CHRYSLER / UMTRI

WIND-STEER VEHICLE SIMULATION

User's Manual

Version 1.0

(Volume I of II)

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16. Abstract
The Wind-Steer model is a time-based simulation of the handling performance of a passenger car in response to steer inputs from a driver and external wind conditions. The simulation includes the aerodynamic properties of the vehicle, a closed-loop driver model, and vehicle chassis characteristics.

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Notice

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1. GENERAL INFORMATION

1.1 Introduction

This document is the User's Manual for Version 1.0 of the Chrysler/UMTRI Wind-Steer model. It explains how to use the software. A separate Reference Manual (Volume II) accompanies this document and contains more detailed background material defining the equations and computer codes used by the program. Volume II should be consulted when modifying the program.

The Wind-Steer model is a time-based simulation of the handling performance of a passenger car in response to steer inputs from the driver and external wind conditions. In addition to the vehicle simulation software, post-processing software is also available for viewing and analyzing the output responses predicted by the model.

The model and simulation code were originally developed by Mr. Yoram Guy and L. Segel of the Engineering Research Division (ERD) at UMTRI in 1986 and 1987. Subsequent additions and modifications have been performed by M. Sayers and C. MacAdam (also at UMTRI) during 1987 through 1989.

The purpose of the Wind-Steer program is to calculate the time-domain response of a vehicle subject to steering and/or external wind forces. The simulated system also includes a driver model, so that the computed response to a crosswind input can include both vehicle and driver effects. Use of the program is analogous to conducting "vehicle tests" on the computer. As shown conceptually in Figure 1, data from the simulation are interpreted identically as data that would be measured on a test track. In both cases, data are put into a standard type of computer file used at UMTRI, called the "ERD file." (With the simulation approach, most of the signal conditioning activity indicated in the figure is not required.)

1.2 Computer Requirements

The computer code is written completely in Fortran 77 and can be run with minor modifications on most computers that have Fortran 77 compilers. The simulation has been run on the following systems:

- the IBM PC®, XT®, or AT® with 640K memory and a floating-point coprocessor. The program was compiled with version 4.0 of the Microsoft® Fortran 77 Optimizing Compiler.
- the Apple Macintosh® plus, Mac II, and Mac IIcx. The program is compiled using version 2.3 or 2.4 of the Absoft® MacFortran/020 © compiler, or version 2.2 of the Microsoft Fortran compiler for the Macintosh.
- the mainframe computer of the Michigan Terminal System (MTS) at The University of Michigan. (The compiler on MTS is called *FORTRANVS.)

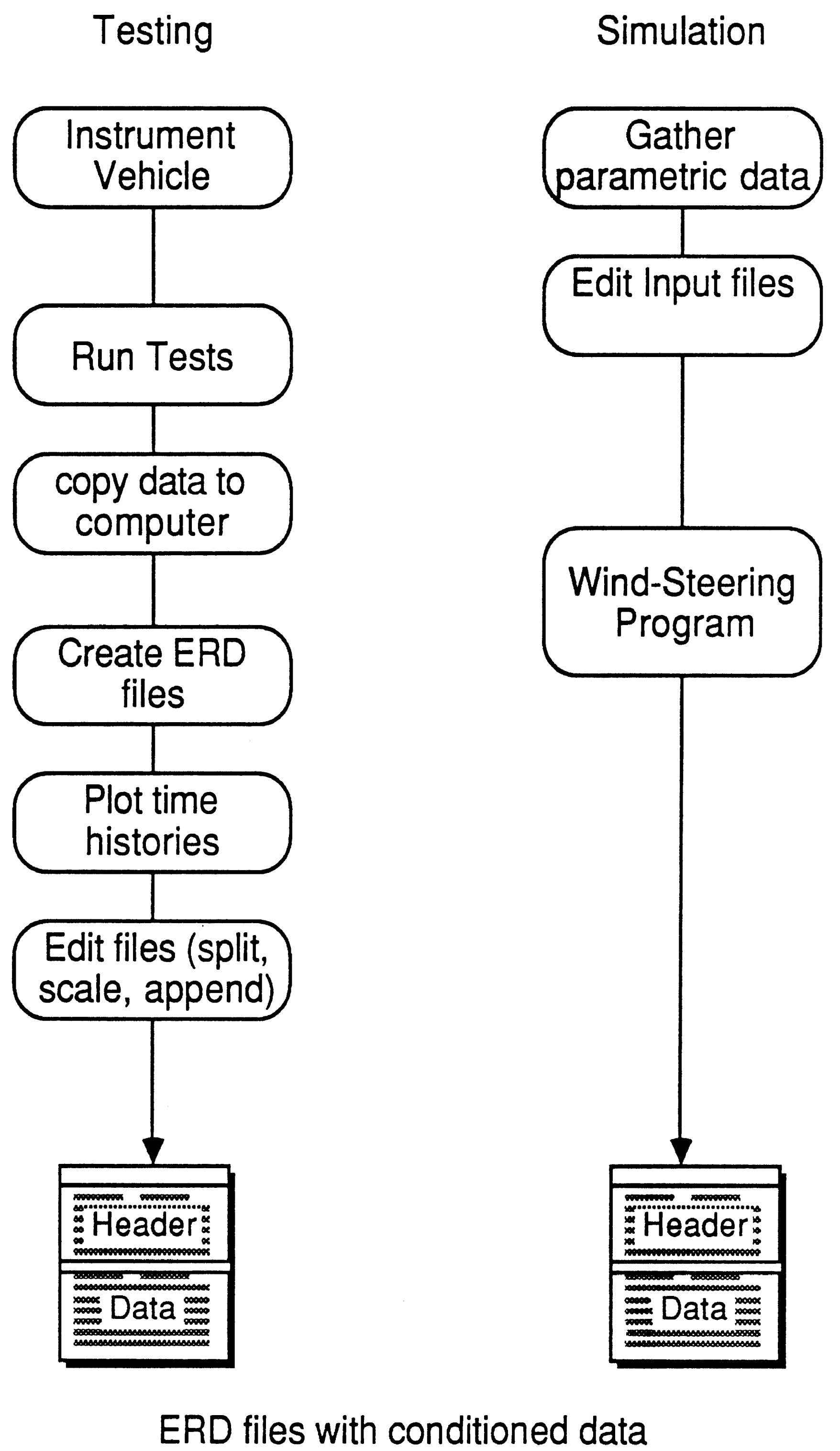


Figure 1. Generating ERD data files for measured and predicted response data.

The outputs from the program can be viewed using UMTRI software for plotting on the Macintosh or MTS. Also, spectral analysis software is available. The UMTRI analysis software has not been converted to run on the IBM PC. However, the files produced by the Wind-Steer program have a simple structure that facilitates conversion to other file formats for compatibility with other software. Also, Appendix C of the Reference Manual (Volume II) describes how the output file format can be modified to meet arbitrary requirements.

1.3 Operation of the Software

The Wind-Steer program is primarily a batch processing program. Three input file names are requested from the user.

input file name — This file must already exist. It contains the input to the program as a list of parameters describing vehicle properties and the simulation maneuver (see Section 3).

echo file name — This file is optional. If a name is entered, a file is created by the program and contains a formatted echo of the entered data. If no name is entered, then no echo file is created.

output file name — This file is required. Two forms of output are possible—binary and text (see Section 4). If the text form is chosen, there is only a single output file. If the binary form is chosen **and** the computer is a Macintosh or IBM PC, a second output file is used for the binary data with ".BIN" appended to the *output file name* as: *output file name*.BIN.

In order to use the program, a text editor is needed to view and edit the input file. Software is also needed to view the output from the program in graphical form. A "user-friendly" plotter is available from UMTRI for the Macintosh that allows viewing of time histories and creation of hard copies (see Section 4). An optional 3-D animation program for the Macintosh can also be used to view results of the simulation in the form of computer videos.

2. THE VEHICLE MODEL

The vehicle is modelled as a rigid body that is free to pitch, roll, and yaw, and translate laterally and vertically. The forward speed is constant. Movements of the four wheels are treated quasi-statically by considering the compliance of the suspensions and tires. Altogether, the vehicle has five dynamic degrees of freedom and is essentially an extension of Segel's original three degree of freedom model [1] which included yaw, roll, and lateral translation. A dynamic steering system option adds a sixth degree of freedom.

Figure 2 shows a block diagram of the Wind-Steer model in its present form. The blocks for the driver model and the steering-system dynamics are both optional, and can be bypassed when desired.

Open-loop control inputs to the model are specified in terms of steering angle, δ_H, or torque, T_{SW}. Alternatively, path inputs may be specified for path following maneuvers using a closed-loop driver model. A crosswind aerodynamic disturbance from a laterally directed air stream of arbitrary magnitude is included as the "disturbance" input, V_{wind}. Vehicle motions are computed as the response to forces and moments generated by the tires and the air stream acting on the vehicle body.

2.1 Vehicle Dynamics and Kinematics

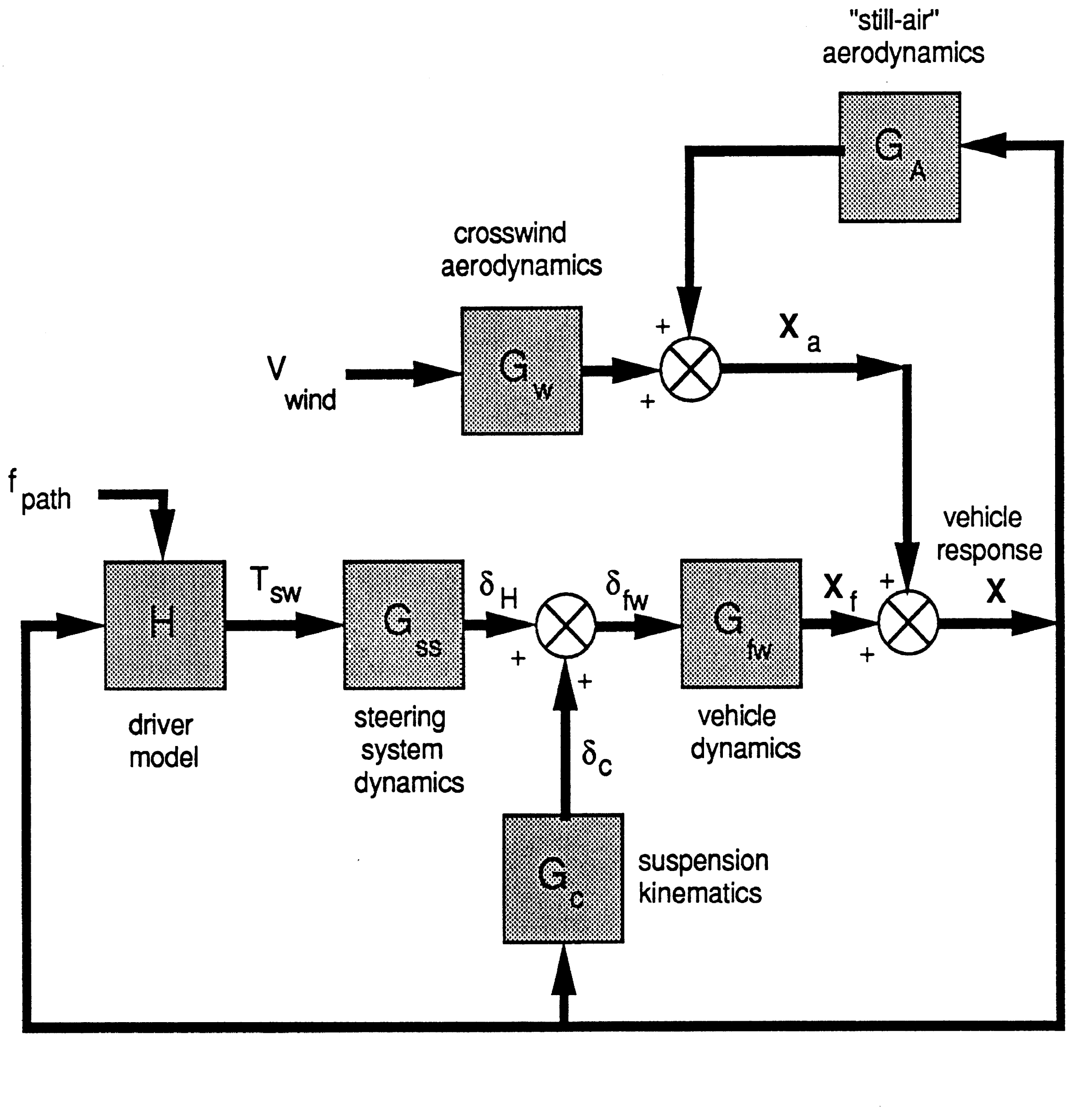
The vehicle model is intended to accurately predict handling behavior for moderate levels of cornering (less than 0.3 g's) and frequencies less than 5 Hz. Higher frequency dynamics which involve unsprung mass motions are not included in the model.

Even though the unsprung masses do not have dynamical degrees of freedom, the equations of motion nonetheless account for the distribution of mass and rotational inertia between the sprung and unsprung masses. In bounce, pitch, and roll, the sprung and unsprung masses are coupled through the compliant suspension elements. In yaw and lateral translation, they are coupled through suspension elements that are essentially rigid. Thus, the force and moment balances for yaw and lateral acceleration involve the mass and rotational inertia of the *entire* vehicle. The force and moment balances for bounce, pitch, and roll involve the mass and rotational inertia of *only* the sprung mass.

The vibrational characteristics of the unsprung masses are absent from the model because they involve frequencies (typically 10 — 15 Hz) well above the bandwidth of interest for steering response. Forces and moments acting on the body through the suspensions depend on the suspension deflections. The model predicts suspension deflections by using a quasi-static force balance between the tire vertical force and the vertical suspension force. That is, vertical tire forces predicted by the models are determined solely by the motions of the sprung mass.

The dynamics of the steering system are also included as an option. When selected, the input to the steering system is a *torque* acting on the steering wheel. The steering wheel

Figure 2. Wind - Steer Model — Block Diagram



torque may be specified as an open-loop time-history input, or instead, it can be calculated by the resident closed-loop driver model during path-following maneuvers.

The equations of motion for the vehicle are presented in Appendix B of the Reference Manual (Volume II). Many of the terms appearing in those equations are the result of subcomponent models, described below.

Suspension Kinematics

The kinematics of the suspensions are treated with the concept of a roll center. That is, the body rolls about an axis defined by two roll centers associated with the front and rear suspensions. The position of a roll center can be derived through an analysis of the suspension kinematics by considering instantaneous centers of rotation for the various links involved. It is often measured in the laboratory, to ensure that subtle effects of compliance in the linkages and their attachments are included.

The roll center for an independent suspension is usually located along the longitudinal centerline of the vehicle, at ground level. The roll center for a "beam" dead-axle is usually above the ground, at the center of the axle.

The positions of the roll centers are valid only for small roll perturbations of the vehicle body. For larger roll angles, the concept can be extended by considering movable roll centers. The Wind-Steer model includes this feature. The equations for the Wind-Steer model were derived assuming that the roll center is a function only of roll angle (that is, changes due to pitch angle or static trim height are assumed to be negligible). This means that the height of the sprung mass center of gravity above the roll center varies with vehicle trim height. Because the trim height is influenced by aerodynamic lift, the c.g. height is a function of speed.

The roll center position for each suspension (front and rear) is defined by a lateral distance and vertical height, relative to a line along the ground under the longitudinal centerline of the vehicle. The height is computed using a quadratic polynomial of roll angle:

$$h_{rc} = h_0 + h_1 \phi + h_2 \phi^2 \qquad (2.1\text{-}1)$$

where h_{rc} is the height of the roll center above ground, h_0 , h_1 , and h_2 are coefficients, and ϕ is the roll angle. A similar polynomial is used for lateral position:

$$y_{rc} = y_1 \phi + y_2 \phi^2 \qquad (2.1\text{-}2)$$

Note that h_0 is the nominal ($\phi = 0$) roll center height that would be used in a linear vehicle analysis, and that the nominal lateral offset is zero. (When only a value of h_0 is available, the other two coefficients should be set to zero.)

The suspension kinematics can also cause the wheels to steer and camber as a result of suspension deflection. The roll steer for each wheel is computed as:

$$\delta_K = \delta_{K1} z + \delta_{K2} z^2 \qquad (2.1\text{-}3)$$

where δ_K is the additional steer angle for a wheel due to kinematics (roll-steer), δ_{K1} and δ_{K2} are coefficients, and z is suspension deflection for that wheel. A similar polynomial is used for camber:

$$\gamma_K = \gamma_{K1}\, z + \gamma_{K2}\, z^2 \tag{2.1-4}$$

where γ_K is the additional camber angle for a wheel, and γ_{K1} and γ_{K2} are coefficients.

Compliance Effects

Steer and camber of each wheel are also affected by side force and aligning moments generated by the tires, due to compliance in the suspensions. The change in steer angle (δ_C) due to compliance is handled by linear functions of side force (F_Y) and aligning moment (M_Z):

$$\delta_C = -\delta_{CF}\, F_Y + \delta_{CM}\, M_Z \tag{2.1-5}$$

A similar equation is used for the change in camber angle due to compliance (γ_C):

$$\gamma_C = -\gamma_{CF}\, F_Y \tag{2.1-6}$$

2.2 Aerodynamic Forces and Moments

Following the convention used in wind tunnels, aerodynamic forces and moments are defined as if they act on a point at ground level, at the center of the vehicle wheelbase. The six forces and moments should be fitted to equations of the following form:

$$Q = \frac{\rho\, V_A^2}{2} \tag{2.2-1}$$

$$F_{XA} = Q\, A\, (C_D + K_D\, \beta_a^2) \tag{2.2-2}$$

$$F_{YA} = -Q\, A\, K_Y\, \beta_a \tag{2.2-3}$$

$$F_{ZA} = -Q\, A\, (C_L + K_L\, \beta_a^2) \tag{2.2-4}$$

$$M_{XA} = -Q\, A\, L\, K_R\, \beta_a \tag{2.2-5}$$

$$M_{YA} = -Q\, A\, L\, (C_M + K_M\, \beta_a^2) \tag{2.2-6}$$

$$M_{ZA} = -Q\, A\, L\, K_N\, \beta_a \tag{2.2-7}$$

where ρ is the air density, V_A is air speed relative to the vehicle, A is the frontal area, β_a is the aerodynamic slip angle, and L is wheelbase. The fitted coefficients C_D, C_L, C_M, K_D, K_Y, K_L, K_R, K_M, and K_N are the input parameters required by the model.

The Wind-Steer model automatically transforms the aerodynamic forces and moments from the ground reference point to the center of gravity of the sprung mass, where they appear in the dynamical equations of the vehicle.

The drag force (F_{XA}) does not affect the predicted motions of the vehicle, because the model does not include longitudinal accelerations due to engine and braking forces. This modeling assumption was made because changes in drag force are generally small enough that it is reasonable to expect the driver to maintain constant speed by throttle control. To check this assumption, the drag force is computed and written into the output file.

2.3 Tire Model

The pneumatic tire is modeled as providing side force (F_Y) and aligning moments (M_Z) as functions of slip angle (α), camber angle (γ), and vertical load (F_Z). The maneuvers of interest generally do not involve angles of more than a few degrees. Therefore, the forces and moments produced by the tires are computed by the linear superposition of the forces and moments due to lateral slip and camber.

Although cornering stiffness is assumed to be linear with respect to slip and camber, the model is nonlinear with respect to load. The equations used for each wheel are:

$$F_Y = C_\alpha \alpha + C_\gamma \gamma \qquad (2.3\text{-}1)$$

$$M_Z = C_{M\alpha} \alpha \qquad (2.3\text{-}2)$$

where

$$C_\alpha = C_{\alpha 0} + C_{\alpha 1} F_Z + C_{\alpha 2} F_Z^2 + C_{\alpha 3} F_Z^3 \qquad (2.3\text{-}3)$$

$$C_\gamma = C_{\gamma 0} + C_{\gamma 1} F_Z + C_{\gamma 2} F_Z^2 + C_{\gamma 3} F_Z^3 \qquad (2.3\text{-}4)$$

$$C_{M\alpha} = C_{M0} + C_{M1} F_Z + C_{M2} F_Z^2 + C_{M3} F_Z^3 \qquad (2.3\text{-}5)$$

The 12 coefficients are fitted to match measured tire data when available. A completely linear model is obtained by setting all of the higher-order terms to zero, and using just the basic linear coefficients $C_{\alpha 0}$, $C_{\gamma 0}$, and C_{M0}.

2.4 Steering System

The Wind-Steer model includes the dynamic steering system model shown in Figure 3. The steering model is characterized by the following elements:

- rotational inertia for the steering wheel and upper column,
- steering column and linkage compliances,
- Coulomb and viscous friction,
- front wheel lash, and
- power boost.

The describing equations are contained in Appendix B of the Reference Manual (Volume II) and are largely patterned after the work of Segel [4,5]. The high frequency rotational motion of the front wheels (approximate 10 Hz "wobble" mode) are not included in the steering system or vehicle model dynamics since these effects are well above the frequency range of interest and intended use of this program.

The dynamic steering system is optional when using the program. (The steering system dynamics are bypassed in the model by specifying a value of 0.0 in the input file for the SSKEY parameter.) Without the steering system, the steering wheel angle is the basic vehicle control input. However, when the dynamic steering system option is active, a steering wheel *torque* input is required instead.

The upper part of Figure 3 shows a sketch of the steering system model and some of the parameters required by the Wind-Steer program. The Wind-Steer program actually uses a simplified approximation that has been found to give excellent agreement with measured data from the test track. The simplified model, shown in the bottom of the figure, includes several lumped "effective" parameters which are computed automatically from the more conventional parameters provided in the input file. The parameters whose values are required as inputs to the program appear in both sketches and are shown in bold typeface.

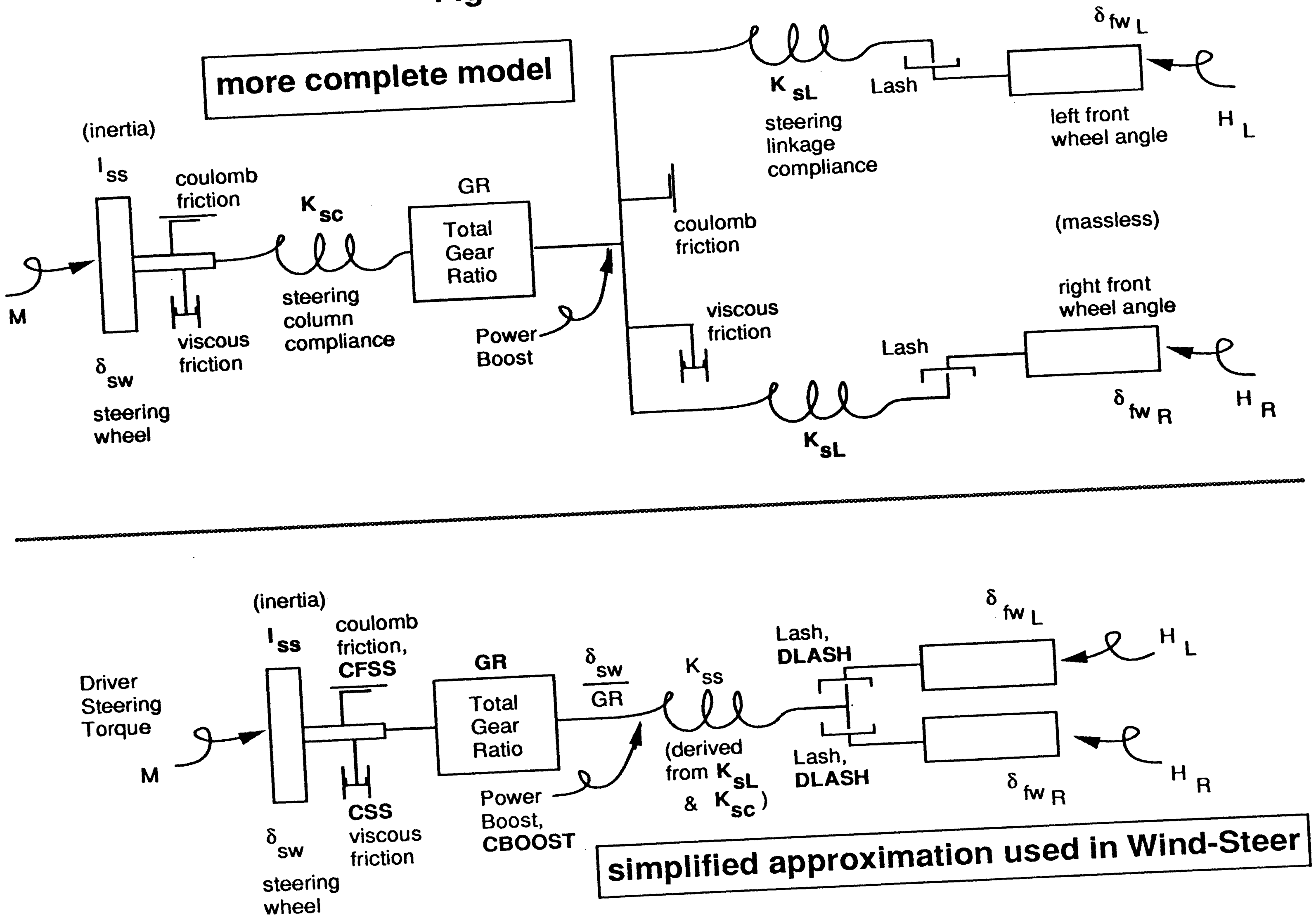
2.5 Driver Model

The UMTRI driver model is included to permit simulation of driver steering control for typical path-following maneuvers. The model requires two driver-related parameters and a table of X-Y coordinates describing the desired path to be followed. The first driver parameter is a time delay representing the neuro-muscular lag of the driver in reacting to external stimuli during the steering control process. (A "typical" or representative value for this model parameter is 0.25 seconds for many path-following steering tasks. Smaller values may be used to represent more "responsive" drivers; larger values can be used to represent more sluggish or impaired driver steering behavior.) The other basic parameter is the driver "look-ahead" or preview time. This parameter represents the preview time interval over which the driver scans ahead and attempts to minimize future deviations of the predicted vehicle trajectory and the desired path. (Values of 1.0 to 3.0 seconds have been found to be representative of many drivers during typical path-tracking maneuvers.) The last piece of information required by the driver model is a set of coordinates defining the desired path to be followed. These are entered in the program as a set of tabular X-Y coordinates and are previewed by the driver model during the course of the simulation as the "desired path." (In general control terms, the driver model is a time-delayed steering controller which minimizes previewed path errors.)

The basic influence of varying the two driver-related parameters is as follows. Increasing the value of the time delay parameter, or decreasing the value of the driver preview time parameter, has the general effect of reducing the level of damping of the total driver/vehicle (closed-loop) system response. Opposite variations in these parameters (decreasing the time delay parameter or increasing the preview time) will result in greater damping and stability of the total system response.

Two versions of the driver model are present in the program code. One version calculates the required driver steering wheel *angle*; the other version calculates the required driver steering wheel *torque*. The program automatically selects the particular version based upon whether or not the dynamic steering system is being used. If the steering system is active, the steering wheel torque version of the driver model is used by the program. If the steering system is not activated, the steering wheel angle version of the driver model is used.

Figure 3. Steering System Model.



The driver model is documented by two technical papers [2,3] which are included in Appendix E of the Reference Manual (Volume II) and a recent technical report [6].

When the control input to the system is specified as a prescribed (open-loop) time history of steering wheel angle or steering wheel torque, then the driver model is not involved in the simulated maneuver.

3. PROGRAM INPUT

The input file to the Wind-Steer simulation is a series of numbers with values corresponding to parameters in the model. This type of file is typical of many Fortran programs. Figure 4 shows an example input file.

3.1 Position and Formatting

Each numerical value required by the program corresponds to a specific position in the input file. The variable associated with each number is determined solely by the position of the number in the file. Thus, it is essential that the numbers be located correctly. For each line in the file, a range of columns is searched for numbers. Anything lying outside of that range is ignored. Thus, comments can be included on the same lines as the numerical data. Also, additional lines following the input data are ignored by the program. Consequently, documentation can be added at the bottom of the file.

When preparing input files, it is very helpful if a text editor is chosen that shows the row and column position of the cursor on the screen.

The program requires that the numbers be written in a format acceptable for standard Fortran input. Numbers are classified internally as integers or reals (floating point numbers). Integers must not include a decimal point. Numbers should not include spaces or commas. If no number is written in an area assigned to an input variable, the value 0 (or 0.0) is assumed. Some Fortran compilers create programs that can read "free form" numerical data. (E.g., numbers separated by commas or other delimiters.) However, this is not a part of standard Fortran 77, so it is a good idea to consult the Fortran manual for the specific compiler used before trying non-standard formats.

3.2 Line-by-Line Description of Input File

The contents of the input file are described below, line-by-line. For each line in the file, the Fortran format is shown, the internal names of the variables are given, and the variables are defined. The first two lines of character information in the file are ignored by the program and can be used to include comments and information about the file. The parameter values begin with line 3.

The first three lines of data involve "strings" of alphanumeric characters. Line three contains a title which is allocated 80 characters. Line four contains a word describing the units convention (metric or English), of which only the first character is actually read. The fifth line contains a Fortran format statement which is allocated 32 characters. The remaining lines contain only numerical data. The numbers in each line are either integer or real. Integers are always read using the format *I4*, with the integer value allowed to appear anywhere in a field of four columns. Reals are always read using the format *F12.*—twelve

Figure 4. Example input file for the Wind-Steer vehicle model.

Line no.	*Contents of line* 1	13	25	37	49
1	Lines 1 and 2 are for documenting the file contents				
2	and are not used by the Wind-Steer model.				
3	Best Aero, 50 mi/h, Step-Steer Input.				(Title line)
4	English				(UNITS)
5	(66F10.3)				(TEXT Output Format)
6	50.0	3.0	.02		(V=MPH, TEND, DT)
7	2				(print interval)
8	90.0	0.0024			(KSYWND, AIRHO)
9	5				(WINDKY)
9.1	0.0	0.0			(WIND TABLE)
9.2	0.1	20.0			[time, wind (mph) input]
9.3	10.0	20.0			
9.4	10.1	0.0			
9.5	20.0	0.0			
10	4				(NSTEER)
10.1	0	0			(Steer Table)
10.2	.1	0.			[time, steer input]
10.3	0.2	25.00			
10.4	9.9	25.00			
11	3160.0	2830.0	0.6140		(WEIGHT,SPWGHT,WRATIO)
12	3000.0	12000.0	18000.0		(IXSCG, IYS, IZZ, IXZ)
13	97.0	11.3	20.0		(WB, WHLRAD, HCGTTL)
14	21.0				(AREA)
15	0.0345	0.0077	0.00918		(KY, KR, KN)
16	0.166	0.00107			(CL0, KL)
17	0.10545	0.0001864			(CM0, KM)
18	0.3431	0.000282			(CD0, KD)
19	0.4	7.0	0.0	3000.	(ISS, KSC, DLASH, KSL)
20	16.9	0.44	0.6		(GR, XTRAIL, CSS)
21	0.62	0.0	3.0		(CBOOST, SSKEY, CFSS)
22	1				(NKINEM)
23	1				(NBEAM)
24	57.5	1.0			(TRACK(1), HOROLC(1))
25	150.0	6000.0			(KZ, KAUX)
26	5.0	10.0			(CZJNCE, CZRBND)
27	0.0	0.0			(ALFA0, GAMMA0)
27.1	0.0	0.0			(YROLCF(1,1),(1,2))
272	0.0	0.0			(HROLCF(1,1),(1,2))
27.3	-0.1	0.0			(CSZ(1,1),(1,2))
27.4	-0.213	-0.071			(CCZ(1,1),(1,2))
28	-0.00015	0.000833	0.0014		(CSFY, CSMZ, CCFY)
29	-26.4	0.589	-0.0003550	7.319E-08	(CALFA(1,1)..(1,4))
30	37.0	0.0	0.0	0.0	(CGAMMA(1,1)..(1,4))
31	-3.592	0.000	0.0007814	-2.743E-07	(CALIGN(1,1)..(1,4))
32	1000.0				(KTIRE)
33	57.5	6.0			(TRACK(2), HOROLC(2))
34	145.0	3360.0			(KZ, KAUX)
35	5.0	10.0			(CZJNCE, CZRBND)
36	0.0	0.5			(ALFA0, GAMMA0)

36.1	0.0	0.0			(YROLCF(2,1),(2,2))
36.2	0.0	0.0			(HROLCF(2,1),(2,2))
36.3	0.0				(CSROLL)
36.4	0.0	0.0			(CCZ(2,1),(2,2))
37	0.00005	0.0001	0.0015		(CSFY, CSMZ, CCFY)
38	-26.4	0.589	-0.0003550	7.319E-08	(CALFA(2,1)..(2,4))
39	37.0	0.0	0.0	0.0	(CGAMMA(2,1)..(2,4))
40	-3.592	0.000	0.0007814	-2.743E-07	(CALIGN(2,1)..(2,4))
41	1000.0				(KTIRE)

spaces are allocated, including the the decimal point and the minus sign for negative numbers.

Data in the input file can be either metric or English, but not a mixture. If metric units are chosen, all inputs should be consistent MKS values, and angular dimensions should be radians. There are two exceptions for MKS inputs: vehicle and wind speed are specified in km/h. For English units, inputs should be based on in-lb-sec and angular dimensions should be in degrees. There are several exceptions:

- vehicle and wind speed are specified in mi/h;
- air density is specified in slug/ft^3;
- cross-section area is specified in ft^2, and
- X-Y path coordinates for the driver model are specified in ft.

SAE conventions [7] are generally used for all the vehicle parameter data. In the following definitions, when English units differ from metric ones, both are shown, separated by a vertical bar, e.g., (in | m).

> NOTE: Some of the entries involve optional lines. Thus, the line numbering convention used below is interrupted several times and will not exactly match the line numbers in an input file.

Line	*Format*	*Fortran Variables*	*Description*
1-2	arbitrary	none	non-program text for documenting file contents.
3	(A80)	TITLE	80-character title printed on screen during run, and put into the output file.
4	(A1)	UNITS	UNITS is a character code that indicates whether English or metric units are used. 'E' = ENGLISH; otherwise METRIC.
5	(A32)	FRMT	FRMT is a character string indicating whether the output will be written in binary or text form. If FRMT begins with '(', e.g. (66F10.3), the output will be written as TEXT according to the specified FORTRAN format; otherwise, output will be BINARY.
6	(3F12.)	V, TEND, DT	V is the forward vehicle speed (mi/h | km/h) TEND is the stop time in (sec). DT is the desired integration time step (sec).

7	(I4)	IPRINT	IPRINT is the number of integration time steps that determines when program variables are written into the output file. For example, IPRINT = 2 indicates output is written every other integration time step.
8	(2F12.)	KSYWND, AIRHO	KSYWND is the wind heading angle (deg | rad). AIRHO is the air density (slug/ft^3 | N•sec^2•m^{-4}).
9	(I4)	WINDKY	WINDKY has two levels of meaning: (1) It is a key indicating the source of the wind input. The **polarity** of the value determines the source of the wind input data. (2) It may also give the number of points in a table input. < 0 — the crosswind amplitude is defined as a function of time with a user-supplied function named WINSUB. > 0 — the crosswind amplitude is defined by a table of time vs. wind amplitude. The number of X-Y pairs in the table is WINDKY. = 0 — no crosswind table follows (no wind).

(WINDKY ≥ 0) Wind input is provided in table form:

9.1	(2F12.)	TIMWIN(1), WINMAG (1)	TIMWIN(1) is the first time in the table, and *must* be 0.0. WINMAG (1) is the first wind entry in the table, and *must* be 0.0.
9.J	(2F12.)	TIMWIN(J), WINMAG (J)	TIMWIN(J) (sec) and WINMAG(J) (mi/h | km/h) define the ongoing time-history of wind values. The time values in the table must start at 0.0 and increase. Repeated times are not permitted. If the simulation extends beyond the end of the table, the steer angle is frozen at WINMAG (WINDKY).

10 (I4) NSTEER

NSTEER has two levels of meaning. (1) It is a code indicating type of steer input. (2) It may also give the number of points in a table input. First, the **polarity** of NSTEER is **inspected**, with the following three possibilities:

< 0 — Driver model is used
= 0 — Sinusoidal steer input
> 0 — Table of steer input vs. time

If NSTEER $\neq$ 0, then the absolute value of this integer also determines how many entries are in the following table.

(NSTEER < 0) Driver model is used.

10.1 (2F12.) XPDR(1), YPDR (1)

XPDR(1) is the first path x-coordinate value in a table of X-Y values (ft | m). (X is the forward direction in the inertial coordinate system).
YPDR(1) is the first path y-coordinate value in the table (ft | m) (Y is the lateral direction to the right in the inertial coordinate system).
The table includes |NSTEER| pairs.

10.J (2F12.) XPDR(J), YPDR (J)

XPDR(J) and YPDR(J) define an X-Y pair of path values. The table should extend to X-Y values **beyond** the expected motion of the vehicle during the simulation run, *plus* the preview distance, *s*, of the driver model. (i.e., s = TFF • V, with proper units conversion)

10.J+1 (F12.) TAUMEM

TAUMEM is the driver time delay (sec).

10.J+2 (F12.) TFF

TFF is the driver model maximum preview time (sec).

(NSTEER = 0) Steering wheel angle SW is defined by three equations:

$$\text{SW} = 0 \qquad \text{for } \text{T} \leq \text{TSWBGN}$$

$$\text{SW} = \text{SWSHFT} + \text{SWAMPL} * \text{SIN}\,(2 * \text{PI} * (\text{T} - \text{TSWBGN}) / \text{TSWPRD} + \text{SWPHSE}) \qquad \text{for TSWBGN} < \text{T} < \text{TSWEND}$$

$$\text{SW} = \text{SWSHFT} + \text{SWAMPL} * \text{SIN}\,(2 * \text{PI} * (\text{TSWEND} - \text{TSWBGN}) / \text{TSWPRD} + \text{SWPHSE}) \qquad \text{for T} < \text{TSWEND}$$

10.1 (2F12.)	TSWBGN, TSWEND	TSWBGN is the start time for steer input (sec). TSWEND is the end time for steer input (sec).
10.2 (2F12.)	SWSHFT, SWAMPL	SWSHFT is a bias in amplitude (deg | rad). SWAMPL is the sinusoidal amplitude (deg | rad).
10.3 (2F12.)	TSWPRD, SWPHSE	TSWPRD is the time period of the sinusoid (sec). SWPHSE is the phase angle of the sinusoid (deg | rad).
(NSTEER > 0)	Steering wheel angle (or torque) is provided in table form.	
10.1 (2F12.)	XPNT(1), YPNT (1)	XPNT(1) is the first time in the table, and *must* be 0.0. YPNT(1) is the first steer angle (or torque) in the table, and *must* be 0.0.
10.J (2F12.)	XPNT(J), YPNT (J)	XPNT(J) (sec) and YPNT(J) define a time-steer pair of values. The time values in the table must start at 0.0 and increase. Repeated times are not permitted. If the simulation extends beyond the end of the table, the steer angle (torque) is frozen at YPNT (NSTEER). The physical meaning of YPNT depends on whether or not the steering system is included. If the steering system is included (as determined by the parameter SSKEY on line 21) then the Y values in the table indicate *torque* at the steering wheel (in-lb | N-m). If the steering system is not included, the Y values in the table indicate the *angle* of the steering wheel (deg | rad).
11 (3F12.)	WEIGHT, SPWGHT, WRATIO	WEIGHT is the total vehicle weight (lbm | N). SPWGHT is the sprung weight (lbm | N). WRATIO is the fraction of the total weight carried by the front axle (thus, it has a value between 0.0 and 1.0).

12	(4F12.)	IXSCG, IYS, IZZ, IXZ	IXSCG is the roll moment of inertia of the sprung mass (about the X axis) (in-lb-sec^2 | N-m-sec^2). IYS is the pitch moment of inertia of the sprung mass (about the Y axis) (in-lb-sec^2 | N-m-sec^2). IZZ is the yaw moment of inertia of the entire vehicle (about the Z axis) (in-lb-sec^2 | N-m-sec^2). IXZ is the cross product of inertia of the sprung mass (involving the X and Z axes) (in-lb-sec^2 | N-m-sec^2).
13	(3F12.)	WB, WHLRAD, HCGTTL	WB is the wheelbase (in | m). WHLRAD is the tire rolling radius (and also the assumed c.g. height of the unsprung masses) (in | m). HCGTTL is the static c.g. height of the total vehicle above the ground (in | m).
14	(F12.)	AREA	Frontal cross section area of total vehicle (ft^2 | m^2).
15	(3F12.)	KY, KR, KN	KY is the aerodynamic side force coefficient. (deg^{-1} | rad^{-1}). KR is the aerodynamic roll moment coefficient (deg^{-1} | rad^{-1}). KN is the aerodynamic yaw moment coefficient (deg^{-1} | rad^{-1}).
16	(2F12.)	CL0, KL	Aerodynamic lift force coefficients (—, deg^{-2} | rad^{-2}).
17	(2F12.)	CM0, KM	Aerodynamic pitch moment coefficients (deg^{-2} | rad^{-2}).
18	(2F12.)	CD0, KD	Aerodynamic drag force coefficients (deg^{-2} | rad^{-2}).

19	(4F12.)	ISS, KSC, DLASH, KSL	ISS is the moment of inertia of the steering wheel & upper column (in-lb-sec^2 I N-m-sec^2) KSC is the stiffness of the upper steering column (in-lb/deg I N-m/rad) DLASH is the lash (+/-) of each front wheel, (deg I rad). KSL is the one-side stiffness of the steering system linkage below the gear box (in-lb/deg I N-m/rad).
20	(3F12.)	GR, XTRAIL, CSS	GR is the overall kinematic ratio of the steering system (deg/deg). XTRAIL is the mechanical trail of a front wheel (in I m). CSS is the viscous damping of the steering system lumped at the steering wheel location (in-lb-sec/deg I N-m-sec).
21	(3F12.)	CBOOST, SSKEY, CFSS	CBOOST is the power boost coefficient for the steering system model (power/power). (E.g., CBOOST = 0.0 implies no power assist; CBOOST = 0.5 implies a 50% power assist.) SSKEY is key which activates the dynamic steering system model. Its meaning is: > 0.0 — dynamic steering model = 0.0 — quasi-static steering model Note that (1) when SSKEY is 0.0, the steer input to the vehicle (from either the driver model or a steer table) is the steering wheel *angle*, and (2) when SSKEY > 0.0, the steer input to the vehicle (from either the driver model or a steer table) is the steering wheel *torque*. CFSS is steering system Coulomb friction, lumped at the steering wheel location (in-lb I N-m).
22	(I4)	NKINEM	NKINEM is a key that defines the sophistication of the model used for independent suspensions. ≠ 0 — advanced model used = 0 — static roll center used

23	(I4)	NBEAM	NBEAM is a key that defines the type of rear suspension. ≠ 0 — beam rear axle = 0 — independent rear suspension
24	(2F12.)	TRACK(1), H0ROLC(1)	TRACK(1) is the track for the front wheels (in I m). H0ROLC(1) is height (above the ground plane) of the static roll center for the front suspension (in I m).
25	(2F12.)	KZ(1), KAUX(1)	KZ(1) is suspension ride stiffness for each front wheel (lb/in I N/m). KAUX(1) is the auxiliary roll stiffness for the front suspensions (in-lb/deg I N-m).
26	(2F12.)	CZJNCE(1), CZRBND(1)	Bi-linear damping coefficients for the front wheels. CZJNCE(1) is the rate for jounce (lb-sec/in I N-sec/m). CZJRBND(1) is the rate for rebound (lb-sec/in I N-sec/m).
27	(2F12.)	ALFA0(1), GAMMA0(1)	Static angular positions of front wheels. ALFA0(1) is the static slip angle (deg I rad). GAMMA0(1) is the static camber angle (deg I rad).

These lines are included only if NKINEM ≠ 0

27.1	(2F12.)	YROLCF(1,1), YROLCF(1,2)	Linear (in/deg I m) and quadratic (in/deg^2 I m) coefficients used to define lateral displacement of front roll center as a function of roll of the sprung mass.
27.2	(2F12.)	HROLCF(1,1), HROLCF(1,2)	Linear (in/deg I m) and quadratic (in/deg^2 I m) coefficients used to define vertical displacement of front roll center as a function of roll of the sprung mass.
27.3	(2F12.)	CSZ(1,1), CSZ(1,2)	Linear (deg/in I m^{-1}) and quadratic (deg/in^2 I m^{-2}) bump steer coefficients for front suspensions.
27.4	(2F12.)	CCZ(1,1), CCZ(1,2)	Linear (deg/in I m^{-1}) and quadratic (deg/in^2 I m^{-2}) bump camber coefficients for front suspensions.

28 (3F12.) CSFY(1), CSMZ(1), CCFY(1)

CSFY(1) is the linear compliant steer coefficient for side force acting on each front wheel (deg/lb | N^{-1}).

CSMZ(1) is the linear compliant steer coefficient for aligning moment acting on each front wheel (deg/in/lb | $N^{-1}m^{-1}$).

CCFY(1) is the linear compliant camber coefficient for side force acting on each front wheel (deg/lb | N^{-1}).

29 (4F12.) CALFA(1,1), CALFA(1,2), CALFA(1,3), CALFA(1,4)

Coefficients for computing cornering stiffness as a cubic function of vertical load.

$C_\alpha = A_1 + A_2 F_z + A_3 F_z^2 + A_4 F_z^3$

The units are: A_1 (lb/deg | N/rad), A_2 (deg^{-1} | —), A_3($lb^{-1}deg^{-1}$ | N^{-1}), A_4($lb^{-2}deg^{-1}$ | N^{-2})

30 (4F12.) CGAMMA(1,1), CGAMMA(1,2), CGAMMA(1,3), CGAMMA(1,4)

Coefficients for computing camber stiffness as a cubic function of vertical load.

$C_\gamma = G_1 + G_2 F_z + G_3 F_z^2 + G_4 F_z^3$

The units are: G_1 (lb/deg | N/rad), G_2 (deg^{-1} | —), G_3($lb^{-1}deg^{-1}$ | N^{-1}), G_4($lb^{-2}deg^{-1}$ | N^{-2})

31 (4F12.) CALIGN(1,1), CALIGN(1,2), CALIGN(1,3), CALIGN(1,4)

Coefficients for computing aligning stiffness as a cubic function of vertical load.

$C_M = M_1 + M_2 F_z + M_3 F_z^2 + M_4 F_z^3$

The units are: M_1 (in-lb/deg | N-m/rad), M_2 (in/deg | m), M_3(in/lb/deg | m/N), M_4(in/lb^2/deg | m/N^2)

32 (F12.) KTIRE(1) Vertical spring rate for each front tire (lb/in | N/m).

33 ... 41 These lines contain parameters for the rear of the vehicle, and correspond to lines 24 through 32. Only one difference exists: line 36.3 (corresponding to line 27.3) depends on whether the rear suspension is independent or a beam.

36.3a (2F12.) CSZ(2,1), CSZ(2,2) Linear (deg/in | m^{-1}) and quadratic (deg/in^2 | m^{-2}) bump steer coefficients for rear suspensions **IF** NBEAM = 0.

36.3b (F12.)	CSROLL	**Roll steer** coefficient for rear suspension **IF NBEAM** $\neq$ 0 (deg/deg).

4. PROGRAM OUTPUT

4.1 ERD Files

The Engineering Research Division (ERD) at The University of Michigan Transportation Research Institute (UMTRI) has developed a standard file format to simplify the processing of data from varied sources, such as experiments, simulations, and data-processing programs. These are called ERD files. The file contains two independent sections, the header and data.

The data section contains nothing but numbers and is organized in a form similar to a spreadsheet, with each column corresponding to a different channel, and each row corresponding to a different sample of all channels. The data are stored in binary form when efficiency is important. Alternatively, the data can be stored in text form, to facilitate transporting the files between different computers.

The header section of the file contains the information needed to read the numerical data. As a minimum, this includes the number of channels, the number of samples, the step size, and similar essential information. In addition, the header usually contains labeling information related to the file and the separate channels. This design allows a data-processing program to first read the header information that maps out the file, and then read the rest of the file based on that information. Thus, a program that can deal with one ERD file can usually deal with any ERD file, even though the other files have different numbers of channels and perhaps different amounts of information included in the headers. Another benefit is that the files are self-documenting. Names of channels, units, notes, etc. can all be put into the header.

Depending on the design of the computer operating system and the form of the data, the two sections may reside in the same file or in two separate files. When the numerical data are written in text form (human readable numbers), both sections are put in the same file. The numerical data follows immediately the header data. On the IBM PC and Apple Macintosh, separate files are used to contain binary and text data. On MTS, the mainframe computer system at The University of Michigan, both sections are always included in the same file, even when binary formats are used.

4.2 Contents of the ERD File

Table 1 lists all of the channels included in the output ERD file. (This listing was obtained using one of the post-processing programs used for generic ERD files.) Figure 5 shows an actual file produced by the Wind-Steer program. In the figure, a vertical line is drawn to separate the line number (not included in the file) from the actual file contents. A second vertical line identifies the first 8 columns of each line, which contain a keyword in

Table 1. Example list of output channels in an (ERD) file.

```
 1 - Time     :  Time - sec
 2 - Steer in:   Input Steer Angle - deg
 3 - SW Torq :   Input Steer Torque - in-#
 4 - X cg     :  X Position, Sprung Mass cg - ft
 5 - Y cg     :  Y Position, Sprung Mass cg - ft
 6 - Z cg     :  Z Position, Sprung Mass cg - in
 7 - Roll     :  Roll Angle - deg
 8 - Pitch    :  Pitch Angle - deg
 9 - Yaw      :  Yaw Angle - deg
10 - p        :  Roll Rate - deg/sec
11 - q        :  Pitch Rate - deg/sec
12 - r        :  Yaw Rate - deg/sec
13 - slip     :  Vehicle Slip Angle - deg
14 - X dot    :  X Velocity, Sprung Mass cg - ft/s
15 - Y dot    :  Y Velocity, Sprung Mass cg - ft/s
16 - w cg     :  Z Velocity, Sprung Mass cg - in/s
17 - Ay cg    :  Lateral Acceleration at cg - g's
18 - Rho cg   :  Vehicle Path Curvature - 1/ft
19 - Fx Aero :   Aerodynamic Drag Force - lb
20 - Fy Aero :   Aerodynamic Side Force - lb
21 - Fz Aero :   Aerodynamic Down Force - lb
22 - Mx Aero :   Aerodynamic Roll Moment - in-#
23 - My Aero :   Aerodynamic Pitch Moment - in-#
24 - Mz Aero :   Aerodynamic Yaw Moment - in-#
25 - V Air    :  Air Speed - ft/s
26 - Slip Air:   Aerodynamic Slip Angle - in-#
27 - L Str 1 :   Total Steer, L side, Axle 1 - deg
28 - L Alph 1:   Slip Angle, L side, Axle 1 - deg
29 - L Gamm 1:   Camber Angle, L side, Axle 1 - deg
30 - L Fy 1   :  Side Force, L side, Axle 1 - lb
31 - L Mz 1   :  Aligning Moment, L side, Axle 1 - in-#
32 - L Fz 1   :  Load, L side, Axle 1 - lb
33 - L Z 1    :  Vert Disp, L side, Axle 1 - in
34 - L Fdmp 1:   Damping Force, L side, Axle 1 - lb
35 - R Str 1 :   Total Steer, R side, Axle 1 - deg
36 - R Alph 1:   Slip Angle, R side, Axle 1 - deg
37 - R Gamm 1:   Camber Angle, R side, Axle 1 - deg
38 - R Fy 1   :  Side Force, R side, Axle 1 - lb
39 - R Mz 1   :  Aligning Moment, R side, Axle 1 - in-#
40 - R Fz 1   :  Load, R side, Axle 1 - lb
41 - R Z 1    :  Vert Disp, R side, Axle 1 - in
42 - R Fdmp 1:   Damping Force, R side, Axle 1 - lb
43 - L Str 2 :   Total Steer, L side, Axle 2 - deg
44 - L Alph 2:   Slip Angle, L side, Axle 2 - deg
45 - L Gamm 2:   Camber Angle, L side, Axle 2 - deg
46 - L Fy 2   :  Side Force, L side, Axle 2 - lb
47 - L Mz 2   :  Aligning Moment, L side, Axle 2 - in-#
48 - L Fz 2   :  Load, L side, Axle 2 - lb
49 - L Z 2    :  Vert Disp, L side, Axle 2 - in
50 - L Fdmp 2:   Damping Force, L side, Axle 2 - lb
51 - R Str 2 :   Total Steer, R side, Axle 2 - deg
52 - R Alph 2:   Slip Angle, R side, Axle 2 - deg
53 - R Gamm 2:   Camber Angle, R side, Axle 2 - deg
54 - R Fy 2   :  Side Force, R side, Axle 2 - lb
55 - R Mz 2   :  Aligning Moment, R side, Axle 2 - in-#
```

```
56 - R Fz 2  :  Load, R side, Axle 2 - lb
57 - R Z 2   :  Vert Disp, R side, Axle 2 - in
58 - R Fdmp 2:  Damping Force, R side, Axle 2 - lb
```

Figure 5. Example output file **produced** by the Wind-Steer vehicle model.

Line no.	*1 — 8*	*Contents of line 9 — 1000*
1	ERDFILEV	2.00
2	66,	-1, -1, 1, 5, 0.500000E-01
3	TITLE	Best Aero, 50 mi/h, Wiggles input.
4	SHORTNAM	Time Steer inX cg Y cg Z cg Roll Pitch ...
5	LONGNAME	Time Input Steer Angle ...
6	&1000	Load, L side, Axle 1 Vert Displacement, L sid...
7	&1000	Vert Displacement, R side, Axle Kinematic Steer, R side ...
8	UNITSNAM	sec deg ft ft in deg deg ...
9	GENNAME	Time Steer Angle ...
10	&1000	Load Vertical Displacement ...
11	&1000	Vertical Displacement Steer Angle ...
12	RIGIBODY	Time Input ...
13	&1000	Left side, Axle 1 Left side, Axle 1 ...
14	&1000	Rght side, Axle 2 Rght side, Axle 2 ...
15	TRUCKSIM	Wind/Steer
16	SPEEDMPH	50
17	FORMAT	(66G13.6)
18	HISTORY	Data generated with Wind/Steer model at 20:29 on Apr 24,...
19	END	
20	.0000	00 .000000 .000000 .000000 .000000 ...
21	0.5000	00E-01 .000000 3.66668 -0.458360E-11-0.354777E-02...
22	.1000	00 .000000 7.33336 -0.780567E-11-0.128985E-01...
23	.1500	00 12.5000 11.0000 0.214312E-02-0.258511E-01...
23	.2000	00 25.0000 14.6667 0.156321E-01-0.383033E-01...
24	.2500	00 25.0000 18.3332 0.462742E-01-0.443594E-01...
.		
.		
.		
80	3.000	00 25.0000 40.3257 .588851 -0.339343E-01...

all lines except the first two. The keywords identify the type of data contained in the remainder of the line. Note that many of the lines are too long to be shown in the figure, as indicated by the ellipsis (...) at the end of those lines.

The contents of the header produced by the Wind-Steer program are described below on a line-by-line basis.

Line	*Keyword*	*Description*
1	—	Identifies file as a Version 2.00 ERD file.
2	—	Defines layout of this file. The numbers in this line correspond to the variables: NCHAN, NSAMP, NRECS, NBYTES, NUMKEY, STEP NCHAN = no. of channels in file (66 channels) NSAMP = no. of samples (-1 = "not known—read until end of file"). NRECS[1] = no. of records (-1 = "not known—read until end of file"). NBYTES[1] = number of bytes / record for binary data, number of "scans" / record for text data. NUMKEY = 1 for binary data, 5 for text data STEP = sample interval
3	TITLE	A line of text used as a comment or title for the file. This line is copied from the third line of the input file.
4	SHORTNAM	This line contains one short name (8 characters) for each channel in the file. The length of this line is 536 characters. (8 characters for the keyword and 8 for each of the 66 channels.)

[1] The parameters NBIN and NRECS together describe how the data are stored in the file. There are three types of file storage used: MTS-binary, PC-Mac-binary, and text.

On MTS, the binary part of the ERD file is structured to contain NREC constant-length records of length NBYTES. Each record contains one sample from each channel (a "scan"), and thus, NRECS = NSAMP and NBYTES = 4 × NCHAN.

On the IBM PC or the Apple Macintosh, the binary data are kept in a separate file that is not structured. The same values of NRECS (NSAMP) and NBYTES (4 × NCHAN) are used for reading and writing the data however.

For text files, NRECS is the number of records containing numbers in text form. NBYTES is set to the number of values for each channel on that line. The text files produced by the Wind/Handling program contain one sample for each channel. Thus, NRECS=NSAMP and NBYTES=1.

5	LONGNAM	This line contains one long name (32 characters) for each channel in the file. The length of this line should be 2120 characters. (8 characters for the keyword and 32 for each of the 66 channels.) The Fortran compiler for the Macintosh does not allow writing lines that are longer than 1024 characters, so the line is split up using the continuation keyword.
6	&1000	This line continues the data from the previous line. The keyword &1000 indicates that the previous line terminated at column position 1000. Thus, the previous line contains long labels for the first 31 channels (31 x 32 + 8 = 1000), and this line continues for channels 32 — 62.
7	&1000	This line also continues data from the previous line, associated with the LONGNAM keyword for channels 63 — 66.
8	UNITSNAM	This line contains the names of the units for all 66 channels. Each name contains 8 characters; thus, the line is 536 characters in length.
9-11	GENNAME	These three lines contain long names (32 characters) for each channel, similar to the labels associated with the LONGNAM keyword. These are "general names" however, which are not unique for each channel. For example, the steer angles for all four wheels are given the same general name of "Steer Angle." The general names are selected automatically by the ERD plotter for labeling plots involving several similar data channels.
12-14	RIGIBODY	These three lines contain long names (32 characters) for each channel, that identify a rigid body or other unit in the vehicle model that is associated with the channel. For example, all motions of the sprung mass have the RIGIBODY name "Sprung Mass." These names are selected automatically by the ERD plotter for labeling plots involving several similar data channels.
15	TRUCKSIM	This line identifies the UMTRI model used to generate the data file.
16	SPEEDMPH	This line contains the simulation speed, with units of mi/h.
(17)	FORMAT	This line appears only when the numerical data are stored in text form. This line contains the Fortran format used to write the numbers—nominally (66G13.6).
18	HISTORY	This line contains a comment indicating the source of the file and the date it was created.
19	END	This keyword indicates the end of the header.

In the example ERD file shown in Figure 5, the numerical data are stored in the same file, beginning with line 20. On the other hand, if the numerical data are stored in a separate file in binary form, any lines after line 19 (END) would be ignored by all UMTRI post-processing software.

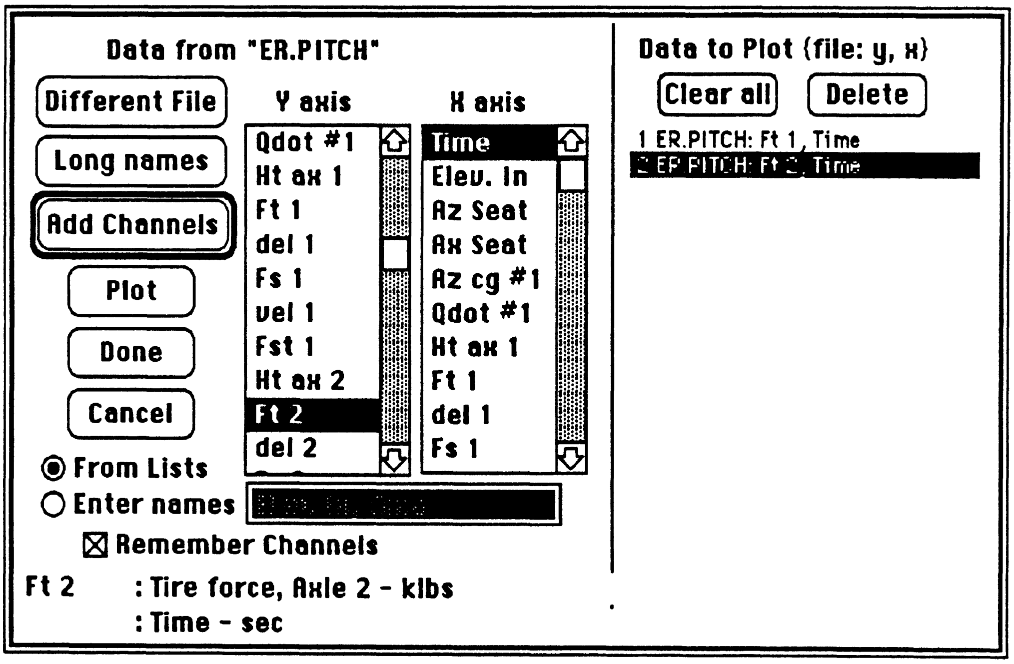
4.3 Post-Processing Software

Software has been developed for viewing and analyzing ERD files on the Macintosh and the mainframe computer at The University. At UMTRI, nearly all analyses of this sort are performed using Macintoshes that are networked together with several IBM PCs.

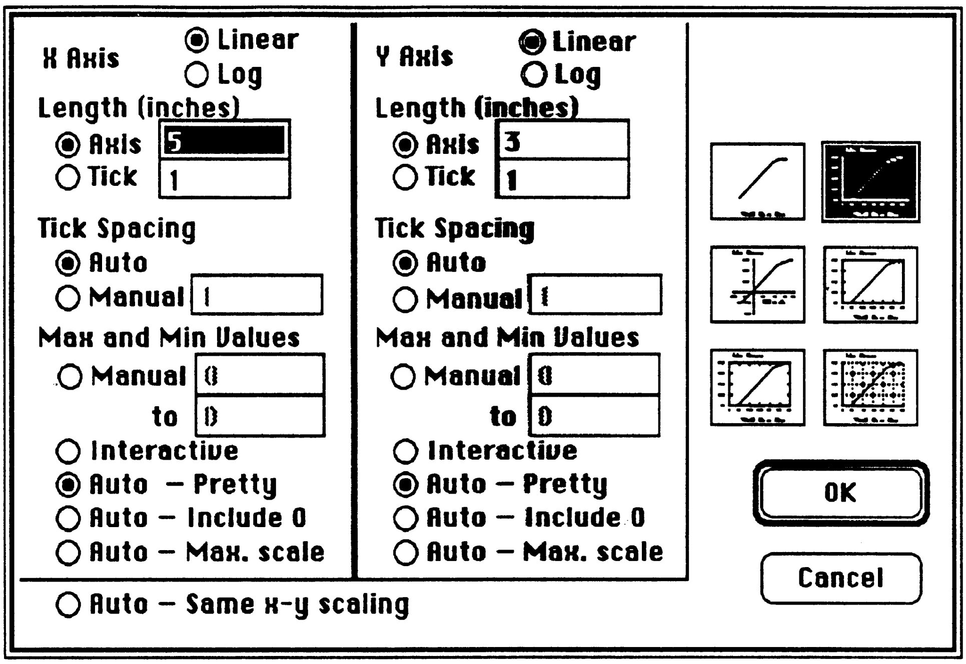
The programs that are relevant to the Wind-Steer simulation are:

- EP, a plotter for ERD files. EP obtains all of the labeling information required for preparing publication-quality plots from the header of the file.
- Spectrum, a spectrum analyzer for computing power spectral density (PSD) functions and transfer functions for variables whose time-histories are stored in ERD files. This program reads a file with time-domain data as input, and produces a file with frequency-domain data as output.
- Split, a utility program for editing ERD files.

These programs are "user friendly" and make full use of the Macintosh interface. For example, the dialog below shows the screen display when selecting channels to plot with EP. (The channels are selected by clicking on them with the mouse.)



As another example, the dialog below shows the various options available in EP for sizing and scaling the plots.



The post-processing software also runs on the UM mainframe computer, MTS. For other systems, there are several ways to view results from the Wind-Steer program using established post-processing (analysis) software:

- The numerical data in the ERD file can be written in text form using virtually any valid Fortran format (i.e., line 5 in the input file). Thus, this format should be selected to match the requirements of the post-processing software. However, it may be necessary to view the file with a text editor and eliminate or modify the header portion of the file.
- A conversion program can be written to read the ERD file and produce a file with a format appropriate for the post-processing software.
- The Wind-Steer program can be modified to produce files with a desired format. Appendix C of the Reference Manual (Volume II) contains instructions for doing this.

5. EXAMPLES

This section of the User's Manual presents two examples of using the Wind-Steer model. The first example is for a simple, open-loop (no driver steering control model) maneuver in which a step-like application of steering wheel angle (10 degrees) occurs at the start of the run. The dynamic steering model is inactivated (SSKEY = 0.0) and no crosswind input is present (WNDKY = 0). The vehicle is running at 100 mph in still air conditions.

The second example is for a driver controlled lane-change maneuver during a 20 mph crosswind. In this run, the dynamic steering system is activated with the driver model producing steering wheel torque as the control input to the model.

5.1 Step Steer Example

The input data set corresponding to the step steer example calculation is seen in Figure 6. The corresponding "echo" file of that input set is provided in Figure 7. An example time history result from the ERD plotter is seen in Figure 8 showing the steering wheel input and resulting vehicle lateral acceleration.

5.2 Lane Change Example

Figure 9 shows the basic maneuver performed for the lane change example. The vehicle starts in a straight line at 85 mph. After 0.5 seconds it encounters the beginning of the 20 mph crosswind blowing from the left. At about the same time, the driver model is beginning to steer the vehicle to the right for the start of the 12 ft lane-change maneuver. The wind assists the vehicle initially by "blowing" it to the right in the direction of the desired path. Following the completion of the lane change maneuver, counter-steering (and torque) are generated by the driver model to "trim" the vehicle against the constant crosswind.

The input data set for the lane change example is seen in Figure 10. The corresponding "echo" file of that input set is provided in Figure 11. Example time histories from the ERD plotter are seen in Figures 12 and 13. Figure 12 shows the steering wheel torque produced by the driver model and the resulting steering wheel angle from the dynamic steering system model. Figure 13 contains plots of the vehicle trajectory and the lateral acceleration time history. The negative torque and steering wheel values at the end of the run are being produced by the driver model in response to the crosswind condition.

Figure 6. Step Steer Example Input File.

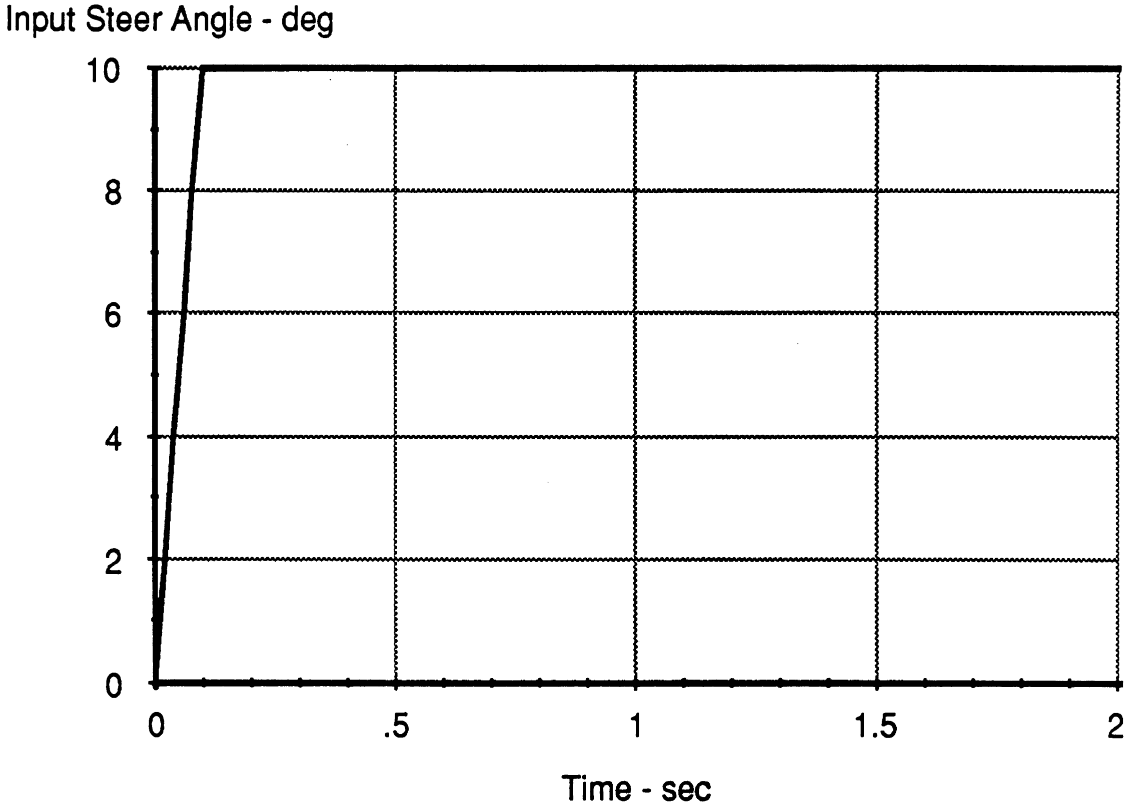
```
This is an example Wind-Steer input file for Version 1.0
The first two lines in the file are ignored, the third is saved as a title:
Best Aero, 100 mi/h, step steering wheel input, no steering system or crosswind.
English                                                          (ENGLISH UNITS)
Binary                                                           (binary FORMAT)
       100.0         2.0        .0100                            (V=MPH, TEND, DT)
2                                                                (print interval)
        90.0      0.0024                                         (VWIND, KSYWND, AIRHO /ft3)
0                                                                (WINDKY)
003                                                              (NSTEER)
0.0           0.0                                                [steering table; time, steer]
0.1          10.0
9.0          10.0
      3160.0      2830.0       0.6140                            [L+C] (WEIGHT, SPWGHT, WRATIO)
      3000.0     12000.0      18000.0               0.0          [A] (IXSCG, IYS, IZZ, IXZ)
        97.0        11.3         20.0                            [C,2(C+A)] (WB, WHLRAD, HCGTTL)
        21.0                                                     [L] (AREA sq ft)
      0.0345      0.0077      0.00918                            [L] (KY, KR, KN)
       0.166     0.00107                                         [L] (CL0, KL)
     0.10545   0.0001864                                         [L] (CM0, KM)
      0.3431    0.000282                                         [L] (CD0, KD)
         0.4         7.0         0.00     3000.                  [A] (ISS, KSC, DLASH, KSL)
        16.9        0.44         0.40                            [A] (GR, XTRAIL, CSS)
        0.55         0.0          3.0                            [A] (CBOOST, SSKEY, CFSS)
   1                                                             (NKINEM)
   1                                                             (NBEAM)
        57.5         1.0                                         [C,A] (TRACK(1), HOROLC(1))
       150.0      6000.0                                         [C] (KZ, KAUX)
         5.0        10.0                                         [A] (CZJNCE, CZRBND)
         0.0         0.0                                         [C] (ALFA0, GAMMA0)
         0.0         0.0                                         [A] (YROLCF(1,1),(1,2))
         0.0         0.0                                         [A] (HROLCF(1,1),(1,2))
        -0.1         0.0                                         [C] (CSZ(1,1),(1,2))
      -0.213      -0.071                                         [C] (CCZ(1,1),(1,2))
    -0.00015    0.000833       0.0014                            [A,C,C] (CSFY, CSMZ, CCFY)
       -26.4       0.589   -0.0003550   7.319E-08                 [G+U] (CALFA(1,1)..(1,4))
        37.0         0.0          0.0         0.0                 [G+U] (CGAMMA(1,1)..(1,4))
      -3.592      -0.000    0.0007814  -2.743E-07                 [G+U] (CALIGN(1,1)..(1,4))
      1000.0                                                     [A] (KTIRE)
        57.5         6.0                                         [C,A] (TRACK(2), HOROLC(2))
       145.0      3360.0                                         [C] (KZ, KAUX)
         5.0        10.0                                         [A] (CZJNCE, CZRBND)
         0.0         0.5                                         [C] (ALFA0, GAMMA0)
         0.0         0.0                                         [A] (YROLCF(2,1),(2,2))
         0.0         0.0                                         [A] (HROLCF(2,1),(2,2))
         0.0                                                     [A] (CSROLL)
         0.0         0.0                                         [C] (CCZ(2,1),(2,2))
     0.00005      0.0001       0.0015                            [C] (CSFY, CSMZ, CCFY)
       -26.4       0.589   -0.0003550   7.319E-08                 [G+U] (CALFA(2,1)..(2,4))
        37.0         0.0          0.0         0.0                 [G+U] (CGAMMA(2,1)..(2,4))
      -3.592      -0.000    0.0007814  -2.743E-07                 [G+U] (CALIGN(2,1)..(2,4))
      1000.0                                                      [A] (KTIRE)
```

Figure 7. Step Steer Example Echo File.

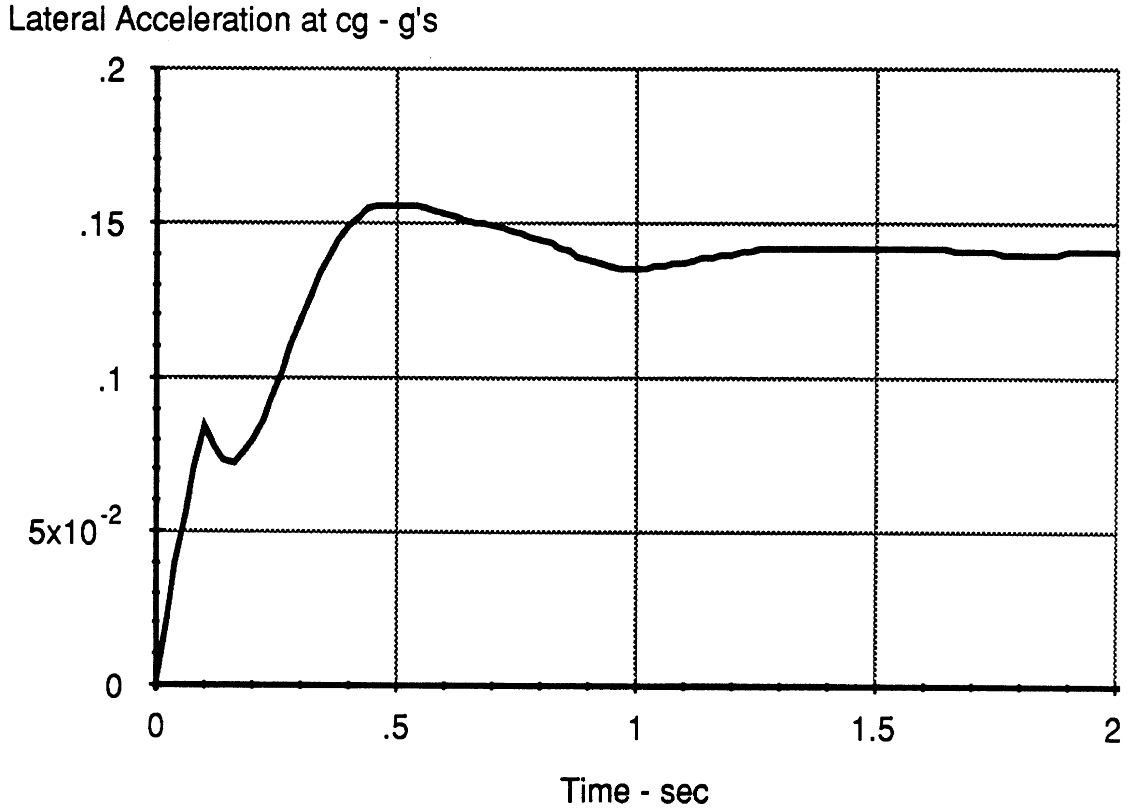
```
 ECHO FROM WIND/HANDLING SIMULATION

 Input file: step100.in

 Run made at 10:09 on Feb 26, 1989

 TITLE: Best Aero, 100 mi/h, step steering wheel input, no steering
system or crosswind.

 GENERAL SIMULATION INFORMATION:

    English Units
    Output format: Binary
    V, TEND, DT:                  100.00        2.0000        0.10000E-01
    Write to file every  2 steps
    KSYWND, AIRHO:                90.000        0.24000E-02

 WIND MAGNITUDE TIME HISTORY INPUT:


 STEER TABLE - time(sec), sw(deg):

      .00000        .00000
      .10000        10.000
      9.0000        10.000

 TOTAL VEHICLE AND SPRUNG MASS PARAMETERS:

    WEIGHT, SPWGHT, WRATIO:       3160.0        2830.0        .61400
    IXSCG, IYS, IZZ, IXZ:         3000.0        12000.        18000.
.00000
    WB, WHLRAD, HCGTTL:           97.000        11.300        20.000

 AERODYNAMIC PARAMETERS:

    AREA:                         21.000
    KY, KR, KN:                   0.34500E-01   0.77000E-02   0.91800E-02
    CL0, KL:                      .16600        0.10700E-02
    CM0, KM:                      .10545        0.18640E-03
    CD0, KD:                      .34310        0.28200E-03

 STEERING SYSTEM:

    ISS, KSC, DLASH, KSL:         .40000        7.0000        .00000
3000.0
    GR, XTRAIL, CSS:              16.900        .44000        .40000
    CBOOST, SSKEY, CFSS:          .55000        .00000        3.0000

 NKINEM <> 0 -- Use full kinematics model

 BEAM <> 0 -- Beam rear suspension

 AXLE NUMBER 1
```

```
  Suspension and tire data
    TRACK, HOROLC:                 57.500         1.0000
    KZ, KAUX:                      150.00         6000.0
    CZJNCE, CZRBND:                5.0000         10.000
    ALFA0, GAMMA0:                 .00000         .00000

  Kinematic coefficients:
    YROLCF:                        .00000         .00000
    HROLCF:                        .00000         .00000
    CSZ:                          -.10000         .00000
    CCZ:                          -.21300       -0.71000E-01

  Compliance coefficients:
    CSFY, CSMZ, CCFY:           -0.15000E-03   0.83300E-03   0.14000E-02

  Tire stiffness coefficients:
    CALFA:        -26.400          .58900       -0.35500E-03   0.73190E-07
    CGAMMA:        37.000          .00000         .00000         .00000
    CALIGN:       -3.5920          .00000        0.78140E-03  -0.27430E-06
    KTIRE:         1000.0

AXLE NUMBER 2

  Suspension and tire data
    TRACK, HOROLC:                 57.500         6.0000
    KZ, KAUX:                      145.00         3360.0
    CZJNCE, CZRBND:                5.0000         10.000
    ALFA0, GAMMA0:                 .00000         .50000

  Kinematic coefficients:
    YROLCF:                        .00000         .00000
    HROLCF:                        .00000         .00000
    Rear axle roll steer:          .00000
    CCZ:                           .00000         .00000

  Compliance coefficients:
    CSFY, CSMZ, CCFY:            0.50000E-04   0.10000E-03   0.15000E-02

  Tire stiffness coefficients:
    CALFA:        -26.400          .58900       -0.35500E-03   0.73190E-07
    CGAMMA:        37.000          .00000         .00000         .00000
    CALIGN:       -3.5920          .00000        0.78140E-03  -0.27430E-06
    KTIRE:         1000.0
```

Figure 8.' Step Steer Example; no steering system or crosswind.



Best Aero, 100 mi/h, step steering wheel input, no steering system or crosswind.



Best Aero, 100 mi/h, step steering wheel input, no steering system or crosswind.

Figure 9. Lane Change Example. Driver Model Performing 12-ft Lane Change Maneuver in the presence of a 20 mph Crosswind.

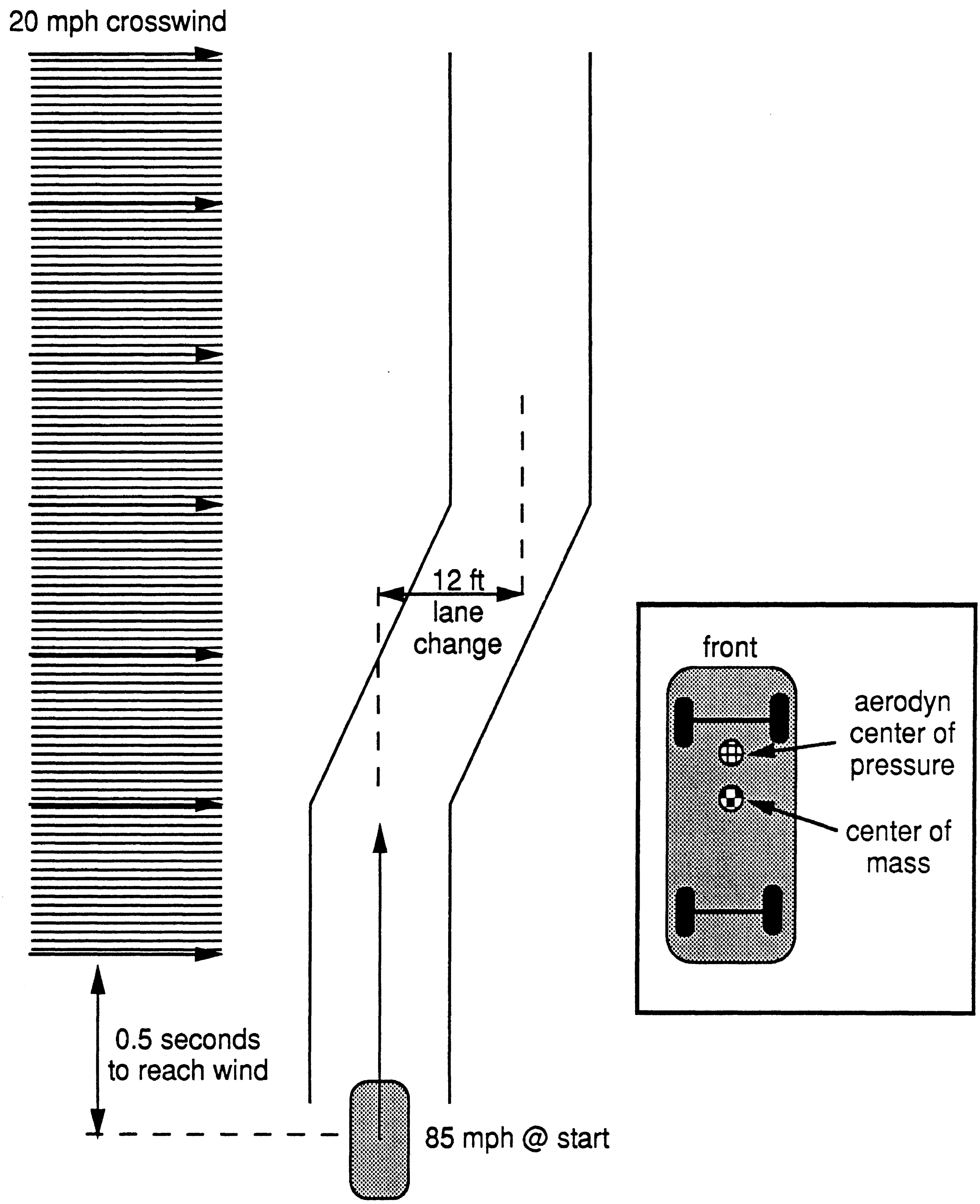


Figure 10. Lane Change Example Input File.

```
This is an example Wind-Steer input file for Version 1.0
The first two lines in the file are ignored, the third is saved as a title:
85 mi/h, 12-ft lane change, driver model + steering system, 20 mph crosswind.
English                                                 (ENGLISH UNITS)
Binary                                                  (binary FORMAT)
        85.0        8.0        .0200                    (V=MPH, TEND, DT)
2                                                       (print interval)
        90.0     0.0024                                 (VWIND, KSYWND, AIRHO /ft3)
04                                                      (WINDKY)
0.0          0.0                                        [time, crosswind table]
0.5          0.0
1.0         20.0                                        [ 20 mph gust @ 1 second ]
99.         20.0
-04                                                     (NSTEER) [ < 0 => driver model]
0.0          0.0                                         [x-y path coordinates table]
200.0        0.0
350.0        12.0                                        [12-ft lane change maneuver]
9999.0       12.0
0.20                                                     driver model time delay
1.25                                                     driver model preview time
      3160.0     2830.0      0.6140                      [L+C] (WEIGHT, SPWGHT, WRATIO)
      3000.0    12000.0     18000.0            0.0       [A] (IXSCG, IYS, IZZ, IXZ)
        97.0       11.3        20.0                      [C,2(C+A)] (WB, WHLRAD, HCGTTL)
        21.0                                             [L] (AREA sq ft)
      0.0345     0.0077     0.00918                      [L] (KY, KR, KN)
       0.166    0.00107                                  [L] (CL0, KL)
     0.10545  0.0001864                                  [L] (CM0, KM)
      0.3431   0.000282                                  [L] (CD0, KD)
         0.4        7.0        0.00     3000.            [A] (ISS, KSC, DLASH, KSL)
        16.9       0.44        0.40                      [A] (GR, XTRAIL, CSS)
        0.62        1.0         3.0                      [A] (CBOOST, SSKEY, CFSS)
   1                                                     (NKINEM)
   1                                                     (NBEAM)
        57.5        1.0                                 [C,A] (TRACK(1), HOROLC(1))
       150.0     6000.0                                 [C] (KZ, KAUX)
         5.0       10.0                                 [A] (CZJNCE, CZRBND)
         0.0        0.0                                 [C] (ALFA0, GAMMA0)
         0.0        0.0                                 [A] (YROLCF(1,1),(1,2))
         0.0        0.0                                 [A] (HROLCF(1,1),(1,2))
        -0.1        0.0                                 [C] (CSZ(1,1),(1,2))
      -0.213     -0.071                                 [C] (CCZ(1,1),(1,2))
    -0.00015   0.000833      0.0014                     [A,C,C] (CSFY, CSMZ, CCFY)
       -26.4      0.589  -0.0003550   7.319E-08          [G+U] (CALFA(1,1)..(1,4))
        37.0        0.0         0.0          0.0         [G+U] (CGAMMA(1,1)..(1,4))
      -3.592     -0.000   0.0007814  -2.743E-07          [G+U] (CALIGN(1,1)..(1,4))
      1000.0                                            [A] (KTIRE)
        57.5        6.0                                 [C,A] (TRACK(2), HOROLC(2))
       145.0     3360.0                                 [C] (KZ, KAUX)
         5.0       10.0                                 [A] (CZJNCE, CZRBND)
         0.0        0.5                                 [C] (ALFA0, GAMMA0)
         0.0        0.0                                 [A] (YROLCF(2,1),(2,2))
         0.0        0.0                                 [A] (HROLCF(2,1),(2,2))
         0.0                                            [A] (CSROLL)
         0.0        0.0                                 [C] (CCZ(2,1),(2,2))
```

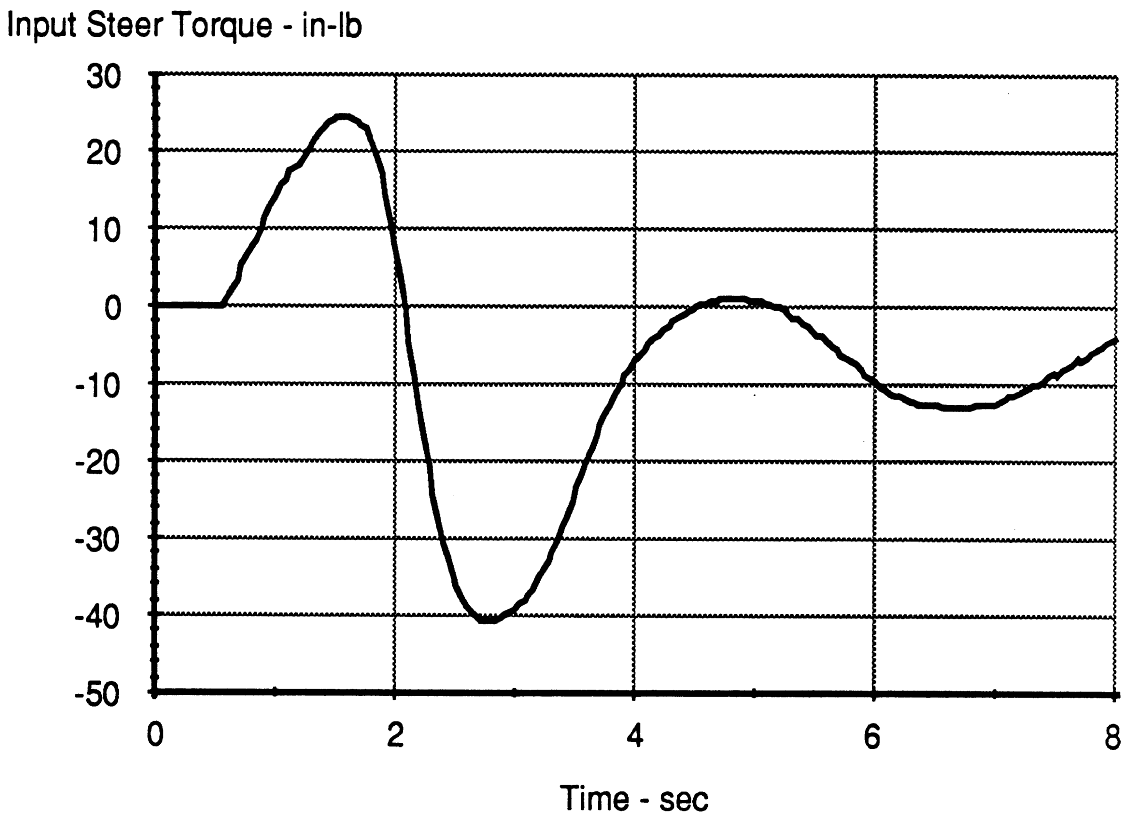
```
0.00005      0.0001      0.0015                 [C] (CSFY, CSMZ, CCFY)
  -26.4       0.589  -0.0003550   7.319E-08  [G+U] (CALFA(2,1)..(2,4))
   37.0         0.0         0.0         0.0  [G+U] (CGAMMA(2,1)..(2,4))
 -3.592      -0.000   0.0007814  -2.743E-07  [G+U] (CALIGN(2,1)..(2,4))
 1000.0                                      [A] (KTIRE)
```

Figure 11. Lane Change Example Echo File.

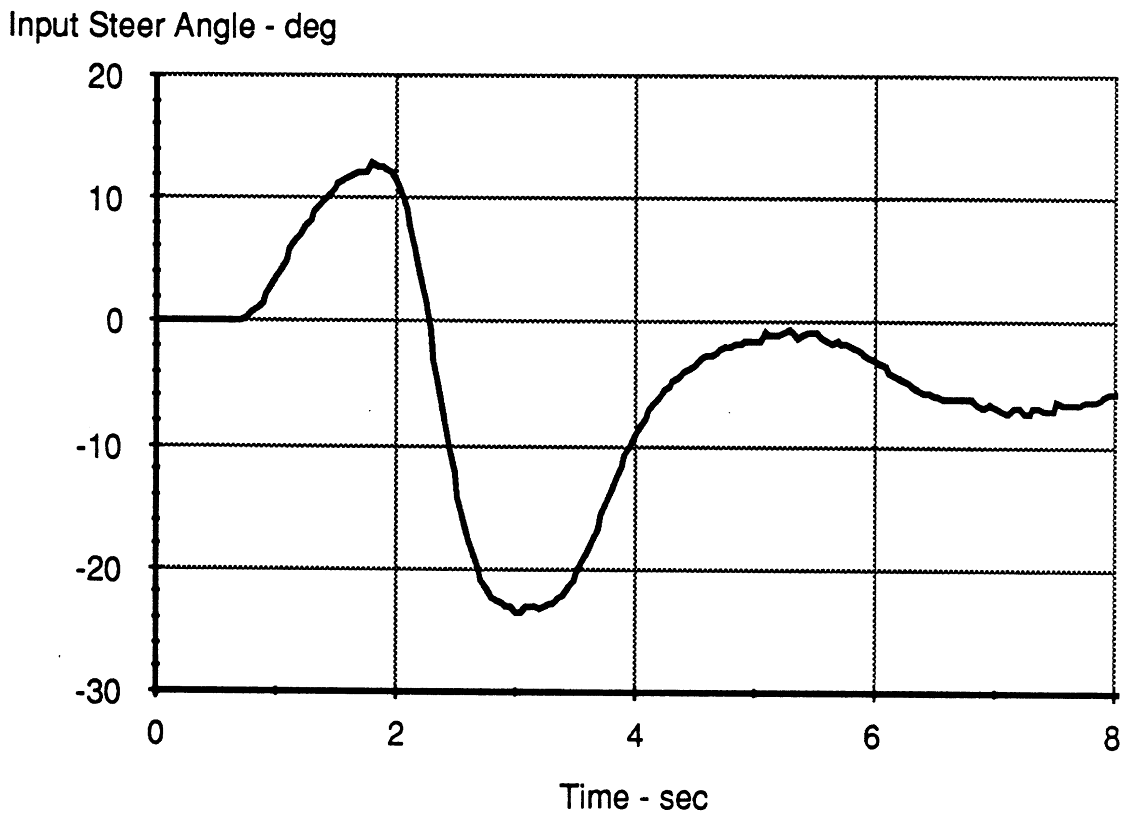
```
 Input file: torque.wind.lc85.in

 Run made at 10:40 on Feb 26, 1989

 TITLE: 85 mi/h, 12-ft lane change, driver model + steering system, 20 mph
crosswind.

 GENERAL SIMULATION INFORMATION:

    English Units
    Output format: Binary
    V, TEND, DT:                  85.000        8.0000        0.20000E-01
    Write to file every  2 steps
    KSYWND, AIRHO:                90.000       0.24000E-02

 WIND MAGNITUDE TIME HISTORY INPUT:

       .00000        .00000
       .50000        .00000
       1.0000        20.000
       99.000        20.000

 DRIVER MODEL INPUT:

    DRLAG, DRPREV:                .20000        1.2500

    X-Y path coordinates:

       .00000        .00000
       200.00        .00000
       350.00        12.000
       9999.0        12.000

 TOTAL VEHICLE AND SPRUNG MASS PARAMETERS:

    WEIGHT, SPWGHT, WRATIO:       3160.0        2830.0        .61400
    IXSCG, IYS, IZZ, IXZ:         3000.0        12000.        18000.        .00000
    WB, WHLRAD, HCGTTL:           97.000        11.300        20.000

 AERODYNAMIC PARAMETERS:

    AREA:                         21.000
    KY, KR, KN:                  0.34500E-01   0.77000E-02   0.91800E-02
    CL0, KL:                      .16600       0.10700E-02
    CM0, KM:                      .10545       0.18640E-03
    CD0, KD:                      .34310       0.28200E-03

 STEERING SYSTEM:

    ISS, KSC, DLASH, KSL:         .40000        7.0000        .00000        3000.0
    GR, XTRAIL, CSS:              16.900        .44000        .40000
    CBOOST, SSKEY, CFSS:          .62000        1.0000        3.0000

 NKINEM <> 0 -- Use full kinematics model
```

```
BEAM <> 0 -- Beam rear suspension

AXLE NUMBER 1

   Suspension and tire data
     TRACK, HOROLC:             57.500        1.0000
     KZ, KAUX:                  150.00        6000.0
     CZJNCE, CZRBND:            5.0000        10.000
     ALFA0, GAMMA0:             .00000        .00000

   Kinematic coefficients:
     YROLCF:                    .00000        .00000
     HROLCF:                    .00000        .00000
     CSZ:                      -.10000        .00000
     CCZ:                      -.21300      -0.71000E-01

   Compliance coefficients:
     CSFY, CSMZ, CCFY:       -0.15000E-03   0.83300E-03   0.14000E-02

   Tire stiffness coefficients:
     CALFA:       -26.400       .58900      -0.35500E-03   0.73190E-07
     CGAMMA:       37.000       .00000        .00000        .00000
     CALIGN:      -3.5920       .00000       0.78140E-03  -0.27430E-06
     KTIRE:        1000.0

AXLE NUMBER 2

   Suspension and tire data
     TRACK, HOROLC:             57.500        6.0000
     KZ, KAUX:                  145.00        3360.0
     CZJNCE, CZRBND:            5.0000        10.000
     ALFA0, GAMMA0:             .00000        .50000

   Kinematic coefficients:
     YROLCF:                    .00000        .00000
     HROLCF:                    .00000        .00000
     Rear axle roll steer:      .00000
     CCZ:                       .00000        .00000

   Compliance coefficients:
     CSFY, CSMZ, CCFY:        0.50000E-04   0.10000E-03   0.15000E-02

   Tire stiffness coefficients:
     CALFA:       -26.400       .58900      -0.35500E-03   0.73190E-07
     CGAMMA:       37.000       .00000        .00000        .00000
     CALIGN:      -3.5920       .00000       0.78140E-03  -0.27430E-06
     KTIRE:        1000.0
```

Figure 12. Lane Change Example; driver model, steering system, & crosswind.

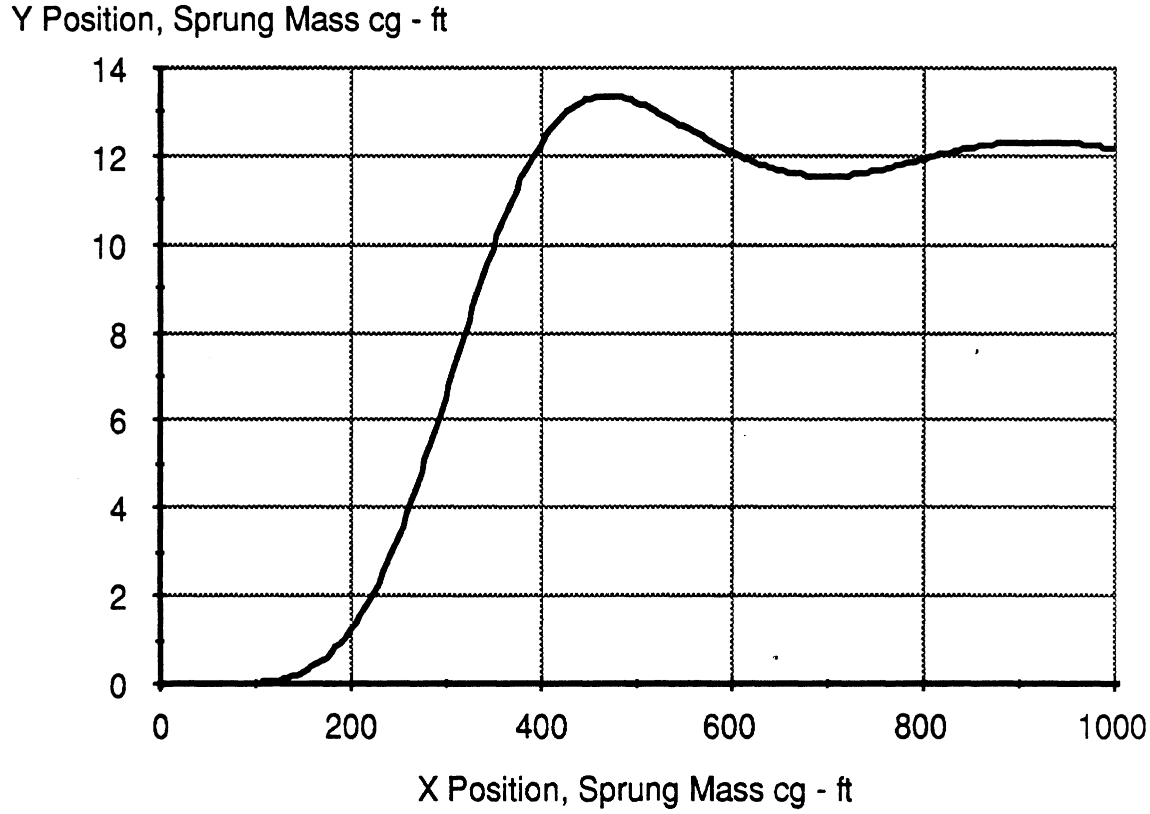


85 mi/h, 12-ft lane change, driver model + steering system, 20 mph crosswind.

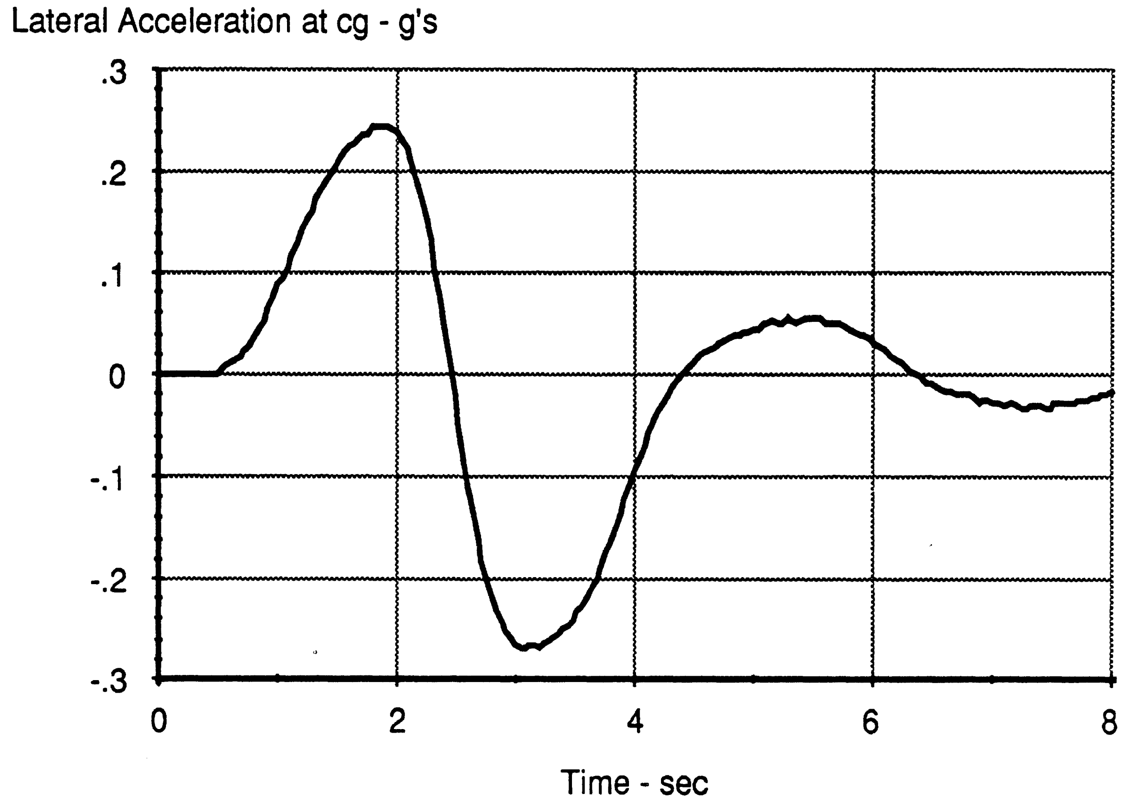


85 mi/h, 12-ft lane change, driver model + steering system, 20 mph crosswind.

Figure 13. Lane Change Example; driver model, steering system, & crosswind.



85 mi/h, 12-ft lane change, driver model + steering system, 20 mph crosswind.



85 mi/h, 12-ft lane change, driver model + steering system, 20 mph crosswind.

6. REFERENCES

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