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Testing the Dynamic Rollover Resistance of Two 15-Passenger Vans With Multiple Load Configurations

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16. Abstract

As a consequence of NTSB Safety Recommendations H-02-26 and H-02-28, NHTSA performed a study to investigate the effects different load conditions may have on the dynamic rollover resistance of 15-passenger vans. The two vans used in this study, a 2003 Ford E-350 and a 2004 GMC Savana 3500, are representative samples from the only two automobile manufacturers producing 15-passenger vans for the 2004 model year. The GMC Savana 3500 was factory-equipped with electronic stability control (ESC). Each van was evaluated with up to four load configurations depending on the test performed. The GMC Savana 3500 was tested with ESC enabled and disabled.

Two maneuvers were used in this study: the Slowly Increasing Steer (SIS) and the NHTSA Road Edge Recovery (RER, also known as the NHTSA Fishhook). The SIS maneuver was used to measure maximum lateral acceleration and terminal yaw stability. The RER maneuver was used to quantify dynamic rollover resistance.

Slowly Increasing Steer tests revealed that the terminal yaw stability of each vehicle was highly asymmetric, strongly depending on what combination of direction of steer and load was used. Generally speaking, Nominal Load tests produced higher lateral accelerations than those performed with 15-Occupant loading.

In the case of the GMC Savana 3500, the yaw stability observed during Nominal Load SIS tests depended on whether ESC was enabled or disabled; stability was much improved when ESC was enabled. When evaluated with the 15-Occupant load, differences between ESC enabled and disabled SIS tests were much less apparent.

Generally speaking, the static stability factors and dynamic rollover resistance of the vans degraded as the number of occupants increased. The only exception was that the maneuver entrance speed capable of producing two-wheel lift with 10-Occupant loading was lower than that required by the 15-Occupant configuration for the Ford E-350.

None of the load configurations used in this study induced two-wheel lift during RER tests performed with the GMC Savana 3500 when its ESC was enabled. However, when ESC was disabled the Savana 3500's dynamic rollover resistance progressively worsened as the number of occupants increased.

Results from this study indicate that installation of ESC on 15-passenger vans may have important safety benefits in some, but not necessarily all, on-road driving situations. Although ESC prevented wheel lift of the GMC Savana 3500 during Road Edge Recovery testing, it could not prevent the vehicle from spinning out during a Slowly Increasing Steer test performed with a 15-Occupant load.

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CONVERSION FACTORS

Approximate Conversions to Metric Measures					**Approximate Conversions to English Measures**				
Symbol	When You Know	Multiply by	To Find	Symbol	Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4	millimeters	mm	mm	millimeters	0.04	inches	in
in	inches	2.54	centimeters	cm	cm	centimeters	0.39	inches	in
ft	feet	30.48	centimeters	cm	m	meters	3.3	feet	ft
mi	miles	1.61	kilometers	km	km	kilometers	0.62	miles	mi
		AREA					AREA		
in^2	square inches	6.45	square centimeters	cm^2	cm^2	square centimeters	0.16	square inches	in^2
ft^2	square feet	0.09	square meters	m^2	m^2	square meters	10.76	square feet	ft^2
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.39	square miles	mi^2
		MASS (weight)					MASS (weight)		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.45	kilograms	kg	kg	kilograms	2.2	pounds	lb
		PRESSURE					PRESSURE		
psi	pounds per $inch^2$	0.07	bar	bar	bar	bar	14.50	pounds per $inch^2$	psi
psi	pounds per $inch^2$	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pounds per $inch^2$	psi
		VELOCITY					VELOCITY		
mph	miles per hour	1.61	kilometers per hour	km/h	km/h	kilometers per hour	0.62	miles per hour	mph
		ACCELERATION					ACCELERATION		
ft/s^2	feet per $second^2$	0.30	meters per $second^2$	m/s^2	m/s^2	meters per $second^2$	3.28	feet per $second^2$	ft/s^2
		TEMPERATURE (exact)					TEMPERATURE (exact)		
°F	Fahrenheit	5/9[(Fahrenheit) - 32°C]	Celsius	°C	°C	Celsius	9/5 (Celsius) + 32°F	Fahrenheit	°F

DISCLAIMER

NOTE REGARDING COMPLIANCE WITH
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For the convenience of visually impaired readers of this report using text-to-speech software, additional descriptive text has been provided for graphical images contained in this report to satisfy Section 508 of the Americans With Disabilities Act (ADA).

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The authors wish to recognize the outstanding support of our research colleagues. Devin Elsasser and Bryan O'Harra served as experimenters for the tests. Additionally, Devin designed the "heavy-duty" titanium outriggers required for this study. Larry Jolliff performed the required driving. Greg Stevens, Jim Preston, and Michael Brown prepared the vehicle for testing by installing instrumentation and outriggers, and assisted with the many necessary tire changes. Dave Dashner and Leslie Portwood performed post-processing of the test and video data. Jan Cooper provided administrative support. Without the tremendous efforts put forth by these individuals, the work discussed in this report would not have been possible.

Garrick J. Forkenbrock
W. Riley Garrott

EXECUTIVE SUMMARY

As a consequence of NTSB Safety Recommendations H-02-26 and H-02-28, NHTSA performed a study to investigate the effects different load conditions may have on the dynamic rollover resistance of 15-passenger vans. The two vans used in this study, a 2003 Ford E-350 and a 2004 GMC Savana 3500, are representative samples from the only two automobile manufacturers currently producing 15-passenger vans (i.e., for the 2004 model year). The GMC Savana 3500 was factory-equipped with electronic stability control, or ESC. The GMC Savana 3500 was tested both with ESC enabled and disabled. Since this vehicle was designed to be driven with ESC enabled, the authors recognize that the ESC disabled testing was not typical of normal usage for this vehicle. These tests were performed to provide information about how ESC may affect dynamic rollover resistance.

Two maneuvers were used in this study: the Slowly Increasing Steer (SIS) and the NHTSA Road Edge Recovery (RER, also known as the NHTSA Fishhook). The SIS maneuver was used to measure maximum lateral acceleration and terminal yaw stability in a quasi steady-state scenario. The RER maneuver was used to quantify dynamic rollover resistance. Each van was evaluated with up to four load configurations depending on the test performed: Nominal Load (2-Occupant), 5-Occupant, 10-Occupant, and 15-Occupant (Maximum Occupancy).

When the Ford E-350 was evaluated with the SIS maneuver, the vehicle produced overall maximum lateral accelerations of 0.76g and 0.72g in the Nominal and 15-Occupant configurations, respectively. Every right-steer Nominal Load test and each left-steer 15-Occupant test produced a spinout (i.e., the vehicle was limit oversteer). Left-steer Nominal Load tests and right-steer 15-Occupant tests did not.

Overall, when ESC was enabled, the GMC Savana 3500 produced a maximum lateral acceleration of 0.78g in the Nominal Load configuration and 0.75g when 15 occupants were used. Similarly, when the Savana 3500's ESC was disabled, the vehicle produced overall maximum lateral accelerations of 0.80g and 0.72g in the Nominal and 15-Occupant configurations, respectively. Like the Ford E-350, the lateral stability of the GMC Savana 3500 was also a function of direction of steer in the Nominal Load configuration when ESC was disabled. Each of the three left-steer tests performed with disabled ESC produced excessive yaw and ultimately resulted in spinouts, whereas right-steer tests produced no such responses. In the Nominal Load configuration, the lateral stability of the GMC Savana 3500 was also found to be a function of whether ESC was enabled or disabled. When ESC was enabled, the vehicle was more stable, especially when left-steer tests are considered.

Only a limited number of left-steer SIS tests were performed with the GMC Savana 3500 in the 15-Occupant configuration. However, in each case the vehicle produced substantial roll oscillations. With ESC enabled, a spinout and two-wheel lift was observed. When ESC was disabled, the test driver terminated the maneuver after the roll oscillations began, but before a spinout or two-wheel lift had a chance of occurring. Therefore, the spinout observed with ESC enabled would likely have occurred with ESC disabled had the driver not terminated the test. Right-steer tests performed with the GMC Savana 3500 in the 15-Occupant configuration with ESC both enabled and disabled were much more stable, not producing spinouts or two-wheel lift.

Although the different load configurations used in this study had similar effects on displacing the center of gravity positions of the Ford E-350 and GMC Savana 3500 15-passenger vans, the dynamic rollover resistance of each vehicle was affected somewhat differently.

Generally speaking, the static stability factors and dynamic rollover resistance of the Ford E-350 were reduced as the number of occupants increased. The only exception to this trend was that the maneuver entrance speed capable of producing two-wheel lift with 10-Occupant loading was lower than that required by the 15-Occupant configuration for the Ford E-350.

In agreement with the trend observed with the Ford E-350, the static stability factor of the GMC Savana 3500 became lower as the number of occupants increased. None of the load configurations used in this study induced two-wheel lift during RER tests performed with ESC enabled. The dynamic rollover resistance of the GMC Savana 3500 progressively worsened as the number of occupants increased when ESC was disabled.

Results from this study indicate that installation of ESC on 15-passenger vans may have important safety benefits in some, but not necessarily all, driving maneuvers. Although ESC improved the dynamic rollover resistance of the GMC Savana 3500 during Road Edge Recovery testing, such improvements were not observed during Slowly Increasing Steer tests. Due to the limited instrumentation used in this study, the authors cannot explain these apparently contradictory results. For this, and other, reasons the GMC Savana 3500 will be included as one of five vehicles used in NHTSA’s 2004 Light Vehicle Handling and ESC Research Program. So as to better understand how and when ESC interacts with vehicles used in this program, more extensive data acquisition will be utilized. Vehicle outputs such as brake line pressure, body slip angle, and GPS-based vehicle position, as well as a more accurate detection of when ESC intervention is initiated, will be measured.

1.0 INTRODUCTION

On November 1, 2002 the National Transportation Safety Board (NTSB) issued Safety Recommendations H-02-26 and H-02-28 to the National Highway Traffic Safety Administration (NHTSA) [1,2]. Both recommendations pertain to the evaluation of 15-passenger van dynamic rollover resistance.

In recommendation H-02-26, NTSB encourages NHTSA to:

> *"Include 15-passenger vans in the National Highway Traffic Safety Administration dynamic testing program. The dynamic testing should test the performance of 15-passenger vans under various load conditions."*

Similarly, in recommendation H-02-28, NTSB indicates NHTSA should:

> *"Evaluate, in conjunction with the manufacturers of 15-passenger vans, and test as appropriate, the potential of technological systems, particularly electronic stability control systems, to assist drivers in maintaining control of 15-passenger vans."*

The Ford Motor Company and General Motors are the only two automobile manufacturers currently producing 15-passenger vans (i.e., for the 2004 model year). The Ford offering is the E-350 Super Duty, while General Motors offers the Chevrolet Express 3500 EXT or the GMC Savana 3500 EXT. The Chevrolet Express 3500 EXT and the GMC Savana 3500 EXT are nearly equivalent "sister" vehicles expected to have the same dynamic rollover resistance. For the 2004 model year, General Motors has equipped certain models of its Chevrolet Express and GMC Savana 3500 12- and 15-passenger vans with electronic stability control, or ESC[1], as standard equipment. These General Motors vans are the first vehicles of their kind to offer such technology to the consumer.

As a consequence of NTSB Safety Recommendations H-02-26 and H-02-28, NHTSA decided to perform a study to investigate the effects different load conditions and the presence or absence of ESC may have on the dynamic rollover resistance of 15-passenger vans. Two vans and four load configurations were used. The results of this study are documented in this report.

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[1] The automotive industry has not agreed on a standard designation for electronic stability control, however the Society of Automotive Engineers (SAE) had recommended that "ESC" be used when referring to such systems. In the case of the Chevrolet Express and GMC Savana 3500 vans, the General Motors designation is "Stabilitrak."

2.0 OBJECTIVE

The objectives of this study were twofold. First, the dynamic rollover resistance of two 15-passenger vans, ballast with different load configurations, was to be determined. This research was performed in response to NTSB Safety Recommendation H-02-26. To accomplish this goal, two vans were used: a 2003 Ford E-350 and a 2004 GMC Savana 3500. Both vehicles were purchased new by NHTSA.

The second objective of this study was to assess the influence of ESC on 15-passenger van dynamic rollover resistance. This research was performed in response to NTSB Safety Recommendation H-02-28. Although it was not originally marketed as a means of reducing the likelihood of on-road, untripped rollover, ESC has improved the Road Edge Recovery test performance (i.e., dynamic rollover resistance) of all six ESC-equipped sport utility vehicles[2] evaluated by NHTSA since year 2000. Of the two vehicles used for the research discussed in this study, only the GMC Savana 3500 was equipped with ESC. Therefore, only one vehicle was used for tests in support of this study's second objective.

Note: Although Dodge has produced 15-passenger vans in the past, DaimlerChysler stopped producing such a van after the 2002 model year. Since NHTSA only regulates new vehicles, the authors did not attempt to obtain a Dodge van for this study.

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[2] At the time of this report, NHTSA had evaluated the following ESC-equipped sport utility vehicles: 2004 Volvo XC90, 2003 Toyota 4Runner 4x4, 2003 Toyota 4Runner 4x2, 2001 Toyota 4Runner 4x4, 2000 Lexus LX470, and 1999 Mercedes ML320.

3.0 TEST CONDITIONS

3.1 Test Vehicles

The vehicles evaluated in this study are the only two contemporary 15-passenger van models sold in the United States. Although each vehicle was purchased new, the Ford E-350 was a 2003 model[3], while the GMC Savana 3500 was an early production 2004 offering. The 2004 Savana 3500 is the first 15-passenger van to be offered with ESC. This system, named "Stabilitrak" by General Motors, is installed as standard equipment.

Table 3.1 provides several descriptive parameters for each test vehicle. These parameters are not intended to be comprehensive descriptions of each vehicle, but to highlight certain features the authors deem relevant to rollover propensity. This table presents baseline data only. Used here, the term "baseline" refers to the state of the vehicle as received from the dealer, with a full tank of fuel and the addition of a 50th percentile male driver (161.4 lbs). The effects of outrigger installation, instrumentation, etc. are not represented in Table 3.1; rather they are discussed in a later section of this chapter. Appendix Tables A-1 and A-2 summarize the baseline weights, center of gravity locations, static stability factors, and pitch, roll, and yaw inertia measurements of the test vehicles.

Table 3.1. Test Vehicle Descriptive Parameters.

Vehicle	Miscellaneous Features	GVWR (lbs)	GAWR (lbs)		Steering Ratio (deg/deg)	Wheelbase (in)	Mean Track Width (in)	Static Stability Factor
			Front	Rear				
2003 Ford E-350	15-passenger seating; 5.4L V8; 4-spd auto; RWD	9100	3250	6084	22.8	138.0	68.3	1.073
2004 GMC Savana 3500	15-passenger seating; 6.0L V8; 4-spd auto; RWD; Stabilitrak	9600	4300	6084	17.1	155.5	68.2	1.091

3.2 Tires

3.2.1 Description

All tires were new and of the same make, model, size, and DOT specification as those installed by the manufacturer as original equipment. A description of the tires used in this study is provided in Table 3.2. All tests in this study were performed with the tires inflated to the pressures recommended by each manufacturer on the vehicle identification placards.

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[3] Although the Ford E-350 used in this study was a 2003 model year vehicle, Ford has told NHTSA that no significant changes were made to the chassis, suspension, or tires for 2004. For this reason, the rollover resistance of the 2003 and 2004 model year vans should be identical.

Table 3.2. Tire Specifications.

Vehicle	Size	Load Range	Load Index	Make	Model	Front/Rear Placard Inflation Pressure (psi)
2003 Ford E-350	LT245/75R16	E	120-116	Goodyear	Wrangler HT	55 / 80
2004 GMC Savana 3500	LT245/75R16	E	120/116 S	Bridgestone	V-Steel Rib 265 (TPC 2012MS)	50 / 80

3.2.2 Break-In Procedure

Prior to the beginning of any test series, the tires were "scrubbed in" to wear away mold sheen and/or to be brought up to operating temperature. The break-in/warm-up procedure used in for the tests performed in this study was identical to that used in NHTSA's Dynamic Rollover NCAP Test Procedure [3].

3.2.3 Mounting Technique

No lubricant was used when mounting tires to the rims used for testing. This was done to eliminate the possibility of tire lubricant contributing to debeading.

3.2.4 Frequency of Changes

To minimize the effects of tire wear on vehicle response characteristics, multiple tire changes were utilized. The following guidelines were followed:

- One set of tires was used for all Slowly Increasing Steer (SIS) performed to ≈0.5g and Road Edge Recovery (RER) tests performed in the same configuration, provided no two-wheel lift was observed during the respective RER tests (i.e., those performed in the Default Procedure and during Supplemental Procedure Part 1; explained in greater detail in Chapter 4). In this study, a "configuration" was defined as one combination of a particular load and ESC state, if applicable.

- If two-wheel lift was observed during a test begun with a maneuver entrance speed greater than 45 mph in the Default Procedure, each tire was replaced with new, and additional RER tests were performed. These tests were to confirm the occurrence of two-wheel lift was a vehicle-based characteristic and not just the result of excessive tire wear.

- No tire change was deemed necessary between the completion of SIS tests performed to ≈0.5g and initiation of RER testing. This was because all SIS tests performed to ≈0.5g were within, or just outside of, the linear range of lateral acceleration—a region of low-severity shown to produce minimal tire wear.

- SIS tests used to measure maximum lateral acceleration required one tire set per load configuration. These tires were not used during any Road Edge Recovery tests. In the case of the GMC Savana 3500, ESC enabled and disabled tests used the same tire set per load configuration. For this vehicle, the ESC enabled tests always preceded those performed with disabled ESC.

3.2.5 Use of Inner Tubes

The occurrence of debeads can result in significant damage to the test surface. To reduce the likelihood of tire debeading, inner tubes designed for radial tires were installed prior to every test performed in this study. Inner tubes were appropriately sized for the test vehicle's tires.

Note: NHTSA has never observed debeading or rim-to-pavement contact during the conduct of SIS tests. For this reason, the authors do not believe installation of inner tubes is necessary for SIS tests, regardless of vehicle or load condition. That said, the most current RER test procedure (described in Chapter 4 and in [3]) specifies that the SIS and some RER tests may use the same tire set. For the sake of convenience, it was therefore desirable to install inner tubes prior to SIS tests to minimize disruption between conclusion of SIS testing and the beginning of the RER maneuver.

3.3 Load Configurations

The test vehicles were evaluated with multiple load configurations. Configuration descriptions were as follows:

Nominal Load. The Nominal Load consisted of the driver, instrumentation, a steering machine, and NHTSA's "heavy-duty" titanium outriggers in lieu of the front and rear bumpers. A data acquisition system (DAS) was installed on or near the front passenger seat. The total weight addition of the DAS, instrumentation, and steering machine hardware was approximately that of an average person. The vehicle was fully fuelled in the Nominal Load configuration. The Nominal configuration approximates a 2-occupant load.

5-Occupant Load. In addition to the equipment used in the Nominal configuration, 5-Occupant tests used three water dummies, each weighing approximately 175 lbs, positioned in each second row seating position for which an adult passenger may be restrained with a seatbelt (see Figure 3.1). Note that regardless of the vehicle configuration being considered, water dummies were never installed in the front passenger seat; it was always occupied by the DAS.

10-Occupant Load. In addition to the equipment used in the Nominal configuration, 10-Occupant tests used eight water dummies, each weighing approximately 175 lbs. Three water dummies were positioned in each second and third row seating position for which an adult passenger may be restrained with a seatbelt. Additionally, two water dummies were placed in the fourth seating row, to the left and right of the center seating position (see Figure 3.1). An empty water dummy was positioned in the center of the fourth row as a way of restricting the lateral movement of the two fourth-row dummies. This dummy weighs only 15 lbs, and was not considered a simulated occupant.

15-Occupant Load. In addition to the equipment used in the Nominal configuration, Maximum Occupancy tests used 13 water dummies, each weighing approximately 175 lbs, positioned at each seating position for which an adult passenger may be restrained with a seatbelt, with the exception of the front passenger seat (see Figure 3.1).

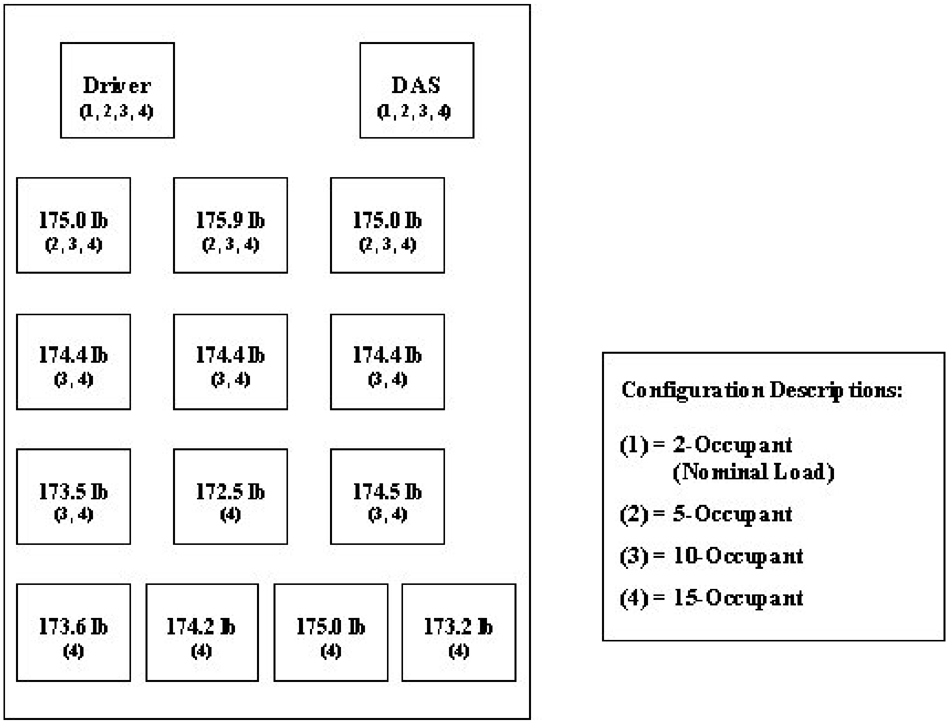


Figure 3.1. Water dummy weights used in the evaluation of the Ford E-350 and GMC Savana 3500. The numbers in parentheses indicate which water dummies were used in what load configuration.

Center of gravity and inertial characteristics of the water dummies used by NHTSA have been measured and/or calculated. These results are available in [4].

To quantify the influence of each load configuration on center of gravity location and mass moments of inertia, both vehicles were tested on the Vehicle Inertia Measurement Facility (VIMF) at SEA, Inc (see Appendix Tables A-1 and A-2). Results from tests performed in the various configurations were compared with those measured in the baseline condition. Tables 3.4 and 3.5 summarize these data for the Ford E-350 and GMC Savana 3500, respectively.

Table 3.3. Change from Baseline Condition (2003 Ford E-350).

Load	Parameter									
	Vehicle Weight		SSF		Pitch Inertia		Roll Inertia		Yaw Inertia	
	Value (lbs)	Percent	Value	Percent	Value (ft-lb-sec^2)	Percent	Value (ft-lb-sec^2)	Percent	Value (ft-lb-sec^2)	Percent
Nominal	337.9	5.2	0.012	1.1	718.0	10.5	83.0	8.4	749.0	10.7
5-Occupant	875.6	13.5	-0.019	-1.8	774.0	11.3	155.0	15.6	766.0	11.0
10-Occupant	1768.5*	27.3*	-0.062*	-5.8*	2010.3*	29.5*	185.3*	18.7*	1926.8*	27.6*
15-Occupant	2662.1	41.1	-0.107	-10.0	3024.0	44.3	233.0	23.5	2867.0	41.1

*VIMF measurements of the Ford E-350 were not taken in the 10-Occupant configuration. The percentages provided in Table 3.4 were computed with calculated C.G. height and mass moments of inertias.

Table 3.4. Change from Baseline Condition (2004 Savana 3500).

Load	Parameter									
	Vehicle Weight		SSF		Pitch Inertia		Roll Inertia		Yaw Inertia	
	Value (lbs)	Percent	Value	Percent	Value (ft-lb-sec^2)	Percent	Value (ft-lb-sec^2)	Percent	Value (ft-lb-sec^2)	Percent
Nominal	304.3	4.5	0.009	0.8	642.0	8.3	79.0	6.7	743.0	9.3
5-Occupant	844.7	12.5	-0.029	-2.7	681.0	8.8	131.0	11.1	745.0	9.3
10-Occupant	1733.0*	25.9*	-0.071*	-6.5*	1638.4*	21.3*	183.1*	15.5*	1746.7*	21.8*
15-Occupant	2623.7	38.8	-0.117	-10.7	2422.0	31.5	242.0	20.5	2554.0	31.9

*VIMF measurements of the GMC Savana 3500 were not taken in the 10-Occupant configuration. The percentages provided in Table 3.4 were computed with calculated C.G. height and mass moments of inertias.

Load configuration had a substantial effect on the centers of gravity (C.G.) height (and therefore SSFs) of both vans. In the case of the Ford E-350, the Nominal configuration increased the vehicle's SSF by 1.1 percent (C.G. height was lowered by 0.4 inches). However, when loaded with 15 occupants, the SSF decreased by 10 percent (C.G. height was raised 3.5 inches). Similar changes were seen with the GMC Savana 3500, where changes in SSF ranged from an increase of 0.8 percent (C.G. height was lowered by 0.2 inches) in the Nominal configuration, to a 10.7 percent decrease when loaded with 15 occupants (C.G. height was raised 3.8 inches).

Due the lower Baseline vehicle weight of the Ford E-350 and because identical load configurations were used for each van, the number of occupants affected the Ford E-350's mass moments of inertia to a greater extent than for the GMC Savana 3500. When compared to its Baseline numbers, 5- and 15-occupant loads increased the pitch inertia of the Ford E-350 by 11.3 and 44.3 percent, respectively. Yaw inertia was similarly affected. The respective roll inertias increased by 15.6 and 23.5 percent. In contrast, when the GMC Savana 3500's 5- and 15-occupant pitch inertias were compared to the Baseline numbers, respective increases of 8.8 and 31.5 percent were observed. Yaw inertia was similarly affected. The 5- and 15-occupant roll inertias increased 9.3 and 31.9 percent over that of the Baseline condition, respectively.

Note that in the case of the Ford E-350, the use of completely filled water dummies in every designated seating position caused the vehicle's Gross Vehicle Weight Rating (GVWR) to be exceeded slightly (by 41.4 lbs, or 0.46 percent). Although NHTSA does not typically evaluate vehicles at weights exceeding their respective GVWRs, the authors did not attempt to reduce the weight of the 15-Occupant load used for the Ford E-350 (i.e., the vehicle was evaluated at 9141 lbs). This decision preserved configuration consistency between the two vans.

3.4 Installation of Outriggers

The bumper assemblies were removed from each test vehicle for outrigger installation. The subsequent reduction in vehicle weight was entirely offset by the additional weight of the outriggers and their mounting systems. For both vehicles, the outriggers and their related hardware outweighed the bumper assemblies.

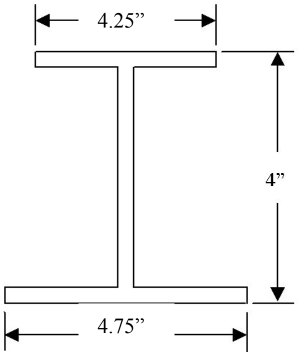
The outriggers used in this study were designed to minimize the effect of their installation on test vehicle roll inertia. The beams were CNC machined from extruded 6AL-4V titanium I-beams, and were attached to the front and rear bumper attachment points with aluminum and steel brackets. Pictures of a representative mount and installation are featured in Figures 3.2 and 3.3, respectively.

Figure 3.2. "Heavy-Duty" outrigger bracket installed at the left rear of a 2004 GMC Savana 3500.

Figure 3.3. "Heavy-Duty" outrigger installed on the front of a 2003 Ford E-350.

Table 3.5 presents the length, weight, cross-sections, mass moments of inertia, and C.G. location of the outriggers used in this study. A detailed schematic of a "heavy-duty" outrigger is presented in Appendix Figure A-1.

Table 3.5. NHTSA's "Heavy Duty" Outrigger Specifications.

Description	Value
Length	153 inches
Upper Flange Thickness	0.300 inches
Lower Flange Thickness	0.325 inches
Web Thickness	0.250 inches
Weight	78.5 lbs
Cross-section	
Moment of Inertia About Pitch Axis (Through Outrigger C.G.)	≈ 0
Moment of Inertia About Roll and Yaw Axes* (Through Outrigger C.G.)	27.9 ft-lb-s^2
Vertical C.G. Location*	2.1 inches (below top of the top flange)

*Calculated with the software used to design the outriggers (Solid Edge**).**

3.5 Instrumentation

Each test vehicle was similarly instrumented with sensors, a data acquisition system, and a programmable steering machine. The instrumentation package was identical to that used during Phases VI and VII testing except no wheel lift sensors were used during tests performed with the Ford E-350. Descriptions of this equipment, and how it was utilized, have been previously documented and are available in past NHTSA rollover reports [4,5].

4.0 TEST MANEUVERS

Two test maneuvers were used in this study: the Slowly Increasing Steer (SIS) and the NHTSA Road Edge Recovery (RER, also known as the NHTSA Fishhook). Most SIS maneuvers were used to provide data in the linear range of lateral acceleration, while some were used to measure maximum lateral acceleration. The maneuvers are described in Sections 4.2 and 4.3.

4.1 Test Matrix

The test matrix used for this study is provided in Table 4.1. Each maneuver was performed with up to four load configurations. For each load configuration, SIS maneuvers performed to ≈0.5g used three left turns followed by three right turns. SIS tests used to measure maximum lateral acceleration used two load configurations, but the same combinations and repetitions of left and right steering. However, in the case of the GMC Savana 3500, separate SIS tests performed with ESC enabled and disabled required a total of six left turns and six right turns (see Table 4.1). Road Edge Recovery tests were used to assess what effect loading may have on the test vehicles' dynamic rollover propensity. Four load configurations were used for this assessment.

Table 4.1. Test Group 1 Test Matrix.

Test Vehicle	Maneuver	Load Configuration			
		Nominal (2-Occupant)	5-Occupant	10-Occupant	15-Occupant (Max Occupancy)
2003 Ford E-350	SIS (to ≈0.5g)	3L/3R	3L/3R	3L/3R	3L/3R
	SIS (to $A_{y,max}$)	3L/3R	--	--	3L/3R
	RER	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)
2004 GMC Savana 3500 (Enabled ESC)	SIS (to ≈0.5g)	3L/3R	3L/3R	3L/3R	3L/3R
	SIS (to $A_{y,max}$)	3L/3R	--	--	3L/3R
	RER	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)
2004 GMC Savana 3500 (Disabled ESC)	SIS (to ≈0.5g)	--	--	--	--
	SIS (to $A_{y,max}$)	3L/3R[1]	--	--	3L/3R[2]
	RER	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)	Default Procedure; Supplemental Procedures (if needed)

[1] Performed after the 3L/3R tests performed with the Nominal Load and enabled ESC using the same tire set.

[2] Performed after the 3L/3R tests performed with the 15-Occupant load and enabled ESC using the same tire set.

4.2 Slowly Increasing Steer (SIS)

The SIS maneuver was used to characterize the lateral dynamics of each vehicle, and was based on the “Constant Speed, Variable Steer” test defined in SAE J266 [6]. NHTSA indicated its intent to use the SIS for this purpose in the October 2002 Notice of Proposed Rulemaking that was published in the Federal Register. As stated in that notice:

> *“The Slowly Increasing Steer maneuver provides data to assess the amount of turning capability of a vehicle (the Maximum Attainable Lateral Acceleration) and whether the vehicle’s handling degrades gracefully at the limit (did the vehicle plow or spin when the maximum achievable turn was attained). We performed this maneuver for every vehicle tested during Phases II, III, and IV of NHTSA Rollover Research. Based on our experience we believe that this maneuver can be performed with excellent objectivity and repeatability.”*

The intent of the SIS maneuver is not to simulate a “real-world” driving situation, but rather to function as a means of providing valuable insight into the terminal behavior of a vehicle being driven at the limit of lateral adhesion.

There is not general agreement with NHTSA’s use of the SIS to characterize the lateral dynamics of each vehicle. While NHTSA has not received any written comments arguing against the use of the SIS maneuver for this purpose, one auto manufacturer has verbally told NHTSA that use of the SIS maneuver to characterize a vehicle’s limit lateral dynamics is not appropriate.

In this study, two sets of SIS tests were performed, differing only in the final magnitude of the steering angle. The first set provided the data used to define RER handwheel input magnitudes. The second set was used to determine the maximum lateral acceleration of each van in two load configurations.

To begin the maneuver, the vehicle was driven in a straight line at 50 mph. The driver was instructed to maintain as constant a test speed as possible before, during, and after the steering inputs using smooth throttle modulation. For either test group, handwheel position was linearly increased at a rate of 13.5 degrees per second, as shown in Figure 4.1, briefly held constant, then returned to zero as a convenience to the driver. The steering ramp was slow enough that lateral acceleration performance in the linear range could be accurately evaluated.

For the tests used define RER handwheel input magnitudes, the final magnitude of the steering ramp was set so that a lateral acceleration of approximately 0.5g was produced. The final handwheel angle of the SIS tests used to measure maximum lateral acceleration was 270 degrees. All SIS tests used steering to the left and right. Three repetitions of each SIS test condition were performed.

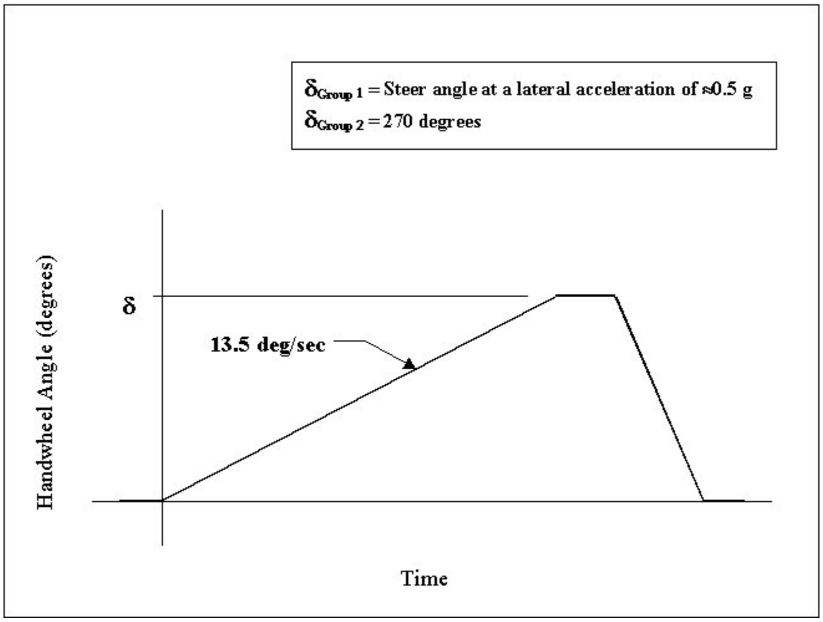


Figure 4.1. Slowly Increasing Steer (SIS) handwheel steering input description.

4.3 Road Edge Recovery (RER)

The handwheel inputs defining the RER maneuver approximate the steering a startled driver might use in an effort to regain lane position on a two-lane road after dropping two wheels off onto the shoulder. Of the nine Rollover Resistance maneuvers studied in the Agency's earlier Phase IV tests (see [5]), only the RER maneuver received "Excellent" ratings in each of the four maneuver evaluation factors (Objectivity and Repeatability, Performability, Discriminatory Capability, and Appearance of Reality). NHTSA considers the RER to be the best overall maneuver for evaluating dynamic rollover propensity. Phase IV testing has demonstrated the handwheel input rates and magnitudes of the RER are within the capabilities of an actual driver. Road Edge Recovery tests performed in this study used procedures identical to those used to by NHTSA's NCAP dynamic rollover rating system.

NHTSA's latest refinement of the RER test procedure includes up to four components. For a given vehicle, each component differs in two ways: the steering angle utilized and the range entrance speeds the maneuvers are begun at. The four components are:

1. Default Procedure
2. Supplemental Procedure Part 1
3. Supplemental Procedure Part 2
4. Supplemental Procedure Part 3

4.3.1 Maneuver Overview

To begin the maneuver, the vehicle was driven in a straight line at a speed slightly greater than the desired entrance speed. The driver released the throttle, and when at the target speed, initiated the handwheel commands described in Figure 4.2 using a programmable steering machine. If a counterclockwise initial steer was input, the steering reversal following completion of the first handwheel ramp was to occur when the roll velocity of the vehicle was 1.5 degrees per second. If a clockwise initial steer was input, the steering reversal following completion of the first handwheel ramp occurred when the roll velocity of the vehicle was -1.5 degrees per second.

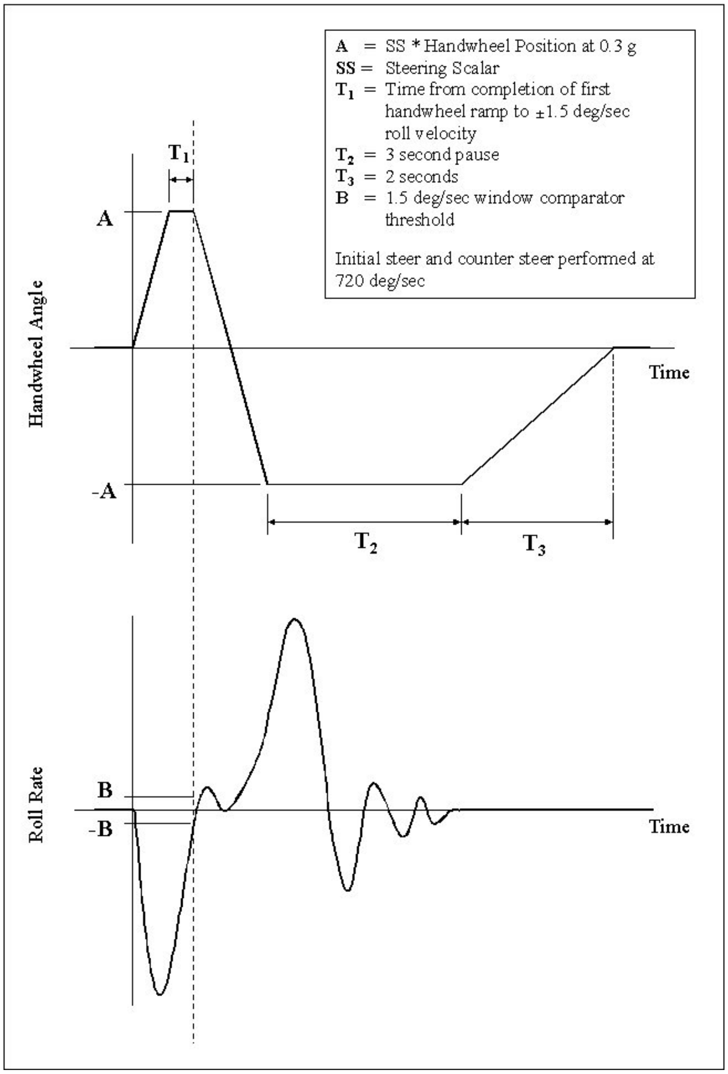


Figure 4.2. NHTSA Road Edge Recovery maneuver description.

The handwheel rates of the initial steer and countersteer were 720 degrees per second for all test vehicles. Following completion of the countersteer, handwheel position was maintained for three seconds. As a convenience to the test driver, the handwheel was then returned to zero.

Each RER test series contained two sequences, with exceptions noted in the following sections: tests performed with left-right steering (first sequence), and tests performed with right-left steering (second sequence). The sequence of left-right tests always preceded those performed with right-left steering.

4.3.2 Default Procedure

RER handwheel angles were calculated with lateral acceleration and handwheel angle data (δ) collected during a series of six SIS tests; a total of three left-steer and three-right steer tests were performed). For each SIS test, a linear regression line was fitted to the lateral acceleration data from 0.1 to 0.375g. Using the slopes of these regression lines, the handwheel angles at 0.3g were determined for each individual test ($\delta_{0.3g}$). The six individual handwheel angles were then averaged to produce an overall value ($\delta_{0.3\text{ g, overall}}$).

$$\delta_{0.3g,\text{ overall}} = (\left|\delta_{0.3g,\text{ left (1)}}\right| + \left|\delta_{0.3g,\text{ left (2)}}\right| + \left|\delta_{0.3g,\text{ left (3)}}\right| + \delta_{0.3g,\text{ right (1)}} + \delta_{0.3g,\text{ right (2)}} + \delta_{0.3g,\text{ right (3)}}) / 6$$

The RER steering angles were calculated by multiplying $\delta_{0.3\text{ g. overall}}$ by a steering scalar (SS). The default steering scalar was 6.5.

$$\delta_{\text{RER (Default)}} = 6.5 \times \delta_{0.3g,\text{ overall}}$$

As explained in Section 3.2.4, most RER tests performed in this study began on the same tire set used for SIS tests performed with the same load configuration. The only exception was when two-wheel lift validation was required, as these processes require use of a new tire set (further explained in Sections 4.3.3.1 and 4.3.3.3).

4.3.2.1 Maneuver Entrance Speed

For the sake of driver safety, and as a final step in the tire scrub-in procedure, each Default Procedure sequence began with a Maneuver Entrance Speed (MES) equal to 35 mph. The MES was measured at the initiation of the first steering ramp, and was increased until a termination condition was satisfied. The order of MES for a sequence was, in mph: 35, 40, 45, 47.5, 50. For each test run, the actual MES was required to be within 1 mph of the target MES.

Note: NHTSA’s experience with the RER maneuver indicates that an incremental increase in MES of 5 mph, up to 45 mph, minimizes tire wear without compromising test driver safety. However, when a MES greater than 45 mph is used, the severity of the responses produced with some vehicles can increase substantially from that observed at lesser entrance speeds. This is especially true if a vehicle has a propensity to oscillate in roll, and/or is able to produce two-wheel lift slightly less than NHTSA's threshold criterion of two inches. In some of these cases, the driver and/or experimenter may not be comfortable with a final 5 mph upwards increment in MES, and might, for the sake of driver safety, deviate from a test procedure that requires it. Generally speaking, such a deviation typically involves the experimenter's use of a more gradual 2.5 mph increase in MES.

To promote driver safety while also eliminating inconsistencies in the way RER maneuvers are performed, the test procedure used in this study (and during dynamic rollover tests used for NHTSA’s NCAP rating metric, for that matter) *required* a MES increment equal to 2.5 mph be used above 45 mph if a test performed at 45 mph did not produce two-wheel lift, regardless of the vehicle being evaluated.

4.3.2.2 Outrigger Contact

If either outrigger contacted the pavement without two-wheel lift during a RER test run, the affected outrigger was raised 0.75 inches and the test was repeated at the same MES. If both safety outriggers contacted the pavement without two-wheel lift, both outriggers were raised 0.75 inches and the test was repeated at the same MES.

4.3.2.3 Termination and Conclusion Conditions

A test sequence was terminated if a MES capable of producing two-wheel lift was observed and the MES was 45 mph or lower. If two-wheel lift was observed during a left-right sequence at 45 mph or lower, the [entire] series was terminated. If no two-wheel lift was observed during a left-right sequence, right-left tests were performed. If two-wheel lift was observed during a right-left sequence performed with a MES of 45 mph or lower, the test series was terminated.

If the MES capable of producing two-wheel lift during a left-right or right-left sequence was 47.5 mph or higher, a new set of tires was installed on the vehicle and the procedure described in Section 4.3.3 was implemented.

A test series was deemed complete if both test sequences within a given series were performed at the maximum maneuver entrance speed without two-wheel lift, rim-to-pavement contact, tire debeading, or outrigger-to-pavement contact. No two-wheel lift, rim-to-pavement contact, or tire debeading was observed during the tests performed in this study.

The flowchart presented in Figure A-2 describes the sequence of events for the Default Test Series.

4.3.3 Supplemental Procedures

Note: If the results of the Default Test Series required the implementation of the Supplemental Procedure Part 1, neither Supplemental Procedure Part 2 nor Part 3 was used in this study.

Note: Depending on the load configuration, the response of test vehicles to elements of the Road Edge Recovery protocol, Supplemental Procedure, Parts 1, 2, and 3 may have required a change in the steering scalar. The steering machine used by NHTSA had the capability for making such changes in vehicles during test sessions via selection of a pre-programmed steering schedule and the adjustment of overall steering angles.

4.3.3.1 Supplemental Procedure Part 1

Following the tire scrub-in procedure outlined in Section 3.2.3, tests were performed with handwheel angles equal to $\delta_{RER\ (Default)}$, as explained in Section 4.3.2. The steering combination (i.e., either left-right or right-left) that produced two-wheel lift in the Default Test Series was used. The first test was to be performed at a MES of 35 mph. This test was performed to ensure any mold sheen remaining from the tire break-in procedure had been removed from the tires. The second test was to be performed at the MES at which two-wheel lift had been previously observed (i.e., in the Default Procedure, with the previous tire set). If two-wheel lift was produced during the test performed with handwheel angles equal to $\delta_{\text{RER (Default)}}$, the test series deemed complete. If two-wheel lift was not produced and the MES was 47.5 mph, the MES was increased to 50 mph. If two-wheel lift was produced during the test performed with a MES equal to 50 mph, the tip-up was considered a valid outcome, and the test series deemed complete.

The flowchart presented in Figure A-3 describes the sequence of events for the Supplemental Procedure Part 1.

4.3.3.2 Supplemental Procedure Part 2

If two-wheel lift was not produced during tests performed with the Default Procedure, the steering scalar was reduced from 6.5 to 5.5. Using the same tires used for tests performed with the Default Test Series, tests were performed with steering angles calculated by multiplying $\delta_{\text{0.3g. overall}}$ by a steering scalar of 5.5.

$$\delta_{\text{RER (Supplemental)}} = 5.5 \text{ x } \delta_{\text{0.3 g, overall}}$$

For the sake of driver safety, the first test of the left-right sequence with the reduced steering scalar applied was performed at a MES of 45 mph. If this test did not produce two-wheel lift, the MES was increased to 47.5 mph. If the test with MES equal to 47.5 mph did not produce two-wheel lift, the MES was increased to 50 mph (the maximum MES used for Road Edge Recovery testing). If no two-wheel lift was observed during the left-right sequence, the right-left test sequence was initiated using the same process as the left-right sequence. If any test in the Supplemental Procedure Part 2 test series produced two-wheel lift, a new set of tires was installed on the vehicle, and the Supplemental Procedure Part 3 described Section 4.3.3.3 implemented.

A test series was deemed complete if both test sequences within the series were been performed at the maximum maneuver entrance speed without two-wheel lift. The flowchart presented in Figure A-4 describes the sequence of events for the Supplemental Procedure Part 2.

4.3.3.3 Supplemental Procedure Part 3

Following the tire scrub-in procedure outlined in Section 3.2.3, two tests were performed with handwheel angles equal to $\delta_{\text{RER (Supplemental)}}$. The steering combination that produced two-wheel lift during Supplemental Procedure Part 2 testing was used (i.e., either left-right or right-left). The first test was performed at a MES of 35 mph. This test was performed to ensure any mold sheen remaining from the tire break-in procedure had been removed from the tires. The second test was performed at the MES that had produced two-wheel lift during Supplemental Procedure Part 2 testing (i.e., with the previous tire set). If two-wheel lift was produced during the test performed with handwheel angles equal to $\delta_{\text{RER (Supplemental)}}$, the test series was deemed complete. If two-wheel lift was not produced and the MES was 45 mph, the MES was increased to 47.5 mph. If two-wheel lift was not produced and the MES was 47.5 mph, the MES was increased to

50 mph. If two-wheel lift was produced during any test performed during Supplemental Procedure Part 3, the tip-up produced during Supplemental Procedure Part 2 was deemed valid.

If two-wheel lift was <u>not</u> produced during Supplemental Procedure Part 3, the test series was deemed complete, and the occurrence of two-wheel lift during Supplemental Procedure Part 2 considered to be the result of maneuver-induced tire wear. As such, this MES that produced the two-wheel lift seen in Supplemental Procedure Part 2 was not reported in the two-wheel lift summary table presented later in this report. The flowchart presented in Figure A-5 describes the sequence of events for the Supplemental Procedure Part 3.

Note: Use of Supplemental Procedure Part 3 was not required during the evaluations performed in this study; its description is provided in this report simply for the sake of completeness.

4.3.4 Summary of Road Edge Recovery Handwheel Angles

A summary of the RER handwheel angles used in this study is presented in Table 4.2. Additionally, Table 4.2 presents the overall range of dwell times observed during tests performed with each vehicle and load configuration. As previously indicated in Figure 4.2, dwell time is defined as the time from completion of the first steering ramp to the initiation of the steering reversal.

Table 4.2. Road Edge Recovery Handwheel Angles and Dwell Times.

Vehicle	2003 Ford E-350			2004 GMC Savana 3500			
	Steering Scalar	Handwheel Angle (degrees)	Dwell Time Range (ms)	Steering Scalar	Handwheel Angle (degrees)	Dwell Time Range (ms)	
						ESC Enabled	ESC Disabled
2 Occupants (Nominal Load)	6.5	372	65 – 105	6.5	291	105 - 135	100 - 135
	5.5	315	140 – 175	5.5	246	160 - 170	170 - 180
5 Occupants (Multi-Passenger)	6.5	364	105 – 160	6.5	312	105 - 145	95 - 140
	5.5	TNP		5.5	264	165 - 180	170 - 185
10 Occupants	6.5	373	165 – 185	6.5	319	130 - 180	150 - 175
	5.5	TNP		5.5	270	205 - 225	TNP
15 Occupants (Maximum Occupancy)	6.5	350	200 – 375	6.5	335	135 - 235	185
	5.5	TNP		5.5	284	240 - 255	TNP

Note: TNP = Test Not Performed. Vehicle did not require the use of steering calculated with a steering scalar of 5.5.

5.0 TEST RESULTS

Two maneuvers were used in this study: the SIS and RER. Since each maneuver provides different information about the vehicle (i.e., linear range and limit handling versus dynamic rollover propensity), this chapter presents results from each maneuver separately. In the case of the GMC Savana 3500, the effects of ESC are presented for each maneuver.

5.1 Slowly Increasing Steer (SIS) Maneuver Results

The SIS maneuver was used to assess the linear range understeer gradient, maximum lateral acceleration, and terminal yaw stability of each test vehicle. Additionally, the SIS maneuver was used to provide the lateral acceleration versus handwheel angle correlation required by the RER test procedure.

5.1.1 Understeer Gradient

The understeer gradients were calculated with the same SIS tests used to provide the lateral acceleration versus handwheel angle correlation required by the RER test procedure. As such, these maneuvers used steering within, or just beyond, the linear range of each vehicle's lateral acceleration. This is important because the tire wear accumulated during the tests was minimal, thereby removing the confounding effect tire wear can have on test outcome (i.e., the responses of the vehicle were as repeatable as possible).

Table 5.1 summarizes the understeer gradients observed in this study for each van. Note that there is only one set of data for the GMC Savana 3500, although the vehicle was later evaluated with enabled and disabled ESC. Since ESC does not intervene when the vehicle is being operated in the linear range of lateral acceleration, due to the small slip angles present at each wheel, the understeer gradients of the GMC Savana 3500 with enabled and disabled ESC are identical. The data presented in Table 5.1 differ slightly from those contained in a recent NHTSA report on 15-passenger van handling [8] because the vehicles in this study were equipped with outriggers.

The overall understeer gradient of the GMC Savana 3500 increased as a function of the number of occupants, although there was often overlap of the respective left and right steer ranges calculated for each load configuration. As the number of occupants was raised from two to five, the overall understeer gradient GMC Savana 3500 increased by 15.0 percent. When the load increased from five to ten occupants, this value was increased by another 4.7 percent. Use of the 15-Occupant configuration further increased the understeer gradient by 10.2 percent (32.8 percent greater than that calculated with Nominal Load data).

Unlike the GMC Savana 3500, the overall understeer gradient of the Ford E-350 increased as a function of the number of occupants only as the load was increased from two to five passengers. Use of configurations with additional occupants was found to lower the understeer gradient. As the number of occupants was raised from two to five, the overall understeer gradient of the Ford E-350 increased by 14.4 percent. When the load increased from five to ten occupants, this value *decreased* by 2.2 percent. Use of the 15-Occupant configuration further decreased the understeer gradient by 20.3 percent (10.8 percent greater than that calculated with Nominal Load data).

Table 5.1. Understeer Gradient Summary.

Vehicle	2003 Ford E-350			2004 GMC Savana 3500		
	Left Range (deg/deg)	Right Range (deg/deg)	Overall Average (deg/deg)	Left Range (deg/deg)	Right Range (deg/deg)	Overall Average (deg/deg)
2 Occupants (Nominal Load)	2.95 – 3.17	2.98 – 3.11	3.05 (0.08)	2.52 – 3.03	3.50 – 3.95	3.26 (0.54)
5 Occupants	3.66 – 3.92	3.19 – 3.25	3.49 (0.30)	2.86 – 3.32	4.30 – 4.65	3.75 (0.78)
10 Occupants	3.10 – 3.44	2.83 – 4.07	3.42 (0.46)	3.10 – 3.25	4.42 – 4.88	3.92 (0.82)
15 Occupants (Maximum Occupancy)	2.79 – 3.10	2.22 – 2.75	2.72 (0.29)	3.77 – 4.31	4.44 – 4.99	4.32 (0.45)

Note: Standard deviations are presented in parentheses.

There was no overlap of the respective left and right steer ranges calculated for the Nominal and 5-Occupant load configurations for the Ford E-350. This was not the case for 10- and 15-Occupant loading—many of the values calculated with data from these configurations fell within the ranges established with the other configurations.

Generally speaking, manipulation of load configuration resulted in only small changes of the understeer gradients calculated for each vehicle. As such, the authors believe these changes are not of practical significance (as discussed in [8]).

5.1.2 Maximum Lateral Acceleration

Table 5.2 summarizes the maximum lateral accelerations observed in this study. Since the scope of this study was biased towards an evaluation of rollover resistance, maximum lateral acceleration was measured in only the two extremes of the four load configurations used in this study: Nominal Load (2-Occupant) and 15-Occupant. Unlike the SIS tests performed to generate the linear range steering data required by the understeer gradient and RER steering calculations, the SIS tests used to measure maximum lateral acceleration are considered "limit" tests, and were therefore influenced by the whether the GMC Savana 3500's ESC was active or disabled.

Ford E-350

Of the two configurations used to evaluate the Ford E-350's maximum lateral acceleration[4], the Nominal Load produced the greatest peak magnitudes. This trend was observed regardless of steering direction. Overall, the Ford E-350 produced a maximum lateral acceleration of 0.76g when tested in the Nominal Load configuration, 5.7 percent greater than the 0.72g overall average magnitude achieved when 15 occupants were used.

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[4] NHTSA has performed numerous SIS tests to the limit of lateral adhesion with the Ford E-350. Some of these tests were performed with different front and/or rear tire inflation pressures. The results of these tests are available in [8].

GMC Savana 3500

When ESC was enabled, the GMC Savana 3500 produced an overall average maximum lateral acceleration of 0.78g when tested in the Nominal Load configuration, 3.6 percent greater than the 0.75g overall magnitude achieved when 15 occupants were used. Similarly, when the Savana 3500's ESC was disabled, an overall maximum lateral acceleration of 0.80g was achieved, 10.3 percent greater than the 0.72g overall magnitude achieved when 15 occupants were used.

In agreement with the Ford E-350 findings, use of the Nominal Load produced the greatest peak lateral accelerations during tests performed with the GMC Savana 3500, regardless of whether ESC was enabled or disabled and, with one exception, direction of steer. As shown in Table 5.2, only one left-steer test was performed in each of the two 15-occupant loading conditions (i.e., with enabled and disabled ESC).

When evaluated with enabled ESC, the left-steer SIS maneuver produced spinout and two-wheel lift (described in greater detail in Section 5.1.3). For the sake of driver safety and reduced wear on the vehicle, no additional left-steer tests were performed with enabled ESC. Due to the unintended severity of the maneuver, a high peak lateral acceleration was achieved. Similarly, while evaluating the vehicle with a left-steer SIS maneuver and disabled ESC, the test driver believed vehicle spin out was imminent, and terminated the test prematurely (the throttle was released at $t \approx 15$ seconds). For this reason, the authors believe it is very likely that the peak lateral acceleration produced during this test is lower than that which would have been achieved had the driver actually attempted to maintain vehicle speed throughout the entire maneuver. Data traces for the two left-steer SIS tests performed with the GMC Savana 3500 and 15-passenger loading are shown in Figure 5.7, presented later in Section 5.1.3.

Table 5.2. Maximum Lateral Acceleration Summary.

Vehicle	2003 Ford E-350			2004 GMC Savana 3500					
	Left Range (g)	Right Range (g)	Overall Average (g)	ESC Enabled			ESC Disabled		
				Left Range (g)	Right Range (g)	Overall (g)	Left Range (g)	Right Range (g)	Overall Average (g)
2 Occupants (Nominal Load)	0.76 – 0.78	0.73 – 0.77	0.76 (0.020)	0.79 – 0.82	0.75 – 0.76	0.78 (0.030)	0.79 – 0.83	0.77 – 0.78	0.80 (0.028)
15 Occupants (Maximum Occupancy)	0.74 – 0.75	0.69 – 0.71	0.72 (0.025)	0.82*	0.72 – 0.75	0.75 (0.048)	0.75*	0.68 – 0.73	0.72 (0.032)

Note: Standard deviations are presented in parentheses.

*Only one left-steer SIS was performed.

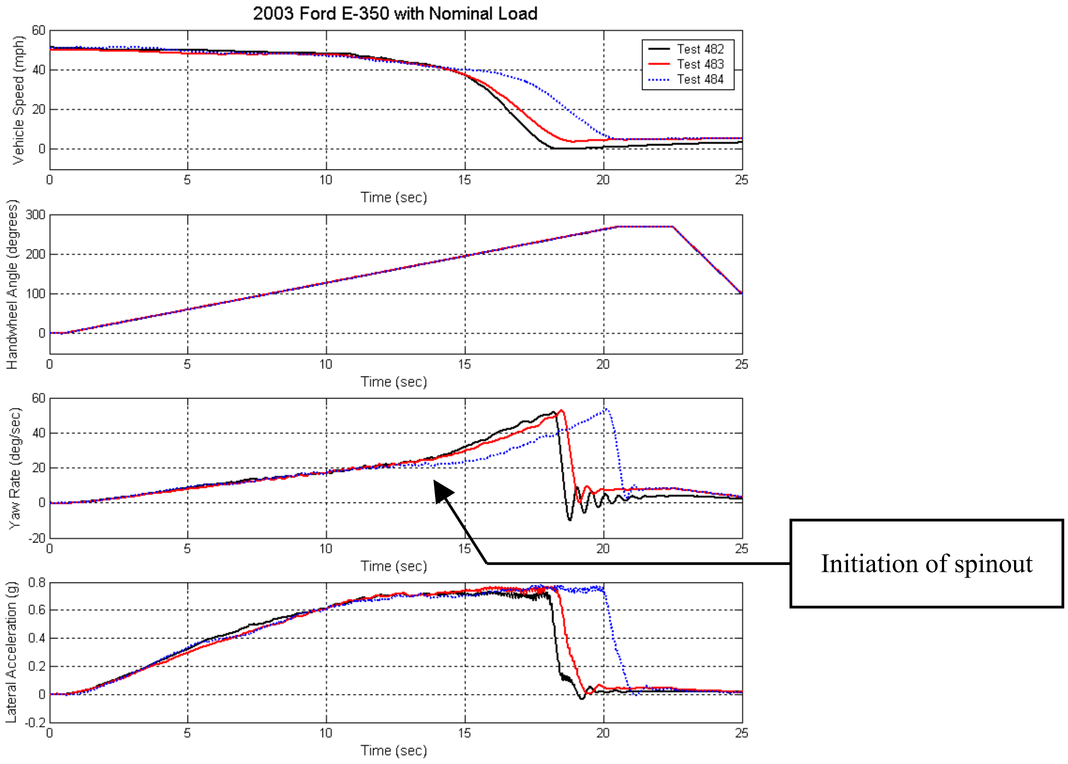
5.1.3 Yaw Stability

Although an in-depth examination of 15-passenger van handling characteristics is beyond the scope of this report, the authors believe a brief discussion of the yaw stability observed during the SIS tests performed to the limit of lateral adhesion is prudent. A vehicle with low lateral stability is expected to be at greater risk of departing the roadway during an abrupt, obstacle avoidance maneuver, and once off road, 15-passenger vans have a high rate of rollover.

Ford E-350

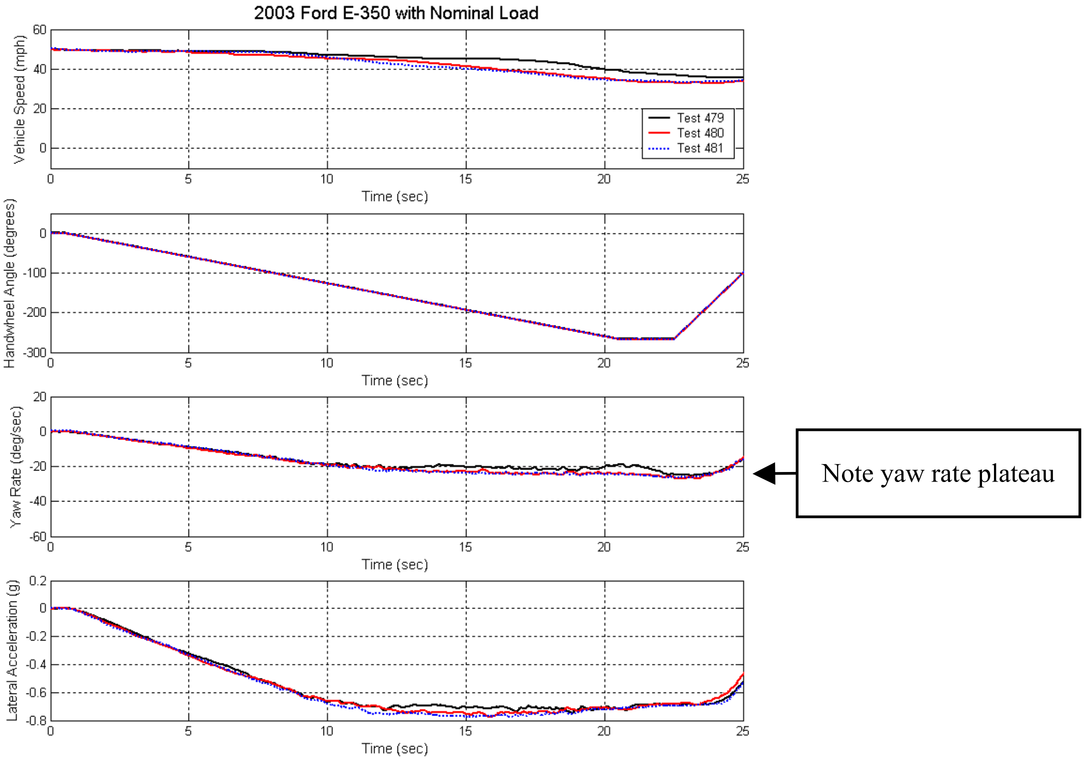
Every right-steer test performed with the Ford E-350 in the Nominal Load configuration produced a spinout (i.e., the vehicle was limit oversteer). This can be seen by the significant increases in yaw rate at $t \approx 13\text{-}14$ seconds in Figure 5.1. Interestingly, left-steer tests performed with this vehicle and load were stable; yaw rate reached a plateau and the vehicle was always limit understeer. Figure 5.2 presents these tests.

In contrast to the asymmetry observed with the Ford E-350 in the Nominal Load configuration, use of the 15-Occupant load produced spinouts during every left-steer test. When compared with the spinouts seen during the right-steer Nominal Load tests, Figure 5.3 shows the loss of yaw stability occurred earlier in the maneuver when the 15-Occupant configuration was used, as indicated by the significant increases in yaw rate at $t \approx 8$ seconds. The authors are unsure of why this phenomenon occurred. Like the left-steer tests performed with the Ford E-350 at Nominal Load, each right-steer test (shown in Figure 5.4) performed with this vehicle in the 15-Occupant configuration was stable.



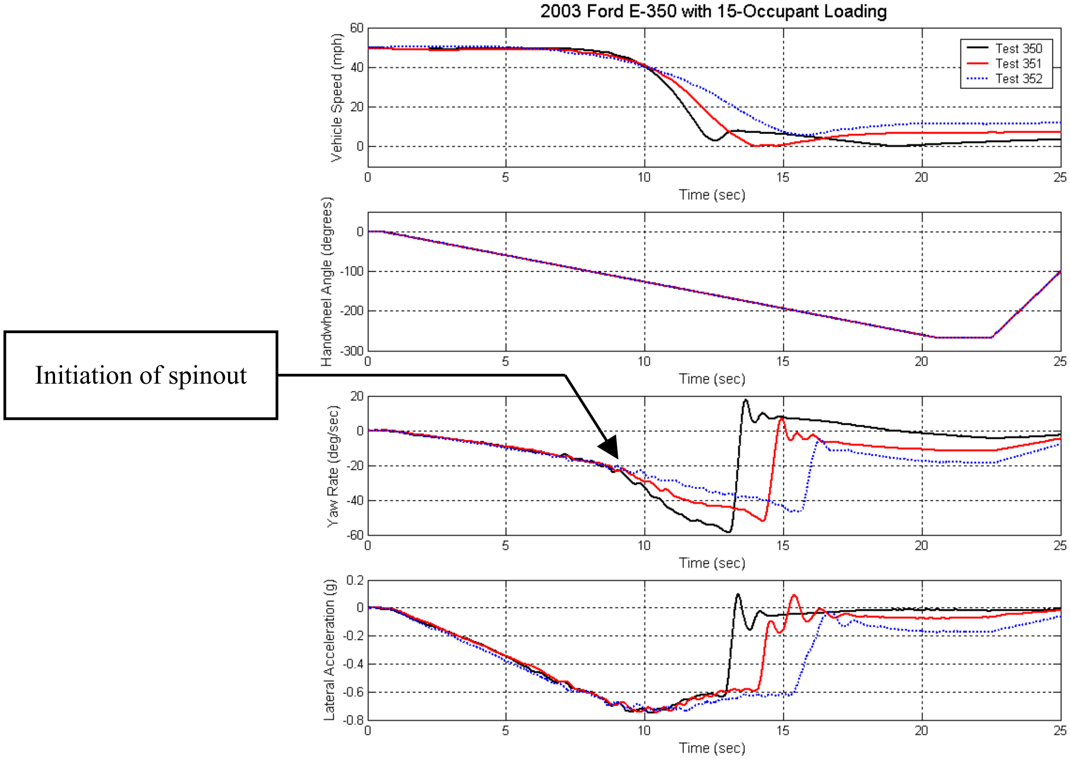
Initiation of spinout

Figure 5.1. Comparison of three Slowly Increasing Steer maneuvers performed with the Ford E-350 (right steer, Nominal Load).



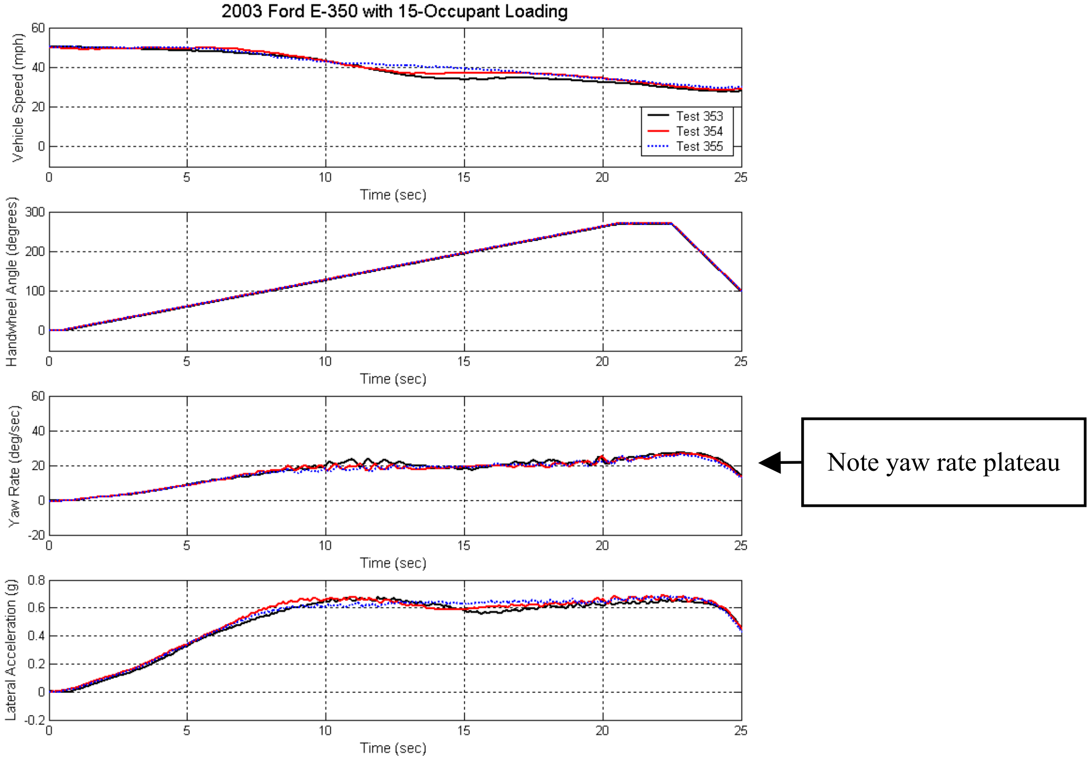
Note yaw rate plateau

Figure 5.2. Comparison of three Slowly Increasing Steer maneuvers performed with the Ford E-350 (left steer, Nominal Load).



Initiation of spinout

Figure 5.3. Comparison of three Slowly Increasing Steer maneuvers performed with the Ford E-350 (left steer, 15-Occupant load).



Note yaw rate plateau

Figure 5.4. Comparison of three Slowly Increasing Steer maneuvers performed with the Ford E-350 (right steer, 15-Occupant load).

GMC Savana 3500

In the Nominal Load configuration, the lateral stability of the GMC Savana 3500 was found to be a function of whether ESC was enabled or disabled. When ESC was enabled, the vehicle was much more stable, especially when left-steer tests are considered. In Figure 5.5, this is indicated by the plateau of the yaw rates (i.e., the van was limit understeer) and small body slip angles[5] observed when ESC was enabled. While these slip angles remained small and consistent over the entire duration of the maneuvers with enabled ESC, they began to build rapidly from $t \approx 12$ seconds to the point of spinout during the disabled ESC tests. Note that the lateral accelerations produced during each left-steer test were nearly identical, up to the instance of spinout, regardless of whether ESC was enabled or disabled.

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[5] NHTSA has just recently started to measure body slip angle, a metric expected to reveal valuable information about the orientation of the vehicle with respect to the path of it's C.G. Since most tests performed in this study were performed prior to procurement of the sensor capable of measuring body slip angle, the metric was only measured during Nominal Load SIS tests performed with the GMC Savana 3500.

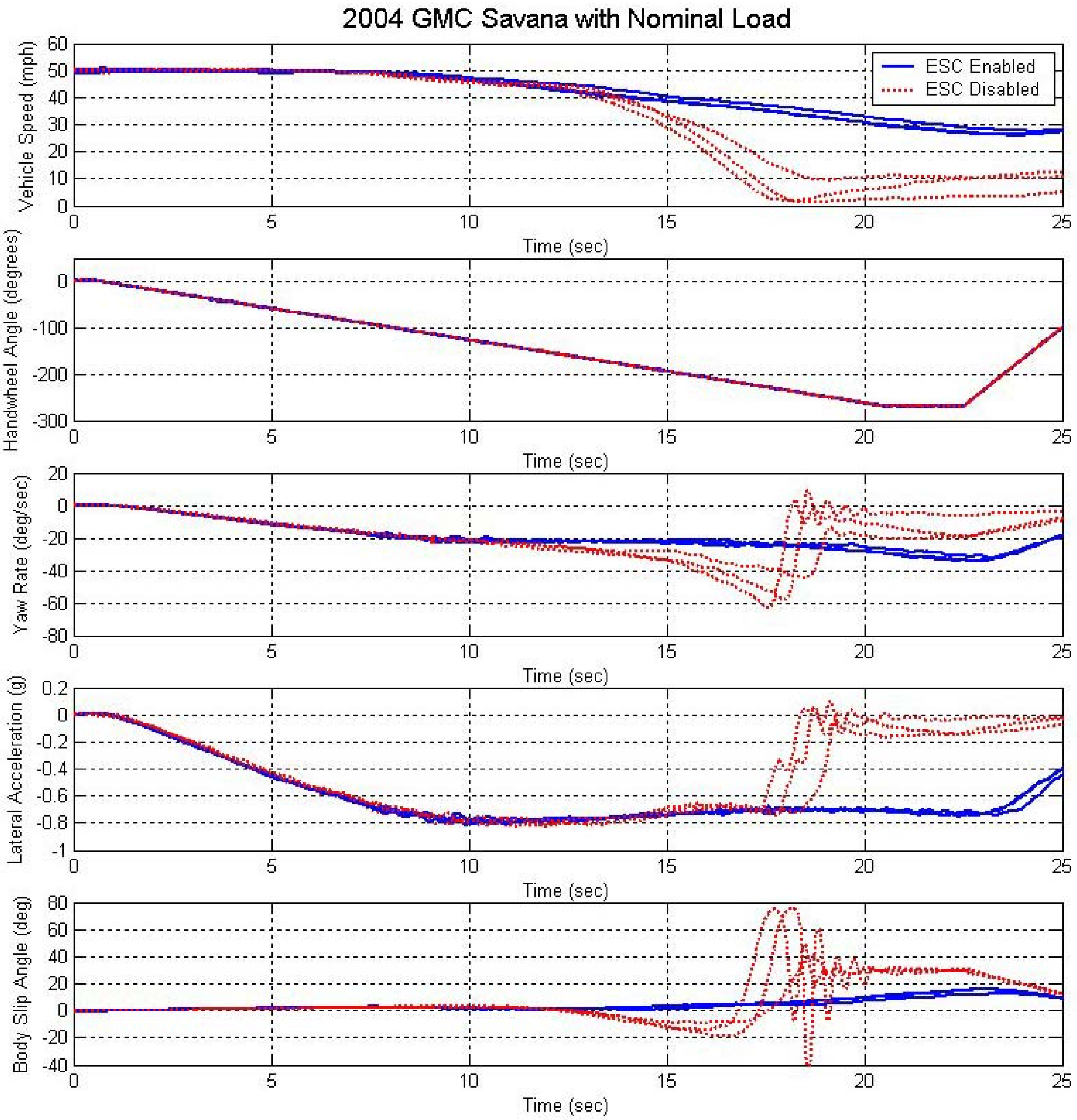

Figure 5.5. Comparison of five Slowly Increasing Steer maneuvers performed with the GMC Savana 3500. Enabled and disabled ESC tests are presented (left steer, Nominal Load). Note that the sensor used to measure body slip angle is accurate only up to 40 degrees).

No right-steer test performed with Nominal Load produced a spinout with the GMC Savana 3500, and the yaw rates and lateral accelerations of each right-steer, disabled ESC test were nearly identical to the respective values observed during enabled ESC testing. That said, differences in body slip angle were present when disabled and enabled ESC test results were compared, as shown in Figure 5.6. In this figure, the slip angle data indicate the vehicle is near the point of exhibiting a *tendency* towards oversteer at $t \approx 15 - 16$ seconds (i.e., body slip angle is increasing in the direction of steer and peaks at a moderate level), however the yaw rates collected during these tests give no indication the vehicle will actually spinout.

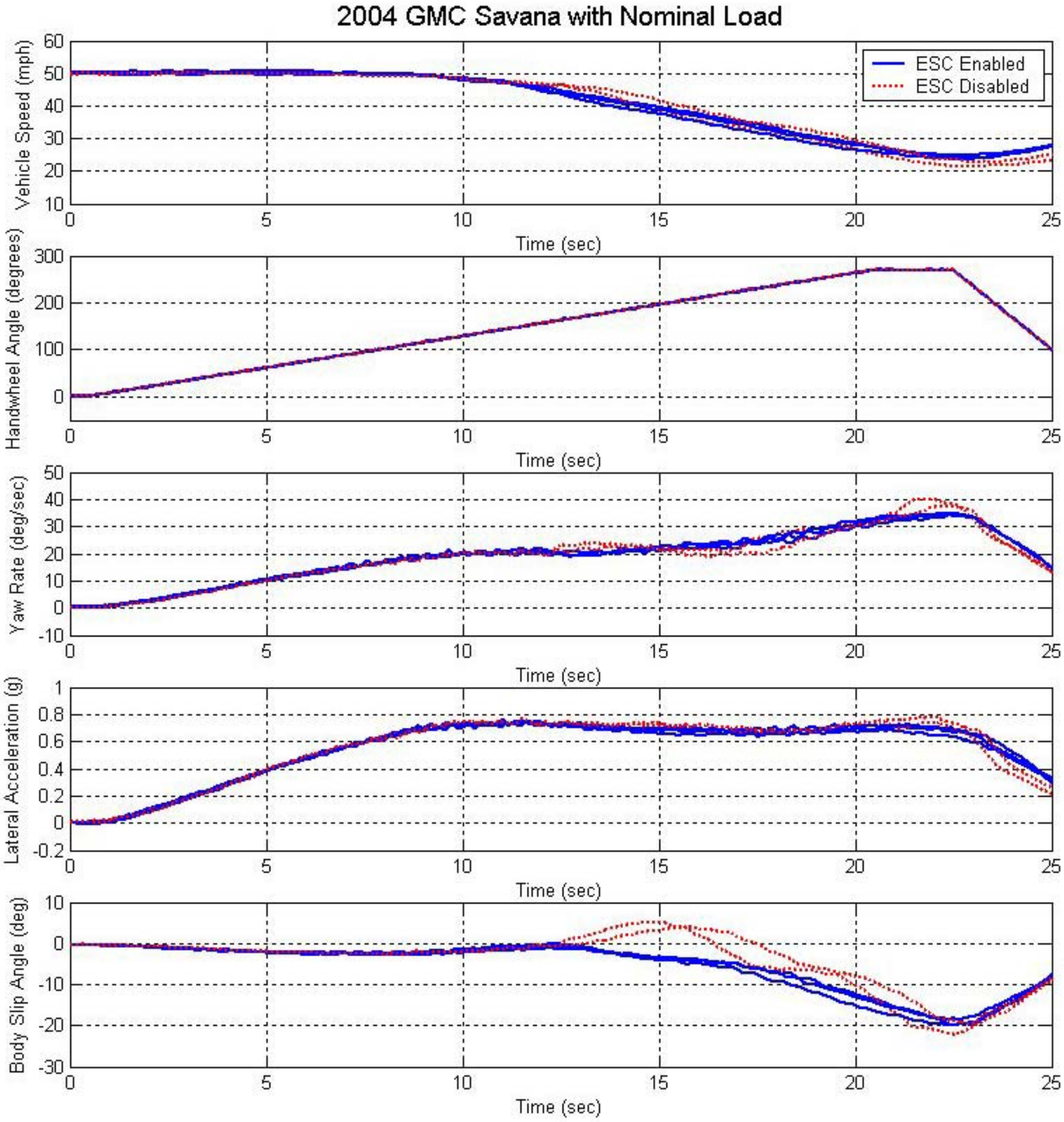

Figure 5.6. Comparison of five Slowly Increasing Steer maneuvers performed with the GMC Savana 3500. Enabled and disabled ESC tests are presented (right steer, Nominal Load).

Figure 5.5 and 5.6 indicate that like the Ford E-350, the lateral stability of the GMC Savana 3500 was also a function of direction of steer in the Nominal Load configuration when ESC was disabled. Each of the three left-steer tests performed with disabled ESC produced excessive yaw and ultimately resulted in spinouts, as indicated by the increased yaw rate at $t \approx 15 - 16$ seconds and large body slip angles. However, as previously discussed, right-steer produced no such spinouts. Furthermore, the yaw rates and lateral accelerations of each right-steer test performed with disabled ESC were nearly identical to the respective values observed during enabled ESC testing.

Some of the most interesting SIS tests observed in this study occurred during evaluation of the GMC Savana 3500 with the 15-Occupant load. In this configuration, considerable roll oscillations were produced midway through the first (and only) left-steer SIS test performed with ESC enabled, as shown in Figure 5.7. These oscillations began as the vehicle lost yaw stability, as indicated by the yaw rate data trace at $t \approx 10$ seconds. As the yaw rate increased, the roll oscillations became more severe. The vehicle was ultimately oversteer in this configuration (i.e., it spun out), however just prior to the completion of the spin, its roll oscillations had become so great that two-wheel lift was produced at $t \approx 15$ seconds. This was the first time NHTSA has observed two-wheel lift during a SIS test that was not attributable to surface irregularities[6] [9].

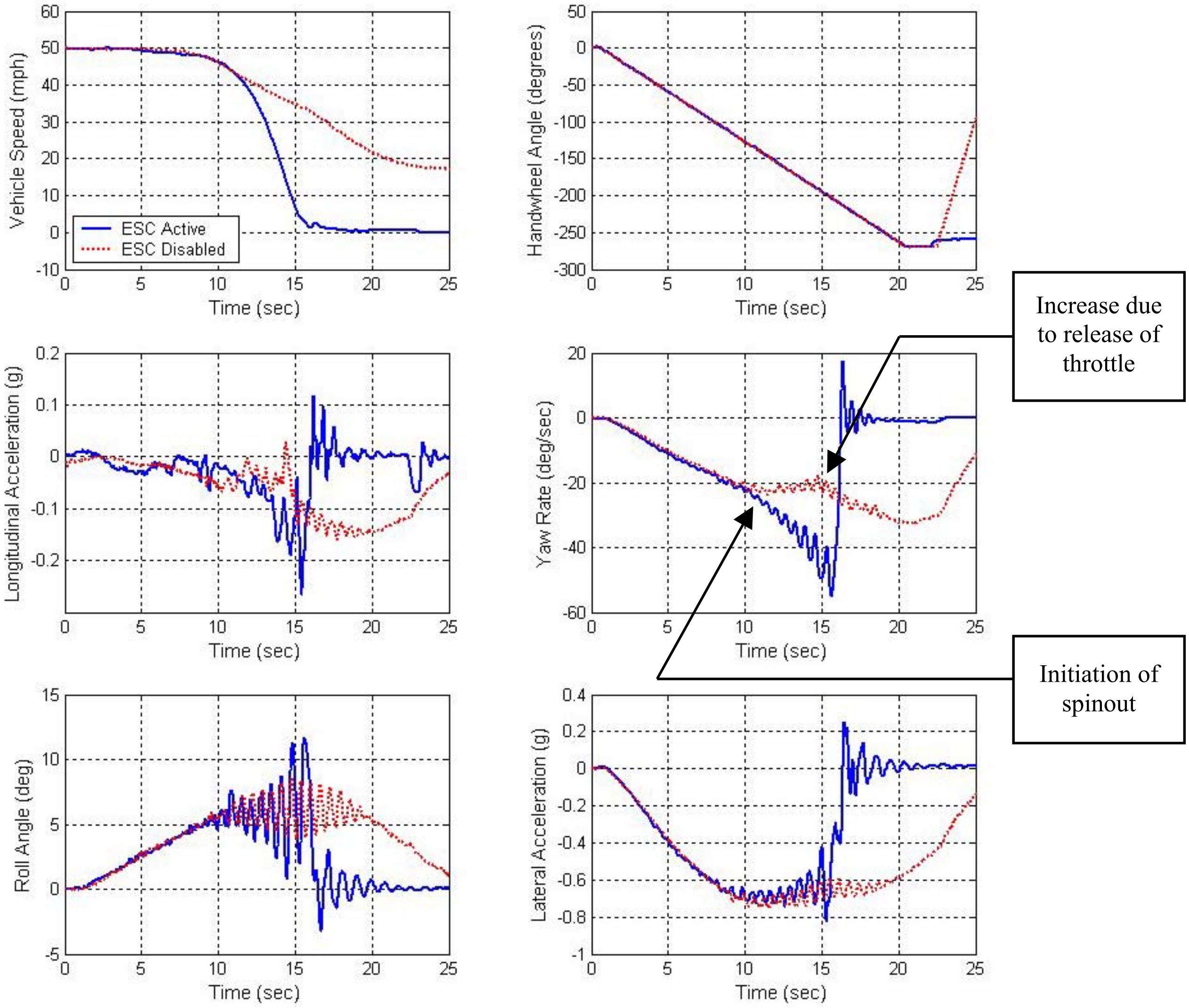

Figure 5.7. Comparison of two Slowly Increasing Steer maneuvers performed with the GMC Savana 3500. Enabled and disabled ESC tests are presented (left steer, 15-Occupant load).

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[6] Some NHTSA SIS tests performed at the DaimlerChrysler Arizona Proving Grounds (APG) located in Whitman, Arizona produced instances of two-wheel lift thought to be due to surface irregularities.

When ESC was disabled, the GMC Savana 3500 did not produce two-wheel lift when loaded to the 15-Occupant configuration. However, the authors believe that it would have if the test had been taken to its intended conclusion. Like the left-steer test performed with enabled ESC, a yaw rate divergence was seen at *t* ≈ 10 seconds (albeit in the opposite direction; the vehicle's yaw rate began to stabilize), at which point the roll oscillations increased from until *t* ≈ 15 seconds. Not wanting to subject the vehicle to the violence of another SIS test producing two-wheel lift, a maneuver not intended to do so, the driver released the throttle at *t* ≈ 15 seconds. Although the throttle position was not directly monitored during these tests, the approximate time of the release can be seen in some of the Figure 5.7 data traces at *t* ≈ 15 seconds: (1) the yaw rate began to increase due to the dynamic load transfer, (2) a decrease in the longitudinal acceleration, and (3) a reduction in the roll oscillation magnitudes.

The right-steer SIS tests performed to maximum lateral acceleration with the GMC Savana 3500 were much less extreme than those that used left steering. As shown in Figure 5.8, not only were the roll and lateral acceleration responses nearly identical regardless of whether ESC was enabled or disabled, they were void of the severe oscillations. Although each test performed with disabled ESC ultimately achieved peak yaw rates greater than those of the enabled ESC condition, these differences were most apparent after the completion of the SIS steering ramp (i.e., during the portion of the maneuver steering angle is not slowly increasing).

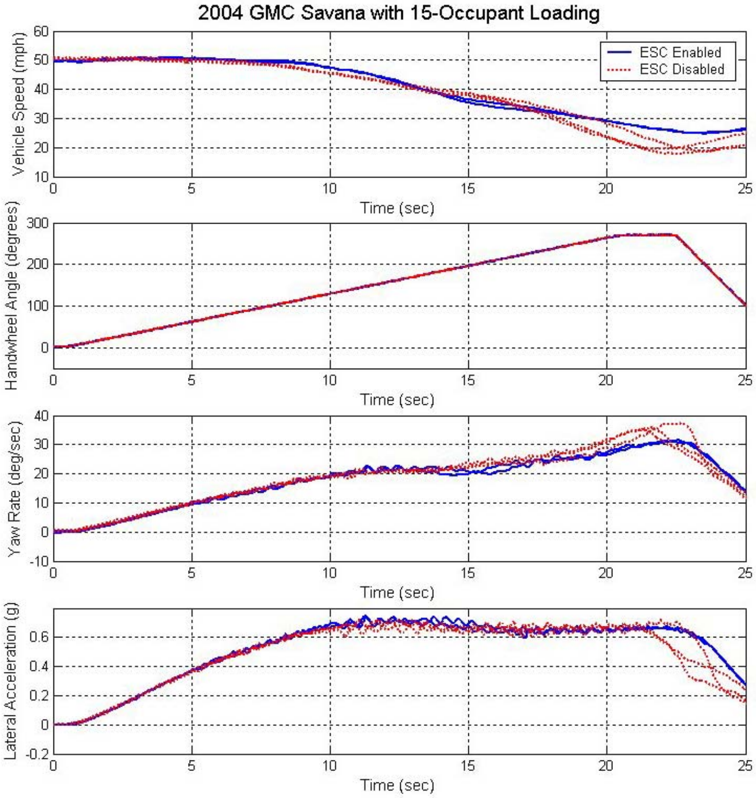

Figure 5.8. Comparison of five Slowly Increasing Steer maneuvers performed with the GMC Savana 3500. Enabled and disabled ESC tests are presented (right steer, 15-Occupant Load).

Although NHTSA has limited experience with ESC intervention, differences between SIS tests performed with ESC enabled and disabled have been observed in various research programs. For example, the yaw responses of the 2001 Toyota 4Runner 4x4 (see Figure 5.9) and 1999 Mercedes ML320 (see Figure 5.10), two sport utility vehicles evaluated during Phase IV of NHTSA's Light Vehicle Rollover Research Program, were clearly affected by ESC intervention. In the case of the Toyota 4Runner, the yaw rate of the vehicle was affected via use of varying levels of front and rear braking and a reduction of drive torque via throttle modulation. The yaw rate of the Mercedes ML320 was influenced in a similar manner, however this was accomplished solely via the use of throttle modulation—no brake intervention was observed. Regardless of what intervention strategy was employed, the overall influence was the essentially the same; the subsequent reduction in vehicle speed helped stabilize the vehicle.

Review of the in-vehicle and test video data does not provide a clear indication of how ESC influences the lateral stability and rollover resistance of the GMC Savana 3500 in a limit SIS test. As it approached maximum lateral acceleration during the SIS test performed in this study, none of the yaw rates produced by the vehicle (i.e., those presented in Figure 5.5 - 5.8) revealed trends like those seen during tests performed with the Toyota 4Runner or Mercedes ML320, regardless of load configuration. Therefore it is not clear what attempt, if any, the ESC made to prevent the spinout and roll oscillations from occurring during the left steer tests performed in the 15-Occupant configuration. Also, since there is no clear indication ESC intervention actually occurred, the authors cannot ascertain whether ESC may have contributed to these instabilities.

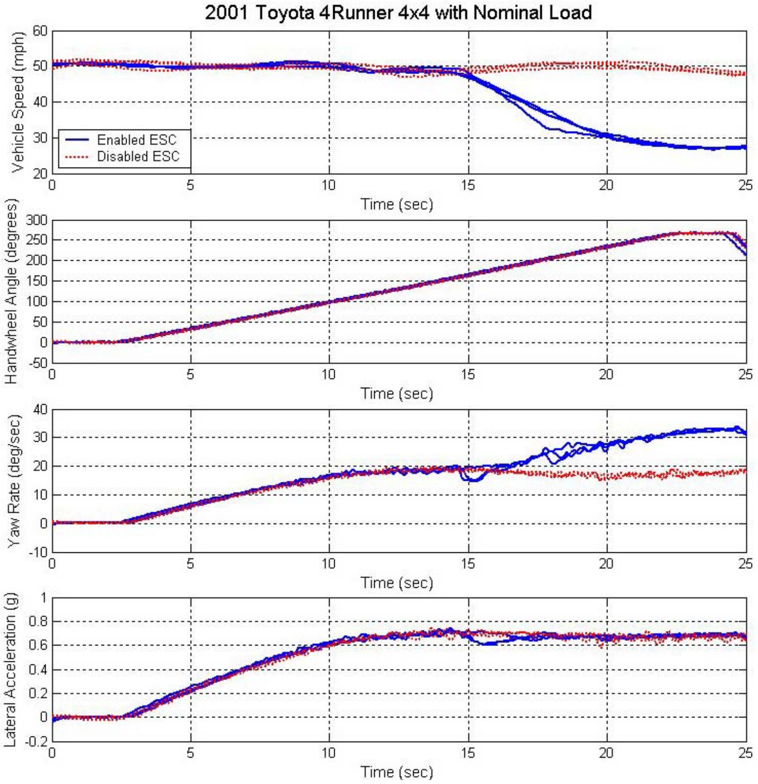

Figure 5.9. Right-steer Slowly Increasing Steer tests performed with a 2001 Toyota 4Runner 4x4. Tests were performed with ESC enabled and disabled.

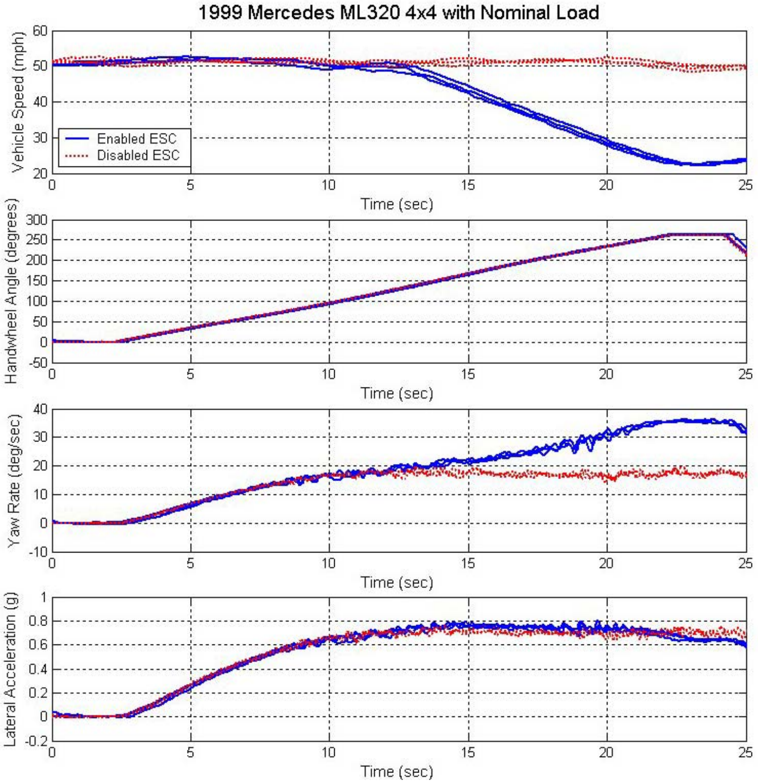

Figure 5.10. Right-steer Slowly Increasing Steer tests performed with a 1999 Mercedes ML320 4x4. Tests were performed with ESC enabled and disabled.

5.2 Road Edge Recovery (RER) Maneuver Results

Increasing the number of occupants raised the C.G. of each van, thus lowering the respective SSFs. For this reason the dynamic rollover resistance of the vehicles would be expected to degrade as a function of the number of occupants. Although such an outcome has been predicted by tests performed in the simulation environment [10], this was not always the case on the test track. This section presents results from the Road Edge Recovery tests performed in this study. Each load configuration is discussed separately, and a summary of the maneuver entrance speeds that produced two-wheel lift is presented at the end of Section 5.2 in Table 5.3.

5.2.1 Nominal Load

No two-wheel lift was produced during tests performed with the Nominal Load, regardless of vehicle, maneuver entrance speed (i.e., 35 to 50 mph), steer combination (i.e., left-right or right-left), steering magnitude (i.e., steering scalar of 6.5 or 5.5), or ESC state (i.e., for the Savana 3500; enabled or disabled).

5.2.2 5-Occupant Load

No two-wheel lift was produced during any valid test performed with the 5-Occupant Load. Although the Ford E-350 and GMC Savana 3500 (disabled ESC) both produced two-wheel lift during a 50-mph test using the Default Procedure, the wheel lift could not be replicated when a new set of tires was installed and supplemental tests were used. For this reason, the authors deemed the two-wheel lifts produced during the Default Procedure to be the result of tire wear, and considered their occurrence to be non-valid.

When the GMC Savana 3500 was evaluated with enabled ESC, no two-wheel lift was produced during any test performed with 5-Occupant loading.

5.2.3 10-Occupant Load

Road Edge Recovery tests performed with 10 occupants proved to be “worst-case” for the Ford E-350. Of the maneuver entrance speeds capable of producing two-wheel lift, that associated with the 10-Occupant configuration was the lowest. In this configuration, two-wheel lift was produced during a left-right steer test initiated at 44.6 mph; during the third test of the Default Procedure. Since only two lower-speed RER tests had been performed prior to the occurrence of two-wheel lift, the authors do not believe tire wear had any effect on the test outcome. Consequentially, the occurrence of two-wheel lift was deemed valid.

Two-wheel lift was also produced during 10-Occupant RER tests performed with the GMC Savana 3500, but only when ESC was disabled. Only one test was performed before the GMC Savana 3500 produced two-wheel lift; during a left-right steer test begun with a maneuver entrance speed of 39.8 mph. The authors do not believe tire wear had any effect on the vehicle’s tip-up propensity.

When the GMC Savana 3500 was evaluated with enabled ESC, no two-wheel lift was produced during any 10-Occupant test, including those using the supplemental procedures.

5.2.4 15-Occupant Load

Use of 15-Occupant loading raised the C.G. the most upwards and rearwards of any configuration used in this study. The SSFs of the Ford E-350 and GMC Savana 3500 were 10.0 and 10.7 percent less, respectively, than those measured in each vehicle's baseline condition. For this reason, the authors had anticipated RER tests performed in the 15-Occupant configuration would require the lowest maneuver entrance speeds to induce two-wheel lift.

Ford E-350

When evaluated using the Default Procedure, the Ford E-350 required a maneuver entrance speed of 48.5 mph to induce two-wheel lift. Since this speed was greater than 45 mph, the RER test procedure required that each tire be replaced with new, and the test repeated to verify the wheel lift was not confounded by tire wear. Use of the supplemental procedures verified the wheel lift with minimal tire wear, during a test that began at 47.9 mph. The fact that the maneuver entrance speed required to produce two-wheel lift with 15 occupants was greater than that required when 10 occupants were used was surprising. The explanation for this behavior is as follows:

When fully loaded with 15 occupants, the Ford E-350 has been shown to be limit oversteer during some SIS tests. When this tendency towards oversteer was translated to the RER maneuver, the result was an inability of the vehicle to effectively respond to the steering reversal, as shown in Figure 5.11. In each of the three tests presented in this figure, the timing of the automated steering reversal function commanded by the steering machine was correct (i.e., it occurred within 10 ms of the vehicle achieving 1.5 deg/sec).

Despite the differences in load configuration, Figure 5.11 shows the roll, yaw, and acceleration responses of the vehicle to the *initial* steering inputs of the two tests initiated at 46.1 mph (15-Occupant) and 44.6 mph (10-Occupant) were nearly equivalent. However, there were substantial differences in the manner in which the vehicle was able to respond to the respective steering *reversals*. When evaluated with 10 occupants, the Ford E-350 was able to achieve its first local lateral acceleration peak approximately 1.7 seconds after the reversal had been initiated and, after three roll oscillations, ultimately produced two-wheel lift. Conversely, when evaluated with 15 occupants the vehicle was unable to achieve its first local post steering reversal lateral acceleration peak until 4.0 seconds after the test's respective reversal—2.3 seconds (132%) later than during the comparable 10-Occupant test.

Although the 10-Occupant test produced two-wheel lift at 44.6 mph, the 15-Occupant configuration was unable to do so until an entrance speed of 48.5 mph was used. This was due to the fact the when a 46.1 mph entrance speed was used with the 15-Occupant load (the most similar entrance speed to that producing two-wheel lift with 10 occupants), the vehicle was in a lateral skid between the initiation of the steering reversal at t = 0.8 seconds until t = 4.1 seconds, when yaw rate transitioned from negative to positive. While in this skid, the vehicle expended significant kinetic energy. Once the vehicle was finally able to "catch up" to the steering input, there was simply not enough momentum available to generate the load transfer required to produce two-wheel lift. In other words, had it not been limit oversteer, the Ford E-350 would have likely tipped up with a lower maneuver entrance speed in the 15-Occupant configuration.

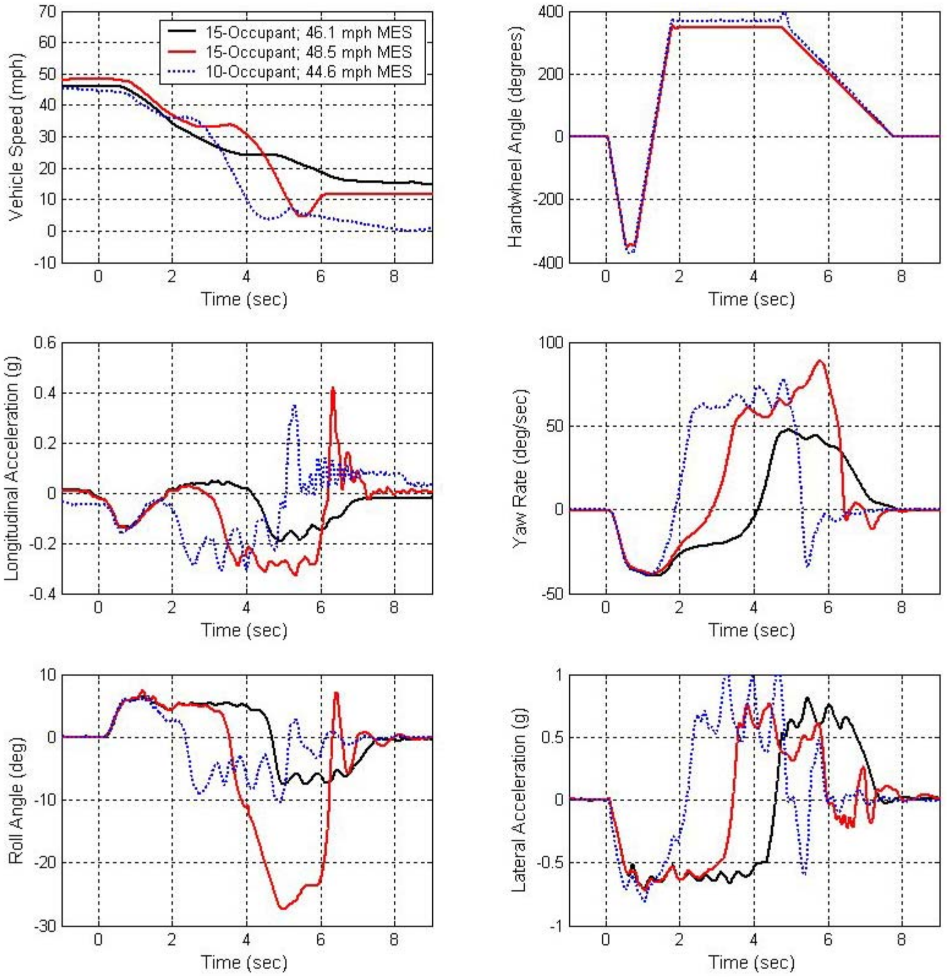

Figure 5.11. Comparison of three left-right Road Edge Recovery tests performed with the Ford E-350 using different combinations of load and maneuver entrance speed.

When loaded with 15 occupants, the Ford E-350's pre- and post-reversal roll responses of the RER tests initiated at 46.1 and 48.5 mph were nearly identical until $t \approx 2.5$ seconds. After this time, the vehicle not only responded to the steering reversal used during the higher speed test, but also abruptly produced two-wheel lift and substantial roll.

The authors are unsure of why the Ford E-350 was able to respond to the RER performed at 48.5 mph more effectively than during the test initiated at 46.1 mph, especially since both tests were performed with the same 15-Occupant load configuration. Given the van's response to the initial steer at 46.1 mph, the authors had anticipated its propensity to oversteer would continue to increase as a function of maneuver entrance speed until the vehicle ultimately spun out (i.e., no response to the steering reversal would be possible). As indicated in Figure 5.11, this was clearly not the case.

GMC Savana 3500

Only one RER test was required to produce two-wheel lift with the GMC Savana 3500 when its ESC was disabled and the 15-Occupant load was used. In this configuration, two-wheel lift was observed during a left-right steer test begun with a maneuver entrance speed of 34.9 mph. The lift was the result of maneuver-induced roll oscillations, as shown in Figure 5.12. Since this test was the first of the test series, there was no chance tire wear could have confounded the test outcome. For this reason, the occurrence of two-wheel lift in this configuration was deemed valid.

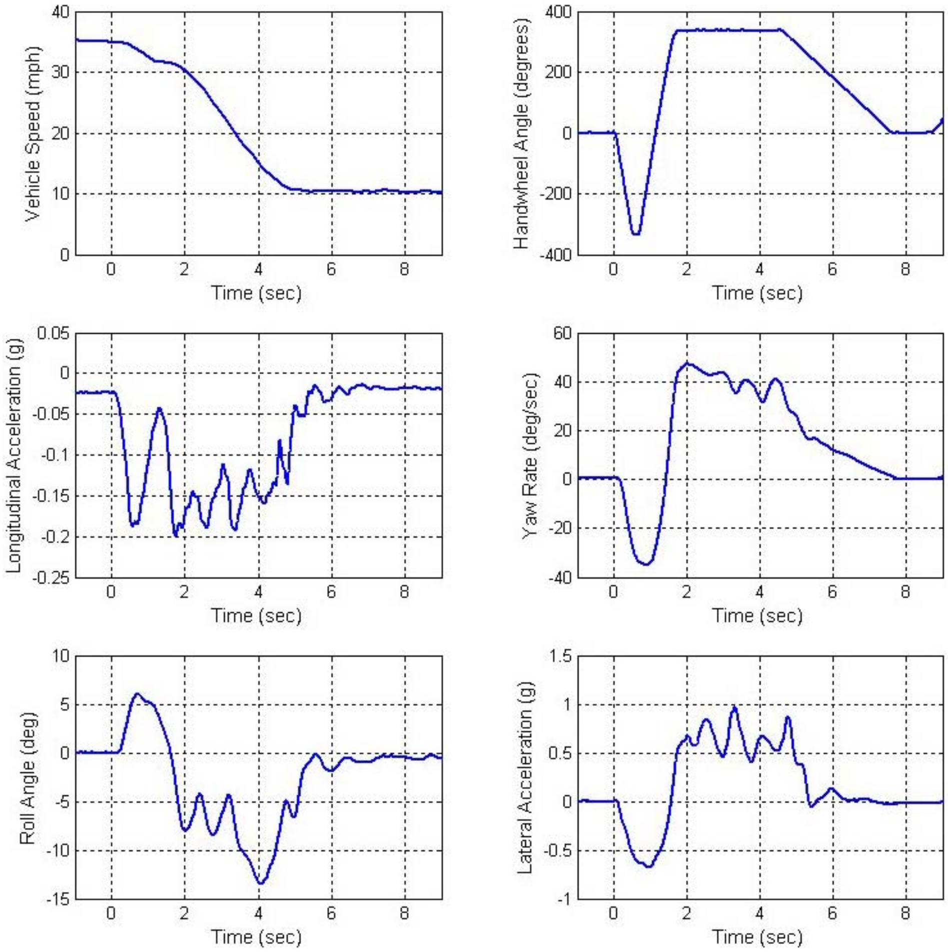

Figure 5.12. Left-right Road Edge Recovery test performed with the GMC Savana 3500 loaded with 15 occupants. Maneuver entrance speed was 34.9 mph. Note roll oscillations.

ESC intervention significantly improved the rollover resistance of the GMC Savana 3500. When this vehicle was evaluated with enabled ESC, no two-wheel lift was produced during any 15-

Occupant test, including those using the supplemental procedures. This is a stark contrast to the 34.9 mph entrance speed required when ESC was disabled. Figure 5.13 presents two 35 mph tests performed with the GMC Savana 3500 (one with ESC enabled, one with ESC disabled). For the sake of comparison, a 50 mph test performed with enabled ESC is also featured.

Clearly, ESC allowed the GMC Savana 3500 to limit excessive yaw more effectively than when it was disabled. Two-wheel lift was suppressed by nearly eliminating the post steering reversal roll oscillations, most likely the result of a strong application of left front wheel braking. The authors believe that by applying brake torque to at least the outside front wheel, the ESC was able to generate a stabilizing moment to limit excessive yaw (i.e., the tendency to spin out). This braking also introduced enough longitudinal slip to reduce the lateral force capable of being generated by the left front tire. By reducing the lateral adhesion at this instant of the maneuver, the ESC was able to prevent the vehicle from producing the severe roll oscillations (i.e., exciting its roll natural frequency) present during the test performed with disabled ESC.

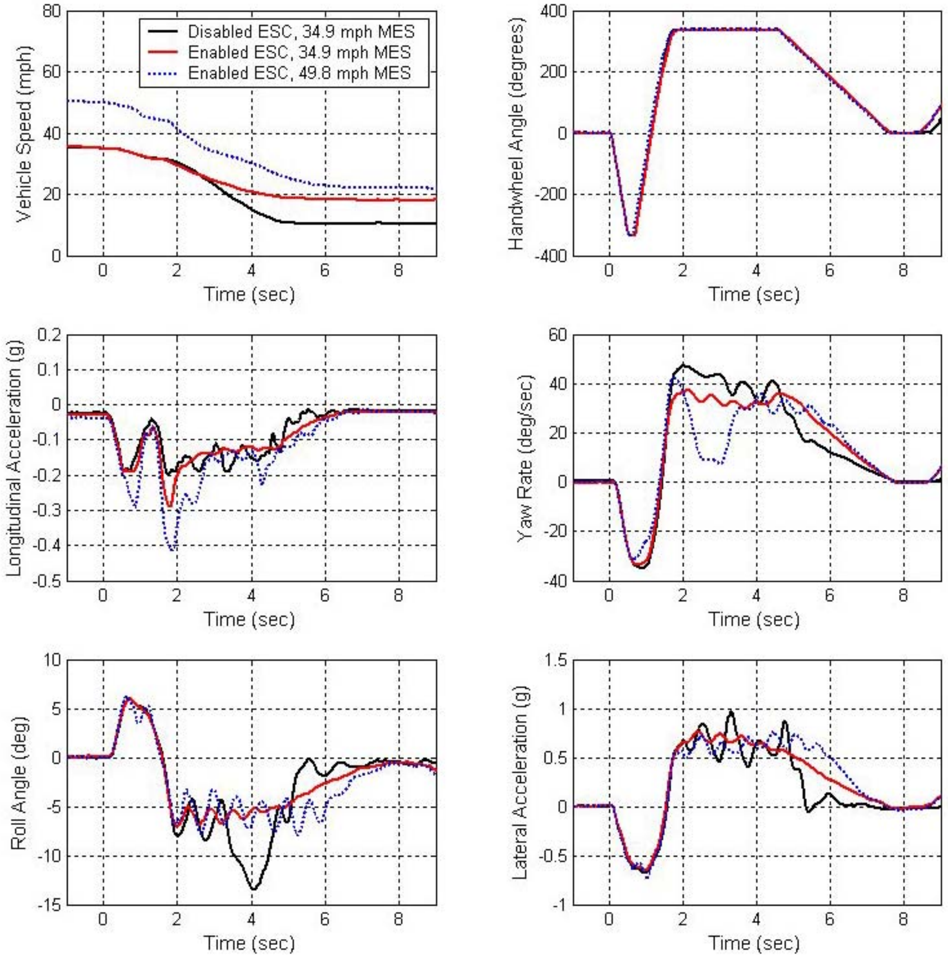

Figure 5.13. Left-right Road Edge Recovery tests performed with the GMC Savana 3500 loaded with 15 occupants. Two 35 mph tests (ESC enabled and disabled) and one 50 mph test (ESC enabled) are presented.

Table 5.3. Maneuver Entrance Speeds For Which Two-Wheel Lift Was Observed During Road Edge Recovery Testing.

Vehicle	2003 Ford E-350		2004 GMC Savana 3500			
	Left-Right Steering	Right-Left Steering	ESC Enabled		ESC Disabled	
			Left-Right Steering	Right-Left Steering	Left-Right Steering	Right-Left Steering
2 Occupants (Nominal Load)	--	--	--	--	--	--
5 Occupants (Multi-Passenger)	--	--[1]	--	--	--[2]	--
10 Occupants	44.6	TNP	--	--	39.8	TNP
15 Occupants (Maximum Occupancy)	47.9	TNP	--	--	34.9	TNP

Note: TNP = Test Not Performed

[1] Two-wheel lift was observed during a left-right test performed at 49.5 mph during "Default Procedure" testing, however it was not confirmed with a "Supplemental Procedure 1" test performed at 49.6 mph. For this reason, the first occurrence of two-wheel lift was deemed to be the result of tire wear, and considered to be non-valid.

[2] Two-wheel lift was observed during a left-right test performed at 49.5 mph during "Default Procedure" testing, however it was not confirmed with a "Supplemental Procedure 1" test performed at 49.8 mph. For this reason, the first occurrence of two-wheel lift was deemed to be the result of tire wear, and considered to be non-valid.

6.0 CONCLUSIONS

The maneuvers used in this study were selected on the basis of their ability to provide basic, but fundamental, information about the rollover resistance and lateral stability of light vehicles. Rollover resistance was quantified with NHSTA's Road Edge Recovery maneuver (also known as the NHTSA Fishhook), a test that approximates the steering a startled driver might use in an effort to regain lane position on a two-lane road after dropping the two passenger-side wheels off onto the shoulder. Lateral stability was quantified with the Slowly Increasing Steer maneuver, a test that gradually increases the steering wheel angle over a long period of time. Although the Slowly Increasing Steer is not a maneuver performed in the "real world," its utility is unquestionable, since it provides valuable insight into the behavior of a vehicle being driven at the limit of lateral adhesion

When the Ford E-350 was evaluated with the SIS maneuver, the vehicle produced overall maximum lateral accelerations of 0.76g and 0.72g in the Nominal and 15-Occupant configurations, respectively. Every right-steer Nominal Load test and each left-steer 15-Occupant test produced a spinout (i.e., the vehicle was limit oversteer). Left-steer Nominal Load tests and right-steer 15-Occupant tests did not.

Overall, when ESC was enabled, the GMC Savana 3500 produced a maximum lateral acceleration of 0.78g in the Nominal Load configuration and 0.75g when 15 occupants were used. Similarly, when the Savana 3500's ESC was disabled, the vehicle produced overall maximum lateral accelerations of 0.80g and 0.72g in the Nominal and 15-Occupant configurations, respectively. Like the Ford E-350, the lateral stability of the GMC Savana 3500 was also a function of direction of steer in the Nominal Load configuration when ESC was disabled. Each of the three left-steer tests performed with disabled ESC produced excessive yaw and ultimately resulted in spinouts, whereas right-steer tests produced no such responses. In the Nominal Load configuration, the lateral stability of the GMC Savana 3500 was also found to be a function of whether ESC was enabled or disabled. When ESC was enabled, the vehicle was more stable, especially when left-steer tests are considered.

Only a limited number of left-steer SIS tests were performed with the GMC Savana 3500 in the 15-Occupant configuration. However, in each case the vehicle produced substantial roll oscillations. With ESC enabled, a spinout and two-wheel lift was observed. When ESC was disabled, the test driver terminated the maneuver after the roll oscillations began, but before a spinout or two-wheel lift had a chance of occurring. Therefore, the spinout observed with ESC enabled would likely have occurred with ESC disabled had the driver not terminated the test. Right-steer tests performed with the GMC Savana 3500 in the 15-Occupant configuration with ESC both enabled and disabled were much more stable, not producing spinouts or two-wheel lift.

Although the different load configurations used in this study had similar effects on displacing the center of gravity positions of the Ford E-350 and GMC Savana 3500 15-passenger vans, the dynamic rollover resistance of each vehicle were affected somewhat differently. Generally speaking, the static stability factors and dynamic rollover resistance of the Ford E-350 were reduced as the number of occupants increased. The only exception to this trend was that the maneuver entrance speed capable of producing two-wheel lift with 10-Occupant loading was lower than that required by the 15-Occupant configuration with the Ford E-350.

Like the Ford E-350, the static stability factors of the GMC Savana 3500 became lower as the number of occupants increased. Although the dynamic rollover resistance of the GMC Savana 3500 progressively worsened as the number of occupants increased when ESC was disabled, none of the load configurations used in this study were able to induce two-wheel lift during RER tests when the vehicle's ESC remained enabled.

Results from this study indicate that installation of ESC on 15-passenger vans may have important safety benefits in some, but not necessarily all, driving maneuvers. Although ESC improved the dynamic rollover resistance of the GMC Savana 3500 during Road Edge Recovery testing, such improvements were not observed during Slowly Increasing Steer tests. Due to the limited instrumentation used in this study, the authors cannot explain these apparently contradictory results. For this, and other, reasons the GMC Savana 3500 will be included as one of five vehicles used in NHTSA's 2004 Light Vehicle Handling and ESC Research Program. So as to better understand how and when ESC interacts with vehicles used in this program, more extensive data acquisition will be utilized. Vehicle outputs such as brake line pressure, body slip angle, and GPS-based vehicle position, as well as a more accurate detection of when ESC intervention is initiated, will be measured.

7.0 REFERENCES

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10. Garrott, Riley W., Rhea, Barbara, Subramanian, Rajesh, Heydinger, Gary J., "The Rollover Propensity of Fifteen-Passenger Vans," NHTSA Research Note, April 2001.

APPENDIX

Table A-1. 2003 Ford E-350 15-Passenger Van Weights, C.G. Locations, and Mass Moments of Inertia.

Configuration	Weight (lbs)	C.G.			SSF	Mass Moments of Inertia		
		Longitudinal (in)	Height (in)	Lateral Offset (in)		Pitch (ft-lb-sec^2)	Roll (ft-lb-sec^2)	Yaw (ft-lb-sec^2)
Baseline (E-350 15-passenger van, 161 lb driver, fully fuelled)	6479.3	72.96	31.83	-0.54	1.073	6820	991	6969
Nominal Load (2-Occupant) (E-350 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers)	6817.2	72.62	31.46	-0.31	1.085	7538	1074	7718
5-Occupant (Multi-Passenger) (E-350 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, five 175 lb occupants)	7354.9	73.17	32.39	-0.69	1.054	7594	1146	7735
10-Occupant (E-350 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, eight 175 lb occupants)	8247.8*	81.49*	33.87*	-0.88*	1.011*	8830*	1176*	8896*
15-Occupant (Maximum Occupancy) (E-350 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, thirteen 175 lb occupants)	9141.4	88.36	35.36	-1.15	0.966	9844	1224	9836

*VIMF measurements of Ford E-350 were not taken in the 10-Occupant configuration. The values provided in Table A-1 were calculated.

Table A-2. 2004 GMC Savana 3500 15-Passenger Van Weights, C.G. Locations, and Mass Moments of Inertia.

Configuration	Weight (lbs)	C.G.			SSF	Mass Moments of Inertia		
		Longitudinal (in)	Height (in)	Lateral Offset (in)		Pitch (ft-lb-sec^2)	Roll (ft-lb-sec^2)	Yaw (ft-lb-sec^2)
Baseline (Savana 3500 15-passenger van, 161 lb driver, fully fuelled)	6770.8	75.89	31.22	-0.87	1.091	7699	1181	8000
Nominal Load (2-Occupant) (Savana 3500 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers)	7075.1	75.10	30.98	-0.69	1.100	8341	1260	8743
5-Occupant (Multi-Passenger) (Savana 3500 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, five 175 lb occupants)	7615.5	75.28	32.08	-1.03	1.062	8380	1312	8745
10-Occupant (Savana 3500 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, eight 175 lb occupants)	8503.8*	82.64*	33.49*	-1.22*	1.020*	9337*	1364*	9747*
15-Occupant (Maximum Occupancy) (Savana 3500 15-passenger van, 161 lb driver, fully fuelled, instrumentation, outriggers, thirteen 175 lb occupants)	9394.5	88.63	34.98	-1.48	0.974	10121	1423	10554

*VIMF measurements of GMC Savana 3500 were not taken in the 10-Occupant configuration. The values provided in Table A-2 were calculated.

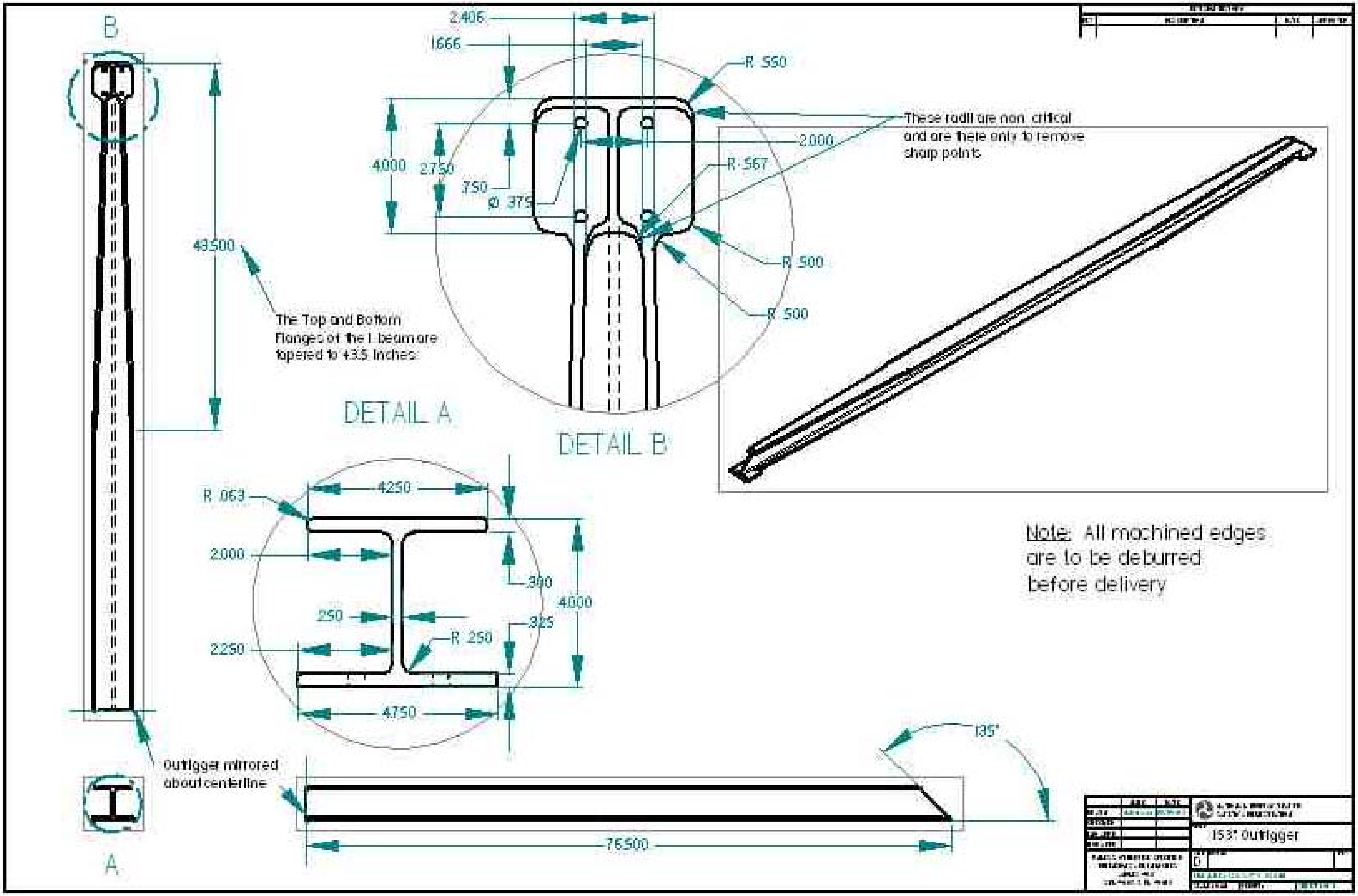

Figure A-1. NHTSA's "Heavy-Duty" outrigger design specifications.

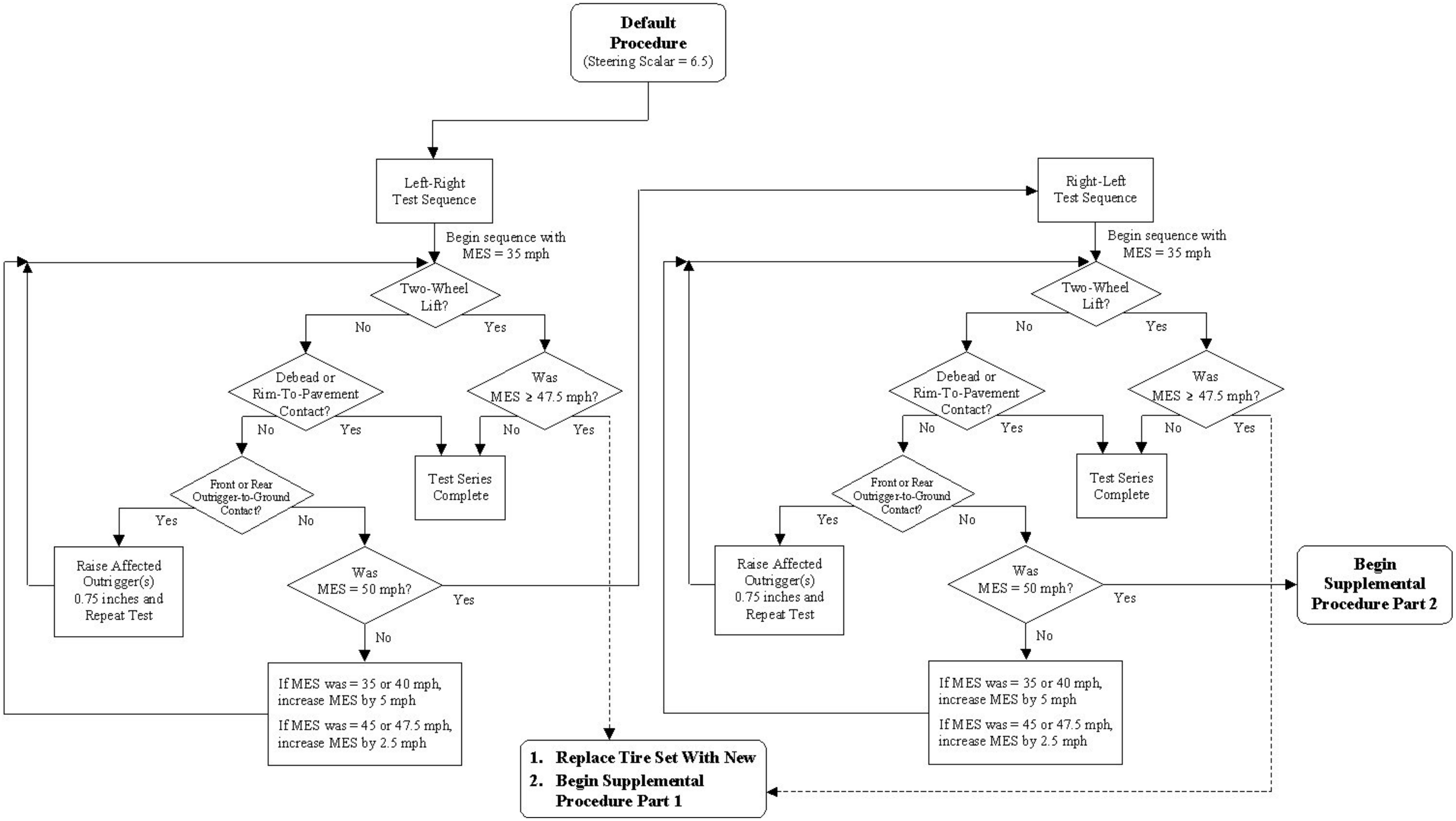

Figure A-2. Road Edge Recovery Default Procedure.

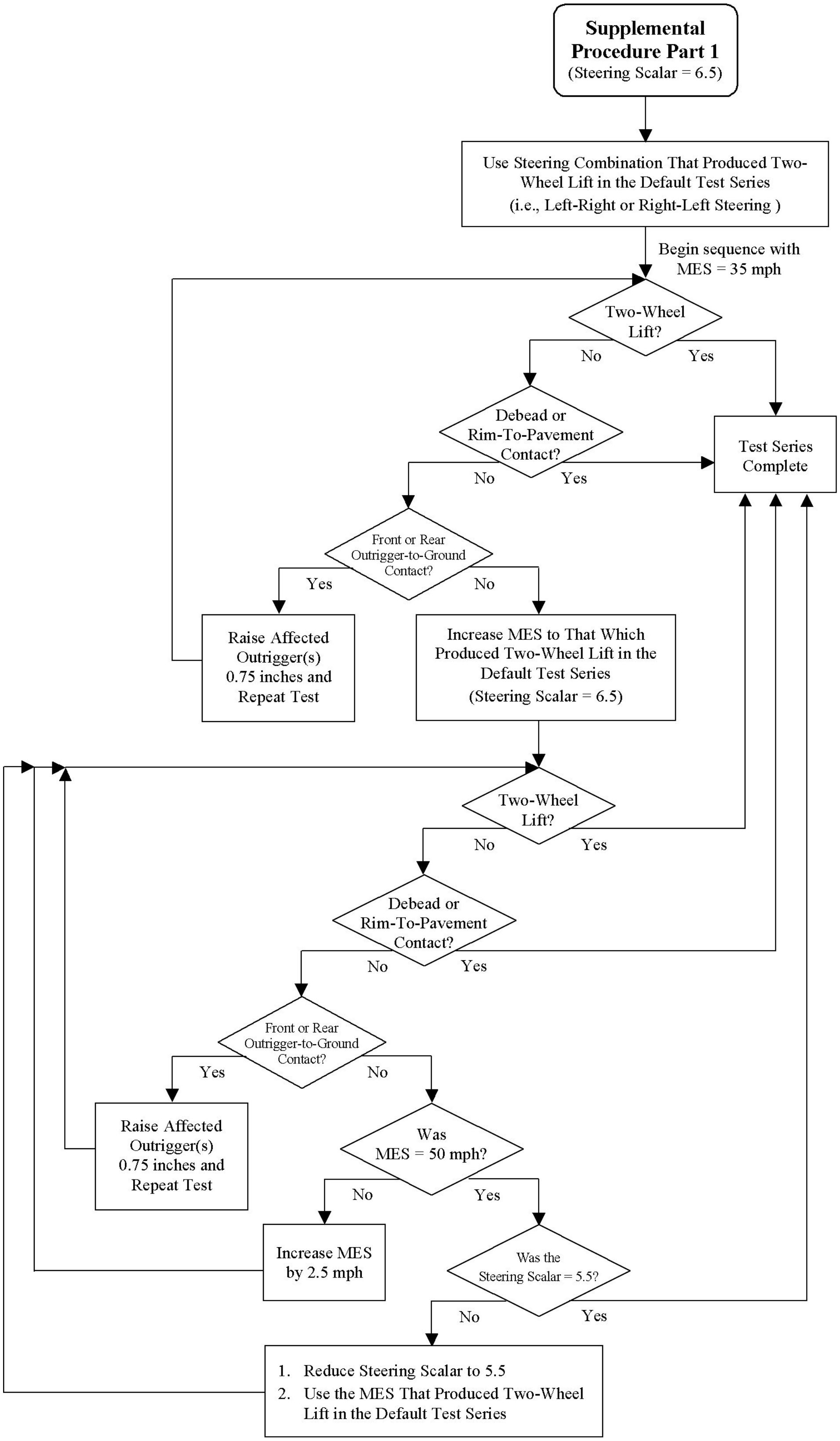

Figure A-3. Road Edge Recovery Supplemental Procedure Part 1.

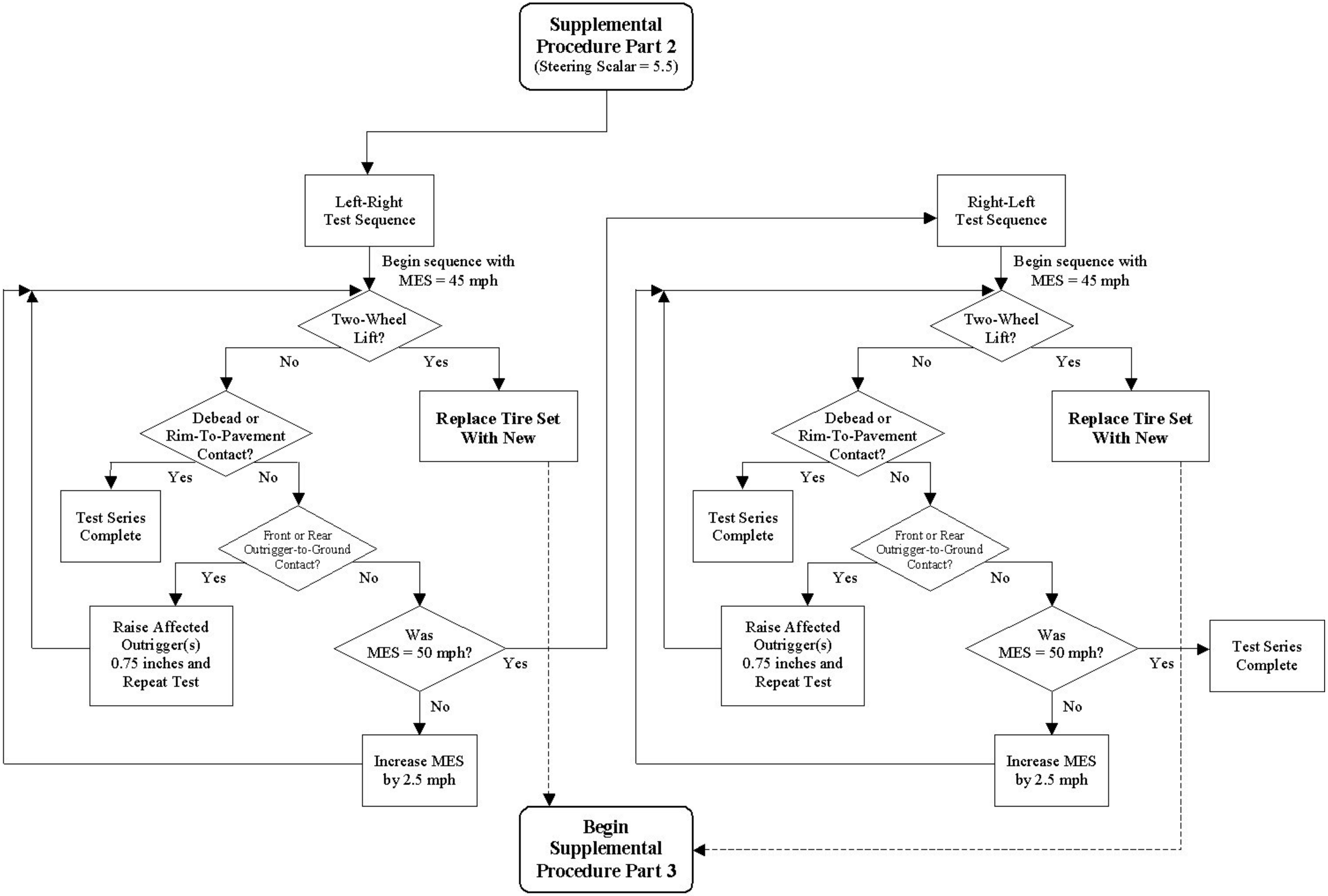

Figure A-4. Road Edge Recovery Supplemental Procedure Part 2.

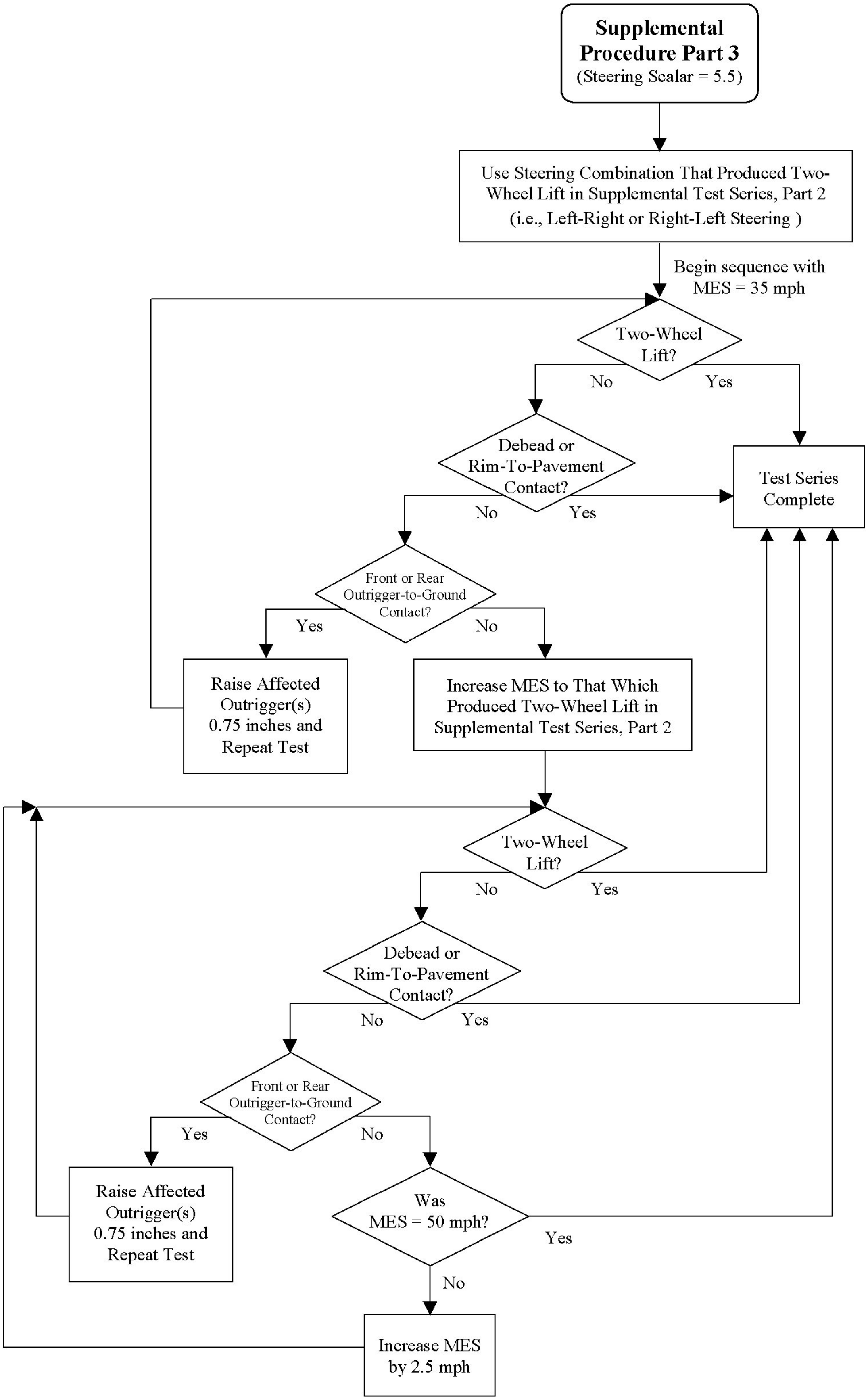

Figure A-5. Road Edge Recovery Supplemental Procedure Part 3.