Bump-steer Measurement Background Information

Introduction:

The term bump-steer is widely known in automotive circles, but the causes, consequences, and solutions are not so well understood. The complexity and potential for issues just in measuring bump-steer became obvious during LVVTA's development of the LVVTA bump-steer swing-check bars.

This document is intended to summarise the development process of the bump-steer swing-check bars and the measurement system used with the bars, and the questions that arose during that development process along with explanations and answers. Understanding this background information is not essential in order to conduct a bump-steer swing-check, but rather is intended for those who want to understand the subject further.

Tests were conducted in order to check that the LVVTA bump-steer bars operate effectively and to compare results with electronic wheel alignment machines. The results are listed in Appendix 1 of this document, and Appendix 2 provides some technical information on the geometry relationship of toe angles.

Questions and Answers:

<u>When should LVVTA bump-steer bars be used?</u>

It should be clarified that the aim of the LVVTA bump-steer bar test is to confirm that bump-steer is within acceptable limits on low volume vehicles; - it is not a tool for setting up suspension. However, it is important to know that the results produced by the LVVTA bump-steer bars are comparable to those that would be produced by a wheel alignment machine. The use of wheel alignment machines as an alternative has been raised, and this is discussed below.

The more recent testing indicates that the bars can produce results that are in line with alignment machines. Early tests did not show such good correlation but the reasons for this are now better understood, which, again, is discussed below.

The bars as designed have not had any issues. Minor improvements could be made (e.g. spirit level bubbles to aid adjustment) but are not considered necessary at this time.

<u>What is the level of accuracy when using LVVTA bump-steer bars?</u>

The accuracy of measurement using the bars is in the order of +/-1 mm, limited by the use of tape measure and the operator's accuracy. This converts to 0.1 degrees, which is well within vehicle manufacturers' tolerances. The test process requires repeated measurements to gather data over the range of suspension movement.

One person must read and record all measurements so that the method is consistent.

Can all suspension types be tested with this method?

The process may need to be tweaked to suit other suspension types, but in general most will be catered for. In some cases a vehicle with torsion bar suspension that cannot be unloaded may have to be checked by the pull-down method on an alignment rig.

Is a steering wheel lock required for testing?

Alignment machine measurements require the steering wheel to be locked in order to accurately centre and adjust the steering and suspension. Is this critical just for toe-change measurements? Large changes (10 degrees or more) will affect the measurement due to Ackermann, but steering slightly off-centre will not have much effect, nor will slight steering movement of a degree or so.

Steering movement should be avoided during testing, but this is not difficult. A steering lock mechanism is not seen as essential in order to achieve this – just care by the operator during the process will prevent steering movement. To avoid additional cost a steering lock has not been provided.

Is a brake lock required for testing?

Alignment machines lock the brakes so that the wheel-mounted sensors remain in one place. It is not necessary to do this with the LVVTA bars as the process requires the bars to remain horizontal throughout. The bars feature a drop leg to adjust and hold at the horizontal position. The small wheels on the legs allow the bars to move freely on the ground as the toe changes.

The brakes can be locked if desired – this may be required if the vehicle is up on a hoist with no place to rest the legs of the bars. With brakes on, the bars will not remain parallel with the ground when suspension height is changed; - this is acceptable as it does not significantly affect the results.

Can Individual and total toe be measured?

An alignment machine can display individual toe for each wheel. The LVVTA bars only record total toe. Variations in individual toe can arise due to uneven suspension or steering, such as an off-centre rack.

The purpose of the bump-steer bars is not to highlight these types of issue – this usually requires a full wheel alignment. The bars could be used to record individual toe-change by setting up a datum line on the floor down the centre of the car and measuring from this to each bar throughout suspension travel.

After dismantling of suspension to perform a bump-steer swing-check, it is highly recommended that a full alignment is carried out.

Does loaded and unloaded suspension make a difference to measurement?

The compliance of suspension and steering bushes has an effect on the tolerance of measurement. This can be seen on some vehicles when tested with suspension hanging free, versus suspension loaded by vehicle weight. This tolerance is geometry dependent – it can be present on double wishbone set-ups but not MacPherson struts. The bars-measured toe change figures can be greater or less than the alignment machine measurement, depending on suspension configuration. For example, a front mounted or rear mounted steering rack will have the opposite influence.

Loading suspension through the tyres is arguably more representative than a measurement with the bars, where the suspension is unloaded. In reality the suspension will be subject to a range of loads on-road so there is no single method that will accurately reflect this. The majority of tests with the bars have given good toe-change correlation with the alignment machine, so the method is suitable.

Alternative forms of suspension compression have been suggested, for example compression of the suspension via arms or through the centre of the spring. However, these methods will not necessarily give the same result as the loading through the tyre, so are not seen as providing any real benefits.

Can an alignment machine be used instead of the LVVTA bars?

It is not always the best solution to use the LVVTA bars to measure toe-change, especially for finished production vehicles, for instance when springs would be difficult or time consuming to remove. In these cases an alternative method of bump-steer assessment is desirable. A wheel alignment machine can be used, but a method to extend and compress the suspension will be required to give the toe-change measurement across the full range of suspension travel.

Testing has shown that there is a method to pull down the vehicle that is feasible with a tie-down strap and the vehicle mounted on a hoist. It may not be possible or desirable to pull down to full compression due to the high loads involved, especially on stiff springs – safety is a concern. This method will necessitate a limit to the measurement range, which could be based on the range of suspension travel likely to be encountered on road.

This limited range needs to be established, based on the minimum that is adequate to assess bump-steer. Data from the internet indicates that in the USA, +/-50 mm (2 inches) is the most commonly-used to report bump-steer data, but this may not be appropriate for a softly sprung vehicle with extensive travel. One of the reasons that LVVTA is keen to gather bump-steer data from the LVV Certifiers as they carry out their assessments is so that in the future, LVVTA can make informed decisions on such matters. So, it is only with further knowledge that this question can be answered.

Note that the alignment machine method has limited use. It cannot be used to measure part-built vehicles and scratch-built vehicles which must always be checked over their full range of suspension travel. This can be done at the same time as the check for suspension bind.

Wheel alignment machines – degrees or millimetres?

Testing has highlighted an issue with wheel alignment machine settings. When set to measure in mm, the machine must assume a reference diameter to measure across. This varies with brand of machine and can be a set figure or dependent on the vehicle data input.

The reference diameter can be any of the following when using a wheel alignment machine:

- a constant figure based on an average wheel rim diameter, for example 15 inches (381 mm); or
- the diameter of the original equipment wheel, for example 18 inches (457 mm); or
- a constant figure based on an average tyre diameter, for example 22 inches (559 mm); or
- the diameter of the original equipment tyre, for example 24 inches (610 mm).

This variation presents an issue when trying to compare the LVVTA bar measurements to manufacturer data in mm or inches. This is not an issue when the machines are set to measure in degrees, as the angle is not dependent on a reference diameter. As an example, 1 degree of toe would be 7 mm measured across a 15 inch wheel, or 11 mm measured across a 24 inch tyre. To remove any doubt, if a wheel alignment machine is used, it must be set to measure in degrees.

The marks on the bump-steer bars are set 575 mm apart (22.6 inches), so that it is simple to convert between degrees and mm. When the toe on the bars measures 10 mm, this equals 1 degree of toe. This 575 mm distance always gives a 10:1 ratio of mm to degrees. Some examples:

- 5 mm of toe equals 0.5 degrees
- 13 mm of toe equals 1.3 degrees
- 21 mm of toe equals 2.1 degrees

<u>I can't get zero toe change so what should I aim for?</u>

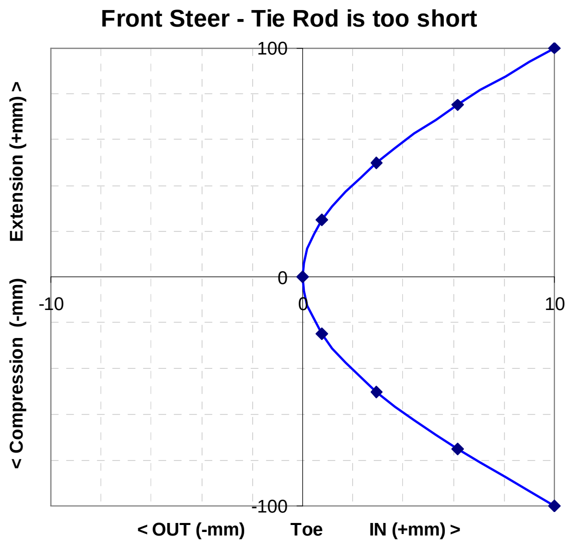
It is common to have some toe change as it can't always be dialled out. If this is the case then the best situation is to have toe-in on suspension compression. Any toe out should be restricted to a minimal amount on suspension droop.

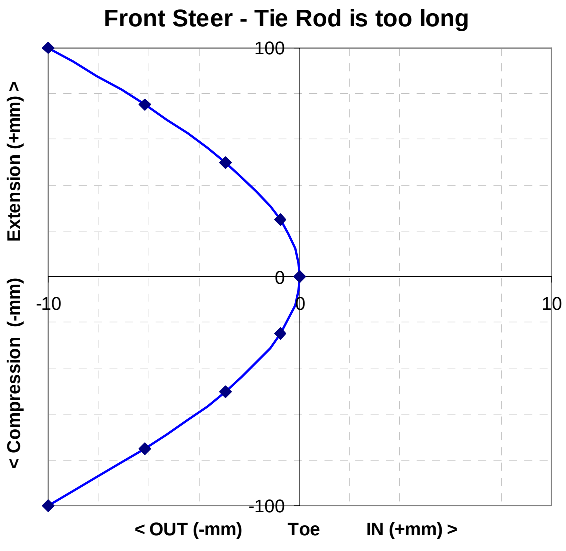
<u>How do I fix excessive toe change?</u>

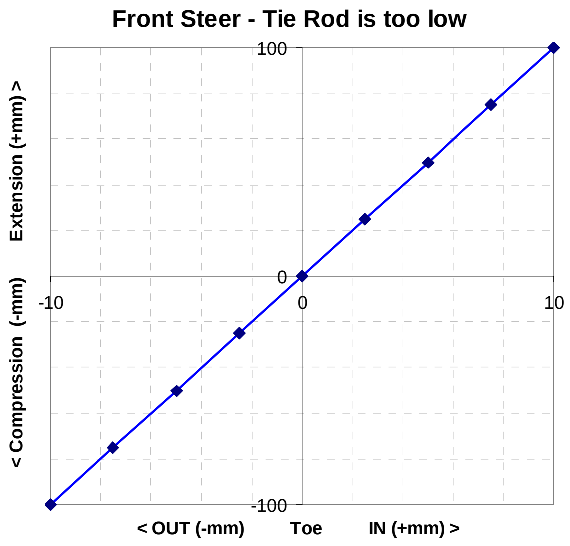
The shape of the graph produced by the bump-steer swing-check will indicate which aspect of the geometry is incorrect. Note that the solutions are reversed for rear-facing steering arms compared to front-facing arms. Ensure that the correct graphs are referred to below, and check that the axes on the graph are the same way round as the graph of the measured data.

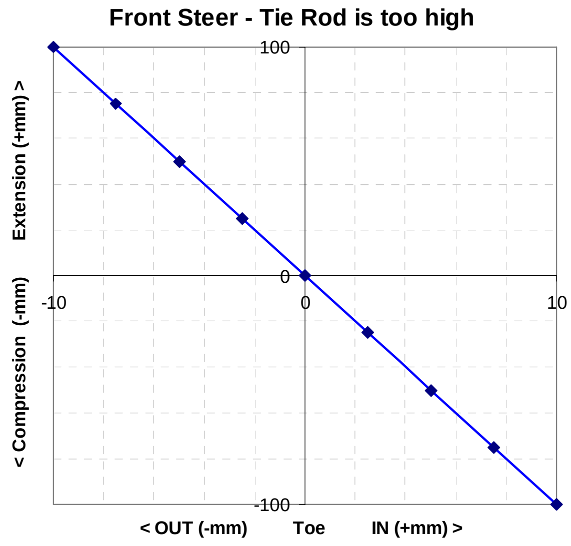
The bump-steer data can be a combination of the curve and straight line, creating an ‘S’ shape.

- Steering arms facing to the front of suspension (‘Front steer’):

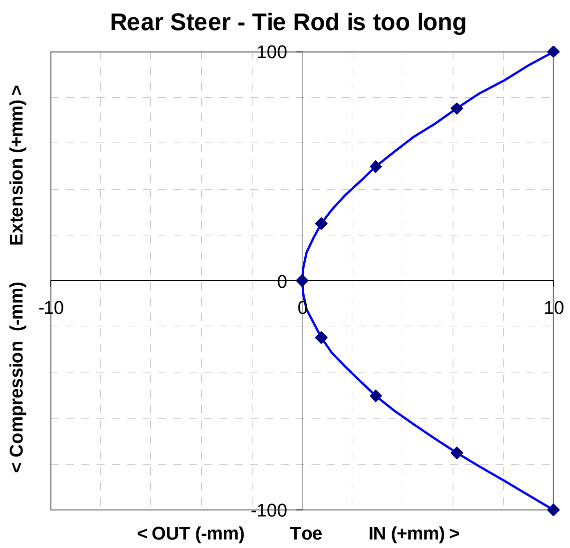


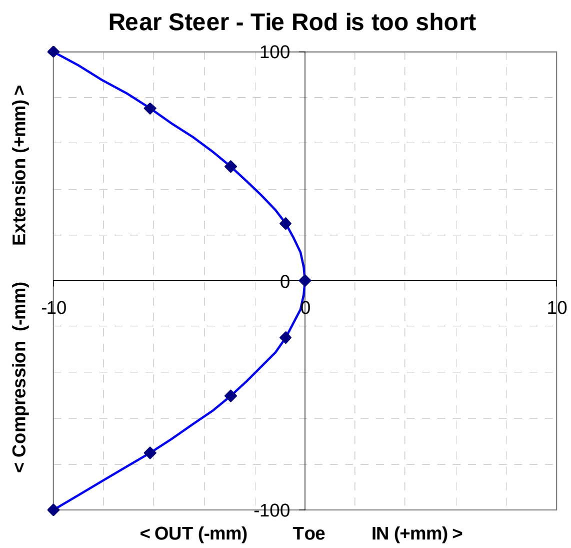


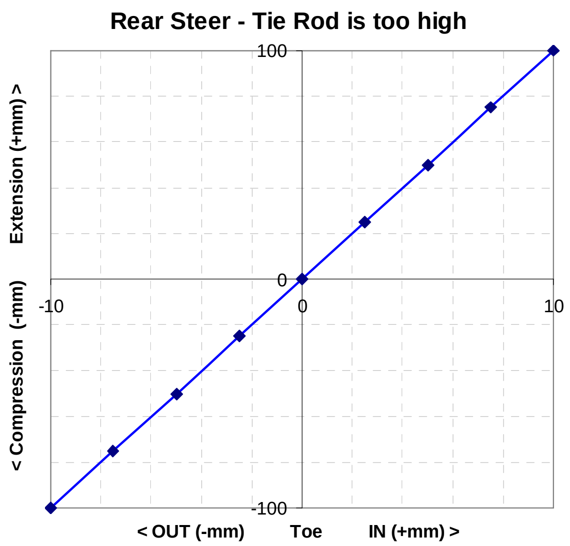


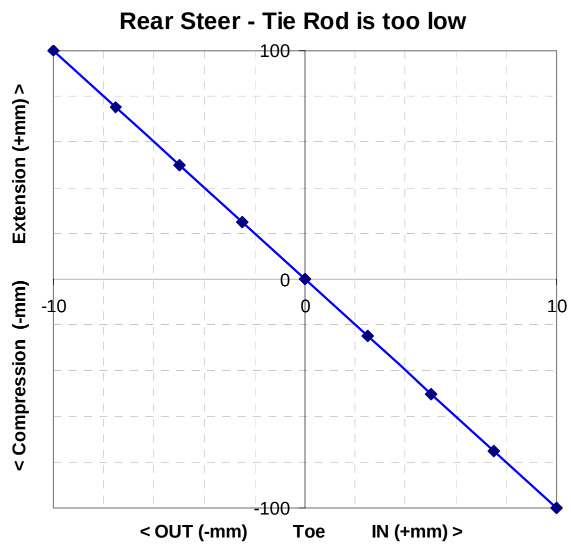


- Steering arms facing to the rear of suspension ('Rear steer'):









<u>What maximum figure to put on toe?</u>

It is impossible to put a single number on acceptable toe at this stage, as this is dependent on suspension type, vehicle type, and proposed use. For instance, soft suspension might hide bump-steer toe change, whereas a go-kart-like ride will not. As an example, a standard 1960s Ford Mustang (renowned for having very poor toe geometry) has about 20 mm toe-change over a 100 mm range, but still drives ok. If it were fitted with low-profile tyres and stiff bushes, it may suddenly not drive as well and could be less safe than standard. As a comparison, a 2009 Chevrolet Camaro has about 2 mm over a similar range.

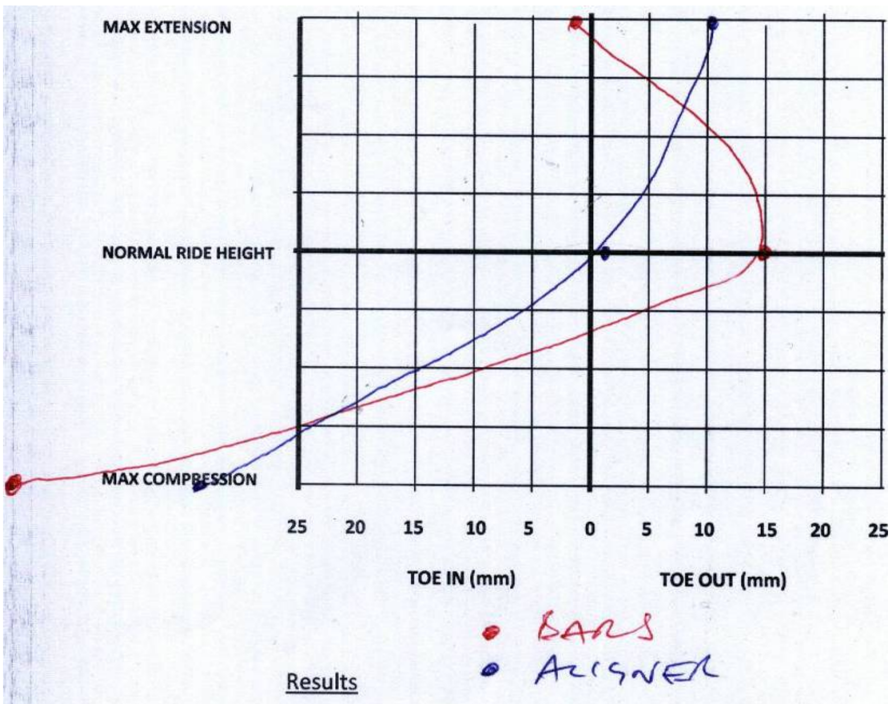
It must be remembered that the toe-change figure is relative to the suspension travel it is measured across. If a limit were set, there is debate over whether it should be measured at maximum suspension travel, or over a smaller but more commonly used range.

There is little data readily available so LVVTA will be relying on data from LVV Certifiers to build up a picture of common figures for standard and modified vehicles over time.

Appendix 1 - Summary of testing

<u>April 2010 - 1963 Chevrolet Impala – Johnsonville Autos</u>

This vehicle was fitted with an airbag suspension system which allowed bump-steer to be checked without removal of suspension components. Three measurements were taken using the bars, and then the vehicle was driven a short distance and checked on a Hunter wheel alignment machine. The machine was set to read in mm and not degrees, and the machine measurement diameter was unknown. At the time (being our first comparative test) we were unaware of the importance of knowing the wheel diameter being used by the machine, or the necessity for having the machines set at degrees and not mm. The results are as shown in the graph below.



<u>Results</u>

	Max extn.	Normal	Max comp.
Bars:	-2mm	+15mm	-41mm
Aligner:	+10mm	-1mm	-32mm
Diff:	-12mm	14mm	-11mm

As can be seen, the curves cross over, indicating no correlation between data. This could be caused by one or a combination of several factors, including:

- the toe was not set to zero prior to the check;
- the steering wheel was not centred or locked in place;
- the suspension was unloaded with the bump-steer bars, but loaded on the wheel alignment machine with vehicle weight on the wheels;
- there may have been worn or soft suspension bushes, ball joints, steering joints, and steering box free play;
- measurement error.

Regarding the measurement error, if one measurement across the bars was taken to the inside edge of the bar instead of the outside, it would give a 25mm error. If this happened during the normal ride height measurement, the bars would give -10 mm instead of +15 mm and the difference between the bars and alignment machine would then be -12 mm, -9 mm, -11 mm which is much more consistent.

The cause of the different test results between measurement methods is not known, but led to further discussion and testing to check the theories. This vehicle was not available to recheck.

<u>May 2010 – Ford pick-up - Cheers Autos, Carterton</u>

The Ford pick-up was fitted with a Torana front end and an airbag suspension system which allowed bump-steer to be checked without removal of suspension components.

Wheel aligner method:

Measurements were taken on a Beissbarth wheel alignment machine, with the vehicle on 4-post hoist. Toe was set to zero and wooden blocks were wedged into rear suspension to prevent movement or sagging of airbags. The steering wheel was locked in centre position. The front sub-frame sat on the jack of the 4-post hoist and the wheels were raised and lowered by the airbag control system. The alignment machine measurement diameter was unknown at the time.

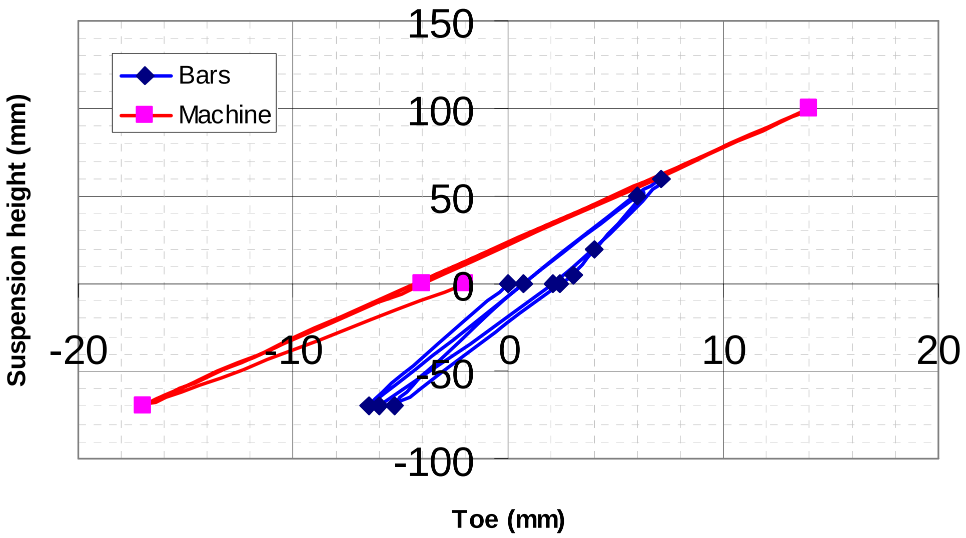
LVVTA bump-steer bar method:

Vehicle on 2-post hoist with 2 trolley jacks to support the front suspension. The bars were mounted to the same wheel studs each side so that bars were even and measurement was parallel to the front of vehicle. The tyre diameter was measured as 610 mm. The reference distance set on bars was 600 mm (this figure was chosen before the change to 575 mm).

Several measurements were made using the bars, to check repeatability. There was variation of figures when the measurements were repeated, by around 2 mm for both the bars and alignment machine. This was thought to be due to suspension bush compression. The results are as shown in the table and graph below.

	Toe figures (mm):	
Ride height:	machine:	bars:
• 320	0	-2
• 260	-6	-17
• 370	+6	+14

Ford pick-up data



The bump-steer bar measurement is over 600 mm (distance from AA measurement to BB measurement). The electronic alignment machine does not specify measurement distance, but by switching between mm and degrees on the read-out it could be calculated. This was done on the Commodore and it was found that 2 mm toe equates to zero degrees and 15 minutes. This indicates that the machine uses a measurement distance of about 460 mm (18 inches). However, this may change depending on the vehicle type entered into the computer – the Commodore had 18 inch wheels as standard.

Assuming the 460 mm figure is relevant for the truck measurement, the aligner data can be corrected to be equivalent to the bars (600 mm) and the measurement difference between bars is reduced.
Here is a comparison of the corrected machine figures (to 600 mm):

	Toe figures (mm):	
Ride height:	machine:	bars:
• 320	0	-2
• 260	-7.8	-17
• 370	+7.8	+14

These figures are slightly closer but still not comparable. If the alignment machine was using a smaller wheel diameter to measure across, the data would be closer (13 inch wheel would change the 7.8 mm figure to 10.9 mm). Regardless of this, the data will not match up exactly as the slope of each line on the graph is different, indicating that there are other differences present.

Unfortunately, the exercise on the Ford pick-up remains a head-scratcher for us, and we still don't know exactly what happened to give us the large and unaccounted for difference in figures. As a result of this unresolved outcome, LVVTA tested a number of different vehicles in different ways at different locations (outlined further on in this Information Sheet), to try and better understand the process and gain confidence that if everything is set correctly and used correctly, the outcome between the LVVTA bars and a wheel alignment machine will be very close.

<u>May 2010 – 2009 Commodore - Cheers Autos, Carterton</u>

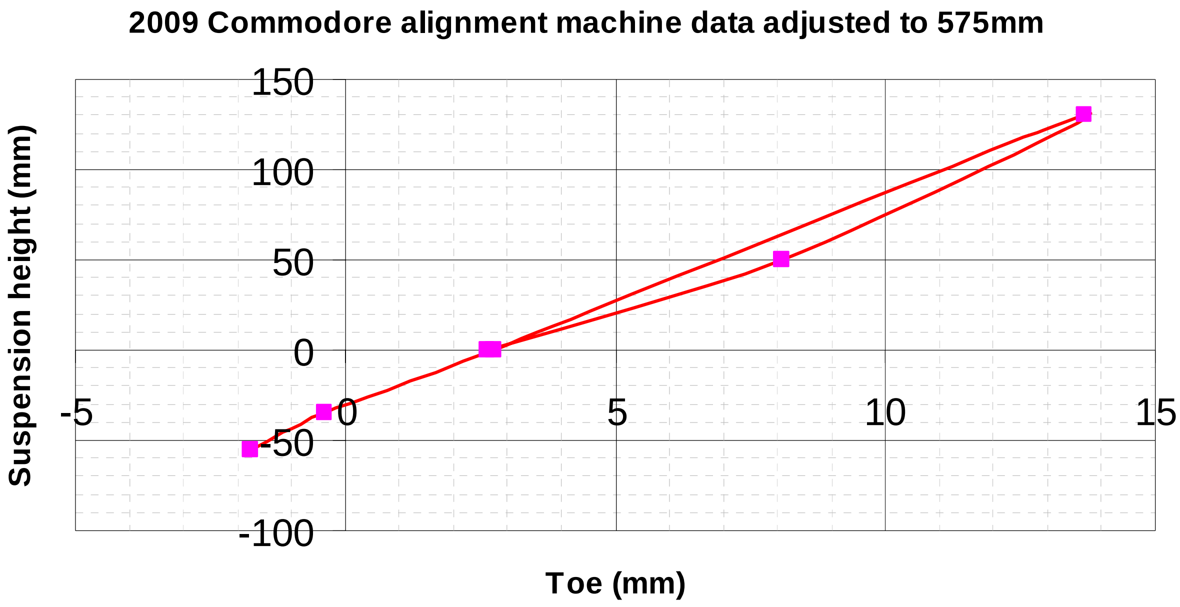
It is often difficult to remove springs from vehicles, so a different test method was assessed. With springs in place and the vehicle on a 4-post hoist, the built-in jack can provide full suspension extension, and the vehicle can be weighed down to provide some suspension compression. This was tested on a 2009 Holden Commodore.

The suspension was fully extended to 130 mm and suspension compression of 35 mm was achieved with approximately 200 kg load, and 55 mm compression was achieved with approximately 350 kg of load.

The reference distance is known so these figures have been adjusted to the equivalent of a 575 mm reference distance in order to be comparable to later data.

The Commodore toe figures on the alignment machine are shown in the following table and graph (575 mm reference distance).

Ride height (mm)	toe (mm)
• 325 (static)	+2.6
• 375	+8.1
• 455 (full ext.)	+13.7
• 290	-0.4
• 270 (55mm comp.)	-1.7

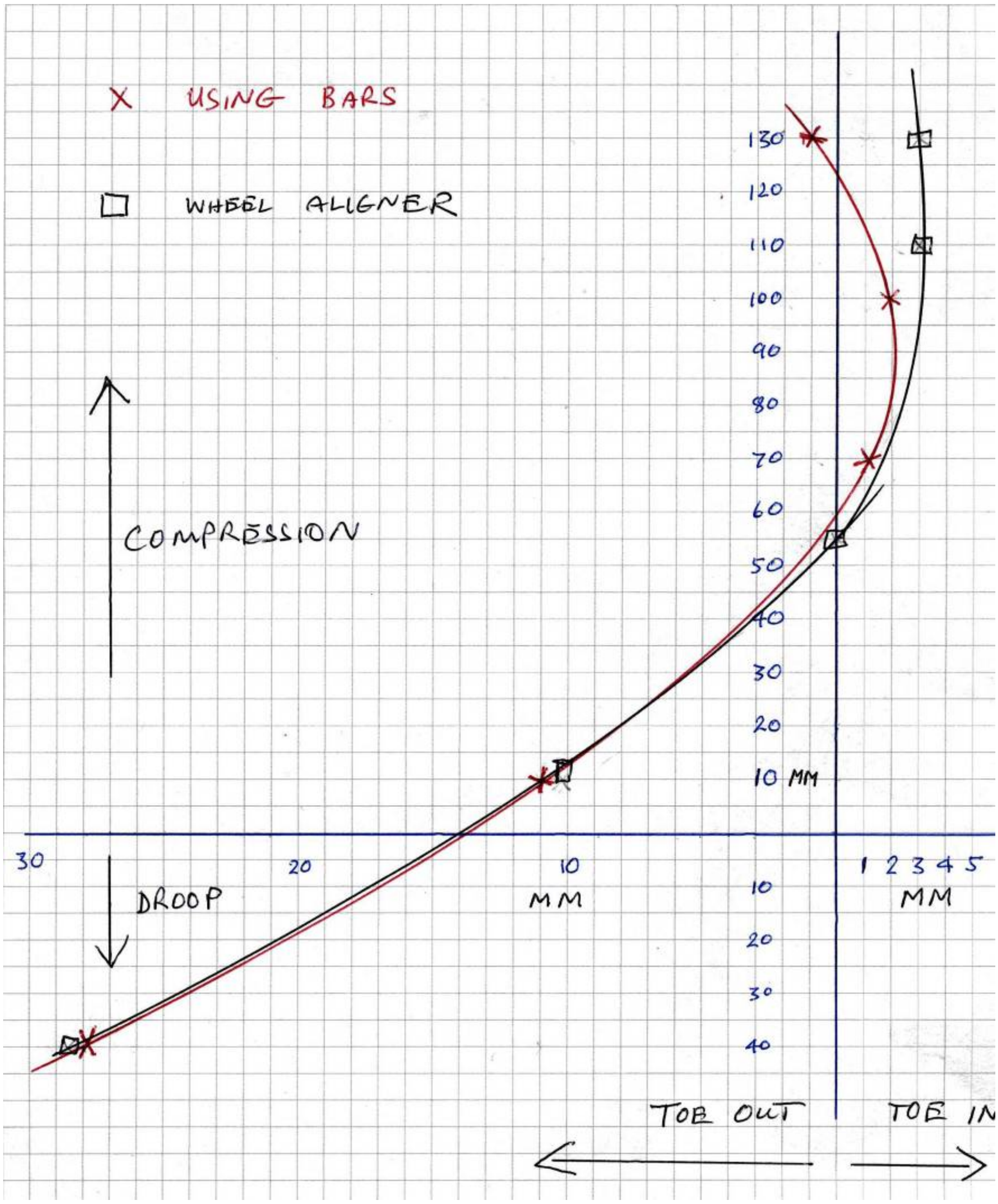


<u>July 2010 - Fraser 7 – Auckland:</u>

Chris Litherland (LVVTA Technical Advisory Committee) and Justin Hansen conducted a comparison test of bars and alignment machine on a scratch-built Fraser 7 sports car. This vehicle was chosen as the suspension features heim joints and so will not suffer from rubber bush compression. Some spacers were made up to fit between the steering arms and the tie rod ends to create some geometry problems so that we would have some toe-change to measure.

This test showed a very close correlation between the LVVTA bars and the wheel alignment machine.

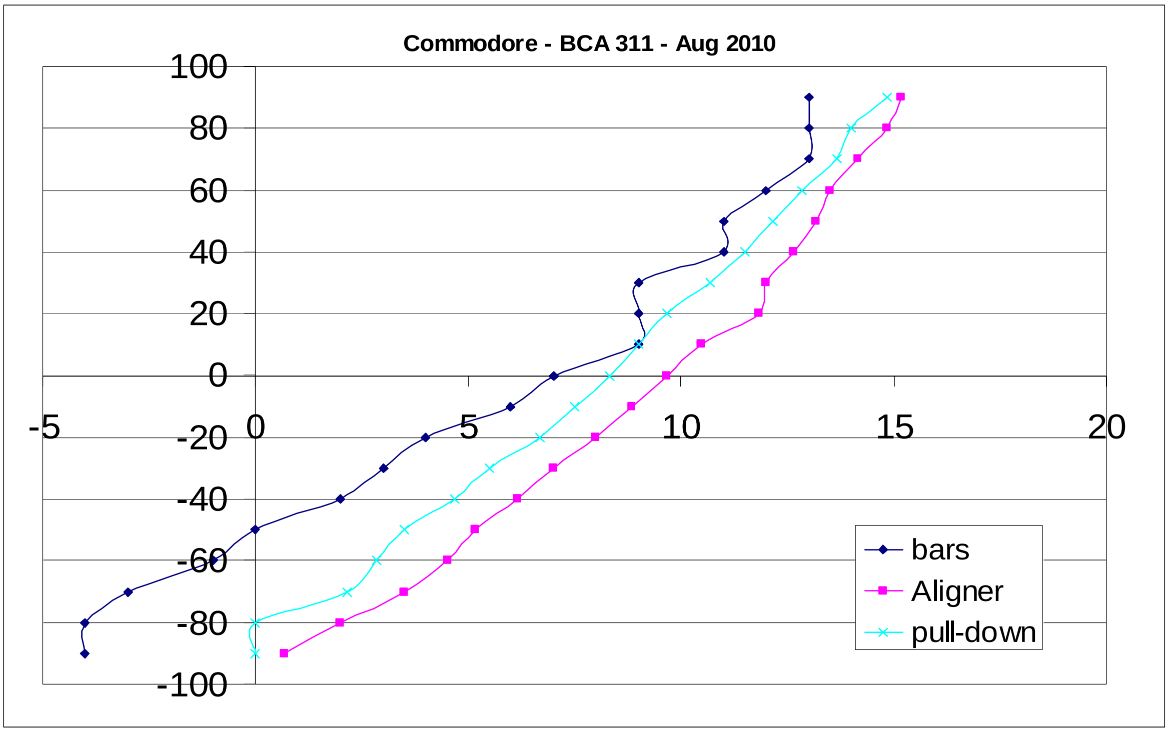
The results are as shown in the following graph:



August 2010 – 1998 Nissan Primera and 2003 Holden Commodore - Auckland

The 1998 Nissan Primera was measured using the bars, with the springs removed. Toe change was minimal throughout suspension travel (maximum of 5 mm away from the static ride height figure).

The 2003 Holden Commodore was also measured using the bars, with the springs removed, and also measured on the wheel alignment machine with springs removed and by the pull-down method. See below the graph showing all of the data (all three different measuring methods) for the Commodore. The following photo shows the chain and tie-down strap used to pull down the vehicle.



The data for the alignment machine with and without springs fitted is separated by about 2 mm but is very consistent. Flex on the suspension bushes will account for the 2 mm variation. The data from the bars is also very close, especially for suspension extension. These tests gave LVVTA the confidence that if carried out correctly the results between all three different ways of carrying out the test will be more or less the same.

<u>September 2010 - Scratchbuilt Almac based on Cortina suspension – Porirua Shock Shop</u>

Lastly, with our theories sorted out, and with a better understanding of the whole issue, a final and very thorough of three consecutive comparative tests were conducted on a Cortina-based Almac with a pair of extended tie-rods (to create some geometry problems) as circled in the photo below.

Test 1 - Alignment machine:

Vehicle on 4-post hoist, pulled down with a chain and bottle jack, as shown. Measurements were taken first with raising the car up, then by pulling it down. The alignment machine was set to measure in degrees, to avoid any question over the measurement distance. The bar's measurement was set at 575 mm to enable a direct comparison (1 degree = 10 mm).

Ride height measurements were taken from top of wheel rim to arch. The wheels are 15" so 190 mm can be added to give centre of wheel to arch measurements.

Test 2 - Bars fitted over the wheels, springs in:

Vehicle on 4-post hoist, pulled down with a chain and bottle jack. The bump steer bars were fitted over the wheels by using long adaptors (accurately machined) mounted to 2 wheel studs. Measurements were taken first by pulling the car down, then raising the car up. Toe at static ride height was measured again after pull-down and the same toe figure was recorded.

The bars were not levelled for each test - the brakes were locked on instead - so at full droop the bars were away from horizontal. To check that this had not affected the results the bars were levelled by readjusting the fitment to the wheels - the result changed by only 1 mm from +37 mm to +36 mm.

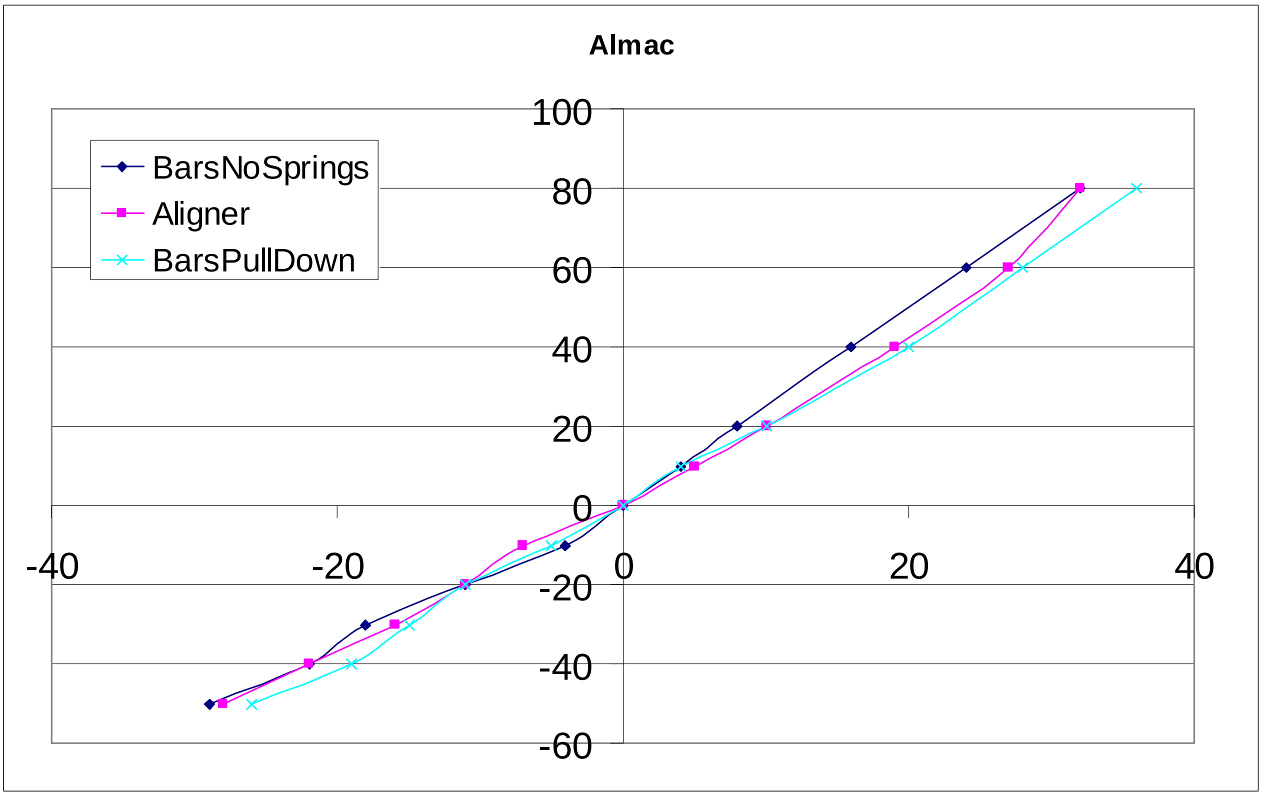
Test 3 - Bars fitted over the wheels, springs removed. Car jacked up on a trolley jack:

The workshop did not have 2 trolley jacks to lift each hub up while the car is on axle stands as we have done previously, so the test was conducted slightly differently; - the wheels were left on the vehicle and the trolley jack lifted the chassis. This will give a similar result to the usual method, with the loads going through the wheel hub instead of the lower arm under the ball joint.

The bars were fitted over the wheels as in the other tests. The tyres were placed on wood blocks to gain ground clearance for the bars so it was not possible to use slip plates. A check was made to ensure that the tyres were not dragging due to friction with the wood. The wheels were briefly lifted up at full droop and placed back down on the wood to relieve any side loads. The measurement across the bars did not alter.

The results of the three different methods showed a very good correlation between methods, and none of the variance we might have expected from the various worn bushes and joints present on this vehicle. Note that the original steering rack was badly worn so a reconditioned item was fitted prior to testing.

This is the graph of all 3 results with the data aligned around the zero point:



The graphs show the difference between measurements of the 3 methods was around 3 mm and fairly consistent.

This difference is negligible, and there can be several explanations for the difference, including:

- measurement error - at least 1 mm error is likely with a hand-held tape measure;
- fitment of bars is unlikely to be perfect so they will never give an absolutely exact toe reading. We tested this by pulling on the bars and re-measuring - we got a change of 2 mm.

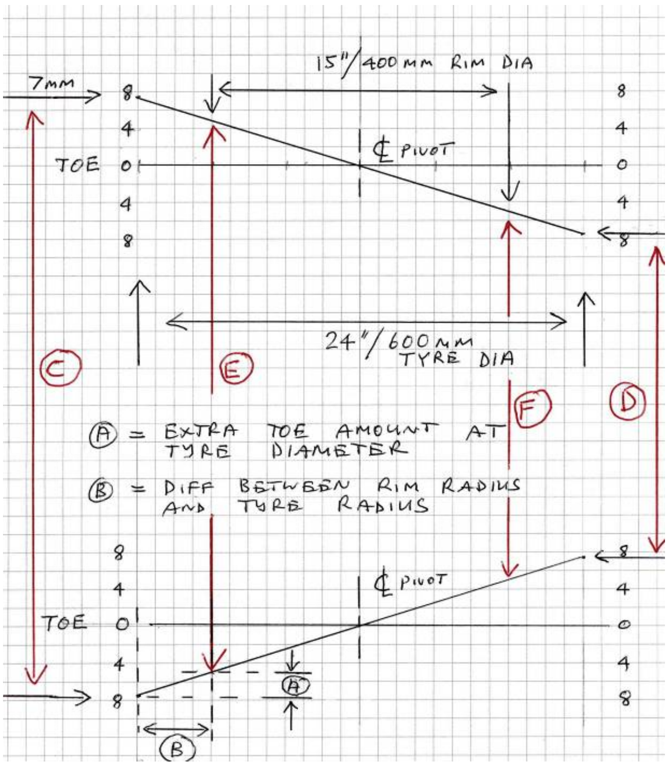
This discrepancy of 1 to 2 mm is not seen as an issue as we are only interested in the change of toe compared to static ride height. Interestingly, skilled operators of computerised wheel alignment equipment report exactly the same issues.

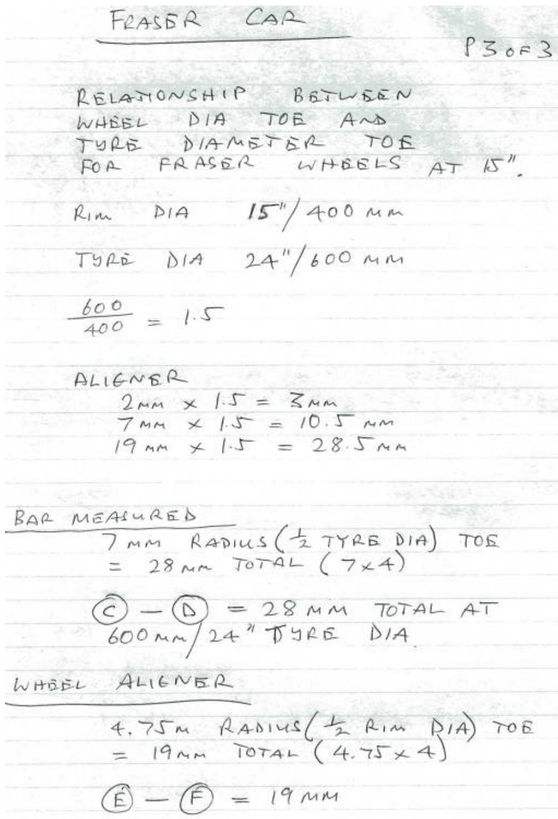
Notes relating to the Cortina-Almac test:

- The lowered tie-rods did their job of providing noticeable toe change. Comparing the data to the graphs on page 4 indicates that better toe-change requires the tie rod end to be raised – this is consistent with the change made and indicates the standard tie rods will give less toe-change.
- The vehicle was relatively softly sprung on shortened Cortina springs. Vehicle weight is 5-10% less than a Cortina.
- The range of suspension travel tested was 80 mm in extension and 50 mm in compression. This was not quite the full extent of travel available - the bump stop was still 10 mm away from contact. The modified tie-rods were almost binding in extension.
- The method of fixing the bars over the wheels is an added convenience - a bump-steer check could be done more simply as it allows the pull-down method. This is especially useful if we only need to see the toe-change over the usual range of suspension travel, not over the complete range capable of being provided with the springs removed.

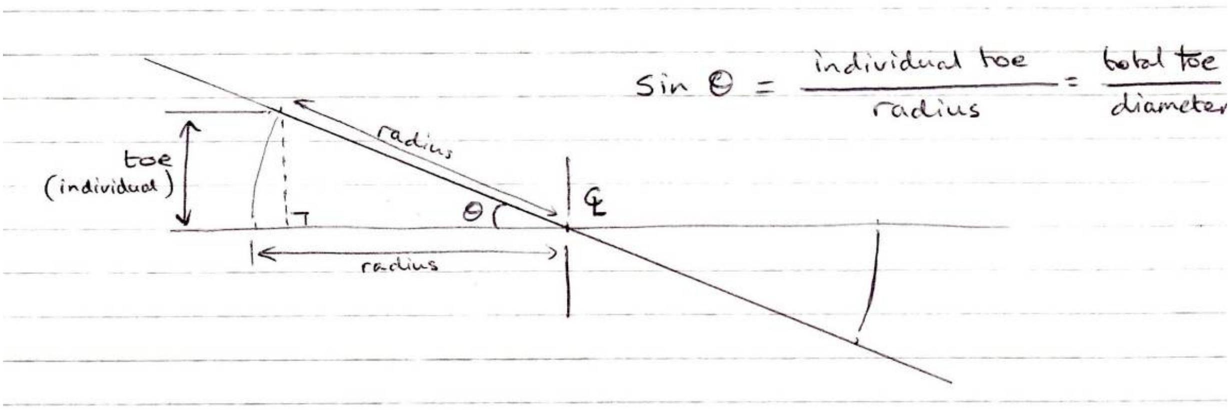
Appendix 2 – Technical explanation of geometry

The following diagram shows the geometrical relationship of toe and compares measurement across a 15 inch rim and a 24 inch tyre, showing that the toe figure is greater with a larger measurement diameter:





Measurements were taken for the Fraser in mm and degrees, so the correlation between them can be checked.



Referring to the illustration above, the relationship between toe and measurement diameter can be defined by: The sin of the toe angle = toe (in mm) divided by the measurement diameter.

The Fraser data gives 3 examples from which to calculate the diameter:

Degrees:	mm:	calculated diameter:
• 2 deg 51 min	19.0	382 mm
• 1 deg 2 min	6.8	377 mm
• 0 deg 18 min	2.0	382 mm

382mm is 15 inches, proving that the alignment machine is using the 15" rim diameter as a reference.

Finally:

We hope that this Information provides helps you to understand some of the issues associated with the process of measuring bump-steer.

If any assistance in the use of this Information Sheet is needed, or if anyone has any information that they think may be useful to LVVTA, please contact an LVVTA technical team member at the Wellington LVVTA office.

Dan Myers
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