CHRYSLER / UMTRI

Wind-Steer Vehicle Simulation

User's Manual
Version 1.4
(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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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 1990.

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1. GENERAL INFORMATION

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This manual is the first of two volumes documenting the Chrysler/UMTRI Wind-Steer Vehicle Simulation, Version 1.3. This volume 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.

This volume is divided into five chapters:

Chapter 1. **General Information**
This chapter describes the basic purpose of the program and the requirements for using it.

Chapter 2. **The Vehicle Model**
This chapter describes the vehicle model underlying the simulation code, including definitions of parameters needed to describe the vehicle and its components.

Chapter 3. **Running the Program**
This chapter explains how the program is operated, and defines in detail the required inputs.

Chapter 4. **Program Output**
This chapter describes the variables whose time histories are predicted by the model. It also shows how they can be viewed with existing software.

Chapter 5. **Example**
This chapter presents input and output data for two example simulation runs.

1.1 Introduction

The purpose of the Wind-Steer program is to calculate the time-domain response of a vehicle subject to steering inputs and crosswind disturbances. The simulated system also includes a driver model, so that the computed response to a crosswind input can include both vehicle and driver effects. In addition to the vehicle simulation software, post-processing software is available for viewing and analyzing the output responses predicted by the model.

Use of the program is analogous to conducting "vehicle tests" on the computer. As shown conceptually in Figure 1.1.1, data from the simulation are interpreted the same 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,

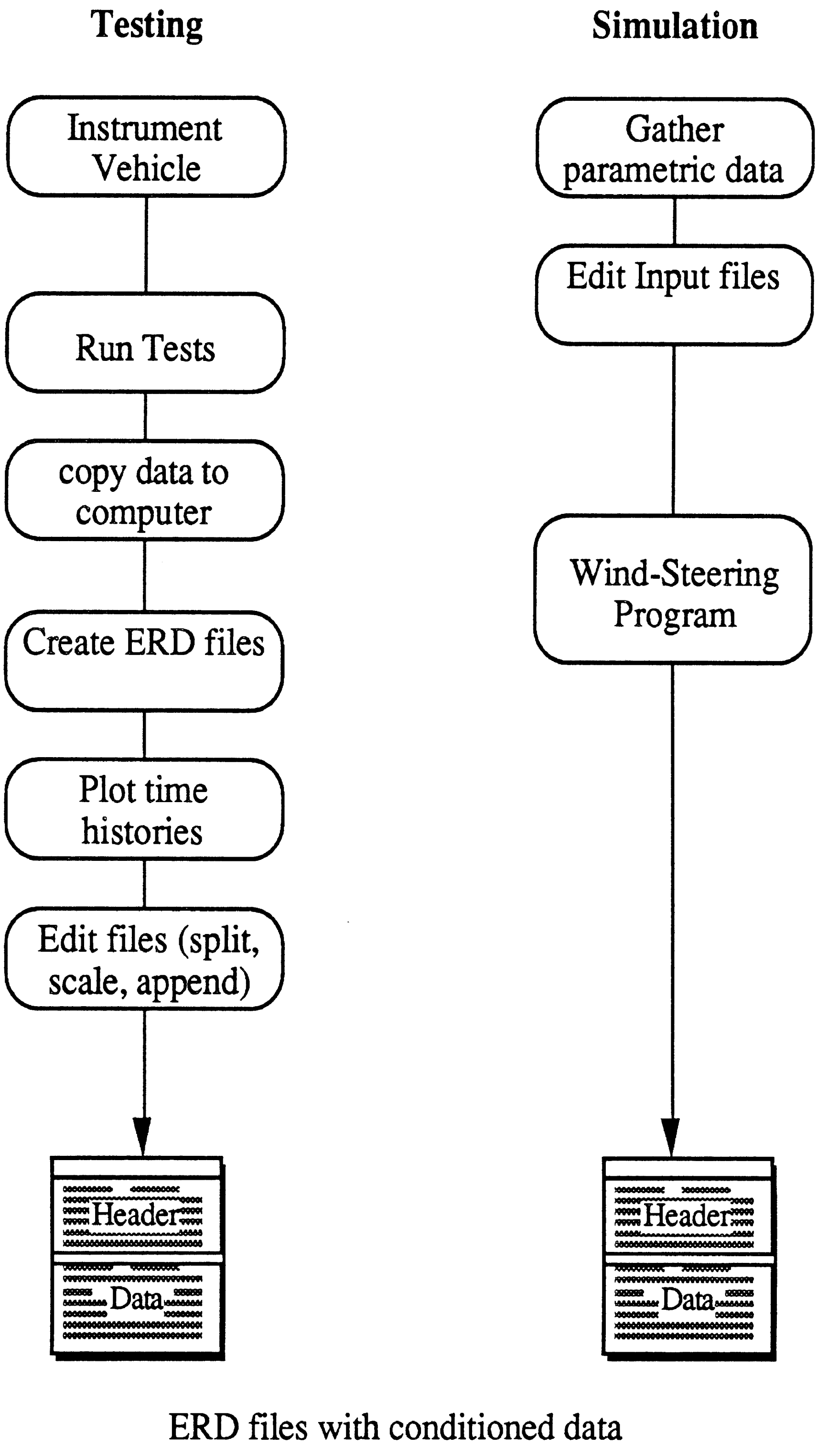

Figure 1.1.1. Simulating vehicle tests with a computer.

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 SE, and members of the Mac II family. The program is compiled using version 2.3 or 2.4 of the Absoft® MacFortran/020© compiler.
- the mainframe computer of the Michigan Terminal System (MTS) at The University of Michigan. (The compiler on MTS is called *FORTRANVS.)

1.3 Software Requirements

The Wind-Steer simulation is a self-contained computer program that requires no additional software to run. However, as a practical matter, a text editor is needed to prepare input text files for the model. Also, software is needed to view and analyze the variables whose behavior is predicted by the program.

The outputs from the program can be viewed using UMTRI software for plotting on the Macintosh. An optional 3-D animation program for the Macintosh can be used to view results of the simulation in the form of computer videos. Spectral analysis software is also available. Although the UMTRI analysis software is ideally suited for the outputs produced by the Wind-Steer program, other graphics packages and analysis programs can be used as well.

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, Section 4.4 of Volume II describes how the output file format can be modified to meet arbitrary requirements of software that might already be in use.

If the program is modified, then a Fortran compiler is needed to compile the new version.

2. THE VEHICLE MODEL

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This chapter explains the physical significance of the parameters used to represent a specific vehicle system. To do so, it describes the conceptual model of each component of the total vehicle-driver system.

This chapter does not include the complete set of equations for the system (see Chapter 3 in Volume II). Only equations that are helpful for understanding the parameter definitions are presented.

2.1 Overview

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 2 Hz. Higher frequency dynamics which involve motions of the unsprung masses or body flexing are not included because they involve frequencies well above the bandwidth of interest for steering response.

Figure 2.1.1 shows a block diagram of the Wind-Steer model. In addition to the basic model of vehicle dynamics and suspension kinematics, the system includes a steering system model, a driver model, and several types of crosswind disturbance.

The dynamics of the steering system are included as an option which can bypassed if desired. When this option is selected, the input to the steering system is a torque, T_{SW}, acting on the steering wheel. Otherwise, the input is the steering wheel angle, δ_H.

The simulation also includes a driver model. When the driver model is used, the input is a path that the driver attempts to follow. Otherwise, the input is a direct steering wheel angle or torque.

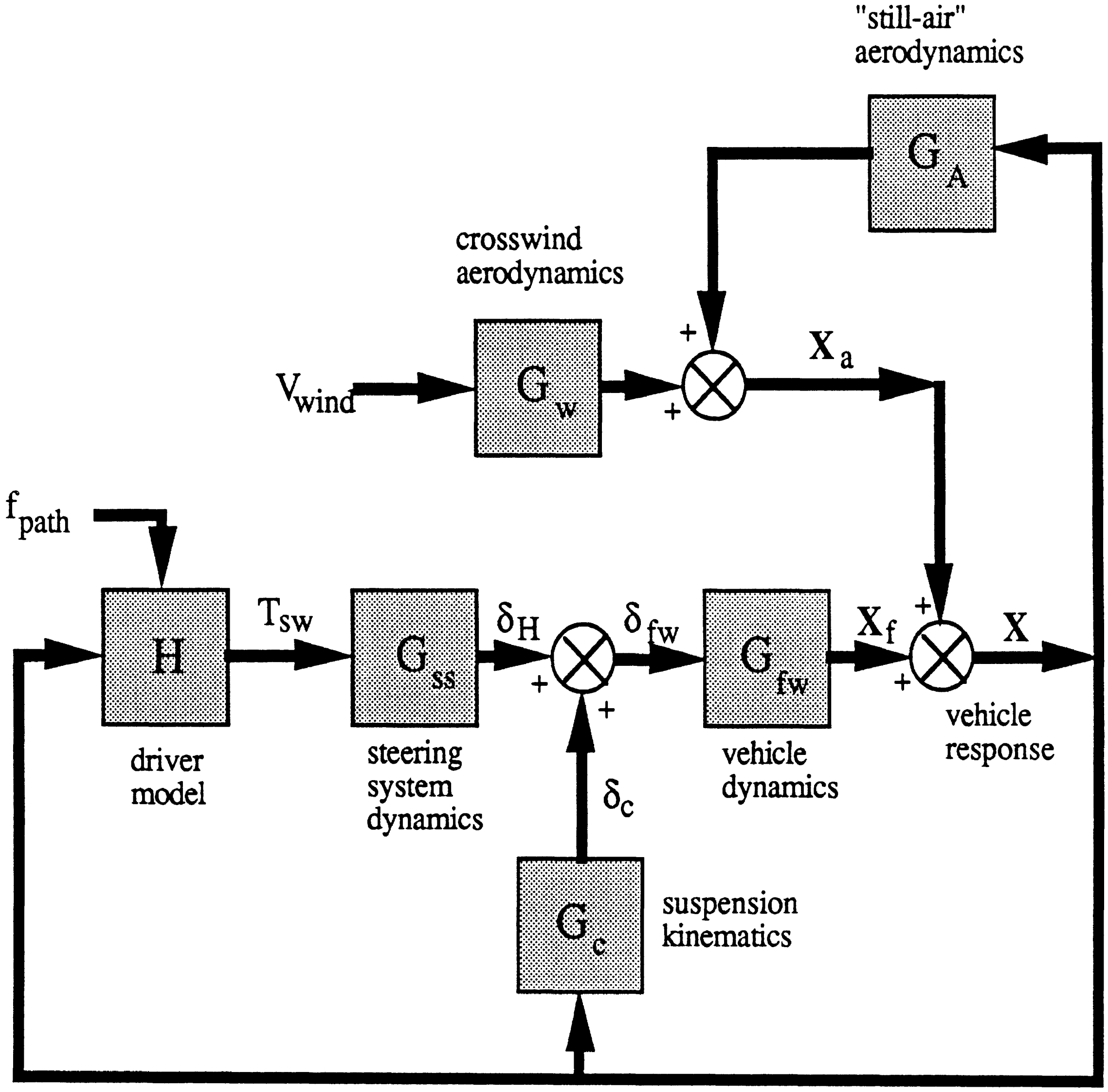

Figure 2.1.1. Wind-Steer Model — Block Diagram

The equations of motion for the vehicle are presented in Chapter 3 of Volume II. Many of the terms appearing in those equations are defined in the various subcomponent models, described below.

2.2 Vehicle Dynamics and Kinematics

The vehicle is modeled as a rigid body that is free to pitch, roll, and yaw, and to 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. The vehicle masss 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. The dynamic steering system option adds a sixth degree of freedom.

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, as illustrated in Figure 2.2.1. 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.

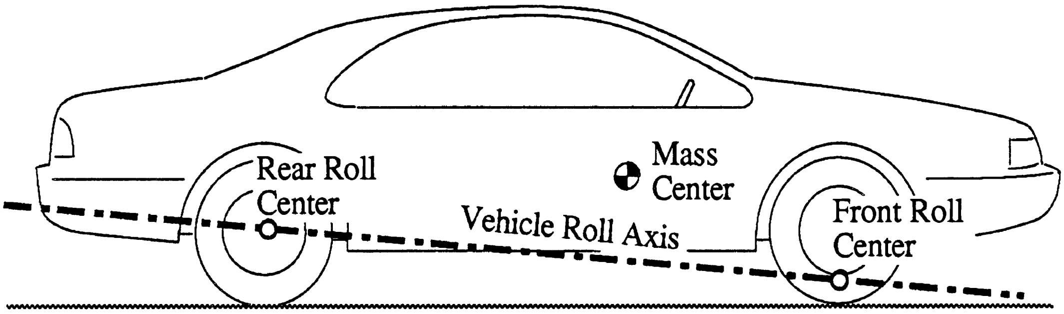

Figure 2.2.1. Roll axis in a passenger car.

The roll center for an independent suspension is usually located along the longitudinal centerline of the vehicle, near ground level. The roll center for a "beam" dead-axle is usually above the ground, near 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 (c.g.) above the roll center varies with vehicle trim height. Because the trim height is influenced by aerodynamic lift, the c.g. height is modeled as 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:

$$h_{rc} = h_0 + h_1 \phi + h_2 \phi^2 \tag{2.2.1}$$

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:

$$y_{rc} = y_1 \phi + y_2 \phi^2 \tag{2.2.2}$$

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 lean as a result of suspension deflection. The steer due to suspension deflection (bounce-steer) for each wheel on the right-hand side of the vehicle is fitted to the equation:

$$\delta_{K_{iR}} = -C_{\delta z1_i} z_{iR} - C_{\delta z1_i} z_{iR}^2 \tag{2.2.3}$$

where $\delta_{K_{iR}}$ is the additional steer angle due to suspension deflection on the right-hand side of the vehicle for axle i, $C_{\delta z1_i}$ and $C_{\delta z2_i}$ are coefficients for axle i, and z_{iR} is suspension deflection for the right-front wheel (positive for compression). On the left-hand side of the vehicle, the same coefficients apply, but in the opposite direction. That is,

$$\delta_{K_{iL}} = C_{\delta z1_i} z_{iL} + C_{\delta z1_i} z_{iL}^2 \tag{2.2.4}$$

Note that the same coefficients (by axle) are used for the left- and right-hand sides of the vehicle, and that different axle coefficients are specified front and rear.

Similar polynomials are used for the change in inclination angle of a wheel on the left- and right-hand sides of the vehicle:

$$\gamma_{K_{iR}} = -C_{\gamma z1_i} z_{iR} - C_{\gamma z2_i} z_{iR}^2 \tag{2.2.5}$$

$$\gamma_{K_{iL}} = C_{\gamma z1_i} z_{iL} + C_{\gamma z2_i} z_{iL}^2 \tag{2.2.6}$$

$\gamma_{K_{iL}}$ and $\gamma_{K_{iR}}$ are the portion of the inclination angle for a wheel on the left- and right-hand side of the vehicle, respectively, on axle i, due to suspension deflection. $C_{\gamma z1_i}$ and $C_{\gamma z2_i}$ are coefficients for axle i.

The inclination angle (γ) is the lean of the wheel to the right (at the top of the wheel) relative to a vertical line normal to the road plane. On the right-hand side of the vehicle, camber equals positive inclination. On the left-hand side of the vehicle, camber equals negative inclination.

Compliance Effects

Steer and inclination 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 on axle i and side S due to compliance ($\delta_{C_{iS}}$) is handled by linear functions of side force ($F_{Y_{iS}}$) and aligning moment ($M_{Z_{iS}}$):

$$\delta_{C_{iS}} = K_{\delta CF_i} F_{Y_{iS}} + K_{\delta CM_i} M_{Z_{iS}} \tag{2.2.7}$$

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

$$\gamma_C = -K_{\gamma CF_i} F_{Y_{iS}} \tag{2.2.8}$$

Note that the sign convention is such that a positive force and a positive coefficient define a negative change in inclination.

2.3 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 are shown in Figure 2.3.1 and should be fitted to equations shown in Table 3.1.

Table 2.3.1. Aerodynamic Forces and Moments

Description	Symbol in Vehicle Dynamics	Equation (Model)	Aerodynamics Form
Drag	$-F_{XA}$	$Q\,A\,(C_{D0} + K_D\,\beta_a^2)$	$Q\,A\,C_D$
Side Force	F_{YA}	$-Q\,A\,K_Y\,\beta_a$	$Q\,A\,C_Y$
Lift	$-F_{Za}$	$Q\,A\,(C_{L0} + K_L\,\beta_a^2)$	$Q\,A\,C_L$
Roll Moment	M_{XA}	$-Q\,A\,WB\,K_R\,\beta_a$	$Q\,A\,WB\,C_{MX}$
Pitch Moment	M_{YA}	$-Q\,A\,WB\,(C_{Y0} + K_M\,\beta_a^2)$	$Q\,A\,WB\,C_{MX}$
Yaw Moment	$-M_{ZA}$	$-Q\,A\,WB\,K_N\,\beta_a$	$Q\,A\,WB\,C_{MZ}$

In the table, A is the frontal area, β_a is the aerodynamic slip angle (equivalent to $-\psi$ in a wind-tunnel setting), WB is wheelbase, and Q is

$$Q = \frac{\rho\, V_A^2}{2} \tag{2.3.1}$$

where ρ is the air density and V_A is air speed relative to the vehicle. The fitted coefficients C_{D0}, C_{L0}, C_{Y0}, K_D, K_Y, K_L, K_R, K_M, and K_N are the input parameters required by the model. As can be seen from the table, these coefficients are combined with β_a to obtain the conventional aerodynamic coefficients (C_D, C_Y, C_L, etc.) internally in the program.

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.

2.4 Tire Model

Figure 2.4.1 shows the directions of the forces and moments acting on the tire from the road. The tire is modeled as providing side force (F_Y) and aligning moment (M_Z) as functions of slip angle (α), inclination 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:

$$F_Y = C_\alpha \alpha + C_\gamma \gamma \qquad (2.4.1)$$

$$M_Z = C_{M\alpha} \alpha \qquad (2.4.2)$$

where

$$C_\alpha = C_{\alpha 0} + C_{\alpha 1} F_Z + C_{\alpha 2} F_Z^2 + C_{\alpha 3} F_Z^3 \qquad (2.4.3)$$

$$C_\gamma = C_{\gamma 0} + C_{\gamma 1} F_Z + C_{\gamma 2} F_Z^2 + C_{\gamma 3} F_Z^3 \qquad (2.4.4)$$

$$C_{M\alpha} = C_{M0} + C_{M1} F_Z + C_{M2} F_Z^2 + C_{M3} F_Z^3 \qquad (2.4.5)$$

The 12 coefficients are fitted to match measured tire data when available. A completely

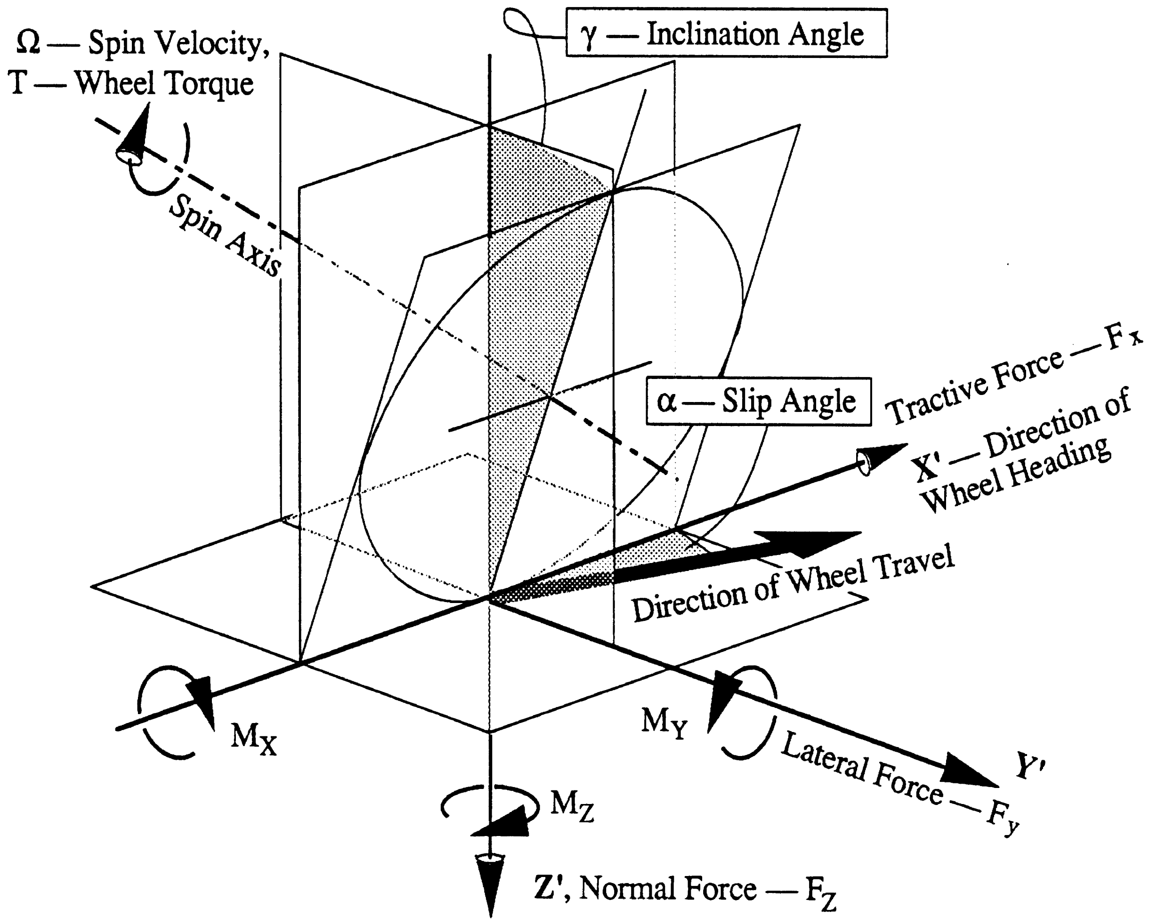

Figure 2.4.1. Tire geometry.

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}.

2.5 Steering System

The Wind-Steer model includes the dynamic steering system model shown in Figure 2.5.1 and 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 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, δ_{sw}, is the basic vehicle control input. However, when the dynamic steering system option is active, a steering wheel torque input, T_{sw}, is required instead.

Parameters whose values are needed by the program are shown in the figure in bold typeface.

The steering system equations are described further in Volume II and are largely patterned after the previous work of Segel [2,3].

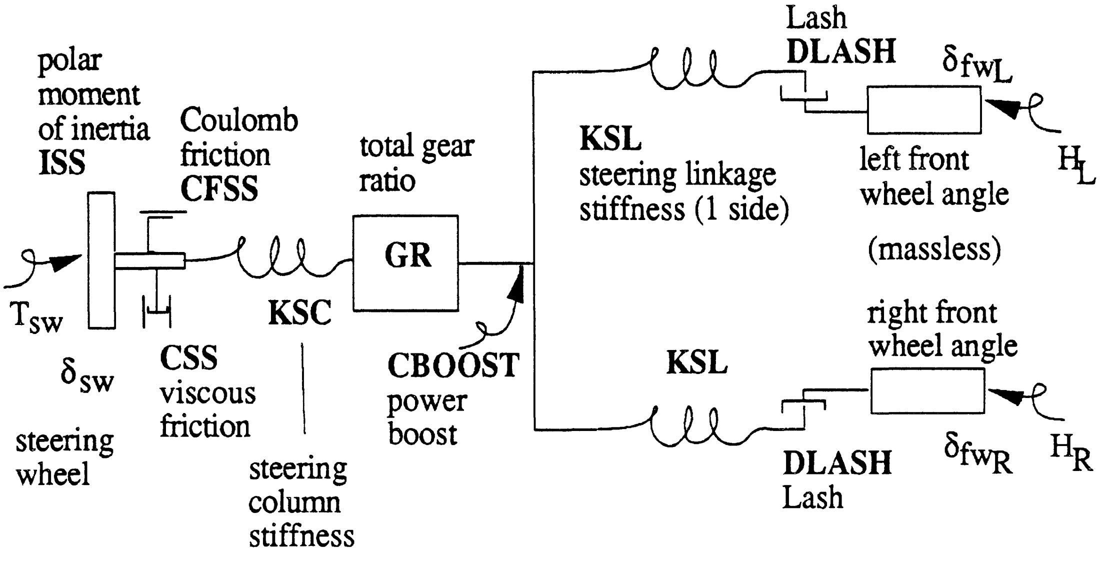

Figure 2.5.1. Complete steering system model.

2.6 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:

- driver time delay (sec).
- driver "look-ahead" (preview) time interval (sec).

The model also requires 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 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 preview parameter represents a 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 two driver-related parameters influence the level of damping of the total driver/vehicle (closed-loop) system response. 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 damping and degrading the system stability. 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.

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.

The driver model is documented by two technical papers [4,5] which are included in Appendix A of Volume II and in a recent UMTRI technical report [6].

3. RUNNING THE PROGRAM

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This chapter (1) explains how the program is operated, and (2) defines in detail the required inputs.

Most of the parameters that describe the vehicle and driver system were defined in the previous chapter. All that remains to learn about using the Wind-Steer program are the details about how to communicate parameter values to the program and view results. This chapter explains in complete detail how to prepare inputs. The outputs of the program are then defined in the next chapter.

3.1 Operation of the Software

The Wind-Steer program is primarily a batch processing program whose operation is shown schematically in Figure 3.1.1. Three files are involved with each "run:"

input file	This file must already exist. It contains the input to the program as a list of parameters describing vehicle properties and the simulation maneuver.
echo file	This file is optional. If a name is entered when the program is run, a file is created by the program that contains a formatted echo of the input data. This file also contains summary indices computed using a quasi-static analysis. If no name is entered, then no echo file is created.
ERD data file	This file is required. Two forms of output are possible—binary and text (see Chapter 4). If the text form is chosen, there is only a single output file. If the binary form is chosen, a second output file is used for the binary data with ".BIN" appended to the name.

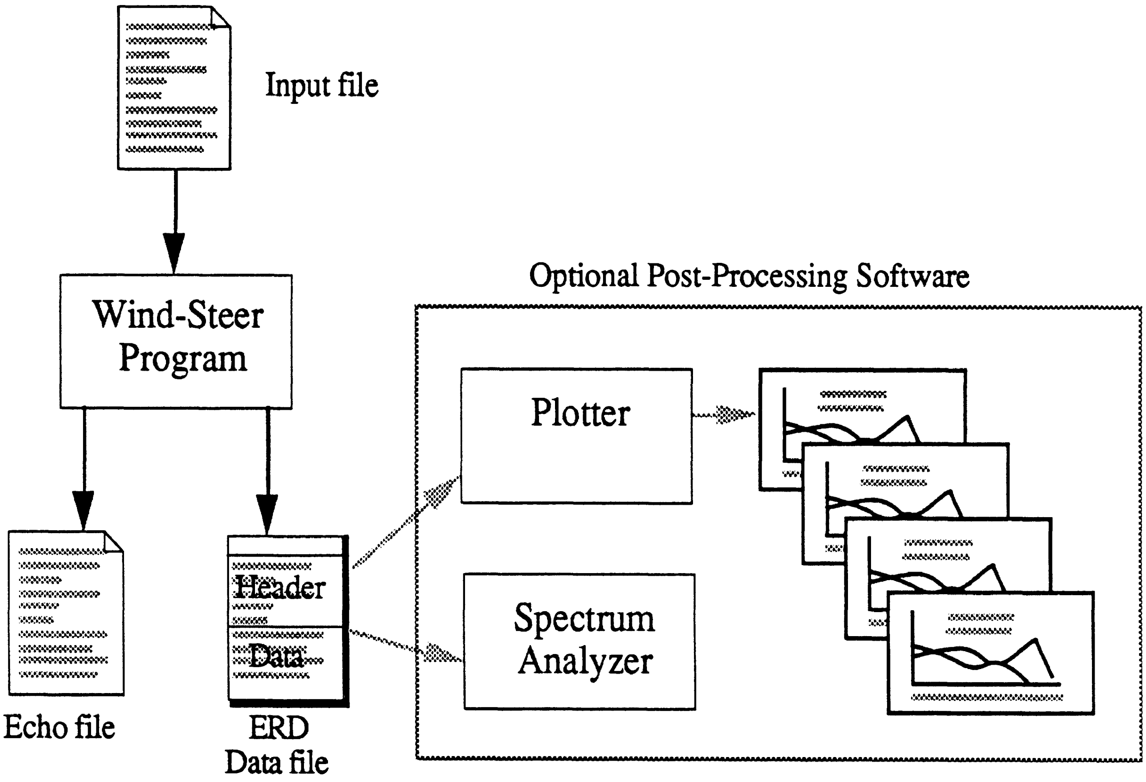

Figure 3.1.1. **Files used by Wind-Steer Program.**

3.2 Position and Formatting

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 3.2.1 shows an example input file. In the figure, vertical lines indicate the positions of columns 1, 13, 25, and 37. The positions are significant because many of the numerical values must fit within column ranges indicated by those vertical lines. It should be noted that the line numbers shown in the figure do not exist in the actual text file. Neither, of course, do the vertical lines.

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.

As mentioned earlier, a text editor is needed to view and edit the input file. It will be very helpful if the text editor shows the row and column position of the cursor on the screen.

Line	*Contents of line*				
no.	*1*	*13*	*25*	*37*	*49*
1	Lines 1 and	2 are for do	cumenting th	e file conte	nts
2	and are not	used by the	Wind-Steer m	odel.	
3	Best Aero, 5	0 mi/h, Step	-Steer Input	.	(Title line)
4	English				(IUNITS)
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, KSS, CFSS)
22	1				(NKINEM)
23	1				(NBEAM)
24	57.5	1.0			(TRACK(1), H0ROLC(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))

Figure 3.2.1 (part 1). Example input file for the Wind-Steer vehicle model.

Line	*Contents of line*				
no.	*1*	*13*	*25*	*37*	*49*
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)

Figure 3.2.1 (part 2). Example input file for the Wind-Steer vehicle model.

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.

It so happens that the compilers used for the Macintosh and IBM PC versions of the Wind-Steer program do permit free-form numerical input. With these versions, multiple numerical entries can be separated by commas. However, the number must still fit within the column ranges shown in the figure.

3.3 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.

All lines in the file after the first five 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 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 (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 wind.

(WINDKY ≥ 0) Wind input is provided in table form			
9.1	(2F12.)	TIMWIN(1), WINMAG(1)	TIMWIN(1) and WINMAG (1) are the first entries and both *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. The number of entries in the table is WINDKY. 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 ≠ 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)	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).

<table>
<tr><td colspan="4">(NSTEER = 0) Steering wheel angle SW is defined by function</td></tr>
<tr><td></td><td colspan="2">IF T ≤ TSWBGN</td><td>SW = 0</td></tr>
<tr><td></td><td colspan="2">IF TSWBGN < T < TSWEND</td><td>SW = SWSHFT + SWAMPL * SIN (2 * PI * (T – TSWBGN) / TSWPRD + SWPHSE)</td></tr>
<tr><td></td><td colspan="2">IF TSWEND ≤ T</td><td>SW = SWSHFT + SWAMPL * SIN (2 * PI * (TSWEND – TSWBGN) / TSWPRD + SWPHSE)</td></tr>
<tr><td>10.1</td><td>(2F12.)</td><td>TSWBGN,
TSWEND</td><td>start and stop times for steer inputs (sec). (See above equations)</td></tr>
<tr><td>10.2</td><td>(2F12.)</td><td>SWSHFT,
SWAMPL</td><td>SWSHFT is a bias in amplitude (deg | rad).
SWAMPL is the sinusoidal amplitude (deg | rad). (See above equations)</td></tr>
<tr><td>10.3</td><td>(F12.)</td><td>TSWPRD,
SWPHSE</td><td>TSWPRD is the time period of the sinusoid (sec). SWPHSE is the phase angle of the sinusoid (deg | rad).</td></tr>
</table>

<table>
<tr><td colspan="4">(NSTEER > 0) Steering wheel angle (or torque) is provided in table form</td></tr>
<tr><td>10.1</td><td>(2F12.)</td><td>XPNT(1),
YPNT(1)</td><td>XPNT(1) is the first time in the table, and <i>must</i> be 0.0. YPNT(1) is the first steer angle (or torque) in the table, and <i>must</i> be 0.0.</td></tr>
<tr><td>10.J</td><td>(2F12.)</td><td>XPNT(J),
YPNT (J)</td><td>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. The table includes NSTEER entries. 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).</td></tr>
</table>

11	(3F12.)	WEIGHT, SPWGHT, WRATIO	WEIGHT is the total vehicle weight (lb | N). SPWGHT is the sprung weight (lb | 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 | N-m-sec^2) KSC is the stiffness of the upper steering column (in-lb/deg | N-m/rad) DLASH is the lash (+/-) of each front wheel, (deg | rad). KSL is the one-side stiffness of the steering system linkage below the gear box (in-lb/deg | 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 | m). CSS is the viscous damping of the steering system lumped at the steering wheel location (in-lb-sec/deg | N-m-sec).
21	(3F12.)	CBOOST, SSKEY, CFSS	CBOOST is the power boost coefficient for the steering system model (power/power). (That is, 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 | 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 | m) and quadratic (in/deg^2 | 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 | m) and quadratic (in/deg^2 | 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 | m^{-1}) and quadratic (deg/in^2 | m^{-2}) bump-steer coefficients for front suspensions.
27.4	(2F12.)	CCZ(1,1), CCZ(1,2)	Linear (deg/in | m^{-1}) and quadratic (deg/in^2 | 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).

3.4 Summary of Program Options

Table 3.4.1 lists the various options that are implemented in Version 1.3. of the Wind-Steer vehicle simulation program.

Table 3.4.1. Simulation options in the Wind-Steer program.

Category	Option	How to Specify Option	Line(s) in input file
Units	English	set UNITS = A	4
	MKS	set UNITS ≠ A	4
Type of Output File	text	set FRMT to valid format	5
	binary	set FRMT to blank	5
Crosswind	"still air"	set WINDKY = 0	9
	table lookup	set WINDKY > 0, provide *n* entries for table	9, 9.1, ...
	compute with subroutine	set WINDKY < 0, provide subroutine WINSUB	9
Steering System Dynamics	no dynamics	set SSKEY = 0, specify steer as angle for "open-loop" inputs	21
	dynamic steering model	set SSKEY > 0, specify steer as torque for "open-loop" inputs	19, 20, 21
Steer Input	"open-loop" steering wheel angle/torque obtained from table	set NSTEER > 0, provide *n* entries for table	10, 10.1, ...
	"open-loop" sinusoidal steering wheel angle/torque	set NSTEER = 0, provide data for sinusoid	10, 10.1, 10.2, 10.3
	"closed-loop" steering to follow specified path	set NSTEER < 0, provide *n* entries for table and two driver parameters	10, 10.1, ..., 10.*n*+2
Independent Suspensions	static roll center	set NKINEM = 0	22
	moving roll center	set NKINEM ≠ 0, specify linear and quadratic coeficients.	22, 27.1, 27.2, 27.3, 27.4
Type of Rear Suspension	independent	set NBEAM = 0	23, 36.3a
	beam rear axle	set NBEAM ≠ 0	23, 36.3b

4. PROGRAM OUTPUT

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4.4 Echo File 34

This chapter describes the form of the program output. It also shows how plots are made of the data.

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 4.2.1 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 4.2.1 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 all but the first two lines in the header portion of the file. 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 in Table 4.2.2.

Table 4.2.1. Example list of output channels in an output (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
```

Line no.	Contents of line 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...

Figure 4.2.1. Example output file produced by the Wind-Steer vehicle model.

Table 4.2.2. Lines in header of ERD file made by Wind-Steer program.

Line	Keyword	Description
1	ERDFILEV2.00	Identify file as a Version 2.00 ERD file.
2	—	Define 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 (this depends on the options used during the run) NSAMP = no. of samples (-1 = "read to end of file"). NRECS[1] = no. of records (-1 = "read to 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	Title for the file. This line is copied from the third line of the input file.
4	SHORTNAM	List with one short name (8 characters) for each channel in the file.
5	LONGNAM	List with one long name (32 characters) for each channel in the file. 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 above 63.

---

[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.

Table 4.2.2 (continued). Lines in header of ERD file made by Wind-Steer program.

8	UNITSNAM	List with 8-character name of the units for each channel.
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	The UMTRI model used to generate the data file.
16	SPEEDMPH	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 [e.g., (66G13.6)].
18	HISTORY	Description of 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 4.2.1, 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

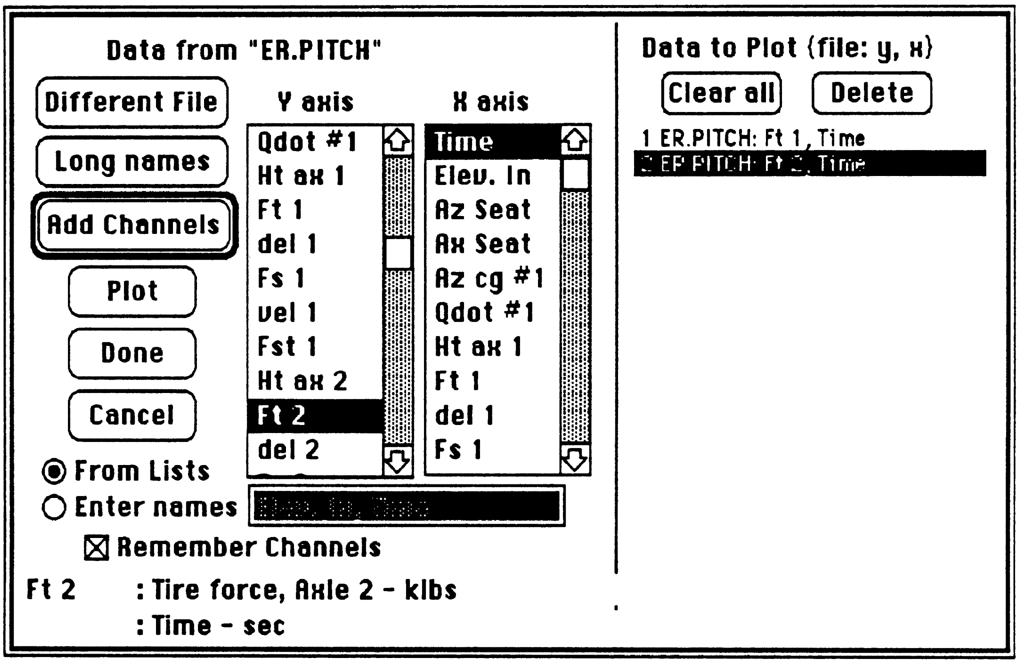
Software has been developed for viewing and analyzing ERD files on the Macintosh and the mainframe computer at The University. At UMTRI, nearly all analyses of this sort are performed using Macintoshes that are networked together with several IBM PCs.

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.)


Data from "ER.PITCH"

Data to Plot (file: y, x)

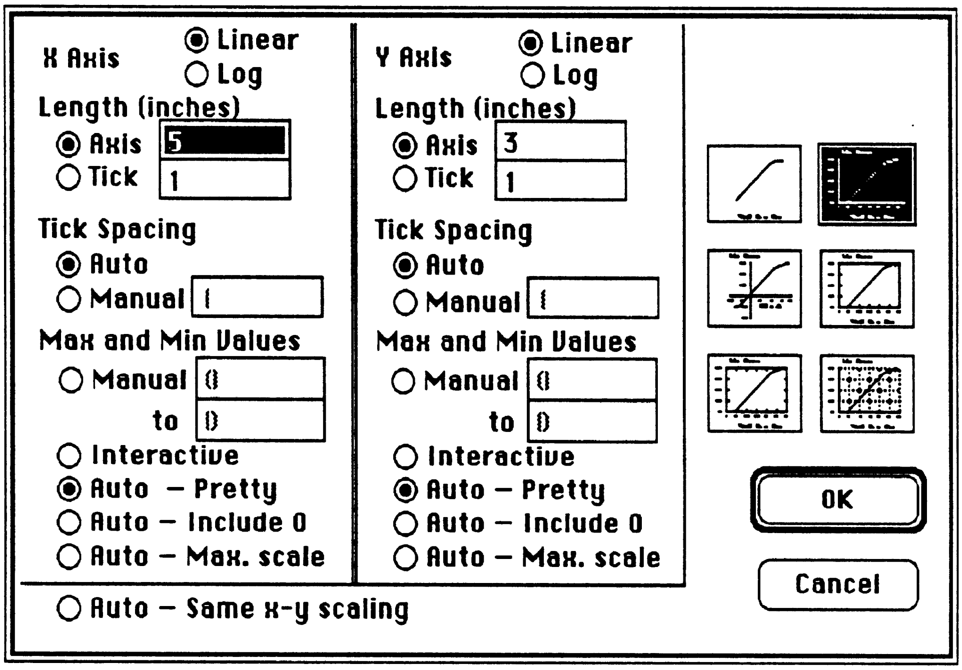
1 ER.PITCH: Ft 1, Time
2 ER.PITCH: Ft 2, Time

● From Lists
○ Enter names

☒ Remember Channels

Ft 2 : Tire force, Axle 2 - klbs
: Time - sec

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


X Axis ● Linear ○ Log
Length (inches)
● Axis 5
○ Tick 1
Tick Spacing
● Auto
○ Manual 1
Max and Min Values
○ Manual 0
to 0
○ Interactive
● Auto – Pretty
○ Auto – Include 0
○ Auto – Max. scale

Y Axis ● Linear ○ Log
Length (inches)
● Axis 3
○ Tick 1
Tick Spacing
● Auto
○ Manual 1
Max and Min Values
○ Manual 0
to 0
○ Interactive
● Auto – Pretty
○ Auto – Include 0
○ Auto – Max. scale

○ Auto – Same x-y scaling

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.

4.4 Echo File

An optional output file containing an "echo" of the input parameters may also be identified at the beginning of a simulation run. The vehicle and simulation parameters are then simply listed in formatted groupings in this echo file. (Examples of these follow in Section 5.) At the end of each echo file, following the parameter listings, is a set of static "Summary Calculations" which identify, among other things, the approximate vehicle understeer gradient and static crosswind sensitivity based upon the input parameters just entered. (These static calculations only account for lateral yaw-plane aerodynamics and do not include aerodynamic lift forces and pitching moments that may re-distribute vertical tire loads away from the assumed "no-air" initial static load condition.) An example "Summary Calculation" listing is seen below:

```
*** Summary Calculations ***


Front C-alpha (lb/deg):       (Effective => 55.4% of front tire-alone)    153.9
Rear  C-alpha (lb/deg):       (Effective => 93.4% of rear tire-alone)     203.1
Pneumatic & mechanical trail (in):                                        2.173
Steering system stiffness (in-lb/deg):                                    1499.5
Steering Syst Compl Reduction Factor:                                     .766
Front Rolling & Camber Reduction Factor:                                  .724
Total Front C-alpha Reduction Factor:        (55.4%)                      .554
Rear Camber & Fy Compl Reduction Factor:                                  .978
Rear Align Torque Compl Reduction Factor:                                 .955
Total Rear C-alpha Reduction Factor:         (93.4%)                      .934
Understeer Gradient (deg/g):                                              3.297
```

Distance from c.g FORWARD to neutral steer pt (in), XCGNS:	-17.73
Distance from WB/2 FORWARD to center of pressure (in), XL2CP:	25.810
Distance from WB/2 FORWARD to c.g (in), XL2CG:	11.058
Distance from WB/2 FORWARD to neutral steer pt (in), XL2NS:	-6.671
Distance from neut steer pt FORWARD to cent of press (in), XNSCP:	32.481
Wind Sensitivity (deg/s of yaw rate / deg of wind sideslip), WSEN:	.090

The C-alpha values seen above are *effective* front and rear tire cornering stiffnesses corresponding to an "equivalent" (and greatly simplified) non-rolling vehicle having no steer, camber, or steering system compliances. These values are derived from the actual tire and vehicle data entered and indicate the *approximate* level of cornering stiffnesses available after accounting for "losses" from the front and rear suspension properties and the steering system compliance. (The actual front and rear tire cornering stiffnesses are obtained by dividing the effective C-alpha values by the corresponding "total reduction factors.") Following the indicated reduction factors, the understeer gradient is then estimated and printed next in units of degrees per g, using the effective tire cornering stiffnesses and the entered vehicle weight distribution.

Following the understeer gradient, distances of the neutral steer point, aerodynamic center of pressure, and mass center relative to one another and to the mid-wheelbase point "WB/2" are then listed. The last parameter shown, "WSEN", is the approximate static crosswind sensitivity of the vehicle. It is listed in units of degrees/second of yaw rate per degree of crosswind and represents the amount of steady-state yaw rate expected from this vehicle *due to a constant crosswind of one degree and no steering wheel input.* (e.g., A constant crosswind of 15 degrees would be predicted to produce a vehicle steady-state turning response of 15 times the WSEN value shown, or, 1.35 degrees/second.) Reference [8] further describes and discusses the static crosswind sensitivity parameter.

The intent of these summary calculations is simply to provide the program user with basic information regarding the locations of the neutral steer point and aerodynamic center of pressure, while also providing nominal estimates of vehicle understeer and static crosswind sensitivity. Such information can often be useful for helping to understand subsequent simulation results, or for conducting more simplified analyses.

5. EXAMPLES

5.1 Step Steer Example 36
5.2 Lane Change Example 41

This chapter presents two example simulations made with the Wind-Steer model. In both cases, the input files, echo files, and example output plots are shown.

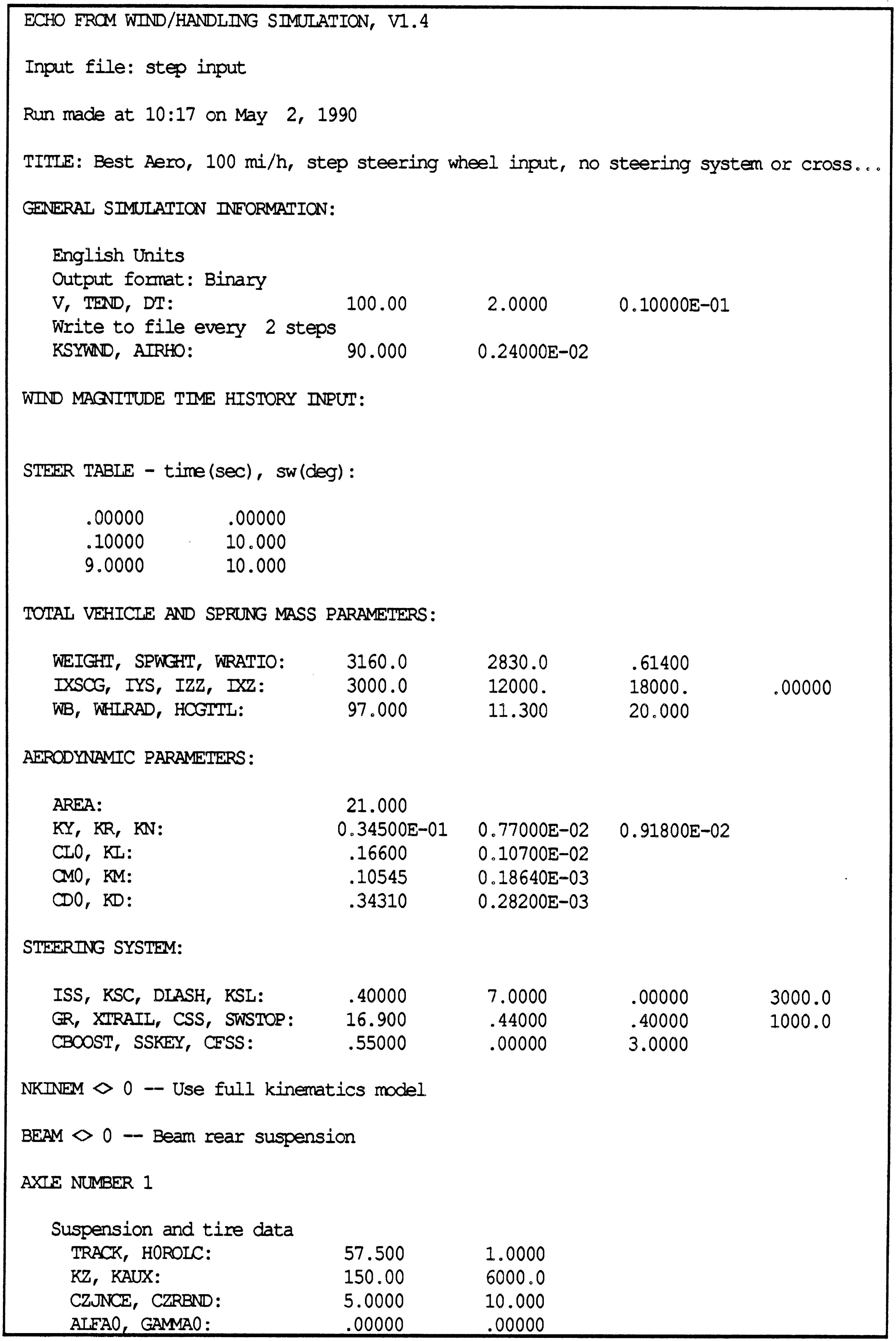
5.1 Step Steer Example

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.

Figure 5.1.1 shows the input data set, and Figure 5.1.2 shows the corresponding "echo" file for that data set. Figure 5.1.3 shows plots of the steering wheel input and the resulting vehicle lateral acceleration.

```
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), H0ROLC(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), H0ROLC(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 5.1.1. Input file for step-steer example.

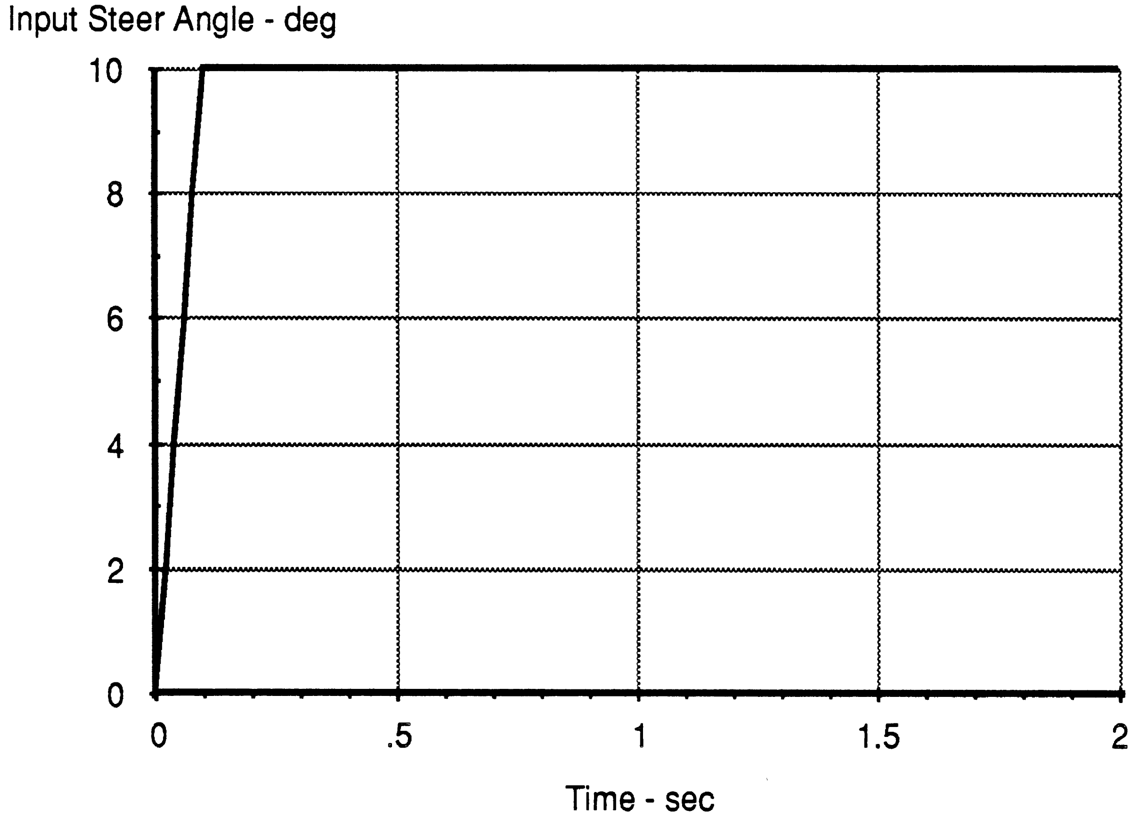


```
ECHO FROM WIND/HANDLING SIMULATION, V1.4

Input file: step input

Run made at 10:17 on May  2, 1990

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

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, SWSTOP:    16.900        .44000        .40000        1000.0
   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
```

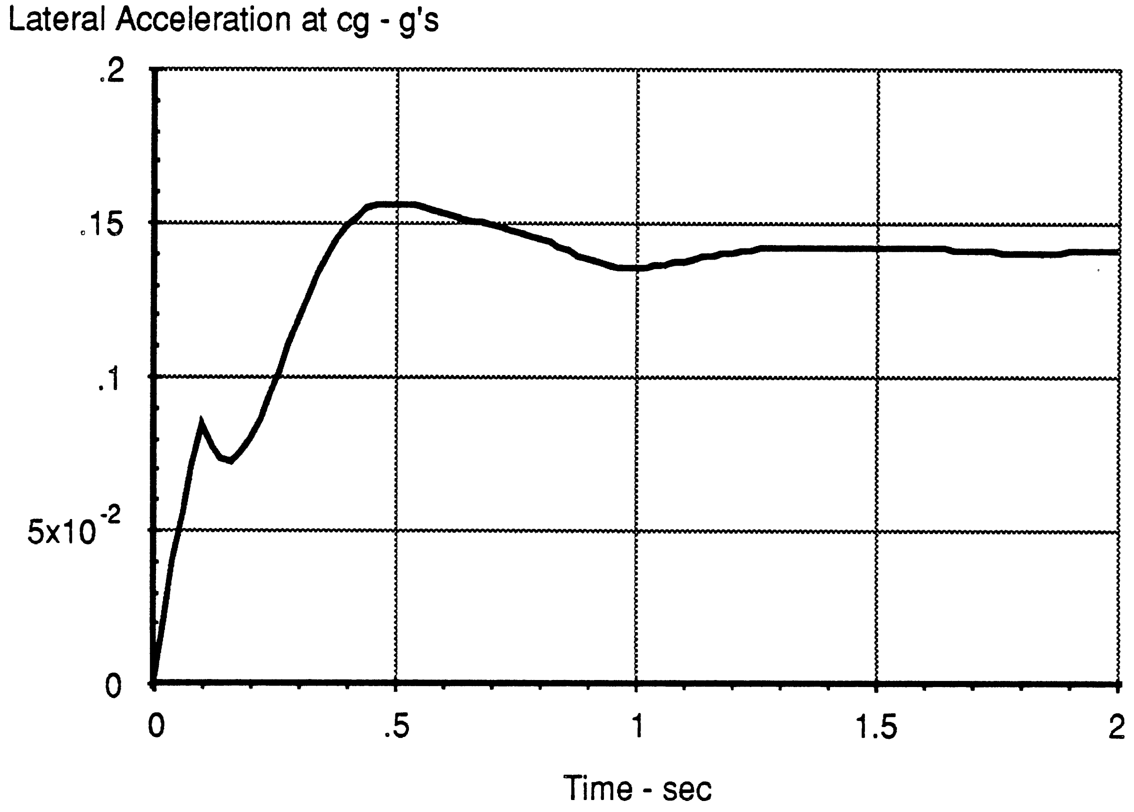
Figure 5.1.2 (part 1). Echo file for step-steer example.

```
  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

  *** Summary Calculations ***

  Front C-alpha (lb/deg):                                    201.101
  Rear  C-alpha (lb/deg):                                    203.110
  Front Rolling & Camber Reduction Factor:                      .724
  Total Front C-alpha Reduction Factor:                         .724
  Rear Camber & Fy Compl Reduction Factor:                      .978
  Rear Align Torque Compl Reduction Factor:                     .955
  Total Rear C-alpha Reduction Factor:                          .934
  Understeer Gradient (deg/g):                                 1.821
  Distance from c.g FORWARD to neutral steer pt (in),  XCGNS:          -11.299
  Distance from WB/2 FORWARD to center of pressure (in), XL2CP:        25.810
  Distance from WB/2 FORWARD to c.g (in),  XL2CG:                      11.058
  Distance from WB/2 FORWARD to neutral steer pt (in), XL2NS:           -.241
  Distance from neut steer pt FORWARD to cent of press (in), XNSCP:    26.052
  Wind Sensitivity (deg/s of yaw rate / deg of wind sideslip), WSEN      .124
  SIMPLIFIED (less accurate) Wind Sensitivity  Measure, WSIMP:           .172
```

Figure 5.1.2 (part 2). Echo file for step-steer example.



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 5.1.3. Example plots for step-steer maneuver.

5.2 Lane Change Example

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.

Figure 5.2.1 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 5.2.2. The corresponding "echo" file of that input set is provided in Figure 5.2.3. Figure 5.2.4 shows the steering wheel torque produced by the driver model and the resulting steering wheel angle from the dynamic steering system model. Figure 5.2.5 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.

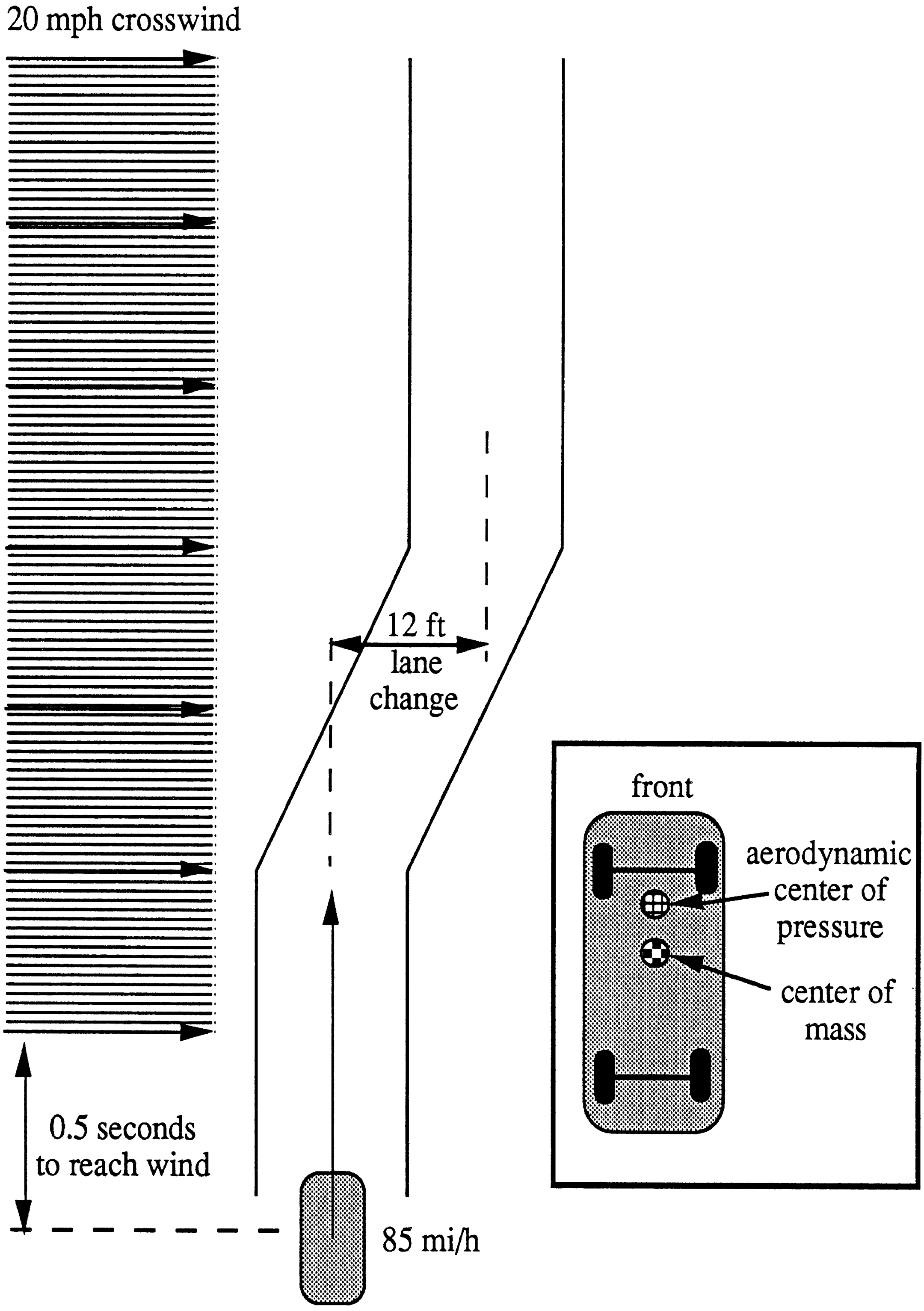


Figure 5.2.1. Lane Change Example. Driver Model Performing 12-ft Lane Change Maneuver in the presence of a 20 mph Crosswind.

```
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 5.2.2. Input file for lane change maneuver.

```
ECHO FROM WIND/HANDLING SIMULATION, V1.4

Input file: lane in

Run made at 10:52 on May  2, 1990

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, SWSTOP:     16.900        .44000        .40000        1000.0
   CBOOST, SSKEY, CFSS:         .62000        1.0000        3.0000

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

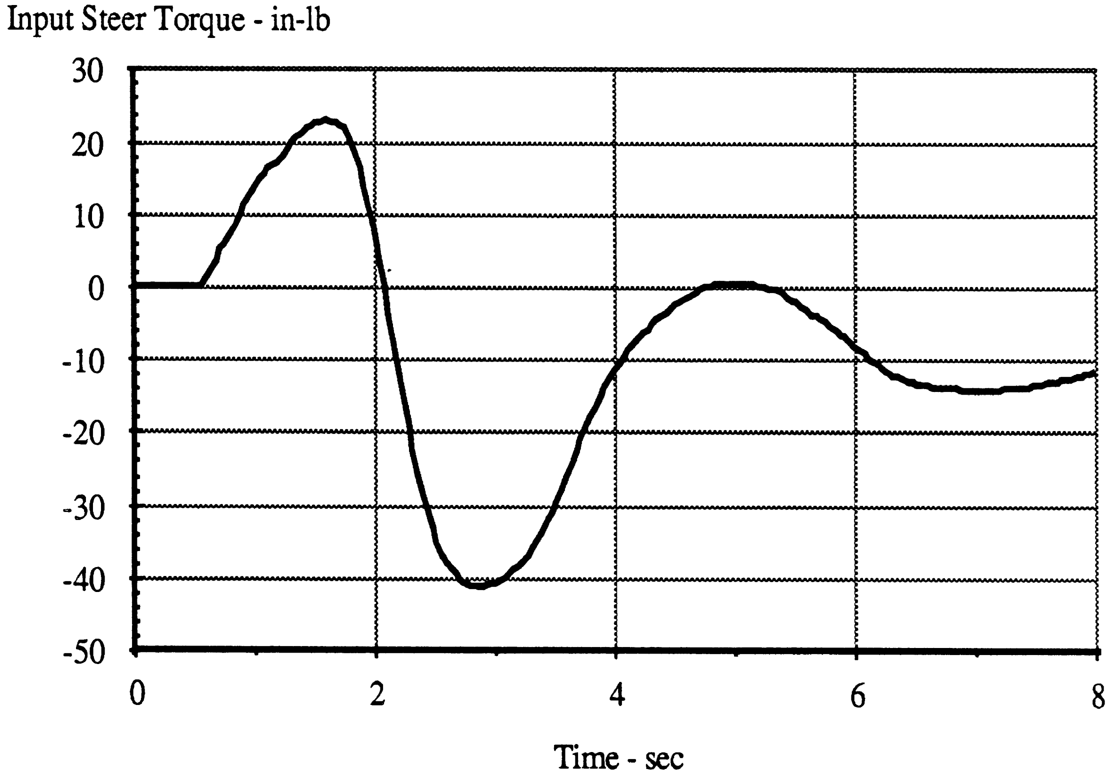
Figure 5.2.2 (part 1). Echo file for lane-change example.

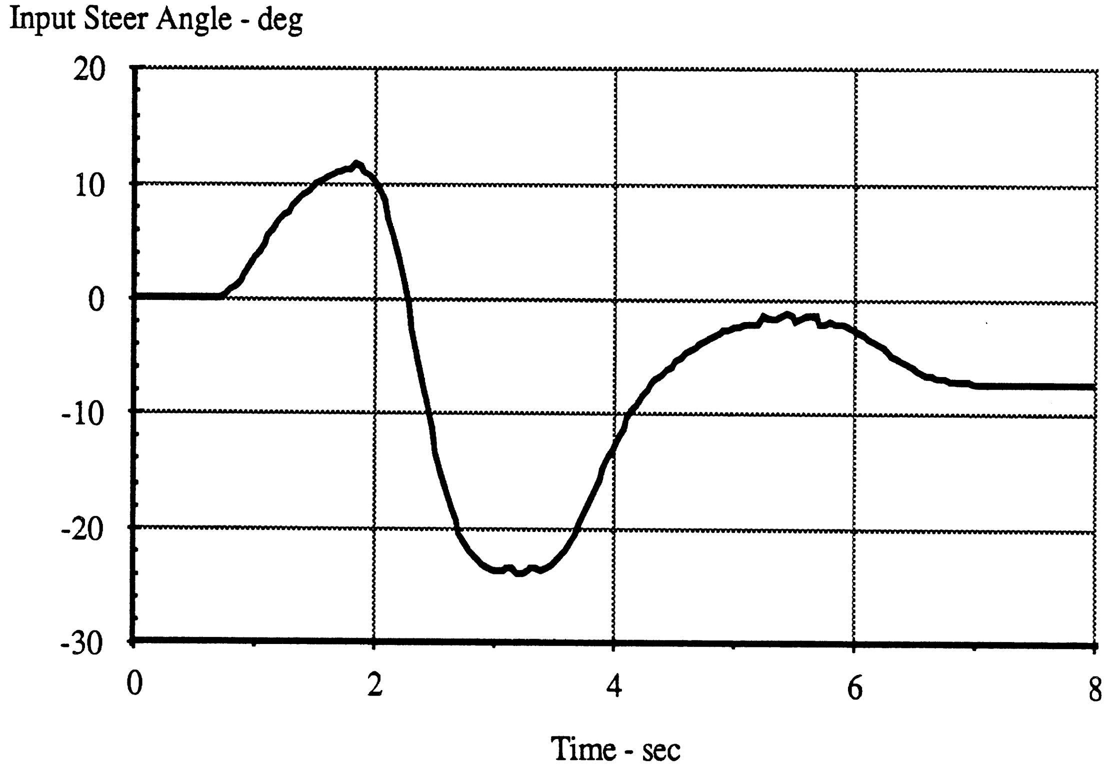
```
BEAM <> 0 -- Beam rear suspension

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 5.2.2 (part 2). Echo file for lane-change example.

```
*** Summary Calculations ***

Front C-alpha (lb/deg):                                      153.995
Rear  C-alpha (lb/deg):                                      203.110
Pneumatic & mechanical trail (in):                             2.173
Steering system stiffness (in-lb/deg):                      1499.589
Steering Syst Compl Reduction Factor:                           .766
Front Rolling & Camber Reduction Factor:                        .724
Total Front C-alpha Reduction Factor:                           .554
Rear Camber & Fy Compl Reduction Factor:                        .978
Rear Align Torque Compl Reduction Factor:                       .955
Total Rear C-alpha Reduction Factor:                            .934
Understeer Gradient (deg/g):                                   3.297
Distance from c.g FORWARD to neutral steer pt (in),  XCGNS:           -17.729
Distance from WB/2 FORWARD to center of pressure (in), XL2CP:          25.810
Distance from WB/2 FORWARD to c.g (in),  XL2CG:                        11.058
Distance from WB/2 FORWARD to neutral steer pt (in), XL2NS:            -6.671
Distance from neut steer pt FORWARD to cent of press (in), XNSCP:      32.481
Wind Sensitivity (deg/s of yaw rate / deg of wind sideslip), WSEN        .090
SIMPLIFIED (less accurate) Wind Sensitivity  Measure, WSIMP:             .116
```

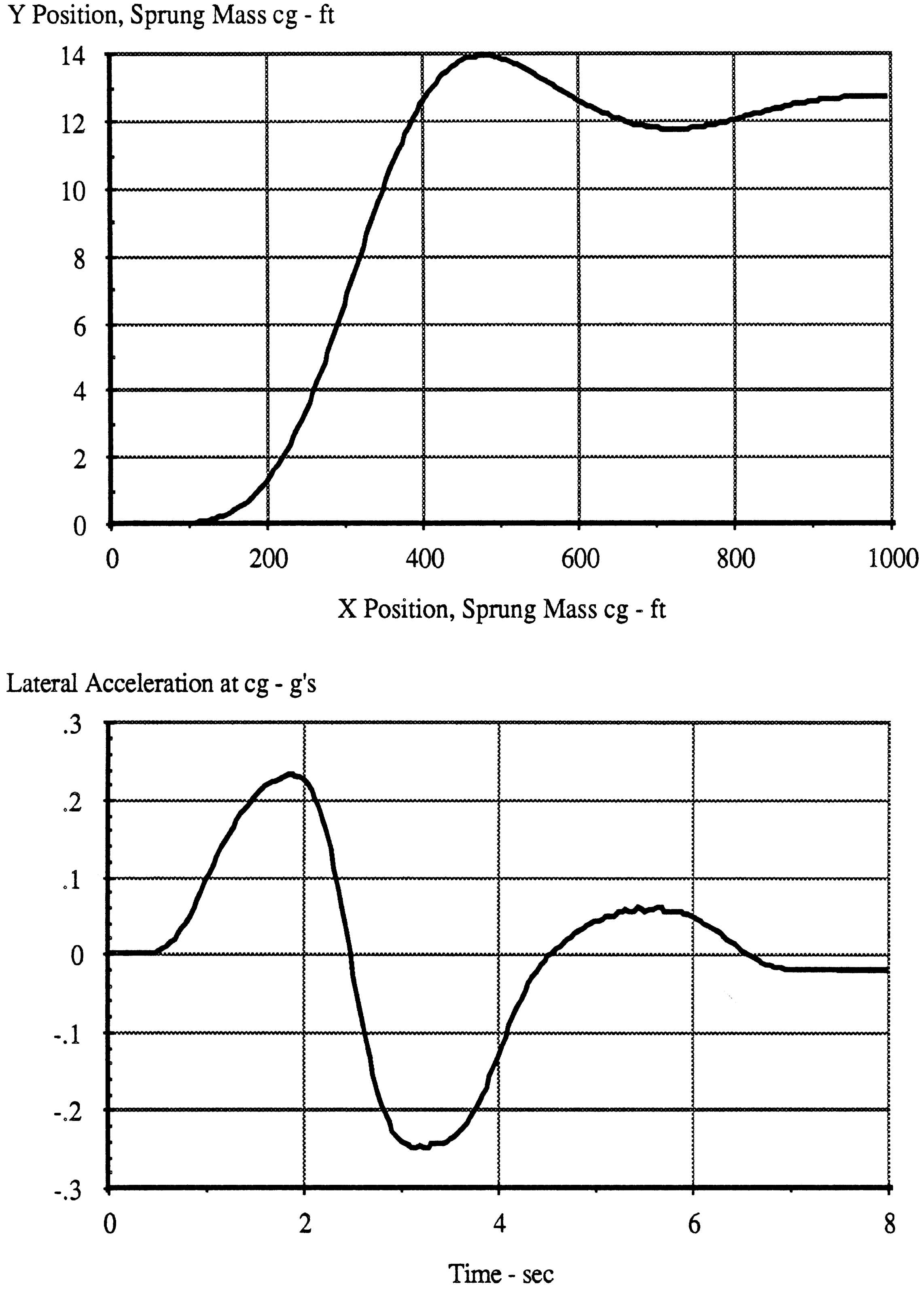
Figure 5.2.2 (part 3). Echo file for lane-change example.





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

Figure 5.2.3. Plots of steer inputs for lane-change maneuver.



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

Figure 5.2.4. Plots of vehicle motion variables in lane-change maneuver.

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