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Wheel Separations

by Mark Bailey MASc, PEng, PE

Wheels suddenly detach from moving cars and trucks more often than many people think. These 'wheel separations' can lead to serious injuries from the vehicle losing control, from the separated wheel colliding with another vehicle or pedestrian, or from another vehicle maneuvering to avoid the projectile.

In 1992 the National Transportation Safety Board ("NTSB Special investigation Report Medium/ Heavy Truck Wheel Separations," 1992, NTSB/ SIR-92/04) estimated the incidence of wheel separations to be about 750 to 1050 per year on heavy trucks, but noted the figure may be low since wheel separations not causing damage or injury may go unreported. In wheel separations from heavy truck trailers, it is not uncommon for the driver to be unaware that a wheel has separated for several minutes or even hours after the event.

We have investigated dozens of wheel separations from passenger cars, light and heavy trucks, and trailers. In these incidents we have observed that vehicle control loss does not occur in front wheel separations or in wheel separations from trailers. Rear wheel separations, however, can lead to control loss and rollover, especially in SUV's. Rollovers have led to occupant ejections and other serious injuries.

Whenever a wheel separates, there is potential for serious injury to anyone in the wheel's path. When a wheel separation occurs on a highway, the separated wheel is launched high in the air (because the weight of the vehicle pushing down on it is suddenly removed) yet is hardly slowed down. The approach speed between the now bouncing projectile and oncoming vehicles can easily exceed 100 mph. The injury potential resides in the escaped wheel's ability to penetrate an oncoming vehicle and strike occupants directly. Figure 1 shows damage to an SUV that was hit head on by a pair of escaped heavy truck wheels. In some cases a separated wheel comes to rest on the roadway, where its inconspicuity can make it difficult to avoid and the combination of its mass and an incoming vehicle's speed make for a collision that has the potential for vehicle damage and occupant injury.

Figure 1. *Front-end damage from head-on impact with separated dual heavy truck wheels.*

From our case data we find that when wheels separate, the majority of them do so in three distinct ways. In order, from most rare to most common, these are:

- an axle fracture, where a piece of the axle breaks free of the vehicle and takes the wheel with it (Figure 2),
- a hub separation, where the bearing or the axle spindle nut fails and releases the hub and wheel from the vehicle (Figure 3),
- a fastening failure, where wheel nuts fall off and/or wheel studs break and release one or two wheels from the vehicle (Figure 4).

In fastening failures we have observed that wheel separations generally occur 175 to 3000 miles, and one to fifteen weeks, after a wheel was taken off and put back on during some service, such as a tire installation. The remainder of this article discusses the causes of wheel separations from fastening failures.

Left vs. right side wheel separations

From our experience and laboratory and on-road testing (Bailey and Bertoch, "Mechanisms of wheel separations," Society of Automotive Engineers 2009) we have found that there is a different pattern of evidence in left vs. right side wheel separations. Left side wheel separations usually occur after the wheel nuts spin off and right side wheel separations tend to occur after the wheel studs break off.

Figure 5 shows a wheel stud and the hole of the left wheel that it was in. The nut has spun off the stud and was never found. The stud threads left an imprint in the aluminum wheel and there is aluminum embedded in the stud threads. The stud is not broken.

Figures 6 and 7 show broken right side wheel studs. These are the portions of the studs that were in the wheel hub. The parts of the stud that broke off, along with the nuts, were never found. The flat fractures with "beach marks" (fine curved parallel lines resembling an aerial view of a beach) on the fracture surface are typical of right-side stud fractures, and are classic examples of what engineers refer to as reversed bending fatigue.

The wheel nuts and studs basically sandwich the wheel and brake components together. The nuts and studs have to squeeze those components together with enormous force, called the clamping force, in order for the sandwich to stay together. The clamping force is made when the nuts are tightened onto the studs. If the clamping force is lost, then the nuts loosen, leading to the different mechanisms of left-side nut spin-off and right-side stud reversed-bending fatigue.

Figure 2. *The end of a Ford Bronco axle broke off one month after it was serviced. During the service an axle bearing was carelessly removed with a cutting torch, which metallurgically altered the axle and led to a catastrophic fatigue fracture.*

Figure 3. *A heavy truck hub had a bearing failure and the consequent friction destroyed the hub and allowed it to come off the end of its axle.*

Figure 4. *Eyewitnesses observed the left rear wheel separate from this SUV before it lost control and rolled. All five nuts were missing from the wheel studs of the left rear wheel.*

Figure 5. *This stud (right) and wheel hole damage (above) is from a left-side wheel separation that occurred 21 days after the wheel was installed.*

Figure 6. *Fatigue fractures on studs from a motor home right-side wheel after 2900 miles. Fatigue fractures are usually flat and transverse to the stud axis.*

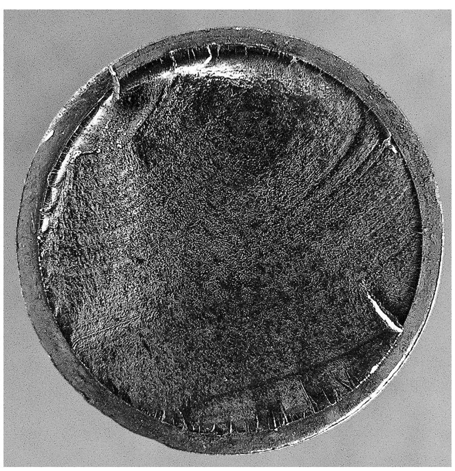

Figure 7. *Beach marks on the fracture surface are clear signs that this stud from the right rear of a van failed from fatigue. Failure was less than 121 days since installation.*

The mechanism for the left side wheel nuts spinning off as the vehicle travels can be understood from the geometry of the wheel and studs when the wheel is slightly loose. Since the stud holes are larger than the studs, the wheel is not perfectly concentric with the axle when the nuts are loose. When the road pushes up on the tire, the wheel tends to be pushed up relative to the axle centerline. This means the wheel centerline is slightly above the axle centerline. This centerline offset gives rise to a relative velocity vector between each wheel nut and the part of the wheel the nuts touch. This vector is in the loosening direction on the left side when the vehicle is driving forward and is the cause of wheel nuts spinning off the left side.

The right side nuts have that same relative velocity vector, but in the opposite (i.e., tightening) direction. It turns out that this vector is not strong enough to make a loose nut tight again. So, on the right side, a loose nut tends to stay loose rather than spin off. But this invites another mechanism – fatigue. When a nut is tight, the clamping force creates large frictional forces at the wheel/hub interface that transfer the vertical forces that support the weight of the car. However, when a nut is loose, there is no clamping force, and the studs now carry the vertical forces. This bends the studs up and down every time the tire rotates. Just as a paper clip breaks when you bend it back and forth a few times, a wheel stud can break when it is bent up and down a few million times. This is called reversed-bending fatigue, and is the reason that right-side studs eventually break off when the nuts are loose.

The starting point for a wheel nut to spin off the left side, or for a stud to break off the right side, is the same: the nut had to be loose. Therefore, the investigation of fastener-related wheel separations should focus on the clamping force.

Making the clamping force

Wheels on most road vehicles are secured with four to ten nuts that are threaded on to steel studs. The studs are usually press-fit through a brake disk or a circular plate on the end of the axle. The threads are almost always right-handed.

The function of the nut and stud is to make the clamping force that squeezes the wheel to the vehicle. Turning the nuts onto the studs causes the studs to stretch. Stretching the studs creates a large tension force in them, which is the clamping force.

Though it is desired to achieve a particular stud tension (measured in pounds force), stud tension is a quantity that is not easily measured. Instead, the proper amount of tension in the stud is achieved by applying a certain torque (a twisting force measured in foot-pounds) to each nut when they are installed. There is an empirical relation between stud tension and nut torque. Vehicle manufacturers specify the torque that should be applied to each wheel nut during tightening. That value can be found in the vehicle owner's manual. Passenger-vehicle and light-truck wheel nut torques range from about 60 to 120 foot-pounds.

Torque to the wheel nuts is applied with a wrench. The wrench can be the one that comes with the vehicle (usually stowed with the jack), or it can be an air-wrench in a tire shop or maintenance garage, or it can be a torque wrench. Garages use air tools to tighten wheel nuts. They will commonly use a 'Torq Stik' on the air wrench, like the one shown in Figure 8. A Torq Stik is a precision-made steel bar that applies a target torque to a wheel nut. There are different sizes of Torq Stiks for different values of torque. The one in Figure 8 is meant to produce 80 foot-pounds. Whether they use a Torq Stik or not, wheel installers should always use a calibrated manual torque wrench, like the one shown in the top of Figure 8, to ensure the proper wheel nut torque is achieved.

Some ways to achieve the wrong clamping force are: mistakenly applying the wrong torque value, failure to use a torque wrench, using a torque wrench that is out of calibration, using the wrong Torq Stik, or using a Torq Stik improperly.

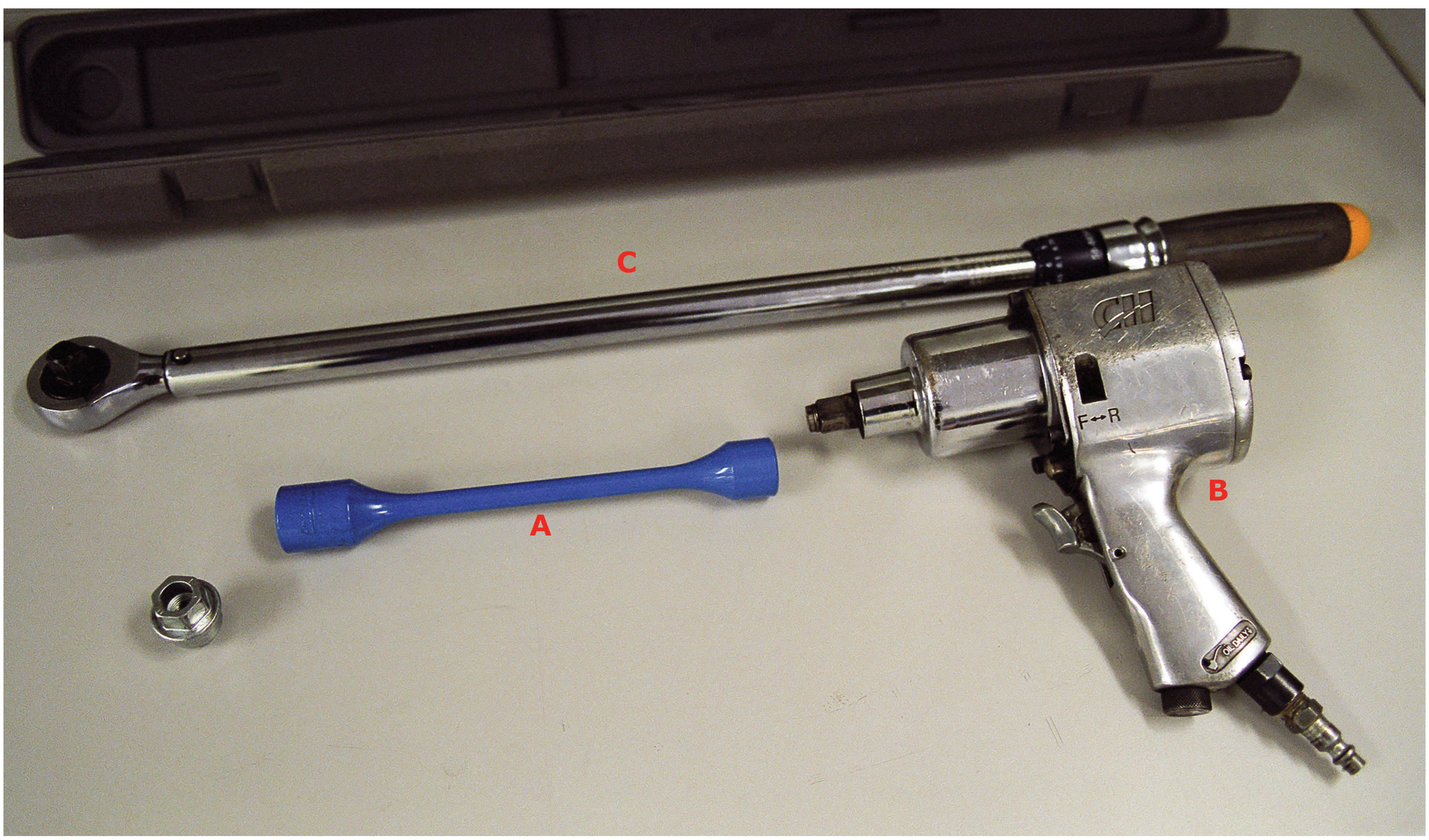

Figure 8. *A: an 80 foot-pound Torq Stik. B: air wrench that Torq Stik attaches to. C: A manual torque wrench.*

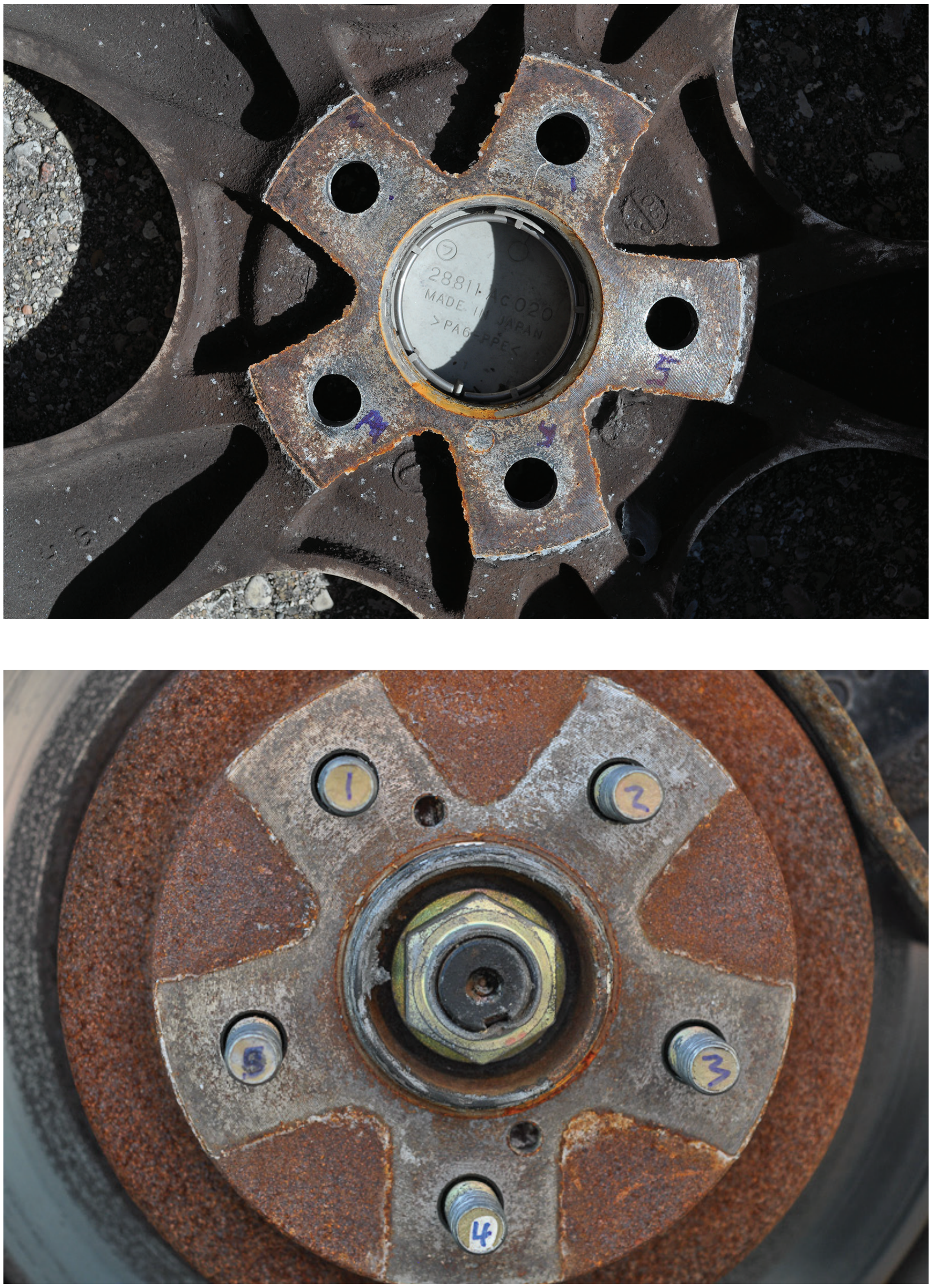

Figure 9. *The minor rust deposits on the edges of the contact area of this aluminum wheel are normal, but the contact patch (five white arms outlined by rust) on the brake rotor must be clean.*

Losing the clamping force

Most often the wheels are put on with the correct clamping force and they stay that way and the wheels never separate. However, under certain conditions even wheel nuts that were properly torqued can lose their clamping force.

One of the leading causes for lost clamping force is that the material being clamped changes. The material being clamped consists of the portion of the wheel surrounding the stud holes and the brake drum or rotor. Thinning the amount of material by even a very small amount can lead to drastic reductions in clamping force.

Some reasons for thinning are wear of paint coatings on brake drums, break up of corrosion deposits or dirt that was in the 'sandwich' when the wheel was put on, and fretting wear of aluminum wheels.

Figure 9 shows an example of corrosion (visible as orange-brown iron oxide) from an iron brake rotor on a passenger car with aluminum (or "alloy") wheels. In this case the corrosion developed on the iron brake rotor in the exposed spaces where the aluminum wheel flange did not press on the rotor, leaving a clean contact patch or "footprint" of the wheel flange on the rotor. The corrosion is not problematic unless it develops on the clean footprint area. If the footprint was corroded instead of clean, as shown in Figure 10 for a steel wheel that separated, then the rust clamped between the wheel and rotor is thinned by crushing from driving, leading to lost clamping force. There are ample warnings for wheel installers to clean wheel surfaces before re-installing a wheel to prevent corrosion and dirt from imperiling the clamping force. Cleaning the wheel interfaces is normally done with a wire brush just before installation.

Fretting wear of aluminum wheels is a complicated process, but essentially involves microscopic bumps on the wheel and hub interfacing surfaces destroying each other. This leads to thinning and also to hard aluminum oxide-wear debris (black in color) that can further promote thinning.

Restoring the clamping force

Fortunately, there is a well-known remedy for lost clamping force. It is simply to re-torque the wheel nuts after a short amount of driving. There is no need to remove the wheels or even jack the vehicle off the ground – just using a torque wrench to apply the manufacturer's specified torque to each wheel nut after a short amount of driving will normally cure any loss of clamping force.

Re-torqueing works because the thinning rate can be high early in the life of the wheel components that are clamped together. Once some thinning has happened, the wheels will securely seat themselves once the clamping force is restored by re-torqueing. Many vehicle manufacturers and wheel or tire installers recommend the re-torqueing procedure take place after the first 15 to 500 miles of driving following a wheel installation. Some wheel or tire installers have customers acknowledge that a re-torque is needed by having them initial the requirement on their invoice.

Summary

Wheel separations are an uncommon but often disastrous event in road transportation. They often occur a short time or distance after a wheel was installed. Injuries can occur to the occupants of the vehicle that lost the wheel, to motorists or bystanders hit by a lost wheel, or in accidents caused by motorists maneuvering to avoid a lost wheel.

Wheel separations can occur from axle failures, hub failures, or fastening failures, with fastening failures being the most common. A fastening failure is when the nuts on the ends of the studs unthread by themselves and fall off (typically on left-side wheels), or when the metal wheel studs break off (typically on right-side wheels). The physical evidence in left- and right-side wheel separations differs, but is most often produced by the same cause: a loss of clamping force, where the clamping force is the force produced by wheel nuts pulling on wheel studs to squeeze the wheel onto the vehicle.

Figure 10. *A badly corroded wheel separated because rust deposits were not cleaned off properly before it was installed.*

A low clamping force can exist because wheels were not put on properly, the leading cause being that the correct torque to the wheel nuts was not applied. Even when the correct torque was applied (and therefore the correct clamping force was achieved), the clamping force can be lost. Causes are wear of corrosion products, dirt in the wheel interface, or other wear processes.

The remedy to the wrong or lost clamping force is to have the wheel nuts re-torqued after a short driving distance. Although wheel separations are rare, they should be entirely preventable with re-torqueing.

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