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HANDLING TEST PROCEDURES FOR LIGHT TRUCKS, VANS, AND RECREATIONAL VEHICLES - SUMMARY REPORT

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16. Abstract

This report summarizes the results of a multidisciplined investigation of the safety-related handling behavior of recreational vehicles. This study satisfied the program's primary objective of developing, validating, and documenting a pragmatic set of dynamic performance test procedures that are suitable for making first-order appraisals and evaluations of the handling performance of light trucks, vans, and truck chassis-based recreational vehicles under realistic highway driving maneuvers.

Specific vehicles considered included a Class A motor home, Class C motor home, VW Van, Pickup and Camper, and a four-wheel drive Jeep Wagoneer. Each vehicle was simulated on an updated hybrid computer to aid in development of test procedures. Vehicle physical properties were measured during the program for use in the computer simulations. The procedures were then validated and refined via testing. A set of six procedures was developed. The procedures are braking-in-a-turn, sinusoidal steer, trapezoidal steer, trapezoidal steer while braking, road roughness in a turn, and crosswind sensitivity.

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1.0 INTRODUCTION

The recent decade has been characterized by a steady increase in the use of four-wheel drive utility vehicles, vans, light trucks, and truck chassis-based recreational vehicles. Sales of these vehicles amount to a significant proportion of total passenger vehicle sales (Table 1).

TABLE 1. SUMMARY OF 1974 VEHICLE SALES IN THE UNITED STATES

Vehicle Type	Sales	Percent of Passenger Car Sales
Passenger Cars	8,701,094	-
Pickup Trucks		
Compact*	73,436	0.84
Conventional	1,387,832	15.95
Total Pickups	1,461,268	16.79
Vans	445,585	5.12
Four-wheel Drive Utility	185,201	2.13
Motor Homes	68,900	0.79
Total Vehicles	10,862,048	24.83
Slide-in Campers	45,400	
Pickup Covers	233,400	
Total Pickup Modifications	278,800	

*Not including imports.

A great percentage of the increase can be attributed to the recreational and practical values of such vehicles to non-commercial users. These vehicles often replace passenger cars that are normally used as a family's primary or secondary means of transportation.

Because of the wide range of application of these vehicles for other than normal driving and loading, such a vehicle typically operates in diverse conditions. Inputs from several sources, including accident analysis, indicate that a potential hazard may exist with respect to the handling characteristics of light trucks, vans, and truck chassis-based recreational vehicles.

In light of the rapid growth in recreational vehicle use, NHTSA initiated an investigation of the safety-related handling behavior of recreational vehicles.

Contained in this report is a brief summary of the results of a multidisciplined investigation performed by the Dynamic Science Division of Ultrasystems, Inc. (under NHTSA Contract DOT-HS-4-00853). This study satisfied the program's primary objective of developing, validating, and documenting a pragmatic set of dynamic performance test procedures that are suitable for making first-order appraisals and evaluations of the handling performance of light trucks, vans, and truck chassis-based recreational vehicles under realistic highway driving maneuvers. These maneuvers may ultimately provide the basis for defining safe or unsafe RV handling.

This study is discussed in more detail in the corresponding final report (Handling Test Procedures for Light Trucks, Vans, and Recreational Vehicles - Final Report, Dynamic Science Report No. 8256-75-168) also submitted under this contract.

2.0 PROGRAM SUMMARY

The object of the contract was to develop test procedures that would apply to the wide range of vehicles known as Recreational Vehicles (RVs). The vehicles examined fall into the following classifications and have a gross vehicle weight rating (GVWR) of less than 20,000 pounds:

- Four-wheel drive utility vehicles
- Van-type vehicles
- Pickup trucks with slide-in campers
- Modified vans with camper conversions
- Motor homes built on truck chassis

A specific vehicle from each class was chosen for detailed analysis and testing. The vehicle was selected from a category so as to be representative of that class of vehicles or because of a suspected tendency to represent a "worst case" performer. The vehicles selected were a Jeep Wagoneer, a Volkswagen Transporter, a Ford F-250 "Camper Special" with an 11-foot Open Road slide-in camper, a 20-foot Open Road mini motor home (Class "C" motor home) built on a Chevrolet van chassis, and a Winnebago Chieftain 25-foot motor home (Class "A" motor home) built on a Dodge truck chassis. A summary of vehicle specifications including suspension systems, tires, and weight ratings is shown in Table 2. The Jeep Wagoneer, Open Road mini motor home, and Winnebago Chieftain motor home were chosen as representative vehicles of the four-wheel drive utility vehicle, modified van with chassis-mount camper conversion, and motor home built on truck chassis classes, respectively. The Volkswagen Transporter was selected because of its large proportion of the van sales in 1973, and it is suspected as a "worst case" performer with regard to roll stability and crosswind susceptibility. It is not typical of vehicles in the van class since it has independent suspension at all four wheels with torsion for springs and a rear engine location. The size and shape of the slide-in camper were chosen to represent the poorest performance to be expected in the pickup-camper class. This configuration is also believed to be dominant in actual practice.

TABLE 2. VEHICLE DATA SUMMARY

Vehicle Class	Description	Gross Vehicle Weight Rating (lb)	Suspension Type Front/Rear	Springing Type Front/Rear	Braking Type Front/Rear	Tire Size	Axle Configuration
Van Type	VW Transporter Model 22	4961	I/I	T/T	Dk/Dm	185R 14C	4 x 2
Four-wheel Drive Utility	Jeep Wagoneer	5600	S/S	L/L	Dm/Dm	F78-14B	4 x 4
Pickup Truck with Slide-in Camper	Ford F-250 with 11-foot Open Road Camper	6900	I/S	C/L	Dk/Dm	8.75-16.5E	4 x 2
Modified Van	Open Road 20-foot Mini Motor Home on a Chevrolet G31305 Chassis	8900	I/SD	C/L	Dk/Dm	8.00-16.5D	4 x 2
Motor Home	Winnebago 25-foot Chieftain Motor Home on a Dodge RM-400 Chassis	14000	S/SD	L/L	Dk/Dm	8.00-19.5D	4 x 2

KEY: I - independent suspension; S - solid axle; D - dual wheels; T - torsion bars; L - leaf springs; C - coil springs; Dk - disk brakes; Dm - drum brakes

Therefore, a large camper with a section overhanging the cab and extending past the rear bed was chosen. When mounted in the pick-up, a high c.g. location and a large cross sectional area result which may lead to poor roll and crosswind stability.

The approach to developing the handling test procedures included the following steps:

- Analyze RVs and their properties with respect to handling performance
- Establish a tentative set of handling maneuvers and vehicle response parameters
- Utilize computer simulations to refine the preliminary test procedures
  - Update passenger car hybrid computer simulation to include characteristics of RVs in the equations of motion
  - Measure vehicle properties
  - Perform computer validation tests
  - Iterate test conditions for preliminary test procedures
- Perform procedure validation tests
- Refine and update procedures.

3.0 TECHNICAL APPROACH

With consideration of previous handling test procedure development, a large set of potential maneuvers was compiled and analyzed. This set was narrowed to those that appeared to be most applicable for demonstrating the limit performance of RVs. When appropriate, the maneuver was chosen similar to those developed under similar programs for other types of vehicles.

The equations of motion for the hybrid computer simulation were then updated to include properties of RVs that passenger vehicles do not have and were not previously included in the simulation, such as:

- Dual rear wheels
- Solid front axle
- Four-wheel drive
- Aerodynamic terms for crosswind evaluation

The computer simulation also requires an extensive definition of vehicle properties which consist of a maximum of 154 parameters and 17 tables which define the vehicle and include:

- Tire properties
- Aerodynamic coefficients
- Wheel rotational system
- Dimensional information
- Force deflection characteristics of front and rear suspension
- Steering system components
- Damping characteristics
- Mass and moments of inertia.

These parameters were obtained from an extensive effort that included direct measurement, reduction from manufacturers' design and test results, and estimations based upon known data of similar vehicles as indicated in Table 3.

TABLE 3. VEHICLE PROPERTY DATA

Property Data	Number of Parameters	Number of Tables	Jeep Wagoneer	VW Van	Pickup	Pickup and Camper	Class C Motor Home	Class A Motor Home
Mass and Inertia	13	-	Measured	Measured	Measured	Measured	Measured	Measured
Front Suspension	23	4	Measured	Design and Test	Estimated	Estimated	Design and Estimated	Design and Estimated
Rear Suspension	26	3	Measured	Design and Test	Estimated	Estimated	Design and Estimated	Design and Estimated
Steering System	27	-	Measured	Design and Test	Estimated	Estimated	Estimated	Estimated
Wheel Rotation System	11	2	Measured	Design and Test	Estimated	Estimated	Test and Estimated	Test and Estimated
Tires	51	1	TIRF	TIRF	TIRF	TIRF	TIRF	TIRF
Aerodynamics	3	7	-	Test	-	Estimated	Estimated	Test
	154	17						

Measured - Direct measurement at Dynamic Science facilities.
Estimated - Estimated from similar measured data for other vehicles.
Design - Calculated from manufacturer's design data (drawings, specifications, etc.).
Test - Calculated from manufacturer's test data.
TIRF - Direct measurement at Calspan's TIRF facility.

The preliminary test procedures were simulated on the computer with an array of initial test conditions. From the parametric study of these computer simulations, the handling test procedures for RVs were defined. Vehicles were then tested to these procedures for verification and the procedures were updated as required.

The final test procedures are as follows:

- Braking-in-a-turn
- Trapezoidal steer
- Trapezoidal steer while braking
- Sinusoidal steer
- Road roughness in a turn
- Crosswind sensitivity.

All of these procedures can be performed using automatic remote control of the steering and braking. Alternative manual control procedures are suggested as an option for some of the procedures.

A brief description of each of the procedures is presented in the following sections.

3.1 BRAKING-IN-A-TURN

Execution of this maneuver involves applying the brakes at a specified force level while the vehicle is negotiating a 0.25G lateral acceleration steady-state turn at 40 mph. Incremental tests are conducted until two wheels on an axle attain a lockup condition or a maximum specified pedal force is attained. A braking machine is necessary to conduct these evaluations. The minimum signal requirements are:

- Longitudinal acceleration
- Lateral acceleration
- Yaw rate
- Vehicle velocity
- Wheel rotations

This maneuver tests the ability of the vehicle to stop while in a steady-state turn. This maneuver is proposed for both a high skid number (dry surface) and a low skid number (wet surface). A desirable vehicle response is to stop in a short distance without deviating from the initial path. A limit response is either a spinout or plowout. The evaluation parameters include longitudinal deceleration (A_x), peak body sideslip ($\dot{\beta}_p$), and average path curvature ratio ($R_o(1/R_{AVE})$). Figures 1 through 3 are the evaluation parameters for the vehicles evaluated during the test procedure verification testing.

3.2 TRAPEZOIDAL STEER

Testing involves the rapid application of a steering input of a given magnitude while the vehicle is traveling in a straight path at a constant velocity of 30 mph. The magnitude of the steering input is increased until a limit response is observed. Upon initiation of the steer the throttle is released. The shape of the steer as a function of time represents a trapezoid. A steering machine should be used although it is not a necessity. The minimum signals requirements for evaluating this maneuver are:

- Longitudinal acceleration
- Lateral acceleration
- Yaw rate
- Fifth wheel velocity
- Roll angle
- Steering wheel torque

This maneuver measures the ability of the vehicle to avoid an object by means of a rapid steer input. The limit responses can be a rollover, plowout, or spinout. The performance parameters are peak sideslip angle (β_p), normalized path curvature ratio ($R_s(1/R_{AVE})$), and peak roll angle (ϕ_p). Figures 4 through 6 are typical summary plots of these parameters from the procedure verification testing. Peak steering wheel torque experienced during the maneuvers was recorded and the summary of the results are presented in Figure 7. The torque values give an indication of the ability of a driver to manually provide the steering input experienced during the test procedure.

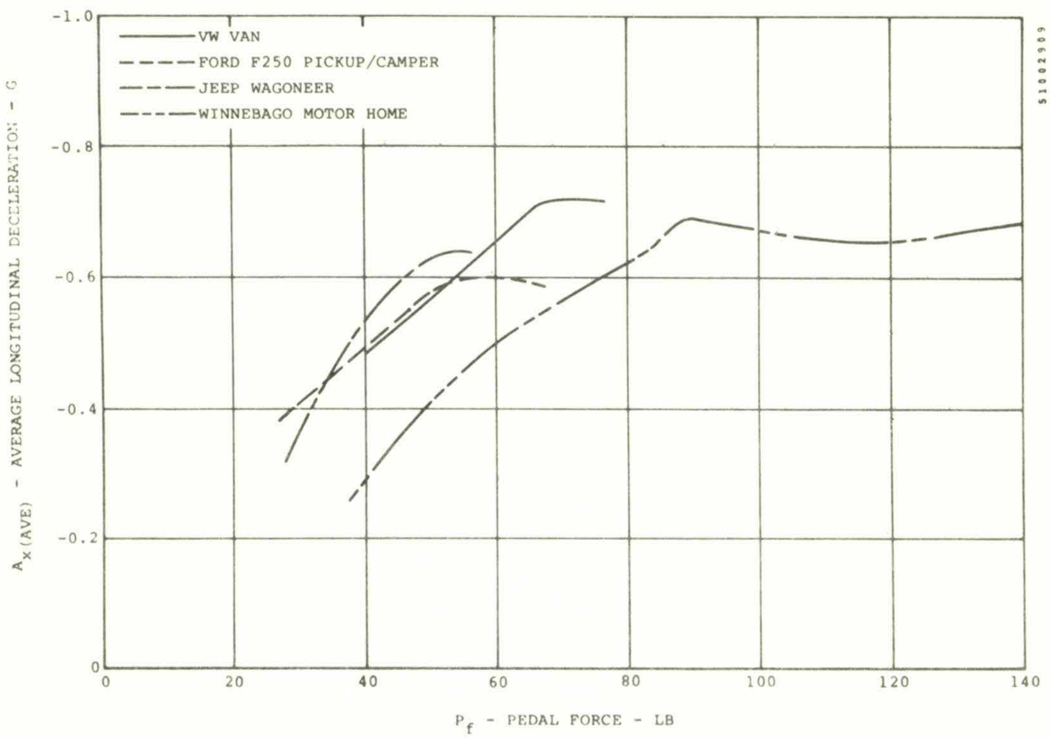


Figure 1. Braking-in-a-Turn - Summary Plot for Average Longitudinal Deceleration.

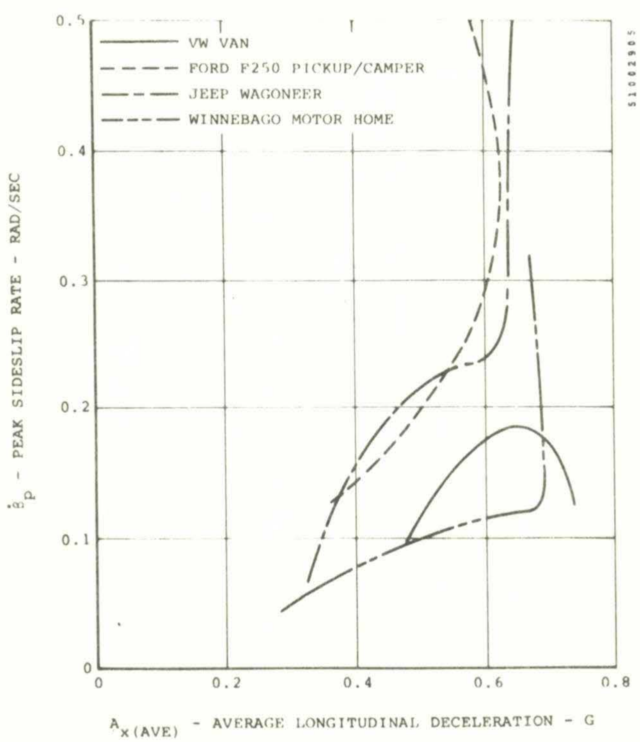


Figure 2. Braking-in-a-Turn - Summary Plot of Peak Sideslip Rate.

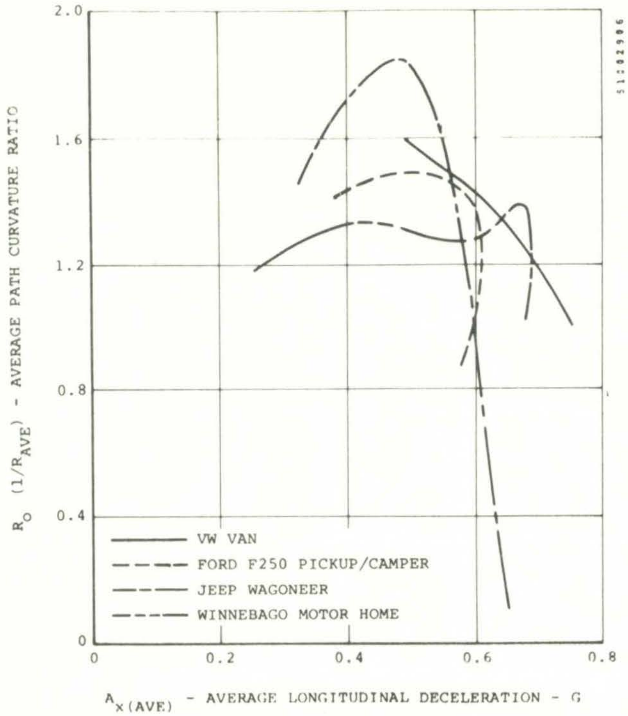


Figure 3. Braking-in-a-Turn - Summary Plot of Average Path Curvature.

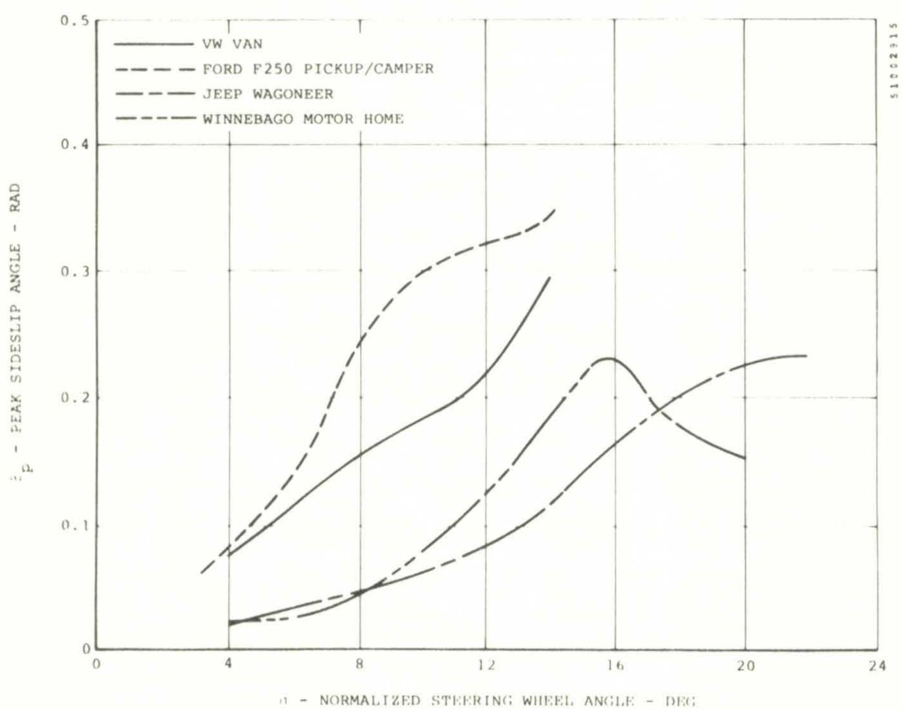


Figure 4. Trapezoidal Steer - Summary Plot for Peak Sideslip.

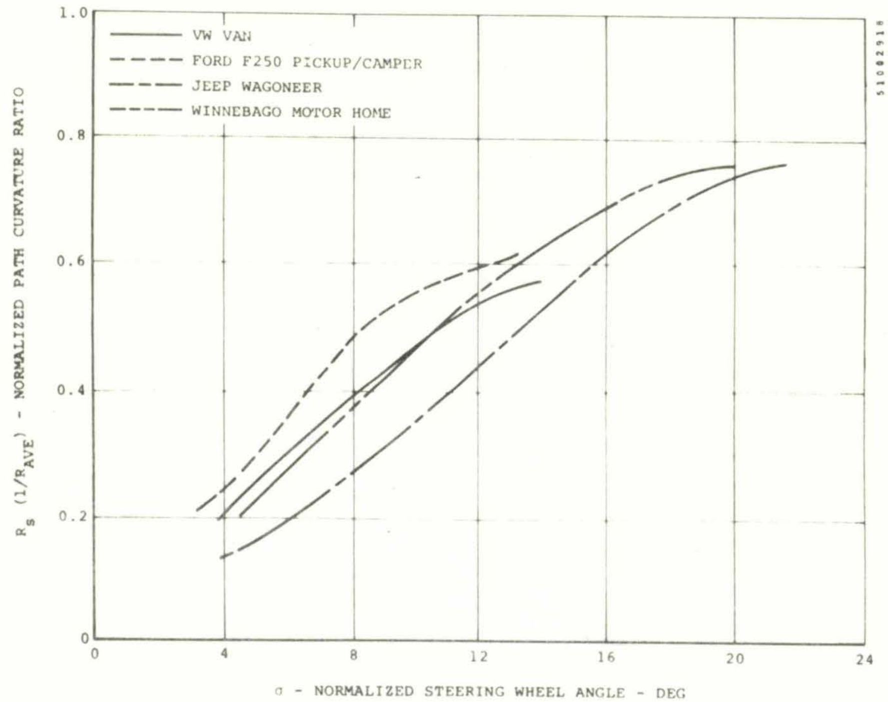


Figure 5. Trapezoidal Steer - Summary Plot for Normalized Path Curvature

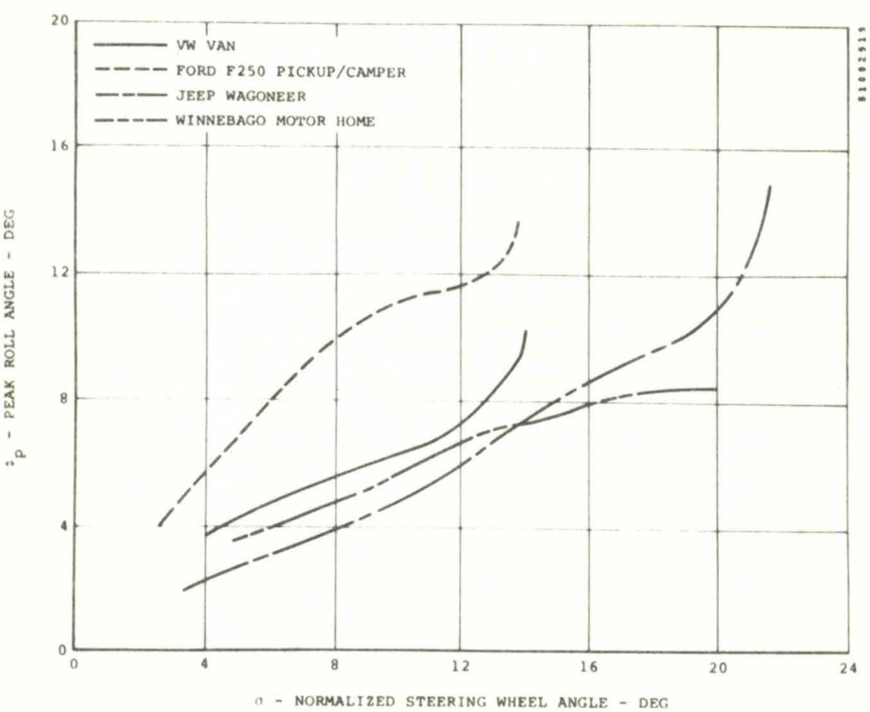


Figure 6. Trapezoidal Steer - Summary Plot for Peak Roll.

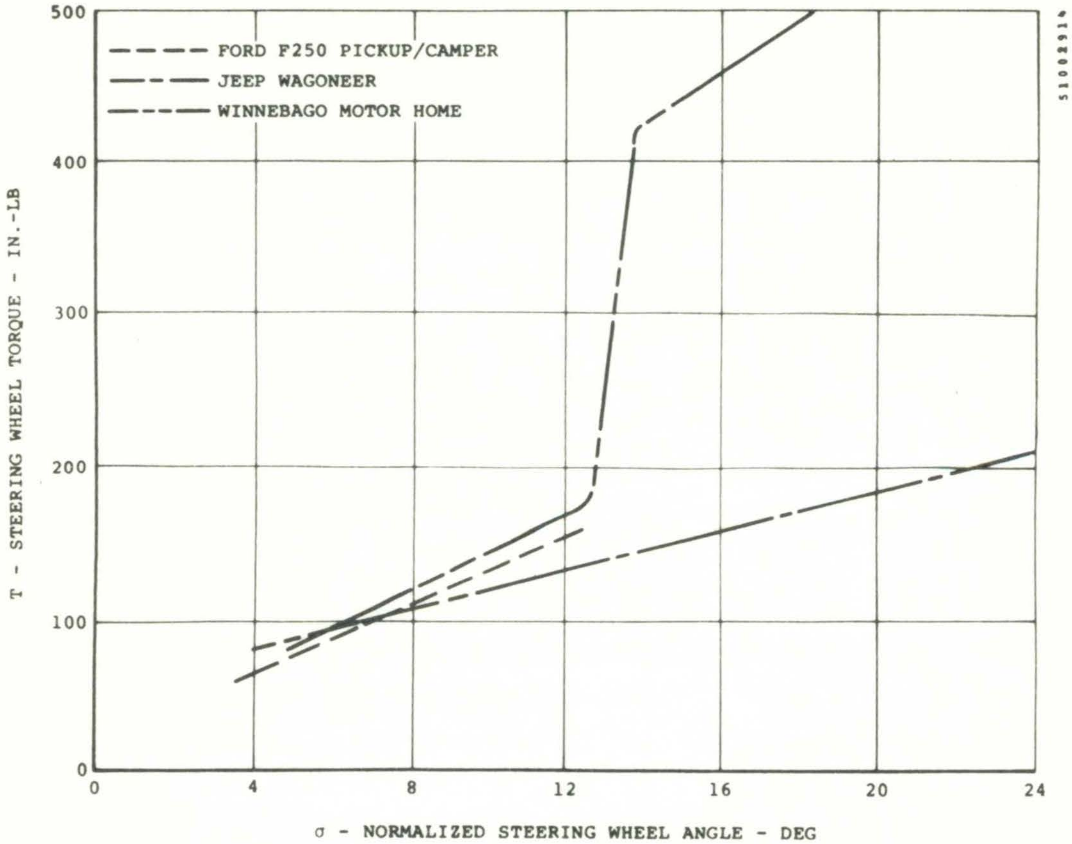


Figure 7. Trapezoidal Steer - Summary Plot for Steering Wheel Torque.

3.3 TRAPEZOIDAL STEER WHILE BRAKING

The test vehicle is driven onto a skid pad at a velocity of 50 mph. The brakes are then applied to give a 0.4G deceleration rate. A rapid steer is applied when the vehicle reaches a velocity of 40 mph. The steer function resembles a trapezoid in shape. The magnitude of the steer function is increased in succeeding runs until a limit response is observed. A steering/braking machine is a necessity for accurate test results. The minimum signals required are:

- Longitudinal acceleration
- Lateral acceleration
- Yaw rate
- Fifth wheel velocity
- Roll angle
- Steering wheel torque

The trapezoidal steer while braking maneuver measures the ability of the vehicle to avoid an object in its path by a steer input while braking at a constant rate. Potential limit responses are rollover, plowout, and spinout. The evaluation parameters are peak sideslip angle, normalized path curvature ratio, and peak roll angle. Figures 8 through 10 summarize results from the test procedure verification tests for this maneuver.

3.4 SINUSOIDAL STEER

The maneuver is run at a constant velocity of 45 mph with a steering wheel input shaped as a single cycle of a sine wave with selected maximum amplitude and frequencies ranging from 1.0 to 3.0 seconds. The magnitude of the steering input is increased in succeeding runs until a limit response is observed. As the steer is initiated, the throttle is released. A steering machine is required. The minimum signals required for evaluation of this maneuver are:

- Longitudinal acceleration
- Lateral acceleration
- Yaw rate
- Fifth wheel velocity
- Roll angle
- Steering wheel torque

This maneuver measures the ability of the vehicle to change lanes. The limit responses can be tendencies to roll over, spinout, and plowout. The evaluation parameters involved the minimum deviation from an ideal lane change (Δ_m), the deviation from the initial heading after the maneuver is completed (ψ), as well as the peak sideslip angle and peak roll angle. Figures 11 through 14 are representative summary plots of results from the test procedure verification testing.

3.5 ROAD ROUGHNESS IN A TURN

Execution of the maneuver involves traversing a roadway disturbance grid while in a steady state turn of 0.35G lateral acceleration with the steering wheel constrained. The road

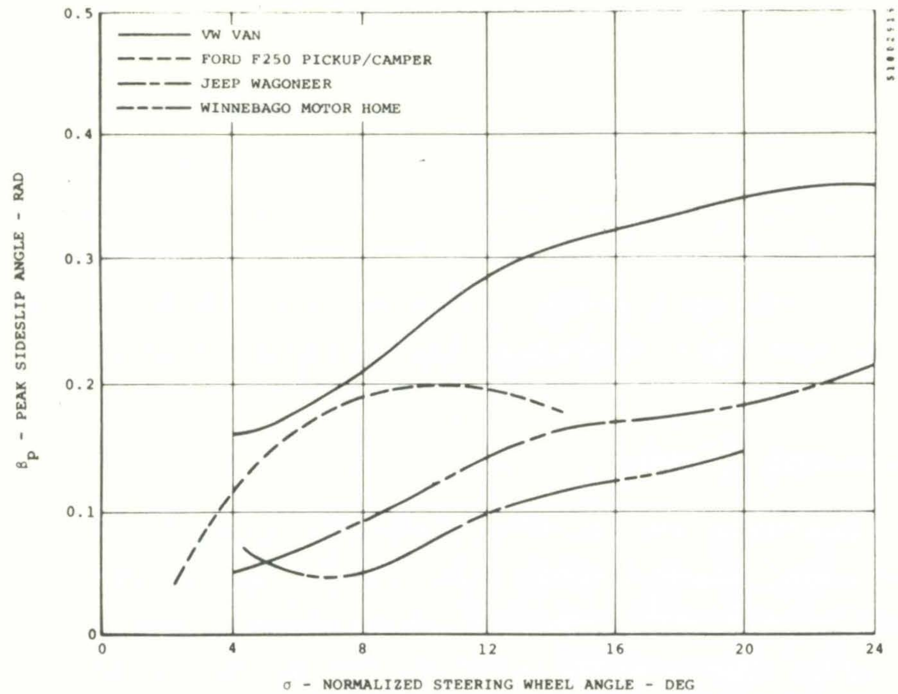


Figure 8. Trapezoidal Steer While Braking - Summary Plot for Peak Sideslip.

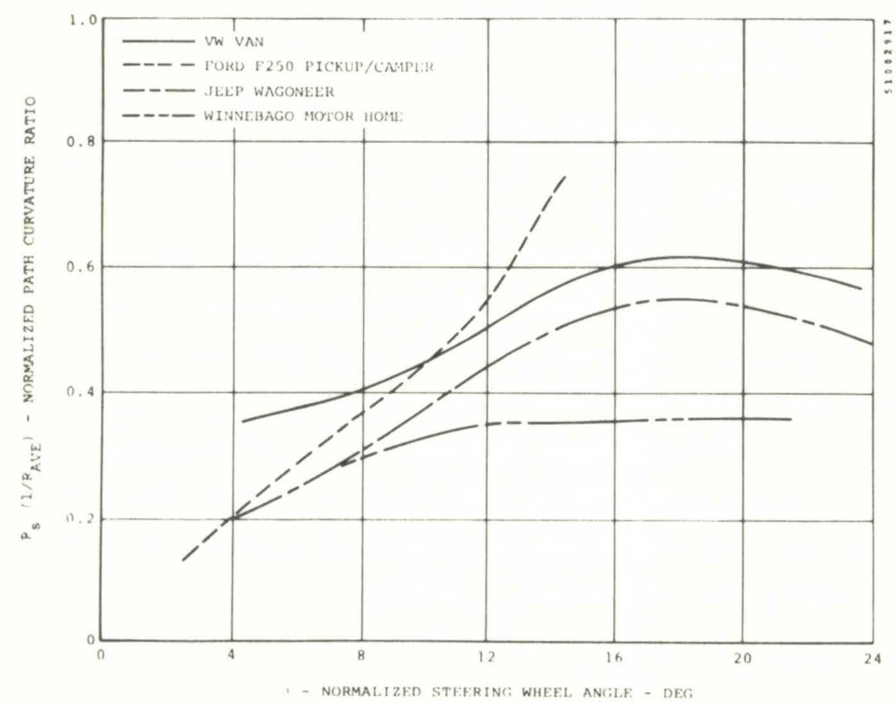


Figure 9. Trapezoidal Steer While Braking - Summary Plot for Normalized Path Curvature.

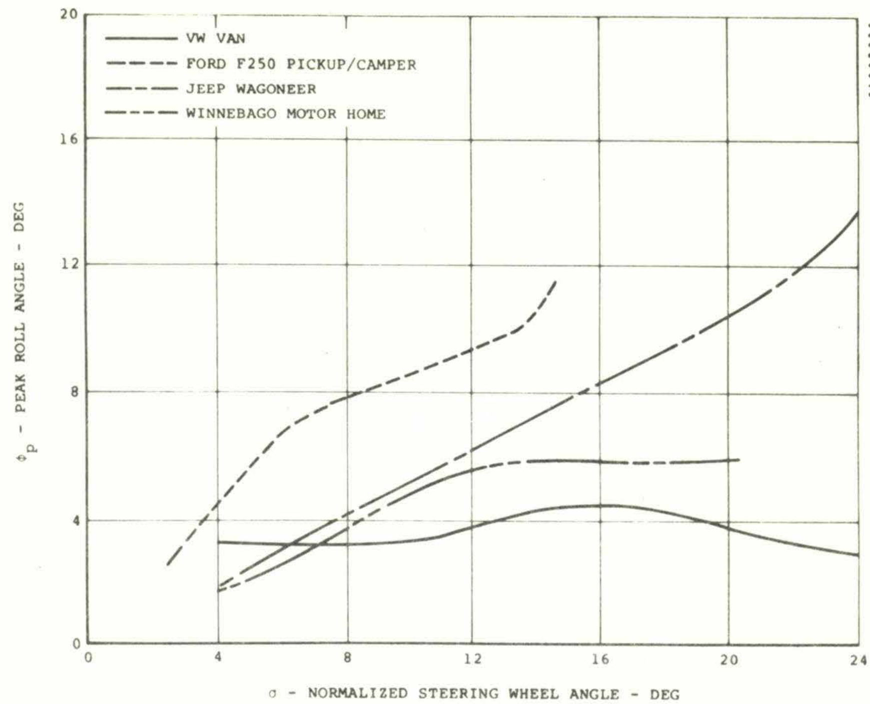


Figure 10. Trapezoidal Steer While Braking - Summary Plot for Peak Roll.

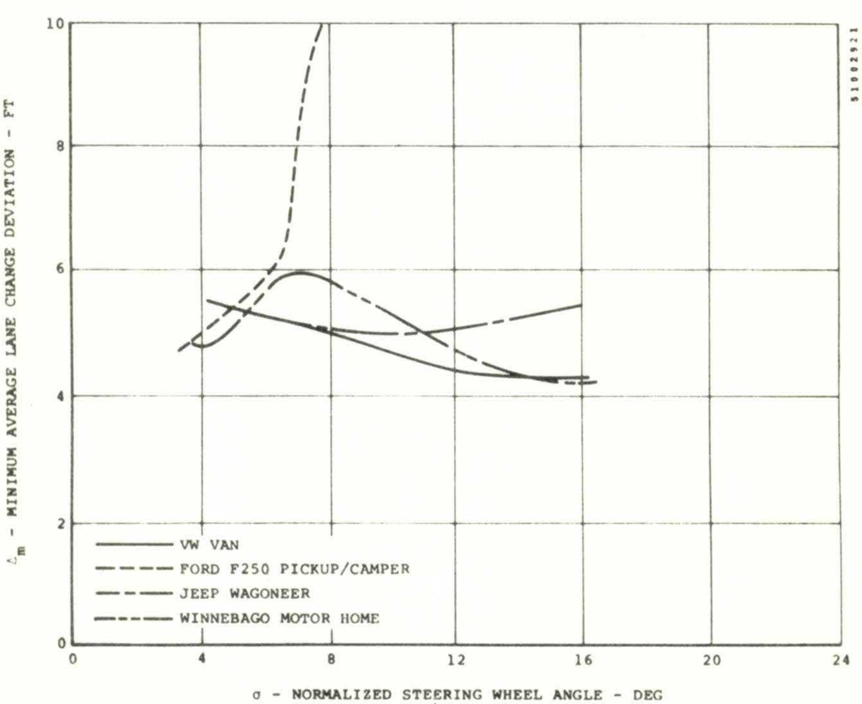


Figure 11. Sinusoidal Steer - Summary Plot for Minimum Lane Change.

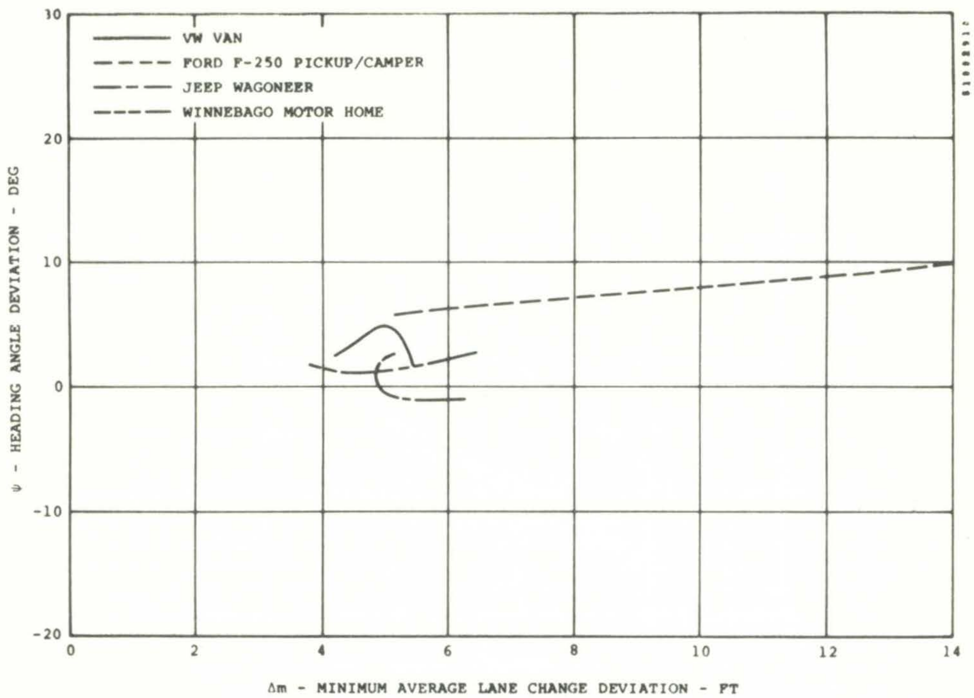


Figure 12. Sinusoidal Steer - Summary Plot for Heading Angle.

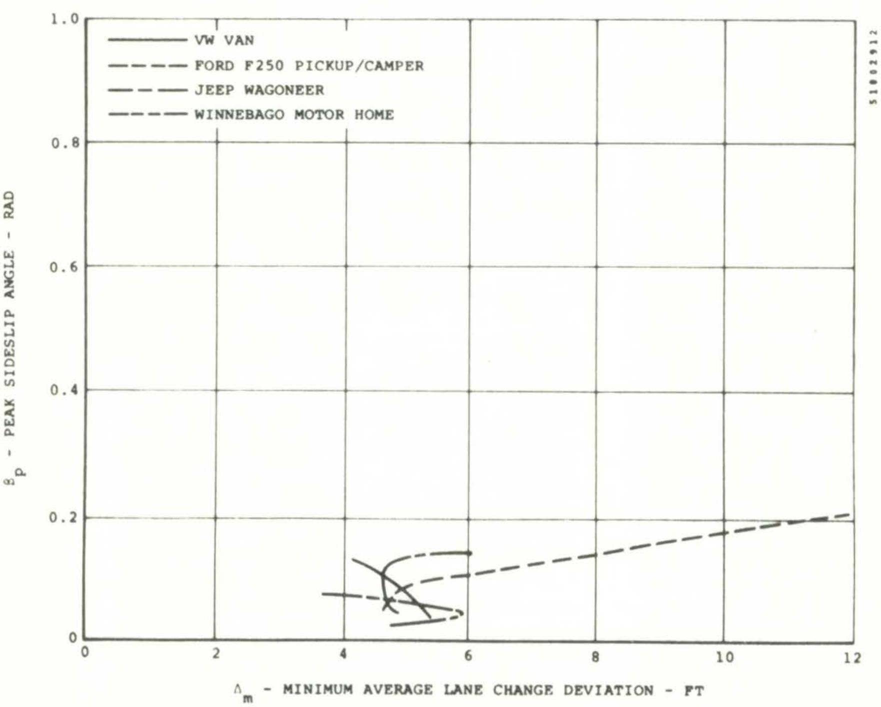


Figure 13. Sinusoidal Steer - Summary Plot for Peak Sideslip.

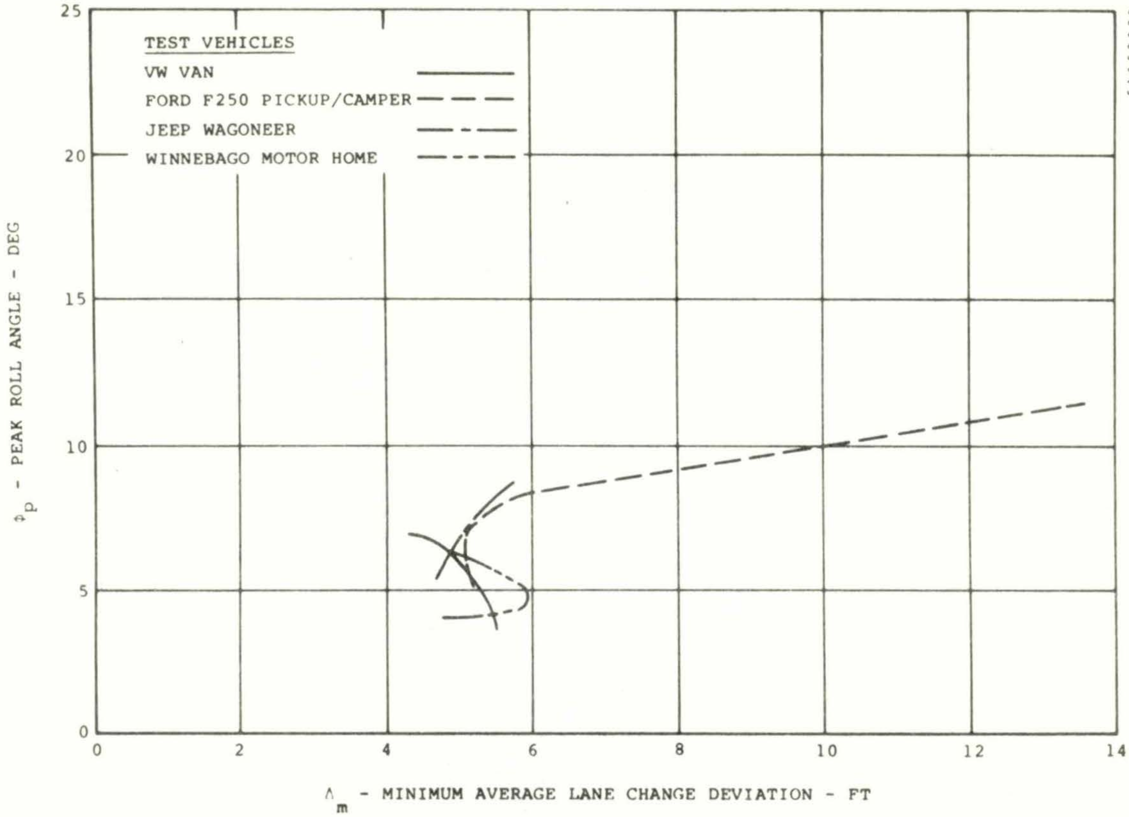
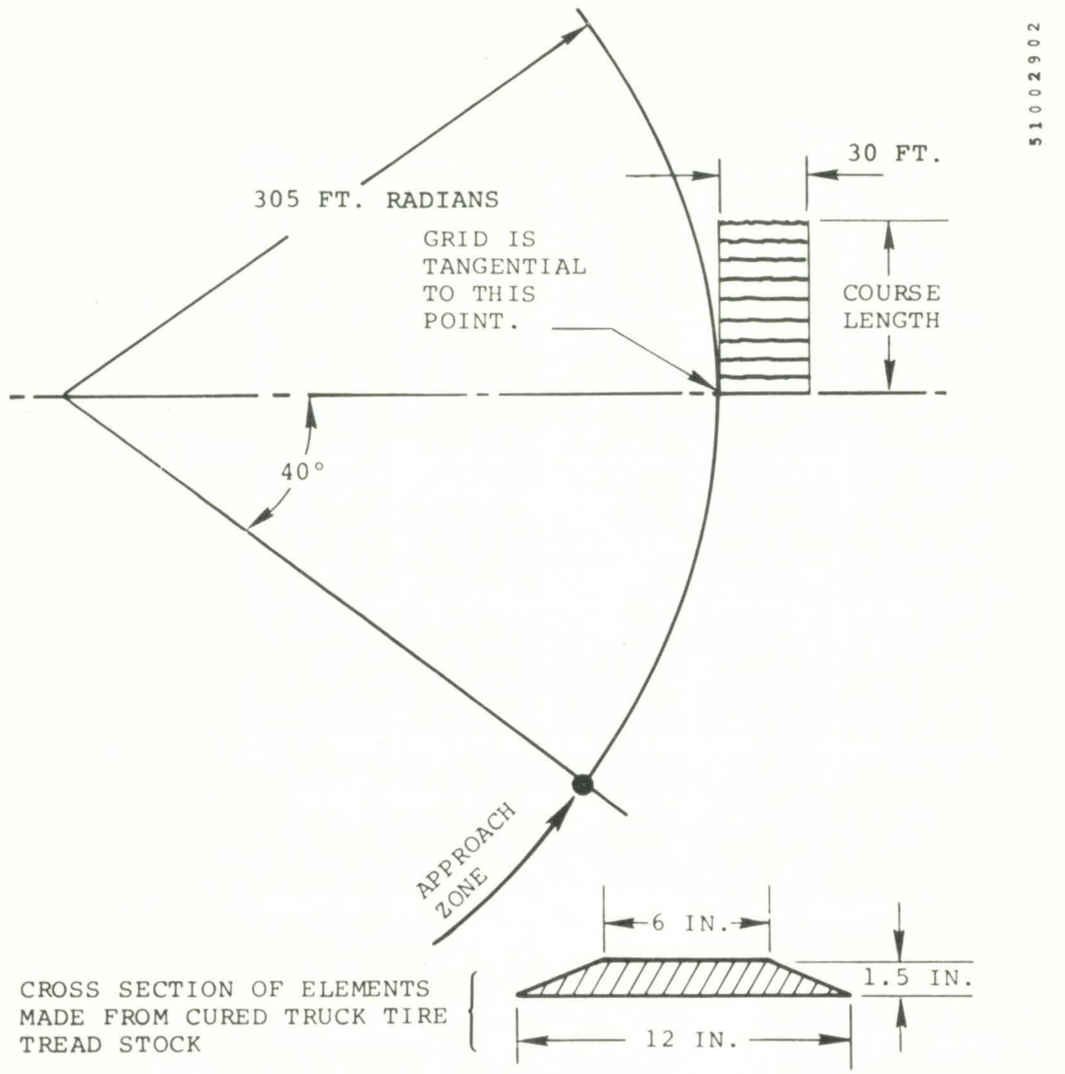


Figure 14. Sinusoidal Steer - Summary Plot for Peak Roll.

disturbance grid is as illustrated in Figure 15. Tests are run at only 40 mph with bump spacing and number varied to alter the disturbance frequency and keep the total length of the disturbance constant. A steering machine is not necessary for executing this test. The minimum signals required to evaluate this maneuver are:

- Longitudinal acceleration
- Lateral acceleration
- Yaw rate
- Fifth wheel velocity
- Roll angle

This maneuver investigates the vehicle responses to road roughness. The limit responses to this maneuver include rollover, spinout, and plowout. The evaluation parameters are once again peak sideslip angle, average path curvature ratio, and peak roll



FUNDAMENTAL FREQUENCY - HZ	8	9	10	11	12	13	15
CENTER SPACING - INCH	88.00	78.22	70.10	64.00	58.67	54.15	46.93
COURSE LENGTH - FEET	59	59	59	59	59	59	59

Figure 15. Road Disturbance Course Layout.

angle. Figures 16 through 18 are representative summary plots of these parameters for the road roughness maneuver during the test procedure verification testing.

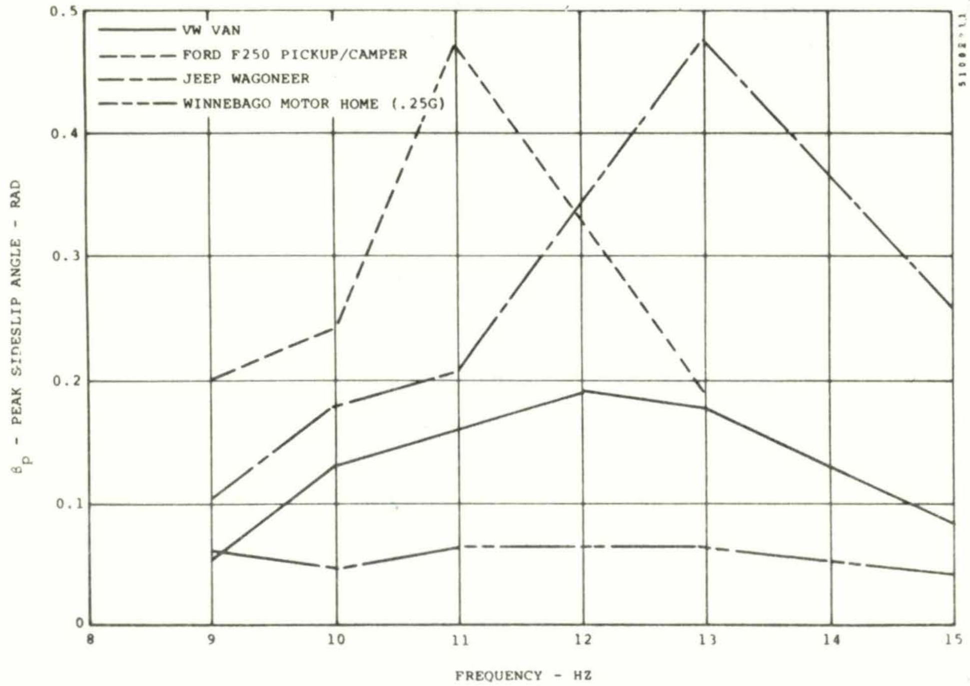


Figure 16. Road Roughness - Summary Plot for Peak Sideslip.

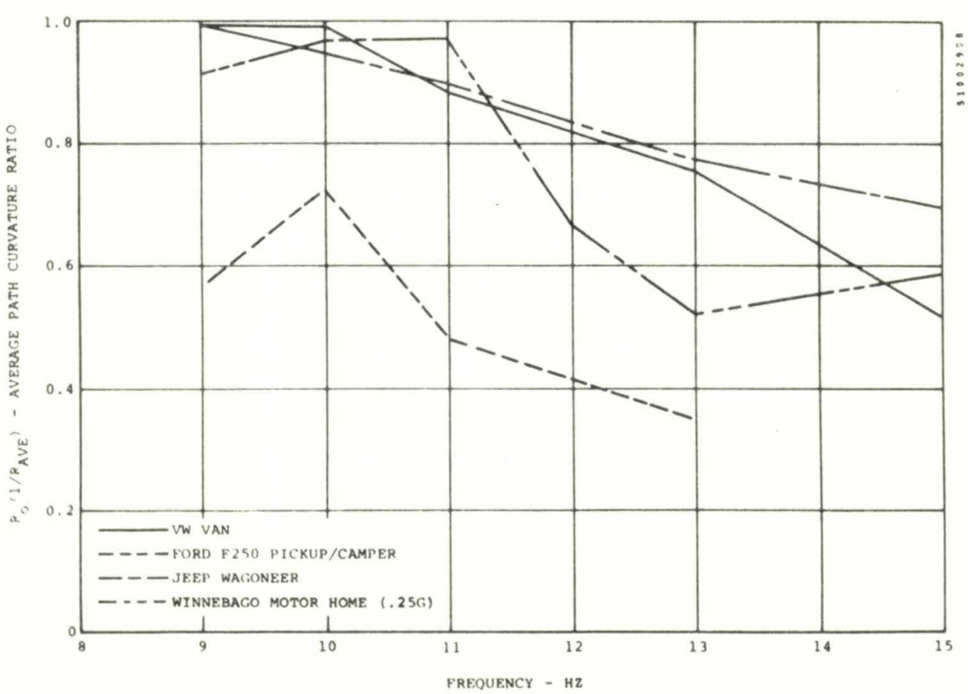


Figure 17. Road Roughness - Summary Plot for Average Path Curvature.

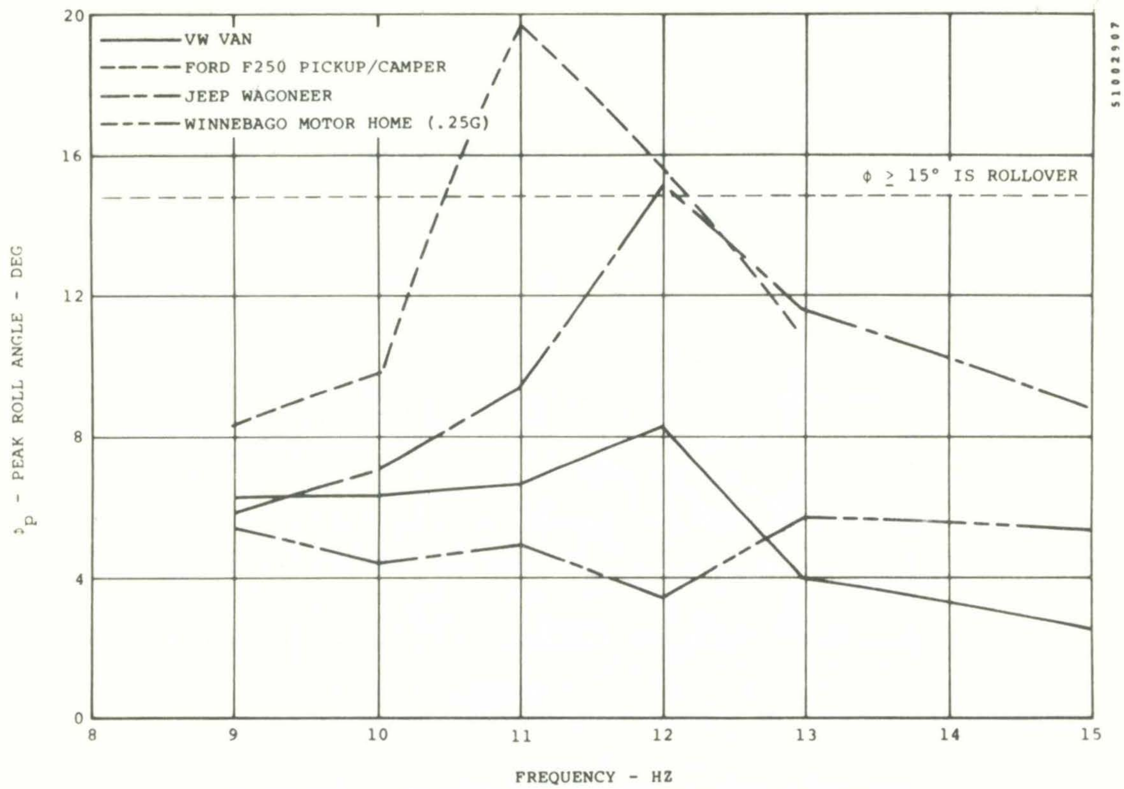


Figure 18. Road Roughness - Summary Plot for Peak Roll.

3.6 CROSSWIND SENSITIVITY

The test vehicle is driven onto a skid pad at the specified speed. The maneuver consists of traversing a 65-mph crosswind disturbance while the steering wheel is held fixed. The minimum signal required is lateral displacement.

The desirable vehicle response is to have no path deviation when subjected to an impulsive side wind.

Figures 19 and 20 are representative results of the crosswind sensitivity maneuver during the test procedure verification testing.

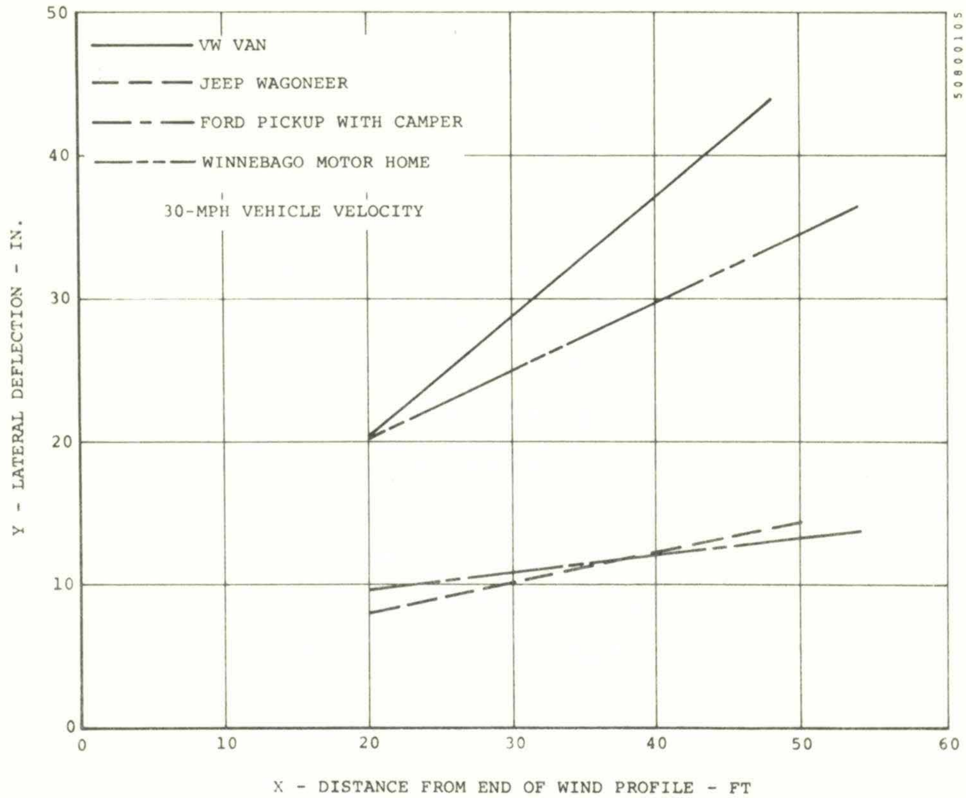


Figure 19. Crosswind Sensitivity - 30 mph.

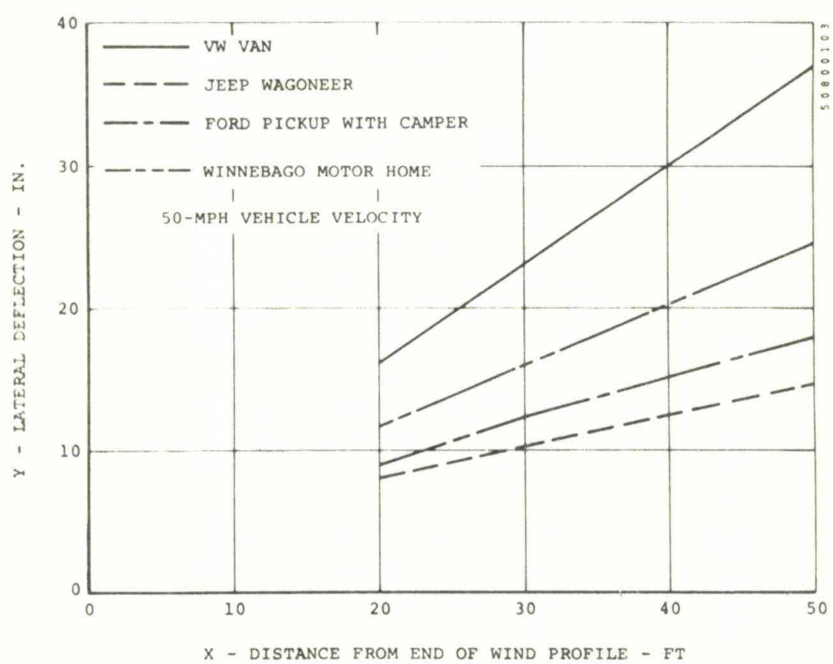


Figure 20. Crosswind Sensitivity - 50 mph.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The set of six handling maneuvers developed during this program can be used as a basis for characterizing limit handling performance for light truck, van, and truck chassis-based recreational vehicles. These procedures were successful in causing rollover, spinout, and plowout responses with the tested recreational vehicles. Further research is recommended to refine certain of these procedures. Parameter boundaries that distinguish between safe and unsafe handling characteristics should be established, utilizing accident analysis and statistics and by further research on driver/vehicle interaction. A definition of what is an unexpected limit response for the driver should also be included. These tasks must be accomplished before any future handling standard on these vehicles can be finalized.

4.1 CONCLUSIONS

Based upon the results of the analysis, simulation, and testing phases of the program, the following observations and conclusions are made:

- A rollover limit response was exhibited by recreational vehicles on a flat level high friction surface that was caused by steering input alone.
- Tire deflation of the outside front tire caused by tire beads unseating during severe maneuvers was evident on certain vehicles.
- A rollover limit response was exhibited by some recreational vehicles on a flat level high friction surface that was caused by a combination of steering and braking inputs.
- More pronounced directional sensitivity to crosswind disturbances was exhibited by the van and motor home than for the other vehicles tested.
- Upon leaving the road disturbance grid on the rough road test, a large yaw acceleration resulted in all vehicles. Under extreme conditions, this situation caused a rollover response on a number of vehicles.

To investigate the driver effort necessary to perform the test maneuvers, brake pedal force and steering wheel torque were measured so that comparisons could be made to "normal" driving. It was found that:

- The pedal force necessary to attain maximum stopping ability of the tested vehicles did not exceed 90 pounds. Since present Federal regulations allow pedal forces up to 150 pounds for straight line braking, this area does not appear to be a problem with these vehicles.

- The peak steering wheel torque input recorded during a trapezoidal steer maneuver was 530 in-lb with the motor home. This peak occurred during the steering ramp interval and was fairly constant during that period. Certain people may not have the physical ability of applying this force level for the necessary time to attain the desired input. Further study should be performed to determine what levels of steering effort the average driver is capable of producing.

4.2 RECOMMENDATIONS FOR TESTING

Certain additional trends are apparent from the testing results but more information is necessary before any definite conclusions can be made. For example:

- Asymmetrical vehicle response with turn direction was observed during the sinusoidal steer maneuver. Since the sinusoidal steer test was the only maneuver performed in both directions, further study is necessary to determine if this phenomenon occurs in the other maneuvers and/or if this characteristic is confined to certain vehicles. The physical mechanisms that are responsible for the different response with turn direction should be identified and defined.

- Four-wheel drive improved the lane changing capability and reduced the spinout tendency of a vehicle during severe maneuvering on low friction surfaces. More investigation is necessary to determine if four-wheel drive improves performance of other vehicles and other maneuvers on slick surfaces.

- The type of limit response exhibited by a vehicle on a low friction surface while braking in a turn is affected by brake lining temperatures. Further investigation is necessary to determine if other maneuvers are also effected.

4.3 RECOMMENDATIONS FOR COMPUTER SIMULATION

The simulation proved to be a useful tool in the development of the recreational vehicle handling test procedures, but comparison between test and simulation results yielded many disparaties. The magnitudes of the performance parameters varied significantly in many cases. The type of limit handling behavior predicted by the computer model was not always the same as that observed while testing. The differences between simulation and testing may be due to a number of factors, including the following:

- The computer model assumes a rigid sprung mass which seems reasonable for passenger cars and smaller vehicles. Frame twisting about the longitudinal axis was evident during the testing on the larger vehicles during severe maneuvering. Therefore, the angles of the tire at the tire/road interface and roll resistances could be significantly different from those predicted by the simulation.

- Brake fade due to temperature may change the front/rear proportioning during a single stop and could affect braking results. Many vehicles possess valving that alters brake proportioning through the range of hydraulic pressure. A simple model for the brake proportioning is used in the simulation. The braking system model in the simulation could be modified to produce a better comparison with test data during braking maneuvers.

- The assumption of small angles and the elimination of certain terms in the equations of motion sprung and unsprung masses appear to be questionable for recreational vehicles.

- The tire model incorporated into the program was developed for passenger car tires. Many recreational vehicles are equipped with truck tires whose mechanical properties vary significantly from passenger car tires. Dynamic tire force and moment characteristics are also not included in the simulation. Modifying the tire model to incorporate these features might improve the simulation results.

Consequently, model improvements may be necessary to utilize the computer simulation for recreational vehicle handling evaluation. At the present time, it is not recommended to use simulation results as a substitute for testing.

The required accuracy of the vehicle input parameter data that describes the vehicle should also be investigated. Sensitivity studies should be performed to determine how sensitive the various vehicle responses are to variation in certain vehicle properties. A standardized procedure should be developed so that computer simulations may be used to evaluate vehicles and allow equitable comparisons between vehicles.

With the sensitivity of the input parameters known, the input parameters could be placed into groups representing various levels of simulation ranging from a simple model to a very complex model. The simplest level would require relatively few input parameters and would generate an inexpensive simulation. The model and the associated input parameters should be defined for each level of desired simulation sophistication. The program and its input would then be more user oriented, allowing use by nonexperts.

4.4 GENERAL RECOMMENDATIONS

Additional recreational vehicle tests should be performed to obtain more information on their handling characteristics.

- Procedure validation testing was performed on only one vehicle in four of the six classes. Additional vehicles from each class should be tested to more clearly define the handling characteristics of a particular class of vehicles. Also, vehicles representing the other two classes, pickup (empty) and class "C" motor home, should be tested to determine their characteristics. It is also strongly recommended that testing of a small pickup with camper be initiated.

- Improper tire inflation and loading are potential problems of concern on recreational vehicles. It is recommended that a study be made on the effect of these factors on vehicle handling characteristics.

- The effect of tires on recreational vehicle handling is another area of concern as replacement tires of varying sizes and tread patterns are common on many recreational vehicles. It is recommended that study be initiated into the effect of various tires and combinations of tires to determine their effect on recreational vehicle handling.

- Another subject that needs research is the variability of handling performance between two vehicles that have identical nominal specifications. These variations may be due to production tolerances or other factors yet to be discovered.

- The procedures developed are the first generation of a set of procedures to evaluate the handling characteristics of recreational vehicles. The procedures could be reviewed and refined. The additional maneuvers mentioned in Section 3.2 could be considered in more detail. The Sinusoidal Steer maneuver could be refined to include a response parameter that measures obstacle avoidance capability (the longitudinal distance traveled when the lateral deviation reaches six feet, for example).

- The response parameters could be refined to improve the evaluation of the vehicles. The normalized path curvature for trapezoidal steer or the average lateral deviation for sinusoidal steer could be refined to separate the transient and steady state effects.