



U.S. Department
of Transportation

National Highway
Traffic Safety
Administration



Research Note

April 2001

The Rollover Propensity of Fifteen-Passenger Vans

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1. Introduction

Fifteen-passenger vans¹ are in widespread use for the transportation of college sports teams, van pools, church outings, and other similar groups. There have been a number of widely-publicized single vehicle crashes that have involved fifteen-passenger vans transporting college sports teams in the last year. All but one of these crashes have involved rollover of the fifteen-passenger van.

These crashes have raised the question as to whether fifteen-passenger vans, especially loaded fifteen-passenger vans, are unusually susceptible to rollover. Fifteen-passenger vans differ from most light truck vehicles in that they have a large payload capacity and the occupants sit fairly high up in the vehicle. Therefore, when loaded the vehicle may have a much worse rollover propensity than when unloaded.

To examine this issue, a brief study has been performed. This study is composed of three parts: a review of crash data to look at the record of fifteen-passenger vans; measurement of the Static Stability Factors (SSF) of a fifteen-passenger van, a seven-passenger van, and a minivan; and a simulation analysis of the handling characteristics of an unloaded and loaded fifteen-passenger van.

¹While these vehicles actually have seating positions for a driver plus fourteen passengers, they are typically called fifteen-passenger vans. Also, these vehicles are actually classified as buses under 49 CFR 571.3.

2. Crash Data Analysis

To examine the rollover experience of fifteen-passenger vans in the population of crashes, the crash data in NHTSA's State Data System were analyzed. The State Data System is a census of crashes from 17 participating states. The data, comprised of fatal, injury or property-damage-only (PDO) crashes, are recorded in the system based on the reporting thresholds in the states concerned. The reporting thresholds for the participating states vary. This study was performed using the crash data from Florida, Maryland, Missouri, New Mexico, Ohio, Pennsylvania and Utah for crash years 1994 through 1997. These seven states were chosen for this study because of the availability of the Vehicle Identification Numbers (VINs) and rollover scenario variables that were essential for the study. The VINs were decoded to determine the vehicle make and models from which the fifteen-passenger vans were identified.

Seven vehicle models, and all model years during which they were sold as fifteen-passenger or comparable vans, were identified. This list was compiled in consultation with vehicle manufacturers and by inferring the seating capacity from the vehicle's manual. The make-models identified are:

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- \$ Chevrolet Express 3500
 - \$ GMC Savana G3500
 - \$ Dodge Ram Van/Wagon B3500
 - \$ Dodge Ram Wagon B350
 - \$ Ford Econoline E350
 - \$ Ford Club Wagon E350
 - \$ GMC Rally/Vandura G3500

The make-models of the vehicles were derived from the reported VINs in the State Data System. The issue of seating capacity, i.e., if the van was a fifteen-passenger van, can neither be determined from the VIN nor is it available in the data system. The seating arrangement is usually decided at the retail level (dealership, etc.) according to the needs of the customer. In the vehicles listed above, only part of the fleet is finally configured as fifteen-passenger vans while some are used as cargo vans. The VIN was used, to the extent possible, to determine if the vans were used to transport passengers or cargo. The Gross Vehicle Weight (GVW) of a fifteen-passenger van was used as a standard to extract comparable passenger vans from the dataset. However, there is no way to ensure that these vehicles actually were configured as fifteen passenger vans.

This analysis examines the *propensity* of these vehicles to rollover in all single vehicle crashes. The issue of rollover propensity considered the effect of higher occupancy levels in the vans.

Passenger vans that were involved only in single vehicle crashes were identified for the purpose of this study. In single vehicle crashes, rollover resistance metrics in combination with vehicle maneuvers may be more of a predictor of rollovers as compared to multiple vehicle crashes where the impact dynamics may be the significant factor in initiating the rollover event.

The crash data were examined to determine the correlation, if any, of the increased risk of rollover with higher occupancy levels.

The calculated rollover ratios are ratios of the numbers of rollovers to the numbers of all single vehicle crashes. The rollover ratios in this research note were not calculated using the same crash selection criteria or the same state crash reporting thresholds as were used in studies published in NHTSA's notices establishing the NCAP rollover resistance ratings. However, they are useful for comparing the vehicles and load conditions addressed here on a common basis, but cannot be used for comparisons to the rollover risk levels reported in the NCAP ratings.

Looking at all rollovers, regardless of the number of vehicle occupants, fifteen-passenger vans have almost the same rollover ratio as does a comparison group: all light trucks and vans (LTVs).

The occupancy levels of the vehicles were determined from the crash data. The rollover ratios have been depicted in Table 1 by the occupancy levels of the fifteen-passenger vans. The rollover ratios were observed over four categories of occupancy levels: under 5, 5-9, 10-15 and over 15 occupants.

Table 1: Number of Crashes, Rollovers and Rollover Ratios by Occupancy Level of Fifteen-Passenger Vans in Single Vehicle Crashes

Occupancy Level	All SV Crashes	All Rollovers	Rollover Ratio	<i>Combined Rollover Ratios 1 to 9 and 10 or more occupants</i>
<i>Less than 5</i>	1,815	224	12.3%	<i>12.7%</i>
<i>5-9</i>	77	16	20.8%	
<i>10-15</i>	55	16	29.1%	<i>35.4%</i>
<i>Over 15</i>	10	7	70.0%	

As seen in Table 1, the propensity to roll over increases with the occupancy level. It can be inferred from Table 1 that a fifteen-passenger van that has over 15 occupants runs almost six times the risk of rolling over as compared to a fifteen-passenger van that has less than 5 occupants (70.0 vs. 12.3 rollovers per 100 crashes), when involved in a single vehicle crash. When confining the analysis to two groups, less than 10 occupants and 10 or more occupants, the rollover ratio for the vehicles with 10 occupants or more occupants is almost 3 times (35.4 percent vs. 12.7 percent) that of vehicles with less than 10 occupants. As previously stated, even though efforts were made to include only vehicles that were intended to transport passengers, there still may be some vehicles that may have been cargo or special-use vans, especially in the category of crashes with less than 5 occupants. Since the rollover propensity of these types of cargo is not

known, the complete removal of cargo vans from this analysis might change the observed occupant loading effect on the propensity to roll over.

3. Rollover Propensity Metrics of Fifteen-Passenger Vans

NHTSA had S.E.A., Inc. measure the lightly and fully loaded inertial parameters of a fifteen-passenger and a seven-passenger van. Past NHTSA research has measured the lightly and fully loaded inertial parameters of several minivans; one of these was selected for comparative purposes. Information about the vehicles for which the inertial parameters were obtained is shown in Table 2. Note that in Table 2 the Lightly Loaded Weight (LLW) column contains the weight of the vehicle with a weight equivalent to fiftieth percentile male dummy in the driver's seat and no other cargo while Gross Vehicle Weight (GVW) is achieved by placing weights equivalent to fiftieth percentile male dummies in every seating position plus ballast (simulated luggage) in the rear cargo space.

Table 2: Information About Vehicles for which Inertial Parameters Were Measured

Vehicle	Max. No. Occupants	Track Width (in)	Wheelbase (in)	LLW (lbs)	GVW (lbs)
<i>1998 Dodge Caravan</i>	7	63.50	113.60	3,816	5,000
<i>1998 Ford E150 Club Wagon</i>	7	69.70	138.00	5,658	7,000
<i>2000 Ford E350 XLT Super Duty</i>	15	68.20	138.15	6,415	9,100

Table 3 shows the lightly and fully loaded measured inertial parameters for each of these three vehicles. Note that the center of gravity height of the fifteen-passenger van rises by 4.0 inches as the vehicle is loaded versus 1.4 inches for the seven-passenger van and 0.9 inches for the minivan.

Table 4 shows a rollover propensity metric, Static Stability Factor (one-half of the vehicle's track width divided by its center of gravity height), in both the lightly and fully loaded conditions for all three of these vehicles. As this table shows, the Static Stability Factors of all three vehicles decrease from the lightly loaded to the fully loaded conditions. The largest change is for the fifteen-passenger van. Based on NHTSA's Rollover Ratio versus Static Stability Factor regression trend line, this change in Static Stability Factor is predicted to increase the rollover ratio by approximately 40 percent. NHTSA uses this trend line to give consumer information on the rollover resistance of passenger cars, vans, pickups trucks, and SUVs. This trend line is based solely on Static Stability Factors measured with only the driver present in the vehicle because this is the most common configuration in which private consumer vehicles are driven. NHTSA is developing information with which to inform consumers of the sensitivity of rollover resistance to the weight of the additional passengers. This consumer information program does not extend to vehicles which carry more than ten occupants.

Table 3: Measured Vehicle Inertial Parameters

Vehicle	Center of Gravity Height (in)		Moments of Inertia (ft-lb-sec ²)					
			Roll		Pitch		Yaw	
	@LLW	@GVW	@LLW	@GVW	@LLW	@GVW	@LLW	@GVW
<i>1998 Dodge Caravan</i>	25.5	26.4	603	704	2,410	3,128	2,588	3,292
<i>1998 Ford E150 Club Wagon</i>	30.1	31.5	939	1,046	4,848	5,617	4,987	5,731
<i>2000 Ford E350 XLT Super Duty</i>	31.9	35.9	1,078	1,393	6,709	9,410	6,901	9,531

Table 4: Lightly and Fully Loaded Static Stability Factors for the Three Vehicles

Vehicle	Static Stability Factor		
	@LLW	@GVW	Percent Change
<i>1998 Dodge Caravan</i>	1.24	1.20	-3%
<i>1998 Ford E150 Club Wagon</i>	1.16	1.11	-5%
<i>2000 Ford E350 XLT Super Duty</i>	1.07	0.95	-11%

4. Handling Characteristics of Loaded and Unloaded Fifteen-Passenger Vans

The preceding section discusses the rollover propensity of lightly and heavily loaded passenger vans. Loading the vehicles to GVW has an adverse effect on the rollover propensity due to the increase in center-of-gravity height. Loading the vans with passengers and cargo also moves the center of gravity rearward, increasing the vertical load on the rear tires. Table 5 contains values for longitudinal distance from the front axle to the center of gravity, *a*, and for percent weight on the rear axle.

Values for all three vehicles measured at LLW and GVW are provided in Table 5. In the case of the fifteen-passenger van, the longitudinal center of gravity moves nearly 18 inches towards the rear of the vehicle when it is loaded to GVW. At GVW, the fifteen-passenger van has over 65 percent of its weight on the rear axle. The seven-passenger van and minivan measured have just over 50 percent of their weight on their rear axles at GVW.

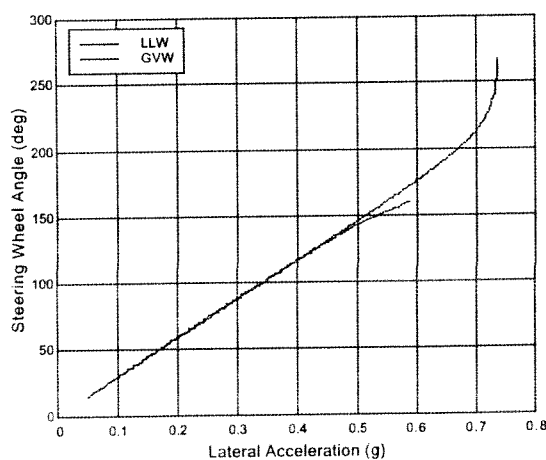
Table 5: Longitudinal Center-of-Gravity Location and Percent Weight on Rear Axle

Vehicle	Wheelbase (in)	@LLW		@GVW	
		a* (in)	% Weight Rear Axle	a* (in)	% Weight Rear Axle
1998 Dodge Caravan	113.6	46.8	41.2 %	59.1	52.0 %
1998 Ford E150 Club Wagon	138.0	62.1	45.0 %	70.9	51.4 %
2000 Ford E350 XLT Super Duty	138.2	72.4	52.4 %	90.3	65.3 %

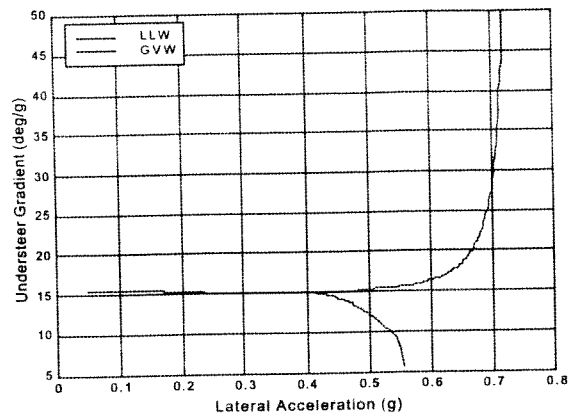
*a: Longitudinal distance from front axle to vehicle center of gravity

To show the effects of occupant loading on the handling of fifteen-passenger vans, computer simulation runs were performed at the driver-only (LLW) and fifteen-occupant plus simulated luggage (GVW) load conditions using the vehicle dynamics simulation Vehicle Dynamics Analysis, Non-Linear (VDANL). The measured values for center-of-gravity location and inertia properties were used in the simulation vehicle models. However, the suspension and tire parameters used to represent the fifteen-passenger van were not directly measured; rather they were based on existing parametric data, to roughly represent those of a fifteen-passenger van. As such, the simulation results presented here are not provided to represent the actual behavior of a specific fifteen-passenger van. Nonetheless, the results are presented to show the effects of loading the vehicle to GVW.

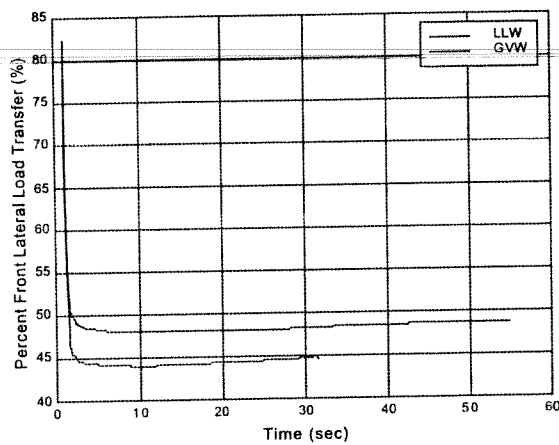
The first maneuver simulated is a slowly increasing steer maneuver using a steering rate of five degrees per second and a constant vehicle speed of 30 mph. This maneuver is useful for determining the understeer and load transfer characteristics of a vehicle. Figures 1 through 4 contain simulation results from the slowly increasing steer maneuver for both the LLW and GVW conditions.



**Figure 1: Lateral Acceleration Versus Steering Input
30 mph Slowly Increasing Steer Maneuver**



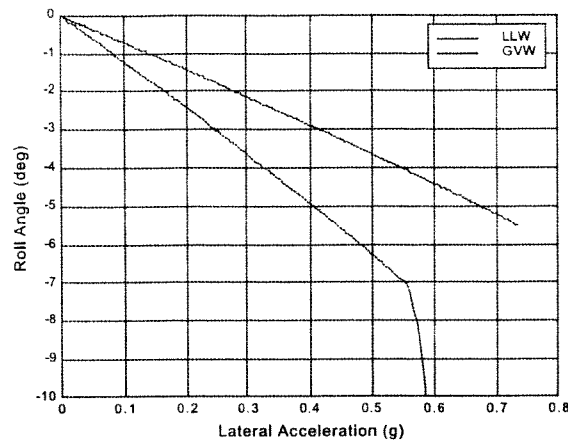
**Figure 2: Understeer Gradient
30 mph Slowly Increasing Steer Maneuver**



**Figure 3: Percent Front Lateral Load Transfer
30 mph Slowly Increasing Steer Maneuver**

Figure 1 contains plots of lateral acceleration versus steering wheel angle, while Figure 2 contains plots of understeer gradient (SAE Understeer Gradient). At GVW the simulated vehicle exhibits a transition towards oversteer above 0.4 g. lateral acceleration, while the LLW vehicle exhibits limit understeer.

The fact that a heavily laden vehicle's understeer characteristics are similar to its lightly loaded condition at low lateral accelerations but different at higher lateral accelerations is a topic of concern. This sort of transition is known to cause safety problems, particularly for drivers who normally only drive smaller passenger vehicles and who are therefore unfamiliar with a loaded fifteen-passenger van's responsiveness and limits.



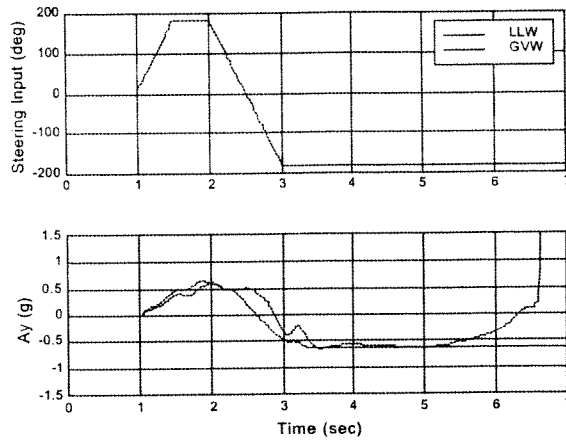
**Figure 4: Lateral Acceleration Versus Roll Angle
30 mph Slowly Increasing Steer Maneuver**

The simulated vehicle is modeled to have 60% of its overall roll stiffness on the front suspension. Figure 3 shows the percent front lateral load transfer. The GVW vehicle has less load transfer at the front axle. This is because the center of gravity is more rearward than the LLW condition. The reductions in the front lateral load transfer and percent weight on the front axle, result in the simulated vehicle becoming oversteer at large lateral accelerations.

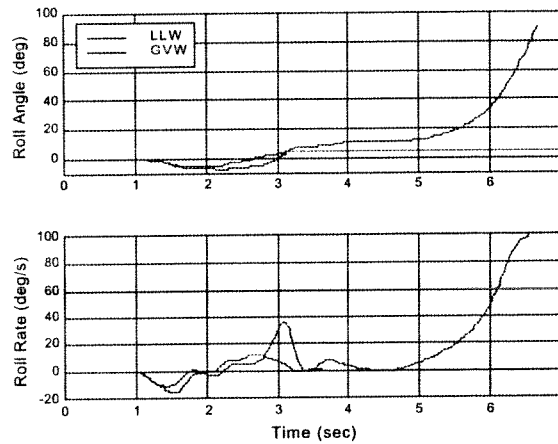
Figure 4 shows lateral acceleration versus roll angle. The roll gradient (roll angle per g. of lateral acceleration) is considerably greater for the GVW condition because the vehicle center of gravity is higher. The simulation predicted a rollover for the GVW vehicle.

The following presentation of simulation predictions during a reverse steer maneuver will be used to further explain the mechanisms leading up to a rollover event.

Figure 5 shows the steering input and lateral acceleration responses for a simulated 30 mph reverse steer maneuver (a maneuver in which the steering wheel is first turned to the right and then turned to the left). Figure 6 shows the roll angle and roll rate responses, and Figure 7 the vehicle side-slip angle (beta) and yaw rate responses. The simulated LLW vehicle remains stable throughout this maneuver while the GVW vehicle rolls over. The rollover is preceded by high side-slip angle, indicating a reduction in rear axle cornering capability. After crossing zero approximately 3.0 seconds into this maneuver, the side-slip angle rapidly increases to 20 degrees by 5.0 seconds. The absolute value of the yaw rate is large throughout this time period, indicating that the vehicle is spinning out. The vehicle continues with ever increasing side-slip until the point of imminent rollover; which starts near 4.5 seconds when both the roll angle and roll rate begin to increase significantly.

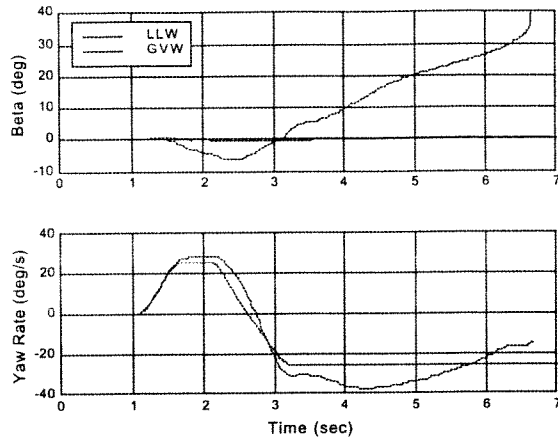


**Figure 5: Steering Input and Lateral Acceleration
30 mph Reverse Steer Maneuver**

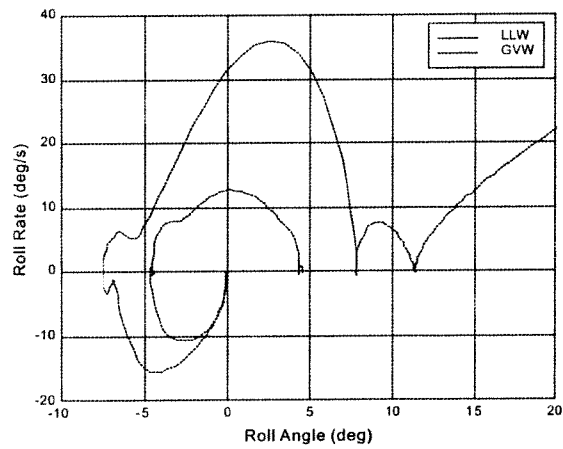


**Figure 6: Roll Angle and Roll Rate
30 mph Reverse Steer Maneuver**

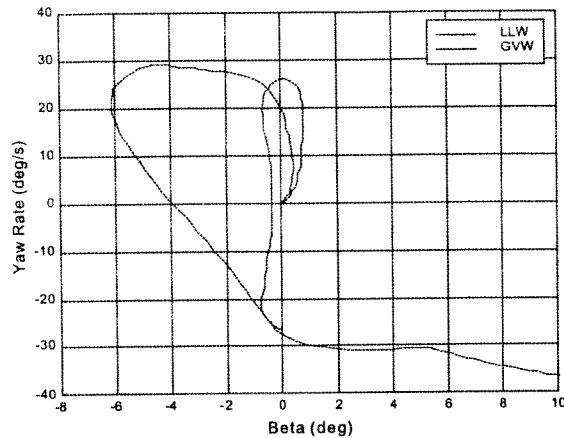
Figures 8 and 9 contain phase plane plots of roll angle versus roll rate and side-slip angle versus yaw rate, respectively. Both figures show stable, convergent responses for the LLW vehicle; and instabilities for the GVW vehicle at the points where the curves diverge.



**Figure 7: Side-Slip Angle (Beta) and Yaw Rate
30 mph Reverse Steer Maneuver**



**Figure 8: Roll Angle Versus Roll Rate
30 mph Reverse Steer Maneuver**



**Figure 9: Side-Slip Angle (Beta) Versus Yaw Rate
30 mph Reverse Steer Maneuver**

These examples show that the simulated GVW fifteen-passenger van exhibits both lateral and roll instabilities under extreme maneuvers. The facts that the center of gravity is higher and further rearward both contribute to the lateral instability. The roll instability results from the facts that the GVW vehicle spins out and that the center of gravity is higher. Note that these instabilities are probably not unique to fifteen-passenger vans; other vehicles with high payload to empty weight ratios may well have similar instabilities.

As mentioned, these simulation results do not represent the response of any specific fifteen-passenger van. These predictions, which do not rely on the measured suspension and tire properties of an actual fifteen-passenger, are presented to illustrate the effects of loading the vehicle to its GVW. Actual vehicles are likely to have different suspension and tire properties than those used in these simulation models. Also, some vehicles rely on using higher rear tire pressures to maintain appropriate handling responses at limit conditions.

Nonetheless, the results presented do illustrate potential handling problems that may occur for a heavily loaded fifteen-passenger van. The essential message is that the handling of this vehicle changes between the two loading conditions during extreme maneuvers and that a fully-loaded van is inherently less stable than an unloaded one.

5. Conclusions

Analyses of crash databases and measurement of rollover propensity metrics indicate that fifteen-passenger vans might be more likely to roll over when fully loaded with occupants than when lightly loaded. For all occupant loadings, fifteen-passenger vans have an overall rollover ratio comparable to that of all light trucks and vans (LTVs). Analysis considering the number of occupants in the vehicle showed that fifteen-passenger vans with ten or more occupants had three times the rollover ratio than those with fewer than ten occupants.

All three sizes of vans for which rollover propensity metrics were measured during NHTSA's field tests had an increase in rollover propensity, measured using SSF, from the driver-only loading condition to the 15-occupant loading condition. However, the effects of occupant loading were greater for the fifteen-passenger van than for the seven-passenger van or the minivan. In measuring the inertial parameters of a fully loaded fifteen-passenger van versus a lightly loaded van, the decrease in stability under the fully-loaded condition correlates to an increase in the rollover risk of approximately 40 percent. Also, sudden vehicle maneuvers could increase the propensity to roll over. Computer simulation predictions illustrated the adverse affects that fully loading a fifteen-passenger van can have on its handling properties (sudden transition from understeer to oversteer) and rollover propensity.

For additional copies of this research note, please call (202) 366-4198 or fax request to (202) 366-3189. For questions regarding the data reported in this research note, please call Rajesh Subramanian (202) 366-5371 of the National Center for Statistics and Analysis or Riley Garrott (937) 666-4511 of the Vehicle Research & Test Center. This research note and other general information on highway traffic safety may be accessed by Internet users at <http://www.nhtsa.dot.gov/people/nca>.