Toyota RAV4 Loss of Control and Collision Study

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1. Introduction

This report discusses a traffic incident involving Mrs Blunt when she was driving a Model 2006 Toyota RAV4, Queensland registered, at a location in the Gold Coast. The vehicle sustained damage and Mrs Blunt was injured.

The motivation for the publication of this report is to inform others of a potential weakness in the subject vehicle model so that a potential accident may be avoided. Other models have not been investigated for possible similarities.

The report discusses loss of control of the vehicle and the potential involvement of Rear Number 1 Suspension Arm.

The component, Rear Number 1 Suspension Arm, is discussed in terms of the mechanism of failure and its effect on the drivability of the vehicle.

An elevation photo of the vehicle type as well as an exploded view of the Rear Number 1 Suspension Arm is shown in Figure 1.

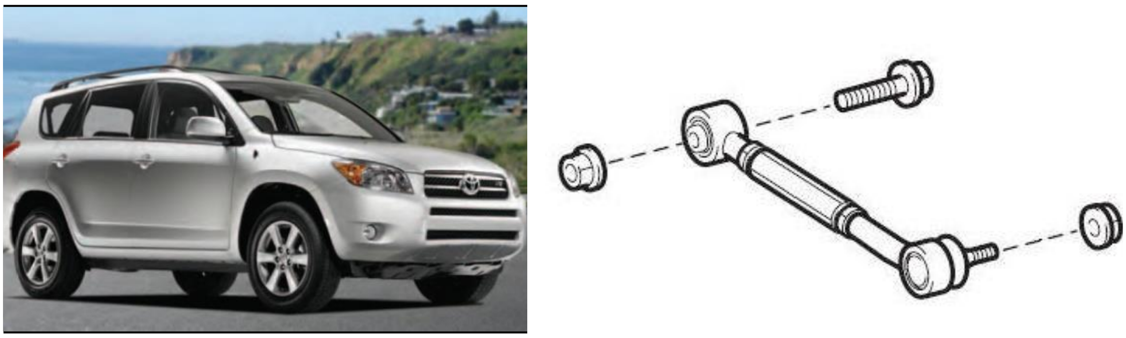

Figure 1 – Typical Toyota model RAV4 with exploded Rear Number 1 Suspension Arm.

The incident Rear Number 1 Suspension Arm, as first photographed by the author upon arrival at a Smash Repair Facility is identified in the actual vehicle by Figure 2.

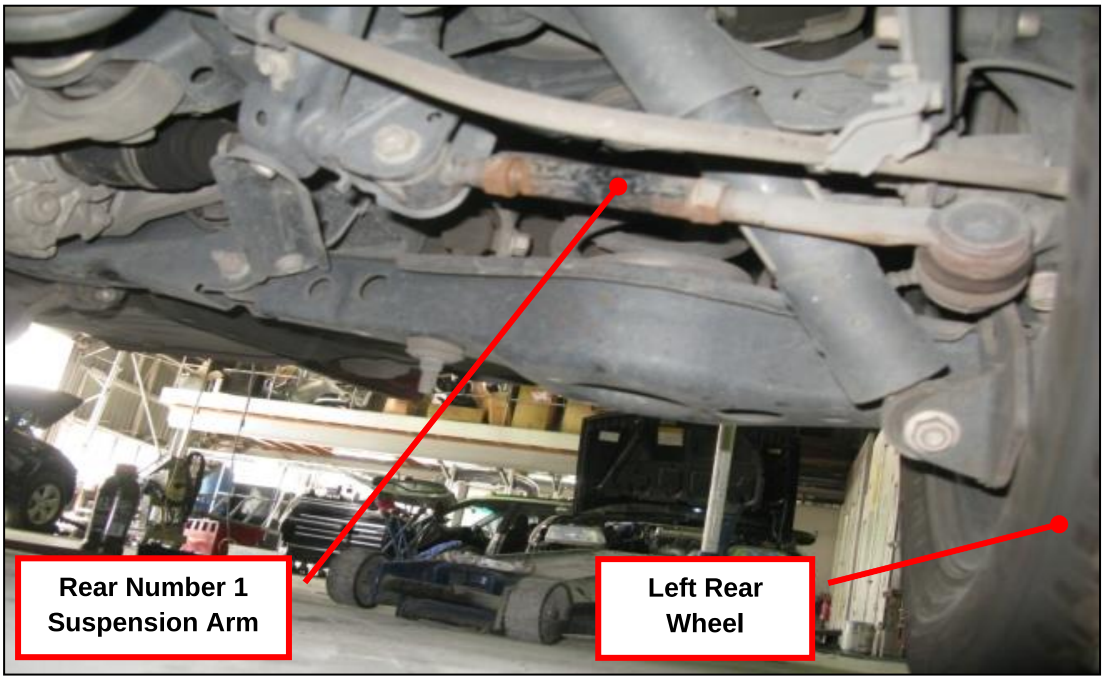

Figure 2 – Photo taken by the author of Rear Number 1 Suspension Arm.

This report is based on inspection of the vehicle, telephone interviews with Mrs Blunt, and component inspection.

2. Description of Incident

Some notes here help in understanding the sequence of events.

1. The vehicle was driven by Mrs Blunt.
2. The incident occurred at approximately 5:00 pm.
3. Vehicle speed was approximately 100km/h, keeping general pace with the prevailing traffic along a straight section of the road.
4. She noted that traffic had been heavy preventing her from changing lanes into the left-hand lane for some distance.
5. Mrs Blunt noticed that the steering wheel was no longer straight.
6. Directly after, the vehicle became difficult to control and steer.
7. Mrs Blunt recalls making a conscious effort not to overreact with steering while trying to regain control.
8. Mrs Blunt's car impacted the Armco rail on her right hand side and the vehicle jostled left and right until she came to rest some metres past the Armco rail in the median nature strip.

3. Description of Vehicle during Inspection.

The vehicle was inspected at the premises of the Smash Repair Facility. The right-hand rear wheel had been removed.

The mechanic at the facility noted that the left-hand rear wheel was displaced at an angle to the vehicle. The front of the left-hand rear tyre pointed outwards and needed to be “kicked” in to manoeuvre the vehicle off the delivery truck, alluding to a procedure of impact to one side of the left-hand rear wheel.

The vehicle was photographed at the facility by the author and the photograph appears below in Figure 3.

It was noted that the left-hand rear wheel was angularly displaced so that the front of the tyre was proud of the vehicle wheel arch while the rear of the tyre was well into the wheel arch. This was photographed by the author and shown in Figure 4, the arrows showing the direction in which the wheel was displaced.

A straightedge from the workshop floor was applied to the wheel to illustrate the degree of angular displacement of the left-hand rear wheel in Figure 4.

Figure 3 – Photo showing angular displacement of rear wheel (arrows show direction).

Figure 4 – Straight-edge on wheel showing outward displacement.

For better understanding a drawing sourced from the Toyota Factory Service Repair Manual[1] is helpful, and is posted in Figure 5.

The relevant sections from the Factory Service Repair Manual for a 2006 Toyota RAV4[1] are attached (Attachment 1) as follows.

- Suspension – Rear Number 1 Suspension Arm Pages SP – 41 to SP – 43
- Suspension – Rear Wheel Alignment Page SP – 7
- Service Specifications – Suspension – Pages SS- 76 to SS -78.

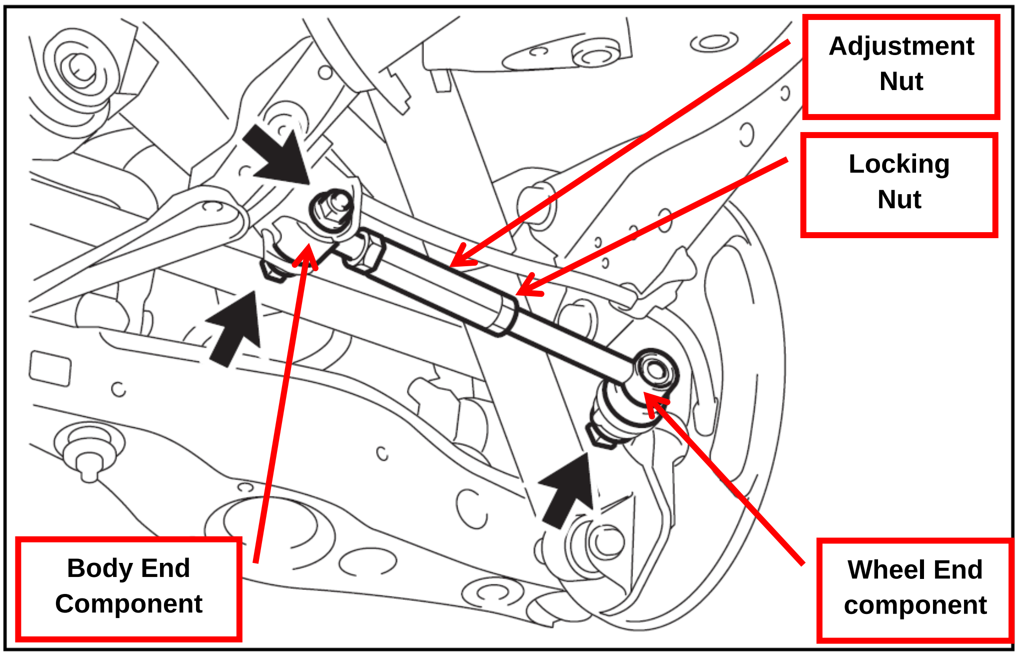

Figure 5 – Rear Number 1 Suspension Arm components[1].

The Rear Number 1 Suspension Arm was photographed by the author upon arrival at Smash Repair Facility and again after manipulation of the rear left wheel, in order to establish at the maximum extent the angular misalignment that could be manipulated by manual methods. Figure 6 and Figure 7 are ‘before and after’ manipulation photographs taken by the author.

It was observed that the Rear Number 1 Suspension Arm was lengthened as a result of the manipulation by an amount approximately equal to the double ended red arrow shown in Figure 7.

Figure 6 – Body end component as photographed before wheel manipulation.

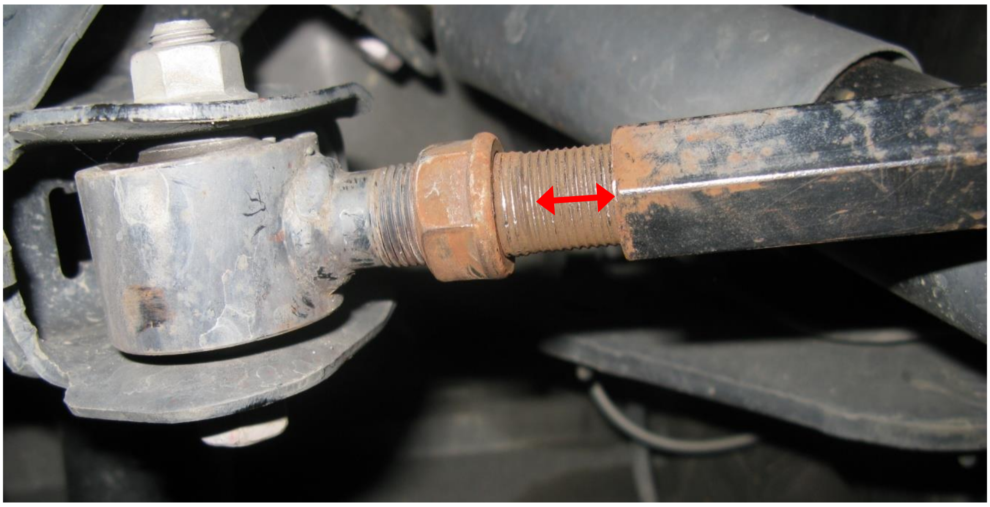

Figure 7 – Body end component as photographed after wheel manipulation.

The Rear Number 1 Suspension Arm was then photographed by the author from various angles to visually assess the extent of damage. These photos appear in Figure 8 to Figure 10. Captions under the figures indicate the nature of damage. The photos in Figure 8 to Figure 10 were taken from the underside of the vehicle. The engagement within the arm was quite loose.

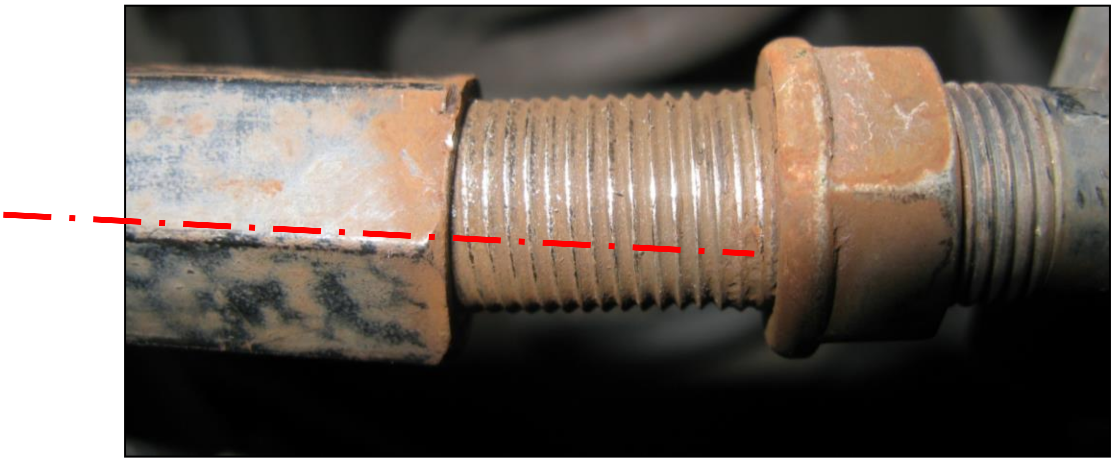

Figure 8 – Highlighting misalignment.

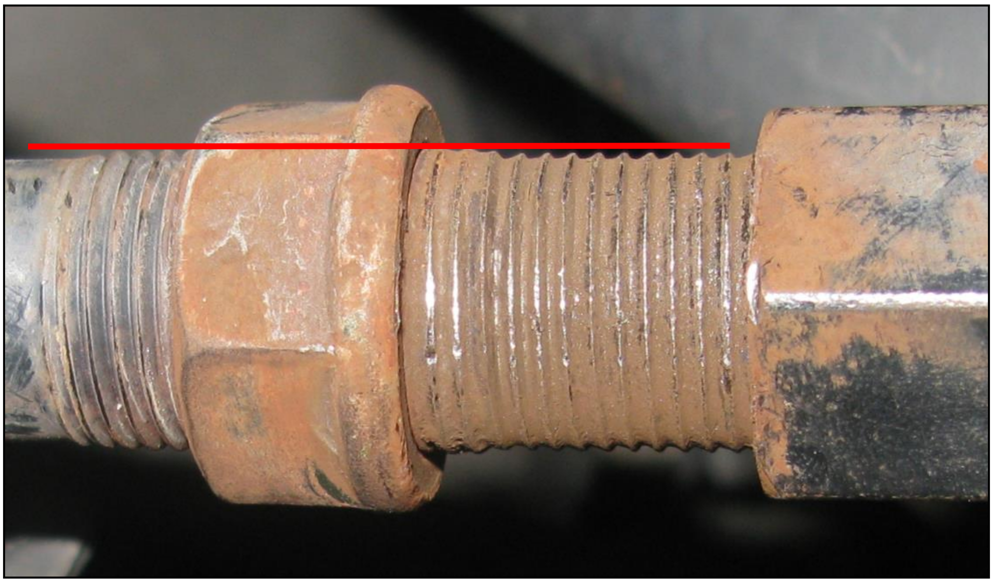

Figure 9 – Highlighting reduction in thread diameter.

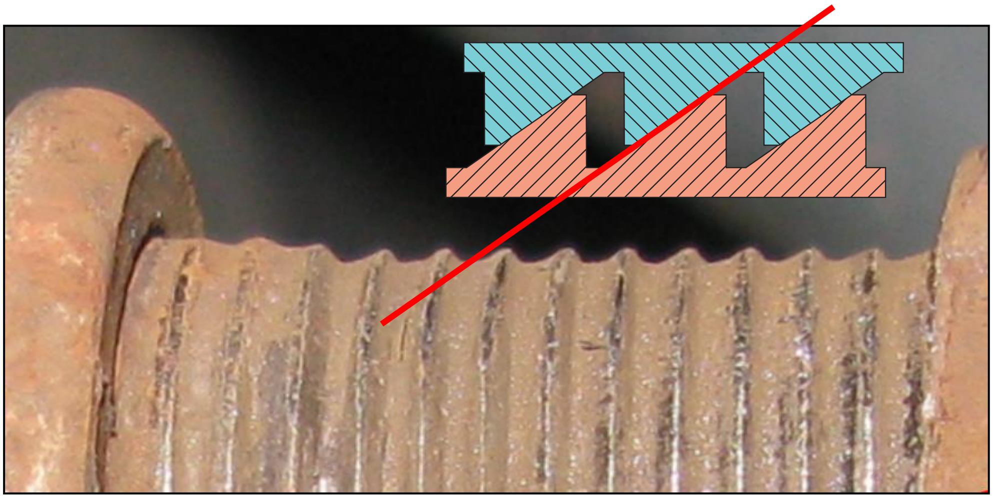

Figure 10 – Highlighting reshaped thread.

3.1.1 Body panel damage

Observation of body panel damage to the left and right-hand side of the vehicle are shown by the following photographs taken by the author in Figure 11 to Figure 15.

Figure 11 – Photograph of rear bumper showing damage to right-hand side. (Bumper was stored upside down)

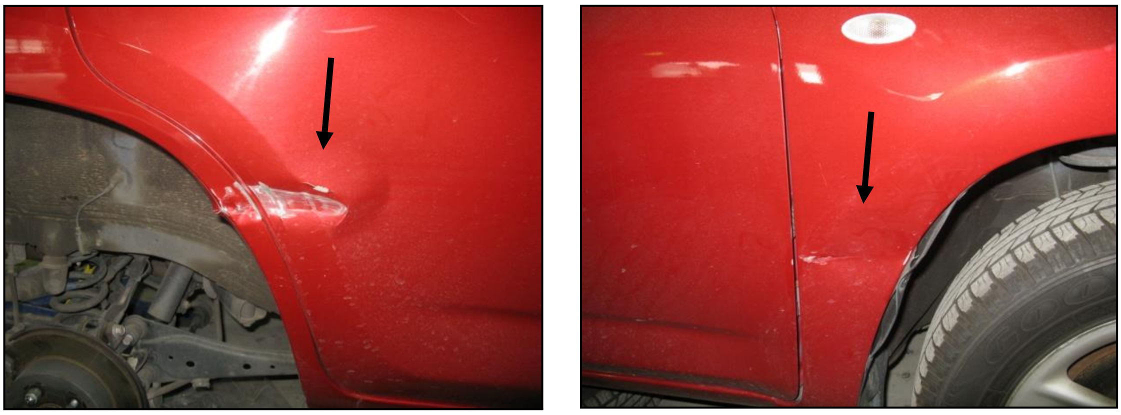

Figure 12 – Photographs of right-hand side damage to rear and front wheel arch.

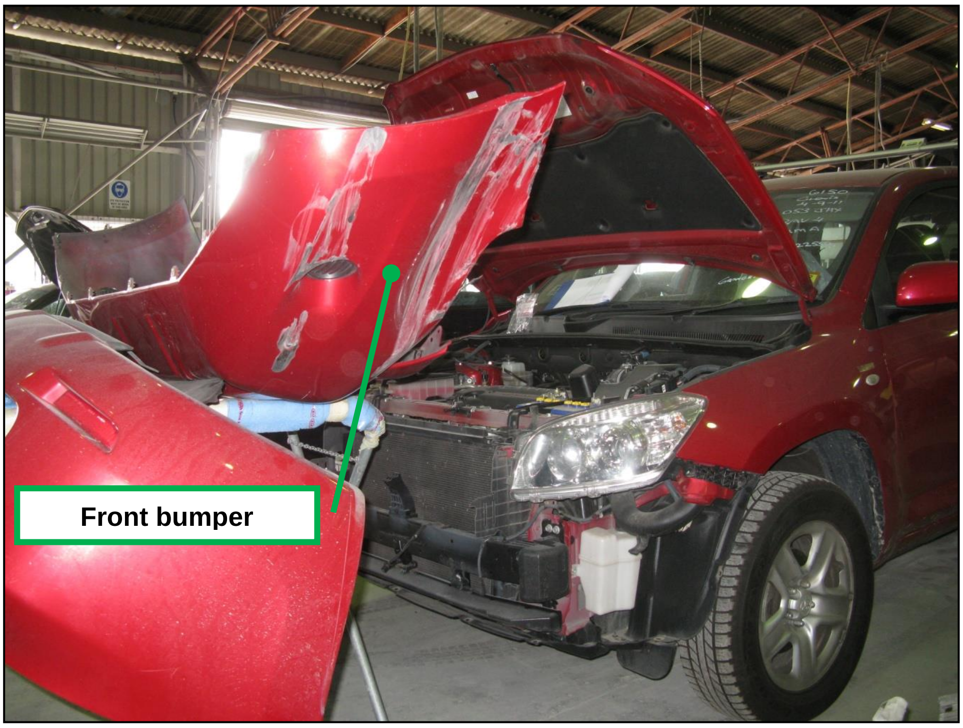

Figure 13 – Photograph of the front bumper showing damage to right-hand side. (Bumper was stored upside down).

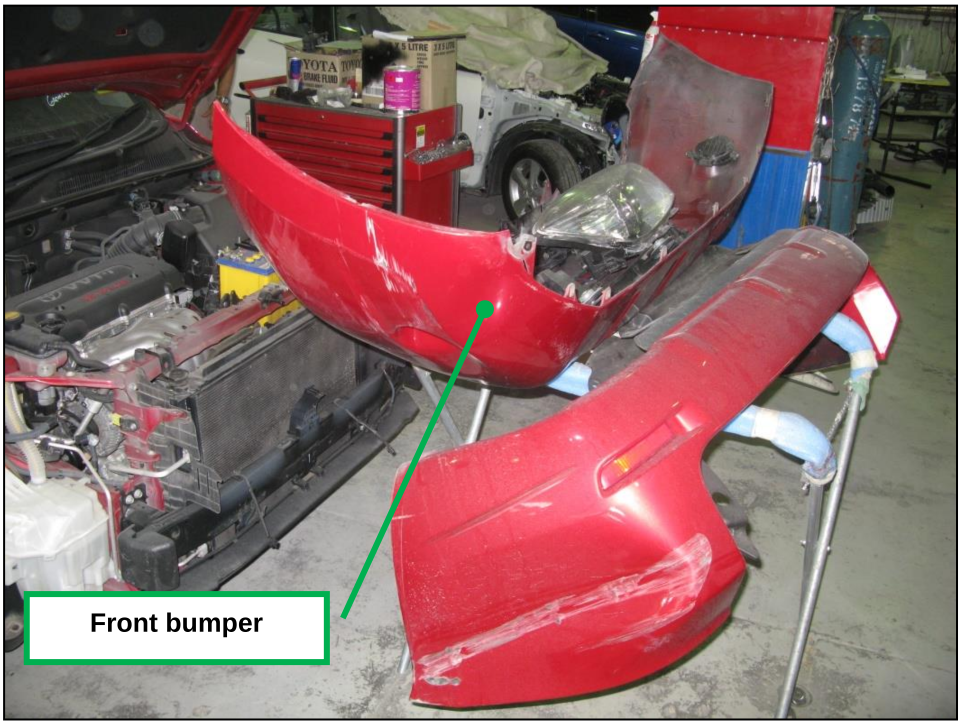

Figure 14 –Photograph of the front bumper showing damage to the left hand side. (Bumper was stored upside down).

Figure 15 – Close-up photograph of the front bumper showing damage to the left hand side. (Bumper was stored upside down).

Photographs were taken by the author that were inconsistent with other aspects of the incident. These appear in Figure 14 and Figure 15.

Enquiries were made with Mrs Blunt who advised that the accident damage described above was reported to the insurance company some five months prior. This is to help the reader understand that the damage observed and presented in Figure 14 and Figure 15 is not related to this incident.

4. Component Inspection

The Rear Number 1 Suspension Arm was recovered by the author from the Mechanic at the Smash Repair Facility, for study.

The Rear Number 1 Suspension Arm was disassembled by the author by simply pulling the components apart manually. There was almost no restraint offered by the thread. The two sub components are shown in Figure 16, comprising body mounted end on the left of the photo and wheel mounted end to the right of the photo.

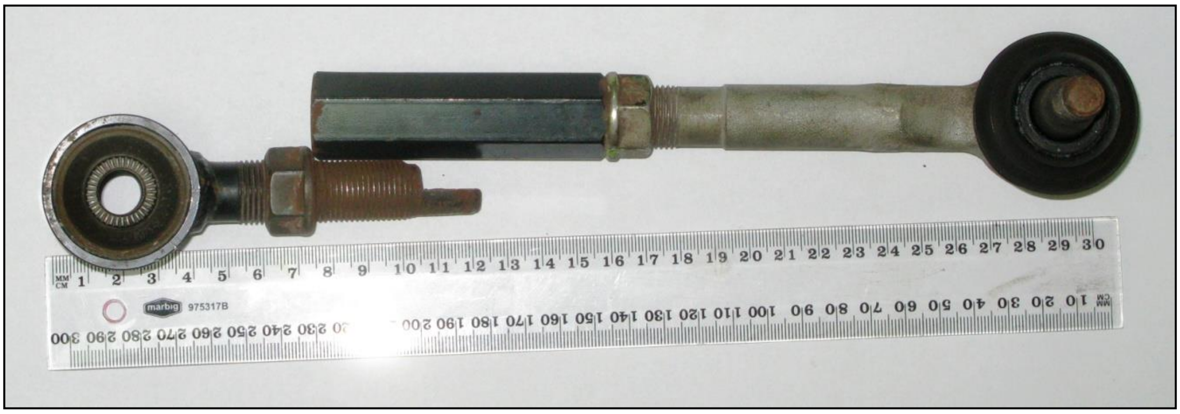

Figure 16 – Disassembled Rear Number 1 Suspension Arm into two sub components.

The subcomponent of the left-hand side of Figure 16 is a welded fabrication whereas the subcomponent on the right-hand side exhibits a forging. An observation made was that while the parts offered little restraint to tensile forces, the Rear Number 1 Suspension Arm in compression did not appear to be impaired. This is highlighted by the observations in Figure 17.

The ends of the subcomponents were photographed to highlight the burnishing of surfaces indicating the presence of heavy rubbing or impact. This is shown in Figure 17.

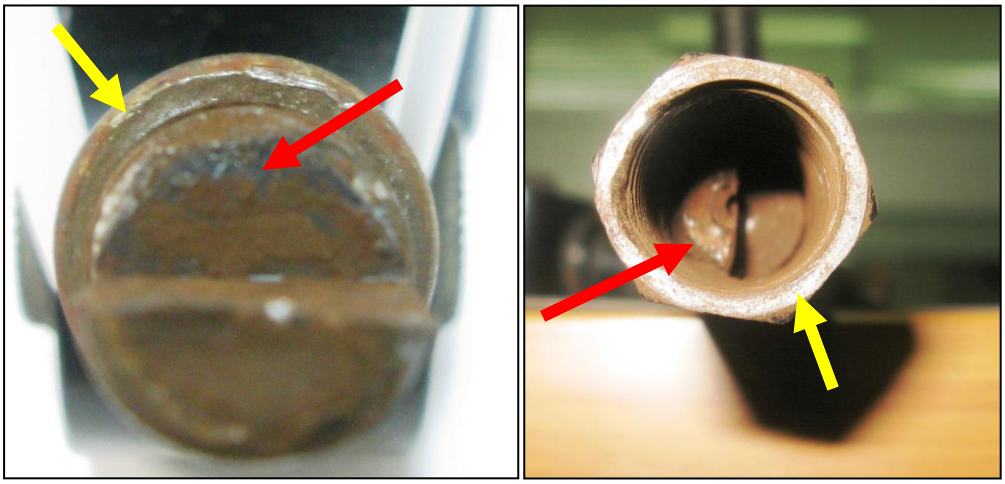

Figure 17 – End view photos of subcomponents showing burnished surfaces (colour of arrows indicates paired surfaces).

Figure 17 shows surfaces have contacted under impact conditions. It would not normally be a feature of these components to be touching when steering alignment is being performed. This is not to say that they couldn't touch if required by the extent of adjustment needed. The burnished surfaces are an indication of continued impact (flogging) over time.

5. Discussion of Arm Failure

It is noted that the Rear Number 1 Suspension Arm is structurally connected, metal to metal, transmitting road vibration up to the antivibration mounting to the body. Thus the arm is susceptible to the effects of road vibration, having implications in the choice of methods of nut retention (e.g. locking nut, spring washer, etc)

The black arrows correspond with values for tightening torque in the Factory Service Repair Manual[1]. Notable is the apparent absence in the manual of a torque value for locking the adjustment nut.

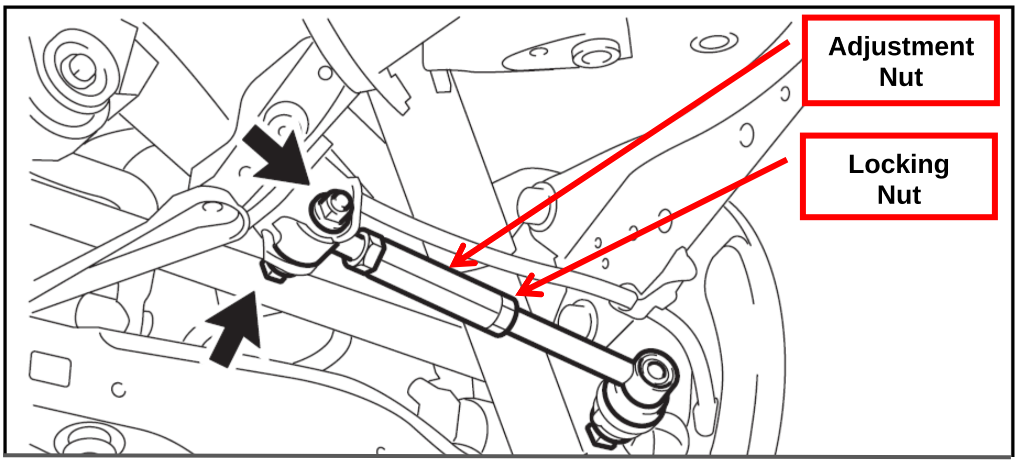

Figure 18 – Rear Number 1 Suspension Arm highlighting adjustment and locking nuts.

The purpose of the locking nuts is to resist loosening of the thread. One flank of each thread must remain in continuous contact to resist vibration. The idea is embodied in Figure 19 below.

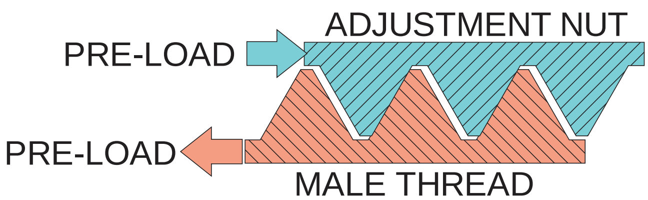

Figure 19 – Visualisation of thread locking.

The intimate contact created by the preload increases friction at the thread flanks, thereby reducing the likelihood of nut loosening.

Bickford (2008)[2] sheds some background on the subject of thread loosening under conditions of vibration:

> *We probably don't know why a fastener will self-loosen under vibration, shock, thermal cycles, or the like. A number of theories have been advanced, and their authors believe they know, but the theories vary. They can't all be right—perhaps none are.*
>
> *All agree that a fastener subjected to shock or vibration or thermal cycles will not lose all preload immediately, but will first undergo a relatively slow loss of preload. No one knows for sure why this progressive loss occurs, but it has been well documented [Most seem to think that cyclic forces applied to the thread surfaces by vibration and the like cause additional embedment and the slow destruction—the breakdown—of contact surfaces. Only after sufficient preload has been lost by this process will the friction forces between thread surfaces be low enough to be overcome by subsequent load cycles. At this point the nut will loosen rapidly.*

The road vibration passes through the Rear Number 1 Suspension Arm as a strain disturbance and mostly dissipates at the rubber insulation mount. If the preload on the locking nut is inadequate, the metal strain can cause the thread flanks as well as locking nut and adjustment nut contact surfaces to separate (and flog). Under these conditions the locking nut can progressively open the gap between the mating faces and thus come loose.

> ***Tightening Bolts****: Bolts are often tightened by applying torque to the head or nut, which causes the bolt to stretch. The stretching results in bolt tension or preload, which is the force that holds a joint together. Torque is relatively easy to measure with a torque wrench, so it is the most frequently used indicator of bolt tension. Unfortunately, a torque wrench does not measure bolt tension accurately, mainly because it does not take friction into account. The friction depends on bolt, nut, and washer material, surface smoothness, machining accuracy, degree of lubrication, and the number of times a bolt has been installed. Fastener manufacturers often provide information for determining torque requirements for tightening various bolts, accounting for friction and other effects. If this information is not available, the methods described in what follows give general guidelines for determining how much tension should be present in a bolt, and how much torque may need to be applied to arrive at that tension.*
>
> *High preload tension helps keep bolts tight, increases joint strength, creates friction between parts to resist shear, and improves the fatigue resistance of bolted connections.*[3]

An Officer at the Toyota Facility informed the author that the pre-tension torque for the Rear Number 1 Suspension Arm locking nuts is required to be 56 Nm, from a Toyota document that he was not permitted to share.

This torque value appears inadequate given the published torque values for much smaller bolts attached to the Rear Number 1 Suspension Arm require 90 and 100 Nm. The expectations from the author's experience would be in the order of approximately 200 Nm and even higher depending on the quality of the material used by Toyota for the components of this arm.

Further, the spanner required for the accurate tensioning has to be an open-ended spanner because of their inability to use a socket that is typically used with a tension wrench. An example of an open-ended tension range can be found in Figure 20 below

Figure 20 – example of a set of open-ended spanners and tension wrench.

An open-ended tension wrench is not commonly found in the toolboxes of small service mechanic establishments. Because of this, a turn-of-the-nut method may be more of a convenient torque control of pre-tension in the Rear Number 1 Suspension Arm after rear steering adjustments, provided that a suitable conversion from Nm to degrees turn-of-the-nut is applied. Such a conversion would require knowledge of material properties from the makers of the components.

Thus it is unlikely that a small service mechanic establishment would have access to this method of a torque control. An indication of the complexity of this method to achieve simplicity at the mechanic level is given by Fisher (2001)[4] in Figure 21 where it can be observed that a ½ turn of the specified nut on certain length bolt of Grade A490 material will produce ~54,000 lbs force in the bolt.

Input parameters into the process are bolt diameter, thread details, lubrication and material properties, etc. Thus, it is recommended that the car manufacturers provide a simpler method of bolting tension control on such an item requiring adjustment by tyre technicians who may not have auto-mechanic qualifications.

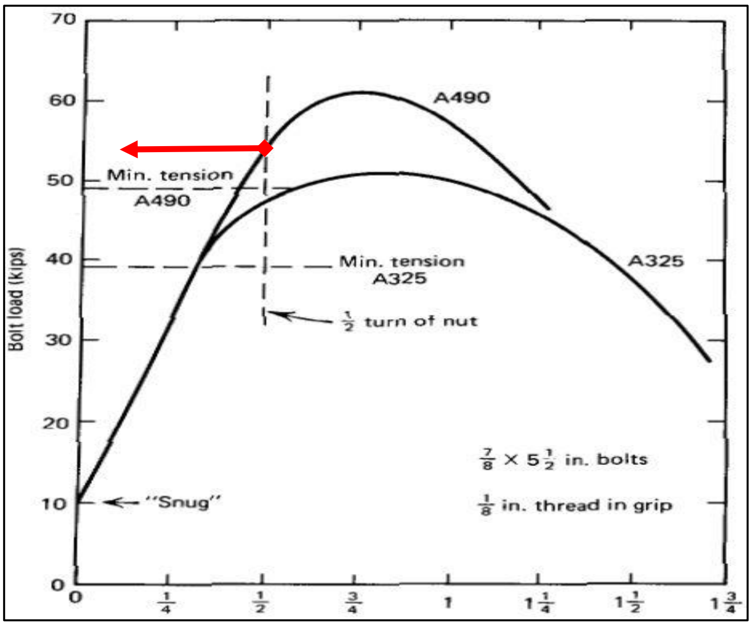

Figure 21 – Example of turn-of-the-nut method of controlling bolting tension

Road surface imperfections and potholes transmit vibrations through the Rear Number 1 Suspension Arm. Material inertial effects occur inside of the Rear Number 1 Suspension Arm as a result of vibration, even though the connection to the body has a vibration mount. These effects manifest in the material as a strain disturbance. Figure 22 is a visualisation of such a strain disturbance to illustrate the importance of adequate preload. The strain disturbance above the inadequate preload line can cause a nut loosening effect. This nut loosening effect manifests as a gap between the surfaces of the underside of the locking nut and the top of the adjustment nut. Once a gap is formed between the two mating surfaces the loosening effect can continue and open the gap further.

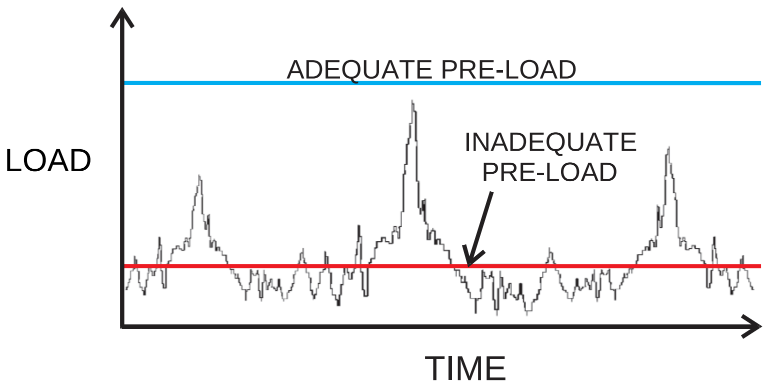

Figure 22 – Visualisation of road vibration strain disturbance passing through Rear Number 1 Suspension Arm.

Once the vibration has achieved a gap between the mating faces of the locking nut and the adjustment nut, impact can develop as a result of road dynamics caused by potholes and other undulations in the road surface. As a result of this impact, the locking nut loosens further until the thread faces begin to impact on each other. The result is that the threads are hammered into each other and reshaped as visualised below (Figure 23).

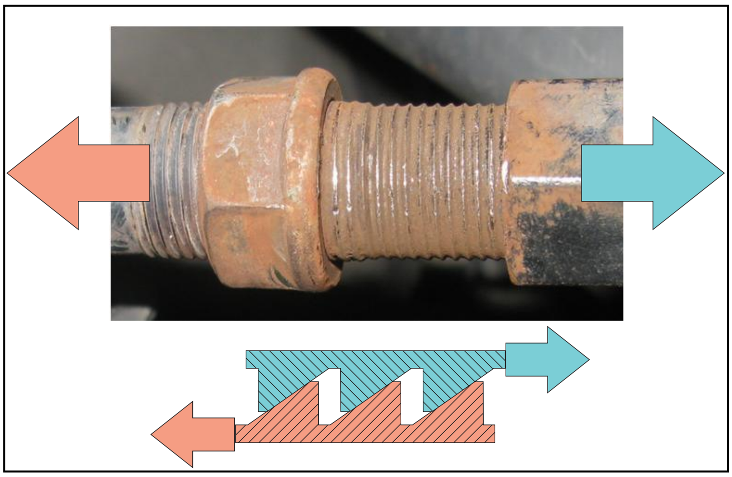

Figure 23 – Impact force direction and thread form reshaping.

The normal shape of thread form can be found in Figure 19.

The process also reduces the diameter of the male component and increases the diameter of the female component until the male part can be extracted from the female part (being the adjustment nut) without a great effort.

The rusting on the surface of the affected area is an indication that the reshaping was not an incident artefact but that it had happened over some time. It is not possible to estimate an exact time any more precisely than measuring in months rather than days.

6. Hypothesis of the Incident

An hypothesis for the incident is considered here and is as follows:

Mrs Blunt lost control of her vehicle because of involvement of the left-hand Rear Number 1 Suspension Arm.

6.1 Observations Which Support Hypothesis

Main items supporting the hypothesis are as follows:

- Left rear wheel out of alignment (Refer inspection report above).
- Burnish marks on left-hand rear wheel arch.
- Steering response.

6.1.1 Burnish Mark on Wheel Arch

An observation was made that the left rear wheel had been rubbing on the inside of left-hand rear wheel arch. This was photographed by the author and is shown in Figure 24. This mark is consistent with the inside of the tyre rubbing against the surface of the wheel arch.

The heavy rubbing mark indicated in Figure 24 is absent on the right-hand side wheel arch. This indicates that the mark was not caused by the normal suspension travel of the rear wheels. It is seen as a direct result of the left rear wheel being out of alignment.

The extent of rubbing would suggest that it had been in progress some time prior to the impact with the Armco rail.

The shiny appearance and absence of products of corrosion of the rubbed surface supports that the rubbing was recent to the incident.

Figure 24 –Heavy rubbing mark in left-hand side rear wheel arch.

6.1.2 Steering Response

A functional requirement for the Rear Number 1 Suspension Arms is to maintain rear wheels in alignment.

Improperly adjusted Rear Number 1 Suspension Arms can have consequences on the directional controllability of the vehicle.

The steering response of the vehicle to sudden loss of function in the Rear Number 1 Suspension Arm is discussed here.

The behaviour of tyres under dynamic conditions of steering is a complex study involving the interaction of the tyre contact patch with the road surface, affected by tyre lateral stiffness, vehicle speed and centripetal/centrifugal forces. Fortunately, a simplistic model being presented here, that treats the dynamic conditions as if they were static conditions, is useful for demonstrating the effect of a rear wheel being out of alignment to the steering response of the vehicle.

In the component inspection section above, it was shown that the Rear Number 1 Suspension Arm is able to lengthen when the thread is no longer functional. It was also indicated that the Rear Number 1 Suspension Arm cannot shorten to any significant amount. This means the wheel[1] can "toe out" but not (to any significant extent) "toe in".

The effect of road/tyre friction at the contact patch creates a moment about the rear wheel steering pivot creating a propensity to rotate about the pivot. This propensity is illustrated in Figure 25 as a torque about the steering pivot. The normal running condition of the Rear Number 1 Suspension Arm is tension.

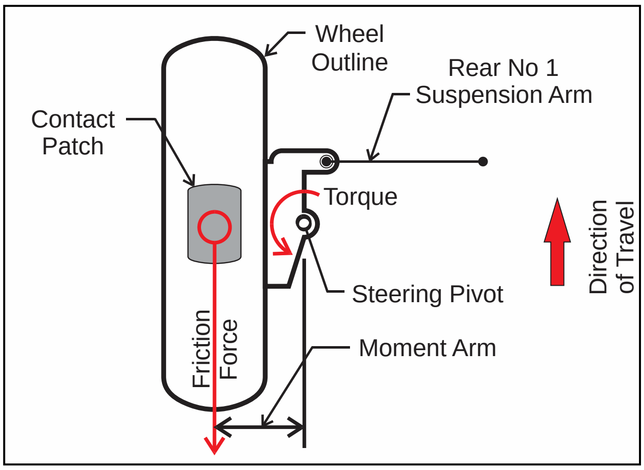

Figure 25 – Graphic for tyre friction creating a torque about the Steering Pivot.

Any movement of the vehicle in direction of travel would cause the wheel to occupy a position as shown in Figure 4 ("toe out") were it not for the tension restraint of the Rear Number 1 Suspension Arm.

It is of value here to consider in isolation the behaviour of a wheel out of alignment with the direction of travel, often called "scrubbing", commonly experienced as a result of poor wheel alignment, referred to as "toe in" or "toe out". In this incident scrubbing occurs analogous to an exaggerated "toe out" condition. This "toe out" condition is demonstrated in the graphic in Figure 26.

[1] Figure 26 is a graphic demonstrating "toe out" condition. "Toe in" condition is opposite.

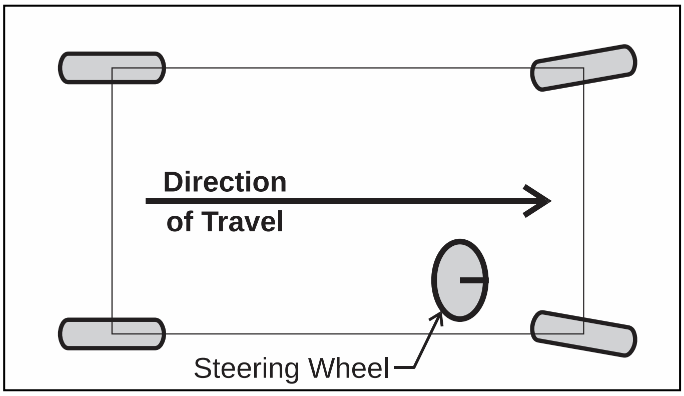

Figure 26 –Exaggerated "toe out" condition in the front wheels.

The angle of wheel misalignment is called the Yaw angle represented in the following graphic (Figure 27). Tyre scrubbing gives rise to a lateral force indicated as a scrubbing force in Figure 27.

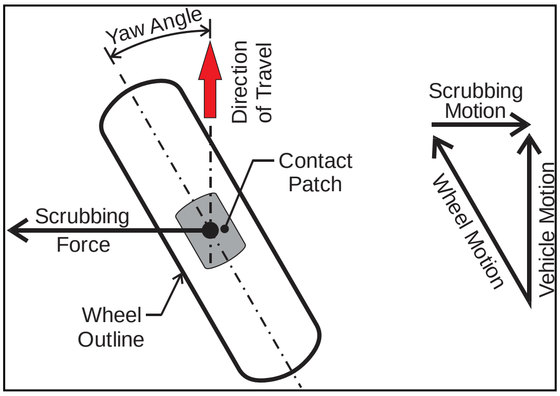

Figure 27 – Tyre scrubbing as a result of wheel yaw angle.

Newton's third Law requires that for every force there is an opposite and equal force. In the behaviour of the vehicle the opposing force is derived from the right-hand side wheel which must be pulled into an angle such that the two yaw angles are equal *(Y^o = Y^o)* *(*Figure 28*).*

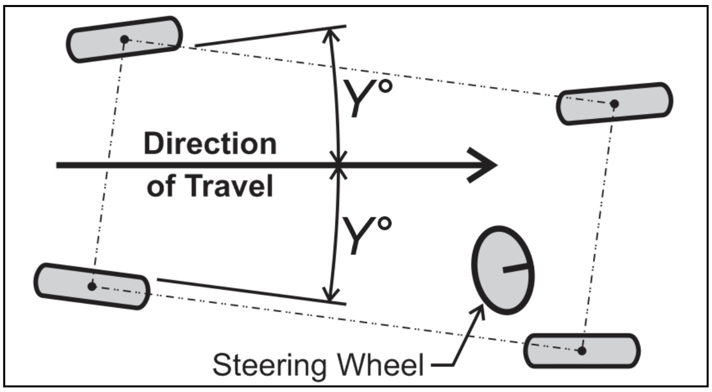

Figure 28 – Equalisation of yaw angles.

To maintain the vehicle on its course, corrective steering wheel action is necessary. It will be observed that the steering wheel in the graphic above is turned an angle to the left of the vehicle and the front wheels are also pointing to the left. This is consistent with Mrs Blunt noticing that the steering wheel had turned to the left.

The depth of penetration at the front and rear bumpers would suggest there was lateral momentum (sideways motion into the Armco rail) bringing the front bumper into contact with the Armco rail first, followed by minor engagement of the middle of the vehicle, followed by a simultaneous disengagement of the front bumper and engagement of the rear bumper. This is visualised in the time sequence; 1, 2, 3 in Figure 29.

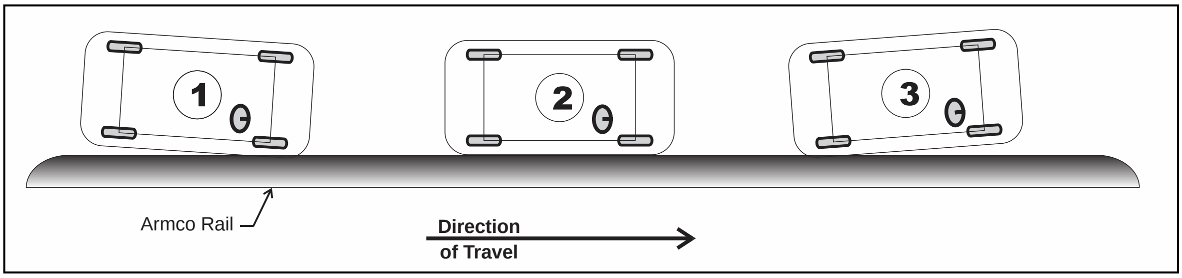

Figure 29 – Visualization of vehicle engagement sequence with Armco rail.

The response of the vehicle to the left rear wheel angular misalignment from the Rear Number 1 Suspension Arm lengthening, leaves no scope for the rear of the vehicle to impact first.

6.2 Observations Which Reject Hypothesis

No observations were made that could reject the hypothesis. No evidence could be found that would support a steering input directing the vehicle into the Armco rail. This would also be inconsistent with Mrs Blunt's recollections of the incident.

6.3 Summary

Observations made regarding the burnish mark present in the left-hand wheel arch and absent in the right-hand wheel arch, support the hypothesis.

It was shown that if the Rear Number 1 Suspension Arm does not provide the tension required to resist the normal torque about the rear steering pivot, angular misalignment in the rear wheel will result during normal driving.

It was also shown that angular misalignment in the rear wheel explains a directional propensity to spear into the Armco rail.

7. Summary and Conclusions

A high likelihood was concluded from the foregoing that the Rear Number 1 Suspension Arm was not locked, or inadequately locked, by the locking nuts at some stage in its life. It is not known whether this occurred during original manufacture or at some stage during rear wheel alignment procedures. Neither possibility could be ruled out on the information available to the author at the time of writing this report.

As a result of the locking nuts not being locked or inadequately locked, a mechanism developed that reshaped the threads of the Rear Number 1 Suspension Arm so that thread engagement and connectivity could be defeated with minimum force on the rear left wheel during normal driving.

It was shown that once this connectivity was defeated a propensity to spear into the Armco rail developed.

As a result, the steering predictability for a driver under such conditions would have been uncertain and account for collisions with other objects, as experienced in this incident.

A simpler method (e.g., “turn-of-the-nut” method) of ensuring the required pre-load in Rear Number 1 Suspension Arm locking nuts is recommended as more suited to a tyre technician’s skills and not requiring specialized tools such as an open-ended torque wrench, not commonly found in a tyre technician’s toolbox.

REFERENCES

[1] 2006 Toyota **RAV4 Owner's Manual**

[2] Bickford, John H (2008) **Introduction to the design and behavior of bolted joints**. - 4th ed, CRC Press, USA

[3] McCauley, C., Ed., **Machinery’s Handbook 26th Edition** P1475, Industrial Press, USA

[4] Fisher, John W., (2001) **Guide to design criteria for bolted and riveted joints.** P58, American Institute of Steel Construction, USA