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16. Abstract

This research was performed to study the operational characteristics of variable pavement cross slopes. Computer simulation of vehicles conducting passing maneuvers on high-speed two-lane highways was the methodology employed. The objective was to determine the effects of cross slope and centerline crossover break on lateral tire acceleration, vehicle roll angle and driver comfort.

The research utilized two simulation models of vehicle dynamics--the Highway Vehicle Object Simulation Model (HVOSM), and the Highway Safety Research Institute/Motor Vehicle Manufacturers Association Phase 4 Model (HSRI/MVMA). Vehicle simulations were performed for a range of vehicle types, and various combinations of design speed and cross slope design.

The research demonstrates the potential severity of the passing maneuver on highways with even minimum cross slopes. On high-speed highways, cross slopes no greater than 2 percent are desirable. A practical maximum of 4 percent on lower speed highways was indicated by the dynamic responses of tractor-trailer combinations. In general, the research stresses the need to provide a cross slope design that is the minimum consistent with drainage requirements.

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FOREWORD

This report summarizes research on the operational characteristics of variable pavement cross slopes on high speed highways. Computer simulation of vehicle dynamics was the methodology employed. The dynamic responses were studied for a range of vehicle types performing high speed passing maneuvers. Research findings provide a basis for defining maximum tolerable pavement cross slopes on high speed, 2-lane highways.

The research should be of interest to highway design professionals.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each regional office, one to each division office, and one copy to each State highway agency. Direct distribution is being made to the division offices.

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Introduction

An important consideration in the design of a two-lane highway is the cross slope of each lane, and the manner in which these slopes join at the centerline of the highway. Frequently, the two plane cross slopes are joined to form a distinct break point or "crossover break." More often, the center portion of this crossover break is slightly rounded.

In the development of AASHTO Policy (1), pavement drainage, driver comfort, and general vehicle control were all considered in the process of selecting recommended values for pavement cross slope. The AASHTO discussion of pavement cross slope is as follows:

> "...Since many highways are on tangent or flat curve alinement, the rate of cross slope for this condition is an important element in cross section design...A reasonably steep lateral slope is desirable to minimize water ponding of flat sections due to pavement imperfections and uneven settlement. On the other hand, pavements with steep cross slopes are objectionable in appearance and may be annoying and uncomfortable in operation. Hazard may attend driving on steep cross slopes on tangents due to the tendency of vehicles to veer toward the low edge of the pavement."

With these considerations in mind, AASHTO policy (1) recommends the following values for cross slope, which relate to the surface type.

Surface Type	Cross Slope (Percent)
High	1-2
Intermediate	1.5-3
Low	2-4

Recent research (2) recommends minimum cross slopes (1 percent for dense surfaces and 2 percent for open or permeable surfaces) on the basis of drainage requirements. The AASHTO values for maximum cross slope have never been scientifically substantiated. There remains the question, therefore, of just how high the cross slope can be designed for various vehicle speeds and still accommodate reasonable vehicle operations without producing undue hazard or discomfort to the motorist. The objective of this research, therefore, was to study the dynamic effects of pavement cross slope and crossover break on expected vehicle maneuvers for the purpose of recommending maximum cross slope designs as a function of vehicle type and design speed. The basic form of research involved the use of computer simulation of nominally critical vehicle maneuvers that can be reasonably expected on high-speed, two-lane highways.

Investigation of Design Maneuvers

Highways should be designed so that each of the design elements does not "cause" or promote loss of control. This philosophy of course must be interpreted within the bounds of reasonable extremes of driver behavior. And, application of this philosophy requires an understanding of how each highway element relates to vehicle operations.

There are three basic vehicle operations that could be affected by the design of the pavement cross slope and centerline crossover break:

(1) Tracking - In steering down the highway, the driver must compensate for the cross slope to keep his vehicle on the designed path. On tangent highway, the driver must, in effect, steer toward the centerline. For steeper cross slopes, this task requires more of the driver's attention and effort to keep from veering off the edge of the traveled way.

(2) Braking - The cross slope also is an important feature with regard to sudden or emergency stops performed by the driver. Very flat cross slopes can add to pavement water depth, thereby reducing skid resistance during periods of wet weather. Steep cross slopes increase the probability that a vehicle would run off the road under severe braking conditions.

(3) Passing - Under normal passing operations on two-lane highways, the higher speed passing vehicle usually performs a reverse curve across the centerline while accelerating. Under this kind of operation, the dynamic effects of path curvature and acceleration conceivably could be heightened by the amount of centerline crossover break encountered as the vehicle crosses the centerline, and by the "negative" or adverse slope in relation to the vehicle path in the opposing lane. Recent research (3) suggests that a fairly large crossover break does not

itself contribute to loss of control or vehicular instability. However, the research does indicate that negative cross slopes (in relation to vehicle path curvature) can produce an incremental increase in lateral acceleration on the vehicle.

Selection of the Basic Design Maneuver

A search of the literature did not reveal definitive research regarding the effect of maximum cross slope on the potential for loss of control under either normal tracking or severe braking operations. Research by Glennon (4), however, does provide insight on both the severity of vehicle operations and the effect of cross slope for automobile passing maneuvers.

Although pavement cross slope design should attempt to reasonably accommodate all expected operations, it is not totally clear which of these three operations would be most dominant in governing the maximum cross slope. However, within reasonable bounds, steeper cross slopes (say 6 to 10 percent) could be expected to seriously degrade all three operations. Therefore, it may be reasonable to infer a maximum cross slope for all operations based on the study of vehicle dynamics of one of the three.

The passing maneuver was selected as the controlling operation for studying the critical dynamic effects of maximum cross slope for the following reasons:

(1) It is the only one of the three basic operations affected by cross slope that is dimensionally described in the literature.

(2) Passing is a relatively frequent maneuver performed on two-lane highways.

(3) Not only does passing occur more often than severe braking, but the severe braking maneuver tends to produce loss of control irrespective of the amount of cross slope.

(4) Because the passing maneuver involves acceleration, high speeds, and a distinctly non-tangent path, it represents a reasonably critical maneuver.

(5) The maximum cross slopes dictated by the passing maneuver could be expected to provide reasonable cross slopes for normal vehicle tracking.

Dimensions of the Passing Maneuver

The only research found that directly measured the passing path of vehicles under normal highway operation was the work of Glennon and Weaver (4,5). This research, conducted on two-lane Texas highways, had two specific objectives: (1) to study the critical nature of time-distance requirements for the purpose of verifying AASHTO passing sight distance requirements; and (2) to study the functional demands of passing vehicles as a potential basis for minimum skid resistance requirements and/or wet weather speed limits.

For the purpose of determining the dimensions of a critical passing maneuver, one phase of the Glennon and Weaver work used photographic techniques to measure the curvature of the initial passing path for about 160 maneuvers at two passing zones. These measurements were distributed among experiments where impeding vehicle speeds were 50, 56, 62 and 68 mph (80, 90, 100 and 110 km/h). For average speeds ranging from 50 to 81 mph (80 to 130 km/h), these studies determined the distribution of minimum vehicle path radius during the initial "pull-out" portion of the passing maneuver. Also, the analysis showed that the severity of this minimum radius was independent of speed. Higher speed passing vehicles were therefore just as likely to undergo critical path maneuvers as other passing vehicles.

Table 1 shows the critical end of the distribution of minimum path radius for the two different lengths of passing zone. Analysis of the data also indicated average automobile acceleration of about 3.28 ft/s^2 (1.00 m/sec^2).

The Glennon and Weaver analysis (5) provides a basis for determining the time-distance aspects of the passing maneuver. The duration of the initial passing maneuver is about 4 seconds. This maneuver includes, in sequence, an initial tangent path (L_1), a curve to the left (L_2), a connecting tangent (L_3), and a curve to the right (L_4) bringing the vehicle back parallel to the roadway.

Table 1

Distribution of Minimum Path Radii For Automobiles in the Passing Maneuver

Percent of Vehicles with Smaller Radius	Minimum Radius of Initial Path Maneuver--ft (m) Site A 984 ft(300 m) Passing Zone		Site B 1684 ft(500 m) Passing Zone	
5%	1614	(492)	1132	(345)
10%	1650	(503)	1289	(393)
15%	2011	(613)	1430	(436)

Source: Reference (4)

Based on these parameters of the passing maneuver it is possible to generate a nominally critical automobile passing traversal (see Figure 1) with the following additional set of assumptions:

(1) The nominally critical minimum path radius is best represented by the path severity exceeded only by 5 percent of all drivers on the longer passing zone. This value is an 1132 ft (345 m) radius, as given in Table 1.

(2) The left tires of the passing vehicle are initially 2.3 ft (0.7 m) right of the centerline.

(3) The total lateral movement of the vehicle is 11.5 ft (3.5 m), which corresponds to a full lane width.

(4) The duration of the initial tangent portion, L_1, of the maneuver is 1 second. The vehicle begins the designated acceleration rate at the beginning of this tangent portion.

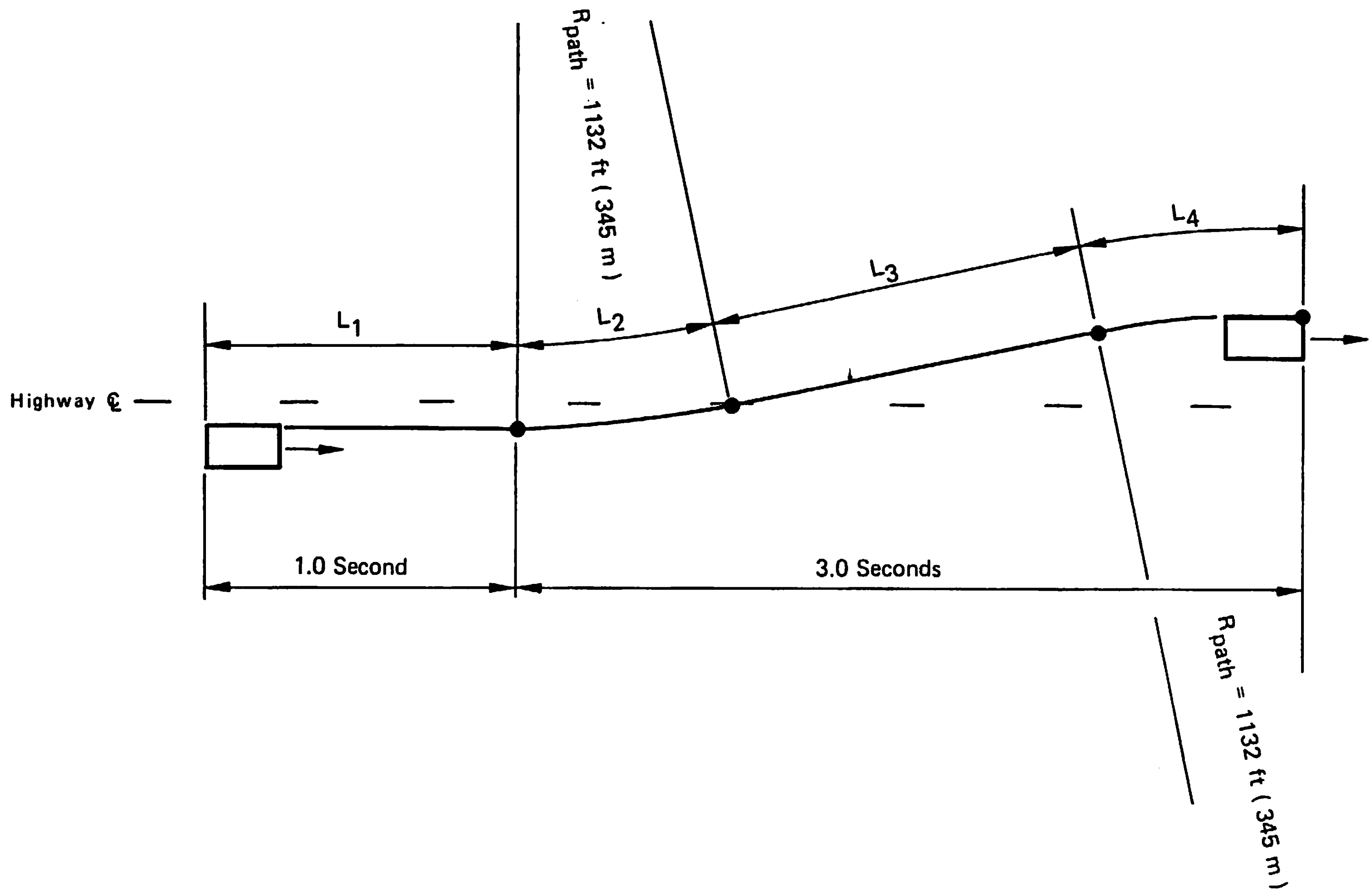


Figure 1. NOMINALLY CRITICAL INITIAL PASSING MANEUVER FOR AUTOMOBILES

(5) A passing automobile accelerates from a starting speed that is 12 mph (20 km/h) slower than design speed.

(6) The connecting tangent, L_3, between the reverse curves of the path is limited to not less than 66 ft (20 m). Under some lower design speed conditions, therefore, the duration of the initial maneuver is somewhat more than 4 seconds.

With these physical and operational parameters and constraints specified, it is possible to mathematically solve the complete geometric description of the initial automobile passing path for various design speeds. Table 2 shows these solutions.

Table 2
Description of Derived Nominally Critical Initial Passing Maneuvers for Automobiles

Design Speed mph	(km/h)	Length of Initial Path Segments* ft (m) L_1	L_2	L_3	L_4
87	(140)	111 (33.8)	41 (12.6)	269 (82.1)	41 (12.6)
74	(120)	93 (28.3)	53 (16.2)	190 (58.0)	53 (16.2)
62	(100)	74 (22.7)	79 (24.1)	85 (25.9)	79 (24.1)
50	(80)	56 (17.2)	86 (26.2)	66 (20.0)	86 (26.2)

* L_1 -- Initial tangent path in proper lane
L_2 -- Initial "pull-out" maneuver to centerline
L_3 -- Tangent path to opposite lane
L_4 -- Curved, reversal path to correct vehicle path in opposite lane

Passing maneuvers undertaken by trucks are also of concern in design of the cross slope and crossover break. To generate the nominally critical initial paths for trucks the following additional assumptions were made:

(1) Trucks initiating a passing maneuver would tend to utilize a rapid rate of acceleration (relative to vehicle type). For this study, loaded single-unit trucks and empty tractor-trailer combinations were assumed to accelerate at 1.64 ft/s^2 (0.50 m/s^2). Fully loaded tractor-trailer combinations accelerate at 0.66 ft/s^2 (0.20 m/s^2). These assumed rates compare with the assumed automobile acceleration rate of 3.28 ft/s^2 (1.00 m/s^2).

(2) In order to manage the passing maneuver with their lower acceleration capabilities, trucks start the initial passing maneuver at higher speeds than automobiles. For single-unit trucks and empty tractor-trailer combinations, the initial speed is 10 mph (16 km/h) below design speed. For loaded tractor-trailer combinations, the initial speed is 7.5 mph (12 km/h) below the design speed. These initial speed assumptions, in combination with the assumed truck acceleration rates, result in a final or critical truck passing speed identical to that of automobiles. This enables direct comparison of the effects of cross slope and crossover break on the full range of vehicle types studied.

With these additional assumptions, the dimensions for the critical initial path maneuvers for trucks are solved as shown in Table 3.

Description of Simulation Models

The dynamic effects of various cross slopes for the initial passing maneuver at various design speeds were studied using two different previously developed computer simulation models. The HVOSM and the HSRI/MVMA PHASE4 model were used to cover the full range of vehicle types on the highway. These two models and their modification for this research are described below.

HVOSM

The HVOSM (Highway-Vehicle-Object Simulation Model) is a computerized mathematical model originally developed at Cornell Aeronautical Laboratories (6) and

Table 3

Description of Derived Nominally Critical Initial Passing Maneuver For Trucks

Loaded Single-Units and Empty Tractor-Trailers

Design Speed mph	(km/h)	Length of Initial Path Segments ft (m)* L_1	L_2	L_3	L_4
87	(140)	114 (34.7)	42 (12.8)	267 (81.5)	42 (12.8)
74	(120)	95 (29.1)	53 (16.2)	190 (58.0)	53 (16.2)
62	(100)	77 (23.6)	77 (23.5)	93 (28.5)	77 (23.5)
50	(80)	59 (18.0)	86 (26.2)	66 (20.0)	86 (26.2)

Loaded Tractor-Trailers

Design Speed mph	(km/h)	Length of Initial Path Segments ft (m)* L_1	L_2	L_3	L_4
87	(140)	117 (35.7)	41 (12.6)	269 (82.1)	41 (12.6)
74	(120)	99 (30.1)	53 (16.2)	192 (58.8)	53 (16.2)
62	(100)	80 (24.5)	79 (24.1)	87 (26.5)	79 (24.1)
50	(80)	62 (19.0)	86 (26.2)	66 (20.0)	86 (26.2)

* L_1 -- Initial tangent path in proper lane

L_2 -- Initial "pull-out" maneuver to centerline

L_3 -- Tangent path to opposite lane

L_4 -- Curved, reversal path to correct vehicle path in opposite lane subsequently refined by Calspan Corporation (7). The HVOSM is capable of simulating the dynamic response of a two-axle vehicle traversing a three-dimensional terrain configuration. The vehicle is composed of four rigid masses; viz., a sprung mass, unsprung masses of the left and right independent suspensions of the front wheels, and an unsprung mass representing a solid rear-axle assembly.

This study used the Roadside Design version of HVOSM that is currently available from FHWA. Certain modifications were necessary to perform the range of studies undertaken in this research. These modifications, described in Appendix A, included the following:

(1) Driver discomfort factor output;
(2) Friction demand output;
(3) Driver model modifications;
(4) Wagon-tongue path-following algorithm; and
(5) Dual rear tire option.

For the centerline crossover break traversal studies, the important parameters of the driver simulation are the probe length, steer velocity and damping. The probe length represents the driver preview of the highway measured from the center of gravity of the vehicle. The steer velocity (PGAIN) is a steering correction factor that is multiplied by the lateral path error of the probe. The damping (QGAIN) is a term that smooths out the steer response.

A longer probe, slower steer response, and larger damping term simulate an attentive and non-aggressive driver by smoothing the path into a combination of sweeping spirals. A shorter probe length, quicker steer response, and smaller damping term simulate a very aggressive driver who turns sharply with a tendency to overshoot the intended path.

It is extremely important to carefully define the driver behavior being modeled. Highly variable dynamic results can be obtained using different driver simulation parameters on the same specified path at the speed. Guidance on appropriate driver behavior parameters was provided by previous simulation research (3).

HSRI/MVMA PHASE4 Model

The PHASE4 simulation program is a general purpose mathematical model for simulating the three-dimensional dynamic responses of trucks, tractor/trailers and triples combinations. The PHASE4 program was developed in 1980 by the Highway Safety Research Institute of the University of Michigan under the sponsorship of the Motor Vehicle Manufacturers Association and the Federal Highway Administration (8,9).

Modifications similar to those made for the HVOSM were made for the PHASE4 model. These modifications, described in Appendix B, included the following:

(1) Driver discomfort factor output;
(2) Friction demand output;
(3) Driver model modifications;
(4) Wagon-tongue path-following algorithm; and
(5) Terrain option.

Comparison of Models

For the purpose of comparing the dynamic effects of cross slope design for various vehicles, it was necessary to obtain some degree of correlation between the HVOSM (2-axle) and the HSRI/MVMA PHASE4 models. Since both models can accommodate single-unit trucks with a single rear axle, a 1974 White Road Boss (4x2) was used for comparison simulations. Measured properties of this vehicle were reported in a study of truck tire properties performed by the Highway Safety Research Institute (10).

The documentation for the comparison of the two models is quite extensive and is reported in a separate project document (11). The conclusions from this effort were: (1) the two models give comparable dynamic responses for the types of maneuvers investigated in this research; and (2) the effects of the small-angle assumption of the PHASE4 model are negligible for the types of maneuvers investigated in this research.

Simulation Experiments

Fourteen basic simulation runs were performed to test the dynamic effects of the centerline crossover break design for various vehicles and design speed. The range of test parameters is shown in Table 4.

Previous project research (3) on pavement/shoulder cross-slope break designs for highway curves had indicated that the centripetal force equation gave a reasonable estimate of tire friction demand. Table 5 shows the computation of the calculated range of lateral tire accelerations for various speeds and cross slopes using the 95th percentile passing automobile path radius described in Table 1. With regard to cross slope, the tentative conclusions that could be made from this analytical result are (1) the effect of cross slope appears reasonably minor; and (2) despite this apparently minor effect, minimal cross slopes are desirable for higher speeds because of the already marginal dynamics of the passing vehicle.

Determination of Driver Simulation Parameters

The results of Table 5 provide a basis for determining the driver simulation parameters to be used in the path-following algorithm. By using various combinations of parameters, preliminary simulations were run until dynamic results similar to Table 5 were produced. This kind of exercise was done using a standard passenger car, with the following parameters determined for testing the effects of pavement cross slope and crossover break:

$$L = 0.25\,V$$
$$PGAIN = 1/L$$
$$QGAIN = 1/(10L)$$

Where
- L = Probe Length ft (m)
- V = Vehicle Speed ft/s (m/s)
- PGAIN = Steer Velocity rad/ft (rad/m)
- QGAIN = Steer Damping rad-s/ft (rad-s/m)

In attempting to use these same parameters for simulation of truck passing maneuvers, very severe and highly unstable dynamics were produced. These results indicated a threshold of dynamic instability related to very aggressive

Table 4

Test Parameters For Simulation Experiments

Vehicles

Mid-Size Automobile (1971 Dodge Coronet)

Compact Automobile (1971 Vega Sports Coupe)

Loaded Single-Unit Truck (White Road Boss)

Loaded Tractor Trailer (PHASE4 spec, 68,855 lbs. (31,298 kg))

Empty Tractor Trailer (PHASE4 spec, 28,855 lbs. (13,116 kg))

Centerline Crossover Break Designs

2 percent each side (no rounding)

4 percent each side (no rounding)

Test Speeds--mph (km/h)

87	(140)
74	(120)
62	(100)
50	(80)

Test Paths

Radius = 1132 ft (345 m) (path segments L_2 and L_4)

Segment Lengths as per Tables 2 and 3

Table 5

Nominal Tire Friction Values Using 1132 Foot (345 Metre) Radius (From Table 1) in Centripetal Force Equation

Cross Slope (Percent)	Speed mph (km/h)	f Calculated at End of Initial Passing Maneuver*
2	87 (140)	0.47
	74 (20)	0.35
	62 (100)	0.25
	50 (80)	0.17
4	87 (140)	0.49
	74 (120)	0.37
	62 (100)	0.27
	50 (80)	0.19
6	87 (140)	0.51
	74 (120)	0.39
	62 (100)	0.29
	50 (80)	0.21

* See Figure 1 for description of Initial Passing Maneuver

sinusoidal steering (and not related to the cross slope or other highway geometrics). It was evident that the parameters selected for simulating nominally critical passenger car drivers were inappropriate for simulating truck driver behavior. It was therefore necessary to test various driver simulation parameters to determine a nominally critical level of operation appropriate for trucks. As always, the objective was to discover a reasonably critical threshold for which dynamic sensitivities associated with the vehicle, its speed and the cross slope could be observed. This exercise produced the following driver simulation parameters for trucks to test the effect of centerline crossover break:

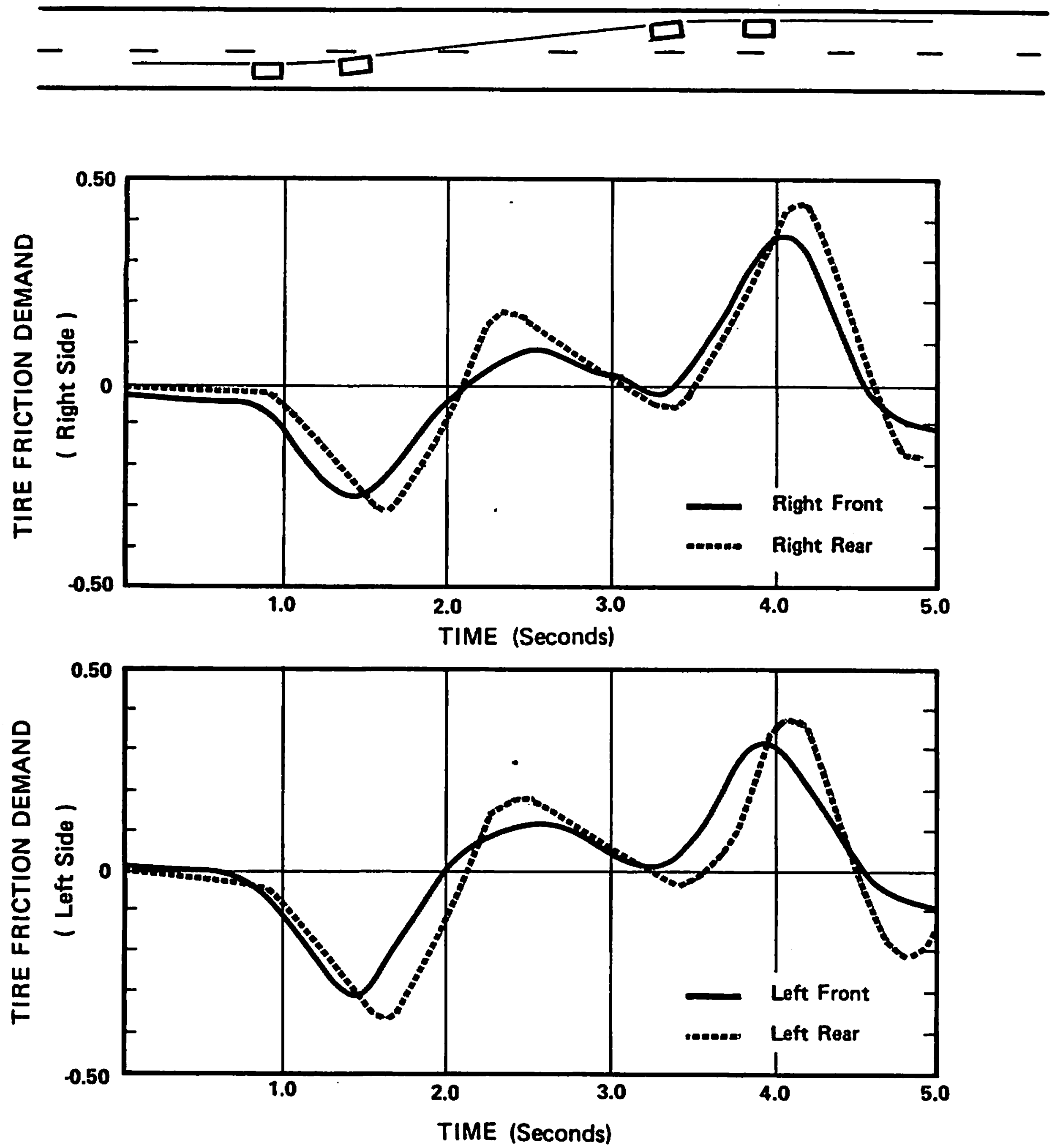
TRUCK DRIVER PARAMETERS

$$L = 0.25\ V$$
$$PGAIN = 1/(2L)$$
$$QGAIN = 1/(5L)$$

Where L, V, PGAIN and QGAIN are as before

Results of Experiments

Figures 2 through 5 show sample results of the 14 simulation experiments. Summaries of the dynamic response for all experiments are shown in three comparison tables which report some of the experiments more than once. Table 6 provides a direct comparison of the dynamic responses of various vehicles for the same test speed and cross slope. Table 7 directly compares the dynamic effect of speed for the same vehicle and cross slope. Table 8 is a direct comparison of the dynamic effects of cross slope for a given vehicle and speed.

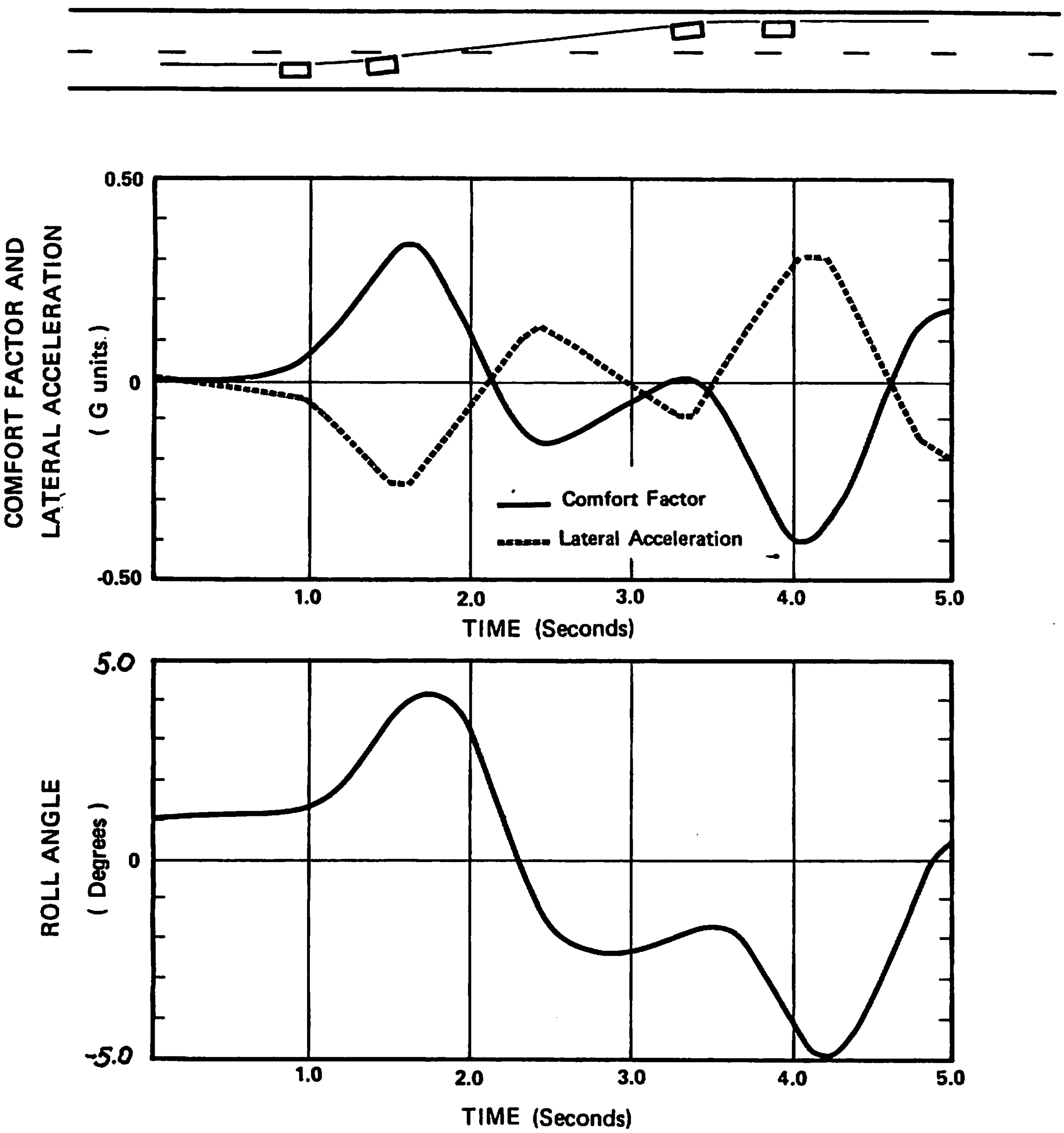


TEST CONDITIONS

Vehicle Type:	**Mid - size Auto**	**Probe Length:**	**6.94 m**
Cross Slope:	**2 percent**	**P Gain:**	**1.44×10^{-1} rad / m**
Initial Speed:	**100 km / h**	**Q Gain:**	**1.44×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**1.00 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 2. SIMULATION RESULTS FOR MID - SIZE AUTOMOBILE USING HVOSM

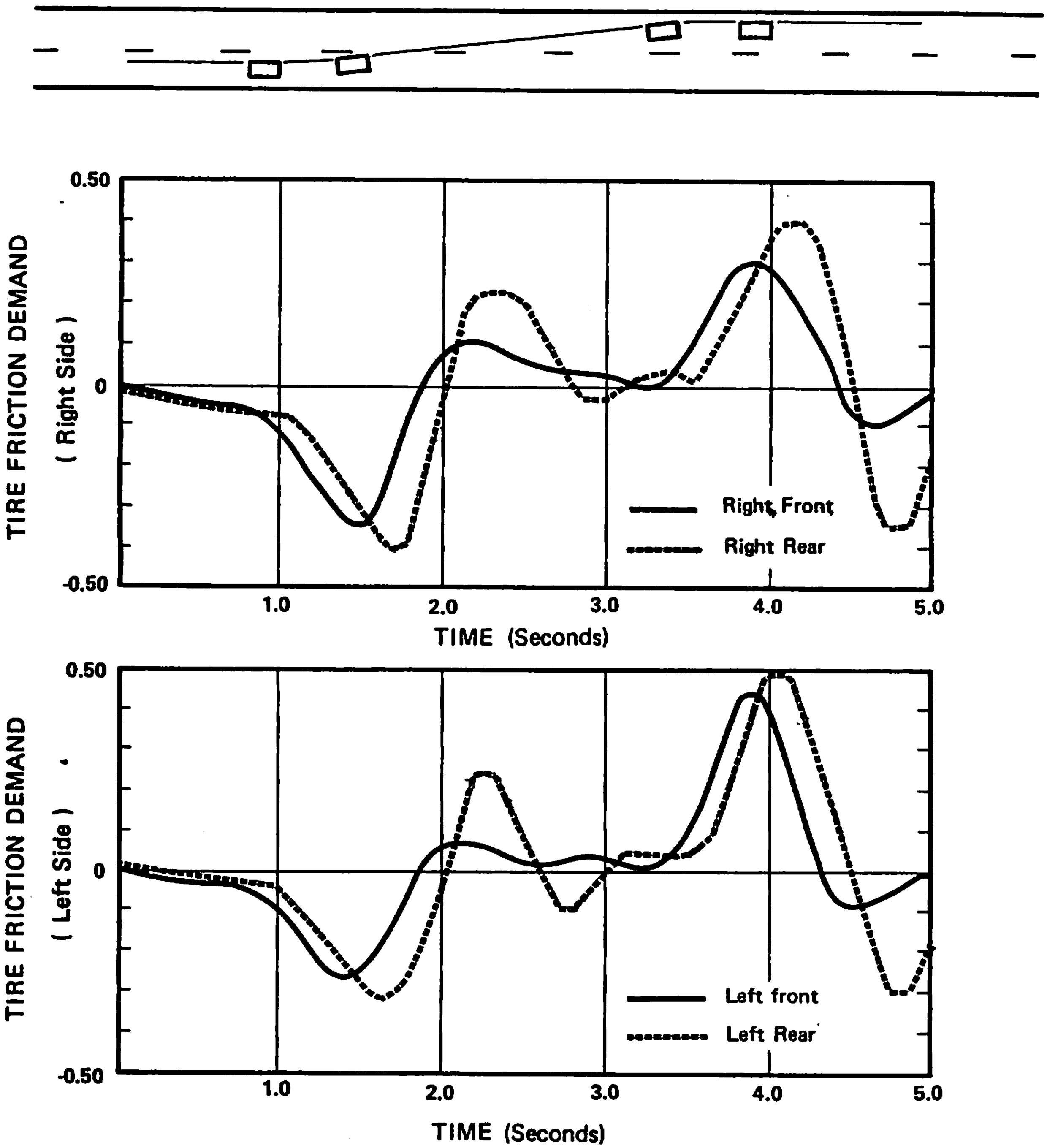


TEST CONDITIONS

Vehicle Type:	Mid - size Auto	Probe Length:	6.94 m
Cross Slope:	2 percent	P Gain:	1.44×10^{-1} rad / m
Initial Speed:	100 km / h	Q Gain:	1.44×10^{-2} rad - s / m
Design Speed:	120 km / h	Acceleration:	1.00 m / s^2

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 2. SIMULATION RESULTS FOR MID - SIZE AUTOMOBILE USING HVOSM (continued)

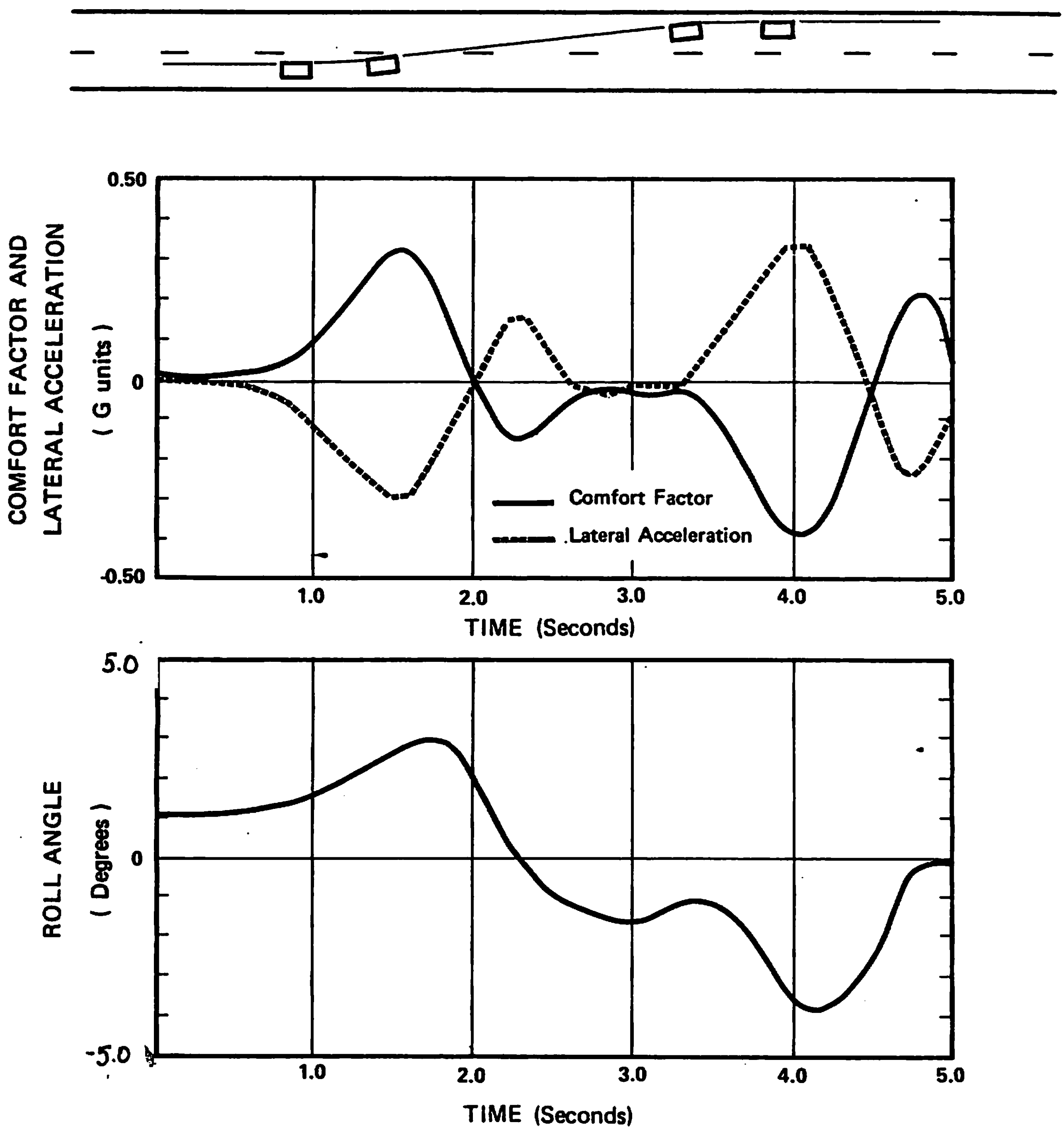


TEST CONDITIONS

Vehicle Type:	**Compact Car**	**Probe Length:**	**6.93 m**
Cross Slope:	**2 percent**	**P Gain:**	**1.46×10^{-1} rad / m**
Initial Speed:	**100 km / h**	**Q Gain:**	**1.46×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**1.00 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 3. SIMULATION RESULTS FOR COMPACT AUTOMOBILE USING HVOSM

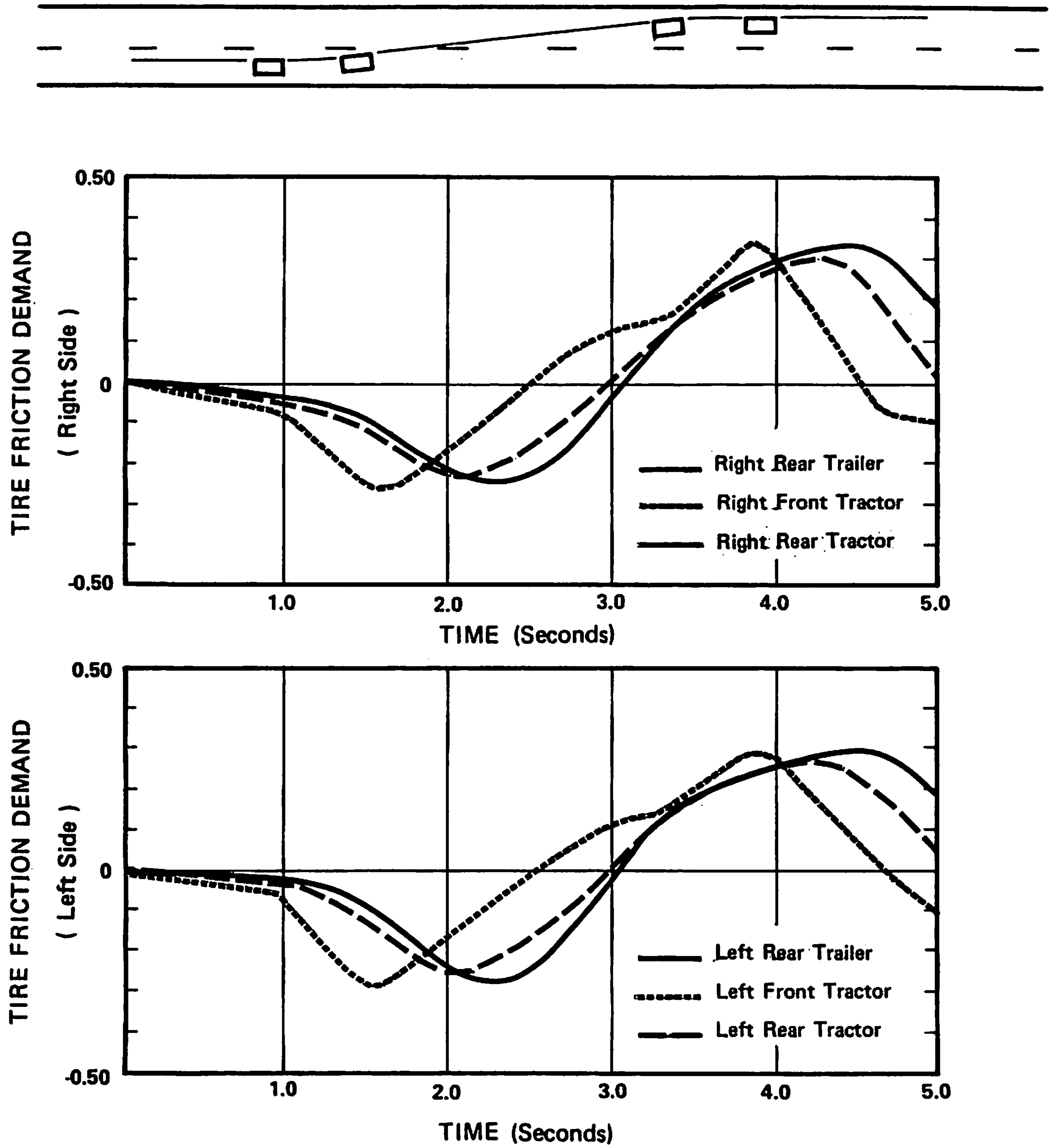


TEST CONDITIONS

Vehicle Type:	**Compact Car**	**Probe Length:**	**6.93 m**
Cross Slope:	**2 percent**	**P Gain:**	**1.46×10^{-1} rad / m**
Initial Speed:	**100 km / h**	**Q Gain:**	**1.46×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**1.00 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 3. SIMULATION RESULTS FOR COMPACT AUTOMOBILE USING HVOSM (continued)

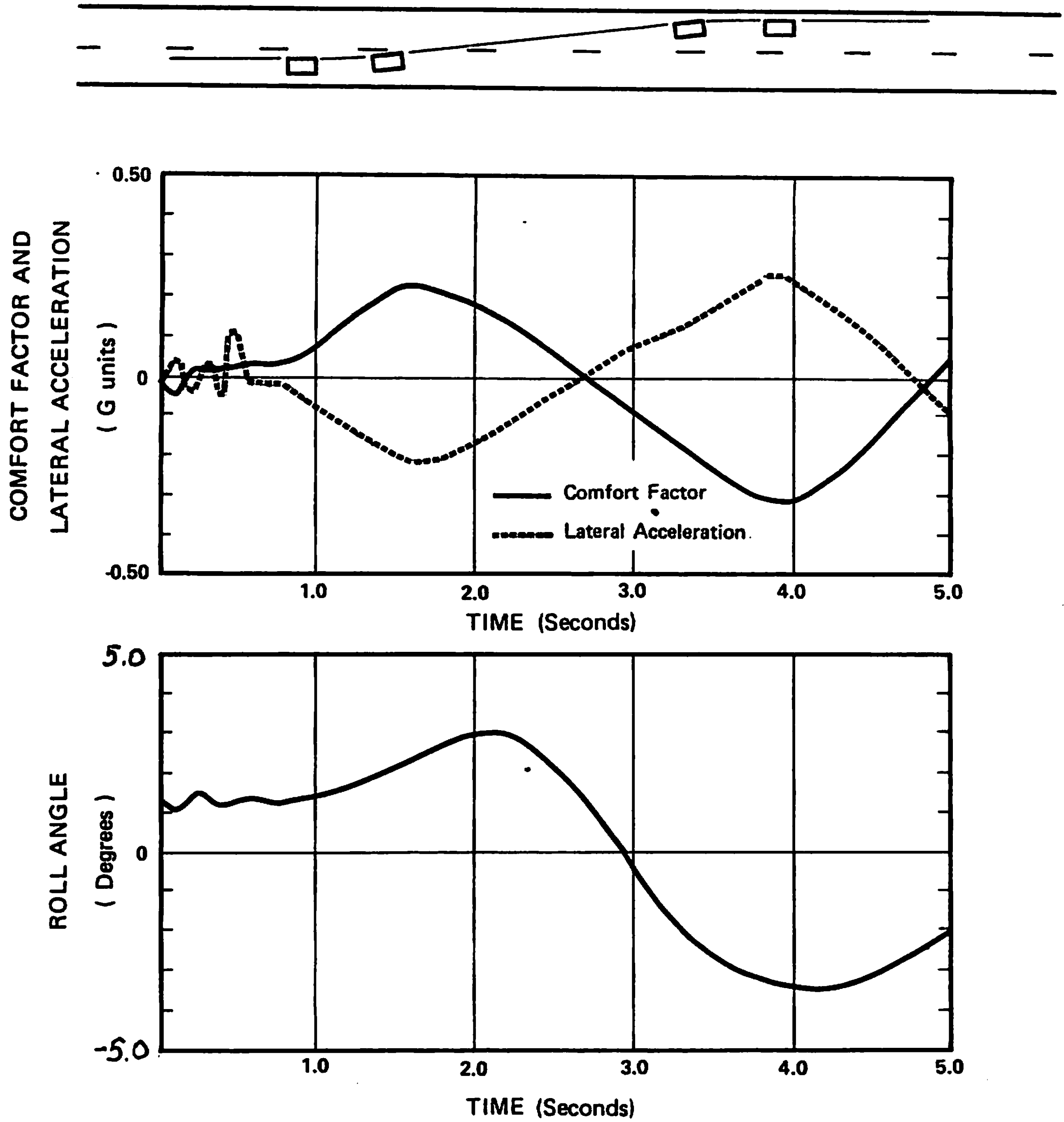


TEST CONDITIONS

Vehicle Type:	**Loaded Semi - trailer**	**Probe Length:**	**7.21 m**
Cross Slope:	**2 percent**	**P Gain:**	**6.9×10^{-2} rad / m**
Initial Speed:	**108 km / h**	**Q Gain:**	**2.8×10^{-2} rad · s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**0.20 m / s ^{2}**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 4. SIMULATION RESULTS FOR LOADED SEMI - TRAILER TRUCK USING HSRI / MVM PHASE 4 MODEL

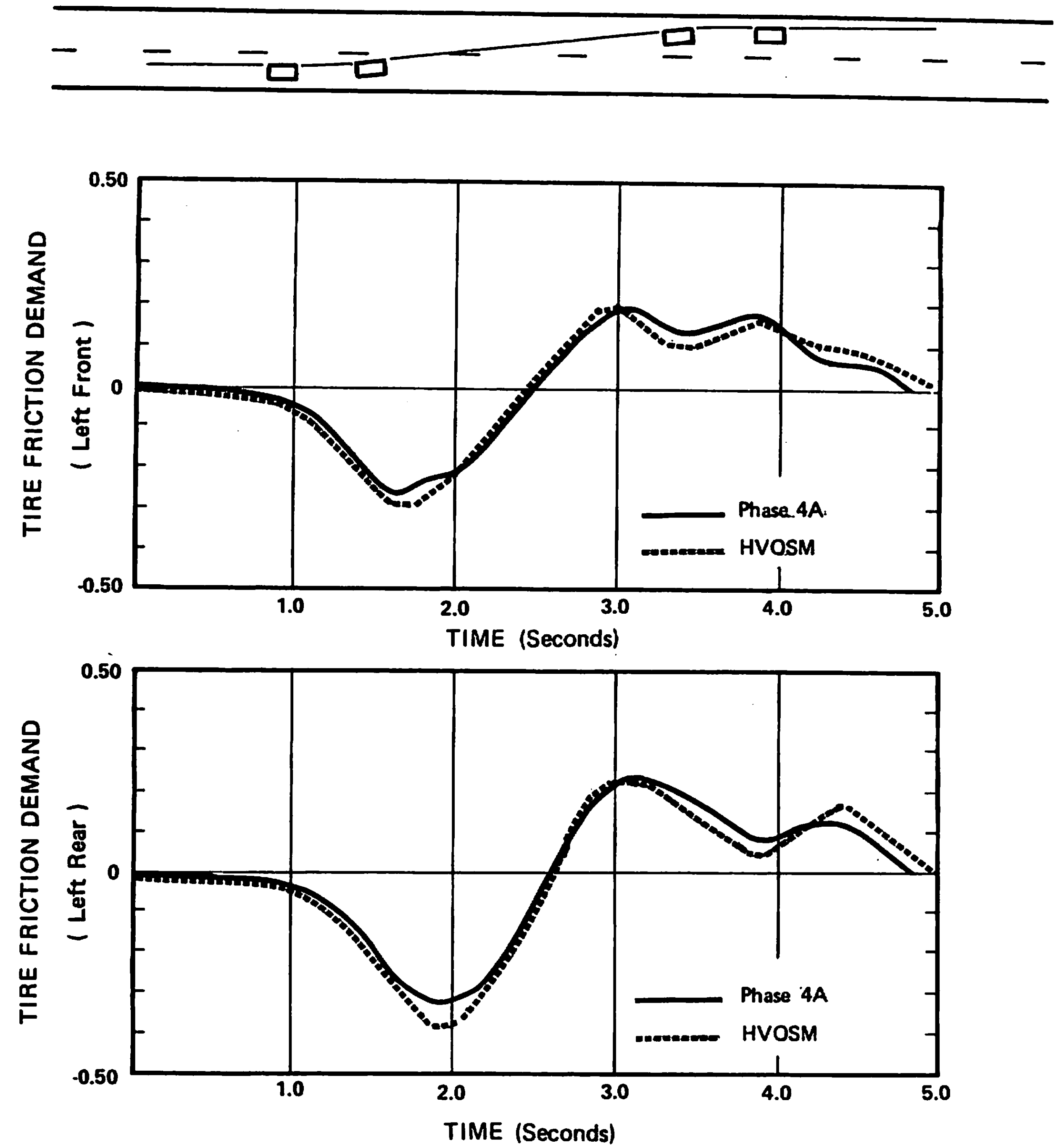


TEST CONDITIONS

Vehicle Type:	**Loaded Semi - trailer**	**Probe Length:**	**7.21 m**
Cross Slope:	**2 percent**	**P Gain:**	**6.9×10^{-2} rad / m**
Initial Speed:	**108 km / h**	**Q Gain:**	**2.8×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**0.2 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 4. SIMULATION RESULTS FOR LOADED SEMI - TRAILER TRUCK USING HSRI / MVM PHASE 4 MODEL (continued)

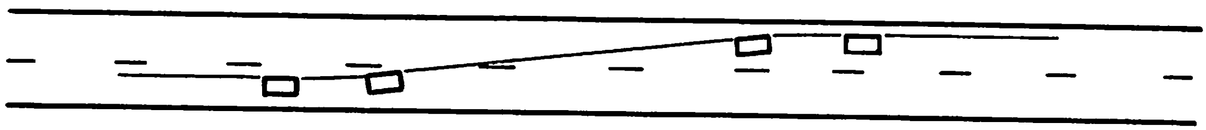


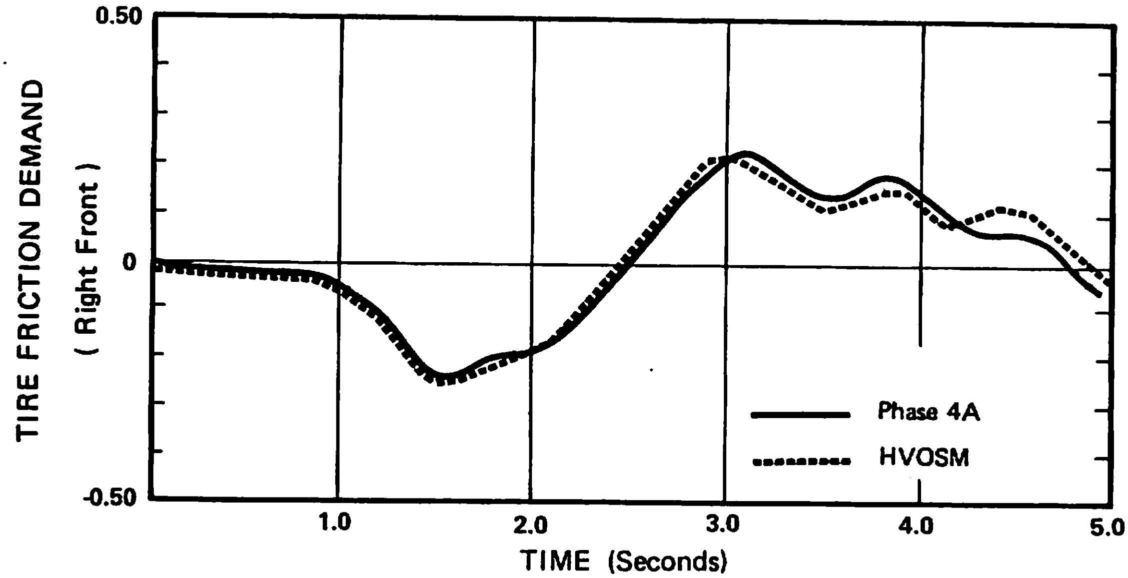
TEST CONDITIONS

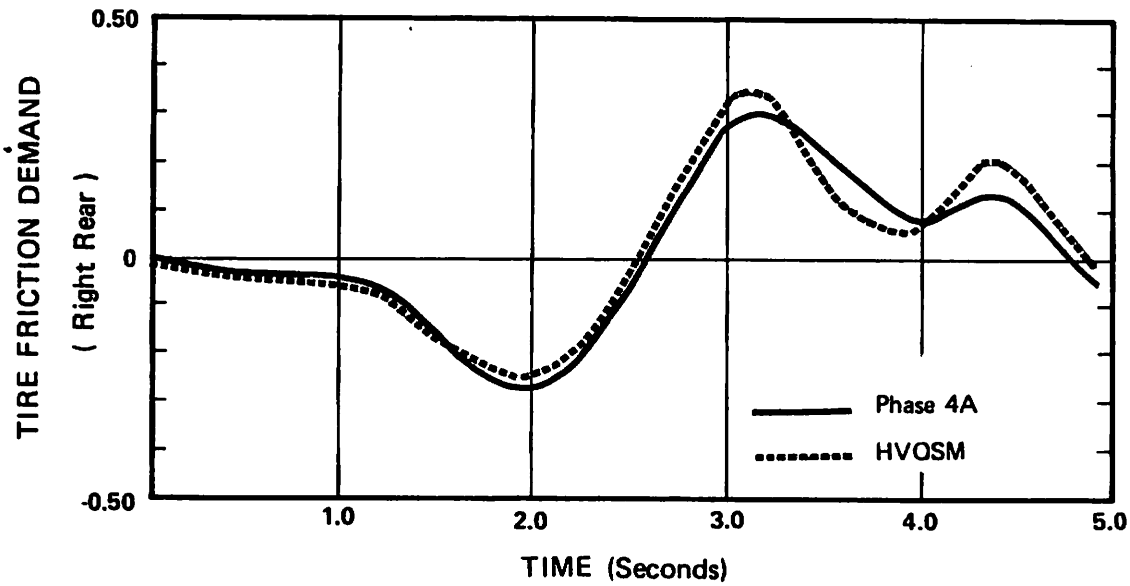
Vehicle Type:	**Single - unit Truck**	**Probe Length:**	**7.21 m**
Cross Slope:	**2 percent**	**P Gain:**	**6.9×10^{-2} rad / m**
Initial Speed:	**104 km / h**	**Q Gain:**	**2.8×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**0.5 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 5. SIMULATION RESULTS FOR SINGLE - UNIT TRUCK — — COMPARISON BETWEEN HVOSM AND HSRI / MVM PHASE 4 MODEL





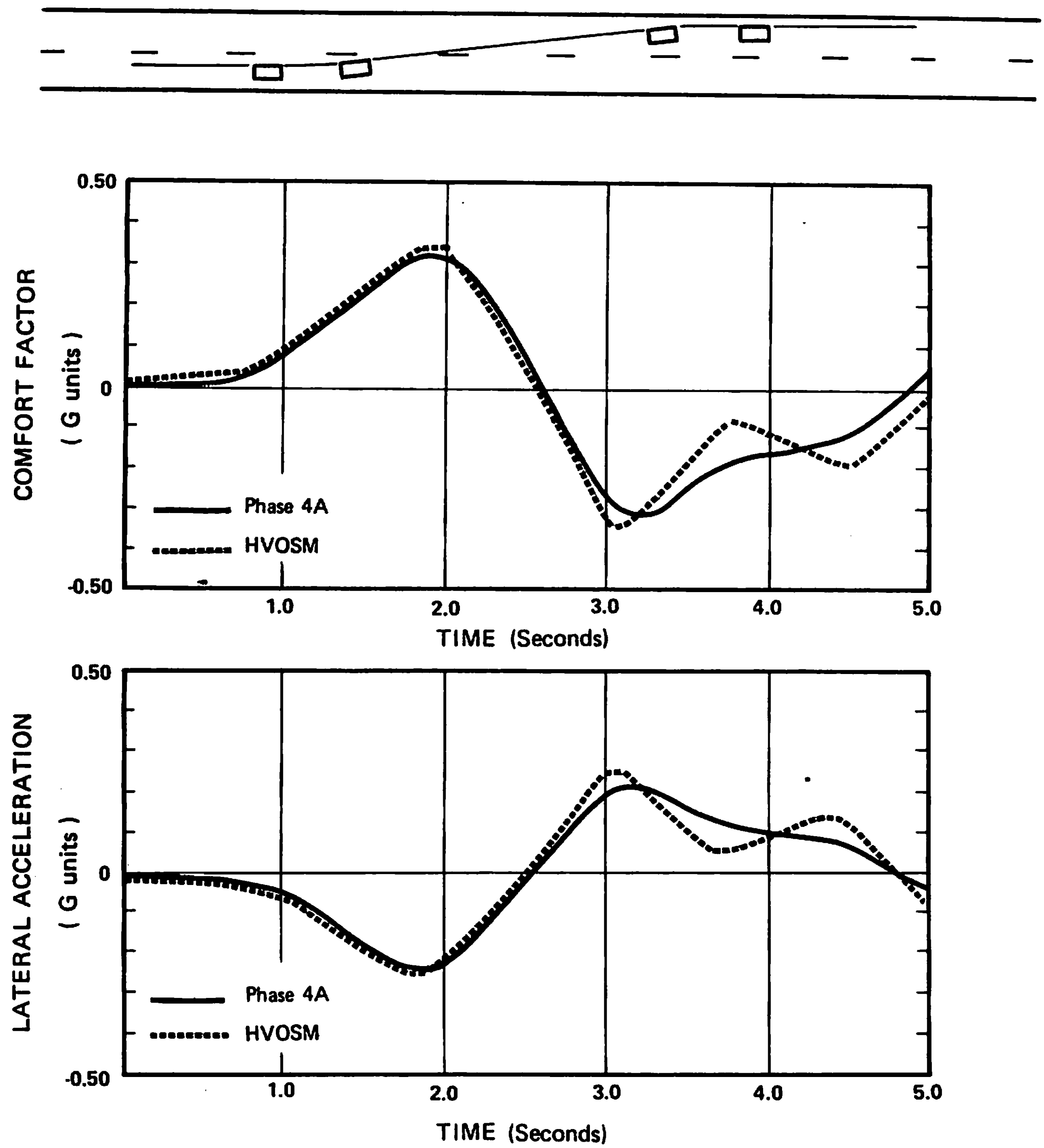


TEST CONDITIONS

Vehicle Type:	Single - unit Truck	Probe Length:	7.21 m
Cross Slope:	2 percent	P Gain:	6.9×10^{-2} rad / m
Initial Speed:	104 km / h	Q Gain:	2.8×10^{-2} rad - s / m
Design Speed:	120 km / h	Acceleration:	0.50 m / s^2

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 5. SIMULATION RESULTS FOR SINGLE - UNIT TRUCK — — COMPARISON BETWEEN HVOSM AND HSRI / MVM PHASE 4 MODEL (continued)

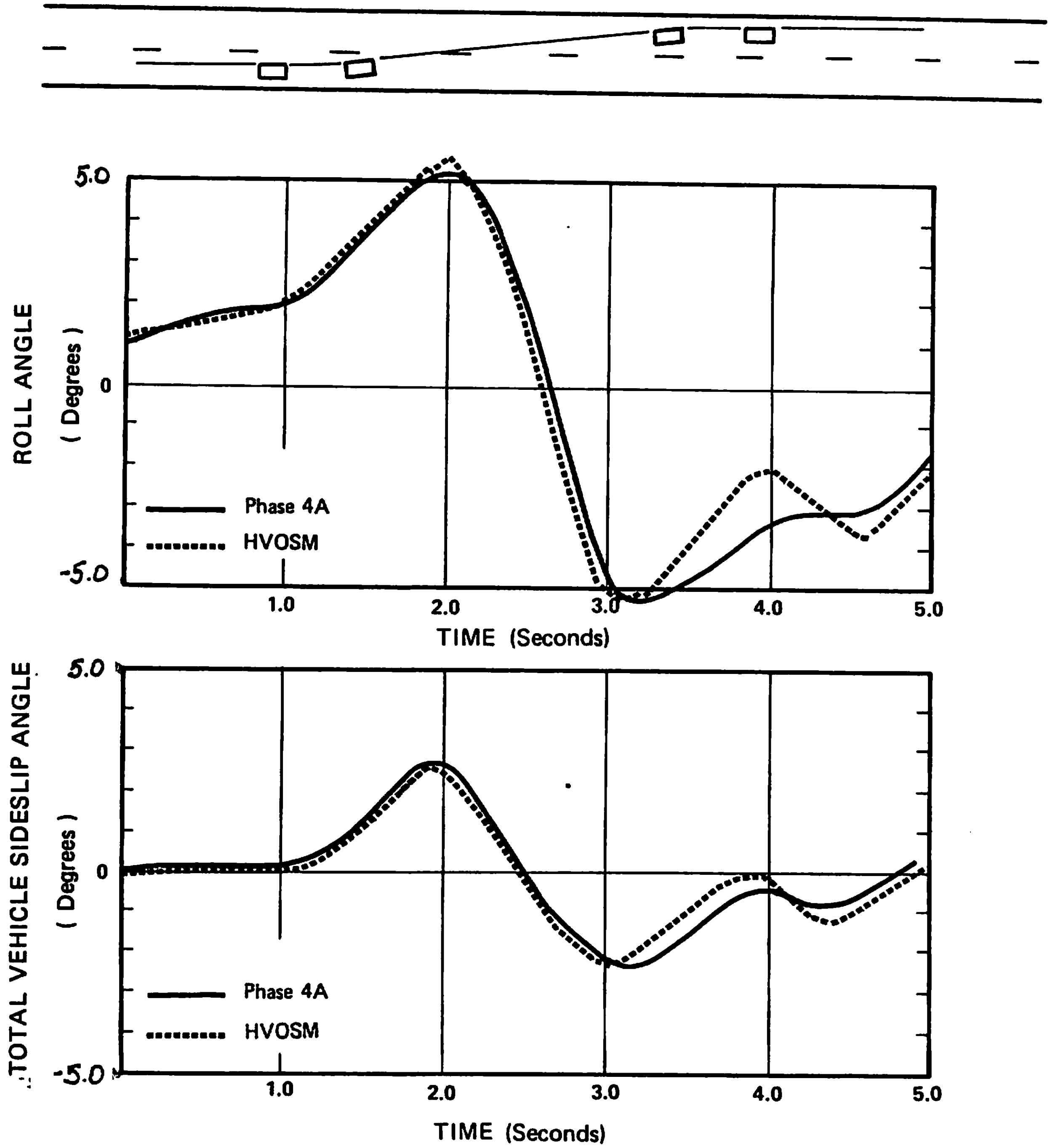


TEST CONDITIONS

Vehicle Type:	Single - unit Truck	Probe Length:	7.21 m
Cross Slope:	2 percent	P Gain:	6.9×10^{-2} rad / m
Initial Speed:	104 km / h	Q Gain:	2.8×10^{-2} rad - s / m
Design Speed:	120 km / h	Acceleration:	0.50 m / s^2

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 5. SIMULATION RESULTS FOR SINGLE - UNIT TRUCK — — COMPARISON BETWEEN HVOSM AND HSRI / MVM PHASE 4 MODEL (continued)



TEST CONDITIONS

Vehicle Type:	**Single - unit Truck**	**Probe Length:**	**7.21 m**
Cross Slope:	**2 percent**	**P Gain:**	**6.9×10^{-2} rad / m**
Initial Speed:	**104 km / h**	**Q Gain:**	**2.8×10^{-2} rad - s / m**
Design Speed:	**120 km / h**	**Acceleration:**	**0.50 m / s^2**

Note : 1 km / h = 0.62 mph, 1 m = 3.28 ft.

Figure 5. SIMULATION RESULTS FOR SINGLE - UNIT TRUCK — — COMPARISON BETWEEN HVOSM AND HSRI / MVM PHASE 4 MODEL (continued)

Table 6
Comparison of Vehicle Effects
on Dynamics of Passing Maneuvers

VEHICLE TYPE	TIRE FRICTION DEMAND (g's)	DRIVER DISCOMFORT (g's)	VEHICLE ROLL ANGLE (degrees)
Test Conditions: 74 mph (120 km/h) Design Speed, 2 percent Cross Slope			
Compact Auto	0.36	0.38	3.7
Mid-Size Auto	0.34	0.38	4.9
Tractor-Trailer (empty)	0.30	0.22	1.8
Tractor-Trailer (loaded)	0.29	0.30	3.3
Single-Unit Truck (HVOSM)	0.23	0.32	6.3
Single-Unit Truck (PHASE 4)	0.22	0.31	6.3
Test Conditions: 62 mph (100 km/h) Design Speed, 4 percent Cross Slope			
Tractor-Trailer (loaded)	0.38	0.42	5.3
Compact Auto	0.32	0.36	4.2
Mid-Size Auto	0.29	0.34	5.2

Summary of Vehicle Comparison

The following conclusions describe the effects of cross slope on the full range of vehicle types tested.

(1) The compact automobile generates higher tire friction demands than the mid-size automobile.

(2) The compact automobile generates the highest tire friction demand on a 2 percent cross slope.

(3) The loaded tractor-trailer generates the highest tire friction demand on a 4 percent cross slope.

(4) The empty tractor-trailer produces similar tire friction demands as a loaded tractor-trailer, but with significantly lower driver discomfort and roll angle.

Table 7
Comparison of Speed Effects
on Dynamics of Passing Maneuvers

Vehicle Type	Speed mph (km/h)	Cross-Slope (percent)	Tire Friction Demand (g's)	Driver Discomfort (g's)	Vehicle Roll Angle (degrees)
Mid-Size Auto	87 (140)	2	0.33	0.36	4.6
	74 (120)	2	0.34	0.38	4.9
	62 (100)	2	0.28	0.32	4.0
Mid-Size Auto	74 (120)	4	0.36	0.40	6.2
	62 (100)	4	0.29	0.34	5.2
	50 (80)	4	0.22	0.26	4.4
Compact Auto	74 (120)	2	0.36	0.38	3.7
	62 (100)	2	0.31	0.34	3.0
Tractor-Trailer (Loaded)	74 (120)	2	0.29	0.30	3.3
	62 (100)	2	0.34	0.37	3.8

Summary of Speed Comparison

The results of comparisons across speeds are mixed. While the comparisons generally show an increase in tire friction demand with an increase in speed, two comparisons show the opposite. Although these discontinuities cannot be directly explained, it is believed they are partially an artifact of the total simulation process, which included varying the driver parameter values and passing path segment lengths with speed.

Table 8
Comparison of Cross Slope Effects
on Dynamics of Passing Maneuvers

Vehicle Type	Speed mph (km/h)	Cross-Slope (percent)	Tire Friction Demand (g's)	Driver Discomfort (g's)	Vehicle Roll Angle (degrees)
Mid-Size Auto	74 (120)	2	0.34	0.38	4.9
	74 (120)	4	0.36	0.40	6.2
Mid-Size Auto	62 (100)	2	0.28	0.32	4.0
	62 (100)	4	0.29	0.34	5.2
Compact Auto	62 (100)	2	0.31	0.34	3.0
	62 (100)	4	0.32	0.36	4.2
Tractor-Trailer (Loaded)	62 (100)	2	0.34	0.37	3.8
	62 (100)	4	0.38	0.42	5.3

<u>Summary of Cross Slope Comparison</u>

The dynamic effect of increasing cross slope from 2 to 4 percent is an increase in the tire friction ranging from 0.01 to 0.04 g's.

Conclusions

Although the simulation experiments only represent a small segment of real highway operations and did produce a few conflicting results with regard to speed effects, the implications with regard to pavement cross slope and centerline crossover break design are reasonably clear. These implications which are generally consistent with AASHTO requirements are as follows:

(1) The passing maneuver on two-lane, high-speed (greater than 60 mph (100 km/h)) highways is potentially severe regardless of the cross slope. Simulation of nominally critical passing behavior produced vehicle dynamic responses on the order of 0.28 to 0.34 g's for cross slopes of 2 percent and a full range of vehicle types.

(2) The dynamic effect of increased cross slopes (say, from 2 percent to 4 percent) is a marginal increase in driver discomfort and tire friction demand. Because of conclusion (1), any such increase is undesirable as it worsens an already critical situation. It is therefore clear that, to minimize the dynamic contribution of cross slope, cross-slope design should be kept to a minimum on high-speed highways.

(3) Higher cross slopes may be permissible on highways with lower design speeds (say, 50 mph (80 km/h) or less). A practical maximum of 4 percent is indicated by the dynamic responses for tractor-trailer passing maneuvers on such highways.

(4) In general, for all design speeds, the cross slope should be kept to the minimum consistent with drainage requirements for the type of surface and highway. It should be recognized that the establishment of a design cross slope affects other design elements. Greater cross slopes generally result in less design flexibility and a reduction in the safety effectiveness of the highway. They require longer superelevation runout lengths, and affect the design of the shoulder slope. As shoulder slopes tend to be designed with greater slope than the cross slope to facilitate drainage of the traveled way, cross slopes of 4 to 6 percent would tend to be accompanied by shoulder slopes of 6 or 8 percent. Recent research on the dynamics of roadside traversals (3) points out the disadvantages of such steep shoulder slopes.

From the above four conclusions, it appears that current AASHTO criteria for maximum centerline cross slope, as shown on page 1, are appropriate. AASHTO policy should explicitly note the operational effects of pavement cross slope on the passing maneuver, and should encourage the use of minimal cross slopes on high speed highways.

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Appendix A - HVOSM Modifications

A number of refinements and revisions to the HVOSM program were required, including additional outputs of vehicle responses, revision of the path-following driver model, and input of dual rear tire specifications. These revisions are described below.

Additional Outputs

Additional calculations and outputs of the existing HVOSM RD2 program were found to be required to enable the evaluation of the centerline crown. The revisions were as follows:

"Discomfort Factor".--The lateral acceleration output of HVOSM corresponds to measurements made with a "hard-mounted," or body-fixed accelerometer oriented laterally on the vehicle. During cornering, the lateral acceleration of the vehicle is directed toward the center of the turn. On a superelevated turn, the component of gravity that acts laterally on the vehicle is also directed toward the turn center. Thus, the lateral acceleration output is increased by superelevation.

Since the vehicle occupants respond to centrifugal force, their inertial reaction is toward the outside of the turn and therefore the component of gravity that acts laterally on them in a superelevated turn reduces the magnitude of the disturbance produced by cornering. A corresponding program output has been defined to evaluate occupant discomfort in turns.

The effects of a vehicle's roll angle and lateral acceleration on occupants are combined in a "discomfort factor" relationship which represents the net lateral disturbance felt by the occupants (i.e., the occupants' reaction to the combined effects of the lateral acceleration and roll angle).

The "discomfort factor" is coded in the following form:

$$\text{DISCOMFORT FACTOR} = -\text{YLAT} + 1.0 * \text{SIN}\ \theta$$

Where: DISCOMFORT FACTOR = G units

YLAT = Vehicle Lateral Acceleration in vehicle-fixed coordinate system, G units

θ = Vehicle roll angle, radians.

Calculations related to the discomfort factor and corresponding outputs were incorporated into the HVOSM.

Friction Demand.--The friction demand is defined to be the ratio of the side force to the normal load of an individual tire. It is indicative of the friction being utilized by each individual tire. The standard outputs of HVOSM include the side force and normal force for each tire. Coding changes were incorporated to calculate and print out the friction demand for each tire at each interval of time.

Driver Model

A recognized problem in the use of either simulation models or full-scale testing in relation to investigations of automobile dynamics is the manner of guiding and controlling the vehicle. Repeatability is essential, and the control inputs must be either representative of an average driver or optimized to achieve a selected maneuver without "hunting" or oscillation. In this investigation of geometric features of highways, the transient portions of the vehicle responses constituted justification for applying a complex computer simulation. The steady-state portions of the vehicle responses can be predicted by means of straightforward hand calculations. Thus, it is essential that the transient responses should not be contaminated by oscillatory steering control inputs.

The Driver model contained in the distributed version of the HVOSM Vehicle Dynamics program was intended to be incorporated into the HVOSM Roadside Design version, but it proved to be inadequate for the present research effort. Therefore, new routines were written for the HVOSM Roadside Design program as described below.

"Wagon-Tongue" Algorithm.--The "wagon-tongue" type of steering control incorporated into the HVOSM Roadside Design Version is one in which the front wheel steer angle is directly proportional to the error of a point on a forward extension of the vehicle X-axis relative to the desired path.

The basic inputs to the "wagon-tongue" algorithm are described in Table 9.

Table 9

Inputs For "Wagon-tongue" Driver Model

Input	Description	Units
TPRB	Time at which driver model is to begin	sec
DPRB	Time between driver model samples	sec
PLGTH	Probe length measured from the center of gravity of the vehicle along the vehicle-fixed X axis	in
PMIN	Null band, minimum acceptable error	in
PMAX	Maximum allowable discomfort factor above which driver model will only reduce steer angle	g-units
PGAIN	Steer correction multiplier--error of probe from desired path multiplied by PGAIN to determine steer correction	rad/in

1 in = 25.4 mm

Desired Path Definition.--The revision to the HVOSM driver model included the incorporation of a "path generating" routine to create a desired path of X,Y data pairs from standard roadway geometric descriptors. Figure 6 lists the path generating routine.

```
C  PATHT.FOR  F12                  30 DECEMBER 1980        J T FLECK
C   PATH GENERATOR
C   ROUTINE TO TEST PATH GENERATION SUBROUTINES SETD AND PATHG
C          MAY BE USED TO GENERATE DATA SETS FOR TERRAIN GENERATOR
C      .   OR HVOSM
C
C   INPUTS:
C       NPTS            NUMBER OF POINTS DESIRED
C       XINIT           X COORDINATE OF FIRST POINT
C       YINIT           Y COORDINATE OF FIRST POINT
C       DELL            SPACING BETWEEN POINTS (ALONG STRAIGHT LINE)
C       PSA             INITIAL HEADING (TANGENT TO PATH)
C       KLI             NUMBER OF SECTIONS (CURVATURES)
C              IF  = 0  PROGRAM DEFAULTS TO POINTS IN DATA STATEMENT
C              IF  > 0  REQUIRES THE FOLLOWING INPUT    L = 1, KLI
C                       DI(L)   CURVATURE     > 0 RIGHT TURN
C                                             = 0 STRAIGHT
C                                             < 0 LEFT TURN
C                       RLI(L)  DISTANCE FROM INITIAL POINT WHERE DI(L)
C                               IS EFFECTIVE.
C                               DISTANCE IS MEASURED IN STAIGHT LINE
C                               SEGMENTS BETWEEN POINTS. IF DISTANCE
C                             ' ALONG ARC IS REQUIRED SUBROUTINE SETD
C                               MUST BE MODIFIED.
C                NOTE: KLI MAY BE 1 OR GREATER
C                       E.G. TO GENERATE A STAIGHT PATH N*DELL UNITS
C                       LONG AND THEN A RIGHT TURN WITH A CURVATURE OF 20
C                       INPUT KLI = 1, DI(1) = 20., RLI(1) = N*DELL
C                       THE ANGLE OF TURN IS GIVEN BY
C                       ANGLE = 2*ARCSIN[(DELL/2)*(PI/180)*(DI(L)/100)]
C
C   OUTPUT
C          X(I), Y(I)   COORDINATES OF POINT I  I = 1 TO NPTS
C         DX(I),DY(I)   TANGENT AT POINT I (DIRECTION OF PATH)
C          D(I)         CURVATURE DEFINING PATH FROM POINT I TO POINT I+1
C
C          THESE ARE WRITTEN ON A DATA SET (SY1:PTH.DAT) FOR USE BY OTHER
C          ROUTINES
C
C
       INTEGER PLOT
       DIMENSION X(100),Y(100),DX(100),DY(100),D(100),DI(100),RLI(100)
       DIMENSION PLOT(70,70)
       DATA RAD/0.01745329/, D /10*0.0,9*20.0,9*-20.0,9*20.0,63*0.0/
       DATA KLI/0/, DI/100*0.0/, RLI/100*0.0/
C
       CALL OPEN(6,'SY1:PTH.DAT ')
C ENTER INITIAL DATA
     1 WRITE(1,5)
     5 FORMAT(1X,' ENTER NPTS,XINIT,YINIT,DELL,PSA '/)
       READ(1,6)NPTS,XINIT,YINIT,DELL,PSA
     6 FORMAT(I4,4F9.0)
       IF(NPTS.LT.2)ENDFILE 6
       IF(NPTS.LT.2)STOP NPTS
C
C ENTER # OF CURVATURES (IF 0 ROUTINE USES D SET BY DATA STATEMENT)
C      AND OUTPUT UNIT IOUT =0 DEFAULTS TO SCREEN, IOUT =2 FOR PRINTER
       WRITE(1,7)
     7 FORMAT(' ENTER KLI,IOUT'/)
       READ(1,11)KLI,IOUT
```

Figure 6. PATH GENERATING ROUTINE

```
   11    FORMAT(2I4)
C
         IF(IOUT.EQ.0)IOUT = 1
CHECK IF DI'S AND RLI' ARE TO BE INPUTTED
         IF(KLI.EQ.0)GO TO 17
         DO 15 I =1,KLI
         WRITE(1,14)
   14    FORMAT(' ENTER DI, RLI'/)
   15    READ(1,16)DI(I),RLI(I)
   16    FORMAT(2F9.0)
C
CALL ROUTINE TO COMPUTE D'S FROM DI'S
         CALL SETD(KLI,DI,RLI,NPTS,DELL,D)
C
C INITIALIZE POINTS
   17    X(1)  = XINIT
         Y(1)  = YINIT
C
C INITIALIZE TANGENT
         DX(1) = COS(PSA *RAD)
         DY(1) = SIN(PSA *RAD)
C
CALL ROUTINE TO SET PATH
         CALL PATHG(NPTS,DELL,X,Y,D,DX,DY)
C
         WRITE(6)NPTS,DELL,PSA ,X,Y,DX,DY,D
         WRITE(IOUT,23)NPTS,KLI,DELL,PSA
   23    FORMAT(1X,'NPTS=',I4,', KLI=',I4,',DELL=',F10.4,',PSA =',F10.4/)
         IF(KLI.GT.0)WRITE(IOUT,24)(L,DI(L),RLI(L),L=1,KLI)
   24    FORMAT(1X,I4,2F10.4)
         WRITE(IOUT,25)
   25    FORMAT(/' POINT #      POSITION',19X,'TANGENT',10X,'CURVATURE')
         WRITE(IOUT,26)(I,X(I),Y(I),DX(I),DY(I),D(I),I=1,NPTS)
   26    FORMAT(1X,I4,2F10.2,10X,2F10.5,F10.2)
```

Figure 6. PATH GENERATING ROUTINE (continued)

```
C
C PRINTER PLOT: SPECIAL ROUTINE TO TEST ABOVE DATA
       M  = NPTS
       XX = X(1)
       XM = X(1)
       YX = Y(1)
       YM = Y(1)
       DO 35 I =1,M
       IF(X(I).GT.XX)XX = X(I)
       IF(X(I).LT.XM)XM = X(I)
       IF(Y(I).GT.YX)YX = Y(I)
   35  IF(Y(I).LT.YM)YM = Y(I)
       SC = XX-XM
       IF(YX-YM.GT.SC)SC = YX-YM
       SX = 60./SC
       SY = 0.6*SX
       DO 38 I=1,70
       DO 38 J=1,70
   38  PLOT(I,J) = ' '
       IMAX = 1
       DO 40 K=1,M
       J = (X(K)-XM)*SX +1.
       I = (Y(K)-YM)*SY +1.
       IF(I.GT.IMAX)IMAX = I
   40  PLOT(I,J) = '*'
       IF(IOUT.EQ.2)WRITE(2,41)

   41   FORMAT(1H1)
C
       DO 50 I=1,IMAX
       LM = 61
       DO 44 J=1,60
       IF(PLOT(I,LM).NE.' ')GO TO 45
   44  LM = LM-1
   45  WRITE(IOUT,47)(PLOT(I,L),L=1,LM)
   47  FORMAT(5X,71A1)
   50  CONTINUE
       GO TO 1
       END
```

Figure 6. PATH GENERATING ROUTINE (continued)

```
C  SUBROUTINE PATH:  PATH.FOR  F12        30 DECEMBER 1980  J T FLECK
C   PATH GENERATOR  HVOSM RD-2
C   ROUTINE USED IN HVOSM RD-2 TO GENERATE PATH DATA
C
C   INPUTS:
C       NPTS              NUMBER OF POINTS DESIRED
C       XINIT             X COORDINATE OF FIRST POINT
C       YINIT             Y COORDINATE OF FIRST POINT
C       DELL              SPACING BETWEEN POINTS (ALONG STRAIGHT LINE)
C       PSA               INITIAL HEADING (TANGENT TO PATH)
C       KLI               NUMBER OF SECTIONS (CURVATURES)
C              IF  = 0    PROGRAM DEFAULTS TO POINTS IN DATA STATEMENT
C              IF  > 0    REQUIRES THE FOLLOWING INPUT    L = 1, KLI
C                         DI(L)   CURVATURE    > 0 RIGHT TURN
C                                              = 0 STRAIGHT
C                                              < 0 LEFT TURN
C                         RLI(L)  DISTANCE FROM INITIAL POINT WHERE DI(L)
C                                 IS EFFECTIVE.
C                                 DISTANCE IS MEASURED IN STAIGHT LINE
C                                 SEGMENTS BETWEEN POINTS. IF DISTANCE
C                                 ALONG ARC IS REQUIRED SUBROUTINE SETD
C                                 MUST BE MODIFIED.
C    -          NOTE: KLI MAY BE 1 OR GREATER
C                        E.G. TO GENERATE A STAIGHT PATH N*DELL UNITS
C                        LONG AND THEN A RIGHT TURN WITH A CURVATURE OF 20
C                        INPUT KLI = 1, DI(1) = 20., RLI(1) = N*DELL
C                        THE ANGLE OF TURN IS GIVEN BY
C                        ANGLE = 2*ARCSIN[(DELL/2)*(PI/180)*(DI(L)/100)]
C
C   OUTPUT
C        X(I), Y(I)    COORDINATES OF POINT I   I = 1 TO NPTS
C       DX(I),DY(I)    TANGENT AT POINT I (DIRECTION OF PATH)
C         D(I)         CURVATURE DEFINING PATH FROM POINT I TO POINT I+1
C
C
C
C
      SUBROUTINE PATH
      COMMON/PATHD/IPATH ,KLI ,DI(10),RLI(10),
     1             NPTS,XINIT,YINIT,PSA,DELL,
     2             ,X(100),Y(100),DX(100),DY(100),D(100)
C LIMIT ARRAY SIZES
      IF(KLI.GT.10)KLI = 10
      IF(NPTS.GT.100)NPTS = 100
      CALL SETD(KLI,DI,RLI,NPTS,DELL,D)
C SETD WAS MODIFIED ON 30 DEC 1980 TO PRODUCE SPIRAL
C INITIALIZE FIRST POINT AND TANGENT
      X(1)  =  XINIT
      Y(1)  =  YINIT
      DX(1) =  COS(PSA)
      DY(1) =  SIN(PSA)
C
      CALL PATHG(NPTS,DELL,X,Y,D,DX,DY)
C
      RETURN
      END
```

Figure 6. PATH GENERATING ROUTINE (continued)

```
C PROBE.FOR  F12                    30 DECEMBER 1980        J T FLECK
C SUBROUTINE PROBE:  CALCULATES DISTANCE OF A POINT FROM CENTERLINE
C
C USED IN HVOSM RD-2 MOD'S
C
C INPUTS
C        XP,YP          GIVEN POINT
C        M              NUMBER OF REFERENCE POINTS (= NPTS)
C        X(I), Y(I)     REFERENCE POINTS OF PATH , I =1,NPTS
C        DX(I),DY(I)    TANGENT VECTOR AT REFERENCE POINT
C        D(I)           DEGREE OF CURVATURE AT BETWEEN POINT I AND I+1
C                          D > 0  RIGHT TURN
C                          D = 0  STRAIGHT LINE
C                          D < 0  LEFT TURN
C
C OUTPUTS
C        I              POINT IDENTIFYING SECTOR OF CLOSEST APPROACH
C        DIST           DISTANCE OF POINT FROM ARC
C                          POSITIVE IF POINT IS TO RIGHT OF ARC
C                          NEGATIVE IF POINT IS TO LEFT  OF ARC
C        XX ,YY         POINT ON ARC NEAREST GIVEN POINT
C
C NOTE: ON FIRST ENTRY ROUTINE STARTS WITH I = 1, ON SUBSEQUENT
C        ENTRIES THE PREVIOUS VALUE OF I IS USED.  THIS LOGIC SHOULD BE
C        ADEQUATE FOR THE PROPOSED USE OF THE ROUTINE.
C
C        CALCULATION OF XX AND YY MAY BE DELETED IF THIS POINT IS NOT NEEDED
C
C
      SUBROUTINE PROBE(XP,YP,M,X,Y,DX,DY,D,I,DIST,XX,YY)
      DIMENSION X(1),Y(1),DX(1),DY(1),D(1)
      DATA RAD/0.01745329251994329 6/,ILAST/1/
C INITIALIZE
      I    = ILAST
      TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
      TSAV = SIGN(1.0,TEST)
      GO TO 15
C
C START SEARCH
C
    7 I = I + 1
      IF(I.LE.M)GO TO 10
      IF(TSAV.LT.0.0)GO TO 20
      I = M
      GO TO 25
   10 TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
      IF(TEST*TSAV.LE.0.0)GO TO 25
   15 IF(TEST)20,25,7
   20 I = I - 1
      IF(I.GE.1)GO TO 10
      IF(TSAV.GT.0.0)GO TO 7
      I = 1
C
C FINISH SEARCH
   25 IF((TEST.LT.0.0).AND.(I.GT.1))I=I-1
      ILAST = I
C FINISH OF DETERMINATION OF I
```

Figure 6. PATH GENERATING ROUTINE (continued)

```
C
CALCULATE DISTANCE
        ZDN  = -DY(I)*(XP-X(I))+DX(I)*(YP-Y(I))
        CONS =  D(I)*RAD*0.005
        ZDZ  =  ((XP-X(I))**2+(YP-Y(I))**2)*CONS
        DIST =  (ZDN-ZDZ)/(0.5+SQRT(0.25-CONS*(ZDN-ZDZ)))
C
CALCULATE POSITION OF CLOSEST APPROACH POINT ON ARC
C THE FOLLOWING CODE MAY BE DELETED AND THE REFERENCES TO XX AND YY TAKEN
C OUT OF THE CALL IF THE POINT OF CLOSEST APPROACH ON THE ARC IS NOT NEEDED
C
        DEN = 1.0-2.0*DIST*CONS
C
        IF(DEN.GT.0.0)GO TO 30
        WRITE(1,26)I,XP,YP,DIST,DEN
   26   FORMAT(' SUBROUTINE PROBE HAS NEGATIVE OR ZERO DENOMINATOR'/
     1  ' IN POSITION  FORMULA; IMPLIES POINT NOT IN SECTOR'/I6,4F10.4)
        STOP PROBE
C THIS STOP SHOULD NEVER OCCUR IN NORMAL USAGE
C
   30   XX = (XP-X(I)+DIST*DY(I))/DEN + X(I)
        YY = (YP-Y(I)-DIST*DX(I))/DEN + Y(I)
   35   RETURN
        END
C
C
C************
C       IF TANGENT VECTOR IS NOT AVAILABLE IT MAY BE REPLACED BY
C               DX = X(I+1)-X(I)   , DY = Y(I+1)-Y(I)   ,I < M
C               DX = X(M)  -X(M-1), DY = Y(M)  -Y(M-1),I = M
C
C               USE DX FOR DX(I) AND DY FOR DY(I) IN CALCULATION OF TEST
C
C       RETURN CAN BE PUT AT END OF DETERMINATION OF I AND THE
C       DISTANCE AND CALCULATION OF XX,YY DONE BY ANOTHER ROUTINE.
C       (FORMULAS FOR DIST, XX AND YY ARE ONLY VALID FOR CIRCULAR ARCS
C        OR STRAIGHT LINES)
```

Figure 6. PATH GENERATING ROUTINE (continued)

```
C PATHG.FOR  F12          30 DECEMBER 1980         J T FLECK
C   PATH GENERATOR, SUBROUTINE PATHG    HVOSM RD-2
C   INPUTS
C        NPTS            NUMBER OF DESIRED POINTS ( > 1)
C        DELL            SPACING BETWEEN POINTS
C         X(1), Y(1)     INITIAL POSITION SET BY CALLING ROUTINE
C        DX(1),DY(1)     INITIAL TANGENT  SET BY CALLING ROUTINE
C        D(I)            DEGREE OF CURVATURE, I = 1 TO NPTS
C                        D(I) > 0  TURN TO RIGHT
C                        D(I) = 0  STRAIGHT
C                        D(I) < 0  TURN TO LEFT
C               NOTE:    RADIUS OF CURVATURE IS DEFINED AS
C                        EQUAL TO  (180/PI)*(100/D) = (5729.6/D)
C                        (D HAS DIMENSION OF DEGREES PER 100 UNITS OF DELL)
C
C   OUTPUTS              I = 1 TO NPTS
C         X(I), Y(I)     COORDINATES OF POINTS
C        DX(I),DY(I)     TANGENT VECTOR (DIRECTION OF PATH AT X,Y)
C
C   NOTE:  ROUTINE PRODUCES SMOOTH CURVE SUCH THAT TANGENTS ARE CONTINUOUS
C
        SUBROUTINE PATHG(NPTS,DELL,X,Y,D,DX,DY)
        DIMENSION X(1),Y(1),DX(1),DY(1),D(1)
        DATA RAD/0.017453292519943296/
C INITIALIZE
        CONS  = DELL*RAD/200.0
C*
        DXX   = DELL*DX(1)
        DYY   = DELL*DY(1)
C*
        DS1   = 0.0
        DC1   = 1.0
C START LOOP
        DO 20 I = 2, NPTS
COMPUTE SINE AND COSINE OF HALF SECTOR ANGLE
        DS2   = CONS*D(I-1)
        DC2   = SQRT((1.0-DS2)*(1.0+DS2))
C**
COMPUTE SINE AND COSINE OF SECTOR ANGLE
        SP    = 2.0*DS2*DC2
        CP    = 1.0 - 2.0*DS2**2
C UPDATE TANGENT VECTOR
        DX(I) =  CP*DX(I-1) - SP*DY(I-1)
        DY(I) =  SP*DX(I-1) + CP*DY(I-1)
C**
COMPUTE SINE AND COSINE OF AVERAGE SECTOR ANGLE
        SP    =     DS1*DC2 + DC1*DS2
        CP    =     DC1*DC2 - DS1*DS2
COMPUTE NEW INCREMENTS
        DXS   =  DXX
        DXX   =  DXS*CP  - DYY*SP
        DYY   =  DXS*SP  + DYY*CP
C UPDATE POSITION
        X(I)  =  X(I-1)  + DXX
        Y(I)  =  Y(I-1)  + DYY
C SAVE SINE AND COSINE OF HALF SECTOR ANGLE FOR NEXT I
        DS1   =  DS2
   20   DC1   =  DC2
        RETURN
        END
```

Figure 6. PATH GENERATING ROUTINE (continued)

Neuro-Muscular Filter.--The "neuro-muscular" filter from the HVOSM-Vehicle Dynamics Version (7) was incorporated into the HVOSM Roadside Design version. The filter structure corresponds to the first-order effects of the neurological and muscular systems of a human driver.

For the curve study, the following inputs were used for the filter for all runs:

TIL	Time lag of filter	0.05	seconds
TI	Time lead of filter	0.00905	seconds
TAUF	Time delay of filter	0.0	seconds

The related revisions to the Driver model were incorporated into the FHWA distributed Roadside Design version of the HVOSM. However, the revised path-following algorithm was found to produce sustained oscillations about a specified path under some operating conditions. Since the extent of oscillation is dependent on the guidance system parameters as well as the vehicle speed and path curvature, it is possible to obtain peak values of transient response predictions that reflect an artifact of the guidance system rather than a real effect of the highway geometrics under investigation. For example, in Reference (12), comparisons are made between peak transient and steady-state response values which are believed to be more reflective of effects of the guidance system than of the simulated roadway geometrics. Therefore, the following additional modifications were added to the Driver model:

(1) Damping
A damping term (QGAIN) was added to limit the extent of steering activity. Initial runs utilizing the damping term exhibited a reduction in the steering activity as expected. The value used in the curve study was QGAIN (rad-sec/m) = PGAIN/10, where PGAIN is the steering velocity term described below.

(2) Steer Velocity

In addition to the damping term, an adjustable limit on the steering angle velocity was incorporated in the path-follower algorithm, enabling the user to limit the maximum instantaneous front wheel steer velocity to a selected value.

(3) Steer Initialization
For runs such as those being performed in relation to the cross-slope break study, the starting point must be relatively close to the cross-slope break to achieve an economical use of computer time. Thus, the input of an initial steer angle to approximate steady-state steer was

required. Previously, the path-follower algorithm was initialized to a steer angle of 0.0 degrees, regardless of the input value for the initial steer angle. Corresponding revisions were made to Subroutine DRIVER to enable input of an initial steer angle.

A revised listing of Subroutine DRIVER, including the cited modifications, is presented in Figure 7.

Dual Tires

To permit the comparison simulation runs to be performed, the HVOSM program had to be modified to enable the simulation of dual rear tires such as are found in many single-unit trucks. The modification required to simulate dual rear tires consisted of a modification to subroutine TIRFRC to double the tire forces at the rear when the option is chosen. While a more elaborate definition of dual rear tires could be pursued, the selected approach was most efficient and equivlanet to that used in the PHASE4 program.

```
C SUBROUTINE DRIVER FOR HVOSM RD-2
C
      SUBROUTINE DRIVER(PSI,DPSI,JJ,IFLAG,A,B,AMTX,OMCPS)
      DIMENSION AMTX(3,3),PPD(50),TPD(50)
      COMMON/PATHD/IPATH,KLI,DI(10),RLI(10),NPTS,XINIT,YINIT,
     1       PSA,DELL,X(100),Y(100),DX(100),DY(100),D(100)
      COMMON/WAGON/IWAGN,TPRB,DPRB,PLGTH,PMIN,PMAX,PGAIN,QGAIN,PSIFD
      COMMON/FILT/ IFILT,TIL ,TI  ,TMT  ,TAUF
      COMMON/INTG/ NEQ  ,T   ,DT  ,VAR(50),DER(50)
      COMMON/ACC/CMFCG,CMFA1,CMFA2
      DATA NPDMAX/50/,NPD/0/,DPSL/0.0/,N/0/
      JJ   = 0
      IF(IWAGN.EQ.0)GO TO 90
      JJ   = 1
      PSIA = PSI
      DTP  = DPRB
      DPS  = 0.0
      DPSI = 0.0
      IF(IFLAG.EQ.0)GO TO 90
      IF(TPRB.GT.T + 0.1*DT)GO TO 10
C  COMPUTE NEW CHANGE IN STEER ANGLE
      TPRB  = TPRB + DPRB
      XP = VAR(18) + AMTX(1,1)*PLGTH
      YP = VAR(19) + AMTX(2,1)*PLGTH
      CALL PROBE(XP,YP,NPTS,X,Y,DX,DY,D,IPRB,DIST,XX,YY)
C  SELECTED POINT INDEX IPRB AND LOCATION OF CLOSEST POINT ON PATH XX,YY
C  ARE NOT CURRENTLY USED
      IF(DIST.EQ.0.0)GO TO 8
      SGND=DIST/ABS(DIST)
      IF(T.NE.TPRB) DDIST = (DIST-DISTA)/DPRB
  9   IF(ABS(DIST).GT.PMIN)DPS = -PGAIN*(ABS(DIST)-PMIN)*SGND
     1                          -QGAIN*DDIST
  8   IF(ABS(DIST).LE.PMIN) DPS= -QGAIN*DDIST
      IF(IFILT.EQ.0)GO TO 55
      IF(NPD.EQ.NPDMAX)GO TO 10
      NPD = NPD + 1
      PPD(NPD) = DPS - PSIA
      TPD(NPD) = T + TAUF
   10 IF(IFILT.EQ.0)GO TO 55
C
C  FILTER
C
      IF(NPD.EQ.NPDMAX) GO TO 10
      TPDTMP = TPD(N)
      DO 20 NN = 1,NPD
      N = NPD + 1 - NN
   20 IF(T.GE.TPD(N))GO TO 30
      GO TO 90
   30 IF(TPDTMP.LT.TPD(N)) DPSL = 0.0
      DPSI = PPD(N)*TMT*EXP(-(T - TPD(N))/TIL)/TIL
      DPSN = PPD(N) - TIL*DPSI
      DTP  = 0.0
      DPS  = DPSN - DPSL
      DPSL = DPSN
      IF(NPD.EQ.1)GO TO 50
C
C
```

Figure 7. SUBROUTINE DRIVER

```
  35  L    = 1
      DO 40 NN = N,NPD
      PPD(L) = PPD(NN)
      TPD(L) = TPD(NN)
   40 L = L + 1
      NPD = L - 1
C
   50 PSI = PSIA + DPS
      GO TO 58
   55 PSI = DPS
   58 CONTINUE
C CHECK PREVIOUS TIME INTERVAL COMFORT FACTOR (SEE SUBROUTINE OUTPUT)
C     IF GREATER THAN PMAX ALLOW ONLY REDUCTION IN STEER ANGLE
      IF((PMAX.GT.0.0).AND.(ABS(CMFA1).LT.PMAX))GO TO 60
      IF(ABS(PSI).GT.ABS(PSIA)) PSI=PSIA
   60 CONTINUE
C CHECK MAX STEER ANGLE
      IF((OMGPS.GT.0.0).AND.(ABS(PSI) .GT.  OMGPS))
     1     PSI = SIGN(OMGPS,PSI)
      IF(DTP.NE.0.0)DPSI = (PSI-PSIA)/DTP
C***   1/16/81   MCI   ***********************************************
      DPSO = DPS*57.2958
      PSIAO = PSIA*57.2958
      PSIO = PSI*57.2958
      DELPSI = PSIO- PSIAO
      XPFT = XP/12.0
      YPFT = YP/12.0
      XXFT = XX/12.0
      YYFT = YY/12.0
C     IF(FKD.EQ.1.0) GO TO 90
      IF(KPAGE.LE.50.AND.T.NE.0.0000) GO TO 110
      WRITE(50,100)
  100 FORMAT(
     A1H1,33X,37HPROBE COORDINATES    PATH COORDINATES,5X,3HPSI,6X,
     B3HDPS,6X,4HPSIA,2X,7HDPSI    ,2X,7HDPSN    ,5HIFLAG,2X,4HIPRB/
     C31H  TIME     DELTA PSIF    ERROR ,6X,1HX,9X,1HY,10X,1HX,8X,1HY/
     D31H  (SEC)      (DEG)       (IN)  ,4X,4H(FT),6X,4H(FT),7X,
     E4H(FT),5X,4H(FT)//)
      KPAGE = 0
  110 WRITE(50,120) T,DELPSI,DIST,XPFT,YPFT,XXFT,YYFT,PSIO,DPSO,
     A              PSIAO,DPSI,DPSN,IFLAG,IPRB
  120 FORMAT(1H ,F7.3,2(4X,F7.3),2(3X,F7.1),2X,2(2X,F7.1),3(2X,F7.4),
     A        2X,F7.5,2X,F7.5,2X,I3,2X,I2)
      KPAGE = KPAGE + 1
   90 RETURN
C*********************************************************************
      END
C*********************************************************************
```

Figure 7. SUBROUTINE DRIVER (continued)

Appendix B - HSRI/MVMA PHASE4 Modifications

New Routines Added to PHASE4 Program

Several new routines were added to the PHASE4 simulation program to permit the use of identical terrain definitions and/or driver model path-following in the PHASE4 and HVOSM simulation programs. The routines added to the PHASE4 program are essentially routines from either the HVOSM-76 (7) or the HVOSM-81 (routines previously added or modified within this contract).

The routines added to the PHASE4 program are as follows:

INPUT2 Purpose:
(1) Obtains card inputs from Fortran Unit 7 for terrain table and/or driver model option(s)
(2) Prints card inputs.
Subroutine called from: INPUT
Subroutines called: BLK04, BLK05, PATH, IDOUT
Origin: Modified version* of subroutine INPUT from HVOSM-76

BLK04 Purpose: Assigns input values of simulation driver model data
Subroutine called from: INPUT2
Subroutine called: none
Origin: Modified version of subroutine BLK04 from HVOSM-76

BLK05 Purpose: Assigns input values of simulation terrain table data
Subroutine called from: INPUT2
Subroutine called: TEREAD
Origin: Modified version of subroutine BLK05 from HVOSM-76

TEREAD Purpose: Reads terrain table input cards
Subroutine called from: BLK04
Subroutines called: none
Origin: Subroutine TEREAD from HVOSM-76

---

* The modifications mentioned herein to the HVOSM routines consisted of the elimination of unnecessary codes and storage prior to their installation into the PHASE4 program.

PATH PURPOSE: Initializes the first point and computes the initial tangent from a specified heading angle

Subroutine called from: IDOUT

Subroutine(s) called: SETD, PATH6

Origin: Subroutine PATH from HVOSM-81

SETD Purpose: Produces a set of degree of curves from a gross description of the path such that a set of equally spaced points describing the path may be computed

Subroutine called from: PATH

Subroutines called: none

Origin: Subroutine SETD from HVOSM-81

PATH6 Purpose: Computes the path coordinates from the degree of curve

Subroutine called from: PATH

Subroutines called: none

Origin: Subroutine PATH6 from HVOSM-81

IDOUT Purpose: Prints terrain table inputs with units and headings

Subroutine called from: INPUT2

Subroutines called: PTHOUT, ROADDZ

Origin: Modified version of subroutine IDOUT from HVOSM-76

PTHOUT Purpose: Prints driver model inputs with units and headings

Subroutine called from: IDOUT

Subroutines called: none

Origin: Subroutine PTHOUT from HVOSM-81

ROAD PURPOSE: Calculates the elevation and slopes of the x,y coordinates passed to the routine

Subroutines called from: IDOUT, FCT1, OUTPUT

Subroutine called: none

Entry points: ROADDZ, ROAD

Origin: Modified version of subroutine INTRP6 from HVOSM-76

DRIVE1 Purpose: Computes the front wheel steer angle from the driver model and path descriptor inputs

Subroutine called from: FCT1

Subroutines called: PROBE, CGERR

Entry points: DRIVER, DRIVE2

Origin: Modified version of subroutine DRIVER from HVOSM-81

PROBE PURPOSE: Calculates the error of an arbitrary point on the vehicle from the desired path

Subroutines called from: DRIVE1

Subroutines called: none

Origin: Subroutine PROBE from HVOSM-81

CGERR Purpose: Calculates the error of the vehicle center of gravity from the desired path

Subroutine called from: DRIVE1

Subroutine called: none

Origin: Subroutine CGERR from HVOSM-81

Modified Routines for the PHASE4

Two routines for the PHASE4 program required modification to enable their use with the program. The modified routines are as follows:

INPUT Purpose: Reads card inputs and echo's input parameters with units and and headings and initializes variables

Modifications:

(1) Print card inputs prior to echo

(2) Call to INPUT2 to input and process terrain table and or driver model inputs

MAIN Purpose: Assign i/O devices, initialize variables, and act as program supervisor

Modifications:

(1) Input and initialize initial heading angle

(2) Permit the setting of initial conditions caused by road when terrain table option used

The program listings for the added and modified routines are shown in Figure 8.

```
              SUBROUTINE INPUT2(DZX,DZY,IROAD,ISTEER)
      C***     MODIFICATIONS PER FH-11-9575, "STUDY OF CENTERLINE CROWN"
      C***     INSTALLED IN HSRI/MVMA PHASE4 SIMULATION MODEL
      C***     NOVEMBER 1982 BY MCHENRY CONSULTANTS, INC.
      C***     UNDER SUBCONTRACT TO JACK E. LEISCH & ASSOC.
      C***     CONTRACT NO. DOT-FH-11-9575
      C***
      C***     INSTALLED ROUTINE TO ENABLE USE OF HVOSM TERRAIN TABLES
      C***     AND HVOSM DRIVER-PATH FOLLOWER ROUTINES IN PHASE4
      C***     ALL ROUTINES FROM HVOSM-76 AND MODIFICATIONS FROM HTIS CONTRACT
      C***
      C***     INPUT2 ROUTINE FORMERLY SUBROUTINE INPUT FROM HVOSM-76 RD2
      C***     ROUTINE TO READ HVOSM CARD IMAGES INTO STORAGE FOR USE
      C***       WITH HSRI/MVMA TRACTOR TRAILOR SIMULATION PROGRAM
              COMMON/PAGE/NP,HEAD(20),R,W
              INTEGER R,W
              DIMENSION CARDIM(20),ICARD(300),DUM(18)
              DATA NBLKS/6/
              WRITE(W,930)
          930 FORMAT('1'
             41H ,5X,' CARD INPUTS FROM UNIT 7 AS FOLLOWS:'//)
      C           SET INPUT CARD COUNTER
              NC = 0
      C           READ A CARD
            1 READ(7,5000) (CARDIM(K),K=1,18),NSEQ,NCARD
         5000 FORMAT(18A4,2I4)
      C           OUTPUT CARD IMAGE
              WRITE(W,6000) (CARDIM(K),K=1,18),NSEQ,NCARD
         6000 FORMAT(1H ,13X,18A4,2I4)
              IF(NCARD.GE.9999) GO TO 20
              IF(NCARD.LE.0) GO TO 90
              IF(NSEQ.GT.0) GO TO 1
              NC = NC+1
              ICARD(NC) = NCARD
              GO TO 1
           20 REWIND 7
      C           TEST FOR AT LEAST ONE CARD OTHER THAN 9999
              IF(NC.LE.0) GO TO 91
      C           SET COUNTER TO PROCESS ALL BLOCK NUMBERED CARDS
              IC = 1
      C         DETERMINE CARD FORMAT AND TRANSFER TO PROPER CARD BLOCK
      C           SUBROUTINE TO STORE DATA
           21 NBLK = ICARD(IC)/100
              NBCRD = ICARD(IC)-NBLK*100
      C           FORMAT TEST
              IF(NBCRD.EQ.0) GO TO 22
      C           NUMERIC INPUT
              READ(7,2000) (DUM(K),K=1,9),NSEQ,NCARD
         2000 FORMAT(9F8.0,2I4)
              GO TO 23
           22 CONTINUE
      C           ALPHANUMERIC INPUT
              READ(7,2001) (DUM(K),K=1,18),NSEQ,NCARD
         2001 FORMAT(18A4,2I4)
      C           BRANCH TO PROPER SUBROUTINE TO STORE INPUT
           23 IF(NBLK .LE.0) GO TO 92
              IF(NBLK.GT.NBLKS) GO TO 93
              GO TO(30,30,30,400,500,30),NBLK
      C  PRINT ERROR MESSAGE HERE ?
              GOTO 94
      400     CALL BLK04(NBLK,NBCRD,NSEQ,NCARD,DUM,NERR)
              IF(NERR.EQ.0) GOTO 30
              GOTO 94
          500 NERR = 0
              CALL BLK05(NBLK,NBCRD,NSEQ,NCARD,DUM,NERR)
              IF(NERR.EQ.0) GO TO 30
              GO TO 94
           30 CONTINUE
      C           TEST IF ALL CARDS ARE READ
              IC = IC+1
              IF(IC.GT.NC) GO TO 40
      C           GET NEXT CARD FROM UNIT 7
              GO TO 21
           40 CONTINUE
      C           SEARCH FOR END OF DATA
              READ(7,2001) (DUM(K),K=1,18),NSEQ,NCARD
              IF(NCARD.NE.9999) GO TO 95
              GO TO 50
           90 WRITE(W,6002)
         6002 FORMAT(56H A CARD NUMBERED LESS THAN OF EQUAL TO ZERO HAS ENCOUNTE
             1          50HRED IN SUBROUTINE INPUT.  CARD IMAGE PRINTED ABOVE   )
              GO TO 49
           91 WRITE(W,6003)
         6003 FORMAT(33H THE NUMBER OF CARDS READ IS ZERO    )
              GO TO 49
           92 WRITE(W,6004)
         6004 FORMAT(56H A BLOCK NUMBER OF LESS THAN OF EQUAL TO ZERO HAS BEEN O
             1          7HBTAINED    )
              GO TO 49
           93 WRITE(W,6005)
         6005 FORMAT(56H A BLOCK NUMBER LARGER THAN THE ALLOWED NUMBER HAS BEEN
             1          8HOBTAINED    )
              GO TO 49
           94 WRITE(W,6006) NBLK,NBCRD,NSEQ,NCARD,NERR
         6006 FORMAT(56H AN ERROR HAS OCCURRED IN STORING INPUT VALUES IN ONE OF
             1          23H THE BLKXX SUBROUTINES.      /
             2          39H THE CALLING ARGUMENTS FROM INPUT ARE :     /
             3           7H NBLK =,I4,2X,7HNBCRD =,I4,2X,6HNSEQ =,I4,2X,7HNCARD =,
             4           I4,2X,6HNERR =,I4      )
              GO TO 49
           95 WRITE(W,6007)
         6007 FORMAT(56H AN EXPECTED 9999 CARD HAS NOT BEEN ENCOUNTERED AFTER ST
             1          20H MT NO. 40 IN INPUT.       )
           49 STOP
           50 IF(IROAD.LT.0)CALL ROAD(0,0,DZX,DZY)
      C    CALL PATH TO SET UP PATH FOLLOWER TABLES
              IF(ISTEER.LT.0) CALL PATH
      C    CALL IDOUT TO ECHO INPUT PARAMETERS
              CALL IDOUT(IROAD,ISTEER)
              RETURN
              END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL

```
                  C
                  C
0001                    SUBROUTINE BLK04(NBLK,NBCRD,NSEQ,NCARD,DUM,NERR)
                  C
                  C
                  C***     MODIFICATIONS PER FH-11-9575,"STUDY OF CENTERLINE CROWN"
                  C***     INSTALLED IN HSRI/MVMA PHASE4 SIMULATION MODEL
                  C***     NOVEMBER 1982 BY MCHENRY CONSULTANTS, INC.
                  C***     UNDER SUBCONTRACT TO JACK E. LEISCH & ASSOC.
                  C***
                  C***     INSTALLED ROUTINE TO ENABLE USE OF HVOSH TERRAIN TABLES IN PHASE4
                  C***     ALL ROUTINES FROM HVOSM-76 RD2
                  C***
                  C***     BLK04 ROUTINE FROM HVOSM-76 RD2
                  C                  HVOSM-RD2 VERSION
                  C                  REVISED OCTOBER 1975   CALSPAN CORPORATION
0002                   COMMON/PATHD/IPATH,KLI,DI(10),RLI(10),NPTS,XINIT,YINIT,
                      1          PSA,DELL,X(100),Y(100),DX(100),DY(100),D(100),CHED(20)
0003                   COMMON/HAGON/IHAGN,TPRB,DPRB,PLGTH,PMIN,PHAX,PGAIN,QGAIN,PSIFD,
                      1                 ITDOPT,TDPSI,THAX
0004                   COMMON/FILT/ IFILT,TIL,TI,TMT,TAUF
0005                   DIMENSION DUM(18)
0006                   DATA NBS/5/
0007                   NBT = NBCRD+1
0008                   IF(NBT.LT.1.OR.NBT.GT.NBS+1) GO TO 98
0009                   GO TO(400,98,402,403,404,405),NBT
0010                   GO TO 98
0011               400 IF(NCARD.NE.400) GO TO 98
0012                   DO 10 I=1,18
0013                10 CHED(I) = DUM(I)
0014                   GO TO 99
0015              402  IF(NCARD.NE.402) GO TO 98
0016                   IPATH = IFIX(DUM(1))
0017                   IHAGN = IFIX(DUM(2))
0018                   IFILT = IFIX(DUM(3))
0019                   TIL   = DUM(4)
0020                   TI    = DUM(5)
0021                   IF(TIL.NE.0.0) TMT   = (TIL-TI)/TIL
0022                   TAUF  = DUM(6)
0023                   GO TO 99
0024              403  IF(NCARD.NE.403.OR.IPATH.NE.1) GO TO 98
0025                   KLI   = IFIX(DUM(1))
0026                   NPTS  = IFIX(DUM(2))
0027                   XINIT = DUM(3)
0028                   YINIT = DUM(4)
0029                   PSA   = DUM(5)
0030                   DELL  = DUM(6)
0031                   GO TO 99
0032              404  IF(NCARD.NE.404.OR .KLI.EQ.0) GO TO 98
0033                   N1 = 1
0034                   N3 = N1 +3
0035             4041  DO 4042 I = N1,N3
0036                   M = (I - N1) * 2 + 1
0037                   DI(I) = DUM(M)
0038                   RLI(I) = DUM(M+1)
0039             4042  CONTINUE
0040                   IF(KLI.LE.4.OR.NSEQ.EQ.1) GO TO 99
0041                   READ(7,5000) (DUM(N),N=1,9), NSEQ,NCARD
0042              5000 FORMAT(9F8.0,2I4)
0043                   IF(NSEQ.NE.1.OR.NCARD.NE.404) GO TO 98
0044                   N1 = 5
0045                   N3 = 9
0046                   GO TO 4041
0047              405  IF(NCARD.NE.405.OR.IHAGN.EQ.0) GO TO 98
0048                   TPRB  = DUM(1)
0049                   DPRB  = DUM(2)
0050                   PLGTH = DUM(3)
0051                   PMIN  = DUM(4)
0052                   PMAX  = DUM(5)
0053                   PSIFD = DUM(6)
0054                   PGAIN = DUM(7)
0055                   QGAIN = DUM(8)
0056                   THAX  = DUM(9)
0057                   GO TO 99
0058                98 NERR = 1
0059                99 RETURN
0060                   END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
0001          SUBROUTINE BLKO5(NBLK,NBCRD,NSEQ,NCARD,DUM,NERR)
        C***   MODIFICATIONS PER FH-11-9575, "STUDY OF CENTERLINE CROWN"
        C***   INSTALLED IN HSRI/MVMA PHASE4 SIMULATION MODEL
        C***   NOVEMBER 1982 BY MCHENRY CONSULTANTS, INC.
        C***   UNDER SUBCONTRACT TO JACK E. LEISCH & ASSOC.
        C***
        C***   INSTALLED ROUTINE TO ENABLE USE OF HVOSM TERRAIN TABLES IN PHASE4
        C***   ALL ROUTINES FROM HVOSM-76 RD2
        C***
        C***   BLKO5 ROUTINE FROM HVOSM-76 RD2
        C                HVOSM-RD2 VERSION
        C                REVISED OCTOBER 1975   CALSPAN CORPORATION
0002          COMMON/HVROAD/GHED(20),NZTAB,XB(5),XE(5),XINCR(5),
             1       YB(5),YE(5),YINCR(5),NZ5,NX(5),NY(5),
             2       XBERO(8,5),XEERO(8,5),YBERO(8,5),YEERO(8,5),IERABX,IERABY,
             3       NBX(5),NBY(5),XBDRY(8,5),PSBDRO(8,5),YBDRY(2,5),
             4       ZGP(21,21,5),YYZGP5(21),XXZGP5(21)
0003          DIMENSION DUM(18)
0004          DATA NBS/15/
0005          NBT = NBCRD+1
0006          IF(NBT.LT.1.OR.NBT.GT.NBS+1) GO TO 98
0007          GO TO (500,501,502,503,504,505,
             1                  514,515),NBT
0008          GO TO 98
0009      500 IF(NCARD.NE.500) GO TO 98
0010          DO 10 I=1,18
0011       10 GHED(I) = DUM(I)
0012          GO TO 99
0013      501 IF(NCARD.NE.501) GO TO 98
0014          IF(NZTAB.LT.1) NZTAB=1
0015          IERABX=0
0016          IERABY=0
0017          I = 1
0018          GO TO 20
0019      502 IF(NCARD.NE.502) GO TO 98
0020          IF(NZTAB.LT.2) NZTAB = 2
0021          I = 2
0022          GO TO 20
0023      503 IF(NCARD.NE.503) GO TO 98
0024          IF(NZTAB.LT.3) NZTAB = 3
0025          I = 3
0026          GO TO 20
0027      504 IF(NCARD.NE.504) GO TO 98
0028          IF(NZTAB.LT.4) NZTAB = 4
0029          I = 4
0030          GO TO 20
0031      505 IF(NCARD.NE.505) GO TO 98
0032          NZTAB = 5
0033          I = 5
        C  20 NPAGE(15) = 1
0034       20 XB(I)     = DUM(1)
0035          XE(I)     = DUM(2)
0036          XINCR(I)  = DUM(3)
0037          YB(I)     = DUM(4)
0038          YE(I)     = DUM(5)
0039          YINCR(I)  = DUM(6)
0040          NBX(I) = IFIX(DUM(7))
0041          NBY(I) = IFIX(DUM(8))
0042          NZ5T = IFIX(DUM(9))
0043          NNBX = NBX(I)
0044          NNBY = NBY(I)
0045          IF(NZ5T.GT.0) GO TO 21
0046          NNX = IFIX((XE(I)-XB(I))/XINCR(I) + 1.2)
0047          NNY = IFIX((YE(I)-YB(I))/YINCR(I) + 1.2)
0048          NX(I) = NNX
0049          NY(I) = NNY
0050          CALL TEREAD(I,NNBX,NNBY,NNX,NNY,NZ5T,NERR)
0051          IF(NERR.NE.0) GO TO 98
0052          GO TO 99
0053       21 NNX = IFIX(DUM(3))
0054          NNY = IFIX(DUM(6))
0055          NX(I) = NNX
0056          NY(I) = NNY
0057          NZ5 = 1
0058          CALL TEREAD(I,NNBX,NNBY,NNX,NNY,NZ5T,NERR)
0059          IF(NERR.NE.0) GO TO 98
0060          GO TO 99
0061     514  IF(NCARD.NE.514) GO TO 98
0062          I = IFIX(DUM(9))
0063          DO 5141 J= 1,4
0064          J1 = (J-1)*2 +1
0065          J2 = J*2
0066          XBERO(J,I) = DUM(J1)
0067          XEERO(J,I) = DUM(J2)
0068     5141 CONTINUE
0069          IF(NBX(I).LE.4) GO TO 5144
0070          READ(7,5142) (DUM(N),N=1,9),NSEQ,NCARD
0071     5142 FORMAT(9F8.0,2I4)
0072          II = IFIX(DUM(9))
0073          IF(II.NE.I) GO TO 98
0074          DO 5143 J = 1,4
0075          J1 = (J-1)*2 + 1
0076          J2 = J*2
0077          JJ = J+4
0078          XBERO(JJ,I) = DUM(J1)
0079          XEERO(JJ,I) = DUM(J2)
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
 5143 CONTINUE
 5144 IF(NZTAB.LE.I) GO TO 5145
      READ(7,5142) (DUM(N),N=1,9),NSEQ,NCARD
      GO TO 514
 5145 IERABX = 1
      GO TO 99
  515 IF(NCARD.NE.515) GO TO 98
      I = IFIX(DUM(9))
      DO 5151 J = 1,4
      J1 = (J-1)*2 + 1
      J2 = J*2
      YBERO(J,I) = DUM(J1)
      YEERO(J,I) = DUM(J2)
 5151 CONTINUE
      IF(NBX(I).LE.4) GO TO 5154
      READ(7,5142) (DUM(N),N=1,9), NSEQ,NCARD
      II = IFIX(DUM(9))
      IF(II.NE.I) GO TO 98
      DO 5153 J = 1,4
      J1 = (J-1)*2 +1
      J2 = J*2
      JJ = J+4
      YBERO(JJ,I) = DUM(J1)
      YEERO(JJ,I) = DUM(J2)
 5153 CONTINUE
 5154 IF(NZTAB.LE.I) GO TO 5155
      READ(7,5142) (DUM(N),N=1,9),NSEQ,NCARD
      GO TO 515
 5155 IERABY = 1
      GO TO 99
   98 NERR = 1
   99 RETURN
      END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
FORTRAN IV G1  RELEASE 2.0          TEREAD          DATE = 83073          21/40/29          PAGE 0001
0001             SUBROUTINE TEREAD(I,NNBX,NNBY,NNX,NNY,NZ5T,NERR)
           C***   MODIFICATIONS PER FH-11-9575 "STUDY OF CENTERLINE CROWN"
           C***   INSTALLED IN HSRI/MVMA PHASE4 SIMULATION MODEL
           C***   NOVEMBER 1982 BY MCHENRY CONSULTANTS, INC.
           C***   UNDER SUBCONTRACT TO JACK E. LEISCH & ASSOC.
           C***
           C***   INSTALLED ROUTINE TO ENABLE USE OF HVOSM TERRAIN TABLES IN PHASE4
           C***   ALL ROUTINES FROM HVOSM-76
           C***
0002             COMMON/HVROAD/GHED(20),NZTAB,XB(5),XE(5),XINCR(5),
                1      YB(5),YE(5),YINCR(5),NZ5,NX(5),NY(5),
                2      XBERO(8,5),XEERO(8,5),YBERO(8,5),YEERO(8,5),IERABX,IERABY,
                3      NBX(5),NBY(5),XBDRY(8,5),PSBDRO(8,5),YBDRY(2,5),
                4      ZGP(21,21,5),YYZGP5(21),XXZGP5(21)
0003             DIMENSION DUM(18)
0004             LSEQ = 0
0005             IF(NNBX.LE.0) GO TO 10
0006             READ(7,2000) (DUM(K),K=1,9),NSEQ,NCARD
0007        2000 FORMAT(9F8.0,2I4)
0008             IF(NSEQ.LT.LSEQ) GO TO 98
0009             LSEQ = NSEQ
0010             IF(NNBX.GT.8) GOTO 98
0011             DO 11 K=1,NNBX
0012          11 XBDRY(K,I) = DUM(K)
0013             READ(7,2000) (DUM(K),K=1,9),NSEQ,NCARD
0014             IF(NSEQ.LT.LSEQ) GO TO 98
0015             LSEQ = NSEQ
0016             DO 12 K=1,NNBX
0017          12 PSBDRO(K,I) = DUM(K)
0018          10 IF(NNBY.LE.0) GO TO 20
0019             IF(NNBY.GT.2) GO TO 98
0020             READ(7,2000) (DUM(K),K=1,9),NSEQ,NCARD
0021             IF(NSEQ.LT.LSEQ) GO TO 98
0022             LSEQ = NSEQ
0023             DO 13 K=1,NNBY
0024          13 YBDRY(K,I) = DUM(K)
0025          20 NYCDS = (NNY-1)/9+1
0026             DO 30 J=1,NNX
0027             M = 0
0028             DO 40 K=1,NYCDS
0029             READ(7,2000) (DUM(N),N=1,9),NSEQ,NCARD
0030             IF(NSEQ.LT.LSEQ) GO TO 98
0031             LSEQ = NSEQ
0032             DO 50 N=1,9
0033             M = M+1
0034             ZGP(J,M,I) = DUM(N)
0035             IF(M.GE.NNY) GO TO 30
0036          50 CONTINUE
```

```
FORTRAN IV G1  RELEASE 2.0          TEREAD          DATE = 83073          21/40/29          PAGE 0002
0037          40 CONTINUE
0038          30 CONTINUE
0039             IF(NZ5T.EQ.0) GO TO 99
0040             M = 0
0041             DO 60 K=1,NYCDS
0042             READ(7,2000) (DUM(N),N=1,9),NSEQ,NCARD
0043             IF(NSEQ.LT.LSEQ) GO TO 98
0044             LSEQ = NSEQ
0045             DO 61 N=1,9
0046             M = M+1
0047             YYZGP5(M) = DUM(N)
0048             IF(M.GE.NNY) GO TO 70
0049          61 CONTINUE
0050          60 CONTINUE
0051          70 NXCDS = (NNX-1)/9 + 1
0052             M = 0
0053             DO 71 K=1,NXCDS
0054             READ(7,2000) (DUM(N),N=1,9),NSEQ,NCARD
0055             IF(NSEQ.LT.LSEQ) GO TO 98
0056             LSEQ = NSEQ
0057             DO 72 N=1,9
0058             M = M+1
0059             XXZGP5(M) = DUM(N)
0060             IF(M.GE.NNX) GO TO 99
0061          72 CONTINUE
0062          71 CONTINUE
0063          98 NERR = 1
0064          99 RETURN
0065             END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
FORTRAN IV G1  RELEASE 2.0                 DATE = 83073        21/40/29        PAGE 0001
                C
                C
0001                  SUBROUTINE PATH
                C
                C
0002                  COMMON/PATHD/IPATH  ,KLI  ,DI(10),RLI(10),
                     1                NPTS,XINIT,YINIT,PSA,DELL,
                     2                X(100),Y(100),DX(100),DY(100),D(100),CHED(20)
                C LIMIT ARRAY SIZES
0003                  IF(KLI.GT.10)KLI = 10
0004                  IF(NPTS.GT.100)NPTS = 100
0005                  CALL SETD(KLI,DI,RLI,NPTS,DELL,D)
                C SETD WAS MODIFIED ON 30 DEC 1980 TO PRODUCE SPIRAL
                C INITIALIZE FIRST POINT AND TANGENT
0006                  X(1)  =  XINIT
0007                  Y(1)  =  YINIT
0008                  DX(1) =  COS(PSA)
0009                  DY(1) =  SIN(PSA)
                C
0010                  CALL PATHG(NPTS,DELL,X,Y,D,DX,DY)
                C
0011                  RETURN
                C**********************************************************************
0012                  END
```

```
FORTRAN IV G1  RELEASE 2.0                 DATE = 83073        21/40/29        PAGE 0001
                C
                C
0001                  SUBROUTINE PATHG(NPTS,DELL,X,Y,D,DX,DY)
                C
                C
                C***    PATHF    MCI   ************************************************
                C***    PATH GENERATOR ROUTINE                                       **
                C***                                                                 **
0002                  DIMENSION X(1),Y(1),DX(1),DY(1),D(1)
0003                  DATA RAD/0.017453292519943296/
                C INITIALIZE
0004                  CONS   = DELL*RAD/200.0
                C*
0005                  DXX    = DELL*DX(1)
0006                  DYY    = DELL*DY(1)
                C*
0007                  DS1    = 0.0
0008                  DC1    = 1.0
                C START LOOP
0009                  DO 20 I = 2, NPTS
                COMPUTE SINE AND COSINE OF HALF SECTOR ANGLE
0010                  DS2    = CONS*D(I-1)
0011                  DC2    = SQRT((1.0-DS2)*(1.0+DS2))
                C**
                COMPUTE SINE AND COSINE OF SECTOR ANGLE
0012                  SP     = 2.0*DS2*DC2
0013                  CP     = 1.0 - 2.0*DS2**2
                C UPDATE TANGENT VECTOR
0014                  DX(I) =   CP*DX(I-1) - SP*DY(I-1)
0015                  DY(I) =   SP*DX(I-1) + CP*DY(I-1)
                C**
                COMPUTE SINE AND COSINE OF AVERAGE SECTOR ANGLE
0016                  SP     =      DS1*DC2 + DC1*DS2
0017                  CP     =      DC1*DC2 - DS1*DS2
                COMPUTE NEW INCREMENTS
0018                  DXS    =   DXX
0019                  DXX    =   DXS*CP  - DYY*SP
0020                  DYY    =   DXS*SP  + DYY*CP
                C UPDATE POSITION
0021                  X(I)   =   X(I-1)  + DXX
0022                  Y(I)   =   Y(I-1)  + DYY
                C SAVE SINE AND COSINE OF HALF SECTOR ANGLE FOR NEXT I
0023                  DS1    =   DS2
0024               20 DC1    =   DC2
0025                  RETURN
                C
                C
                C
                C***************
                C      CODE BETWEEN C**'S MAY BE DELETED IF TANGENT VECTORS
                C         ARE NOT REQUIRED: HOWEVER IN THE CODE BETWEEN THE C*'S
                C         DX(1) IS COS(PSI1) AND DY(1) IS SIN(PSI1), THESE WERE SET
                C         BY CALLING PROGRAM.
                C         POLYNOMIAL OR OTHER TYPE OF FITS TO THE X(I) AND Y(I) MAY
                C         BE DONE BY OTHER ROUTINES
                C**********************************************************************
0026                  END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
FORTRAN IV G1  RELEASE 2.0            IDOUT            DATE = 83073          21/40/29            PAGE 0001
            SUBROUTINE IDOUT(IROAD,ISTEER)
      C***   MODIFICATIONS PER FH-11-9575,"STUDY OF CENTERLINE CROWN"
      C***   INSTALLED IN HSRI/MVMA PHASE4 SIMULATION MODEL
      C***   NOVEMBER 1982 BY MCHENRY CONSULTANTS, INC.
      C***   UNDER SUBCONTRACT TO JACK E. LEISCH & ASSOC.
      C***
      C***   INSTALLED ROUTINE TO ENABLE USE OF HVOSM TERRAIN TABLES IN PHASE4
      C***   ALL ROUTINES FROM HVOSM-76
      C***
      C***   INPUT ECHO ROUTINE FOR TERRAIN TABLE OPTION
            COMMON/PAGE/NP,HEAD(20),R,W
            COMMON/HVROAD/GHED(20),NZTAB,XB(5),XE(5),XINCR(5),
           1        YB(5),YE(5),YINCR(5),NZ5,NX(5),NY(5),
           2        XBERO(8,5),XEERO(8,5),YBERO(8,5),YEERO(8,5),IERABX,IERABY,
           3        NBX(5),NBY(5),XBDRY(8,5),PSBDRO(8,5),YBDRY(2,5),
           4        ZGP(21,21,5),YYZGP5(21),XXZGP5(21)
            COMMON/PATHD/IPATH,KLI,DI(10),RLI(10),NPTS,XINIT,YINIT,
           1        PSA,DELL,XT(100),YT(100),DX(100),DY(100),D(100),CHED(20)
            DIMENSION TTARG(50) ,NTARG(10)
            INTEGER R,W
            DIMENSION TXARG(21), TYARG(21)
            DIMENSION AMUG(5)
            DATA AMUG/5*1.0/
            DATA TTARG/50*0.0/ , NTARG/10*0/
            DATA TXARG/21*0.0/,TYARG/21*0.0/
            DATA CON1/'CONS'/, VARI/'VARI'/
      C
            RAD = 0.0174532925D0
            IF(NZTAB.EQ.0) GO TO 700
        930 FORMAT('1',2X,'HSRI/MVMA BRAKING AND HANDLING SIMULATION OF',
           1        ' TRUCKS, TRACTOR-SEMITRAILORS, DOUBLES, AND TRIPLES - PHASE
           2 4.'/' ',36X,20A4/
           31H0,2X,' OPTIONAL INPUTS ADDED 9/82 BY MCI :',20A4/
           41H ,38X,20A4/)
            DO 601 I=1,50
        601 TTARG(I) = 0.0
            DO 602 I=1,10
        602 NTARG(I) = 0
            DO 603 I=1,NZTAB
            TTARG(I) =      XB(I)
            TTARG(5 + I)= XE(I)
            TTARG(10 + I) = XINCR(I)
            TTARG(15 + I) = YB(I)
            TTARG(20 + I) = YE(I)
            TTARG(25 + I) = YINCR(I)
            TTARG(30 + I) = AMUG(I)
            NTARG(I)      = NBX(I)
            NTARG(5 + I) = NBY(I)
```

```
FORTRAN IV G1  RELEASE 2.0            IDOUT            DATE = 83073          21/40/29            PAGE 0002
        603 CONTINUE
            WRITE(W,930) HEAD,GHED,CHED
            WRITE(W,6001)
       6001 FORMAT(//1H ,26X,25HTERRAIN TABLE ARGUMENTS        )
            WRITE(W,6002)     (TTARG(I),I=1,5),
           1                  (TTARG(I),I=6,10),
           2                  (TTARG(I),I=11,14),ZERO,
           3                  (TTARG(I),I=16,20),
           4                  (TTARG(I),I=21,25),
           5                  (TTARG(I),I=26,29),ZERO,
           6                  (NTARG(I),I=1,5),
           7                  (NTARG(I),I=6,10),
           8                  (TTARG(I),I=31,35),
           9                  NZTAB
       6002 FORMAT(1H0,25X,11H XB(BEGIN)=,5F12.3,7H INCHES   /
           A               26X,11H XE(END)   =,5F12.3,5H    ''    /
           B               26X,11H X(INCR)   =,5F12.3,5H    ''    /
           C               26X,11H YB(BEGIN)=,5F12.3,5H    ''    /
           D               26X,11H YE(END)   =,5F12.3,5H    ''    /
           E               26X,11H Y(INCR)   =,5F12.3,5H    ''    /
           F              25X,12HNO.X BOUNDS=,I8,4I12             /
           G              25X,12HNO.Y BOUNDS=,I8,4I12             /
           H               26X,11H AMUG      =,5F12.3             /
           I               25X,18HNO.TERRAIN TABLES=,I4           )
            IF(NZ5.EQ.0) GO TO 600
            WRITE(W,930) HEAD,GHEAD
            NX5 = NX(NZTAB)
            NY5 = NY(NZTAB)
            WRITE(W,6004) NX5, (XXZGP5(I),I=1,NX5)
       6004 FORMAT(66H0 ARGUMENTS FOR TERRAIN TABLE WITH VARYING INCREMENTS (L
           1AST TABLE) /10H NO.OF X =, I3,2X,9H, X(ZGP)=, 12F9.3/24X,9F9.3)
            WRITE(W,6003) NY5, (YYZGP5(I),I=1,NY5)
       6003 FORMAT(10H0NO.OF Y =, I3,2X,9H, Y(ZGP)=,12F9.3/24X, 9F9.3)
      C
        600 IF(NZTAB) 604,700,604
        604 WRITE(W,930) HEAD,GHED,CHED
            LINES =3
            DO 614 I=1,NZTAB
            NNBX = NBX(I)
            NNBY = NBY(I)
            NNX = NX(I)
            NNY = NY(I)
            LINES = LINES + 9 + (NNY+1)*(NNX/7 + 2)
            IF(I.EQ.1) GO TO 606
            IF(LINES .LT.55) GO TO 606
            WRITE(W,930) HEAD,GHED,CHED
            LINES =3
        606 WRITE(W,6005) I,AMUG(I),(XBDRY(J,I),J=1,NNBX)
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

FORTRAN IV G1 RELEASE 2.0 IDOUT DATE = 83073 21/40/29 PAGE 0003

```
      6005 FORMAT(19HO TERRAIN TABLE NO. ,I3,  20X, 6H AMUG=, F13.5//
          X 1X,16H  X  BOUNDARIES=,8F13.5)
           WRITE(W,6006) (PSBDRO(J,I),J=1,NNBX)
      6006 FORMAT(1X,16H PSI BOUNDARIES=,8F13.5)
           IF(IERABX.EQ.0) GO TO 9003
           WRITE(W,9000) (XBERO(J,I),J=1,NNBX)
      9000 FORMAT(1X,16H  XRANGE : XMIN=,8F13.5)
           WRITE(W,9001) (XEERO(J,I),J=1,NNBX)
      9001 FORMAT(1X,11X,5HXMAX=,8F13.5)
      9003 IF(IERABY.EQ.0) GO TO 9006
           WRITE(W,9004) (YBERO(J,I),J=1,NNBX)
      9004 FORMAT(1X,16H  YRANGE : YMIN=,8F13.5)
           WRITE(W,9005) (YEERO(J,I),J=1,NNBX)
      9005 FORMAT(1X,11X,5HYMAX=,8F13.5)
      9006 CONTINUE
           WRITE(W,6007) (YBDRY(J,I),J=1,NNBY)
      6007 FORMAT(1X,16H  Y  BOUNDARIES=,2F13.5)
           IF( I.EQ.NZTAB .AND. NZ5.NE.0) GO TO 607
           ANAME = CON1
           Y= XB(I)
           YYY = XINCR(I)
           DO 605 J=1,NNX
           TXARG(J) = Y
           Y = Y + YYY
       605 CONTINUE
           Y = YB(I)
           YYY = YINCR(I)
           DO 609 J=1,NNY
           TYARG(J) = Y
           Y = Y + YYY
       609 CONTINUE
           GO TO 610
       607 ANAME = VARI
           DO 611 J=1,NNX
       611 TXARG(J) = XXZGP5(J)
           DO 612 J=1,NNY
       612 TYARG(J) = YYZGP5(J)
       610 WRITE(W,6008)ANAME,(TXARG(J),J=1,NNX)
      6008 FORMAT(1HO,A4,17H. INCREMENTS   X=,2X,7F13.5/26X,7F13.5/28X,7F13.5
          X )
           DO 613 II=1,NNY
           WRITE(W,6009) TYARG(II),(ZGP(JJ,II,I),JJ=1,NNX)
      6009 FORMAT(/2X,3H Y=,F13.5, 6X,7F13.5/26X,7F13.5/28X,7F13.5)
       613 CONTINUE
       614 CONTINUE
     C
     C
     C***   CONVERT PSBDRO TO RADIANS
```

FORTRAN IV G1 RELEASE 2.0 IDOUT DATE = 83073 21/40/29 PAGE 0004

```
           DO 800 I=1,5
           DO 800 J=1,8
       800 PSBDRO(J,I) = PSBDRO(J,I) * RAD
       700 IF(ISTEER.LT.0) CALL PTHOUT
           RETURN
           END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
                C
                C
0001                  SUBROUTINE PTHOUT
                C
                C
0002                  COMMON/PAGE/NP,HEAD(20),R,W
0003                  INTEGER R,W
0004                  COMMON/HVROAD/GHED(20),NZTAB,XB(5),XE(5),XINCR(5),
                     1        YB(5),YE(5),YINCR(5),NZ5,NX(5),NY(5),
                     2        XBERO(8,5),XEERO(8,5),YBERO(8,5),YEERO(8,5),IERABX,IERABY,
                     3        NBX(5),NBY(5),XBDRY(8,5),PSBDRO(8,5),YBDRY(2,5),
                     4        ZGP(21,21,5),YYZGP5(21),XXZGP5(21)
0005                  COMMON/PATHD/IPATH,KLI,DI(10),RLI(10),NPTS,XINIT,YINIT,
                     1        PSA,DELL,X(100),Y(100),DX(100),DY(100),D(100),CHED(20)
0006                  COMMON/WAGON/IWAGN,TPRB,DPRB,PLGTH,PMIN,PMAX,PGAIN,QGAIN,PSIFD,
                     1                 ITDOPT,TDPSI,TMAX
0007                  COMMON/FILT/ IFILT,TIL,TI,TMT,TAUF
0008                  DIMENSION DIO(10),XO(100),YO(100),DXO(100),DYO(100),DO(100)
0009                  PSAO = PSA*57.2958
0010                  WRITE(W,930) HEAD,GHED,CHED
0011              930 FORMAT('1',2X,'HSRI/MVMA BRAKING AND HANDLING SIMULATION OF',
                     1       ' TRUCKS, TRACTOR-SEMITRAILORS, DOUBLES, AND TRIPLES - PHASE
                     2 4.'/' ',36X,20A4/
                     31H0,2X,' OPTIONAL INPUTS ADDED 9/82 BY KCI :',20A4/
                     41H ,38X,20A4/)
0012                  DO 10 I = 1,KLI
0013               10 DIO(I) = DI(I)*12.0
0014                  WRITE(6,1010) IPATH,KLI,NPTS,DELL,XINIT,YINIT,PSAO
0015             1010 FORMAT(
                     A1H0,9X,16HPATH DESCRIPTORS,18X,8HIPATH  =,6X,I1/
                     B1H ,10X,26HNUMBER OF PATH DESCRIPTORS,7X,8HKLI     =,5X,I2/
                     C1H ,10X,24HNUMBER OF POINTS ON PATH,9X,8HNPTS    =,4X,I3/
                     D1H ,10X,23HDISTANCE BETWEEN POINTS,10X,8HDELL    =,3X,F8.3,
                     E7H INCHES/1H ,10X,31HCOORDINATES OF 1ST PATH POINTS:,2X,
                     F8HXINIT  =,4X,F8.3,7H INCHES/
                     G1H ,43X,8HYINIT  =,2X,F8.3,7H INCHES/1H ,10X,
                     H23HINITIAL ROADWAY HEADING,10X,8HPSA     =,3X,F7.2,9H  DEGREES/)
0016                  WRITE(6,1017)
0017             1017   FORMAT(1H0,9X,27HPATH CURVATURE DESCRIPTORS:    //)
0018                  DO 1015 I = 1,KLI
0019                  DI(I) = DI(I) * 12.0
0020             1015 WRITE(6,1020)I, DI(I),I,RLI(I)
0021             1020 FORMAT(
                     A1H ,10X,19HDEGREE OF CURVATURE,9X,'DI(',I1,')  =',3X,F8.4,
                     B8H DEGREES/
                     C1H ,10X,19HDISTANCE ALONG PATH,9X,'RLI(',I1,') =',
                     D3X,F8.2,7H INCHES//)
0022                  IF(ITDOPT.EQ.1) GO TO 1035
0023                  WRITE(6,1030) IWAGN,TPRB,DPRB,PLGTH,PMIN,PMAX,PGAIN,QGAIN,PSIFD
0024             1030 FORMAT(
                     A1H0,9X,30HWAGON TONGUE STEER DESCRIPTORS,4X,8HIWAGN  =,6X,I1/
                     B1H ,10X,25HINITIAL PROBE SAMPLE TIME,8X,8HTPRB    =,3X,F8.3,
                     C8H SECONDS/1H ,10X,30HTIME INCREMENT BETWEEN SAMPLES,3X,
                     D8HDPRB    =,3X,F8.3,8H SECONDS/1H ,10X,15HLENGTH OF PROBE,
                     E18X,8HPLGTH  =,3X,F7.2,8H  INCHES/1H ,10X,
                     F24HMINIMUM ACCEPTABLE ERROR,9X,8HPMIN    =,3X,F8.2,8H  INCHES/
                     G1H ,10X,29HMAXIMUM OCCUPANT ACCELERATION,4X,8HPMAX    =,3X,
                     HF8.3,8H G-UNITS/1H ,10X,23HSTEER CORRECTION FACTOR,10X,8HPGAIN  =,
                     I3X,F8.7,8H RAD/IN /
                     J1H ,10X,31HSTEER CORRECTION DAMPING FACTOR,2X,8HQGAIN  =,3X,F8.7,
                     K11H RAD-SEC/IN/1H ,10X,27HMAXIMUM STEERING WHEEL RATE,6X,
                     L8HPSIFD  =,3X,F8.3,8H DEG/SEC //)
0025                  GO TO 1045
0026             1035 WRITE(6,1036) IWAGN,ITDOPT,TPRB,DPRB,PLGTH,PMIN,PMAX,PGAIN,QGAIN,
                     1                              TMAX,PSIFD
0027             1036 FORMAT(
                     A1H0,9X,30HWAGON TONGUE STEER DESCRIPTORS,4X,8HIWAGN  =,6X,I1/
                     Q1H ,10X,29HTORQUE OPTION USED             ,4X,8HITDOPT =,6X,I1/
                     B1H ,10X,25HINITIAL PROBE SAMPLE TIME,8X,8HTPRB    =,3X,F8.3,
                     C8H SECONDS/1H ,10X,30HTIME INCREMENT BETWEEN SAMPLES,3X,
                     D8HDPRB    =,3X,F8.3,8H SECONDS/1H ,10X,15HLENGTH OF PROBE,
                     E18X,8HPLGTH  =,3X,F7.2,8H  INCHES/1H ,10X,
                     F24HMINIMUM ACCEPTABLE ERROR,9X,8HPMIN    =,3X,F8.2,8H  INCHES/
                     G1H ,10X,29HMAXIMUM OCCUPANT ACCELERATION,4X,8HPMAX    =,3X,
                     HF8.3,8H G-UNITS/1H ,10X,24HTORQUE CORRECTION FACTOR,9X,8HKTQR1  =
                     I,3X,F8.2,12H LB-IN/INCH /
                     J1H ,10X,32HTORQUE CORRECTION DAMPING FACTOR,1X,8HKTQR2  =,3X,F8.2,
                     K15H LB-INCH-SEC/IN/1H ,10X,33HMAXIMUM FRONT  STEER TORQUE       ,
                     L8HTMAX    =,3X,F8.3,8H DEG/SEC / 1H ,10X,
                     M29HINITIAL TORQUE               ,4X,8HTDPSIO =,3X,F8.2,6H LB-IN//)
0028             1045  WRITE(6,1040) IFILT,TIL,TI,TAUF
0029             1040  FORMAT(1H0,
                     A9X,18HFILTER DESCRIPTORS,16X,8HIFILT  =,6X,I1/
                     B1H ,10X,18HTIME LAG OF FILTER,15X,8HTIL     =,3X,F8.6,8H SECONDS/
                     C1H ,10X,19HTIME LEAD OF FILTER,14X,8HTI      =,3X,F8.6,8H SECONDS/
                     D1H ,10X,20HTIME DELAY OF FILTER,13X,8HTAUF    =,3X,F8.6,
                     E8H SECONDS /)
0030                  DO 20 N=1,NPTS
0031                  XO(N) = X(N)/12.0
0032                  YO(N) = Y(N)/12.0
0033                  DXO(N) = ARCOS(DX(N)) * 57.29578
0034                  DYO(N) = ARSIN(DY(N)) * 57.29578
0035             20   DO(N) = D(N)*12.0
0036                  WRITE(W,930) HEAD,GHED,CHED
0037                  WRITE(6,1050)
0038             1050 FORMAT(1H0,13X,16HPATH COORDINATES,7X,15HTANGENT VECTORS,4X,
                     A9HDEGREE OF/1H ,56X,9HCURVATURE/
                     B1H ,4H   N,9X,4HX(N),7X,4HY(N),6X,5HDX(N),5X,5HDY(N),7X,4HD(N)/
                     C1H ,4X,2(8X,4H(FT)),2X,2(5X,5H(DEG)),7X,5H(DEG)/)
0039                  JJ = NPTS
0040                  IF(JJ.GT.50) JJ = 50
0041                  DO 1055 I = 1,JJ
0042             1055 WRITE(6,1060) I,XO(I),YO(I),DXO(I),DYO(I),DO(I)
0043             1060 FORMAT(1H ,1X,I3,4X,5(2X,F9.3))
0044                  IF(NPTS.LE.50) RETURN
0045                  WRITE(W,930) HEAD,GHED,CHED
0046                  WRITE(6,1050)
0047                  DO 1065 I = 51,NPTS
0048             1065 WRITE(6,1060) I,XO(I),YO(I),DXO(I),DYO(I),DO(I)
0049                  RETURN
0050                  END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
FORTRAN IV G1  RELEASE 2.0                            DATE = 83074        08/52/02          PAGE 0001

                  C
0001                     SUBROUTINE DRIVE1
                  C
                  C
0002                     ENTRY DRIVER(T,VAR,PSI)
                  C
                  C      SUBROUTINE DRIVER INSTALLED IN HSRI/MVMA PHASE4 PROGRAM
                  C      BY MCHENRY CONSULTANTS, INC
                  C      UNDER SUBCONTRACT WITH JACK E. LEISCH & ASSOC.
                  C      PER CONTRACT NO. DOT-FH-11-9575
                  C      NEW CALLING ARGUMENTS:
                  C          T = CURRENT TIME
                  C        VAR = 5 MEMBER ARRAY:
                  C                              VAR(1) = Y
                  C                              VAR(2) = YDOT
                  C                              VAR(3) = PSIDOT
                  C                              VAR(4) = VEHICLE HEADING ANGLE
                  C                              VAR(5) = X
                  C        PSI = FRONT WHEEL STEER ANGLE RETURNED BY DRIVER
                  C
0003                     DIMENSION PPD(50),TPD(50),VAR(5)
0004                     COMMON/PATHD/IPATH,KLI,DI(10),RLI(10),NPTS,XINIT,YINIT,
                        1        PSA,DELL,X(100),Y(100),DX(100),DY(100),D(100),CHED(20)
0005                     COMMON/WAGON/IWAGN,TPRB,DPRB,PLGTH,PMIN,PMAX,PGAIN,QGAIN,PSIFD,
                        1                  ITDOPT,TDPSI,TMAX
0006                     COMMON/FILT/ IFILT,TIL  ,TI   ,TMT   ,TAUF
0007                     COMMON/ACC/ ACLONG(4),ACLAT(4),CMFA1(4)
0008                     DATA NPDMAX/50/,NPD/0/,DPSL/0.0/,N/0/
0009                     DATA DISTA/0.0/,RAD/0.01745392/,FT/12.0/
0010                     DATA OMGPS/.4363/,DT/0.005/,TPRNT/0.0/,IFLAG/0/
0011                     IF(IWAGN.EQ.0)GO TO 90
0012                     IFLAG = 0
0013                     PSIA = PSI
0014                     DTP  = DPRB
0015                     DPS  = 0.0
0016                     DPSI = 0.0
0017                     DDIST= 0.0
                  C*       CHECK IF T > TLAST
0018                     IF(T.LT.TLAST) RETURN
                  C        CALCULATE CURRENT TIME INCREMENT
0019                     IF(T-TLAST.GT.0) DT = T-TLAST
0020                     TLAST = T
                  C        CHECK FOR PRINT INTERVAL HERE
0021                     IF(T.LT.TPRNT) GO TO 1
0022                     IFLAG = 1
0023                     TPRNT = TPRNT + 0.010
                  C*       CHECK IF THIS IS A SAMPLE TIME OF FILTER APPLICATION
0024                   1 IF(TPRB.GT.T + 0.0005)GO TO 10
```

```
FORTRAN IV G1  RELEASE 2.0           DRIVE1           DATE = 83074        08/52/02          PAGE 0002

                  C*
                  C*       COMPUTE NEW CHANGE IN STEER ANGLE
                  C*
                  C*
0025                     TPRB  = TPRB + DPRB
0026                     XP = VAR(5) + COS(VAR(4))*PLGTH
0027                     YP = VAR(1) + SIN(VAR(4))*PLGTH
0028                     CALL PROBE(XP,YP,NPTS,X,Y,DX,DY,D,IPRB,DIST,XX,YY)
                  C*
                  C*       SELECTED POINT INDEX: IPRB
                  C*       LOCATION  OF CLOSEST POINT ON PATH : XX,YY
                  C*       NOT CURRENTLY USED
                  C*
0029                     IF(DIST.EQ.0.0)GO TO 8
0030                     SGND=DIST/ABS(DIST)
0031                     DDIST = (DIST-DISTA)/DPRB
0032               9     IF(ABS(DIST).GT.PMIN)DPS = -PGAIN*(ABS(DIST)-PMIN)*SGND
                        1                             -QGAIN*DDIST
0033               8     IF(ABS(DIST).LE.PMIN) DPS= -QGAIN*DDIST
0034                     DISTA = DIST
0035                     IF(IFILT.EQ.0)GO TO 55
0036                     IF(NPD.EQ.NPDMAX)GO TO 10
0037                     NPD = NPD + 1
0038                     PPD(NPD) = DPS - PSIA
0039                     TPD(NPD) = T + TAUF
0040                  10 IF(IFILT.EQ.0)GO TO 55
                  C*
                  C*       NUERO-MUSCULAR FILTER
                  C*
0041                     IF(NPD.EQ.NPDMAX) GO TO 10
0042                     TPDTMP = TPD(N)
0043                     DO 20 NN = 1,NPD
0044                     N = NPD + 1 - NN
0045                     IF(T.GE.TPD(N))GO TO 30
0046                  20 CONTINUE
0047                     GO TO 50
0048                30   IF(TPDTMP.LT.TPD(N)) DPSL = 0.0
0049                     DPSI = PPD(N)*TMT*EXP(-(T - TPD(N))/TIL)/TIL
0050                     DPSN = PPD(N) - TIL*DPSI
0051                     DTP  = 0.0
0052                     DPS  = DPSN - DPSL
0053                     DPSL = DPSN
0054                     IF(NPD.EQ.1)GO TO 50
                  C
                  C
0055               35    L    = 1
0056                     DO 40 NN = N,NPD
0057                     PPD(L) = PPD(NN)
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
      TPD(L) = TPD(NN)
   40 L = L + 1
      NPD = L - 1
C
   50 PSI = PSIA + DPS
      GO TO 58
   55 PSI = DPS
   58 CONTINUE
C*
C*     CHECK PREVIOUS TIME INTERVAL COMFORT FACTOR
C*     IF GREATER THAN PMAX, ALLOW ONLY REDUCTION IN STEER ANGLE
C*     IF TORQUE OPTION, ONLY ALLOW A REDUCTION OF TORQUE
C*
   65 IF((PMAX.GT.0.0).AND.(ABS(CMFA1(1)).LT.PMAX))GO TO 60
      IF(ABS(PSI).GT.ABS(PSIA)) PSI=PSIA
   60 CONTINUE
C*
C*     CHECK MAX STEER ANGLE
C*
      IF((OMGPS.GT.0.0).AND.(ABS(PSI) .GT.  OMGPS))
     1    PSI = SIGN(OMGPS,PSI)
C*
C*     CHECK STEER VELOCITY
C*
      IF(T.NE.0.0) DPSI = (PSI-PSIA)/DT
      IF(DPSI.GT.PSIFD*RAD) PSI=PSIA + PSIFD*RAD*DT
 75   DPSO = DPS/RAD
      PSIAO = PSIA/RAD
      PSIO = PSI/RAD
      DELPSI = PSIO- PSIAO
      XPFT = XP/FT
      YPFT = YP/FT
      XXFT = XX/FT
      YYFT = YY/FT
      XP = VAR(5)
      YP = VAR(1)
      CALL CGERR(XP,YP,NPTS,X,Y,DX,DY,D,IPRB,DIST2,XX,YY)
      RLO = SQRT((XP-XINIT)**2 + (YP-YINIT)**2) / 12.0
      IF(KPAGE.LE.50.AND.T.NE.0.0000) GO TO 110
      WRITE(50,100)
  100 FORMAT(
     A1H1,'HVOSM VEHICLE PATH-FOLLOWING:SUBROUTINE DRIVER',
     B' DIAGNOSTIC DUMP, ROUTINE INSTALLED IN PHASE4 1/83'/
     C1H0,33X,37HPROBE COORDINATES     PATH COORDINATES,5X,
     D'CG-ERROR',3X,'CG DISTANCE',4X,'COMFORT'/
     E31H  TIME      DELTA PSIF     ERROR ,6X,1HX,9X,1HY,10X,1HX,8X,1HY,
     F8X,'DIST',8X,'ALONG PATH',4X,'FACTOR'/
     G31H  (SEC)       (DEG)        (IN)  ,4X,4H(FT),6X,4H(FT),7X,
```

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```
     H4H(FT),5X,4H(FT),7X,'(IN)',12X,'(FT)',6X,'(G-UNITS)'/)
      KPAGE = 0
  110 IF(IFLAG.NE.1) GO TO 90
      WRITE(50,120) T,DELPSI,DIST,XPFT,YPFT,XXFT,YYFT,DIST2,RLO,
     1               CMFA1(1)
  120 FORMAT(1H ,F7.3,2(4X,F7.3),2(3X,F7.1),2X,2(2X,F7.1),
     A            5X,F7.2,8X,F7.1,5X,F8.3)
      KPAGE = KPAGE + 1
      GO TO 90
   90 RETURN
      ENTRY DRIVE2(VEL)
      PSI = 0.0
      DISTA = 0.0
      TLAST = -1.0
      RETURN
      END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

FORTRAN IV G1 RELEASE 2.0 PROBE DATE = 83073 21/40/29 PAGE 0001

```
      SUBROUTINE PROBE(XP,YP,M,X,Y,DX,DY,D,I,DIST,XX,YY)
C
C
C***   PATHF   MC1   ***************************************************
C***   PROBE CALLED FROM DRIVER TO FIND ERROR OF PROBE FROM PATH        **
C***                                                                    **
C
      DIMENSION X(1),Y(1),DX(1),DY(1),D(1)
      DATA RAD/0.01745329251994329G/,ILAST/1/
C INITIALIZE
      I    = ILAST
      TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
      TSAV = SIGN(1.0,TEST)
      GO TO 15
C
C START SEARCH
C
    7 I = I + 1
      IF(I.LE.M)GO TO 10
      IF(TSAV.LT.0.0)GO TO 20
      I = M
      GO TO 25
   10 TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
      IF(TEST*TSAV.LE.0.0)GO TO 25
   15 IF(TEST)20,25,7
   20 I = I - 1
      IF(I.GE.1)GO TO 10
      IF(TSAV.GT.0.0)GO TO 7
      I = 1
C
C FINISH SEARCH
   25 IF((TEST.LT.0.0).AND.(I.GT.1))I=I-1
      ILAST = I
C FINISH OF DETERMINATION OF I
C
C
C
C
CALCULATE DISTANCE
      ZDN  = -DY(I)*(XP-X(I))+DX(I)*(YP-Y(I))
      CONS = D(I)*RAD*0.005
      ZDZ  = ((XP-X(I))**2+(YP-Y(I))**2)*CONS
      DIST = (ZDN-ZDZ)/(0.5+SQRT(0.25-CONS*(ZDN-ZDZ)))
C
CALCULATE POSITION OF CLOSEST APPROACH POINT ON ARC
C THE FOLLOWING CODE MAY BE DELETED AND THE REFERENCES TO XX AND YY TAKE
C OUT OF THE CALL IF THE POINT OF CLOSEST APPROACH ON THE ARC IS NOT NEE
C
```

FORTRAN IV G1 RELEASE 2.0 PROBE DATE = 83073 21/40/29 PAGE 0002

```
      DEN = 1.0-2.0*DIST*CONS
C
      IF(DEN.GT.0.0)GO TO 30
      WRITE(6,26)I,XP,YP,DIST,DEN
   26 FORMAT(' SUBROUTINE PROBE HAS NEGATIVE OR ZERO DENOMINATOR'/
     X' IN POSITION FORMULA: IMPLIES POINT NOT IN SECTOR'/I6,4F10.4)
      STOP
C THIS STOP SHOULD NEVER OCCUR IN NORMAL USAGE
C
   30 XX = (XP-X(I)+DIST*DY(I))/DEN + X(I)
      YY = (YP-Y(I)-DIST*DX(I))/DEN + Y(I)
   35 RETURN
C*********************************************************************
      END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)

```
FORTRAN IV G1  RELEASE 2.0                                DATE = 83073        21/40/29           PAGE 0001
                C
                C
                C
                C
0001                  SUBROUTINE CGERR(XP,YP,M,X,Y,DX,DY,D,I,DIST,XX,YY)
                C
                C
                C
                C***   ITDOPT   MCI   *****************************************************
                C*     CGERR SAME AS PROBE XCEPT CALCULATES ERROR OF CG                     **
                C*                                                                          **
                C
0002                  DIMENSION X(1),Y(1),DX(1),DY(1),D(1)
0003                  DATA RAD/0.01745329251994329 6/,ILAST/1/
                C INITIALIZE
0004                  I    = ILAST
0005                  TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
0006                  TSAV = SIGN(1.0,TEST)
0007                  GO TO 15
                C
                C START SEARCH
                C
0008                7 I = I + 1
0009                  IF(I.LE.M)GO TO 10
0010                  IF(TSAV.LT.0.0)GO TO 20
0011                  I = M
0012                  GO TO 25
0013               10 TEST = DX(I)*(XP-X(I))+DY(I)*(YP-Y(I))
0014                  IF(TEST*TSAV.LE.0.0)GO TO 25
0015               15 IF(TEST)20,25,7
0016               20 I = I - 1
0017                  IF(I.GE.1)GO TO 10
0018                  IF(TSAV.GT.0.0)GO TO 7
0019                  I = 1
                C
                C FINISH SEARCH
0020               25 IF((TEST.LT.0.0).AND.(I.GT.1))I=I-1
0021                  ILAST = I
                C FINISH OF DETERMINATION OF I
                C
                C
                C
                C
                CALCULATE DISTANCE
0022                  ZDN  = -DY(I)*(XP-X(I))+DX(I)*(YP-Y(I))
0023                  CONS = D(I)*RAD*0.005
0024                  ZDZ  = ((XP-X(I))**2+(YP-Y(I))**2)*CONS
0025                  DIST = (ZDN-ZDZ)/(0.5+SQRT(0.25-CONS*(ZDN-ZDZ)))
```

```
FORTRAN IV G1  RELEASE 2.0          CGERR          DATE = 83073        21/40/29           PAGE 0002
                C
                CALCULATE POSITION OF CLOSEST APPROACH POINT ON ARC
                C THE FOLLOWING CODE MAY BE DELETED AND THE REFERENCES TO XX AND YY TAKE
                C OUT OF THE CALL IF THE POINT OF CLOSEST APPROACH ON THE ARC IS NOT NEE
                C
0026                  DEN = 1.0-2.0*DIST*CONS
                C
0027                  IF(DEN.GT.0.0)GO TO 30
0028                  WRITE(6,26)I,XP,YP,DIST,DEN
0029               26 FORMAT(' SUBROUTINE PROBE HAS NEGATIVE OR ZERO DENOMINATOR'/
                     X' IN POSITION FORMULA: IMPLIES POINT NOT IN SECTOR'/I6,4F10.4)
0030                  STOP
                C THIS STOP SHOULD NEVER OCCUR IN NORMAL USAGE
                C
0031               30 XX = (XP-X(I)+DIST*DY(I))/DEN + X(I)
0032                  YY = (YP-Y(I)-DIST*DX(I))/DEN + Y(I)
0033               35 RETURN
0034                  END
```

Figure 8. NEW AND MODIFIED ROUTINES FOR HSRI / MVM PHASE 4 MODEL (continued)