b>Total:</b> | <b>2000</b>   | <b>2350</b> |

*SCHEDULE, PROPOSED /ACTUAL*

Table 12: Schedule

| Shawn Davin          | 8/24/2017 | 8/31/2017 | 9/7/2017 | 9/14/2017 | 9/21/2017 | 9/28/2017 | 10/5/2017 | 10/12/2017 | 10/19/2017 | 10/26/2017 | 11/2/2017 | 11/9/2017 | 11/16/2017 | 11/23/2017 | 11/30/2017 | 12/7/2017 | 12/14/2017 | 12/21/2017 | 12/28/2017 | 1/4/2018 | 1/11/2018 | 1/18/2018 | 1/25/2018 | 2/1/2018 | 2/8/2018 | 2/15/2018 | 2/22/2018 | 3/1/2018 | 3/8/2018 | 3/15/2018 | 3/22/2018 | 3/29/2018 | 4/5/2018 | 4/12/2018 | 4/19/2018 |  |  |  |  |  |
|----------------------|-----------|-----------|----------|-----------|-----------|-----------|-----------|------------|------------|------------|-----------|-----------|------------|------------|------------|-----------|------------|------------|------------|----------|-----------|-----------|-----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|-----------|----------|-----------|-----------|--|--|--|--|--|
| <b>Tasks</b>         |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| <b>Design 1</b>      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Design Draft         |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Finial Design Report |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| <b>Design 2</b>      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Proof of Design      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Concept Selection    |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| 3D Model             |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Design Presentation  |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| <b>Design 3</b>      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Manufacture          |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Test                 |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Tech Expo            |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
| Finial Presentation  |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |
|                      |           |           |          |           |           |           |           |            |            |            |           |           |            |            |            |           |            |            |            |          |           |           |           |          |          |           |           |          |          |           |           |           |          |           |           |  |  |  |  |  |

## FABERICATION AND ASSEMBLY

### *FIXTURE FABRICATION*

The fabrication process started with detailed caster/ camber measurements of existing a-arms using a specialized tool. This tool is a digital caster /camber gauge from Longacre. It mounts to the rim of a car and caster/camber is displayed on the digital readout. The starting caster measurements of my car was  $+1.2^\circ$  caster for the drivers and  $+1.0^\circ$  caster for the passenger's side. The starting camber measurements of my car was  $-0.9^\circ$  camber for the drivers and  $+1.0^\circ$  camber for the passenger's side. The image below shows the gauge mounted to the tire.



Figure 25: Caster/Camber Measurement

Adding shims to the a-arm mounting locations can move the upper ball joint and allow for adjustments in caster and camber. Removing all the shims from the front mount and adding as many shims to the rear mount as possible will achieve the desired result. When all the front shims were removed and an 0.850" shim pack was added to the rear mount caster measurements of  $+2.8^\circ$  and  $+3.1^\circ$  and camber measurements of  $-0.5^\circ$  and  $-0.2^\circ$  were achieved for both drivers and passengers respectively. These measurements were in the desired range, but the a-arms are not useable for any purpose other than taking measurements because the a-arms to hit the steering and engine due the extreme shim pack. The image below shows how adding shims to the mounting location will change caster and camber.

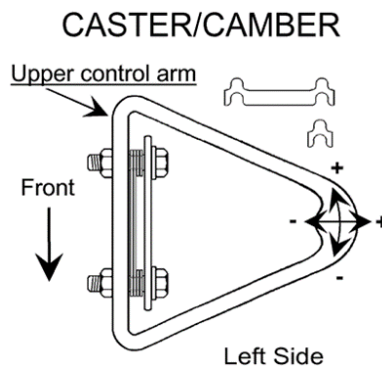


Figure 26: Caster/Camber Adjustment

The next step was to disassembly the original suspension from the car. The upper a-arm were then used to construct a fixture. First two square frames were constructed from simple angle iron. Then two 1x1 square tubes where welded to the frames to simulate the mounting points on the frame of the car. These 1x1 square tubes where then braced with round bar to keep them from flexing. Holes were drilled in these 1x1 square tubes to allow a bolt to be fed through. The stock a -arms were then mounted two their respective fixture using the 0.850” shim pack on the rear mount. The finial step was to weld in a center post for the ball joint mount to bolt to. This fixture aligns the two mounting holes and the desired ball joint location to get the same geometry for each constructed a-arm. Below is an image of the fixture and an image showing how the a-arm mounted to the fixture.



Figure 27: Fixture



Figure 28: Fixture With A-arm Mounted

### ***MANUFACTURING PROCESS***

The next step in the processes involved bending and cutting tubing to the desired shape. Each a-arm consisted of two side tubes and a middle support tube. This process is done by laying out the dimensions from the solid model onto the straight tubing. The tubing was then bent using a JD<sup>2</sup> model 3 tubing bender and cut to desired length. See images of bent tubing below.



Figure 29: Bent and Cut Tubing

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Next step was to take 1.5" tubing and make two sets of hinge tubes for bushings to be pressed into and for the a-arms to pivot on. The tube was cut to 1.280" using a band saw and then the inside diameter was machined to 1.313" using a lathe. The inside diameter allowed for a 0.005" press fit on the bushing. The ball joint mounting plate was rough cut and holes for the ball joint were drilled using a drill press. Tubes needing notched to mate up to other tubes were notched using an angle grinder. The a-arm was then assembled on the fixture and tack welded together. Note that the new a-arms are assembled without the use of the 0.850" shim pack. By constructing the a-arm without using this shim pack the adjustment is built into the arm itself. This should result in an a-arm that has around +3.0° caster and -0.05° camber without the use of an extreme shim set up. The image below shows that mocked up assembly.



Figure 30: Tack Welded Assembly

After every part was situated right the entire assembly was tig welded together. And the ball joint mounting plate was finish cut per spec. The image below shows the finished assembly for the passenger's side. The drivers and the passengers are the same but opposites.



Figure 31: Welded Assembly

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### ***CORROSION RESISTANCE AND FINIAL ASSEMBLY***

After testing was complete on each a-arm, they were sanded to remove any oxidation from the surface. After the surface was prepped the a-arms were cleaned and painted using a specialty chassis and suspension coating. This coating should prevent any oxidation for the life time of the part. After parts were paint the ball joints were bolted on to complete the assembly. The image below shows the complete a-arm after surface coating.



Figure 32: Corrosion Resistance Coating

### ***INSTALLATION***

After completion of the fabrication and testing processes the a-arms where install on the vehicle to perform farther testing and evaluation. This process consisted of completely removing the front suspension. The upper a-arm where previously removed during a prior stage, so the remaining lower a-arms, springs, and shocks were removed. Then the new upper a-arms, original lower a-arms, springs, and shocks were reinstalled. The new a-arm has full travel without binding and does not contact the frame. Below is an image of the installed system.



Figure 33: Installed A-arm

## TESTING AND PROOF OF DESIGN

### *FORCE VS DISPLACEMENT TEST*

To test the integrity of the fabricated a-arms a hydraulic press was used to apply a load to the a-arms. The a-arms were bolted to the frame of the press just as if they were bolted to the frame of a car. A load was applied at the ball joint simulating the straight back loading condition (most stress seen of any loading condition). A pressure gauge was used to measure load based off the size of the hydraulic cylinder. A dial indicator was placed in the area that the solid model states the greatest displacement would be. The a-arms were then gradually loaded by jacking on the hydraulic ram. The recorded displacement was then compared to the FEA model. The table below shows a 20% difference at 2250lb, but the total displacement is still below the maxim displacement allowed of 0.017". Based off these results the integrity and safety of the a-arms is confirmed.

Table 13: Force Vs Displacement Test Results

| Force (lb) | Estimated Displacement (in) | Actual Displacement Drivers (in) | Actual Displacement Passengers (in) | Highest % Difference of Estimated vs Actual |
|------------|-----------------------------|----------------------------------|-------------------------------------|---|
| 450        | 0.002                       | 0.003                            | 0.003                               | 40.0  |
| 900        | 0.004                       | 0.006                            | 0.005                               | 40.0  |
| 1350       | 0.0059                      | 0.007                            | 0.007                               | 17.1  |
| 1800       | 0.0079                      | 0.010                            | 0.009                               | 23.5  |
| 2250       | 0.0099                      | 0.012                            | 0.011                               | 19.2  |

### *CASTER/ CAMBER MEASUREMENTS*

Before and after caster and camber measurements were taken to see if the new a-arms met their specifications. The goal for this project was to achieve between +3.0° thru +4.0° of caster and between -0.4° thru -0.6° of camber. The table below shows that this goal has been accomplished.

Table 14: Starting Caster/ Camber

|        | Passenger | Drivers |
|--------|-----------|---------|
| Caster | +1.2      | +1.0    |
| Camber | -0.9      | -1.1    |

Table 15: Ending Caster/ Camber

|        | Passenger | Drivers |
|--------|-----------|---------|
| Caster | +3.0      | +3.0    |
| Camber | -0.4      | -0.6    |

***TIRE HEAT/ WEAR TESTING***

Old suspension set ups for bias ply tires cause increased tire wear due to the increased camber or tire lean. The top of the tire leans in causing the inside of the tire to wear more than the outside. This uneven wear can be seen by looking at tire heat. The hotter parts of the tire will indicate how the tire is leaning and wearing. A tire with little or no camber (lean) will have an even heat pattern. The images below shows the tire heat patterns of before and after. The new a-arms resulted in an even pattern which will result in even tire wear.

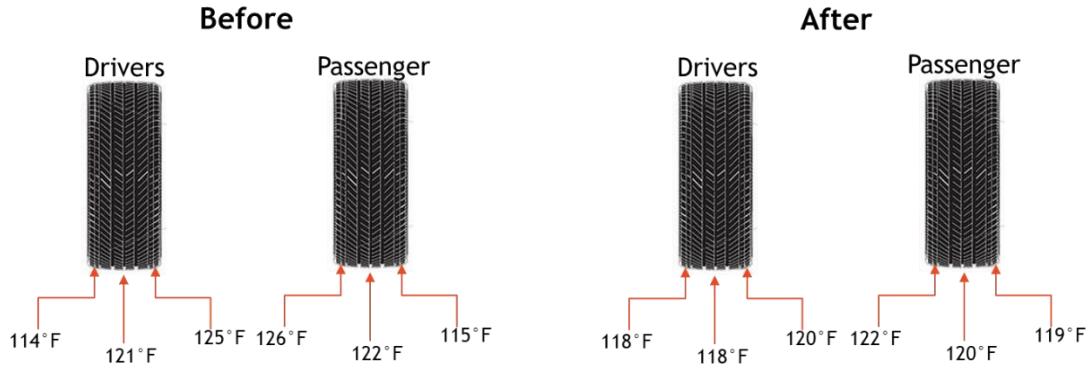


Figure 34: Before and After Tire Heat Comparisons

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# APPENDIX A - SURVEY

## Survey

### 2<sup>nd</sup> Gen Camaro A-arms

This survey results will be used in a University of Cincinnati mechanical engineering senior design project to determine customer needs regarding Camaro A-arms.

**Please circle the answer that applies to you**

1. What is the main use of your Camaro?

Street use      Street with some track      Track use      Drag strip use

2. What geometry best suits you?

caster: 3-4, camber: -0.5 to -1.0      caster: 4-5, camber: -1.5      caster: 7-9, camber: -2 to -3

3. Do you want upper a-arms only or uppers and lowers?

Uppers      Uppers and Lowers

4. What size tires are you running?

15in    16in    17in    18in    19in    20in    21+

5. How often do you adjust your tire alignment?

Just upon install of new suspension      2 to 3 times a year

3 to 5 times a year      More than 5 times a year

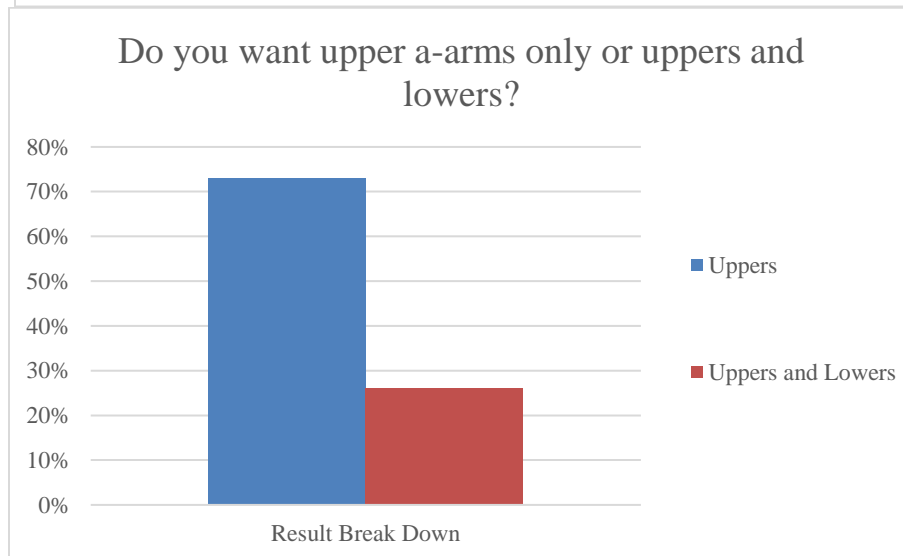
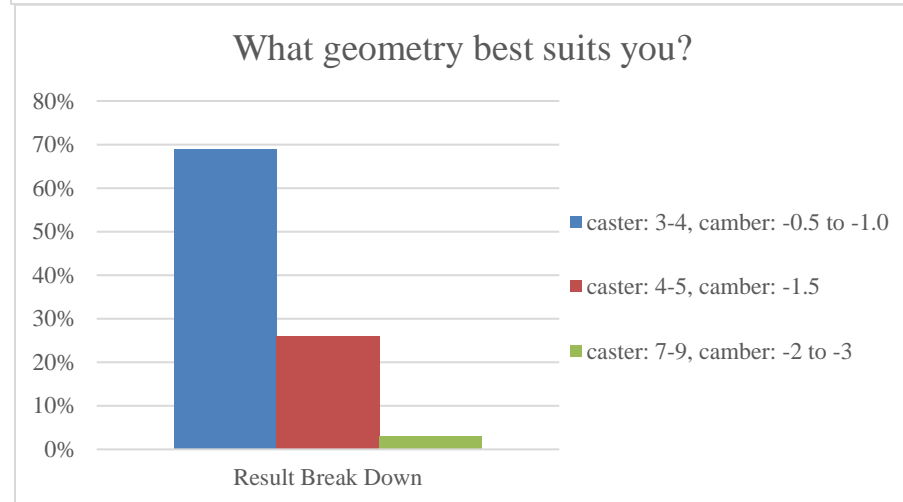
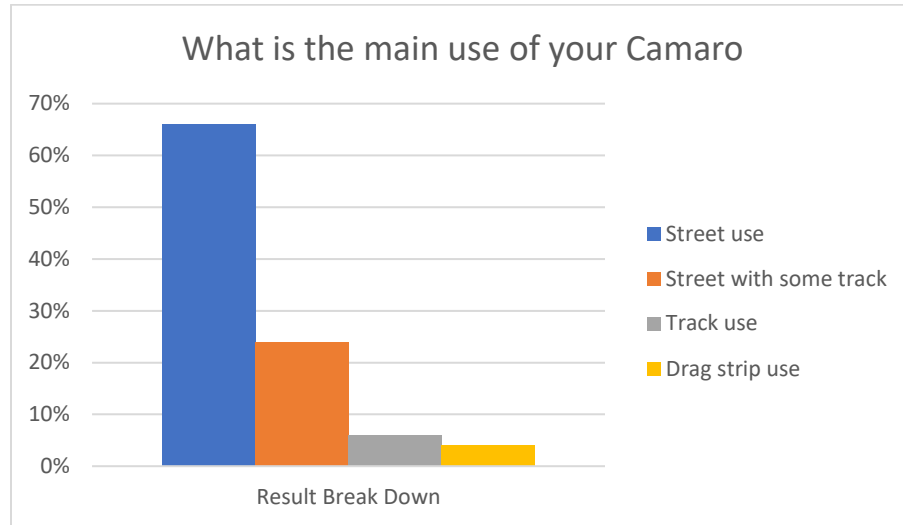
6. How important is tire wear to you?

Not Important      Somewhat Important      Very Important

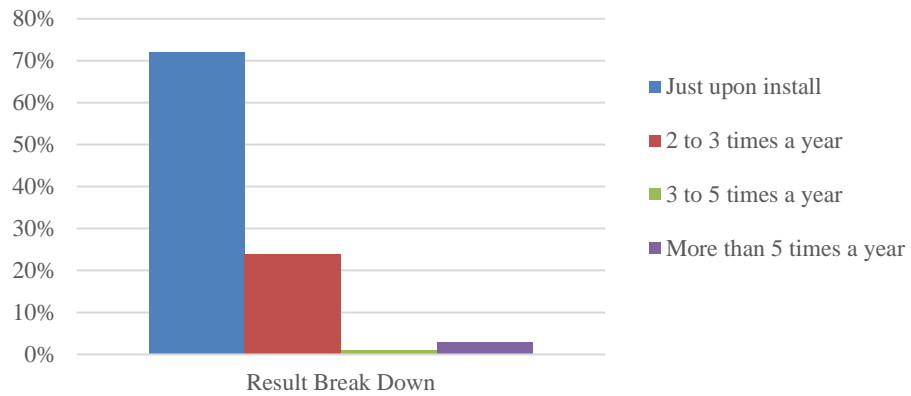
7. How much are you willing to spend on new tubular a-arms?

\$300-500      \$500-700      \$700-900      \$900+

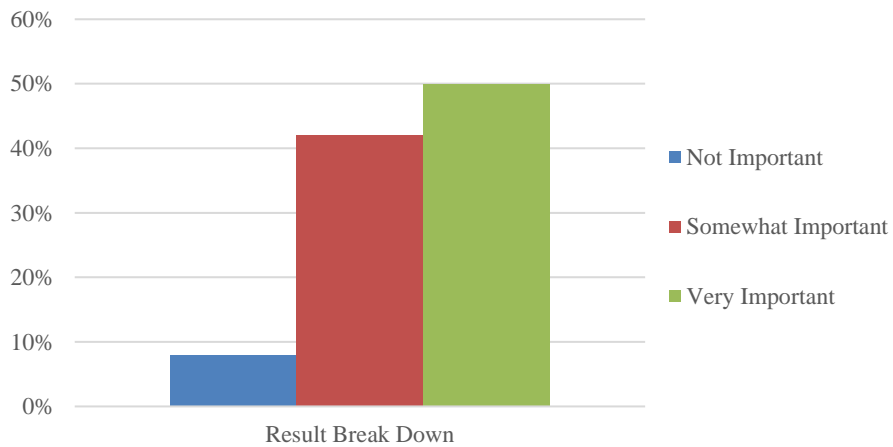
## Survey Results



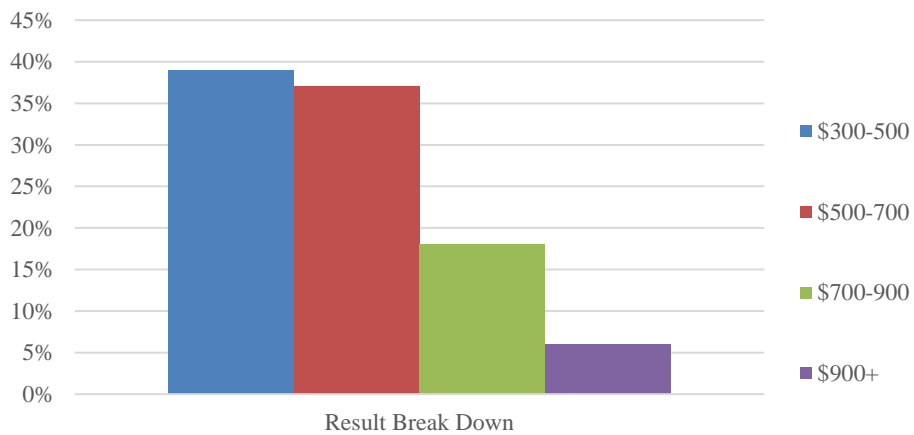
### How often do you adjust your tire alignment?



### How important is tire wear to you?



### How much are you willing to spend on new tubular a-arms?



## APPENDIX B – CURRENT PRODUCTS

### 1970-1981 CAMARO/FIREBIRD TUBULAR UPPER A-ARMS FROM HOTCHKIS SPORT SUSPENSION



Price

**\$821.00**

<http://www.hotchkis.net/product/1970-1981-camarofirebird-tubular-upper-a-arms-from-hotchkis-sport-suspension/?mk=47&yr=1981&md=432&sm=450>

Hotchkis Sport Suspension 1106 1970-1981 Camaro/Firebird Tubular Upper A-Arms. Install the geometry corrected Hotchkis Sport Suspension Tubular Upper A-Arms on your 70-81 Camaro or Firebird and gain vastly increased handling and control. These TIG-welded bolt-on arms offer increased camber and caster adjustment over stock for ultimate driving performance. Finished in gloss black powder coat the Arms are ready to install and are complete with ball joints. Billet cross-shafts and smooth operating Delrin bushings. Exceptional handling performance when combined with the Hotchkis Sport Suspension Tubular Lower A-Arms. Features: Geometry corrected design. Built in - 1.1 deg of Camber 5.2 deg of Caster 100% TIG-welded 1.25 in. tubular steel construction. Silver zinc plated 4130 Chromoly billet cross-shaft. Easy to lubricate Delrin bushings. Upper ball joints and polyurethane droop stops installed. Laser cut Hotchkis logo. Gloss black powder coat finish Benefits: Cross-Shaft allows increased static negative camber without a large alignment shim stack. Great for header clearance issues. Increased Caster improves high speed stability and camber gain during turning thereby increasing front tire traction. Smooth operating Delrin bushings allow minimal deflection through travel range. Achievable specs when using 1106 upper control arm and 1108 lower control arm. MAX Caster with Uppers and Lower = 9 deg MAX Camber with Uppers and Lower = - 3.5 deg

#### **Features and Benefits:**

- Improved Suspension Geometry
- Increased Caster
- Added Camber Adjustability
- Streamlined Appearance
- Added Strength
- 100 Percent TIG-welded Construction
- Gloss Black Powder Coated Finish

## Front Suspension - 1970-1981 F-Body - Tubular Upper Control Arms



Price  
**\$699.00**

<http://www.detroitsspeed.com/1970-1981-F-Body-products/030102-tubular-upper-control-arms.html#>

The Detroit Speed control arm kit is a complete and comprehensive package. DSE has done all the engineering and testing, and supplies all parts needed to complete the installation. All you will need to do is follow the instructions and supply the grease. Installation should take less than one day and should be followed by a professional alignment.

The Detroit Speed upper control arm kit is a bolt on enhancement for 1970-1981 F-Bodies. Suspension geometry is improved over stock by increasing camber gain and improving roll camber. They also increase caster for improved ride and handling. DSE's upper control arms have been computer modeled and the components have undergone finite element analysis. The control arms have CNC stainless steel cross shafts which incorporate DSE's 'Caster Tuner Bushings'. These aluminum bushings adjust caster by moving the upper control arm fore/aft for more or less caster without adding alignment shims. This unique caster adjustment design is engineered to be precise and permanent. The upper control arms also utilize DSE designed bushings. These greaseable aluminum / Delrin bushings have an increased stiffness over stock. This provides more consistent and precise handling. The bushings also have CNC machined bevel stainless washers and stainless ny-lock nuts.

The upper control arms have CNC machined tube ends for precision fits. The arms are then TIG welded in a fixture for accuracy and repeatability of geometry. The ball joint pocket is CNC machined from billet for increased strength. The arms are powder coated gloss black and come assembled with ball joints. Two sets of 'Caster Tuner Bushings' are included. The Detroit Speed upper control arms are ready to bolt on!

## **Camaro Tubular Upper Control Arms with Del-A-Lum Bushings #CTA-71A 1970-81**



Price

**\$598.15**

<http://www.globalwest.net/camaro-tubular-upper-control-arms-del-a-lum-bushings-global-west-1970-1971-1972-1973-1974-1975-1976-.html>

Do you need control arms that are perfect for both autocross and street applications?

The G-Plus tubular upper control arms from Global West Suspension are a direct replacement for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980 and 1981 Camaro applications. The powder coated control arms are shipped assembled with ball joints, billet cross shafts, bump stops, and Del-a-lum bushings.

### **The Global West Advantage:**

Global West has years of experience with these cars on the track. The geometry we learned at the track is now built directly into the control arms you buy. New alignment specifications are also provided for street and road racing applications; therefore, the factory alignment specifications are no longer valid.

We equip these arms with Del-a-lum bushings, which are considered best because they perform like bearings rather than bushings. They work on six surfaces to ensure no bind when the control arm pivots up and down. The bushings also have grease fittings that provide easy access for lubricating the bushing via a grease gun.

Simply put, you will experience performance with no squeaks that is superior over polyurethane. You will find Del-a-lum bushings being used for street, road racing, drag racing, and circle track.

For more information, watch the video above.

# GM Street Control Arms



Price

**\$1204.90**

<https://www.qa1.net/gm-street-control-arms>

QA1's Street Control Arms use a factory replacement ball joint and polyurethane pivot bushings. These work great on vehicles used primarily for cruising and long-distance events. Configured for QA1 Pro Coil Systems, these street control arms feature powder coated tubular construction for increased strength and great looks. A bolt-in spring adapter is available separately to allow the control arms to be used with stock springs. All of the upper arms feature an offset cross shaft letting you quickly and easily adjust camber.

All of these arms are designed to add 3-4 degrees of caster and 0.5 to 1 degree of negative camber when used together. When used independently they will add approximately half of the preceding numbers.

All parts sold in pairs and including mounting hardware. Made in the USA.

[These control arms are also offered in race configurations for added performance for drag racing, pro-touring, and hardcore street applications.](#)

## **Bolt-In Spring Adapters for Stock Springs**

A bolt-in spring adapter is available separately to allow the control arms to be used with stock springs.