SIMPLIFIED MODELS OF TRUCK BRAKING AND HANDLING

A User's Manual for

The Low-Speed and High-Speed Offtracking Models
The Straight Line Braking Model
The Static Roll Model
The Steady Turn Model (Handling)
The Rearward Amplification Model
The Brake Temperature Model

Engineering Research Division

September 1990
Version 3.0

UMTRI The University of Michigan Transportation Research Institute

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Introduction and General Information

Introduction

The *Simplified Models* discussed in this manual were developed by The University of Michigan Transportation Research Institute (UMTRI) through support provided by The Motor Vehicle Manufacturers Association (MVMA).

This *User's Manual* presents general and specific instructions for using the particular *Simplified Models* which you have purchased. The intent of this manual is to provide the information necessary to operate the *Simplified Models* in the IBM PC environment. (It is assumed that the user is experience with the IBM PC or compatible computer.) This manual is *not* intended to be a primer on the principles of vehicle dynamics on which these models are based. A review of the engineering background of all of the UMTRI *Simplified Models* is available in:

Fancher, P.S. and Mathew, A. "A Vehicle Dynamics Handbook for Single-Unit and Articulated Heavy Trucks." Final Rept., Contract No. DTNH22-83-C-07187, Transp. Res. Inst., Univ. of Mich., Rept. No. UMTRI-86-27, May 1987. (US Report No. DOT HS 807 185, NTIS Order. No. PB-88 134044/GAR.)

A companion volume to the "Handbook" is:

Fancher, P.S., et al. "A Factbook of the Mechanical Properties of the Components for Single-Unit and Articulated Heavy Trucks." Final Rept., Contract No. DTNH22-83-C-07187 Transp. Res. Inst., Univ. of Mich., Rept. No. UMTRI-86-12, March 1987. (US Report No. DOT HS 807 125, NTIS Order. No. PB-87 228433/GAR.)

The "Factbook" is largely a review of the descriptive parameter data for commercial vehicles and their components which UMTRI has produced over the past two decades. Representative values for many of the descriptive parameters required by the *Simplified Models* are presented. The significance of these parameters to commercial vehicle dynamic performance is reviewed.

These documents are available through the National Technical Information Service (NTIS) in Springfield, Virginia (Tel. 703 487-4650) or through the UMTRI Library in Ann Arbor, Michigan (Tel. 313 764-2171). Other references of interest are given in the brief bibliography presented at the end of this introductory section.

Users may also wish to know that UMTRI presents two courses of instruction on the principles of commercial vehicle behavior and the specific use of the *Simplified Models*. The more general course is entitled "The Mechanics of Heavy Duty Trucks and Truck Combinations." This five day intensive course is presented each July in Ann Arbor, Michigan, under the auspices of the "Engineering Summer Conferences" of the University. This course includes a "hands on" computer laboratory session based on the *Simplified Models*. Arrangements can be made to present this course away from Ann Arbor on a private basis.

The second course is meant specifically as instruction on the use of the *Simplified Models*. It is a two day course designed especially to be a "road show" presented at the user's facility. The course includes background lectures on the mechanical principles on which each model is based as well as "hands on" instruction on the use of the models.

Promotional and descriptive material for these courses appear in the Appendix.

Engineering Approach and Philosophy

The *Simplified Models* operate in either SI or English units as specified by the user. The programs were originally written in the English form. The SI units are simply the English data and parameters converted for all CRT and printer I/O functions, but the actual data remain in English units. That is, the user may deal with SI or English units, but the program always operates in English units. It is important to note that all data files for both English and SI versions, including the INC.SET file (see *General Program Operation*, page 11) as well as vehicle data files (see *Directions for the Use of Individual Programs*), store data in English units, and may be read by the program regardless of the selection of English or the SI units. Thus, vehicle files may be created or read interchangeably using either English or SI units. In this *Introduction and General Information* section, both English and SI units are covered in defining vehicle parameters. In the later sections giving *Directions for the Use of Individual Programs*), example output appear in English units only.

Some of the features of the *Simplified Models* are summarized in the Table 3. The amount of input information describing the vehicle depends upon the model involved. As can be seen by inspecting the table, a minimal amount of descriptive information is needed for some of the models. Although the models are designed to require as little input data as possible, to use the entire set of models, a significant amount of descriptive information is required. Pertinent information on the force and moment properties of tires, suspensions, and brakes are needed, as well as information on the layout of the vehicle.

Table 2 presents a complete list of all of the vehicle descriptive parameters (as well as some parameters describing "maneuvers") required as input by the *Simplified Models*. The table also gives the engineering units (English and SI) of each parameter and presents a matrix showing in which model each parameter is used. The definitions of all of these parameters are provided in Appendix C: *Glossary of Descriptive Parameters* .

The outputs of the models (see Table 3) are referred to as "performance signatures" (graphs and/or tables) and "performance measures" (numerics). These outputs are tailored to the maneuvers addressed by these *Simplified Models*. The performance signatures and measures are the links to evaluating vehicle designs.

For example, one could set levels of the performance measures to use as performance targets. Then, the *Simplified Models* could be used to obtain first order estimates of whether preliminary designs (or existing vehicles) will meet these performance targets. If a design seems to fall short of desired levels of performance, one can use the models to study the influences of changes in the mechanical properties of the vehicle on the performance signatures of the vehicle. The results of this process could be either changes in design or changes to more realistic levels of performance expectations. In any event, the ultimate goal of these models is to help the user to develop a better understanding of the braking and handling performances of heavy trucks.

Table 2. Correspondence Between Descriptive Parameters and Models
--In Order of Occurrence--

	Unit English	Unit SI	Low Speed Steady State Off tracking	Low Speed Transient Off tracking	High Speed Steady State Off tracking	Straight Line Braking	Static Roll	Steady Turn (Handling)	Rearward Amp	Brake Temperature
Wheelbase	in	cm	X	X	X					
Distance from front suspension to rear articulation	in	cm	X	X	X					
Distance from front articulation to rear articulation	in	cm	X	X	X					
Distance from front suspension to rear extremity	in	cm	X	X	X					
Distance from front articulation to rear extremity	in	cm	X	X	X					
Front suspension load	lbs	N	X	X	X					
Total cornering stiffness of front tires	lb/deg	N/deg	X	X	X					
Rear suspension load	lbs	N	X	X	X					
Total cornering stiffness of rear tires	lb/deg	N/deg	X	X	X					
Radius of the turn	ft	m	X	X	X					
Angle of the turn	deg	deg		X						
Forward velocity	mph	kph			X				X	
g-level	g	g			X					
Total weight	lbs	kg				X	X	X	X	
Total c.g. height	in	cm				X	X	X		
Distance to rear articulation	in	cm				X				
Rear articulation height	in	cm				X				
Suspension # i load	lbs	N				X				
Suspension # i key						X				
Radius of a tire	in	cm				X	X	X		
Pushout pressure	psi	kpa				X				
Brake key						X				
Axle # i brake gain	in-lb/psi	N-m/kpa				X				
Tandem axle separation	in	cm				X				
Inter-axle load transfer coefficient						X				
Unit key						X				
Number of points in the torque table						X				
Number of auxiliary axles						X				
Treadle pressure	psi	kpa				X				
Torque	in-lb	N-m				X				
Spring table							X			
Spring lash	in	cm					X			
Total number of axles on the unit							X	X		
Axle load	lbs	N					X	X		
Track width of the axle	in	cm					X	X		
Weight of the axle	lbs	kg					X	X		

Roll center height	in	cm					X	X		
Spacing between suspension springs	in	cm					X	X		
Auxiliary roll stiffness	in-lb/deg	N-m/deg					X	X		
Total number of tires on the axle							X	X		
Vertical stiffness of a tire	lb/in	N/m					X	X		
Roll coupling key							X	X		
Roll steer coefficient	deg/deg	deg/deg						X		
Suspension stiffness	lb/in	N/m						X		
Distance from c.g. to rear articulation	in	cm						X	X	
Steering gear ratio								X		
Steering stiffness	in-lb/deg	N-m/deg						X		
Tie rod stiffness	in-lb/deg	N-m/deg						X		
Mechanical trail	in	cm						X		
Aligning moment stiffness per tire	in-lb/deg	N-m/deg						X		
C.g. - axle distance	in	cm						X	X	
Nominal load on the tire	lbs	N						X		
Cornering stiffness table								X		
Vertical force	lbs	N						X		
Cornering stiffness	lb/deg	N/deg						X	X	
Distance from c.g. to front articulation	in	cm						X	X	
Type of unit									X	
Yaw moment of inertia	in-lb-sec2	kg-m2								
Initial steering frequency	rad/sec	rad/sec							X	
Final steering frequency	rad/sec	rad/sec							X	
Air drag coefficient										X
Ambient temperature	°F	°C								X
Brake drum weight	lbs	Kg								X
Brake proportioning										X
Cooling coefficient constant, K1	hp/°F	KW/°C								X
Cooling coefficient constant, K2	hp/°F-mpl	KW/°C-Kph								X
Distance (longitudinal)	miles	Km								X
Elevation	ft	m								X
Frontal area	ft2	m2								X
Initial brake temperature	°F	°C								X
Number of points in the auxiliary retarding table										X
Number of points in the road profile										X
Number of stops										X
Road surface coefficient										X
Specific heat of brake drum	hp-hr/lb-°	KW-hr/Kg-°C								X
Stop times	minutes	minutes								X
Total number of axles on the vehicle										X
Type of tire										X
Velocity	mph	Kph								X

Table 2 (continued). Correspondence Between Descriptive Parameters and Models
--In Alphabetical Order--

	Unit English	Unit SI	Low Speed Steady State Off tracking	Low Speed Transient Off tracking	High Speed Steady State Off tracking	Straight Line Braking	Static Roll	Steady Turn (Handling)	Rearward Amp	Break Temperature
Air drag coefficient										X
Aligning moment stiffness per tire	in-lb/deg	N-m/deg						X		
Ambient temperature	°F	°C								X
Angle of the turn	deg	deg		X						
Auxiliary roll stiffness	in-lb/deg	N-m/deg					X	X		
Axle # i brake gain	in-lb/psi	N-m/kpa				X				
Axle load	lbs	N					X	X		
Brake drum weight	lbs	Kg								X
Brake key						X				
Brake proportioning										X
C.g. - axle distance	in	cm						X	X	
Cooling coefficient constant, K1	hp/°F	KW/°C								X
Cooling coefficient constant, K2	hp/°F-mph	KW/°C-Kph								X
Cornering stiffness	lb/deg	N/deg						X	X	
Cornering stiffness table								X		
Distance from c.g. to front articulation	in	cm						X	X	
Distance from c.g. to rear articulation	in	cm						X	X	
Distance from front articulation to rear articulation	in	cm	X	X	X					
Distance from front articulation to rear extremity	in	cm	X	X	X					
Distance from front suspension to rear articulation	in	cm	X	X	X					
Distance from front suspension to rear extremity	in	cm	X	X	X					
Distance (longitudinal)	miles	Km								X
Distance to rear articulation	in	cm				X				
Elevation	ft	m								X
Final steering frequency	rad/sec	rad/sec							X	
Forward velocity	mph	kph			X				X	
Front suspension load	lbs	N	X	X	X					
Frontal area	ft2	m2								X
g-level	g	g			X					
Initial brake temperature	°F	°C								X
Initial steering frequency	rad/sec	rad/sec							X	
Inter-axle load transfer coefficient						X				
Mechanical trail	in	cm						X		
Nominal load on the tire	lbs	N						X		
Number of auxiliary axles						X				

Number of points in the auxiliary retarding table										X
Number of points in the road profile										X
Number of points in the torque table						X				
Number of stops										X
Pushout pressure	psi	kpa				X				
Radius of a tire	in	cm				X	X	X		
Radius of the turn	ft	m	X	X	X					
Rear articulation height	in	cm				X				
Rear suspension load	lbs	N	X	X	X					
Road surface coefficient										X
Roll center height	in	cm					X	X		
Roll coupling key							X	X		
Roll steer coefficient	deg/deg	deg/deg						X		
Spacing between suspension springs	in	cm					X	X		
Specific heat of brake drum	hp-hr/lb-°	KW-hr/Kg-°C								X
Spring lash	in	cm					X			
Spring table							X			
Steering gear ratio								X		
Steering stiffness	in-lb/deg	N-m/deg						X		
Stop times	minutes	minutes								X
Suspension # i key						X				
Suspension # i load	lbs	N				X				
Suspension stiffness	lb/in	N/m						X		
Tandem axle separation	in	cm				X				
Tie rod stiffness	in-lb/deg	N-m/deg						X		
Torque	in-lb	N-m				X				
Total c.g. height	in	cm				X	X	X		
Total cornering stiffness of front tires	lb/deg	N/deg	X	X	X					
Total cornering stiffness of rear tires	lb/deg	N/deg	X	X	X					
Total number of axles on the unit							X	X		
Total number of axles on the vehicle										X
Total number of tires on the axle							X	X		
Total weight	lbs	kg				X	X	X	X	X
Track width of the axle	in	cm					X	X		
Treadle pressure	psi	kpa				X				
Type of tire										X
Type of unit									X	
Unit key						X				
Velocity	mph	Kph								X
Vertical force	lbs	N						X		
Vertical stiffness of a tire	lb/in	N/m					X	X		
Weight of the axle	lbs	kg					X	X		
Wheelbase	in	cm	X	X	X					
Yaw moment of inertia	in-lb-sec2	kg-m2								

Table 3. Features of the Simplified Models

MODEL NAME	INPUTS	OUPUTS (performance signatures and measures) (graphs)	(numerics)
Low-speed offtracking	wheel and hitch locations	paths of each axle in turns of various radii	maximum offtracking
High-speed offtracking	the above plus tire cornering stiffnesses and axle loads	steady turn offtracking at various axles	steady turning offtracking at various g-levels
Constant deceleration braking	brake force characteristics as a function of treadle pressure,inertial properties, wheel and hitch locations	friction utilization and deceleration as a function of treadle pressure	braking efficiencies at various g-levels
Steady turn, roll	suspension roll properties, axle loads, inertial properties, and tire vertical stiffnesses	roll angle versus lateral acceleration	rollover threshold
Handling in a steady turn	the above plus steering system properties, tire cornering stiffnesses, and geometric layout	handling diagram and stability space (if the vehicle is unstable w/o wheel liftoff), steering sensitivity diagrams	steering gain at various lateral acceleration and velocity levels, stability margin
Obstacle avoidance (rearward amplification)	vehicle layout, inertial properties, tire cornering stiffnesses	rearward amplification versus frequency of steering excitation	maximum rearward amplification at low frequencies
Brake temperature	vehicle and brake parameters, and description of the road profile in terms of distance, elevation, and velocity	road profile,brake temperatures, or horsepower demand versus elevation, time, or distance	brake temperature and horsepower demands at each interval along the road profile

Computer Requirements and Information

The *Simplified Models* are programmed in Microsoft FORTRAN for use on an IBM PC or compatible computer with a minimum of 512 kilobytes of random access memory (RAM). The models also require that either an 8087 (for IBM XT computers) or an 80287 (for IBM AT computers) "math co-processor" be installed in the computer.

The results of the simple model calculations are output in numerical and graphical forms. To mechanize the graphical output, the *Simplified Models* contain licensed program materials of the Metagraphics Software Corporation. (Copyright © 1986, 1987 Metagraphics Software Corporation, Scotts Valley, CA 95066.)* The *Simplified Models* and the Metagraphics software support the graphics boards listed in Table 4. To obtain graphical results from the *Simplified Models*, one of these graphics cards must be installed in the computer. (Only the offtracking model *requires* a graphics board since it always produces graphical results. It is possible to use the other models without a graphics card, obtaining only numerical results.)

The *Simplified Models* support Epson/IBM Proprinter and compatible printer devices.

Back Up Your Disks

One "Graphics Files disk" and one or more (depending on how many programs you have purchased) "*Simplified Models* disks" are included with this manual. All of these disks may be copied in a straight forward manner. You should make working copies of these disks immediately, and save the originals as your backup.

Creating A Simplified Models System Disk

The Graphics Files disk contains three files, viz.:

- METAWIND.BAT
- METAWNDO.EXE
- PRTSCRN.EXE

METAWIND.BAT is a "batch" file, which contains the commands needed to install METAWNDO.EXE and PRTSCRN.EXE. METAWNDO.EXE and PRTSCRN.EXE are the components of the MetaWINDOW™ DOS Resident Graphics Driver system by Metagraphics. METAWNDO.EXE is the program which mechanizes the plotting of results on the screen. PRTSCRN.EXE allows the plots on the screen to be output on the printer.

---

* Your programs include Metagraphics MetaWINDOW™ DOS Resident Graphics Driver. This system includes the files METAWNDO.EXE and PRTSCRN.EXE.

Table 4. Graphics Boards Supported by the Simplified Models Programs

1) Amdek 1280 Graphics Display
- 320x200 4-level monochrome
- 640x200 monochrome
- 640x400 monochrome
- 1280x400 monochrome
- 1280x800 monochrome

2) AST-3G Model 1 Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 4-level monochrome

3) ATI Graphics Solution Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 4-color
- 640x200 16-color
- 720x348 monochrome

4) ATronics MegaGraph Plus Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

5) AT&T Display Controller Board
- 320x200 4-color
- 640x200 2-color
- 640x400 2-color

6) AT&T Display Enhancement Board
- 640x400 16-color

7) Classic Technology Monographics Adaptor
- 720x348 monochrome

8) Everex Graphics Edge Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x400 4-color

9) Genoa Spectra EGA Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

10) Hercules Monochrome Graphics Adaptor
- 720x348 monochrome

11) IBM Color Graphics Adaptor (CGA)
- 320x200 4-color
- 640x200 2-color

12) IBM Enhanced Graphics Adaptor (EGA)
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

13) MDS Genius Adaptor & Display
- 738x1004 monochrome

14) NEC GB-1 Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x480 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

15) NSI EPIC Graphics Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

16) Paradise Autoswitch EGA Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

17) Paradise Modular Graphics Adaptor
- 320x200 4-color
- 640x200 2-color

18) PC Designs EGA Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

19) Quadram QuadEGA+
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

20) Quadram ProSync Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x480 16-color
- 752x410 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

21) Sigma Design Color-400 Adaptor
- 320x200 4-color
- 640x200 2-color
- 640x400 16-color

22) Sigma Design SigmaEGA Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

23) STB EGA Plus Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

24) STB Graphics Plus II Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 4-color

25) Tatung TEGA-22 Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 4-level monochrome

26) Tecmar EGA Master Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome

27) Tecmar GraphicsMaster Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x400 16-color
- 720x352 monochrome
- 720x704 monochrome

28) Tseng Labs EVA-480 Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x480 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

29) Video-7 VEGA Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

30) Video-7 VEGA/Deluxe Adaptor
- 320x200 4-color
- 320x200 16-color
- 640x200 2-color
- 640x200 16-color
- 640x350 16-color
- 640x480 16-color
- 752x410 16-color
- 640x350 4-level monochrome
- 720x348 monochrome

31) Wyse WY-700 Graphics Display
- 320x200 4-level monochrome
- 640x200 monochrome
- 640x400 monochrome
- 1280x400 monochrome
- 1280x800 monochrome

METAWIND.BAT must be executed prior to running any of the *Simplified Models* programs.

This can be done "by hand" once your computer is booted, by installing the Graphics Files disk in the active drive, typing "METAWIND" and pressing the **ENTER** (↵) key.

We recommend, however, that you create a *Simplified Models* System disk. To do this, create a normal system startup disk for your computer. Install the three files from the Graphics Files disk on your new startup disk. Then do one of the following two things:

1) If you do not already have an "AUTOEXEC.BAT" file on your system disk, then you may change the name of the METAWIND.BAT file to AUTOEXEC.BAT, **or**
2) You may include as the last line in your AUTOEXEC.BAT file, the command: METAWIND

You will now have created a *Simplified Models* System disk. When you boot your computer with this disk, the required graphics programs will automatically be installed.

Note: The MetaWINDOW™ software must deal with other graphics related hardware besides the graphics board (for example, a mouse) which may be installed in your computer. To help insure proper operation of the *Simplified Models*, be sure that all software driver programs for mouse boards and any other graphics-related hardware are properly installed *before* executing the METAWIND.BAT file.

The remainder of this manual assumes that you are using a *Simplified Models* System disk. As mentioned, however, you may choose to install the graphics drivers "by hand" following a boot with any system disk appropriate for your computer.

General Program Operation

Boot your computer with the *Simplified Models* System disk which you have created. After a few seconds, the screen should appear similar to that shown in Screen #1. This screen indicates that the system has been booted and that the Metagraphics software is installed.

The "Options in effect " refer to PRTSCRN options. This portion of this screen will only appear if IBM DOS Version 3.0 or greater is in use. Earlier versions of DOS do not allow the user to access or control the PRTSCRN options.

The "Options in effect" shown in Screen #1 indicate that the system is configured for an Epson/IBM Proprinter attached to LPT1, and that graphics screens will be printed in "Normal" (black lines on white paper) mode in the "Landscape" (sideways on 8 1/2 x 11 page) position. These are the default options and are generally the more desirable option settings.

```
A:\ ?

              MetaWINDOW Graphics Driver - Version 3.2B
    Copyright (c) 1986, 1987 - Metagraphics Software Corporation

    MetaWINDOW - Resident driver installed.

         MetaWINDOW Print Screen Utility Installed - Version 3.1C
 Copyright (c) 1986 z Metagraphics Software Corporation z Scotts Valley, CA

          MetaWINDOW Print Screen Utility Resident - Version 3.1C

 Options in effect:

     Printer  = Epson/IBM Proprinter
     Port     = LPT1
     Video    = Normal
     Format   = Landscape

 Metagraphics z 4575 Scotts Valley Dr, Scotts Valley, CA   95066 z 408/438-1550

  Copyright (c) 1986 z Metagraphics Software Corporation z Scotts Valley, CA

 IBM Personal Computer DOS Version 3.20

A:\ ?
```

Screen #1

If DOS 3.0 or greater is installed, the user may alter the latter three of these options to allow for a printer attached to LPT2, or to print in "Inverse" mode or in the "Portrait" position. If desired, the user should make these option selections at this time, before running any of the simple model programs. The Metagraphics option commands are:

PRTSCRN /1	Use printer attached to LPT1 (default)
PRTSCRN /2	Use printer attached to LPT2
PRTSCRN /n	Print normal (default)
PRTSCRN /i	Print inverse
PRTSCRN /l	Landscape position
PRTSCRN /p	Portrait position*
PRTSCRN /s or /?	Show options in effect

* The portrait option is appropriate only for wider line printers and papers. The Metagraphis software will "clip" the right side of the graph on printers using 8 1/2 inch wide paper.

Once the computer has been booted using the system disk and the options are set to the users liking, the *Simplified Models* program disk containing the model to be run can be inserted, and the directions for running that particular program (see *Directions for the Use of Individual Models*) should be followed.

In addition to the models themselves, the program disks contain several sample data files for the model or models on that disk, plus a special data file called "INC.SET."

Each of the models involves repetitive calculations accomplished at incremental steps of a basic independent variable. The INC.SET file contains data identifying the size of the increment for each of these variables. Generally, as the size of this increment is made smaller, the solution of the problem becomes more accurate, but also more time consuming. Each program disk is delivered with an INC.SET file containing the recommended values of each increment. The original content of the INC.SET file as provided by UMTRI is shown in Table 5.

Table 5. Original content of the INC.SET file.

Content of File	Comment
1 INCREMENTS CONFIGURATION	
2	(Comment line)
3	(Comment line)
4	(Comment line)
01.0000	(Offtracking, path increment (ft), low speed transient)
01.0000	(Braking, treadle pressure increment (psi))
0.001	(Roll, roll angle increment (rad))
0.025	(Handling, lateral acceleration increment (g's))
0.25	(Rearward Amplification, steering frequency increment (rad/sec))
01.00	(Model not yet implemented, any value will work)
01.00	(Model not yet implemented, any value will work)

The INC.SET file must be present on the program disk to insure the proper functioning of the models. The line-by-line contents of the file are as follows:

1) The first line is a comment line and may contain any information, preceded by a 1 and a space.
2) The second line is a comment line and may contain any information, preceded by a 2 and a space.
3) The third line is a comment line and may contain any information, preceded by a 3 and a space.
4) The fourth line is a comment line and may contain any information, preceded by a 4 and a space.
5) The fifth line specifies the path increment for low speed transient offtracking in feet. Initial setting: 1 ft.

6) The sixth line is the treadle pressure increment for the braking model in psi. Initial setting: 1 psi.
7) The seventh line is the roll angle increment for the roll model in radians. Initial setting: 0.001 rad.
8) The eighth line is the lateral acceleration increment for the handling model in g's. Initial setting: 0.025 g's.
9) The ninth line is the steering frequency increment for the rearward amplification model rad/sec. Initial setting: 0.25 rad/sec.
10) Information for a model that is not yet implemented, any value will work here.
11) Information for a model that is not yet implemented, any value will work here.

The user may experiment with these values by editing the INC.SET file, but a backup copy of the original INC.SET file should be maintained. The contents of this file can be changed by using any editor program, but the INC.SET file should always contain 11 lines as described above.

Each *Simplified Models* program disk contains the font files listed in Table 6. For text to be displayed properly on the graphics screens generated by the *Simplified Models* programs, the necessary font files for the graphics adapter card installed in your machine must be resident in the default directory from which the *Simplified Model* program was executed (i.e., on the same disk or in the same sub-directory of the disk). The font files provided are listed below with their associated adaptor cards indicated. These "system fonts" are designed for a standard 80 column by 25 line display format, with the exception of the Lo-Res 00-07 fonts, which are for a 64x25 display. Unused font files may be deleted from your program disk to conserve disk space.

Table 6. System Font Files

Font Name	Display Class	Adaptors
SYSTEM01.FNT	320x200 2-bits per pixel	IBM CGA, Medium Res
SYSTEM03.FNT	320x200 4-bits per pixel	Tecmar, Lo Res
SYSTEM07.FNT	320x200 8-bits per pixel	VGA, Lo Res
SYSTEM08.FNT	640x200 1-bits per pixel	IBM CGA, Hi Res
SYSTEM11.FNT	640x200 4-bits per pixel	Tecmar 640x200 16-color
SYSTEM16.FNT	640x350 1-bits per pixel	IBM EGA
SYSTEM24.FNT	720x350 1-bits per pixel	Hercules,AST,Tecmar monochromes
SYSTEM32.FNT	640x400 1-bits per pixel	AT&T, AT&T DEB, Sigma Color-400
SYSTEM35.FNT	640x400 4-bits per pixel	Tecmar 640x400 16-color
SYSTEM47.FNT	512x512 8-bits per pixel	#9 Revolution
SYSTEM48.FNT	1280x400 1-bits per pixel	Wyse WY-700
SYSTEM72.FNT	640x480 1-bits per pixel	VGA, EVA/480
SYSTEM96.FNT	800x600 1-bits per pixel	EGA supersets (Vega/VGA, Genoa)

Directions for the Use of

The Low-Speed and High-Speed Offtracking Models

LOW-SPEED AND HIGH-SPEED OFFTRACKING MODELS
TABLE OF CONTENTS

Section *Page*

THE MANEUVER AND THE VEHICLE

The Low-Speed and High-Speed Offtracking Model examines the three different aspects of the offtracking performance of multiple unit vehicles. These aspects are:

- Low-speed steady state offtracking
- Low-speed transient offtracking
- High-speed steady state offtracking.

Each of these aspects is examined in a constant radius turning maneuver where turn radius is defined by the user. For the steady state options, the vehicle is assumed to be turning continuously and have achieved a steady state response. For the low-speed transient option, the maneuver includes a straight line "entry" and straight line "exit" to the constant radius turn. The total arc, or angle, of the turn is defined by the user. The paths of the centerline of each axle and of the rear most extremity of the vehicle are determined.

The subject vehicle, defined by the user, may be composed of as many as six units. Individual units are lead units (trucks or tractors), A-dollies or semitrailers. (Full trailers should be treated as a dolly and semitrailer. B-dollies should be treated as an integral part of the unit which tows them.)

THE PROGRAM DISK

One of the *Simplified Models* program disks which you received will contain the Offtracking Models files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models*.) If you wish to produce backup disks for the Offtracking Models, be certain that all of the required files are copied onto the backup disks. The required files are:

OFFTRAKING.EXE	The main program file.
TRAILERS	A calculation support file.
TRACTORS	A calculation support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "OFF". The Offtracking Model program will only read (and write) vehicle data files with this extension.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Offtracking Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters*. For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

Descriptive Parameter	Unit English	Unit SI	Low Speed Steady State	Low Speed Transient	High Speed Steady State
Angle of the turn	deg	deg		X	
Distance from front articulation to rear articulation	in	cm	X	X	X
Distance from front articulation to rear extremity	in	cm	X	X	X
Distance from front suspension to rear articulation	in	cm	X	X	X
Distance from front suspension to rear extremity	in	cm	X	X	X
Forward velocity	mph	kph			X
Front suspension load	lbs	N	X	X	X
g-level	g	g			X
Radius of the turn	ft	m	X	X	X
Rear suspension load	lbs	N	X	X	X
Total cornering stiffness of front tires	lb/deg	N/deg	X	X	X
Total cornering stiffness of rear tires	lb/deg	N/deg	X	X	X
Wheelbase	in	cm	X	X	X

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, have the program disk in the active drive and then type:

OFFTRACK

After a few seconds the following message will appear on the screen. (See Screen #1 below.)

```
UUUUU    UUUUU MMMMM     MMMMM TTTTTTTTTTTTTTT RRRRRRRRRRR     IIIIIII
UUUUU    UUUUU MMMMMM   MMMMMM TTTTTTTTTTTTTTT RRRRRRRRRRRRR   IIIIIII
 UUU      UUU  MMM MMM MMM MMM TTT   TTT   TTT RRR       RRR     III
 UUU      UUU  MMM  MMMMM  MMM TTT   TTT   TTT RRR      RRR      III
 UUU      UUU  MMM   MMM   MMM       TTT       RRRRRRRRRRR       III
 UUU      UUU  MMM   MMM   MMM       TTT       RRRRRRRRRRR       III
 UUUU    UUUU  MMM         MMM       TTT       RRR      RRR      III
   UUUUUUUUU   MMMMM     MMMMM     TTTTTTT     RRR       RRR   IIIIIII
     UUUUU     MMMMM     MMMMM     TTTTTTT     RRR        RRR  IIIIIII

               ****************************************
               *                                      *
               *                                      *
               *      OFFTRACKING MODEL V3.0          *
               *                                      *
               *                                      *
               ****************************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                              HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
ENGLISH
METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen #2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

```
ENTER DATA FROM:
================
KEYBOARD
FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your OFFTRACK model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

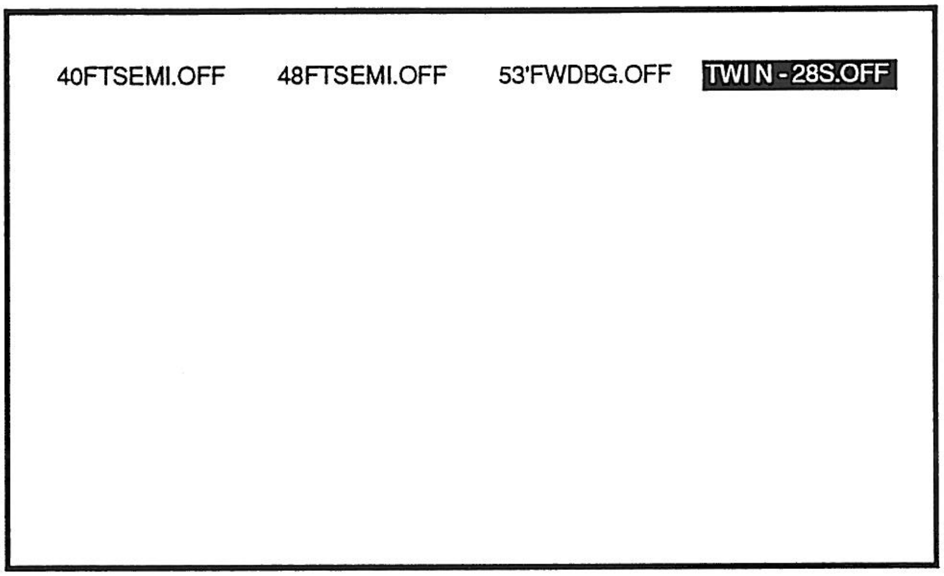
Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

If you selected FILE, the following screen will appear.

```
SELECT DRIVE
============
DRIVE A
DRIVE B
DRIVE C
DRIVE D
DRIVE E
DRIVE F
DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the OFFTRACK model disk by pressing the up (↑) and down (↓) arrow keys and then **RETURN** (↵) or **End**.



Screen #5

All of the OFFTRACK model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select one of the example data files.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
=========
NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

Selecting NEW DATA would result in returning to Screen #3 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing technique.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. You will find that there is a page for each unit of the vehicle. These pages vary slightly depending on the type and position of the unit. The individual parameters on these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the OFFTRACK model are shown on the following pages (Screens #7 through 10).

```
                    LOW AND HIGH SPEED OFFTRACKING
----------------------------------------------------------------------
                      Information for Unit # 1

   *Wheelbase = 144.000 inches
   *Distance from front suspension to rear articulation = 120.000 inches
   *Front suspension load = 11600.0 lbs
   *Total cornering stiffness of front tires = 1600.09  lbs/deg
   *Rear suspension load = 23505.0 lbs
   *Total cornering stiffness of rear tires = 4025.40 lbs/deg
----------------------------------------------------------------------

            PgDn=PAGE DOWN    Esc=EXIT     End=PgDn
```

Screen #7

```
                    LOW AND HIGH SPEED OFFTRACKING
----------------------------------------------------------------------
                      Information for Unit # 1

   *Wheelbase = 312.000 inches
   *Distance from front suspension to rear extremity = 456.000 inches
   *Front suspension load = 15420.0 lbs
   *Total cornering stiffness of front tires = 1608.34  lbs/deg
   *Rear suspension load = 46580.0 lbs
   *Total cornering stiffness of rear tires = 7976.63 lbs/deg
----------------------------------------------------------------------

            PgDn=PAGE DOWN    Esc=EXIT     End=PgDn
```

Screen #8

```
                 LOW AND HIGH SPEED OFFTRACKING
-----------------------------------------------------------------
                   Information for Unit # 2

  *Wheelbase = 258.000 inches
  *Distance from front articulation to rear articulation = 306.000 inches
  *Front suspension load = 25395.0 lbs
  *Total cornering stiffness of rear tires = 4327.05 lbs/deg
-----------------------------------------------------------------



         PgDn=PAGE DOWN    Esc=EXIT     End=PgDn
```

Screen #9

```
                 LOW AND HIGH SPEED OFFTRACKING
-----------------------------------------------------------------
                   Information for Unit # 2

  *Wheelbase = 258.000 inches
  *Distance from front articulation to rear extremity = 306.000 inches
  *Front suspension load = 25395.0 lbs
  *Total cornering stiffness of rear tires = 4327.05 lbs/deg
-----------------------------------------------------------------



         PgDn=PAGE DOWN    Esc=EXIT     End=PgDn
```

Screen #10

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. When KEYBOARD is selected from the ENTER DATA menu, the user is requested to ENTER THE NUMBER OF UNITS which make up the vehicle. After making that entry and pressing the **ENTER** key (↵) or the **End** key, the KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following page contains an example of printed data.

LOW AND HIGH SPEED OFFTRACKING

FILE NAME:A:S1D05.OFF

Date: 3- 8-1988 Time:11:22:33

Information for Unit #. 1

Wheelbase = 144.000 inches
Distance from front suspension to rear articulation = 120.000 inches
Front suspension load = 11600.0 lbs
Total cornering stiffness of front tires = 1600.09 lbs/deg
Rear suspension load = 23505.0 lbs
Total cornering stiffness of rear tires = 4025.40 lbs/deg

Information for Unit # 2

Wheelbase = 258.000 inches
Distance from front articulation to rear articulation = 306.000 inches
Rear suspension load = 25395.0 lbs
Total cornering stiffness of rear tires = 4327.05 lbs/deg

Information for Unit # 3

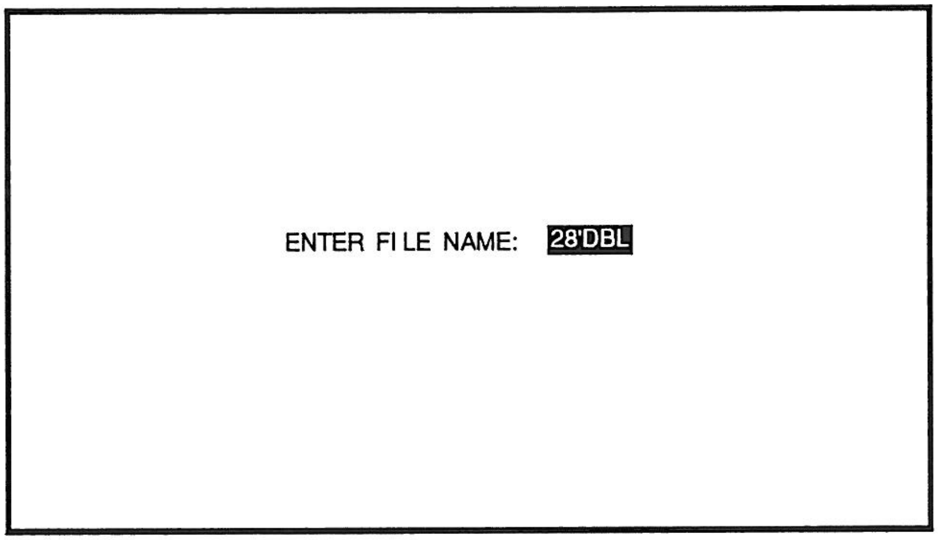
Wheelbase = 96.000 inches
Distance from front articulation to rear articulation = 96.000 inches
Rear suspension load = 23605.0 lbs
Total cornering stiffness of rear tires = 4041.84 lbs/deg

Information for Unit # 4

Wheelbase = 258.000 inches
Distance from front articulation to rear extremity = 306.000 inches
Rear suspension load = 25395.0 lbs
Total cornering stiffness of rear tires = 4327.05 lbs/deg

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #11).



Screen #11

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "OFF" is added to all files saved from the OFFTRACK model program. When reading data files, the OFFTRACK program only recognizes files with this extension.

CALCULATE

Selecting this option will display the following menu.

```
OFFTRACKING
=============

LOW SPEED STEADY STATE
LOW SPEED TRANSIENT
HIGH SPEED STEADY STATE
EXIT TO MAIN MENU
```

Screen #12

This menu allows the user to select the type of offtracking calculation to be performed. The three different calculation possibilities will now be considered.

Low-Speed Steady State

When "Low Speed Steady State" is chosen, a screen of the following form will appear.

```
                    RADIUS OF THE TURN (FT) = 1200.00


                         Esc=EXIT     End = OK
```

Screen #13

After entering the desired radius of turn and pressing the **End** key or **ENTER** (↵) key, the calculations will be performed. The results will be displayed on the screen in numerical form. The prompt at the bottom of the screen gives the user the opportunity to print the results.

An example of the low-speed steady state offtracking calculation results appears below.

```
                 STEADY STATE RESULTS
                LOW-SPEED OFFTRACKING

                FILE NAME:

             RADIUS OF THE TURN (FT) = 1200.00
       SUSP. NUM.                        RADIUS (FT)
           1                              1200.00
           2                              1199.94
           3                              1199.75
           4                              1199.73
           5                              1199.54

       REAR EXTREMITY SWING = 1199.54 FT

       LOW-SPEED OFFTRACKING =   .45691 FT

     DO YOU WANT TO PRINT THE RESULTS ?Y
```

Screen #14

Answer the print function prompt and press the **End** key or **ENTER** (↵) key to print the results and/or return to the OFFTRACK menu.

Low-Speed Transient

When "Low Speed Transient" is chosen, a screen of the following form will appear.

```
CALCULATION PARAMETERS

RADIUS OF THE TURN (FT) = 45.00

ANGLE OF THE TURN (DEG) = 90.00




Esc=EXIT      End = OK
```

Screen #15

After entering the desired radius and angle of turn and pressing the **End** key or **ENTER** (↵) key, the calculations will be performed. The results will be displayed on the screen in numerical and in graphical form. Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.

An example of the low-speed transient offtracking calculation results appears on the following page.

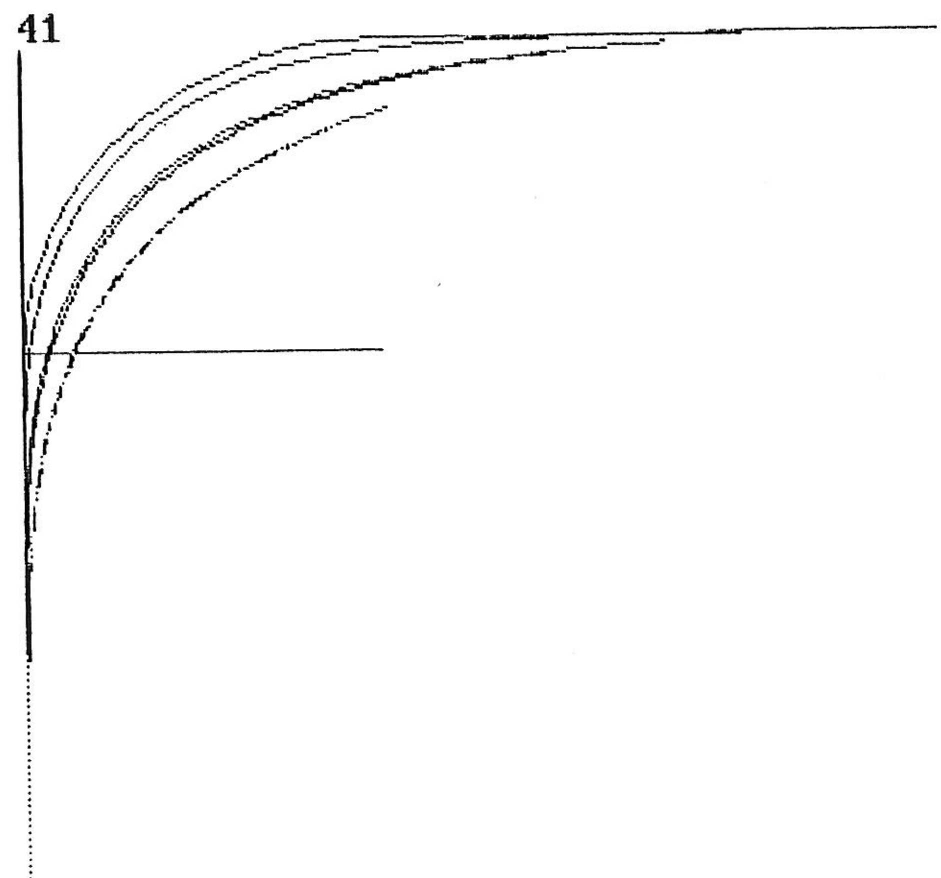
To return to the OFFTRACK menu, press any key other than **P** (or **p**).

TRANSIENT LOW SPEED
OFFTRACKING
B:S1D05.OFF
MINIMUM RADIUS

SUSPENSION NUMBER	RADIUS (FEET)	ANGLE DEGREES
1	41	0
2	39.084	73.822
3	33.756	62.889
4	33.112	60.077
5	28.533	57.373

MAX OFFTRACKING=12.467FT

REAR SWING-OUT=.0043259FT



High-Speed Offtracking Steady State

When "Low Speed Transient" is chosen, a screen of the following form will appear.

```
RADIUS OF THE TURN (FT) = 1200.00
FORWARD VELOCITY (MPH) = 55.00
G-LEVEL =    .1684



        Esc=EXIT      End = OK
```

Screen #16

After entering the desired radius of turn and forward velocity and pressing the **End** key or **ENTER** (↵) key, the calculations will be performed. The results will be displayed on the screen in numerical form similar to that used for the low-speed steady state results. The prompt at the bottom of the screen gives the user the opportunity to print the results.

Answer the print function prompt and press the **End** key or **ENTER** (↵) key to print the results and/or return to the OFFTRACK menu.

Exit to Main Menu

Selecting this option (from Screen #12) will return the user to Screen #6 where further calculations may be made or the user may **QUIT** the program.

Directions for the Use of

The Straight Line Braking Model

STRAIGHT LINE BRAKING MODEL
TABLE OF CONTENTS

THE MANEUVER AND THE VEHICLE

The Straight Line Braking Model examines the steady state (constant deceleration), straight line braking performance of multiple unit vehicles over the full range of brake application capability. The model predicts deceleration and braking efficiency of the vehicle, and the friction utilization at each axle, as a function of brake application pressure. The calculations *do not* depend on tire-to-road friction. Rather, they predict the friction level required (i.e., friction utilization), assuming that all wheels remain rolling.

The subject vehicle, defined by the user, may be composed of as many as six units. Individual units are lead units (trucks or tractors), converter dollies and semitrailers, and full trailers. (Full trailers using turn table dollies are considered as one unit. Full trailers composed of converter dollies and semitrailers are treated as two units. See the definition of Unit Type in Appendix C: *Glossary of Descriptive Parameters.*

THE PROGRAM DISK

One of the *Simplified Models* program disks which you received will contain the Straight Line Braking Model files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models.*) If you wish to produce backup disks for the Straight Line Braking Model, be certain that all of the required files are copied onto the backup disks. The required files are:

BRAKING.EXE	The main program file.
AXIS	A plotting support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "BRK". The Straight Line Braking Model program will only read (and write) vehicle data files with this extension.

WHAT'S NEW IN VERSION 3.0 ?

Version 3.0 of the Straight Line Braking model has increased the type of suspension(s) of each unit. The suspension(s) of each unit can be either single, tandem, or tridem axle, with a user specified inter-axle load transfer coefficient for the later two. The capability to add auxiliary, tag or belly axles is also included for each unit.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Straight Line Braking Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters*. For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

	English Units	SI Units
Axle # i brake gain	in-lb/psi	N-m/kpa
Brake key		
Distance to rear articulation	in	cm
Inter-axle load transfer coefficient		
Number of auxiliary axles		
Number of points in the torque table		
Pushout pressure	psi	kpa
Radius of a tire	in	cm
Rear articulation height	in	cm
Suspension # i key		
Suspension # i load	lbs	N
Tandem axle separation	in	cm
Torque	in-lb	N-m
Total c.g. height	in	cm
Total weight	lbs	kg
Treadle pressure	psi	kpa
Unit key		

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, insert the program disk in any drive and then type:

BRAKING

After a few seconds the following message will appear on the screen. (see Screen #1 below.)

```
UUUUU      UUUUU  MMMMM      MMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRR       IIIIIII
UUUUU      UUUUU  MMMMMM    MMMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRRRR     IIIIIII
 UUU        UUU   MMM MMM MMM MMM   TTT   TTT   TTT  RRR        RRR      III
 UUU        UUU   MMM  MMMMM  MMM   TTT   TTT   TTT  RRR       RRR       III
 UUU        UUU   MMM   MMM   MMM         TTT        RRRRRRRRRRR         III
 UUU        UUU   MMM   MMM   MMM         TTT        RRRRRRRRRRR         III
 UUUU      UUUU   MMM         MMM         TTT        RRR       RRR       III
   UUUUUUUUUU     MMMMM      MMMMM      TTTTTTT      RRR        RRR    IIIIIII
     UUUUU        MMMMM      MMMMM      TTTTTTT      RRR         RRR   IIIIIII

               ****************************************
               *                                      *
               *                                      *
               *    BRAKE TEMPERATURE MODEL V3.0      *
               *                                      *
               *                                      *
               ****************************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                              HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
ENGLISH
METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen #2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

```
ENTER DATA FROM:
=================
KEYBOARD
FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your BRAKING model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

If you selected FILE, the following screen will appear.

```
SELECT DRIVE
============
 DRIVE A
 DRIVE B
 DRIVE C
 DRIVE D
 DRIVE E
 DRIVE F
 DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the BRAKING model disk by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

4AXLSEMI.BRK	STRUCK-L.BRK	STRUCK-E.BRK	ICEBSEMT.BRK
ICEBEMLV.BRKL	ESEMLK35.BRK		

Screen #5

All of the BRAKING model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select the data file EXAMPLE.BRK.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
=========
NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

Selecting NEW DATA would result in returning to Screen #3 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing technique.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. You will find that there is a General Information page an a Suspension Identification page for each unit of the vehicle, and a Suspension Information page and Brake Gain page(s) for each suspension of each unit. The individual parameters on these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the BRAKING model are shown on the following pages (Screens #7 through 19).

```
                GENERAL INFORMATION FOR UNIT #1

*Total weight (lbs) = 16500.00
*Primary Wheelbase (in) = 144.00
*Total c. g. height (in) = 34.79
*Distance to rear articulation (in) = 120.00
 from front articulation if dolly or semitrailer
 from front suspension if full trailer-fix dolly
*Rear articulation height (in) =  48.00
*Number of Auxiliary (Tag) Axles for this unit =  0



      PgDn=PAGE DOWN    Esc=EXIT     End=PAGE DOWN
```

Screen #7

```
        Unit # 1

*Suspension #1 load (lbs) = 11600.00
*Suspension #2 load (lbs) = 23505.0
*Suspension #2 key:  2
        1 - Single
        2 - Tandem
        3 - Tridem



PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #8

```
        Unit # 1, Suspension # 1

             Axle # 1

*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1



PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #9

```
Brake information for Unit # 1, Suspension # 1


*Axle #1 brake gain (in-lb/psi) = 2000.00




PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #10

```
Unit # 1, Suspension # 2

*Tandem axle separation (in) = 48.00
*Interaxle load transfer coefficient (between and -1) =    .0000
          Axle # 1
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1
          Axle # 2
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1

PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #11

```
Brake information for Unit # 1, Suspension # 2


*Axle #1 brake gain (in-lb/psi) = 3000.00
*Axle #2 brake gain (in-lb/psi) = 3000.00



PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #12

```
GENERAL INFORMATION FOR UNIT #2

*Total weight (lbs) = 44000.00
*Primary Wheelbase (in) = 258.00
*Total c. g. height (in) = 79.05
*Number of Auxiliary (Tag) Axles for this unit   =  1
*Unit key (1 - Indedpendent unit, dolly or semi) =  1
          (2 - Full trailer with fixed dolly)


PgUp=PAGE UP    PgDn=PAGE DOWN    End=PgDn    Esc=EXIT
```

Screen #13

```
Unit #2

*Suspension #1 load (lbs) = 20395.00
*Suspension #1 key:  3
        1 - Single
        2 - Tandem
        3 - Tridem
*Suspension #2 Auxiliary axle load (lbs) =  5000.00
*Distance to Auxiliary Axle from front articulation (in) = 150.0


PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #14

```
            Unit # 2, Suspension # 1

*Front Tridem axle separation (in) = 48.00
*Rear Tridem axle separation (in) = 48.00
*Front Interaxle load transfer coefficient (between 1 and -1) = -.050
*Rear Interaxle load transfer coefficient (between 1 and -1) =  .050
                 Axle # 1
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1
                 Axle # 2
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1
                 Axle # 3
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 1



            PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #15

```
           Brake information for Unit # 2, Suspension # 1


     *Axle #1 brake gain (in-lb/psi) = 3000.00
     *Axle #2 brake gain (in-lb/psi) = 3000.00
     *Axle #3 brake gain (in-lb/psi) = 3000.00


        PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #16

```
        Unit # 2, Suspension # 2

             Axle # 1
*Radius of a tire (in) = 19.50
*Pushout pressure (psi) = 7.00
*Brake key (1=Linear, 2=Non-linear) = 2



    PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #17

```
        Unit # 2, Suspension # 2
                Axle # 1
Number of points in the table (max.10):  4



    PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #18

```
              Unit # 2, Suspension # 2
                 Table for Axle # 1
Treadle Pressure (psi)              Torque (in-lb)

        .00                                 .00
       7.00                                 .00
      30.00                            69000.00
      40.00                            92000.00


  PgUP=PAGE UP  PgDn=PAGE DOWN  End=PgDn  Esc=Exit
```

Screen #19

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. When KEYBOARD is selected from the ENTER DATA menu, the user is requested to ENTER THE NUMBER OF UNITS which make up the vehicle. After making that entry and pressing the **ENTER** key (↵) or the **End** key, the KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following pages contain examples of printed data.

STRAIGHT LINE BRAKING MODEL

FILE NAME:C:4AXLSEMI.BRK

Date: 9-14-1990 Time: 7: 6:16

Information for Unit # 1

General Information

Total weight = 16500.00 lbs
Primary Wheelbase = 144.000 inches
Distance to rear articulation from front suspension = 120.00 inches
Rear articulation height = 48.00 inches
Total c.g. height = 34.79 inches
Number of Auxiliary Axles for this unit = 0

Suspension # 1 (Single)
Suspension load = 11600.0 lbs
Axle # 1
Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 2000.00 in-lb/psi

Suspension # 2 (Tandem)
Suspension load = 23305.0 lbs
Tandem axle separation = 48.00 inches
Inter axle load transfer coefficient (between -1 & 1) = .0000
Axle # 1
Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 3000.00 in-lb/psi
Axle # 2
Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 3000.00 in-lb/psi

Information for Unit # 2

General Information

Total weight = 44000.00 lbs
Primary Wheelbase = 258.000 inches
Distance to rear articulation from front articulation = 306.00 inches
Rear articulation height = 44.00 inches
Total c.g. height = 79.05 inches
Number of Auxiliary Axles for this unit = 1
Unit Key (1 - Independent unit, dolly or semi) = 1
(2 - Full trailer with fixed dolly)

Suspension # 1 (Tridem)

Suspension load = 20395.0 lbs
First axle separation = 48.00 inches
Interaxle load transfer coefficient (between -1 & 1) = .0250
Second axle separation = 48.00 inches
Interaxle load transfer coefficient (between -1 & 1) = .0250

Axle # 1

Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 3000.00 in-lb/psi

Axle # 2

Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 3000.00 in-lb/psi

Axle # 3

Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 1
Brake gain = 3000.00 in-lb/psi

Suspension # 2 (Auxiliary)

Suspension load = 5000.0 lbs
Distance to Auxiliary Axle from front suspension = 150.00 inches

Axle # 1

Radius of a tire = 19.50 inches
Pushout pressure = 7.00 psi
Brake key (1=Linear, 2=Non-linear) = 2

Brake Table

Treadle Pressure(psi)	Torque(in-lb)
.00	.0
7.00	.0
30.00	69000.0
40.00	92000.0

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #20).

```
ENTER FILE NAME: 4AXLSEMI
```

Screen #20

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "BRK" is added to all files saved from the BRAKING model program. When reading data files, the BRAKING program only recognizes files with this extension.

CALCULATE

Selecting this option initiates the BRAKING model calculations. First a prompt will appear asking whether you wish to print the results as they are calculated. If the answer is "Y" or "y", then make sure that the printer is turned on. If the answer is "N" or "n", the results will be printed only on the screen.

Calculations occur at increments of treadle pressure beginning at zero psi and proceeding to higher levels. The pressure increment is established by data in the INC.SET file. (The initial value is 1 psi.) Calculations are stopped when either:

- The treadle pressure has exceeded a value of 100 psi, or
- A friction utilization for any axle of the vehicle is greater than 1.0.

Results are printed for every 10 psi. of treadle pressure. Examples of the printed numerical results are shown on the following page.

At each printed increment of treadle pressure, the treadle pressure, vehicle deceleration and the vehicle's braking efficiency is given. Following these, (also for each increment of pressure) the following data are presented in column format:

- Unit No (counting from the front to the rear of the vehicle)
- Susp No (counting from the front to the rear of the unit)
- Axle No (counting from the front to the rear of the suspension)
- Brake Force (the total brake force produced at the wheels of the axle)
- Vertical Load (the total vertical load on all of the wheels of the axle)
- Friction Utilization (the level of friction utilization required at the axle)

STRAIGHT LINE BRAKING MODEL
FILE NAME:C:4AXLSEMI.BRK

Treadle Pressure= .00 psi
Deceleration= .00000 gs
Braking Efficiency= .00000

Unit No	Susp No	Axle No	Brake Force(Lbs)	Vertical Load(Lbs)	Friction Utilization
1	1	1	.00	11600.00	.0000
1	2	1	.00	11752.50	.0000
1	2	2	.00	11752.50	.0000
2	1	1	.00	6798.33	.0000
2	1	2	.00	6798.33	.0000
2	1	3	.00	6798.33	.0000
2	2	1	.00	5000.00	.0000

Treadle Pressure= 10.00 psi
Deceleration= .05086 gs
Braking Efficiency= .55096

Unit No	Susp No	Axle No	Brake Force(Lbs)	Vertical Load(Lbs)	Friction Utilization
1	1	1	307.69	12189.25	.0252
1	2	1	461.54	11764.26	.0392
1	2	2	461.54	11764.26	.0392
2	1	1	461.54	6640.23	.0695
2	1	2	461.54	6594.07	.0700
2	1	3	461.54	6547.92	.0705
2	2	1	461.54	5000.00	.0923

Treadle Pressure= 20.00 psi
Deceleration= .22039 gs
Braking Efficiency= .55096

Unit No	Susp No	Axle No	Brake Force(Lbs)	Vertical Load(Lbs)	Friction Utilization
1	1	1	1333.33	14153.42	.0942
1	2	1	2000.00	11803.48	.1694
1	2	2	2000.00	11803.48	.1694
2	1	1	2000.00	6113.20	.3272
2	1	2	2000.00	5913.20	.3382
2	1	3	2000.00	5713.20	.3501
2	2	1	2000.00	5000.00	.4000

Treadle Pressure= 30.00 psi
Deceleration= .38991 gs
Braking Efficiency= .53757

Unit No	Susp No	Axle No	Brake Force(Lbs)	Vertical Load(Lbs)	Friction Utilization
1	1	1	2358.97	16117.60	.1464
1	2	1	3538.46	11842.70	.2988
1	2	2	3538.46	11842.70	.2988
2	1	1	3538.46	5586.18	.6334
2	1	2	3538.46	5232.33	.6763
2	1	3	3538.46	4878.49	.7253
2	2	1	3538.46	5000.00	.7077

After the calculations end a screen similar to the following appears.

```
DO YOU WANT TO SEE THE PLOTS ? Y
```

Screen #21

If your answer is "yes" just press the **End** key, and the following menu will appear (Screen #22)

```
SELECT PLOT
=============

BRAKING EFF. AND DECELERATION
FRICTION UTILIZATION
EXIT TO MAIN MENU
```

Screen #22

This menu allows you to chose which results to plot. The available results for plotting are the BRAKING EFFICIENCY and the DECELERATION of the vehicle or the FRICTION UTILIZATION of the individual axles of the vehicle. In these plots, the selected variables will appear on the ordinate with treadle pressure on the abscissa.

VIEW PLOTS

Once you have made your selection a plot will appear on the screen. Examples of the two types appear on the following pages. The numerical values associated with the cursor position are printed in the box beneath the graph.

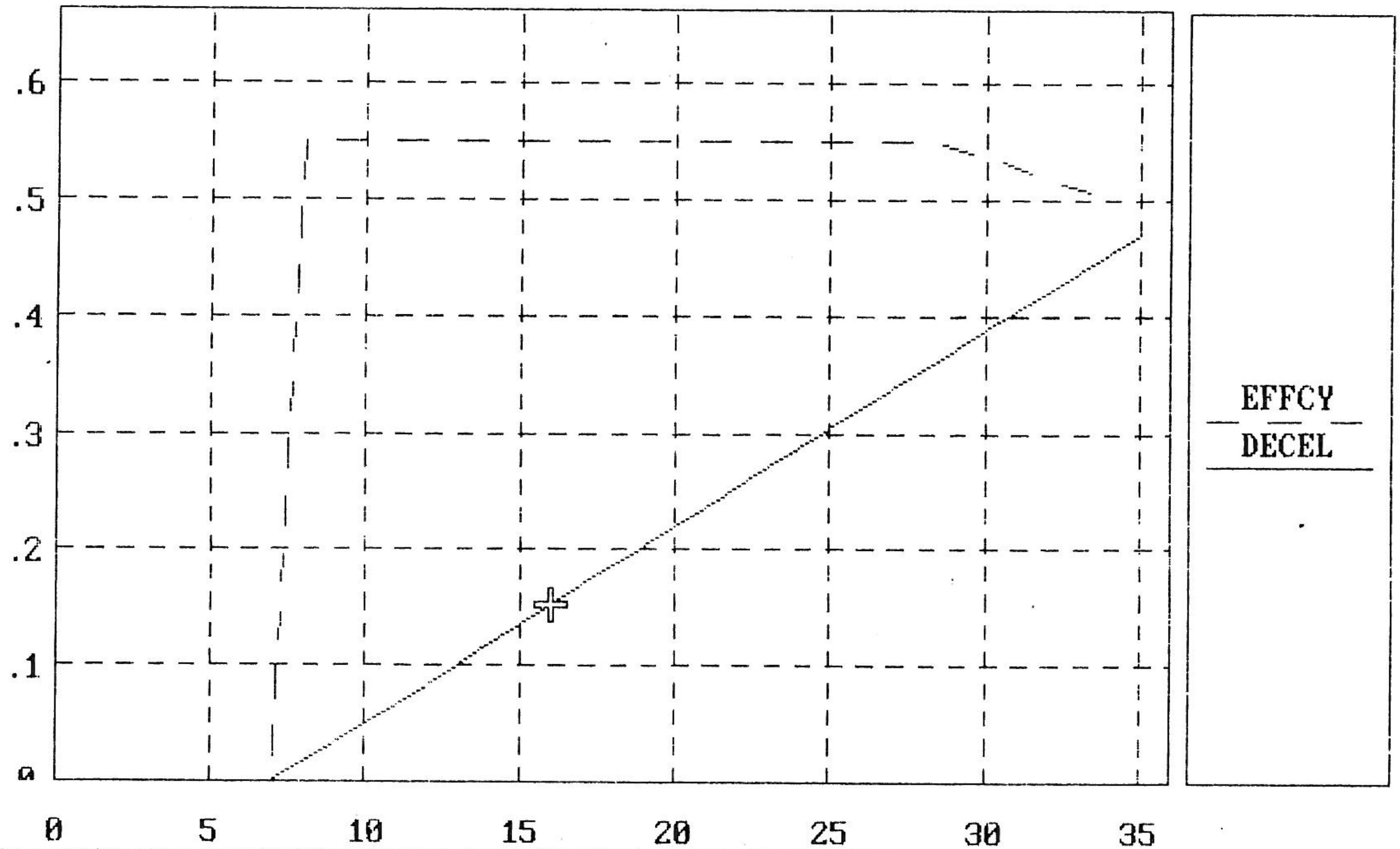
You can manipulate the cross cursor and modify the form of the graph. The following identifies the control keys and describes their function.

- The **ENTER** key (↵) shifts the cross cursor among the different curves, and indicates on the lower view port the legend of the curve selected. The "Y" and "X" values at the position of the cursor are shown on the same port.
- The right (→) and left (←) arrow keys move the cross cursor on the current curve right or left and updates the values in the lower view port. (Holding down the **Ctrl** key while using the arrow keys results in faster, but courser, cursor motion along the curve.)
- The up arrow (↑) key scrolls the "Y" axis upward.
- The down arrow (↓) key scrolls the "Y" axis downward.
- The **PgUp** key (page up) scrolls the "X" axis forward.
- The **PgDn** key (page down) scrolls the "X" axis backward.
- The + (plus) or - (minus) keys hit either once or twice and followed by the letter X or Y will zoom the respective axis up or down.
- Typing **S** allows the user to set the scales of the graph. A screen appears which allows the user to enter the desired maximum and minimum values for the ordinate and abscissa scales, using the screen editing technique described in the EDIT-VIEW DATA section. Pressing the **End** key causes the graph to be reprinted with the specified scaling.
- Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.
- **End** key, gets you out of the chart and sends you to the plot menu (Screen #22).

Exit to Main Menu

Selecting this option will return the user to Screen #6 where further selections may be made or the user may **QUIT** the program.

BRAKING EFFCY & DECELR (gs) vs PRESS(psi)   C:4AXLSEMI.BRK



DECEL = .1526 gs   PRESS = 16.0000 psi

Directions for the Use of

The Static Roll Model

STATIC ROLL MODEL
TABLE OF CONTENTS

THE MANEUVER AND THE VEHICLE

The Static Roll Model examines the steady state (constant lateral acceleration) roll response of multiple unit vehicles over the full range of lateral acceleration from zero up to the roll stability limit of the vehicle. The model predicts roll angle response of the vehicle (sprung and unsprung masses) and the side-to-side load transfer occurring at each axle of the vehicle as a function of lateral acceleration. (Actually, total roll angle is assumed and lateral acceleration is calculated, but it is more useful to view the results in the opposite light.) Only roll plane aspects of the vehicle are considered. No forward motion of the vehicle is considered. (That is, the lateral acceleration might have derived from a tight radius turn at high speed or a lower radius turn at higher speed.) The calculations which are performed might be considered as analogous to a tilt table experiment.

The subject vehicle, defined by the user, may be composed of as many as eight units. Individual units are lead units (trucks or tractors), dollies and semitrailers. (All full trailers are treated as two units, a dolly and semitrailer.) Mathematically, dollies and semitrailers are treated similarly; trailing units are distinguished by the nature of their front articulation (roll coupling). Roll couplings may be either rigid (fifth wheels, turn tables or B-dolly pintle joints) or free (A-dolly pintle joints). Portions of the vehicle separated by free roll couplings are treated as independently rolling elements of the vehicle. See the definition of Roll Coupling Type Appendix C: *Glossary of Descriptive Parameters.*

THE PROGRAM DISK

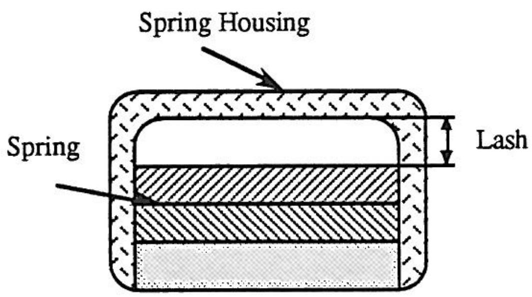
One of the *Simplified Models* program disks which you received will contain the Roll Model files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models.*) If you wish to produce backup disks for the Roll Model, be certain that all of the required files are copied onto the backup disks. The required files are:

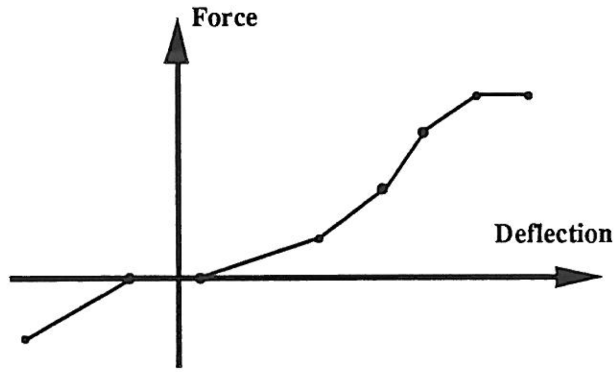
ROLL.EXE	The main program file.
AXIS	A plotting support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "ROL". The Roll Model program will only read (and write) vehicle data files with this extension.

WHAT'S NEW IN VERSION 3.0 ?

Version 3.0 has an enhanced capability from the analyst point of view by enabling the study of vehicles with nonlinear springs. In previous versions, the suspension characteristics were represented by a single value of a constant spring rate throughout the computational process, and without any lashes. In this version, the suspensions springs can be treated as nonlinear: The user's input is a forces versus deflections table (up to 13 points) for the spring, and a separate value for the spring lash .





The program then uses a perturbation approach to progress along the roll process by computing different spring rates for each deflection, according to the table provided by the user. At each "bending" point on the force-deflection graph, the model iterates to find the solution for the lateral acceleration within an error of ±0.0002 g's.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Static Roll Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters*. For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

Descriptive Parameters	English Unit	SI Unit
Auxiliary roll stiffness	in-lb/deg	N-m/deg
Axle load	lbs	N
Radius of a tire	in	cm
Roll center height	in	cm
Roll coupling key		
Spacing between suspension springs	in	cm
Spring lash	in	cm
Spring table		
Total c.g. height	in	cm
Total number of axles on the unit		
Total number of tires on the axle		
Total weight	lbs	kg
Track width of the axle	in	cm
Vertical stiffness of a tire	lb/in	N/m
Weight of the axle	lbs	kg

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, have the program disk in the active drive and type:

ROLL

After a few seconds the following message will appear on the screen. (See Screen #1 below.)

```
 UUUU      UUUUU  MMMMM     MMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRR      IIIIIII
UUUUU      UUUUU  MMMMMM   MMMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRRRR    IIIIIII
 UUU         UUU  MMM MMM MMM MMM  TTT   TTT   TTT  RRR        RRR     III
 UUU         UUU  MMM  MMMMM  MMM  TTT   TTT   TTT  RRR       RRR      III
 UUU         UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUU         UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUUU       UUUU  MMM         MMM        TTT        RRR       RRR      III
   UUUUUUUUUU     MMMMM     MMMMM      TTTTTTT      RRR        RRR  IIIIIII
     UUUUU        MMMMM     MMMMM      TTTTTTT      RRR         RRR IIIIIII

                       ******************************
                       *                            *
                       *                            *
                       *   STATIC ROLL MODEL V3.0   *
                       *                            *
                       *                            *
                       ******************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                             HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
 ENGLISH
 METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen#2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

```
ENTER DATA FROM:
================
 KEYBOARD
 FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your ROLL model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

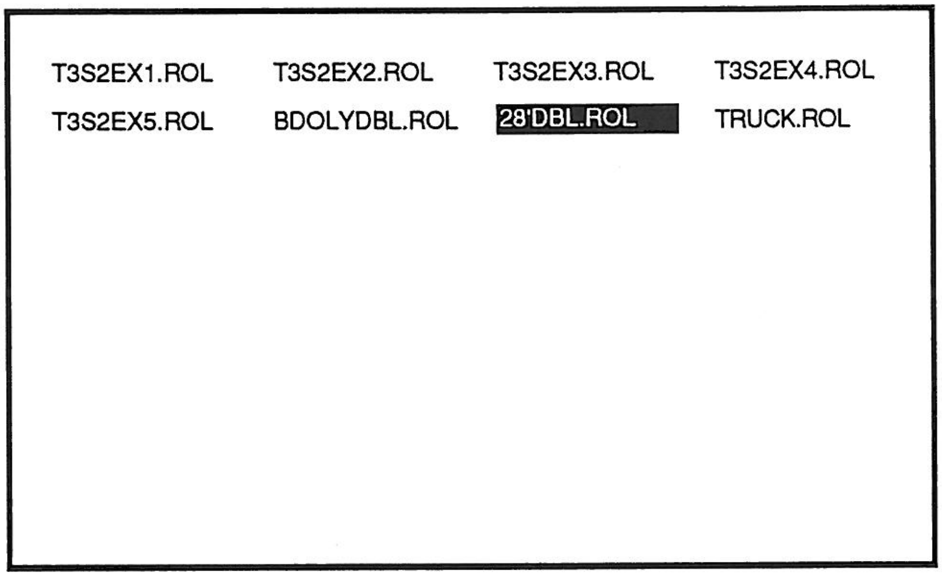
If you selected FILE, the following screen will appear.

```
SELECT DRIVE
=============
 DRIVE A
 DRIVE B
 DRIVE C
 DRIVE D
 DRIVE E
 DRIVE F
 DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the ROLL model disk by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

Important note: Due to the enhanced capabilities of Version 3.0, the format of the data files it needs for computing the model, is different from the one used by earlier versions. Nevertheless, in order to enable the use of previously saved data, the program will accept those files as input, but the user should then perform **EDIT-VIEW DATA** (see p. ROL—7), and provide the requested springs data information. Failing to do so, will result in a computational "crash" and the termination of the program. After editing the data, save it under the same file name to supersede the old file.



Screen #5

All of the ROLL model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select one of the example data files.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
==========

NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End**.

Selecting NEW DATA would result in returning to Screen #3 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing technique.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. You will find that there is a "General Information" page for each unit of the vehicle, and a "Axle Information" page for each axle of each unit. These pages vary slightly depending on the type and position of the unit. The individual parameters on these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the ROLL model are shown on the following pages (Screens #7 through 11).

```
            GENERAL INFORMATION FOR UNIT # 1

*Total weight (lbs) = 16500.00
*Total c. g. height (in) = 34.79
*Total number of axles on the unit (max 8) = 3








PgDn=PAGE DOWN    Esc=EXIT     End=PAGE DOWN
```

Screen #7

```
            Unit # 1, Axle # 1
       Axle Information

*Axle load (lbs) = 11600.00
*Track width of the axle (in) = 80.00
*Weight of the axle (lbs) 1200.00
*Roll center height (in)  20.00
*Spacing between springs (in) = 35.00
*Auxiliary roll stiffness (in-lb/deg) = 8000.00

       Tire Information

*Total number of tires on the axle = 2
*Vertical stiffness of a tire (lb/in) = 4500.00
*Radius of a tire (in) = 19.50


PgDn=PAGE DOWN    Esc=EXIT     End=PAGE DOWN
```

Screen #8

```
GENERAL INFORMATION FOR UNIT # 2

*Total weight (lbs) = 55000.00
*Total c. g. height (in) = 82.00
*Total number of axles on the unit (max 8) = 2
*Roll coupling key (1 - Rigid; e.g. semitrailer) = 1
                   (2 - Free; e.g. A-dolly)



PgDn=PAGE DOWN    Esc=EXIT    End=PAGE DOWN
```

Screen #9

```
Unit # 1, Axle # 1
Spring Information (per spring)

*Spring Lash (in) = 1.0
*No. of points in Spring Table (max 13) = 6

Vertical Load (lbs)          Deflection (in)
        100.0                       .000
       8250.0                      1.500
       8555.0                      1.600
       9133.0                      1.670
       9133.0                      2.000


PgDn=PAGE DOWN    Esc=EXIT    End=PAGE DOWN
```

Screen #10

The spring lash in Screen #10 represents the free travel of the spring from the point where there is no load on it, to the point where it starts lifting the axle (the space between the top of the spring and its housing).

If you use an input file from a version earlier than 3.0, the program will default to linear springs and flag the user. If you use the keyboard to enter the parameters and wish to simulate linear springs, set the value of spring lash to be 0.0, and provide two points to the spring table that will determine the linear spring slope. Screen #11 shows an example for a linear spring of 1200 lb./in.

```
                Unit # 1, Axle # 1
        Spring Information (per spring)

    *Spring Lash (in) = 0.0
    *No. of points in Spring Table (max 13) = 2

          Vertical Load (lbs)              Deflection (in)
                   0.0                           .000
                1200.0                          1.000






          PgDn=PAGE DOWN     Esc=EXIT      End=PAGE DOWN
```

Screen #11

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. When KEYBOARD is selected from the ENTER DATA menu, the user is requested to ENTER THE NUMBER OF UNITS which make up the vehicle. After making that entry and pressing the **ENTER** key (↵) or the **End** key, the KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following pages contain examples of printed data.

STATIC ROLL MODEL

FILE NAME:D:28'DBL.ROL

Date: 8-14-1990 Time:15:45:16

Information for Unit # 1 (Towing unit)

General Information

Total weight = 16200.00 lbs
Total c.g. height = 40.00 inches
Total number of axles = 2

Axle Information, Unit # 1

Axle # 1
Axle load = 10000.00 lbs
Track width of the axle = 80.00 inches
Weight of the axle = 1200.00 lbs
Roll center height = 19.00 inches
Spacing between suspension springs = 32.00 inches
Auxiliary roll stiffness = 8700.00 in-lb/deg

Tire Information
Total number of tires on the axle = 2
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 20.00 inches

Spring Data
Spring Lash = .0 inches
Spring table:

Vertical load (lbs)	Deflection (in.)
.0	.000
1200.0	1.000

Axle # 2
Axle load = 19000.00 lbs
Track width of the axle = 72.00 inches
Weight of the axle = 2300.00 lbs
Roll center height = 27.00 inches
Spacing between suspension springs = 38.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 20.00 inches

Spring Data
Spring Lash = .0 inches
Spring table:

Vertical load (lbs)	Deflection (in.)
.0	.000
5500.0	1.000

Information for Unit # 2 (Semitrailer)

General Information

Total weight = 29600.00 lbs
Total c.g. height = 78.37 inches
Total number of axles = 1

Axle Information, Unit # 2

Axle # 1
Axle load = 17000.00 lbs
Track width of the axle = 78.00 inches
Weight of the axle = 1500.00 lbs
Roll center height = 27.00 inches
Spacing between suspension springs = 44.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 20.00 inches

Spring Data
Spring Lash = 1.0 inches
Spring table:

Vertical load (lbs)	Deflection (in.)
.0	.000
2250.0	.500
5500.0	.800
10000.0	1.500
10000.0	2.000

Information for Unit # 3 (Dolly)

General Information

Total weight = 2500.00 lbs
Total c.g. height = 29.30 inches
Total number of axles = 1

Axle Information, Unit # 3

Axle # 1
Axle load = 17000.00 lbs
Track width of the axle = 78.00 inches
Weight of the axle = 1500.00 lbs
Roll center height = 27.00 inches
Spacing between suspension springs = 44.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 20.00 inches

Spring Data
Spring Lash = 1.0 inches
Spring table:

Vertical load (lbs)	Deflection (in.)
.0	.000
4400.0	.800
11275.0	1.500

Information for Unit # 4 (Semitrailer)

General Information

Total weight = 31500.00 lbs
Total c.g. height = 79.01 inches
Total number of axles = 1

Axle Information, Unit # 4

Axle # 1
Axle load = 17000.00 lbs
Track width of the axle = 78.00 inches
Weight of the axle = 1500.00 lbs
Roll center height = 27.00 inches
Spacing between suspension springs = 44.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg

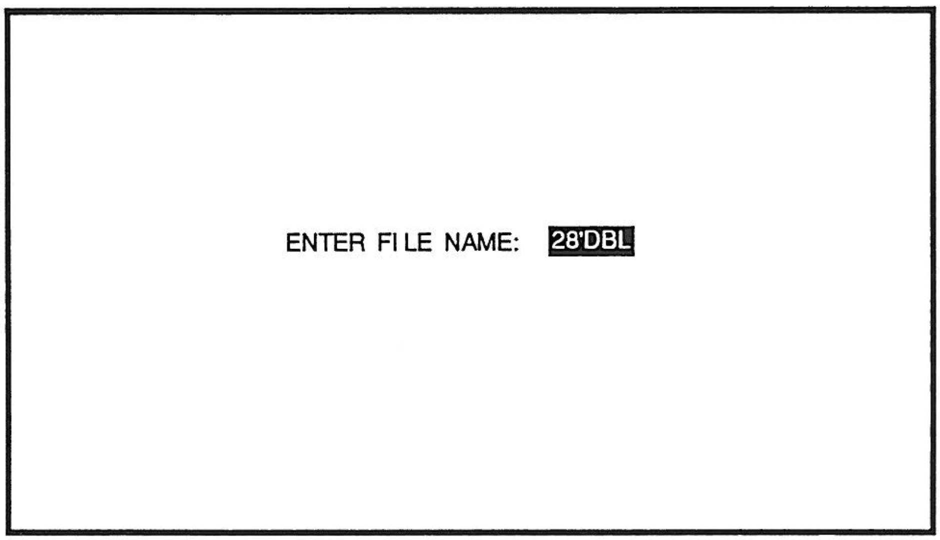
Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 20.00 inches

Spring Data
Spring Lash = 1.0 inches
Spring table:

Vertical load (lbs)	Deflection (in.)
.0	.000
2250.0	.500
5500.0	.800
10000.0	1.500
10000.0	2.000

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #12).



Screen #12

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "ROL" is added to all files saved from the ROLL model program. When reading data files, the ROLL program only recognizes files with this extension.

CALCULATE

Selecting this option initiates the ROLL model calculations. First a prompt will appear asking whether you wish to print the results as they are calculated. If the answer is "Y" or "y", then make sure that the printer is turned on. If the answer is "N" or "n", the results will be printed only on the screen.

Calculations occur at increments of roll angle beginning at zero roll and proceeding to higher levels. The lateral acceleration need to achieve the roll angle is calculated as are the "load transfer" and roll conditions of all of the axles of the vehicle. Calculations are accomplished at roll angle increments established by the INC.SET file. (The initial value of the roll increment is 0.001 radians.) Calculations are stopped when either:

- All of the light-side (inside of the turn) wheels of the vehicle have lifted off of the ground, or
- The lateral acceleration result has been *decreasing* for 0.02 radians of increasing roll angle (and the vehicle is presumably unstable in roll).

Results are printed for every 0.05 radians of roll *and* at the occurrence of the liftoff of any axle. A review of the "Axle Liftoff" conditions is printed after the calculations are complete. Examples of the printed numerical results are shown on the following page.

The incremental printed results include columns for:

- Unit (counting from the front to the rear of the vehicle)
- Axle (counting from the front to the rear of the unit)
- Roll angles (see the figure on the page ROL-16 for definitions of the unsprung, sprung, and total roll angles)
- Load transfer (the vertical load transferred from the tires on the light side (inside of turn) of the axle to the tires on the heavy side (outside of the turn) of the axle.
- Lateral acceleration (the steady state lateral acceleration required to produce the roll angle and load transfer conditions)

The printed review data gives the unit, axle, total roll angle and lateral acceleration at the point of liftoff of each axle.

STATIC ROLL MODEL
FILE NAME:D:28`DBL.ROL

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00000	.00000	.00000	.00	.00000
1	2	.00000	.00000	.00000	.00	.00000
2	1	.00000	.00000	.00000	.00	.00000
3	1	.00000	.00000	.00000	.00	.00000
4	1	.00000	.00000	.00000	.00	.00000

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00821	.05727	.05000	1477.72	.27673
1	2	.01687	.05380	.05000	5464.47	.27673
2	1	.01660	.05423	.05000	5826.60	.27673
3	1	.01618	.05083	.05000	5677.84	.29651
4	1	.01618	.05083	.05000	5677.84	.29651

Axle # 1 of Unit # 2 has Lift Off. Data is below:

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01198	.08358	.07300	2156.29	.40374
1	2	.02461	.07852	.07300	7974.09	.40374
2	1	.02425	.07910	.07300	8503.19	.40374
3	1	.02361	.07417	.07300	8286.11	.43271
4	1	.02361	.07417	.07300	8286.11	.43271

Axle # 1 of Unit # 3 has Lift Off. Data is below:
Axle # 1 of Unit # 4 has Lift Off. Data is below:

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01220	.08587	.07500	2196.54	.40706
1	2	.02513	.08074	.07500	8142.75	.40706
2	1	.02639	.07869	.07500	8503.19	.40706
3	1	.02423	.07608	.07500	8500.80	.44382
4	1	.02423	.07608	.07500	8500.80	.44382

Axle # 2 of Unit # 1 has Lift Off. Data is below:

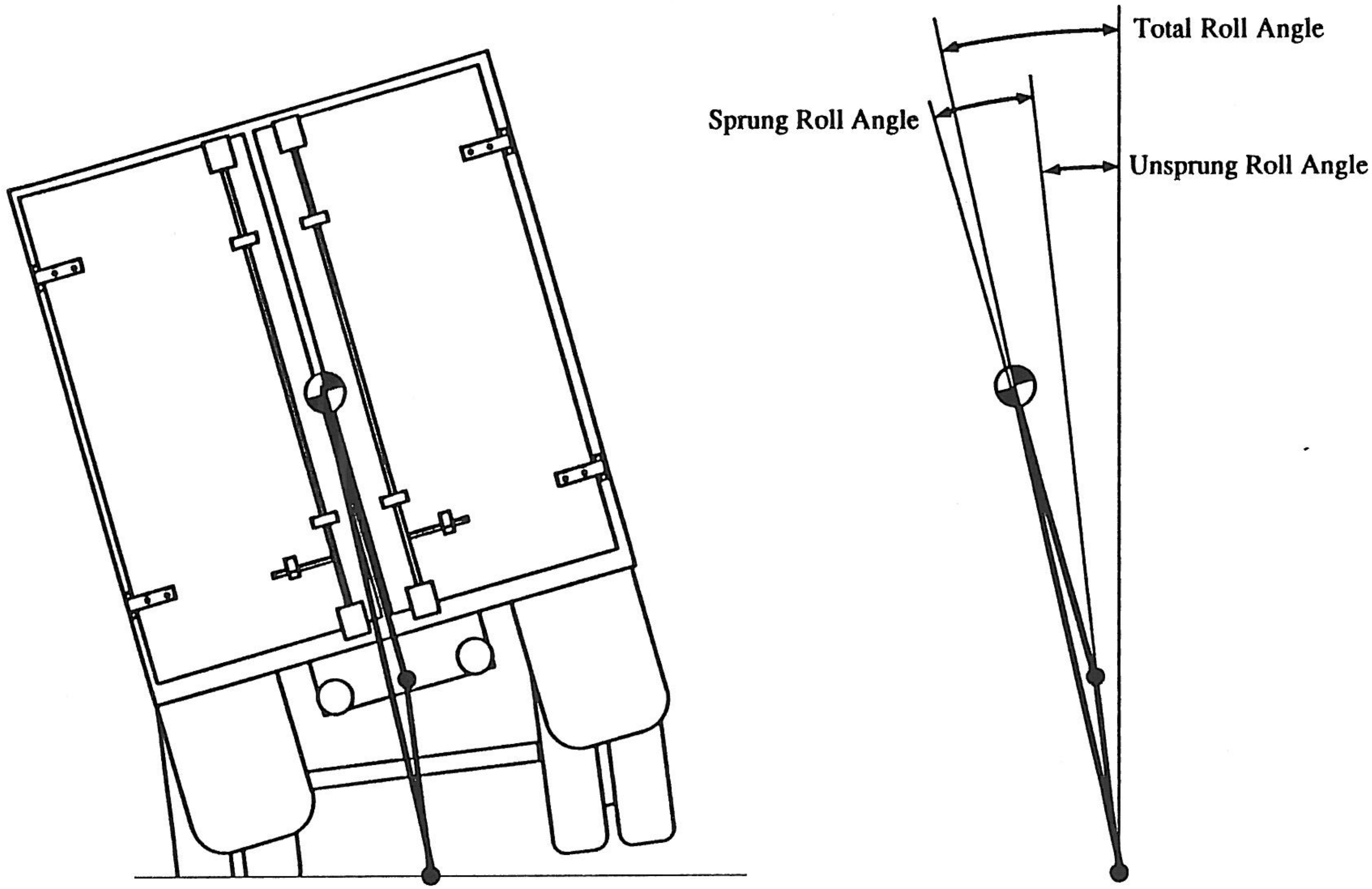
Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01400	.10430	.09025	2520.85	.43368
1	2	.02938	.09861	.09025	9503.19	.43368
2	1	.04368	.07539	.09025	8503.19	.43368
3	1	.03948	.07608	.09025	8500.80	.42857
4	1	.03948	.07608	.09025	8500.80	.42857

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01491	.11677	.10000	2683.17	.42812
1	2	.03969	.09810	.10000	9503.19	.42812
2	1	.05390	.07504	.10000	8503.19	.42812

Axle Liftoffs

Unit No	Axle No	Roll Angle (rad)	Lateral Acceleration (g`s)
1	2	.09025	.43368
2	1	.07300	.40374
3	1	.07500	.44382
4	1	.07500	.44382

Roll Angle Definitions



After the calculations end a screen similar to the following appears.

```
DO YOU WANT TO SEE THE PLOTS ? Y
```

Screen #13

If your answer is "yes" just press the **End** key, and the following menu will appear (Screen #14)

```
SELECT PLOT
=============

 ay1
 ay2
 ALL OF THEM
 EXIT TO MAIN MENU
```

Screen #14

This menu allows you to chose which results to plot. The available results for plotting are the lateral accelerations of the various rolling elements of the unit, "ay1", "ay2", ... which may be plotted individually, or "All of them" implying that all results will be plotted on the same graph. (See the definition of "Roll Coupling Key" in the *Glossary*.) The number of rolling elements of the unit will be equal to one plus the number of type 2 Roll Couplings. In these plots, lateral acceleration will appear on the ordinate and total roll angle on the abscissa.

VIEW PLOTS

Once you have made your selection a plot will appear on the screen. An example appears on the following page. The numerical values associated with the cursor position are printed in the box (lower view port) beneath the graph.

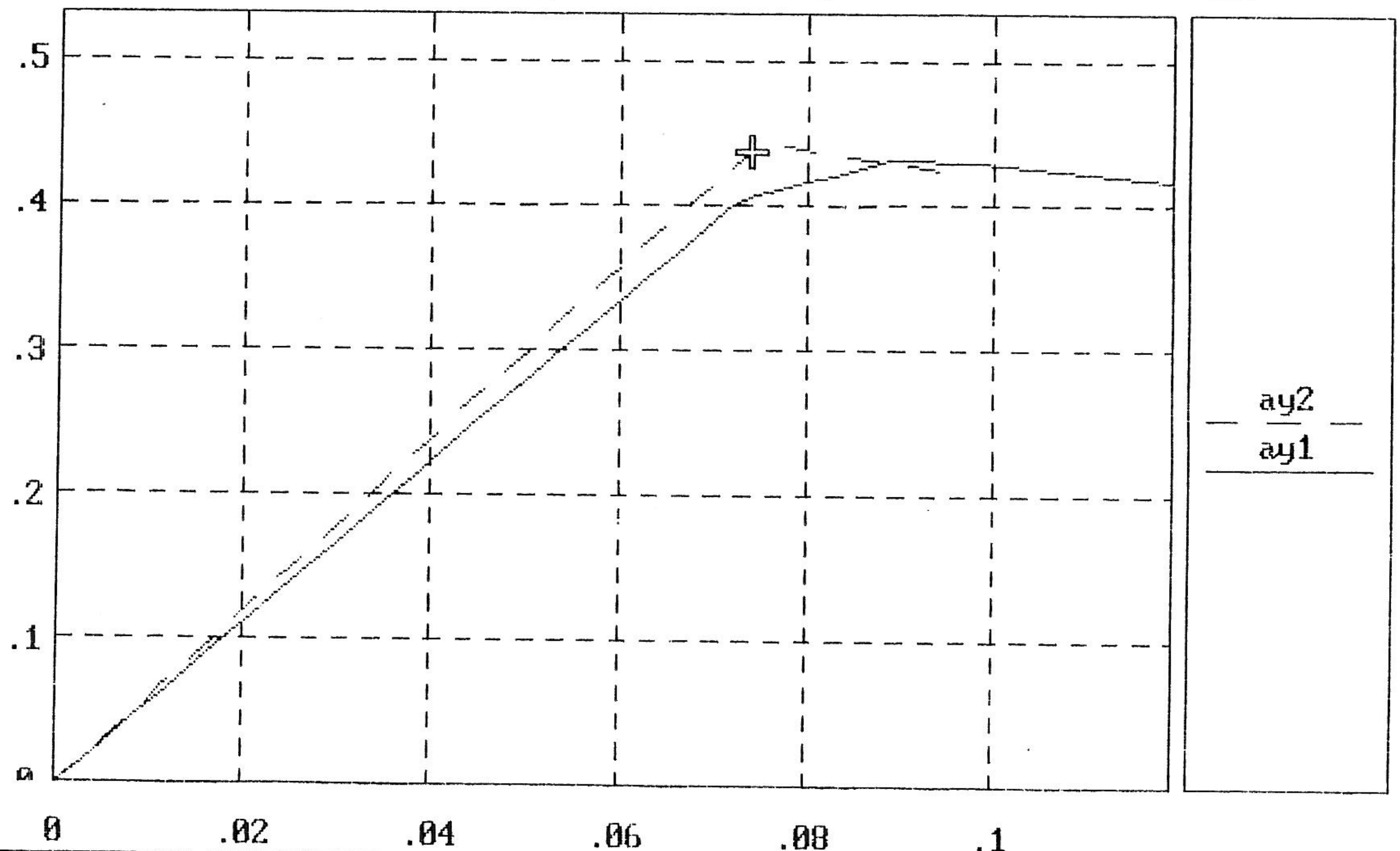
You can manipulate the cross cursor and modify the form of the graph. The following identifies the control keys and describes their function.

- The **ENTER** key (↵) shifts the cross cursor among the different curves, and indicates on the lower view port the legend of the curve selected. The "Y" and "X" values at the position of the cursor are shown on the same port.
- The right (→) and left (←) arrow keys move the cross cursor on the current curve right or left and updates the values in the lower view port. (Holding down the **Ctrl** key while using the arrow keys results in faster, but courser, cursor motion along the curve.)
- The up arrow (↑) key scrolls the "Y" axis upward.
- The down arrow (↓) key scrolls the "Y" axis downward.
- The **PgUp** key (page up) scrolls the "X" axis forward.
- The **PgDn** key (page down) scrolls the "X" axis backward.
- The + (plus) or - (minus) keys hit either once or twice and followed by the letter X or Y will zoom the respective axis up or down.
- Typing **S** allows the user to set the scales of the graph. A screen appears which allows the user to enter the desired maximum and minimum values for the ordinate and abscissa scales, using the screen editing technique described in the EDIT-VIEW DATA section. Pressing the **End** key causes the graph to be reprinted with the specified scaling.
- Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.
- **End** key, gets you out of the chart and sends you to the plot menu (Screen #14).

Exit to Main Menu

Selecting this option will return the user to Screen #6 where further selections may be made or the user may **QUIT** the program.

Lateral Accelerations (g's) vs Roll Angle (rad)   D:28'DBL.ROL



ay2	=	.4386 g's	Roll Angle	=	.0740 rad

Directions for the Use of

The Steady Turn Model (Handling)

STEADY TURN MODEL (HANDLING)
TABLE OF CONTENTS

THE MANEUVER AND THE VEHICLE

The Steady Turning Model (Handling) examines the steady state (constant lateral acceleration) yaw and roll response of multiple unit vehicles over the full range of lateral acceleration from zero up to the point where one wheel of the vehicle lifts off of the ground. The emphasis is on the yaw response of the lead unit of the vehicle. In the yaw plane, the program predicts the front wheel steer angle, effective wheelbase, understeer gradient and critical velocity of the lead unit of the vehicle as a function of lateral acceleration and forward speed. In order to include the influence of changing vertical loads on the tires, the model also calculates the roll angle response of the vehicle (sprung and unsprung masses) and the side-to-side load transfer occurring at each axle of the vehicle as a function of lateral acceleration. This portion of the calculations is the same as those performed in the Static Roll Model.

The subject vehicle, defined by the user, may be composed of as many as eight units. Individual units are lead units (trucks or tractors), dollies and semitrailers. (All full trailers are treated as two units, a dolly and semitrailer.) Mathematically, dollies and semitrailers are treated similarly. Rather, trailing units are distinguished by the nature of their front articulation (roll coupling). Roll couplings may be either rigid (fifth wheels, turn tables or B-dolly pintle joints) or free (A-dolly pintle joints). Portions of the vehicle separated by free roll couplings are treated as independently rolling elements of the vehicle. See the definition of Roll Coupling Type in Appendix C: *Glossary of Descriptive Parameters.*

THE PROGRAM DISK

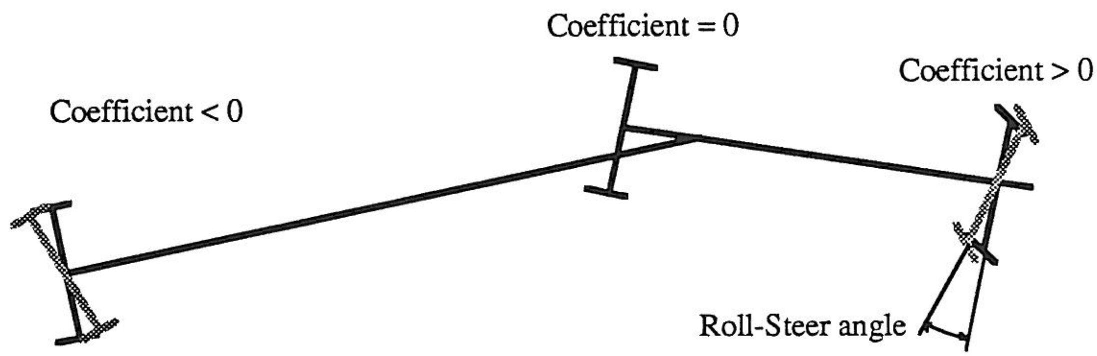
One of the *Simplified Models* program disks which you received will contain the Handling Model files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models*.) If you wish to produce backup disks for the Handling Model, be certain that all of the required files are copied onto the backup disks. The required files are:

HANDLING.EXE	The main program file.
AXIS	A plotting support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "HND". The Handling Model program will only read (and write) vehicle data files with this extension.

WHAT'S NEW IN VERSION 3.0 ?

Version 3.0 has an enhanced capability from an analyst's point of view as it incorporates the influence of suspension roll-steer effects. As the tractor/trailing units roll and lateral load transfer occurs, due to unequal loads at each side of the axles, they may rotate relative to the longitudinal axis of the vehicle and establish a steer angle, even though they are not steering axles. Each suspension layout or design is associated with some roll-steer coefficient. The value of the coefficient can be positive (wheels are steered towards the inside of the turn), negative (wheels are steered outside of the turn), or zero (no roll-steer effect).



The value of the coefficient is supplied to the program by the user as the amount of steer angle developed for each degree of roll of the sprung mass (see Screen # 7). Obviously, running this model with zero roll steer coefficient, and running the older version for the same vehicle parameters, would produce the same results. Obtaining the values for the roll-steer coefficient is done on a suspension test facility.

As seen from the above illustration, a positive coefficient at the steered axle and negative at all the rear axles, will result in a vehicle with a high tendency for oversteer. Such a combination was used in the example data file herein.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Steady Turn (Handling) Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters.* For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

Descriptive Parameters	English Units	SI Units
Aligning moment stiffness per tire	in-lb/deg	N-m/deg
Auxiliary roll stiffness	in-lb/deg	N-m/deg
Axle load	lbs	N
C.g. - axle distance	in	cm
Cornering stiffness	lb/deg	N/deg
Cornering stiffness table		
Distance from c.g. to front articulation	in	cm
Distance from c.g. to rear articulation	in	cm
Mechanical trail	in	cm
Nominal load on the tire	lbs	N
Radius of a tire	in	cm
Roll center height	in	cm
Roll coupling key		
Roll steer coefficient	deg/deg	deg/deg
Spacing between suspension springs	in	cm
Steering gear ratio		
Steering stiffness	in-lb/deg	N-m/deg
Suspension stiffness	lb/in	N/m
Tie rod stiffness	in-lb/deg	N-m/deg
Total c.g. height	in	cm
Total number of axles on the unit		
Total number of tires on the axle		
Total weight	lbs	kg
Track width of the axle	in	cm
Vertical force	lbs	N
Vertical stiffness of a tire	lb/in	N/m
Weight of the axle	lbs	kg

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, have the program disk in active drive and type:

HANDLING

After a few seconds the following message will appear on the screen. (See Screen #1 below.)

```
 UUUU     UUUUU  MMMMM     MMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRR      IIIIIII
UUUUU     UUUUU  MMMMMM   MMMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRRRR    IIIIIII
 UUU        UUU  MMM MMM MMM MMM  TTT   TTT   TTT  RRR        RRR     III
 UUU        UUU  MMM  MMMMM  MMM  TTT   TTT   TTT  RRR       RRR      III
 UUU        UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUU        UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUUU      UUUU  MMM         MMM        TTT        RRR       RRR      III
   UUUUUUUUU     MMMMM     MMMMM      TTTTTTT      RRR        RRR   IIIIIII
     UUUUU       MMMMM     MMMMM      TTTTTTT      RRR          RRR IIIIIII

                 *****************************************
                 *                                       *
                 *                                       *
                 *   STEADY TURN MODEL (HANDLING) V3.0   *
                 *                                       *
                 *                                       *
                 *****************************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                               HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
 ENGLISH
 METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen #2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

```
ENTER DATA FROM:
================
 KEYBOARD
 FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your HANDLING model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

If you selected FILE, the following screen will appear.

```
SELECT DRIVE
=============
 DRIVE A
 DRIVE B
 DRIVE C
 DRIVE D
 DRIVE E
 DRIVE F
 DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the HANDLING model disk by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

DOUBLE-L.HND STRUCK-L.HND TRSEMI-L.HND B-TRAIN.HND

Screen #5

All of the HANDLING model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select one of the example data files.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
=========

NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

Selecting NEW DATA would result in returning to Screen #2 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing technique.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. You will find that there is a "General Information" page for each unit of the vehicle, and a "Axle Information" page for each axle of each unit. These pages vary slightly depending on the type and position of the unit. The individual parameters on these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the HANDLING model are shown on the following pages (Screens #7 through 10).

```
                    GENERAL INFORMATION FOR UNIT #1

    *Total weight (lbs) = 15500.00
    *Total c. g. height (in) = 34.83
    *Total number of axles on the unit (max 8) = 3
    *Distance from c.g. to rear articulation (in) = 68.57

               Steering System Information
    *Steering gear ratio = 28.00
    *Steering stiffness (in-lb/deg) = 11000.00
    *Tie rod stiffness (in-lb/deg) = 11000.00
    *Mechanical trail (in) = 1.000
    *Aligning moment stiffness per tire (in-lb/deg) = 1600.00


               PgDn=PAGE DOWN  Esc=EXIT  End=PAGE DOWN
```

Screen #7

```
                       Unit # 1, Axle # 1

            Axle Information
   *C.g. - axle distance (negateive if rear of c.g.) (in) = 60.85
   *Axle load (lbs) = 12000.00
   *Track width of the axle (in) = 80.00
   *Weight of the axle (lbs) = 1200.00
   *Roll center height (in) = 20.00
   *Suspension stiffness (per spring) (lb/in) = 1200.0
   *Spacing between suspension springs (in) = 32.0
   *Auxiliary roll stiffness (in-lb/deg) = 8000.0
   *Roll-Steer Coefficient (Steering per Roll angle) =    .1000

              Tire information
   *Total number of tires on the axle = 2
   *Vertical stiffness of a tire (lb/in) = 4500.00
   *Radius of a tire (in) = 19.50
   *Nominal load of the tire (lbs) = 5430.00

 Vertical force (lbs)          Cornering stiffness (lb/deg)
       5000.00                         499.95
       6000.00                         523.33
       7000.00                         525.05

           PgUp=PAGE UP  PgDn=PAGE DOWN End=PgDn Esc=EXIT
```

Screen #8

```
                    Unit # 1, Axle # 2
        Axle Information
*C.g. - axle distance (negative if rear of c.g.) (in) = -50.17
*Axle load (lbs) = 11752.50
*Track width of the axle (in) = 72.00
*Weight of the axle (lbs) = 2500.00
*Roll center height (in) = 29.00
*Suspension stiffness (per spring) (lb/in) = 8033.0
*Spacing between suspension springs (in) = 40.25
*Auxiliary roll stiffness (in-lb/deg) = 25000.0
*Roll-Steer Coefficient (Steering per Roll angle) =  -.1000
              Tire information
*Total number of tires on the axle = 2
*Vertical stiffness of a tire (lb/in) = 4500.00
*Radius of a tire (in) = 19.50
*Nominal load of the tire (lbs) = 6040.00

                   CORNERING STTIFFNESS TABLE
 Vertical force (lbs)           Cornering stiffness (lb/deg)
       5000.00                            499.95
       6000.00                            523.33
       7000.00                            525.05

    PgUp=PAGE UP  PgDn=PAGE DOWN End=PgDn Esc=EXIT
```

Screen #9

```
                  GENERAL INFORMATION FOR UNIT #2

*Total weight (lbs) = 64500.00
*Total c. g. height (in) = 81.44
*Total number of axles on the unit (max 8) = 2
*Distance from c.g. to rear articulation (in) = 240.28
*Distance from c.g. to front articulation (in) = 227.72
*Roll coupling key (1 - Rigid; e.g. semitrailer) = 1
                   (2 - Free; e.g. A-dolly)



     PgUp=PAGE UP   PgDn=PAGE DOWN  End=PgDn    Esc=Exit
```

Screen #10

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. When KEYBOARD is selected from the ENTER DATA menu, the user is requested to ENTER THE NUMBER OF UNITS which make up the vehicle. After making that entry and pressing the **ENTER** key (↵) or the **End** key, the KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following pages contain examples of printed data.

HANDLING MODEL

FILE NAME:D:STR-01RS.HND

Date: 8-15-1990 Time:16:22:12

Information for Unit # 1 (Towing unit)

General Information

Total weight = 15500.00 lbs
Total c.g. height = 34.83 inches
Total number of axles = 3
Distance from c.g. to rear articulation point = 68.75 inches

Steering System Information
Steering gear ratio = 28.00
Steering stiffness = 11000.00 in-lb/deg
Tie rod stiffness = 11000.00 in-lb/deg
Mechanical trail = 1.000
Aligning moment stiffness per tire = 1600.00in-lb/deg

Axle Information, Unit # 1

Axle # 1
C.g. - axle distance (negative if rear of c.g.) = 60.85 inches
Axle load = 12000.00 lbs
Track width of the axle = 80.00 inches
Weight of the axle = 1200.00 lbs
Roll center height = 20.00 inches
Suspens ion stiffness (per spring) = 1200.00 lbs/in
Spacing betwe en suspension springs = 32.00 inches
Auxiliary roll stiffness = 8000.00 in-lb/deg
Roll Steer Coefficient (Steering per Roll angle) = .1000

Tire Information
Total number of tires on the axle = 2
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 19.50 inches
Nominal load of the tire = 5430.00 lbs

Cornering Stiffness Table

Vertical force (lbs)	Cornering stiffness (lb/deg)
5000.00	499.95
6000.00	523.33
7000.00	525.05

Axle # 2
C.g. - axle distance (negative if rear of c.g.) = -59.15 inches
Axle load = 17000.00 lbs
Track width of the axle = 72.00 inches
Weight of the axle = 2300.00 lbs
Roll center height = 29.00 inches
Suspens ion stiffness (per spring) = 5500.00 lbs/in
Spacing betwe en suspension springs = 38.00 inches

Auxiliary roll stiffness = 11000.00 in-lb/deg
Roll Steer Coefficient (Steering per Roll angle) = -.1000

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 19.50 inches
Nominal load of the tire = 5430.00 lbs

Cornering Stiffness Table

Vertical force (lbs)	Cornering stiffness (lb/deg)
5000.00	499.95
6000.00	523.33
7000.00	525.05

Axle # 3
C.g. - axle distance (negative if rear of c.g.) = -107.15 inches
Axle load = 17000.00 lbs
Track width of the axle = 72.00 inches
Weight of the axle = 2300.00 lbs
Roll center height = 29.00 inches
Suspens ion stiffness (per spring) = 5500.00 lbs/in
Spacing betwe en suspension springs = 38.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg
Roll Steer Coefficient (Steering per Roll angle) = -.1000

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 19.50 inches
Nominal load of the tire = 5430.00 lbs

Cornering Stiffness Table

Vertical force (lbs)	Cornering stiffness (lb/deg)
5000.00	499.95
6000.00	523.33
7000.00	525.05

Information for Unit # 2 (Semitrailer)

General Information

Total weight = 64500.00 lbs
Total c.g. height = 81.44 inches
Total number of axles = 2
Distance from c.g. to rear articulation point = 240.28 inches
Distance from c.g. to front articulation point = 227.72 inches

Axle Information, Unit # 2

Axle # 1
C.g. - axle distance (negative if rear of c.g.) = -180.28 inches
Axle load = 17000.00 lbs
Track width of the axle = 72.00 inches
Weight of the axle = 1500.00 lbs
Roll center height = 29.00 inches
Suspens ion stiffness (per spring) = 6500.00 lbs/in
Spacing betwe en suspension springs = 38.00 inches

Auxiliary roll stiffness = 11000.00 in-lb/deg
Roll Steer Coefficient (Steering per Roll angle) = -.1000

Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 19.50 inches
Nominal load of the tire = 5430.00 lbs

Cornering Stiffness Table

Vertical force (lbs)	Cornering stiffness (lb/deg)
5000.00	499.95
6000.00	523.33
7000.00	525.05

Axle # 2
C.g. - axle distance (negative if rear of c.g.) = -228.28 inches
Axle load = 17000.00 lbs
Track width of the axle = 72.00 inches
Weight of the axle = 1500.00 lbs
Roll center height = 29.00 inches
Suspens ion stiffness (per spring) = 6500.00 lbs/in
Spacing betwe en suspension springs = 38.00 inches
Auxiliary roll stiffness = 11000.00 in-lb/deg
Roll Steer Coefficient (Steering per Roll angle) = -.1000

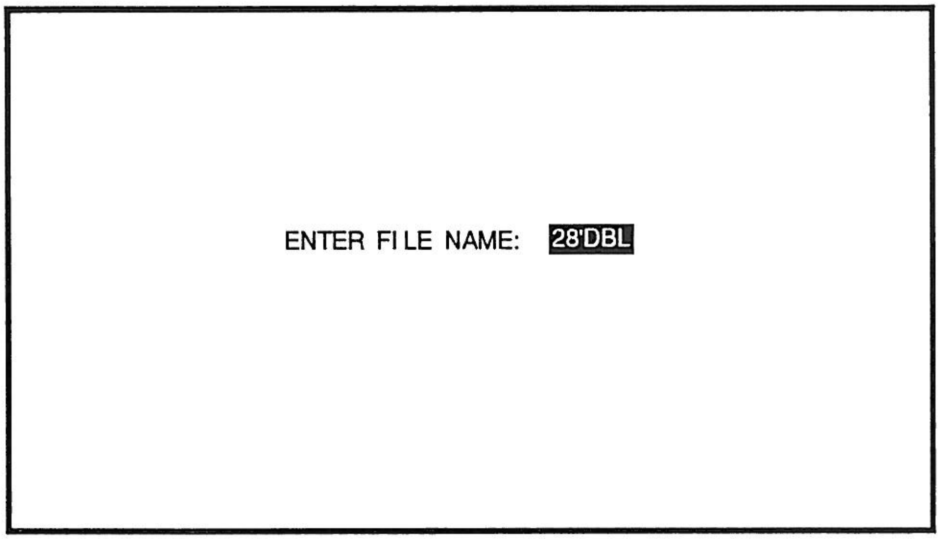
Tire Information
Total number of tires on the axle = 4
Vertical stiffness of a tire = 4500.00 lbs/in
Radius of a tire = 19.50 inches
Nominal load of the tire = 5430.00 lbs

Cornering Stiffness Table

Vertical force (lbs)	Cornering stiffness (lb/deg)
5000.00	499.96
6000.00	523.34
7000.00	525.13

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #11).



Screen #11

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "HND" is added to all files saved from the HANDLING model program. When reading data files, the HANDLING program only recognizes files with this extension.

CALCULATE

Selecting this option initiates the HANDLING model calculations. First, a screen of the following form will appear.

FORWARD VELOCITY (mph) = 55.00

Screen #12

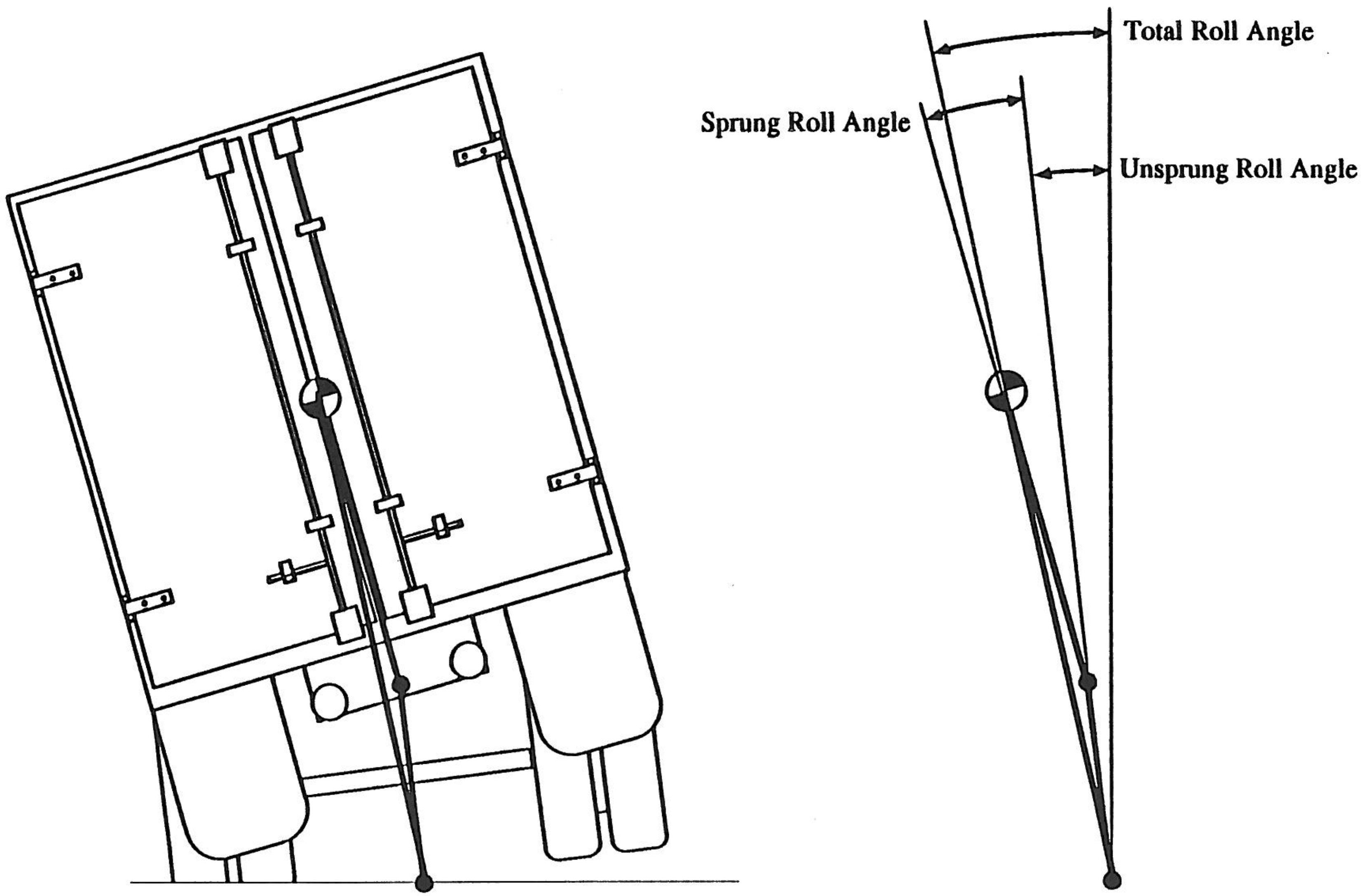
After making the required entry on Screen #12 and pressing the **ENTER** key (↵), a prompt will appear asking whether you wish to print the results as they are calculated. If the answer is "Y" or "y", then make sure that the printer is turned on. If the answer is "N" or "n", the results will be printed only on the screen.

Calculations occur at increments of steady state lateral acceleration beginning at zero roll and proceeding to higher levels. The incremental step of lateral acceleration is established by the INC.SET file. (The original incremental step value is 0.025 g's.) Calculations are continued to higher levels of lateral acceleration until one wheel of the vehicle lifts off of the ground.

Results are printed for every 0.05 g increase in lateral acceleration. The printed results concern both the roll and the yaw performance of the vehicle. Roll results are printed in a column wise format. From left to right, the columns are:

- Unit (counting from the front to the rear of the vehicle)
- Axle (counting from the front to the rear of the unit)
- Roll angles (see the figure on the following page for definitions of the unsprung, sprung, and total roll angles)
- Roll steer angle (see figure on page HND-2) of the axle due to sprung mass roll and roll-steer coefficient.

Roll Angle Definitions



- Load transfer — The vertical load transferred from the tires on the light side (inside of turn) of the axle to the tires on the heavy side (outside of the turn) of the axle.
- Lateral acceleration (the steady state lateral acceleration required to produce the roll angle and load transfer conditions).

Following the roll behavior results, yaw performance results are printed. These include:

- Reference wheelbase (Lr). The input wheelbase for the first unit of the vehicle.
- Effective wheelbase (Le). The effective wheelbase of the first unit of the vehicle. Effective wheelbase differs from the reference wheelbase due to the influence of tandem axles and turn radius. This result is *not* valid if the first unit has a total of only two axles.
- Rate of change of Le. The change of the effective wheelbase of the first unit per unit change in steady state lateral acceleration. This result is *not* valid if the first unit has a total of only two axles.
- The understeer gradient (Ue). The understeer gradient of the first unit of the vehicle.
- Rate of change of Ue. The change of the understeer gradient of the first unit of the vehicle per unit change of steady state lateral acceleration.
- Critical velocity. The critical velocity of the first unit of the vehicle, i.e., forward speed at which the lead unit becomes unstable in yaw. If the critical speed is equal to or greater than 600 mph, or is nonexistent, this value is reported as 600 mph.
- Steer angle (delta). The steer angle of the *front wheels* of the first unit of the vehicle.
- Rate of change of delta. The change of the steer angle of the *front wheels* of the first unit of the vehicle per unit change of steady state lateral acceleration.
- Force at the fifth wheel. The lateral force at the articulation point between the first and second units of the vehicle. (This parameter is zero for single unit vehicles.)

An example of the printed results for the HANDLING program appears on the following pages.

STEADY TURN MODEL Ver. 3.0
FILE NAME:D:STR-01RS.HND
FORWARD VELOCITY = 55.00 MPH

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00000	.00000	.00000	.00000	.00	.00000
1	2	.00000	.00000	.00000	.00000	.00	.00000
1	3	.00000	.00000	.00000	.00000	.00	.00000
2	1	.00000	.00000	.00000	.00000	.00	.00000
2	2	.00000	.00000	.00000	.00000	.00	.00000

*Reference Wheelbase (Lr)	=	144.00	in
*Effective Wheelbase (Le)	=	168.6040	in
*Rate of Change of Le	=	.0000	in/g
*Understeer Gradient (Ue)	=	.1365	rad
*Rate of Change of Ue	=	.000	rad/g
*Critical Velocity	=	600.0000	mph
*Steer Angle (delta)	=	.0000	rad
*Rate of Change of delta	=	.1593	
*Force at the Fifth Wheel	=	.00	Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00174	.01186	.01060	.00119	313.88	.05000
1	2	.00334	.01147	.01060	-.00115	1082.26	.05000
1	3	.00334	.01147	.01060	-.00115	1082.26	.05000
2	1	.00362	.01103	.01060	-.00110	1172.31	.05000
2	2	.00362	.01103	.01060	-.00110	1172.31	.05000

*Reference Wheelbase (Lr)	=	144.00	in
*Effective Wheelbase (Le)	=	168.4977	in
*Rate of Change of Le	=	-4.1199	in/g
*Understeer Gradient (Ue)	=	.0894	rad
*Rate of Change of Ue	=	-.0216	rad/g
*Critical Velocity	=	600.0000	mph
*Steer Angle (delta)	=	.0079	rad
*Rate of Change of delta	=	.1576	
*Force at the Fifth Wheel	=	1530.86	Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00349	.02372	.02120	.00237	627.76	.10000
1	2	.00668	.02295	.02120	-.00229	2164.52	.10000
1	3	.00668	.02295	.02120	-.00229	2164.52	.10000
2	1	.00724	.02207	.02120	-.00221	2344.62	.10000
2	2	.00724	.02207	.02120	-.00221	2344.62	.10000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 168.1766 in
*Rate of Change of Le = -8.6975 in/g
*Understeer Gradient (Ue) = .0877 rad
*Rate of Change of Ue = -.0454 rad/g
*Critical Velocity = 600.0000 mph
*Steer Angle (delta) = .0157 rad
*Rate of Change of delta = .1521
*Force at the Fifth Wheel = 3061.45 Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00523	.03558	.03180	.00356	941.64	.15000
1	2	.01002	.03442	.03180	-.00344	3246.78	.15000
1	3	.01002	.03442	.03180	-.00344	3246.78	.15000
2	1	.01085	.03310	.03180	-.00331	3516.94	.15000
2	2	.01085	.03310	.03180	-.00331	3516.94	.15000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 167.6337 in
*Rate of Change of Le = -13.4277 in/g
*Understeer Gradient (Ue) = .0847 rad
*Rate of Change of Ue = -.0765 rad/g
*Critical Velocity = 600.0000 mph
*Steer Angle (delta) = .0231 rad
*Rate of Change of delta = .1414
*Force at the Fifth Wheel = 4591.49 Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00698	.04744	.04240	.00474	1255.51	.20000
1	2	.01336	.04589	.04240	-.00459	4329.04	.20000
1	3	.01336	.04589	.04240	-.00459	4329.04	.20000
2	1	.01447	.04414	.04240	-.00441	4689.25	.20000
2	2	.01447	.04414	.04240	-.00441	4689.25	.20000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 166.8570 in
*Rate of Change of Le = -18.0054 in/g
*Understeer Gradient (Ue) = .0798 rad
*Rate of Change of Ue = -.1213 rad/g
*Critical Velocity = 600.0000 mph
*Steer Angle (delta) = .0297 rad
*Rate of Change of delta = .1228
*Force at the Fifth Wheel = 6120.73 Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.00872	.05930	.05300	.00593	1569.39	.25000
1	2	.01670	.05737	.05300	-.00574	5411.31	.25000
1	3	.01670	.05737	.05300	-.00574	5411.31	.25000
2	1	.01809	.05517	.05300	-.00552	5861.56	.25000
2	2	.01809	.05517	.05300	-.00552	5861.56	.25000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 165.8293 in
*Rate of Change of Le = -23.3459 in/g
*Understeer Gradient (Ue) = .0722 rad
*Rate of Change of Ue = -.1874 rad/g
*Critical Velocity = 600.0000 mph
*Steer Angle (delta) = .0351 rad
*Rate of Change of delta = .0912
*Force at the Fifth Wheel = 7648.88 Lbs.

Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01046	.07116	.06359	.00712	1883.27	.30000
1	2	.02004	.06884	.06359	-.00688	6493.57	.30000
1	3	.02004	.06884	.06359	-.00688	6493.57	.30000
2	1	.02171	.06620	.06359	-.00662	7033.87	.30000
2	2	.02171	.06620	.06359	-.00662	7033.87	.30000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 164.5263 in
*Rate of Change of Le = -28.9917 in/g
*Understeer Gradient (Ue) = .0603 rad
*Rate of Change of Ue = -.2956 rad/g
*Critical Velocity = 82.7568 mph
*Steer Angle (delta) = .0384 rad
*Rate of Change of delta = .0358
*Force at the Fifth Wheel = 9175.72 Lbs.

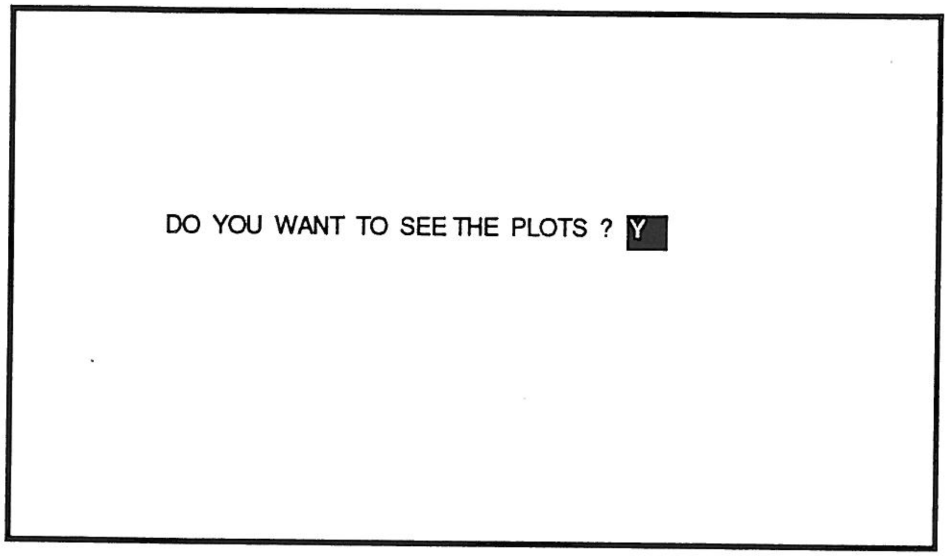
Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
1	1	.01221	.08302	.07419	.00830	2197.15	.35000
1	2	.02338	.08031	.07419	-.00803	7575.83	.35000
1	3	.02338	.08031	.07419	-.00803	7575.83	.35000
2	1	.02533	.07724	.07419	-.00772	8206.18	.35000
2	2	.02533	.07724	.07419	-.00772	8206.18	.35000

*Reference Wheelbase (Lr) = 144.00 in
*Effective Wheelbase (Le) = 162.9163 in
*Rate of Change of Le = -35.7056 in/g
*Understeer Gradient (Ue) = .0414 rad
*Rate of Change of Ue = -.4818 rad/g
*Critical Velocity = 38.3743 mph
*Steer Angle (delta) = .0380 rad
*Rate of Change of delta = -.0654
*Force at the Fifth Wheel = 10701.01 Lbs.

Axle # 1 of Unit # 2 has Lift Off

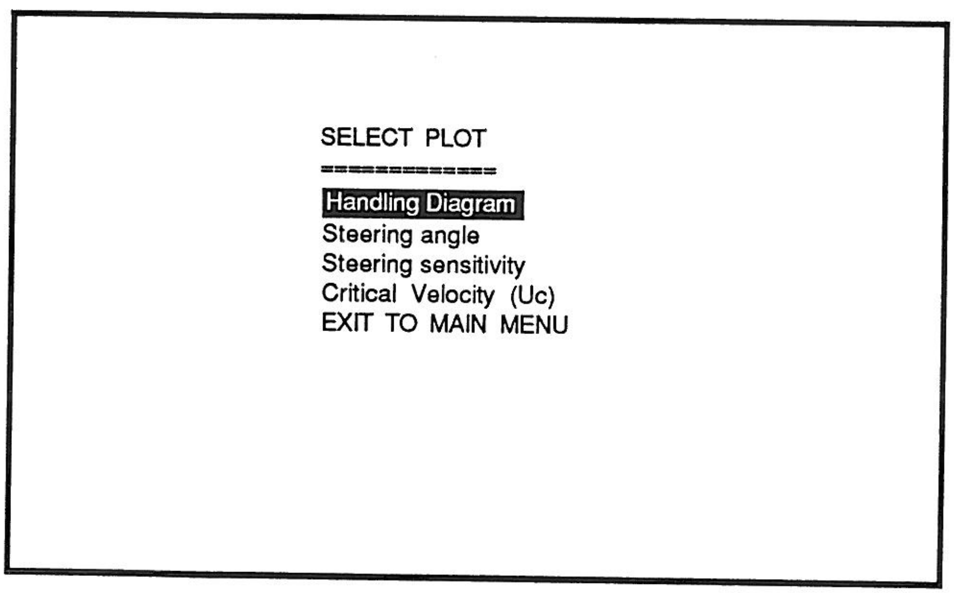
Unit	Axle	Roll Angles (rad) Unsprung	Sprung	Total	Roll Steer (rad)	Load Transfer (Lbs)	Lateral Acceleration (g`s)
2	1	.02714	.08275	.07949	-.00828	8792.34	.37500

After the calculations end, a screen similar to the following appears.



Screen #13

If your answer is "yes" just press the **End** key, and the following menu will appear (Screen #14)



Screen #14

This menu allows you to chose which results to plot. There are four graphs which may be plotted. All of these represent handling related results of the first unit of the vehicle.

The first selection in this menu is the "handling diagram". In this plot, lateral acceleration is on the ordinate and the quantity (Lr*r/u-delta) is on the abscissa. Where:

- Lr is the reference wheelbase,
- r is the yaw rate,
- u is the forward velocity, and
- delta is the front wheel steering angle.

The second selection produces a plot of steering angle on the ordinate versus lateral acceleration on the abscissa.

The third selection produces a plot of steering sensitivity, i.e., rate of change of front wheel steering angle on the ordinate versus lateral acceleration on the abscissa.

The fourth selection produces a plot of critical velocity (Uc) on the ordinate versus lateral acceleration on the abscissa. This menu item will not appear if critical velocity does not exist.

VIEW PLOTS

Once you have made your selection a plot will appear on the screen. An example of each of these four plots appears on the following pages. The numerical values associated with the cursor position are printed in the box (lower view port) beneath the graph.

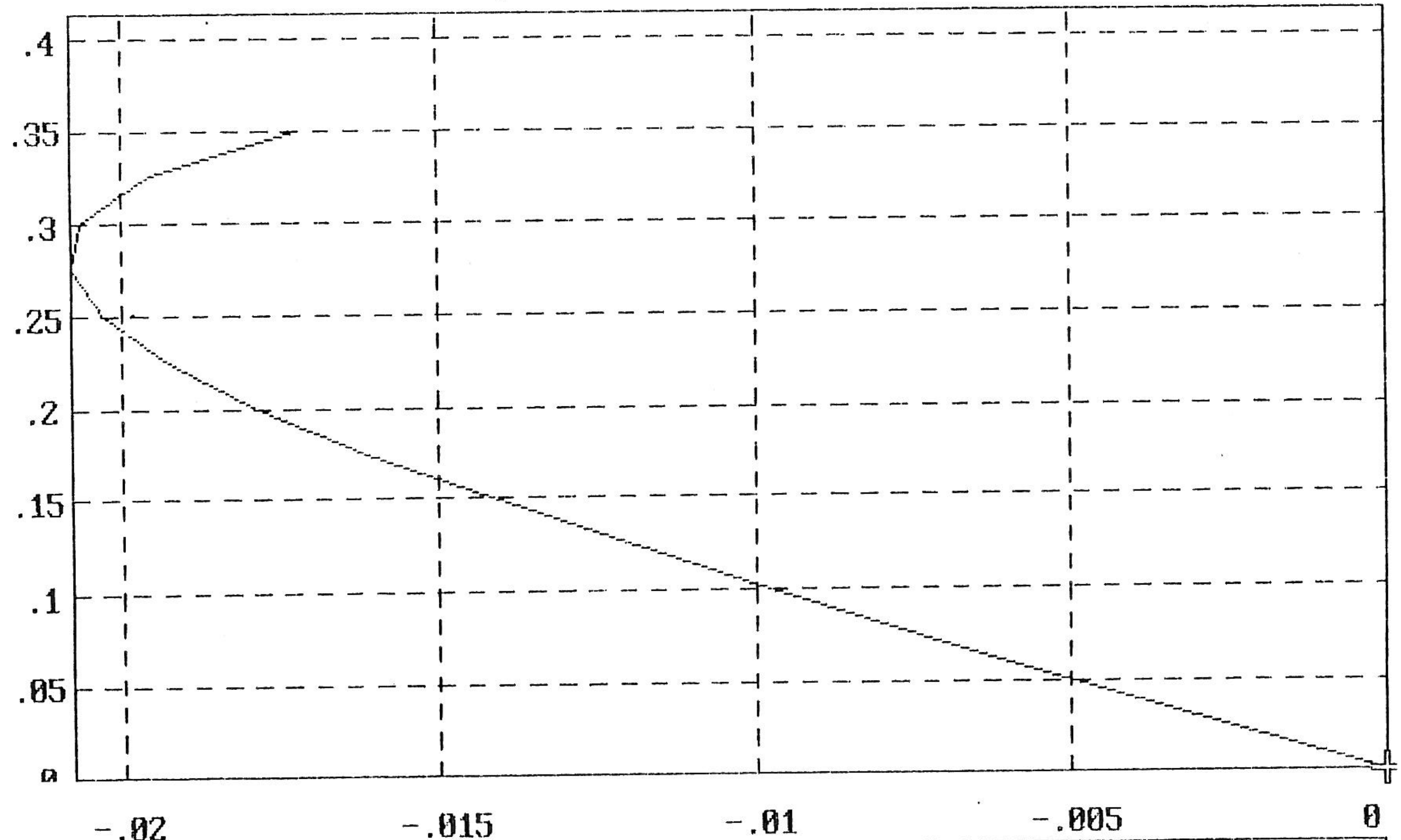
You can manipulate the cross cursor and modify the form of the graph. The following identifies the control keys and describes their function.

- The **ENTER** key (↵) shifts the cross cursor among the different curves, and indicates on the lower view port the legend of the curve selected. The "Y" and "X" values at the position of the cursor are shown on the same port.
- The right (→) and left (←) arrow keys move the cross cursor on the current curve right or left and updates the values in the lower view port. (Holding down the **Ctrl** key while using the arrow keys results in faster, but courser, cursor motion along the curve.)
- The up arrow (↑) key scrolls the "Y" axis upward.
- The down arrow (↓) key scrolls the "Y" axis downward.
- The **PgUp** key (page up) scrolls the "X" axis forward.
- The **PgDn** key (page down) scrolls the "X" axis backward.
- The + (plus) or - (minus) keys hit either once or twice and followed by the letter X or Y will zoom the respective axis up or down.
- Typing **S** allows the user to set the scales of the graph. A screen appears which allows the user to enter the desired maximum and minimum values for the ordinate and abscissa scales, using the screen editing technique described in the EDIT-VIEW DATA section. Pressing the **End** key causes the graph to be reprinted with the specified scaling.
- Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.
- **End** key, gets you out of the chart and sends you to the plot menu (Screen #14).

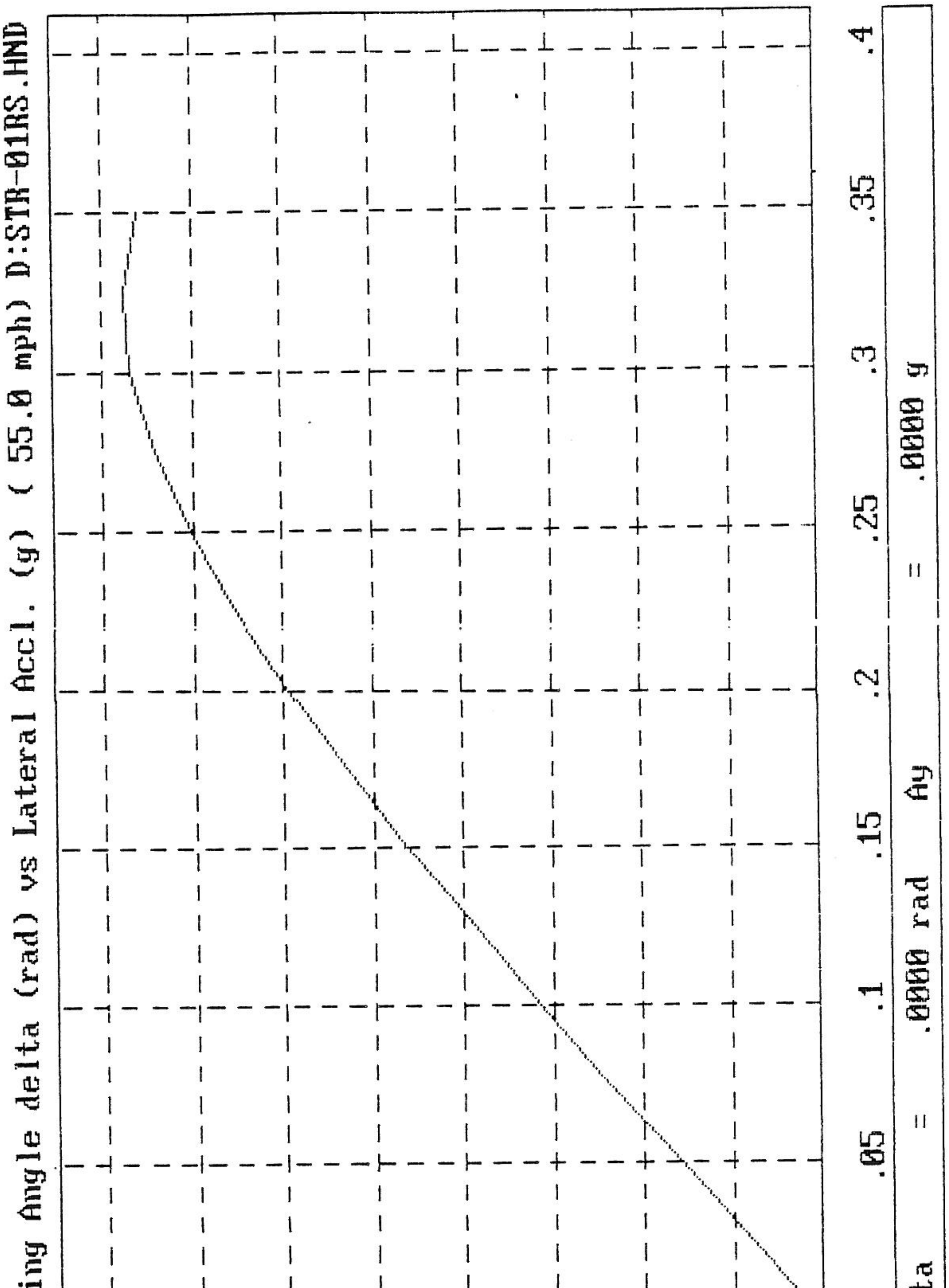
Exit to Main Menu

Selecting this option will return the user to Screen #6 where further selections may be made or the user may **QUIT** the program.

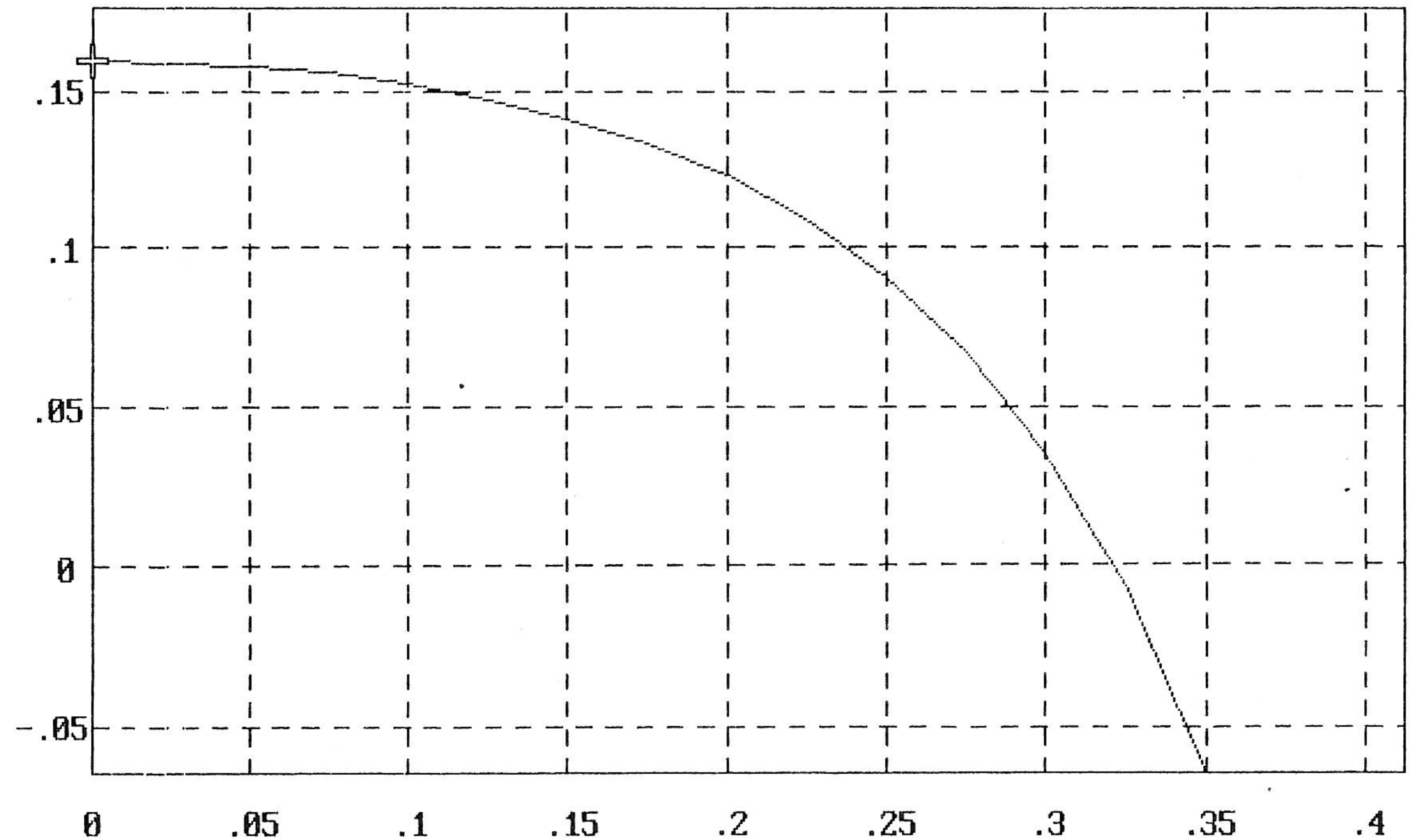
Lateral Acceleration (gs) vs Lr*r/u-delta (55.0 mph) D:STR-01RS.HND



Ay	=	.0000 g	Lr*r/u-delta=	.0000

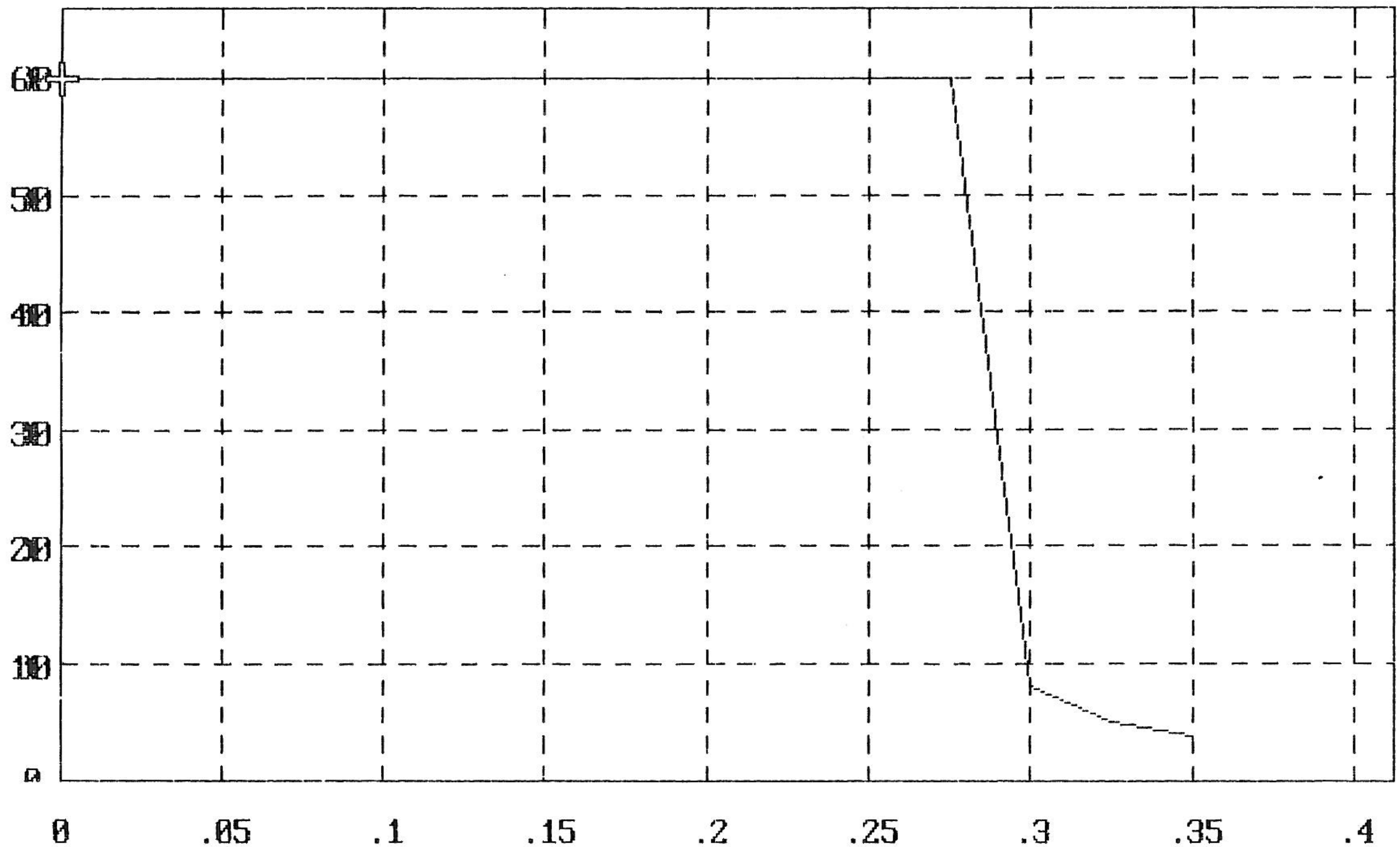

Steering Angle delta (rad) vs Lateral Accl. (g) (55.0 mph) D:STR-01RS.HND
.04
.035
.03
.025
.02
.015
.01
.005
0
.05
.1
.15
.2
.25
.3
.35
.4
delta = .0000 rad Ay = .0000 g

Steering Sensitivity (rad/g) VS Lateral Accl. (g) (55.0 mph) D:STR-01RS.HND



Sensitivity = .1593 rad/ Ay = .0000 g

Critical Velocity, Uc (mph) vs Lateral Accl. (gs) D:STR-01RS.HND



Uc = 600.0000 mph Ay = .0000 g

Directions for the Use of

The Rearward Amplification Model

REARWARD AMPLIFICATION MODEL
TABLE OF CONTENTS

THE MANEUVER AND THE VEHICLE

The Rearward Amplification Model determines the lateral acceleration gain (rearward amplification) between the first and last units of multiple unit vehicles as would derive from the vehicle's steady state response to sinusoidal steering. (Note that this model determines rearward amplification based on the steady state osculatory response, i.e. the response to a *continuous* sinusoidal input. When time based simulation is used it is common to determine rearward amplification from the response to a *single* sinusoidal wave input.) The calculations are done in the frequency domain, and rearward amplification is determined over a range of frequencies specified by the user. The calculations are accomplished by determining the lateral acceleration transfer function between certain strategic points along the length of the vehicle (hitch points and centers of gravity). The overall rearward amplification is the product of all of the transfer function gains in the frequency domain.

This rearward amplification program applies to three specific vehicle configurations — truck-full trailer, double and triple (of the so-called A-train configurations only). See the definition of Type of Unit in Appendix C: *Glossary of Descriptive Parameters* .

THE PROGRAM DISK

One of the *Simplified Models* program disks which you received will contain the Rearward Amplification Model files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models.*) If you wish to produce backup disks for the Rearward Amplification Model, be certain that all of the required files are copied onto the backup disks. The required files are:

REARWARD.EXE	The main program file.
AXIS	A plotting support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "RWA". The Rearward Amplification Model program will only read (and write) vehicle data files with this extension.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Rearward Amplification Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters*. For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

Descriptive Parameters	English Units	SI Units
Air drag coefficient		
C.g. - axle distance	in	cm
Cornering stiffness	lb/deg	N/deg
Distance from c.g. to front articulation	in	cm
Distance from c.g. to rear articulation	in	cm
Final steering frequency	rad/sec	rad/sec
Forward velocity	mph	kph
Initial steering frequency	rad/sec	rad/sec
Total weight	lbs	kg
Type of unit		

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, have the program disk in the active drive and then type:

REARWARD

After a few seconds the following message will appear on the screen. (See Screen #1 below.)

```
uuuuu      uuuuu  MMMMM      MMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRR       IIIIIII
uuuuu      uuuuu  MMMMMM    MMMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRRRR     IIIIIII
 uuu        uuu   MMM MMM MMM MMM   TTT   TTT   TTT  RRR         RRR     III
 uuu        uuu   MMM  MMMMM  MMM   TTT   TTT   TTT  RRR        RRR      III
 uuu        uuu   MMM   MMM   MMM         TTT        RRRRRRRRRRR         III
 uuu        uuu   MMM   MMM   MMM         TTT        RRRRRRRRRRR         III
 uuuu      uuuu   MMM         MMM         TTT        RRR        RRR      III
   uuuuuuuuuu     MMMMM      MMMMM      TTTTTTT      RRR         RRR   IIIIIII
     uuuuu        MMMMM      MMMMM      TTTTTTT      RRR          RRR  IIIIIII

                 ****************************************
                 *                                      *
                 *                                      *
                 *  REARWARD AMPLIFICATION MODEL V3.0   *
                 *                                      *
                 *                                      *
                 ****************************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                                HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
 ENGLISH
 METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen #2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

```
ENTER DATA FROM:
================
 KEYBOARD
 FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your REARWARD model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

If you selected FILE, the following screen will appear.

```
SELECT DRIVE
=============
 DRIVE A
 DRIVE B
 DRIVE C
 DRIVE D
 DRIVE E
 DRIVE F
 DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the REARWARD model disk by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End**.

TURNER2.RWA	TRUCK.RWA	28'DBL.RWA	TRIPLE.RWA
BIASTRIP.RWA			

Screen #5

All of the REARWARD model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select one of the example data files.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
=========
NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End**.

Selecting NEW DATA would result in returning to Screen #3 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing technique.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. On the first page you are asked to identify the type of vehicle. The second page requests the number of axles on the vehicle. Then you will find that there is a "General Information" page for each unit of the vehicle. The individual parameters on all of these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the REARWARD model are shown on the following pages (Screens #7 through 9).

```
*Total number of axles on Unit 2 (max 8) = 2
```

Screen #7

```
                    GENERAL INFORMATION FOR UNIT #2

*Total weight (lbs) = 44000.00
*Yaw moment of inertia (in-lb-sec^2) = 1260000.00
*Distance from c.g. to front articulation (in) = 148.91
*Distance from c.g. to rear articulation (in) = 157.09

                    Axle Information

Axle #   C.g. - axle distance (in)   Cornering stiffness (lb/deg/axle)
           (neg. if behind c.g.)
   1               -85.09                       2163.60
   2              -133.09                       2163.60



   PgUp=PAGE UP   PgDn=PAGE DOWN   End=PgDn      Esc=EXIT
```

Screen #8

```
                    GENERAL INFORMATION FOR UNIT #3

*Total weight (lbs) = 49000.00
*Yaw moment of inertia (in-lb-sec^2) = 1490000.00
*Distance from c.g. to front articulation (in) = 133.72
*Distance from c.g. to rear articulation (in) = 172.28

                Axle Information

Axle #   C.g. - axle distance (in)   Cornering stiffness (lb/deg/axle)
           (neg. if behind c.g.)
   1             157.72                     2021.00
   2             109.72                     2021.00
   3            -100.28                     2163.60
   4            -148.28                     2163.60

   PgUp=PAGE UP   PgDn=PAGE DOWN   End=PgDn     Esc=EXIT
```

Screen #9

```
SELECT THE TYPE OF UNIT
=======================

Truck-Full Trailer
Double
Triple
```

Screen #10

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. When KEYBOARD is selected from the ENTER DATA menu, the user is requested to ENTER THE TYPE OF UNIT which make up the vehicle. (See Screen #10.) After making that entry and pressing the **ENTER** key (↵) or the **End** key, the KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following pages contain examples of printed data.

REARWARD AMPLIFICATION MODEL

FILE NAME:A:S1D05.RWA

Date: 3- 8-1988 Time:13:13:53

Information for Unit # 2

General Information

Total weight = 44000.00 lbs
Yaw moment of inertia = 1260000.00 in-lb-sec^2
Distance from c.g. to front articulation point = 148.91 inches
Distance from c.g. to rear articulation point = 157.09 inches
Total number of axles in the unit = 2

Axle Information

Axle No	C.g.-axle distance (in) (neg if behind c.g.)	Axle cornering stiffness (lb/deg)
1	-85.09	2163.60
2	-133.09	2163.60

Information for Unit # 3

General Information

Total weight = 49000.00 lbs
Yaw moment of inertia = 1490000.00 in-lb-sec^2
Distance from c.g. to front articulation point = 133.72 inches
Distance from c.g. to rear articulation point = 172.28 inches
Total number of axles in the unit = 4

Axle Information

Axle No	C.g.-axle distance (in) (neg if behind c.g.)	Axle cornering stiffness (lb/deg)
1	157.72	2021.00
2	109.72	2021.00
3	-100.28	2163.60
4	-148.28	2163.60

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #11).

```
ENTER FILE NAME:  28'DBL
```

Screen #11

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "RWA" is added to all files saved from the REARWARD model program. When reading data files, the REARWARD program only recognizes files with this extension.

CALCULATE

Selecting this option initiates the REARWARD model calculations. First, a screen of the following form will appear.

Simulation Parameters

Forward Velocity (mph) = 55.00

Initial Steering Frequency (rad/sec) = .500

Final Steering Frequency (rad/sec) = 10.000

Screen #12

After making the required entries on Screen #12 and pressing the **ENTER** key (↵), a prompt will appear asking whether you wish to print the results as they are calculated. If the answer is "Y" or "y", then make sure that the printer is turned on. If the answer is "N" or "n", the results will be printed only on the screen.

The programs calculates the rearward amplification (lateral acceleration transfer function gain) as a function of steering frequency beginning and ending at the specified values (Screen #11). The calculations are performed at increments of steering frequency established by the INC.SET file data (initially 0.25 rad/sec). Amplification (gain) is calculated for discrete portions of the vehicle and the total amplification (gain) is determined by multiplying all of the discrete values. The discrete steps are from the c.g. of a unit to the articulation point at the rear of that unit (e.g., Ay1R/Ay1cg) and from the articulation point at the front of a unit to the c.g. of that unit (e.g., Ay2cg/Ay1R). The entire length of the unit is consider through a combination of these discrete steps. (Refer to the definition of "Type of Unit" in Appendix C: *Glossary of Descriptive Parameters* for the special definitions of units.)

Results are printed for every 0.25 radians/sec of steering frequency. Frequency, rearward amplification for the discrete elements and total rearward amplification are printed in columns. At the completion of the calculations, the maximum total rearward amplification and the steering frequency at which it occurs is printed. Examples of the printed numerical results are shown on the following page.

REARWARD AMPLIFICATION MODEL
FILE NAME:A:28'DBL.RWA
FORWARD VELOCITY = 55.00 MPH

Transfer Functions

Freq(rad/sec)	Ay2R/Ay1cg	Ay3cg/Ay2R	Total
.5000	1.0091	1.0081	1.0173
.7500	1.0204	1.0181	1.0390
1.0000	1.0365	1.0318	1.0695
1.2500	1.0573	1.0488	1.1089
1.5000	1.0830	1.0682	1.1569
1.7500	1.1139	1.0889	1.2129
2.0000	1.1500	1.1092	1.2755
2.2500	1.1916	1.1264	1.3422
2.5000	1.2389	1.1374	1.4092
2.7500	1.2922	1.1385	1.4712
3.0000	1.3517	1.1263	1.5224
3.2500	1.4175	1.0987	1.5575
3.5000	1.4898	1.0558	1.5729
3.7500	1.5686	.9997	1.5682
4.0000	1.6537	.9345	1.5454
4.2500	1.7446	.8648	1.5087
4.5000	1.8406	.7945	1.4624
4.7500	1.9405	.7267	1.4101
5.0000	2.0425	.6631	1.3545
5.2500	2.1445	.6049	1.2971
5.5000	2.2436	.5521	1.2386
5.7500	2.3366	.5047	1.1793
6.0000	2.4203	.4623	1.1190
6.2500	2.4914	.4246	1.0577
6.5000	2.5473	.3909	.9956
6.7500	2.5864	.3608	.9331
7.0000	2.6081	.3339	.8707
7.2500	2.6130	.3097	.8094
7.5000	2.6026	.2881	.7498
7.7500	2.5793	.2686	.6927
8.0000	2.5454	.2509	.6387
8.2500	2.5037	.2350	.5883
8.5000	2.4564	.2205	.5416
8.7500	2.4057	.2073	.4986
9.0000	2.3531	.1952	.4593
9.2500	2.3001	.1842	.4236
9.5000	2.2476	.1740	.3912
9.7500	2.1962	.1647	.3618
10.0000	2.1466	.1562	.3352

Max Total Transf. Function = 1.5729 at w = 3.500 rad/sec

After the calculations end a screen similar to the following appears.

```
DO YOU WANT TO SEE THE PLOTS ? Y
```

Screen #13

If your answer is "yes", just press the **End** key, and a screen similar to the following will appear (Screen #14)

```
SELECT PLOT
============
Ay2R/Ay1cg
Ay 3cg / Ay 2R
Total
All of Them
EXIT TO MAIN MENU
```

Screen #14

This menu allows you to chose which results to plot. The available results for plotting are the discrete elements of rearward amplification, the total rearward amplification, or "All of them" implying that all results will be plotted on the same graph. In these plots, rearward amplification will appear on the ordinate with steering frequency on the abscissa.

VIEW PLOTS

Once you have made your selection a plot will appear on the screen. An example appears on the following page. The numerical values associated with the cursor position are printed in the box (lower view port) beneath the graph.

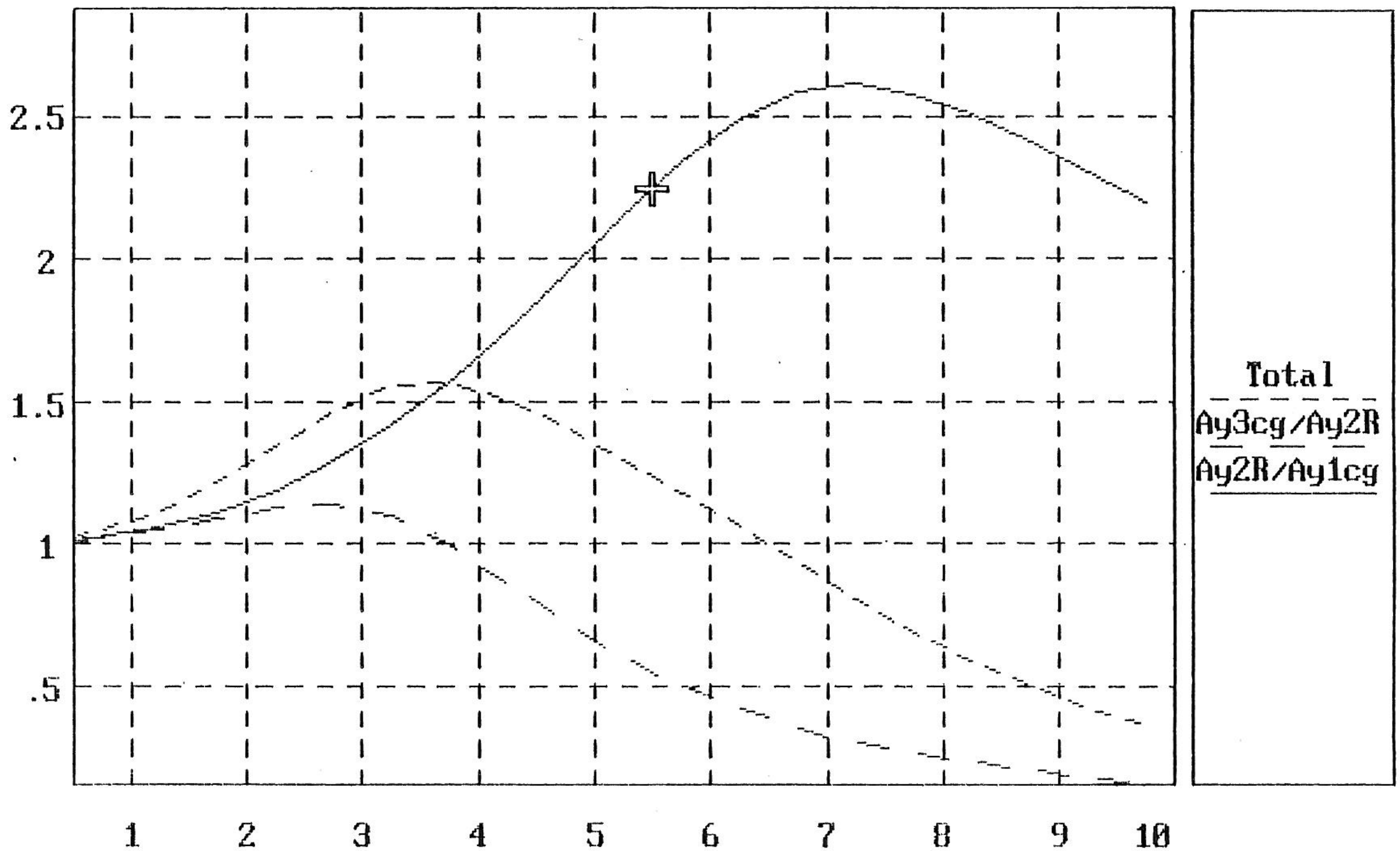
You can manipulate the cross cursor and modify the form of the graph. The following identifies the control keys and describes their function.

- The **ENTER** key (↵) shifts the cross cursor among the different curves, and indicates on the lower view port the legend of the curve selected. The "Y" and "X" values at the position of the cursor are shown on the same port.
- The right (→) and left (←) arrow keys move the cross cursor on the current curve right or left and updates the values in the lower view port. (Holding down the **Ctrl** key while using the arrow keys results in faster, but courser, cursor motion along the curve.)
- The up arrow (↑) key scrolls the "Y" axis upward.
- The down arrow (↓) key scrolls the "Y" axis downward.
- The **PgUp** key (page up) scrolls the "X" axis forward.
- The **PgDn** key (page down) scrolls the "X" axis backward.
- The + (plus) or - (minus) keys hit either once or twice and followed by the letter X or Y will zoom the respective axis up or down.
- Typing **S** allows the user to set the scales of the graph. A screen appears which allows the user to enter the desired maximum and minimum values for the ordinate and abscissa scales, using the screen editing technique described in the EDIT-VIEW DATA section. Pressing the **End** key causes the graph to be reprinted with the specified scaling.
- Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.
- **End** key, gets you out of the chart and sends you to the plot menu (Screen #14).

Exit to Main Menu

Selecting this option will return the user to Screen #6 where further selections may be made or the user may **QUIT** the program.

Transfer Functions vs Steering Frequency (rad/sec)   A:28'DBL.RWA



Ay2R/Ay1cg = 2.2436   Frequency = 5.5000 rad/sec

Directions for the Use of

The Brake Temperature Model

BRAKE TEMPERATURE MODEL
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THE MANEUVER AND THE VEHICLE

The Brake Temperature Model examines the internal energy in the brake due to the conversion of mechanical energy to thermal energy by the brake and the heat transfer out of the brake. The model predicts the brake temperatures reached at intervals along a specified road profile prescribed by the user. The brake temperatures calculated are dependent upon vehicle and brake parameters and the road profile defined by the user.

The subject vehicle, defined by the user, may consist of as many as 13 axles (triple configuration with tandem axles).

THE PROGRAM DISK

One of the *Simplified Models* program disks which you received will contain the Brake Temperature Model files and will be so labeled. In addition to the program file itself, that disk will also contain several "support" files required by the program for proper operation. (The disk may also contain files associated with others of the *Simplified Models*.) If you wish to produce backup disks for the Brake Temperature Model, be certain that all of the required files are copied onto the backup disks. The required files are:

BRKTEMP.EXE	The main program file.
AXIS	A plotting support file.
INC.SET	A program control data file. (See General Program Operation of the Introduction.)
SYSTEMij.FNT	MetaWindow data files containing font descriptions. (i and j are integers. Not all of these files are required. The files which are required depends on the graphics card installed in your computer.)

The *Simplified Models* program disk also contains several example vehicle data files. These are designated with the extension "BKT". The Brake Temperature Model program will only read (and write) vehicle data files with this extension.

DESCRIPTIVE PARAMETERS

The following table gives the descriptive parameters found in the Brake Temperature Model. Definitions of the parameters are found in Appendix C:*Glossary of Descriptive Parameters*. For a complete list of the vehicle descriptive parameters for all of the models see Table 2 in the introduction.

Descriptive Parameter	English Units	SI Units
Air drag coefficient		
Ambient temperature	°F	°C
Brake drum weight	lbs	Kg
Brake proportioning		
Cooling coefficient constant, K1	hp/°F	KW/°C
Cooling coefficient constant, K2	hp/°F-mph	KW/°C-Kph
Distance (longitudinal)	miles	Km
Elevation	ft	m
Frontal area	ft2	m2
Initial brake temperature	°F	°C
Number of points in the auxiliary retarding table		
Number of points in the road profile		
Number of stops		
Road surface coefficient		
Specific heat of brake drum	hp-hr/lb-°F	KW-hr/Kg-°C
Stop times	minutes	minutes
Total number of axles on the vehicle		
Total weight	lbs	Kg
Type of tire		
Velocity	mph	Kph

RUNNING THE PROGRAM AND ENTERING NEW DATA

To run the program, insert the program disk in any drive and then type:

BRKTEMP

After a few seconds the following message will appear on the screen. (see Screen #1 below.)

```
UUUUU      UUUUU  MMMMM     MMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRR      IIIIIII
UUUUU      UUUUU  MMMMMM   MMMMMM  TTTTTTTTTTTTTTT  RRRRRRRRRRRRR    IIIIIII
 UUU         UUU  MMM MMM MMM MMM  TTT   TTT   TTT  RRR        RRR     III
 UUU         UUU  MMM  MMMMM  MMM  TTT   TTT   TTT  RRR       RRR      III
 UUU         UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUU         UUU  MMM   MMM   MMM        TTT        RRRRRRRRRRR        III
 UUUU       UUUU  MMM         MMM        TTT        RRR       RRR      III
   UUUUUUUUUU     MMMMM     MMMMM      TTTTTTT      RRR        RRR  IIIIIII
     UUUUU        MMMMM     MMMMM      TTTTTTT      RRR         RRR IIIIIII

                 ****************************************
                 *                                      *
                 *                                      *
                 *   BRAKE TEMPERATURE MODEL V3.0       *
                 *                                      *
                 *                                      *
                 ****************************************

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    Graphics by MetaWINDOW
MetaGraphics Software Corporation
                                   HIT ANY KEY TO CONTINUE_
```

Screen #1

To continue, simply press any key on the keyboard. The next screen that appears will state the graphic device recognized by metawindow, simply press the return key to continue. If metawindow was not installed, an error message will appear instead of the graphic message and the program will terminate.

```
SELECT UNITS:
=============
ENGLISH
METRIC (SI )
```

Screen #2

The menu to select the type of units now appears on the screen (screen #2). This menu allows the data to be represented in either English or Metric (SI) on the screen and in the printer output. The actual files read and/or saved always store the data in English units, so the program can use the same files for either English or Metric representation. Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

```
ENTER DATA FROM:
================
KEYBOARD
FILE
```

Screen #3

The menu to select the source of input now appears on the screen (Screen #3). This menu allows you to chose to enter a new data set from the keyboard or to read a complete input data file from disk (or tape or similar device).

If you were to select KEYBOARD right away, you would, in effect, be presented with a blank (i.e., all parameter values set to zero) data sheet to fill out. If you select KEYBOARD after having previously entered a data set, you would be able to edit that data set. (In fact, the KEYBOARD function is simply a slight modification of the EDIT-VIEW DATA function which will be introduced shortly. Further comment will be made on the KEYBOARD function following the discussion of the EDIT-VIEW DATA function.)

If you select FILE you may read in a previously stored input data set. Your BRKTEMP model program disk contains several example data files. Since it is generally easier to edit an existing file than to enter a new data set, you should select FILE at this time.

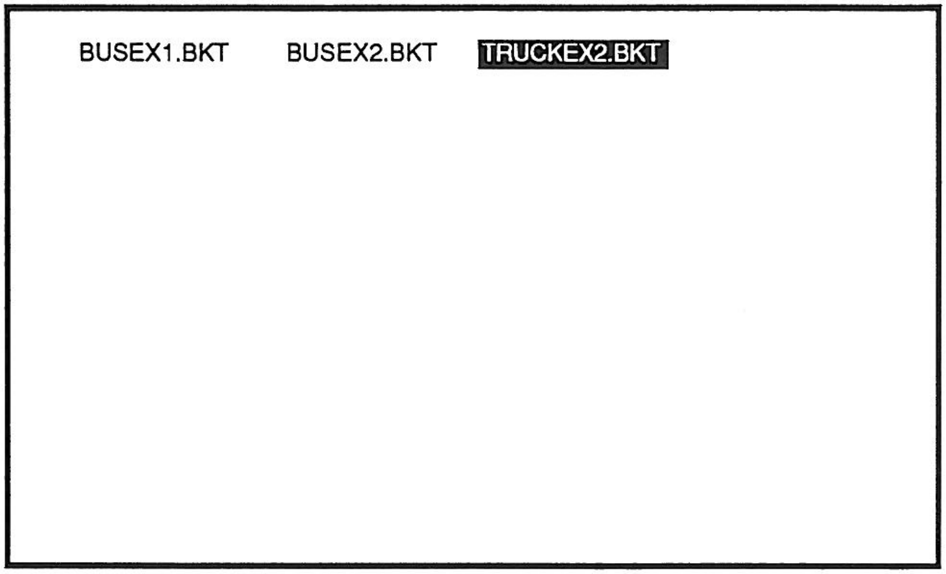
Make your selection by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**

If you selected FILE, the following screen will appear.

```
SELECT DRIVE
============
 DRIVE A
 DRIVE B
 DRIVE C
 DRIVE D
 DRIVE E
 DRIVE F
 DRIVE G
```

Screen #4

This menu allows you to select the drive from which you will read a data file. Select the drive that contains the BRKTEMP model disk by pressing the up (↑) and down (↓) arrow keys and then **ENTER** (↵) or **End.**



Screen #5

All of the BRKTEMP model data files available on the selected drive will now be listed on the screen.

The file selection is made by using the cursor with the four arrow keys (↑, ↓, →, and ←) and then pressing **End** to complete the selection. (The **ENTER** key (↵) has the same effect as the right arrow key (→).)

To continue following this discussion, select the example file TRUCKEX2.BKT.

THE MAIN MENU

Once data has been read into memory, the main menu appears (Screen #6).

```
MAIN MENU
==========
NEW DATA
EDIT-VIEW DATA
CALCULATE
PRINT DATA
SAVE DATA
QUIT
```

Screen #6

Selections are also made from this menu by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

Selecting NEW DATA would result in returning to Screen #3 and repeating the process just described.

To follow this discussion, select the EDIT-VIEW DATA option.

EDIT-VIEW DATA

The first "page" of data from the data file which you selected will now appear. In general, when the user selects EDIT-VIEW DATA from the main selection menu, the current input data set stored in memory is displayed in a series of data screens. The data may simply be viewed, or it may be altered by the user through standard page editing techniques.

The controls for page editing are the following:

- Up arrow (↑) and down arrow (↓) keys move the cursor to the data field on the next higher or lower data line on the screen.
- **Ctrl** right (→) and **Ctrl** left (←) arrow keys, (right (→) and left (←) arrow keys with **Ctrl** key held down) move the cursor to the data field to the right or left on the screen.
- Right (→) and left (←) arrow keys, move the text cursor to the right or left within the current data field.
- **PgUp** key (page up) causes the program to return to the previous data page.
- **PgDn** key (page down) causes the program to advance to the next data page, or to exit to the main menu from the last page.
- **ENTER** key (↵), has the same function as the **Ctrl** Right (→) key.
- **Esc** key exits to the main menu at any point during the page editing session.
- **End** key has the same effect as the **PgDn** key.

Editing is accomplished simply by locating the cursor over the value to be altered and typing in the new value.

Using the **PgDn** or **End** key and the **PgUp** key, move through the various pages of data from your selected file. You will find that there are separate pages for Vehicle, Road, and Ambient Parameters, the Auxiliary Retarding Table, Brake Parameters, the Road Profile, and Stop Times. The individual parameters on these pages are defined in Appendix C: *Glossary of Descriptive Parameters*. Try editing some parameter values.

Several example data pages from the BRKTEMP model are shown on the following pages (Screens #7 through 13). When entering brake data follow the numbering convention given in figure 1.

BRAKE NUMBERING CONVENTION: TRACTOR AND SEMITRAILER

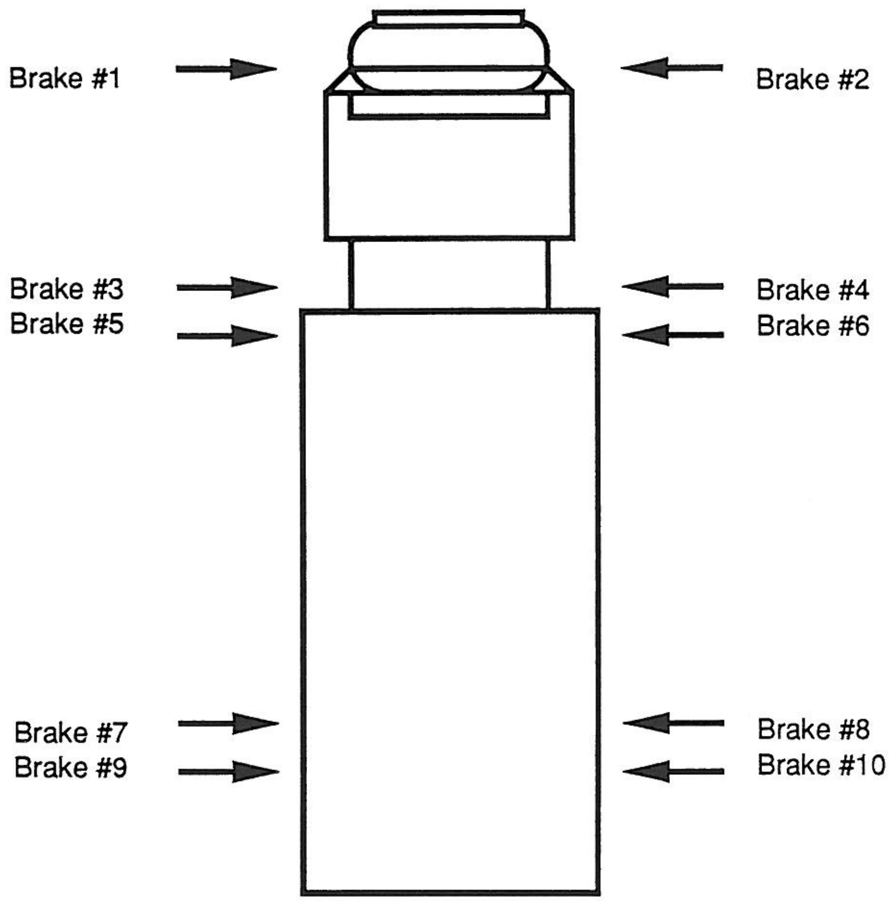


Figure 1.

```
-------------------------------------------------
               VEHICLE PARAMETERS
Total Weight (lb) = 50000.00
Frontal Area (Ft^2) = 100.00
Total Number of Axles = 5
Type of Tires :  2
   (1 = BIAS PLY   2 = RADIALS)
-------------------------------------------------
          ROAD AND AMBIENT PARAMETERS
Ambient Temperature (F) = 90.00
Air Drag Coefficient = .8500
Road Surface Coefficient = 1.5000
Number of Points in Road Profile = 24
Number of Points in Aux. Retarding Table = 2
Number of Stops = 3
-------------------------------------------------



   PgDn=PAGE DOWN     Esc=EXIT     End=PAGE DOWN
```

Screen #7

```
       TOTAL AUXILIARY RETARDING POWER TABLE
-------------------------------------------------
VELOCITY (MPH)                RETARDING POWER (HP)
       .00                               .0000
     40.00                            100.0000
-------------------------------------------------



  PgUp=PAGEUP  PgDn=PAGE DOWN  End=PgDn  Esc=EXIT
```

Screen #8

BRAKE PARAMETERS

Axle	Brake	Initial Brake Temperature (F)	Brake Drum Weight (lbs)	Specific Heat Cp (hp-hr/lbs-F)
1	1	100	65	.813E-04
	2	100	65	.813E-04
2	3	100	105	.813E-04
	4	100	105	.813E-04
3	5	100	105	.813E-04
	6	100	105	.813E-04
4	7	100	105	.813E-04
	8	100	105	.813E-04
5	9	100	105	.813E-04
	10	100	105	.813E-04

PgUp=PAGE UP PgDn=PAGE DOWN End=PgDn Esc=EXIT

Screen #9

BRAKE PARAMETERS (CONT.)

Axle	Brake	Cooling Coefficients K1 (hp/F)	K2 (hp/F-mph)	Proportioning
1	1	.0136	.000531	.0600
	2	.0136	.000531	.0600
2	3	.0136	.000797	.1100
	4	.0136	.000797	.1100
3	5	.0136	.000797	.1100
	6	.0136	.000797	.1100
4	7	.0136	.000797	.1100
	8	.0136	.000797	.1100
5	9	.0136	.000797	.1100
	10	.0136	.000797	.1100

PgUp=PAGE UP PgDn=PAGE DOWN End=PgDn Esc=EXIT

Screen #10

ROAD PROFILE

DISTANCE (MILES)	ELEVATION (FT)	VELOCITY (MPH)
.000	1700.00	50.00
.250	1615.32	49.00
.500	1531.04	48.00
.750	1446.56	47.00
1.000	1362.08	46.00
1.250	1277.60	45.00
1.500	1193.12	44.00
1.750	1108.64	43.00
2.000	1024.16	42.00
2.250	939.68	41.00
2.500	900.00	40.00
2.750	880.00	30.00
3.000	860.00	.00
3.000	860.00	.00
3.250	900.00	40.00
3.500	800.00	40.00

PgUp=PAGE UP PgDn=PAGE DOWN End=PgDn Esc=EXIT

Screen #11

ROAD PROFILE

DISTANCE (MILES)	ELEVATION (FT)	VELOCITY (MPH)
3.750	700.00	30.00
4.000	650.00	.00
4.000	650.00	.00
4.250	800.00	40.00
4.500	700.00	35.00
4.750	600.00	30.00
5.000	500.00	.00
5.000	500.00	.00

PgUp=PAGE UP PgDn=EXIT End=EXIT Esc=EXIT

Screen #12

```
                         STOP TIMES
--------------------------------------------------------------------
    TIME (MINUTES)
    --------------
        .500
       1.000
       2.000




          PgUp=PAGE UP  PgDn=EXIT  End=EXIT  Esc=EXIT
```

Screen #13

KEYBOARD REVISITED

Moving through the data pages and editing the parameter values, as explained in the EDIT-VIEW DATA section, is the manner in which all data is entered from the keyboard in all of the simple models. In fact, as mentioned earlier, the KEYBOARD data entry function is simply a slight modification of the EDIT-VIEW DATA function. The KEYBOARD function proceeds just as the EDIT-VIEW DATA function. If data has previously been entered, those parameter values will appear; if no data has been entered, parameter values will be zero.

PRINT DATA

This option allows the user to send the descriptive data set in memory to the printer. A prompt appears to check whether the printer is connected and turned on. If so, just hit the **End** key and the data set in memory will be printed. The following pages contain examples of printed data.

BRAKE TEMPERATURE

FILE NAME:A:TRUCKEX3.BKT

Date: Time: 0: 4:58

Vehicle Parameters

Total Weight = 50000.00 lbs
Frontal Area = 100.00 ft^2
Total Number of Axles = 5
Type of Tires: Radials

Road and Ambient Parameters

Ambient Temperature = 90.00 F
Air Drag Coefficient = .8500
Road Surface Coefficient = 1.5000
Number of Points in Road Profile = 24
Number of Points in Aux. Retarding Power Table = 2
Number of Stops = 3

Auxiliary Retarding Power Table

Velocity (mph)	Retarding Power (hp)
.00	.0000
40.00	100.0000

Brake Parameters

Axle	Brake	Initial Brake Temperature (F)	Brake Drum Weight (lbs)	Specific Heat Cp (hp-hr)/(lbs-F)
1	1	100.00	65.00	.813E-04
	2	100.00	65.00	.813E-04
2	3	100.00	105.00	.813E-04
	4	100.00	105.00	.813E-04
3	5	100.00	105.00	.813E-04
	6	100.00	105.00	.813E-04
4	7	100.00	105.00	.813E-04
	8	100.00	105.00	.813E-04
5	9	100.00	105.00	.813E-04
	10	100.00	105.00	.813E-04

Brake Parameters (Cont.)

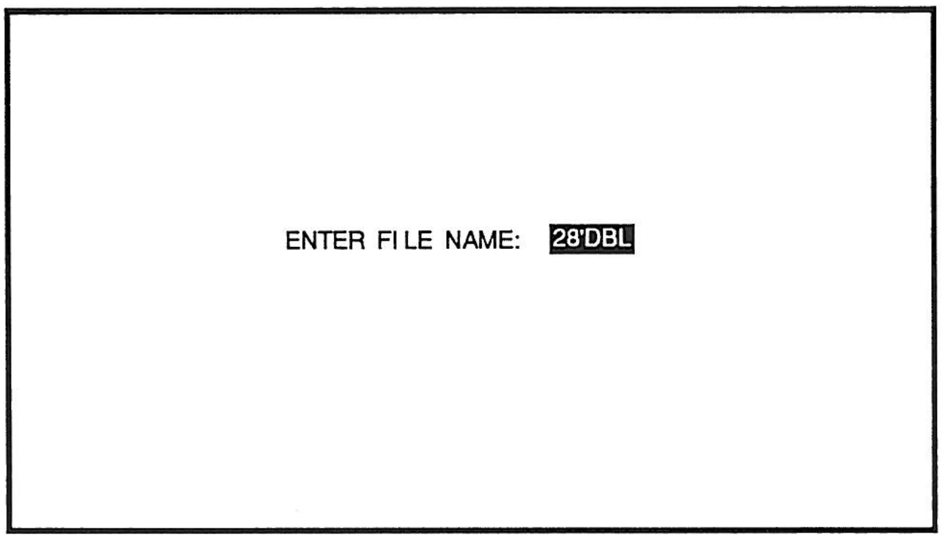
Axle	Brake	Cooling Coefficients K1 (hp/F)	Cooling Coefficients K2 (hp/F-mph)	Proportioning
1	1	.0136	.000531	.0600
	2	.0136	.000531	.0600
2	3	.0136	.000797	.1100
	4	.0136	.000797	.1100
3	5	.0136	.000797	.1100
	6	.0136	.000797	.1100
4	7	.0136	.000797	.1100
	8	.0136	.000797	.1100
5	9	.0136	.000797	.1100
	10	.0136	.000797	.1100

Distance (Miles)	Road Profile Elevation (Ft)	Speed (MPH)
.000	1700.00	50.00
.250	1615.52	49.00
.500	1531.04	48.00
.750	1446.56	47.00
1.000	1362.08	46.00
1.250	1277.60	45.00
1.500	1193.12	44.00
1.750	1108.64	43.00
2.000	1024.16	42.00
2.250	939.68	41.00
2.500	900.00	40.00
2.750	880.00	30.00
3.000	860.00	.00
3.000	860.00	.00
3.250	900.00	40.00
3.500	800.00	40.00
3.750	700.00	30.00
4.000	650.00	.00
4.000	650.00	.00
4.250	800.00	40.00
4.500	700.00	35.00
4.750	600.00	30.00
5.000	500.00	.00
5.000	500.00	.00

Stop Times Time (Minutes)
.500
1.000
2.000

SAVE DATA

Choosing this option allows the user to save a data set into a file. The computer prompts the user for the drive to which data will be sent (see Screen #4) and then prompts for the file name (see Screen #14).



Screen #14

If the file already exists a message indicating so will be printed on the screen, allowing the user to either replace the old file with the new file, or enter a different name for the new file.

Note that the extension "BKT" is added to all files saved from the BRKTEMP model program. When reading data files, the BRKTEMP program only recognizes files with this extension.

CALCULATE

Selecting this option initiates the BRKTEMP model calculations. First a prompt will appear asking whether you wish to print the results as they are calculated. If the answer is "Y" or "y", then make sure that the printer is turned on. If the answer is "N" or "n", the results will be printed only on the screen.

Calculations occur over the distances which compose the road profile. The number of points in the road profile and the road profile itself are determined by the user. Calculations are stopped when the end of the road profile has been reached.

Results are printed for every interval between two points in the road profile. Examples of the printed numerical results are shown on the following page (note that some intervals have been omitted from examples).

At each printed interval of the road profile, the vehicle acceleration, total power demand, net power to the brakes, total time, total distance (with respect to initial distance entered), elevation, and velocity are given. Following these, the temperature results are printed in column format following the brake numbering convention in Figure 1:

- Axle No. (counting from front to rear of vehicle)
- Temp No. (the temperature of the brake numbered)

BRAKE TEMPERATURE

FILE NAME:A:TRUCKEX2.BKT
TIME HISTORY OF BRAKE TEMPERATURES

Initial Conditions:

```
Time      =      .000 Sec.
Distance  =      .000 Mi.
Elevation =  1700.000 Ft.
Velocity  =    50.000 MPH.
```

Axle No.	Temp 1 (F)	Temp 2 (F)
1	100.000	100.000

Axle No.	Temp 3 (F)	Temp 4 (F)
2	100.000	100.000

Axle No.	Temp 5 (F)	Temp 6 (F)
3	100.000	100.000

Axle No.	Temp 7 (F)	Temp 8 (F)
4	100.000	100.000

Axle No.	Temp 9 (F)	Temp10 (F)
5	100.000	100.000

Interval 1: from .000 Mi. to .250 Mi.

```
Acceleration   = -.251E-02 Gs.
Total Demand   =   434.833 HP.
Net to Brakes  =   191.279 HP.

Time      =    18.182 Sec.
Distance  =      .250 Mi.
Elevation =  1615.520 Ft.
Velocity  =    49.000 MPH.
```

Axle No.	Temp 1 (F)	Temp 2 (F)
1	110.335	110.335

Axle No.	Temp 3 (F)	Temp 4 (F)
2	112.152	112.152

Axle No.	Temp 5 (F)	Temp 6 (F)
3	112.152	112.152

Axle No.	Temp 7 (F)	Temp 8 (F)
4	112.152	112.152

Axle No.	Temp 9 (F)	Temp10 (F)
5	112.152	112.152

Interval 3: from .500 Mi. to .750 Mi.

Acceleration = -.240E-02 Gs.
Total Demand = 416.808 HP.
Net to Brakes = 188.068 HP.

Time = 55.686 Sec.
Distance = .750 Mi.
Elevation = 1446.560 Ft.
Velocity = 47.000 MPH.

Axle No.	Temp	Temp
1	Temp 1 (F) 129.661	Temp 2 (F) 129.661
2	Temp 3 (F) 135.080	Temp 4 (F) 135.080
3	Temp 5 (F) 135.080	Temp 6 (F) 135.080
4	Temp 7 (F) 135.080	Temp 8 (F) 135.080
5	Temp 9 (F) 135.080	Temp10 (F) 135.080

Interval 4: from .750 Mi. to 1.000 Mi.

Acceleration = -.235E-02 Gs.
Total Demand = 407.358 HP.
Net to Brakes = 186.197 HP.

Time = 75.041 Sec.
Distance = 1.000 Mi.
Elevation = 1362.080 Ft.
Velocity = 46.000 MPH.

Axle No.	Temp	Temp
1	Temp 1 (F) 139.179	Temp 2 (F) 139.179
2	Temp 3 (F) 146.476	Temp 4 (F) 146.476
3	Temp 5 (F) 146.476	Temp 6 (F) 146.476
4	Temp 7 (F) 146.476	Temp 8 (F) 146.476
5	Temp 9 (F) 146.476	Temp10 (F) 146.476

Interval 12: from 2.750 Mi. to 3.000 Mi.

```
  Acceleration   = -.228E-01 Gs.
  Total Demand   =     3.793 HP.
  Net to Brakes  =     1.298 HP.

  Time          =   286.535 Sec.
  Distance      =     3.000 Mi.
  Elevation     =   860.000 Ft.
  Velocity      =      .000 MPH.
```

Axle No.	Temp 1 (F)	Temp 2 (F)
1	173.820	173.820
Axle No.	**Temp 3 (F)**	**Temp 4 (F)**
2	192.115	192.115
Axle No.	**Temp 5 (F)**	**Temp 6 (F)**
3	192.115	192.115
Axle No.	**Temp 7 (F)**	**Temp 8 (F)**
4	192.115	192.115
Axle No.	**Temp 9 (F)**	**Temp10 (F)**
5	192.115	192.115

Interval 13: Vehicle Stopped at 3.000 Mi.
Duration of stop = .500 Min.

```
  Time          =   316.535 Sec.
  Distance      =     3.000 Mi.
  Elevation     =   860.000 Ft.
  Velocity      =      .000 MPH.
```

Axle No.	Temp 1 (F)	Temp 2 (F)
1	172.041	172.041
Axle No.	**Temp 3 (F)**	**Temp 4 (F)**
2	190.768	190.768
Axle No.	**Temp 5 (F)**	**Temp 6 (F)**
3	190.768	190.768
Axle No.	**Temp 7 (F)**	**Temp 8 (F)**
4	190.768	190.768
Axle No.	**Temp 9 (F)**	**Temp10 (F)**
5	190.768	190.768

Interval 18: Vehicle Stopped at 4.000 Mi.
Duration of stop = 1.000 Min.

Time = 529.749 Sec.
Distance = 4.000 Mi.
Elevation = 650.000 Ft.
Velocity = .000 MPH.

Axle No.	Temp 1 (F)	Temp 2 (F)
1	198.235	198.235
Axle No.	Temp 3 (F)	Temp 4 (F)
2	226.836	226.836
Axle No.	Temp 5 (F)	Temp 6 (F)
3	226.836	226.836
Axle No.	Temp 7 (F)	Temp 8 (F)
4	226.836	226.836
Axle No.	Temp 9 (F)	Temp10 (F)
5	226.836	226.836

Interval 19: from 4.000 Mi. to 4.250 Mi.

Acceleration = .405E-01 Gs.
Total Demand = -812.862 HP.
Net to Brakes = .000 HP.

Time = 574.749 Sec.
Distance = 4.250 Mi.
Elevation = 800.000 Ft.
Velocity = 40.000 MPH.

Axle No.	Temp 1 (F)	Temp 2 (F)
1	192.197	192.197
Axle No.	Temp 3 (F)	Temp 4 (F)
2	220.902	220.902
Axle No.	Temp 5 (F)	Temp 6 (F)
3	220.902	220.902
Axle No.	Temp 7 (F)	Temp 8 (F)
4	220.902	220.902
Axle No.	Temp 9 (F)	Temp10 (F)
5	220.902	220.902

Interval 21: from 4.500 Mi. to 4.750 Mi.

Acceleration = -.822E-02 Gs.
Total Demand = 338.337 HP.
Net to Brakes = 215.819 HP.

Time = 626.442 Sec.
Distance = 4.750 Mi.
Elevation = 600.000 Ft.
Velocity = 30.000 MPH.

Axle No.	Temp (F)	Temp (F)
1	Temp 1: 221.508	Temp 2: 221.508
2	Temp 3: 256.194	Temp 4: 256.194
3	Temp 5: 256.194	Temp 6: 256.194
4	Temp 7: 256.194	Temp 8: 256.194
5	Temp 9: 256.194	Temp10: 256.194

Interval 22: from 4.750 Mi. to 5.000 Mi.

Acceleration = -.228E-01 Gs.
Total Demand = 3.284 HP.
Net to Brakes = 2.454 HP.

Time = 686.442 Sec.
Distance = 5.000 Mi.
Elevation = 500.000 Ft.
Velocity = .000 MPH.

Axle No.	Temp (F)	Temp (F)
1	Temp 1: 238.547	Temp 2: 238.547
2	Temp 3: 278.077	Temp 4: 278.077
3	Temp 5: 278.077	Temp 6: 278.077
4	Temp 7: 278.077	Temp 8: 278.077
5	Temp 9: 278.077	Temp10: 278.077

Interval 23: Vehicle Stopped at 5.000 Mi.
Duration of stop = 2.000 Min.

```
Time      =   806.442 Sec.
Distance  =     5.000 Mi.
Elevation =   500.000 Ft.
Velocity  =      .000 MPH.
```

Axle No.	Temp 1 (F)	Temp 2 (F)
1	226.331	226.331
Axle No.	**Temp 3 (F)**	**Temp 4 (F)**
2	268.347	268.347
Axle No.	**Temp 5 (F)**	**Temp 6 (F)**
3	268.347	268.347
Axle No.	**Temp 7 (F)**	**Temp 8 (F)**
4	268.347	268.347
Axle No.	**Temp 9 (F)**	**Temp10 (F)**
5	268.347	268.347

After the calculations end, the following screen appears.

```
DO YOU WANT TO SEE THE PLOTS ? Y
```

Screen #15

If your answer is "yes" just press the **End** key, and the following menu will appear (Screen #16)

```
MAIN PLOT MENU
================
ROAD PROFILE
TEMPERATURES
HP DEMANDS
EXIT TO MAIN MENU
```

Screen #16

This menu allows you to chose which results to plot. There are three types of graphs which may be plotted.

The first selection in this menu is the "road profile". In this plot, distance is on the abscissa and the ordinate may be chosen to be elevation, velocity, or both elevation and velocity (Screen #17).

SELECT Y VARIABLE
==================

ELEVATION
VELOCITY
BOTH
EXIT TO MAIN PLOT MENU

Screen #17

Choose the Y variable by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

The second selection from the main plot menu produces a plot of brake temperatures on the ordinate versus either distance, elevation, or time on the abscissa. The number of temperatures to plot and the corresponding brake numbers, as well as the variable for the abscissa, must be entered (Screens #18,#19, and #20 respectively).

NUMBER OF TEMPERATURES TO PLOT: 2

Esc = EXIT TO PLOT MENU   End = GO

Screen #18

Enter the number of temperatures from the keyboard that you wish to see on the plot, then press **ENTER** (↵) or **End**. The next screen will prompt you for the brake numbers corresponding to the temperatures that you want to plot (Screen #19).

```
ENTER BRAKE NUMBERS

1
3

PgUp=PAGE UP   PgDn=PAGE DOWN   Esc=EXIT   End=OK
```

Screen #19

Enter the numbers of the brake temperatures you wish to plot. Use the up (↑) and down (↓) arrow keys and **ENTER** (↵) key to move between entries, then press the **End** key to continue. The next screen allows you to select distance, elevation, or time, as the variable for the abscissa in the temperature plot (Screen #20).

```
SELECT  X VARIABLE
==================
DISTANCE
ELEVATIONTIME
EXIT TO MAIN PLOT MENU
```

Screen #20

Choose the X variable by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

The third selection from the main plot menu produces a plot of either total HP demand, net HP to brakes, or both total HP demand and net HP to brakes, on the ordinate versus either distance, elevation, or time, on the abscissa. The first screen prompts you for either total HP demand, net HP to brakes, or both, as the Y variable (Screen #21).

```
SELECT  Y VARIABLE
==================
 TOTAL HP DEMAND
 NET  HP TO BRAKES
 BOTH
 EXIT TO MAIN MENU
```

Screen #21

Choose the Y variable by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End**. The next screen will prompt you to select either distance, elevation, or time, as the X variable (Screen #22).

```
SELECT X VARIABLE
=================
DISTANCE
ELEVATION
TIME
EXIT TO MAIN PLOT MENU
```

Screen #21

Choose the X variable by using the up (↑) and down (↓) arrow keys and then pressing **ENTER** (↵) or **End.**

VIEW PLOTS

Once you have made your selections a plot will appear on the screen. Three examples appear on the following pages. The numerical values associated with the cursor position are printed in the box beneath the graph.

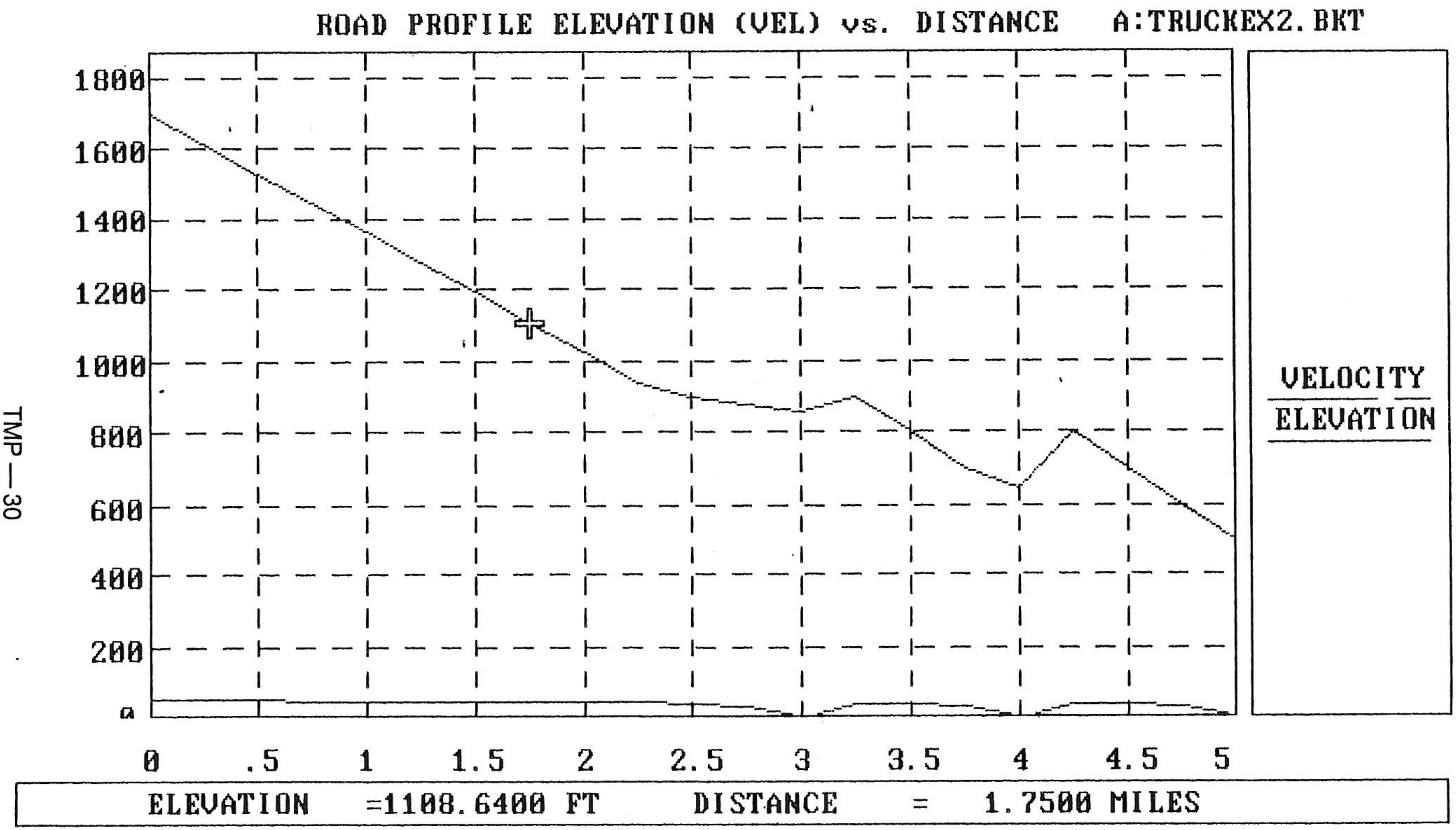
You can manipulate the cross cursor and modify the form of the graph. The following identifies the control keys and describes their function.

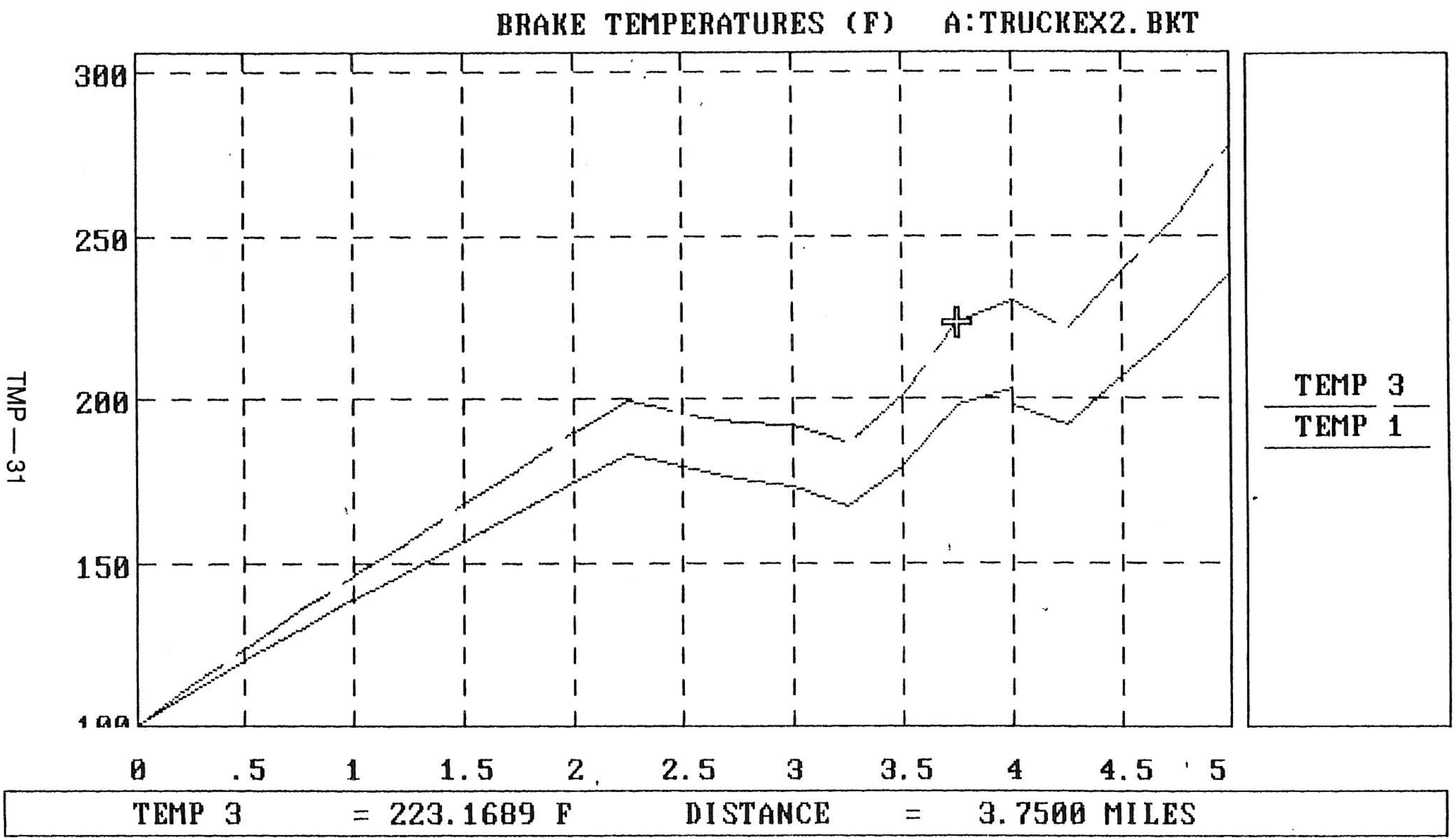
- The **ENTER** key (↵) shifts the cross cursor among the different curves, and indicates on the lower view port the legend of the curve selected. The "Y" and "X" values at the position of the cursor are shown on the same port.
- The right (→) and left (←) arrow keys move the cross cursor on the current curve right or left and updates the values in the lower view port. (Holding down the **Ctrl** key while using the arrow keys results in faster, but courser, cursor motion along the curve.)
- The up arrow (↑) key scrolls the "Y" axis upward.
- The down arrow (↓) key scrolls the "Y" axis downward.
- The **PgUp** key (page up) scrolls the "X" axis forward.
- The **PgDn** key (page down) scrolls the "X" axis backward.
- The + (plus) or - (minus) keys hit either once or twice and followed by the letter X or Y will zoom the respective axis up or down.

- Typing **S** allows the user to set the scales of the graph. A screen appears which allows the user to enter the desired maximum and minimum values for the ordinate and abscissa scales, using the screen editing technique described in the EDIT-VIEW DATA section. Pressing the **End** key causes the graph to be reprinted with the specified scaling.
- Typing **P** (or **p**) **W** (or **w**) (print window) will cause the chart on the screen to be sent to the printer.
- **End** key, gets you out of the chart and sends you to the plot menu (Screen #15).

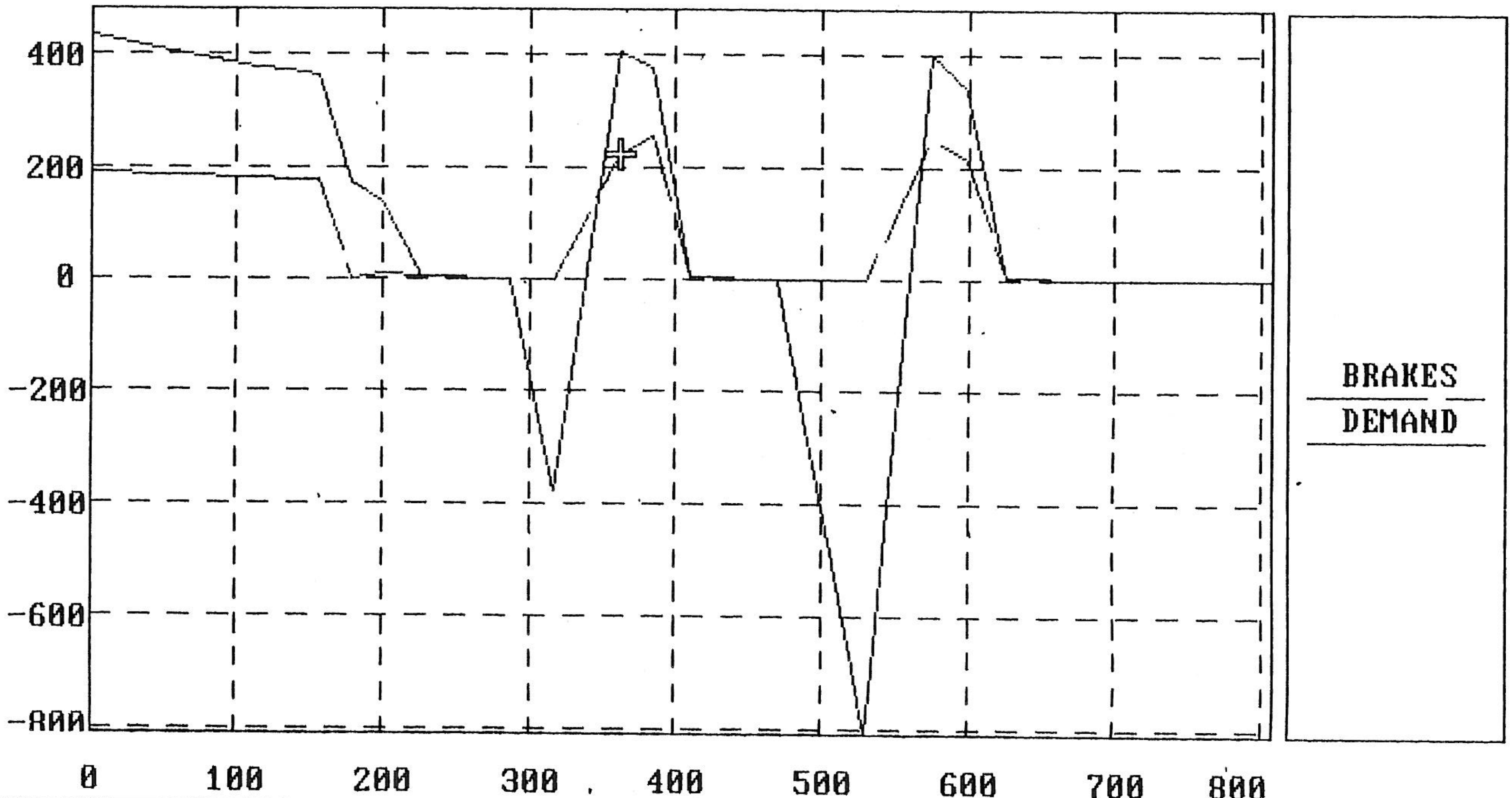
Exit to Main Menu

Selecting this option will return the user to Screen #6 where further selections may be made or the user may **QUIT** the program.


ROAD PROFILE ELEVATION (VEL) vs. DISTANCE A:TRUCKEX2.BKT
1800
1600
1400
1200
1000
800
600
400
200
0
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
VELOCITY
ELEVATION
ELEVATION =1108.6400 FT DISTANCE = 1.7500 MILES


BRAKE TEMPERATURES (F)   A:TRUCKEX2.BKT
300
250
200
150
0
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
TEMP 3
TEMP 1
TEMP 3 = 223.1689 F   DISTANCE = 3.7500 MILES

TOTAL DEMAND & HP TO BRAKES (HP) - (INT. VALUES)   A:TRUCKEX2.BKT



BRAKES = 224.1811 HP   TIME = 361.5350 SEC

Appendices

APPENDIX A
TABLE OF CONTENTS

Section *Page*

The Mechanics of Heavy-Duty Trucks and Truck Combinations

The University of Michigan
Engineering Summer Conferences
Ann Arbor, Michigan

Given yearly in July

Heavy-duty trucks and truck combinations, or tractors towing one or more trailers, are increasing in numbers. They account for an expanding proportion of the number of vehicle miles traveled. Indeed, the transportation of goods by truck is a major part of the U.S.transportation industry.

With increasing frequency engineers are called upon to answer questions wit respect to traffic safety, pavement loadings, and driver-vehicle compatibility. This intensive course is designed to assist engineerings in answering such questions. It acquaints attendants with the methods and tools available to analyze truck behavior in terms of design and operating variables. The course is also intended for persons engaged other technical activities, such as: truck equipment selection, fleet operations and maintenance, accident reconstruction, and development of truck safety standards.

Vehicle research shows that the heavy truck is a complex pneumatic-tired vehicle requiring its own analysis programs, parameter measurement methods, and test procedures. This course summarizes findings concerning the physics of the components of the heavy truck which determine the braking, steering, and ride performance of the complete system.

PREREQUISITE

Participants should have a bachelor's degree in engineering or the equivalent background to obtain maximum benefit from the course. It is desirable that participants have some experience or training in analysis or measurement of braking, steering, or ride behavior of cars or trucks. A familiarization with the mathematics of large-scale dynamic systems and the means for simulating system behavior using computers is not necessary but is helpful.

COURSE CONTENT

Basic Properties of the Pneumatic-tired Vehicle: Identification of (a) categories of performance, (b) subsystems of the motor vehicle, and (c) the terminology, sign conventions, and symbols to be used in the course. Brief overview of vehicle dynamics theory to show how these subsystems influence the behavior of the motor vehicle, with contrasts drawn between motor-car and heavy truck behavior

Motor Truck Components--Physics & Mathematical Models: The mechanics of heavy-truck tires. Modeling the truck tire. The mechanics of suspensions used on heavy-duty trucks. Analysis and modeling of truck suspension. Steering systems and articulation geometry required to minimize offtracking. The kinematic and mechanical characteristics of truck steering systems and models. Performance of the mechanical friction brake as influenced by design and operating variables. Statics and dynamics of pneumatic actuation systems. The thermal aspects of brakes. Antilock systems and brake system modeling. The truck frame as a load carrier and load distributor.

Truck Parameter Measurement & Estimation Methods: Properties of tires, steering systems, suspension systems, brake systems, and frames.

The Heavy-Vehicle System Modeling Process: Specialized models versus all-inclusive models. Simplifying assumptions. Models of the single-unit truck. Articulated vehicle models. The utility of a driver model. Computational laboratory.

Dynamic Behavior of Trucks & Truck Combinations: Longitudinal acceleration performance. Motion response caused by uneven roads and non-uniform rolling components. Steady turning of single and multi-unit trucks. Transient response to steering inputs Behavior in the linear and nonlinear regime. Statics and dynamics of the braking process.. Rollover processes. Influence of slosh and shifting loads.

Special Topics: As suggested by course participants.

STAFF

The lecturers are members of the Engineering Research Division of the University of Michigan Transportation Research Institute (UMTRI). Much of the course material is based on research by this unit.

Leonard Segel, Professor Mechanical Engineering and Applied Mechanics, Research Scientist, Transportation Research Institute, Chairman of the Course
Paul S. Fancher, Research Scientist, UMTRI
Robert D. Ervin, Research Scientist, UMTRI

Thomas D. Gillespie, Research Scientist, UMTRI
Christopher B. Winkler, Associate Research Scientist, UMTRI
Charles C. MacAdam, Assistant Research Scientist, UMTRI

ADDITIONAL INFORMATION

For additional information including application forms and housing information, contact:

Engineering Summer Conferences
400 Chrysler Center, North Campus
The university of Michigan
Ann Arbor, Michigan 48109
Telephone: (313) 764-8490

UMTRI

THE MECHANICS OF HEAVY-DUTY TRUCKS AND TRUCK COMBINATIONS

The University of Michigan
Engineering Summer Conferences
Chrysler Center for Continuing Education
Ann Arbor, Michigan

Lecture Schedule

Monday

8:30-8:40	Introduction
8:40-9:25	Motivating Films
9:25-9:45	Objectives and Scope of the Course, Definitions
Break	
10:00-10:50	Basic Properties of the Four-Wheeled Vehicle
Break	
11:00-12:00	Basic Properties (Cont.)
Lunch Hour	
1:00-1:55	Mechanics of the Pneumatic Tire
Break	
2:05-3:00	Mechanics of the Pneumatic Tire (Cont.)
Break	
3:30-4:20	Heavy Truck Suspension: Mechanics & Kinematics
Break	
4:30-5:20	Heavy Truck Suspension (Cont.)
5:30	Social Hour

Tuesday

8:30	Conference Participants Assemble in the W.E. McCormick Seminar Room at UMTRI
8:30 -8:40	UMTRI: What Is It?
8:40 - 9:10	Overview of UMTRI Laboratory Facilities
9:10 - 10:10	Tour of UMTRI Labs
Break	(Includes 10 min. for returning to the Chrysler Center)

10:50 -11:50	Steering Systems: Geometry, Mechanical & Kinematic Properties
Lunch Hour	
12:50 -1:40	Mechanical & Thermal Properties of Brakes and Brake Actuation Systems
Break	
1:50 -2:50	Mechanical & Thermal Properties (Cont.)
Break	
3:20 - 4:10	The Truck Frame

Wednesday

8:30 -9:20	Measurement & Estimation of the Mechanical & Inertial Properties of the Components of Heavy Trucks
Break	
9:30 -10:20	Measurement & Estimation (Cont.)
Break	
10:50 -11:30	The Offtracking Phenomenon at Very Low Speeds
11:30 -12:00	The Offtracking Phenomenon: A Computational Exercise
Lunch Hour	
1:00-1:50	Steady and Transient Turning at Finite Speed (Linear)
Break	
2:00-2:50	Turning (Continued)
Break	
3:10-4:00	Cornering in the Nonlinear Regime
Break	
4:10-5:00	Cornering in the Nonlinear Regime

Thursday

8:30 -9:45	Methods of Modeling the Driver
Break	
10:00 -10:50	The Ride Behavior of Heavy-Duty Trucks
Break	
11:10 -12:00	The Ride Behavior (Cont.)
Lunch Hour	
1:00 -1:50	Braking Capabilities of Heavy-Duty Trucks

Break	
2:00 -2:50	Braking Capabilities (Cont.)
Break	
3:20 -4:10	The Longitudinal Acceleration Performance of Heavy Trucks
Break	
4:20 -4:50	Overview of Simulation Programs - MacAdam
Evening Session	
7:00 - 9:00 pm	Computational Laboratory

Friday

8:30 -9:20	Rollover Processes (Including the Influence of Sloshing & Shifting Loads)
Break	
9:30 -10:20	Rollover Processes (Cont.)
Break	
10:50 -12:00	Special Topics & Discussion
Lunch Hour	
	(Formal lectures completed; opportunity for one-on-one discussions for those who desire to do so)

UMTRI

THE MECHANICS OF HEAVY-DUTY TRUCKS AND TRUCK COMBINATIONS

The University of Michigan
Engineering Summer Conferences
Chrysler Center for Continuing Education
Ann Arbor, Michigan

COURSE NOTES

TABLE OF CONTENTS

A TUTORIAL COURSE USING THE UMTRI SIMPLIFIED MODELS OF TRUCK BRAKING AND HANDLING

The UMTRI Simplified Models Course is based on seven "user-friendly" computer models, packaged in six programs written for the IBM PC microcomputer. Each individual model addresses one specific aspect of the performance of heavy-duty trucks and truck-trailer combinations. The models are "simple" in that they limit the analysis to the more important vehicle properties influencing the performance quality of interest. This approach minimizes the required parametric data describing the vehicle, and the associated burden on the user, while providing meaningful insight into the performance sensitivities of commercial vehicles.

The models used in the course are:

Low-Speed Offtracking Model
High-Speed Offtracking Model
Straight Line Braking Model
Static Roll Model
Steady Turn Model (Handling)
Rearward Amplification Model
Brake Temperature Model

The Simple Models Course covers two full days and is generally taught by three staff members from the Engineering Research Division of UMTRI. A representative schedule of course lectures is attached. A "Lecture" and an "Operation" session is presented for each model. Each lecture generally conforms to the following outline:

- *Definition and Motivation.* The specific aspect examined by the model is defined and the reasons for examining this performance aspect are identified.
- *Concepts and Principles.* The physical concepts and principles which control this aspect of performance, and which are analyzed mathematically in the model, are discussed.
- *Vehicle Descriptors.* The parametric data describing the vehicle which the user must provide are identified.
- *Performance Signatures and Measures.* The graphical output of the model is interpreted as a performance signature of the vehicle. Specific performance measures available from the output are identified.

- *Sensitivity Exercise.* The lecturer uses the model to demonstrate some fundamental sensitivities of the performance measures to the vehicle descriptors. This introduces the "Operation" session in which the students exercise the model.

Logistical arrangements are made by the host party, and site costs are apportioned over the attendants or absorbed by the host. Venue requirements are as follows:

- One IBM microcomputer for (at most) each 2-3 participants. These computers may be PC's, XT's, or AT's with a minimum of 512K memory. Each must be equipped with:
  - A "math co-processor"
  - A graphics board (the Simplified Models programs support most boards)

  It is desirable that each be equipped with a printer (Epson, Citizen, etc.)
- One IBM microcomputer for the lecturers. This computer may be an XT or AT. UMTRI will provide the necessary hardware to allow the screen image of this computer to be projected via an ordinary transparency projector.
- Tables for the computers permitting participants to all be seated more or less at their computer workstations while viewing screen projections in the front of the room.
- Microphone and sound system, preferably with microphone of a style worn by speaker.
- 2 transparency projectors and 2 large screens. One of these two projectors must have an illumination power of 400 watts or *less*.
- The ability to dim lights without completely darkening room.
- Refreshments at morning coffee break and afternoon break.
- Access to luncheon facilities (1 hour for lunch).

Arrangements for teaching the UMTRI Simple Models Course. Please do not hesitate to write or call for further information. Our numbers are:

Telephone:	(313) 764-2168
FAX:	(313) 936-1081
TELEX:	432-0815

UMTRI

A Tutorial Course Using The UMTRI Simplified Models Of Truck Braking And Handling

The University of Michigan
Transportation Research Institute

Ann Arbor, Michigan

Representative Schedule of Lectures

1st Day

8:30	Introduction
9:00	Lecture on Low and High -Speed Offtracking
10:15	Break
10:35	Operation of Low and High -Speed Offtracking
12:00	Lunch
1:00	Lecture on Straight Line Braking
2:00	Break
2:20	Operation of Straight Line Braking
3:50	Lecture on Static Roll Model
4:50	Break
5:10	Operation of Static Roll Model
6:30	Finish

2nd Day

8:00	Lecture on Model 4
9:30	Introduction to Operation of Steady Turn Model (Handling)
10:00	Break
10:20	Operation of Steady Turn Model (Handling) continued
12:00	Lunch
1:00	Lecture on Rearward Amplification Model
1:45	Operation of Rearward Amplification Model
2:45	Break
3:05	Lecture on Brake Temperature Model
3:50	Operation of Brake Temperature Model
4:40	Summary Discussion
5:00	Adjourn

SUMMARY OF THE TUTORIAL COURSE USING THE UMTRI SIMPLIFIED MODELS OF TRUCK BRAKING AND HANDLING

The following material outlines the contents of the presentations pertaining to each of the maneuvering situations included in the course.

Constant Deceleration Braking

Definition and Motivation

The vehicle is presumed to be decelerating uniformly after the initial braking transient is over. Braking pressure is nearly constant and the influence of fade is neglected. The purpose of the analysis is to examine the relationships between brake proportioning and the wheel loads that prevail during wheels-unlocked stops on surfaces with different levels of tire/road friction. Basically, the program calculates vehicle deceleration and the friction utilization at each axle.

Concepts and Principles

- load transfer at constant deceleration
  - static axle loads
  - equilibrium of forces during constant deceleration
  - interaxle load transfer in tandem suspensions
- brake proportioning
- friction utilization
  - relationship between braking force and vertical load at each axle
- braking efficiency
  - relationship between the level of deceleration and the maximum friction level required at any axle

Vehicle Descriptors

- static loads
- axle and hitch locations
- c.g. heights
- brake proportioning (pressure vs. torque)
- interaxle load transfer
- tire radius

Performance Signatures and Measures

- signatures (empty and loaded)
  - friction utilizations vs. pressure
  - deceleration vs. pressure
  - braking efficiency vs. deceleration
- measures
  - braking efficiency at 0.2 and 0.4 g

Low-Speed Offtracking

Definition and Motivation

The vehicle is making a tight turn at nearly zero speed. The front axle follows a predetermined path. The tracking of the trailing axles is computed.

Concepts and Principles

- paths taken by "rear" axles
  - rear tires move tangent to their paths, that is, along a tractrix
  - explanation of the tractrix
  - graphical demonstration of the determination of tractrices
- paths taken by hitches tractrices for articulated vehicles
- transient and steady-state motions

Vehicle Descriptors

- axle and hitch locations
- equivalent wheelbases for units with multiple-axle suspensions

Performance Signatures and Measures

- signatures
  - the paths of each axle and the rear of the vehicle
- measures
  - inward offtracking
  - outward swingout

High-Speed Offtracking

Definition and Motivation

The vehicle is performing a steady turn such as that required on an entrance or exit ramp. As in low-speed offtracking, the front axle follows a predetermined path radius. In this case, the vehicle is proceeding at highway speed. The tracking fidelity of the trailing axles is computed.

Concepts and Principles

- slip angles of tires and the generation of lateral forces
- the lateral forces required for steady turning
- geometric relationships pertaining to the steady-turning situation
- the factors corresponding to low-speed offtracking and those factors corresponding to the slip angles needed to generate lateral forces

Vehicle Descriptors

- axle and hitch locations
- tire cornering stiffnesses
- tire vertical loads
- equivalent wheelbases for units with multiple-axle suspensions

Performance Signatures and Measures

- signatures
  - the paths of each axle and the rear of the vehicle
- measures
  - outwards offtracking (swingout)
  - the speed for zero offtracking for the rearmost axle set

Steady Turn, Roll

Definition and Motivation

In this model the vehicle is simulated to perform a steady turn under equilibrium conditions of roll and lateral acceleration (if such conditions exist for the lateral acceleration level involved). Calculations are made at increasing severities of turning until the level of lateral acceleration equivalent to the vehicle's "rollover threshold" is reached.

Concepts and Principles

- sprung and unsprung masses
- suspension roll center heights
- lateral translation of the centers of gravity of sprung and unsprung masses
- roll stiffness definitions and concepts
- saturation of roll stiffness after wheel liftoff
- concept of a "stiff" and non-linear suspension
- hitches with and without roll coupling

Vehicle Descriptors

- c.g. heights of sprung and unsprung masses
- roll center heights
- tire vertical stiffnesses
- between tire track widths
- suspension stiffnesses and lashes
- sprung and unsprung weights

Performance Measures and Signatures

- signatures
    - lateral acceleration vs. "roll" angle for each independently rolling unit
- measures
    - rollover thresholds

Steady Turning, Handling

Definition and Motivation

The vehicle is again envisioned to be in a steady turn. The lateral acceleration is constant and the rolling motions have reached equilibrium as in the roll analysis. The objective of the calculation is to examine the steering gain in response to small perturbations in front-wheel angle. This program determines the stability margin of the vehicle. If the vehicle can be divergently unstable, the velocity and lateral acceleration levels corresponding to the transition to instability are calculated .

Concepts and Principles

Some examples:

- conditions for turning equilibrium
- the handling equation
- the influence of vertical load on cornering stiffness
- side-to-side load transfer
- perturbations about equilibrium conditions
- steering system stiffness and effective cornering stiffness
- roll steer effects
- multiple-axle suspensions and their influences on damping in yaw, damping in sideslip, and coupling coefficient
- effective wheelbase and understeer coefficient for articulated vehicles with multiple-axle suspensions

Vehicle Descriptors

- roll-related parameters
  - c.g. heights
  - roll center heights
  - track widths
  - suspension roll stiffnesses
  - sprung and unsprung weights
  - roll steer coefficients
- tracking-related parameters
  - axle and hitch locations
- tire properties
  - cornering stiffness
  - influence of vertical load on cornering stiffness
- steering system properties
  - steering compliances
- axle loads, c.g. locations

Performance Measures and Signatures

- Signatures
  - steering gain as a function of lateral acceleration and velocity
  - stability boundary if the vehicle is divergently unstable

- steering angle as a function of lateral acceleration at a selected velocity

- measures
  - gain at 0.3 g and 55 mph
  - instability speed at 0.3 g if it exists

Rearward Amplification

Definition and Motivation

Rearward amplification pertains to the motions of the rear units of articulated vehicles in response to the motion of the first unit. The lateral acceleration of the last unit may be larger than that of the first unit in rapid obstacle-avoidance maneuvers. Consequently, the rear unit may not follow the path of the front unit with adequate fidelity and the rear unit may be susceptible to early rollover. This phenomenon is quite complicated to analyze in detail, but first-order results can be obtained using frequency-domain techniques. The program computes the transfer function between the lateral accelerations of the first and last units.

Concepts and Principles

- transfer functions from c.g.'s to hitches
- transfer functions from hitches to c.g.'s
- simplified transfer functions for full trailers
- the importance of the frequency of the input motion
- the importance of the velocity of the vehicle

Vehicle Descriptors

- axle and hitch locations
- tire cornering stiffnesses
- c.g. locations and masses
- yaw moments of inertia (or assum*ption of uniform loading)*

Performance Signatures and Measures

- signatures
  - plots of transfer function magnitude vs. frequency
- measures
  - maximum magnitude and the frequency at which it occurs

APPENDIX B
BIBLIOGRAPHY OF RELATED PUBLICATIONS

This section contains a chronological listing of publications relating directly to the *Simplified Models* (17, 19, 20, 21,22) or to the principles of vehicle mechanics on which the model calculations are based. Table 7 indicates the correspondence between models and publications.

Table 7. Correspondence Between Models and Listed Publications

SIMPLE MODEL	LISTED PUBLICATIONS
Low- and High-Speed Offtracking	1, 5, 9, 15, 17, 18, 20, 21,22
Straight Line Braking	9, 15, 17, 18, 20, 21,22
Static Roll	6, 7, 8, 15, 17, 18, 20, 21,22
Steady Turn (Handling)	4, 8, 12, 13, 15, 17, 18, 20, 21,22
Rearward Amplification	2, 3, 8, 9, 13, 15, 16, 17, 18, 19, 20, 21,22
Brake Temperature	11, 17, 18, 20, 21, 22, 23

Publications

1. Morrison, W.R.B. "A Swept Path Model Which Includes Tyre Mechanics." *Proceedings*, Sixth Conference, Australian Road Research Board, Vol. 6, Part 1, Canberra, 1972.

2. Ervin, R.D., et al. "Ad Hoc Study of Certain Safety-Related Aspects of Double-Bottom Tankers." Final Rept., Highway Safety Res. Inst., Univ. of Michigan, Rept. No. UM-HSRI-78-18, Sponsored by Mich. State Office of Highway Safety Planning, Contract No. MPA-78-002A, May 7, 1978.

3. Mallikarjunarao, C. and Fancher, P.S. "Analysis of the Directional Response Characteristics of Double Tankers." SAE Paper No. 781064, December 1978.

4. Ervin, R.D., et al. "The Yaw Stability of Tractor-Semitrailers During Cornering." Final Report, Contract No. DOT-HS-7-01602, Highway Safety Res. Inst., Univ. of Michigan, Rept. No. UM-HSRI-79-21, June 1979.

5. Bernard, J.E. and Vanderploeg, M. "Static and Dynamic Offtracking of Articulated Vehicles." SAE Paper No. 800151, 1980.

6. Mallikarjunarao, C. “Road Tank Design: Its Influence on the Risk and Economic Aspects of Transporting Gasoline in Michigan.” Ph.D. Dissertation, Univ. of Michigan, 1982.

7. Mallikarjunarao, C., Ervin, R.D., and Segel, L. “Roll Response of Articulated Motor Trucks During Steady-Turning Maneuvers.” *Proceedings*, 103rd Winter Annual Meeting of Amer. Society of Mech. Engrs., Phoenix, November 1982.

8. Winkler, C.B., Fancher, P.S., and MacAdam, C.C. “Parametric Analysis of Heavy-Duty Truck Dynamic Stability.” Final Report, Contract No. DTNH22-80-C-07344, Transportation Res. Inst., Univ. of Michigan, Rept. No. UMTRI-83-13, March 1983.

9. Winkler, C.B., and Nisonger, R.L. “Steering and Suspension System - Descriptive Parameters Used in Analyzing the Braking and Handling of Heavy Trucks.” Vol. 4, Second Ed., Final Rept., Transp. Res. Inst., Univ. of Mich., Rept. No. UMTRI-83-16, April 1983.

10. Ervin, R.D. et al. “Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks.” Final Report, Contract No. FH-11-9577, Transportation Res. Inst., Univ. of Michigan, Rept. No. UMTRI-83-10, May 1983.

11. Fancher, P.S. and Winkler, C.B. "Retarders for Heavy Vehicles: Phase III--Experimentation and Analysis; Performance, Brake Savings, and Vehicle Stability." Final Rept., Contract No. DOT-HS-9-02239, Transp. Res. Inst., Univ. of Mich., Rept. No. UMTRI-84-4, January 1984.

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APPENDIX C
GLOSSARY OF DESCRIPTIVE PARAMETERS

This section contains an alphabetical listing of all of the descriptive parameters (of the vehicle and of the "maneuvers") which are required as input by the *Simplified Models*. Table 3, presented earlier, indicates the correspondence between models and parameters. Terminology in brackets ([ ]) applies to the English version of the programs; terminology in braces ({ }) applies to the SI version of the programs.

Air drag coefficient:
: This is the coefficient for the aerodynamic drag of the vehicle. The value of this parameter must lie between 0.0 and 1.0. Suggested values are 0.80 for a truck not equipped with aerodynamic aids and 0.64 for a truck equipped with aerodynamic aids.

Aligning moment stiffness per tire [in-lb/deg] {N-m/deg}:
: The torsional stiffness about a vertical axis of the elastic properties of the tire in response to slip angle. The ratio of aligning moment stiffness to cornering stiffness is the pneumatic trail of the tire.

Ambient temperature [°F] {°C}:
: The temperature of the surroundings in which the vehicle is operating.

Angle of the turn (deg):
: The subtended angle of an arc of constant radius followed by the lateral centerline of the front axle of the vehicle. In all of the offtracking models, the vehicle negotiates a turn of constant radius equal to the "Radius of the turn." In the transient, low-speed offtracking model, the "path" consists of straight line segment followed by an arc of constant radius (equal to the "Radius of the turn") and of arc length equal to the "Angle of the turn" followed by another straight line segment. Both straight line segments are tangential to the curved arc.

Auxiliary roll stiffness [in-lb/deg] {N-m/deg}:
: The portion of the total roll stiffness of this axle which is not accounted for by a simple suspension model of two springs (of the "Suspension Stiffness") separated laterally (by the "Spacing between Suspension Springs").

Axle # i brake gain [in-lb/psi] {N-m/kpa}:
: The summation of the brake gains of all the brakes on the i^{th} axle of the suspension counting from the front axle of the suspension toward the rear. The brake torque increases linearly, starting from zero torque at the "pushout pressure" and increasing with pressure at a slope equal to the "brake gain".

Axle load [lbs] {N}:

The total load supported by all of the tires of this axle. This load is measured at the tire-to-road interface, not at the springs.

Brake drum weight [lbs] {Kg}:

The weight of each brake drum is multiplied by its specific heat to obtain the thermal capacity of the brake. Suggested values for cast iron brake drums range from 60-125 lbs for the front drum to 100-175 lbs for the rear drum.

Brake key (1 = linear, 2 = nonlinear):

If the linear option is chosen, the braking program will ask for a "brake gain [in-lb/psi] {N-m/kpa}" for each axle in the suspension. If the nonlinear option is chosen, the program will ask for the "Number of points in the table". This means that brake "Torque" is going to be entered as a tabular function of "Treadle pressure".

Brake proportioning:

This is the decimal percentage of the total horsepower taken in by each brake to decelerate the vehicle. A value between 0.0 and 1.0 must be entered for each individual brake so that the sum of these values equals 1.0.

C.g. – axle distance [in] {cm}:

The longitudinal distance from this axle to the composite center of gravity of this entire unit. This distance is a negative value if the axle lies aft of the c.g.

Cooling coefficient constants: K1: [hp / °F] {KW/°C}
K2: [hp /°F-mph] {KW/°C-Kph}

The cooling coefficient constants, K1 and K2, represent static cooling and cooling as a function of velocity in the brakes. Both constants must have a value between 0.0 and 99.99 for every individual brake. Suggested values for cooling coefficient constants on a two axle vehicle are 1.364×10^{-2} hp / °F for K1 for both the front and rear brakes, and 5.315×10^{-4} hp / °F-mph and 7.97×10^{-4} hp / °F-mph for K2 on the front and rear brakes, respectively.

Cornering stiffness [lb/deg] {N/deg}:

The cornering stiffnesses used in the "Cornering stiffness table". These cornering stiffnesses apply to a single tire regardless of the number of tires installed on this axle.

Cornering stiffness table:

This table always has three entries giving values of "Cornering Stiffness [lb/deg] {N/deg}" at three levels of "Vertical Force [lbs] {N}". Ideally, these entries would correspond to tire test data measured at vertical loads in the range of the loads expected to apply to the vehicle to be analyzed. These entries are on a per tire basis, that is, they pertain to a single tire. The cornering stiffness values are often selected as the lateral tire force measured at one degree slip angle and a specified vertical force (load).

Distance (longitudinal) [miles] {Km}:

These values are simply the odometer readings of the vehicle at every point in the road profile. They are used to determine the longitudinal distance between the points in the road profile.

Distance from c.g. to front articulation [in] {cm}:

The distance from the center of gravity of the unit to the forward articulation point (pintle hitch, fifth wheel, or turntable) needed for the type of unit being analyzed. In the handling program, vehicles are treated as combinations of dollies and semitrailers and the meaning of the front articulation point is clear. However, the rearward amplification program treats full trailers as a separate unit in which the front articulation point is the location of the fifth wheel or turntable of the dolly and not the pintle hitch at the front of the dolly.

Distance from c.g. to rear articulation [in] {cm}:

The distance from the center of gravity of the entire unit to the rear articulation point (pintle hitch, fifth wheel, or turntable).

Distance from the front articulation to the rear articulation [in] {cm}:

The longitudinal distance from the front articulation point (pintle hitch, fifth wheel, or turntable) of a trailing unit to the rear articulation point (pintle hitch or fifth wheel) of the same unit. Trailing units may be A-dollies or semitrailers; full trailers are treated as a dolly and a semitrailer.

Distance from the front articulation to the rear extremity [in] {cm}:

The longitudinal distance from the front articulation point (pintle hitch, fifth wheel, or turntable) of a trailing unit to the rear most extremity (e.g. the rear of the cargo area) of the same unit. Trailing units may be A-dollies or semitrailers; full trailers are treated as a dolly and a semitrailer. This parameter is only required for the rear most unit.

Distance from the front suspension to the rear articulation [in] {cm}:

The longitudinal distance from the centerline of the front suspension of the first unit to the rear articulation point (pintle hitch or fifth wheel) of the first unit when the vehicle consists of more than one unit.

Distance from the front suspension to the rear extremity [in] {cm}:

The longitudinal distance from the centerline of the front suspension of the first unit to the rear most extremity (e.g. the rear of the cargo area) of the same unit when the vehicle consists of only one unit.

Distance to rear articulation [in] {cm}:

From front articulation if dolly or semitrailer:

The longitudinal distance from the front articulation point (pintle hitch or fifth wheel) of a dolly or semitrailer unit to the rear articulation point (pintle hitch or fifth wheel) of the same unit.

From front suspension if full trailer-fixed dolly:

The longitudinal distance from the centerline of the front suspension of a full trailer unit to the rear articulation point (pintle hitch or fifth wheel) of the same unit.

Note: This parameter is requested as input for the last unit even though it is not appropriate. Any value may be entered.

Elevation [ft] {m}:

These values describe the changes in elevation of the vehicle as it travels. These values are relative to the starting elevation of the vehicle which may be taken as zero, and need not refer specifically to feet above sea level.

Final steering frequency (rad/sec):

The results for rearward amplification are given over a range of frequencies corresponding to different periods for the steering input. The highest frequency to be analyzed is called the "final steering frequency".

Forward velocity [mph] {kph}:

The forward speed of the vehicle in high-speed offtracking or rearward amplification models.

Front suspension load [lbs] {N}:

The total load supported by all of the tires of the front suspension of the truck or tractor. This load is measured at the tire-to-road interface, not at the springs, and may be composed of the loads at one or more axles.

Frontal area of vehicle [ft^2] {m^2}:

This is the total area of the front of the vehicle. Suggested values are 75 ft^2 for conventional tankers, 85 ft^2 for cab-over tankers, 84 ft^2 for transit buses, and 64 ft^2 for school buses.

Initial brake temperatures [°F] {°C}:

The initial temperature of each individual brake (2 per axle) must be entered.

Initial steering frequency (rad/sec):

The results for rearward amplification are given over a range of frequencies corresponding to different periods for the steering input. The lowest frequency to be analyzed is called the "initial steering frequency".

Interaxle load transfer coefficient:

The coefficient indicates the fraction of the braking torque that is reacted by the couple composed of the vertical loads acting at the tires of the tandem/tridem suspension. Negative values indicate that vertical load is transferred from the front to the rear axle. The value of this parameter must lie between plus and minus one. (Measurements indicate that some four spring suspensions may have values between -0.1 and -0.2, other suspensions may have values near zero.)

Mechanical trail [in] {cm}:

The longitudinal distance from the steering axis to the projection of the wheel center onto the ground plane. Essentially the product of the caster angle of the front wheel (radians) multiplied by the tire radius in inches.

Nominal load on the tire [lbs] {N}:

The value of this entry is used to calculate cornering stiffness as a function of load. Any value could be used but usually either the rated load of the tire or the static load to be carried by the tire is entered here.

Number of auxiliary (tag) axles:

The braking program allows auxiliary (tag) axles to be attached to the unit. The suspension of an auxiliary axle is treated the same as a single axle suspension *(if they are present, the auxiliary axles are always the last numbered suspensions on each unit).*

Number of points in the auxiliary retarding table (max. 10):

This value, which must be between 2 and 10, indicates the number of data points that will be used to describe the retardation capabilities of the vehicle. Values for velocity and retarding power [hp] must be entered for each data point in the auxiliary retarding table.

Number of points in the road profile (max. 100):

The entry here indicates the number of data points that are going to be used to describe the velocity and elevation profiles of the vehicle and its route. For every point in the road profile, a value for distance, elevation, and velocity must be entered.

Number of points in the torque table (max 10):

The entry here indicates the number of data points that are going to be used to describe the relationship between brake "Torque" and "Treadle pressure". (If tandem axles are involved, the program requires the same number of data points, up to ten, for each axle.)

Number of stops (max. 99):

This value prescribes the number of instances which the vehicle is at rest and must coincide with the number of stops entered into the road profile. A "stop" is recognized by the program as two lines of identical data with zero velocities occurring back to back in the road profile. A prompt will appear after the road profile requesting the time spent at each stop.

Number of units (max 6):

Individual units are lead units (trucks or tractors), dollies and semitrailers. All full trailers are treated as two units, a dolly and semitrailer.

Pushout pressure [psi] {kpa}:

The pressure at which the brakes on this suspension start to apply brake torque. (This entry is ignored when the "brake key" equals 2, that is, when brake tables are used rather than a linear brake gain.)

Radius of a tire [in] {cm}:

The nominal rolling radius of the tires of this axle or suspension under the static load implied by the given axle or suspension load. This dimension is also used to define the center of gravity height of the unsprung mass of this axle or suspension.

Radius of the turn [ft] {m}:

The radius of the turn followed by the lateral centerline of the front axle of the vehicle. In all of the offtracking models, the vehicle negotiates a turn of constant radius. In the transient, low-speed offtracking model, the turn is further described by the "Angle of the turn."

Rear articulation height [in] {cm}:

The height of the fifth wheel, turntable, or pintle hitch at the rear of the unit, that is the vertical distance from the ground to the point of articulation.

Rear suspension load [lbs] {N}:

The total load supported by all of the tires of the rear suspension of the unit (truck, tractor, dolly or semitrailer). This load is measured at the tire-to-road interface, not at the springs, and may be composed of the loads at one or more axles.

Retarding power [hp] {KW}:

This value serves as input to the auxiliary retarding table and includes engine, driveline, and trailer axle retarding power.

Road surface coefficient:

This coefficient reflects the type and condition of surface on which the vehicle is operating. The value of this parameter must lie between 0.0 and 99.99. Suggested values are 1.0 for smooth concrete, 1.5 for worn concrete, brick, and cold blacktop, and 2.0 for hot blacktop.

Roll center height [in] {cm}:

The height of the roll center of this axle above the ground. The roll center is assumed to lie on the longitudinal plane of symmetry of the vehicle.

Roll coupling key: (1 - Rigid; e.g. semitrailer)
(2 - Free; e.g. A-dolly)

A parameter which defines the nature of the roll coupling between this unit of the vehicle and the unit which is towing this unit. A Roll Coupling Key of (1) implies a rigid roll coupling between these units (similar to the fifth wheel coupling of a semitrailer are the double drawbar coupling of a B-dolly). A Roll Coupling Key of (2) implies a free roll coupling between these units (similar to the pintle hitch coupling of an A-dolly). Units connected by type (1) couplings are assumed to roll together as a single element. Units connected by type (2) couplings assumed to roll separately as a individual elements.

Roll steer coefficient (deg/deg):

The amount of steer angle developed in an axle as it skews due to some angle of roll of the sprung mass.

Spacing between suspension springs [in] {cm}:

The lateral distance between the centerlines of the left and right springs of the axle.

Specific heat of brake drum [hp-hr/lb-°F] {KW-hr/Kg-°C}:

The specific heat of each brake drum is multiplied by its weight to obtain the thermal capacity of the brake. A suggested value for the specific heat of cast iron brake drums is 8.13×10^{-5} hp-hr/lb-°F.

Spring lash [in] {cm}:

The clearance above the spring in its housing. As the spring unloads to zero, it has to travel that additional distance before lifting the axle.

Spring stiffness table:

This table is composed of pairs of entries, each pair relates some spring deflection value [in] {cm} to a corresponding vertical spring load [lbs] {N}. Typically, the values required for this table are obtained from a spring test facility. Since the table is used to compute stiffness (spring slope), a minimum of two pairs of entries is required. It will accept entries up to 13 pairs.

Steering gear ratio:

The total steering ratio from the front wheels to the steering wheel. (Side-to-side differences due to Ackerman geometry are averaged together.)

Steering stiffness [in-lb/deg] {N-m/deg}:

The stiffness in the steering system from the steering wheel to the left front wheel. The difference between the steering wheel angle divided by the steering gear ratio and the left front wheel angle is used in determining this stiffness.

Stop times in minutes:

The period of time at which the vehicle is at rest. A value between 0.0 and 99.99 minutes must be entered for every stop made.

Suspension # i key:

The braking program treats either single, tandem, or tridem axle suspensions. (Suspensions with multiple axles have to be treated as equivalent tridem, tandem, or single axle suspensions.) The key indicates whether a single, tandem, or tridem suspension is to be considered at the i^{th} suspension of the unit, counting from the front of the unit toward the rear *(this convention holds except in the case of auxiliary (tag) axles which, if present, are the last suspensions numbered on the unit)*. If a tandem or tridem suspension is chosen, the program asks for an "interaxle load transfer coefficient".

Suspension # i load [lbs] {N}:

The total load supported by all of the tires of the i^{th} suspension of this unit, where i = 1 or 2 counting from the front of the unit toward the rear. (Trucks, tractors, and full trailers have two suspensions. Dollies and semi-trailers have only one suspension.) This load is measured at the tire-to-road interface, not at the springs, and may be composed of the loads at one or more axles.

Suspension stiffness (per spring) [lbs/in] {N/m}:

The average linear suspension rate (wheel rate) of this axle. (As per the definition of suspension rate (wheel rate) given in SAE J670e).

Tie rod stiffness [in-lb/deg] {N-m/deg}:

The stiffness in the steering system between the left front wheel and the right front wheel. The right front wheel follows the motion of the left front wheel through the action of the tie rod.

Torque [in-lb] {N-m}:

This is the brake torque corresponding to the values of "Treadle pressure" given in the table of "brake information" entered for a particular unit and suspension when the "brake key" is set to select the nonlinear option. It is the summation of the torque produced by both of the brakes on the axle.

Total c.g. height [in] {cm}:

The height of the center of gravity of the total mass of this unit above the ground. This is a composite c.g. height which includes the influence of all of the mass elements (sprung and unsprung masses) of this unit.

Total cornering stiffness of front tires [lb/deg] {N/deg}:

The summation of the cornering stiffnesses of all of the tires on the front suspension of the unit.

Total cornering stiffness of rear tires [lb/deg] {N/deg}:

The summation of the cornering stiffnesses of all of the tires on the rear suspension of the unit.

Total number of axles on the unit (max 8):

The total number of axles on this unit of the vehicle. An "Axle information" data set and a "Tire information" data set is required for each axle specified. Each unit may have from one to eight axles.

Total number of axles on the vehicle (max. 13):

This is the total number of axles on the vehicle. For each axle specified, data pertaining to both brakes is required.

Total number of tires on the axle:

The total number of tires on this axle. It is assumed that one half of this number of tires are "lumped" at either end of an axle whose length is equal to the "Track Width of the Axle."

Total weight [lbs] {Kg}:

The total weight of this unit of the vehicle. This includes the sprung mass weight (chassis and load) and the weights of all of the unsprung masses of this unit. Note: The sum of all of the "Total weights" of the whole vehicle must equal the sum of all of the axle or suspension loads of that vehicle. The programs do *not* check this condition.

Track width of the axle [in] {cm}:

For axles with single tires, track width is measured from the centerline of the left tire to the center line of the right tire. For axles with dual tires, track width is measured from the centerline of the left side dual tire pair to the centerline of the right side dual tire pair.

Treadle pressure [psi] {kpa}:

The pressure at the brake valve (foot valve, treadle valve, etc.). This pressure is the reference pressure for the brake information entered for a particular unit and suspension when the "brake key" is set to select the nonlinear option.

Type of tire: (1)- Bias ply
(2)- Radial

This parameter indicates the type of tires the vehicle is equipped with and is used in determining rolling resistance.

Type of unit:

This rearward amplification program applies to three vehicle configurations — Truck-full trailer, double and triple. If the first unit of the vehicle is a truck, the rearward amplification program asks for parameters describing the truck. If the first unit is a tractor, the program does not use any tractor parameters in estimating rearward amplification. That is, when a double or a triple is selected, the interactive program starts with data for unit # 2, the semitrailer. Once the truck or leading semitrailer are described, the program asks for data on the remaining full trailers in the combination vehicle. Each full-trailer is treated as an individual unit. (In particular, see the definition of "Distance from c.g. to front articulation".)

Unit key (1– Independent unit, dolly or semi) (2 – full trailer fixed dolly):

The unit key identifies whether the unit has a converter dolly or a turntable dolly. A converter dolly is treated like any semitrailer and fits under option 1. Full trailers that have permanently fixed dollies fit under option 2. Since the turntable in a fixed dolly transmits a pitch moment, the equations of motion for this unit are different from those of a converter dolly that employs a fifth wheel. In addition, the fixed dolly has a pitch hinge in the drawbar such that vertical load is not applied at the pintle hitch of the unit pulling the full trailer with a fixed dolly.

Velocity [mph] {Kph}:

These values describe the velocity profile of the vehicle throughout its route. In order to signify a "stop", two zero velocities must be entered back to back in the road profile for the brake temperature model.

Vertical force [lbs] {N}:

The vertical loads used in the "Cornering stiffness table". These loads apply to a single tire regardless of the number of tires installed on this axle.

Vertical stiffness of a tire [lb/in] {N/m}:

The linear vertical spring rate of one average tire on this axle.

Weight of the axle [lbs] {kg}:

The weight of this unsprung mass, including the axle, tires, wheels, etc.

Wheelbase [in] {cm}:

The wheelbase of the unit. In the case of the first unit (truck or tractor) or of a full trailer, the longitudinal distance from the centerline of the front suspension to the centerline of the rear suspension. In the case of dollies or semitrailer units, the longitudinal distance from the forward articulation point to the centerline of the rear suspension. (In the Handling model, one calculated result is the effective wheelbase. In the Offtracking models, the user can improve the accuracy of the result by entering the effective wheelbase.)

Yaw moment of inertia [in-lb-sec^2] {kg-m^2}:

This is the moment of inertia of the entire unit about a vertical axis through the center of gravity of the entire unit. For full-trailers, the dolly and semitrailer are treated as a single composite unit in determining the yaw moment of inertia.