U.S. Department of Transportation
National Highway Traffic Safety Administration

ODI RESUME

Investigation: EA 03-004
Prompted By: PE02-085
Date Opened: 04/10/2003 Date Closed: 08/30/2004
Principal Investigator: Chris Lash
Subject: Wheel Stud Fracture

Manufacturer: Ford Motor Company
Products: MY 1997-2000 Windstar
Population: 811,429

Problem Description: The wheel mounting studs can break resulting in potential wheel separation.

FAILURE REPORT SUMMARY

	ODI	Manufacturer	Total
Complaints:	18	173	191
Crashes/Fires:	2	15	17
Injury Incidents:	0	5	5
# Injuries:	0	5	5
Fatality Incidents:	0	0	0
# Fatalities:	0	0	0
Other*:	0	1644	1644

*Description of Other: WHEEL STUD WARRANTY CLAIMS.

Action: this Engineering Analysis has been closed.

Engineer: *Christopher Lash* Date: *08/30/2004*
Div. Chief: *Jeffrey L. Quandt* Date: *08/30/2004*
Office Dir.: *Kathleen C. DeMeter* Date: *08/30/2004*

Summary: The subject vehicles range in age from 4 to 7 years in service, with average mileages estimated to range from 50 to 100 thousand miles. At these mileages, the subject wheels are likely to have been removed and reinstalled multiple times for various service procedures. ODI is concerned about the high wheel separation rates in the MY 1997-98 Windstar vehicles equipped with aluminum alloy wheels. However, analysis of failure data indicates that most of the incidents in that population of vehicles occur after the vehicles had accumulated 30 thousand miles of service. The factors that increase the risk that inadequate clamp loads may be achieved during service-related wheel installation are not unique to the subject vehicles. Testing conducted by Ford and VRTC indicate that the MY 1998 Windstar aluminum wheel fastening system performs similar to the wheel fastening systems on peer minivans. No design or manufacturing defects were identified in the wheel fastening systems of the subject vehicles. Ford will send a mailing to owners of Windstar vehicles with aluminum wheels that have high wheel separation rates that reviews the appropriate wheel fastening procedures and states that the wheel nuts should be tightened to the nominal torque, 100 ft-lbs (136 nm), and re-tightened to the same torque after 500 miles. Ford's letter also states that it is a good practice to be sure that before installing the wheel the aluminum wheel mounting surface, wheel lug nut area, and the mounting flange are free from dirt, debris, and loose rust to ensure the wheel is seated correctly and the wheel lug nuts remain fully tightened.

ODI will continue to monitor the incidence of wheel fastener failures in the subject vehicle population. Accordingly, this investigation is closed. The closing of this investigation does not constitute a finding by NHTSA that a safety-related defect does not exist. The agency will take further action if warranted by the circumstances. For additional information, see the attached closing report.

VKJ 9-2-04

ENGINEERING ANALYSIS CLOSING REPORT

SUBJECT: Wheel stud fracture.

EA No: EA03-004 **Date Opened:** 10-Apr-2003 **Date Closed:** AUG 30 2004

BASIS: On November 18, 2002, the Office of Defects Investigation opened a Preliminary Evaluation (PE02-085) of wheel fastener failures in model year (MY) 1998 through 2000 Ford Windstar minivans. PE02-085 was prompted by 26 complaints of wheel stud failure, including 15 wheel separations and 2 alleged crashes, and 12 insurance claims related to wheel stud failure, including 1 crash. PE02-085 was upgraded to an Engineering Analysis (EA03-004) covering MY 1997 through 2000 Windstar vehicles on April 10, 2003, based on 123 complaints to ODI and Ford.

THE ALLEGED DEFECT: Wheel stud fracture, with the potential for wheel separation.

COMPONENT DESCRIPTION: The subject wheel fastening system consists of five M12x1.5 mm bolts arranged in a 107.9 mm bolt circle (Figure 1). The nominal specified torque is 100 ft-lbs., with an allowable range of 83 – 113 ft-lbs. Ford's owner's manual specifies re-torque after 500 miles.

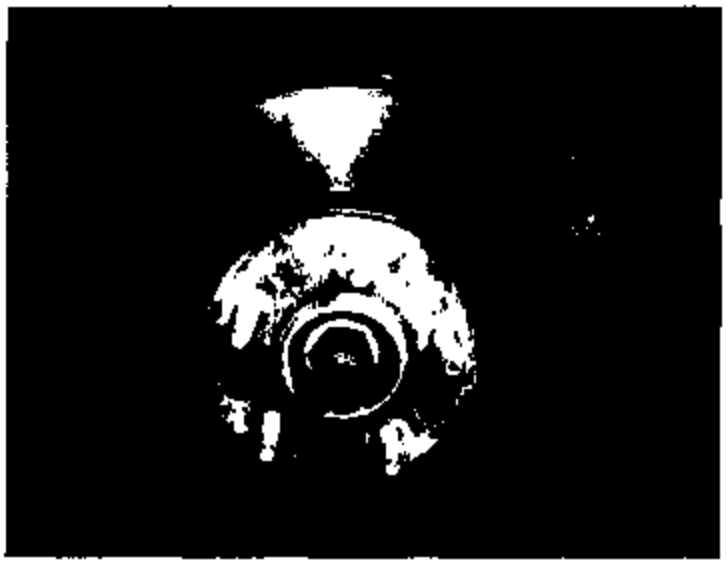

Figure 1. MY98 Windstar left-front wheel attachment.

FAILURE MECHANISM: Ford identified three likely causes for the alleged defect in the subject vehicles: (1) stud fracture during lug nut removal or installation due to excessive torque application; (2) insufficient clamp load between the road wheel and brake rotor or drum and hub assembly, resulting from failure to tighten the lug nut to the specified 100 lb-ft torque; and (3) corrosion, dirt, or damage present on the road wheel at the nut interface, resulting in a reduction of clamp load produced by the applied torque. Ford also indicated that corrosion and/or dirt build-up on the wheel mounting surface and rotor or drum to hub mounting surfaces can cause installation clamp loads to relax during service, possible resulting in stud failure in

bending fatigue (Figures 2 and 3). ODI's testing and analysis indicate that the third cause identified by Ford is the primary factor contributing to the reported incidents of stud fracture and wheel separation in the subject vehicles.

Figure 2. Windstar wheel stud bending fatigue fracture surface.

Figure 3. Magnified (50x) cross-section of stud fracture surface from Figure 2.

POPULATION: The subject vehicles are MY 1997 through 2000 Ford Windstar minivans. Ford has sold over 800 thousand subject vehicles in the United States. Table 1 shows the vehicle sales volumes by model year and wheel type.

MY	Aluminum wheels	Steel wheels	Total
1997	16,019	20,992	37,011
1998	135,317	199,612	334,929
1999	158,495	47,036	205,531
2000	145,258	88,700	233,958
Total	455,089	356,340	811,429

Table 1. Subject vehicle population.

PROBLEM EXPERIENCE: Analysis of ODI and Ford complaint and field report data has identified 191 reports related to the alleged defect in the subject vehicles (Table 2). One hundred eight of these reports allege that the failures resulted in wheel separations, with 17 of these alleging that a crash resulted.

Category	ODI	Ford	Total
Complaints	18	173	191
Wheel separations	8	100	108
Crashes	2	15	17
Injury incidents	0	5	5
Injuries	0	5	5
Fatal incidents	0	0	0
Fatalities	0	0	0

Table 2. Failure summary.

WARRANTY: Ford provided 1,644 warranty claims related to the alleged defect in the subject vehicle population, including 25 that resulted in wheel separation incidents.

DESIGN, MATERIAL, AND/OR PRODUCTION MODIFICATIONS: The general design and manufacture of the wheels, wheel studs and wheel nuts did not change during production of the subject vehicles. A change in the front brake rotors from a "floating" rotor to a "fixed" rotor design was identified as a possible contributor to the higher failure rates in MY 1998 and earlier vehicles.

Prior to MY 1999, Ford used a "floating" brake rotor design on the front wheels of the subject vehicles (Figure 4), where the rotor is held in position by the clamp load between the wheel and hub. Starting in MY 1999, Ford implemented a "fixed" brake rotor design, in which three machine screws secure the rotor to the hub prior to the installation of the wheel (Figure 5).

Figure 4. Floating rotor, prior to MY99.

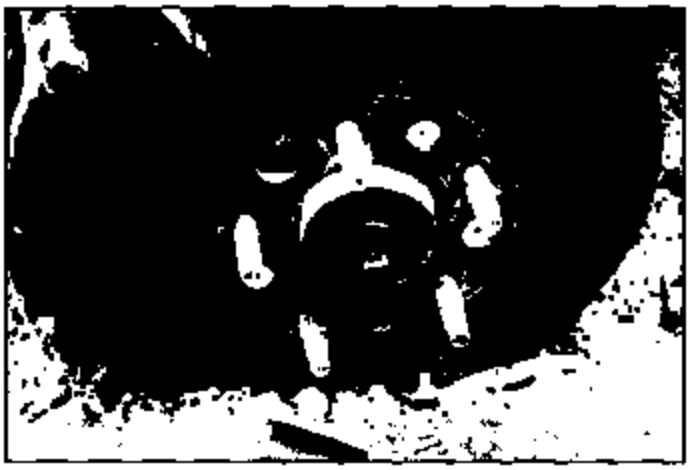

Figure 5. Fixed rotor design, MY99 and later.

FORD TESTING: Ford submitted data during the investigation concerning the clamp loads produced at various fastener torques for the subject wheels and for two peer minivans. Ford provided the data for new fasteners at the initial installation ("rundown") and up to 30 additional rundowns. Ford also submitted data concerning subject and peer fastener performance following 40 hours of exposure to salt spray. One peer had significantly higher clamp loads than the subject fastener for the initial installation, but similar clamp loads for subsequent rundowns and for the post-salt spray evaluation. The second peer had lower clamp loads than the subject fasteners for all of the test cycles.

VRTC TESTING: The Vehicle Research and Test Center (VRTC) in East Liberty, Ohio conducted testing to assess the torque-tension variability just above the minimum specified torque, 83 ft-lbs, for: (1) subject alloy wheels; (2) subject steel wheels; and (3) peer alloy wheels. VRTC's testing also measured the changes in clamp load after completion of a specified drive cycle.

Stud Tension	Used wheels, as received with no cleaning/preparation			Used wheels, with cleaning/preparation	
	Windstar - alloy[1]	Windstar – steel[2]	Caravan - alloy	Windstar - alloy[2]	Caravan - alloy
Mean, (lb.)	3,016	3,144	3,279	10,209	4,597
Minimum Measured, (lb.)	2,111	2,351	1,856	9,733	3,665
3 Sigma Range, (± lb.)	1,564	1,193	2,568	1,331	841

Table 3. Wheel Fastener Torque-Tension Variability Test Data, 84 ft-lbs.

The testing indicated that, when fastened to the minimum specified torque, average stud tensions of in-service fasteners were only slightly above the minimum required level given by Ford for used parts (2,900 lbs.), with a relatively high amount of variability (Table 3). The minimum measured and predicted tensions were well below the specification and the tensions exhibited significant further reductions after completion of the drive cycle. This performance was observed in the subject alloy and steel used wheels tested in the as-received condition and in the peer alloy used wheel tested by VRTC. All of the wheels showed substantial improvements after the stud and nut threads and wheel and nut interface surfaces were cleaned with a wire brush and the threads lubricated.

VRTC's testing indicated that dirt, corrosion, or damage (e.g., material transfer, surface discontinuities) to the wheel nut-seating surface (Figure 6) have a significant effect on the clamp loads produced by wheel fastener installation torques. In addition, the test results demonstrate that stud threads and wheel-rotor (Figure 7) and rotor-hub interface surfaces should be cleaned of dirt and corrosion prior to wheel installation and that the wheels should be tightened to at least the nominal torque level of 100 ft-lbs.

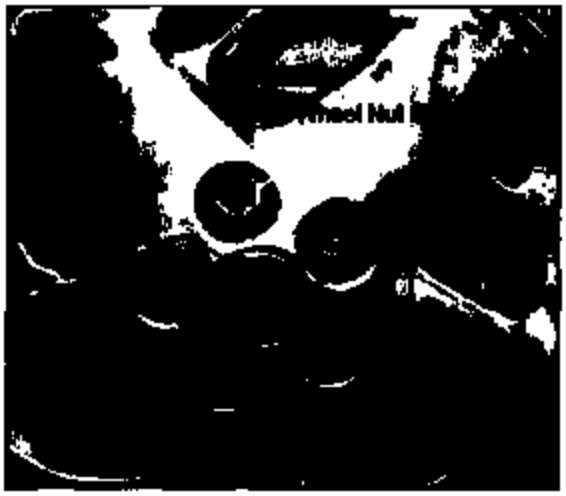

Figure 6. MY99 alloy wheel conical nut seats (wheel-nut interface)

Figure 7. MY99 alloy wheel rear surface (interface with brake rotor surface).

[1] Final calibration completed.
[2] Using assumed calibration factor (for final results, see VRTC test report).

In general, the tightening of wheel nuts to within the specified torque range (83-113 ft-lbs) is not sufficient to ensure that the minimum clamp load has been achieved. If the wheel fastening system is not properly cleaned and prepared prior to the wheel installation, nut torque may not achieve the necessary stud tension and clamp load due to frictional losses at the wheel nut interface and the stud-nut threads. It should also be noted that the Ford Owner's Manual for the subject vehicles calls for re-torquing the wheel fasteners 500 miles after each installation (peer minivans evaluated by VRTC did not have any re-torque requirements/recommendations).

FORD'S POSITION: Ford believes that there is no evidence of a defect in the design or manufacture of the wheel fastening system in the subject vehicles. Ford attributes the incidence of wheel stud failure in the subject vehicles to improper service or maintenance, as noted in the February 3, 2003 letter responding to PE02-085:

> **Ford does not believe the reported events identify the presence of a safety defect trend in the design, manufacture, or assembly of the wheel attachment for the subject vehicles. Rather, we believe that the reported loose attachments and stud failures are likely due to 1) improper tightening of the fasteners to the specified torque of 100 lb-ft during the vehicle servicing that typically has occurred by the vehicle mileages at which these incidents have been alleged or 2) other improper service, such as assembling the wheel to the vehicle with excessive dirt or corrosion present. Wheel separation due to stud fracture should be preceded by adequate warnings of noise or vibration during vehicle operation or the visual observation that a lug nut is missing or a stud is broken during vehicle maintenance, such as brake inspection or tire rotation, or during vehicle cleaning or checking of tire pressure. For these reasons and other reasons more fully explained in the attachment to this response, Ford believes that wheel stud breakage on the subject vehicles does not constitute an unreasonable risk to motor vehicle safety.**

ODI ANALYSIS: ODI's analysis of the failure data showed that stud fractures and consequent wheel separations occur more frequently in the subject vehicles equipped with aluminum alloy wheels than in subject vehicles with steel wheels and in peer vehicles, regardless of wheel type. The differences are more pronounced for alloy wheel separation rates, which do not exceed 10 events per 100 thousand vehicles for the Windstar steel wheels or any of the peer alloy or steel wheels.

Over 90 percent of the wheel separation incidents in the subject vehicles occurred on the front axle, where braking torques place the greatest demands on fastener clamp loads. This indicates that insufficient clamp load is the most probable cause of such stud fractures in the subject vehicle population.[3] The highest failure rates were observed in the MY 1997 and 1998 vehicles equipped with aluminum alloy wheels and floating front brake rotors (Table 4).

[3] Note that stud fractures during nut removal or installation due to excessive torque application are readily detected when they occur and are not believed to be a factor in wheel separation incidents.

Make/Model	MY	Aluminum/Alloy Wheels			Steel Wheels		
			Wheel Separations			Wheel Separations	
		Population	No.	R/100k	Population	No.	R/100k
Ford Windstar	1997	16,019	6	37.5	20,922	1	4.8
	1998	135,217	72	53.2	199,611	16	8.0
	1999	158,495	29	18.3	47,036	4	8.5
	2000	145,258	1	0.7	88,700	1	1.1
	Total	**454,989**	**108**	**23.7**	**356,269**	**22**	**6.2**

Table 4. Wheel separations by model year and wheel type (all sources).

Approximately 76 percent of known wheel separations have occurred at greater than 15,000 miles in service (Table 5), when it is highly likely that the wheel had been removed and reinstalled for some service repair prior to the fastener failure. This is particularly true for the MY 1997 and 1998 vehicles, which have the highest failure rates and the greatest differences from peers after 30 thousand miles of service. In the MY 1997 and 1998 vehicles, 88 percent of the failures occurred at greater than 15,000 miles and 69 percent occurred after 30,000 miles of service. Up to 15,000 miles of service, the rate of separations in the MY 1998 vehicles with aluminum wheels and floating front brake rotors is about 40 percent lower than that of the MY 1999 vehicles with aluminum wheels and fixed front brake rotors. After 30,000 miles of service, the rate in the MY 1998 vehicles with aluminum wheels is over 10 times that of the MY 1999 vehicles with aluminum wheels.

Wheel Type/MY			Reports by Mileage Range			R/100k by Mileage Range		
Wheel	MY	Pop	0-15k	15-30k	>30k	0-15k	15-30k	>30k
Aluminum	1997	16,019	0	1	5	0.0	6.2	31.2
	1998	135,217	9	12	43	6.7	8.9	31.8
	1999	158,495	17	6	4	10.7	3.8	2.5
	2000	145,258	0	0	1	0.0	0.0	0.7
	Total	**454,989**	**26**	**19**	**53**	**5.7**	**4.2**	**11.6**
Steel	1997	20,922	1	0	0	4.8	0.0	0.0
	1998	199,611	1	1	13	0.5	0.5	6.5
	1999	47,036	0	1	2	0.0	2.1	4.3
	2000	88,700	0	1	0	0.0	1.1	0.0
	Total	356,269	2	3	15	0.6	0.8	4.2

Table 5. Windstar wheel separations by wheel type, model year and mileage range (all sources).

Table 6 compares the wheel separation complaint rates of the subject vehicles with the rates recorded during two prior investigations of wheel fastener failures involving Ford vehicles. The comparison is given both per 100 thousand vehicles sold and per million vehicle years of service. The latter adjusts for the differences in field exposure of the EA97-027 and SQ00-016 vehicles, which had relatively short service lives during the investigations, and the subject vehicles, which have been in service for 4-7 years. The exposure-adjusted analysis indicates that the subject vehicles are similar to the vehicles investigated in SQ00-016 and well under the failure rate observed in EA97-027. If the MY 1998 Windstar vehicles with aluminum alloy wheels are considered separately, the exposure adjusted report rate increases to 51.9 R/MVY.

Inv. No.	Vehicles	Population	Wheel Separation Reports (consumer complaints & field rpts)			Outcome
			No.	R/100k	R/MVY	
EA97-027	1997 F-150, Expedition	939,000	81	8.6	135.0	98V-095
SQ00-016	2000 Expedition, Navigator	280,000	25	8.9	27.8	Closed
EA03-004	1997-2000 Windstar	811,000	108	13.3	25.7	Closed

Table 6. ODI Wheel Fastener Investigations by Wheel Separation Report Rate per Million Vehicle Years of Service (R/MVY).

EA97-027 influenced Ford to recall approximately 1.5 million MY 1997-98 F-150, Expedition and Navigator vehicles to correct a defect condition resulting in insufficient clamp load from the fastening system in the wheels installed by Ford at vehicle assembly. Ford attributed the problem to interference from an o-ring located between the wheel and hub and to excessive fastener torque-tension variability due to finish. To correct the problem, Ford removed the o-ring and replaced the two-piece lug nuts in the recalled vehicles with parts using a different finish. According to Ford, the subject vehicles do not have an o-ring interference issue or an issue with excessive torque-tension variability due to fastener finish (the subject vehicles use a one-piece lug nut).

The experience of the subject vehicles is considered similar to that observed in the MY 2000 Expedition and Navigator vehicles investigated in SQ00-016. ODI closed SQ00-016 in December 2001, stating, "Due to the mileages the incidents occurred, it is most likely that improper wheel nut torques were applied during servicing." The vehicles investigated in SQ00-016 were approximately 2 years old when the investigation was closed. The subject vehicles have been in service for at least twice as long.

REASON FOR CLOSING: The subject vehicles range in age from 4–7 years in service, with average mileages estimated to range from 50 to 100 thousand miles. At these mileages, the subject wheels are likely to have been removed and reinstalled multiple times for various service procedures. ODI is concerned about the high wheel separation rates in the MY 1997-98 Windstar vehicles equipped with aluminum alloy wheels. However, analysis of failure data indicates that most of the incidents in that population of vehicles occur after the vehicles had accumulated 30 thousand miles of service.

The factors that increase the risk that inadequate clamp loads may be achieved during service-related wheel installation are not unique to the subject vehicles. Testing conducted by Ford and VRTC indicate that the MY 1998 Windstar aluminum wheel fastening system performs similarly to the wheel fastening systems on peer minivans. No design or manufacturing defect was identified in the wheel fastening system of the subject vehicles.

Ford will send a mailing to owners of MY 1997-98 Windstar vehicles with aluminum wheels that reviews the appropriate wheel fastening procedures and states that the wheel nuts should be tightened to the nominal torque, 100 ft-lbs (136 Nm), and re-tightened to the same torque after 500 miles. Ford's letter also states that it is "a good practice to be sure that before installing the wheel the aluminum wheel mounting surface, wheel lug nut area, and the mounting flange are free from dirt, debris, and loose rust to ensure the wheel is seated correctly and the wheel lug nuts remain fully tightened." ODI will continue to monitor the incidence of wheel fastener failures in the subject vehicle population. Accordingly, this investigation is closed. The closing

of this investigation does not constitute a finding by NHTSA that a safety-related defect does not exist. The agency will take further action if warranted by the circumstances.

Safety Defects Engineer — Date: 8/30/04

I Concur:

Chief, Vehicle Control Division — Date: 8/30/04

Director, Office of Defects Investigation — Date: 8/30/04