Office of Transport Safety Investigations

TECHNICAL INSPECTION FINDINGS

WHEEL DETACHED FROM BUSABOUT BUS MO5184

CATHERINE FIELD

14 JANUARY 2014

TECHNICAL INSPECTION FINDINGS

WHEEL DETACHED FROM BUSABOUT BUS MO5184

CATHERINE FIELD

14 JANUARY 2014

Released under the provisions of

Section 45C (2) of the *Transport Administration Act 1988*

File Reference: 04642

Published by: The Office of Transport Safety Investigations
Postal address: PO Box A2616, Sydney South, NSW 1235
Office location: Level 17, 201 Elizabeth Street, Sydney NSW 2000
Telephone: 02 9322 9200
Accident and incident notification: 1800 677 766
Facsimile: 02 9322 9299
E-mail: info@otsi.nsw.gov.au
Internet: www.otsi.nsw.gov.au

THE OFFICE OF TRANSPORT SAFETY INVESTIGATIONS

The Office of Transport Safety Investigations (OTSI) is an independent NSW agency whose purpose is to improve transport safety through the investigation of accidents and incidents in the rail, bus and ferry industries. OTSI investigations are independent of regulatory, operator or other external entities.

Established on 1 January 2004 by the Transport Administration Act 1988, and confirmed by amending legislation as an independent statutory office on 1 July 2005, OTSI is responsible for determining the causes and contributing factors of accidents and to make recommendations for the implementation of remedial safety action to prevent recurrence. Importantly, however, OTSI does not confine itself to the consideration of just those matters that caused or contributed to a particular accident; it also seeks to identify any transport safety matters which, if left unaddressed, might contribute to other accidents.

This OTS investigation was conducted under powers conferred by the Passenger Transport Act 1990. OTSI investigators normally seek to obtain information cooperatively when conducting an accident investigation. However, where it is necessary to do so, OTSI investigators may exercise statutory powers to interview persons, enter premises and examine and retain physical and documentary evidence.

It is not within OTSI's jurisdiction, nor an object of its investigations, to apportion blame or determine liability. At all times, OTSI's investigation reports strive to reflect a "Just Culture" approach to the investigative process by balancing the presentation of potentially judgemental material in a manner that properly explains what happened, and why, in a fair and unbiased manner.

Summary of the Incident

At approximately 1135 on Tuesday 14 January 2014, a Busabout Route 850 service from Narellan to Minto was travelling north-east along Camden Valley Way in Catherine Field with the driver and two passengers on board. As the bus approached Catherine Field Road, the driver noticed a slight heaviness in the steering and slowed down to around 30 km/h. As he did so, he saw a wheel roll past the left of the bus and onto Catherine Field Road where it struck the rear of the right side of a utility waiting to turn right onto Camden Valley Way.

The driver stopped and alighted from the bus, and found that the outer left rear wheel was no longer on the bus, leaving the left rear of the bus supported only by the inner wheel. He also noticed that all ten of the wheel nuts were missing and one of the studs could not be seen. A photograph taken by the driver using his mobile phone appears below as *Photograph 1*.

Photograph 1: What the driver saw

After the incident the bus was taken to the Busabout depot at West Hoxton where it was examined by OTSI investigators.

Incident location

The incident occurred on Camden Valley Way at Catherine Field, an outer Sydney suburb approximately 43 kilometres west-south-west of the Sydney Central Business District (*Figure 1*).

Camden Valley Way is a major arterial road linking the Hume Highway, M5 and M7 at Prestons with the Camden area. At the time of the incident, the road was undergoing a major upgrade, increasing it from two lanes to a four lane divided road for a distance of over 10 kilometres. The speed limit on the road at the incident location was 80 km/h.

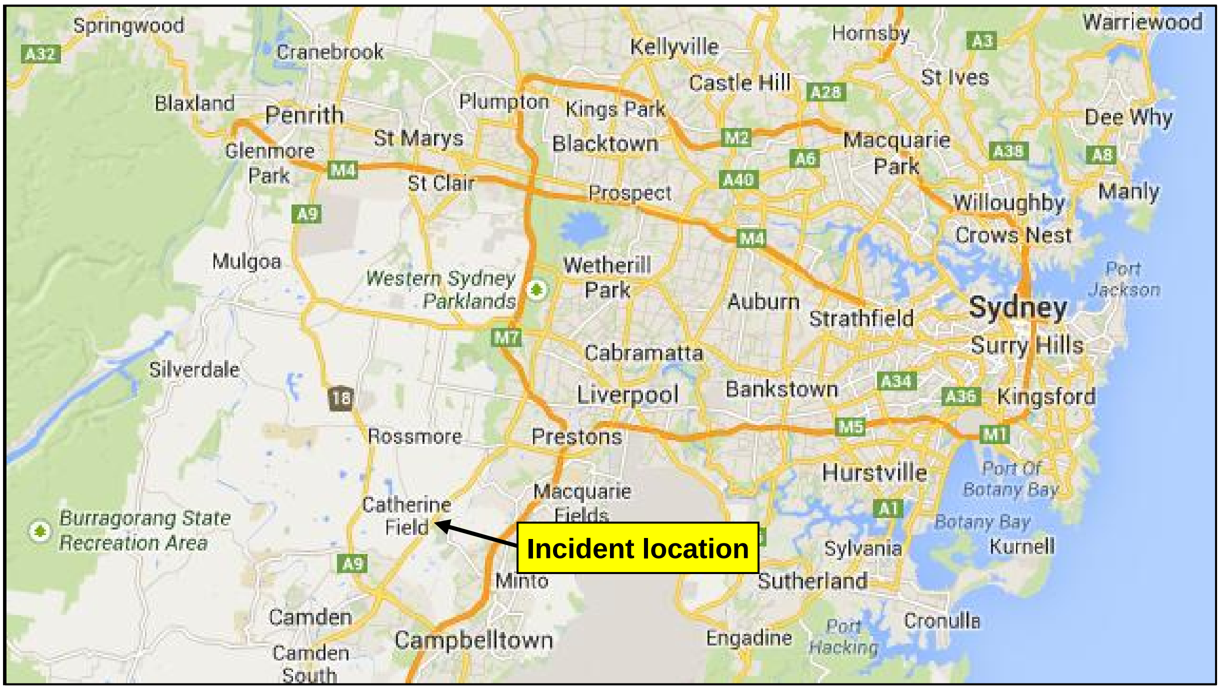


Figure 1: Incident location

The bus was travelling in a north-easterly direction along Camden Valley Way on a Route 850 service from Narellan to Minto, and was slowing in order to make a left turn into Catherine Field Road (*Figure 2*). The driver brought the bus to a stop just before Catherine Field Road after seeing the detached wheel roll past the bus. The wheel struck a utility waiting to turn right from Catherine Field Road into Camden Valley Way, causing minor damage but no injuries.

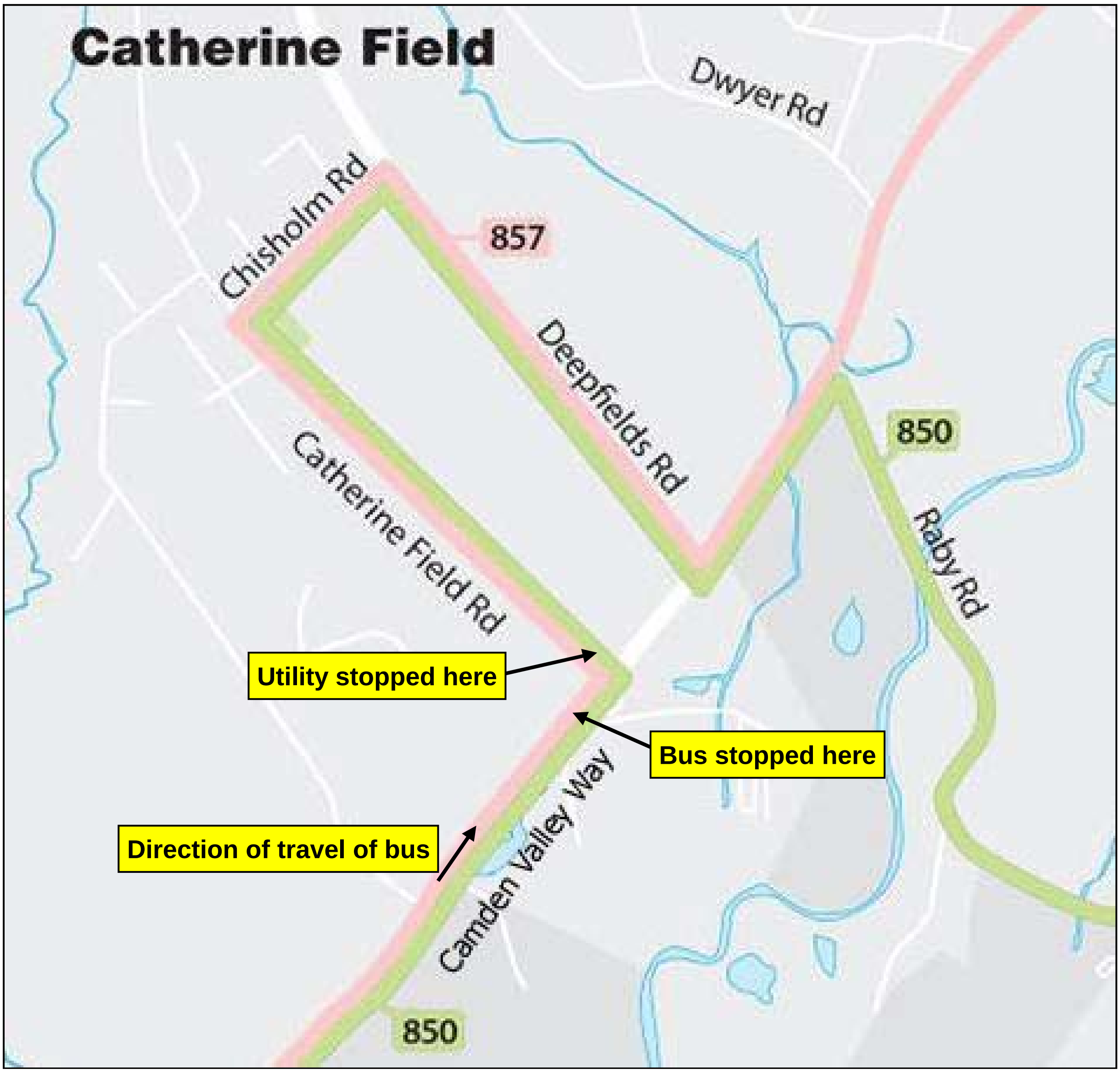


Figure 2: Incident configuration

The bus

The bus was a 2008 Mercedes-Benz OC500LE with a Bustech VST body on a Mercedes-Benz OH1830LE chassis. It provided seating for 52 including the driver, and standing space for 20. It was registered as MO5184.

The bus had been regularly serviced at nominal 5000 km intervals, with no intervals exceeding 5000 km during the preceding 12 months. No services or repairs during this 12 month period necessitated removal of the left hand rear wheels, although the right hand rear tyres were replaced at 305874 km and both front tyres were replaced at 324652 km. The last service prior to the incident was on 23 December 2013 at 343625 km and at the time of the incident the bus had travelled 347791 km.

The wheel fitting procedure stated to have been used by Busabout entailed lubricating the wheel studs with a proprietary lubricant, fitting the wheel nuts and then progressively tightening them in a specified sequence to a final torque of 625 ± 75 Nm. The tightness would then be checked and the nuts re-torqued if necessary, after the bus had travelled a distance of around 30 km.

Checking of the nut tightness was stated to have been performed at each service by applying torque to a selection of wheel nuts using a bar, without use of a torque wrench. Daily checking of wheel retention prior to the first run was visual.

The driver, a 34 year old male, had been driving for Busabout for 10 years. Prior to commencing his first run each day he conducted a number of checks, one of which was to visually check wheel security. He stated that this was done on the day of the incident and he noticed nothing irregular.

Examination of the bus

In order for the bus to be moved to the operator's depot from the incident location, replacement wheels had been temporarily fitted, as seen in *Photograph 2*. These wheels remained in place throughout the initial inspection of the bus as no jacking equipment was available to facilitate their removal.

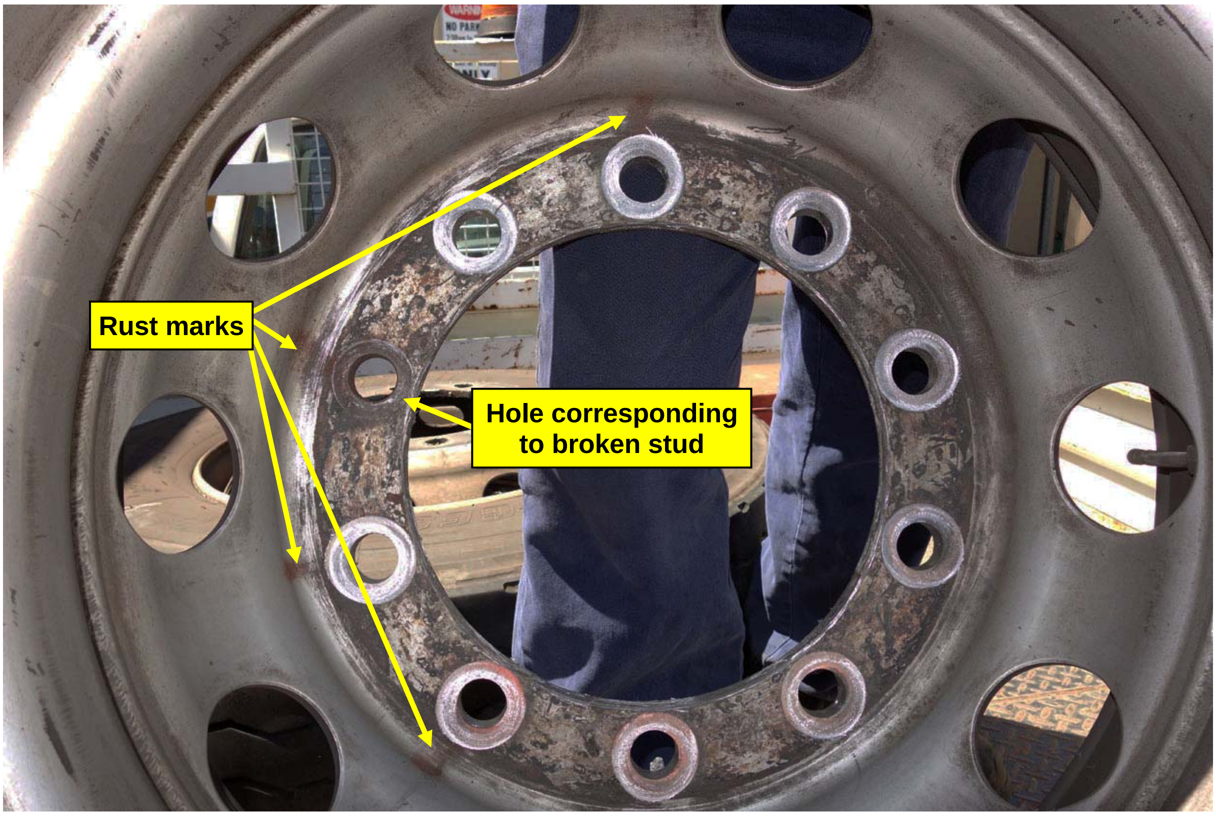
The left hand rear wheels were returned to the depot from the scene of the incident and were examined.

Photograph 2: Left rear wheels temporarily fitted

Wheels

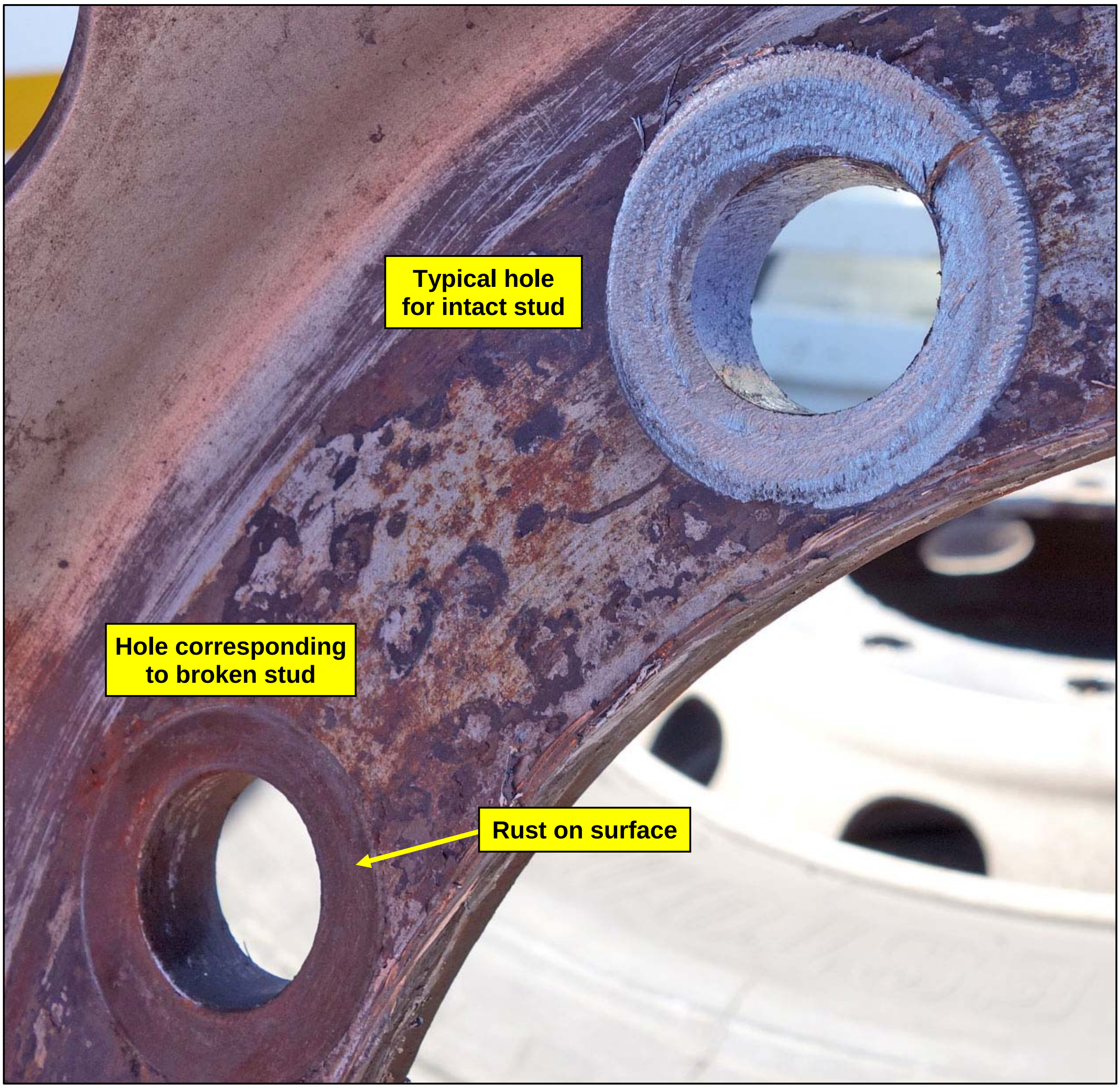
MO5184 was fitted with single wheels on the steer (front) axle and dual wheels on the drive (rear) axle. All wheels were identical in design and were of steel construction with 8.25 x 22.5 inch rims. Each wheel was centred on a spigot on the corresponding hub and secured by flanged nuts on 10 studs passing from behind the drive flange of the hub and through the centre disc of the wheel. The holes through which the studs passed were 28 mm in diameter.

The detached wheel and the inner left rear wheel were examined at the depot. With the exception of the stud hole associated with the broken stud, all stud holes in the outer wheel exhibited severe scuffing on the surrounding face as seen in *Photograph 3*. There were also rust marks radiating outwards from some of the stud holes.



Photograph 3: Condition of detached wheel

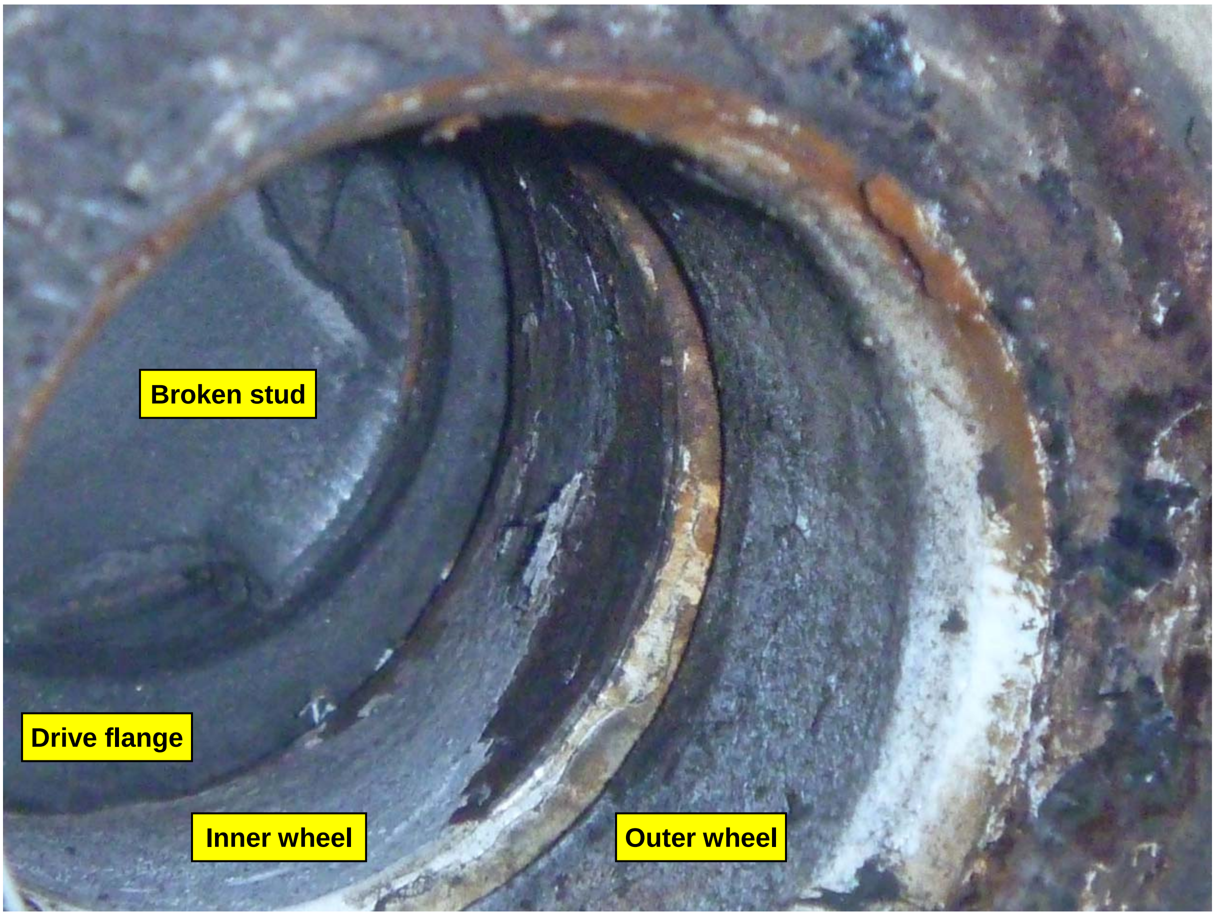
The inner surfaces of these holes were similarly scuffed, the contrast between the hole associated with the broken stud and the other holes being as seen in *Photograph 4*. Rust was visible on the face surrounding the hole associated with the broken stud.



Photograph 4: Contrast between stud holes

Wheel studs

When the bus was examined at the depot, nine of the wheel securing studs were intact although damaged. The tenth stud was broken off just inside the surface of the drive flange, the remainder being retained in the hub as seen in *Photograph 5*. The outer part of the broken stud could not be located after the incident.



Photograph 5: Broken stud in situ

The head of each stud bore the markings shown in *Photograph 6*. The identity of the manufacturer (Peiner) was shown, and the code 10.9 refers to a property class defined in International Standard ISO 898-1[1]. In summary, property class 10.9 specifies a carbon or alloy steel, quenched and tempered, with a minimum tensile strength of 1040 MPa.

1 ISO 898-1:2009, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread.*

Photograph 6: Identification marks on studs

Use of this class of material indicated that the studs were intended to be tensioned so that the engine torque was transmitted by friction between the drive flange and wheel rather than by sheer forces across the studs. For this to be effective, stud tension must be carefully controlled.

The procedure specified by Mercedes-Benz involved ensuring that the contact surfaces of the wheels and hub were clean, sanding off any excessive paint, and derusting if necessary. The threads of the nuts and studs were to be undamaged and free of corrosion, oil and grease. The nuts, a two-piece design with an integral thrust washer, must be lightly oiled between the hexagon head and the thrust washer. The wheels were then to be centred on the hub and secured, with the wheel nuts being tightened in several stages in a crosswise pattern, and torqued to 600 Nm. Re-torquing of the nuts was required after the bus had travelled 50 to 150 km.

The studs were removed from the drive flange for further examination.

One of the unbroken wheel studs is shown in *Photograph 7*, and the broken stud in *Photograph 8*.

Photograph 7: Unbroken wheel stud

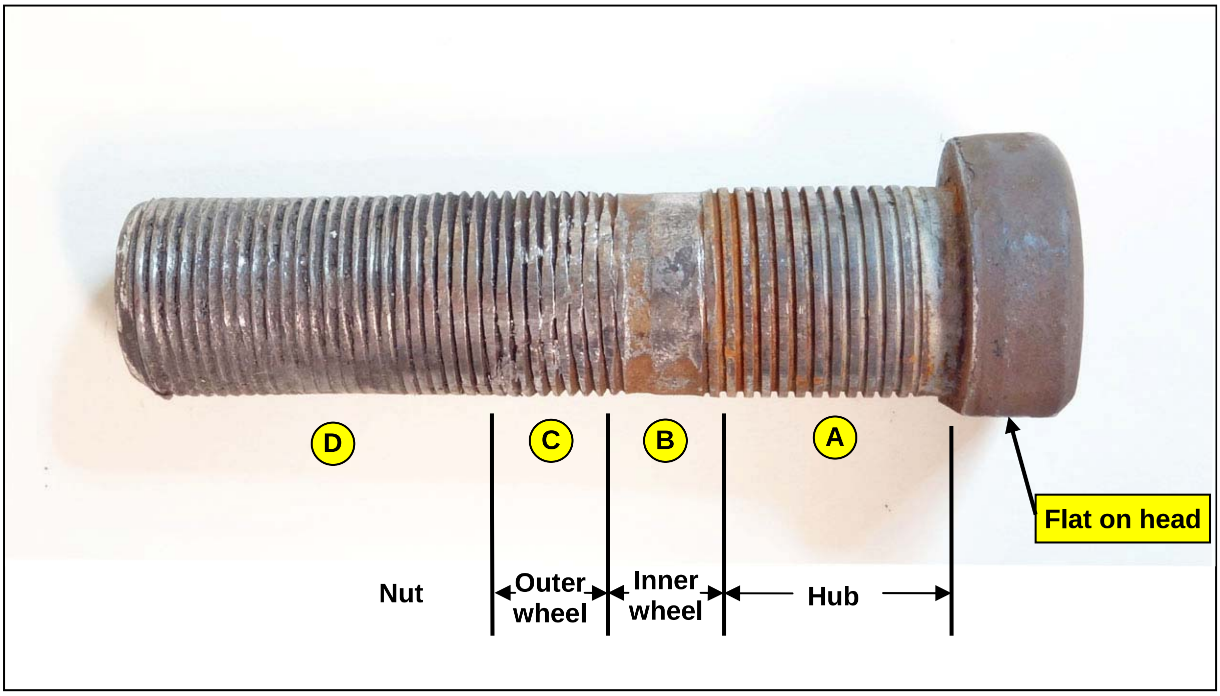
Photograph 8: Broken wheel stud

It was noted that the studs were dry and free from residual lubrication.

Analysis

Detailed examination of components

Photograph 9 illustrates the relationship between the stud, the drive flange of the hub, the wheels and the nut.



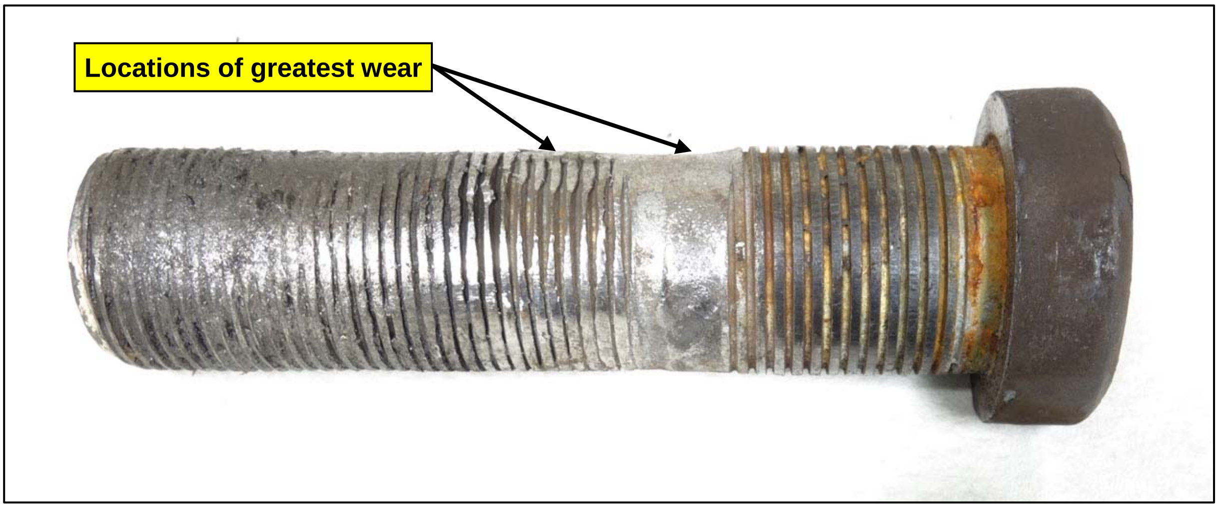
Photograph 9: Diagram of unbroken stud

A flat on one side of the head engaged a shoulder on the hub to prevent rotation in the drive flange.

The section labelled “A” had a square thread with a diameter measuring 22.05 mm machined on it, to provide an interference fit when pressed into the drive flange. The profile of the machined thread is shown in *Photograph 10*.

Photograph 10: Close-up of square thread

The section of the stud labelled “**B**” was the transition from the diameter of section “**A**” to the slightly smaller diameter of sections “**C**” and “**D**”. It was also the section of the stud that passed through the inner wheel. As stated earlier, in normal operation the inner wheel would be clamped sufficiently tightly between the outer wheel and the drive flange for driving and braking torques to be transferred by friction. However, significant wear marks were seen on section “**B**” of all intact studs, indicating that movement had occurred between the wheel and the drive flange. Marking was greater on the face that would have been in contact with the wheel when the engine was under power rather than when the bus was braking (see *Photograph 11*). This is to be expected, as during normal use a far greater proportion of time is spent with the engine under power than with the vehicle coasting or the brakes being applied.



Photograph 11: Wear on stud due to wheel movement

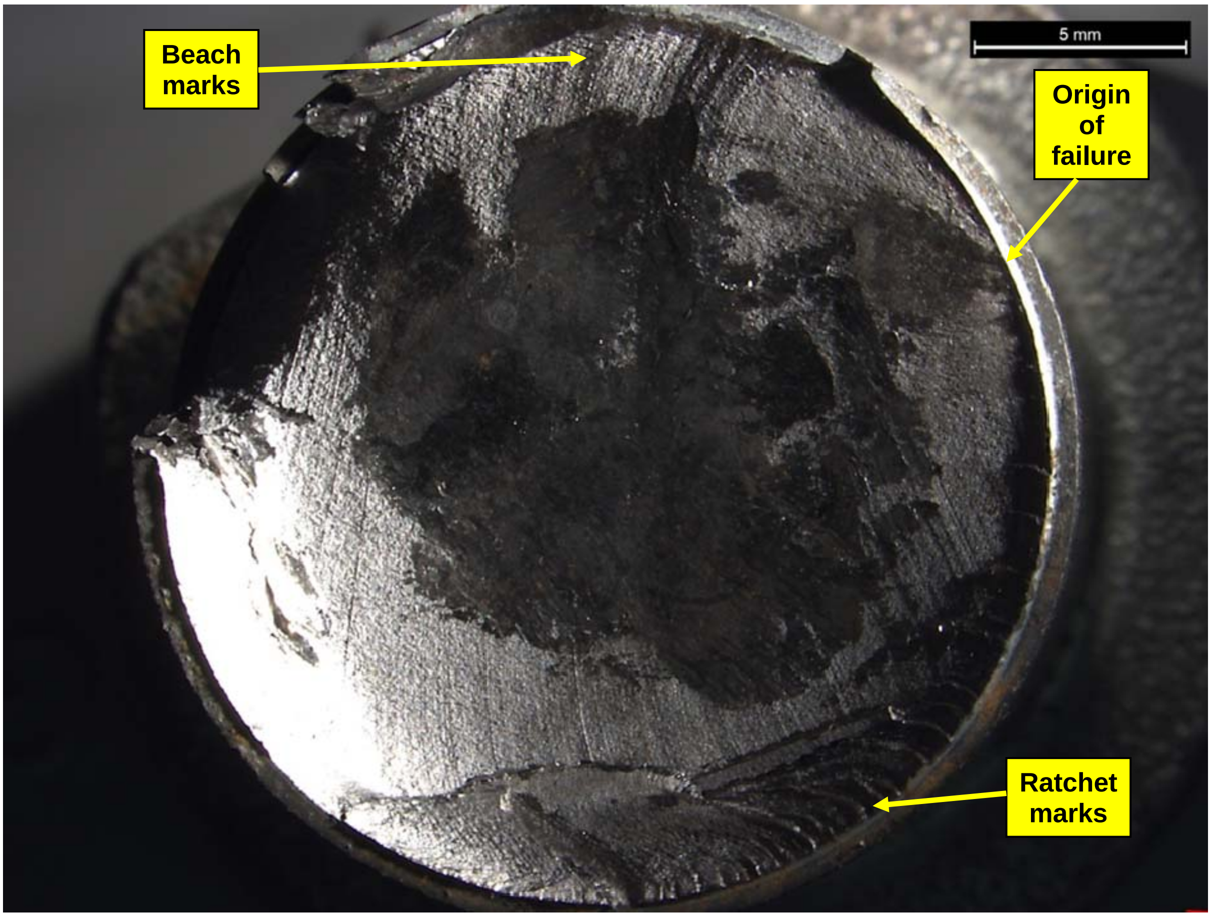
The sections labelled "**C**" and "**D**" carried the thread by which the wheels were secured. This was a 22 mm diameter metric fine thread with a pitch of 1.5 mm. Section "**C**" passed through the outer wheel, and the wheel securing nut was fitted to section "**D**".

Section "**C**" of the stud, corresponding to the position of the outer wheel, showed evidence of wear adjacent and similar to that on section "**B**".

The damage to the thread on section "**D**" of the stud was more evenly distributed around the circumference of the stud, and would have occurred as the wheel nuts loosened and allowed both wheels to move progressively further out on the studs.

The broken stud and an intact stud were examined microscopically by the Australian Transport Safety Bureau (ATSB) to assist in determination of the cause of the stud failure. The ATSB's report described the presence of beach marks and ratchet marks on the fracture surface of the broken stud, indicating a fatigue failure with fractures on multiple planes (*Photograph 12*). The origin of the fatigue failure could also be seen.

The darkened central area on the fracture surface was due to damage that occurred during removal of the stud, obliterating the beach marks in this area.



Photograph 12: Fracture surface of stud (Photograph by ATSB)

The absence of any witness marks on the wheel at the position of the broken stud to indicate movement between the wheel and this stud prior to its failure suggests that its flange nut remained tight as all the other nuts loosened, subjecting it to excessive load and consequent fatigue failure. However, the rust marks observed in *Photograph 4* show that there was sufficient movement for surface rust on the wheel to be expelled from the interface and thrown radially out onto the wheel prior to failure of the stud.

It has been noted that no repairs conducted in the 12 months preceding the incident required removal of the left hand rear wheels. During this period the bus travelled over 60,000 km and was serviced at least every 5000 km.

Previous incidents

A search of wheel retention failures reported to OTSI in the eight years to 14 January 2014 identified 14 such incidents. In two of these cases no information was given to indicate the side of the bus involved. In the remaining 12, nine were on the left side of the bus, and three on the right. In all cases, the incidents involving left hand wheels resulted in complete detachment of the wheels, while of those on the right side two were completely detached and one was loose with the wheel nuts remaining in place.

A search of notifications recorded on an incident database managed by Transport for New South Wales found five wheel retention failures in the three years to 14 January 2014. All of these were of wheels on the left side. In one case the wheel was detached due to wheel bearing failure, in three cases the wheels were completely detached, and in one case eight of the 10 nuts had come off and the remaining two were almost off when the loose wheel was detected.

Wheel fitting and retention

By far the most common wheel retention method in current use on heavy vehicles is the hub piloted or spigot mounted method where the wheel is accurately located on a spigot on the hub, and is clamped tightly to the hub so that forces are transmitted directly between the hub and wheel. This was the method in use on MO5184.

This method relies on sufficient tension being developed in the wheel studs to prevent any movement between the wheel and the hub under operating conditions, so that the studs are not subject to bending or shear stress.

The wheel fitting instructions provided by the manufacturer, Mercedes-Benz, specify lightly oiling the wheel nut between the hexagon head and the thrust washer at the location shown in *Figure 3*, and tightening the wheel nuts in several stages in a crosswise pattern to a final torque of 600 Nm. The instructions also specify re-tightening after the vehicle has travelled 50 to 150 km.

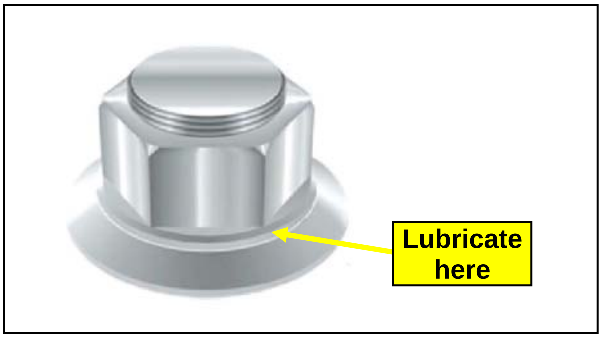


Figure 3: Wheel nut lubrication

Other authorities provide similar instructions, the most common significant difference being in relation to lubrication where it is often recommended that the outer end of the threaded section of each stud be lightly lubricated. For example, the *Australian Trucking Association* recommends to "Lightly lubricate between the nut and flange, and on the outer end of the stud threads."[2]

The effect of lubrication of the thread is to reduce friction between the nut and the stud, resulting in a higher clamping force and, at the extreme, the possibility of stud failure. Conversely, a dry thread that is not clean or is worn, will result in a lower clamping force and the possibility of wheel movement relative to the hub, and consequent loosening of the nuts.

The clamping force developed between wheel and hub can, for practical purposes, be considered to be directly proportional to the torque applied to the wheel nuts when they are tightened. The following three factors determine the efficiency with which this torque is converted into clamping force: [3]

1. A geometric factor based on the shape of the threads.
2. A thread friction related factor.
3. An underhead friction factor related to the nut rotating on the surface it contacts. With two-piece flanged nuts this is the friction between the nut and the thrust washer, as the thrust washer is not intended to rotate on the surface of the wheel.

SAE International Standard J1965[4] specifies a minimum – maximum relationship between torque and clamping force or stud tension for two-piece flange nuts. A minimum torque of 500 Nm must result in at least 133 kN of stud tension, and a maximum torque of 678 Nm must result in no more than 276 kN of stud tension.

Woodroofe & Associates[5] state that re-use of flange nuts can result in the clamping force being reduced to 50% of the design value. This is likely to result in insufficient

2 *Commercial Vehicle Wheel Security*, Australian Trucking Association Industry Technical Council Advisory Procedure, 2008.

3 *Bolted Joint Design*, Federal Engineering & Design Support, 2009.

4 *Road Vehicles – Wheels for Commercial Vehicles and Multipurpose Passenger Vehicles – Fixing Nuts – Test Methods*, SAE J 1965:2008, SAE International 2008.

5 *Heavy Vehicle Wheel Separations: Exploring the Causes*, Woodroofe & Associates, Ontario 2002.

clamping force with consequent movement of the wheel relative to the drive flange, and loosening of the nuts.

Titan Technologies International states that lubrication of all surfaces with a molybdenum-based lubricant can increase stud tension for a specified torque by a factor of 2.5.[6] The consequence of this could be over-stressing of the stud to the point of failure. Over-tensioning allowed by lubrication can also cause thread distortion with a consequent loss of clamping force.

This potential degree of variability illustrates the importance of consistently following the manufacturer's specifications when fitting and maintaining wheels, and of using threaded fasteners that are clean and not worn.

When asked about the procedure used by Busabout for wheel installation and maintenance, the representative provided an excerpt from a maintenance guide specifying that the wheel nuts were to be tightened in stages in a set sequence, to a torque of 625 +/- 75 Nm. When asked about lubrication, they stated that the studs were lubricated with Inox®, a readily available lubricant.[7] Maintenance records for MO5184 indicated that the wheel nuts were checked at its two most recent services, on 2 December 2013 at 338745 km, and 23 December 2013, at 343624 km. The bus had travelled 347791 km at the time of the incident.

Mechanism of retention failure

The two most common modes of wheel retention failure are failure of the wheel bearings or failure of the wheel to hub attachment system. As wheel bearing failure is not relevant to the subject incident, discussion will be restricted to the latter mode.

A tendency for wheel retention failures to occur more commonly on left side wheels than the right is supported by a number of reports. For example, a 2006 report by TRL Limited on research conducted for the Department for Transport in the United Kingdom[8] on heavy vehicle wheel detachment found that 79% of detachments were of left hand wheels and 21% were of right hand wheels. Although there are flaws in the way figures from six different sources were combined in this study, the trend is

---

6 *K Factor data sheet*, Titan Technologies International, Inc, www.titanti.com, accessed 3 July 2014.

7 *Inox* is a proprietary lubricant made in Australia by Candan Industries Pty Ltd.

8 *Heavy Vehicle wheel detachment: frequency of occurrence, current best practice, and potential solutions*, Project Report PPR086, TRL Limited, August 2006.

consistent, with the figure for left hand detachments ranging from a low of 71% to a high of 88%.

Although left hand threaded wheel nuts were commonly used on left hand wheels in the past, they are now generally restricted to vehicles with a single central wheel nut, such as Formula1 race cars.

It is noted that, although wheel detachments were biased towards the left side, TRL reported that loosening of fixings without wheel detachment was more evenly distributed between left and right (56% left, 44% right).

It has been suggested that the bias toward left hand wheel detachment in the United Kingdom and Australia where vehicles drive on the left, is related to the left hand wheels being subjected to more severe operating conditions such as broken pavement edges and kerb impact. However, the TRL report comments that, in studies in Finland, Canada and Japan where vehicles drive on the right, the results were "broadly comparable with those in the UK". For example, of 38 incidents of wheel detachment studied in Finland, 34 or 89%, were left side wheels.

The reason for this bias has been discussed in a number of papers, with the most comprehensive treatment perhaps being that of Bailey and Bertoch.[9] Their analysis and experiments are based, however, on passenger cars, light trucks and RVs, where the wheels were secured using tapered nuts rather than flange nuts. The salient difference is that, when tapered nuts are used, the stud holes in the wheel provide clearance around the stud, with the wheel being accurately located by the taper. When the nuts loosen, the wheel centre can move relative to the hub centre in a manner that Bailey and Bertoch suggest will cause right hand threaded nuts on the left side of the vehicle to further loosen, while right hand threaded nuts on the right side will tend to be prevented from further loosening. Bailey and Bertoch do not discuss the situation with hub-piloted wheels and flange nuts, where the ability of the wheel centre to move relative to the hub centre when the nuts loosen is much more limited.

In the case of MO5184, the loss of nine of the 10 flange nuts indicates that wheel to hub clamping force was reduced sufficiently for the wheel to move relative to the hub.

[9] *Mechanisms of Wheel Separations*, SAE Technical Paper 2009-01-0111.

This movement was limited initially by the remaining nut that maintained sufficient stud tension to retain the wheel, as evidenced by the lack of scuffing in and around the corresponding wheel stud hole. As a consequence, this stud was subjected to a high level of rotational fatigue loading until it rapidly suffered a fatigue fracture as indicated in the ATSB analysis reported earlier.

Loosening of the wheel nuts generally indicates a loss of clamping force. This can be due to one or more of the following factors:

- Lower than recommended torque when fitting the wheel nuts.
- Failure to re-torque the wheel nuts after an initial settling-in period.
- Over-tightening of the wheel nuts, resulting in thread distortion or stretching of the studs.
- Foreign material such as rust or excessive paint between surfaces.
- Dirty or worn threads.

In this case, visible rust on the surface of the wheel surrounding the broken stud, and the evidence of rust having been expelled from the nut/wheel interface in a number of locations, indicates that initial relaxation of clamping force may have occurred over a considerable time, and may have been precipitated by the presence of rust.

Preventive measures

Regular checking of wheel nut security in its most basic form involves the checking of nut tightness on a regular basis. Most manufacturers and authorities state that the first check should be shortly after the wheels are fitted, when the vehicle has travelled somewhere in the range of 40 to 160 km. This check should be performed with a torque wrench, without first slackening the wheel nuts. It is important the driver be informed of the need for this check to be performed, and that its performance be recorded. If a torque wrench is not available, as is often the case away from a workshop, frequent checks should be performed until one is available. Pre-trip visual checks of wheel nuts and studs should also be routine.

There are aftermarket products available that are intended to aid in the prevention of wheel loss. These fall into three basic groups:

1. Products which give a visual indication of nut movement.
2. Products that arrest slackening of wheel nuts.
3. Products that lock the wheel nuts so that they cannot move.

There is also at least one product that combines the characteristics of categories 1 and 2 above.

An internet search found little objective information on the in-service effectiveness of these devices. The TRL study reported on a survey conducted with the Vehicle Operator and Services Agency (VOSA) in which 2% of recorded wheel defects involved wheels equipped with nut retention devices and 15% involved visual nut movement indicators. However, no information was available on the presence of these devices across the vehicle population, so their level of effectiveness could not be ascertained. It is clear, however, that they were not 100% effective, so they cannot be seen as a substitute for routine maintenance checks. In fact, the VOSA survey reported from face to face consultation with operators, that:

> ".. concern was expressed about the possibility of operators becoming complacent and relying on the devices, to the detriment of basic maintenance. Most of the small group of operators spoken to and most manufacturers of the add-on devices themselves agreed that such solutions could form a valuable supplement to rigorous maintenance procedures but could not replace them."

Conclusions

The detachment of the left outer rear wheel from Busabout bus MO5184 was due to the loosening of the wheel securing flange nuts until nine spun off completely and the 10th stud failed due to fatigue.

Although the reason for the loosening of the wheel nuts cannot be known with certainty, it is possible that use of a wheel fitting procedure, which did not follow the manufacturer's specifications, resulted in sub-optimal stud tension and clamping force. The presence of rust on the wheel face, and evidence of rust being expelled from between some wheel nuts and the wheel, suggests that this was a contributing factor to the initial relaxation of wheel clamping force.

It is probable that wheel stud tension then degraded over time and was not detected by the checking method used at each service. A visual check at the start of each day without the assistance of any positive form of nut movement indication is unlikely to have detected a gradual degradation of clamping force.