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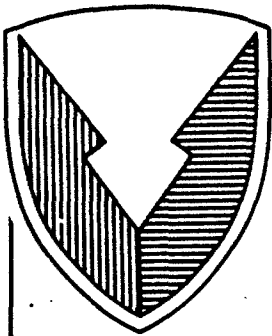
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Technical Report



No. 13391

AN INVESTIGATION INTO THE LATERAL STABILITY OF THE
M1037 TRUCK PULLING THE M101 TRAILER

SEPTEMBER 1988

Best Available Copy

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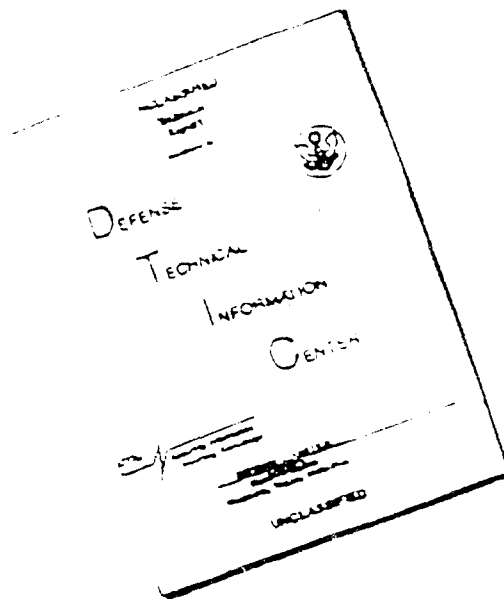
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Form Approved
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Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release: Distribution is unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) *			7a. NAME OF MONITORING ORGANIZATION U.S. Army Tank-Automotive Command		
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Tank-Automotive Command		6b. OFFICE SYMBOL (If applicable) AMSTA-RYA	7b. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000		
6c. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8a. NAME OF FUNDING / SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	10. SOURCE OF FUNDING NUMBERS		
8c. ADDRESS (City, State, and ZIP Code)		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) An Investigation into the Lateral Stability of the M1037 Truck Pulling the M101 Trailer (u)					
12. PERSONAL AUTHOR(S)					
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM 88Feb TO 88Sep		14. DATE OF REPORT (Year, Month, Day) 1988 September	
15. PAGE COUNT					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Simulation, DADS, HMMWV, Dynamic, Vehicle Stability		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report documents an investigation into the lateral stability of the M1037 Truck pulling the M101 Trailer. The Multibody Dynamic Simulation Program Dynamic Analysis and Design System (DADS) was used to produce a Dynamic Simulation Model for both the M1037 Truck with the Mobile Subscriber Equipment (MSE) payload and the M101 Trailer systems. The simulation model was validated with instrumented road tests. Once the validity of the model was established, it was used to determine the stability boundaries of the M1037/M101 System for lane change, steady turn and nump course maneuvers. The report presents recommendations to improve the dynamic stability of the system.					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL C.W. Mousseau			22b. TELEPHONE (Include Area Code) (313) 574-5032		22c. OFFICE SYMBOL AMSTA-RYA

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1.0. INTRODUCTION

This report presents the final results of an analytical and experimental program to evaluate the stability proprieties of the M1037 and the M101 trailer system for on road operation.

The Analytical and Physical Simulation Branch (AMSTA-RYA) was requested by the Light Tactical Vehicle Project Manager (AMCPM-TVL) to quantify the stability limits of M1037 Mobile Subscriber Equipment (MSE) payload vehicle pulling the M101 trailer. The M1037 is a the shelter carrier version of the High Mobility Military Wheeled Vehicle (HMMWV). The M101 is the utility trailer that is normally used with the M151 vehicle. The Gross Vehicle Weight (GVW) of the M1037 vehicle and M101 trailer considered in this study with the MSE payload were 8,800 lb and 3,160 lb respectively.

AMCPM-TVL requested the study because there has been concern from the test and user communities that the M1037/M101 system may not have adequate control and handling properties. Recent accidents with the M1037/M101 system at Aberdeen Proving Grounds (APG) have raised the need for the quantification of the stability limits of the system.

Dynamic simulation models of the M1037 and M1037/M101 vehicles were developed for the purpose of studying the system's dynamic behavior. The general purpose computer program Dynamic Analysis and Design System (DADS) was used to generate the the M1037 and M1037/M101 dynamic simulation models. The DADS simulation model of the M1037/M101 vehicle developed for this study featured the following:

- Full six degree of freedom dynamic vehicle simulation .
- Detailed dynamic representation of the vehicle and trailer suspension systems.
- Optimal preview control driver modeling to steer the vehicle.
- Quasi-static three dimensional tire modeling.
- A simple feedback control power train modeling that propels the vehicle at a constant speed.

DADS has been used by the U.S. Army Tank-Automotive Command (TACOM) and other organizations for over five years to successfully model the dynamic response of vehicle systems. The military vehicles that have been modeled with the DADS program include the M1, and M60 tanks, Heavy Expanded Mobility Tactical Truck/Heavy Expanded Mobility Ammunition Trailer (HEMTT/HEMAT) truck/trailer , and the M113 personal carrier.

The simulation model was validated by road testing the actual vehicle system. The simulation and the test vehicle were subjected to identical constant speed lane change, steady turn, and bump

course maneuvers. Comparisons between the simulation output and test vehicle measurements showed that simulation modeling reproduced the dynamic response of the test vehicle with sufficient accuracy.

The DADS simulation model was used to evaluate the dynamic response of both vehicle systems during lane change, steady turn, and bump course maneuvers. Simulations of both the M1037 vehicle, and the M1037 vehicle towing the M101 trailer were conducted. Speeds at which vehicle instability or violent response occurred in a maneuver were isolated to within 5 miles per hour (mph). Only constant speed maneuvers were examined in this project. Simulations of braking maneuvers were not conducted.

2.0. OBJECTIVES

The objectives for this project were to:

- Develop a validated simulation model of the M1037/M101 vehicle system.
- Generate stability boundaries for standard maneuvers that will allow users of the M1037/M101 vehicle system to set safe operating limits.

3.0. CONCLUSIONS

Validation tests described in section 5.4.1 showed that the simulation model reproduced the dynamics behavior of the M1037/M101 with sufficient accuracy. The simulation model accurately reproduced both the magnitude and the shape of the actual vehicle dynamic response.

The simulation showed that the vehicle could negotiate a 100 ft by 12 ft lane change for speeds up to 60 mph without loss of control. Secondly, the vehicle could negotiate a 500 ft radius steady turn at 50 mph (0.33 g lateral acceleration), but went unstable at 55 mph (0.40 g lateral acceleration). Third, the simulation model showed no vehicle instability for traveling downhill on a 15% slope for vehicle speeds of up to 60 mph. Finally, the vehicle did not show any stability problems on the 6 inch bump course described in Figure 5.4-2.

The addition of a 3,160 GVW M101 trailer to M1037 significantly degrades the stability of the system. Simulations described in section 5.6.2 showed that the M1037/M101 system stability limit for a 500 ft radius steady turn was bracketed between 45 mph (0.27 g lateral acceleration) and 50 mph. Moreover, the dynamic simulation presented in section 5.6.3 showed that the trailer produced a considerable amount of roll at vehicle speeds of 10 mph through 20 mph on 6 inch bump course described in Figure 5.4-2. The M1037/M101 system did however, negotiate the 100

ft by 12 ft lane change course described in Figure 5.4-1 at up to speeds of 60 mph with no problem. When the M1037/M101 was required to negotiate a lane change on a 15% down hill slope the system showed no signs of instability. However, when the slope was increased to 29% the system was only marginally stable.

4.0. RECOMMENDATIONS

The recommendations are summarized below:

- To improve system stability, the MSE payload should be moved as far forward in the vehicle as possible.
- The front tire inflation pressure of the M1037 should be raised to 30 psi for on road use. This action will improve the vehicle's on road handling proprieties.
- If stability tests are conducted with the M1037/MSE system, outriggers should be installed on both the M1037 vehicle and the M101 trailer to prevent accidental roll over.
- The dynamic performance of M101 trailer with the M1037 as the prime mover is inadequate for off road use, and only marginally stable for on road use. A new trailer that better suits the capabilities of the HMMWV system should be designed.
- The maximum off-road speed of the M1037/M101 system should be no more than 10 mph.
- Additional simulations should be conducted to determine the sensitivity of the systems dynamic response to parameter variations.

The simulation revealed that the extreme rearward fore-aft position of the M1037 payload limits the vehicle's lateral stability to between 0.33 g and 0.4 g in a steady turn. Placing the payload further forward improves the traction of the front tires by reducing lateral load transfer in the front suspension. Moreover, the simulations showed slightly better on road vehicle response with the tires inflated at 30 pounds per square inch (psi) all the way around, than with the tires inflated at normal 20 psi front, and 30 psi rear. The effect of different set of tire inflation pressures would have on the vehicle's off road performance is uncertain. Additional off road vehicle tests should be conducted to determine if inflating the front tires to 30 psi improves vehicle response.

Adding the 3,160 lb GVW M101 trailer to the vehicle reduces the overall stability of the system. The simulations showed that the trailer has a lower stability threshold than the HMMWV for both the bump course and the steady turn maneuver. In fact, the bump course simulations show that the trailer is unsuitable for off road use in rough terrain. The primary causes for the instability are the trailer's track width (10 inches less than that of the HMMWV), and inadequate jounce travel (only 2.5 inches from the static position).

Since not all possible off road driving conditions were simulated, a maximum safe off road vehicle speed can only be approximated. Simulation results for the 6 inch bump show that the vehicle is probably not safe to drive above 10 mph.

The following additional analysis should be made of the system. First, it is uncertain how sensitive the stability of the system is to parameter variations. Additional simulations should be done with at least 10% variations in vehicle center of gravity (CG) position, weight, and tire cornering properties to see if minor changes in vehicle parameters will cause significant changes in dynamic response. Second, maximum safe down hill slope for the M1037/M101 system should be better quantified. Simulations results presented so far show that the system is stable for a 15% downhill slope, but may be unstable for a 29% slope. Additional simulation runs can help isolate the maximum safe downhill slope to within a few percentage points.

The M101 trailer should be replaced with another trailer that will degrade the HMMWV's performance only minimally, and have the same roll stability and mobility abilities as the prime mover. The dynamic simulation models developed under this project should be used to develop dynamic performance specifications for future trailer purchases.

5.0. DISCUSSION

5.1. Roll/Yaw Instability

Vehicles are subjected to two classes of instability: Divergent roll behavior, i.e., vehicle roll over, and divergent yaw behavior, i.e., spin out, jackknifing or trailer swing (in the case of articulated vehicles). Generally, the directional controllability of the vehicle for a given maneuver, is determined by the mode of instability that occurs at the lowest vehicle speed.

Vehicle dynamics researchers have found that the roll stability of a vehicle negotiating a steady turn can be expressed in terms of its lateral acceleration. See reference [1]. If the lateral acceleration is below a given level, the vehicle is roll stable. Above that level it is roll unstable. Furthermore, yaw divergent behavior can in many instances produce roll divergence. A yaw divergent vehicle may produce sufficiently high levels of lateral acceleration to cause roll over.

The yaw response of articulated vehicles can be characterized by lightly damped modes that represent trailer oscillations. These modes may cause the rear unit to produce large yaw oscillations during a lane change or some other transient maneuver. The rear unit may momentarily experience a level of acceleration high enough to produce roll divergent behavior. The general

phenomenon of exaggerated lateral acceleration response of the rear unit is called "rearward amplification".

5.2. Analysis/Simulation Approach

Both analytical and simulation methods can be applied to the vehicle stability problem. Dynamic simulation provides an accurate method of predicting the dynamic behavior of a vehicle for a given set of circumstances, but it does not tell how to vary the parameters of the system to correct a stability problem. Moreover it also does not provide a direct measure of the stability of the vehicle. Analytical methods, such as eigenvalue methods, can show how parameters effect the systems stability. They also show how close a particular vehicle configuration may be to being unstable. However, many simplifications must be made to a vehicle model in order to apply analytical methods. Thus, the results predicted by an analytical approach may only approximate the stability of the actual vehicle system.

In practice, simulation, analysis, and road testing can all be used in concert to solve vehicle dynamics problems. Yaw plane analysis provides course predictions on the onslaught of yaw instability, and predictions on how parameters affect vehicle stability. Spatial vehicle simulations provide finer predictions then yaw plane analysis, but more situations must be evaluated to produce the stability boundary. Finally, road testing provides a means for gaining confidence in the predictions generated from the simulation and the analytical models.

5.3. The Simulation Model

DADS [2,3] was used to model the dynamic behavior of the M1037 vehicle and M101 trailer system. DADS is a general purpose computer program that simulates the dynamic behavior of spatial multibody mechanical systems. It can model the dynamic response of both rigid and flexible systems, and it uses a library of joints and constraints to model the kinematics of the mechanism. The user assembles a dynamic model of vehicle with a language that consists of bodies, joints, constraints, and force elements. This capability minimizes the amount of equation derivation and computer programing the must do to develop a dynamic simulation model. Thus, the dynamics of a complex mechanical system can be modeled in the fraction of the time which would be required if the equations of motion were developed manually.

5.3.1. The Truck Simulation Model

The M1037 vehicle model is documented in a report by Aardema [4], therefore only a brief description of the model will be provided. Figure 5.3.1-1 shows the M1037 system and Table 5.3.1-1 provides a summary of significant parameters and overall dimensions used in the

simulation model. The standard DADS rigid body and joint constraint elements that were used to model the kinematic and dynamic structure of the vehicle are shown in Table 5.3.1-2. A schematic representation for the vehicle that shows how the rigid body elements in the simulation model are interconnected is provided in Figure 5.3.1-2. Figures 5.3.1-3 through 5.3.1-11 show top and side views of the HMMWV vehicle front and rear suspensions.

Table 5.3.1-1 Vehicle parameters used for the vehicle and trailer simulation.

Description	Value
Truck Weight	8800 lb
Truck Roll Inertia	13320 in-lb-s ²
Truck Pitch Inertia	52680 in-lb-s ²
Truck Yaw Inertia	56280 in-lb-s ²
Truck center of gravity height	50.0 in
Distance between truck CG and front wheels	83.8 in
Distance between truck CG and rear wheels	46.2 in
Distance from truck rear axle to trailer hitch	37.5 in
Wheel base of truck	130.0 in

Table 5.3.1-2 Element types used in M1037 simulation model.

Vehicle Component	Element Type Used in Model
Chassis	Rigid body
Upper & lower control arms	Rigid body
Pitman Arm	Rigid body
Wheel hub	Rigid body
Upper & lower ball joints	Spherical joint
Steer Link, and tie rods	Spherical - spherical joint
Rear rad arms	Spherical - spherical joint
Chassis/control arm connection	Revolute Joint
Springs, shocks	Translational spring damper actuator
Tire	Specially developed software
Driver model	Specially developed software
Power train	Specially developed software

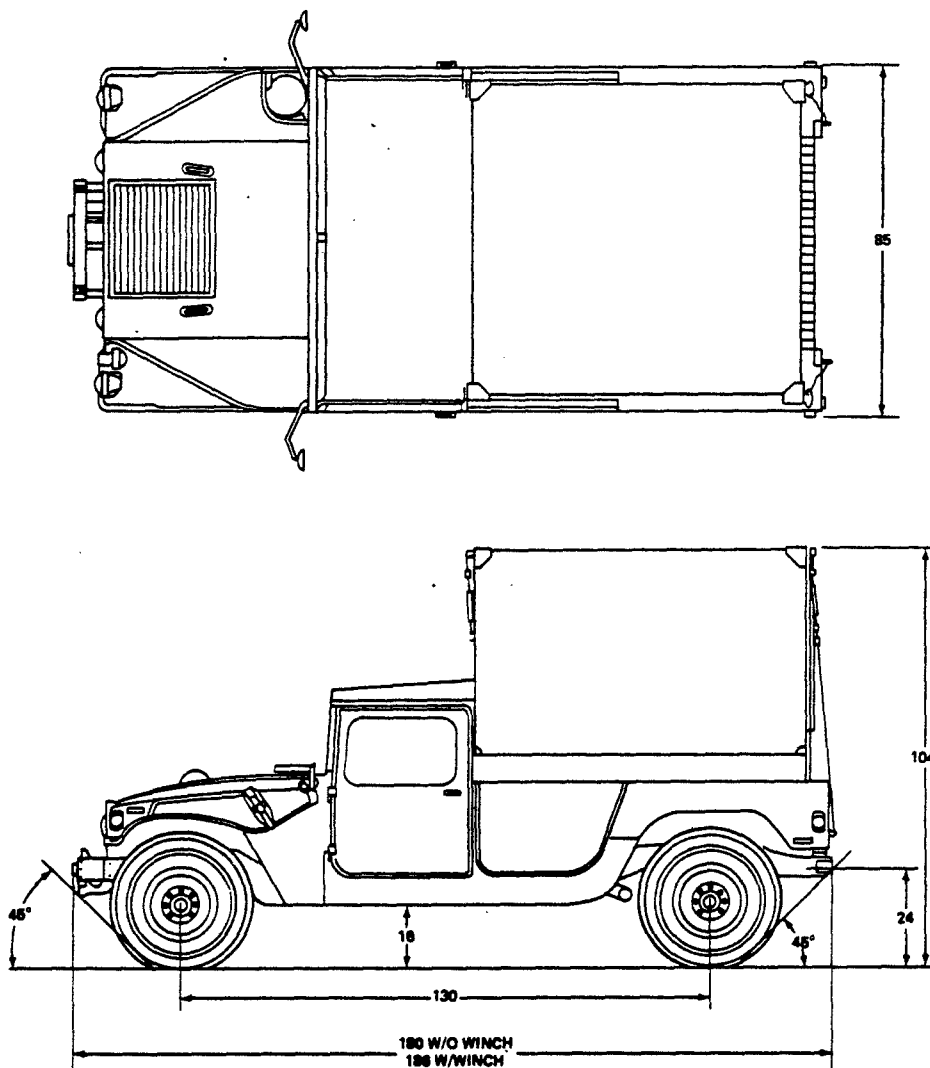


Figure 5.3.1-1 The M1037 truck.

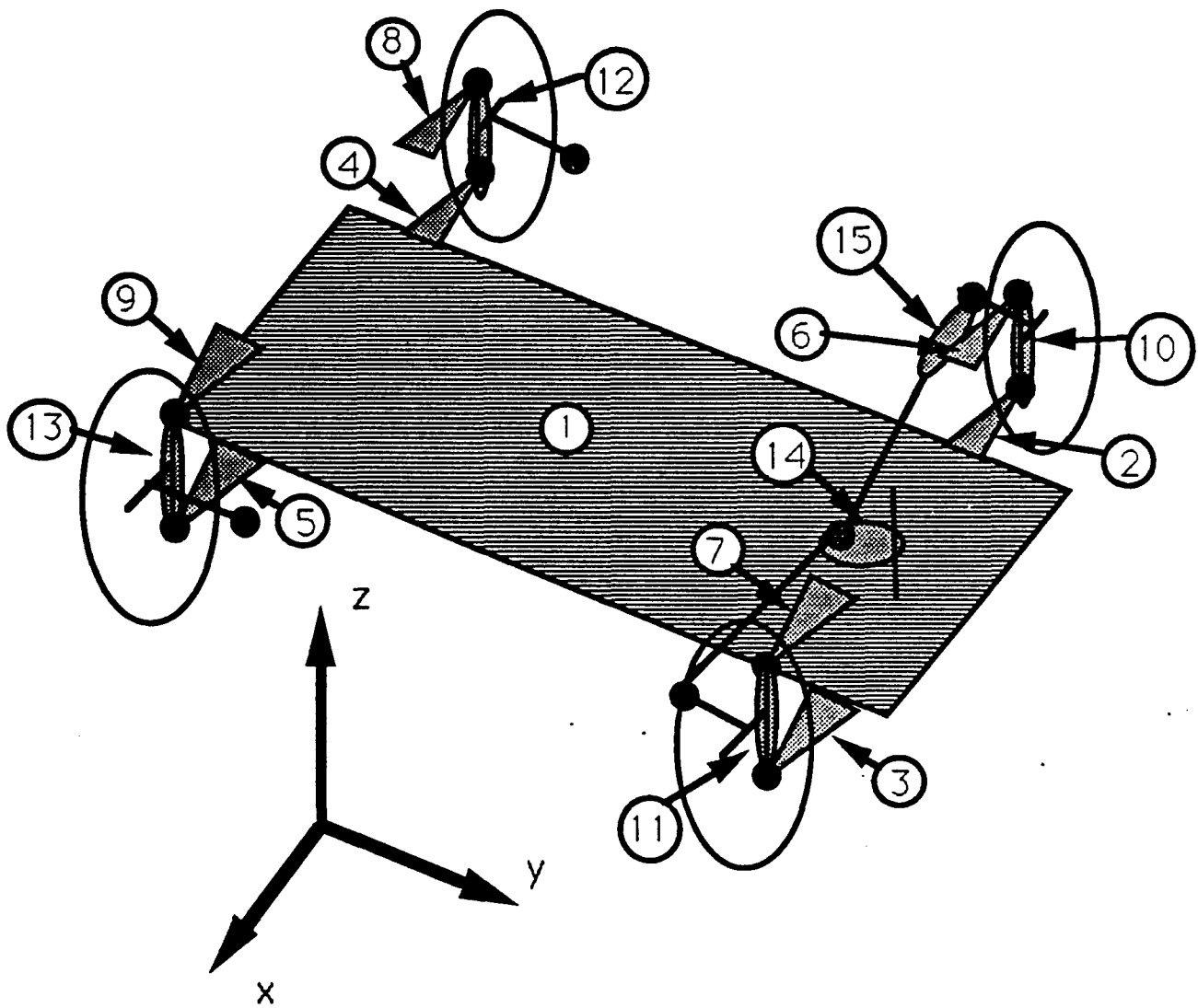


Figure 5.3.1-2 Schematic representation for the M1037 truck.

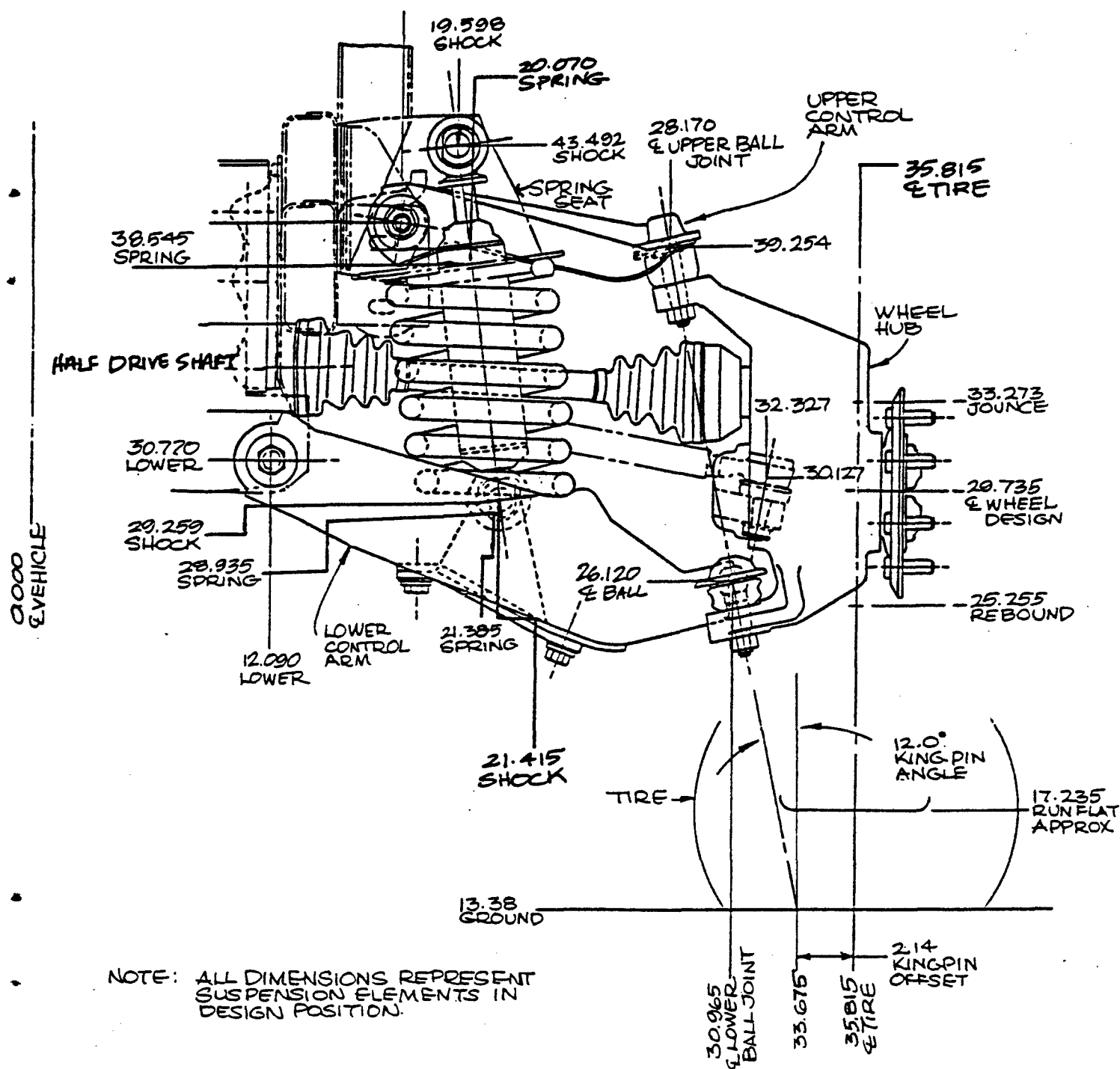


Figure 5.3.1-3 The M1037 front left suspension, front view.

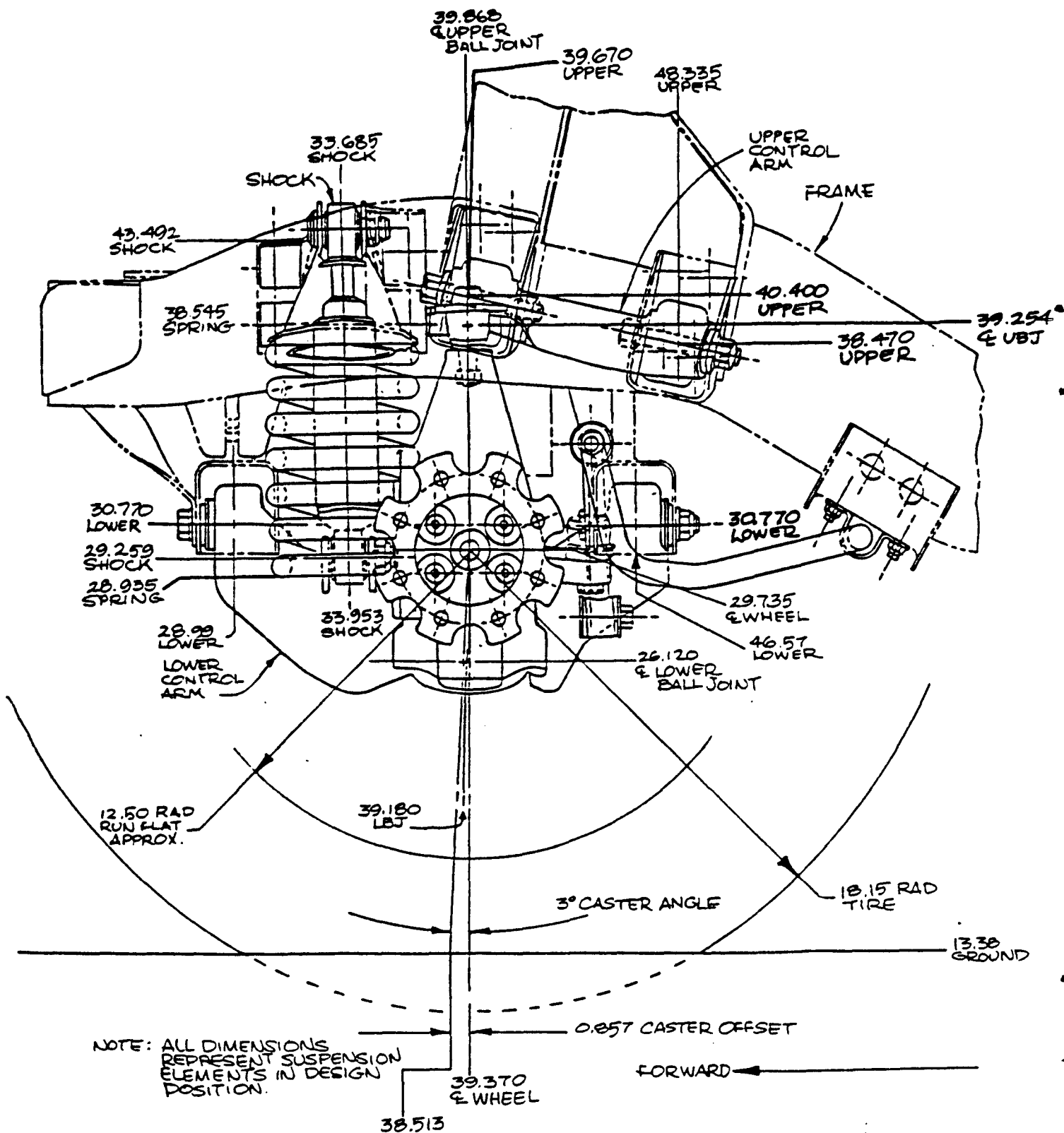


Figure 5.3.1-4 The M1037 front left suspension, left side view.

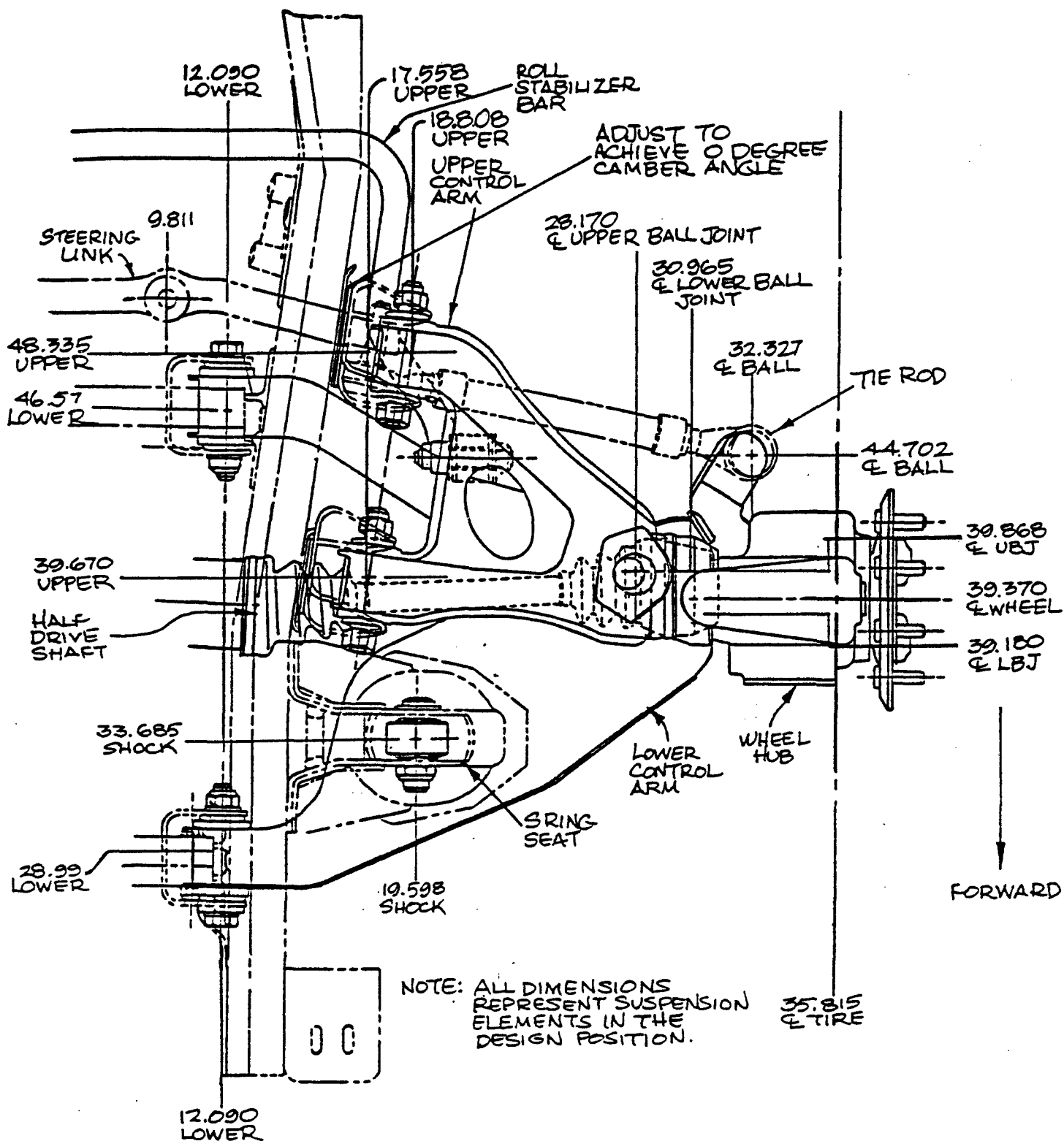


Figure 5.3.1-5 The M1037 front left suspension, top view.

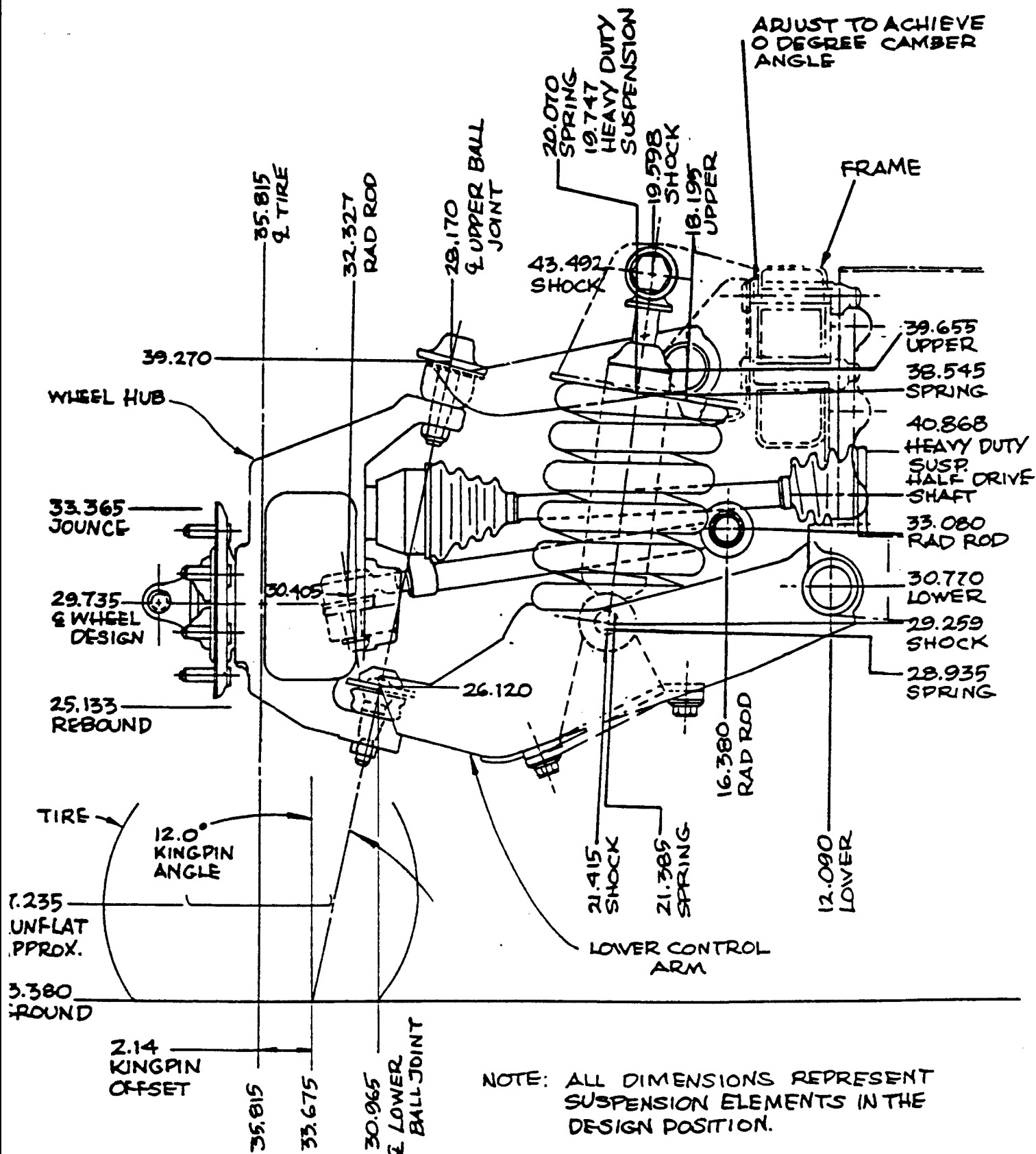


Figure 5.3.1-6 The M1037 rear left suspension, rear view.

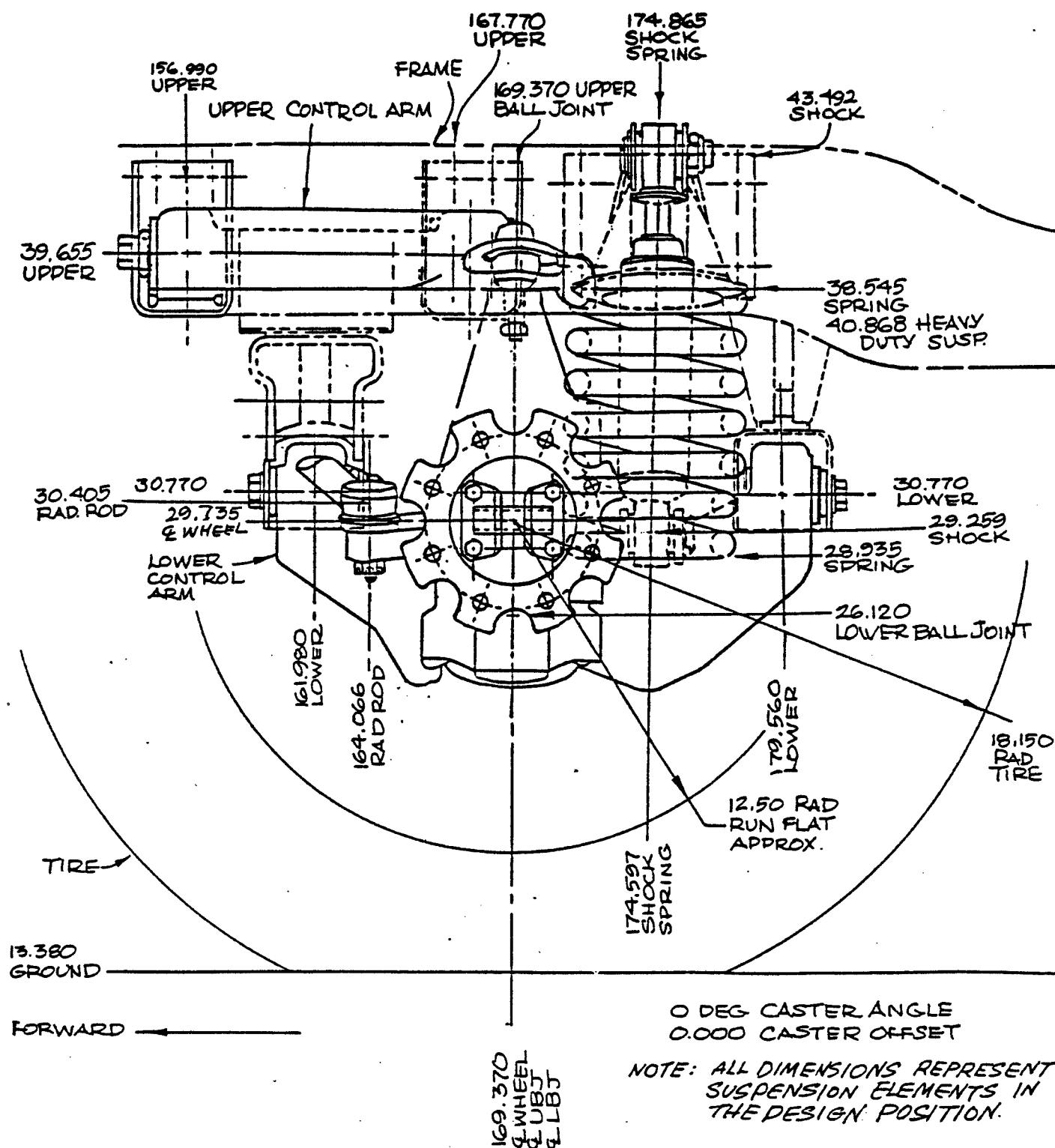


Figure 5.3.1-7 The M1037 front left suspension, left side view

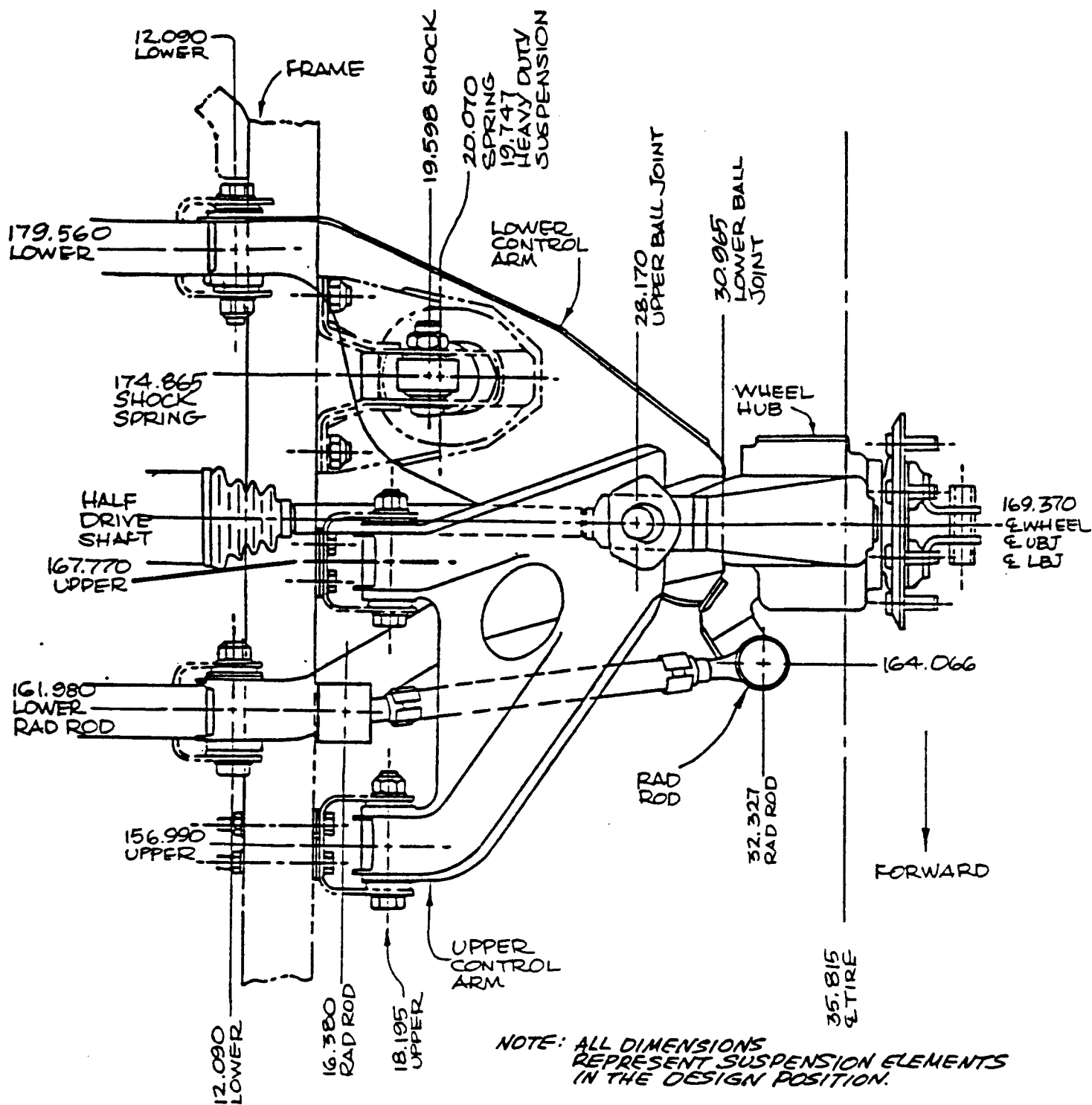


Figure 5.3.1-8 The M1037 rear left suspension, top view

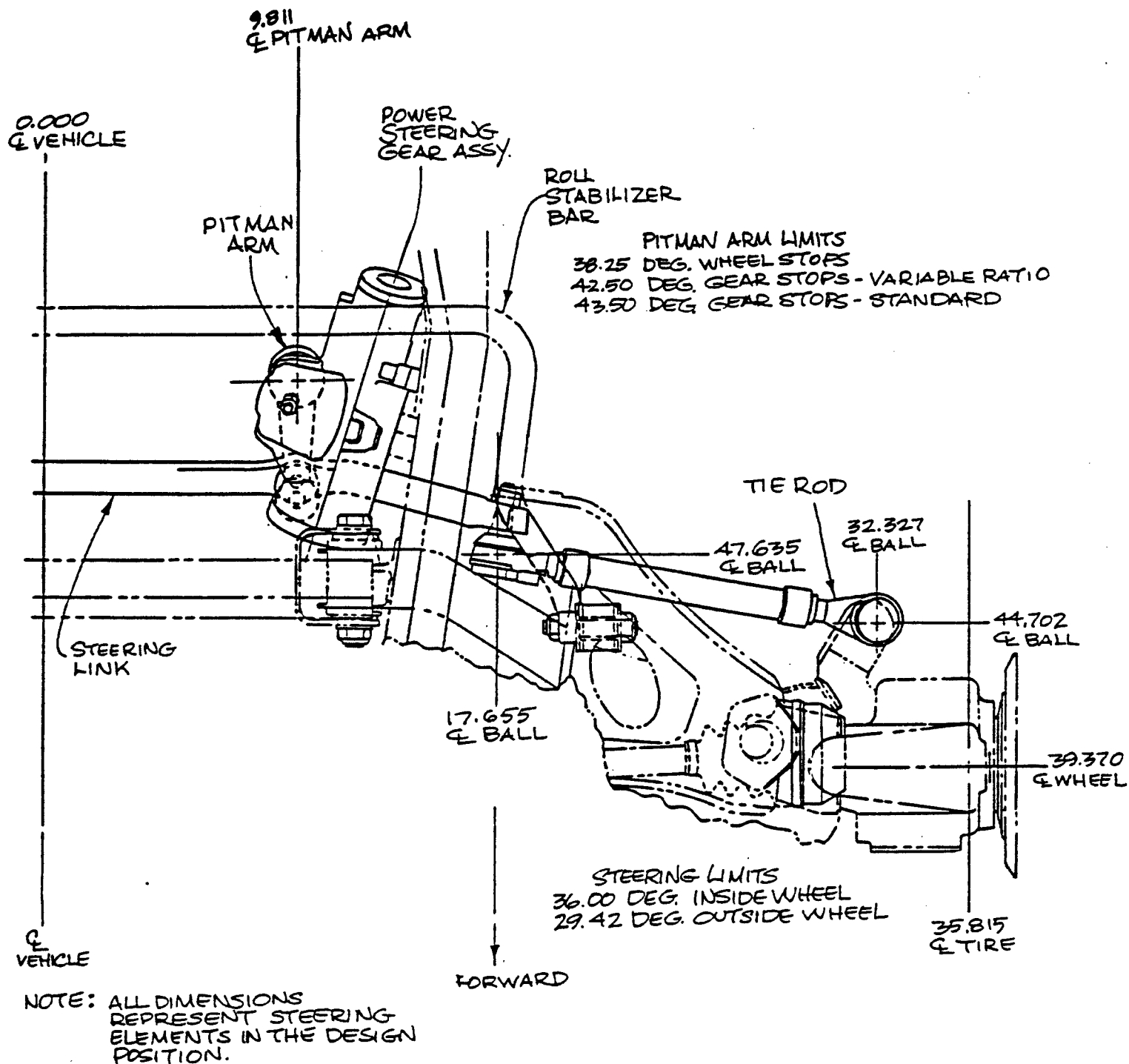


Figure 5.3.1-9 The M1037 steering left side, top view

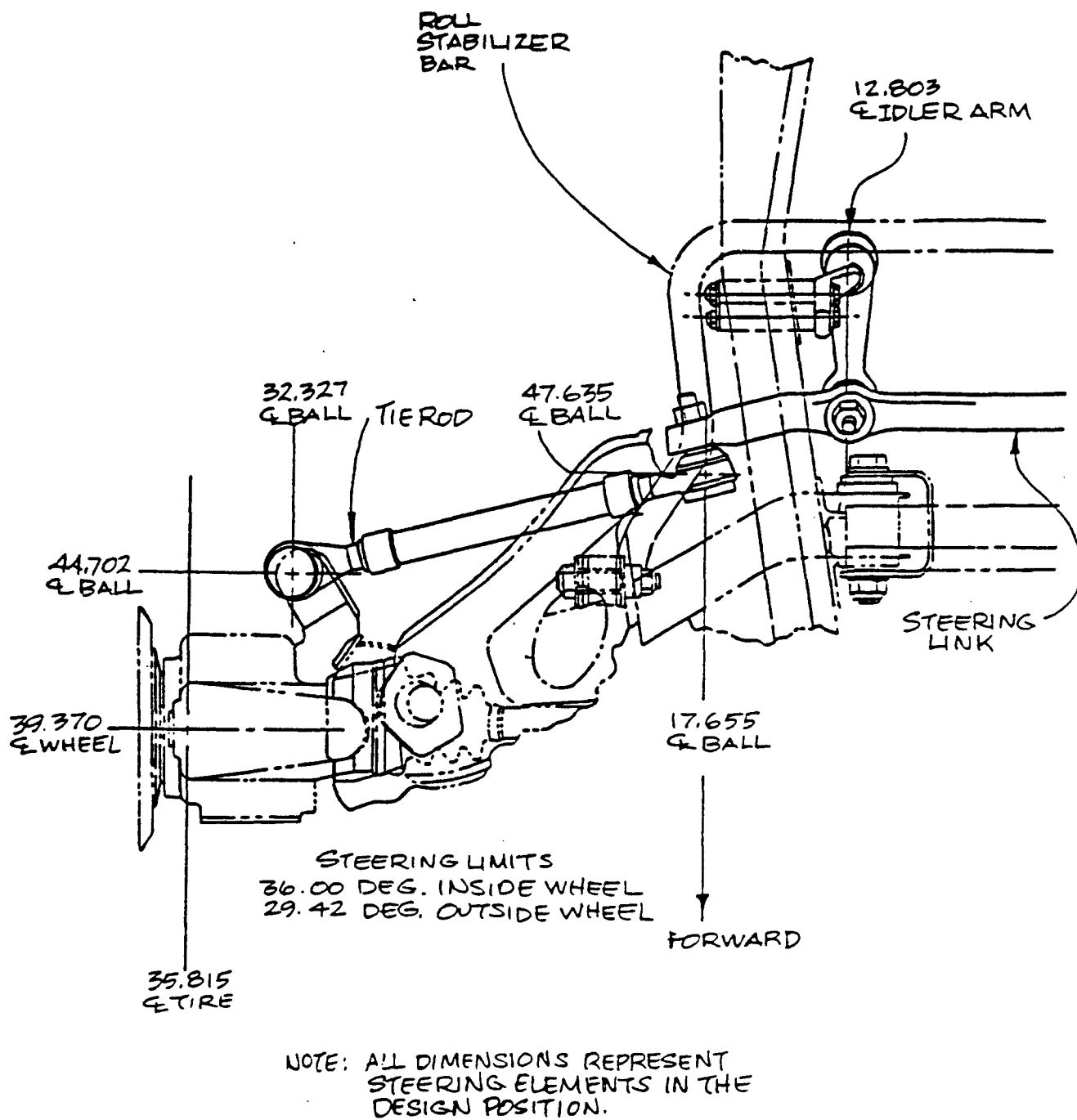
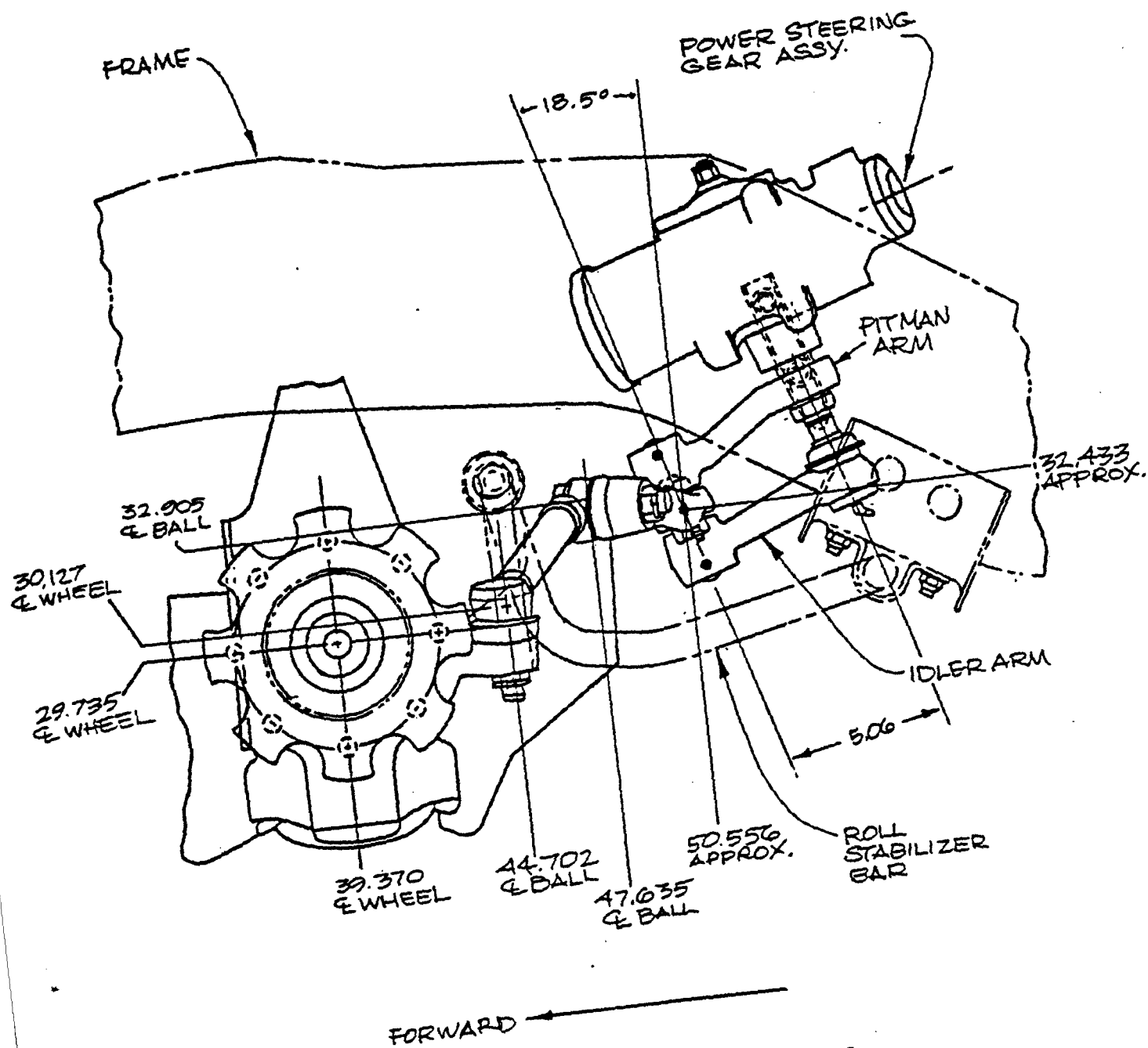


Figure 5.3.1-10 The M1037 steering right side, top view

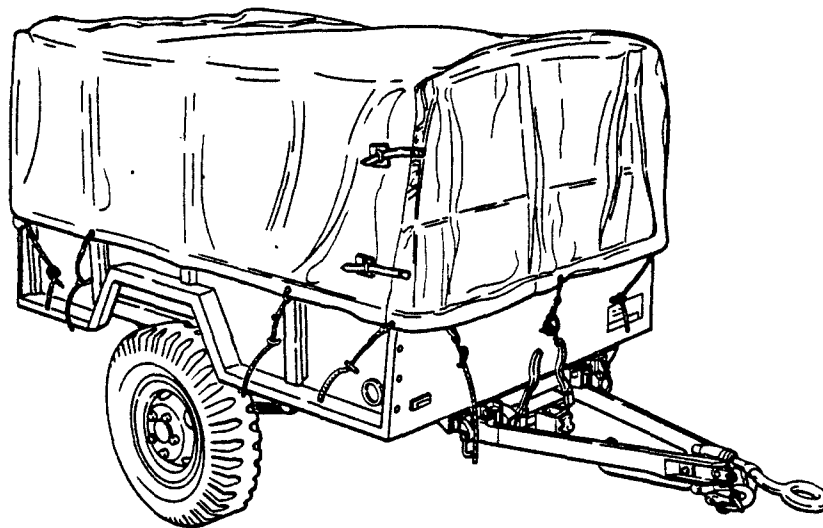


NOTE: ALL DIMENSIONS REPRESENT ELEMENTS IN THE DESIGN POSITION.

Figure 5.3.1-11 The M1037 steering, left side view

5.3.2. Trailer Simulation Model

Figure 5.3.2-1 shows the M101 trailer, and Table 5.3.2-1 shows pertinent dynamic and dimensional parameters used in the trailer simulation model. Table 5.3.2-2 shows simulation elements used to model the trailer components and Figure 5.3.2-2 shows a schematic of the connectivity of the rigid bodies.



NOTE:
ALL DIMENSIONS ARE IN INCHES.

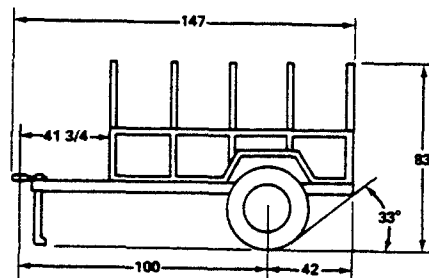
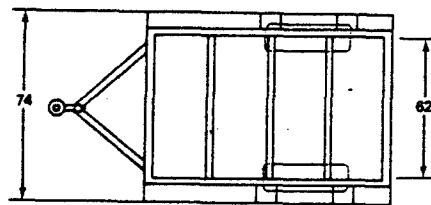


Figure 5.3.2-1 The M101 trailer.

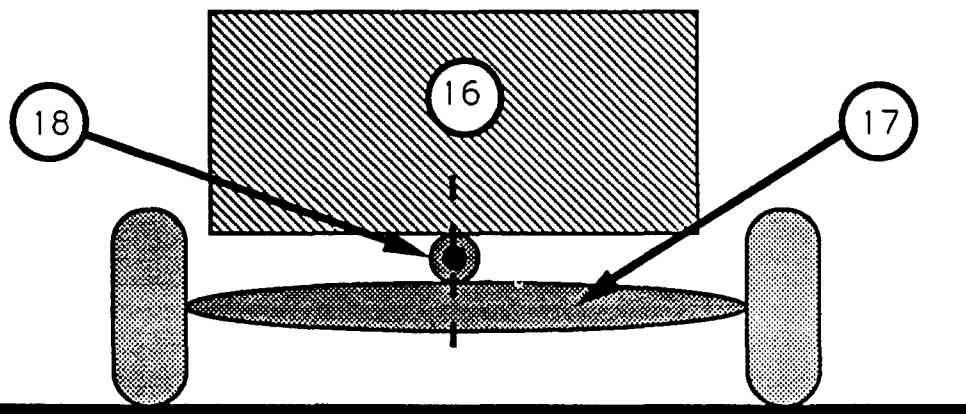


Figure 5.3.2-2 Schematic representation of the M101 trailer.

Table 5.3.2-1 Vehicle parameters used for the M101 simulation model.

Description	Value
Trailer Weight (GVW)	3160 lb
Trailer Roll Inertia	2600 in-lb-s ²
Trailer Pitch Inertia	10000 in-lb-s ²
Trailer Yaw Inertia	10000 in-lb-s ²
Trailer center of gravity height	41.2 in
Distance from trailer CG to hitch	95.65 in
Distance from trailer CG to axle	3.35 in
Distance from trailer CG to hitch	99.0 in
Trailer hitch load	176 lbf

Table 5.3.2-2 Element types used in the trailer simulation model.

Vehicle Component	Element Type Used in Model
Chassis	Rigid body
Axle	Rigid body
Suspension	Rigid body, trans and rev joints
Auxiliary roll stiffness	Rotary spring, damper actuator (RSDA)
Trailer hitch	Spherical joint
Tires	Specially developed software

Figures 5.3.2-3 and 5.3.2-4 show respectively, the damping and load characteristics used in the simulation model. The leaf spring is assumed to have constant spring rate deflections between the jounce and rebound stops. For penetration of the jounce and rebound stops, the effective spring rate is increased by a factor of 10. When the trailer rotates relative to the axle it twists the leaf springs producing a moment that resists roll. This phenomenon can be modeled as a moment that is proportional to the relative rotation of the trailer chassis and axle. This moment is applied with equal and opposite signs to the trailer chassis and axle. The constant of proportionality is also known as auxiliary roll stiffness. Since M101 suspension system has not been characterized, the value of trailer auxiliary roll stiffness was not available, so a value of 10% of the vertical spring rate was estimated. This value is typical of small trailer leaf spring suspensions.

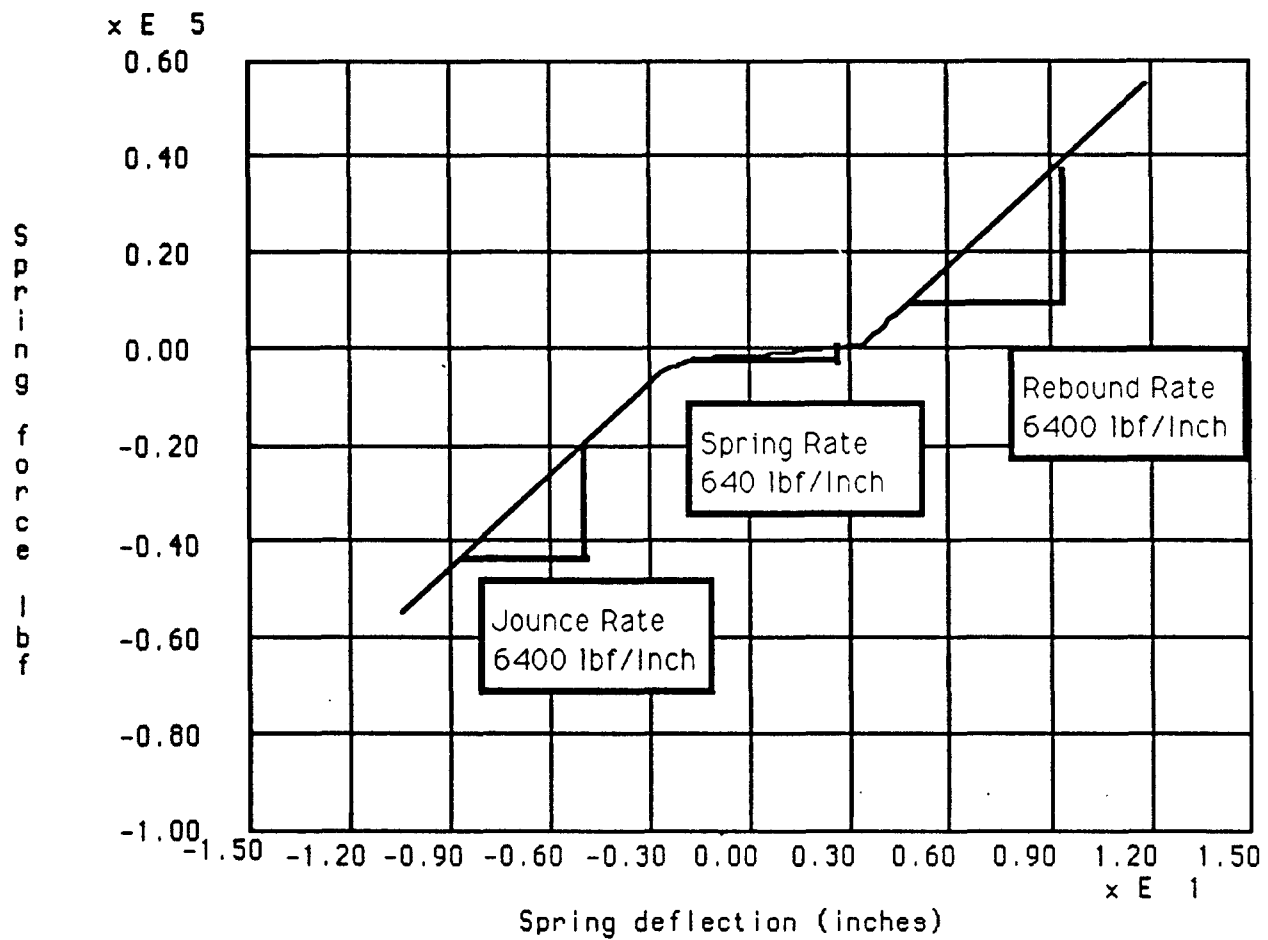


Figure 5.3.2-3 Force deflection characteristics of the M101 trailer leaf spring.

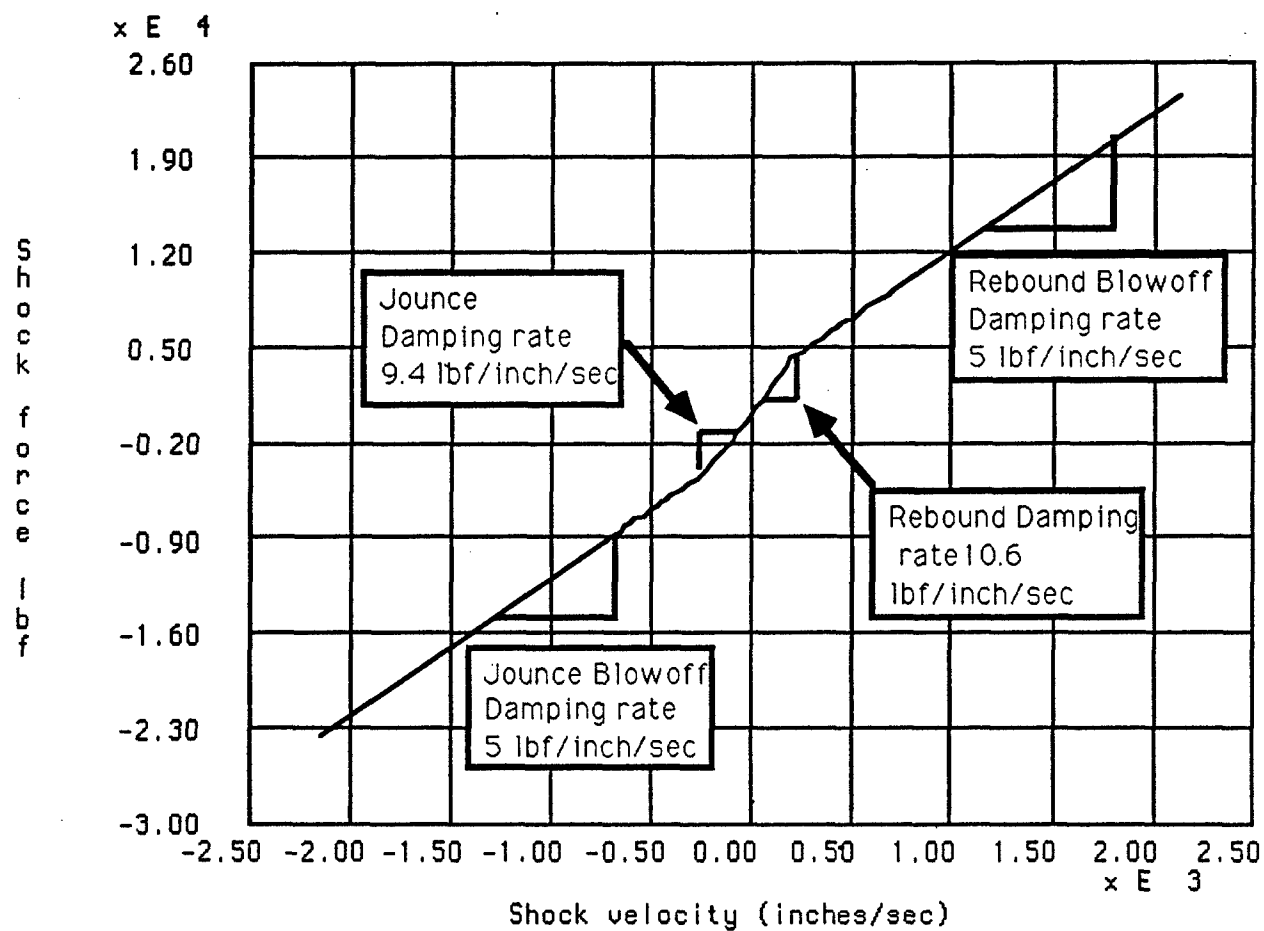


Figure 5.3.2-4 Damping characteristics of M101 shocks

5.3.3. The Tire Model

The dynamics of the tire during vehicle on road operation is represented by a semi-empirical model, primarily based upon work performed by Bergman [5], Dugoff, et. al. [6]. The block diagram in Figure 5.3.3-1 indicates the tire model flow of control. The model calculates the lateral and longitudinal slip, vertical tire deflection and drive torque in the FORTRAN subroutine FRC38. The subroutine TIREF calculates the tire lateral, longitudinal, and vertical forces, and aligning moment. The model assumes that the lateral force and aligning moment is a function of both lateral slip and vertical tire load. Tire cambering effects are not considered in the model. A friction circle model limits the tractive forces (lateral and longitudinal) acting upon the tire. The forces and moments are applied to the wheel hub in the manner shown in Figure 5.3.3-2.

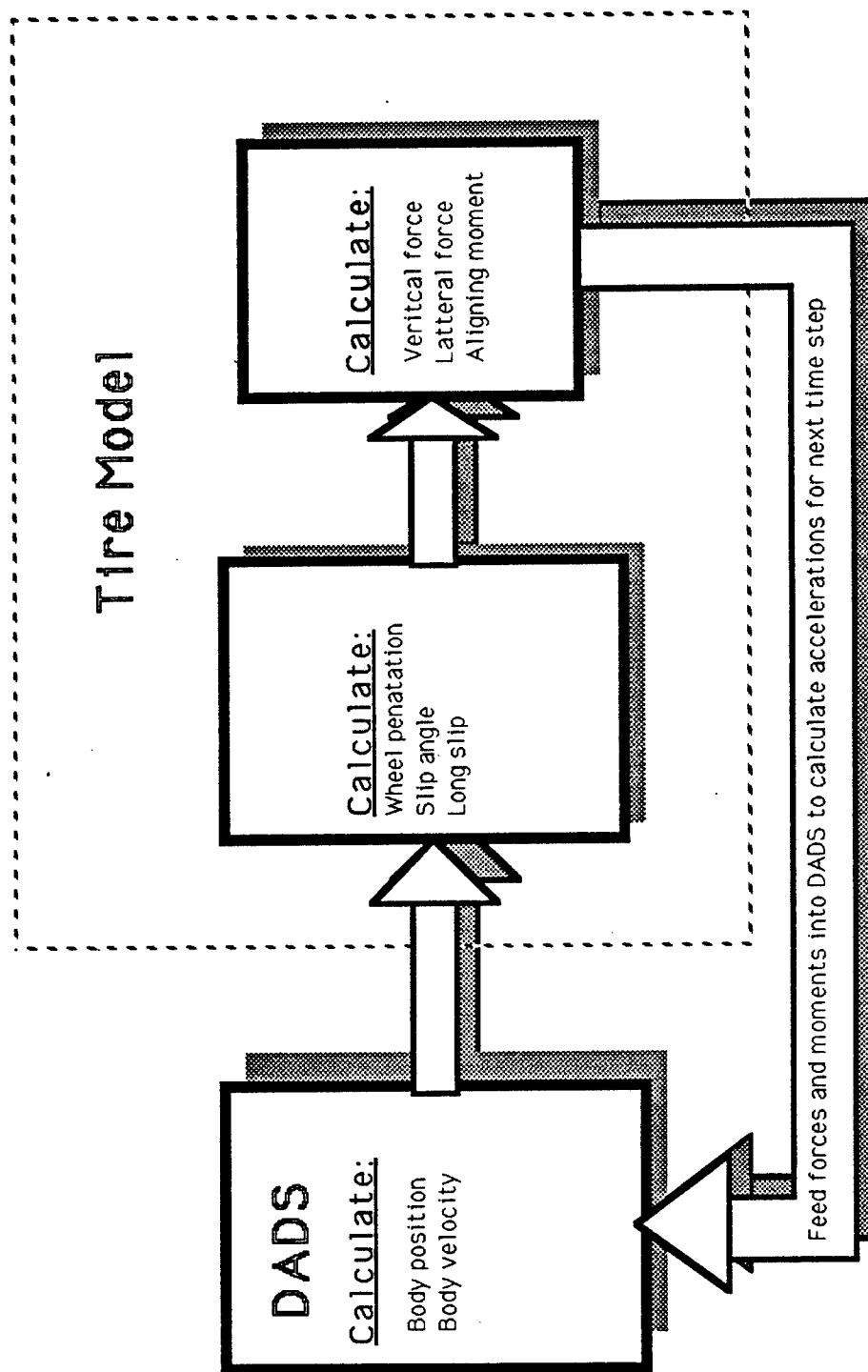


Figure 5.3.3-1 The flow of control for tire model

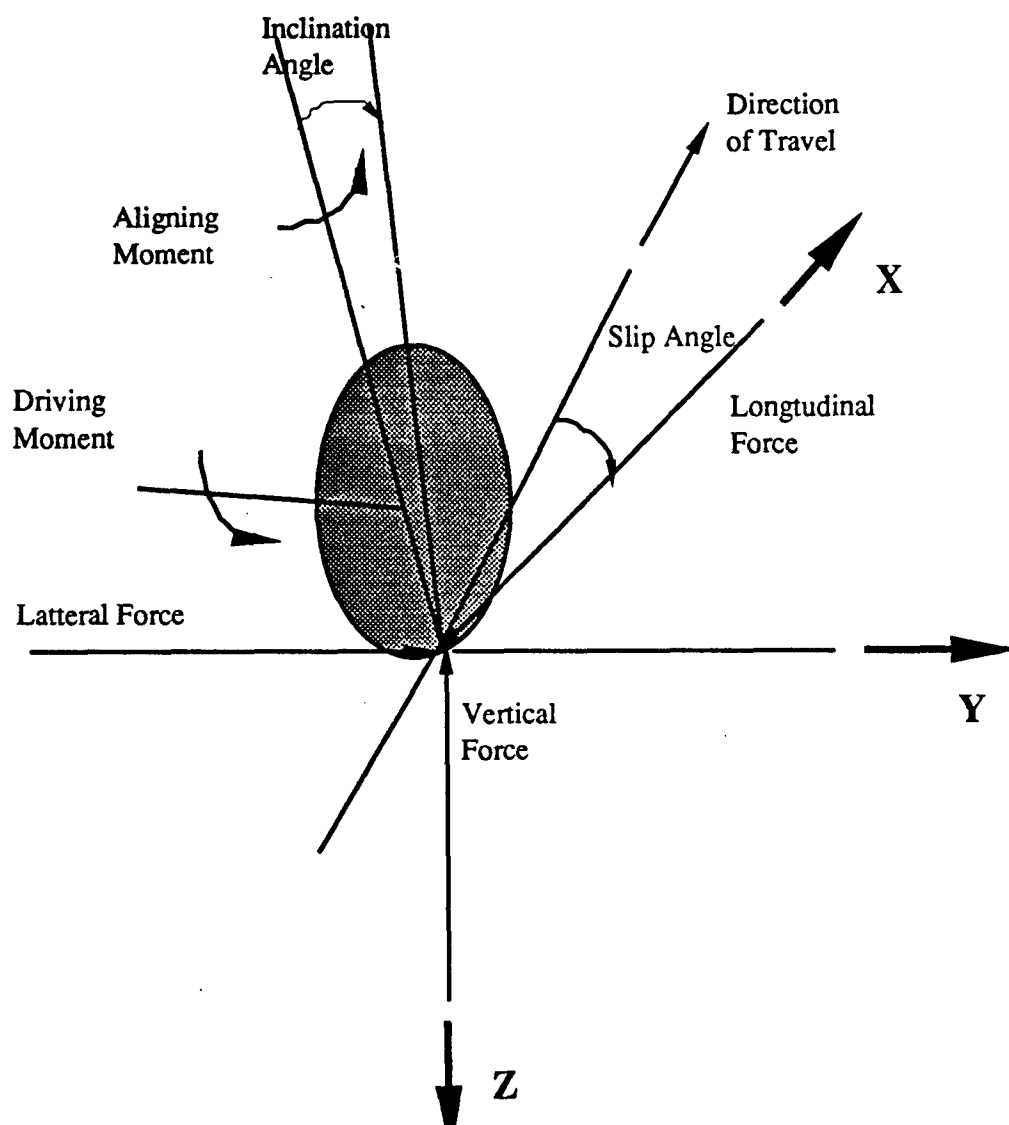


Figure 5.3.3-2 The forces and moments acting upon a tire

The lateral force/slip and aligning moment/slip data for the M1037 vehicle and M101 trailer tires is shown in figures 5.3.3-3 through 5.3.3-6. The 36x12.50-16.5 LT tire used on the HMMWV vehicle was measured by the University of Michigan Transportation Research Institute (UMTRI). These measurements were performed on a flat bed testing machine at tire inflation pressures of 20 psi and 28 psi. Measured test data was not available for the LT235/85R16 tire specified for the M101 trailer. However, tire lateral force/slip and aligning moment slip data for a 8.75R16.5 tire, which is close in configuration to the LT235/85R16 tire was available in reference [7]. Figure 5.3.3-7 shows the longitudinal force data used for both the M1037 vehicle and M101 trailer tires. The data in Figure 5.3.3-7 was generated from descriptions of average tire properties provided in reference [7].

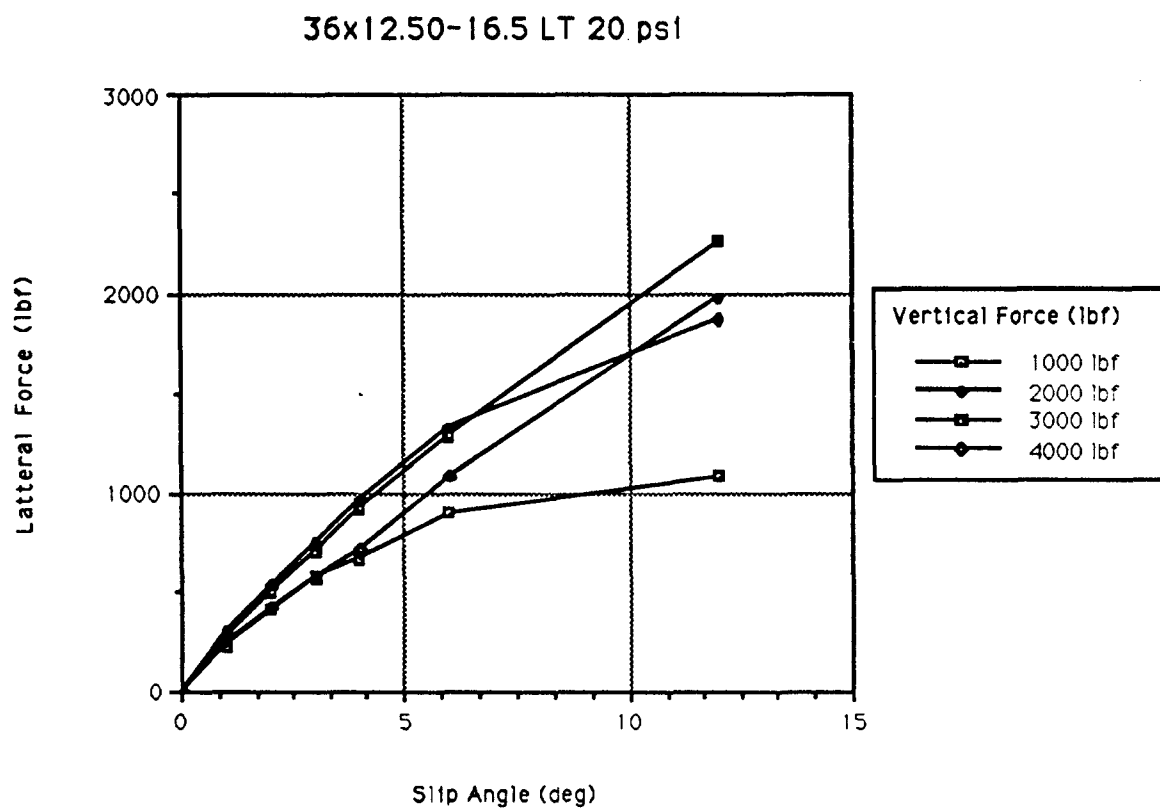


Figure 5.3.3-3 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 20 psi

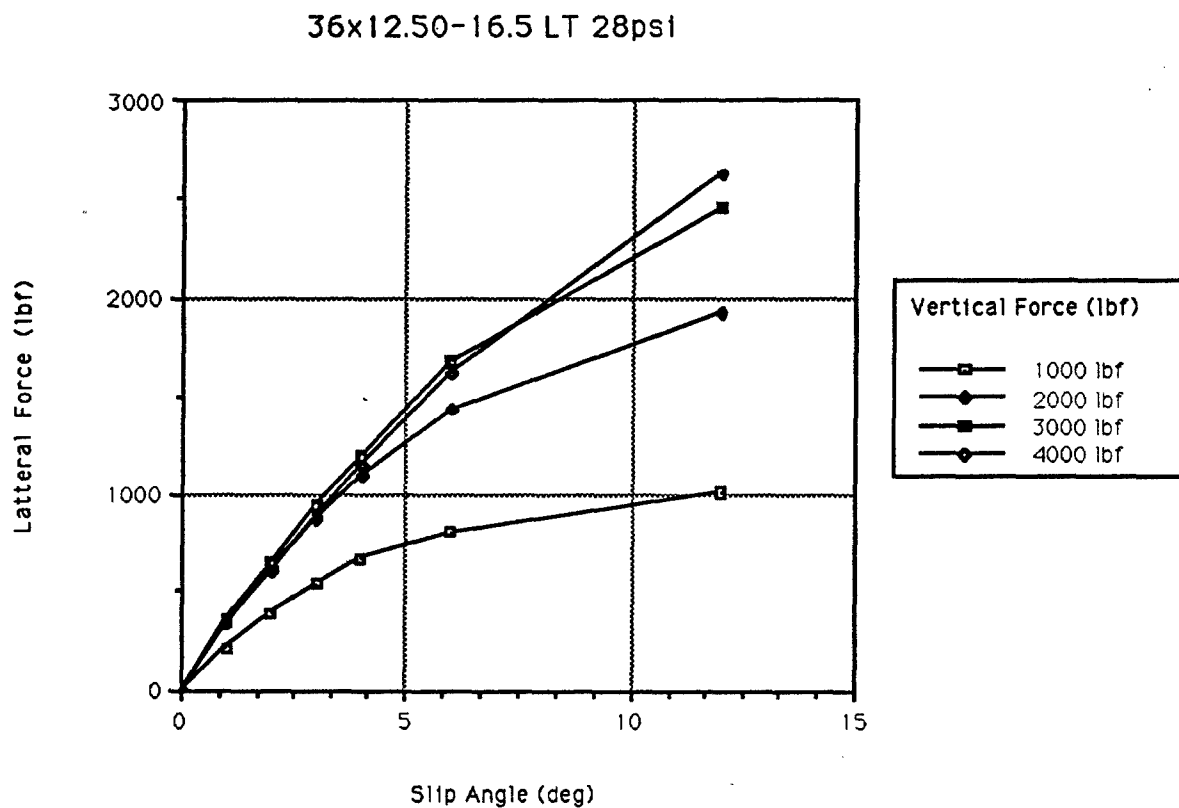


Figure 5.3.3-4 The trailer tire lateral force versus slip data for the 36x12.50-16.5LT tire at 28 psi

8.75R16.5 85PSI GY 85 Psi

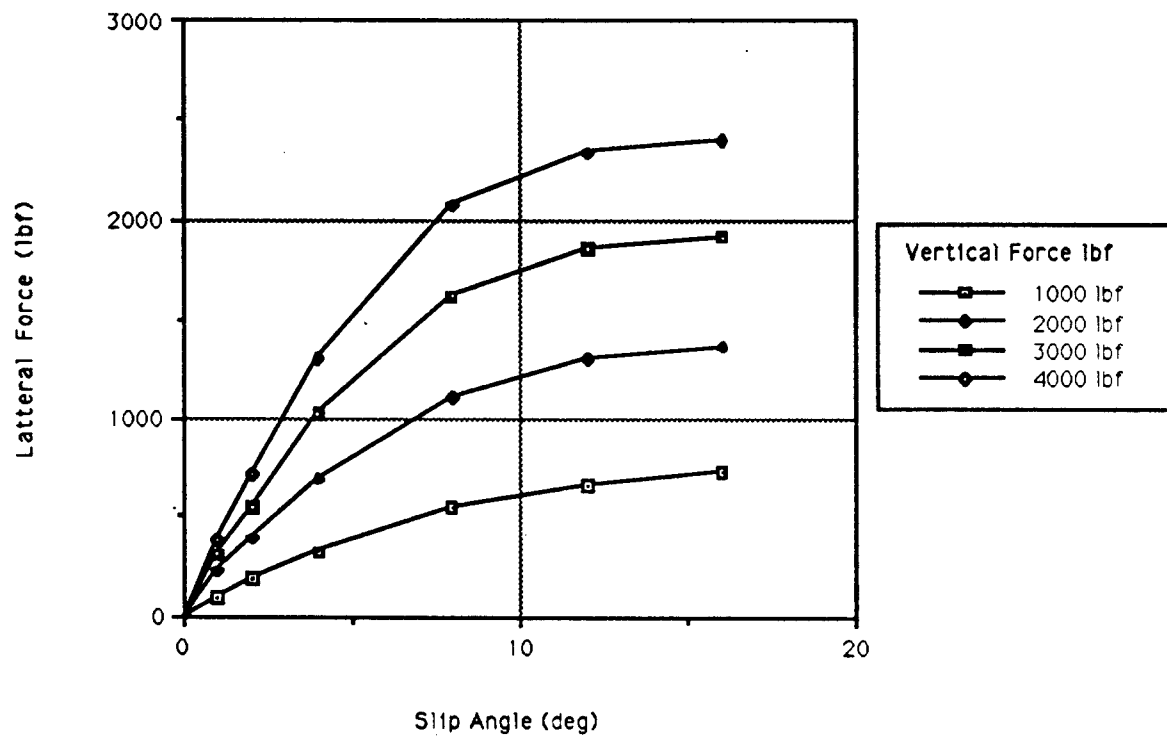


Figure 5.3.3-5 The trailer tire lateral force versus slip data

8.75R16.5 85PSI GY

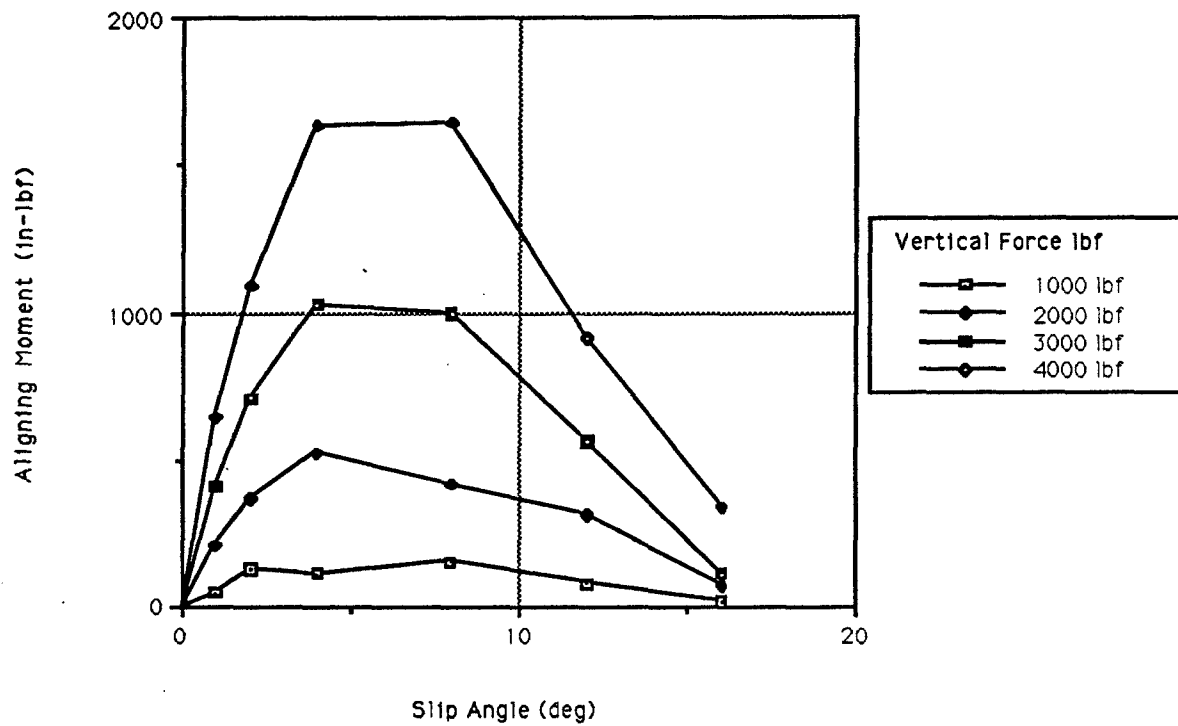


Figure 5.3.3-6 The trailer tire aligning moment versus slip data

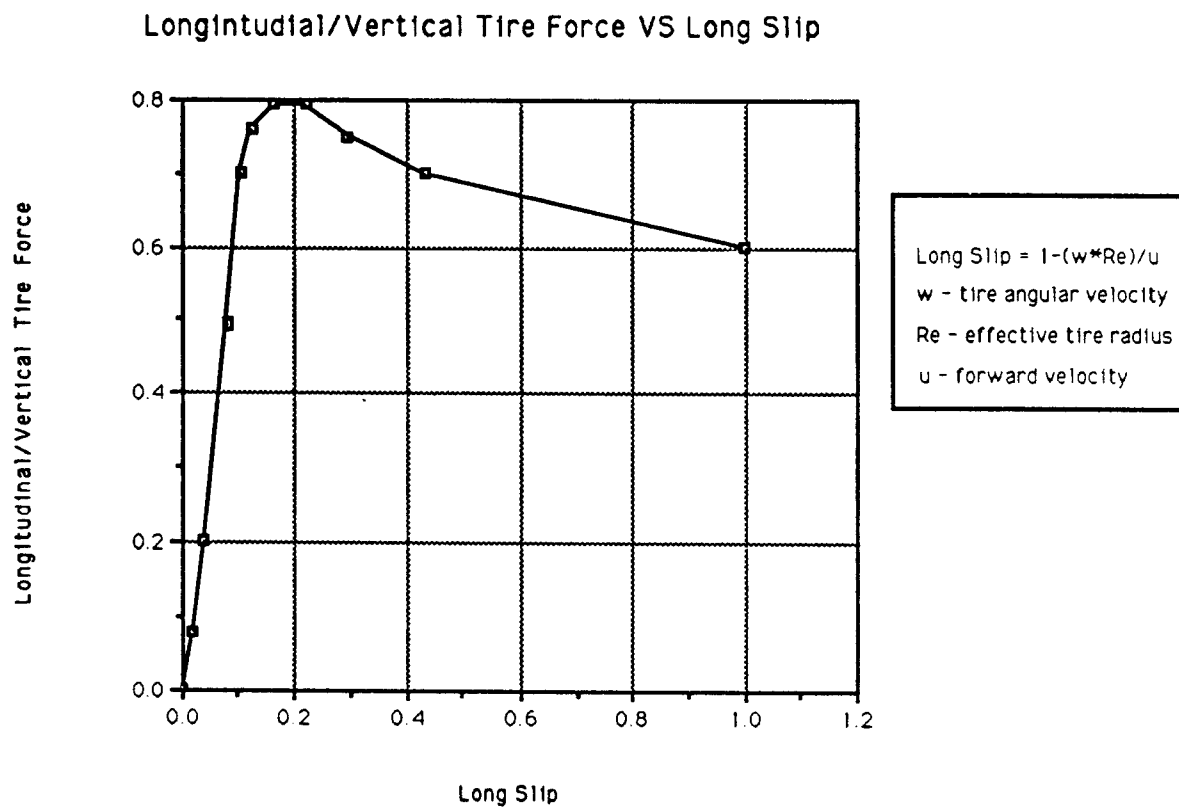


Figure 5.3.3-7 The trailer tire longitudinal/vertical force versus longitudinal slip data.

5.3.4. The Driver Model

Realistic simulation of vehicle systems requires an adequate representation of driver dynamics. A driver during normal driving conditions is required to:

- Navigate the vehicle through a roadway.
- Reject wind and ground disturbances acting upon the vehicle.
- Maintain system stability and compensate for the vehicle's nonlinear behavior and dynamic deficiencies.

The above requirements compare to those of a feedback control system. See Figure 5.3.4-1. The driver and vehicle respectively fulfil the basic requirements of a control and the plant.

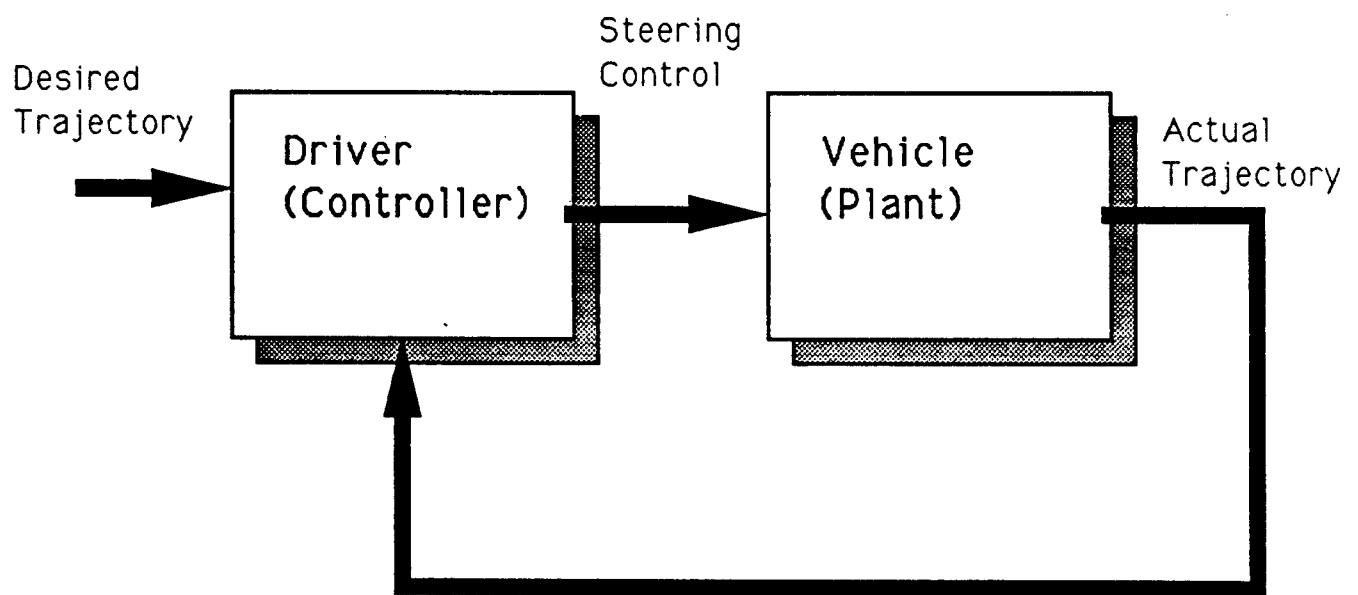


Figure 5.3.4-1 Driver control strategy.

Measurements performed on human drivers over the past 30 years revealed they maintain certain closed loop dynamic properties. First, a human operator will maintain a 20 decibel (dB) per decade slope through the region cross over frequency ω_c . See Figure 5.3.4-2. Furthermore, McRuer [8] has shown the the transport delay of τ seconds represents a good approximation of the dynamic behavior of the driver at frequencies below ω_c . At higher frequencies, neither of the approximations provide adequate representation for the dynamic response of the driver. However, the plant transfer function rolls off in this region enough to have little effect on system response. The bottom line is this: for any model to adequately represent the dynamics of the driver, it must produce a 20 dB per decade drop in closed loop response in the region of the cross over frequency and must approximate a time delay of τ seconds.

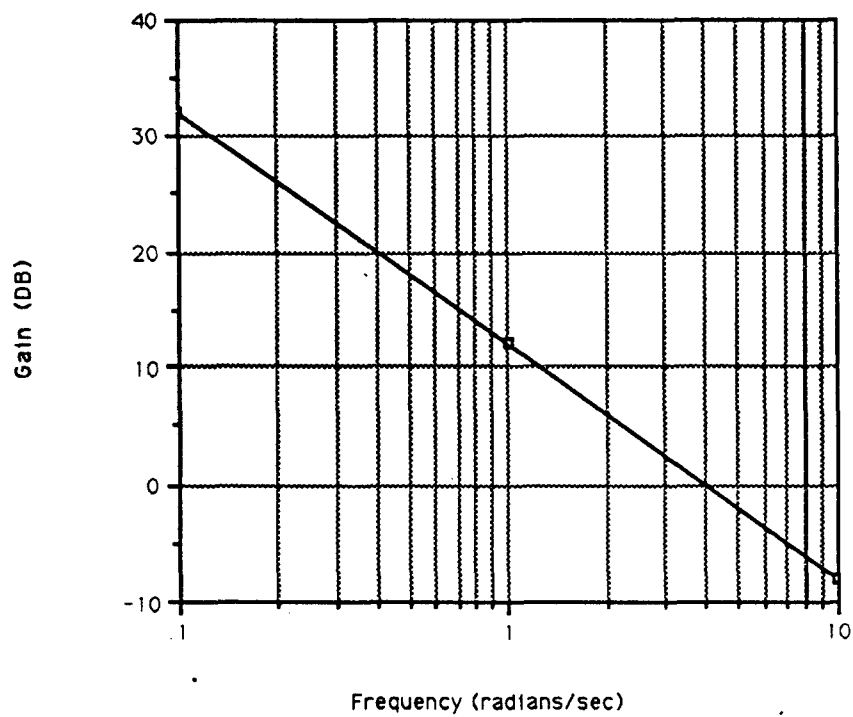


Figure 5.3.4-2 Closed loop frequency response gain (from Ref. 9)

An optimal preview control method, developed by MacAdam [9,10], was adapted for this analysis to model the dynamic behavior of the driver. In this approach, it is assumed that a well trained driver employs a preview control strategy to control the vehicle. See Figure 5.3.4-3. The optimal steering control is determined from minimizing the performance measure

$$J = \frac{1}{T} \int_t^{t+T} \left\{ [f(\eta) - y(\eta)]^2 W(\eta - t) \right\} d\eta \quad (5.3.4-1)$$

and the constraints

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{F} \mathbf{x} + \mathbf{g} u \\ y &= \mathbf{m}^T \mathbf{x} \end{aligned} \quad (5.3.4-2)$$

J in equation (5.3.4-1) represents the mean square preview error, and equation (5.3.4-2) is a linearized representation of the yaw plane vehicle dynamics. The matrix¹ $\mathbf{W}$ is an arbitrary weighting matrix.

¹ In this report, matrices and vectors will be printed in bold type.

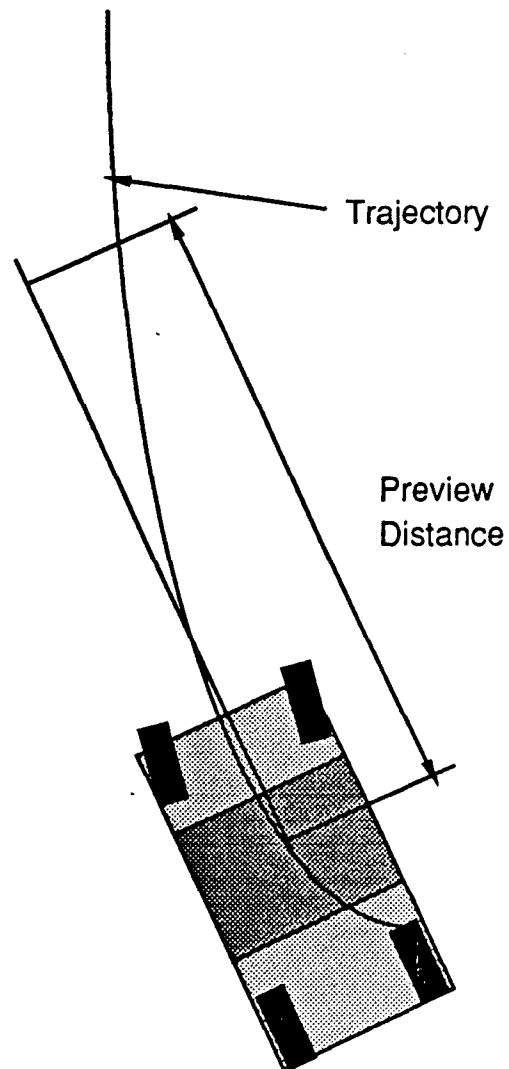


Figure 5.3.4-3 Preview control strategy

For the special case where $W(\eta - t) = \delta(T^*)$, the Dirac delta function, the optimal control was derived in [9] to be

$$u^*(t) = u(t) + \frac{\varepsilon(t + T^*)}{T^* K} \quad (5.3.4-3)$$

where

$$K = m^T \left[I + \sum_{n=1}^{\infty} \frac{F^n(T^*)^n}{(n+1)!} \right] g$$

and $u(t)$ is the current system input and $\varepsilon()$ is the preview output error, defined as:

$$\varepsilon(\eta) = f(\eta) - m^T \Phi(\eta, t) x(t) - u(t) A(\eta) \quad (5.3.4-4)$$

where Φ is the state transition matrix for equation 2.2

$$\Phi(\eta, t) = I + \sum_{n=1}^{\infty} \frac{F^n(\eta - t)^n}{n!}$$

and

$$A(\eta) = (\eta - t) m^T \left[I + \sum_{n=1}^{\infty} \frac{F^n(\eta - t)^n}{(n+1)!} \right] g$$

The block diagram in Figure 5.4.3-2 shows the control strategy for the single point feedback steering control system.

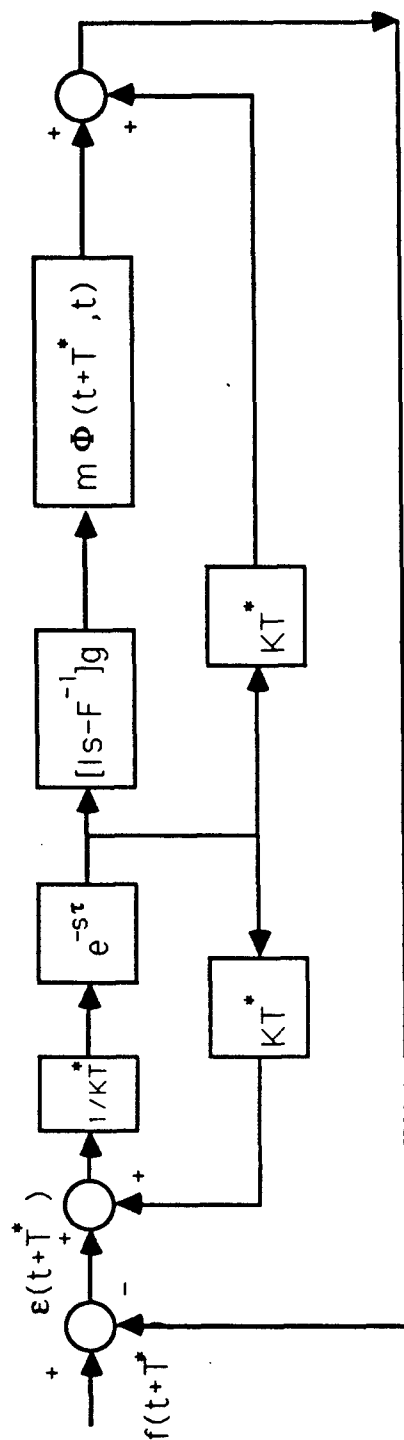


Figure 5.3.4-2 Single point preview control block diagram.

The feedback control gain matrix c^T is given by

$$c^T = F - \left\{ g m^T \left[I + \sum_{n=1}^{\infty} \frac{F^n (\eta)^n}{(n+1)!} \right] \right\} / (T^* K) \quad (5.3.4-5)$$

The state space representation for the feedback control system including the driver transport lag τ , is given by

$$\begin{aligned} \dot{x} &= F x + g u^0(t - \tau) \\ u^0 &= -c^T x \end{aligned} \quad (5.3.4-6)$$

If the driver transport lag is approximated by a first order Padé polynomial

$$\frac{1 - \frac{\tau}{2}s}{1 + \frac{\tau}{2}s}$$

then the closed loop state equations become,

$$\begin{Bmatrix} \dot{x} \\ \dot{u} \end{Bmatrix} = \begin{bmatrix} F & g \\ c^T \left(F - \frac{2}{\tau} I \right) & c^T g - \frac{2}{\tau} \end{bmatrix} \begin{Bmatrix} x \\ u \end{Bmatrix} \quad (5.3.4-7)$$

Thus, the system is stable if all the eigenvalues of the matrix in equation (5.4.3-7) lie in the left hand plane.

MacAdam [7] has shown that the driver controller strategy described above has the two closed loop dynamic properties described in the start of this section. The closed loop response of the vehicle has a 20 db per decade slope through the cross over frequency, and a time delay of τ seconds.

Two parameters in the driver model, the time delay τ , and preview time T have a significant effect on the dynamic response of the system. When the value of τ is increased the system becomes more oscillatory, or less stable. When the value of T is increased the system has a more damped response. These parameters actually characterize the performance of the driver. A skillful driver will have a small value of τ while an impaired driver will have a large value of τ . Typical ranges of values for τ and T for well trained drivers are respectively 0.1-0.3, and 1.0 - 2.0 .

5.3.5. Implementation of the Driver Model

The block diagram in Figure 5.3.5-1 shows the driver model is interfaced to the DADS program. Steering of the vehicle is accomplished with a constraint element between the pitman arm and chassis rigid bodies. The constraint element controls the rotation of the pitman arm. The FORTRAN subroutine USER49 provides the means of interfacing the driver model software to the DADS code. USER49 has access to the position and velocity of each rigid body in the simulation model. USER49 can control the pitman arm rotation by feeding the rotation and its first and second derivative into the constraint element.

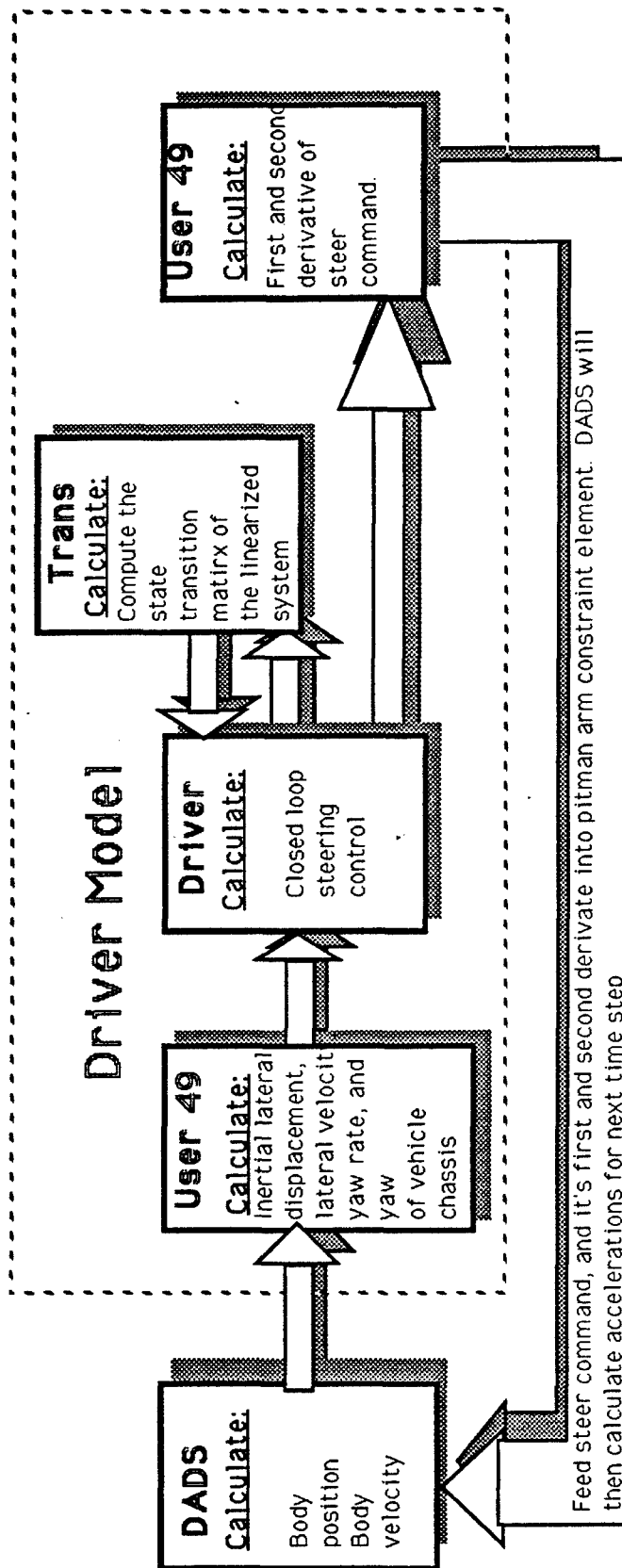


Figure 5.3.5-1 Driver model implementation

The driver model uses the subroutine DRIVGO to initialize it, and the subroutine DRIVER to calculate the closed loop steer command. After each successful integration step the DADS program has the position, orientation, and velocity of each body in the simulation. See Figure 5.3.5-1. USER49 calculates the global lateral position, velocity, yaw angle, yaw rate of the chassis and then calls subroutine DRIVER. If the current integration time is not at the start of a preview interval, then DRIVER will use equations 5.3.4-3 and 5.3.4-4 to calculate the control that will minimize the preview error performance measure defined in equation 5.3.4-1. If the current integration time step is at the start of the preview interval, DRIVER will also call subroutine TRANS to calculate and store away the state transition matrix of linearized vehicle model and its integral. The current vehicle tire cornering stiffnesses are provided to TRANS from the subroutine TIREF through a common block. DRIVER provides USER49 with the steer command for the current integration time. Two second order low pass filters estimate the steering commands first and the second derivative before they are provided to the DADS code.

5.4. Validation of Simulation Model

Validation tests for the simulation model were conducted in June and July 1988 at the Chrysler Chelsea Proving Grounds (CPG) in Chelsea Michigan, and at UMTRI in Ann Arbor, Michigan. The tests were designed to verify the quality of the output from the simulation, and to determine qualitatively how the vehicle handles in various types of maneuvers. Table 5.4-1 shows how the vehicle and trailer were instrumented to measure a system state variables.

Table 5.4-1 Truck/Trailer measurements.

State variable	Measurement
Vehicle lateral acceleration	Accelerometer near vehicle CG
Vehicle longitudinal acceleration	Accelerometer near vehicle CG
Vehicle yaw rate	Gyro orientated along vertical axis
Vehicle roll	Tilt angle of stabilized platform
Steer angle	Potentiometer on steering wheel
Front wheel steer front	Linear potentiometers between chassis and wheels
Vehicle speed	Fifth wheel and tachometer
Brake system pressure	Pressure transducer
Trailer lateral acceleration	Accelerometer near trailer CG
Articulation angle	String potentiometer between trailer and truck chassis
Trailer axle vertical position/roll angle	Two linear potentiometers placed +/- 18 inches from trailer center line between trailer axle and chassis

For safety reasons, the tests were conducted with the vehicle loaded to GVW of 7,500 lb rather than the normal 8,800 lb weight GVW. The difference in vehicle weight should pose no problem. The simulation model is still valid for a range of vehicle weights and CG locations. The trailer was loaded to a GVW of 3,160 lbs, with a center of gravity height of 41 inches. This configuration duplicates a generator payload, the trailer load most likely to roll over.

The vehicle and trailer was driven through a 100 by 12 ft lane change, 500 ft constant radius turn, and bump maneuvers. Vehicle braking during straight line and steady turn maneuvers was also conducted. Figures 5.4-1 and 5.4-2 show, respectively, the lane change course layout and the bump course cross section. The 100 by 12 lane change and 500 ft constant radius turn maneuvers are good measures of the on road stability of the vehicle, while the bump course provides an indication of the vehicle's off road stability.

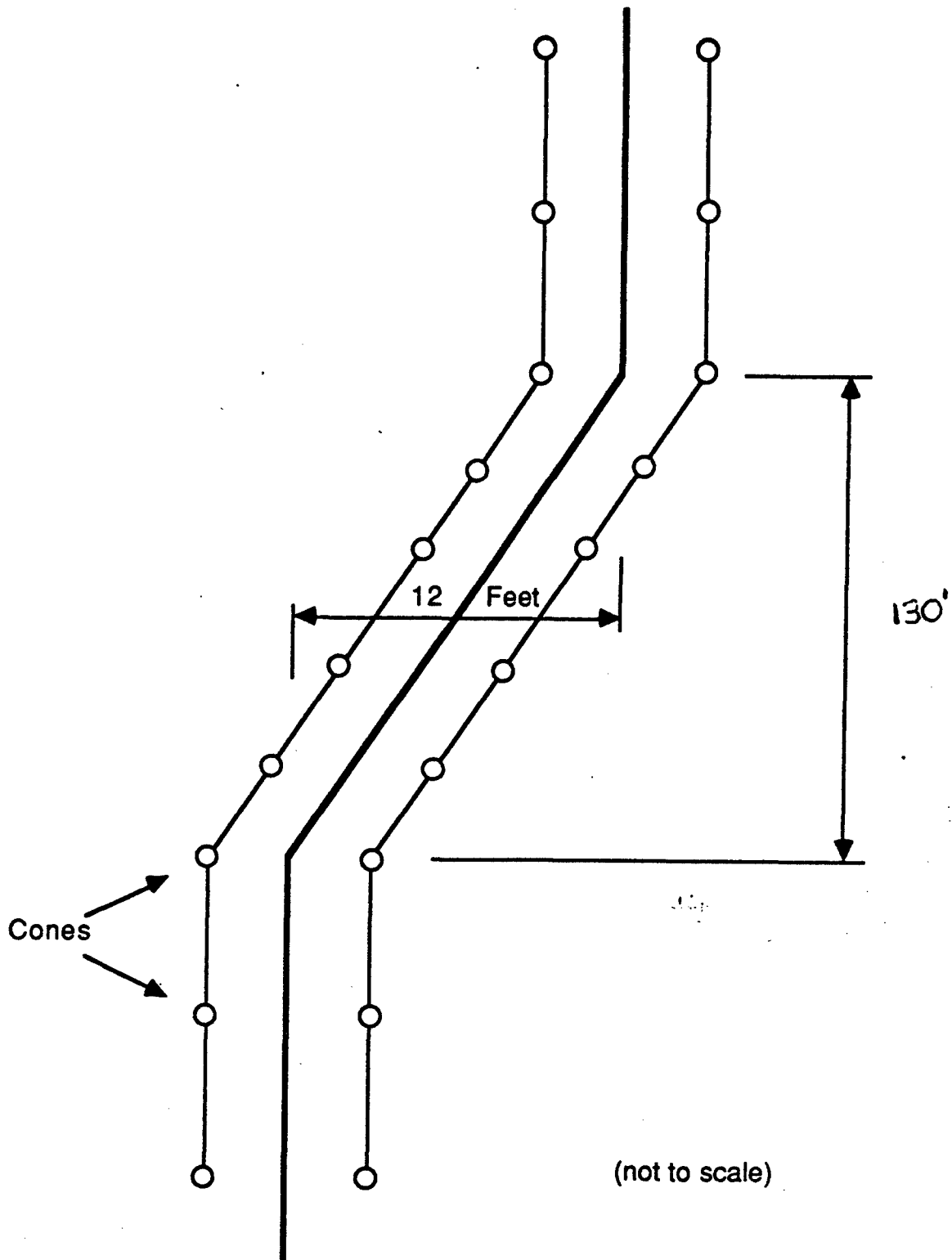


Figure 5.4-1 100 by 12 ft lane change course.

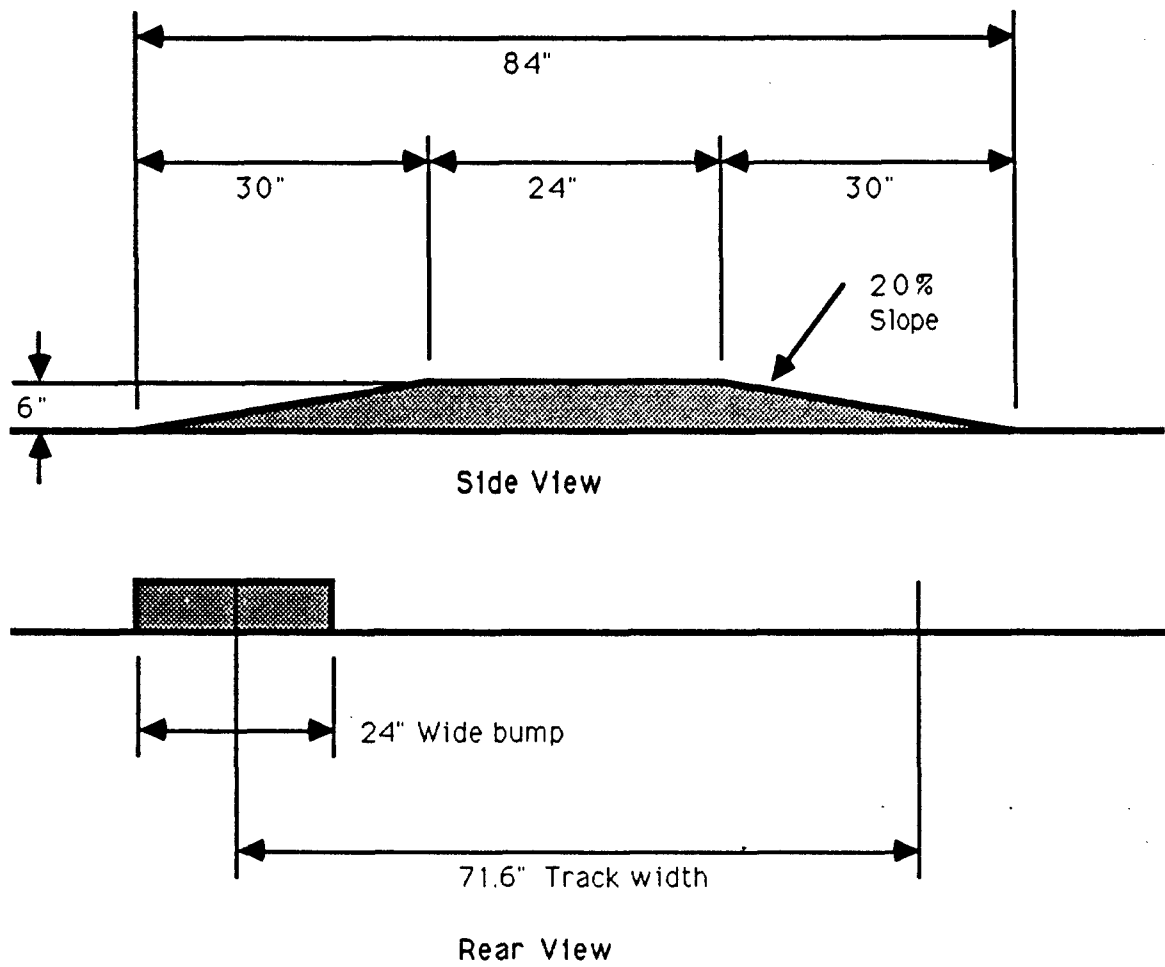


Figure 5.4-2 Bump course.

5.4.1. Validation of the M1037/M101 Simulation Model

Figures 5.4.1-1 through 5.4.1-8 show comparisons between the road tests and DADS simulation for a 45 mph 100 ft by 12 ft lane change maneuver. The yaw rate measurement in Figure 5.4.1-3, and the vehicle roll measurement in Figure 5.4.1-4 have a respective 2.5 deg/s and 0.5 deg bias. The measurement biases are the result of signal drift in the instrumentation, and do not exist in the actual system. In Figure 5.4.1-4 there is a large drop in the measurement at the end of the maneuver. The drop in the value of the signal is probably a result of bad spots in the stabilized platform potentiometer. The stabilized platform provides an inertial reference for vehicle roll and acceleration measurements.

The simulations were generated with preview and delay times for the driver model of 1.3 s and 0.1 s respectively.

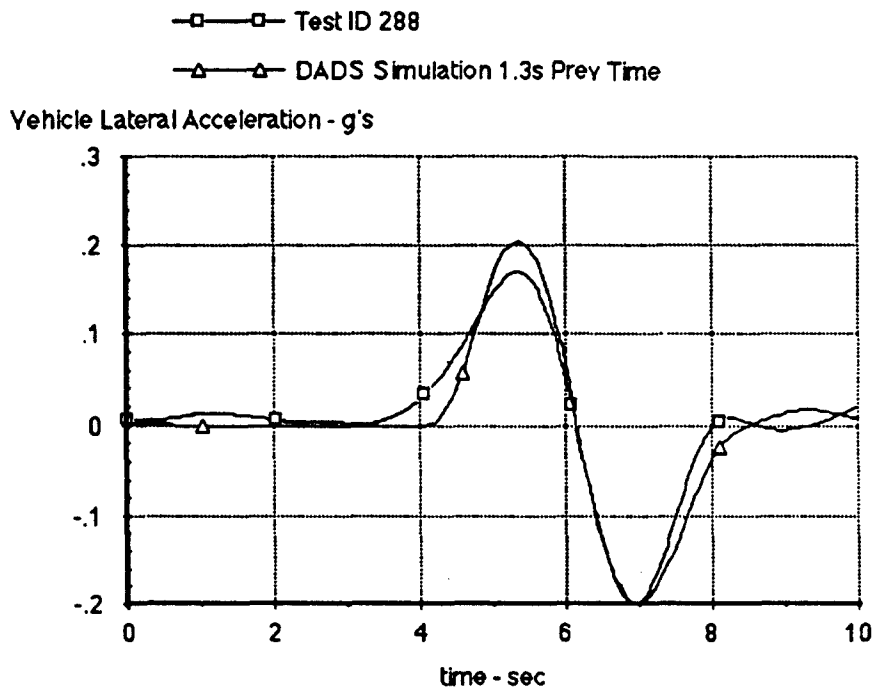


Figure 5.4.1-1 Lateral vehicle acceleration for a 45 mph 100 ft by 12 ft lane change.

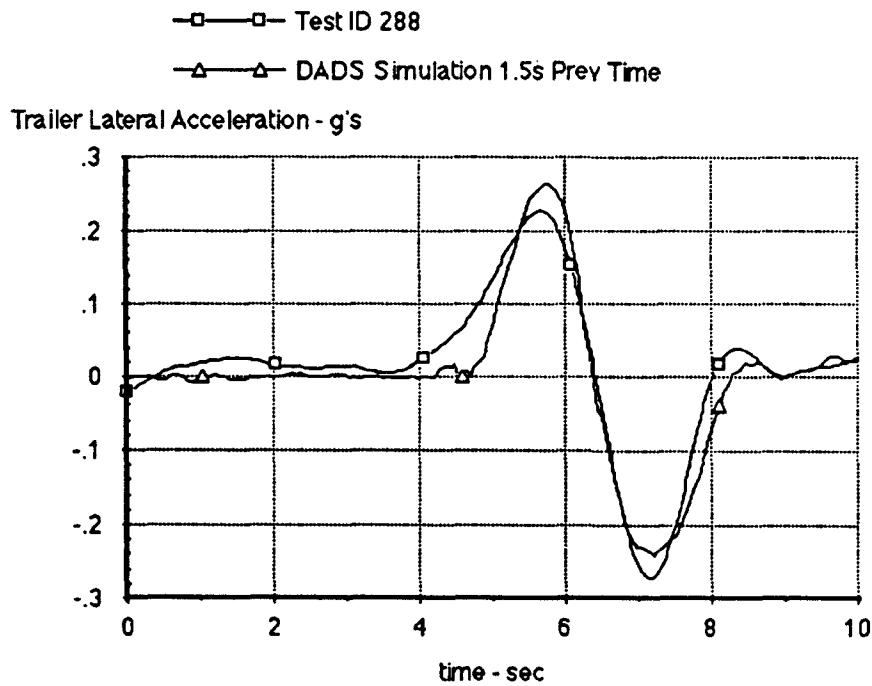


Figure 5.4.1-2 Lateral trailer acceleration for a 45 mph 100 ft by 12 ft lane change.

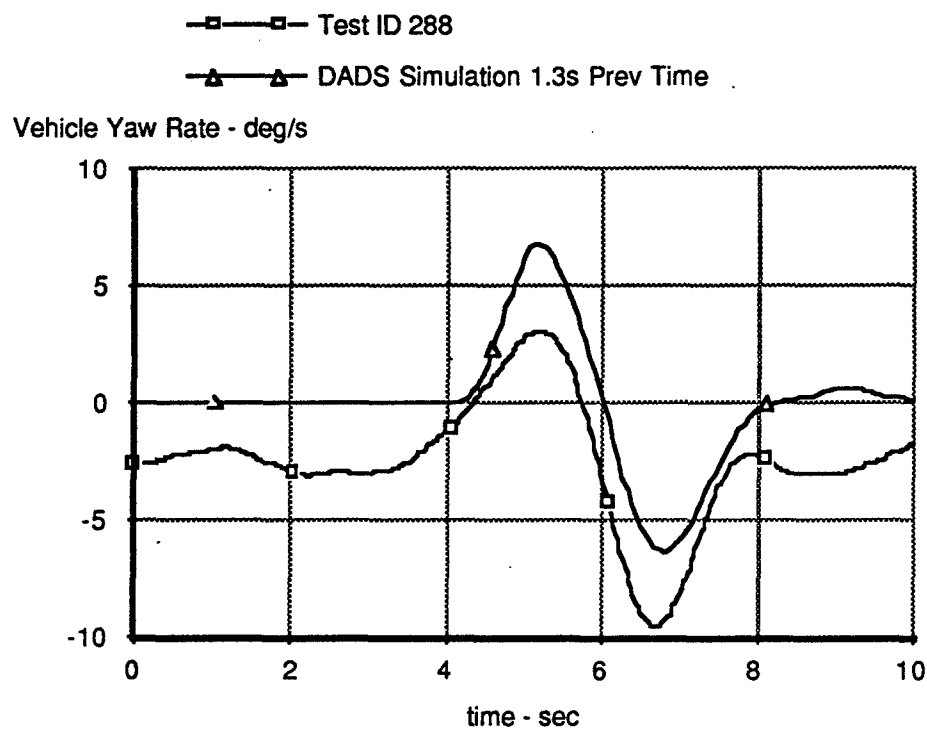


Figure 5.4.1-3 Vehicle yaw rate for a 45 mph 100 ft by 12 ft lane change.

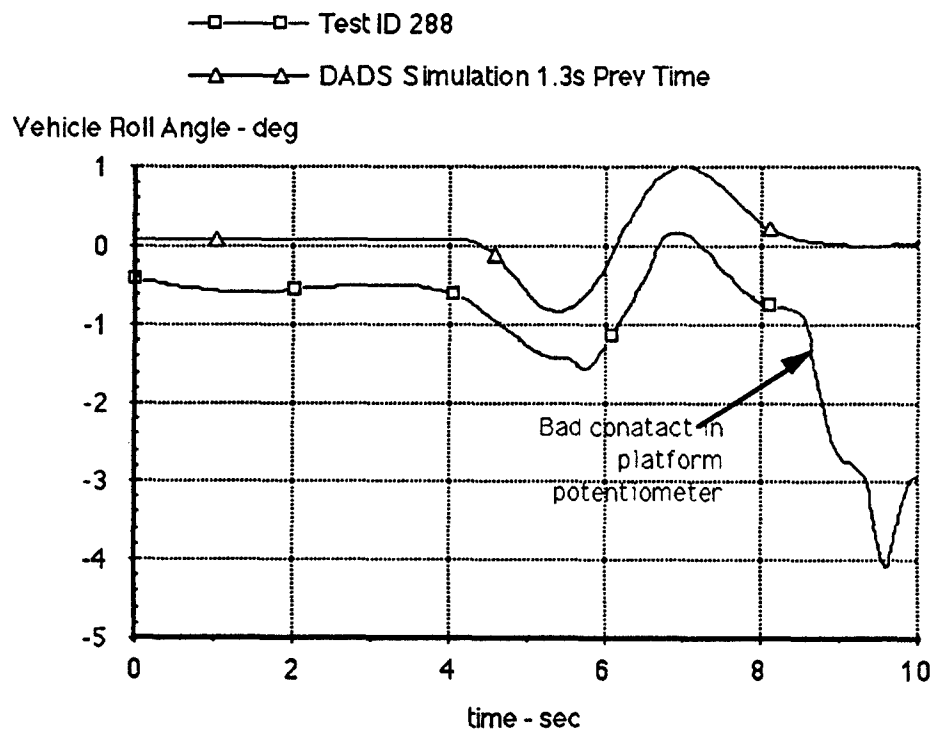


Figure 5.4.1-4 Vehicle roll for a 45 mph 100 ft by 12 ft lane change.

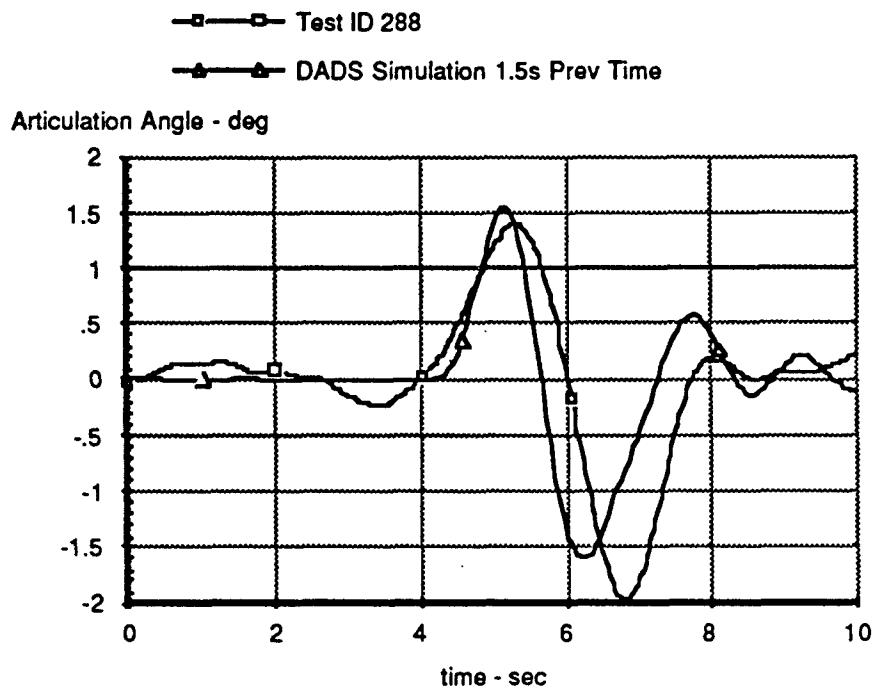


Figure 5.4.1-5 Articulation angle for a 45 mph 100 ft by 12 ft lane change.

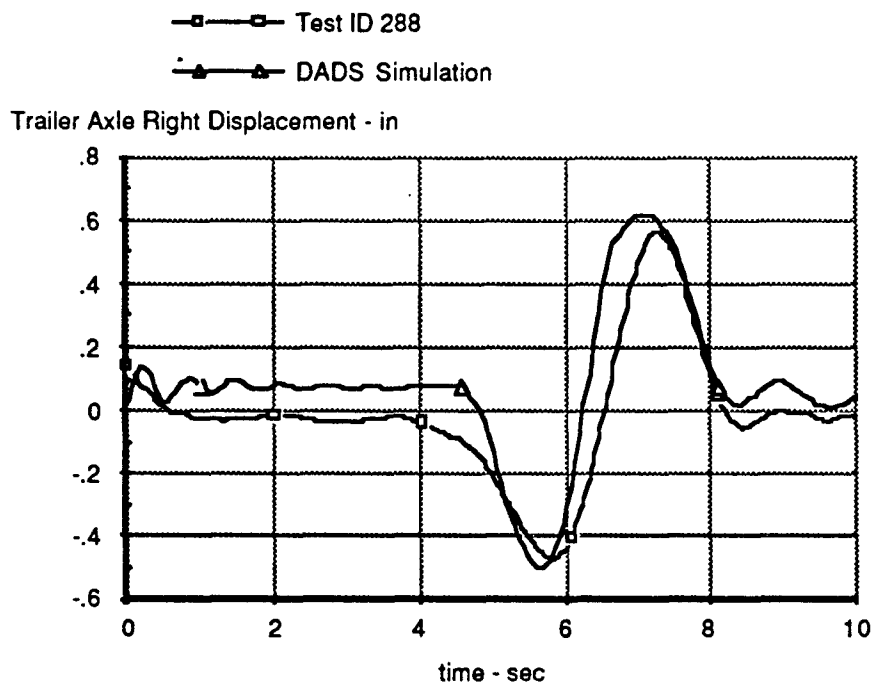


Figure 5.4.1-6 Trailer right axle displacement for a 45 mph 100 ft by 12 ft lane change.

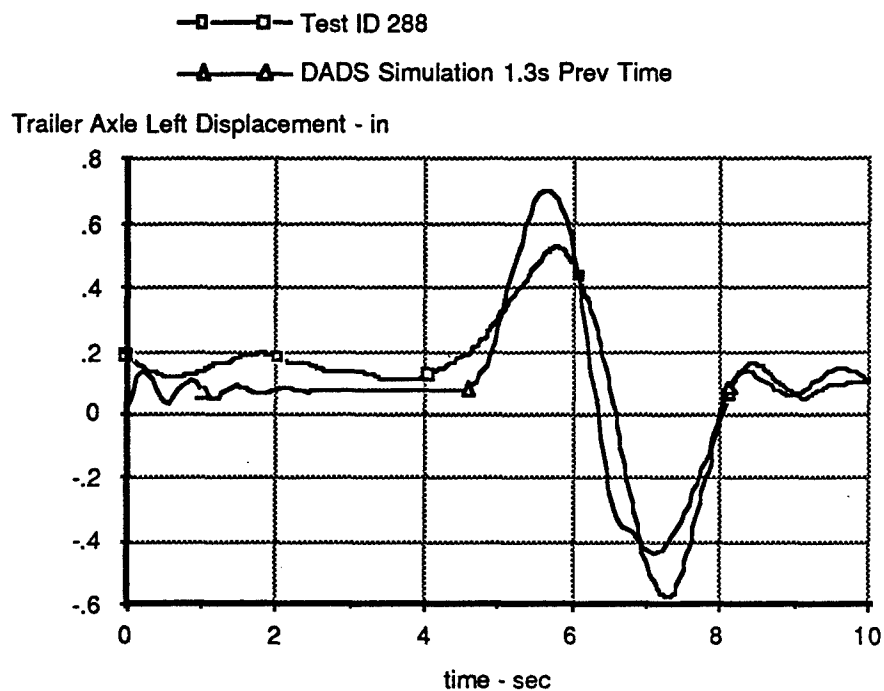


Figure 5.4.1-7 Trailer left axle displacement for a 45 mph 100 ft by 12 ft lane change.

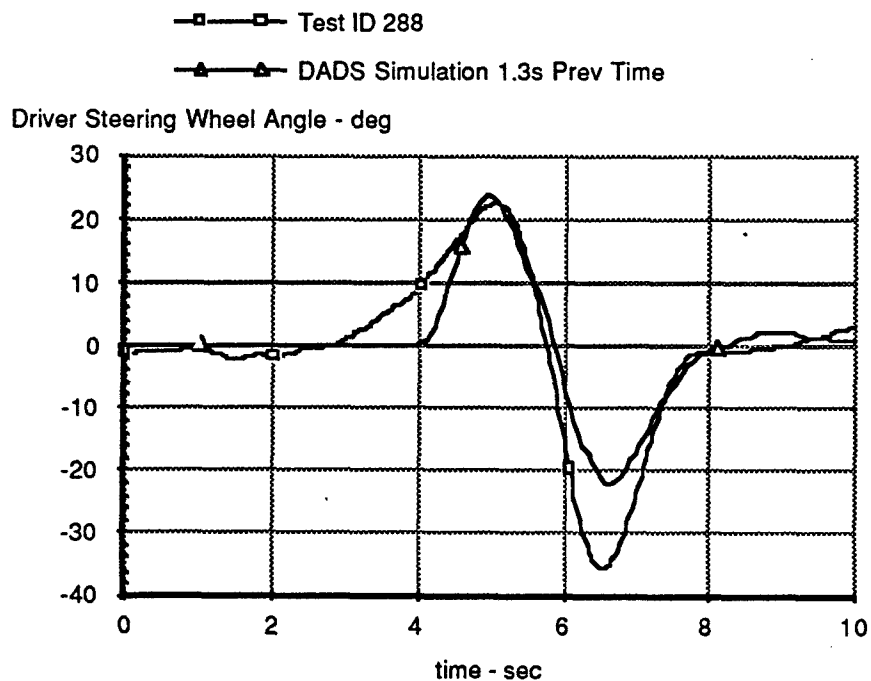


Figure 5.4.1-8 Steering wheel angle for a 45 mph 100 ft by 12 ft lane change.

Figures 5.4.1-9 through 5.4.1-15 show the simulated and measured response for a vehicle speed of 45 mph, 500 ft radius turn. With one exception, there was agreement between the simulation and test data. Figure 5.4.1-12 shows that the simulation underestimated the articulation angle. This could be due to a instrumentation calibration error for this particular test, or to some minor deficiency in the simulation model.

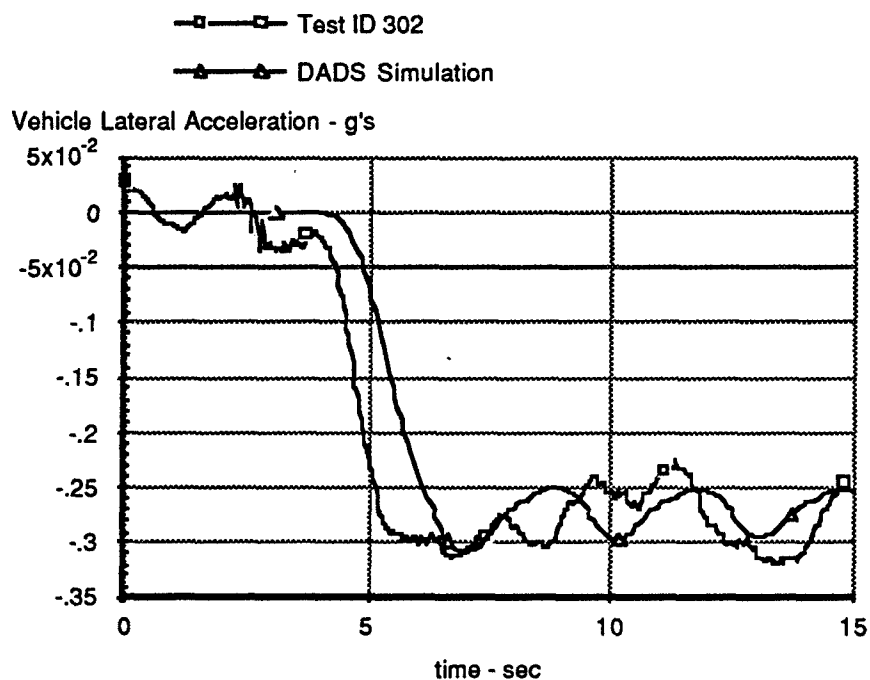


Figure 5.4.1-9 Lateral vehicle acceleration for a 45 mph 500 ft radius turn.

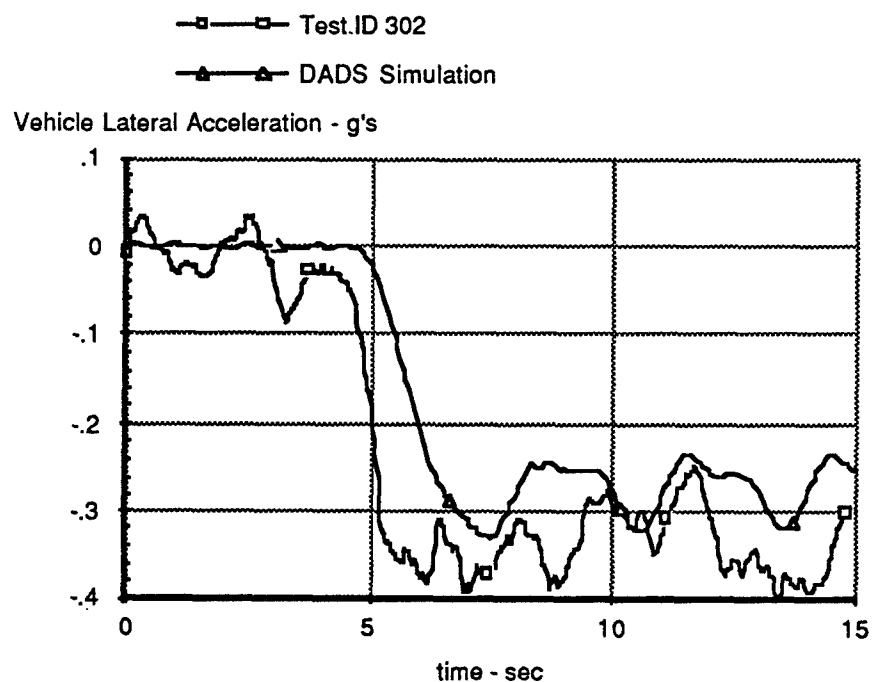


Figure 5.4.1-10 Lateral trailer acceleration for a 45 mph 500 ft radius turn.

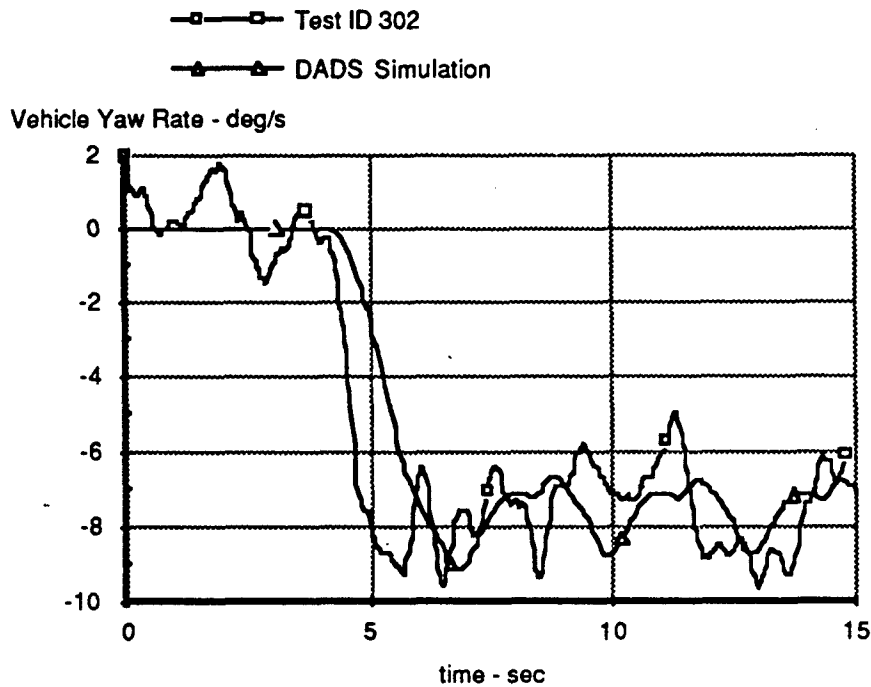


Figure 5.4.1-11 Vehicle yaw rate for a 45 mph 500 ft radius turn.

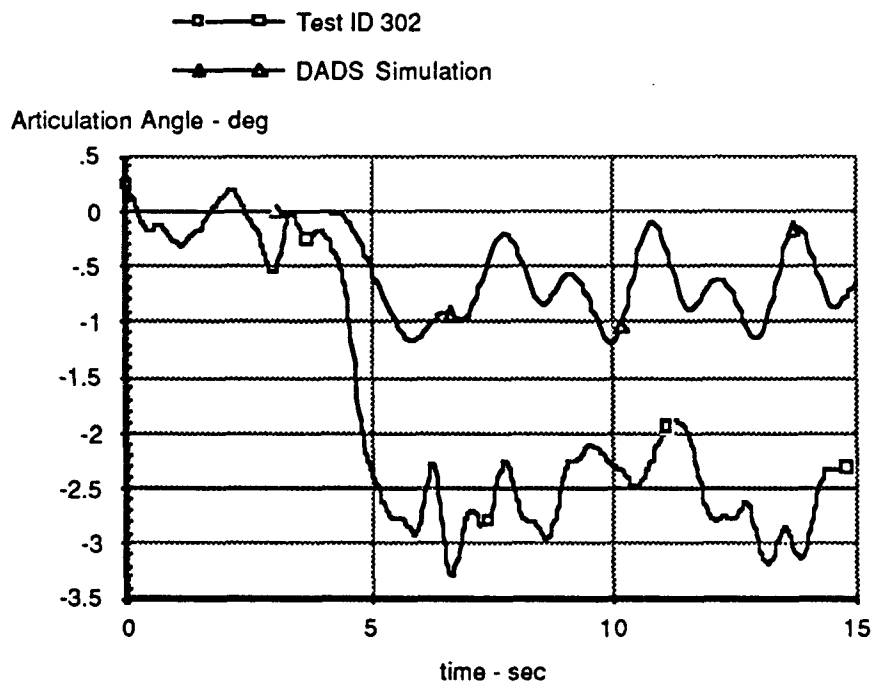


Figure 5.4.1-12 Articulation angle for a 45 mph 500 ft radius turn.

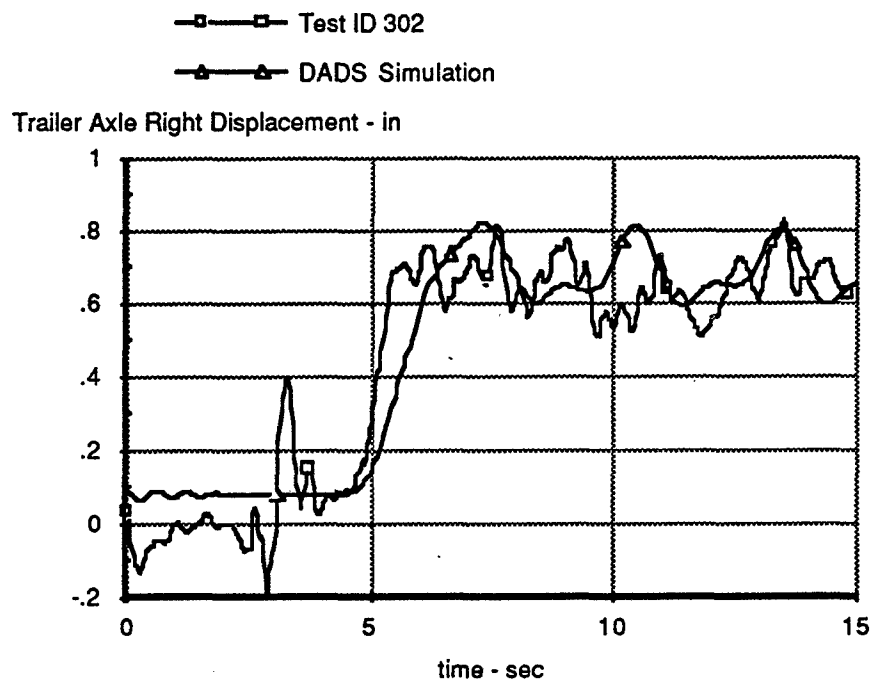


Figure 5.4.1-13 Trailer right axle displacement for a 500 ft radius turn.

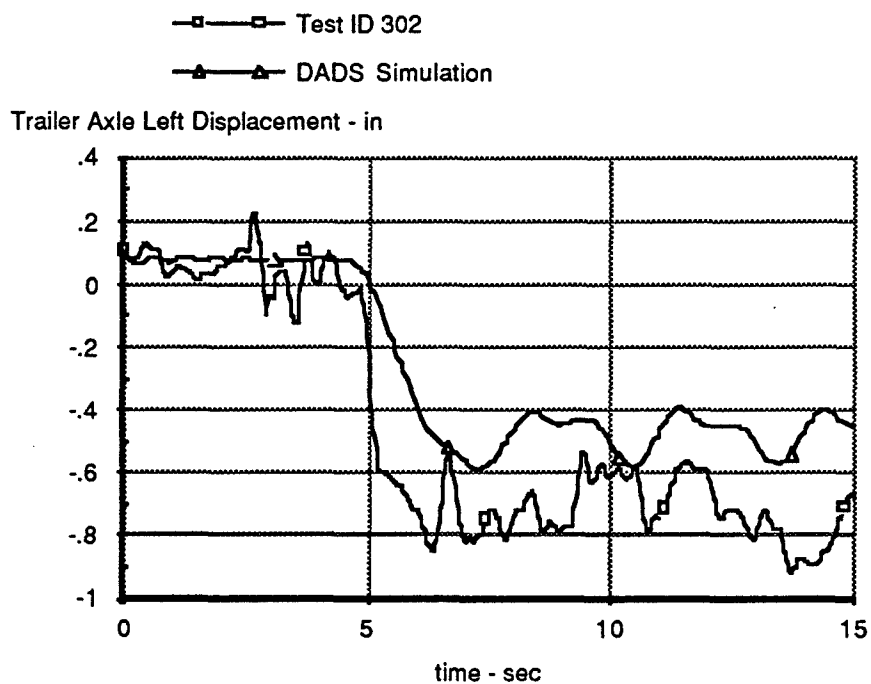


Figure 5.4.1-14 Trailer left axle displacement for a 45 mph 500 ft radius turn.

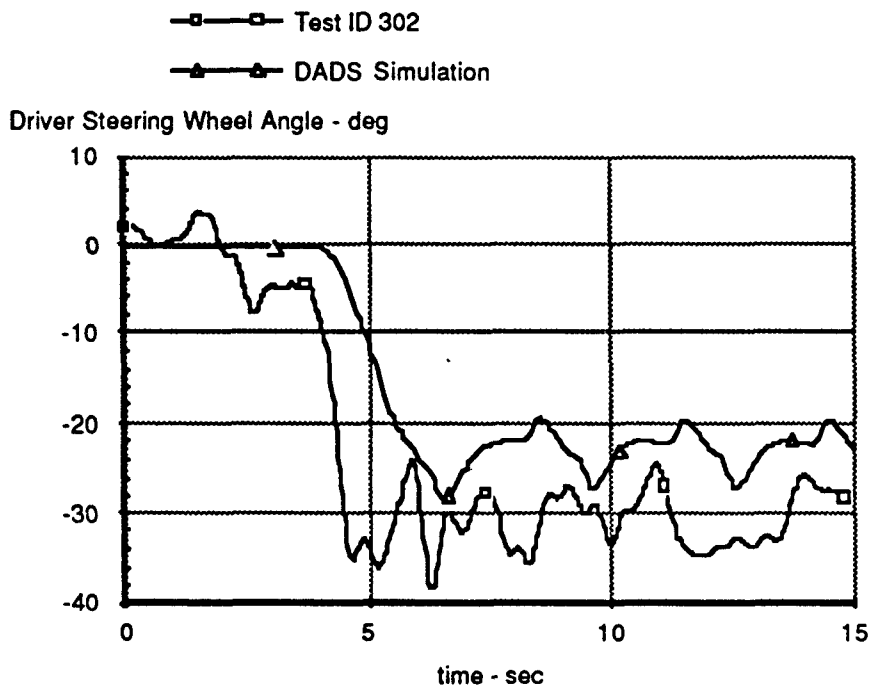


Figure 5.4.1-15 Steering wheel angle for a 45 mph 500 ft radius turn.

Figures 5.4.1-16 through 5.4.1-21 show vehicle response while traveling 10 mph over the bump course described in Figure 5.4-2. These figures indicate that there is reasonable agreement between simulation and road test vehicle responses with the exception of the articulation angle and left trailer axle displacement. The test data for the left trailer axle displacement did show a large negative spike at 7.2 s which the simulation did not fully reproduce. The cause of the spike has not yet been determined. One possible explanation is that the bump, which was not anchored to the ground, shifted while the trailer drove over it. The right trailer axle displacement measurement (the side where the vehicle traveled over the bump) did agree with the simulation results, however.

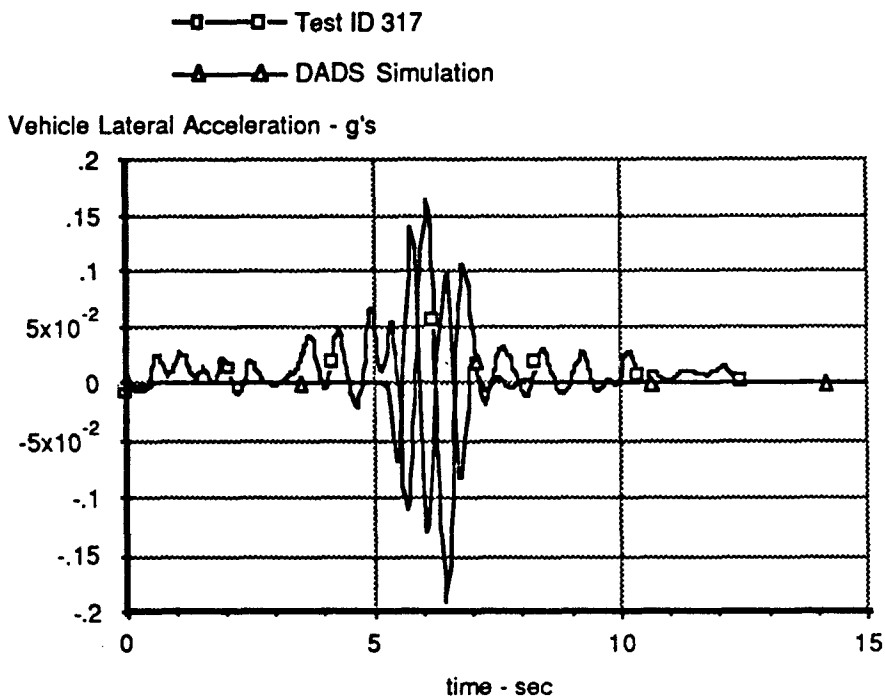


Figure 5.4.1-16 Lateral vehicle acceleration for a 6 inch bump course at 10 mph.

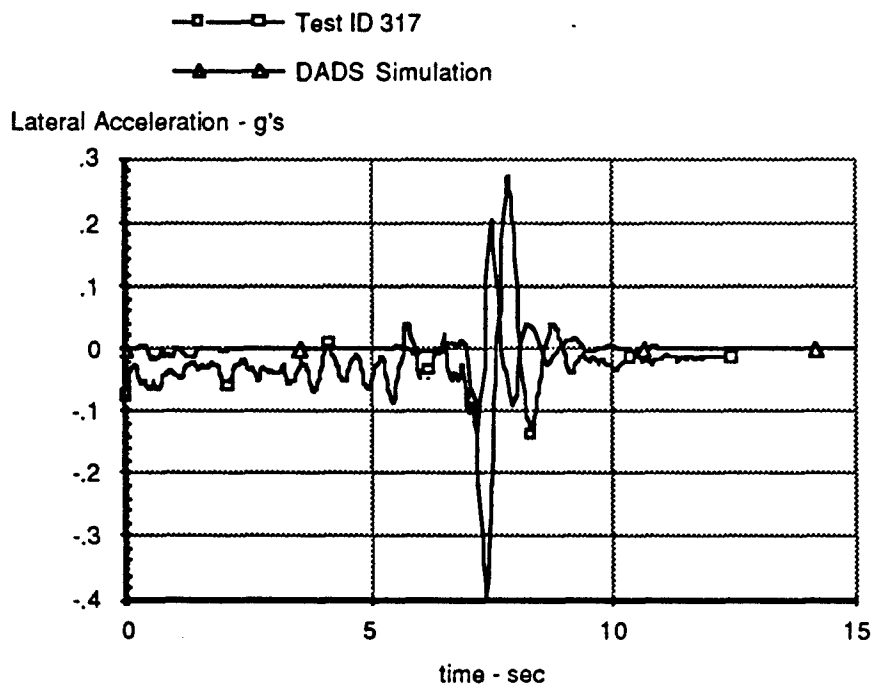


Figure 5.4.1-17 Lateral trailer acceleration for a 6 inch bump course at 10 mph.

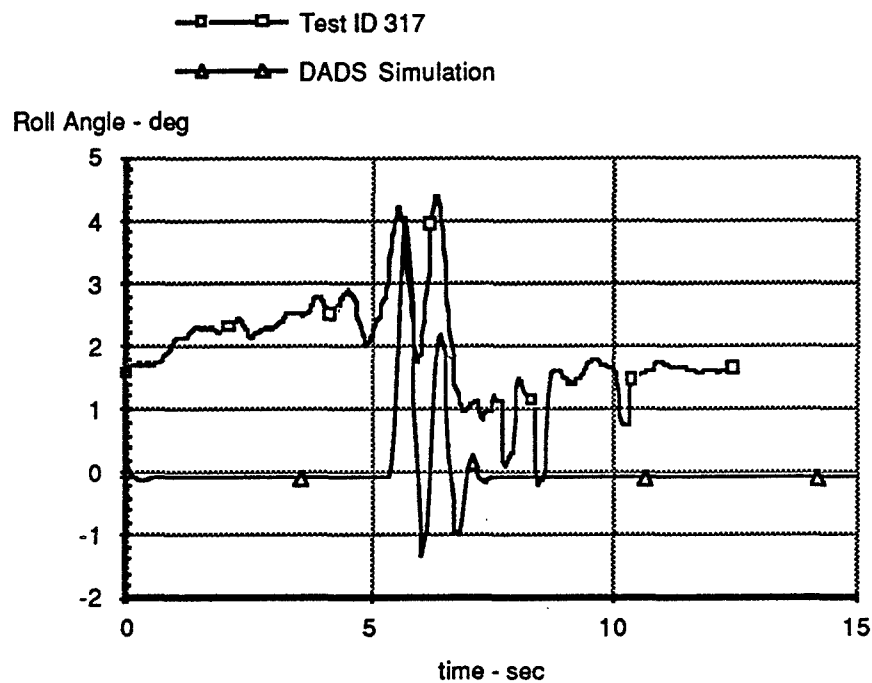


Figure 5.4.1-18 Vehicle roll for a 6 inch bump course at 10 mph.

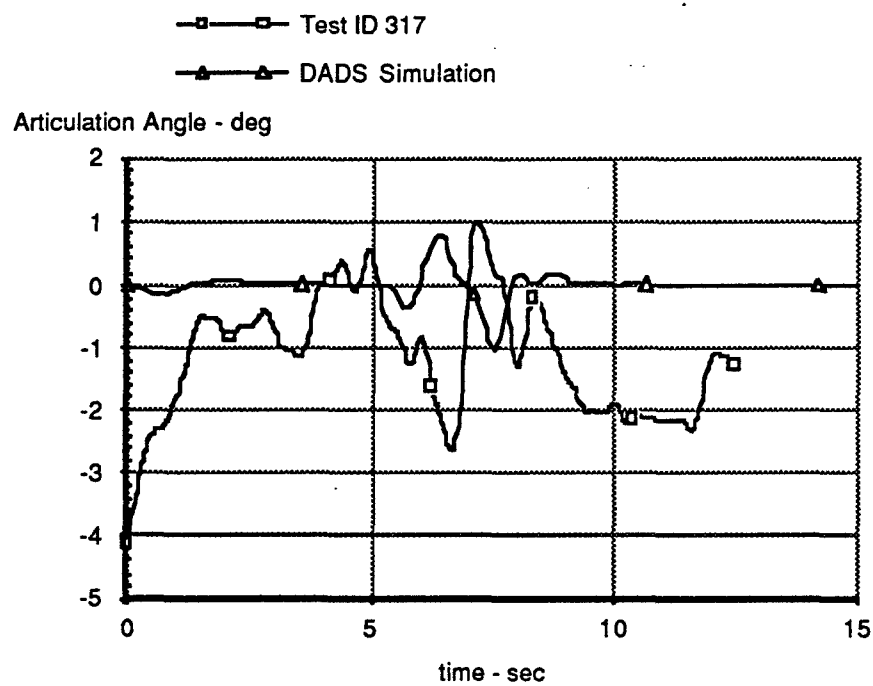


Figure 5.4.1-19 Articulation angle for a 6 inch bump course at 10 mph.

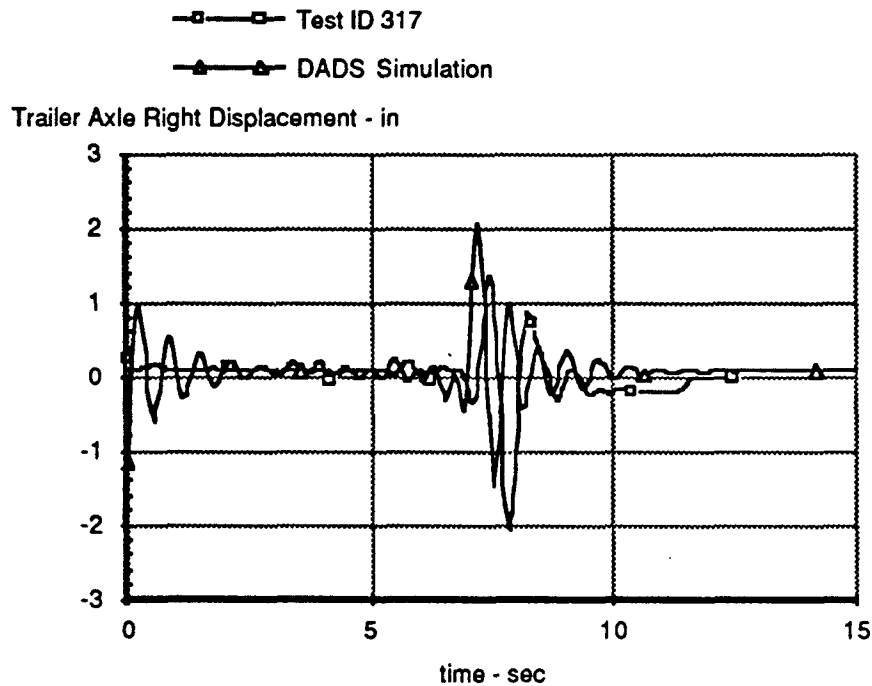


Figure 5.4.1-20 Trailer right axle displacement for a 6 inch bump course at 10 mph.

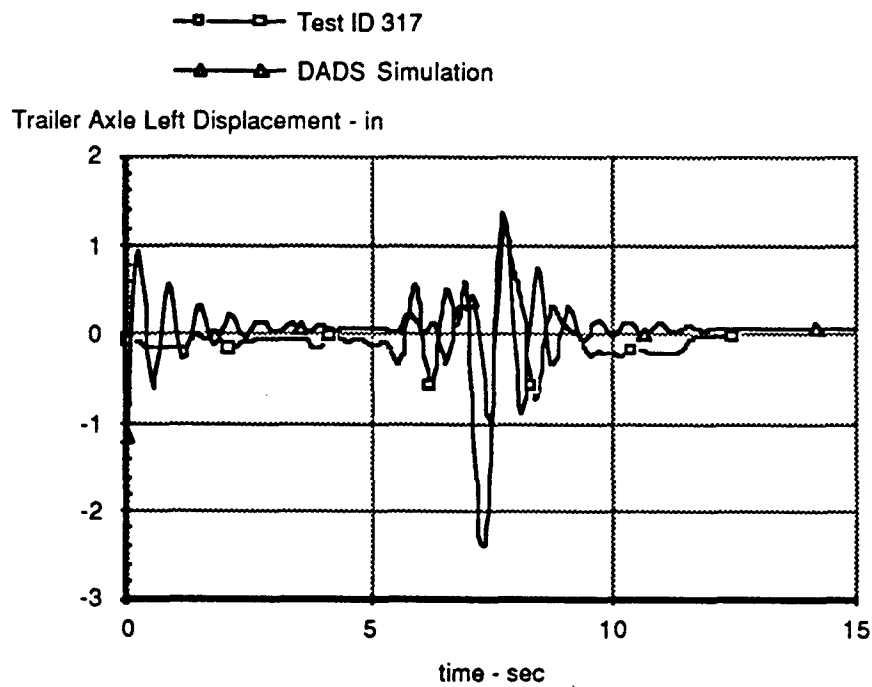


Figure 5.4.1-21 Trailer left axle displacement for a 6 inch bump course at 10 mph.

The figures in this section show that for the most part, the simulation model and actual tests agree. In most cases, both the magnitude and shape of the vehicle dynamic response were accurately reproduced. The results of the validation tests show that the simulation model should be adequate for predicting vehicle stability.

5.5. M1037 Simulation Results

The goal for this phase of the project was to determine the stability boundaries for the system during constant speed with on road and off road operation. To accomplish this, several maneuvers were chosen that taxed the stability of vehicle. The maneuvers included a lane change, a lane change on an inclined road, a constant radius turn, and a bump course. The first three maneuvers provide a measure of the vehicle on road performance, while the last maneuver generates a rough indication of the off-road stability.

5.5.1. Lane Change

In this part the vehicle was required to negotiate 100 ft by 12 ft lane change maneuver shown in Figure 5.4-1. Two combinations of front and rear tire inflations were examined. The first case was the nominal condition, 20 psi in the front tires and 30 psi in the rear tires. Simulations were conducted for vehicle speeds of 25 and 60 mph. Figures 5.5.1-1 through 5.5.1-6 show the vehicle response during a 60 mph lane change. Figure 5.5.1-1 shows the position of the vehicle CG in the global x-y plane. The vehicle tracks the prescribed trajectory with a maximum overshoot of about 3 ft, peak yaw rate of -8 deg/s, and peak lateral acceleration at the vehicle CG of about 0.28 g. Figure 5.5.1-5 shows a peak tire slip of about 3.3 deg. Table 5.5.1-1 shows peak values for all the vehicle speeds simulated.

Table 5.5.1-1 Peak values for the M1037 100 ft by 12 ft lane change simulations.

Speed	Tire Press	Lateral Acc.	Yaw rate	Roll	Tire Def	Tire Slip	Steer
mph	psi/psi	g's	deg/s	deg	inches	deg	deg
25	20/30	0.159	-8.2	1.24	2.06	1.46	2.79
25	30/30	0.159	-8.2	1.12	2.06	1.44	2.54
60	20/30	0.36	15.3	2.85	2.35	5.65	3.9
60	30/30	0.375	15.2	2.85	2.33	5.02	-4.3

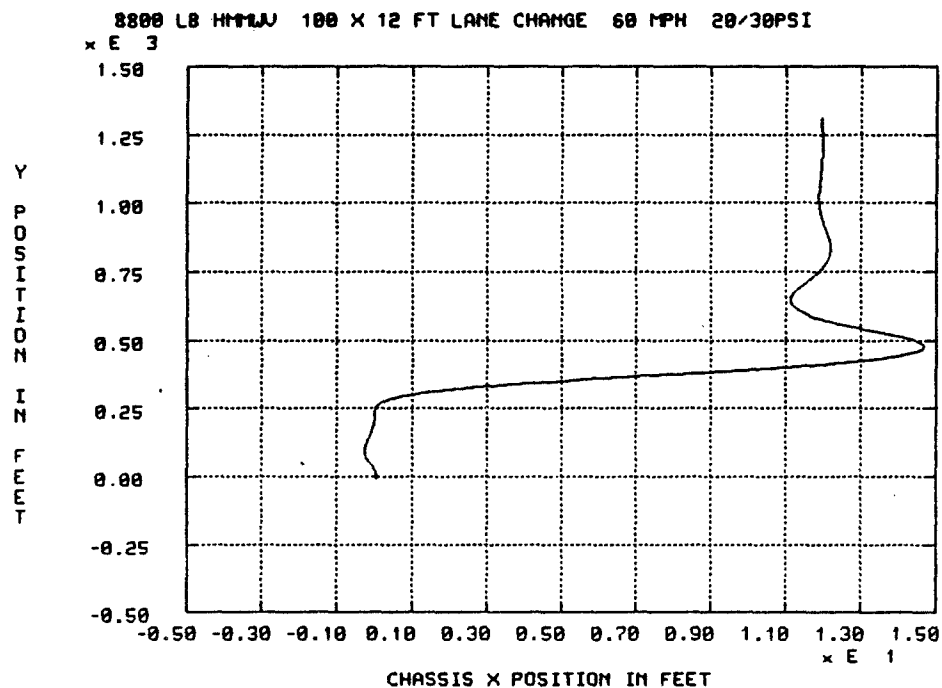


Figure 5.5.1-1 M1037 CG position for a 100 ft by 12 ft 60 mph lane change.

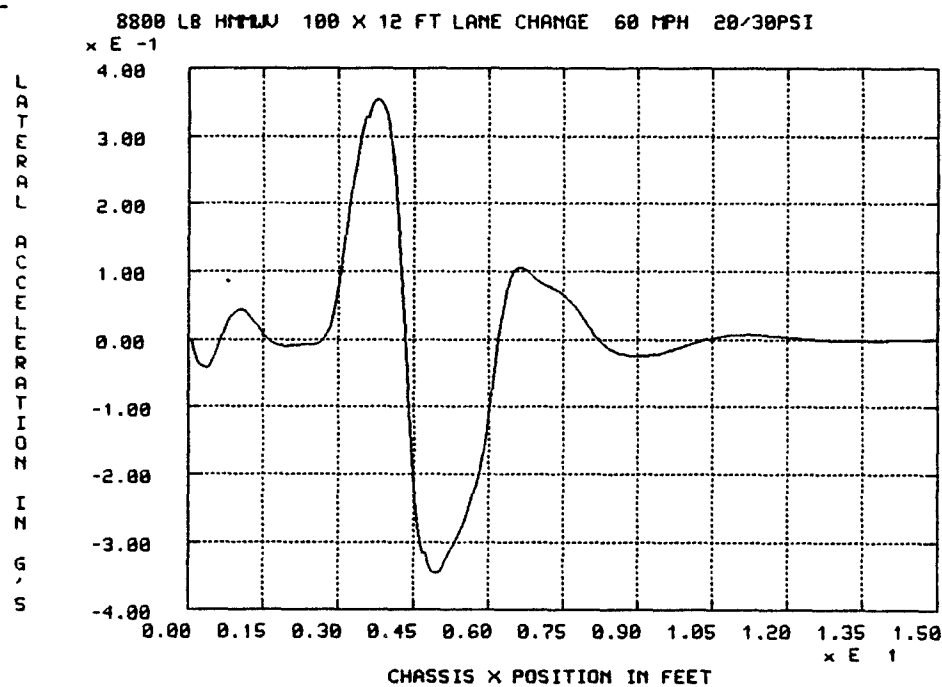


Figure 5.5.1-2 M1037 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change.

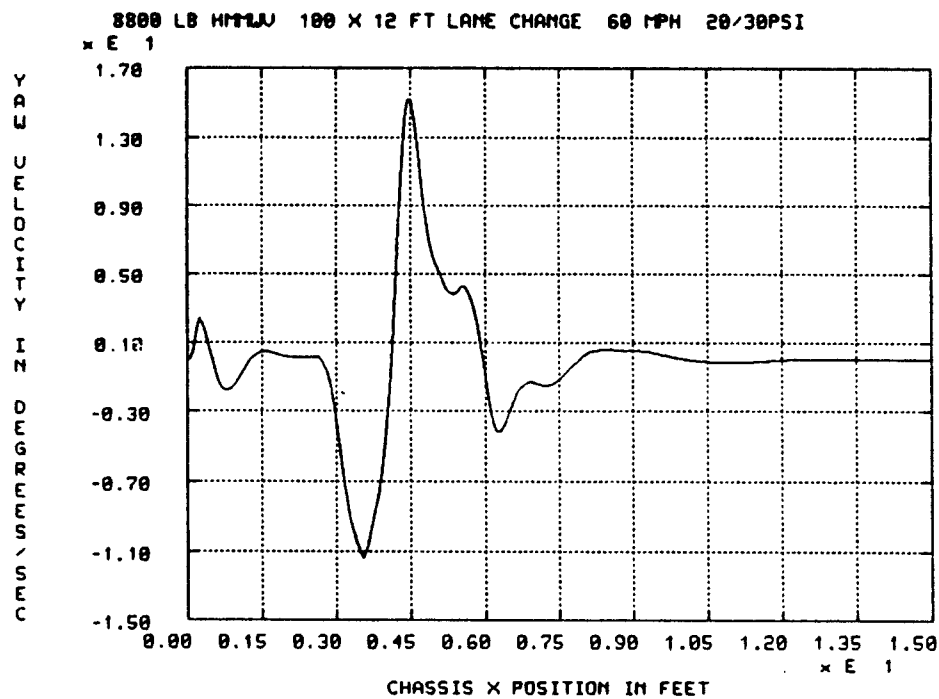


Figure 5.5.1-3 M1037 yaw rate for a 100 ft by 12 ft 60 mph lane change.

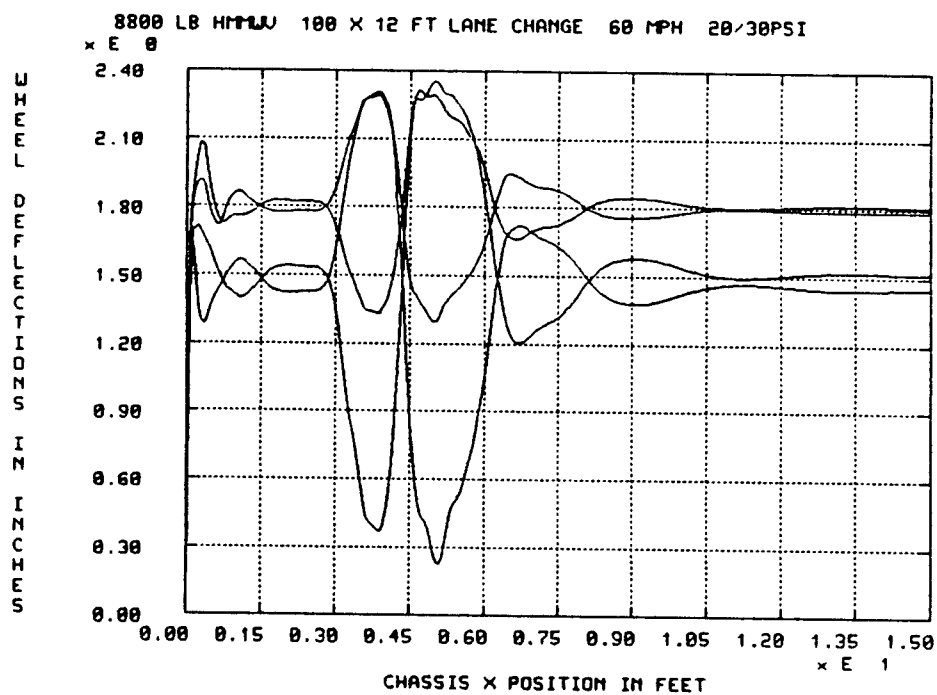


Figure 5.5.1-4 M1037 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change.

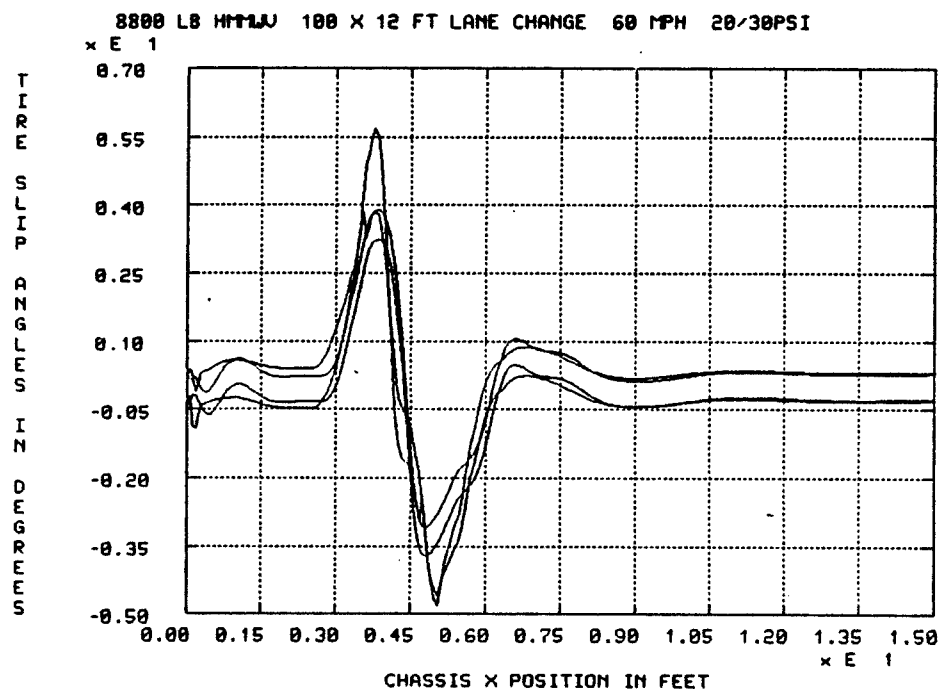


Figure 5.5.1-5 M1037 tire slip angles for a 100 ft by 12 ft 60 mph lane change.

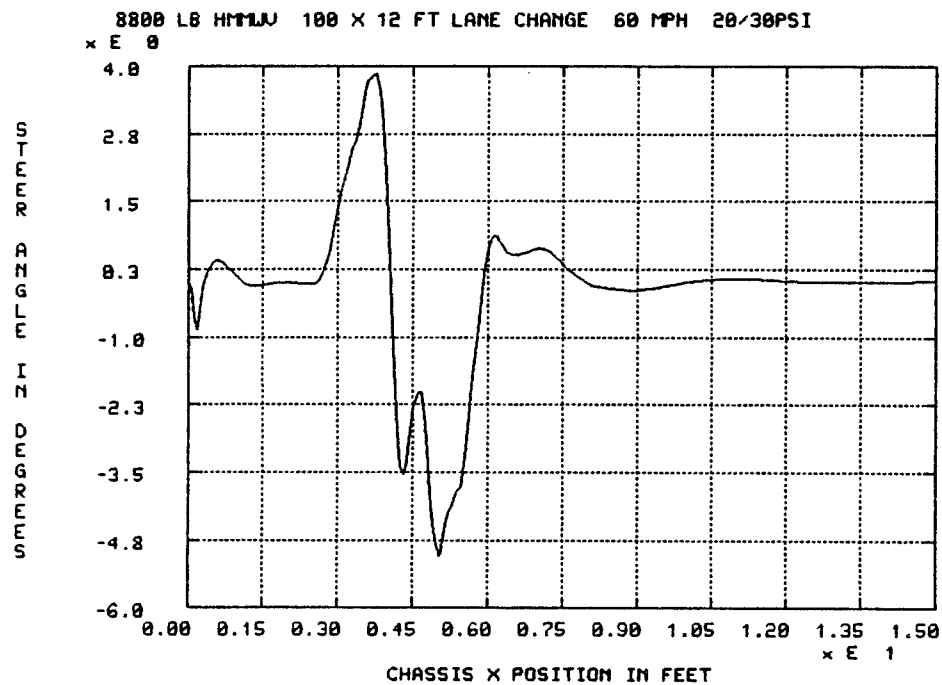


Figure 5.5.1-6 M1037 steer angle for a 100 ft by 12 ft 60 mph lane change.

5.5.2. Steady Turn

In this part of the study, the vehicle is required to maintain a constant speed through a 500 ft radius turn. As with section 5.5.1, both 20/30 psi and 30/30 psi front/rear inflation pressure combinations were simulated. Figures 5.5.2-1 through 5.5.2-6 show selected 50 mph simulation results for the 20/30 psi case. The simulation results in Table 5.5.2-1 showed that raising the inflation pressure of the front tires produced slightly lower peak responses. The simulation shows that the vehicle can maintain vehicle speeds of 50 mph (lateral accelerations of 0.3 g's) without yaw or roll instability, but was not stable at 55 mph (lateral accelerations of 0.405 g's).

Table 5.5.2-1 Peak values for the M1037 500 ft radius steady turn simulations.

Speed	Tire Press	Lateral Acc.	Yaw rate	Steer	Tire Def	Tire Slip
mph	psi/psi	g's	deg/s	deg	inches	deg
25	20/30	0.093	-4.7	1.44	2.00	0.96
25	30/30	0.092	-4.55	1.42	2.03	0.90
50	20/30	0.425	-13.7	8.5	2.56	10.3
50	30/30	0.396	-11.0	5.2	2.30	6.5
55	20/30	(unstable)				

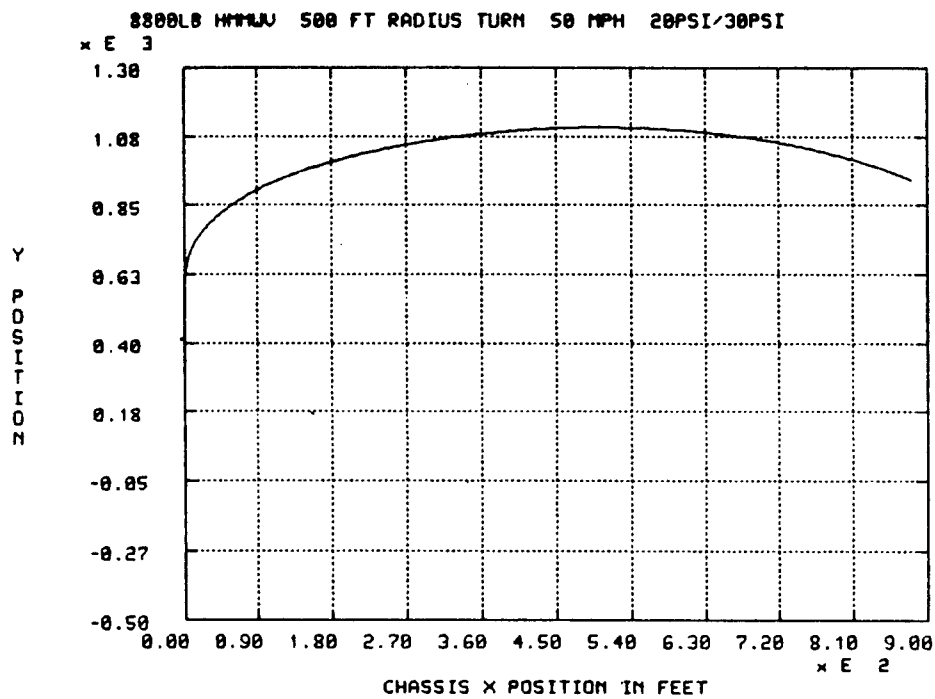


Figure 5.5.2-1 M1037 CG position, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

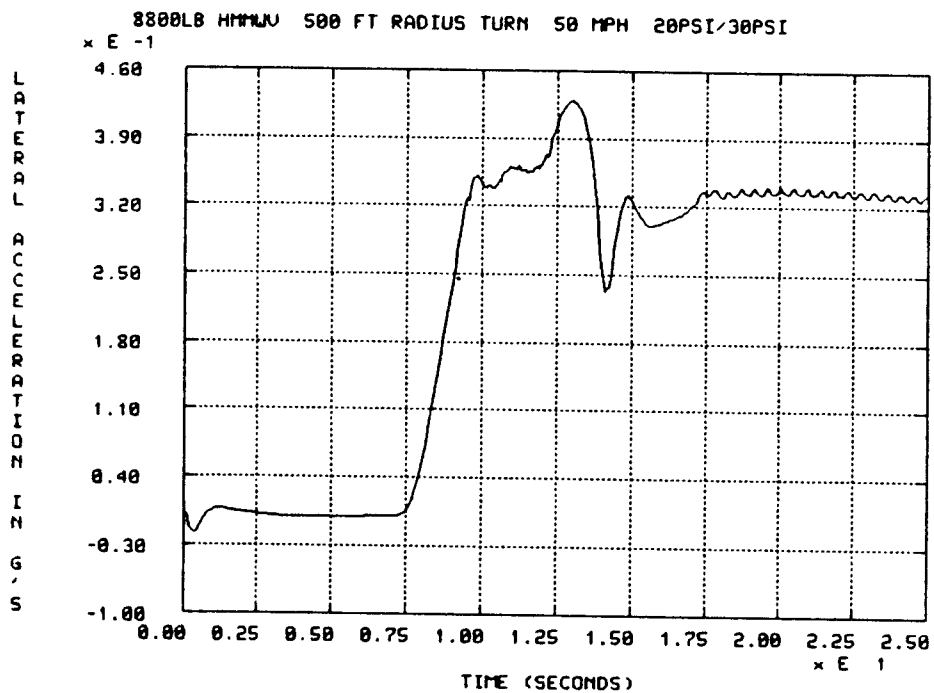


Figure 5.5.2-2 M1037 CG lateral acceleration, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

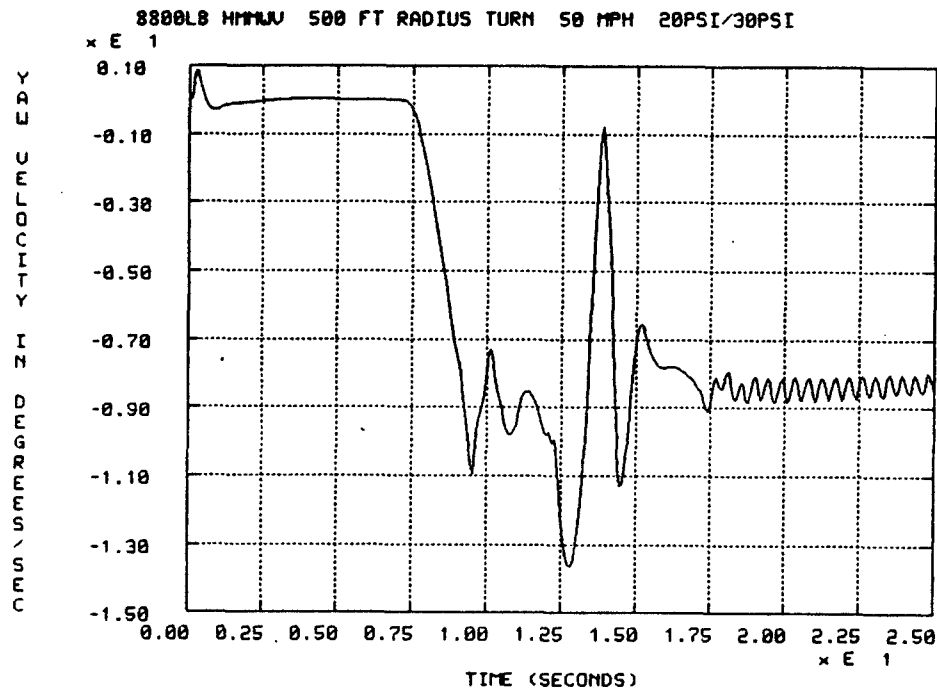


Figure 5.5.2-3 M1037 yaw rate, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

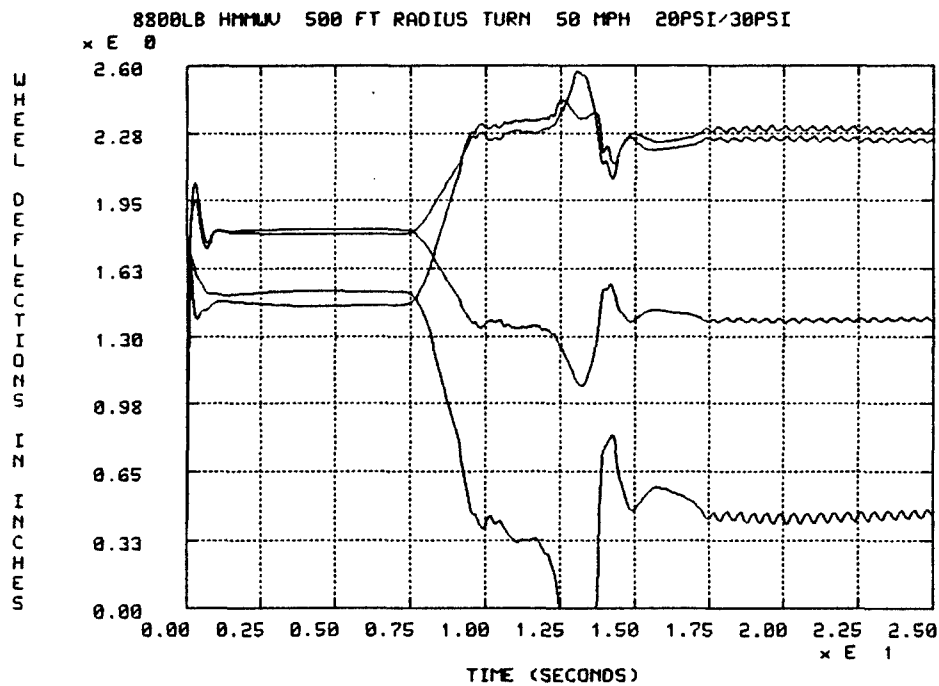


Figure 5.5.2-4 M1037 vertical tire deflections, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

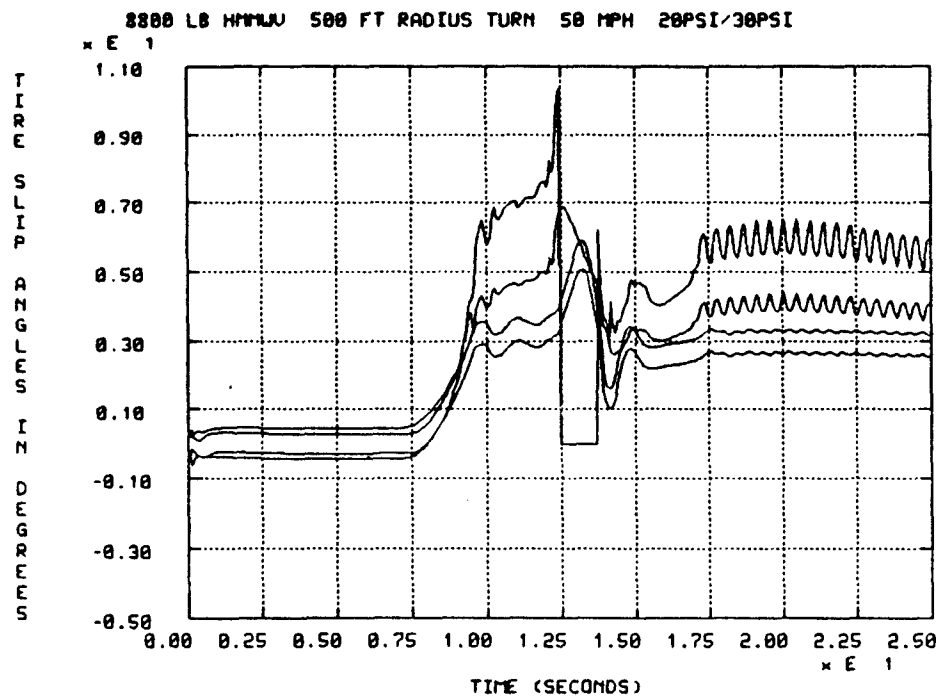


Figure 5.5.2-5 M1037 tire slip angles, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

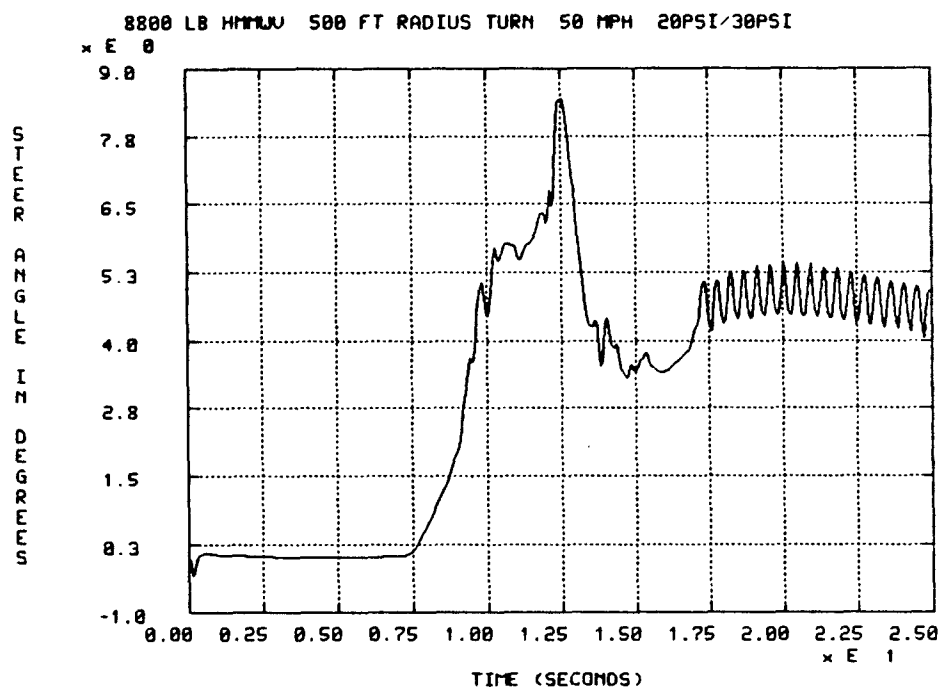


Figure 5.5.2-6 M1037 steer angle, 500 ft radius steady turn, 20/30 front/rear tire inflation, 50 mph.

5.5.3. Bump Course

To evaluate roll stability, the vehicle was driven over the 6 inch high bump described in section 5.4. The 20/30 psi pressure front/rear tire inflation pressure combination was simulated in this case. Figures 5.5.3-1 through 5.5.3-8 show the vehicle's response while traveling over the bump at 15 mph. Table 5.5.3-1 shows the corresponding peak values for the responses.

Table 5.5.3-1 Peak values for the M1037 bump course simulations.

Speed	Tire Press	Lateral Acc.	Vertical Acc.	Roll	Tire Def	Suspen Roll
mph	psi/psi	g's	g's	deg	inches	deg
10	20/30	-0.26	-0.37	-4.2	3.6	1.11
15	20/30	0.214	-0.42	-3.8	3.55	1.23
20	20/30	0.192	-0.44	-3.4	3.75	1.21
25	20/30	0.161	-0.44	-3.0	3.90	1.46
30	20/30	-0.159	0.43	-2.85	3.35	1.47
35	20/30	0.122	-0.39	-2.52	4.6	1.44
40	20/30	-0.184	0.465	-2.25	3.7	1.61
45	20/30	0.145	0.495	-2.18	5.1	1.16
50	20/30	0.134	-0.42	-1.99	5.4	1.18
55	20/30	0.144	0.98	-1.97	3.7	1.48

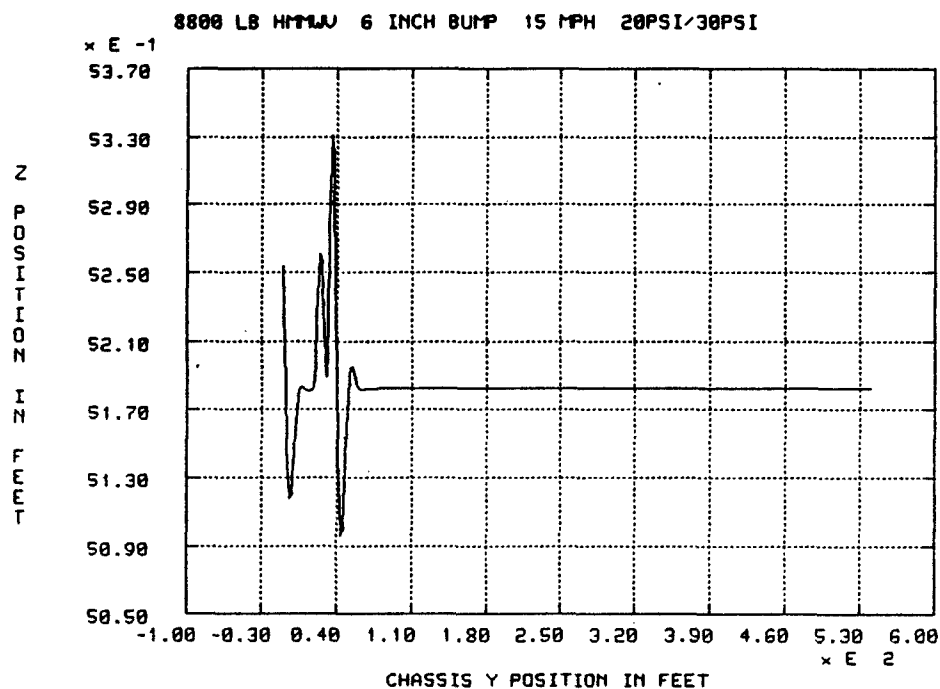


Figure 5.5.3-1 M1037 chassis CG vertical position, 6 inch bump course, 15 mph.

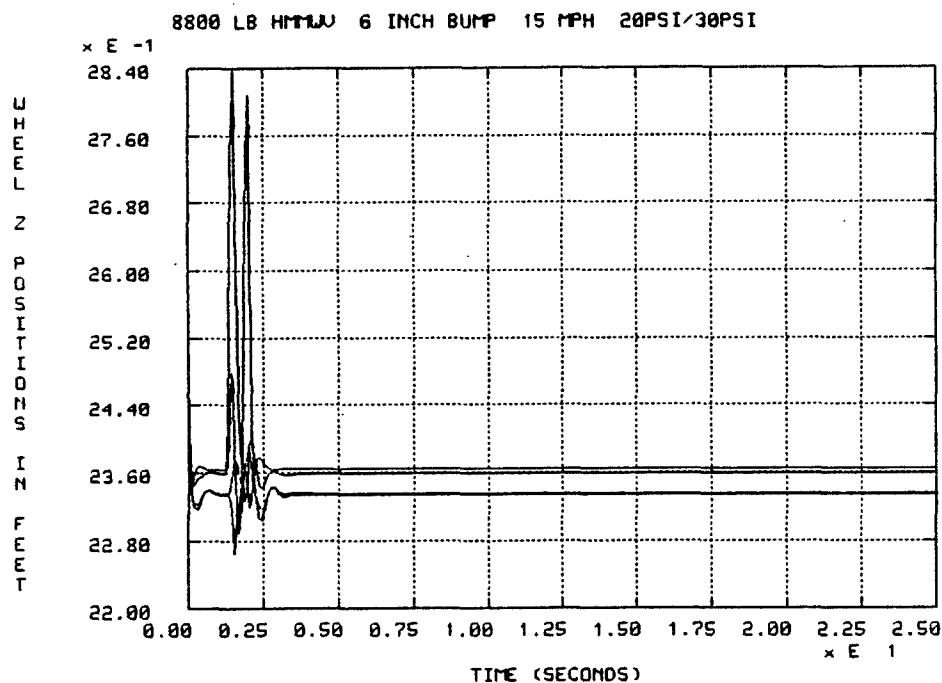


Figure 5.5.3-2 M1037 tire vertical position, 6 inch bump course, 15 mph.

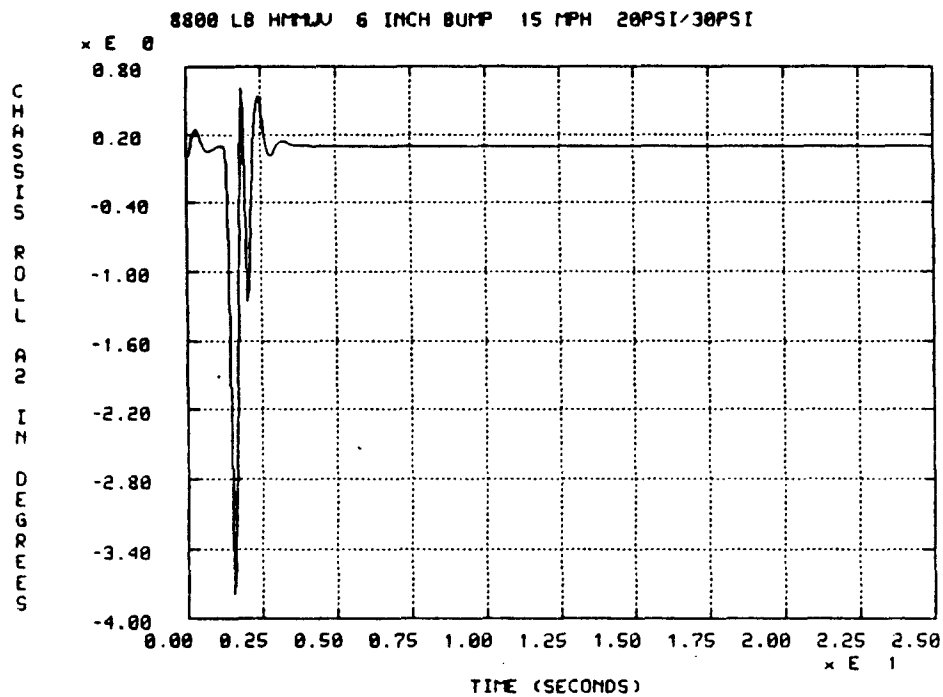


Figure 5.5.3-3 M1037 chassis roll angle, 6 inch bump course, 15 mph.

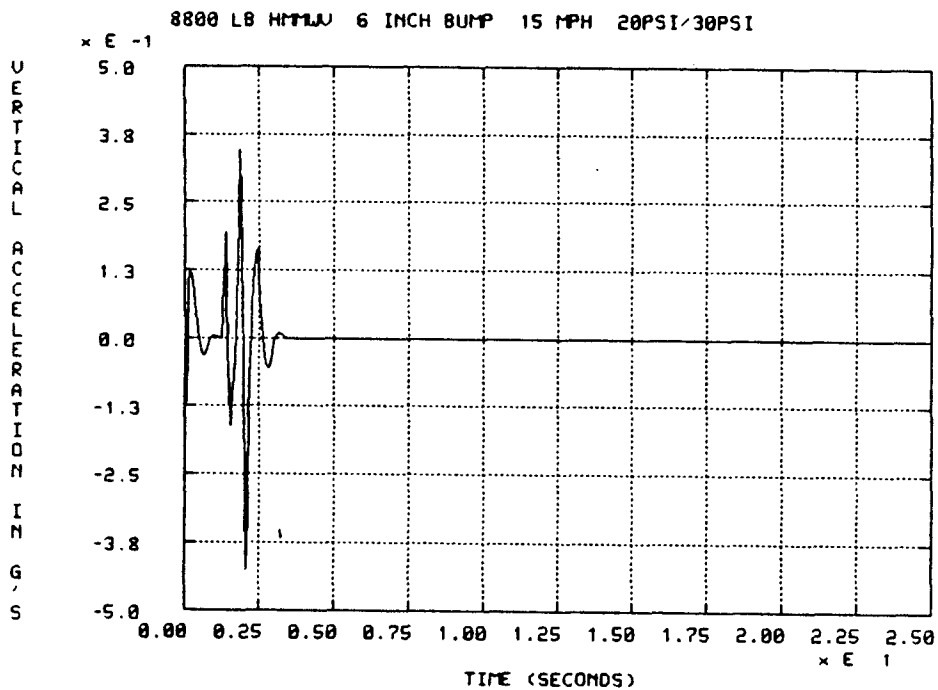


Figure 5.5.3-4 M1037 chassis vertical acceleration, 6 inch bump course, 15 mph.

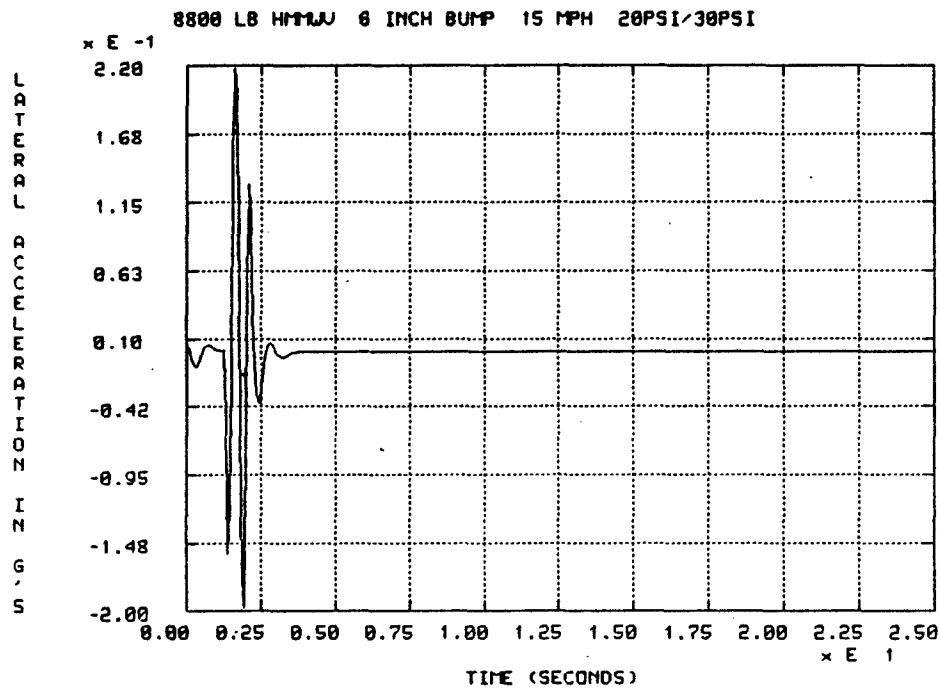


Figure 5.5.3-5 M1037 chassis CG lateral acceleration, 6 inch bump course, 15 mph.

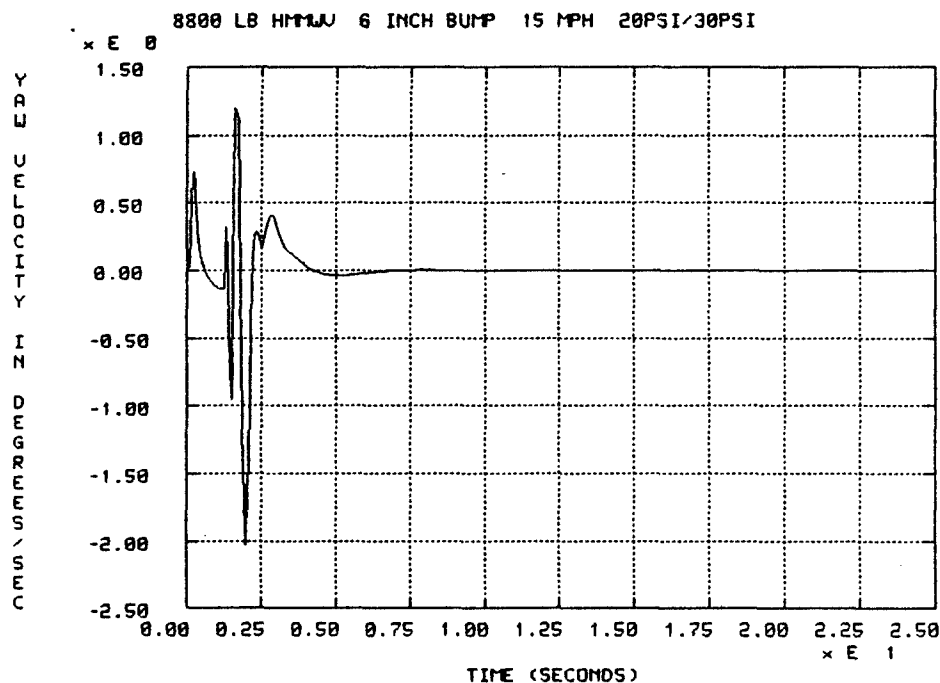


Figure 5.5.3-6 M1037 chassis yaw rate, 6 inch bump course, 15 mph.

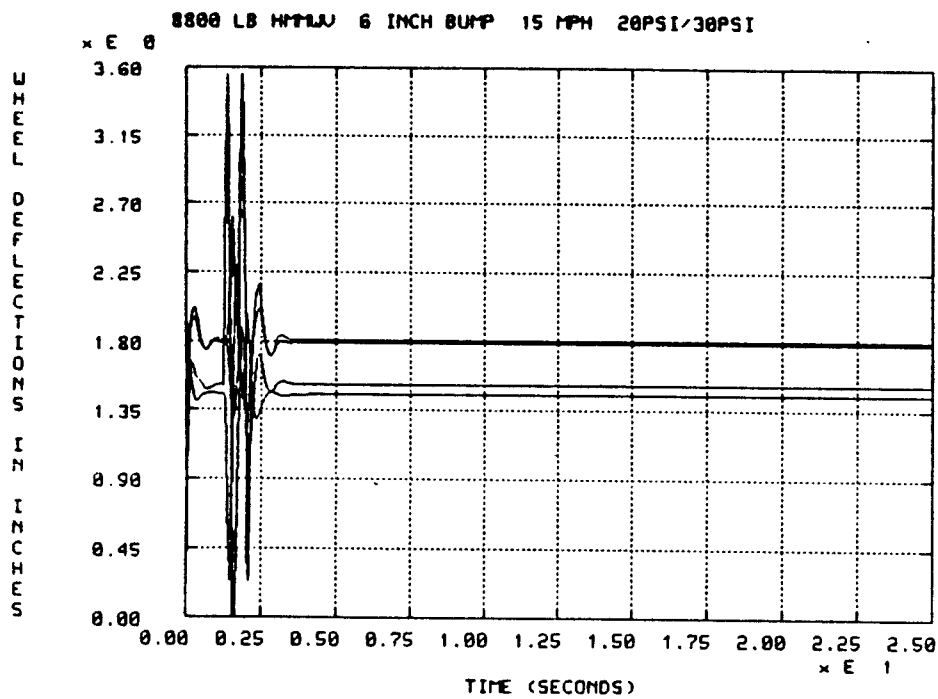


Figure 5.5.3-8 M1037 wheel deflection, 6 inch bump course, 15 mph.

5.5.4. Maneuvering on an Inclined Slope

100 ft by 12 ft lane change vehicle simulations were generated for both a 15% and 29% down hill grade, and 15% side slope. Steady turning of the vehicle in a 500 ft radius turn on a 15% inclined slope was also simulated. Table 5.5.4-1 shows the peak values generated by the simulations. The vehicle became unstable during the 45 mph 15% side slope lane change maneuver. The vehicle was also marginally stable during the 60 mph 29% downhill lane change maneuver.

Table 5.5.4-1 Peak values for the M1037 inclined slope simulations.

Speed	Course	Lateral Acc.	Yaw rate	Steer	Tire Def	Tire Slip
mph		g's	deg/s	deg	inches	deg
25	15% Slope turn	0.093	-4.7	1.44	2.00	0.96
50	15% Slope turn	0.092	-4.55	1.42	2.03	0.90
25	15% DH LC	0.425	-13.7	8.5	2.56	10.3
60	15% DH LC	0.396	-11.0	5.2	2.30	6.5
25	29% DH LC	0.153	-8.2	2.9	2.08	2.18
60	29% DH LC	-0.32	10.7	-6.3	2.46	7.6
25	15% SS LC	0.159	8.7	-4.06	2.26	-3.56
35	15% SS LC	0.21	8.65	-6.3	2.35	-7.4
40	15% SS LC	0.257	-11.1	-8.4	2.53	-9.5

5.6. M1037/M101 Simulation Results

In this part, the stability of the M1037 truck and M101 trailer was examined for the maneuvers described in section 5.5.

5.6.1. Lane Change

In this part, the M1037/M101 is required to negotiate a 100 ft by 12 ft lane change maneuver. See Figure 5.4-1. Table 5.6.1-1 shows peak values from the simulation results. The vehicle had no difficulty negotiating the maneuver for speeds of up to 60 mph. Figures 5.6.1-1 through 5.6.1-8 show the simulation output for the 60 mph maneuver.

Table 5.6.1-1 Peak values for the M1037/M101 100 ft by 12 ft lane change simulations.

Speed	Truck/Traller Lateral Acc.	Truck/Traller Yaw rate	Articulation angle	Steer	Tire Def	Tire Slip
mph	g's	deg/s	deg	deg	inches	deg
25	-0.116/ 0.138	6.2/6.9	-2.02	-1.85	2.56/2.36	2.56
60	-0.270/-0.495	10.3/21.5	-4.6	-2.06	2.63/2.34	4.4

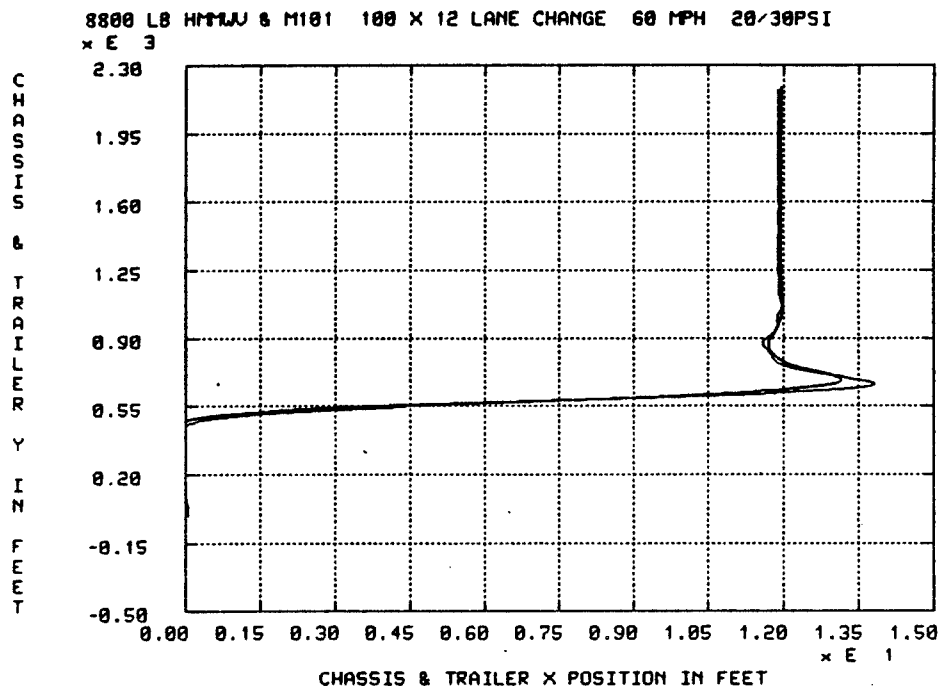


Figure 5.6.1-1 M1037/M101 CG position for a 100 ft by 12 ft 60 mph lane change.

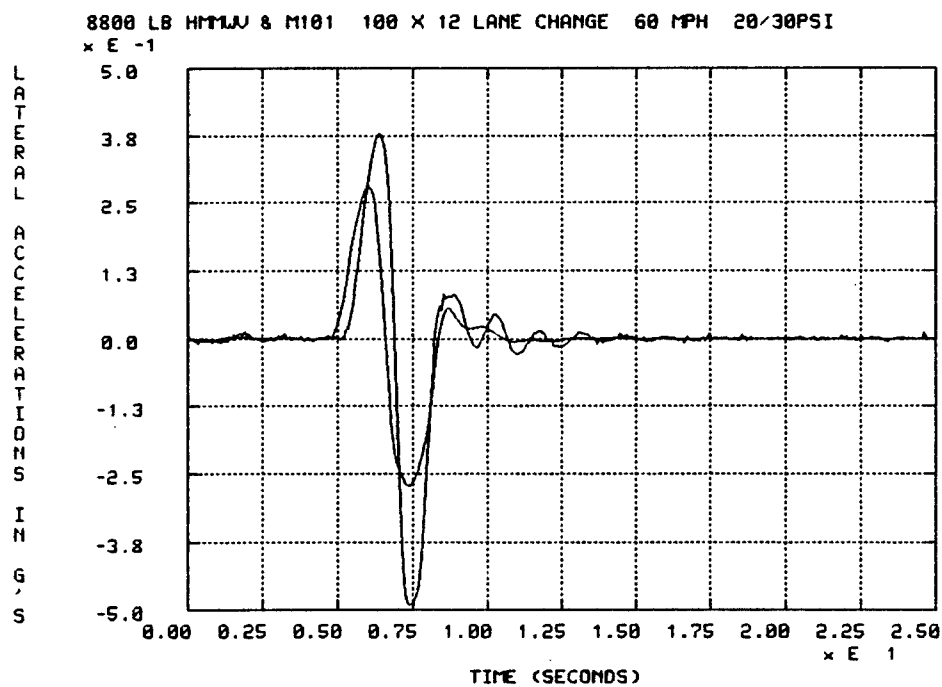


Figure 5.6.1-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 100 ft by 12 ft 60 mph lane change.

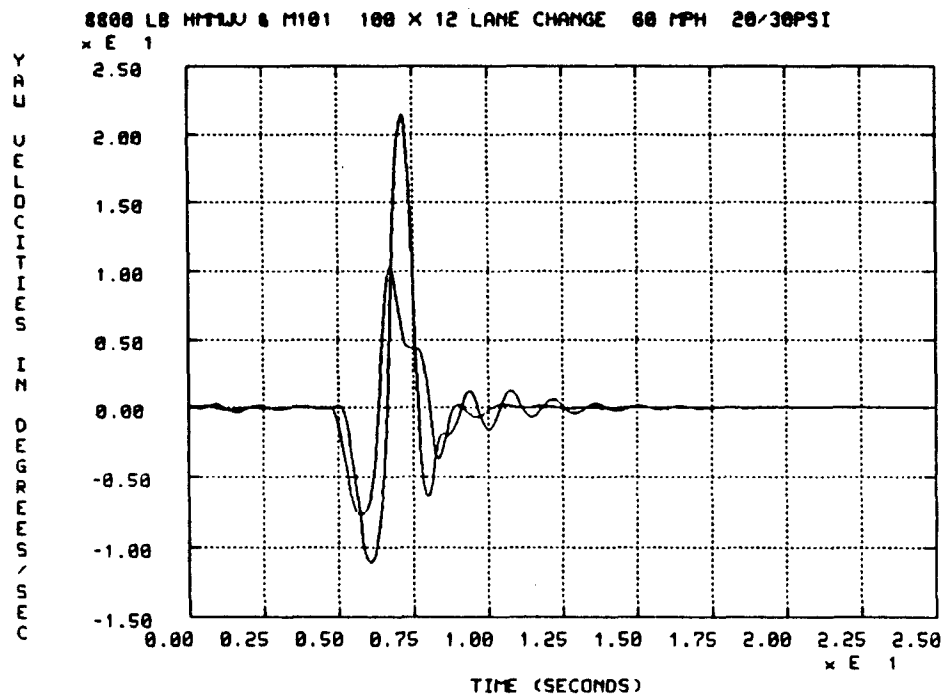


Figure 5.6.1-3 M1037/M101 yaw rate for a 100 ft by 12 ft 60 mph lane change.

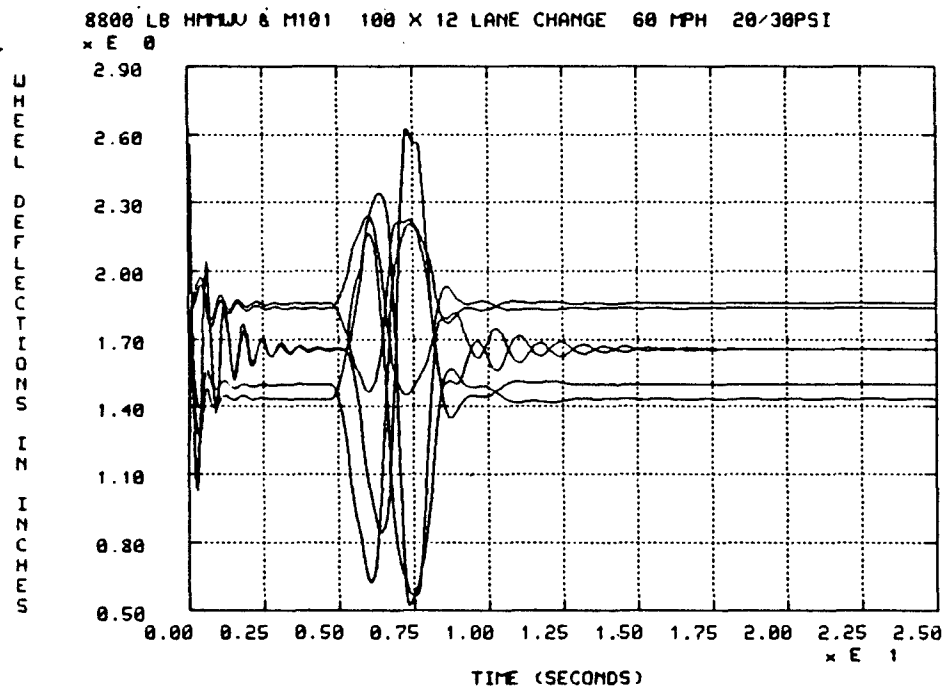


Figure 5.6.1-4 M1037/M101 vertical tire deflections for a 100 ft by 12 ft 60 mph lane change.

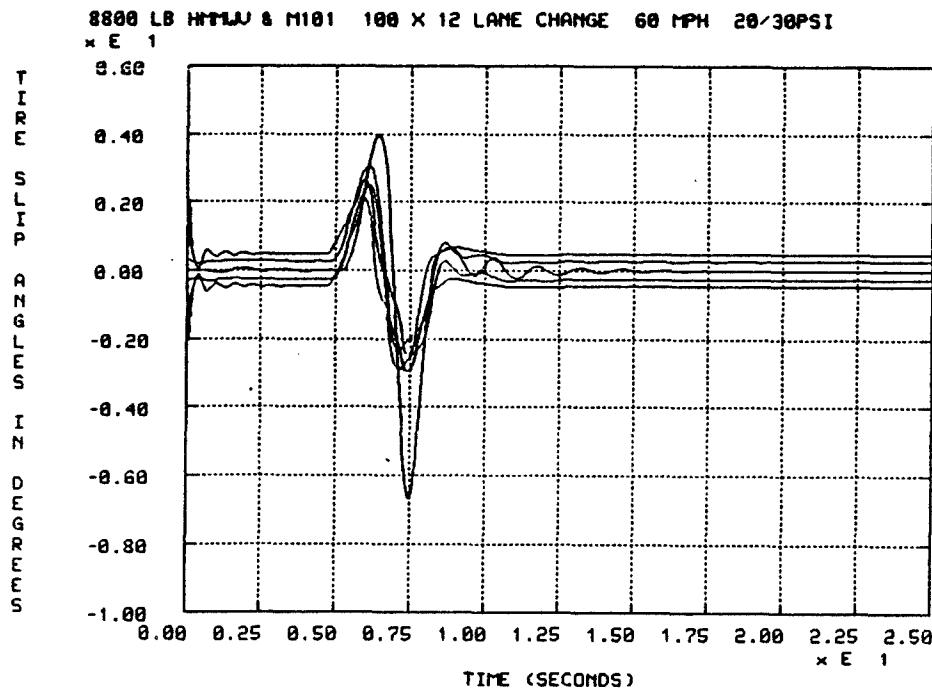


Figure 5.6.1-5 M1037/M101 tire slip angles for a 100 ft by 12 ft 60 mph lane change.

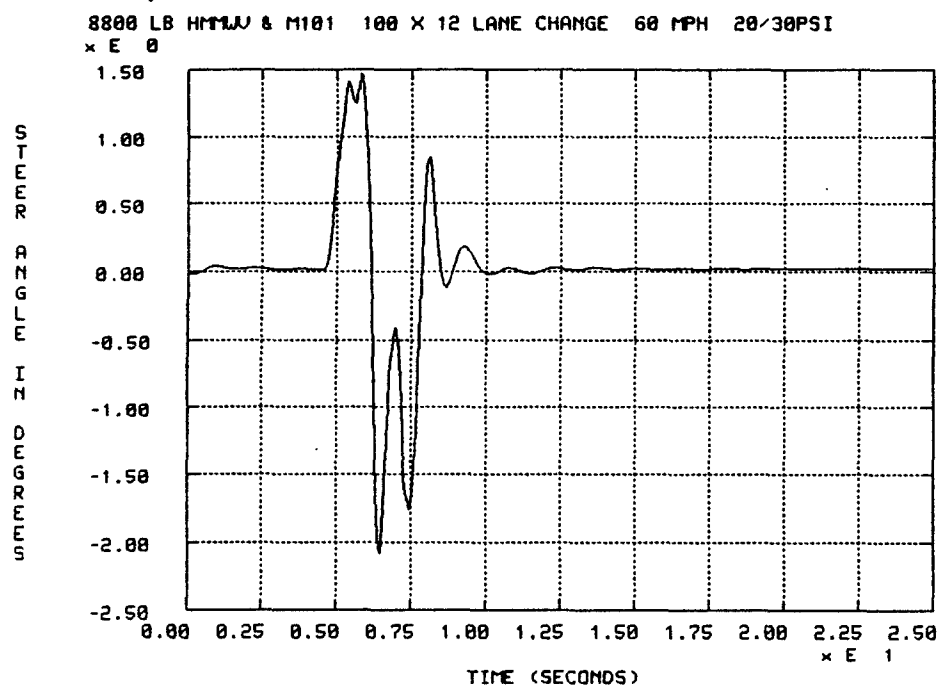


Figure 5.6.1-6 M1037/M101 steer angle for a 100 ft by 12 ft 60 mph lane change.

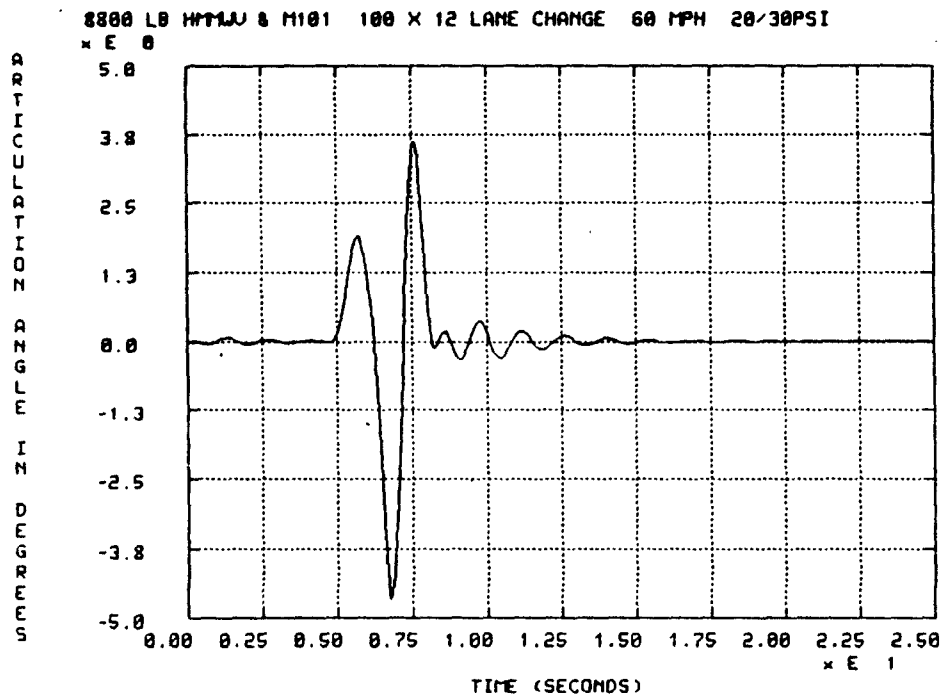


Figure 5.6.1-7 M1037/M101 articulation angle for a 100 ft by 12 ft 60 mph lane change.

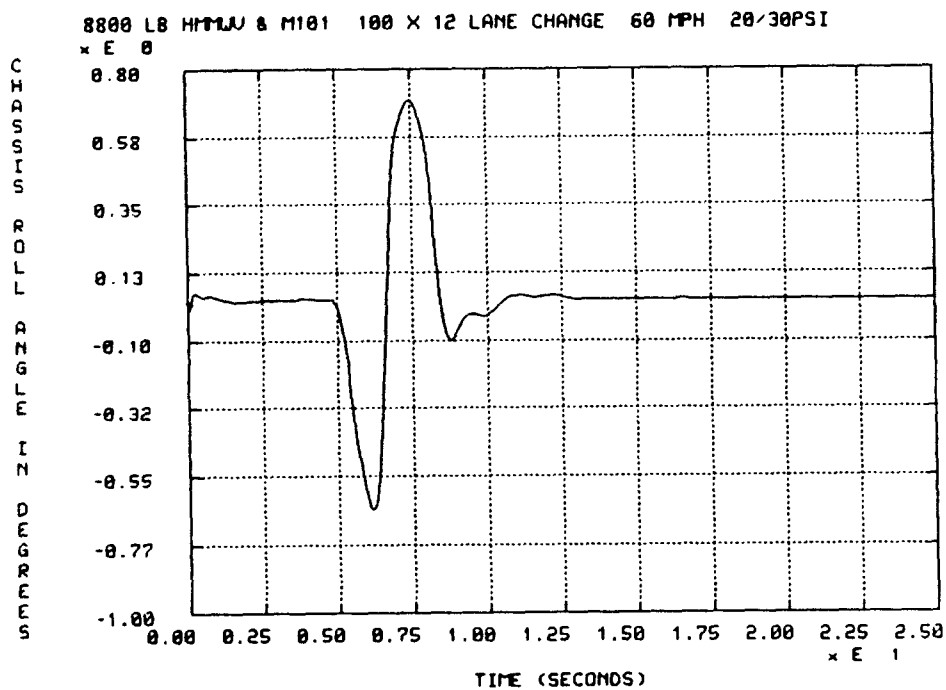


Figure 5.6.1-8 M1037/M101 roll angle for a 100 ft by 12 ft 60 mph lane change.

5.6.2. Steady Turn

In this part, the M1037/M101 system was required to perform a 500 foot radius steady turn maneuver. Figures 5.6.2-1 through 5.6.2-8 show the simulation results for a vehicle speed of 45 mph. At 50 mph the vehicle became unstable. Figure 5.6.2-8 shows the roll of the vehicle and trailer chassis relative to their respective suspensions. Note in Figure 5.6.2-4 that the front left tire deflection is close to zero indicating loss of traction in the front suspension. Results from the 50 mph simulation showed the front left tire lost traction completely. This phenomenon produced yaw divergence of the system, which eventually made the trailer roll over.

Table 5.6.2-1 Peak values for the M1037/M101 500 ft radius steady turn simulations.

Speed	Truck/Trailer Lateral Acc.	Truck/Trailer Yaw rate	Truck/Trailer Articulation angle	Steer	Truck/Trailer Tire Def	Truck/Trailer Tire slp
mph	g's	deg/s	deg	deg	inches	deg
25	0.090/ 0.099	-4.52/-4.55	1.38	1.38	1.94/2.57	1.3/ 0.67
40	0.278/ 0.302	-9.2/-10.2	2.0	2.4	2.55/2.55	2.89/ 2.92
45	0.309/ 0.403	-11.2/-12.8	2.28	4.15	2.56/2.35	4.90/ 4.05
50	(unstable)					

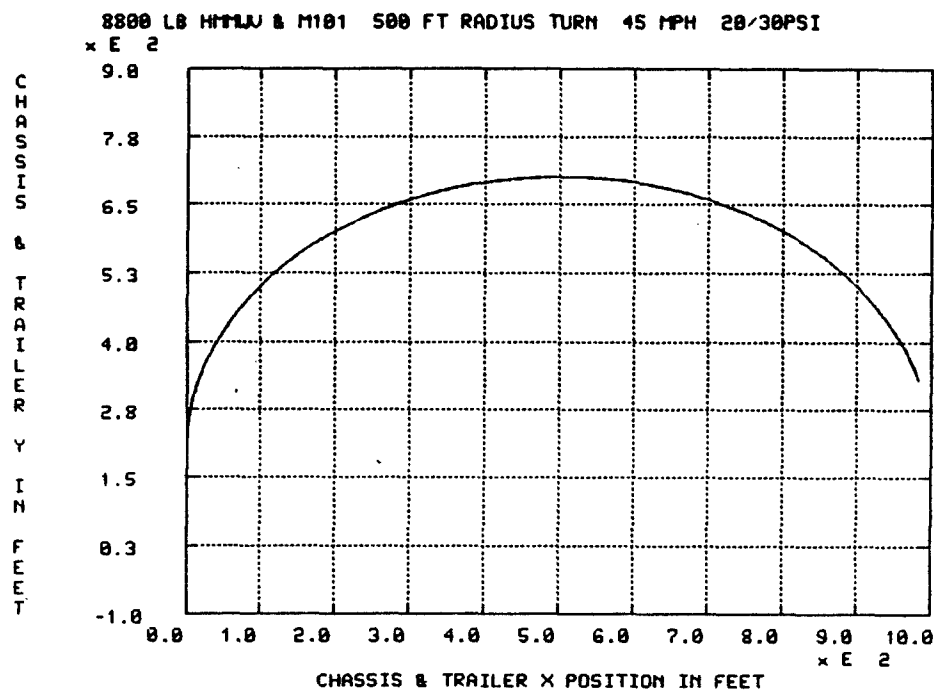


Figure 5.6.2-1 M1037/M101 CG position for a 500 ft radius steady turn simulation, 45 mph.

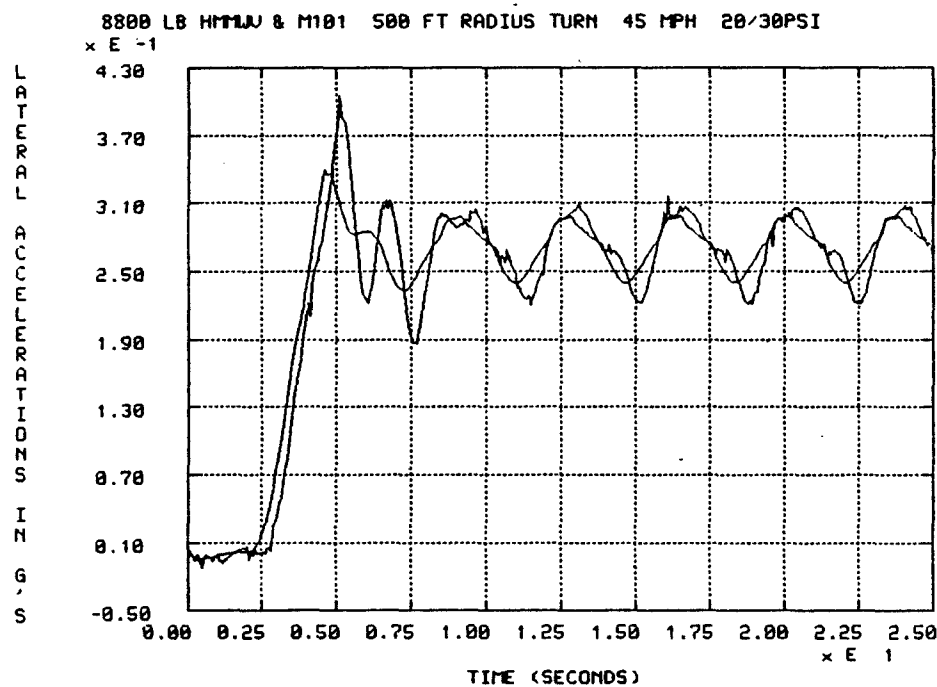


Figure 5.6.2-2 M1037/M101 CG Lateral acceleration of vehicle CG for a 500 ft radius steady turn simulation, 45 mph.

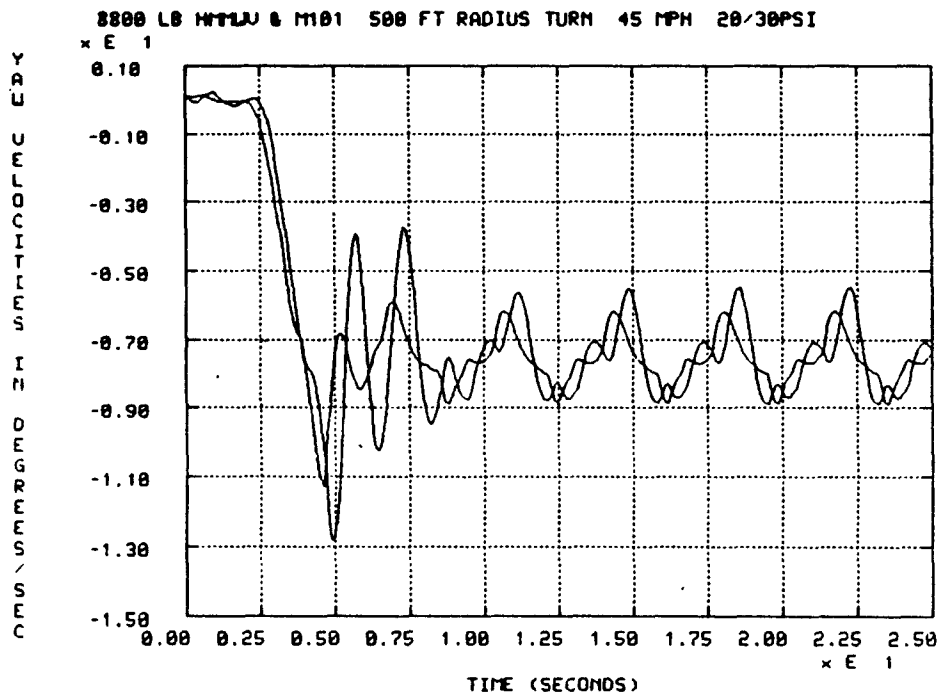


Figure 5.6.2-3 M1037/M101 yaw rate for a 500 ft radius steady turn simulation, 45 mph.

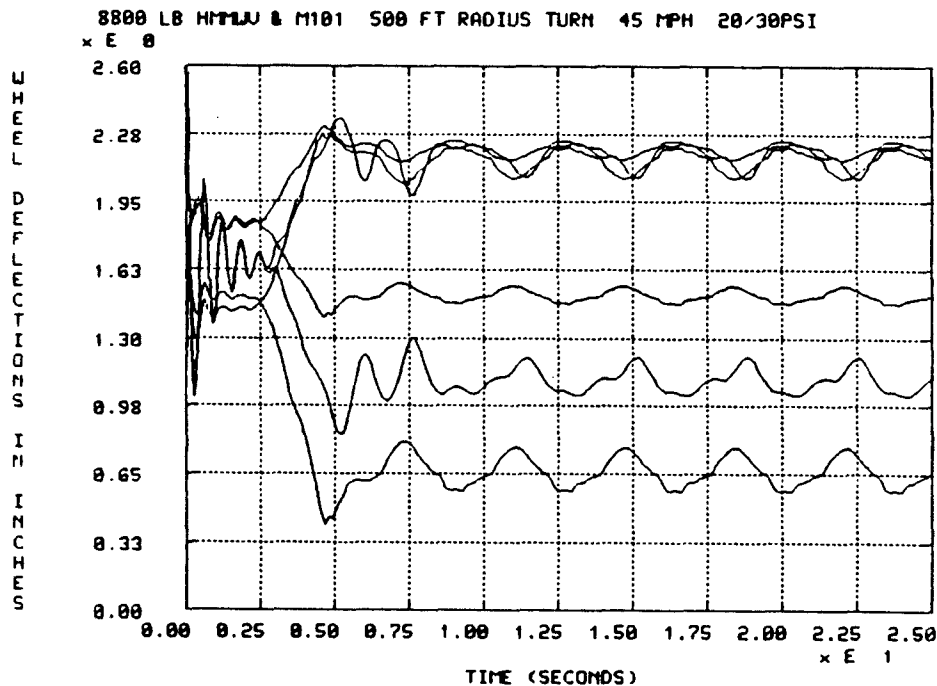


Figure 5.6.2-4 M1037/M101 vertical tire deflections for a 500 ft radius steady turn simulation, 45 mph.

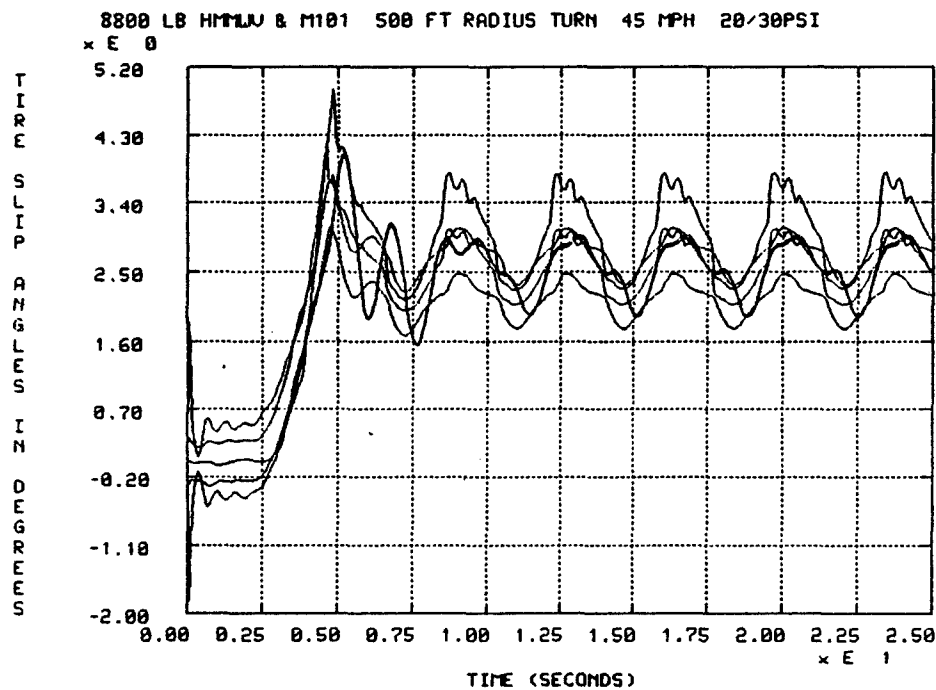


Figure 5.6.2-5 M1037/M101 tire slip angles for a 500 ft radius steady turn simulation, 45 mph.

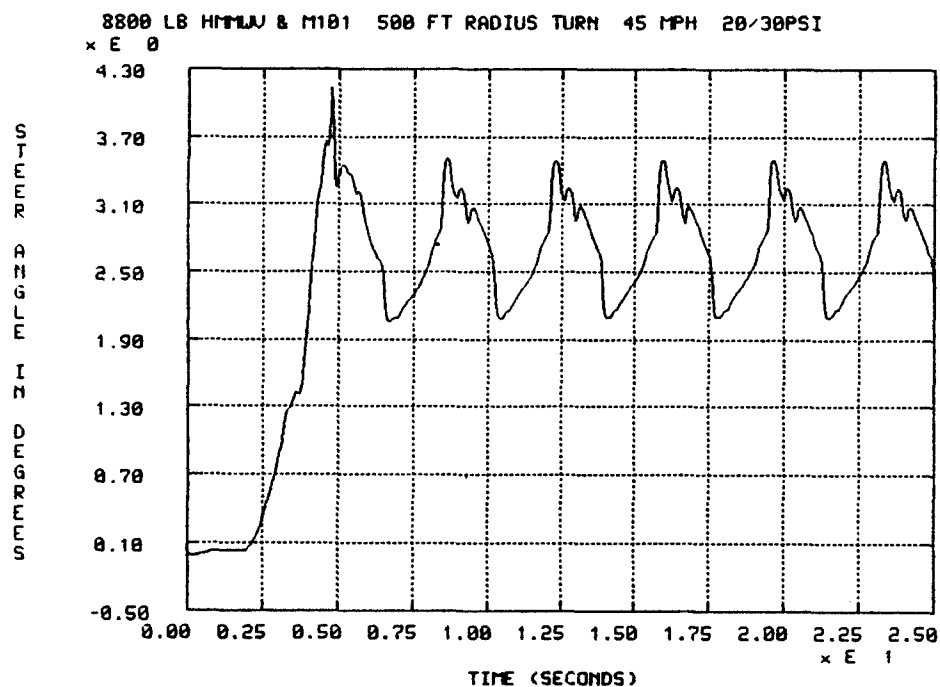


Figure 5.5.1-6 M1037/M101 steer angle for a 500 ft radius steady turn simulation, 45 mph.

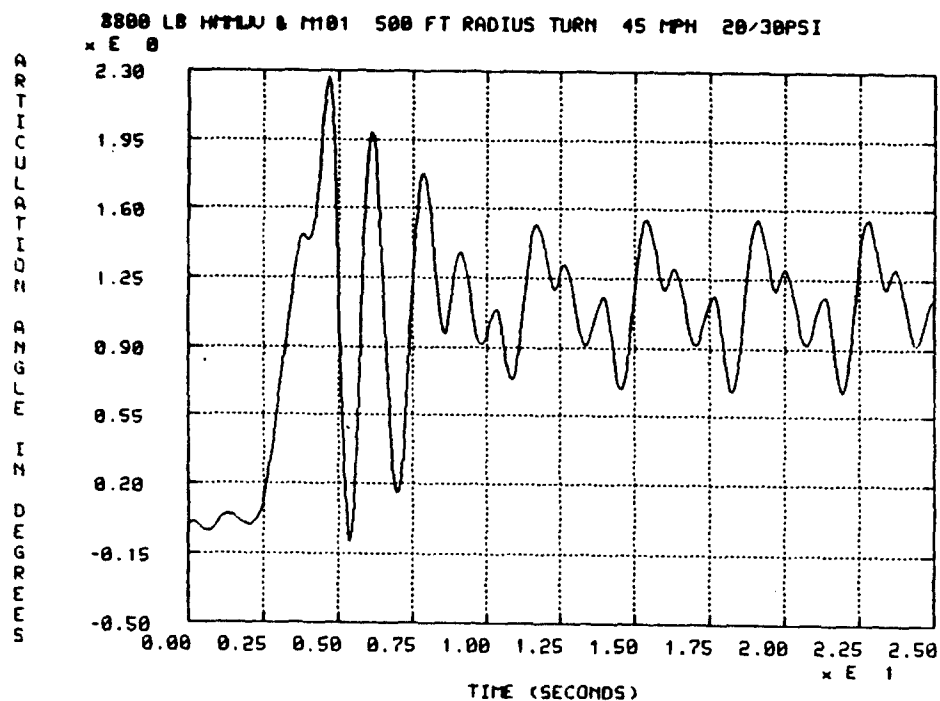


Figure 5.6.2-7 M1037/M101 articulation angle for a 500 ft radius steady turn simulation, 45 mph.

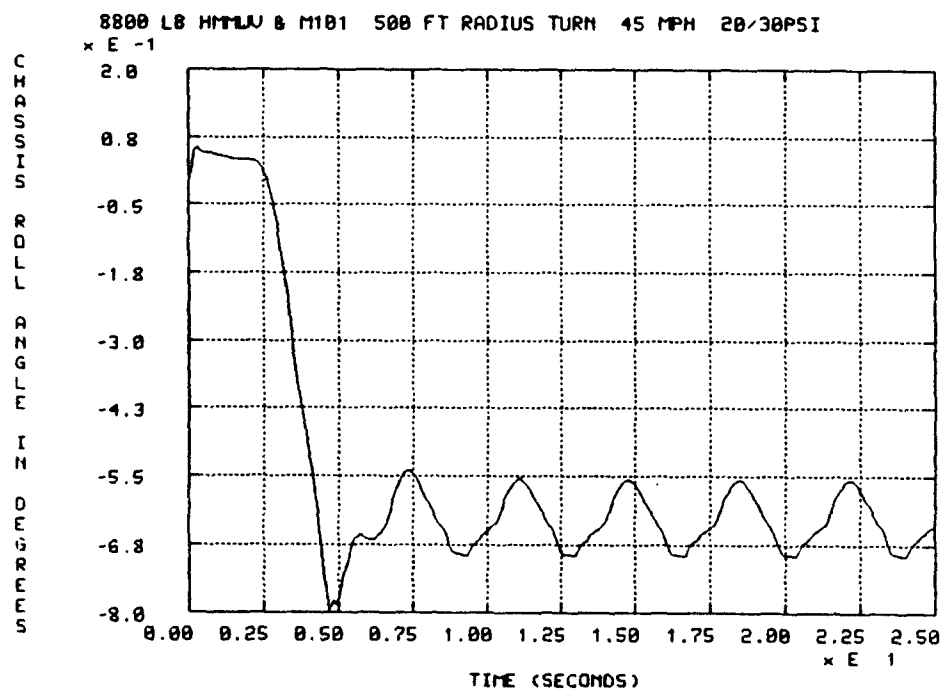


Figure 5.6.2-8 M1037/M101 Chassis roll angle for a 500 ft radius steady turn simulation, 45 mph.

5.6.3. Bump Course

In this part the M1037/M101 system was driven over the 6 inch bump course described in section 5.4. Table 5.6.3-1 shows the peak response values produced from the simulation. The simulation results showed that the vehicle could negotiate the bump course at speeds of up to 55 mph. However, Table 5.6.3-1 showed that the trailer response was violent at speeds of between 10 mph and 20 mph. This phenomenon was also observed in the validation tests described in section 5.4.2. Even though the simulation did not show that the trailer rolled over, there is still a good chance that the system may be unsafe for off road operation at speeds above 10 mph. Figures 5.6.3-1 through 5.6.3-9 show the results for 15 mph bump course simulation.

Table 5.6.3-1 Peak values for the M1037/M101 bump course simulations.

Speed	Truck/Trailer Lateral Acc.	Truck/Trailer Vertical acc.	Truck/Trailer roll	Articulation angle	Truck/Trailer Tire Def	Suspension roll
mph	g's	deg/s	deg	deg	inches	deg
10	-0.130/ 0.33	2.25/-5.5	-0.4/-7.85	-0.97	3.59/2.72	0.97
15	-0.090/ 0.475	3.4/-7.9	-1.4/-8.8	-1.62	3.53/2.55	1.13
20	0.110/ 0.46	3.9/ 9.8	-3.2/ 10.0	-2.2	3.75/2.78	1.32
25	0.100/ -0.5	-10.9/ 2.6	0.7/-7.1	-1.98	3.85/2.60	1.54
35	0.135/-0.495	-3.1/-13.5	0.65/-5.3	1.48	4.45/3.18	1.30
55	0.09/-0.54	-3.4/-9.7	-0.49/-4.18	1.34	4.72/2.55	1.02

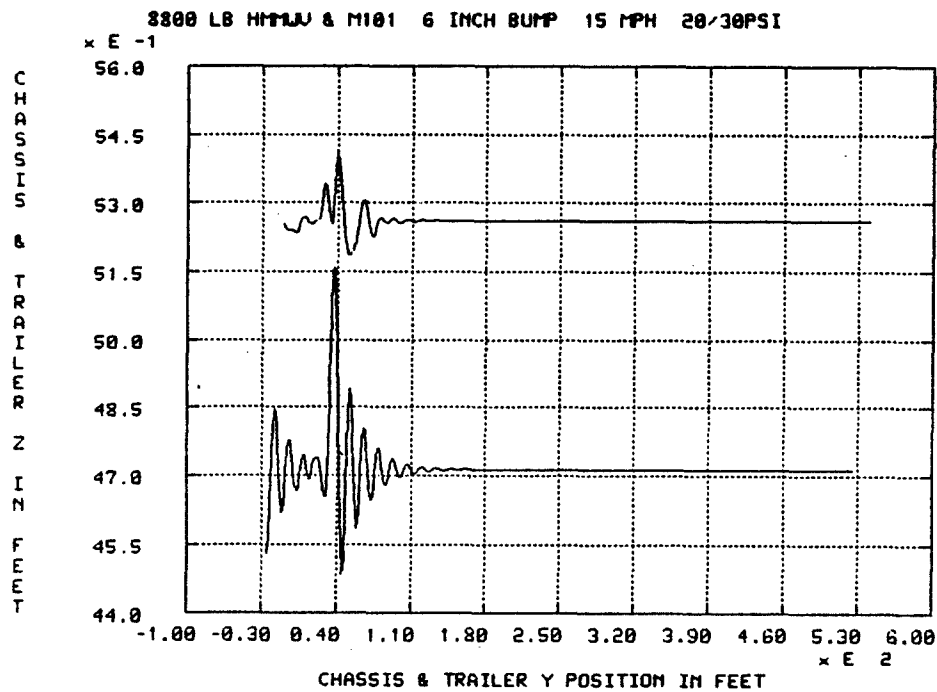


Figure 5.6.3-1 M1037/M101 CG position for the 6 inch bump course simulation, 15 mph.

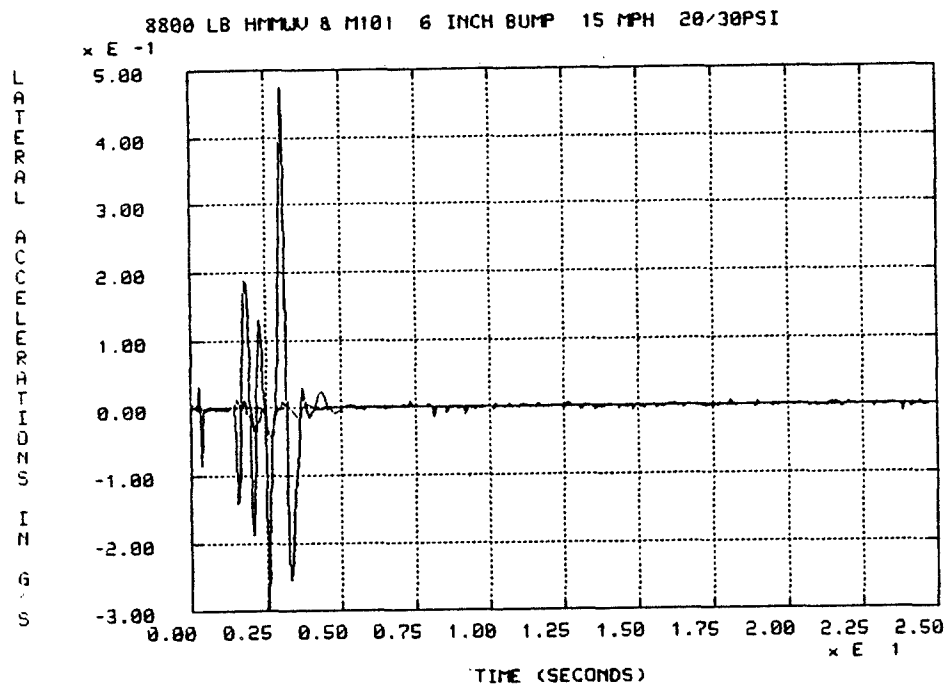


Figure 5.6.3-2 M1037/M101 CG Lateral acceleration of vehicle CG for the 6 inch bump course simulation, 15 mph.

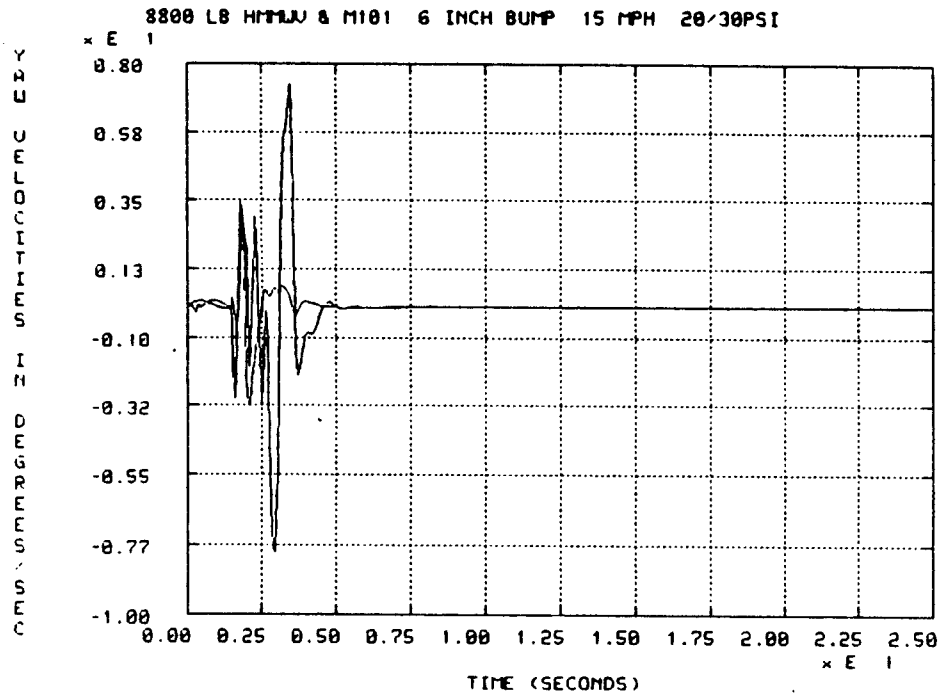


Figure 5.6.3-3 M1037/M101 yaw rate for the 6 inch bump course simulation, 15 mph.

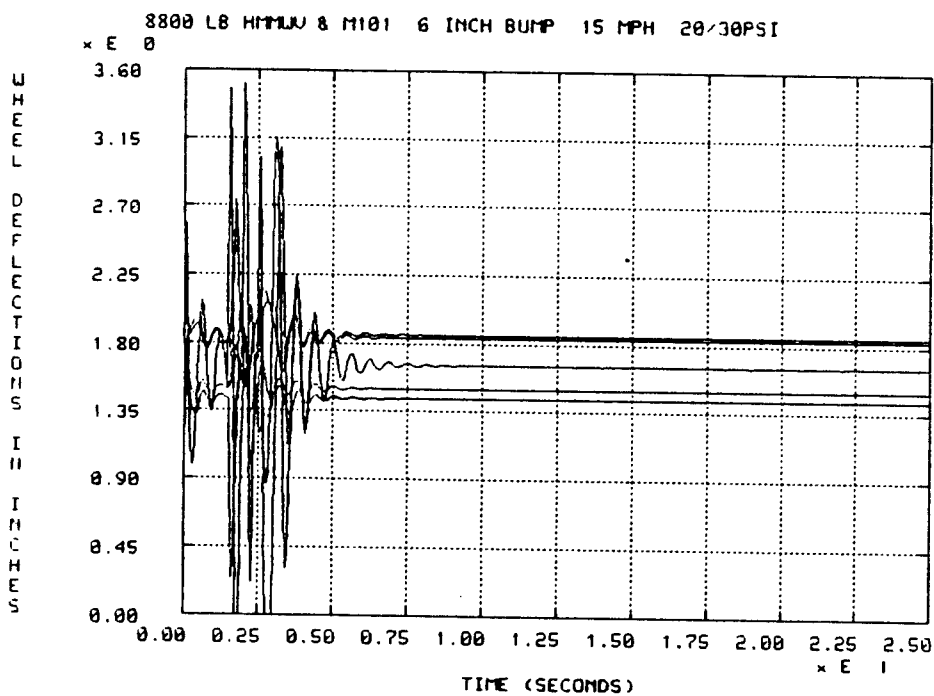


Figure 5.6.3-4 M1037/M101 vertical tire deflections for the 6 inch bump course simulation, 15 mph.

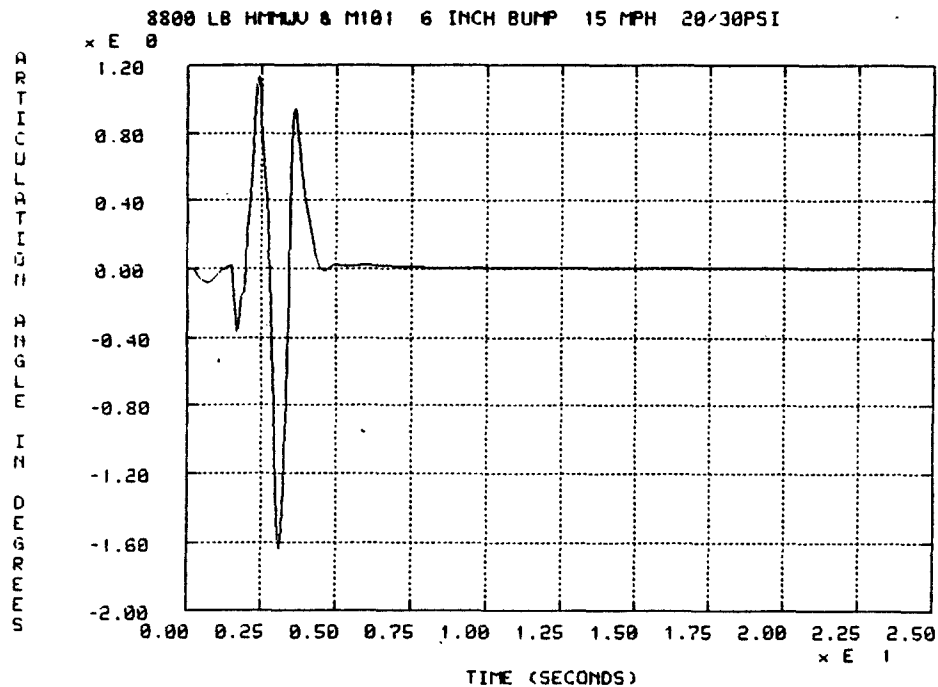


Figure 5.6.3-5 M1037/M101 articulation angle for the 6 inch bump course simulation, 15 mph.

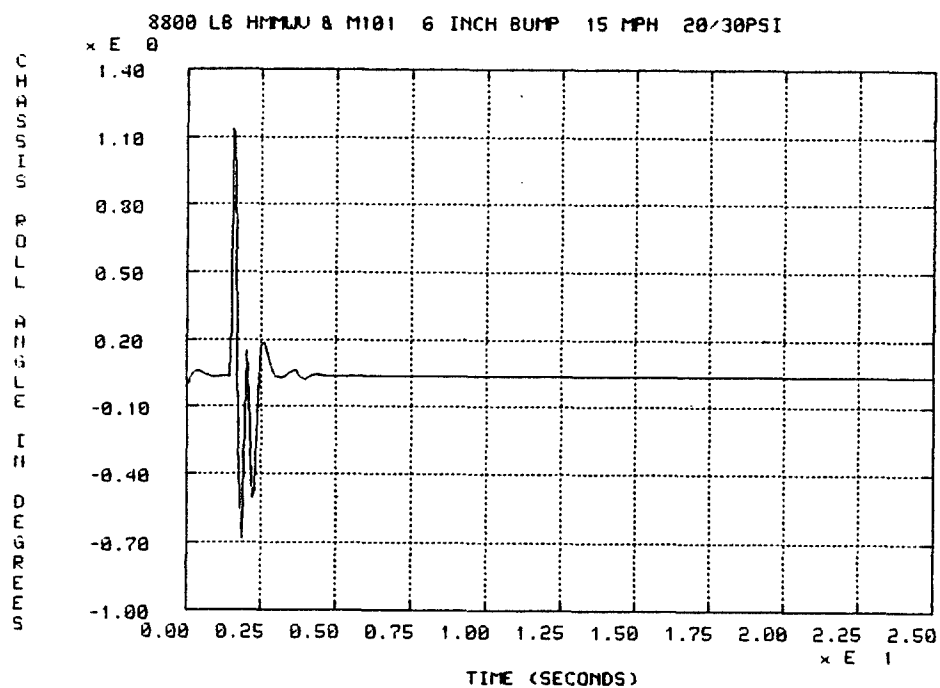


Figure 5.5.3-6 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph.

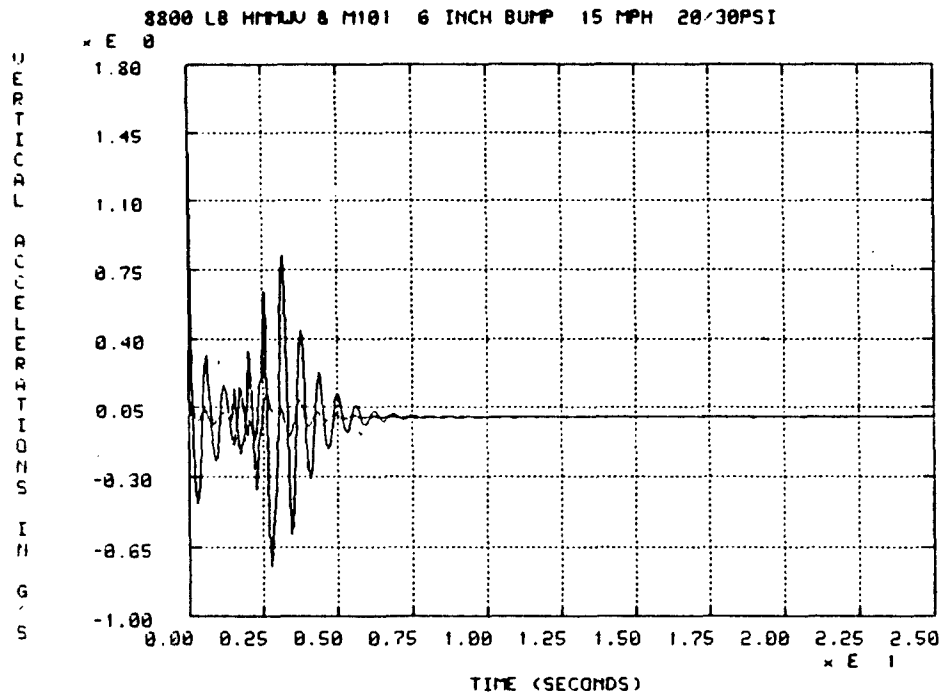


Figure 5.6.3-7 M1037/M101 chassis CG vertical acceleration for the 6 inch bump course simulation, 15 mph.

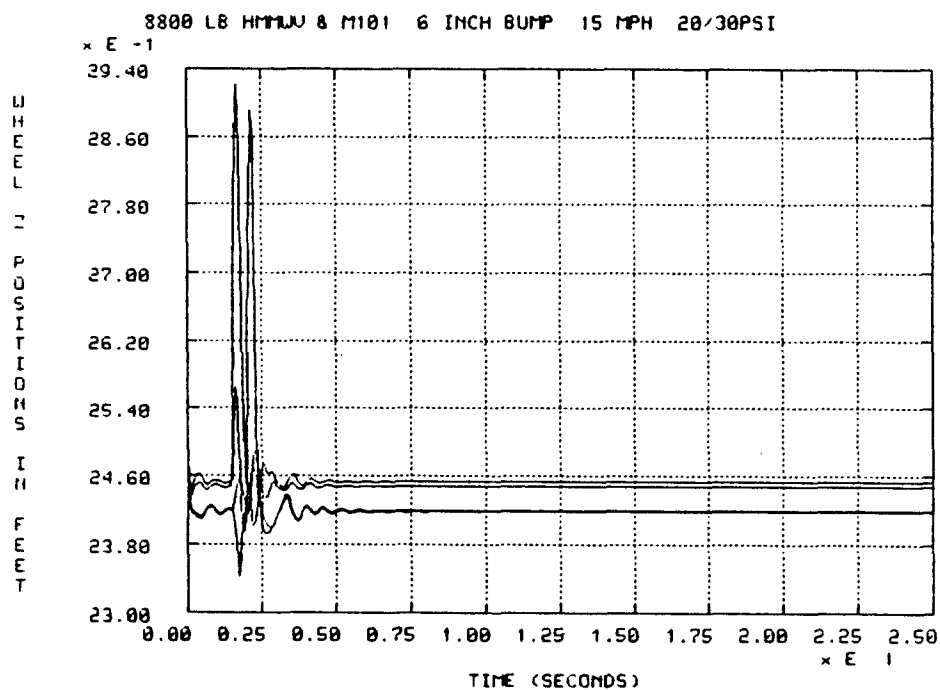


Figure 5.6.3-8 M1037/M101 vertical wheel position for the 6 inch bump course simulation, 15 mph.

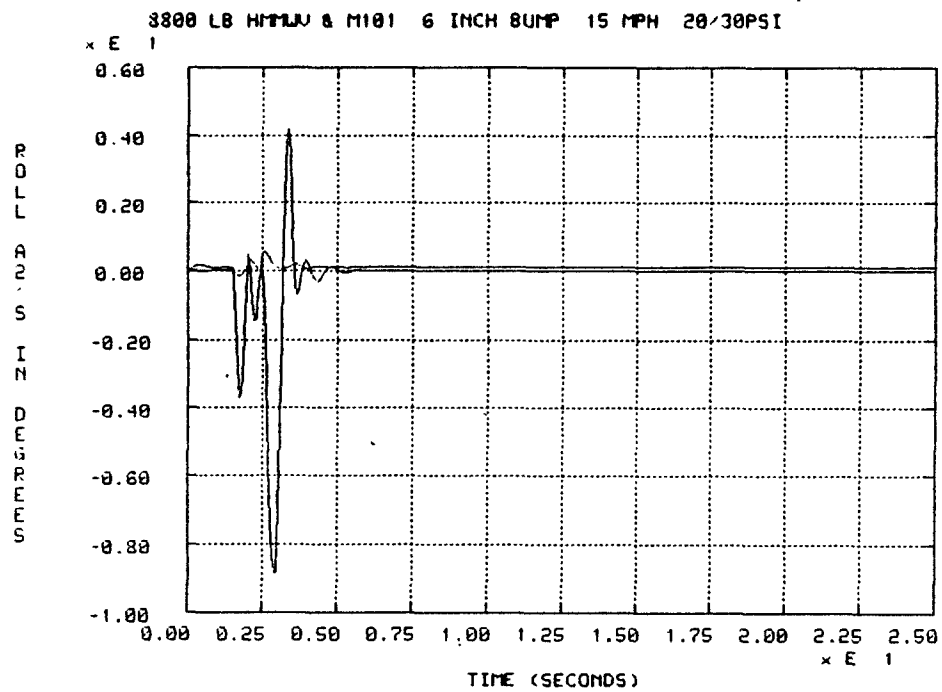


Figure 5.6.3-9 M1037/M101 chassis roll angle for the 6 inch bump course simulation, 15 mph.

5.5.4. Maneuvering on an Inclined Slope

In this part, the vehicle was subjected to a 100 ft by 12 ft lane change maneuver on down hill grades of 15% and 29%. Table 5.6.4-1 shows the peak values of the simulation results. The 15% down hill slope results showed no instability. However, they did show slightly higher peak response values. Compare the values in tables 5.6.4-1 and 5.6.1-1. The 29% down hill simulations exhibited more unusual behavior. Out of all the simulation runs conducted on the 29% slope, the 15 mph showed the highest peak dynamic response.

Table 5.6.4-1 Peak values for the M1037/M101 inclined slope lane change simulations

Speed	Course	Truck/Trailer Lateral Acc.	Truck/Trailer Yaw rate	Truck/ Trailer Art. angle	Steer	Truck/Trailer Tire Slip
mph		g's	deg/s	deg	deg	deg
25	15% DH LC	-0.116/-0.138	6.2/ 6.9	-2.08	-2.0	2.42/ 1.1
60	15% DH LC	-0.221/-0.365	2.56/ 2.34	3.55	-2.68	-4.4/-3.8
15	29% DH LC	-0.300/ 0.430	11.0/ 19.0	5.0	12.0	-
25	29% DH LC	-0.335/-0.255	-9.8/ 16.1	-3.15	-10.9	-12.1/2.8
60	29% DH LC	0.178/0.244	-4.1/-7.6	-1.81	3.29	4.81/2.89

5.7. Analytical results

5.7.1. Yaw Plane Modeling

For this analysis, the vehicle is assumed to experience only planar motion. Only yaw, lateral, and fore-aft motion of the system is allowed. Roll, pitch and vertical motion is not considered to take place. Figure 5.7.3-1 shows a plane view of a two axle truck towing a single axle trailer. This Figure shows a system which has four degrees of freedom, including the forward, lateral, and yaw motion of the truck, and the articulation of the trailer with respect to the truck.

The tire behavior in the yaw plane case is simpler than the spatial mode presented in section 5.1. The vertical tire load, aligning moment, and traction forces are neglected. Furthermore, in the spatial case, the tires' lateral force characteristics are a function of vertical load, while the yaw plane approach assumes the lateral force is only dependent upon the slip angle and it is independent of the vertical force. This assumption limits the application of yaw plane to quasi-static situations, i.e., straight line motion or fixed radius turns at a steady speed.

The yaw plane dynamic equations of motion for the truck/trailer system are derived in [9]. The general form of the equations is

$$\mathbf{M}(\mathbf{q}) \dot{\mathbf{u}} = \mathbf{g}(\mathbf{u}, \mathbf{q}) \quad (5.7.1-2)$$

where $\mathbf{M}$ is the n by n system mass matrix, $\mathbf{g}$ is the continuously differentiable nonlinear function of generalized and velocity dependent forces of dimension n , $\mathbf{u}$ is the generalized speed vector of dimension n , and $\mathbf{q}$ is the vector of generalized coordinates. Another form for equation (5.7-1) is

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) \quad (5.7.1-3)$$

where $\mathbf{f}(\mathbf{x}) = \mathbf{M}^{-1}(\mathbf{x}) \mathbf{g}(\mathbf{x})$, and the state vector $\mathbf{x} = [\mathbf{q} \ \mathbf{u}]^T$.

5.7.1. Inaccuracies

Possible sources of error in this analysis include: change in tire lateral force properties resulting from load transfer between tires, and nonlinear coupling between planar and neglected out of plane coordinates. The former item probably has the greatest influence on vehicle response. MacAdam [10] has shown that the nonlinear sensitivity of the truck tire cornering stiffness can contribute to yaw divergent behavior of a vehicle. Furthermore, a high vehicle center of gravity coupled with a

low roll center can produce a large amount of load transfer between tires on an axle, altering the lateral force characteristics of a tire. This change in tire behavior will modify the dynamics of the vehicle. Nominally, the vehicle equations of motion developed under the yaw plane assumptions do not allow for the phenomenon mentioned above, and thus can reach erroneous conclusions if one is not careful.

5.7.2. Linearized Equations

The most commonly used analytical method for examining the stability of a nonlinear system utilizes linearization. In this approach, the stability of small perturbations about an equilibrium point in state space is examined. The equilibrium point can be a static equilibrium, i.e. stationary object, or a quasi-static equilibrium point, i.e. vehicle traveling at a constant speed in a constant radius turn. Provided the function f in equation (5.7.1-2) is continuously differentiable, the following linearized form exists.

$$\dot{\mathbf{x}} = \mathbf{A} \mathbf{x} \quad (5.7.2-1)$$

where, $\mathbf{x}$ represents the vector of perturbations about an equilibrium point in state space, and the n by n matrix $\mathbf{A}$ is the given by

$$\mathbf{A} = \frac{\partial f(\mathbf{x})}{\partial \mathbf{x}} \quad (5.7.2-2)$$

A theorem from nonlinear systems analysis, Liapunov's first method [11], states that if the function f is continuously differentiable, an equilibrium point $\mathbf{0}$ is stable if eigenvalues of $\mathbf{A}$ have all negative real parts¹. Likewise, if the matrix $\mathbf{A}$ has at least one eigenvalue with one positive real part then the system is unstable. Since equation (5.7.1-2) is continuously differentiable, all the necessarily requirements for Liapunov's first method are met. Therefore, the quasi-static yaw stability of the vehicle and trailer system can be determined by examining the eigenvalues of $\mathbf{A}$.

Figure 5.7.3-1 shows how the eigenvalues of $\mathbf{A}$ are distributed in the complex plane. Associated with each eigenvalue is a modal vector that describes a fundamental motion. The modes that are of primary interest in this analysis are the jackknife and trailer oscillatory modes. The vehicle configuration that corresponds to the jackknife mode is shown in Figure 5.7.2-1. The oscillatory mode shown in Figure 5.7.2-2, represents an oscillation of the vehicle and trailer about the hitch.

¹ There is no loss of generality with an equilibrium point of $\mathbf{0}$, since the state vector $\mathbf{x}$ can be redefined as $\mathbf{z} = \mathbf{x} + \mathbf{x}^*$, where $\mathbf{x}^*$ is the equilibrium point, and $f(\mathbf{x}, \mathbf{u})$ can be redefined as $f(\mathbf{z} - \mathbf{x}^*, \mathbf{u})$.

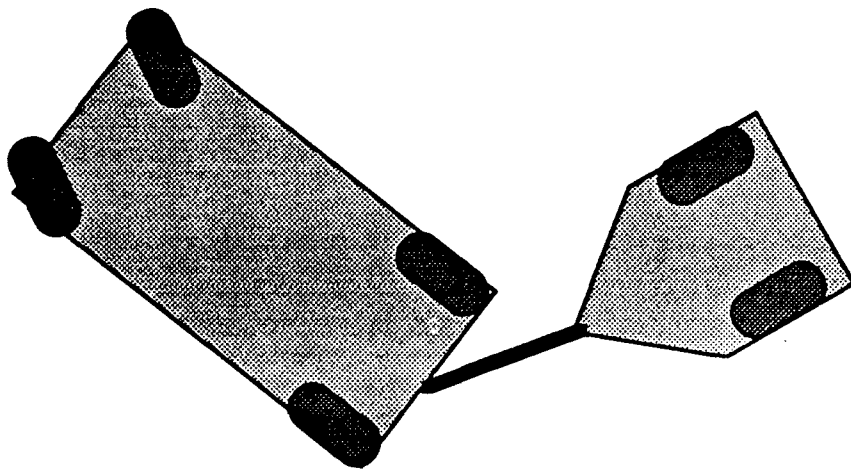


Figure 5.7.2-1 Yaw plane jackknife mode.

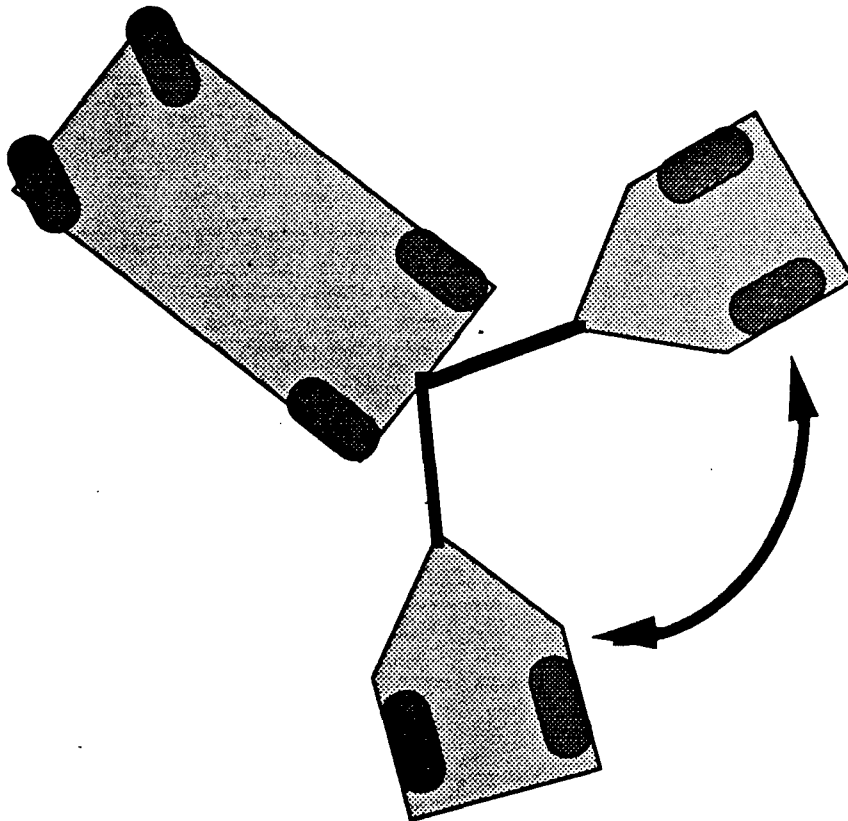


Figure 5.7.2-2 Yaw Plane articulation oscillatory mode.

5.7.3. Vehicle Stability During Forward Travel

The eigenvalues for the M1037/M101 were evaluated for straight line motion. Figure 5.7.3-1 shows the position of the eigenvalues in the complex plane. This Figure shows how the modes of oscillation move toward the right half plane as the vehicle's speed increases. Figure 5.7.3-2 shows how the damping ratio of the articulation mode decreases with increasing vehicle speed. A small amount of movement of the jackknife mode into the right half plane can be tolerated, since that mode can be controlled by the steering of the driver. However, the driver has no effective control of the articulation mode, and therefore any excitement of that mode may cause excessive trailer whip or produce vehicle instability.

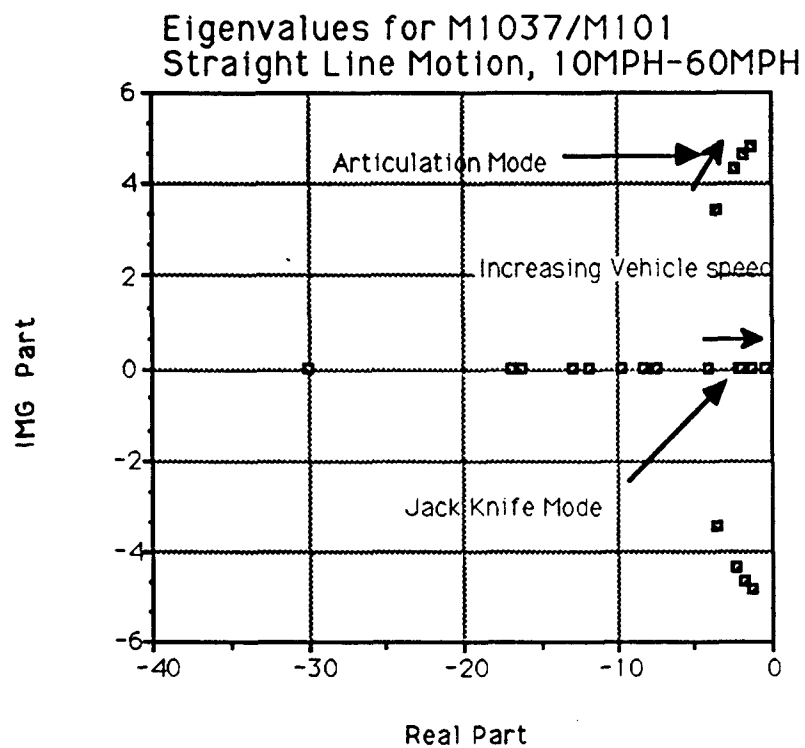


Figure 5.7.3-1 M1037/M101 eigenvalues during straight line motion.

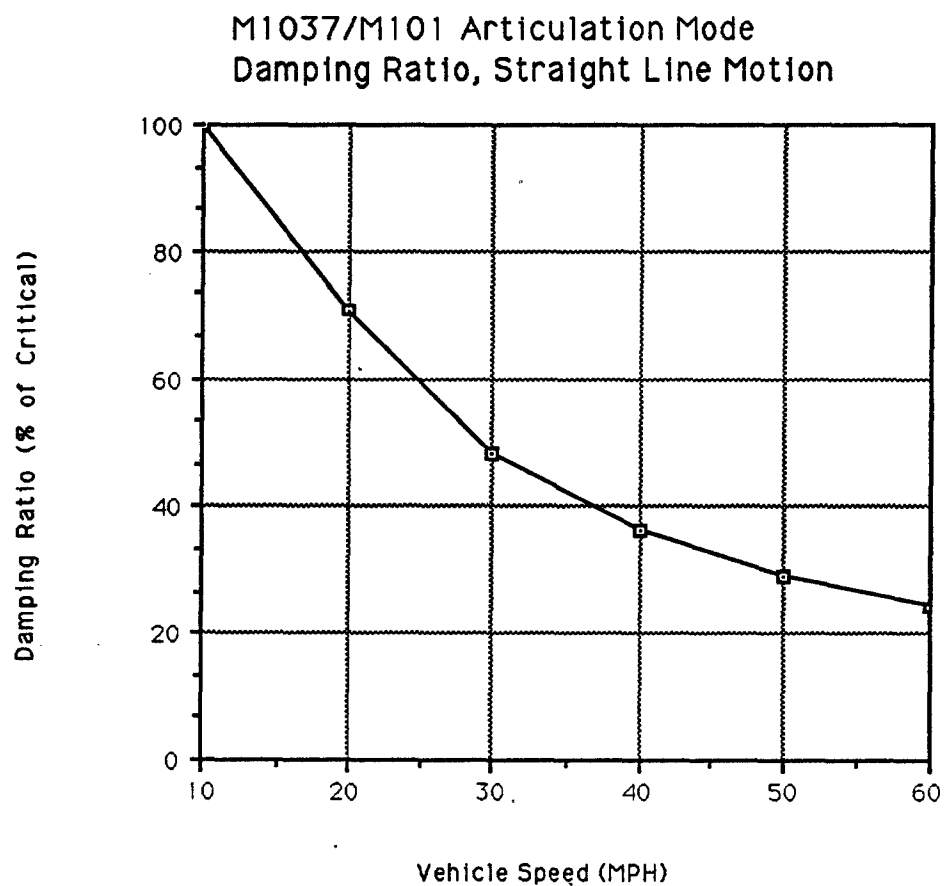


Figure 5.7.3-2 M1037/M101 articulation mode damping ratio during straight line motion.

The speed of instability predicted by the Yaw Plane model (higher than 60 mph) is greater than the speed arrived at from the multibody dynamic simulation results described in section 5.6. An explanation of why the current Yaw Plane model will not provide accurate results is presented in section 5.7.1. In the case of the M1037/M101 system, the rearward position of the vehicle CG makes the front suspension susceptible to load transfer between the front tires. Since the yaw plane model does not account for any type of load transfer between the tires, it can not predict any sort of traction loss which could produce instability. However, the Yaw plane model does provide a upper bound on the safe vehicle speed for straight line constant speed operation, and can generate very accurate results for low CG systems.

5.8. Vehicle braking

Braking tests were performed for both the truck alone and for the truck/trailer. Both straight line braking and braking in a 500 ft radius were conducted for the M1037. Braking in a 500 ft radius turn was conducted for the M1037/M101 system. All tests were performed on flat, dry pavement. No studies of vehicle braking were performed on inclined slopes or on wet pavement.

During each test, barrier cones were set up at between 125 and 200 ft from a marked line that indicated the start of braking. As with the lane change and 500 ft radius maneuvers, the driver had to maintain the vehicle in 12 foot corridor that was marked with cones. The driver had to both initiate braking at the start line and to stop short of the barrier cones. The tests were repeated several times (between 5 and 14) with the barrier cones positioned at random distances between 125 and 200 ft. The cones were moved when the driver was out of viewing range. This precaution prevented the driver from anticipating barrier cone placement.

5.8.1. M1037 Braking Results

Table 5.8.1-1 presents the straight line braking test results. All tests were performed on level, dry pavement, and the brakes were not inspected for wear or adjustment. No vehicle instability was observed in any of the tests.

Table 5.8.1-1 Results from M1037 braking tests.

Test ID	Speed	Comments
203	50	Straight braking, 143 ft stopping distance.
204	50	Straight braking, 120 ft stopping distance, short brake lock front, and rear.
205	50	Straight braking, 170 ft stopping distance.
206	50	Straight braking, 195 ft stopping distance.
207	50	Slight vehicle draft to right, 130 ft stopping distance, all locked. Brake locking started 14 ft into maneuver.
208	50	Straight braking, 140 ft stopping distance.
209	50	Straight braking, 150 ft stopping distance.
210	50	Straight braking, 200 ft stopping distance, slight brake lock at end.
211	50	Straight braking, 170 ft stopping distance
212	50	Straight braking, 150 ft stopping distance.
213	50	Straight braking, 200 ft stopping distance.
214	50	Straight braking, 125 ft stopping distance, front and rear brakes locked.
215	50	Straight braking, 145 ft stopping distance.
216	50	Straight braking, 175 ft stopping distance.

5.8.2. M1037/M101 Braking Results

Table 5.8.2-1 shows the results from the 500 radius turn braking tests. A reaction brake was installed and was operational in the trailer provided for these tests. No vehicle instability was observed during the braking tests. All tests were conducted on level, dry pavement.

Table 5.8.2-1 Results from the M1037/M101 braking tests.

Test ID	Speed	Comments
303	45	180 ft stopping distance, one wheel locked up.
304	45	220 ft stopping distance.
305	50	170 ft stopping distance.
306	50	180 ft stopping distance, vehicle locked up all four brakes. Over 50 ft of skid marks.
307	50	143 ft stopping distance.
308	50	169 ft stopping distance.
309	50	147 ft stopping distance. Intermittent brake lockup, 25 ft of skid marks.
310	48	145 ft stopping distance.

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- [7] Ervin, R.D. *et al.*, "Effects of Tire Properties on Truck and Bus Handling" Final Report Contract No. DOT-HS-4-00943, University of Michigan Transportation Res. Inst., Univ. of Mich., Rept. No. UM-HSRI-76-11-3, December 1976.
- [8] McRuer, D. T., *et al.*, "New Approaches to Human-Pilot/Vehicle Analysis," Systems Technology, Inc., Technical Report, AFFDL-TR-67-150, February 1968.
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- [10] MacAdam, C. C., "Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis," Interim Technical Report Contract DAAE07-85-C-R069, University of Michigan Transportation Research Institute, July 1986.
- [11] Vidyasagar, M., *Nonlinear Systems Analysis*, Prentice Hall, Englewood Cliffs, N.J., 1978.

APPENDIX A

Test Plan for Road Testing



The University of Michigan
Transportation Research Institute
2901 Baxter Road, Ann Arbor, Michigan 48109-2150

March 30, 1988

U.S. Army Tank-Automotive Command
AMSTA-ZSA Attn: Mr. Ric Mousseau
Warren, MI 48397-5000

Subj: Development of Driver/Vehicle
Steering Interaction Model for
Dynamic Analysis, DAAE07-85-C-R069

Dear Mr. Mousseau:

Enclosed with this letter for your review and approval is a copy of the Vehicle/Driver Test Plan for upcoming tests of the HMMWV to be performed at the Chrysler Proving Grounds. Also enclosed is a revised set of charts updating the planned expenditures for the project through its completion in September. An additional \$15,000 of project funding is included in these projections to cover the costs of the trailer testing and other analyses you requested. The May expenditures include an estimate of approximately \$7000 (including University indirect costs) for renting the Chrysler Proving Grounds (Vehicle Dynamics Facility) for about 6 full days.

Sincerely yours,

Charles C. MacAdam
Project Director

xc: D. M. Maxinoski
J. Thomson
R. Ervin
P. Fancher
C. Winkler

Vehicle / Driver Test Plan

Task A -- Instrumenting and Preparation of the Test Vehicle

The test vehicle will be the four-wheeled HMWWV operating in a low center-of-gravity configuration. A small payload will be carried to help locate the fore-aft position of the vehicle center-of-gravity. The vehicle will be instrumented with appropriate transducers and the UMTRI data acquisition package to measure the following signals and vehicle responses:

- Lateral Acceleration
- Longitudinal Acceleration
- Vehicle Velocity
- Yaw Rate
- Roll Rate
- Front Wheel Steer Angle(s)
- Steering Wheel Angle
- Brake Pedal Pressure

The UMTRI stable platform will be used to measure the lateral and longitudinal accelerations as well as the yaw and roll rates. A conventional fifth wheel will be used to measure forward velocity. Front wheel angles will be measured with linear potentiometers; driver steering wheel angle with a rotary potentiometer; and driver brake pedal force with an hydraulic pressure transducer.

Task B -- Vehicle Weight & Length Measurements

The HMMWV will be weighed in its test condition (with instrumentation and two passengers) to obtain front and rear tire loads and total weight. Estimates of yaw, pitch, and roll inertias will be estimated or obtained from previous inertial measurements of the same vehicle. Likewise, center of gravity height will also be estimated, if not available from previous measurements. Measurements of wheelbase, wheel track, suspension locations, and overall geometry will also be performed.

Task C -- Tire Force Measurements

One tire from the test vehicle will be tested on the UMTRI flat-bed tire test machine to obtain lateral tire force measurements at three different loads (test load, 50% test load, 150% test load) and six slip angles (-1, 0, +1, 2, 4, 8 degrees). Tire cornering stiffness parameters needed by the driver model in subsequent model/test validation activities, as well as complete lateral tire force representation within the DADS model, will be based upon these measurements.

Task D -- Full Scale Vehicle Tests

Three sets of driver/vehicle maneuvers are planned for the test program. (1) The first test maneuver is simple steady turning by a driver along a circular path. The purpose of this test is to obtain estimates of the vehicle understeer and basic cornering properties, as well as, driver closed-loop steering control behavior into and during the steady turning maneuver. (2) The second maneuver is similar to the first, but braking will be applied during the turning maneuver by the driver so as to bring the vehicle to a stop at selected points along the curve. (3) Lastly, the third type of maneuver will be to drive through a set of different obstacle courses, as defined by a pattern of traffic cones.

All of the tests will be conducted at the Chrysler Proving Grounds at Chelsea, Michigan. The circular turning and braking-in-a-turn tests are planned for the skid pad area of the vehicle dynamics facility; the obstacle course runs will be performed along the straights (2-lane widths) of the facilities' oval track.

- **Driver-Controlled Constant Radius Turning Tests**

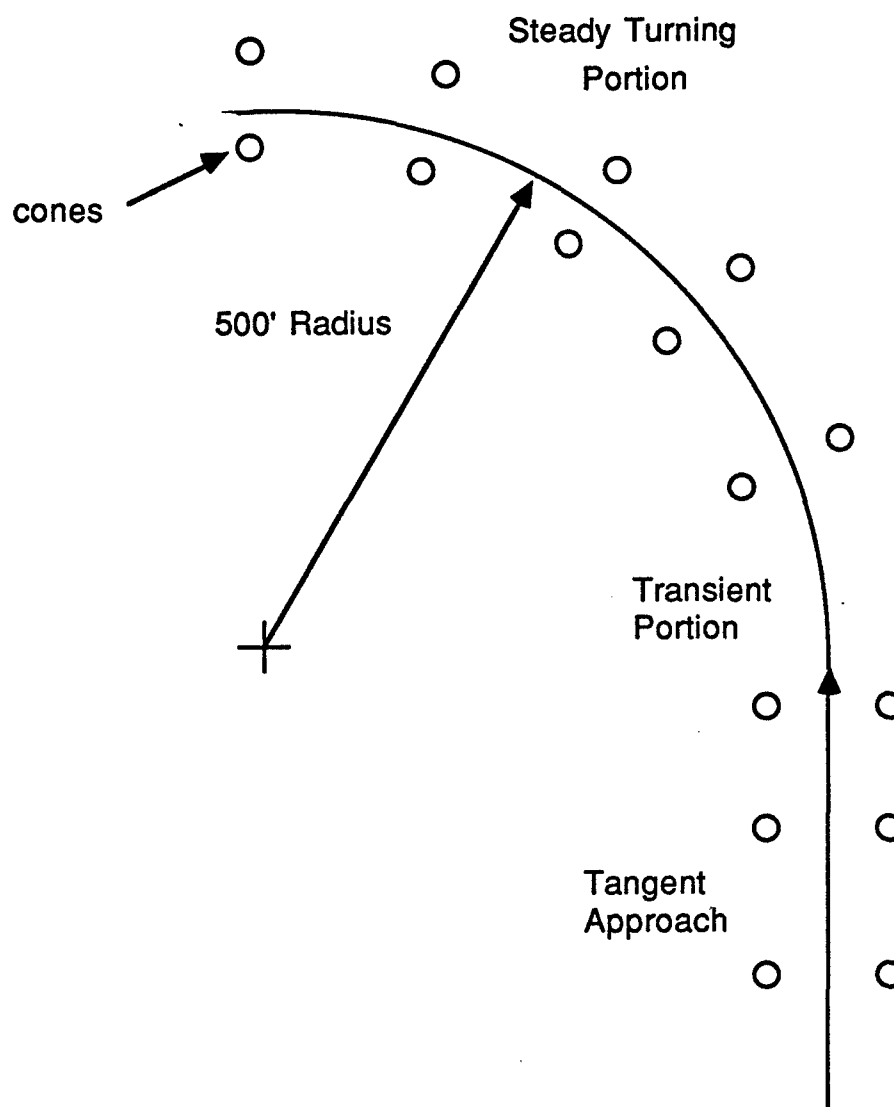
The turning tests will be conducted at 25 and 50 mph with the test driver attempting to track a cone-marked turn of fixed radius (500'). (A radius of 500 feet will produce a lateral acceleration of 0.33 g's at 50 mph and can easily be accommodated on the 800' x 800' Chrysler skid pad area.) The maneuver will begin by having the driver approach the circular turn along a straight tangent and, then, track the curve at constant speed. See Figure 1. Transient driver/vehicle response information due to entering the curve, as well as steady-state driver/vehicle response information due to tracking the curve, will be gathered from these tests. Influence of forward speed upon system damping will be obtained by conducting the same tests at the two different speeds.

Vehicle turning properties, such as understeer level and steering control gains, will also be derived from the steady turning data in these tests. Further, since both front wheel angles and steering wheel angle are being measured, the effective steering gear ratio and steering system compliance properties will be available from these tests. (An additional low speed test may be added to the 25 and 50 mph cases if the lateral tire force data measured under Task C proves to be significantly sensitive to load or slip angle in the 0.0 to 0.3 g operating range.)

- **Driver-Controlled Braking-in-a-Turn Tests**

The braking-in-a-turn tests will be conducted from an initial speed of 50 mph with the test driver attempting to stop the vehicle in a fixed distance. The stopping distances will be varied, thereby requiring the driver to achieve different deceleration levels during each stop. This type of test will serve as a closed-loop braking control task for the driver, while simultaneously, yield information on the basic braking performance / capabilities of the test vehicle. Wheel lock-up occurrences will be recorded for the shorter stopping distance cases. The driver treadle pressure responses and corresponding deceleration time histories will be used to evaluate and refine the closed-loop braking algorithm.

Figure 1. Driver Controlled Constant Radius Turning Test



• Obstacle Course Tests

The purpose of these tests is to gather transient driver/vehicle response data for both path-following and obstacle avoidance maneuvers. The basic type of maneuver consists of performing various lane-to-lane movements with the vehicle as it traverses a cone-marked course. Tests will be conducted at speeds of 25 and 50 mph. Three basic obstacle course patterns are planned and are shown in Figure 2:

A) Simple Path-Constrained Lane Change (Figure 2a)

B) Simple Unconstrained Lane Change (Figure 2b)

and,

C) Unconstrained Obstacle Course (Figure 2c)

The first two cases are included primarily to evaluate the influence of path constraints on driver steering control behavior. The lane width will be systematically varied to help detect changes in driver steering behavior as the lane width narrows. Most of the obstacle course tests, however, will take place with the layout shown in Figure 2c. In these tests, the distance between rectangular obstacles, and their respective sizes, will be varied.

In all cases, the lane change geometry (shoot-to-shoot forward travel distance, L ; or $L1$ and $L2$) will be adjusted to produce approximately 0.30 g's of peak lateral acceleration during the 50 mph maneuvers. The same course geometry will be used for the 25 mph tests in order to evaluate the influence of forward speed upon driver preview and system damping. Nominal course layouts will be initially selected on the basis of computer simulation runs performed during April.

Each of the unconstrained obstacle course tests will be repeated at least five times, but in a random-like sequence. The test driver will continuously drive the vehicle dynamics oval — encountering a different obstacle course layout each time around the track. Data collection will begin several seconds prior to, and end several seconds after, the obstacle course maneuver.

Figure 2a. Path-Constrained Lane Change Maneuver

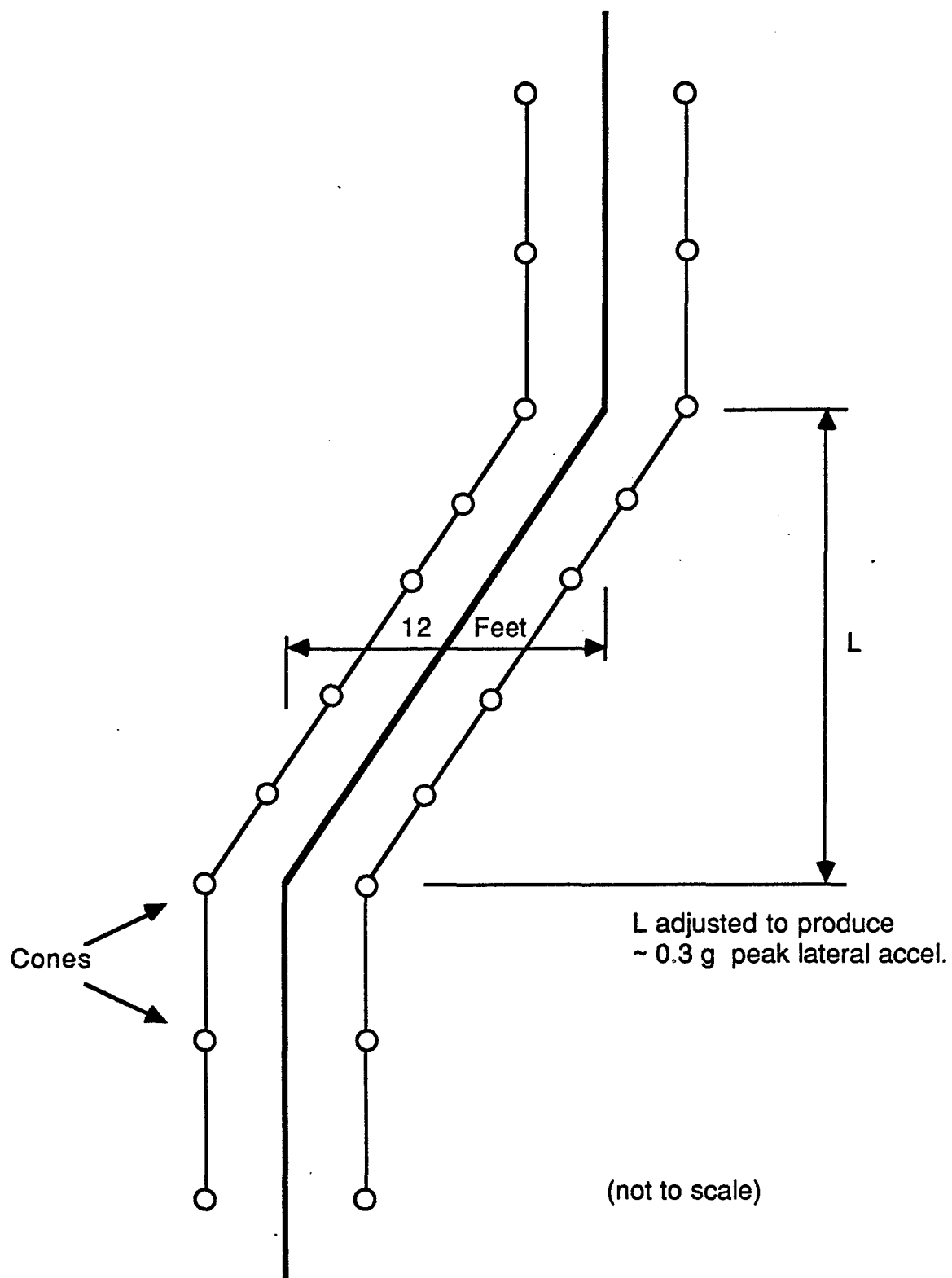


Figure 2b. Unconstrained Lane Change Maneuver

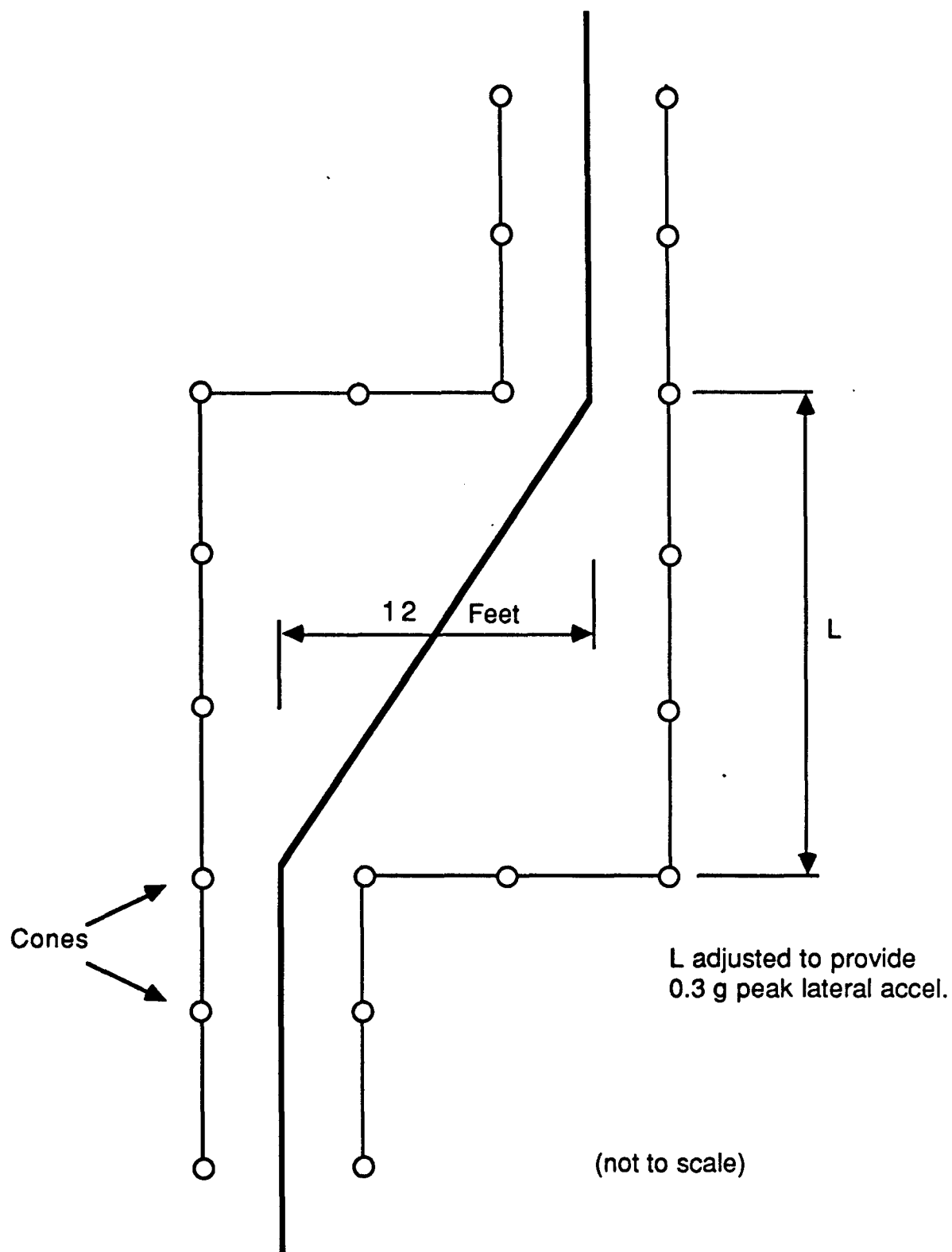
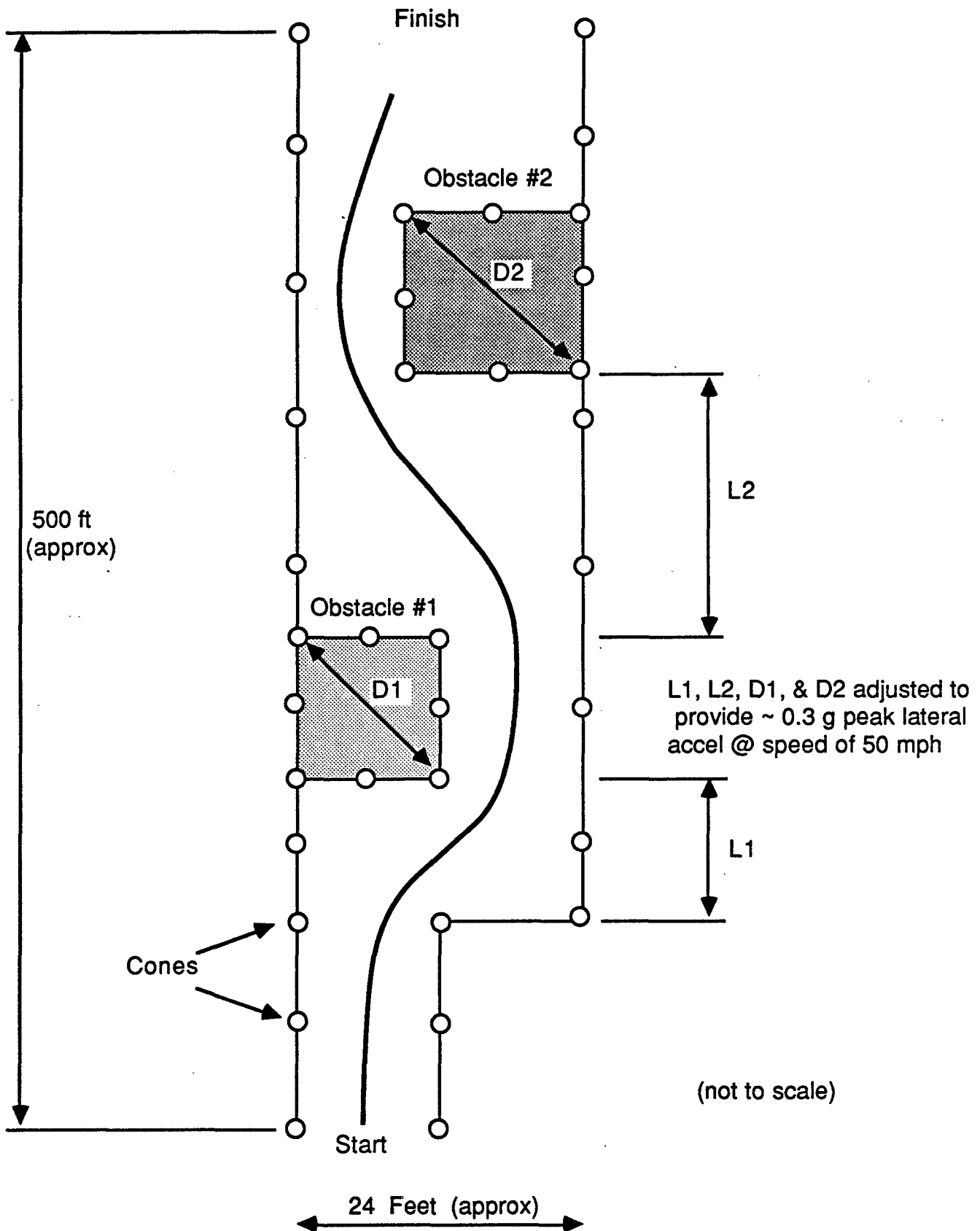


Figure 2c. Obstacle Course



- **Special HMMWV-Trailer Tests**

A short sequence of articulated vehicle tests will be conducted using a single-axle utility trailer attached to the HMMWV via its rear pintle-hook. The fore-aft location of the trailer load (in a low c.g. configuration) will be varied to produce different levels of damping in the trailer-swing motion. The resulting articulation angle response, and its possible effect upon driver steering control activity, will be evaluated during a repeat of several of the unconstrained obstacle course tests.

Straight-line stability tests may also be conducted with the trailer payload located in an adverse rearward location, thereby exciting a limit-cycle response in the articulation motion. The resulting driver steering action in response to the limit cycle motion will be useful in later analyzing and comparing with results from comparable simulation runs.

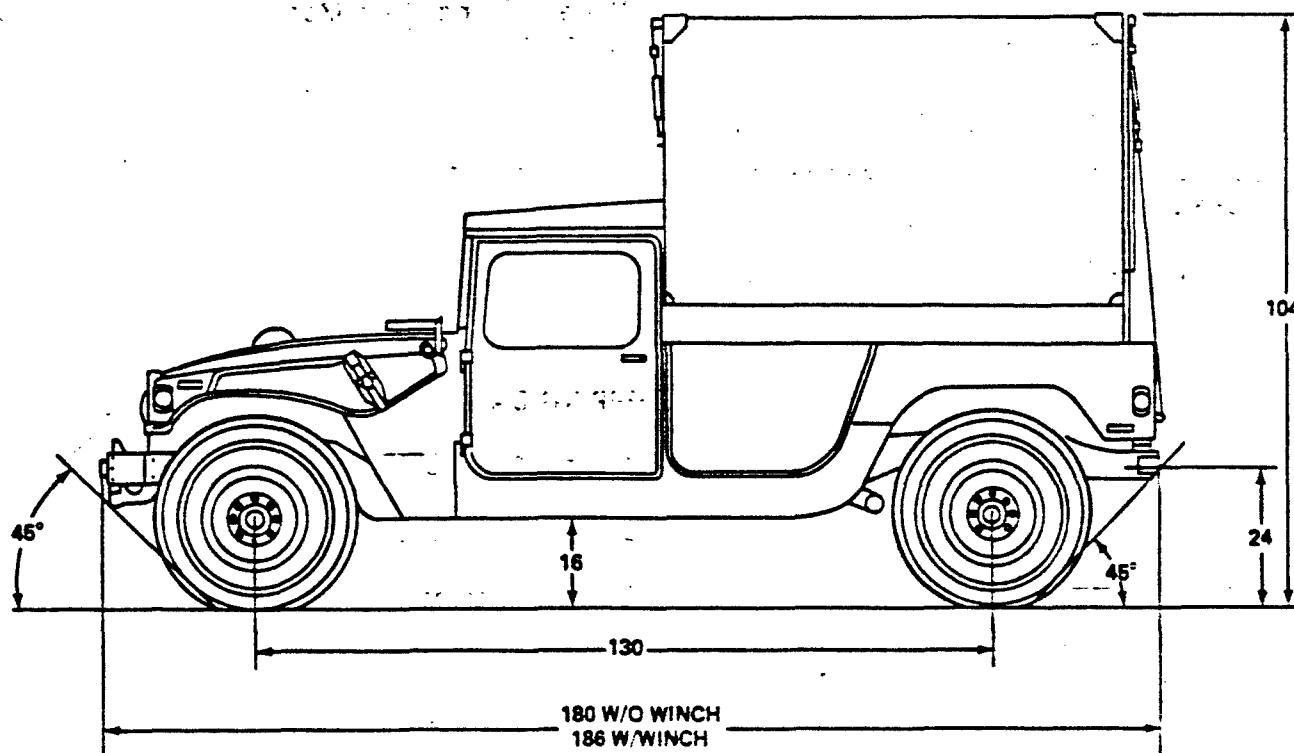
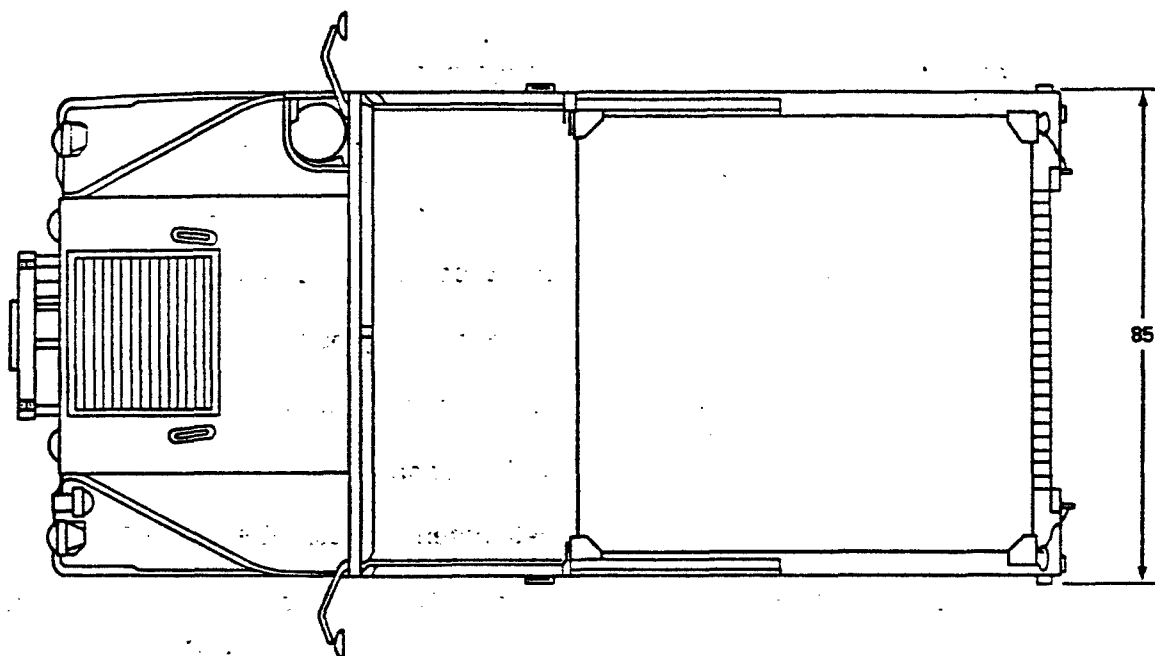
The trailer will be instrumented with four additional transducers to measure the following vehicle responses:

- Trailer Lateral Acceleration
- Trailer Yaw Rate
- HMMWV-Trailer Articulation Angle
- Trailer Roll Rate

Figures 3 and 4 show drawings of the HMMWV and utility trailer to be used in the test program.

43-0001-31

Figure 3. HMMWV Test Vehicle

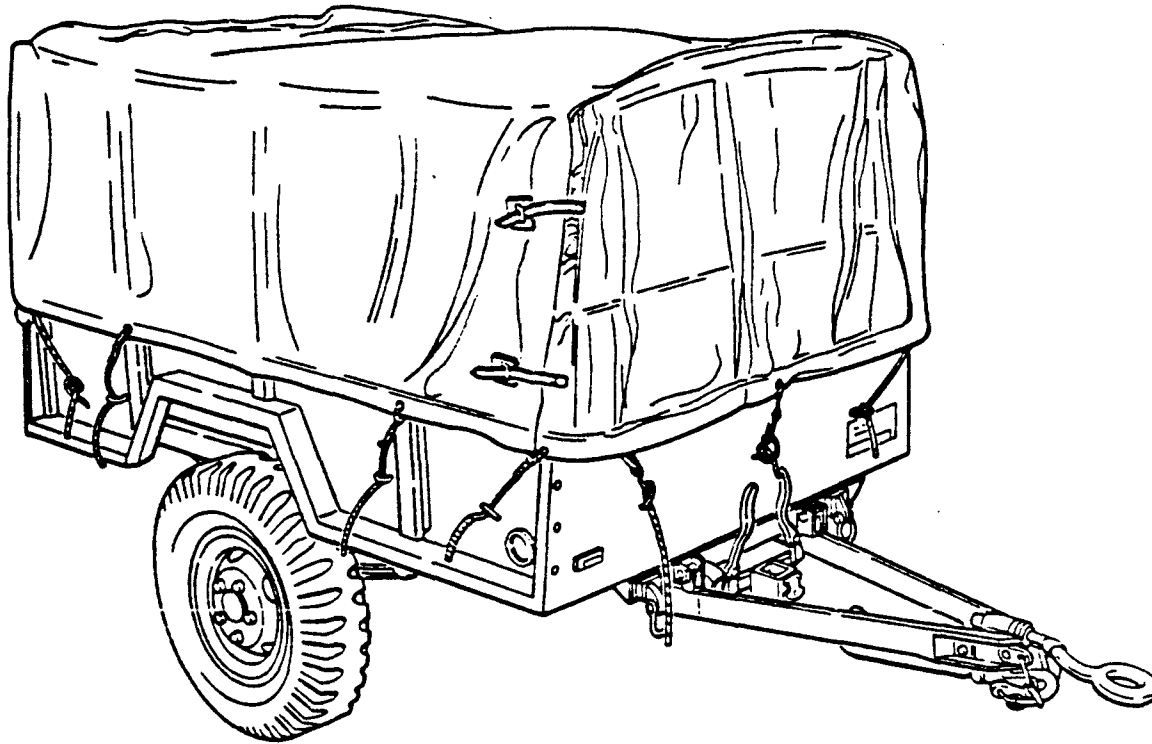


NOTE:
ALL DIMENSIONS ARE IN INCHES.

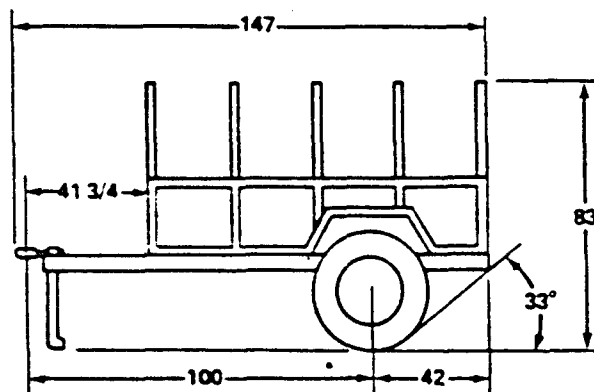
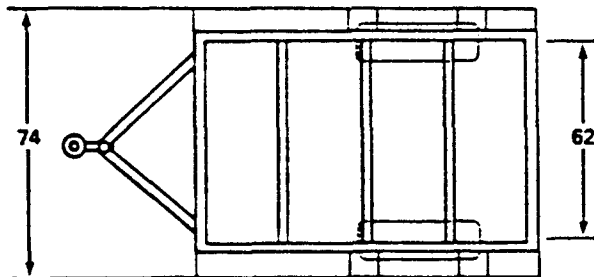
Figure 4. Trailer Test Vehicle

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TM 43-0001-31



NOTE:
ALL DIMENSIONS ARE IN INCHES.



TA208564

Data Acquisition Equipment

Test data will be collected using the UMTRI portable data acquisition system. The system consists of a Texas Instruments TM 990 microprocessor, signal-conditioning units, programmable filters, and analog/digital converters. A CRT unit and keyboard are used to operate and control the system. Data are stored on high capacity digital tape cartridges for subsequent post-processing. Simple statistical calculations and background calibrations can be performed as well.

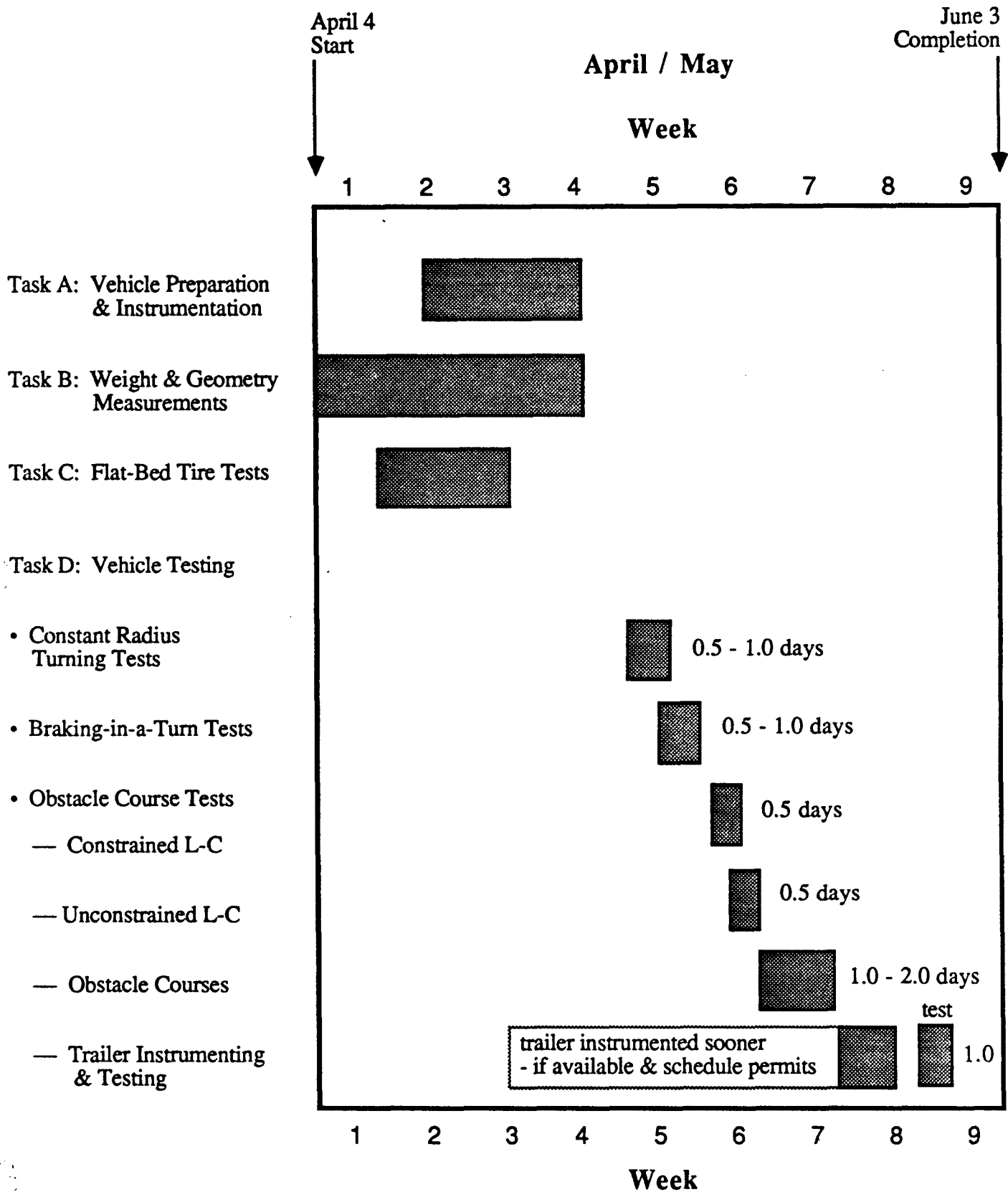
Spot checks of the collected data will occur periodically throughout the duration of the test program to guard against undetected instrumentation failures. However, most of the data processing for these tests will take place following the test program during June and July.

Test Schedule

Figure 5 shows the nominal schedule to be followed for completing the vehicle tests during April and May. Tasks A and B (vehicle preparation & instrumentation; weight & geometry measurements) will begin in April. Approximately 2-3 weeks of time are allotted to these tasks to allow for possible UMTRI staff technician commitments to other projects. Task C (flat-bed tire tests) is scheduled as well during this same time frame. An additional week is provided to account for possible staff conflicts and any unexpected problems. Finally, Task D (vehicle testing) is allocated one month of time during May, allowing for weather interruptions and instrumentation breakdowns.

As of this date, approximately two days per week (8 days) of track testing has been tentatively reserved with the Chrysler Proving Grounds for the month of May. It is expected that the skid pad testing can be completed during the first week of the test track schedule. The next week or two will be spent on the obstacle course testing. Depending upon the readiness of the trailer at this point, it will be instrumented (if not previously) and tested during the final week of scheduled tests.

Figure 5. TACOM Test Schedule / Spring 1988



APPENDIX B

Vehicle Data Files

CREATE HEADER

*

1. This a model of the high C.G. HMMWV M1037 S-250 Shelter Carrier vehicle with bias tires and the M101 3160 lbf GVW trailer with radial tires.

2. See the user written subroutine USER_TSDA.FOR for the shock model. The subroutine will provide additional comments in more detail.

*

3. The umtri driver model implemented to steer the vehicle. The file DMINPUT.INP contains the parameters for the model. The programs LANE_CHANGE.EXE and CIRCLE generate the input file for the driver model. Right now the model is used just to steer the vehicle down a given trajectory. The parameters for the driver model my not be the precise required values.

*

4. The trailer hitch load is set at about 176 lbf which is about 6.3% of the trailer spring weight.

*

5. This model is the 3rd config, i.e. the trailer cenetr of gravity height of the trailer is 41.1 inches above the ground.

*

7. The front tires are bias type at 20 psi
The rear tires are bias type at 30 psi
There is no lateral force and aligning torque data at 30 psi so the data for 28 psi was used as an approximation.

*

8. Assume the center of gravity of each wheel is at the wheel center. The angle of 0.247 degrees associated with each wheel represents the toe-in of the front wheels and the toe-out of the rear wheels. See the HMMWV Technical Manual TM 9-2320-280-20, sections 8-6 and 8-7.

*

ANALYSIS

CREATE SYSTEM.DATA

UNITS	:= 'ENG'
ANALYSIS.TYPE	:= 'DYNAMIC'
STARTING.TIME	:= '0.0'
ENDING.TIME	:= '25.0'
PRINT.INTERVAL	:= '0.06'
GRAVITY.SEA.LEVEL	:= '386.400'
X.GRAVITY	:= '0.0'
Y.GRAVITY	:= '0.0'
Z.GRAVITY	:= '-1.0'
SCALE.GRAVITY.COEF	:= '1.0'
MATRIX.OPERATIONS	:= 'SPARSE'
REDUNDANCY.CHECK	:= 'TRUE'
LU.TOL	:= '1.0D-12'
ASSEMBLY.TOL	:= '1.0D-3'
BYPASS.ASSEMBLY	:= 'FALSE'
OUTPUT.FILE	:= 'BINARY'
REFERENCE.FRAME	:= 'GLOBAL'
DEBUG.FLAG	:= 'TRUE'

UP

CREATE DYNAMIC.DATA

REACTION.FORCES	:= 'TRUE'
FORCE.COORDINATES	:= 'GLOBAL'
PRINT.METHOD	:= 'INTERPOLATED'
MAX.INT.STEP	:= '0.05'
SOLUTION.TOL	:= '0.001'
INTEGRATION.TOL	:= '0.0001'

UP

UP

CONSTRAINTS

CREATE DISTANCE.CONSTRAINT

NAME	:= 'RAD-ROD.RL'
BODY.1.NAME	:= 'CHASSIS'
BODY.2.NAME	:= 'WHEEL.RL'
P.ON.BODY.1	:= (-16.380, -161.980, 33.080)
P.ON.BODY.2	:= (-32.327, -164.066, 30.405)
Q.ON.BODY.1	:= (-16.380, -161.980, 34.080)
Q.ON.BODY.2	:= (-32.327, -164.066, 31.405)
R.ON.BODY.1	:= (-15.380, -161.980, 33.080)
R.ON.BODY.2	:= (-31.327, -164.066, 30.405)
DISTANCE	:= '16.303798023773'
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE DISTANCE.CONSTRAINT

NAME	:= 'RAD-ROD.RR'
BODY.1.NAME	:= 'CHASSIS'
BODY.2.NAME	:= 'WHEEL.RR'
P.ON.BODY.1	:= (16.380, -161.980, 33.080)
P.ON.BODY.2	:= (32.327, -164.066, 30.405)
Q.ON.BODY.1	:= (16.380, -161.980, 34.080)
Q.ON.BODY.2	:= (32.327, -164.066, 31.405)
R.ON.BODY.1	:= (17.380, -161.980, 33.080)
R.ON.BODY.2	:= (33.327, -164.066, 30.405)
DISTANCE	:= '16.303798023773'
NODE.1	:= '0'
NODE.2	:= '0'

UP

FORCE

CREATE RSDA

NAME	:= 'TRAILER.AUX.ROLL.STIFFNESS'
JOINT.NAME	:= 'TRAILER.REV'
ORIENTATION.ANGLE	:= '0.0'
SPRING.CONSTANT	:= '73153.0'
DAMPING.COEFFICIENT	:= '0.0'
ACTUATOR.TORQUE	:= '0.0'
CURVE.SPRING	:= 'NONE'
CURVE.DAMPER	:= 'NONE'
CURVE.ACTUATOR	:= 'NONE'
ANGULAR.UNITS	:= 'RADIANS'

UP

CREATE TIRE

NAME	:= 'TIRE.FL'
TIRE.BODY	:= 'WHEEL.FL'
CHASSIS.BODY	:= 'CHASSIS'
TYPE	:= 'BASIC'
P.ON.TIRE	:= (-35.815, -39.370, 29.735)
RADIUS	:= '18.150'
ROLLING.RESISTANCE	:= '0.0'
DAMPING.CONSTANT	:= '20.000'
VERTICAL.STIFF	:= '0.0'
LATERAL.STIFF	:= '0.0'
STEER.ANGLE	:= '0.0'
FRICTION.COEFF	:= '0.8'
CURVE.UTILITY	:= 'TIRE.COEFF'
CURVE.VERTICAL	:= 'BIAS.TIRE.20PSI'
CURVE.TORQUE	:= 'NONE'

```

CURVE.STEER                := 'TRAJECTORY'
ANGULAR.UNITS              := 'DEGREES'

UP
CREATE TIRE
NAME                        := 'TIRE.FR'
TIRE.BODY                  := 'WHEEL.FR'
CHASSIS.BODY               := 'CHASSIS'
TYPE                       := 'BASIC'
P.ON.TIRE                  := ( 35.815, -39.370, 29.735 )
RADIUS                     := '18.150'
ROLLING.RESISTANCE         := '0.0'
DAMPING.CONSTANT           := '20.000'
VERTICAL.STIFF             := '0.0'
LATERAL.STIFF              := '0.0'
STEER.ANGLE                := '0.0'
FRICTION.COEFF             := '0.8'
CURVE.UTILITY              := 'TIRE.COE'
CURVE.VERTICAL              := 'BIAS.TIRE.20PSI'
CURVE.TORQUE               := 'NONE'
CURVE.STEER                := 'NONE'
ANGULAR.UNITS              := 'DEGREES'

UP
CREATE TIRE
NAME                        := 'TIRE.RL'
TIRE.BODY                  := 'WHEEL.RL'
CHASSIS.BODY               := 'CHASSIS'
TYPE                       := 'BASIC'
P.ON.TIRE                  := ( -35.815, -169.370, 29.735 )
RADIUS                     := '18.150'
ROLLING.RESISTANCE         := '0.0'
DAMPING.CONSTANT           := '20.000'
VERTICAL.STIFF             := '0.0'
LATERAL.STIFF              := '0.0'
STEER.ANGLE                := '0.0'
FRICTION.COEFF             := '0.8'
CURVE.UTILITY              := 'TIRE.COE'
CURVE.VERTICAL              := 'BIAS.TIRE.30PSI'
CURVE.TORQUE               := 'NONE'
CURVE.STEER                := 'NONE'
ANGULAR.UNITS              := 'DEGREES'

UP
CREATE TIRE
NAME                        := 'TIRE.RR'
TIRE.BODY                  := 'WHEEL.RR'
CHASSIS.BODY               := 'CHASSIS'
TYPE                       := 'BASIC'
P.ON.TIRE                  := ( 35.815, -169.370, 29.735 )
RADIUS                     := '18.150'
ROLLING.RESISTANCE         := '0.0'
DAMPING.CONSTANT           := '20.000'
VERTICAL.STIFF             := '0.0'
LATERAL.STIFF              := '0.0'
STEER.ANGLE                := '0.0'
FRICTION.COEFF             := '0.8'
CURVE.UTILITY              := 'TIRE.COE'
CURVE.VERTICAL              := 'BIAS.TIRE.30PSI'
CURVE.TORQUE               := 'NONE'
CURVE.STEER                := 'NONE'
ANGULAR.UNITS              := 'DEGREES'

UP

```

CREATE TIRE

NAME	:= 'TRAILER.TIRE.RH'
TIRE.BODY	:= 'TRAILER.AXLE'
CHASSIS.BODY	:= 'TRAILER.CHASSIS'
TYPE	:= 'BASIC'
P.ON.TIRE	:= (31.0, -305.37, 27.88)
RADIUS	:= '16.0'
ROLLING.RESISTANCE	:= '0.0'
DAMPING.CONSTANT	:= '0.000'
VERTICAL.STIFF	:= '0.0'
LATERAL.STIFF	:= '0.0'
STEER.ANGLE	:= '0.0'
FRICTION.COEFF	:= '0.8'
CURVE.UTILITY	:= 'TIRE.COEFF'
CURVE.VERTICAL	:= 'RADIAL.TIRE.LT235.85R16'
CURVE.TORQUE	:= 'NONE'
CURVE.STEER	:= 'NONE'
ANGULAR.UNITS	:= 'DEGREES'

UP

CREATE TIRE

NAME	:= 'TRAILER.TIRE.LH'
TIRE.BODY	:= 'TRAILER.AXLE'
CHASSIS.BODY	:= 'TRAILER.CHASSIS'
TYPE	:= 'BASIC'
P.ON.TIRE	:= (-31.0, -305.37, 27.88)
RADIUS	:= '16.0'
ROLLING.RESISTANCE	:= '0.0'
DAMPING.CONSTANT	:= '0.000'
VERTICAL.STIFF	:= '0.0'
LATERAL.STIFF	:= '0.0'
STEER.ANGLE	:= '0.0'
FRICTION.COEFF	:= '0.8'
CURVE.UTILITY	:= 'TIRE.COEFF'
CURVE.VERTICAL	:= 'RADIAL.TIRE.LT235.85R16'
CURVE.TORQUE	:= 'NONE'
CURVE.STEER	:= 'NONE'
ANGULAR.UNITS	:= 'DEGREES'

UP

CREATE TSDA

NAME	:= 'SPRING.FL'
BODY.1.NAME	:= 'CHASSIS'
BODY.2.NAME	:= 'ARM.LFL'
SPRING.CONSTANT	:= '954.000'
FREE.LENGTH.SPRING	:= '13.360'
DAMPING.COEFFICIENT	:= '0.0'
ACTUATOR.FORCE	:= '0.0'
P.ON.BODY.1	:= (-20.070, -33.685, 38.545)
P.ON.BODY.2	:= (-21.385, -33.953, 28.935)
Q.ON.BODY.1	:= (-20.070, -33.685, 39.545)
Q.ON.BODY.2	:= (-21.385, -33.953, 29.935)
R.ON.BODY.1	:= (-19.070, -33.685, 38.545)
R.ON.BODY.2	:= (-20.385, -33.953, 28.935)
CURVE.SPRING	:= 'NONE'
CURVE.DAMPER	:= 'NONE'
CURVE.ACTUATOR	:= 'NONE'
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE TSDA

NAME	:= 'SPRING.FR'
------	----------------

```

BODY.1.NAME           := 'CHASSIS'
BODY.2.NAME           := 'ARM.LFR'
SPRING.CONSTANT        := '954.000'
FREE.LENGTH.SPRING     := '13.360'
DAMPING.COEFFICIENT    := '0.0'
ACTUATOR.FORCE         := '0.0'
P.ON.BODY.1           := ( 20.070, -33.685, 38.545 )
P.ON.BODY.2           := ( 21.385, -33.953, 28.935 )
Q.ON.BODY.1           := ( 20.070, -33.685, 39.545 )
Q.ON.BODY.2           := ( 21.385, -33.953, 29.935 )
R.ON.BODY.1           := ( 21.070, -33.685, 38.545 )
R.ON.BODY.2           := ( 22.385, -33.953, 28.935 )
CURVE.SPRING           := 'NONE'
CURVE.DAMPER           := 'NONE'
CURVE.ACTUATOR         := 'NONE'
NODE.1                := '0'
NODE.2                := '0'

```

UP

CREATE TSDA

```

NAME                  := 'SPRING.RL'
BODY.1.NAME           := 'CHASSIS'
BODY.2.NAME           := 'ARM.LRL'
SPRING.CONSTANT        := '2108.000'
FREE.LENGTH.SPRING     := '15.030'
DAMPING.COEFFICIENT    := '0.0'
ACTUATOR.FORCE         := '0.0'
P.ON.BODY.1           := ( -19.747, -174.865, 40.868 )
P.ON.BODY.2           := ( -21.385, -174.597, 28.935 )
Q.ON.BODY.1           := ( -19.747, -174.865, 41.868 )
Q.ON.BODY.2           := ( -21.385, -174.597, 29.935 )
R.ON.BODY.1           := ( -18.747, -174.865, 40.868 )
R.ON.BODY.2           := ( -20.385, -174.597, 28.935 )
CURVE.SPRING           := 'NONE'
CURVE.DAMPER           := 'NONE'
CURVE.ACTUATOR         := 'NONE'
NODE.1                := '0'
NODE.2                := '0'

```

UP

CREATE TSDA

```

NAME                  := 'SPRING.RR'
BODY.1.NAME           := 'CHASSIS'
BODY.2.NAME           := 'ARM.LRR'
SPRING.CONSTANT        := '2108.00'
FREE.LENGTH.SPRING     := '15.030'
DAMPING.COEFFICIENT    := '0.0'
ACTUATOR.FORCE         := '0.0'
P.ON.BODY.1           := ( 19.747, -174.865, 40.868 )
P.ON.BODY.2           := ( 21.385, -174.597, 28.935 )
Q.ON.BODY.1           := ( 19.747, -174.865, 41.868 )
Q.ON.BODY.2           := ( 21.385, -174.597, 29.935 )
R.ON.BODY.1           := ( 20.747, -174.865, 40.868 )
R.ON.BODY.2           := ( 22.385, -174.597, 28.935 )
CURVE.SPRING           := 'NONE'
CURVE.DAMPER           := 'NONE'
CURVE.ACTUATOR         := 'NONE'
NODE.1                := '0'
NODE.2                := '0'

```

UP

CREATE TSDA

```

NAME                  := 'SHOCK.FL'

```

```

BODY.1.NAME           := 'CHASSIS'
BODY.2.NAME           := 'ARM.LFL'
SPRING.CONSTANT       := '0.0'
FREE.LENGTH.SPRING    := '0.0'
DAMPING.COEFFICIENT   := '0.0'
ACTUATOR.FORCE        := '0.0'
P.ON.BODY.1           := ( -19.598, -33.685, 43.492 )
P.ON.BODY.2           := ( -21.415, -33.953, 29.259 )
Q.ON.BODY.1           := ( -19.598, -33.685, 44.492 )
Q.ON.BODY.2           := ( -21.415, -33.953, 30.259 )
R.ON.BODY.1           := ( -18.598, -33.685, 43.492 )
R.ON.BODY.2           := ( -20.415, -33.953, 29.259 )
CURVE.SPRING          := 'NONE'
CURVE.DAMPER          := 'NONE'
CURVE.ACTUATOR        := 'NONE'
NODE.1                := '0'
NODE.2                := '0'

```

UP

CREATE TSDA

```

NAME                 := 'SHOCK.FR'
BODY.1.NAME          := 'CHASSIS'
BODY.2.NAME          := 'ARM.LFR'
SPRING.CONSTANT      := '0.0'
FREE.LENGTH.SPRING   := '0.0'
DAMPING.COEFFICIENT  := '0.0'
ACTUATOR.FORCE       := '0.0'
P.ON.BODY.1          := ( 19.598, -33.685, 43.492 )
P.ON.BODY.2          := ( 21.415, -33.953, 29.259 )
Q.ON.BODY.1          := ( 19.598, -33.685, 44.492 )
Q.ON.BODY.2          := ( 21.415, -33.953, 30.259 )
R.ON.BODY.1          := ( 20.598, -33.685, 43.492 )
R.ON.BODY.2          := ( 22.415, -33.953, 29.259 )
CURVE.SPRING         := 'NONE'
CURVE.DAMPER         := 'NONE'
CURVE.ACTUATOR       := 'NONE'
NODE.1               := '0'
NODE.2               := '0'

```

UP

CREATE TSDA

```

NAME                 := 'SHOCK.RL'
BODY.1.NAME          := 'CHASSIS'
BODY.2.NAME          := 'ARM.LRL'
SPRING.CONSTANT      := '0.0'
FREE.LENGTH.SPRING   := '0.0'
DAMPING.COEFFICIENT  := '0.0'
ACTUATOR.FORCE       := '0.0'
P.ON.BODY.1          := ( -19.598, -174.865, 43.492 )
P.ON.BODY.2          := ( -21.415, -174.597, 29.259 )
Q.ON.BODY.1          := ( -19.598, -174.865, 44.492 )
Q.ON.BODY.2          := ( -21.415, -174.597, 30.259 )
R.ON.BODY.1          := ( -18.598, -174.865, 43.492 )
R.ON.BODY.2          := ( -20.415, -174.597, 29.259 )
CURVE.SPRING         := 'NONE'
CURVE.DAMPER         := 'NONE'
CURVE.ACTUATOR       := 'NONE'
NODE.1               := '0'
NODE.2               := '0'

```

UP

CREATE TSDA

```

NAME                 := 'SHOCK.RR'

```

```

BODY.1.NAME      := 'CHASSIS'
BODY.2.NAME      := 'ARM.LRR'
SPRING.CONSTANT  := '0.0'
FREE.LENGTH.SPRING := '0.0'
DAMPING.COEFFICIENT := '0.0'
ACTUATOR.FORCE   := '0.0'
P.ON.BODY.1      := ( 19.598, -174.865, 43.492 )
P.ON.BODY.2      := ( 21.415, -174.597, 29.259 )
Q.ON.BODY.1      := ( 19.598, -174.865, 44.492 )
Q.ON.BODY.2      := ( 21.415, -174.597, 30.259 )
R.ON.BODY.1      := ( 20.598, -174.865, 43.492 )
R.ON.BODY.2      := ( 22.415, -174.597, 29.259 )
CURVE.SPRING     := 'NONE'
CURVE.DAMPER     := 'NONE'
CURVE.ACTUATOR   := 'NONE'
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE TSDA

```

NAME      := 'TIEROD.FL'
BODY.1.NAME := 'STEERING.LINK'
BODY.2.NAME := 'WHEEL.FL'
SPRING.CONSTANT := '4280.0'
FREE.LENGTH.SPRING := '15.2179994513076'
DAMPING.COEFFICIENT := '11.0'
ACTUATOR.FORCE := '0.0'
P.ON.BODY.1 := ( -17.65, -47.635, 32.905 )
P.ON.BODY.2 := ( -32.327, -44.702, 30.127 )
Q.ON.BODY.1 := ( -17.65, -47.635, 33.905 )
Q.ON.BODY.2 := ( -32.327, -44.702, 31.127 )
R.ON.BODY.1 := ( -16.65, -47.635, 32.905 )
R.ON.BODY.2 := ( -31.327, -44.702, 30.127 )
CURVE.SPRING := 'NONE'
CURVE.DAMPER := 'NONE'
CURVE.ACTUATOR := 'NONE'
NODE.1       := '0'
NODE.2       := '0'

```

UP

CREATE TSDA

```

NAME      := 'TIEROD.FR'
BODY.1.NAME := 'STEERING.LINK'
BODY.2.NAME := 'WHEEL.FR'
SPRING.CONSTANT := '4280.0'
FREE.LENGTH.SPRING := '15.2179994513076'
DAMPING.COEFFICIENT := '11.0'
ACTUATOR.FORCE := '0.0'
P.ON.BODY.1 := ( 17.655, -47.635, 32.905 )
P.ON.BODY.2 := ( 32.327, -44.702, 30.127 )
Q.ON.BODY.1 := ( 17.655, -47.635, 33.905 )
Q.ON.BODY.2 := ( 32.327, -44.702, 31.127 )
R.ON.BODY.1 := ( 18.655, -47.635, 32.905 )
R.ON.BODY.2 := ( 33.327, -44.702, 30.127 )
CURVE.SPRING := 'NONE'
CURVE.DAMPER := 'NONE'
CURVE.ACTUATOR := 'NONE'
NODE.1       := '0'
NODE.2       := '0'

```

UP

CREATE TSDA

```

NAME      := 'TRAILER.SPRING.LH'

```

```

BODY.1.NAME                := 'TRAILER.AXLE'
BODY.2.NAME                := 'TRAILER.CHASSIS'
SPRING.CONSTANT            := '0.0'
FREE.LENGTH.SPRING        := '18.2'
DAMPING.COEFFICIENT       := '0.0'
ACTUATOR.FORCE            := '0.0'
P.ON.BODY.1               := ( -21.25, -305.37, 27.38 )
P.ON.BODY.2               := ( -21.25, -305.37, 43.38 )
Q.ON.BODY.1               := ( -21.25, -305.37, 28.38 )
Q.ON.BODY.2               := ( -21.25, -305.37, 44.38 )
R.ON.BODY.1               := ( -20.25, -305.37, 27.38 )
R.ON.BODY.2               := ( -20.25, -305.37, 43.38 )
CURVE.SPRING              := 'TRAILER.SPRING.CURVE'
CURVE.DAMPER              := 'TRAILER.SPRING.FRICT'
CURVE.ACTUATOR            := 'NONE'
NODE.1                    := '0'
NODE.2                    := '0'

UP
CREATE TSDA
NAME                      := 'TRAILER.SPRING.RH'
BODY.1.NAME               := 'TRAILER.AXLE'
BODY.2.NAME               := 'TRAILER.CHASSIS'
SPRING.CONSTANT           := '0.0'
FREE.LENGTH.SPRING        := '18.2'
DAMPING.COEFFICIENT       := '0.0'
ACTUATOR.FORCE            := '0.0'
P.ON.BODY.1               := ( 21.25, 305.37, 27.38 )
P.ON.BODY.2               := ( 21.25, 305.37, 43.38 )
Q.ON.BODY.1               := ( 21.25, 305.37, 28.38 )
Q.ON.BODY.2               := ( 21.25, 305.37, 44.38 )
R.ON.BODY.1               := ( 22.25, 305.37, 27.38 )
R.ON.BODY.2               := ( 22.25, 305.37, 43.38 )
CURVE.SPRING              := 'TRAILER.SPRING.CURVE'
CURVE.DAMPER              := 'TRAILER.SPRING.FRICT'
CURVE.ACTUATOR            := 'NONE'
NODE.1                    := '0'
NODE.2                    := '0'

UP
CREATE TSDA
NAME                      := 'TRAILER.SHOCK.LH'
BODY.1.NAME               := 'TRAILER.CHASSIS'
BODY.2.NAME               := 'TRAILER.AXLE'
SPRING.CONSTANT           := '0.0'
FREE.LENGTH.SPRING        := '0.0'
DAMPING.COEFFICIENT       := '0.0'
ACTUATOR.FORCE            := '0.0'
P.ON.BODY.1               := ( -9.85, -308.82, 37.88 )
P.ON.BODY.2               := ( -18.9, -308.82, 25.48 )
Q.ON.BODY.1               := ( -9.85, -308.82, 38.88 )
Q.ON.BODY.2               := ( -18.9, -308.82, 26.48 )
R.ON.BODY.1               := ( -8.85, -308.82, 37.88 )
R.ON.BODY.2               := ( -17.9, -308.82, 25.48 )
CURVE.SPRING              := 'NONE'
CURVE.DAMPER              := 'TRAILER.SHOCK.CURVE'
CURVE.ACTUATOR            := 'NONE'
NODE.1                    := '0'
NODE.2                    := '0'

UP
CREATE TSDA
NAME                      := 'TRAILER.SHOCK.RH'

```

```

BODY.1.NAME      := 'TRAILER.CHASSIS'
BODY.2.NAME      := 'TRAILER.AXLE'
SPRING.CONSTANT  := '0.0'
FREE.LENGTH.SPRING := '0.0'
DAMPING.COEFFICIENT := '0.0'
ACTUATOR.FORCE   := '0.0'
P.ON.BODY.1      := ( 9.85, -308.82, 37.88 )
P.ON.BODY.2      := ( 18.9, -308.82, 25.48 )
Q.ON.BODY.1      := ( 9.85, -308.82, 38.88 )
Q.ON.BODY.2      := ( 18.9, -308.82, 26.48 )
R.ON.BODY.1      := ( 10.85, -308.82, 37.88 )
R.ON.BODY.2      := ( 19.9, -308.82, 25.48 )
CURVE.SPRING     := 'NONE'
CURVE.DAMPER     := 'TRAILER.SHOCK.CURVE'
CURVE.ACTUATOR   := 'NONE'
NODE.1           := '0'
NODE.2           := '0'

```

UP

UP

JOINTS

CREATE REVOLUTE.JOINT

```

NAME      := 'REV.LFL'
BODY.1.NAME := 'CHASSIS'
BODY.2.NAME := 'ARM.LFL'
P.ON.BODY.1 := ( -12.09, -37.78, 30.770 )
P.ON.BODY.2 := ( -12.09, -37.78, 30.770 )
Q.ON.BODY.1 := ( -12.09, -36.78, 30.770 )
Q.ON.BODY.2 := ( -12.09, -36.78, 30.770 )
R.ON.BODY.1 := ( -11.09, -37.78, 30.770 )
R.ON.BODY.2 := ( -11.09, -37.78, 30.770 )
NODE.1      := '0'
NODE.2      := '0'

```

UP

CREATE REVOLUTE.JOINT

```

NAME      := 'REV.LFR'
BODY.1.NAME := 'CHASSIS'
BODY.2.NAME := 'ARM.LFR'
P.ON.BODY.1 := ( 12.09, -37.78, 30.770 )
P.ON.BODY.2 := ( 12.09, -37.78, 30.770 )
Q.ON.BODY.1 := ( 12.09, -36.78, 30.770 )
Q.ON.BODY.2 := ( 12.09, -36.78, 30.770 )
R.ON.BODY.1 := ( 13.09, -37.78, 30.770 )
R.ON.BODY.2 := ( 13.09, -37.78, 30.770 )
NODE.1      := '0'
NODE.2      := '0'

```

UP

CREATE REVOLUTE.JOINT

```

NAME      := 'REV.LRL'
BODY.1.NAME := 'CHASSIS'
BODY.2.NAME := 'ARM.LRL'
P.ON.BODY.1 := ( -12.09, -170.77, 30.770 )
P.ON.BODY.2 := ( -12.09, -170.77, 30.770 )
Q.ON.BODY.1 := ( -12.09, -169.77, 30.770 )
Q.ON.BODY.2 := ( -12.09, -169.77, 30.770 )
R.ON.BODY.1 := ( -11.09, -170.77, 30.770 )
R.ON.BODY.2 := ( -11.09, -170.77, 30.770 )
NODE.1      := '0'
NODE.2      := '0'

```

UP

CREATE REVOLUTE.JOINT

```

NAME                               := 'REV.LRR'
BODY.1.NAME                        := 'CHASSIS'
BODY.2.NAME                        := 'ARM.LRR'
P.ON.BODY.1                       := ( 12.09, -170.77, 30.770 )
P.ON.BODY.2                       := ( 12.09, -170.77, 30.770 )
Q.ON.BODY.1                       := ( 12.09, -169.77, 30.770 )
Q.ON.BODY.2                       := ( 12.09, -169.77, 30.770 )
R.ON.BODY.1                       := ( 13.09, -170.77, 30.770 )
R.ON.BODY.2                       := ( 13.09, -170.77, 30.770 )
NODE.1                            := '0'
NODE.2                            := '0'

UP
CREATE REVOLUTE.JOINT
NAME                               := 'REV.UFL'
BODY.1.NAME                        := 'CHASSIS'
BODY.2.NAME                        := 'ARM.UFL'
P.ON.BODY.1                       := ( -18.183, -44.003, 39.435 )
P.ON.BODY.2                       := ( -18.183, -44.003, 39.435 )
Q.ON.BODY.1                       := ( -17.558, -39.670, 40.400 )
Q.ON.BODY.2                       := ( -17.558, -39.670, 40.400 )
R.ON.BODY.1                       := ( -17.193, -44.146, 39.435 )
R.ON.BODY.2                       := ( -17.193, -44.146, 39.435 )
NODE.1                            := '0'
NODE.2                            := '0'

UP
CREATE REVOLUTE.JOINT
NAME                               := 'REV.UFR'
BODY.1.NAME                        := 'CHASSIS'
BODY.2.NAME                        := 'ARM.UFR'
P.ON.BODY.1                       := ( 18.183, -44.003, 39.435 )
P.ON.BODY.2                       := ( 18.183, -44.003, 39.435 )
Q.ON.BODY.1                       := ( 17.558, -39.670, 40.400 )
Q.ON.BODY.2                       := ( 17.558, -39.670, 40.400 )
R.ON.BODY.1                       := ( 19.173, -43.860, 39.435 )
R.ON.BODY.2                       := ( 19.173, -43.860, 39.435 )
NODE.1                            := '0'
NODE.2                            := '0'

UP
CREATE REVOLUTE.JOINT
NAME                               := 'REV.URL'
BODY.1.NAME                        := 'CHASSIS'
BODY.2.NAME                        := 'ARM.URL'
P.ON.BODY.1                       := ( -18.195, -162.380, 39.655 )
P.ON.BODY.2                       := ( -18.195, -162.380, 39.655 )
Q.ON.BODY.1                       := ( -18.195, -161.380, 39.655 )
Q.ON.BODY.2                       := ( -18.195, -161.380, 39.655 )
R.ON.BODY.1                       := ( -17.195, -162.380, 39.655 )
R.ON.BODY.2                       := ( -17.195, -162.380, 39.655 )
NODE.1                            := '0'
NODE.2                            := '0'

UP
CREATE REVOLUTE.JOINT
NAME                               := 'REV.URR'
BODY.1.NAME                        := 'CHASSIS'
BODY.2.NAME                        := 'ARM.URR'
P.ON.BODY.1                       := ( 18.195, -162.380, 39.655 )
P.ON.BODY.2                       := ( 18.195, -162.380, 39.655 )
Q.ON.BODY.1                       := ( 18.195, -161.380, 39.655 )
Q.ON.BODY.2                       := ( 18.195, -161.380, 39.655 )
R.ON.BODY.1                       := ( 19.195, -162.380, 39.655 )

```

```

R.ON.BODY.2      := ( 19.195, -162.380, 39.655 )
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE REVOLUTE.JOINT

```

NAME             := 'PITMAN.REV'
BODY.1.NAME      := 'CHASSIS'
BODY.2.NAME      := 'PITMAN.ARM'
P.ON.BODY.1      := ( -9.811, -55.355, 34.039 )
P.ON.BODY.2      := ( -9.811, -55.355, 34.039 )
Q.ON.BODY.1      := ( -9.811, -55.038, 34.987 )
Q.ON.BODY.2      := ( -9.811, -55.038, 34.987 )
R.ON.BODY.1      := ( -8.811, -55.355, 34.039 )
R.ON.BODY.2      := ( -8.811, -55.355, 34.039 )
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE REVOLUTE.JOINT

```

NAME             := 'TRAILER.REV'
BODY.1.NAME      := 'TRAILER.DUMMY'
BODY.2.NAME      := 'TRAILER.AXLE'
P.ON.BODY.1      := ( 0.0, -305.37, 32.88 )
P.ON.BODY.2      := ( 0.0, -305.37, 32.88 )
Q.ON.BODY.1      := ( 0.0, -304.37, 32.88 )
Q.ON.BODY.2      := ( 0.0, -304.37, 32.88 )
R.ON.BODY.1      := ( 1.0, -305.37, 32.88 )
R.ON.BODY.2      := ( 1.0, -305.37, 32.88 )
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE REV-SPHR.JOINT

```

NAME             := 'IDLER.ARM'
REV.BODY.1.NAME  := 'CHASSIS'
SPHR.BODY.2.NAME := 'STEERING.LINK'
P.ON.BODY.1      := ( 12.803, -55.355, 34.039 )
P.ON.BODY.2      := ( 12.803, -50.556, 32.433 )
Q.ON.BODY.1      := ( 12.803, -55.038, 34.987 )
Q.ON.BODY.2      := ( 12.803, -50.239, 33.381 )
R.ON.BODY.1      := ( 13.803, -55.355, 34.039 )
R.ON.BODY.2      := ( 13.803, -50.556, 32.433 )
DISTANCE         := '5.06'

```

UP

CREATE SPHERICAL.JOINT

```

NAME             := 'SPH.LFL'
BODY.1.NAME      := 'ARM.LFL'
BODY.2.NAME      := 'WHEEL.FL'
P.ON.BODY.1      := ( -30.965, -39.180, 26.120 )
P.ON.BODY.2      := ( -30.965, -39.180, 26.120 )
Q.ON.BODY.1      := ( -30.757, -39.232, 27.097 )
Q.ON.BODY.2      := ( -28.170, -39.868, 39.254 )
R.ON.BODY.1      := ( -31.943, -39.180, 26.328 )
R.ON.BODY.2      := ( -44.099, -39.180, 28.915 )
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE SPHERICAL.JOINT

```

NAME             := 'SPH.LFR'
BODY.1.NAME      := 'ARM.LFR'
BODY.2.NAME      := 'WHEEL.FR'
P.ON.BODY.1      := ( 30.965, -39.180, 26.120 )

```

```

P.ON.BODY.2      := ( 30.965, -39.180, 26.120 )
Q.ON.BODY.1      := ( 30.757, -39.232, 27.097 )
Q.ON.BODY.2      := ( 28.170, -39.868, 39.254 )
R.ON.BODY.1      := ( 31.943, -39.180, 26.328 )
R.ON.BODY.2      := ( 44.099, -39.180, 28.915 )
NODE.1           := '0'
NODE.2           := '0'

UP
CREATE SPHERICAL.JOINT
NAME              := 'SPH.LRL'
BODY.1.NAME      := 'ARM.LRL'
BODY.2.NAME      := 'WHEEL.RL'
P.ON.BODY.1      := ( -30.965, -169.370, 26.120 )
P.ON.BODY.2      := ( -30.965, -169.370, 26.120 )
Q.ON.BODY.1      := ( -30.757, -169.422, 27.097 )
Q.ON.BODY.2      := ( -28.170, -169.370, 39.270 )
R.ON.BODY.1      := ( -31.943, -169.370, 26.328 )
R.ON.BODY.2      := ( -44.115, -169.370, 28.915 )
NODE.1           := '0'
NODE.2           := '0'

UP
CREATE SPHERICAL.JOINT
NAME              := 'SPH.LRR'
BODY.1.NAME      := 'ARM.LRR'
BODY.2.NAME      := 'WHEEL.RR'
P.ON.BODY.1      := ( 30.965, -169.370, 26.120 )
P.ON.BODY.2      := ( 30.965, -169.370, 26.120 )
Q.ON.BODY.1      := ( 30.757, -169.422, 27.097 )
Q.ON.BODY.2      := ( 28.170, -169.370, 39.270 )
R.ON.BODY.1      := ( 31.943, -169.370, 26.328 )
R.ON.BODY.2      := ( 44.115, -169.370, 28.915 )
NODE.1           := '0'
NODE.2           := '0'

UP
CREATE SPHERICAL.JOINT
NAME              := 'SPH.UFL'
BODY.1.NAME      := 'ARM.UFL'
BODY.2.NAME      := 'WHEEL.FL'
P.ON.BODY.1      := ( -28.170, -39.868, 39.254 )
P.ON.BODY.2      := ( -28.170, -39.868, 39.254 )
Q.ON.BODY.1      := ( -27.962, -39.920, 40.231 )
Q.ON.BODY.2      := ( -25.375, -40.556, 52.388 )
R.ON.BODY.1      := ( -29.148, -39.868, 39.462 )
R.ON.BODY.2      := ( -41.304, -39.868, 42.049 )
NODE.1           := '0'
NODE.2           := '0'

UP
CREATE SPHERICAL.JOINT
NAME              := 'SPH.UFR'
BODY.1.NAME      := 'ARM.UFR'
BODY.2.NAME      := 'WHEEL.FR'
P.ON.BODY.1      := ( 28.170, -39.868, 39.254 )
P.ON.BODY.2      := ( 28.170, -39.868, 39.254 )
Q.ON.BODY.1      := ( 27.962, -39.920, 40.231 )
Q.ON.BODY.2      := ( 25.375, -40.556, 52.388 )
R.ON.BODY.1      := ( 29.148, -39.868, 39.462 )
R.ON.BODY.2      := ( 41.304, -39.868, 42.049 )
NODE.1           := '0'
NODE.2           := '0'

UP

```

CREATE SPHERICAL.JOINT

NAME	:= 'SPH.URL'
BODY.1.NAME	:= 'ARM.URL'
BODY.2.NAME	:= 'WHEEL.RL'
P.ON.BODY.1	:= (-28.170, -169.370, 39.270)
P.ON.BODY.2	:= (-28.170, -169.370, 39.270)
Q.ON.BODY.1	:= (-25.375, -169.370, 52.420)
Q.ON.BODY.2	:= (-25.375, -169.370, 52.420)
R.ON.BODY.1	:= (-41.320, -169.370, 42.065)
R.ON.BODY.2	:= (-41.320, -169.370, 42.065)
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE SPHERICAL.JOINT

NAME	:= 'SPH.URR'
BODY.1.NAME	:= 'ARM.URR'
BODY.2.NAME	:= 'WHEEL.RR'
P.ON.BODY.1	:= (28.170, -169.370, 39.270)
P.ON.BODY.2	:= (28.170, -169.370, 39.270)
Q.ON.BODY.1	:= (25.375, -169.370, 52.420)
Q.ON.BODY.2	:= (25.375, -169.370, 52.420)
R.ON.BODY.1	:= (41.320, -169.370, 42.065)
R.ON.BODY.2	:= (41.320, -169.370, 42.065)
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE SPHERICAL.JOINT

NAME	:= 'TRAILER.HITCH'
BODY.1.NAME	:= 'CHASSIS'
BODY.2.NAME	:= 'TRAILER.CHASSIS'
P.ON.BODY.1	:= (0.0, -206.37, 33.38)
P.ON.BODY.2	:= (0.0, -206.37, 33.38)
Q.ON.BODY.1	:= (0.0, -206.37, 34.38)
Q.ON.BODY.2	:= (0.0, -206.37, 34.38)
R.ON.BODY.1	:= (1.0, -206.37, 33.38)
R.ON.BODY.2	:= (1.0, -206.37, 33.38)
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE TRANSLATIONAL.JOINT

NAME	:= 'TRAILER.TRANS'
BODY.1.NAME	:= 'TRAILER.CHASSIS'
BODY.2.NAME	:= 'TRAILER.DUMMY'
P.ON.BODY.1	:= (0.0, -305.37, 32.88)
P.ON.BODY.2	:= (0.0, -305.37, 32.88)
Q.ON.BODY.1	:= (0.0, -305.37, 35.14)
Q.ON.BODY.2	:= (0.0, -305.37, 35.14)
R.ON.BODY.1	:= (1.0, -305.37, 32.88)
R.ON.BODY.2	:= (1.0, -305.37, 32.88)
NODE.1	:= '0'
NODE.2	:= '0'

UP

CREATE UNIVERSAL.JOINT

NAME	:= 'PITMAN.UNIV'
BODY.1.NAME	:= 'PITMAN.ARM'
BODY.2.NAME	:= 'STEERING.LINK'
P.ON.BODY.1	:= (-9.811, -50.556, 32.433)
P.ON.BODY.2	:= (-9.811, -50.556, 32.433)
Q.ON.BODY.1	:= (-9.811, -50.239, 33.381)
Q.ON.BODY.2	:= (-9.811, -49.608, 32.116)

```

R.ON.BODY.1      := ( -8.811, -50.556, 32.433 )
R.ON.BODY.2      := ( -8.811, -50.556, 32.433 )
NODE.1           := '0'
NODE.2           := '0'

```

UP

CREATE BODY

```

NAME              := 'CHASSIS'
CENTER.OF.GRAVITY := ( 0.585, -123.170, 63.064 )
TYPE.ANGULAR.COORD := 'BRYANT'
ANGLE.1           := '0.0'
ANGLE.2           := '0.0'
ANGLE.3           := '0.0'
FIXED.TO.GROUND   := 'FALSE'
MASS              := '20.049'
INERTIA.XXL       := '52680.0'
INERTIA.YYL       := '13320.0'
INERTIA.ZZL       := '56280.0'
INERTIA.XYL       := '0.0'
INERTIA.XZL       := '0.0'
INERTIA.YZL       := '0.0'
XG.FORCE          := '0.0'
YG.FORCE          := '0.0'
ZG.FORCE          := '0.0'
XL.TORQUE         := '0.0'
YL.TORQUE         := '0.0'
ZL.TORQUE         := '0.0'
CURVE.XGF         := 'NONE'
CURVE.YGF         := 'NONE'
CURVE.ZGF         := 'NONE'
CURVE.XLT         := 'NONE'
CURVE.YLT         := 'NONE'
CURVE.ZLT         := 'NONE'
SIGN.E0           := 'POSITIVE'
ANGULAR.UNITS     := 'DEGREES'
FLEXIBLE          := 'FALSE'
SUPERELEMENT      := 'FALSE'

```

UP

CREATE BODY

```

NAME              := 'ARM.LFL'
CENTER.OF.GRAVITY := ( -21.5275, -37.78, 28.445 )
TYPE.ANGULAR.COORD := 'BRYANT'
ANGLE.1           := '0.0'
ANGLE.2           := '-13.84'
ANGLE.3           := '0.0'
FIXED.TO.GROUND   := 'FALSE'
MASS              := '0.0932'
INERTIA.XXL       := '1.0'
INERTIA.YYL       := '1.0'
INERTIA.ZZL       := '1.0'
INERTIA.XYL       := '0.0'
INERTIA.XZL       := '0.0'
INERTIA.YZL       := '0.0'
XG.FORCE          := '0.0'
YG.FORCE          := '0.0'
ZG.FORCE          := '0.0'
XL.TORQUE         := '0.0'
YL.TORQUE         := '0.0'
ZL.TORQUE         := '0.0'
CURVE.XGF         := 'NONE'

```

CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE BODY

NAME	:= 'ARM.LFR'
CENTER.OF.GRAVITY	:= (21.5275, -37.78, 28.445)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '13.84'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0932'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE BODY

NAME	:= 'ARM.LRL'
CENTER.OF.GRAVITY	:= (-21.5275, -170.77, 28.445)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '-13.84'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0932'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'

XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'ARM.LRR'
CENTER.OF.GRAVITY	:= (21.5275, -170.77, 28.445)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '13.84'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0932'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'ARM.UFL'
CENTER.OF.GRAVITY	:= (-23.1765, -41.935, 39.3445)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '12.557'
ANGLE.2	:= '0.0'
ANGLE.3	:= '-8.209'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0311'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'

INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'ARM.UFR'
CENTER.OF.GRAVITY	:= (23.1765, -41.935, 39.3445)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '12.557'
ANGLE.2	:= '0.0'
ANGLE.3	:= '8.209'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0311'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'ARM.URL'
CENTER.OF.GRAVITY	:= (-23.1825, -165.875, 39.4625)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '-2.21'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0311'
INERTIA.XXL	:= '1.0'

INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'ARM.URR'
CENTER.OF.GRAVITY	:= (23.1825, -165.875, 39.4625)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '2.21'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0311'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'WHEEL.FL'
CENTER.OF.GRAVITY	:= (-35.815, -39.37, 29.735)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'

ANGLE.3	:= '-0.246'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.5047'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE BODY

NAME	:= 'WHEEL.FR'
CENTER.OF.GRAVITY	:= (35.815, -39.37, 29.735)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.246'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.5047'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE BODY

NAME	:= 'WHEEL.RL'
------	---------------

CENTER.OF.GRAVITY	:= (-35.815, -169.37, 29.735)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.246'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.5046'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

CREATE BODY

NAME	:= 'WHEEL.RR'
CENTER.OF.GRAVITY	:= (35.815, -169.37, 29.735)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '-0.246'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.5046'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'

SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'PITMAN.ARM'
CENTER.OF.GRAVITY	:= (-9.811, -52.956, 33.236)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '-18.5'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.0129'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'STEERING.LINK'
CENTER.OF.GRAVITY	:= (0.000, -50.556, 32.433)
TYPE.ANGULAR.COORD	:= 'BRYANT'
ANGLE.1	:= '-18.5'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '.0518'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'

CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'TRAILER.CHASSIS'
CENTER.OF.GRAVITY	:= (0.0, -302.02, 54.38)
TYPE.ANGULAR.COORD	:= 'EULER'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '7.25'
INERTIA.XXL	:= '10000.0'
INERTIA.YYL	:= '2600.0'
INERTIA.ZZL	:= '10000.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'
UP	
CREATE BODY	
NAME	:= 'TRAILER.AXLE'
CENTER.OF.GRAVITY	:= (0.0, -305.37, 27.88)
TYPE.ANGULAR.COORD	:= 'EULER'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '1.0'
INERTIA.XXL	:= '50.0'
INERTIA.YYL	:= '10.0'
INERTIA.ZZL	:= '50.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'

CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE BODY

NAME	:= 'TRAILER.DUMMY'
CENTER.OF.GRAVITY	:= (0.0, -305.37, 32.88)
TYPE.ANGULAR.COORD	:= 'EULER'
ANGLE.1	:= '0.0'
ANGLE.2	:= '0.0'
ANGLE.3	:= '0.0'
FIXED.TO.GROUND	:= 'FALSE'
MASS	:= '0.1'
INERTIA.XXL	:= '1.0'
INERTIA.YYL	:= '1.0'
INERTIA.ZZL	:= '1.0'
INERTIA.XYL	:= '0.0'
INERTIA.XZL	:= '0.0'
INERTIA.YZL	:= '0.0'
XG.FORCE	:= '0.0'
YG.FORCE	:= '0.0'
ZG.FORCE	:= '0.0'
XL.TORQUE	:= '0.0'
YL.TORQUE	:= '0.0'
ZL.TORQUE	:= '0.0'
CURVE.XGF	:= 'NONE'
CURVE.YGF	:= 'NONE'
CURVE.ZGF	:= 'NONE'
CURVE.XLT	:= 'NONE'
CURVE.YLT	:= 'NONE'
CURVE.ZLT	:= 'NONE'
SIGN.E0	:= 'POSITIVE'
ANGULAR.UNITS	:= 'DEGREES'
FLEXIBLE	:= 'FALSE'
SUPERELEMENT	:= 'FALSE'

UP

CREATE INITIAL.CONDITION

NAME	:= 'INIT.CHASSIS.ORIEN'
BODY.1.NAME	:= 'CHASSIS'
BODY.2.NAME	:= 'NONE'
ELEMENT.NAME	:= 'NONE'
TYPE.INITIAL.COND	:= 'ORIENTATION'
INITIAL.VALUE	:= '0.0'
TIME.DERIVATIVE	:= '0.0'
OMEGA.Y	:= '0.0'
OMEGA.Z	:= '0.0'
P.ON.BODY.1	:= (0.0, 0.0, 0.0)
P.ON.BODY.2	:= (0.0, 0.0, 0.0)
EXTRA.COORD	:= '0'
ANGULAR.UNITS	:= 'DEGREES'

CREATE INITIAL.CONDITION

NAME	:= 'INIT.CHASSIS.X'
BODY.1.NAME	:= 'CHASSIS'

```

BODY.2.NAME           := 'NONE'
ELEMENT.NAME          := 'NONE'
TYPE.INITIAL.COND     := 'X'
INITIAL.VALUE         := '0.0'
TIME.DERIVATIVE       := '0.0'
OMEGA.Y               := '0.0'
OMEGA.Z               := '0.0'
P.ON.BODY.1           := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2           := ( 0.0, 0.0, 0.0 )
EXTRA.COORD           := '0'
ANGULAR.UNITS         := 'DEGREES'

```

UP

```

* CREATE INITIAL.CONDITION
  NAME                 := 'INIT.CHASSIS.Y'
  BODY.1.NAME          := 'CHASSIS'
  BODY.2.NAME          := 'NONE'
  ELEMENT.NAME         := 'NONE'
  TYPE.INITIAL.COND    := 'Y'
  INITIAL.VALUE        := '0.0'
  TIME.DERIVATIVE      := '440.0'
  OMEGA.Y              := '0.0'
  OMEGA.Z              := '0.0'
  P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
  P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
  EXTRA.COORD          := '0'
  ANGULAR.UNITS        := 'DEGREES'

```

UP

```

CREATE INITIAL.CONDITION
  NAME                 := 'INIT.CHASSIS.Z'
  BODY.1.NAME          := 'CHASSIS'
  BODY.2.NAME          := 'NONE'
  ELEMENT.NAME         := 'NONE'
  TYPE.INITIAL.COND    := 'Z'
  INITIAL.VALUE        := '0.0'
  TIME.DERIVATIVE      := '0.0'
  OMEGA.Y              := '0.0'
  OMEGA.Z              := '0.0'
  P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
  P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
  EXTRA.COORD          := '0'
  ANGULAR.UNITS        := 'DEGREES'

```

UP

```

* CREATE INITIAL.CONDITION
  NAME                 := 'INIT.WHEEL.FL'
  BODY.1.NAME          := 'WHEEL.FL'
  BODY.2.NAME          := 'NONE'
  ELEMENT.NAME         := 'NONE'
  TYPE.INITIAL.COND    := 'Z'
  INITIAL.VALUE        := '0.0'
  TIME.DERIVATIVE      := '0.0'
  OMEGA.Y              := '0.0'
  OMEGA.Z              := '0.0'
  P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
  P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
  EXTRA.COORD          := '0'
  ANGULAR.UNITS        := 'DEGREES'

```

UP
CREATE INITIAL.CONDITION

```

  NAME                 := 'INIT.WHEEL.FR'
  BODY.1.NAME          := 'WHEEL.FR'

```

```

BODY.2.NAME           := 'NONE'
ELEMENT.NAME          := 'NONE'
TYPE.INITIAL.COND     := 'Z'
INITIAL.VALUE         := '0.0'
TIME.DERIVATIVE       := '0.0'
OMEGA.Y               := '0.0'
OMEGA.Z               := '0.0'
P.ON.BODY.1           := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2           := ( 0.0, 0.0, 0.0 )
EXTRA.COORD           := '0'
ANGULAR.UNITS         := 'DEGREES'

```

UP

CREATE INITIAL.CONDITION

```

NAME                 := 'INIT.WHEEL.RL'
BODY.1.NAME          := 'WHEEL.RL'
BODY.2.NAME          := 'NONE'
ELEMENT.NAME         := 'NONE'
TYPE.INITIAL.COND    := 'Z'
INITIAL.VALUE        := '0.0'
TIME.DERIVATIVE      := '0.0'
OMEGA.Y              := '0.0'
OMEGA.Z              := '0.0'
P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
EXTRA.COORD          := '0'
ANGULAR.UNITS        := 'DEGREES'

```

UP

CREATE INITIAL.CONDITION

```

NAME                 := 'INIT.WHEEL.RR'
BODY.1.NAME          := 'WHEEL.RR'
BODY.2.NAME          := 'NONE'
ELEMENT.NAME         := 'NONE'
TYPE.INITIAL.COND    := 'Z'
INITIAL.VALUE        := '0.0'
TIME.DERIVATIVE      := '0.0'
OMEGA.Y              := '0.0'
OMEGA.Z              := '0.0'
P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
EXTRA.COORD          := '0'
ANGULAR.UNITS        := 'DEGREES'

```

UP

CREATE INITIAL.CONDITION

```

NAME                 := 'WHEEL.FL.ORIEN'
BODY.1.NAME          := 'WHEEL.FL'
BODY.2.NAME          := 'NONE'
ELEMENT.NAME         := 'NONE'
TYPE.INITIAL.COND    := 'E3'
INITIAL.VALUE        := '-0.002155'
TIME.DERIVATIVE      := '0.0'
OMEGA.Y              := '0.0'
OMEGA.Z              := '0.0'
P.ON.BODY.1          := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2          := ( 0.0, 0.0, 0.0 )
EXTRA.COORD          := '0'
ANGULAR.UNITS        := 'DEGREES'

```

CREATE INITIAL.CONDITION

```

NAME                 := 'WHEEL.FR.ORIEN'
BODY.1.NAME          := 'WHEEL.FR'

```

BODY.2.NAME	:= 'NONE'
ELEMENT.NAME	:= 'NONE'
TYPE.INITIAL.COND	:= 'E3'
INITIAL.VALUE	:= '0.002138'
TIME.DERIVATIVE	:= '0.0'
OMEGA.Y	:= '0.0'
OMEGA.Z	:= '0.0'
P.ON.BODY.1	:= (0.0, 0.0, 0.0)
P.ON.BODY.2	:= (0.0, 0.0, 0.0)
EXTRA.COORD	:= '0'
ANGULAR.UNITS	:= 'DEGREES'
UP	
CREATE INITIAL.CONDITION	
NAME	:= 'INITIAL.TRAILER.CH.ORIEN'
BODY.1.NAME	:= 'TRAILER.CHASSIS'
BODY.2.NAME	:= 'NONE'
ELEMENT.NAME	:= 'NONE'
TYPE.INITIAL.COND	:= 'ORIENTATION'
INITIAL.VALUE	:= '0.0'
TIME.DERIVATIVE	:= '0.0'
OMEGA.Y	:= '0.0'
OMEGA.Z	:= '0.0'
P.ON.BODY.1	:= (0.0, 0.0, 0.0)
P.ON.BODY.2	:= (0.0, 0.0, 0.0)
EXTRA.COORD	:= '0'
ANGULAR.UNITS	:= 'DEGREES'
UP	
CREATE INITIAL.CONDITION	
NAME	:= 'TRAILER.AXLE.VERTICAL'
BODY.1.NAME	:= 'TRAILER.AXLE'
BODY.2.NAME	:= 'NONE'
ELEMENT.NAME	:= 'NONE'
TYPE.INITIAL.COND	:= 'Z'
INITIAL.VALUE	:= '0.0'
TIME.DERIVATIVE	:= '0.0'
OMEGA.Y	:= '0.0'
OMEGA.Z	:= '0.0'
P.ON.BODY.1	:= (0.0, 0.0, 0.0)
P.ON.BODY.2	:= (0.0, 0.0, 0.0)
EXTRA.COORD	:= '0'
ANGULAR.UNITS	:= 'DEGREES'
UP	
CREATE INITIAL.CONDITION	
NAME	:= 'TRAILER.AXLE.Y.ORIEN'
BODY.1.NAME	:= 'TRAILER.AXLE'
BODY.2.NAME	:= 'NONE'
ELEMENT.NAME	:= 'NONE'
TYPE.INITIAL.COND	:= 'E2'
INITIAL.VALUE	:= '0.0'
TIME.DERIVATIVE	:= '0.0'
OMEGA.Y	:= '0.0'
OMEGA.Z	:= '0.0'
P.ON.BODY.1	:= (0.0, 0.0, 0.0)
P.ON.BODY.2	:= (0.0, 0.0, 0.0)
EXTRA.COORD	:= '0'
ANGULAR.UNITS	:= 'DEGREES'
CREATE DRIVER	
NAME	:= 'DRIVER'
BODY.1.NAME	:= 'NONE'

```

BODY.2.NAME           := 'NONE'
TYPE.DRIVER           := 'REL.ANGLE'
DRIVING.FUNCTION       := 'GENERAL'
FUNCTION.PARAMETERS    := ( 0.0, 0.0, 0.0, 0.0 )
P.ON.BODY.1           := ( 0.0, 0.0, 0.0 )
P.ON.BODY.2           := ( 0.0, 0.0, 0.0 )
Q.ON.BODY.1           := ( 0.0, 0.0, 1.0 )
Q.ON.BODY.2           := ( 0.0, 0.0, 1.0 )
R.ON.BODY.1           := ( 1.0, 0.0, 0.0 )
R.ON.BODY.2           := ( 1.0, 0.0, 0.0 )
CURVE.DRIVER          := 'TRAJECTORY'
JOINT.NAME             := 'PITMAN.REV'
ANGULAR.UNITS          := 'DEGREES'

```

UP

CREATE CURVE

```

NAME                 := 'TIRE.COEF'
TYPE.DATA             := 'PAIRED.XY'
SLOPE.LEFT           := '4.000'
SLOPE.RIGHT          := '0.000'
SCALE.X              := '1.0'
SCALE.Y              := '1.0'
START.X              := '0.0'
INCREMENT.X           := '0.0'
INTERPOLATION         := 'CUBIC'

```

DATA

0.0000000000E+00	0.0000000000E+00	0.2000000000E-01	0.8000000000E-01
0.4000000000E-01	0.2000000000	0.8000000000E-01	0.4950000000
0.1050000000	0.7000000000	0.1250000000	0.7600000000
0.1650000000	0.7950000000	0.2200000000	0.7950000000
0.2950000000	0.7500000000	0.4300000000	0.7000000000
1.0000000000	0.6000000000		

ENDDATA

UP

CREATE CURVE

```

NAME                 := 'BIAS.TIRE.20PSI'
TYPE.DATA             := 'PAIRED.XY'
SLOPE.LEFT           := '0.0'
SLOPE.RIGHT          := '1600.000'
SCALE.X              := '1.0'
SCALE.Y              := '1.0'
START.X              := '0.0'
INCREMENT.X           := '0.0'
INTERPOLATION         := 'CUBIC'

```

DATA

0.0000000000E+00	0.0000000000E+00	0.1000000000	66.67000000
0.2000000000	125.0000000	0.3000000000	175.0000000
0.4000000000	250.0000000	0.5000000000	375.0000000
0.6000000000	475.0000000	0.7000000000	600.0000000
0.8000000000	700.0000000	1.0000000000	975.0000000
1.2000000000	1250.000000	1.4000000000	1500.000000
1.6000000000	1800.000000	1.8000000000	2100.000000
2.0000000000	2425.000000	2.2000000000	2700.000000
2.4000000000	3125.000000	2.6000000000	3350.000000
2.8000000000	3675.000000	3.0000000000	3975.000000
3.2000000000	4300.000000		

ENDDATA

CREATE CURVE

```

NAME                 := 'BIAS.TIRE.30PSI'
TYPE.DATA             := 'PAIRED.XY'

```



UP

CREATE CURVE

4

```

0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00
0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0.0000000000E+00

```

ENDDATA

UP

CREATE CURVE

```

NAME                := 'RADIAL.TIRE.LT235.85R16'
TYPE.DATA           := 'PAIRED.XY'
SLOPE.LEFT          := '0.0'
SLOPE.RIGHT         := '1600.000'
SCALE.X             := '1.0'
SCALE.Y             := '0.82'
START.X             := '0.0'
INCREMENT.X         := '0.0'
INTERPOLATION       := 'LINEAR'

```

DATA

0.0000000000E+00	0.0000000000E+00	0.1000000000	66.67000000
0.2000000000	125.000000	0.3000000000	175.000000
0.4000000000	250.000000	0.5000000000	375.000000
0.6000000000	475.000000	0.7000000000	600.000000
0.8000000000	700.000000	1.0000000000	975.000000
1.2000000000	1250.000000	1.4000000000	1500.000000
1.6000000000	1800.000000	1.8000000000	2100.000000
2.0000000000	2425.000000	2.2000000000	2700.000000
2.4000000000	3125.000000	2.6000000000	3350.000000
2.8000000000	3675.000000	3.0000000000	3975.000000
3.2000000000	4300.000000		

ENDDATA

CREATE CURVE

```

NAME                := 'TRAILER.SHOCK.CURVE'
TYPE.DATA           := 'PAIRED.XY'
SLOPE.LEFT          := '5.0'
SLOPE.RIGHT         := '5.0'
SCALE.X             := '1.0'
SCALE.Y             := '2.0'
START.X             := '0.0'
INCREMENT.X         := '0.0'
INTERPOLATION       := 'LINEAR'

```

DATA

-723.00000000	-4600.000000	-223.00000000	-2100.000000
0.0000000000E+00	0.0000000000E+00	198.00000000	2100.000000
700.00000000	4600.000000		

ENDDATA

UP

CREATE CURVE

```

NAME                := 'TRAILER.SPRING.CURVE'
TYPE.DATA           := 'PAIRED.XY'
SLOPE.LEFT          := '6400.0'
SLOPE.RIGHT         := '6400.0'
SCALE.X             := '1.0'
SCALE.Y             := '1.0'
START.X             := '0.0'
INCREMENT.X         := '0.0'
INTERPOLATION       := 'LINEAR'

```

DATA

-3.0000000000	-7480.000000	-2.5000000000	-4280.000000
-1.5000000000	-2360.000000	0.0000000000E+00	-1400.000000
3.4370000000	800.000000	4.4370000000	7200.000000

ENDDATA

UP

CREATE CURVE

NAME	:= 'TRAILER.SPRING.FRICT'
TYPE.DATA	:= 'PAIRED.XY'
SLOPE.LEFT	:= '0.0'
SLOPE.RIGHT	:= '0.0'
SCALE.X	:= '10.0'
SCALE.Y	:= '100.0'
START.X	:= '0.0'
INCREMENT.X	:= '0.0'
INTERPOLATION	:= 'LINEAR'

DATA

-10.00000000	-1.000000000	-8.000000000	-.9440000000
-5.000000000	-.6250000000	-2.000000000	-.2960000000
0.000000000E+00	0.000000000E+00	2.000000000	0.2960000000
5.000000000	0.6250000000	8.000000000	0.9440000000
10.00000000	1.000000000		

ENDDATA

UP

superi>

USER INPUT FILE:

TERRAIN: flat Ground Data because NX = 0

234567890123456789012345678901234567890123456789012345678901234567890

Roll Stiffness (lbs/rad) :

140000.0

Fore-Aft Offset used to give some distance before entering terrain (YOFFSET)

250.0

Vertical offset for each tire: (ZOFFSET(I), I=1, # of tires)

12.73 12.73 12.73 12.73 13.56 13.56

Rotational Inertia of each wheel: (ROTINT(I), I=1, # of wheels)

40.0 40.0 40.0 40.0 40.0 40.0

Run Flat Radius

12.50

Run Flat Stiffness

10000.0

Run Flat Damping

0.00

Trajectory Curve Name

TRAJECTORY

Speed Controller Command Vehicle Velocity:

440.00

Position error feedback gain PKP:

0.0

Velocity error feedback gain PKV:

500.0

Maximum output torque at each wheel @ 100% engine power TORMAX:

28620.0

Rotation Point about global Z to get new vehicle orientation

0.0 0.0 0.0

Rotation Angle about global Z

0.0

Lateral Force versus slip and vertical force - BIAS.TIRE.20PSI

7 5

Slip Angle Data

0.0 0.01745 0.03491 0.05236 0.06981 0.10470 0.2094

Vertical Force Data

0.000 1000.000 2000.000 3000.000 4000.000

Lateral Force Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	230.000	422.000	578.000	680.000	902.000	1084.000
0.0	296.000	546.000	752.000	962.000	1330.000	1865.000
0.0	275.000	508.000	712.000	928.000	1293.000	2266.000
0.0	249.000	435.000	575.000	726.000	1080.000	1976.000

Lateral Force versus slip and vertical force - BIAS.TIRE.28PSI

7 5

Slip Angle Data

0.0 0.01745 0.03491 0.05236 0.06981 0.10470 0.2094

Vertical Force Data

0.000 1000.000 2000.000 3000.000 4000.000

Lateral Force Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	217.000	392.000	544.000	671.000	803.000	1018.000
0.0	333.000	623.000	863.000	1101.000	1436.000	1924.000
0.0	362.000	645.000	942.000	1191.000	1671.000	2463.000
0.0	348.000	602.000	892.000	1142.000	1613.000	2625.000

Lateral Force versus slip and vertical force - Goodyear 8.75R16.5 85PSI

8 5

Slip Angle Data

0.0 0.01745 0.035 0.070 0.140 0.209 0.279 0.5

Vertical Force Data

0.000	804.0	1742.0	2680.0	3618.0
-------	-------	--------	--------	--------

Lateral Force Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	99.8	192.5	329.5	557.6	666.2	740.75	740.5
0.0	223.0	397.7	693.0	1104.5	1302.5	1360.0	1360.0
0.0	309.5	557.8	1025.5	1614.5	1858.9	2390.5	2390.5
0.0	382.3	718.0	1303.5	2077.0	2343.1	2395.5	2395.5

Aligning Torque versus slip and vertical force - BIAS.TIRE.20PSI

7 15

Slip Angle Data

0.0	0.01745	0.03491	0.05236	0.06981	0.08727	0.1047
-----	---------	---------	---------	---------	---------	--------

Vertical Force Data

0.000	179.840	517.040	854.240	1191.440	1528.640	1865.840	2203.040
2540.240	2877.440	3214.640	3551.840	3889.040	4226.240	4563.440	

Aligning Torque Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	58.08	78.410	96.800	77.440	67.760	58.080
0.0	116.160	156.820	193.600	154.880	135.520	116.160
0.0	232.320	313.635	387.200	309.760	271.040	232.320
0.0	387.200	619.530	696.970	696.970	658.250	619.530
0.0	542.090	933.000	1115.150	1161.600	1115.150	1084.200
0.0	774.410	1277.780	1548.820	1672.700	1672.700	1626.260
0.0	929.290	1548.820	2013.500	2168.300	2207.060	2245.800
0.0	1084.170	1858.580	2400.670	2710.400	2865.300	2942.756
0.0	1161.614	2168.350	2787.870	3175.080	3407.400	3562.280
0.0	1277.780	2323.230	3097.630	3639.700	4026.930	4182.800
0.0	1394.000	2555.550	3407.400	4065.650	4569.020	4801.340
0.0	1471.380	2710.433	3717.160	4491.570	4956.220	5420.866
0.0	1510.098	2787.870	3872.050	4723.890	5420.866	5885.512
0.0	1548.810	2942.760	4026.930	4956.220	5730.630	6195.280

Aligning Torque versus slip and vertical force - BIAS.TIRE.28PSI

7 15

Slip Angle Data

0.0	0.01745	0.03491	0.05236	0.06981	0.08727	0.1047
-----	---------	---------	---------	---------	---------	--------

Vertical Force Data

0.000	179.840	517.040	854.240	1191.440	1528.640	1865.840	2203.040
2540.240	2877.440	3214.640	3551.840	3889.040	4226.240	4563.440	

Aligning Torque Data

0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	19.360	38.721	58.080	58.080	38.721	38.721
0.0	38.720	77.441	116.162	226.162	77.441	77.441
0.0	77.441	154.882	232.323	232.323	154.882	154.882
0.0	232.323	464.646	542.087	542.087	464.646	464.646
0.0	464.646	774.410	851.851	851.851	851.851	851.851
0.0	619.528	1006.733	1239.056	1239.056	1239.056	1277.777
0.0	774.410	1316.497	1548.820	1703.702	1703.702	1781.143
0.0	929.292	1548.820	2013.466	2168.348	2245.789	2323.230
0.0	1084.175	1858.584	2400.671	2710.435	2787.876	2865.317
0.0	1161.615	2168.348	2787.876	3097.640	3329.963	3484.845
0.0	1316.497	2400.671	3097.640	3639.727	3949.491	4065.652
0.0	1393.938	2632.994	3407.404	4026.932	4414.137	4646.460
0.0	1471.379	2787.876	3717.168	4414.137	4878.783	5111.106
0.0	1548.820	2942.758	3949.491	4685.180	5265.988	5653.193

Aligning torque versus slip and vertical force - Goodyear 8.75R16.5 85PSI

8 5

Slip Angle Data

0.0	0.01745	0.035	0.070	0.140	0.209	0.279	0.5
-----	---------	-------	-------	-------	-------	-------	-----

Vertical force data

0.000	804.0	1742.0	2680.0	3618.0
-------	-------	--------	--------	--------

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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APPENDIX C

Tire Model FORTRAN Source Code

C---ROUTINE: FRC38 Calculate tire forces.

C-----Author and Modification Section-----

C Author: James A. Aardema, Rick Mousseau, Roger Wheahage

C Date written: March 25, 1987

C Written on: Digital VAX Workstation II

C Modifications:

C-----Algorithm Description-----

C Purpose and use:

C Calculates the tire forces when a body has a tire attached.

C The derivation assumes the vehicle is pointed along the global Y axis initially and that the velocity vector is along that axis, and that the global Z axis is vertical.

C Error conditions: none

C Machine dependencies: none

C Called by: MM38.FOR

SUBROUTINE FRC38 (Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA, NB,
& NTR, MPTRS, NPTRS, NPRB, UDE, DUDE)

C=====Variable Descriptions=====

C

C---Arguments passed-----

C

C Q.....Array of generalized coordinates.
C QD.....Array of velocities.
C QDD.....Array of acceleration values.
C FRC....Array of generalized forces.
C ITIR...Array of integer data from this module.
C TIR....Array of real data from this module.
C RB.....Array of rigid body real data.
C A.....Vector of all real data.
C IA.....Vector of all integer data.
C NB.....Number of rigid bodies.
C NTR....Number of tire elements.
C NPTRS..Number of real data per element.
C MPTRS..Number of integer data per element.
C NPRB...Number of real data per rigid body.
C UDE....Array of user differential equations, Position terms
C DUDE...Array of user differential equations, Velocity terms

IMPLICIT DOUBLE PRECISION (A-H,P-Z)

INTEGER NTR,NPTRS,MPTRS,NPRB,NB,IA(0:1)
INTEGER ITIR(MPTRS,NTR)

DOUBLE PRECISION A(0:1),Q(7,1),QD(7,1),FRC(7,1),
& TIR(NPTRS,NTR), RB(NPRB,NB), QDD(7,1),
& UDE(NTR+NTR), DUDE(NTR+NTR)

C

C---COMMON blocks-----

C

INCLUDE 'DISK\$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'
INCLUDE 'DISK\$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]PARAM.BLK'

C---STEPHT common Variables-----

C

C H.....Integration predictor step size.
C HMAX....Maximum integration predictor step size.
C TSTART...Time at the start of the simulation.
C TEND.....Time when simulation is to stop.
-C TSTEP....Integration step size.
C T.....Current time during the simulation.
C HSTLEN...Length of the history arrays.
C HSTPTR...Pointer to the last used location in the history arrays.
C HSTCNT...Count of the number of time steps for which integration
C history was saved.
C HSTH.....Past history of the integration time step.
C HSTK.....Past history of the integration order.
C HSTERR...Past history of the integration error estimate.

C

C

C---PARAM.BLK Common Variables-----

C This file contains a number of constants which are used in various
C subroutines throughout the code and are stored here to insure
C accuracy and make any changes easier.

```

C
C PI.....pi
C TWOPI....two times pi
C DEGRAD...degrees per radian
C MCHEPS...machine epsilon
C BODMOD...number of the rigid body module
C CRVMOD...number of the curve module
C INPEPS...epsilon value used to check error in normalized input
C          values
C
C

```

```

INCLUDE '[-.COMMON]POWER.T.BLK'
INCLUDE '[-.COMMON]ROLLBAR.BLK'
INCLUDE '[-.COMMON]STEER.BLK'
INCLUDE '[-.COMMON]SURF.BLK'
INCLUDE '[-.COMMON]UPLOT.BLK'
INCLUDE '[-.COMMON]WHEEL.BLK'

```

```

C---POWER.T.BLK Common Variables-----

```

```

C
C PKP.....Position error feedback gain
C PKV.....Velocity error feedback gain
C VELCMD...Command velocity (constant)
C TORMAX...Maximum Allowable Torque applied to each wheel
C X0.....Initial X position of the vehicle in global coordinates
C Y0.....Initial Y position of the vehicle in global coordinates
C

```

```

C---ROLLBAR.BLK Common Variables-----

```

```

C
C RSTIFF....Stiffness of the roll stabilizer bar
C

```

```

C---STEER.BLK Common Variables-----

```

```

C
C ITRAJ.....Curve number of the trajectory
C NDRVDE....Number of driver differential equations
C

```

```

C---SURF.BLK Common Variables:-----

```

```

C
C IGROUND..Ground flag (logical)
C NX.....Number of X data points in the terrain data file
C NY.....Number of Y data points in the terrain data file
C XX.....Array (DBLE) containing terrain X (longitude) data points
C YY.....Array (DBLE) containing terrain Y (latitude) data points
C GRID....Array (DBLE) containing terrain Z (elevation) data points
C IPX.....Array containing pointers to the latest grid X coordinate
C          for each wheel. Initially set to 1 by READ_TERRAIN
C IPY.....Array containing pointers to the latest grid Y coordinate
C          for each wheel. Initially set to 1 by READ_TERRAIN
C UV.....Array (double precision) containing 3 unit vectors
C          which describes the grid element
C          UV(C,1,I) Unit vector in the X-Z plane of the grid
C          UV(C,2,I) Unit vector in the Y-Z plane of the grid
C          UV(C,3,I) Unit vector normal to the plane of the grid
C GDE1....UNKNOWN
C YOFFSET..Fore-Aft distance before vehicle enters desired trajectory
C          This allows for some initial vehicle settling
C ZOFFSET..Elevation offset for each wheel. This distance is added
C          to the surface elevation.
C

```

```

C---UPLOT.BLK Common Variables-----

```

```

C
C  UPLOT....Array for storing user variables
C  NPLOT....Number of plot variables used
C
C-----WHEEL.BLK Common Variables-----
C
C  NWHDE....Number of wheel differentiation equations NWHDE = 2 * NCT
C  UDE0.....Initial condition of the wheel differential equations
C  ROTINT...Rotational Inertia of each wheel
C  WHDAMP...Rotational Damping of each wheel
C  WHLBOD...Body number the tire is attached to
C
C---Local variables-----
C
C---Local Variables at process block 1-----
C
C  ACH.....Transformation array to convert local chassis coordinates
C           to global coordinates
C  ALGNTQ ...Aligning moment.
C  ETA     ...Local Y coordinate from body CG to tire center.
C  FLAT    ...Lateral force acting perpendicular to the tire.
C  FLONG   ...Longitudinal force acting in line with the tire.
C  FNORM   ...Normal tire force acting perpendicular to the road.
C  FX      ...Global X component of the tire force.
C  FXB     ...Local X component of the tire force.
C  FY      ...Global Y component of the tire force.
C  FYB     ...Local Y component of the tire force.
C  FZ      ...Global Z component of the tire force.
C  FZB     ...Local Z component of the tire force.
C  IBDY    ...Body number the tire is attached to.
C  OVERM...Overturning moment.
C  RAD.....Radius of the tire.
C  SLIP....Slip angle of the tire.
C  TIREX...Global X position of the tire center.
C  TIREY...Global Y position of the tire center.
C  TIREZ...Global Z position of the tire center.
C  TQETA...Torque about the local eta axis.
C  TQXI...Torque about the local xi axis.
C  TQZETA...Torque about the local zeta axis.
C  VTIREX...Local X velocity of the tire/road interface.
C  VTIREY...Local Y velocity of the tire/road interface.
C  VTIREZ...Local Z velocity of the tire/road interface.
C  XI.....Local X coordinate from body CG to tire center.
C  ZETA....Local Z coordinate from body CG to tire center.
C  NUSED...Number of plot variables used before this time.
C  E0 - E3...Euler parameters

```

```

      INTEGER I, IBDY, ICHS, ITIRE(2), NUSED

```

```

      DOUBLE PRECISION XI,ETA,ZETA,ZETA2,RAD,ROLLM,OVERM,ZROAD,
&                      AM(3,3),YAW,SYAW,CYAW,YAWB,TIREX,TIREY,
&                      TIREZ,VTIRE1,VTIRE2,VTIRE3,VTIREX,VTIREY,
&                      VTIREZ,FX,FY,FZ,FXB,FYB,FZB,TQXI,TQETA

```

```

      DOUBLE PRECISION TQZETA, FLAT, FNORM, TIRE1, TIRE2,
&                      TIRE3, SLIP, GFRC, ALGNTQ,
&                      S, FLONG, E0, E1, E2, E3,
&                      OMEGAX, OMEGAY, OMEGAZ,
&                      TIRECX, TIRECY, TIRECZ

```

C---Local Variables at Process Block 2-----

```

C
C  ACHS.....Chassis Transformation Matrix
C  POSCMD...Command Position
C  POS.....Actual vehicle position
C  XD.....Global X chassis velocity
C  YD.....Global Y chassis velocity
C  ZD.....Global Z chassis velocity
C  YDCHS....Chassis Y velocity in body coordinates
C  ZDCHS....Chassis Z velocity in body coordinates
C  PITCH....Pitch angle
C  VEL.....Actual vehicle velocity
C  POSERR...Position error
C  VELERR...Velocity error
C  FORCE....Controlled force to correct position and velocity errors
C  AVGRAD...Average Radius of each tire
C  TORQUE...Equivalent torque applied to each wheel
C
C      DOUBLE PRECISION ACHS(3,3), POSCMD, POS, XD, YD, ZD,
&      YDCHS, ZDCHS, PITCH, VEL, POSERR,
&      VELERR, FORCE, AVGRAD, TORQUE

```

C---Local Variables at Process Block 3-----

```

C
C  ACHS.....Chassis Transformation Matrix
C  DELTAP...Array containing the X, Y, and Z global components of
C           a vector between the two lower control arms C.G.
C  DXCH.....The above vector along the chassis X axis
C  DZCH.....The above vector along the chassis Z axis
C  VECLen...Length of the above vector
C  ANG.....The angle between of the vector in the chassis X-Z plane
C  ARMFOR...Verticle arm force due to roll stabilization bar
C  CHTOR....Reaction Torque acting about the Chassis Y (fore-aft) Axis
C  TQ.....Reaction Torque in Global Coordinate System
C  TQE.....Reaction Torque in Euler Parameter Coordinate System
C  FP.....Array containing the X, Y, and Z roll bar vertical force
C           in global coordinates
C
C      DOUBLE PRECISION DELTAP(3), DXCH, DZCH, ANG, ARMFOR, FP(3),
&      CHTOR, TQ(3), TQE(4), VECLen

```

C---Functions and subroutines-----

DOUBLE PRECISION FSPLIN, CUBIC, CUBIC1

EXTERNAL TIREF, FSPLIN, CUBIC, CUBIC1, ETS

INTRINSIC DSQRT, DSIN, DCOS, DACOS, DASIN, DSIGN, DABS,
& DATAN, DATAN2, DMIN1

C=====Process Block=====

C---First get the number of plot variables used before this time

C See USER_TSDA.FOR for others

C NUSED must not be modified while in the DO LOOP

NUSED = NPLOT ! Number of plot variables used thus far

C---For each tire do the following routine

DO 1000 I = 1,NTR

C---Initialize local variables for convenience.

```
IBDY = ITIR(1,I)
ICHS = ITIR(2,I)
C IUTIL = ITIR(3,I)
C ITK = ITIR(4,I)
C ILNG = ITIR(5,I)
C ISTR = ITIR(6,I)
C TYPE = ITIR(7,I)
```

```
XI = TIR(1,I)
ETA = TIR(2,I)
ZETA = TIR(3,I)
RAD = TIR(4,I)
C RR = TIR(5,I)
C TD = TIR(6,I)
C TK = TIR(7,I)
C CALP = TIR(8,I)
C STRAGL = TIR(9,I)
C MU = TIR(10,I)
```

C global
C---Define the local to global transformation matrix, [AM].
C local

```
AM(1,1) = RB(38,IBDY)
AM(2,1) = RB(39,IBDY)
AM(3,1) = RB(40,IBDY)
AM(1,2) = RB(41,IBDY)
AM(2,2) = RB(42,IBDY)
AM(3,2) = RB(43,IBDY)
AM(1,3) = RB(44,IBDY)
AM(2,3) = RB(45,IBDY)
AM(3,3) = RB(46,IBDY)
```

C---Define the yaw angle of the axle or wheel center.

C The result of DATAN2 is in radians.

C The range of the result for DATAN2 is $-\pi < \text{result} < \pi$

C
C Does this put limitations on the model????????????????????????????????????

```
YAW = -DATAN2(AM(1,2),AM(2,2))
SYAW = DSIN(YAW)
CYAW = DCOS(YAW)
```

C---Define the vector from the body CG to the tire bottom in the

C global system relative to the axle CG.

C Update ZETA; Zeta is now the local Z coordinate from body CG to tire bottom.

C This assumes that body positive Z axis is upward verticle.

```
ZETA2 = ZETA
ZETA = ZETA - RAD
TIREX = AM(1,1)*XI + AM(1,2)*ETA + AM(1,3)*ZETA
TIREY = AM(2,1)*XI + AM(2,2)*ETA + AM(2,3)*ZETA
TIREZ = AM(3,1)*XI + AM(3,2)*ETA + AM(3,3)*ZETA
```

C---Define the angular velocity of the body assoc with the wheel

```

OMEGAX = RB(32,IBDY)
OMEGAY = RB(33,IBDY)
OMEGAZ = RB(34,IBDY)

```

---Define vector between body CG and wheel center in global cordinates

```

TIRECX = AM(1,1)*XI + AM(1,2)*ETA + AM(1,3)*ZETA2
TIRECY = AM(2,1)*XI + AM(2,2)*ETA + AM(2,3)*ZETA2
TIRECZ = AM(3,1)*XI + AM(3,2)*ETA + AM(3,3)*ZETA2

```

C---Define the global XYZ velocities of the axle or wheel center.

C global [vtire]

```

VTIRE1=QD(1,IBDY) - OMEGAZ*TIRECY + OMEGAY*TIRECZ
VTIRE2=QD(2,IBDY) + OMEGAZ*TIRECX - OMEGAX*TIRECZ
VTIRE3=QD(3,IBDY) - OMEGAY*TIRECX + OMEGAX*TIRECY

```

```

C VTIRE1 = QD(1,IBDY)
C VTIRE2 = QD(2,IBDY)
C VTIRE3 = QD(3,IBDY)

```

C---Transform the velocity vector to the road system.

C road [vtire] = [AYAW] transpose * global [vtire]

```

VTIREX = VTIRE1*CYAW + VTIRE2*SYAW
VTIREY =-VTIRE1*SYAW + VTIRE2*CYAW
VTIREZ = VTIRE3

```

C---Define the global position of the tire bottom.

```

TIREX = TIREX + Q(1,IBDY)
TIREY = TIREY + Q(2,IBDY)
TIREZ = TIREZ + Q(3,IBDY)

```

C---Define the global position of the tire center.

```

TIRE1 = TIREX + RAD*AM(1,3)
TIRE2 = TIREY + RAD*AM(2,3)
TIRE3 = TIREZ + RAD*AM(3,3)

```

C---Calculate the ground elevation if IGROUND flag is not equal to zero.

```

C First intialize ground elevation to 0.0
C Add verticle ground elevation offset

```

```

ZROAD = 0.D0
IF (IGROUND) THEN
    ZROAD=SURF(TIREY-YOFFSET,-TIREX,I)
ENDIF
ZROAD = ZROAD+ZOFFSET(I)

```

C---Save the values calculated thus far

```

TIR(11,I) = YAW
TIR(12,I) = VTIREX
TIR(13,I) = VTIREY
TIR(14,I) = VTIREZ
TIR(15,I) = TIRE1
TIR(16,I) = TIRE2
TIR(17,I) = TIRE3

```

```

TIR(18,I) = TIREX
TIR(19,I) = TIREY
TIR(20,I) = TIREZ
TIR(21,I) = ZROAD

```

C---Calculate the tire forces.

```

CALL TIREF ( I, Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA,
&          NB, NTR, MPTRS, NPTRS, NPRB, UDE, DUDE, NWHDE )

```

.C---Get information for reporting later.

```

DEFL  = TIR(22,I)
FSPR  = TIR(23,I)
FDAMP  = TIR(24,I)
FNORM  = TIR(25,I)
SLIP  = TIR(26,I)
FLAT  = TIR(27,I)
S      = TIR(28,I)
FLONG  = TIR(29,I)
GFRC  = TIR(30,I)
PENRF  = TIR(31,I)
FRF    = TIR(32,I)
ALGNTQ = TIR(33,I)

```

C---Assign torque on tire due to longitudinal force to the wheel
C angular acceleration intergrator to calculate new turning wheel velocity.
C Assign result of acceleration integration to the wheel angular velocity
C integrator to calculate new turning wheel position.

```

DUDE(I+NTR) = GFRC/ROTINT(I)
DUDE(I)      = UDE(I+NTR)

```

C---Transform FLAT and FLONG from the road plane to global.

```

FX = FLAT*CYAW - FLONG*SYAW
FY = FLAT*SYAW + FLONG*CYAW
FZ = FNORM

```

.C---Transform the global forces to the local body system.

```

FXB = AM(1,1)*FX + AM(2,1)*FY + AM(3,1)*FZ
FYB = AM(1,2)*FX + AM(2,2)*FY + AM(3,2)*FZ
FZB = AM(1,3)*FX + AM(2,3)*FY + AM(3,3)*FZ

```

C---Calculate Sxf, the cross product of the S vector and the local force.

```

C N' = S'F' where N' ==> local torque
C S' ==> local vector from CG to point of force
C F' ==> local force

```

```

TQXI = -ZETA*FYB + ETA*FZB
TQETA = ZETA*FXB - XI*FZB
TQZETA = -ETA*FXB + XI*FYB

```

.C---Subtract the torque due the longitudinal tire forces because those
torques get applied to the wheel position and velocity integrators.

```

TQXI = TQXI - GFRC

```

C---Convert the local torques to the Euler parameter system using:

C
$$N_p = 2L \overset{T}{n'} \quad \text{or} \quad N_p = 2G \overset{T}{n'}$$

C where N' is the local torques

C---and update the generalized force vector with the tire forces converted to the global coordinate system. The last four elements are $2*G(T)*N$.

E0 = Q(4,IBDY)

E1 = Q(5,IBDY)

E2 = Q(6,IBDY)

E3 = Q(7,IBDY)

FRC(1,IBDY) = FRC(1,IBDY) + FX

FRC(2,IBDY) = FRC(2,IBDY) + FY

FRC(3,IBDY) = FRC(3,IBDY) + FZ

FRC(4,IBDY) = FRC(4,IBDY) +

& $2.0D0 * (-E1*TQXI - E2*TQETA - E3*TQZETA)$

FRC(5,IBDY) = FRC(5,IBDY) +

& $2.0D0 * (E0*TQXI - E3*TQETA + E2*TQZETA)$

FRC(6,IBDY) = FRC(6,IBDY) +

& $2.0D0 * (E3*TQXI + E0*TQETA - E1*TQZETA)$

FRC(7,IBDY) = FRC(7,IBDY) +

& $2.0D0 * (-E2*TQXI + E1*TQETA + E0*TQZETA)$

C---The aligning torque acts along the vertical axis and in the vertical plane; not the local wheel plane. For a point follower type wheel model such as this the vertical axis is also the global z axis

C---Transform the global aligning torque to euler parameter torques using:

$$N_p = 2G \overset{T}{N}$$

C where N is now a global torque

FRC(4,IBDY) = FRC(4,IBDY) - $2.0D0 * (E3*ALGNTQ)$

FRC(5,IBDY) = FRC(5,IBDY) - $2.0D0 * (E2*ALGNTQ)$

FRC(6,IBDY) = FRC(6,IBDY) + $2.0D0 * (E1*ALGNTQ)$

FRC(7,IBDY) = FRC(7,IBDY) + $2.0D0 * (E0*ALGNTQ)$

C---Report out to report

I1 = NUSED + I	! Start of user plot variables
UPLOT(I1) = YAW	! Yaw angle of the Tire
I2 = I1 + NTR	
UPLOT(I2) = VTIREX	! Tire Velocity in local X direction
I3 = I2 + NTR	
UPLOT(I3) = VTIREY	! Tire Velocity in local Y direction
I4 = I3 + NTR	
UPLOT(I4) = VTIREZ	! Tire Velocity in local Z direction
I5 = I4 + NTR	
UPLOT(I5) = TIRE1	! Global X position of tire center
I6 = I5 + NTR	
UPLOT(I6) = TIRE2	! Global Y position of tire center
I7 = I6 + NTR	
UPLOT(I7) = TIRE3	! Global Z position of tire center
I8 = I7 + NTR	
UPLOT(I8) = TIREX	! Global X position of tire bottom
I9 = I8 + NTR	
UPLOT(I9) = TIREY	! Global Y position of tire bottom
I10 = I9 + NTR	

```

UPLOT(I10)      = TIREZ      ! Global Z position of tire bottom
I11 = I10 + NTR
UPLOT(I11)      = ZROAD      ! Road or surface elevation
I12 = I11 + NTR
UPLOT(I12)      = DEFL       ! Wheel Penetration into surface
I13 = I12 + NTR
UPLOT(I13)      = FSPR       ! Wheel normal force due to penetration
I14 = I13 + NTR
UPLOT(I14)      = FDAMP       ! Wheel normal force due to pene rate
I15 = I14 + NTR
UPLOT(I15)      = FNORM       ! Normal force on wheel
I16 = I15 + NTR
UPLOT(I16)      = SLIP       ! Slip
I17 = I16 + NTR
UPLOT(I17)      = FLAT       ! Lateral force
I18 = I17 + NTR
UPLOT(I18)      = S          ! Longitudinal slip
I19 = I18 + NTR
UPLOT(I19)      = FLONG      ! Longitudinal force
I20 = I19 + NTR
UPLOT(I20)      = GFRC       ! Torque on turning wheel
I21 = I20 + NTR
UPLOT(I21)      = PENRF      ! Penetration into run flat assembly
I22 = I21 + NTR
UPLOT(I22)      = FRF        ! Run flat force
I23 = I22 + NTR
UPLOT(I23)      = ALGNTQ     ! Aligning Torque due to slip

```

C---End of routine calculation for a wheel. Continue for next wheel.

1000 CONTINUE

C---Define more variables for user plot.

```

UPLOT(1)=T      ! Time
NPLOT = I23     ! Number of plot variables used so far

```

C-----Process Block 2-----

C---Calculate torques nesscary to drive vehicle at specified speed-----

```

C   UDE(1)  : Front left wheel angular position
C   UDE(2)  : Front right wheel angular position
C   UDE(3)  : Rear left wheel angular position
-C  UDE(4)  : Rear right wheel angular position
C   UDE(5)  : Front left wheel angular velocity
C   UDE(6)  : Front right wheel angular velocity
C   UDE(7)  : Rear left wheel angular velocity
C   UDE(8)  : Rear right wheel angular velocity

```

C---Get the chassis body number from one of the tire elements

```

ICHS = ITIR(2,1)

```

C---Calculate the command vehicle postion

```

POSCMD = VELCMD*T

```

C---Get the actual vehicle position (the distance the vehicle travel thus far)
C using the TRAJECTORY curve. The vehicle position can be estimated knowing

C the vehicle's current forward position and calculating the arclength of
C the TRAJECTORY. This is a good estimate if the vehicle is on course.

C YPOS = Q(2,ICHS) - Y0
C POS = FSPLIN(YPOS, 0.0D0, ITRAJ, 1, A, IA, -2, 0)

C---Get the chassis transformation matrix

ACHS(1,1) = RB(38,ICHS)
ACHS(2,1) = RB(39,ICHS)
ACHS(3,1) = RB(40,ICHS)
ACHS(1,2) = RB(41,ICHS)
ACHS(2,2) = RB(42,ICHS)
ACHS(3,2) = RB(43,ICHS)
ACHS(1,3) = RB(44,ICHS)
ACHS(2,3) = RB(45,ICHS)
ACHS(3,3) = RB(46,ICHS)

C---Get the global velocity of the chassis

XD = QD(1,ICHS)
YD = QD(2,ICHS)
ZD = QD(3,ICHS)

C---Transform to get the Y and Z velocity components in the chassis C.S.

YDCHS = ACHS(1,2)*XD + ACHS(2,2)*YD + ACHS(3,2)*ZD
ZDCHS = ACHS(1,3)*XD + ACHS(2,3)*YD + ACHS(3,3)*ZD

C---Get the vehicle pitch angle

PITCH = -DATAN2(ACHS(2,3),ACHS(3,3))

C---Calculate the vehicle velocity in the Y direction and contained
C in a horizontal plane

VEL = YDCHS*DCOS(PITCH) - ZDCHS*DSIN(PITCH)

C---Calculate the position and velocity error

C POSERR = POSCMD - POS
C VELERR = VELCMD - VEL

C---Calculate controlled force to correct position and velocity error

FORCE = PKV*VELERR

C---Calculate the average tire radius

AVGRAD = 0.0D0
DO 200 I = 1,NTR
AVGRAD = AVGRAD + (TIR(4,I) - TIR(22,I))
200 CONTINUE
AVGRAD = AVGRAD/4.0D0

C---Convert vehicle force to equivalent wheel torque at each

C---Use negative sign because a negative torque will result in
C the wheel propelling the vehicle forward

TORQUE = -FORCE*AVGRAD

C---Divide the torque evenly between all the wheels

TORQUE = TORQUE/4.0D0

C---Limit the torque at each wheel

IF (TORQUE .GT. TORMAX) TORQUE = TORMAX
IF (TORQUE .LT. -TORMAX) TORQUE = -TORMAX

C---Append torques to each wheel for integration

DUDE(5) = TORQUE/ROTINT(1) + DUDE(5)
DUDE(6) = TORQUE/ROTINT(2) + DUDE(6)
DUDE(7) = TORQUE/ROTINT(3) + DUDE(7)
DUDE(8) = TORQUE/ROTINT(4) + DUDE(8)

C---Report out Torques

UPLOT(NPLOT+1) = UDE(1)
UPLOT(NPLOT+2) = UDE(2)
UPLOT(NPLOT+3) = UDE(3)
UPLOT(NPLOT+4) = UDE(4)
UPLOT(NPLOT+5) = UDE(5)
UPLOT(NPLOT+6) = UDE(6)
UPLOT(NPLOT+7) = UDE(7)
UPLOT(NPLOT+8) = UDE(8)
UPLOT(NPLOT+9) = DUDE(1)
UPLOT(NPLOT+10) = DUDE(2)
UPLOT(NPLOT+11) = DUDE(3)
UPLOT(NPLOT+12) = DUDE(4)
UPLOT(NPLOT+13) = DUDE(5)
UPLOT(NPLOT+14) = DUDE(6)
UPLOT(NPLOT+15) = DUDE(7)
UPLOT(NPLOT+16) = DUDE(8)
UPLOT(NPLOT+17) = POSCMD
UPLOT(NPLOT+18) = POS
UPLOT(NPLOT+19) = PITCH
UPLOT(NPLOT+20) = VEL
UPLOT(NPLOT+21) = POSERR
UPLOT(NPLOT+22) = VELERR
UPLOT(NPLOT+23) = FORCE
UPLOT(NPLOT+24) = AVGRAD
UPLOT(NPLOT+25) = TORQUE

NPLOT = NPLOT+25

! Number of plots used so far

C=====Process Block 3=====

C---Perform roll bar calculations-----

C
C Necessary Conditions:
C 1. Body 1 must be chassis
C 2. Body 2 must be lower front left control arm
C 3. Body 3 must be lower front right control arm
C

C---Get the chassis transformation matrix

ICHS = 1

ACHS(1,1) = RB(38,ICHS)
ACHS(2,1) = RB(39,ICHS)

```

ACHS(3,1) = RB(40,ICHS)
ACHS(1,2) = RB(41,ICHS)
ACHS(2,2) = RB(42,ICHS)
ACHS(3,2) = RB(43,ICHS)
ACHS(1,3) = RB(44,ICHS)
ACHS(2,3) = RB(45,ICHS)
ACHS(3,3) = RB(46,ICHS)

```

C Get a global position vector components required to define a vector
C from the right control arm CG to the Left control arm CG.

```

DELTAP(1) = Q(1,3) - Q(1,2)
DELTAP(2) = Q(2,3) - Q(2,2)
DELTAP(3) = Q(3,3) - Q(3,2)

```

C---Calculate the length of the vector

```

VECLEN = DSQRT( DELTAP(1)**2 + DELTAP(2)**2 + DELTAP(3)**2 )

```

C---Convert global position vector to chassis coordinate system
C and make it into a unit vector

```

DXCH = ( DELTAP(1)*ACHS(1,1) +
&        DELTAP(2)*ACHS(2,1) +
&        DELTAP(3)*ACHS(3,1) ) / VECLN

```

```

DZCH = ( DELTAP(1)*ACHS(1,3) +
&        DELTAP(2)*ACHS(2,3) +
&        DELTAP(3)*ACHS(3,3) ) / VECLN

```

C---Calculate the angle using the dot product between DXCH and a
C vector along the chassis X axis

```

DXCH = DMIN1 ( DXCH, 1.0D0 )
ANG = DACOS ( DXCH )
ANG = DSIGN ( ANG, DZCH )

```

C---Calculate the vertical arm force due to roll bar stiffness

C Force = K * angle

C

C K = lbs/rad

```

ARMFOR = RSTIFF*ANG

```

C---Calculate the reaction torque acting about the chassis Y axis

C based upon a moment arm of 43.06 inches from left arm CG

C to right arm CG

```

CHTOR = -43.06D0*ARMFOR

```

C---Convert the chassis torque to global system

```

TQ(1) = CHTOR*ACHS(1,2)
TQ(2) = CHTOR*ACHS(2,2)
TQ(3) = CHTOR*ACHS(3,2)

```

C---Convert the chassis torque to the Euler Parameter Coordinate System

```

CALL ETS ( Q(4,ICHS), TQ, TQE )

```

C---Append the reaction torque onto the chassis

```
FRC(4,1) = FRC(4,1) + TQE(1) * 2.0D0
FRC(5,1) = FRC(5,1) + TQE(2) * 2.0D0
FRC(6,1) = FRC(6,1) + TQE(3) * 2.0D0
FRC(7,1) = FRC(7,1) + TQE(4) * 2.0D0
```

C---Convert the roll bar vertical force in chassis to global system

```
FP(1) = ARMFOR*ACHS(1,3)
FP(2) = ARMFOR*ACHS(2,3)
FP(3) = ARMFOR*ACHS(3,3)
```

C---Append the equal but opposite force to both left and right lower arms

```
DO 1100 I=1,3
  FRC(I,2)=FRC(I,2)+FP(I)
  FRC(I,3)=FRC(I,3)-FP(I)
1100 CONTINUE
```

C---Report out aux roll stiff data

```
UPLOT(1+NPLLOT) = ANG           ! Roll Bar angle
UPLOT(2+NPLLOT) = ARMFOR        ! Roll Bar Force
UPLOT(3+NPLLOT) = CHTOR         ! Reaction Torque on Chassis
UPLOT(4+NPLLOT) = DXCH
UPLOT(5+NPLLOT) = DZCH
NPLLOT = NPLLOT + 5             ! Update number of plot variables used
```

C---Report out articulation angle of hitch

```
IF (NB .GT. 15) THEN
  UPLOT(1+NPLLOT) = -DATAN2(RB(41,16),RB(42,16)) +
&    DATAN2(RB(41,1),RB(42,1))
  NPLLOT = NPLLOT + 1
END IF

RETURN
END
```

superi>

C---TIREF: Calculates the forces exerted on the tire through the road.

C-----Author and Modification Section-----

C
C Author: James A. Aardema, Rick Mousseau, Roger Weahage

C Date written: Unknown

C Written on:

C Modifications:

C-----

C-----Algorithm Description-----

C
C Purpose and use: Calculates the slip angle, lateral,
C longitudinal, and normal tire forces for a
C point follower tire model.
C
C

C-----

SUBROUTINE TIREF (I, Q, QD, QDD, FRC, ITIR, TIR, RB, A, IA,
& NB, NTR, MPTRS, NPTRS, NPRB, UDE, DUDE, NWHDE)

IMPLICIT DOUBLE PRECISION (A-H,P-Z)

C-----Variable Descriptions-----

C
C---Arguments passed-----

C
C I.....Current tire being calculated
C Q.....Array of generalized coordinates.
C QD.....Array of velocities.
C QDD....Array of acceleration values.
C FRC....Array of generalized forces.
C ITIR...Array of integer data from this module.
C TIR....Array of real data from this module.
C RB.....Array of rigid body real data.
C A.....Vector of all real data.
C IA.....Vector of all integer data.
C NB.....Number of rigid bodies.
C NTR....Number of tire elements.
C NPTRS..Number of real data per element.
C MPTRS..Number of integer data per element.
C NPRB...Number of real data per rigid body.
C UDE....Array of user differential equations, Position terms
C DUDE...Array of user differential equations, Velocity terms

INTEGER NB, IA(0:1), ITIR(MPTRS,NTR), I,
& NTR, MPTRS, NPTRS, NPRB, NWHDE

DOUBLE PRECISION A(0:1), Q(7,1), QD(7,1), QDD(7,1), FRC(7,1),
& TIR(NPTRS,NTR), RB(NPRB,NB),
& UDE(NWHDE), DUDE(NWHDE)

```

C
C---COMMON blocks-----
C
  INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'
  INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]PARAM.BLK'
  INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]POTEN.BLK'
  INCLUDE '[-.COMMON]CSTIFF.BLK'

C---STEPHT common Variables-----
C
C  H.....Integration predictor step size.
C  HMAX....Maximum integration predictor step size.
C  TSTART...Time at the start of the simulation.
C  TEND....Time when simulation is to stop.
C  TSTEP....Integration step size.
C  T.....Current time during the simulation.
C  HSTLEN...Length of the history arrays.
C  HSTPTR...Pointer to the last used location in the history arrays.
C  HSTCNT...Count of the number of time steps for which integration
C            history was saved.
C  HSTH....Past history of the integration time step.
C  HSTK....Past history of the integration order.
C  HSTERR...Past history of the integration error estimate.
C
C
C---PARAM.BLK Common Variables-----
C
C  This file contains a number of constants which are used in various
C  subroutines throughout the code and are stored here to insure
C  accuracy and make any changes easier.
C
C  PI.....pi
C  TWOPI....two times pi
C  DEGRAD...degrees per radian
C  MCHEPS...machine epsilon
C  BODMOD...number of the rigid body module
C  CRVMOD...number of the curve module
C  INPEPS...epsilon value used to check error in normalized input
C            values
C
C---POTEN Common Variables-----
C
C  MSTAT....Flag controlling whether total energy is to be calculated.
C  V.....Scalar of potential energies.
C  VBGN.....Working vector.
C  F.....Function value working vector.
C
C---RUNFLAT.BLK Common Variables-----
C
C  RFRAD....Run Flat Radius
C  RFSTIF...Run Flat Stiffness
C  RFDAMP...Run Flat Damping
C
C---CSTIFF.BLK Common Variables-----
C
C  CSTIFF...Array containing cornering stiff of front wheels
C
C---Local variables-----
C
C  IBDY.....ITIR(1,I)...Body number wheel is attached to

```

```

C   ICHS.....ITIR(2,I)...Body number defined as the chassis
C   IUTIL....ITIR(3,I)...Utility curve number
C   ITK.....ITIR(4,I)...Vertical Spring rate Curve number
C   ILNG.....ITIR(5,I)...Torque Curve number
C   ISTR.....ITIR(6,I)...Steer Curve number
C   TYPE.....ITIR(7,I)...Model type
C   RC(1)....TIR(1,I)....Wheel center postion in local coordinates
C   RC(2)....TIR(2,I)
C   RC(3)....TIR(3,I)
C   RAD.....TIR(4,I)....Tire Radius
C   RR.....TIR(5,I)....Rolling Resistance
C   TD.....TIR(6,I)....Tire Damping constant
C   TK.....TIR(7,I)....Tire Vertical Spring Stiffness
C   CALP.....TIR(8,I)....Lateral Stiffness of the tire
C   STRAG....TIR(9,I)....Steer angle
C   MU.....TIR(10,I)...Friction Coefficient
C   YAW.....TIR(11,I)...Yaw angle of the wheel body
C   VX.....TIR(12,I)...Velocity of wheel center in road system
C   VY.....TIR(13,I)
C   VZ.....TIR(14,I)
C   TIRE1....TIR(15,I)...Global position of the tire center
C   TIRE2....TIR(16,I)
C   TIRE3....TIR(17,I)
C   TIREX....TIR(18,I)...Global postion of the tire bottom
C   TIREY....TIR(19,I)
C   TIREZ....TIR(20,I)
C   ZROAD....TIR(21,I)...Ground Elevation
C   DEFL....TIR(22,I)...Tire Deflection - Ground Penetration
C   FSPR....TIR(23,I)...Spring Force
C   FDAMP....TIR(24,I)...Damping Force
C   FNORM....TIR(25,I)...Normal Force
C   SLIP....TIR(26,I)...Tire Slip
C   FLAT....TIR(27,I)...Lateral force
C   S.....TIR(28,I)...Longitudinal slip
C   FLONG....TIR(29,I)...Longitudinal force
C   GFRC....TIR(30,I)...Wheel torque
C   PENRF....TIR(31,I)...Penetration into the run flat assembly
C   FRF.....TIR(32,I)...Run flat force due to penetration onto run flat
C   ALGNTQ...TIR(33,I)...Aligning Torque due to lateral slip
C   FNTEMP.....Tempary Variable to hold normal force
C   ANGV.....Angular Velocity of the wheel
C   SCO.....Absoulute value of the longitudinal slip
C   FCOEF.....Coefficient relating long force and normal force
C   FMAX.....Maximum force on tire allowed by friction
C   FTOT.....Magniutude of the force on the tire
C   RATIO.....Ratio between Maximum and total force

```

```

INTEGER   IBDY, ICHS, IUTIL, ITK, ILNG, ISTR, TYPE

```

```

DOUBLE PRECISION RC(3), RAD, RR, TD, TK, CALP, STRAGL, MU,
&                YAW, VX, VY, VZ, TIRE1, TIRE2, TIRE3,
&                TIREX, TIREY, TIREZ, ZROAD,
&                DEFL, FSPR, FDAMP, FNORM, SLIP, FLAT,
&                S, FLONG, GFRC, FRF, PENRF,
&                FNTEMP, ANGV, SCO, FCOEF, FMAX, FTOT,
&                RATIO, ALGNTQ

```

```

C---Functions and subroutines-----

```

```

DOUBLE PRECISION FSPLIN, FLINEAR, CUBIC, CUBIC1, C

```

EXTERNAL

FSPLIN, FLINEAR, CUBIC, CUBIC1, CARPET

INTRINSIC

DABS, DSIGN, DCOS, DSIN, DATAN2,
DSQRT, DMAX1

&

C=====Process Block=====

C---Initialize the output quantities to zero in case wheel is off ground

```
FLONG = 0.0D0      ! Tire Longitudinal force
GFRC  = 0.0D0      ! turning wheel torque
FLAT  = 0.0D0      ! Tire Lateral force
ALGNTQ = 0.0D0     ! Aligning Torque

FSPR  = 0.0D0      ! Tire Spring Force
FDAMP  = 0.0D0      ! Tire Damping Force
FNORM  = 0.0D0      ! Total Normal Force
FRF    = 0.0D0      ! Run Flat Force
PENRF  = 0.0D0      ! Penetration into run flat
SLIP   = 0.0D0      ! Lateral Slip
S      = 0.0D0      ! Longitudinal Slip
```

C---Calculate the tire-spring deflection.

```
C  Difference between road elevation and tire bottom elevation
C  Ground penetration if DEFL > 0.0
C  Wheel off the ground if DEFL <= 0.0
```

```
TIREZ = TIR(20,I)
ZROAD = TIR(21,I)
DEFL  = ZROAD - TIREZ
```

C---Calculate the normal force from ground if the wheel has deflected
C into the ground. If the tire is not deflected there are no
C forces on the tire, skip to the end

```
IF ( DEFL .LE. 0.0D0 ) THEN
  DEFL = 0.0D0
  GOTO 1000
ENDIF
```

C---The wheel has penetrated the ground so we must calculate tire forces

C---Get variables from ITIR and TIR arrays

```
C  IBDY = ITIR(1,I)      ! Body number wheel is attached to
C  ICHS = ITIR(2,I)      ! Body number defined as the chassis
C  IUTIL = ITIR(3,I)     ! Utility curve number
C  ITK  = ITIR(4,I)      ! Vertical Spring rate Curve number
C  ILNG = ITIR(5,I)      ! Torque Curve number
C  ISTR = ITIR(6,I)      ! Steer Curve number
C  TYPE = ITIR(7,I)      ! Model type

C  RC(1) = TIR(1,I)      ! Wheel center position in local coordinates
C  RC(2) = TIR(2,I)
C  RC(3) = TIR(3,I)
C  RAD  = TIR(4,I)      ! Tire Radius
C  RR   = TIR(5,I)      ! Rolling Resistance
C  TD   = TIR(6,I)      ! Tire Damping constant
C  TK   = TIR(7,I)      ! Tire Vertical Spring Stiffness
```

```

C      CALP = TIR(8,I)           ! Lateral Stiffness of the tire
      STRAGL= TIR(9,I)           ! Steer angle
      MU    = TIR(10,I)          ! Friction Coefficient

      YAW    = TIR(11,I)         ! Yaw angle of the wheel body
      VX     = TIR(12,I)         ! Velocity of wheel center in road system
      VY     = TIR(13,I)
      VZ     = TIR(14,I)
C      TIRE1 = TIR(15,I)         ! Global position of the tire center
C      TIRE2 = TIR(16,I)
C      TIRE3 = TIR(17,I)
C      TIREX = TIR(18,I)         ! Global position of the tire bottom
C      TIREY = TIR(19,I)
C      TIREZ = TIR(20,I)
C      ZROAD = TIR(21,I)         ! Ground Elevation

```

C---Define the normal force, test for a constant spring or curve data

```

      IF ( ITK .EQ. 0 ) THEN           ! No Spring Curve defined
        FSPR = TK * DEFL               ! Tire Stiffness
      ELSE
        FSPR = FSPLIN ( DEFL, 0.00, ITK, 1, A, IA, 0, 0 )
      ENDIF

```

C---Define potential energy for static analysis

```

      IF ( MSTAT .LE. 1 ) THEN
        IF ( ITK .EQ. 0 ) THEN
          V = V + TK * DEFL**2 / 2.000
        ELSE
          V = V + FSPLIN ( DEFL, 0.00, ITK, 1, A, IA, -1, 0 )
        ENDIF
      ENDIF

```

C---Define the normal force resulting from tire damping

```

      FDAMP = -VZ * TD * CUBIC1(DEFL)   ! Tire Damping force

```

C---The radius of the run flat assembly is given by (RFRAD)

```

C      Add 1 inch to this radius to account for tire carcass thickness
C      Check to see if the tire has deflected into the run flat assembly
C      If TRUE, then add additional forces
C      Run flat stiffness is stored in RFSTIF
C      Run flat damping is stored in RFDAMP
C      Use cubic1 with a tolerance of plus on minus 1/16 inch

```

```

      PENRF = RFRAD + 1.000 + 0.062500 - (RAD-DEFL)   ! Run flat penetration
      IF ( PENRF .GT. 0.000 ) THEN
        FRF = RFSTIF * PENRF * CUBIC1(8.000*PENRF)
        &    + RFDAMP * (-VZ) * CUBIC1(8.000*PENRF)   ! Run flat force
        FRF = DMAX1(0.000,FRF)
      ELSE
        PENRF = 0.000   ! Reset for reporting
        FRF = 0.000
      ENDIF

```

C---Sum up all the forces that may act on the tire

C Limit the normal force so that it can not go negative

```

      FNORM = FSPR + FDAMP + FRF           ! Normal force on tire

```

FNORM = DMAX1(0.0D0, FNORM)

C---If the tire is off the ground there are no longitudinal forces,
C lateral forces, or torques turning the wheel.
C else if the tire has penetrated the ground then calculate the
C tire slip angle.

IF (DSQRT (VX*VX + VY*VY) .GT. 1.D-2) THEN
SLIP = -DATAN2 (VX, VY)
ELSE
SLIP = 0.D0
END IF

C---For the front tires use the Lateral Force Data and Aligning Torque
C Date from the first data arrays

IF (I .EQ. 1 .OR. I .EQ. 2) THEN ! Front Tires

C---Save the normal force in a temporary variable
C Calculate lateral force from the carpet plot
C Carpet plot is a family of normal force Curves versus slip angle

FNTEMP = FNORM
FLAT = CARPET(CSTIFF(I), SLIP, FNTEMP, I, 1, NTR)

C---Calculate aligning torque from carpet plot

ALGNTQ = CARPET(C, SLIP, FNTEMP, I, 4, NTR)
END IF

C---For the Rear tires use the Lateral Force Data and Aligning Torque
C Date from the second data arrays

IF (I .EQ. 3 .OR. I .EQ. 4) THEN ! Rear Tires

C---Save the normal force in a temporary variable
C Calculate lateral force from the carpet plot
C Carpet plot is a family of normal force Curves versus slip angle

FNTEMP = FNORM
FLAT = CARPET(CSTIFF(I), SLIP, FNTEMP, I, 2, NTR)

C---Calculate aligning torque from carpet plot

ALGNTQ = CARPET(C, SLIP, FNTEMP, I, 5, NTR)
END IF

C---For the trailer tires use the Lateral Force Data and Aligning Torque
C Date from the second data arrays

IF (I .EQ. 5 .OR. I .EQ. 6) THEN ! Trailer tires

C---Save the normal force in a temporary variable
C Calculate lateral force from the carpet plot
C Carpet plot is a family of normal force Curves versus slip angle

FNTEMP = FNORM
FLAT = CARPET(C, SLIP, FNTEMP, I, 3, NTR)

C---Calculate aligning torque from carpet plot

```

      ALGNTQ = CARPET(C,SLIP,FNTEMP,I,6,NTR)
END IF

```

```

C---Define the longitudinal force for the turning wheel model
C  Get local velocity in the steer direction
C  Get the angular velocity of the wheel; Postive velocity is in the
C  the negative Y direction

C  Defn: Long Slip = ( Velocity - R*W ) / Velocity

C  if Vel > R*w then slip > 0.0   Wheel is turning to slow causing slip
C  if Vel = R*w then slip = 0.0
C  if Vel < R*w then slip < 0.0   Wheel is turning to fast causing slip

      ANGV = UDE( I+NTR )           ! Angular velocity of wheel
      IF ( DABS(VY) .GT. 0.0001D0 ) THEN
        S = ( VY + ANGV*(RAD-DEFL) ) / VY   ! Definition of Long. Slip
      ELSE
        S = 0.D0
      END IF
      SCO = DABS( S )                ! temporary variable
      IF ( SCO .GT. 1.D0 ) SCO=1.D0        ! Limit slip

```

```

C---The Utility spline curve is used for calculating slip.
C  Longitudinal force = Fcoef * Fnorm

```

```

      FCOEF = FSPLIN ( SCO, 0.D0, IUTIL, 1, A, IA, 0, 0 )
      FLONG = -DSIGN ( FCOEF*FNORM, S )

```

```

C---Limit the long. and lateral forces using the friction ellipse (circle).

```

```

      FMAX = MU*DABS(FNORM)
      FTOT = DSQRT(FLONG**2 + FLAT**2)
      IF ( FTOT .GT. FMAX ) THEN
        RATIO = FMAX/FTOT
        FLAT = RATIO*FLAT
        FLONG = RATIO*FLONG
      END IF

```

```

C---Calculate the torque due to the longitudinal force causing the wheel
C  to turn

```

```

      GFRC = FLONG * ( RAD-DEFL )

```

```

1000 CONTINUE

```

```

C---Save values in ITIR and TIR arrays

```

```

      TIR(22,I) = DEFL           ! Tire Deflection - Ground Penetration
      TIR(23,I) = FSPR           ! Spring Force
      TIR(24,I) = FDAMP          ! Damping Force
      TIR(25,I) = FNORM          ! Normal Force
      TIR(26,I) = SLIP           ! Tire Slip
      TIR(27,I) = FLAT           ! Lateral force
      TIR(28,I) = S              ! Longitudinal slip
      TIR(29,I) = FLONG          ! Longitudinal force
      TIR(30,I) = GFRC           ! Wheel torque
      TIR(31,I) = PENRF          ! Penetration into run flat
      TIR(32,I) = FRF            ! Force due to run flat

```

TIR(33,I) = ALGNTQ

! Aligning Torque

RETURN

END

APPENDIX D

Driver Model FORTRAN Source Code

```
=====Author and Modification Section=====
```

```
=====Algorithm Description=====
```

```

SUBROUTINE USER49 ( IRE, FN, AJ, ND, DRV, IDRV, Q, QD, A, IA,
& MPTRS, NPTRS, RB, NPRB, QDR, QDDR, NB, RVLT,
& TRAN, CYL, NPRT, NPTRN, NPCYL, QDD,
& CST, CSTD, CSTDD, IDRIVER )

```

=====Variable Descriptions=====

```
---Arguments passed-----
```

D-2

CSTD ... first derivative of driving function
 CSTDD ... second derivative of driving function
 IDRIVER...Current driver being analyzed

```

INTEGER MPTRS, NPTRS, ND, IDRV(MPTRS,ND), IA(0:1),
&      IRE(1),NPRB, NB, NPTRN, NPCYL, NPRT, IDRIVER

```

```

DOUBLE PRECISION FN(1), AJ(1), DRV(NPTRS,ND), Q(7,1), QD(7,1),
&      RB(NPRB,NB), QDR(1), QDDR(1), A(0:1),
&      TRAN(NPTRN,1), CYL(NPCYL,1), RVLN(NPRT,1),
&      QDD(7,1), CST, CSTD, CSTDD

```

-----COMMON blocks-----

```

INCLUDE 'DISK$DISK2:[DADSUSER.DADS5_SOURCE.COMMON]STEPHT.BLK'

```

```

INCLUDE '[-.COMMON]UPLOT.BLK'

```

-----COMMON Variables-----

-----STEPHT common block variables-----

```

H.....Integration predictor step size.
HMAX....Maximum integration predictor step size.
TSTART...Time at the start of the simulation.
TEND....Time when simulation is to stop.
TSTEP....Integration step size.
T.....Current time during the simulation.
HSTLEN,..Length of the history arrays.
HSTPTR...Pointer to the last used location in the history arrays.
HSTCNT...Count of the number of time steps for which integration
          history was saved.
HSTH....Past history of the integration time step.
HSTK....Past history of the integration order.
HSTERR...Past history of the integration error estimate.

```

-----UPLOT.BLK Common Variables-----

```

UPLOT....Array for storing user variables
NPLOT....Number of plot variables used

```

-----Local variables-----

```

K11.... EQ.0 : do not evaluate Jacobian matrix
          EQ.1 : evaluate Jacobian matrix
K22.... EQ.1 : evaluate Jacobian matrix
          EQ.2 : evaluate constraint equation
          EQ.3 : evaluate r.h.s. of the velocity equation
          EQ.4 : evaluate r.h.s. of the acceleration equation
JB1    ... first body number of driving constraint is imposed
JB2    ... second body number of driving constraint is imposed
JTYPE  .. type of driving constraint joint.
          =1 Revolute joint
          =2 Cylindrical joint
          =3 Translational joint
FTYPE  .. Driving function.
          EQ.1 : polynomial driving function
                  coeff1 + coeff2*T + coeff3*T**2 + coeff4*T**3
          EQ.2 : harmonic driving function
                  coeff1 + coeff2 * SIN ( coeff3*T - coeff4 )

```

EQ.3 : general driving function

	polynomial	harmonic	general
--	------------	----------	---------

coeff1:	constant term	constant term	not used
coeff2:	1st order coef.	amplitude	not used
coeff3:	2nd order coef.	frequency	not used
coeff4:	3rd order coef.	phase shift	not used

DTYPE ...Type of constraint defined:

EQ.1 : constrain Xpi
EQ.2 : constrain Ypi
EQ.3 : constrain Zpi
EQ.4 : constrain Xpj - Xpi
EQ.5 : constrain Ypj - Ypi
EQ.6 : constrain Zpj - Zpi
EQ.7 : constrain distance between two position
EQ.8 : relative angle constraint on revolute or cylindrical joint
EQ.9 : constrain relative position on translational or cylindrical joint

FT ... value of general curve
NZHS ... pointer for Jacobian array
ITEMP ... temporary value
PNTR ... pointer into the input data array
DNAME ... name of a distance driver
JN ... joint number.
ICHS...Body number of the chassis

INTEGER JB1, JB2, DTYPE, JTYPE, K11, K22, NZHS, ITEMP,
& PNTR, FTYPE, JN, ICHS

DOUBLE PRECISION ACHS(3,3), PHI, STEER, DSTEER, DDSTEER

REAL Y(5), DFWOUT, DFWOLD, DF, DFVEL, DFACC, DFF
REAL TDRIV

CHARACTER*20 DNAME

-----Functions and subroutines-----

EXTERNAL FSPLIN, SIMDR, ELMDR, DISTDR, TRANDR, SINE, COSINE,
& TRULEN, DRIVER, FILTR1, FILTR2
EXTERNAL EULANG

INTEGER TRULEN

DOUBLE PRECISION FSPLIN
DOUBLE PRECISION YANIM(3)

INTRINSIC DCOS, MOD, DSIN, DABS, DATAN, DSIGN, DATAN2,
& SNGL, DBLE
SAVE DFWOLD

=====Process Block=====

DFWOUT = 0.0
STEER = 0.0

---Get the chassis body number

ICHS = IDRV(1, IDRIVER) ! IDRIVER is the current driver being analyzed

---Get the chassis transformation matrix

ACHS(1,1) = RB(38, ICHS)
ACHS(2,1) = RB(39, ICHS)
ACHS(3,1) = RB(40, ICHS)
ACHS(1,2) = RB(41, ICHS)
ACHS(2,2) = RB(42, ICHS)
ACHS(3,2) = RB(43, ICHS)
ACHS(1,3) = RB(44, ICHS)
ACHS(2,3) = RB(45, ICHS)
ACHS(3,3) = RB(46, ICHS)

Call to EulAng for Animation Output

YANIM(1) = Q(2, ICHS) / 12.
YANIM(2) = Q(1, ICHS) / 12.
YANIM(3) = -(Q(3, ICHS) - RB(20, ICHS)) / 12.
CALL EULANG(T, YANIM, ACHS)

Y(2) = SNGL(ACHS(1,1)*QD(1, ICHS) +
& ACHS(2,1)*QD(2, ICHS) +
& ACHS(3,1)*QD(3, ICHS))/12.0 ! lateral velocity in body cs

---Get the current vehicle global position

Y(1) = SNGL(Q(1, ICHS))/12.0 ! LATERAL DISPLACEMENT
Y(5) = SNGL(Q(2, ICHS))/12.0 ! FORWARD DISPLACEMENT

Y(3) = -SNGL(RB(34, ICHS)) ! YAW RATE - GLOBAL
PHI = DATAN2(ACHS(1,2), ACHS(2,2))
Y(4) = SNGL(PHI)

UPLOT(NPLOT+1) = DBLE(Y(1))
UPLOT(NPLOT+2) = DBLE(Y(2))
UPLOT(NPLOT+3) = DBLE(Y(3))
UPLOT(NPLOT+4) = DBLE(Y(4))
UPLOT(NPLOT+5) = DBLE(Y(5))

---Calculate the steering control from the steering model

If STEER > 0.0 Turn Right
If STEER < 0.0 Turn Left

TDRIV = SNGL(T)
CALL DRIVER (TDRIV, Y, DFWOUT, DFWOLD)

CALL FILTR1 (TDRIV, DFWOUT, DF, DFVEL, DFACC)

UPLOT(NPLOT+6) = DBLE(DF)
UPLOT(NPLOT+7) = DBLE(DFVEL)
UPLOT(NPLOT+8) = DBLE(DFACC)

```
CALL FILTR2 ( TDRIV, DF, DFF, DFVEL, DFACC )
DFWOLD = DFF
```

```
UPLOT(NPLOT+9) = DBLE(DFF)
UPLOT(NPLOT+10) = DBLE(DFVEL)
UPLOT(NPLOT+11) = DBLE(DFACC)
```

```
STEER  = DBLE(DFF)
DSTEER = DBLE(DFVEL)
DDSTEER = DBLE(DFACC)
```

```
UPLOT(NPLOT+12) = STEER
UPLOT(NPLOT+13) = DSTEER
UPLOT(NPLOT+14) = DDSTEER
```

---Calculate the pitman arm angle from the tire steering angle
The ratio between steering angle and pitman arm angle is 1.166D0

```
CST  = 1.166D0 * STEER
CSTD = 1.166D0 * DSTEER
CSTDD = 1.166D0 * DDSTEER
```

---Pitman arm travel is limited to 38.25 degrees or 0.668 radians

```
IF ( DABS(CST) .GE. 0.668D0 ) THEN
  CST  = DSIGN(0.668D0,CST)
  CSTD = 0.0D0
  CSTDD = 0.0D0
ENDIF
NPLOT = NPLOT + 14
```

```
RETURN
END
```

superi>

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