



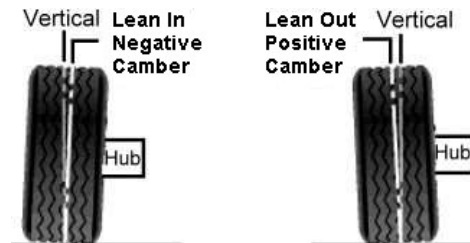
TR250 & TR6 Steering & Suspension Rear Suspension Geometry

Background: I recently set out to "fix" the negative camber problem on my '76TR6. I decided to work carefully, take notes and many photos thinking I'd later write something about it for the Buckeye Triumphs Newsletter and possibly for the technical section of the Buckeye Triumphs Website. The plan was to use Brian Lanoway's table of trailing arm bracket configuration and relative camber angles published in the Moss Catalogue and available from at least one website. I did identical changes to each side and found the measured result in the right direction and in fact fixed the problem. Thank You Brian!

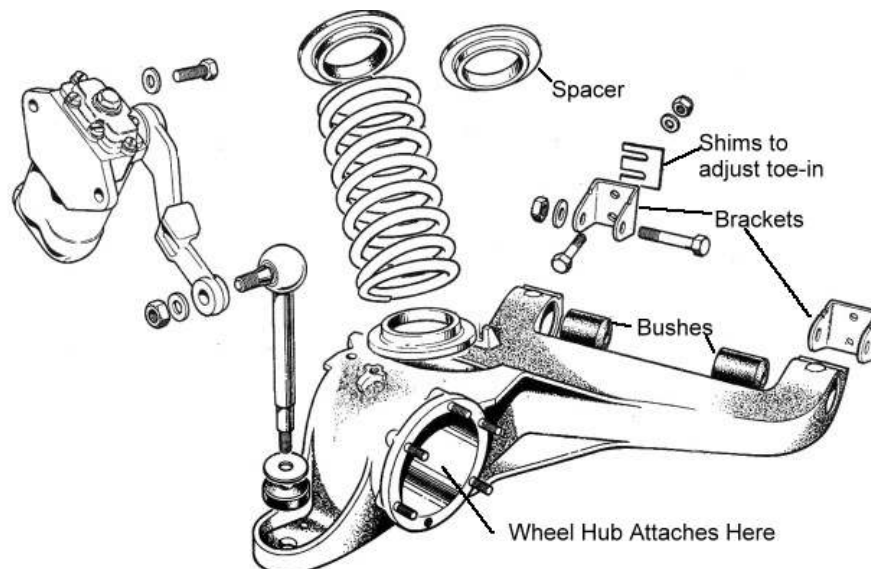
In spite of the success, I was disturbed that the amount of change was less than 2/3 of what I'd expected using Brian's table. I measured the brackets involved, did a calculation and found a result closer to what I measured. I then emailed Brian and asked where I went astray and also if my bracket measurements were accurate. He responded that his original data and calculations were lost in a computer crash. He did say that I'd included one more factor than he did; his object was to get in the right ballpark. He further suggested that maybe I should put together a revised table.

Well, I jumped right in and measured, calculated, analyzed, etc and came up with results that were way off from the measured results. This was using my normal ready, fire then aim technique. Getting a sign mixed up here and there didn't help either. Did it a few more times and began to understand some interesting symmetries, and more importantly discovered yet another variable. I finally went back and measured the brackets very carefully and then did the calculations one-step at a time. I've described the methods and all calculation steps in the following in the hope that others will check over the work and point out any and all errors. This is really an extension of Brian's work and we are all fortunate that he brought organization to this area.

The Problem: The diagram on the right shows positive and negative camber on a rear wheel. In many cases the camber is negative with the top of the tire leaning in. The specifications are for a no load rear camber of between +1.0 degree and -0.25 degree. As load is added, the back of the car goes down and the negative camber increases, so a little positive camber with no load is fine. (You can observe this by pushing down on the rear bumper and watch the top of the tire move toward the car.) Many TRs have several degrees of negative camber with the top of the wheels really leaning in. I seem to recall that VWs of the same era also had this problem. Apparently some TRs had the negative camber when delivered new and others seemed to grow it over time.

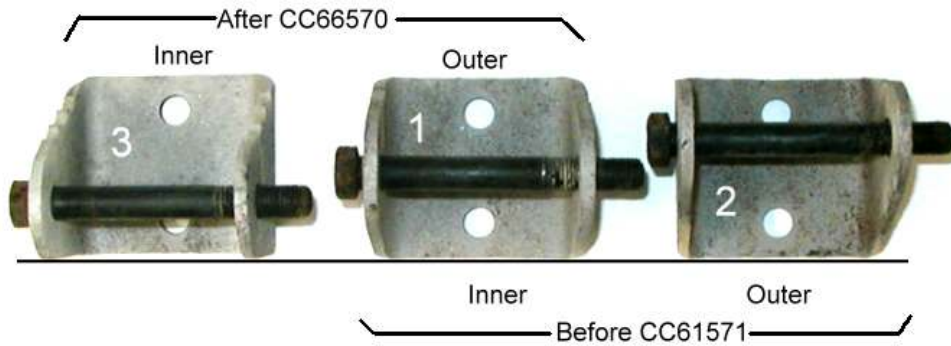


The next sketch of the right rear suspension arm came from a TRF catalog. I processed it a bit to remove unwanted items and then added the text.



Rear Suspension Geometry

One thing that influences the camber is the angle the trailing arm bushing axis makes with the horizontal. This angle is determined by the brackets and the frame member to which the brackets attach. Three different brackets were made for the TR250/TR6, each identified by the number of notches in the top (1, 2 or 3 notches). The factory changed the standard configuration at commission number CC66571. The following photo shows both configurations for the right side.



Brian Lanoway noted that by reversing the inside and outside brackets and by allowing the brackets to be mounted with the notches up or down, a total of 36 combinations are possible. He then measured the position of the bush bolt in each bracket and used that to compute the relative angle of the bush axis. My first step was to determine the bush bolt position as accurately as possible. Actually this took several steps (one forward then two back, etc.) until I drilled a couple holes in a steel plate to hold the bracket for measurement. The holes were drilled as far apart as possible so that there is no slack in the bracket position even before the nuts are tightened. I then clamped a steel block (from the scrap pile) to the plate as shown in the next photo.



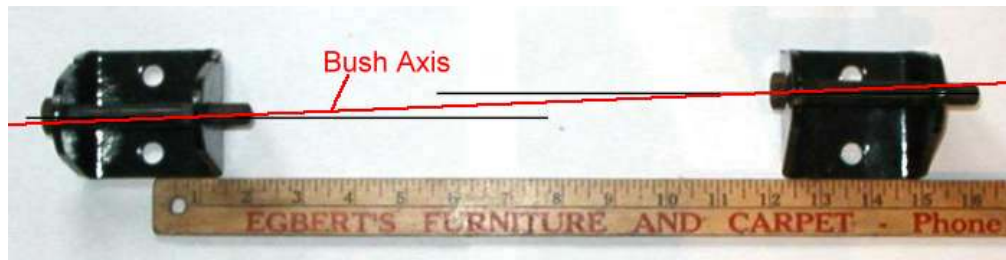
The block had been machined on the sides and end and the end was square. I aligned the block perpendicular to the bush bolt. I then measured the distance between the end of the block and the bush bolt as shown in the next photo.



This measurement was taken in the middle of the bracket and care was taken to keep caliper perpendicular to the end of the block. This measurement was recorded and then the bracket was removed and reversed without disturbing the position of the steel block. A second measurement was then taken with the bracket in the reversed position. Next, the difference in the two measurements was determined (one measurement subtracted from the other). This difference is the amount the bush bolt position moves when the bracket is reversed. If the two measurements are the same, the bush bolt is on the centerline of the bracket. If the difference is one inch for example, then the bush bolt is 1/2 inch above the centerline in one position and 1/2 inch below the centerline in the other position. Note that the specific position of the block relative to the bracket is unimportant as long as it is the same for both measurements on a bracket. The position of the bush bolt (BBP) relative to the centerline for both positions of each bracket is shown in the table below. A positive number means the bush bolt is above the center. The U or D indicates whether the bracket has the notches on the top (U-normal position) or on the bottom (D). For example 3U means the three-notch bracket positioned with the notches pointed up and 1D means the 1 notch bracket positioned with the notches pointed down.

Bracket	Bush Bolt Position (BBP)
3D	0.622"
2U	0.368"
1D	0.126"
1U	-0.126"
2D	-0.368"
3U	-0.622"

The next photo shows a typical bracket configuration. The distance between the center of the two brackets is ~13.625". The example shows the brackets where the BBP of the right bracket is above the BBP of the left bracket. Since the right bracket is above the left bracket, the bush axis is at an angle with the centerline between the two brackets.



The angle (in radians) between the bracket centerline and the bush axis is approximately equal the difference in the bush bolt positions of the two brackets divided by the distance between the center of the brackets (13.635"). The angle can be converted from radians to degrees by multiplying by 57.3. I defined a positive angle as the case where the inner BBP is above the outer BBP. Combining all this, the Bush Angle is approximately:

$$\text{Bush Angle} = (57.3/13.625) \times (\text{BBP}_{\text{inner}} - \text{BBP}_{\text{outer}})$$

The results of this calculation are shown on the right. The table is arranged in ascending order of Bush Axis Angle. There

Relative Bush Axis Angle and Resulting Camber Angle due to Bush Bolt Position for Various Trailing Arm Bracket Configurations

Rear Suspension Geometry

are six configurations in the middle of the table where the inner and out brackets are the same resulting in an angle of zero degrees.

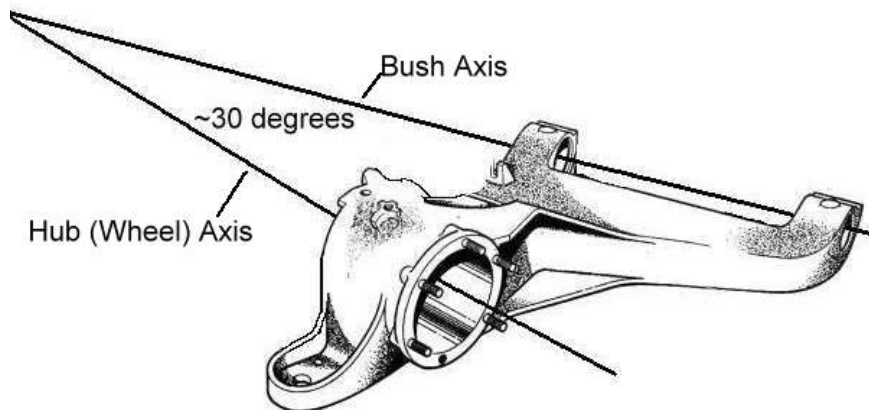
There is symmetry with respect to the middle of the table. For example the top entry has the 3D-3U configuration. The bottom entry is the 3U-3D configuration. Makes sense, reversing the brackets gives the same angle but with the opposite sign. This is true for every entry except the zero angles in the middle of the list. --- the second from the top is symmetrical with the second from the bottom, etc. In fact, if one looks for all the permutations there are 6 more identical entries with zero angle exactly duplicating the six listed. They were eliminated because they were redundant.

There is one more bit of symmetry; for each case where the two brackets are different, there is another combination with the same angle achieved by turning the brackets upside down and reversing them. For example 3D-2D and 2U-3U both give a -4.16 degree angle.

One can conclude from these data that there are many less than 36 possible angles, in fact there are only 11 combinations with differences of greater than a tenth of a degree. This isn't the whole story; when everything is included we'll find a few more combinations.

The bush axis angle reflects a tilting of the trailing arm. This tilting is not transferred directly to the wheel because the axis of the rear hub and the bushes are different -- there is a 30 degree angle between them as shown in the next diagram. If the two axes were parallel (angle = zero) the wheel camber and the bush axis angle would be the same. If it were 90 degrees (the two axes perpendicular) the wheel camber would be independent of the bush axis angle. The relationship between the bush axis angle and the wheel camber is the cosine of the angle between the two axes, in this case cosine 30 degrees = 0.866. In other words, the change in wheel camber is only 86% of the change in the bush axis angle. This is reflected in the right column of the adjacent table.

Bracket Configuration Outer-Inner	Bush Bolt Position (Inches)		Bush Axis Angle	Camber Angle due to Bush Axis Angle
	Outer	Inner		
3D-3U	0.62	-0.62	-5.23	-4.53
3D-2D	0.62	-0.37	-4.16	-3.61
2U-3U	0.37	-0.62	-4.16	-3.61
3D-1U	0.62	-0.13	-3.15	-2.72
1D-3U	0.13	-0.62	-3.15	-2.72
2U-2D	0.37	-0.37	-3.10	-2.68
3D-1D	0.62	0.13	-2.09	-1.81
1U-3U	-0.13	-0.62	-2.09	-1.81
2U-1U	0.37	-0.13	-2.08	-1.80
1D-2D	0.13	-0.37	-2.08	-1.80
3D-2U	0.62	0.37	-1.07	-0.93
2D-3U	-0.37	-0.62	-1.07	-0.93
1D-1U	0.13	-0.13	-1.06	-0.92
1U-2D	-0.13	-0.37	-1.02	-0.88
2U-1D	0.37	0.13	-1.02	-0.88
3D-3D	0.62	0.62	0.00	0.00
2U-2U	0.37	0.37	0.00	0.00
1D-1D	0.13	0.13	0.00	0.00
1U-1U	-0.13	-0.13	0.00	0.00
2D-2D	-0.37	-0.37	0.00	0.00
3U-3U	-0.62	-0.62	0.00	0.00
1D-2U	0.13	0.37	1.02	0.88
2D-1U	-0.37	-0.13	1.02	0.88
1U-1D	-0.13	0.13	1.06	0.92
2U-3D	0.37	0.62	1.07	0.93
3U-2D	-0.62	-0.37	1.07	0.93
2D-1D	-0.37	0.13	2.08	1.80
1U-2U	-0.13	0.37	2.08	1.80
1D-3D	0.13	0.62	2.09	1.81
3U-1U	-0.62	-0.13	2.09	1.81
2D-2U	-0.37	0.37	3.10	2.68
1U-3D	-0.13	0.62	3.15	2.72
3U-1D	-0.62	0.13	3.15	2.72
2D-3D	-0.37	0.62	4.16	3.61
3U-2U	-0.62	0.37	4.16	3.61
3U-3D	-0.62	0.62	5.23	4.53



Trailing Arm Rotation: The angle of the trailing arm relative to the bush axis (i.e. trailing arm rotation around the bush axis) influences not only the height of the car but also the rear wheel camber. This is easily observed by pushing down the rear of the car and observing the top of the rear wheels move toward the center of the car --- reduced positive camber --- or increased negative camber. If the wheel axis and the bush axis were parallel, rotating the trailing arm around the bush axis would have no effect on the wheel camber. On the other hand, if the wheel axis and the bush axis were perpendicular, any change in the angle of rotation of the trailing arm around the bush axis would be reflected 100% in the camber angle. I think the camber change due to trailing arm rotation is related to the sine of the angle between the bush axis and the wheel axis, in this case sine 30 degrees or 0.5.

Each of the brackets has a different bush bolt height. Changing the bush bolt height changes the bush axis height. Changing the bush axis height while keeping the spring the same results in a rotation of the trailing arm and thus affects the car height and rear wheel camber. The next photo shows the dimensions necessary to compute the effects of changing the bush axis height. The spring is located about 10.5 inches from the bush axis and the tire is about 19 inches from the bush axis.



The first thing is to get our directions straight. If the bush axis is raised, the front of the trailing arm goes up and the back goes down resulting in raising the car and increasing the positive camber. If you draw a couple sketches you'll see that the car height changes 10.5"/19" or 55% of the change in the bush axis height.

For small changes in the bush axis height, the amount the trailing arm rotates (in radians) is approximately the change in bush axis height divided by the distance between the bush axis and the spring (10.5"). This can be converted to degrees by multiplying by 57.3 degrees. The effect this has on the wheel camber must then be multiplied by the sine of 30 degrees or 0.5. I'm going to abbreviate the change in camber angle due to a change in bush axis height as Camber Angle (BAH):

$$\text{Camber Angle}_{(BAH)} = (57.3/10.5) \times (0.5) \times (\text{change in bracket height})$$

$$\text{Camber Angle}_{(BAH)} = (\text{change in bracket height}) \times (2.7 \text{ degrees})$$

The change in bracket height must be in inches since the distance between the bush axis and spring position was in inches. I decided to reference the Camber Angle (BAH) to the bracket centerline. The bush axis height relative to the bracket centerline is merely the average of the bolt position of the two brackets. The results of these calculations are shown in the next table.

Relative Camber Angle and Ride Height for Various Trailing Arm Bracket Configurations								
Bracket Configuration Outer-Inner	Bush Bolt Position (Inches)		Bush Axis Angle	Camber Angle due to Bush Axis Angle	Bush Axis Height (Inches)	Camber Angle due to Bush Axis Height (Degrees)	Total Camber Angle (Degrees)	Ride Height (Inches)
	Outer	Inner						
3D-3U	0.62	-0.62	-5.23	-4.53	0.00	0.00	-4.53	0.00
2U-3U	0.37	-0.62	-4.16	-3.61	-0.13	-0.34	-3.95	-0.07
1D-3U	0.13	-0.62	-3.15	-2.72	-0.25	-0.67	-3.39	-0.14
3D-2D	0.62	-0.37	-4.16	-3.61	0.13	0.34	-3.26	0.07

Rear Suspension Geometry

1U-3U	-0.13	-0.62	-2.09	-1.81	-0.37	-1.01	-2.82	-0.21
2U-2D	0.37	-0.37	-3.10	-2.68	0.00	0.00	-2.68	0.00
2D-3U	-0.37	-0.62	-1.07	-0.93	-0.50	-1.34	-2.26	-0.27
1D-2D	0.13	-0.37	-2.08	-1.80	-0.12	-0.33	-2.13	-0.07
3D-1U	0.62	-0.13	-3.15	-2.72	0.25	0.67	-2.05	0.14
3U-3U	-0.62	-0.62	0.00	0.00	-0.62	-1.68	-1.68	-0.34
1U-2D	-0.13	-0.37	-1.02	-0.88	-0.25	-0.67	-1.55	-0.14
2U-1U	0.37	-0.13	-2.08	-1.80	0.12	0.33	-1.47	0.07
2D-2D	-0.37	-0.37	0.00	0.00	-0.37	-0.99	-0.99	-0.20
1D-1U	0.13	-0.13	-1.06	-0.92	0.00	0.00	-0.92	0.00
3D-1D	0.62	0.13	-2.09	-1.81	0.37	1.01	-0.80	0.21
3U-2D	-0.62	-0.37	1.07	0.93	-0.50	-1.34	-0.41	-0.27
1U-1U	-0.13	-0.13	0.00	0.00	-0.13	-0.34	-0.34	-0.07
2U-1D	0.37	0.13	-1.02	-0.88	0.25	0.67	-0.21	0.14
2D-1U	-0.37	-0.13	1.02	0.88	-0.25	-0.67	0.21	-0.14
1D-1D	0.13	0.13	0.00	0.00	0.13	0.34	0.34	0.07
3D-2U	0.62	0.37	-1.07	-0.93	0.50	1.34	0.41	0.27
3U-1U	-0.62	-0.13	2.09	1.81	-0.37	-1.01	0.80	-0.21
1U-1D	-0.13	0.13	1.06	0.92	0.00	0.00	0.92	0.00
2U-2U	0.37	0.37	0.00	0.00	0.37	0.99	0.99	0.20
2D-1D	-0.37	0.13	2.08	1.80	-0.12	-0.33	1.47	-0.07
1D-2U	0.13	0.37	1.02	0.88	0.25	0.67	1.55	0.14
3D-3D	0.62	0.62	0.00	0.00	0.62	1.68	1.68	0.34
3U-1D	-0.62	0.13	3.15	2.72	-0.25	-0.67	2.05	-0.14
1U-2U	-0.13	0.37	2.08	1.80	0.12	0.33	2.13	0.07
2U-3D	0.37	0.62	1.07	0.93	0.50	1.34	2.26	0.27
2D-2U	-0.37	0.37	3.10	2.68	0.00	0.00	2.68	0.00
1D-3D	0.13	0.62	2.09	1.81	0.37	1.01	2.82	0.21
3U-2U	-0.62	0.37	4.16	3.61	-0.13	-0.34	3.26	-0.07
1U-3D	-0.13	0.62	3.15	2.72	0.25	0.67	3.39	0.14
2D-3D	-0.37	0.62	4.16	3.61	0.13	0.34	3.95	0.07
3U-3D	-0.62	0.62	5.23	4.53	0.00	0.00	4.53	0.00

As predicted, when the bush axis height is included, there are many more unique adjustment possibilities. The camber angles and ride heights in the table are relative and make sense only in the context of differences between configurations. For example, I started with the late standard 1U-3U configuration with - 2.82 degrees camber angle and -0.21" ride height. I then changed the outer bracket from 1U to 3U to give a 3U-3U configuration of -1.68 degrees camber angle -0.34" ride height. The net effect computed from the table should have been a increase in camber of 1.14 degrees and a decrease in ride height of 0.13". The actual results were a slight **increase** in ride height (I'm using a yard stick so the ride height measurement isn't very precise) and an increase in camber angle of 1.2 degrees on one side and 1.3 degrees on the other. The measured camber changes were really close to that predicted from the table.

The following is a more useful presentation of the data. Because of the approximations used in the calculations and limited precision of measurement of the various dimensions, I reduced the resulting data to a single decimal point precision.

Relative Camber Angle and Ride Height for Various Trailing Arm Bracket Configurations		
Bracket Configuration Outer-Inner	Total Camber Angle (Degrees)	Ride Height (Inches)
3D-3U	-4.5	0.0
2U-3U	-4.0	-0.1
1D-3U	-3.4	-0.1
3D-2D	-3.3	0.1
1U-3U	-2.8	-0.2
2U-2D	-2.7	0.0
2D-3U	-2.3	-0.3
1D-2D	-2.1	-0.1

Rear Suspension Geometry

3D-1U	-2.1	0.1
3U-3U	-1.7	-0.3
1U-2D	-1.6	-0.1
2U-1U	-1.5	0.1
2D-2D	-1.0	-0.2
1D-1U	-0.9	0.0
3D-1D	-0.8	0.2
3U-2D	-0.4	-0.3
1U-1U	-0.3	-0.1
2U-1D	-0.2	0.1
2D-1U	0.2	-0.1
1D-1D	0.3	0.1
3D-2U	0.4	0.3
3U-1U	0.8	-0.2
1U-1D	0.9	0.0
2U-2U	1.0	0.2
2D-1D	1.5	-0.1
1D-2U	1.6	0.1
3D-3D	1.7	0.3
3U-1D	2.1	-0.1
1U-2U	2.1	0.1
2U-3D	2.3	0.3
2D-2U	2.7	0.0
1D-3D	2.8	0.2
3U-2U	3.3	-0.1
1U-3D	3.4	0.1
2D-3D	4.0	0.1
3U-3D	4.5	0.0

Ride Height - Second Order Effect: I was troubled about the difference between the calculated and measured ride height when I changed from the 1U-3U configuration to the 3U-3U configuration. The data from the table indicated that the ride height should be about 0.1" lower and in fact it was about 0.1" higher. This occurred on both sides and was measured several times. While the magnitude of the error is of no consequence, the fact that it went in the opposite direction indicated that I was missing something. I took another look at the trailing arm and realized that as the angle of the bush axis is changed to increase the camber, the wheel is pushed down relative to the spring causing an increased height. The next photo shows a measurement of the lever arm that rotates when the trailing arm rotates with a change of bush axis angle. The precision yardstick shows the distance from the center of the spring to the center of the tire tread to be about 8".



Rear Suspension Geometry

The small angle formula can be used to compute the change in road height --- it is 8 inches times the change in camber angle in radians or using 57.3 degrees per radian:

$$\text{Ride Height Change}_{(\text{Bush Axis Angle})} = (8"/57.3) \times (\text{Camber angle change in degrees})$$

$$\text{Ride Height Change}_{(\text{Bush Axis Angle})} = (0.14") \times (\text{Camber angle change in degrees})$$

The camber angle change used here is that due only to the bush axis change excluding any change due to changing the height of the bush axis. This angle for going from the 1U-3U configuration to 3U-3U is 1.81 degrees. Plugging this into the formula above gives a ride height change of 0.25". The change in ride height due to rotation of the trailing arm around the bush axis was computed to be -0.13". Adding this to the 0.25 increase just computed gives a net ride height increase of +0.12" --- nearly exactly matching the 0.1" increase measured with the precision yardstick. Now that I know what's going on, I'm going to ignore this second order effect.

Spacers: The factory recommended using spacers under the springs as the standard way to increase the rear suspension camber. A spacer will have the exactly the same effect on the camber as moving the bush axis height:

$$\text{Camber Angle Change}_{(\text{Spacer})} = (\text{Spacer height}) \times (2.7 \text{ degrees})$$

The effect on the ride height is however different; it is magnified by the lever effect of the trailing arm so that the ride height change is:

$$\text{Ride Height Change}_{(\text{Spacer})} = (19"/10.5") \times (\text{Spacer height})$$

$$\text{Ride Height Change}_{(\text{Spacer})} = (1.8) \times (\text{Spacer height})$$

I obtained a set of 0.44" high spacers from TRF. From the calculations above, these should increase the camber by 1.2 degrees and ride height by 0.8". The measured results were an increase in camber of 1.2 degrees on one side and 1.1 degrees on the other. The measured ride height increased by 0.8". This agreement is in part luck since the height readings with the yardstick are to the closest 1/8 inch and the camber measurement accuracy is probably + or - 0.1 degree at best.

Note: One person has reported that the 3D configuration (3 notch bracket with notches pointed down) raises the the trailing arm so high that it is against the body above the bush. I would probably avoid the configurations with a 3D bracket, there are other configurations that will give similar angles.

Measuring Camber: The technique I use to measure the camber is shown in the accompanying note "Adjusting Rear Suspension"