U.S. Department
of Transportation

Federal Railroad
Administration

Safety Aspects of New and Untried Freight Cars

Office of Research and
Development
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Appendix

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NOTICE

APPENDIX A

USERS MANUAL

FOR

NUCARS, VERSION S

TABLE A1

FILES INCLUDED ON NUCARSS DISKS

<u>DISK 1</u>:

NUCARSS.EXE	The executable file for NUCARS Version S.
G2U	The unformatted wheel/rail geometry file.
EMPTY.CAR	An empty car file - see Chapter 5.
EMPTY.RUN	An empty run file - see Chapter 6.
SAMPLE.RUN SAMPLE.CAR	Two sample data programs are included to allow you to run the program and to generate an output file for trying the programs on disk 2.
SCHECK.OUT	The car is a light weight 2-axle car. SCHECK.OUT should be identical to the output produced.

<u>DISK 2</u>:

TEXTVU.EXE	The executable file - see section 4.2.
PLOTVU.EXE	The executable file - see section 4.3.
PLTBAT.EXE	The executable file - see section 4.4.
TRACK.DAT	Sample track scenarios for the run file.
LWC.DAT	The car file for the light weight FRONTRUNNER car.

TABLE A2

FILES INCLUDED ON NUCARSR DISKS

DISK 1:

NUCARSR.EXE	The executable file for NUCARS, Version R.
G2U	The unformatted wheel/rail geometry file.
LWC.DAT	The car file for the light weight FRONTRUNNER car (same as used for NUCARSS).
RUNR.DAT	Sample run file for NUCARSR.
BALLOON.TRK	Measured Track Data File for TTC Balloon Loop, 7.5 degree curve, with bunched spiral, 1180 feet long.

DISK 2:

PTTBOUNC.TRK	Measured Track Data File for TTC Multiple Bounce Test Zone on PTT, 697 feet long.
PTTLAT.TRK	Measured Track Data File for TTC Lateral Sinusoid Test Zone on PTT, 1296 feet long.
PTTRKRLL.TRK	Measured Track Data File for TTC Rock and Roll Test Zone on PTT, 1097 feet long.
NORTHY.TRK	Measured Track Data for TTC Dynamic Curving Test Zone on North Wye, 771 feet long.

NOTE: Run Length must be shorter than Test Zone Length by at least the length of the test car wheelbase.

USERS MANUAL

for

NUCARS, Version S

as delivered to the

FEDERAL RAILROAD ADMINISTRATION

manual written by

Fred Blader

written for the Association of American Railroads

December 30, 1988

Table of Contents

1 INTRODUCTION

1.1 Organization of the Manual

This manual provides the basic information necessary for the running of NUCARSS (NUCARS version S) and the peripheral programs TEXTVU, PLOTVU and PLTBAT. Readers who have the software already installed on their computer may make a quick start by going to chapter 4, which describes how to run the programs, using the sample data provided. It is recommended that the programs be installed on a hard disk, as described in section 3.2.

For first time users and readers, the manual provides a sequential description of what is needed to use the programs. It is recommended that you read the manual through and use the sample data to run the program, as described in chapter 4, before attempting to create your own data and runs. Chapter 1 gives an overview of the program NUCARS and its objectives and uses. Chapter 2 describes the hardware on which the programs will run satisfactorily, including the computers, displays, printers and plotters. Installation is covered in chapter 3, for systems with no hard disk as well as for the preferred hardware.

Chapters 5 and 6 describe how to set up your own car and run files for the cases which you wish to study. Some additional car files and suggested track geometries have been included on disk #2. These may be used as a basis for modification. It is important that you have a word processor, capable of processing ASCII files, for this purpose. Some other vehicle and track data are provided in Chapter 7.

1.2 A General Description of the Program NUCARS

NUCARS is an acronym for,

New & Untried Car Analytical Regime Simulation.

Originally conceived as a means of assessing the performance of new and untried car designs, NUCARS can be used to examine most new or existing cars for performance under a wide variety of track configurations and conditions. It represents the first attempt in North America to provide a unified approach to the simulation of the performance of any possible vehicle on any track, in any self-excited dynamic regime.

Recent advances in personal computers have significantly reduced the cost of long computer runs and advantage has been taken of this. The method of analysis is that of a time stepping procedure operating on a generalized set of second order differential equations. These include the modeling requirements of the vehicle and track needed to examine the safety of the vehicle from derailment in service conditions.

The prediction of safety, for which NUCARS has been designed, represents a most demanding effort on behalf of the analyst, since simplifications of small motions and linear devices are not sufficiently accurate. Furthermore, rail vehicles are often designed with connections between adjacent moving parts, simple in concept, but very nonlinear, including friction, or slack, or both. To represent the vehicle performance with sufficient accuracy, the model used for the vehicle characteristics in NUCARS is both general and fully nonlinear. The effects of large excursions between the wheel and the rail are represented in NUCARS by a detailed state-of-the-art model of the wheel-on-rail interaction.

NUCARS uses matrix techniques to ensure the most general approach to model construction. These are generally transparent to the user. They permit assembly of the equations for a wide range of vehicle arrangements and designs. Since these matrices are sparse, methods are used to conserve storage and improve the speed of multiplication.

The output from the program has been checked against the expected frequency response for various cars and modes of oscillation and has been compared with the results of other analyses with known car data. More importantly, validation has been carried out and will continue through comparisons of NUCARS predictions with the results of vibration and track tests at the Transportation Test Center and elsewhere.

1.3 Objectives of the Program

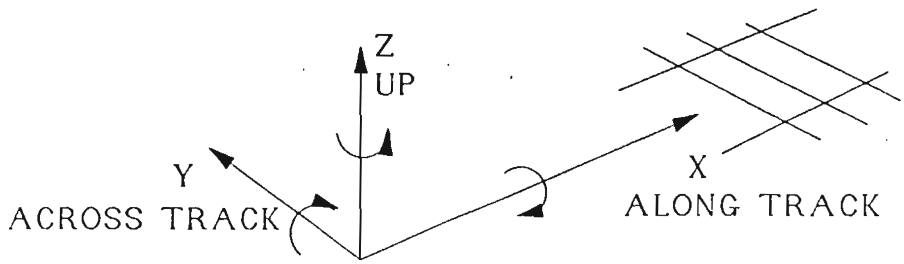
The objectives of the program NUCARS are:

* the creation of a single industrywide standard
* easy availability and use including personal computers
* applicability to all the performance regimes up to the onset of unsafe conditions
* applicability to all car types
* regular and controlled updating
* ongoing validation through old results and new tests in all important regimes
* increased potential for advances in the state-of-the-art

Significant savings in the cost of testing and enhanced safety assessment in rail transportation are benefits seen from using NUCARS.

1.4 Organization of the Program

Vehicle model insertion into the program structure is carried out through an ASCII input file. A separate ASCII file is created for the run variables, including a choice of wheel-on-rail geometries. Track input data is inserted into the run file. This includes representation of track for the investigation of hunting, twist & roll, pitch & bounce, yaw & sway, steady state curving, spiral negotation, and dynamic curving. The conventions used are illustrated below.



LUMPED MASS WITH SIMPLE MODAL SHAPES
RIGHT HAND SCREW RULE & COORDINATES

The inputs include:

* track design data including,
  curvature and superelevation vs distance
* track perturbations including, linear,
  sinusoidal and exponential shapes in the form of,
  vertical and lateral cusps, bumps, waves etc.
* car types and data including,
  several bodies with bending and twist
  degrees of freedom
  inter-body articulation over truck suspension
  trucks with and without centerplates, slewing rings
  trucks with H-frames, single or more axles
  independent wheels, 3-piece trucks with or
  without primary suspensions, equalization
  piecewise linear suspension characteristics
  interconnected axles and trucks
* different rail/wheel conditions
* different operating speeds and conditions

Cross-plots are possible from any of the variables, either during, or after, the run. Post processors are provided for obtaining both a variety of text file formats, for printing or inserting into other plotting or spreadsheet programs, and for the direct screen display and plotting of the output.

The ouputs include:

* time and distance of the vehicle along the track
* a full set of track inputs and rail positions
* a full set of primary degrees of freedom
* derivatives and forces for each degree
* all wheel creepages and axle moments
* all wheel and axle lateral and vertical forces
* all wheel and truck L/V ratios
* wheel/rail relative motions
* suspension motions and forces
* all axle lateral positions and yaw angles

1.5 Disks and Software Provided

The 2 360k floppy disks provided, contain the following files.

1.5.1 Disk 1

NUCARSS.EXE	The executable file for NUCARS, version S.
GTU	The unformatted wheel/rail geometry file
EMPTY.CAR	An empty car file - see chapter 5
EMPTY.RUN	An empty run file - see chapter 6
SAMPLE.RUN	Sample data "run" files to allow you to run the program.
SAMPLE.CAR	Sample data "car" file for use with SAMPLE.RUN.
SCHECK.OUT	Sample output file, should be identical to the output produced by SAMPLE.RUN.

1.5.2 Disk 2

TEXTVU.EXE	The executable file - see section 4.2
PLOTVU.EXE	The executable file - see section 4.3
PLTBAT.EXE	The executable file - see section 4.4
LWC.DAT	The car file for the Light-Weight Front-Runner car
TRACK.DAT	Sample track scenarios for the run file

2 HARDWARE REQUIREMENTS AND COMPATIBILITY

The following sections describe the hardware requirements of the programs supplied. The classifications are abstracted from the Computer Software Directory of the AAR. Further information is available from the Association of American Railroads, Chicago Technical Center, Software Distribution, 3140 S. Federal St., Chicago, IL 60616, or by calling (312) 567-3647

2.1 Computers

Minimum necessary	modified AAR Class II, or, or suitable compatible high speed CPU >7mhz preferred 2 Floppy Disk Drives at least 640k bytes memory 8087 Math Coprocessor DOS 2.1 or above
Recommended	AAR Class III, or, IBM PC/AT or PS-2/model 60 or compatible with 80286 chip Hard Disk desirable, at least 640k bytes memory 80287 Math Coprocessor DOS 3.0 or above
Highly recommended	AAR Class IV, or, IBM PS-2/model 80 or Compaq 386 or compatible with 80386 chip Hard Disk desirable, at least 640k bytes memory 80387 or other floating point board DOS 3.0 or above

2.2 Displays

NUCARS and PLOTVU are linked with the GRAFMATICS(tm) library of callable routines. They are called in a mode to provide screen images of 640 pixel cols x 200 pixel rows in B/W. The library is available from Microcompatibles, 11443 Oak Leaf Drive, Silver Spring, Md 20901, Tel: (301) 593-0683. The resulting NUCARS and PLOTVU programs require an adapter compatible with the IBM Color Graphics Adapter or CGA. Most graphics adapters, which provide more advanced displays, will default to this mode, and are therefore suitable for use with the software provided. Any monitor capable of displaying graphics in CGA mode is suitable, including monochrome monitors.

2.3 Printers

There exist too many printers, capable of printing graphics images, to list. The only requirement for NUCARS and PLOTVU is that the printer is compatible with the users' own software for dumping the screen, as discussed in more detail in section 3.3.2. The program TEXTVU provides for a text printout, suitable for direct printing to any printer linked to your PC. The paper width is selectable for 80 or 132/6 column arrangements.

2.4 Plotters

The programs PLOTVU and PLTBAT are linked with the PLOTMATICS(tm) library of callable routines. These can be obtained for use with plotters from HP and Houston Instruments as required. PLOTMATICS is available from Microcompatibles, 11443 Oak Leaf Drive, Silver Spring, Md 20901, Tel: (301) 593-0683. In the standard form, the programs are provided for HP plotters, numbers 7470 or 7475, or others compatible with them. The switches should be set to give 2400 baud operation, for an 8 bit word, with 1 stop bit, no parity and for US size paper. Further information on compatibility with plotters is available from the Association of American Railroads, Chicago Technical Center, Software Distribution, 3140 S. Federal St., Chicago, IL 60616, or by calling (312) 567-3647

3 INSTALLATION

It is important first to ensure that you have a suitable computer and any peripheral equipment you may need, as defined in the previous section.

In this and subsequent sections, the prompt line displayed on the computer screen will be shown in capital letters. The required response, or recommended inclusion in other files, which you are asked to provide, will be shown **bold** and **UNDERLINED**. It may be in UPPER or lower case. Typing an enter, generally required to complete the entry, is not shown.

Screen display	Reason or Meaning
C:>**prompt pg** C:\DOS>	full DOS prompt,(may be switched on by typing **Prompt pg** from directory DOS), full prompt for directory DOS
C:\NCRS>**dir** A:>**plotvu**	asks for a file list when in C:\NCRS starts the program PLOTVU from drive A

Whether your computer has a hard disk or not, on start-up, the operating system or DOS, loads the file COMMAND.COM into memory and searches for the batch file AUTOEX-EC.BAT. A DOS error results if the system and command files are not available. DOS configures the system and uses the file CONFIG.SYS to identify any special needs. The following suggestions may assist you in defining the system arrangement best suited to your needs or equipment.

3.1 Using Two Floppy Disk Drives

This arrangement represents a minimum requirement and, although possible, is not recommended. A Hard Disk is recommended for convenient operation. However, instructions on the use of NUCARS with two floppy drives are included. Prepare two new 360k double-sided, double-density system disks, using the FORMAT utility from DOS, with the DOS disk in drive A. Follow this by inserting your Disk 1 into drive A and copying NUCARSS.EXE and its associated files on to one of the newly formatted disks, and by a similar process for copying PLOTVU.EXE and TEXTVU.EXE from Disk 2 on to the second prepared disk. The procedure is as follows.

A:>**format b:/s**	Requests formatting of disks in drive B. /s adds the system files. The request is followed by a set of self explanatory instructions which should be used to format 2 disks.
A:>**copy *.* b:**	Copies the files from drive A to drive B

If you would like to make NUCARSS run automatically when the computer is switched on, you may add the appropriate instructions to the existing ASCII file, called AUTOEXEC.BAT, or create a new one of the same name. You may use a word processor for this purpose, so long as it can be made to write its output to an ASCII file on the new disk. An alternative method is given below. It is assumed that the new NUCARS disk is in drive A and that a blank formatted disk is placed in drive B for the output file.

Screen display	Reason or Meaning
A:>COPY CON AUTOEXEC.BAT copy g2u b: copy *.dat b: b: a:nucarss ^Z or F6	COPY the instructions from the CONsole (key-board) to the file AUTOEXEC.BAT. The COPY is completed with ^Z (type Ctrl Z) or function key F6.

The instructions in the AUTOEXEC file created are, on starting up:
Copy the files G2U and the *.dat files to drive B, make drive B the default drive and read NUCARSS.EXE on drive A and start.
Other instructions may also be added.

3.2 Installation on a Hard Disk

It is useful to create a new subdirectory on your hard disk for NUCARS. Although you will want to choose a name to suit your own scheme, the examples which follow will use the subdirectory name NCRS. The files on both disks supplied should be copied to this directory. It is assumed that the process starts at the DOS prompt for the root directory on the hard disk, which is assumed to be drive C.

C:>MD\NCRS	Makes a Directory called NCRS.
C:>CD\NCRS	Changes the current Directory to NCRS.
C:>PROMPT PG C:NCRS\>	Ensures that the prompt includes the current directory, NCRS on C:.

Place the disks supplied in drive A, one at a time, and repeat the next step.

C:\NCRS>COPY A:*.*	Copies the files from drive A on to the current drive on C:

Suggestions are made below for modifying or creating AUTOEXEC.BAT and CONFIG.SYS files in the root directory. The changes to CONFIG.SYS are not essential to the running of the programs, but the default values for DOS are unnecessarily small and can give rise to problems.

Screen display	Reason or Meaning
C:\NCRS>CD\	Changes the directory to the root directory
C:\>COPY CON AUTOEXEC.BAT prompt pg path c:\;c:\ncrs;....etc. C:\printer\grafplus =A ^Z or F6	COPY the instructions from the CONsole (key-board) to the file AUTOEXEC.BAT. The COPY is completed with ^Z (meaning control Z) or function key F6.

The instructions in the file AUTOEXEC.BAT above are:

Ensure that the full DOS prompt is shown on the promt line;

Add a PATH for the executable files, NUCARSS, TEXTVU and PLOTVU to save having to identify the directory when they are called from other directories. Other paths can be included.

Automatically read into memory a resident graphics screen dump program, such as GRAFPLUS(tm), here assumed to be on the subdirectory C:\printer (=A means across the paper for an Epson printer).

Other instructions may also be added.

C:\>COPY CON CONFIG.SYS files=20 buffers=32 break=on ^Z or F6	COPY the instructions from the CONsole (key-board) to the file CONFIG.SYS The COPY is completed with ^Z (meaning control Z) or function key F6.

The instructions in the file are:

Increase the number of buffers or files and switch the extended break on.

Other instructions may also be added.

It is now possible to run NUCARS, Version S, from the Hard Disk, with the computer already switched on in the directory C.

C:\>cd\ncrs C:\NCRS>nucarss	Makes NCRS the default directory on C: Reads the NUCARS executable file into memory and starts the run.

3.3 Associated Software

The program NUCARS produces an output file for further analysis, data reduction or plotting. Several utilities are available for this purpose. Three are included on Disk 2 in the package.

3.3.1 Utilities Provided with NUCARS

TEXTVU is provided to use on the output file from NUCARS. It permits a screen display of chosen variables, creates new files in formats suitable for printing, or a file suitable for further data analysis in a spreadsheet program such as Lotus 1-2-3.

PLOTVU is also for further data processing. It permits the screen display of graphs of up to 3 variables against any other variable. It also contains the necessary code for driving a plotter, so that the screens can be made permanent in high quality reports.

PLTBAT is for the batch production of the plotter files from PLOTVU.

3.3.2 Other software

The user may make arrangements for downloading graphics images from the screen to the printer. An example of general software for this purpose is GRAFPLUS(tm), available from Jewel Technologies, Inc., 4740 44th Ave SW Suite 203, Seattle, Washington 98116, Tel: (800) 628-2828, ext 527. Other programs may be suitable but have not been tested.

Spreadsheet programs are also useful in manipulating the output data, and in plotting the output from NUCARS. One such program is Lotus 1-2-3 (tm), available from the Lotus Development Corporation, 55 Cambridge Parkway, Cambridge, MA 02142, or from other distributors. The program TEXTVU can provide a text file of results from the NUCARS output file, suitable for reading into 1-2-3. The best 1-2-3 format, chosen by entering "/" when 1-2-3 is ready, is scientific with 4 places of decimals and a cell size of 12. Smaller cell sizes cut the headings and limit the accuracy. Other spreadsheet programs may also be suitable but have not been tested.

The setting up of the data files will require a suitable word processor. Every experienced computer programmer has a favorite. The only important feature is that it can work with files directly in the ASCII format. Many such word processors exist. Further advice can be obtained from the Association of American Railroads, Chicago Technical Center, Software Distribution, 3140 S. Federal St., Chicago, IL 60616, or by calling (312) 567-3647

4 GETTING STARTED

The prompt line, displayed on the computer screen in full, will be shown again in the table, in UPPER CASE letters. The required response, or recommended inclusion in other files, which you are asked to provide, will be shown **bold and UNDERLINED**. This response may be in UPPER or lower case. Typing an Enter is generally assumed to complete an entry.

4.1 Using NUCARS

4.1.1 Starting from a 2-Floppy System

If you have set up the AUTOEXEC.BAT file for an immediate start up, as given in section 3.1, you may place the prepared disk into drive A, a blank disk in drive B, and switch on the computer.
If your computer is already switched on, insert the newly prepared disk with NUCARS, Version S, into drive A and a blank formatted disk into drive B, and proceed as follows,

Screen display	Reason or Meaning
A:>B:	Makes B the default drive
B:>COPY A:G2U	Copies the required data to drive B
B:>COPY A:*.DAT	Reads the NUCARS executable file into
B:>A:NUCARSS	memory and starts the run

Note: The wheel-on-rail profile data file G2U, must be on the default directory when running NUCARS, Version S.

4.1.2 Starting from a Hard Disk

Go to your hard disk directory, change to the NUCARS subdirectory and start, as follows,

A:\>C:	Makes C the default drive
C:\>CD\NCRS	Changes to the subdirectory NCRS
C:\NCRS>NUCARSS	Starts the program running

Note: The wheel-on-rail profile data file G2U, must be on the default directory when running NUCARS, Version S.

4.1.3 Running NUCARS with SAMPLE.RUN and SAMPLE.CAR

In addition to the required file G2U, containing the selection of wheel-on-rail profiles, two sample data programs are provided to allow you to run the program, and to generate an output file for trying the programs, TEXTVU, PLOTVU and PLTBAT. The necessary run file is SAMPLE.RUN, and it calls for a car file called SAMPLE.CAR.

On start-up you will be presented with the title screen, which can be dismissed by typing <u>**Enter**</u>, and by a request for the name of the run file. You should respond as follows,

Screen display	Reason
********************************* * * . (TITLE PAGE) . . .. * (c) copyright ..... * ********************************* Pause (followed by message) <u>**Enter**</u>	To dismiss the Title page

Default input file is RUNS.DAT Enter: 1 - to keep default input file 2 - to specify a new filename <u>2</u> Enter new RUN file name enclosed in single quotes <u>**'SAMPLE.RUN'**</u>	For a new name, SAMPLE.RUN

Note: An alternative procedure would have been to rename or copy the file SAMPLE.RUN to RUNS.DAT before starting and to respond with <u>1</u>. Both SAMPLE.RUN and SAMPLE.CAR must be with G2U in the default directory, since SAMPLE.CAR is named in the run file SAMPLE.RUN as the file containing the required car information.

There will be a delay while the files are read in, followed by additional messages, which require the responses shown below.

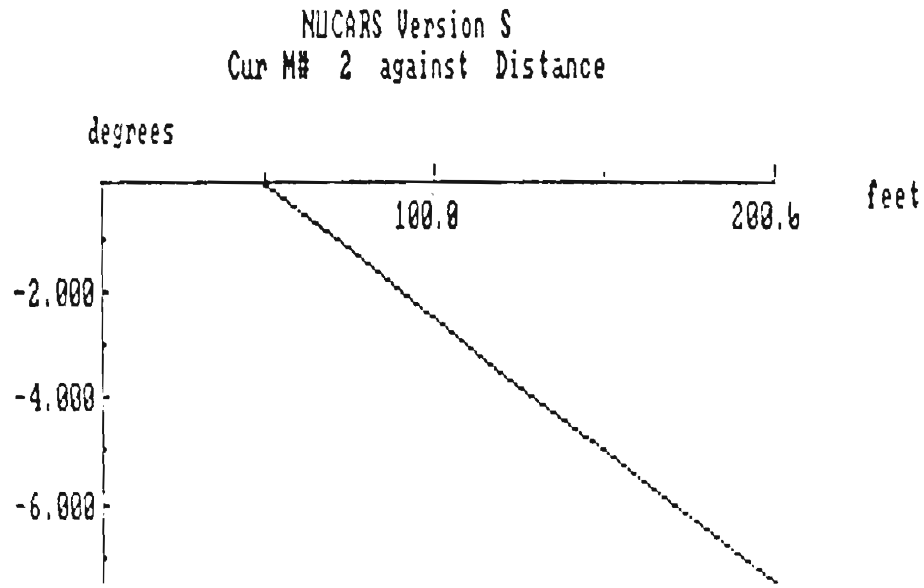
Default output file is SAMPLE.OUT Enter: 1 - to keep default output file 2 - to specify a new filename <u>1</u>	To accept the name, SAMPLE.OUT

The output file, SAMPLE.OUT, will be written to the default drive unless otherwise indicated. The final typing of <u>Enter</u>, after <u>1</u>, will be followed by the initial message of the program during the run, containing the name and chosen wheel-on-rail data.

```
                         NUCARS Version 5

CNH1365 - 30 mph on 7.5 deg. curve, 2-axle SAMPLE.CAR, step = 0.50, mu = 0.4

New CN modified Heumann wheel on new 136 lb/yd. rail profiles, standard gauge



              Computing at the distance & time shown below

                DISTANCE =     .3 feet ; TIME =  .008 secs
```

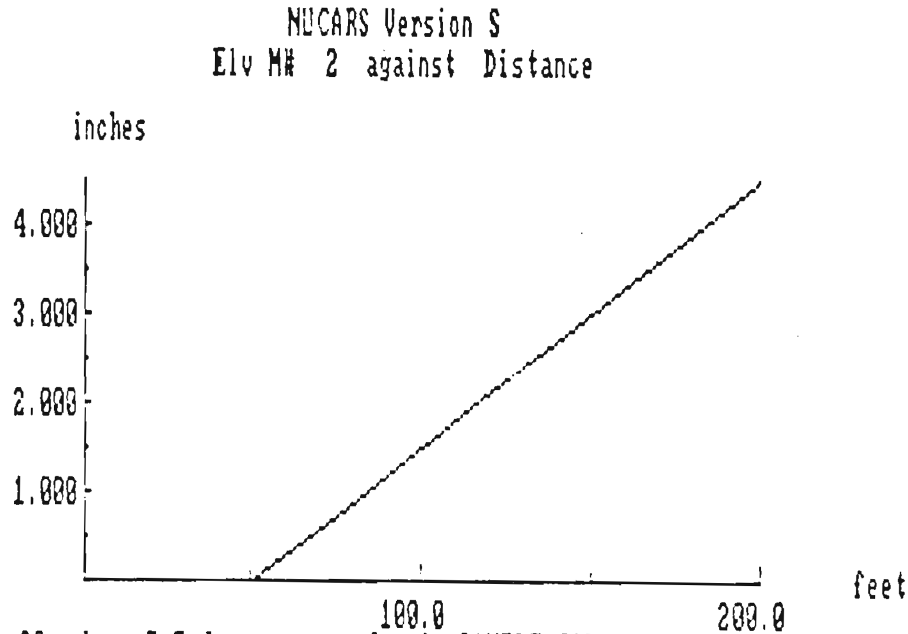
TITLE SCREEN.

The SAMPLE.RUN will scroll through a set of graphs every 50 ft and complete the run at 400 ft. The following six graphs show how they should appear on the screen at 200 ft. The chosen screen displays are for the curvature, superelevation, lateral displacement of axle no. 1, yaw of axle no. 1, lateral displacement of axle no. 2, and yaw of axle no. 2.



CNH136S - 30 mph on 7.5 deg. curve, 2-axle SAMPLE.CAR, step = 0.50, mu = 0.4

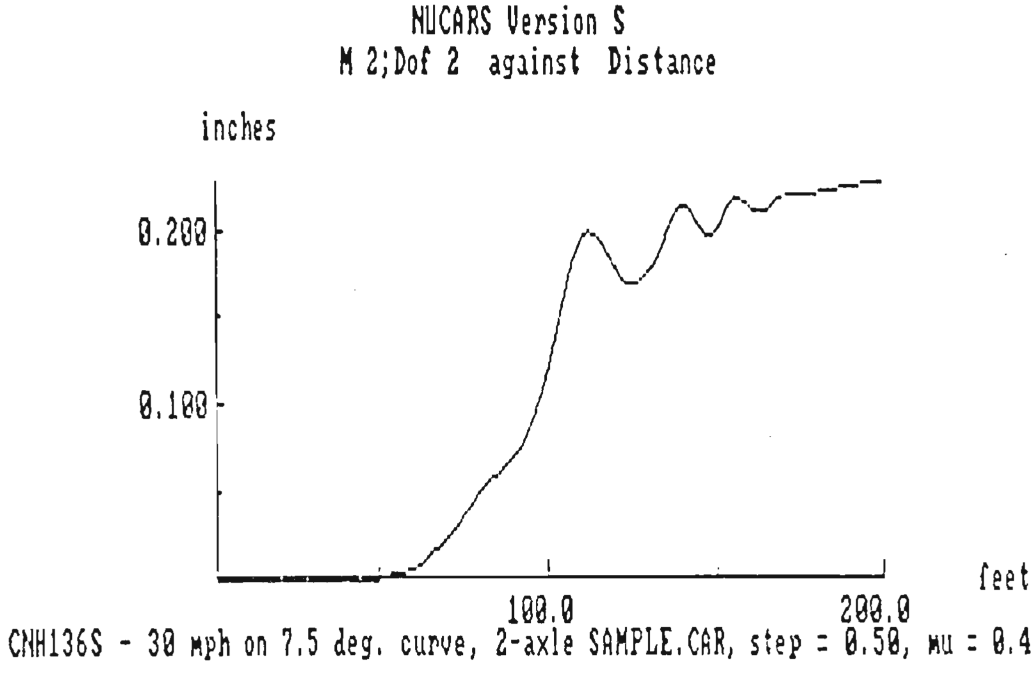
GRAPH 1.
and,



CNH136S - 30 mph on 7.5 deg. curve, 2-axle SAMPLE.CAR, step = 0.50, mu = 0.4

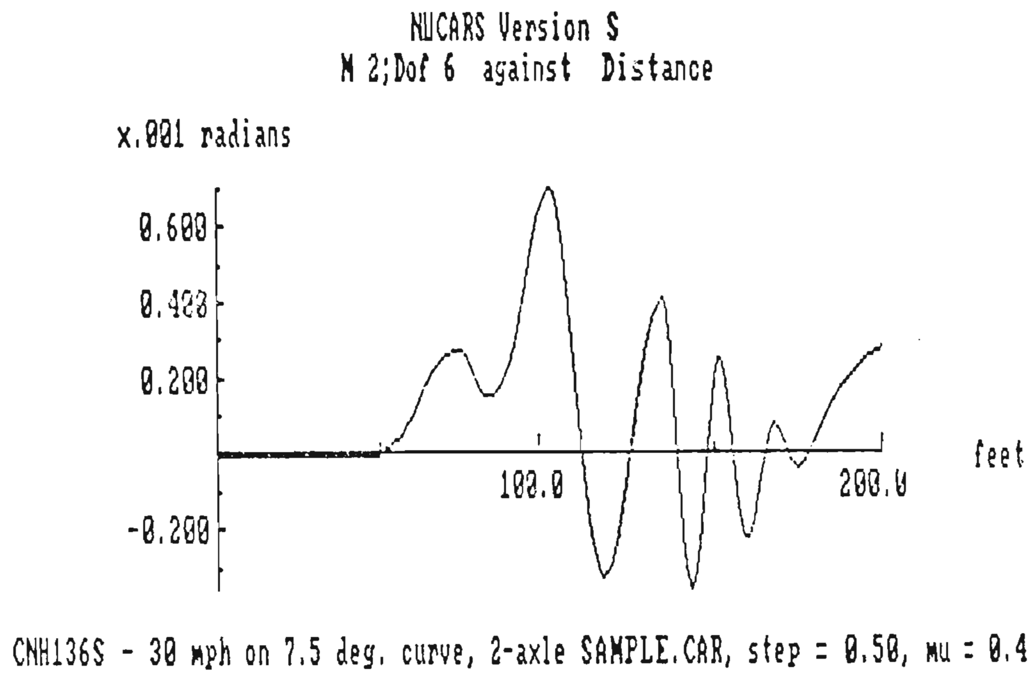
GRAPH 2.

and,



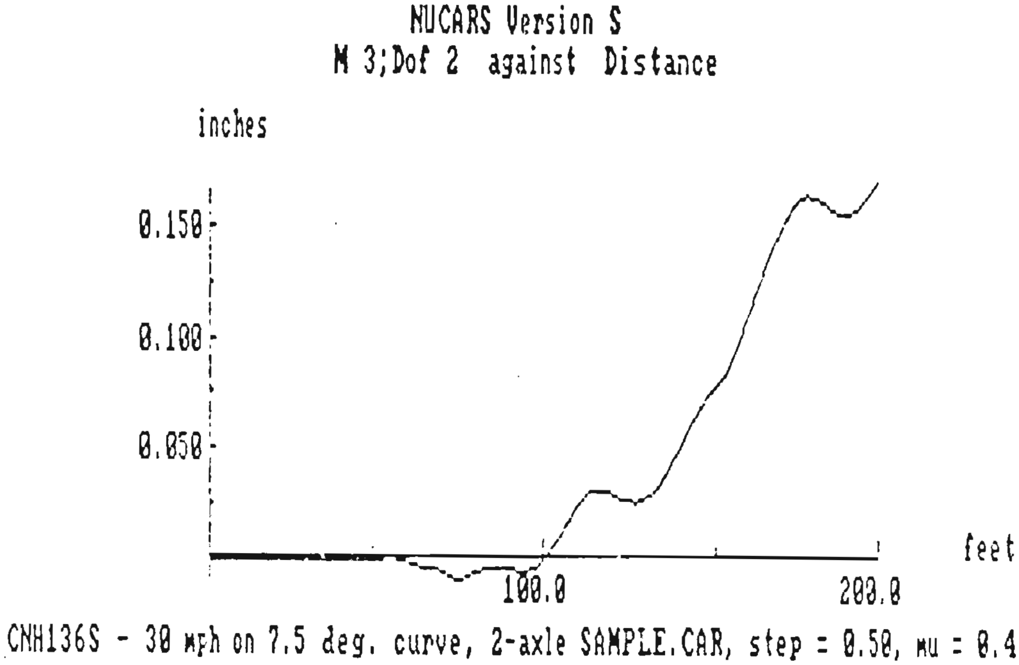
GRAPH 3.

and,



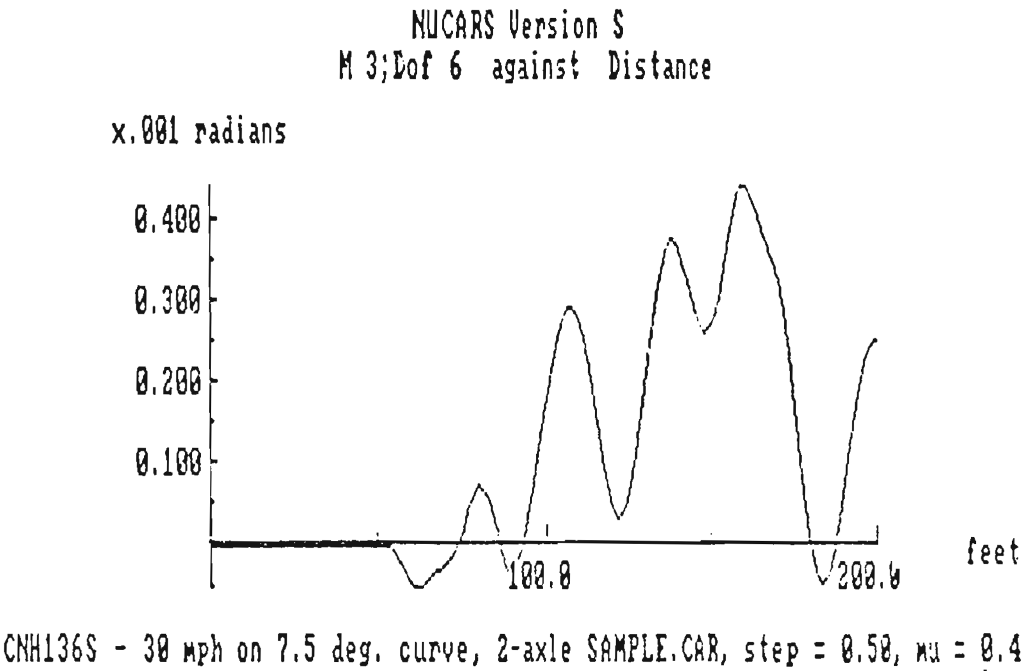
GRAPH 4.

and,



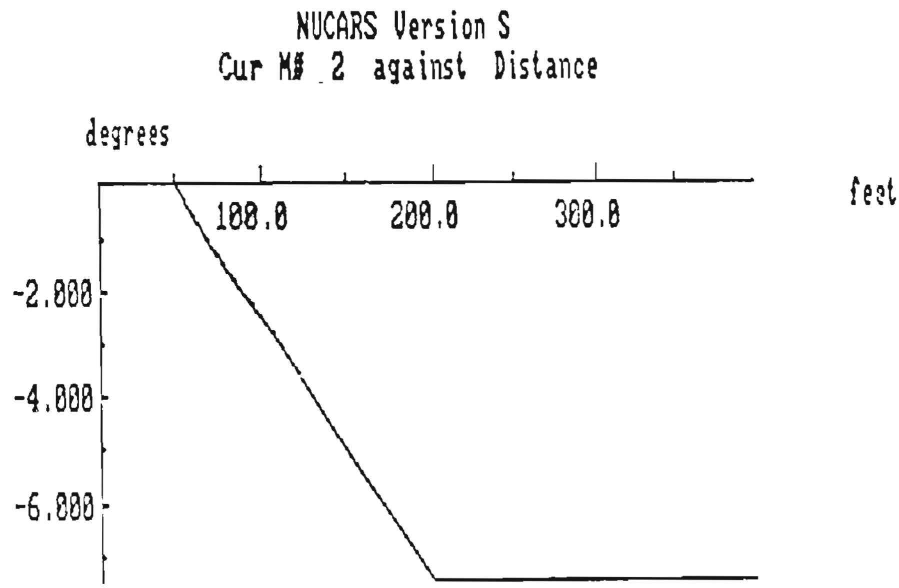
GRAPH 5.

and,



GRAPH 6.

At the end of the SAMPLE.RUN, the screen will again scroll, but will pause at each graph for inspection.
The appearance is shown below for the first graph.



CNH136S - 30 mph on 7.5 deg. curve, 2-axle SAMPLE.CAR, step = 0.50, mu = 0.4

Type Enter to move on as requested.

The final messages are as follows.

Screen display	Reason or Meaning
Run completed successfully Stop - Program terminated B:> or C:\NCRS>	Final message followed by return to the default DOS Prompt

4.2 Using TEXTVU

4.2.1 Starting from a 2-Floppy System

If your computer is already switched on, insert the newly prepared disk with TEXTVU into drive A and the formatted disk with the output from NUCARS, SAMPLE.OUT, into drive B, and proceed as follows,

A:>B: B:>A:TEXTVU	Makes B the default drive Starts the program

4.2.2 Starting from a Hard Disk

Go to your hard disk directory, change to the NUCARS subdirectory and start, as follows,

A:>C: C:>CD\NCRS C:\NCRS>TEXTVU	Makes C the default drive Changes to the subdirectory NCRS Starts the program

4.2.3 Running TEXTVU

On start-up you will be presented with the title screen, which can be dismissed by typing Enter, and by a request for the name of the output file. You should respond as follows,

*********************************** * * . (TITLE PAGE) . . .. * (c) copyright ..... * *********************************** Pause (followed by message) **Enter**	To dismiss the Title page
Type the name of the file from NUCARS, in quotes. 'SAMPLE.OUT'	as requested

There will be a delay while the file is read in, followed by additional displays and messages, which require the responses shown.

Screen display	Reason
NUCARS Version S Your Chosen Run Title............... The chosen Wheel/Rail Geometry...... The velocity for this run was....... The number of steps.......of length.......feet Enter the distance...start and the end........ ...., in feet, separated by a comma, 0,500	 see comments below
Do you require a screen display, (reply 1), an 80 column file for printing, (reply 2), a 132 column file for printing, (reply 3), or a Lotus readable text file, (reply 4) ? 1 Every how many steps..............? 10 Do you require a list of variables ? y	 see comments below see comments below

You should take the opportunity to run TEXTVU several times and try different answers. If you are looking for the values of a particular variable over a limited distance into the run, choose the required range, otherwise the screen will be filled with numbers of no interest to you and may scroll past the required values. If you exceed the number of columns possible in the "print files", replies 2 or 3, the values and headings continue on the next line.

You may create more than one file of different names, if more than 20 variables are needed for further data analysis or plotting. You may not need to have every output point displayed or printed. The response to the penultimate question above, suggests that you need every tenth value. Other values may be chosen. If you require them all choose 1.

If your answer to the last question above is y or Y, then a list of the variables in the output file is displayed, followed by pauses. It is worthwhile to make a list of those which you require for printing or plotting.

Screen display	Reason
How many variables are required, (max=20) ?	
<u>2</u>	choose
Identify by number, each chosen variable.	
For Variable No. 1	
<u>1</u>	from list
For Variable No. 2	
<u>2</u>	from list
Pause..........	
<u>Enter</u>	to start

The chosen action will be taken and followed by,

Do you need more output of the run, (Y or N)?	Start again ?
<u>N</u>	No to end

4.3 Using PLOTVU

4.3.1 Starting from a 2-Floppy System

If your computer is already switched on, insert the newly prepared disk with PLOTVU into drive A and the formatted disk with the output from NUCARS, SAMPLE.OUT, into drive B, and proceed as follows,

Screen display	Reason or Meaning
A:><u>B:</u>	Makes B the default drive
B:><u>A:PLOTVU</u>	Starts the program

4.3.2 Starting from a Hard Disk

Go to your hard disk directory, change to the NUCARS subdirectory and start, as follows,

A:\><u>C:</u>	Makes C the default drive
C:\><u>CD\NCRS</u>	Changes to the subdirectory NCRS
C:\NCRS><u>PLOTVU</u>	Starts the program

4.3.3 Running PLOTVU

On start-up you will be presented with the title screen, which can be dismissed by typing **Enter**, and by a request for the name of the output file. You should respond as follows,

Screen display	Reason
*********************************** * * . (TITLE PAGE) . . .. * (c) copyright ..... * *********************************** Pause (followed by message) **Enter**	To dismiss the Title page
Enter the name of the file for plotting,....... **'SAMPLE.OUT'**	as requested

There will be a delay while the file is read in, followed by additional displays and messages, which require the responses shown.

NUCARS Version S Your Chosen Run Title............... The chosen Wheel/Rail Geometry...... The velocity for this run....... and the distance............feet	
Enter the distance...start and the end........ ...., in feet, separated by a comma, 0,500	see comments below
Do you require a list of variables ? y	see comments below

You should take the opportunity to run PLOTVU several times and try different answers. If you are looking for the values of a particular variable over a limited distance into the run, choose the required range, otherwise the graph will be no interest to you.

If your answer to the last question above is y or Y, then a list of the variables in the output file is displayed, followed by pauses. It is worthwhile to make a list of those which you require for plotting. Note that up to three y values are possible against x. However, the program checks to see that the y's all have the same units, to prevent errors in typing choices.

Screen display	Reason
How many plots are required, (max=20) ?	
2	choose
For each plot, identify............	
separated by commas, the first on the x-axis...	
by 3 on the y-axis, setting unwanted values to zero	
For Plot No. 1	
2,3,0,0	from list
For Plot No. 2	
2,4,0,0	from list
Pause..........	
Enter	to start

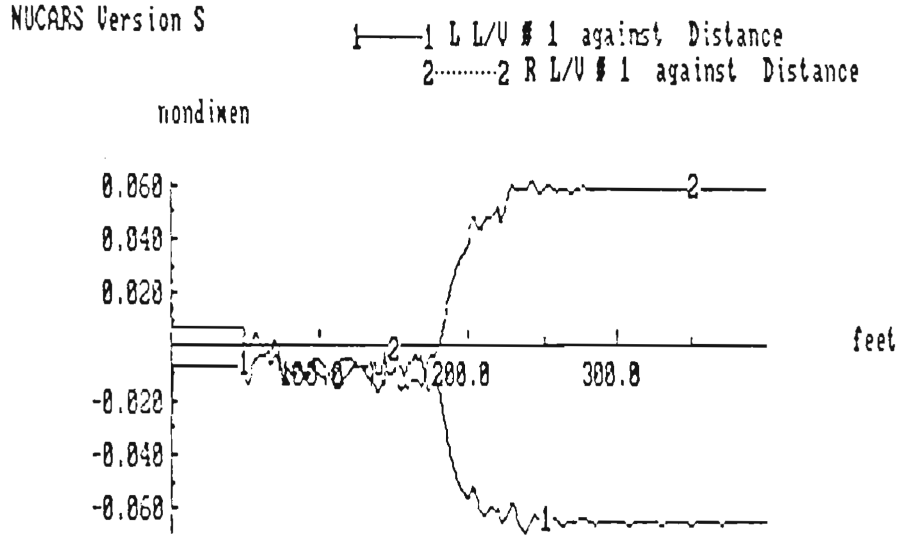
The above response will be followed by a screen message as follows.

Each plot chosen will be displayed on the screen.
To move to the next plot, hit ENTER.
Some computers allow printed copies to be made by
typing the SHIFT and PRTSC keys simultaneously.

MAKE SURE THAT THE PRINTER IS SWITCHED ON !

Pause..........
Enter

For more information on the downloading of screen graphics, see section 3.3.2 of this manual. Following Enter, the screen display of the graphs chosen will appear in the order chosen, similar to the example given below. This shows the L/V ratio of the lead axle for the output file SAMPLE.OUT of the sample run. Both wheel L/Vs are shown, separating at flange contact. The variables chosen and entered for plotting this graph are 2,31,32,0.



CNH136S - 30 mph on 7.5 deg. curve, 2-axle SAMPLE.CAR, step = 0.50, mu = 0.4
Do you want a plot of this graph, Y or N ?

PLOTVU SCREEN.

The graphs displayed may be plotted immediately, or saved for plotting later with the program PLTBAT, The following are alternative responses to the questions at the bottom of the graph.

Screen display	Reason
Do you want a plot of this graph, Y or N ?	
y	to proceed
Identify plot later (0), or now (1). If......	
.... e.g. 0,fname.plt.	
1	to plot now

or,

Do you want a plot of this graph, Y or N ? y Identify plot later (0), or now (1). If...... .... e.g. 0,fname.plt. 0,NUCARS01.PLT	 to proceed to plot later with PLTBAT

When the chosen screen displays are complete, the following message will be displayed.

Do you need more output of the run, (Y or N)? N	Start again ? No to end

4.4 Using PLTBAT

4.4.1 Starting from a 2-Floppy System

If your computer is already switched on, insert the newly prepared disk with PLTBAT into drive A and the formatted disk with the output from PLOTVU, into drive B, and proceed as follows,

Screen display	Reason
A:>B:	Makes B the default drive
B:>A:PLTBAT	Starts the program

4.4.2 Starting from a Hard Disk

Go to your hard disk directory, change to the NUCARS subdirectory and start, as follows,

A:\>C:	Makes C the default drive
C:\>CD\NCRS	Changes to the subdirectory NCRS
C:\NCRS>PLTBAT	Starts the program

4.4.3 Running PLTBAT

On start-up you will be presented with the title screen, which can be dismissed by typing Enter. Respond as follows,

*********************************** * * . (TITLE PAGE) . . .. * (c) copyright ..... * *********************************** Pause (followed by message) <u>Enter</u>	To dismiss the Title page
How many files do you want to plot, (max=50) ? <u>2</u> Enter the name, between single quotes, for number 1 <u>'file1'</u> for number 2 <u>'file2'</u>	as required first file's name second file's name

There will be a delay while the files are read in, followed by,

New paper in the plotter ? Please press <return> to continue <u>Enter</u>	to start

This will be followed by the plotting with appropriate pauses for changing the paper between plots.

5 SETTING UP A NEW CAR FILE

This section gives an explanation of the data, which NUCARS requires to identify the car, and the format in which it must be provided. An empty file has been provided on Disk 1, called EMPTY.CAR, which can be copied on to a file of another name of your choice. Under your new name, this file can be used to add your own data, for the car you wish to study. You will require a word processor, suitable for editing ASCII text files, for this purpose.

Both input ASCII files, required by NUCARS, are arranged as fortran 77, standard list-directed input files. The instructions provided in them, are expected by NUCARS to take a prearranged number of lines. The messages may be reworded to suit your own way of describing the required values, but the number of lines taken must be the same as those provided in the examples.

Any list of values must be separated by "value separators". In general, these may be a comma, one or more blanks, an end-of-record or a slash, /. The files prepared for reading into NUCARS, in the following example, are given blanks as value separators. However, in interactive mode, the values requested, for example by PLOTVU, for entry by the keyboard, are separated by commas. Using a slash, /, stops execution at the previous value and is not used. The end-of-record separator permits the "wrapping" of a long list of values on to the next line, although this has not been necessary in the examples used.

The data required for the car file is now described, following the general format in the EMPTY.CAR file provided. As in previous sections the values you are required to furnish are shown **bold** and **underlined.** First, part of the data is given, outlined in a box, together with a sample list of values. This is followed by a fuller description, with other examples where necessary as an aid to understanding.

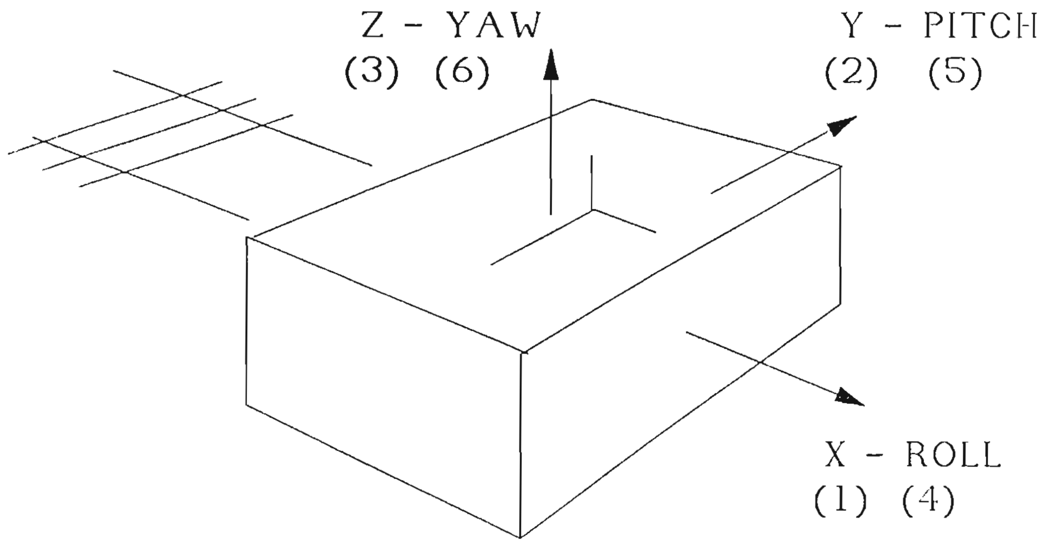
```
-CARFIL for NUCARS in lb., in. & sec. unless otherwise stated.
----------------------------------------------------------------------
-Enter data below the names given, (integers begin with letter I)
----------------------------------------------------------------------
-FOR THE BODIES
-How many Bodies (IBHV), and in addition how many axle bodies (IBAX)
   IBHV        IBAX
    1           2
```

Axles are treated differently from the other bodies and must be listed separately. In the example given, the car has a single body and 2 axles. A hopper car would have 7 bodies,(IBHV = heavy bodies), and 4 axles. The 7 bodies are 2 bolsters, 4 sideframes, and 1 main body.

-List the number & position each body, (& axle body), relative to a datum on the track center, in., followed by the number of degrees of freedom required, followed by a list of degrees of freedom for each, in turn, from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz.
The required 4 degrees of freedom for each axle are 2 3 4 6
THE AXLE BODIES MUST BE LISTED LAST !

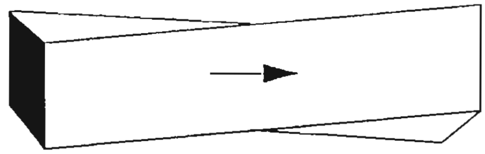
Body no.	Position in X, Y & Z			No. of DoF's	List of chosen DoF's
1	-219.0	0.0	30.0	8	2 3 4 5 6 7 8 9
2	0.0	0.0	14.0	4	2 3 4 6
3	-438.0	0.0	14.0	4	2 3 4 6

It is recommended that you choose the datum on the track centerline under the lead axle. This permits the whole car to run on to the track from behind the original zero position. The rigid and flexible degrees of freedom are illustrated in the next two figures.

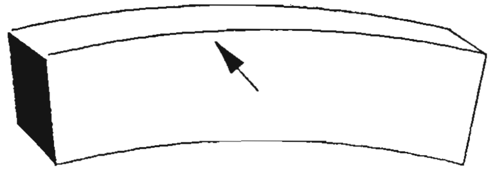


RIGID BODY MODES

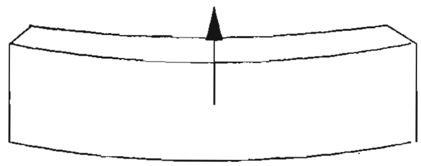
7. TWIST (about X)



8. BENDING (about Y)



9. BENDING (about Z)



FLEXIBLE BODY MODES

In the example used, the carbody degrees of freedom include all but the longitudinal motion, which is assumed not to vary from that given by the constant speed. This is not always so. The sideframe of a 3-piece truck, for example, has longitudinal, lateral, vertical, pitch and yaw degrees of freedom. Its body would be represented as,

Body no.	Position in X, Y & Z	No. of DoF's	List of chosen DoF's
no	position	5	1 2 3 5 6

The program needs to know which are the axles, and assumes them to be last. Each axle may have lateral, vertical, roll and pitch displacements. The vertical and roll come from the assumption of vertically flexible rails.

-Identify the track semi-gauge, and wheel radii for each axle, in inches,

HAFGAG	WRAD(1),	(2), (3), (4), (5), (6) etc.
29.75	14.0	14.0

The semi-gauge required is to the rail center. It is assumed that the wheels on any given axle have the same nominal radius, but that the radius may differ between axles.

-For all the bodies which have flexible modes, give the position of each geometric center, along the track from the datum, backward is -ve, its length in inches, the natural frequencies, in rad./sec., and damping ratios in twist, vertical & lateral bending, as required.

Body no.	X-Posn	X-Length	Nat Frequencies(rad/sec)			Damping Ratios		
1	-219.0	606.0	44.0	56.5	55.0	0.05	0.01	0.07

The only body having flexible modes in the sample data, is the main carbody, body number 1. Since NUCARS treats it as a beam, a length is required. Also required are the first modal natural frequencies and their damping ratios. No higher order modes are included.

-List the mass, roll, pitch and yaw inertias, in order

For each body in order, excluding axles,

55.694	3.7E04	2.5E06	2.25E06

For the axles, in turn, in the order defined above

5.75	2.6E03	1.5E03	2.6E03
5.75	2.6E03	1.5E03	2.6E03

This is basic data for determining the dynamic forces.

The units are,

mass in lb-sec^2/in.; inertia in lb-in-sec^2.

The axle values are listed in order and may differ from each other.

-FOR THE CONNECTIONS

Identify the following parameters

-Number of X-conn.,(IALLXS); Y-conn.,(IALLYS); Z-conn.,(IALLZS)

IALLXS	IALLYS	IALLZS
0	2	8

All connections between bodies are regarded as suspensions and must have a characteristic. They are divided into the 3 principal directions. Rotational suspensions, such as an anti-roll bar, take their direction from the axis about which they rotate. Thus, the total number of x suspensions is the sum of both translational suspensions, in the x direction, and rotational suspensions about the x axis.

To minimize the time of the program run, it is often advantageous to combine pairs of linear suspensions into a single rotational one, reducing the number of suspensions calculated. For example, two longitudinal, x, suspensions between the axle ends and a truck frame may be replaced by a single yaw suspension in z. No other longitudinal suspension is required, since the axle is assumed to travel at the same constant speed, along the track, as the car body. It is also best to combine suspension elements which are parallel functions of the same variable into a single suspension, with a combined characteristic. Thus the springs which comprise the suspension in the sideframe of a 3-piece truck may not have individually the same characteristic, but should be represented by their combined characteristic as a spring group.

-Complete the following tables for each X, Y, and Z connection,
identifying the following required variables against its number,
its position relative to the chosen datum in inches;
the number of the body at each of its ends;
whether the connection is one of translation 1 or rotation 2;
the type 1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring;
and the number designating each pair of type 1, 2 and 3.
Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.

-Complete for all X connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type &	Pair no

-Complete for all Y connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type &	Pair no
1	0.0	0.0	18.0	1	2	1	1	1
2	-438.0	0.0	18.0	1	3	1	1	1

-Complete for all Z connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type &	Pair no
1	0.0	0.0	18.0	1	2	2	1	2
2	-438.0	0.0	18.0	1	3	2	1	2
3	etc							

The above information is required for the location, connecting bodies, and type of each suspension or connection. In the example shown, there are no X-suspensions, and consequently a single blank line is required. The bodies for each connection are designated by their number from the list of bodies, given in the second set of values above.

All connections are assumed to have a pair of characteristics. For connections which comprise damping or stiffness only, the parallel pair should be chosen, and the absent characteristic indicated by a zero in the list of parallel pairs below. In general, the pairs may be dampers and springs in parallel or in series, or hysteresis elements, which require upper and lower bounds to the stiffness characteristic. All characteristics are piecewise linear, that is they are made up of a series of straight lines. They are discussed more completely under the data required for their characteristics. The numbering of the pairs is separate for each of the three types indicated, say, 1...n1 for type 1, 1...n2 for type 2, and 1...n3 for type 3. Each type list may contain both translating and rotating suspensions.

-List for each pair of type 1 - parallel connections, its number,
the identification numbers of the piecewise linear characteristics
for the stiffness and damping respectively, zero if absent, and
the combined force or moment limit in extn & compn, lb or lb-in.
(If no limit exists, set the F-values outside the expected range.)

Pair no.	Stiff PWL	Damp PWL	F-extn.	F-compn.
1	5	6	1.0E08	-1.0E08
2	etc.			

This list of parallel pairs of spring and damper characteristics, requires an identification number for each, so that the program knows which characteristic to use from the list of these given below. Thus, in the example given the stiffness characteristic is number 5 from the piecewise linearity, or PWL list, and the damping is number 6.

For individual characteristics, i.e. springs without damping or damping without stiffness, the number of the missing characteristic is set to zero. For example if the spring in pair 1 did not exist, the entry would
be,

Pair no.	Stiff PWL	Damp PWL	F-extn	F-compn
1	0	6	1.0E08	-1.0E08

An additional feature of the parallel pairs is that you can choose a limiting force or moment, in lb. or lb.-in., for the combined pair. This is useful, for example, where it is required to represent a separation of a body from its suspension group, such as the lift of the body from a combined spring/damper group at its unloaded length. In this case the F-extn. would be set to 0.0. If not required, the limit must be set outside the expected range. A displacement limit, such as that representing the closing of a spring's coils, can always be added as a sudden increase in stiffness in the spring part of the combined characteristic.

-List for each pair of type 2 - series connections, its number,
the identification numbers of the piecewise linear characteristics
for the stiffness and damping respectively, and the stroke limit
in extension & compression for the pair, in or rad, and the stiffness
of the stop at the limit in lb/in or lb-in/rad.
(If no limit exists, set the S-values outside the expected range.)

Pair no.	Stiff PWL	Damp PWL	S-extn.	S-compn.	Stop K
1	3	4	1.0E00	-1.0E00	1.0E08

The series connections are listed in a manner similar to the previous parallel connections. However, they too have some special features, and one important constraint. The constraint is in the damper characteristic. A positive slope is necessary to permit the inversion of the damping characteristic in the algorithm used to solve for the motion at the intermediate point connecting the spring and damper. Thus, in the series damper element, there cannot be a constant force, independent of velocity. This might seem to eliminate the friction or saturating element. The difficulty is easily overcome by providing the characteristic for the damper with a small slope at all points. This is illustrated below, in the setting up of data for the piecewise linear characteristics.

Since placing a stop on the movement of the spring in the series element does not limit the travel of the pair, an additional feature has been added to permit this. The extension or compression at which this occurs must be stated as shown, together with the required stop stiffness. If no stop is required, the extension and/or compression must be set outside the expected range.

-List the type 3 - hysteresis loop characteristics, identifying its number, the numbers of the piecewise linear characteristics and the beta exponent during extension and during compression respectively.

Loop no.	Extn PWL	Extn Beta	Comp PWL	Comp Beta
1	7	0.05	8	0.05

The hysteresis loop characteristic consists of 2 force-displacement characteristics, forming asymptotes for the movement of the suspension. One asymptote is approached during compression and the other during tension. The speed with which the asymptote is approached, in either sense, is an exponential function of the distance away from the asymptote and a controlling constant, called beta. Beta must be given and may be different in extension and compression. The values given are typical.

One example of a suspension with hysteresis is the parallel combination of a spring and a Coulomb friction damper. In the hysteresis pair representation, the asymptotes on the force-displacement plot have the slope and shape of the characteristic of the spring, separated by the addition of the force due to the friction, in the direction appropriate to compression or extension. It is usually more convenient to use the parallel pair to represent this suspension. However, there are circumstances where the asymptotes in extension and compression are not parallel, such as in the carriage or leaf spring. In this case the separation of the asymptotes, caused by the friction, varies with the value and direction of the displacement and a hysteresis representation is appropriate. The value of beta must be determined from experimental data.

-How many different piecewise linear, (PWL), characteristics are required

10

-List the data required for the connection characteristics,
the number of Break Points in each PWL characteristic,

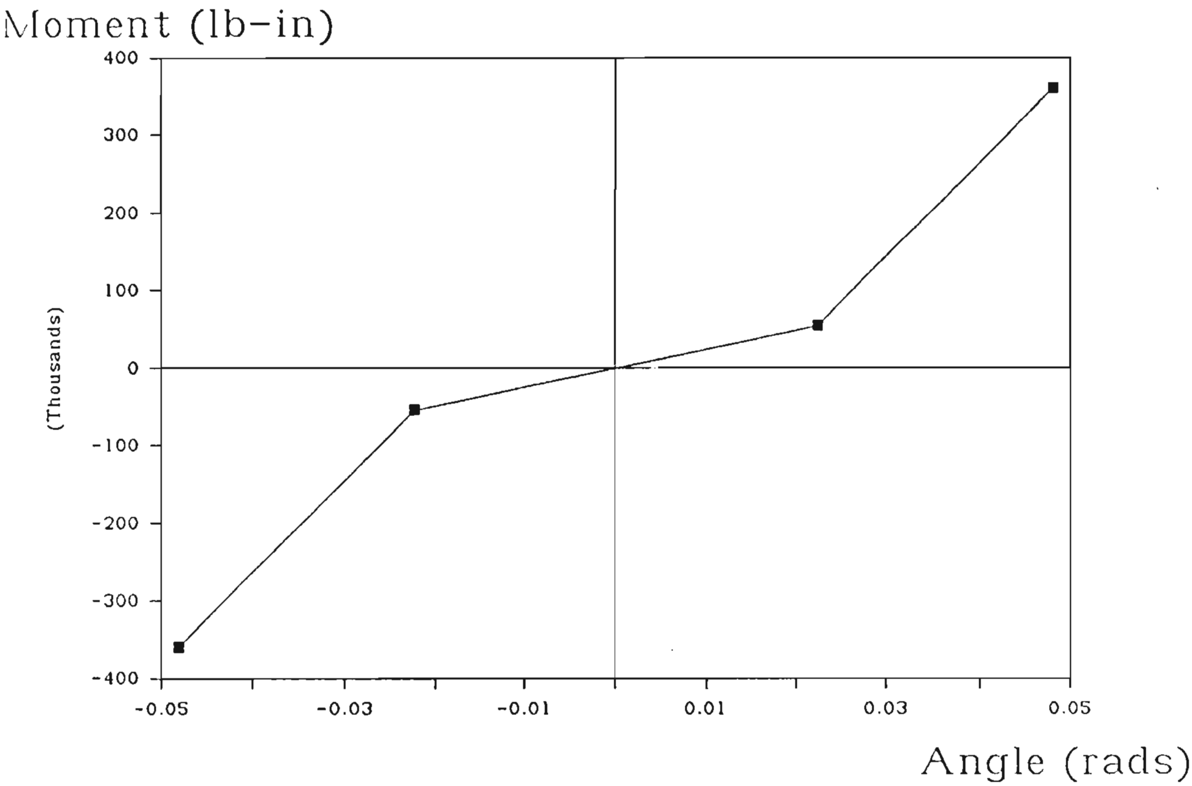
4 4 2 6 6 4 3 3 3 3

PWL Ordinate, lb or lb-in, over abscissa, in or rad, at each Break Pt

1	-3.6E05	-5.38E04	5.38E04	3.6E05
	-0.0481	-0.0224	0.0224	0.0481
2	-1.56E04	-1.56E04	1.56E04	1.56E04
	-1.0	-0.02	0.02	1.0
3	etc.			

All the nonlinear suspension characteristics are represented by piecewise linear elements and the shapes and values are reduced to identifying the values at the corners, or Break Points. The extreme ends of the shapes are extrapolated linearly to infinity at the last slope and do not represent a limit to the excursion.

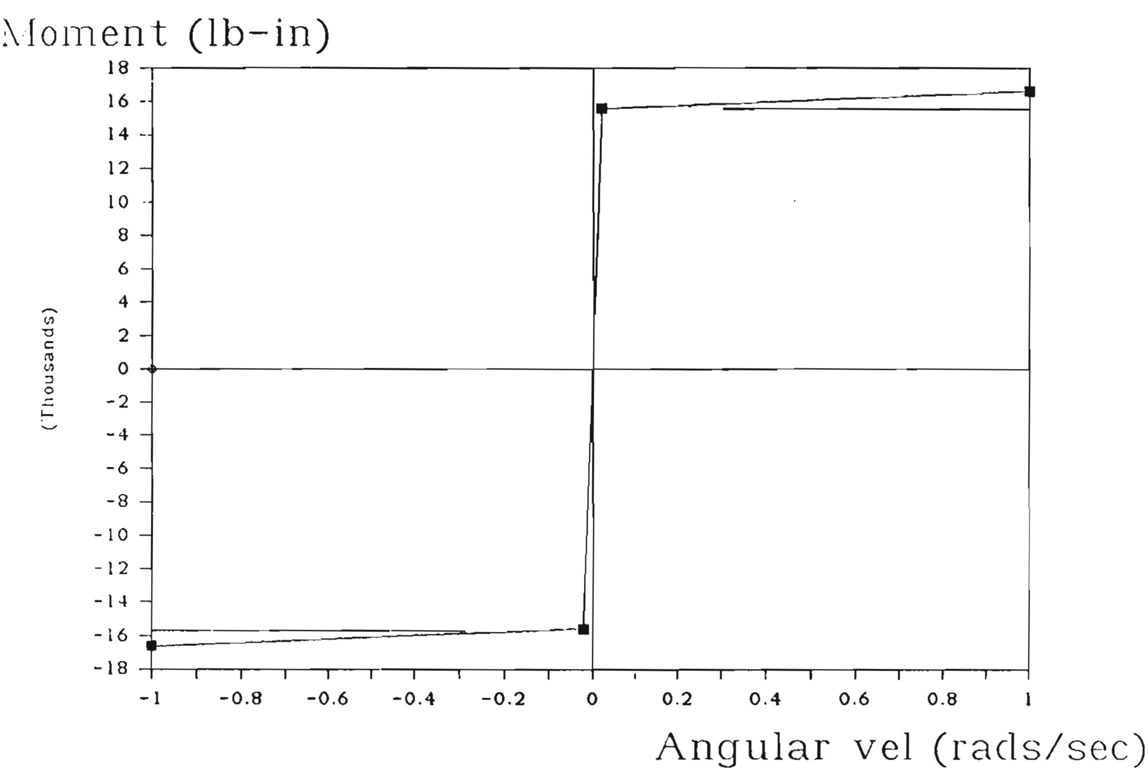
The yaw stiffness characteristic of PWL 1 above, is plotted in the graph below. The characteristic is for a yaw suspension, with stops. In this car model, difficulty was obtained in providing analytically stable running, for cases where the angle across the suspension caused it to hit the stops. The slope at the stops is intentionally low at about 10^7 lb-in/rad. Stiff springs may often be represented by values of 10^8 lb-in/rad for rotational springs and 10^5 lb/in for translational springs, when using a step length for the run of 0.5 msec. The example demonstrates the importance of checking the validity of the data, not only in representing the actual suspension stiffness, but also in giving a stable analytical result.



Yaw Stiffness with Stops

The yaw damping characteristic of PWL 2 above is shown in the next graph. The "leading edge" of the characteristic, which might be nearly vertical in reality, is made less steep, to prevent analytic instabilities and inaccuracies. For a step length of 0.5 msec., a reasonable guess for the leading edge slope is 10^6 lb-in-sec/rad for a rotational and 10^3 lb-sec/in for a translational element. However, the value should always be confirmed by ensuring that no change in the response occurs for small variations around that chosen. It must be large enough for accuracy in the model and small enough for analytic stability. The accuracy of the model can be best determined by examining the force and velocity across the element, during the run, to ensure that it is generally stable. If slipping is expected, the velocity should appear beyond the range of the leading edge. A first approximation for the appropriate value may often be determined from an assessment of that required to give critical damping for the system, in the dominant mode affected.

As stated previously, a damping characteristic with a constant force, would not be acceptable for a series suspension pair. For this purpose their must be no horizontal lines. The figure, therefore, also illustrates the characteristic with a slope added to overcome the difficulty. A small slope is adequate.



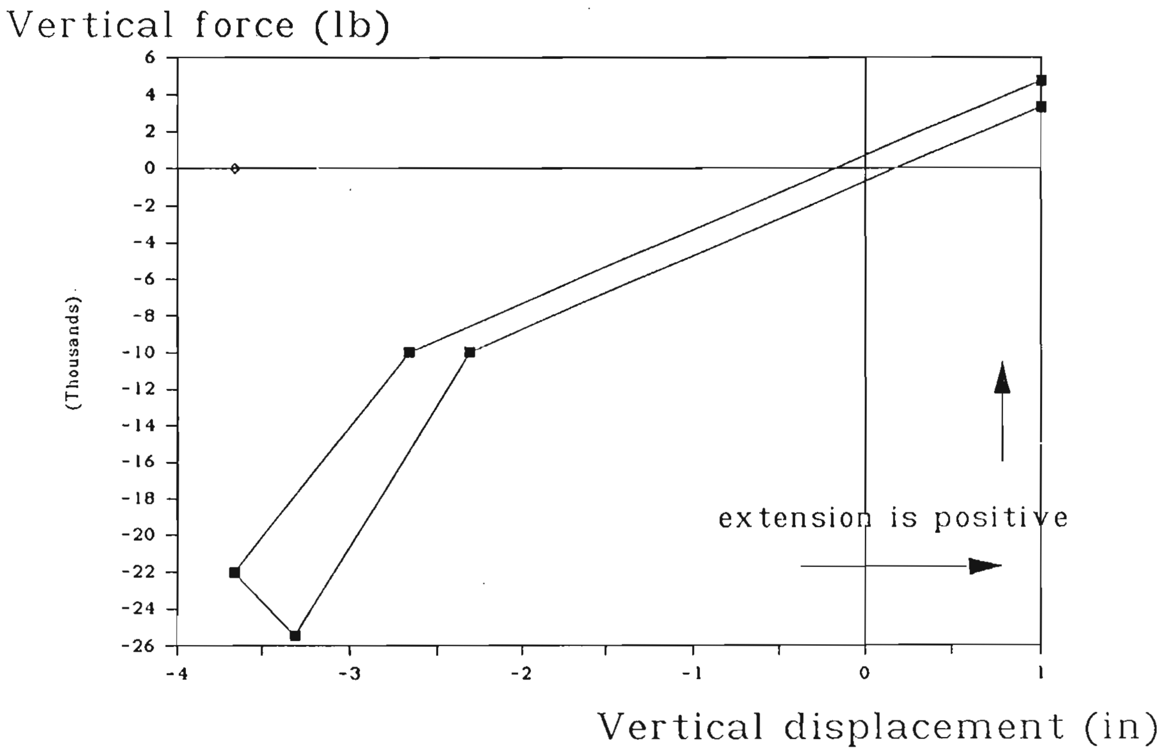
Yaw Friction for Series Pair

The final type of car suspension, requiring two PWL characteristics, is the hysteresis suspension. The form of the asymptotes for a vertical leaf spring suspension is given in the graph below. The two characteristics for this example are,

PWL Ordinate, ..., over abscissa, ..., at each Break Pt

7	-2.2E04	-1.0E04	4.73E03
	-3.66	-2.66	1.0
8	-2.54E04	-1.0E04	3.33E03
	-3.31	-2.31	1.0

The lines in this case are nearly parallel and may be represented approximately by a parallel pair with a stiffness equal to the mean of the stiffnesses and a friction level of half the difference in force between the lines. It is important to note the direction of the plot and the fact that the zero is for the unloaded state. The normal weight of the car will put the static position below zero and to the left, or in compression, by an amount equal to the static load on the suspension.



Hysteresis in Vertical Suspension

Two final pieces of data, not strictly car data, are required to complete the car file. The model in NUCARS calculates the vertical force between the wheel and rail assuming that the rail has vertical flexibility. This permits a more accurate model of the vehicle to track interaction, retaining a simpler method of analysis. It also permits the force between the wheel and rail to be set to zero during wheel lift. The values suggested below are reasonable for the general state of track and provide stable analytical results.

-Provide information on the linear vertical rail characteristics

Stiffness lb/in	Damping lb-sec/in
1.0E05	1.0E03

6 SETTING UP A NEW RUN FILE

This section gives an explanation of the data required for the program run, and the format in which it must be provided. An empty file has been provided on Disk 1, called EMPTY.RUN, which can be copied on to another name of your choice. Under your new name, this file can be used to add your own data for the car you wish to study. You will require a word processor, suitable for editing ASCII text files, for this purpose.

The format of the run file is similar to that of the car file. It is described again here for readers who have started with this file. If you have already read the car file format description, please proceed to the beginning of the file creation.

Both input ASCII files, required by NUCARS, are arranged as Fortran 77, standard list-directed input files. The descriptive comments provided in them, are expected by NUCARS to take a prearranged number of lines. The messages may be reworded to suit your own way of describing the required values, but the number of lines taken must be the same as those provided in the examples. All names, other than the initial title in the run file, are list-directed character strings and must be entered between single quotation marks, as requested.

Any list of values must be separated by "value separators". In general, these may be a comma, one or more blanks, an end-of-record or a slash, /. The file discussed below is given blanks as value separators. Using a slash, /, stops execution at the previous value and is not used. The end-of-record separator permits the "wrapping" of a long list of values on to the next line, although this has not been necessary in the examples used.

The data required for the car file is now described, following the general format in the EMPTY.RUN file provided. As in previous sections the values you are required to furnish are shown **bold** and **underlined.** First, part of the data is given, outlined in a box, together with a sample list of values. This is followed by a fuller description, with other examples where necessary as an aid to understanding.

```
-This file is required for a run of NUCARS, Version S
------------------------------------------------------------------------
-Enter data below the names given, (integers begin with letter I)
------------------------------------------------------------------------
-Enter a title up to 80 characters long on the next line,
50 mph thro' a lateral alignment sin wave; CNH132S, step = 0.5, mu = 0.4
```

The title inserted here is repeated on graphs and data throughout the output data and files. It is therefore useful, if not vital, that it contains as complete a description of the run as possible in the space of the one line or 80 characters permitted. You may wish to develop a standard short method of identifying your runs. Quotation marks should not be used here.

```
-Choose the wheel and rail profile geometry,
   1 = new AAR 1/20 on AREA 132 lb/yd rail, standard gauge
   2 = new AAR 1/20 on AREA 136 lb/yd rail, standard gauge
   3 = average worn wheel on AREA 132 lb/yd rail, standard gauge
   4 = average worn wheel on AREA 136 lb/yd rail, standard gauge
   5 = new CN Heumann wheel on AREA 132 lb/yd rail, standard gauge
   6 = new CN Heumann wheel on AREA 136 lb/yd rail, standard gauge
   7 = new CN Heumann wheel on AREA 136 lb/yd rail, 1 in wide gauge
   8 = new CN Heumann wheel on AREA 136 lb/yd rail, 1/20 tie plates
 5
```

The wheel/rail geometries provided, cover a reasonable cross section of those found in North America. The choice is important. Worn wheels are known to improve steering in curves and encourage hunting. A similar effect is apparently true for the Canadian National Railways modified Heumann, here called the CN Heumann, which is in increasing use. If runs are required through track which generally has wide gauge, it is more accurate to use a profile geometry with wide gauge than to use the lateral rail perturbations to widen it. This is due to the nature of the assumptions made in calculating the wheel-on-rail forces.

```
-Name of car data input & file for subsequent print & plot for this run
  must be entered below their names IN SINGLE QUOTES,

 CARFIL            OUTFIL
 'test.car'        'test.out'
```

As indicated, choose your own names, but don't forget the 'single quotes'.

```
-Integration control constants, DD is the interval for OUTS, & GRAF,
 enter 0.0 if GRAF not required, max. plot points = 800. The indicators
 for the screen display at the end of the run, IFEND, & for wheel lift &
 derailment messages & pauses during the run, IFMSG, 1 = yes, 2 = no.
 DSTEP      DSTOP     DDOUTS    DDGRAF    IFEND     IFMSG
 <msec.>    < ft. >   < ft. >   < ft. >   < # >     < # >
 0.5        400.0     1.0       100.0     1         1
```

The integration control constants are as follows,

DSTEP - The integration step length in msecs., 0.5 is a good starting guess. Make the value as large as possible, consistent with analytically stable running. It is generally wise to try several values, looking for the largest which gives the same response, and an analytically stable result.

DSTOP - The end of the run in feet.

DDOUTS - The step, in feet, between output of the required values to OUTFIL. It should be noted that there cannot be more than 800 output points. So that, for example, if DSTOP is greater than 800 feet, DDOUTS should be increased to 2.0.

DDGRAF - The distance, in feet, between screen displays. If these are not required, set this value to 0.0.

IFEND - Set to 1 if the screen display, chosen, is required to be given at the end of the run.

IFMSG - Provision is made for messages to be sent to the screen, in the event of a wheel lift, or a lateral wheel displacement beyond the wheel/rail geometry, termed a derailment. Each message requires a response and stops the program run.
The continuation, especially beyond a derailment, may hang the computer. However, in some cases, the display, noting the event on the screen is not required and can be eliminated by setting IFMSG to 2.

-Enter the forward velocity in mph and friction coefficients on the left and right treads ; left and right flanges

VMPH	MU(1)	MU(2)	MU(3)	MU(4)
30.0	0.4	0.4	0.3	0.3

The speed chosen is assumed to be constant throughout the run. There is provision in the program for changing the coefficient of friction when passing from the tread to the flange on either side. The values chosen may be different, as for the case of flange lubrication.

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of distance along the track, in feet, curvature at that distance, in degrees, & track superelevation, high rail above low, in inches, also at that distance. N.B. Positive curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

4

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
100.0	0.0	0.0
250.0	-10.0	4.5
2000.0	-10.0	4.5

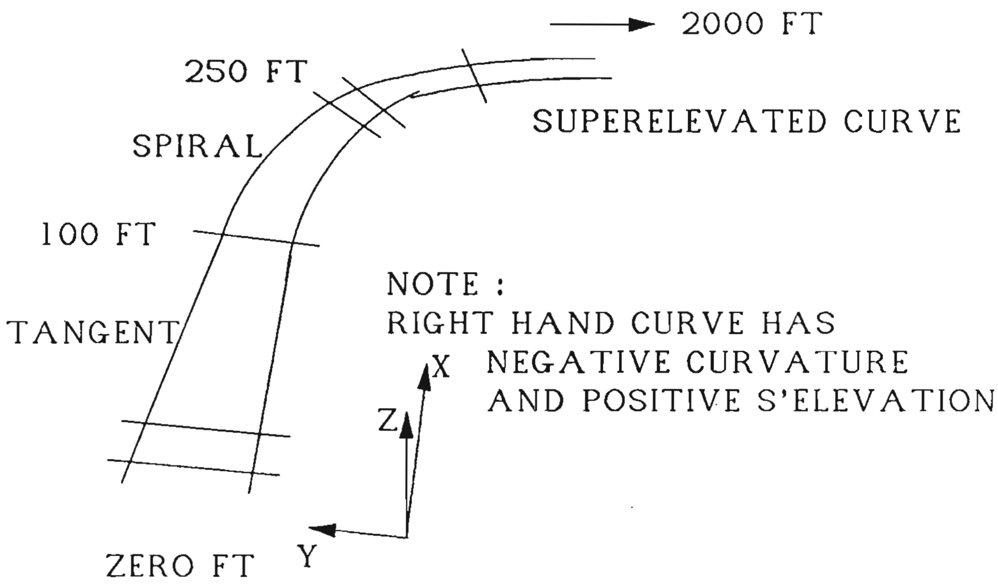
The above tabular information defines the track design for the required run. A linear interpolation is made between the points along the track identified. The example data provided may be described as follows,

A 100 foot section which has no curve or elevation, allowing the car position to settle prior to,

A spiral to the right, with curvature increasing to 10 degrees and track superelevation to 4.5 inches, at 250 feet, followed by,

A steady curve of 10 degrees to the right with superelevation of 4.5 inches, beyond the required run length.

You may find it preferable to use the negative, or right-hand curve, since this gives positive lateral displacementsto the output, i.e. upwards on the graphs. The track appears as in the following figure.

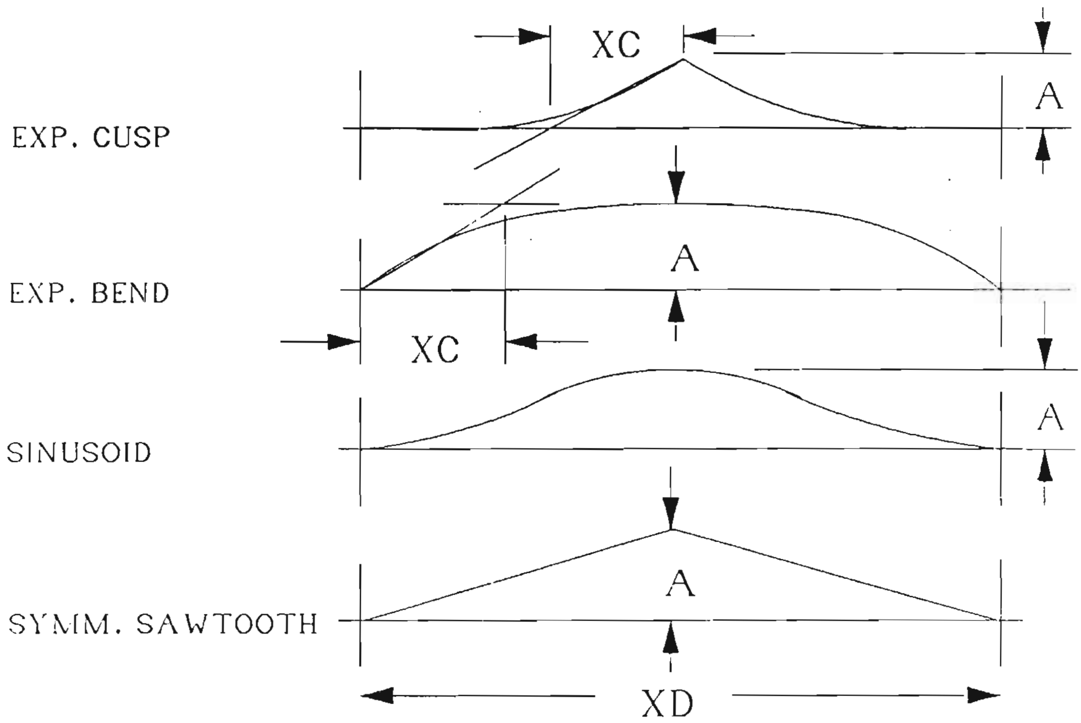


TRACK GEOMETRY INPUT

-The following information is required for the rail perturbations
The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbations, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.
XC = characteristic length, XD = dist. over which the shape repeats,
Y = lateral, Z = vertical, L = left, & R = right rail, respectively.
They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

The data above is required to define the amplitude of the perturbation in the rail from such causes as dips at the joints or lateral sinusoidal patterns. Four shapes are possible and the displacement due to each is summed to give the total perturbation of each rail, in the lateral and vertical direction. The values given in the example, for the exponential cusp and bend, are typical of those required for jointed rail. The four shapes are illustrated below.



RAIL SHAPES

-How many segments are required for the left rail ? (max=10)

3

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	217.0	2000.0
Lateral			
'CUSP'	0.000	0.500	1.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000
Vertical			
'CUSP'	0.000	-0.250	-0.500
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

The example above, for the left or outer rail in the curve, provides perfect rail for the first 100 feet, followed by rail joints giving outward and downward cusps at the joints. The amplitude of the cusps are 0.5 in. outwards and 0.25 in. downwards in the spiral and twice these values in the full curve.

-How many segments are required for the right rail ? (max=10)
 3
-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	119.5	236.5	2000.0
Lateral			
'CUSP'	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000
Vertical			
'CUSP'	0.000	-0.250	-0.500
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

For the right or inner rail in the curve, the perfect rail for the first 119.5 feet is followed by rail joints with downward cusps at the joints. The amplitude of the cusps are 0.25 in. downwards in the spiral and 0.5 in. in the full curve.

-INITIAL CONDITIONS for the CAR
-Provide the starting position of each body/axle degree of freedom, in turn, in the same order as that given in the car file, (CARFIL),

0.0	-1.4	0.0	0.0	0.0	0.0	0.0	0.085	0.0
0.0	0.0	0.0	0.0					
0.0	0.0	0.0	0.0					

-Provide the starting velocity of each body/axle degree of freedom, in turn, in the same order as that given in the car file,

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0				
0.0	0.0	0.0	0.0				

-Provide the starting vertical position of the rail at each axle, in turn,

Left	Right
0.0	0.0
0.0	0.0

The initial position and velocity must be given for each of the degrees of freedom, previously identified in the car data file. These are often zero, but may be offset, for example, to initiate hunting. The vertical position may be defined to reflect the static vertical position, as shown for the car body, reducing the settling time.

-SELECTION OF OUTPUT
The following data are selected from the lists of variables computed
to define a vector of output variables for subsequent printing
and/or plotting. The variables are identified from their names as,
IN = integer number of :-
CUR, ELV - track curvature & elevation;
Q - DoF's, QD - vels, QDD - accns; F - total forcing terms on DoFs;
SX,SY,SZ & SDX,SDY,SDZ - x,y,z suspn. strokes & stroke velocities;
FX,FY,FZ - x,y,z forces or moments on the suspensions;
TR,TS,TY - axle roll, pitch (or spin about axle center), yaw torques;
FLN,FLT,FVR - longitudinal, lateral and vertical wheel forces;
RLV - FLT/FVR, (L/V), lateral to vertical force ratio;
WLV - axles for combined sum of absolute wheel L/V's, (Weinstock);
SLV - number of combinations of sums of L's over sum of V's by side;
RY - axles for rail lateral positions with flangeway clearance.

INCUR	INELV	INQ	INQD	INQD	INF				
1	1	10	0	D	0				
INSX	INSY	INSZ	INSDX	0	INSDZ	INFX	INFY	INFZ	
0	2	0	0	INSDY	0	0	2	0	
INTR	INTS	INTY	INFLN	2	INFVR	INRLV	INWL	INSLV	INRY
0	0	2	0	INFLT	4	4	V	1	4
				4			2		

The total number of each of the above outputs, depends upon the selection made below. It is therefore best to select the outputs first and count them for later insertion in the section above.

-The curvature of track at center of the masses numbered as in CARFIL
2
-The elevation of track at center of the masses numbered as in CARFIL
2

If the lead axle is chosen for the datum, it is useful to select the curvature and superelevation at this position. This choice is, of course, not necessary on straight track.

-List the degrees of freedom of required masses with their designation
1 = Lon, 2 = Lat, 3 = Ver, 4 = Roll, 5 = Ptch, 6 = Yaw, 7 = Twist, 8 = V.bend, 9 = L.bend

Mass no.	No. Dof's reqd?	List of Dof numbers as above.
1	4	2 4 6 7
2	3	2 4 6
3	3	2 4 6

-List the 1st derivatives or velocities as for the degrees of freedom

Mass no.	No. Vel's reqd?	List 1 = long, 2 = lat, 3 = vert, 4 = roll etc.

-List the 2nd derivatives or accelerations as for the degrees of freedom

Mass no.	No. Acc's reqd?	List 1 = long, 2 = lat, 3 = vert, 4 = roll etc.

-List the forces or moments in the directions of the degrees of freedom

Mass no.	No. Forces reqd?	List 1 = long, 2 = lat, 3 = vert, 4 = roll etc.

In NUCARS, an equation of motion is written for each degree of freedom chosen in the car file relative to the local track coordinate system. This process is generally transparent to the user. However the value of the variable, its derivative, its second derivative or the total forcing term in any of the equations, may be selected as an output, using the data requested above. The inserted data takes the form given for the variables. The degree of freedom is selected by identifying the mass on which it occurs, and its number as one of a chosen group.

-The list of x suspension strokes in the order chosen in CARFIL

-The list of y suspension strokes in the order chosen in CARFIL
1 2

-The list of z suspension strokes in the order chosen in CARFIL

-The list of x suspension stroke velocities in the order chosen in CARFIL

-The list of y suspension stroke velocities in the order chosen in CARFIL
1 2

-The list of z suspension stroke velocities in the order chosen in CARFIL

-The list of x suspension forces in the order chosen in CARFIL

-The list of y suspension forces in the order chosen in CARFIL
1 2

-The list of z suspension forces in the order chosen in CARFIL

Any suspension, having the direction and number chosen in the car file, may be selected for output. This may be in the form of the displacement or velocity across it, or the force or moment through it. The only exceptions are for the parallel suspensions without damping, which do not have the velocity calculated, and those without stiffness, which do not have a displacement calculated.

-The torques on the axles in roll, listed by axle number

-The torques on the axles in pitch, (spin), listed by axle number

-The torques on the axles in yaw, listed by axle number
1 2

The forces between the wheel and rail are important in any assessment of the performance of the vehicle, and are therefore included in the list of output variables. These forces take two forms. First as an option are the torques on the axle about the three axes x, y, and z. The y torque is balanced during the computation, and is included for checking the validity of the run. The yaw or z torque is important in assessing the overall balance of the suspension in curving. The choices are made by listing the axles on which the torques are required.

-The longitudinal force on each wheel by side, (1=left,2=right),
over the chosen axle numbers

-The lateral force on each wheel by side, (1=left,2=right),
over the chosen axle numbers
1 2 1 2
1 1 2 2
-The vertical force on the wheel by side, (1=left,2=right),
over the chosen axle numbers
1 2 1 2
1 1 2 2

Provision is also made for the individual wheel forces to be output. These permit a careful study of the guiding forces. The wheel forces are chosen by listing the side required, 1 for left and 2 for right, above the axle numbers as for the torques.

-The lateral to vertical force ratio on each wheel by side,
(1 = left,2 = right), over the chosen axle numbers
1 2 1 2
1 1 2 2
-The sum of the absolute values of lateral to vertical force ratios
on any axle by its number; the Weinstock criterion
1 2
-The sum of lateral to sum of vertical forces on a combination of wheels
designated by the number of wheels, over the required side,
(1 = left,2 = right), over a list of the axle numbers
2
1
1 2

Certain important derived values have been added to the output options. The best known of these is the L/V ratio, calculated directly from the lateral and vertical forces in the preceding block, and chosen by listing them in a manner similar to the wheel forces.

Two further derived variables may be chosen. The sum of the absolute values of the L/V ratio on any axle is a useful guide to its proximity to wheel climb. A criterion using this variable was proposed by Weinstock of the Transportation Systems Center as an improvement to Nadal's criterion from individual wheel L/V values. The second derived variable has been used frequently to assess the proximity to rail rollover. It consists of the sum of the lateral forces divided by the sum of the vertical forces on the axles on the same side of a truck or car. Several groupings are possible. For a standard car with two 3-piece trucks, the values for both trucks, separately, on the left side, could be chosen as follows,

-The sum of lateral to sum of vertical forces on a comb.. wheels
designated by the number of wheels, over the required side,
(1 = left,2 = right), over a list of the axle numbers
2 2
1 1
1 2 3 4

-The lateral rail position, with flangeway clearance, by side,
(1 = left,2 = right), over the chosen axle numbers
1 2 1 2
1 1 2 2

The lateral rail position may be compared directly to the lateral position of the axle, to assess the proximity to flange contact. To improve the display, the clearance between the wheel and rail, with the axle centered, is added to the lateral rail position. The method of choosing of these output values is identical to that used for the wheel forces.

-Number of X,Y, and Z tranducers for which to calculate output responses

IALLXT	IALLYT	IALLZT
0	2	2

-List for each transducer, beginning with X directional transducers:
The number of the body on which the transducer is mounted;
whether it is translational = 1, or rotational = 2,
the type of transducer, 1 = displacement, 2 = velocity, 3 = acceln;
& X, Y ,Z coordinates of the location of transducers, in inches.

X Transducer parameters for

Body no.	Trans/Rot	Type	Posn in x,y,z		

Y Transducer parameters for

Body no.	Trans/Rot	Type	Posn in x,y,z		
1	1	3	0.0	0.0	30.0
1	1	3	-430.0	0.0	30.0

Z Transducer parameters for

Body no.	Trans/Rot	Type	Posn in x,y,z		
1	1	3	0.0	0.0	30.0
1	1	3	-430.0	0.0	30.0

NUCARS provides a general capability for adding transducers to the car at any position and on any body, excluding the axles. These transducers may be displacement, velocity or acceleration. Translational acceleration is output in units of gravity, since most linear accelerometers are calibrated in these units. The translational displacements are in inches and the velocities in in./sec. Rotational transducers may also be chosen. These are in degrees or their time derivatives. The position is stated relative to the same datum as that chosen for the measurements of the car in the car file. The chosen transducers are added to the end of the list of output variables and may also be chosen for screen display below.

-SCREEN OUTPUT - also used to define the printed output variables !
How many graphs are required to be screened at interval DDGRAF
6
-For each graph screened during the run, identify the no. of the output ordinate, (y), over the abscissa, (x), using time = 1 and distance = 2 and 3 onwards in the same order as the chosen output variables above.

3	4	9	11	12	14
2	2	2	2	2	2

Finally for the run file, the particular variables to be displayed on the screen during and/or at the end of the run, must be chosen. They are chosen by number from the order they are requested in the output file. Their display to the screen is time consuming during a run, and should be kept to the minimum required to see that the run is progressing as desired. For production running, it is often more convenient to eliminate them by choosing a distance of 0.0 between displays. The display may be in any order. The sample display given above, is for the curvature, superelevation, and lateral and yaw displacements of the two axles. The list may also include cross plots between variables. Thus the list might have been,

-For each graph screened during the run, identify the no....put
ordinate, (y), over the abscissa, (x), using time = 1 .... = 2
and 3 onwards in the same order as the chosen output ..above.

3	4	38	40	19	20
1	2	2	2	15	16

This omits the displacements of the axles, plots the curvature against time, adds the lateral and vertical transducers above the leading axle against distance, and adds cross plots of the total lateral suspension forces against their displacements, for each axle.

7 ADDITIONAL DATA FOR CAR AND RUN FILES

For simplicity, the case used in most of the preceding examples has been that of a structurally simple car with 2 single axle trucks. In section 7.1 the input data for the empty two axle light weight 'front-runner' car is presented. This data is exactly as used when performing the NUCARS validations and comparisons. Modelling the loaded car can be accomplished by modifying this input file with the addition of appropriate masses and suspensions to represent the trailer load. Alterations in the two axle car suspension will allow simulation of alternate two axle vehicle designs.

In section 7.2, a number of track scenarios are presented. These may be inserted directly into your own run files and are available on the second disk supplied, under the file name TRACK.DAT. They also give an overview of the possibilities, using the track definition provided in NUCARS. Once again, it is important to check all values if they are used to define the track in your own run files.

7.1 The Lightweight Two Axle 'Front-Runner' car

-CARFIL for NUCARS in lb., in. & sec. unless otherwise stated.

-Enter data below the names given, (integers begin with letter I)

-FOR THE BODIES

-How many Bodies (IBHV), and in addition how many axle bodies (IBAX)

IBHV	IBAX
1	2

-List the number, position of each body (& axle body) rel. to a datum on the track center, in., followed by the no. of degrees of freedom required, followed by a list of degrees of freedom for each, in turn, from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz. The required 4 degrees of freedom for each axle are 2 3 4 6
THE AXLE BODIES MUST BE LISTED LAST !

Body no.	Position in X, Y & Z			No. of DoF's	List of chosen DoF's						
1	-226.4	0.0	30.0	8	2	3	4	5	7	8	9
2	0.0	0.0	14.0	4	2	3	4	6			
3	-438.0	0.0	14.0	4	2	3	4	6			

-Identify the track semi-gauge, and wheel radii for each axle, inches,

HAFGAG	WRAD(1), (2), (3), (4), (5), (6) etc.	
29.75	14.0	14.0

-For the bodies which have flexible modes, give the position of each geometric center, along the track from the datum, backward -ve, its length in inches, the natural frequencies, in rad./sec, & the damping ratios in twist, vertical & lateral bending, as required.

Body no.	X-Posn	X-Length	Nat Frequency(rad/sec)			Damping Ratio		
1	-219.0	606.0	7.0	56.5	55.0	0.05	0.01	0.07

-List the mass, roll, pitch and yaw inertias, in order
For each body in order, excluding axles,

57.729	3.7E04	2.5E06	2.25E06

For the axles, in turn, in the order defined above

5.75	2.6E03	1.5E03	2.6E03
5.75	2.6E03	1.5E03	2.6E03

-FOR THE CONNECTIONS
Identify the following parameters
-Number of X-conn., (IALLXS); Y-conn., (IALLYS); Z-conn., (IALLZS)

IALLXS	IALLYS	IALLZS
0	2	8

-Complete the following tables for each X, Y, and Z connection,
identifying the following required variables against its number,
its position relative to the chosen datum in inches;
the number of the body at each of its ends;
whether the connection is one of translation 1 or rotation 2;
the type 1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring;
and the number designating each pair of type 1, 2 and 3.
Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.
-Complete for all X connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type & Pair no	

-Complete for all Y connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type & Pair no	
1	0.0	0.0	18.0	1	2	1	1	1
2	-438.0	0.0	18.0	1	3	1	1	1

-Complete for all Z connections in turn,

Susp no.	Position in x,y,z			Body 1	Body 2	Trans/Rot	Type & Pair no	
1	0.0	0.0	18.0	1	2	2	1	2
2	-438.0	0.0	18.0	1	3	2	1	2
3	0.0	0.0	18.0	1	2	2	2	1
4	-438.0	0.0	18.0	1	3	2	2	1
5	0.0	39.0	18.0	1	2	1	3	1

6	0.0	-39.0	18.0	1	2	1	3	1
7	-438.0	39.0	18.0	1	3	1	3	2
8	-438.0	-39.0	18.0	1	3	1	3	2

-List for each pair of type 1 - parallel connections, its number,
the identification numbers of the piecewise linear characteristics
for the stiffness and damping respectively, zero if absent, and
the combined force or moment limit in extn & compn, lb or lb-in.
(If no limit exists, set the F-values outside the expected range.)

Pair no.	Stiff PWL	Damp PWL	F-extn.	F-compn.
1	5	6	1.0E08	-1.0E08
2	1	2	1.0E08	-1.0E08

-List for each pair of type 2 - series connections, its number,
the identification numbers of the piecewise linear characteristics
for the stiffness and damping respectively, and the stroke limit
in extension & compression for the pair, in or rad, and the stiffness
of the stop at the limit in lb/in or lb-in/rad.
(If no limit exists, set the S-values outside the expected range.)

Pair no.	Stiff PWL	Damp PWL	S-extn.	S-compn.	Stop K
1	3	4	10.0	-10.0	1.0E08

-List the type 3 - hysteresis loop characteristics, identifying its,
number, the numbers of the piecewise linear characteristics and the
beta exponent during extension and during compression respectively.

Loop no.	Extn PWL	Extn Beta	Comp PWL	Comp Beta
1	7	0.05	8	0.05
2	9	0.05	10	0.05

-How many different piecewise linear, (PWL), char-istics are required
10
-List the data required for the connection characteristics,
the number of Break Points in each PWL characteristic,

6 4 2 8 6 4 3 3 3 3

PWL Ordinate, lb lb-in, over abscissa, in rad, at each Break Point

1	-3.6E06	-6.14E04	-5.38E04	5.38E04	6.14E06	3.6E06
	-0.0481	-0.0231	-0.0224	0.0224	0.0231	0.0481

2	-1.56E04	-1.56E04	1.56E04	1.56E04				
	-1.0	-0.02	0.02	1.0				
3	-6.084E07	6.084E07						
	-1.0	1.0						
4	-1.5785E5	-9.36E4	-2.42E4	-2.06E4	2.06E4	2.42E4	9.36E4	1.57585E5
	-0.303	-0.017	-0.0054	-0.0026	0.0026	0.0054	0.017	0.0303
5	-1.0E04	-3.58E03	-1.0E03	1.0E03	3.58E03	1.0E04		
	-1.30	-1.20	-0.90	0.90	1.20	1.30		
6	-9.0E02	-9.0E02	9.0E02	9.0E02				
	-1.0	-0.009	0.009	1.0				
7	-2.2E04	-1.0E04	4.755E03					
	-3.661	-2.661	1.0					
8	-2.54E04	-1.0E04	3.305E03					
	-3.301	-2.301	1.0					
9	-2.2E04	-1.0E04	4.73E03					
	-3.66	-2.66	1.0					
10	-2.54E04	-1.0E04	3.33E03					
	-3.31	-2.31	1.0					

-Provide information on the linear vertical rail characteristics

Stiffness lb/in	Damping lb-sec/in
1.0E05	1.0E03

7.2 Additional Track Scenarios

Scenario no. 1 - Straight Unperturbed Track

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

2

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

1

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

Vertical

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

-How many segments are required for the right rail ? (max=10)

1

-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral -- etc. as for the left rail --

Scenario no. 2 - 7 deg curve, 6 in elev, 120 ft spiral, no lead tangent

----

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

5

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
120.0	-7.0	6.0
320.0	-7.0	6.0
440.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

1

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

Vertical

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

-How many segments are required for the right rail ? (max=10)

1

-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral -- etc. as for the left rail --

Scenario no. 3 - 10 deg curve, 5 in elev, 100 ft spirals, 100 ft lead

----

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

6

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
100.0	0.0	0.0
200.0	-10.0	5.0
500.0	-10.0	5.0
600.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)
1
-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

Vertical

'CUSP'	0.000
'BEND'	0.000
'SIN '	0.000
'SSAW'	0.000

-How many segments are required for the right rail ? (max=10)
1
-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	2000.0

Lateral -- etc. as for the left rail --

Scenario no. 4 - 10 Staggered 39 ft rail joints on tangent, 100 ft lead

----

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

2

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)
3
-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	529.0	2000.0
Lateral			
'CUSP'	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000
Vertical			
'CUSP'	0.000	-0.750	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

-How many segments are required for the right rail ? (max=10)
3
-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)' 119.5 509.5 2000.0

Lateral -- etc. as for the left rail --

Scenario no. 5 - 10 Symmetric 39 ft rail joints on tangent, 100 ft lead

---

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

2

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

3

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	490.0	2000.0

Lateral

'CUSP'	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

Vertical

'CUSP'	0.000	-0.750	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

-How many segments are required for the right rail ? (max=10)

3

-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	490.0	2000.0

Lateral -- etc. as for the left rail --

Scenario no. 6 - 36 ft long, 2 in. high, vert. bump at 100 ft, tangent

----

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

2

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

5

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	106.0	130.0	136.0	2000.0
Lateral					
'CUSP'	0.000	0.000	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000	0.000	0.000
Vertical					
'CUSP'	0.000	0.000	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000	0.000	0.000
'SIN '	0.000	2.000	0.000	-2.000	0.000
'SSAW'	0.000	0.000	0.000	0.000	0.000

-How many segments are required for the right rail ? (max=10)

5

-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	106.0	130.0	136.0	2000.0

Lateral -- etc. as for the left rail --

Scenario no. 7 - 5 alignment sinusiods, 39 ft wavelength, 1.25 in. p/p

----

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

2

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
2000.0	0.0	0.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

5

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	100.0	119.5	314.5	334.5	2000.0
Lateral					
'CUSP'	0.000	0.000	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000	0.000	0.000
'SIN '	0.000	0.625	-1.250	-0.625	0.000
'SSAW'	0.000	0.000	0.000	0.000	0.000
Vertical					
'CUSP'	0.000	0.000	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000	0.000	0.000

-How many segments are required for the right rail ? (max=10)

5

-The amplitudes of each perturbed shape on the right rail, inches, e ow given belthdistance,
are
during which they occur, iin feet, to the end of the segment of rail
n order,

'Xend(ft)' 100.0 119.5 314.5 334.5 2000.0

Lateral -- etc. as for the left rail --

Scenario no. 8 - Perturbed dynamic 12 degree curve

-TRACK AND RAIL INPUTS

-The following list, is required for the track curves. It consists of a distance along the track, in feet, the curvature at that distance, degrees, and the track elevation, high rail above low, inches, also at that distance. N.B. +ve curvature and elevation are indicated by their direction of rotation about the z & x axes, with z upwards. Curvature is -ve with +ve track superelevation, if to the right.

How many distances and values of curvature and elevation ? (max = 20)

4

They are - Distance-ft	Curvature-deg	Elevation-in
0.0	0.0	0.0
117.0	0.0	0.0
273.0	-12.0	5.0
2000.0	-12.0	5.0

-The following information is required for the rail perturbations

The parameters, XCYL, XCZL, XDYL, XDZL, and XCYR, XCZR, XDYR, XDZR, governing the shape of the rail perturbation, must be listed for the four shapes offered, CUSP, BEND, SIN, and SSAW respectively.

XC = characteristic length, XD = dist over which the shape repeats,

Y = lateral, and Z = vertical, L = left, and R = right rail, resp.

They are in inches.

	XCYL	XCZL	XDYL	XDZL	XCYR	XCZR	XDYR	XDZR
'CUSP'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'BEND'	96.0	96.0	468.0	468.0	96.0	96.0	468.0	468.0
'SIN '	468.0	4 68.0	468.0	468.0	468.0	468.0	468.0	468.0
'SSAW'	900.0	9 00.0	1800.0	1800.0	900.0	900.0	1800.0	1800.0

-How many segments are required for the left rail ? (max=10)

3

-The amplitudes of each perturbed shape on the left rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	273.0	507.0	2000.0
Lateral			
'CUSP'	0.250	1.000	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000
Vertical			
'CUSP'	0.250	-0.500	0.000
'BEND'	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000

-How many segments are required for the right rail ? (max=10)

4

-The amplitudes of each perturbed shape on the right rail, inches, are given below the distance, in feet, to the end of the segment of rail during which they occur, in order,

'Xend(ft)'	19.5	253.5	526.5	2000.0
Lateral				
'CUSP'	0.000	0.000	0.000	0.000
'BEND'	0.000	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000	0.000
Vertical				
'CUSP'	0.000	-0.250	-0.500	0.000
'BEND'	0.000	0.000	0.000	0.000
'SIN '	0.000	0.000	0.000	0.000
'SSAW'	0.000	0.000	0.000	0.000

APPENDIX B

CHAPTER XI

SERVICE-WORTHINESS TESTS AND ANALYSES FOR NEW FREIGHT CARS

CHAPTER XI

SERVICE-WORTHINESS TESTS AND ANALYSES FOR NEW FREIGHT CARS

11.1. PURPOSE AND SCOPE

This chapter presents guidelines for testing and analysis to ascertain the interchange-service worthiness of freight cars. The regimes of vehicle performance to be examined are divided into two sections. Section 1 covers structural static and impact requirements. Section 2 covers vehicle dynamic performance, with the following regimes to be examined: hunting, car body twist and roll, pitch and bounce, yaw and sway and longitudinal train action.

Braking performance, structural fatigue life, car handling, and other design considerations must be considered in accordance with requirements outlined by other chapters of this specification.

The methods presented provide acceptable approaches to the analysis and measurement of car parameters and performance. Other rational methods may be proposed at the time of submission for design approval. Their use and applicability must be agreed to by the Car Construction Committee.

11.2. STATIC AND IMPACT TEST REQUIREMENTS

Application for approval of new and untried types of cars, along with supporting data specified in paragraph 1.2.3, shall be submitted to the Director, Technical Committees–Freight Car Construction prior to initiation of official AAR testing. A proposed testing schedule and testing procedures will be submitted sufficiently in advance of tests to permit review and approval of the proposal and assignment of personnel to witness tests as AAR observers. Tests will be in conformity with the following and all costs are to be borne by the applicant, including observers.

11.2.1. TEST CONDITIONS

11.2.1.1.

A car of the configuration proposed for interchange service must be utilized for all tests. Deviation from such configuration is only permitted with the explicit permission of the Car Construction Committee.

During impact tests, the test car will be the striking car and shall be loaded to AAR maximum gross rail load for the number and size of axles used under car (see 2.1.5.17). Exceptions to this procedure will be considered by the Car Construction Committee when justified by the applicant.

Cars designed for bulk loading shall have a minimum of 85% of the total volume filled.

Cars designed for general service, other than bulk loading, shall be loaded so that the combined center of gravity of car and loading is as close as practicable to the center of gravity computed in accordance with the requirements of 2.1.3, except that general service flat cars may be loaded by any practicable method. The loads shall be rigidly braced where necessary, and various types of loads should be used to test each component to its maximum load.

The test car may be equipped with any AAR-approved draft gear or any AAR-approved cushioning device for which the car was designed.

6 1 88

11.2.1.2.

The cars, other than the test car, shall be of seventy ton nominal capacity, loaded to the allowable gross weight on rails prescribed in 2.1.5.17. A high density granular material should be used to load cars to provide a low center of gravity, and the load should be well braced to prevent shifting. Such cars shall be equipped with draft gears meeting the requirements of AAR Specification M-901, except at the struck end where M-901E rubber friction gear shall be used.

Free slack between cars is to be removed, draft gears are not to be compressed. No restraint other than handbrake on the last car is to be used.

11.2.2. INSTRUMENTATION

The coupler force shall be measured by means of a transducer complying with AAR Specification M-901F, or other approved means. Instrumentation used for recording of other data shall be generally acceptable type properly calibrated and certified as to accuracy.

Speed at impact shall be recorded.

11.2.3. STATIC TESTS

11.2.3.1. COMPRESSIVE END LOAD

A horizontal compressive static load of 1,000,000 lbs, shall be applied at the centerline of draft to the draft system of car/unit structure interface areas, and sustained for a minimum 60 seconds. The car/unit structure tested shall simulate an axially loaded beam having rotation free-translation fixed end restraints. (See Figure 11.2.3.1).

No other restraints, except those provided by the suspension system in its normal running condition, are permissible. Multi-unit car must have each structurally different unit subjected to such test, also two empty units joined together by their connector shall undergo this test to verify the connectors compressive adequacy and its anti-jackknifing properties.

The test is to be performed with the car subjected to the most adverse stress or stability conditions (empty and/or loaded).

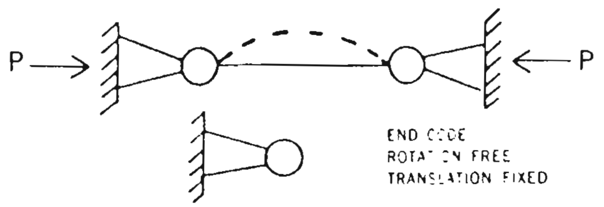


Figure 11.2.3.1

11.2.3.2. COUPLER VERTICAL LOADS

A vertical upward load shall be applied to the coupler shank immediately adjacent to the striker face or to the face of the cushion unit body at one end of the car, sufficient in magnitude to lift the fully loaded car free of the truck nearest the applied load, and held for sixty seconds. Cushion underframe cars having sliding sill are excluded from the requirements of this paragraph.

For cushion underframe cars having sliding sills, a vertical upward load shall be applied to the sliding sill in a plane as near the ends of the fixed center sills as practicable, sufficient in magnitude to lift the fully loaded car free of the truck nearest the applied load, and held for sixty seconds.

For all cars, a load of 50,000 pounds shall be applied in both directions to the coupler head as near to the pulling face as practicable and held for sixty seconds.

11.2.3.3. CURVE STABILITY

The test consist is to undergo a squeeze and draft load of 200,000 lbs. without car body-suspension separation or wheel lift. Load application shall simulate a static load condition and shall be of minimum 20 seconds sustained duration.

Cars consisting of more than two units shall be tested with a minimum of three units in the test consist. The number of units used shall generate maximum load in the critical L/V location of the car.

For the purpose of this test, wheel lift is defined as a separation of wheel and rail exceeding ⅛" when measured 2⅝" from the rim face at the inside of curve for buff and outside for draft.

Empty car shall be subjected to squeeze and draft load on a curve of not less than 10 degrees. The curve is to have ½" maximum superelevation. The test car is to be coupled to a "base car" as defined in paragraph 2.1.6.1. or a like car which ever is most severe and a "long car" having 90' over strikers, 66' truck centers, 60" couplers and conventional draft gear.

The test consist shall have means for measuring and recording coupler forces.

11.2.3.4. RETARDER AND "HOT BOX" DETECTION

Cars with other than conventional 3 piece trucks must be operated while fully-loaded over a hump and through a retarder. Retarder shall be operated to determine capability to brake the test cars. Such cars must also demonstrate their compatibility with hot box detection systems or be equipped with on-board hot box detection systems.

11.2.3.5. JACKING

Vertical load capable of lifting a fully loaded car/unit shall be applied at designated jacking locations sufficient to lift the unit and permit removal of truck or suspension arrangement nearest to the load application points.

11.2.3.6. TWIST LOAD

Loaded car/unit shall be supported on the side bearings or equivalent load points only. Diagonally opposite bearing or load point support shall be lowered through a distance resulting from a calculated 3" downward movement of one wheel of the truck or suspension system supporting it. No permanent deformation of car/unit structure shall be produced by this test.

11.2.4. IMPACT TESTS

These requirements apply to all cars except those exempted by other specification requirements.

11.2.4.1. SINGLE CAR IMPACT

The loaded car shall be impacted into a string of standing cars consisting of three nominal 70-ton capacity cars, loaded to maximum gross weight on rails as described in paragraph 2.1.5.17. with sand or other granular material, equipped with M-901E rubber-friction draft gear at the struck end and with the hand brake on the last car on the non-struck end of the string tightly set. Free slack between cars is to be removed; however, draft gears are not to be compressed. No restraint other than handbrake on the last car is to be used.

A series of impacts shall be made on tangent track by the striking car at increments of two miles per hour starting at six miles per hour until a coupler force of 1,250,000 pounds or a speed of fourteen miles per hour has been reached, whichever occurs first.

A car consisting of two or more units must also undergo impact testing as outlined above with the leading unit of the test car being empty for a two-unit car, or with the first two units being empty for a three (or more) unit car. No carbody-suspension disengagement or wheel lift is permitted during the partially loaded impact tests.

11.2.4.2. DYNAMIC SQUEEZE

(Optional–May be performed in lieu of or in addition to static end compression test if requested by the Car Construction Committee.)

The striking and standing car groups shall each consist of six cars, in which the test car may be the lead car in either group. All cars except the test car shall be as prescribed in 11.2.1.2. The brakes shall be set on all standing cars after all slack between cars has been eliminated. There shall be no precompression of the draft gears. The standing cars shall be on level tangent track. The striking cars, coupled together, shall be adjusted, if necessary, to restore the original conditions.

A series of impacts shall be made at increments of two miles per hour starting at six miles per hour until a coupler force of 1,250,000 pounds or a speed of fourteen miles per hour has been reached, whichever occurs first.

11.2.5. INSPECTION

A visual inspection of the test car shall be made after each static test and after each impact. Following the impact tests, the car shall be unloaded and inspected.

Any permanent damage to any major structural part of the car, found before or after all tests are completed, will be sufficient cause for disapproval of the design. Damage will be considered permanent when the car requires shopping for repairs.

11.3. TRACK-WORTHINESS ASSESSMENT

11.3.1. METHODOLOGY

Regimes are identified, representative of the performance of the car in service. Tests are defined for each regime. The results of the tests are an indication of the car's track-worthiness. In most regimes, analytic methods are also available to permit prediction to be made of the performance of the car, to the degree of accuracy required.

The characteristic properties of the car body and its suspension, required for the analysis, shall be supported by evidence of their validity. Characterization tests, such as those defined in Appendix A, are required to verify the values used in the analyses.

11.3.2. TRACK-WORTHINESS CRITERIA

The criteria applied to the analyses and tests are chosen from a consideration of the processes by which cars deviate from normal and required guidance. They are also subject to the requirement of observability in tests. Typical of these are lateral and vertical forces, the lateral over vertical force (L/V) ratios, dynamic displacements, and accelerations of the masses. These criteria are based on considerations of the processes of wheel climb, rail and track shift, wheel lift, coupler and component separation and structural integrity.

The values chosen for the criteria selected have been used in tests on cars presently in service. Those included in the body of this chapter are shown in Table 11.1. Values worse than these are regarded as having a high risk of unsafe behavior. Values better than these are regarded as indicating the likelihood of safe car performance.

Table 11.1 Criteria for Assessing the Requirements for Field Service

Regime	Section	Criterion	Limiting Value
Hunting (empty)	11.5.2	minimum critical speed (mph)	70
		maximum lateral acceleration (g)	1.0
		maximum sum L/V axle	1.3
Constant curving (empty and loaded)	11.5.3	maximum wheel L/V	0.8
		or	
		maximum sum L/V axle	1.3
Spiral (empty and loaded)	11.5.4	minimum vertical load (%)	10
		maximum wheel L/V	0.8
Twist, Roll (empty and loaded)	11.6.2	maximum roll (deg) **	6
		maximum sum L/V axle	1.3
		minimum vertical load (%)	10
Pitch, Bounce (loaded)	11.6.3	minimum vertical load (%)	10
Yaw, Sway (loaded)	11.6.4	maximum L/V truck side	0.6
		maximum sum L/V axle	1.3
Dynamic curving (loaded)	11.6.5	maximum wheel L/V	0.8
		or	
		maximum sum L/V axle	1.3
		maximum roll (deg) **	6
		minimum vertical load (%)	10
Vertical curve	11.7.2	to be added *	
Horizontal curve	11.7.3	to be added *	

* see the introduction to section 11.7.1
** peak-to-peak

11.4. GLOSSARY OF TERMS

Radial misalignment of axles in a truck or car is the difference in yaw angle in their loaded but otherwise unforced condition. It causes a preference to curving in a given direction.

Lateral misalignment is the difference in lateral position between axles. It causes both axles to be yawed in the same direction on straight track.

Inter-axle shear stiffness, equivalent to the lozenge or tramming stiffness in 3-piece trucks, is the stiffness between axles in a truck or car found by shearing the axles in opposite directions along their axes, and measuring the lateral deflection between them.

Inter-axle bending stiffness is the stiffness in yaw between axles in a truck or car.

Bounce is the simple vertical oscillation of the body on its suspensions in which the car body remains horizontal.

Pitch of the body is the rotation about its transverse axis through the mass center.

Body yaw is the rotation of the body about a vertical axis through the mass center.

Body roll is the rotation about a longitudinal axis through the mass center.

Upper and lower center roll are the coupled lateral motion and roll of the body center of mass. They combine to give an instantaneous center of rotation above or below the center of mass. When below the center of mass, the motion is called lower center roll. When above, the motion is called upper center roll.

Sway is the coupled body mode in roll and yaw and it occurs where the loading is not symmetrical.

Unbalance is used in this chapter to mean the additional height in inches, which if added to the outer rail in a curve, at the designated car speed, would provide a single resultant force, due to the combined effects of weight and centrifugal force on the car, having a direction perpendicular to the plane of the track. Thus, the unbalance (U) is defined as:

$$\text{Unbalance } U = \frac{V^2 D}{1480} - H$$

where,
- D is the degree of the curve.
- V is the vehicle speed in mph.
- H is the height, in inches, of the outer rail over the inner rail in the curve.

Effective conicity, E, of a wheel on a rail is its apparent cone angle used in the calculation of the path of the wheel on the rail. It is defined as:

$$E = A\left(\frac{R_w}{R_w - R_R}\right)$$

where,
- A is the angle of the contact plane, between the wheel and rail, to the plane of the track.
- R_w is the transverse profile radius of the wheel.
- R_R is the transverse profile radius of the rail.

The effective conicity of the modified Heumann wheel of Figure 8.1 on AREA 132 1b rail, under conditions of tight gage, is between 0.1 and 0.3.

Three ratios of lateral (L) to vertical (V) forces are used as criteria in the assessment of car performance. These are:

(1) **The individual wheel L/V, (or wheel L/V).** This is defined as the ratio of the lateral force to the vertical force between the wheel and rail on any individual wheel. It is used to assess the proximity of the wheel to climbing the rail.

(2) **The instantaneous sum of the absolute wheel L/V's on an axle,** (or sum L/V axle). This is defined as the sum of the absolute values of the individual wheel L/V's on the same axle, as given in the following algebraic equation. They must be measured at the same time.

$$\text{Sum L/V axle} = |\text{L/V (left whl)}| + |\text{L/V (right whl)}|$$

It is used to assess the proximity of the wheel to climbing the rail and is more appropriate where the angle of attack of the flanging wheel to the rail does not result in full slippage at the area of contact.

(3) **The truck side L/V,** (or L/V truck side). This is defined as the total sum of the lateral forces between the wheels and rails on one side of a truck divided by the total sum of the vertical forces on the same wheels of the truck, as given in the following algebraic expression.

$$\text{Truck side L/V} = \frac{\Sigma \text{L (truck side)}}{\Sigma \text{V (truck side)}}$$

It is used to indicate the proximity to moving the rail laterally.

11.5. SINGLE CAR ON UNPERTURBED TRACK

11.5.1. GENERAL

The regimes described in this section are chosen to test the track-worthiness of the car running on premium track. They are required to establish the safety of the car from derailment under conditions basic to its performance in service and are carried out under operating conditions similar to those found in normal service, but without the effects of dynamic variations due to adjacent cars or large perturbations associated with poor track.

The parameters used in the analysis shall be confirmed in characterization tests described in Appendix A. The results of the following analyses and tests shall be included for the consideration of approval by the Car Construction Committee.

11.5.2. LATERAL STABILITY ON TANGENT TRACK (HUNTING)

This requirement is designed to ensure the absence of hunting, which can result from the transfer of energy from forward motion into a sustained lateral oscillation of the axle between the wheel flanges, in certain car and suspension designs. The analyses and tests are required to show that the resulting forces between the wheel and rail remain within the bounds necessary to provide an adequate margin of safety from any tendency to derail.

11.5.2.1. PREDICTIONS AND ANALYSES

An analysis shall be made of the critical speed at which continuous full flange contact is predicted to commence, using a validated mathematical model and the parameters measured for the empty test car. This analysis shall include predictions on tangent and on 1/2 and 1 degree curves.

The analytic requirement is that no hunting be predicted for the empty car below 70 miles per hour assuming a coefficient of friction of 0.5 and an effective conicity of 0.15, for the modified Heumann wheel profile given in Figure 8.1 of Chapter VIII, on new AREA 136 lb. rail, for axle lateral displacements up to +/− 0.2 in. on track with standard gauge.

11.5.2.2. TEST PROCEDURE AND CONDITIONS

The empty test car shall be placed at the end of the test consist, behind a stable buffer car, and operated at speeds up to 70 miles per hour on tangent class 5 or better track, with dry rail.

All axles of the lead unit or car shall be equipped with modified Heumann profile wheels as shown in Figure 8.1 of Chapter VIII, with the machining grooves worn smooth on the tread.

The rail profile shall be new AREA 136 lb. or an equivalent which, with the Heumann wheel specified, gives an effective conicity of at least 0.15 for lateral axle displacements of +/− 0.2 inch from the track center. The track gage may be adjusted in order to achieve this minimum effective conicity. If hunting is predicted for curved track in section 11.5.2.1, a special hunting test in shallow curves may be requested.

11.5.2.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets, and each truck location on the end unit or car shall be equipped with a lateral accelerometer on the deck above the center of the truck.

Sustained truck hunting shall be defined as a sustained lateral acceleration greater than 1 g peak-to-peak for at least 20 consecutive seconds. No occurrences of greater than 1.5 g peak-to-peak are permitted within the same time period. The instantaneous sum of the absolute values of the L/V ratios shall not exceed 1.3 on any instrumented axle. Components of the measured accelerations and forces having frequencies above 15 hertz are to be filtered out.

The car shall not experience sustained truck hunting during the test. A record of maximum lateral acceleration and the wheel L/V's on the same axle, against speed, at the worst location, shall be submitted as required test data.

11.5.3. OPERATION IN CONSTANT CURVES

This requirement is designed to ensure the satisfactory negotiation of track curves. The analyses and tests are required to show that the resulting forces between the wheel and rail are safe from any tendency to derail and to confirm other predictions of the car behavior relating to the guidance of the car and absence of interferences.

11.5.3.1. PREDICTIONS AND ANALYSES

An analysis shall be made of the wheel forces and axle lateral displacements and yaw angles on a single car, empty and fully loaded, using a validated mathematical model. The model shall include a fundamental representation of the rolling contact forces using the geometry of the profiles of the wheel and rail, and car parameters from the measurements described in Appendix A.

Either the individual wheel L/V shall be less than 0.8 on all wheels measured, or the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3, for any curve up to 15 degrees. The range of unbalance assumed shall be −3 inches to +3 inches, with a coefficient of friction of 0.5 and modified Heumann profiled wheels on new AREA 132 lb. or 136 lb. rail.

11.5.3.2. TEST PROCEDURE AND CONDITIONS

The test car shall be operated at constant speeds equivalent to unbalances of −3, 0, and +3 inches. The tests shall be run with the test car in both empty and fully loaded conditions, between two heavy buffer cars, one of which may be replaced by an instrumentation car. A complete set of tests shall be carried out in both directions and with the test consist turned in each direction, on dry rail.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new. The test curve shall be of not less than 7 degrees with a balance speed of 20 to 30 mph, and with class 5 or better track.

11.5.3.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The lateral and vertical forces and their ratio, L/V, shall be measured for the length of the body of the curve, which must be at least 500 ft., and their maxima and means computed. Measured force components having frequencies above 15 hertz are to be filtered out.

Either the individual wheel L/V shall be less than 0.8 on all wheels measured, or the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3. A record of L/V on both wheels of the instrumented axles, for each test run, shall be submitted as required test data.

11.5.4. SPIRAL NEGOTIATION AND WHEEL UNLOADING

This requirement is designed to ensure the satisfactory negotiation of spirals leading into and away from curves. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail, especially under reduced wheel loading, and to confirm other predictions of the car behavior.

11.5.4.1. PREDICTIONS AND ANALYSES

An analysis shall be carried out of the lateral and vertical wheel forces on a single car, with the car loaded asymmetrically, consistent with AAR loading rules, to give maximum wheel unloading.

The analysis shall be made for a speed equivalent to a mean unbalance at the car center of −3 inches to +3 inches with a coefficient of friction of 0.5 and modified Heumann wheel and new AREA 132 lb. or 136 lb. rail profiles.

The predicted lateral-to-vertical force ratio shall not exceed 0.8, and no vertical wheel load shall be less than 10 percent of its static value, in a bunched spiral, with a change in superelevation of 1 inch in every 20 ft, leading into a curve of at least 7 degrees and a minimum of 3 inches superelevation.

11.5.4.2. TEST PROCEDURE AND CONDITIONS

This test may be carried out concurrently with the previous test, paragraph 11.5.3.2. The test car shall be operated, empty and fully loaded, between two heavy buffer cars, one of which may be an instrumentation car, at constant speeds equivalent to an unbalance of −3, 0, and +3 inches at the maximum curvature.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

The maximum curvature shall be not less than 7 degrees, with a minimum of 3 inches superelevation. A bunched spiral, with a change in superelevation of not less than 1 inch in every 20 ft., is required. The track shall be class 5 or better and dry. Tests shall be run in both directions and with the consist turned.

11.5.1.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets.

The lateral and vertical forces and their ratio, L/V, shall be measured continuously through the bunched spiral, in both directions, and their maxima and minima computed. Measured force components having frequencies above 15 hertz are to be filtered out.

The maximum L/V ratio on any wheel shall not exceed 0.8, and the vertical wheel load shall not be less than 10 percent of the measured static value. A record of L/V's and vertical forces on both wheels of the two worst axles in a car, and car body roll angle, for each test, shall be submitted as required test data.

11.6. SINGLE CAR ON PERTURBED TRACK

11.6.1. GENERAL

The analyses and tests described in this section are designed to establish the track-worthiness of the car under conditions associated with variations in the track geometry. They include the dynamic response due to perturbations in the track but exclude the dynamic effects due to coupling with adjacent cars.

The investigations are designed to demonstrate that the car design provides an adequate margin of safety from structural damage and from any tendency to derail.

The tests shall be completed and their results found satisfactory by the AAR observers. The results identified shall be added as required data for the consideration of the Car Construction Committee.

11.6.2. RESPONSE TO VARYING CROSS-LEVEL (TWIST AND ROLL)

This requirement is designed to ensure the satisfactory negotiation of oscillatory cross-level excitation of cars, such as occurs on staggered jointed rail, which may lead to large car roll and twist amplitudes. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail.

11.6.2.1. PREDICTIONS AND ANALYSES

A review shall be made of any tests and analyses for the natural frequency and damping of the car body, in the roll and twist modes, in the empty and fully loaded conditions, and an estimate made of the speed of the car at each resonance.

The maximum amplitude of the carbody in roll and twist, the maximum instantaneous sum of the absolute values of the wheel L/V ratios on any axle, the minimum vertical wheel load, and the number of cycles to reach them, shall be predicted at resonant speed of 70 mph or below, on tangent track, with staggered jointed rails of 39 ft. length, and a maximum cross-level at the joints of 0.75 in. as shown in Fig. 11.1.

The instantaneous sum of the absolute values of the wheel L/V ratios on any axle shall be less than 1.3, the predicted roll angle of the carbody shall not exceed 6 degrees peak-to-peak, and the vertical wheel load shall not be less than 10 percent of its static value, within 10 rail lengths of the start, at any speed at or below 70 mph.

11.6.2.2. TEST PROCEDURE AND CONDITIONS

The test car shall be between two cars chosen for their stable performance. Tests shall be carried out with the test car empty and fully loaded.

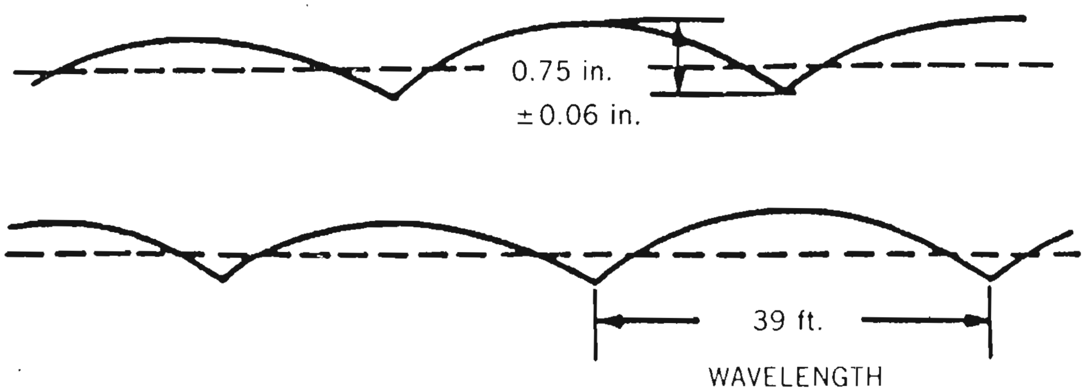


Figure 11.1.

TRACK CROSS LEVEL FOR THE TWIST AND ROLL TEST

The test shall be on tangent track with staggered 39 ft. rails on good ties and ballast, shimmed to a cross level of 0.75 in., low at each joint as shown in Fig. 11.1, over a test zone length of 400 ft., but otherwise held to class 5 or better.

The test shall be carried out at constant speed, increasing in 2 mph steps from well below any predicted resonance until it is passed, or approaching it from a speed above that expected to give a resonant condition. The test shall be stopped if an unsafe condition is encountered or if the maximum of 70 mph is reached. It shall be regarded as unsafe if a wheel lifts or if the car body roll angle exceeds 6 degrees, peak-to-peak.

11.6.2.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The car body roll angle shall also be measured at a minimum of each end of an end unit.

The wheel forces, the mean roll angle and difference in roll between ends for each unit, shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The sum of the absolute values of wheel L/V on any instrumented axle shall not exceed 1.3, the roll angle of the carbody of any unit shall not exceed 6 degrees peak-to-peak and the vertical wheel load shall not be less than 10 percent of its static value at any speed tested.

A record of the vertical loads measured at the axle with the lowest measured vertical load, and the roll angles measured at each end of the most active unit of the car, taken at the resonant speeds for each car load, shall be submitted as required test data.

11.6.3. RESPONSE TO SURFACE VARIATION (PITCH AND BOUNCE)

This requirement is designed to ensure the satisfactory negotiation of the car over track which provides a continuous or transient excitation in pitch and bounce, and in particular the negotiation of grade crossings and bridges, where changes in vertical track stiffness may lead to sudden changes in the loaded track profile beyond those measured during inspection. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car to derail, to uncouple, or to show interference either between subsystems of the car or between the car components and track.

11.6.3.1. PREDICTIONS AND ANALYSES

A review shall be made of any tests and analyses for the natural frequency and damping of the car body, fully loaded, in the modes of pitch and bounce, and an estimate made of the resonant speed of the car when excited by a track wavelength of 39 feet.

The vertical wheel load shall be predicted at these speeds or at 70 mph, whichever is greater, for a continuous near sinusoidal excitation with a vertical amplitude to the track surface of 0.75 inches peak-to-peak and a single symmetric vertical bump in both rails, of the shape and amplitude shown in Fig. 11.2, predicted vertical wheel load shall not be less than 10 percent of its static value at any resonant speed at or below 70 mph, within 10 rail lengths of the start of the continuous sinusoid or following the single bump.

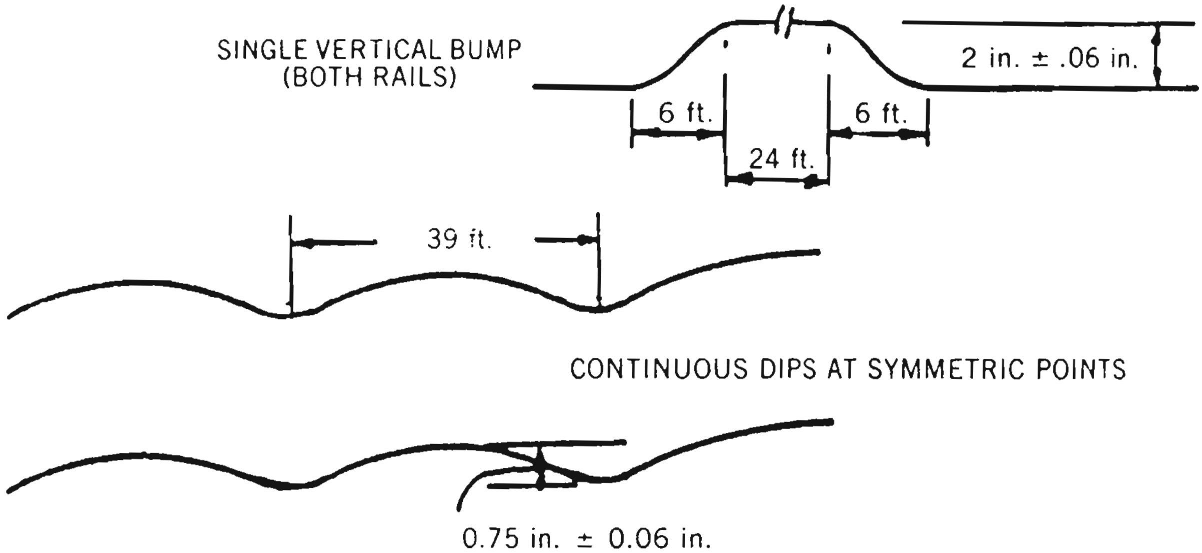


Figure 11.2.

TRACK SURFACE VARIATION FOR PITCH AND BOUNCE

11.6.3.2. TEST PROCEDURE AND CONDITIONS

The fully loaded test car shall be tested between two light cars that have at least 45 ft. truck center spacing.

Tests shall be carried out on tangent track with surface deviations providing a continuous, near sinusoidal, excitation with a vertical amplitude to the track surface of 0.75 inches peak-to-peak and a single symmetric vertical bump in both rails of the shape and amplitude shown in Fig. 11.2. These tests may be carried out separately, or together, with a separation of at least 100 feet. The track shall otherwise be held to class 5 or better.

Testing shall start at constant speed well below any predicted resonant speed, increasing in 5 mph steps until an unsafe condition is encountered, the resonance is passed, or the maximum of 70 mph is reached. The speed at which resonance is expected may be approached from a higher speed, using steps to decrease the speed. It shall be regarded as unsafe if any wheel lifts.

11.6.3.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The vertical wheel forces shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The vertical wheel load shall not be less than 10 percent of its static value on any wheel at any speed tested. A record of the vertical loads measured on the axle with the lowest vertical load shall be submitted as required test data.

11.6.4. RESPONSE TO ALIGNMENT VARIATION ON TANGENT TRACK (YAW AND SWAY)

This requirement is designed to ensure the satisfactory negotiation of the car over track with misalignments which provide excitation in yaw and sway. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car forces to move the track or rail or to give interference either between subsystems of the car or between the car components and track.

11.6.4.1. PREDICTIONS AND ANALYSES

A review shall be made of the previous tests and analyses for the natural frequency and damping of the car body, fully loaded, in the yaw and roll modes. These may combine in a natural motion referred to as sway, which, if present, must be included in this analysis. Using the values for frequency and damping identified, an estimate shall be made of the resonant speed of the car, in each mode.

The car shall be assumed to be excited by a symmetric, sinusoidal track alignment deviation of wavelength 39 feet, on tangent track. The ratio of the sum of the lateral to that of the vertical forces on all wheels on one side of any truck shall be predicted at resonance or at 70 mph, whichever is greater, for a sinusoidal double amplitude of 1.25 inches peak-to-peak on both rails and a constant wide gage of 57.5 inches, as shown in Fig. 11.3.

The predicted truck side L/V shall not exceed 0.6, and the sum of the absolute values of L/V on any axle shall not exceed 1.3, at any speed at or below 70 mph, within 5 rail wavelengths of the start.

11.6.4.2. TEST PROCEDURE AND CONDITIONS

The fully loaded test car shall be placed at the end of the test consist, behind a buffer car of at least 45 feet truck center spacing, chosen for its stable performance.

Tests shall be carried out on dry tangent track, with symmetric, sinusoidal alignment deviations of wave length 39 feet, alignment amplitude 1.25 inches peak-to-peak and a constant wide gage of 57.5 inches, over a test zone of 200 feet as shown in Fig. 11.3. The track shall otherwise be held to class 5 or better.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

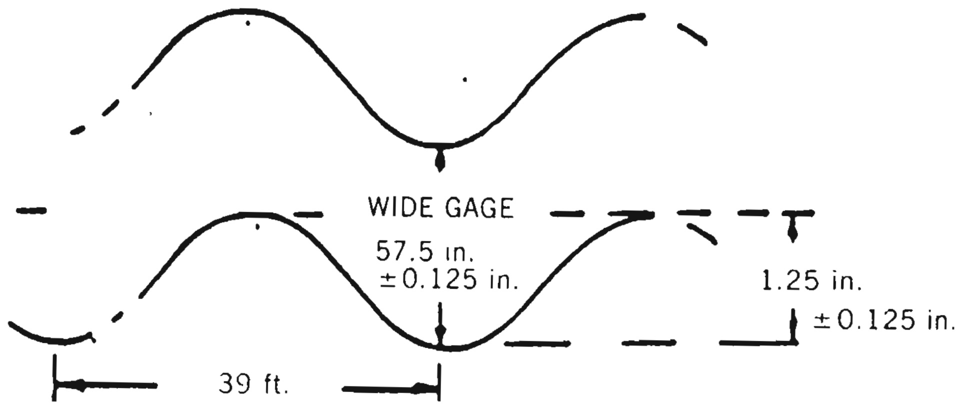


Figure 11.3.

TRACK ALIGNMENT VARIATIONS FOR YAW AND SWAY

Testing shall start at constant speed well below any predicted resonant speed, increasing in 5 mph steps until an unsafe condition is encountered, the resonance is passed, or the maximum of 70 mph is reached. It shall be regarded as unsafe if the ratio of total lateral to vertical forces, on any truck side measured, exceeds 0.6 for a duration equivalent to 6 feet of track.

11.6.4.3. INSTRUMENTATION AND CRITERIA

All axles on the truck estimated to provide the worst total truck side L/V, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The wheel forces shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The truck side L/V measured shall not exceed 0.6 for a duration equivalent to 6 feet of track, and the sum of the absolute values of L/V on any axle shall not exceed 1.3, at any speed at or below 70 mph. A record of the lateral and vertical loads, measured on the truck with the largest truck side L/V, shall be submitted as required test data.

11.6.5. ALIGNMENT, GAGE AND CROSS-LEVEL VARIATION IN CURVES (DYNAMIC CURVING)

This requirement is designed to ensure the satisfactory negotiation of the car over jointed track with a combination of misalignments at the outer rail joints and crosslevel due to low joints on staggered rails at low speed. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car forces to cause the wheel to climb the rail or to move the track or rail or to give unwanted interference, either between subsystems of the car, or between the car components and track.

11.6.5.1. PREDICTIONS AND ANALYSES

A review shall be made of the previous tests and analyses for the natural frequencies and response of the car body, fully loaded, in the yaw and roll modes.

No analysis is presently available, which can predict the results accurately for this test, for all possible designs. It is therefore necessary to provide additional safety features in the running of the test program to prevent unexpected derailments or unnecessary damage.*

*Analyses suitable for predictions of new car performance in this test are under development and will be added later.

11.6.5.2. TEST PROCEDURE AND CONDITIONS

The test car shall be operated between two cars that are loaded to provide them with a low center of gravity. If suitable, an instrumentation car may be used as one of these cars.

Tests shall be carried out on dry rail, in a curve of between 10 and 15 degrees with a balance speed of between 15 and 25 mph, with the test car empty and fully loaded.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

The track shall consist of staggered rails, 39 feet long, on good ties and ballast, shimmed to provide a cross level of 0.5 inch, low at each joint, over the test zone length of 200 feet, as shown in Figure 11.4.

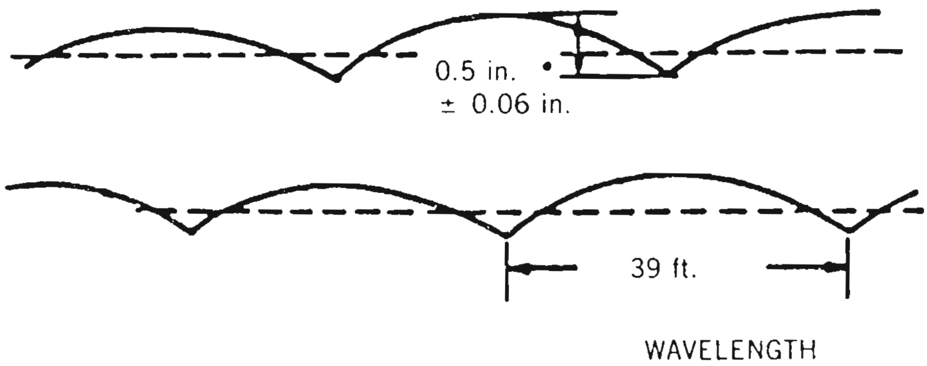


Figure 11.4.

CROSS LEVEL FOR DYNAMIC CURVING TESTS

Combined gage and alignment variation shall be provided in the test zone by shimming the outer rail in the form of an outward cusp, giving a maximum gage of 57.5 inches at each outer rail joint and a minimum gage of 56.5 inches at each inner rail joint, the inner rail being within class 5 standards for alignment in curves, as given in Figure 11.5.

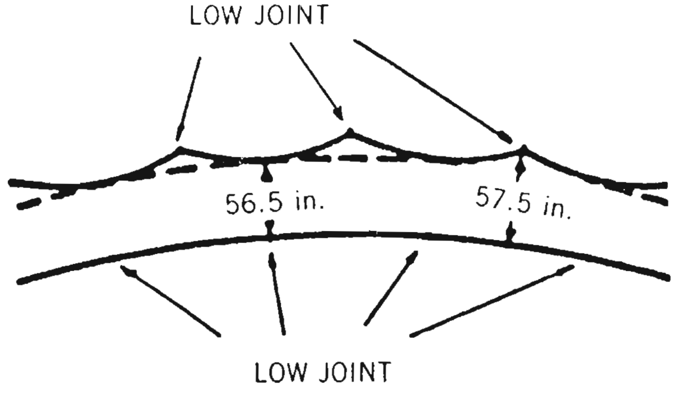


Figure 11.5.

GAGE AND ALIGNMENT VARIATION IN DYNAMIC CURVING

It is recommended that a guard rail be used to prevent unpredicted derailment; however, it must not be in contact with the wheel during normal test running. The test shall be carried out at constant speeds up to 3 inches of overbalance, increasing in 2 mph steps from well below any predicted lower center roll resonance until it is passed. The resonance may be approached from a speed above that predicted to give a lower center roll resonance.

The test shall be stopped if an unsafe condition is encountered or if the maximum unbalance is reached. It shall be regarded as unsafe if a wheel lifts, the instantaneous sum of the absolute L/V values of the individual wheels on any axle exceeds 1.3, or car body roll exceeds 6 degrees, peak-to-peak.

11.6.5.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The car body roll angle shall also be measured at one end of the lead unit. The lateral and vertical wheel forces and the roll angle shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The maximum roll angle shall not exceed 6 degrees, peak-to-peak, the vertical wheel load shall not be less than 10 percent of its static value, the individual wheel L/V shall be less than 0.8, and the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3, at any test speed.

A record of both wheel loads measured on the axle with the lowest measured vertical load and largest measured lateral load, and the roll angles measured, taken at the resonant speeds for each car load, shall be submitted as required test data.

11.7. COUPLED CARS AND UNITS

11.7.1. GENERAL

The tests described in this section will be designed to establish the track-worthiness of the car under conditions associated with the realistic operation of cars within a train. This may include severe transient forces due to coupling with adjacent cars. These forces may have a significant effect on the stability of cars and may lead to derailment. The investigations will be designed to demonstrate that the car design provides an adequate margin of safety from structural damage and from any tendency to derail.

11.7.2. VERTICALLY CURVED TRACK *

* This section to be added at a later date

11.7.3. HORIZONTALLY CURVED TRACK +

+ Investigations are currently underway which will allow the addition of this section in the near future.

APPENDIX A
VEHICLE CHARACTERIZATION

A.1. GENERAL

The characteristic properties of the car body and its suspension, required for analysis of its track-worthiness, must be supported by test results providing evidence of their validity. Forces and motions between suspension components and the body modal frequencies of the car, as assembled, can vary significantly from the values calculated or specified in the design, and may be important to the safe performance of the vehicle.

A.1.1. TEST CAR

It is important that characterizations be carried out on the particular car in the same condition that it is to be track tested so that accurate predictions of its performance can be made. For cars with more than one type of suspension, at least one of each type should be tested.

The tests apply to all new car suspensions, including trucks retrofitted with devices such as inter-axle connections, sideframe cross-bracing and additional suspension elements, which have not been tested previously.

Tests for horizontal characteristics of the suspension of trucks with at least two axles, may be carried out with the truck separated from the body. In this case static vertical loads must be applied to simulate those due to the body or bodies and the rotational and lateral characteristics between the truck and body must be measured separately.

Where connections exist between the truck and body that may affect the truck characteristics, such as with a truck steered through links to the body, and for all cars with single axle trucks, the suspension characteristics must be tested while connected to the body.

Where the truck is at the junction of two articulated bodies, both must be simulated or used in the suspension characterization tests specified.

A.1.2. TEST LOADS

Modal tests, and tests for the horizontal and vertical suspension characteristics are required with vertical loads equivalent to the car in the loaded condition required for the analyses in which the results will be used. This includes tests to measure the alignment of the axles to each other and to other elements in the system.

A.1.3. GENERAL PROCEDURE

In tests for the suspension characteristics, the recommended procedure is to load the suspension and to measure the load and displacement, or velocity, across the particular suspension element, in the required direction. These should be recorded up to the required maximum and down to the required minimum identified.

The loads may be applied, either through automatic cycling at an appropriate frequency or through manual increase and decrease of load through at least two complete cycles. If manual loading is used, delays and intermediate load reversals between measurements should be avoided. For the determination of stiffness and frictional energy dissipation, the frequency of cycling must be between 0.2 and 0.5 hertz.

Graphs of load versus displacement or velocity are desirable for the determination of the required stiffness or damping.

A.2. TESTS WITH THE WHEELS RESTRAINED

A.2.1. GENERAL

In the tests described in this section, the wheels are rigidly attached to the rails or supporting structure and the frame is moved relative to them.

The methods described are not suitable for trucks having steering links, which couple the lateral or roll motion of the body or truck frame to the yaw motion of the axles. In such a case, provision must be made for unrestrained longitudinal movement of the wheels, discussed in section A.3. The steering links may be disconnected to measure the characteristics of suspension elements in the unsteered condition.

All tests require that the actuators and restraining links, other than those at the wheels, have the equivalent of ball joints at both ends to allow for motion perpendicular to their axis.

A.2.2. VERTICAL SUSPENSION STIFFNESS

For this test, equal measured vertical loads are applied across the spring groups in the range from zero to 1.5 times the static load, if possible, and at least to the static load of the fully loaded car. Vertical actuators are attached to each side of the body or the structure simulating it. The load may also be applied by adding dead load or a combination of both dead and actuator loads.

Vertical deflections are required across all significant spring elements under load. It is important to report any differences in the measurements taken between each axle and frame or sideframe.

A.2.3. TOTAL ROLL STIFFNESS

A roll test is required if the roll characteristic between the body and axle includes movement at or forces due to elements other than the vertical suspension, such as clearances at sidebearings, or anti-roll bars.

For the roll test, two vertical actuators are required as in the vertical test, but with the loads in the actuators in opposite directions. The range of roll moments, in inch-pounds, applied to the truck should be between plus and minus 30 times its static load, in pounds, or until the wheels lift. The roll angle across all suspension elements may be measured directly or deduced from displacements.

A.2.4. TOTAL LATERAL STIFFNESS

The lateral stiffness characteristic may be found by attaching an actuator to apply loads laterally to the body or bodies, which should be positioned as if on tangent track. If the lateral motion of the truck frame is coupled to its yaw through a steering mechanism, it should be disconnected to prevent the yaw resistance of the frame from affecting the measurement of lateral stiffnesses.

The minimum and maximum lateral loads applied per truck should be minus and plus one fifth of the static load carried. Measurements are required of the lateral displacements across all suspension elements.

A.2.5. INTER-AXLE TWIST AND EQUALIZATION

This test is carried out with only one axle fixed to the track. One wheel of the other axle in the car or truck is jacked up to a height of 3 inches, and the vertical load and displacement are measured. The stiffness between the axles in twist is the ratio of the load to the displacement multiplied by the square of the gage. It is a measure of the truck equalization.

A.3. TESTS WITH UNRESTRAINED WHEELS

A.3.1. GENERAL

These tests involve movements in the suspension system and axles relative to other elements of the system or to other axles, without restraint between the wheel and rail, but with the normal static vertical load.

The shear resistance between the rail and the wheel must be eliminated by the provision of a device having very low resistance, such as an air bearing, under each axle.

A.3.2. AXLE ALIGNMENT

Both radial and lateral misalignments may be deduced from measurements of the yaw angle of each axle from a common datum. The radial misalignment between axles is half the difference in their yaw angles, taken in the same sense, and the lateral misalignment is their mean yaw angle.

In the case of trucks which have significant clearance between the axle and frame, it may be necessary to establish the axle in the center of the clearance for the purpose of identifying the mean axle misalignments.

A.3.3. LONGITUDINAL STIFFNESS

A longitudinal load must be applied to the axle, equivalent to a single load at its center, and cycled between tension and compression up to half the static load on the axle.

The load may be applied directly between axles, or between the test axle and ground through an appropriate structure, with the body or truck frame restrained. The load may also be applied directly between the axle and frame, or in the case of a car with single axle trucks, between the axle and the body.

The longitudinal deflection across each spring element must be measured and the results plotted.

Where the load is applied directly between the axles of a truck or car, this measurement may be combined with the inter-axle shear test in section A.3.4., or the inter-axle bending stiffness test in section A.3.5.

A.3.4. AXLE LATERAL AND INTER-AXLE SHEAR STIFFNESS

The inter-axle shear stiffness may be found by shearing the axles, or moving them in opposite directions along their axes, and measuring the shear or lateral deflection between them. The shear force on each axle must be at least one tenth of the static vertical axle load.

This test may be combined with the inter-axle longitudinal test of section A.3.3., where the required load can be achieved.

In the case of direct inter-axle loading, the locations of the applied force and restraint are such that they are equal and opposite, diagonally across the truck or car.

The actuator and restraint each provide two components of force on the axle to which they are attached. One component lies along the direction of the track and provides tension and compression, as in section A.3.3., for the longitudinal stiffness. The other component lies along the axle and applies the required shear force between axles. This component may be applied separately with a suitable arrangement of actuators and restraints.

Measurements are made of the lateral misalignment of the axles during the load cycle. The shear stiffness is the ratio of shear force to the lateral misalignment.

For single axle trucks, a test similar to that described above may be used to determine the lateral stiffness, with force applied laterally between ground and the axle with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle. For trucks which also provide steering through coupling axle lateral motion to its yaw angle, this test may be preferred over the lateral test of section A.2.4. for finding the lateral stiffness, since the axles are free to yaw.

A.3.5. AXLE YAW AND INTER-AXLE BENDING STIFFNESS

The inter-axle bending stiffness may be found by yawing the axles in the opposite directions and measuring the yaw angle between them. The yaw moment applied, in inch-pounds, must be at least equal to the axle load in pounds.

This test may be combined with the inter-axle longitudinal test of section A.3.3. If this is done, the test is carried out by applying an effective force on the axle a known distance laterally from the truck centerline.

In the case of direct inter-axle loading the restraint must be applied to the axle, at the other end of the car or truck, on the same side as the applied force. The applied and restraining forces each provide a longitudinal force and a yaw moment on the axle to which they are attached. The force provides the tension and compression as in section A.3.3. for the longitudinal stiffness and the moment is applied between the truck axles in yaw. This moment may be applied independently of the longitudinal force.

Measurements are made of the resulting radial mis-alignment of the axles during the load cycle. The bending stiffness is the ratio of applied bending moment to the radial misalignment.

A similar test of the axle yaw stiffness may be arranged with forces applied in yaw between a single axle and ground, with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle.

A.3.6. YAW MOMENT BETWEEN THE SUSPENSION AND BODY

The required yaw stiffness and breakout torque between the car body and truck must be measured by applying a yaw moment, using actuators in equal and opposite directions at diagonally opposite corners of the truck to rotate the truck in yaw. The car body must be restrained.

The applied yaw moment must be increased until gross rotation is observed, representing the breakout torque, or to the limit recommended for the yaw of the secondary suspension.

The angle in yaw between the car body and truck bolster or frame must be measured.

A.4. RIGID AND FLEXIBLE BODY MODAL CHARACTERISTICS

A.4.1. GENERAL

Tests are required to identify the rigid and flexible body modal frequencies and damping. The rigid body modal frequencies may be compared to predictions using estimated or measured body masses, and inertias and the suspension parameters measured according to the requirements of sections A.2. and A.3. Tests and estimates should be made with the car in the empty and fully loaded state.

A.4.2. TEST CAR BODY

For cars consisting of more than one coupled unit, tests for body modes are required on one of each of the unit bodies having a different structural design. Dead loads may be added to give the required additional loading to any shared suspensions.

Where coupling exists between the modes of adjacent bodies, such as in roll or torsion, this may be examined in a dynamic analysis, validated for the case of tests without coupling.

The frequency and modal damping are only required for the flexible body modes which are predicted to have a natural frequency below 12 hertz.

A.4.3. GENERAL PROCEDURE

Transient or continuous excitation may be applied, using one or more actuators or dropping the car in a manner to suit the required mode of excitation.

The modal frequency and damping are required for an amplitude typical of the car running on class 2 track.

In the case of the rigid body modes, the actuators must be located at the rail level or the level of the truck frame with the body free to oscillate on its suspension. In the case of the flexible body modes, the excitation may be applied directly to the body.

The frequency in hertz may be determined from the wavelength in the transient test, or from the peak response, or from the 90 degree phase shift between the response and excitation where continuous excitation is used.

The percentage modal damping may be determined using the logarithmic decrement in transient tests or the bandwidth of the response from a range of frequencies.

A.4.4. RIGID BODY MODES

The rigid body modes for the car are:

Body bounce
Body pitch
Body yaw and sway
Lower center roll
Upper center roll

In the case where the normal load on the body is not centered between the suspensions, the body bounce mode may be coupled to the body pitch. The required measurement of bounce and pitch may be achieved by two vertical measurements at the ends of the car. Their weighted sum provides bounce and their weighted difference pitch. The weighting is dependent on their position relative to the center of mass.

Yaw and sway are deduced from lateral measurements made at each end of the body, a known distance from its mass center, similarly to the determination of pitch.

Measurement of the upper and lower center roll modes are determined from lateral displacements taken at two heights, or by a single lateral displacement and a roll angle measurement.

A.4.5. FLEXIBLE BODY MODES

The flexible body modes for the car are:

Torsion
Vertical bending
Lateral bending

Determination of the frequency and damping in the torsion mode requires excitation and measurement of roll at one end of the car.

The excitation is similar to that for roll but resonance occurs at a higher frequency. The response between the ends of the car is out of phase for modes number 1,3, and in phase for modes number 2,4, although it is unlikely that modes above 2 will be significant.

Vertical or lateral bending modes are measured as a response to the vertical or lateral excitation at one end or both ends of the car. The first bending mode has a maximum amplitude at or near the car center. The second bending mode has a node or point of minimum response at the center.

A.5. PARAMETER ESTIMATION *

* Tests are presently being conducted to examine this method.

APPENDIX C

Table of Contents

Instrumentation List - VTU Tests

Table C-1. List of Measurements for the VTU Tests

Measurements	Location
	Input Displacements
1DZ	1A - Axle 1 - Right Wheel - Vertical
2DZ	1B - Axle 1 - Left Wheel - Vertical
3DX	1C - Axle 1 - Lateral
4DZ	3A - Axle 2 - Right Wheel - Vertical
5DZ	3B - Axle 2 - Left Wheel - Vertical
6DX	3C - Axle 2 - Lateral
	Wheel - Rail Forces
RF1AZ(7FZ)	A-End - Right - Vertical
RF1AX(8FX)	A-End - Right - Lateral
RF1BZ(9F)	A-End - Left - Vertical
RF1BX(10FX)	A-End - Left - Lateral
RF3AZ(11FX)	B-End - Right - Vertical
RF3AX(12FX)	B-End - Right - Lateral
RF3BZ(13FZ)	B-End - Left - Vertical
RF3BX(14FX)	B-End - Left - Lateral
	Carbody Displacements
15DZ	A-End - Right - Side Sill to Ground
16DZ	A-End - Left - Side Sill to Ground
17DX	A-End - Left - Side Sill to Ground
18DZ	B-End - Right - Side Sill to Ground
19DZ	B-End - Left - Side Sill to Ground
20DX	B-End - Left - Side Sill to Ground
	Trailer Displacements
21DZ	Hitch End - Right Side to Carbody
22DZ	Hitch End - Left Side to Carbody
23DZ	Tandem Axle - Right Side to Carbody
24DZ	Tandem Axle - Left Side to Carbody
25DX	Hitch End - Lateral to Carbody
26DX	Tandem End - Lateral to Carbody
50DZ	Tandem End - Center to Carbody

Table C-1. List of Measurements for the VTU Tests (Continued)

Measurements	Location
	Carbody Accelerometers
27AZ	A-End - Right Side
28AZ	A-End - Left Side
29AX	A-End - Center - Along Center Line
30AZ	Center - Right Side
31AZ	Center - Left Side
32AX	Center - Along Center Line
33AZ	B-End - Right Side
34AZ	B-End - Left Side
35AX	B-End - Center - Along Center Line
	Trailer Accelerometers
36AZ	Hitch End - Vertical Right Side
37AZ	Hitch End - Vertical Left Side
38AX	Hitch End - Lateral - Along Center Line
39AZ	Tandem End - Vertical Right Side
40AZ	Tandem End - Vertical Left Side
41AX	Tandem End - Lateral - Along Center Line
42AZ	Center Vertical
43AX	Center Lateral
	Roll Gyros
GR1	Tandem End Trailer
GR2	A-End - Carbody
GR3	B-End - Carbody
	Strain Gages
S47X	B-End - Carbody on Crossbeam - Lateral
S48X	A-End - Carbody on Crossbeam - Lateral
S49Y	A-End - On Centersill - Longitudinal

Loaded Car Modal Analysis

Discussion and Data Plots

C.1 Loaded Car Bounce Mode

Transfer functions for each end of the car (D18Z and D19Z) and the door end of the trailer (D50Z) are presented in Figures C-1 to C-3. The input channel is 1AZ, the displacement of the left side A-end wheel. A clear bounce mode resonance can be picked out at 1.8 Hz in all three plots.

In Figure C-2 (D19Z/1AZ, B-end) another resonance is apparent at 2.8 Hz. By comparing the phase and anti-resonance shown in Figure C-1 (D16Z/1AZ), A-end) at 2.7 Hz, this can be seen to be a pitch resonance with only the B-end (trailer hitch end) responding. Comparison of the trailer motion at 2.7 Hz (D50Z, Figure C-3) with carbody motion at the same end (Figure C-1), the trailer can be seen to be undergoing a resonance, in which the trailer is bouncing on the car at its tandem end. This is clearly illustrated in Figure C-4, which is a transfer function between trailer motion (D50Z) and carbody motion (D16Z), occurring at about 2.7 Hz. This trailer motion, although bouncing at the tandem end, is actually a pitch mode due to the constraint of the trailer hitch. This drives the asymmetric carbody pitch mode seen at 2.7 Hz. The pitch mode of the trailer, by itself, was previously found (Section 5.3) to be 3.0 Hz so this coupling with the car motion lowers the apparent resonant frequency.

C.2 Loaded Car Pitch Mode

Figures C-5 to C-7 show the transfer functions for D16Z, D19Z, and D50Z for 0.3 inch amplitude pitch input. In this case, the pitch resonance of 2.7 Hz is clearly seen for all locations. Again, the B-end (D19Z) of the car shows much greater motion than the A-end (D16Z). This could be due to the motion of the trailer, acting as a "vibration absorber" for the car at the A-end (tandem wheel end).

C.3 Loaded Car Yaw Mode

A clear carbody yaw resonance can be seen at 1.7 Hz, in Figures C-8 and C-9, with the two ends of the car moving out of phase.

A yaw resonance for the trailer moving on the carbody is shown in Figures C-10 and C-11 which appears at about 2.0 Hz. The yaw-roll mode of the trailer alone was previously found (Section 5.4) to be 2.4 Hz. This mode, coupled with the 1.7 Hz carbody yaw mode, results in the apparent 2.0 Hz trailer yaw mode.

The third yaw resonance is somewhat evident at the B-end of the car (D20X) at about 2.7 Hz. This appears to be driven by the 2.4 Hz trailer yaw-roll mode.

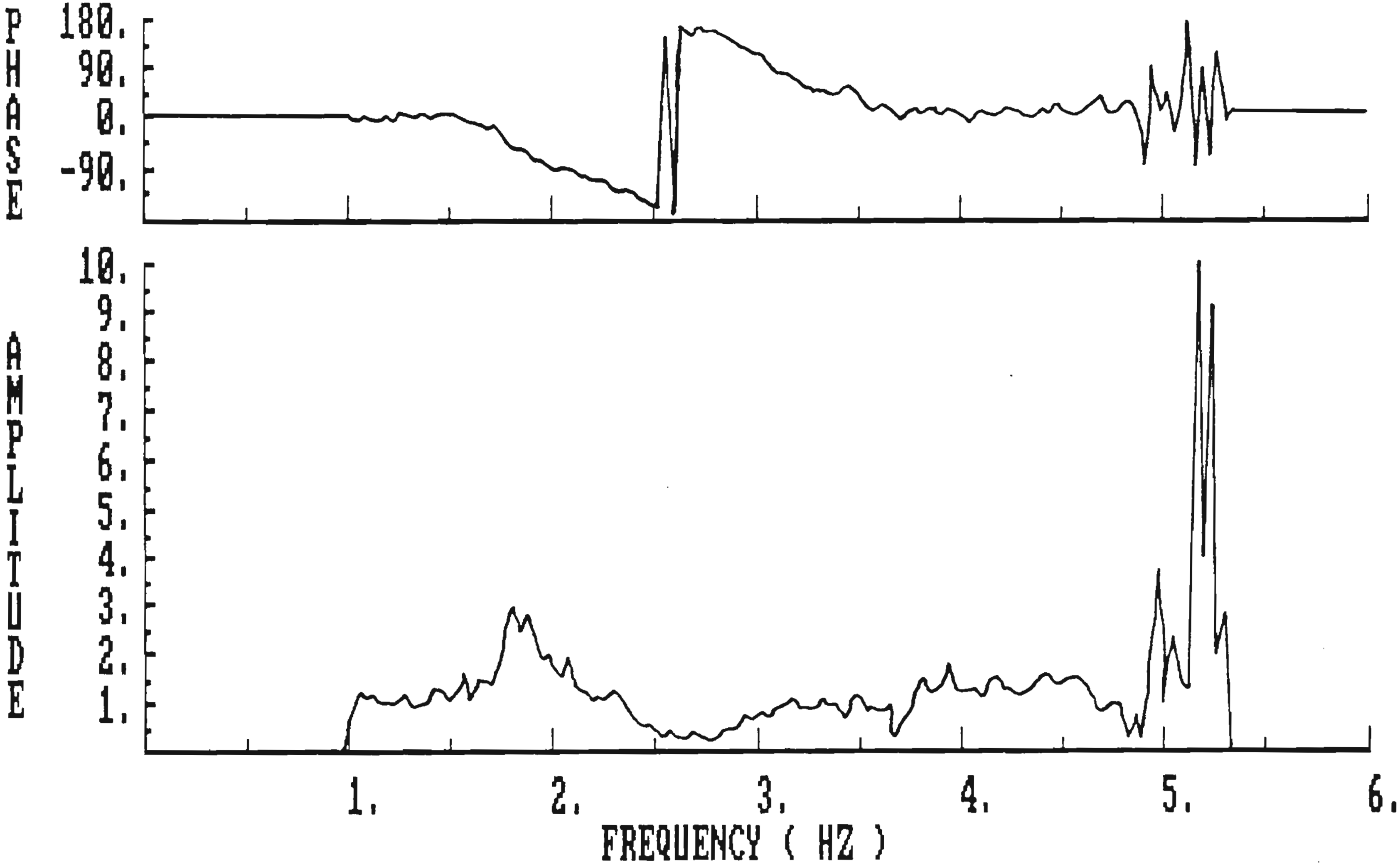


FIG. C-1 LOADED CAR BOUNCE MODE, TRANSFER FUNCTION OF VERTICAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D16Z/1AZ) OF 0.3 INCH

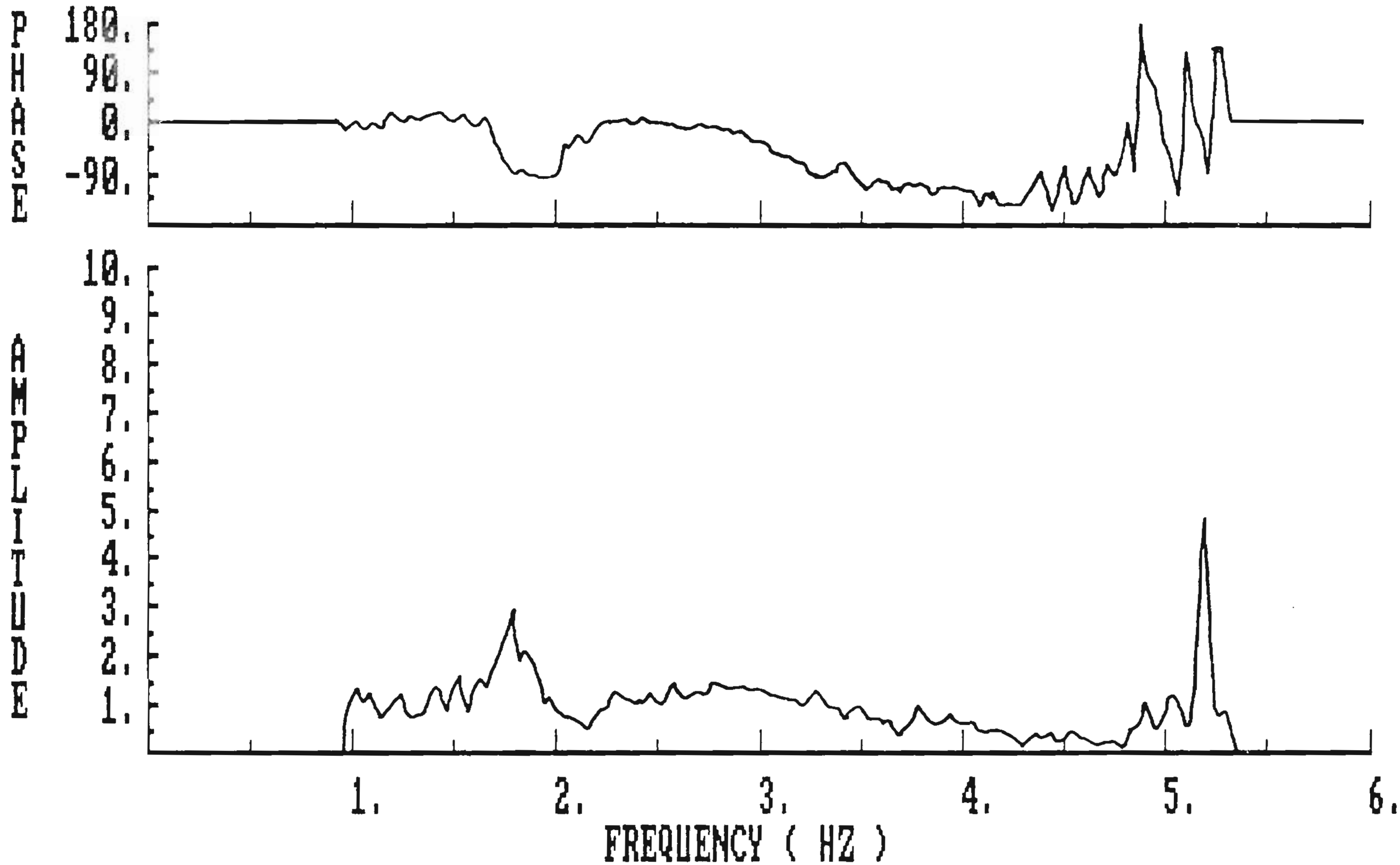


FIG. C-2 LOADED CAR BOUNCE MODE, TRANSFER FUNCTION OF VERTICAL CARBODY DISPLACEMENT, B-END LEFT SIDE, RELATIVE TO VTU INPUT (D19Z/1AZ) OF 0.3 INCH

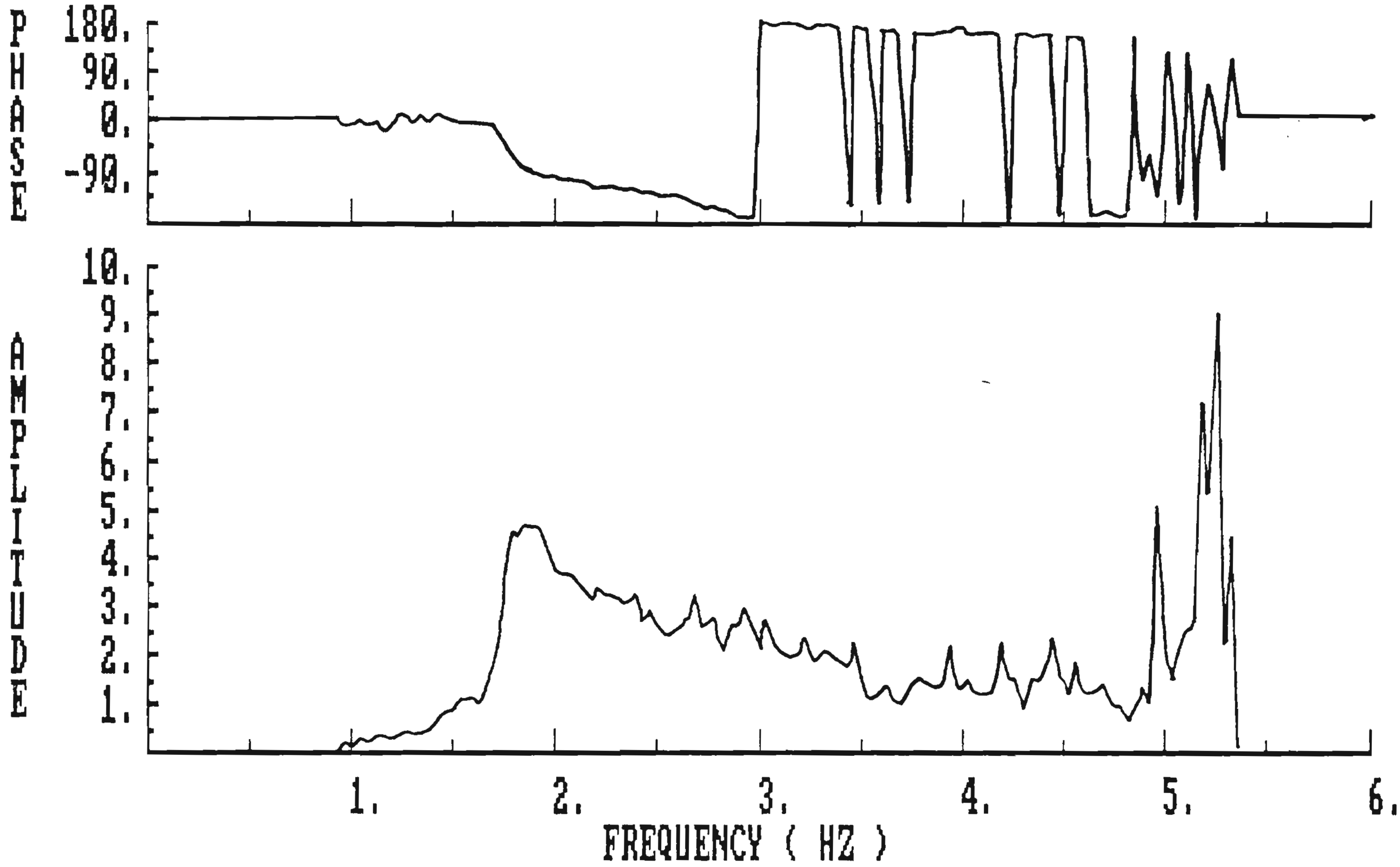


FIG. C-3 LOADED CAR BOUNCE MODE, TRANSFER FUNCTION OF VERTICAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VTU INPUT (D50Z/1AZ) OF 0.3 INCH

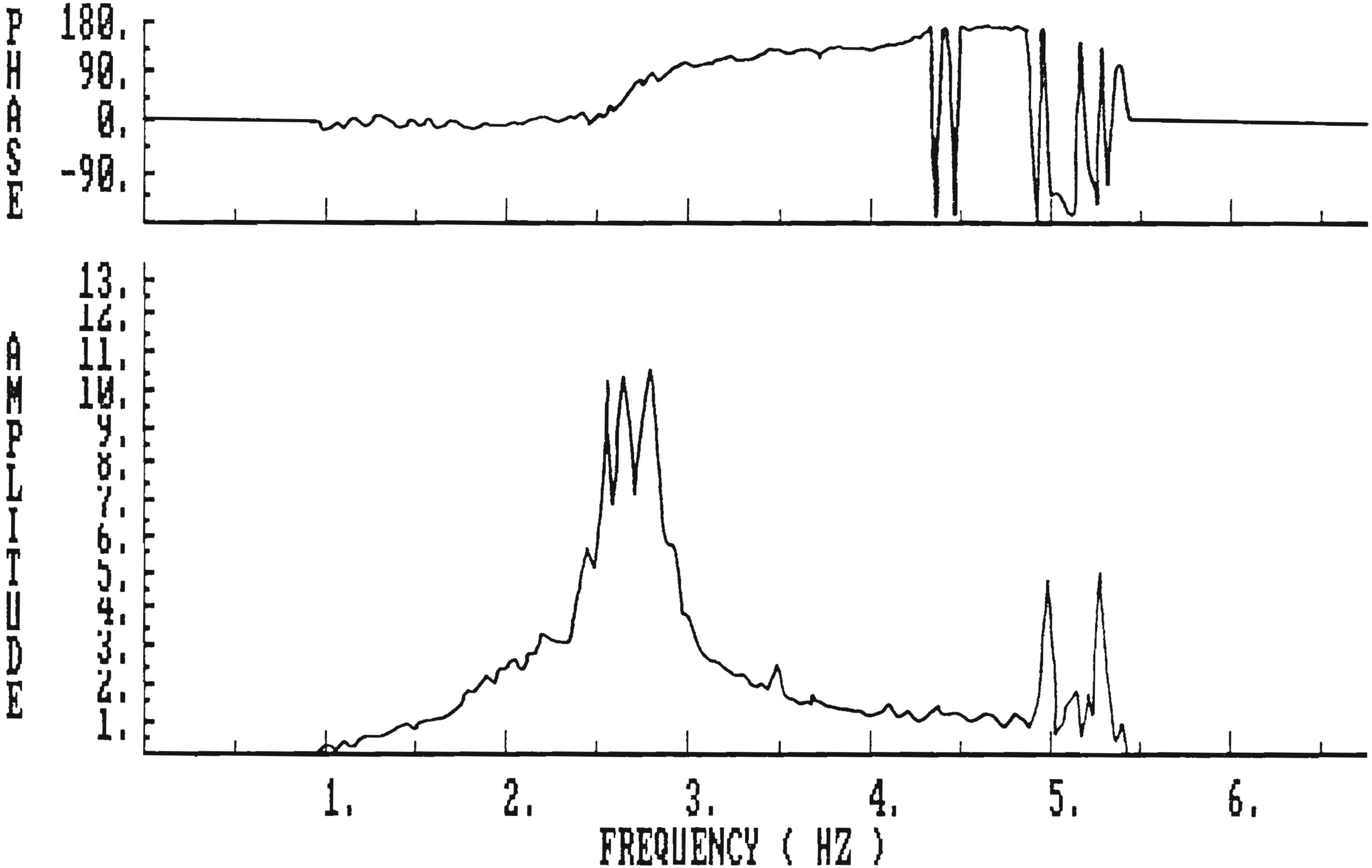


FIG. C-4 LOADED CAR BOUNCE MODE, TRANSFER FUNCTION OF VERTICAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VERTICAL CARBODY DISPLACEMENT, A-END LEFT SIDE, (D50Z/D16Z)

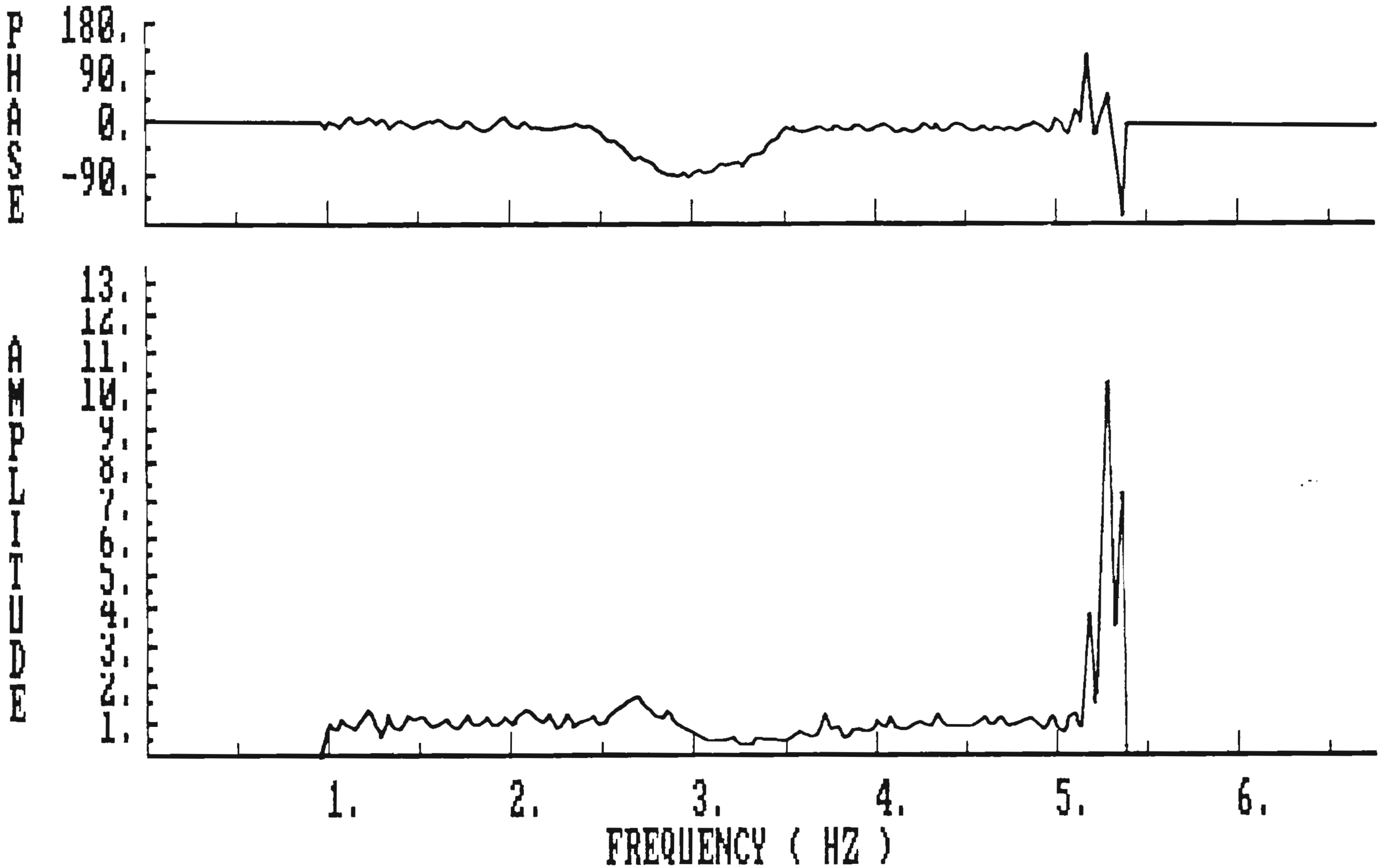


FIG. C-5 LOADED CAR PITCH MODE, TRANSFER FUNCTION OF VERTICAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D16Z/1AZ) OF 0.3 INCH

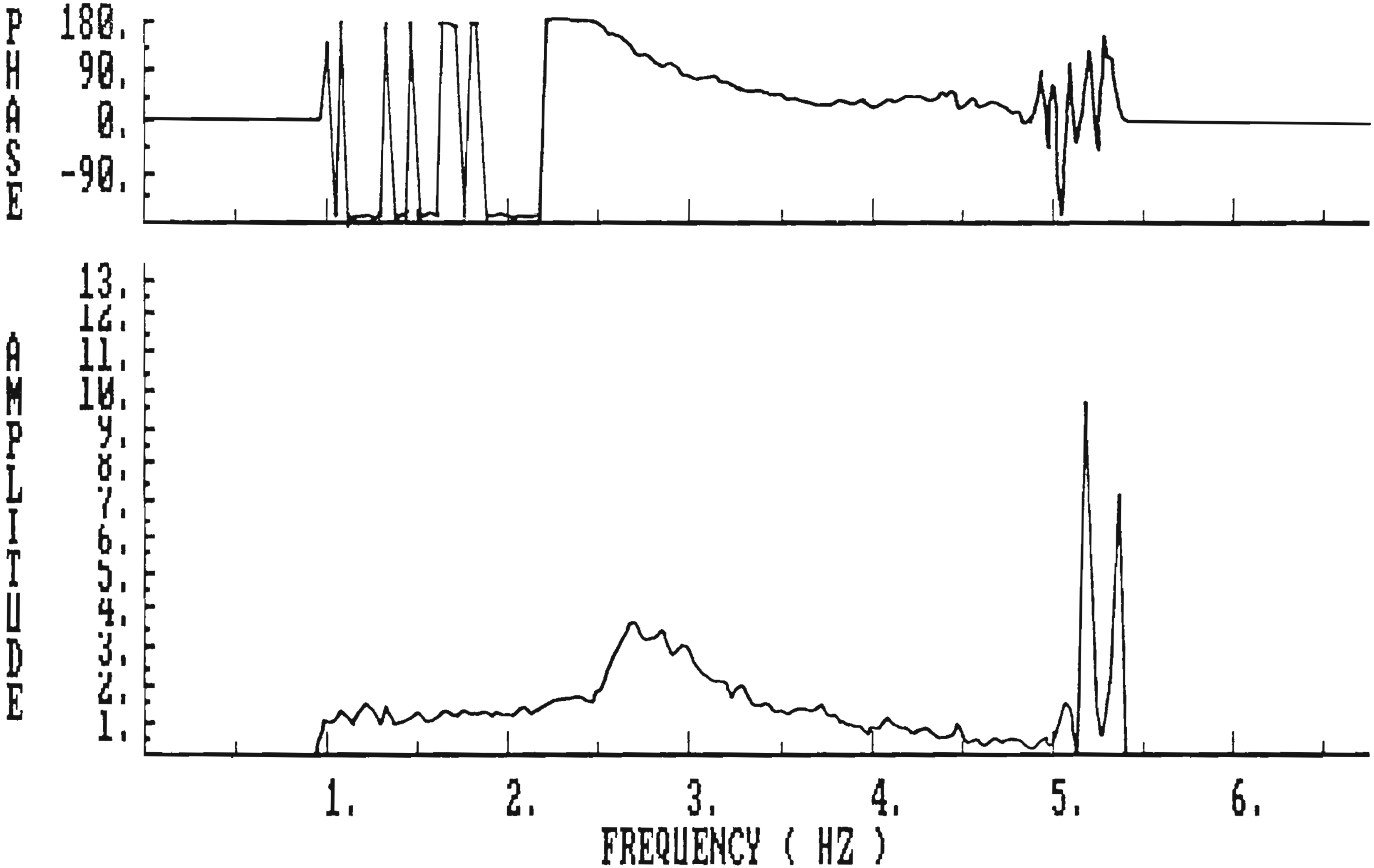


FIG. C-6 LOADED CAR PITCH MODE, TRANSFER FUNCTION OF VERTICAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D19Z/1AZ) OF 0.3 INCH

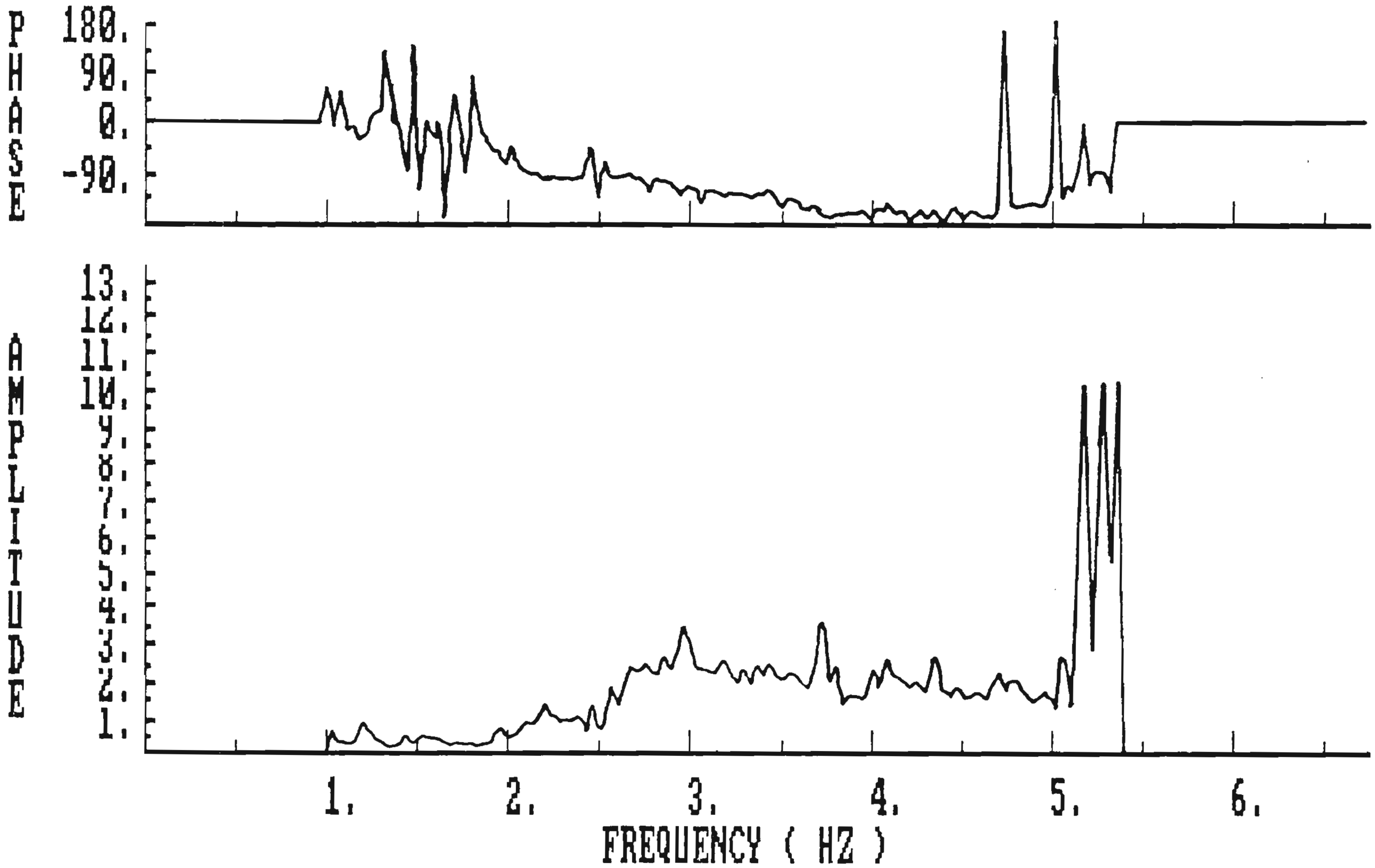


FIG. C-7 LOADED CAR PITCH MODE, TRANSFER FUNCTION OF VERTICAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VTU INPUT (D50Z/1AZ) OF 0.3 INCH

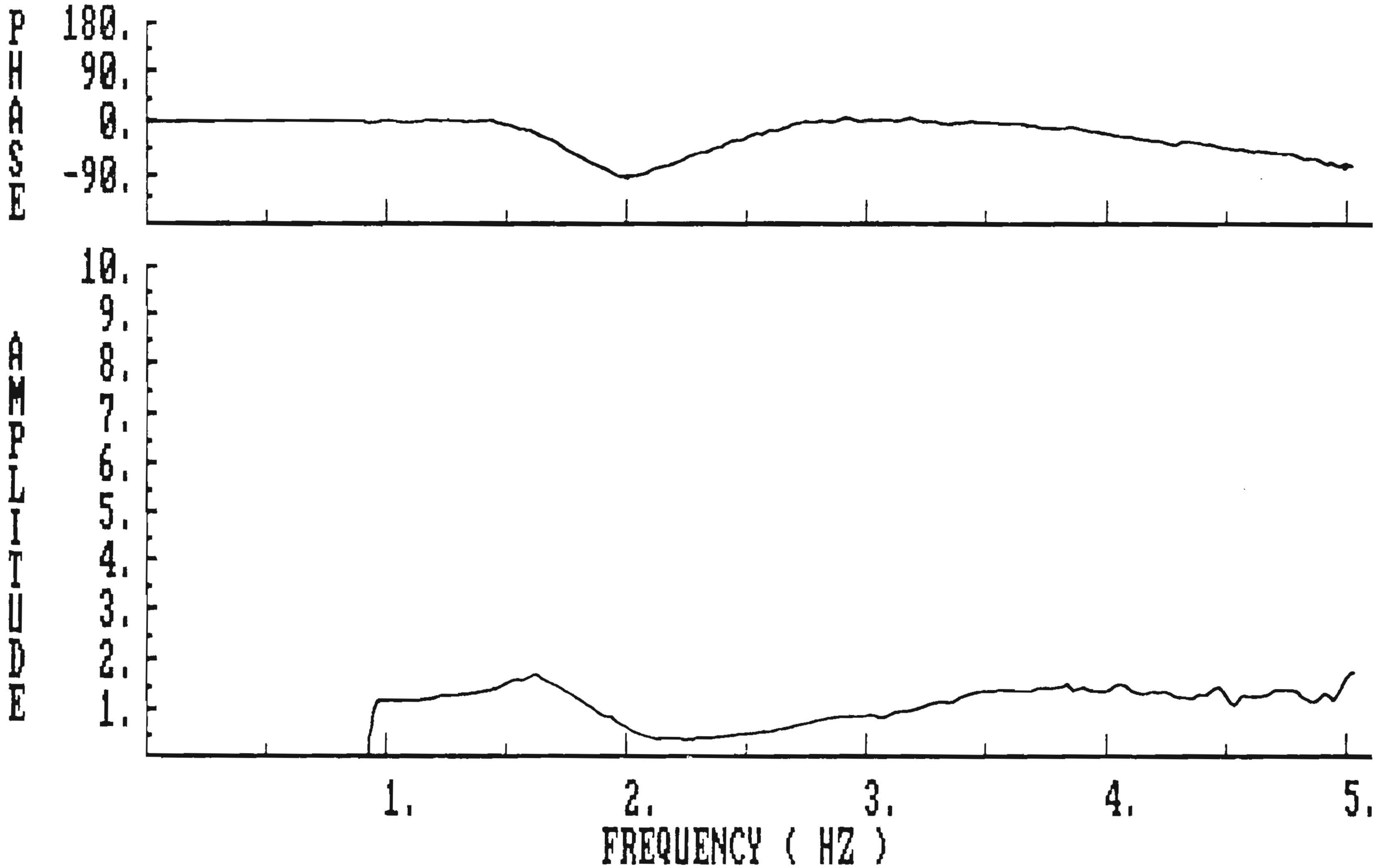


FIG. C-8 LOADED CAR YAW MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D17X/1CX) OF 0.4 INCH

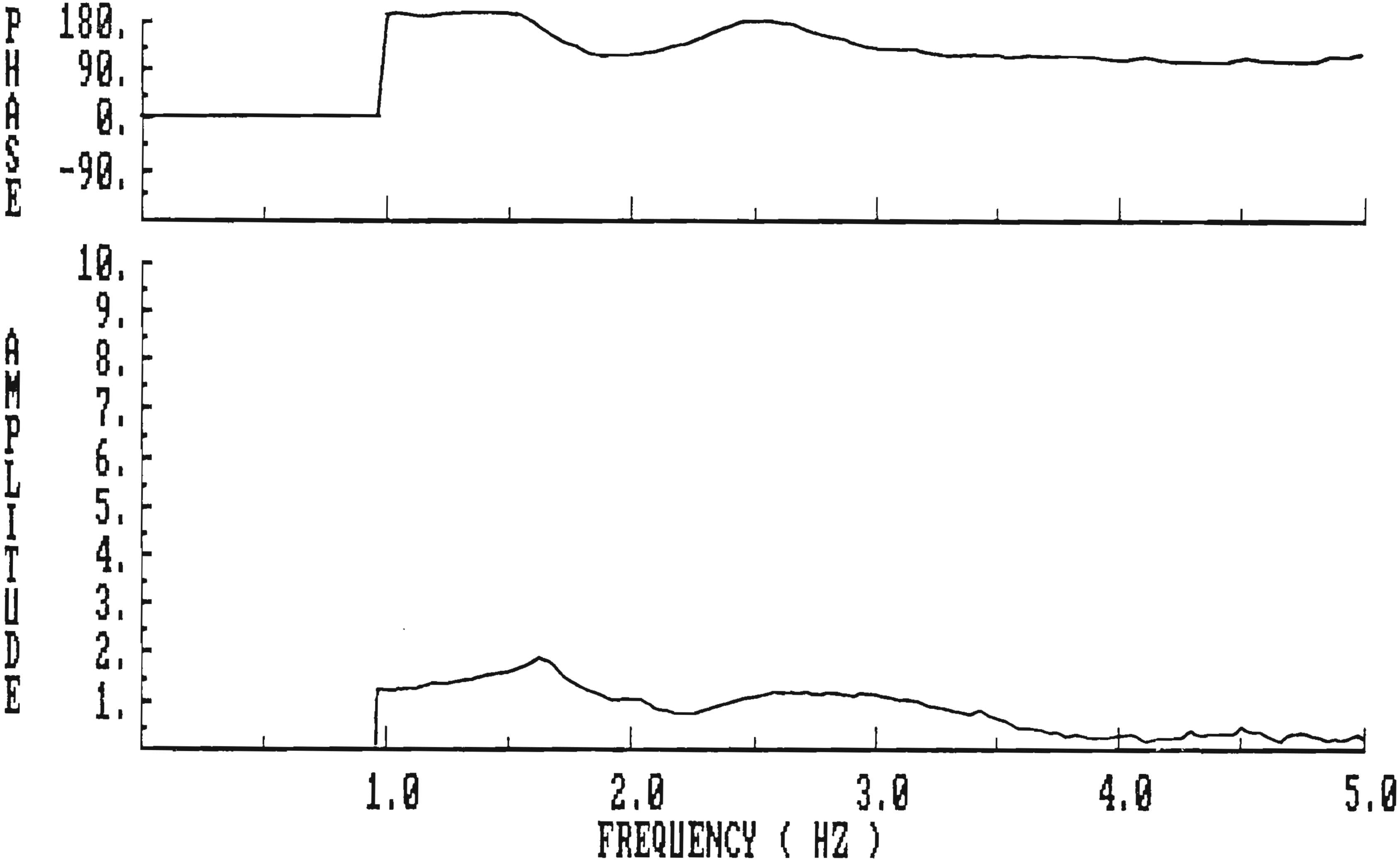


FIG. C-9 LOADED CAR YAW MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, B-END LEFT SIDE, RELATIVE TO VTU INPUT (D20X/1CX) OF 0.4 INCH

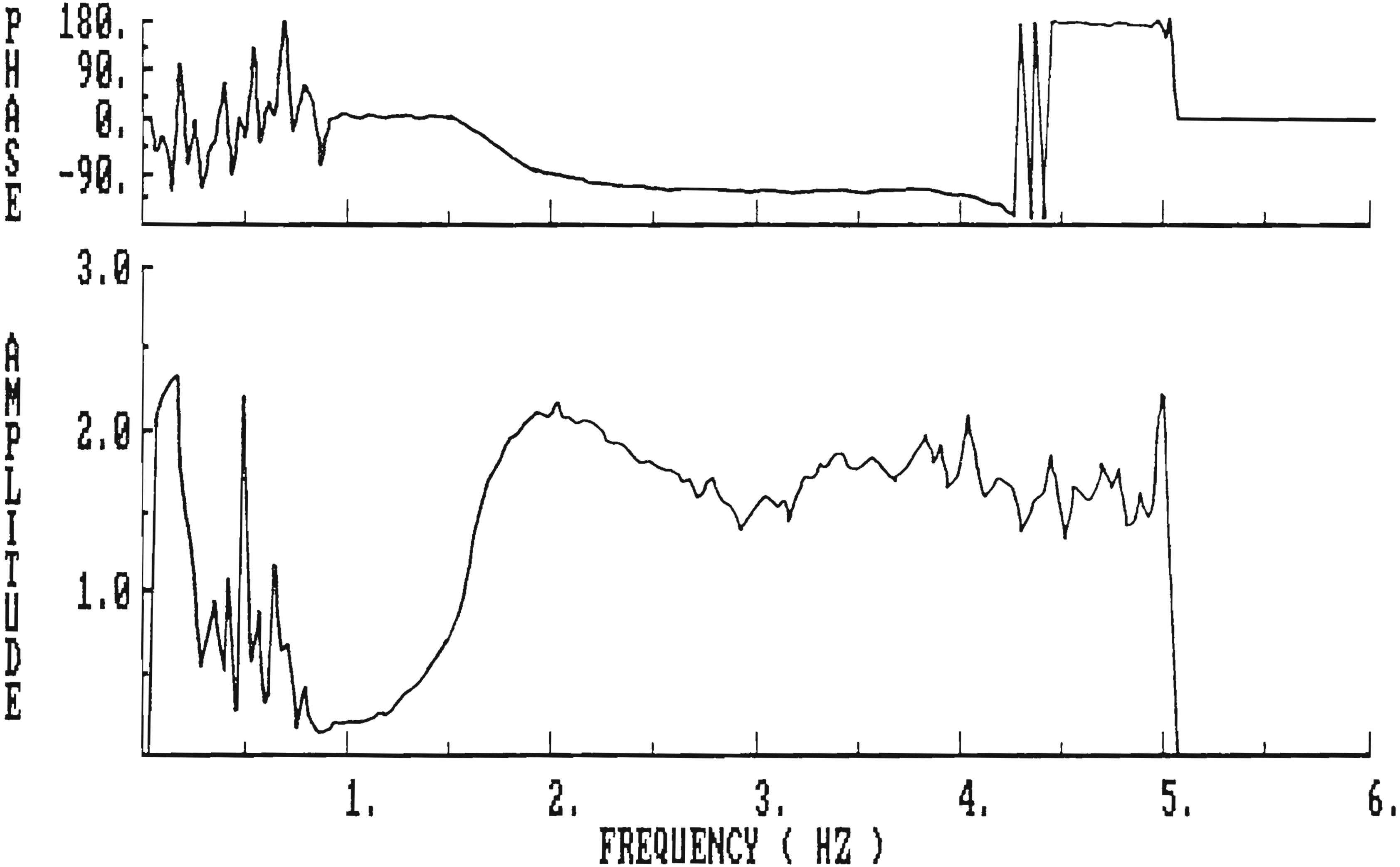


FIG. C-10 LOADED CAR YAW MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VTU INPUT (D26X/1CX) OF 0.4 INCH

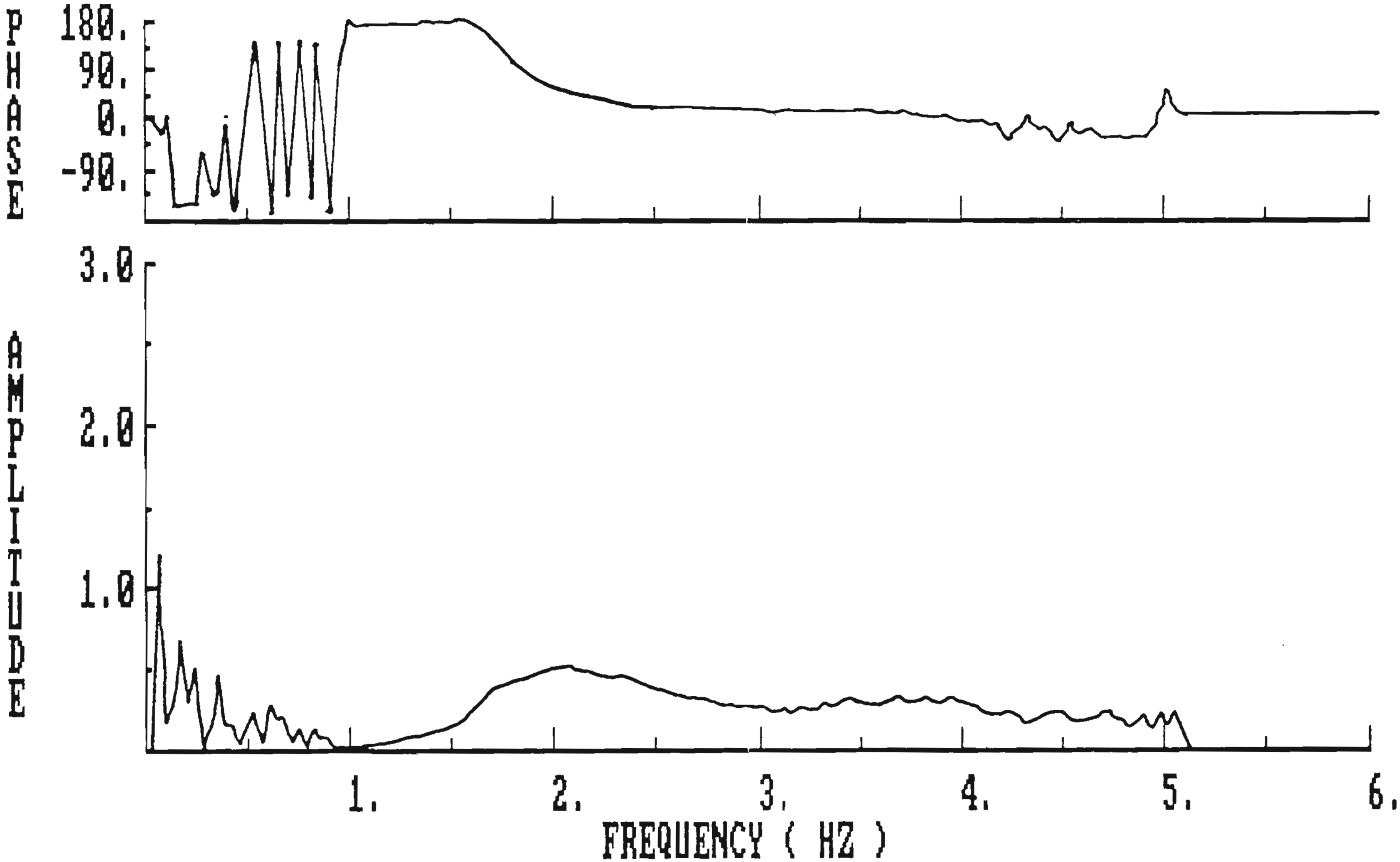


FIG. C-11 LOADED CAR YAW MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, HITCH END, RELATIVE TO VTU INPUT (D25X/1CX) 0.4 INCH

C.4 Loaded Car Sway Mode

Results of the 0.4 inch amplitude sway tests are shown in Figures C-12 to C-15. Lateral transfer functions for D17X, D20X, D25X, and D26X are shown in all figures for both trailers and the carbody at 0.75 Hz. This mode is, however, barely evident for the trailer at the hitch end, while the tandem end shows considerably more motion. The roll mode for the trailer alone is 1.1 Hz (Section 5.4). The trailer is shown to be moving out of phases with carbody at 1.1 Hz, so the large amplitude seen for the tandem end (D26X, Figure C-15) is probably due to coupling with this mode.

C.5 Loaded Car Lower Center Roll

Figures C-16 and C-17 show the transfer functions of the roll gyro's mounted on the car (GR2, GR3) relative to the vertical input at the left A-end wheel (1AZ). A clear carbody roll resonance is shown at 0.65 Hz, with both trailer and carbody in phase at that frequency.

The trailer roll resonance of approximately 1.0 Hz can be seen by looking at the transfer function of the trailer roll gyro (GR1) relative to the carbody roll gyro (GR2) in Figure C-18. The trailer and carbody can be seen to be in phase up to 0.7 or 0.8 Hz, but by 1.0 Hz they are completely out of phase and the trailer is at resonance relative to the carbody. This can also be seen in Figure C-17, where at 1.0 Hz there is an anti-resonance for carbody roll, while the trailer is at resonance on top of it.

C.6 Loaded Car Upper Center Roll

The upper center roll data is confusing showing what appears, at first, to be a very broad roll resonance. Transfer functions of the carbody roll gyro (GR2) and trailer roll gyro (GR1), versus the vertical displacement of the A-end left wheel are shown in Figures C-19 and C-20. A resonant peak appears somewhere between 2.0 and 3.0 Hz for the trailer roll motion, while the carbody shows no roll resonance throughout the test range.

The actual frequency of the roll resonance can be ascertained by reference to transfer functions of the trailer and carbody lateral motions relative to vertical wheel motion. These are shown in Figures C-21 and C-22 for the A and B-ends of the carbody (D17X, D20X) and in Figures C-23 and C-24 for the A and B-ends of the trailer (D26X, D25X). D17X and D20X both show resonant peaks at 2.0 and 2.8 Hz, although these are most clearly defined for D20X, the B or hitch end of the car. By comparing the phase plots, the 2.0 Hz resonance shows out of phase motion (yaw), while the 2.8 Hz mode is in phase (sway). The same situation holds true for the trailer motions, although D25X, the hitch end, shows very little amplitude of motion as expected throughout the frequency range.

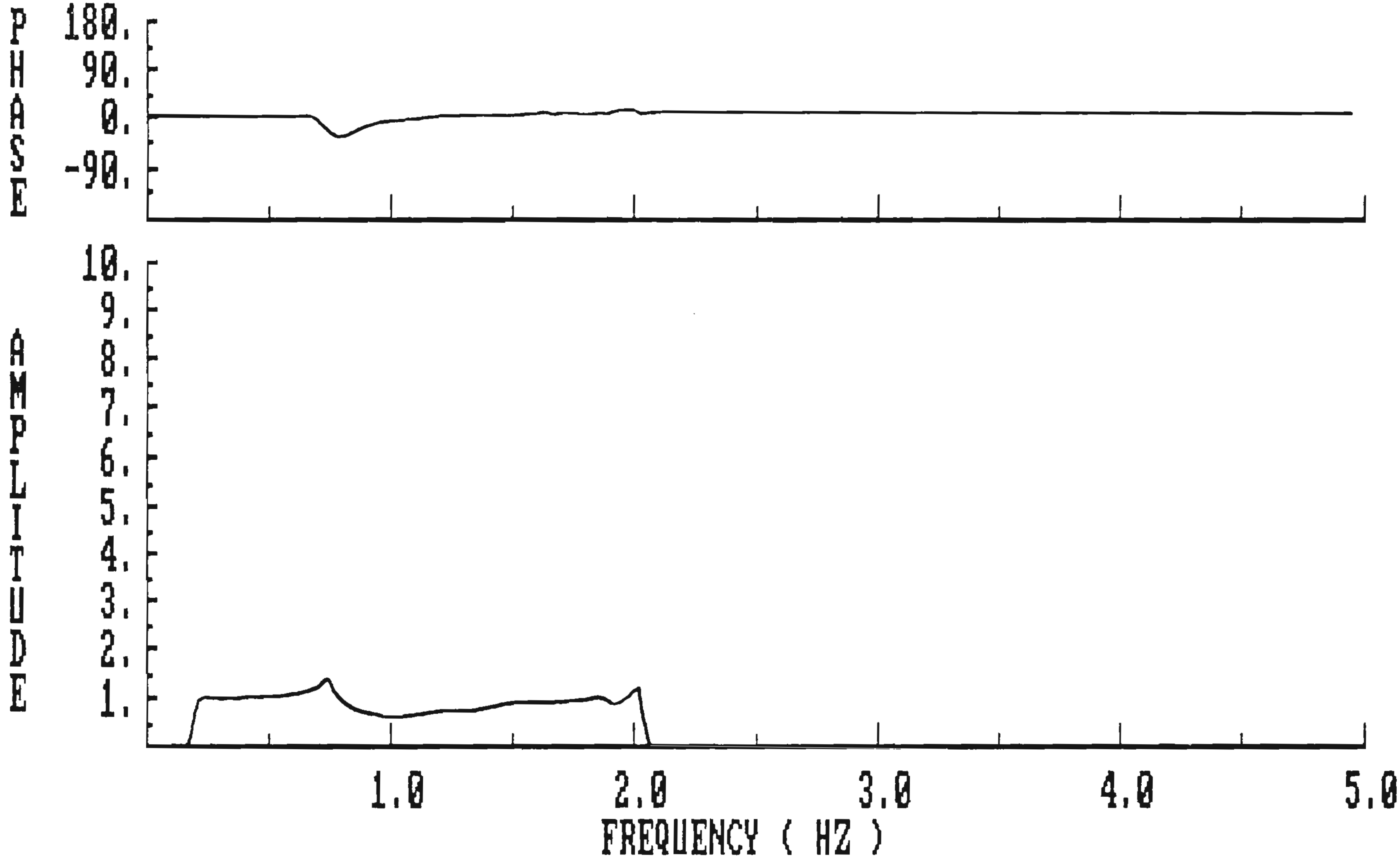


FIG. C-12 LOADED CAR SWAY MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D17X/1CX) 0.4 INCH

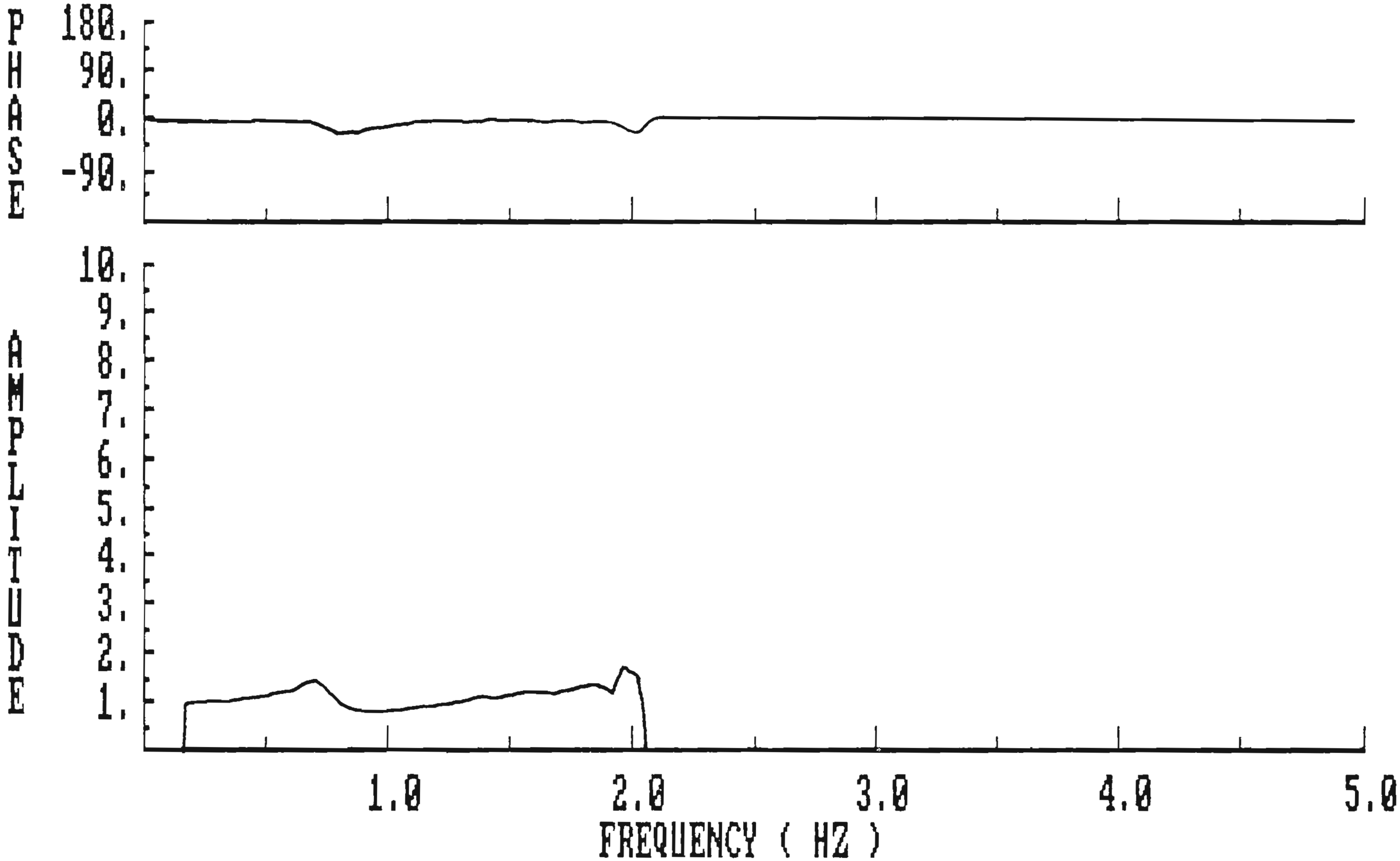


FIG. C-13 LOADED CAR SWAY MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, B-END LEFT SIDE, RELATIVE TO VTU INPUT (D20X/1CX) 0.4 INCH

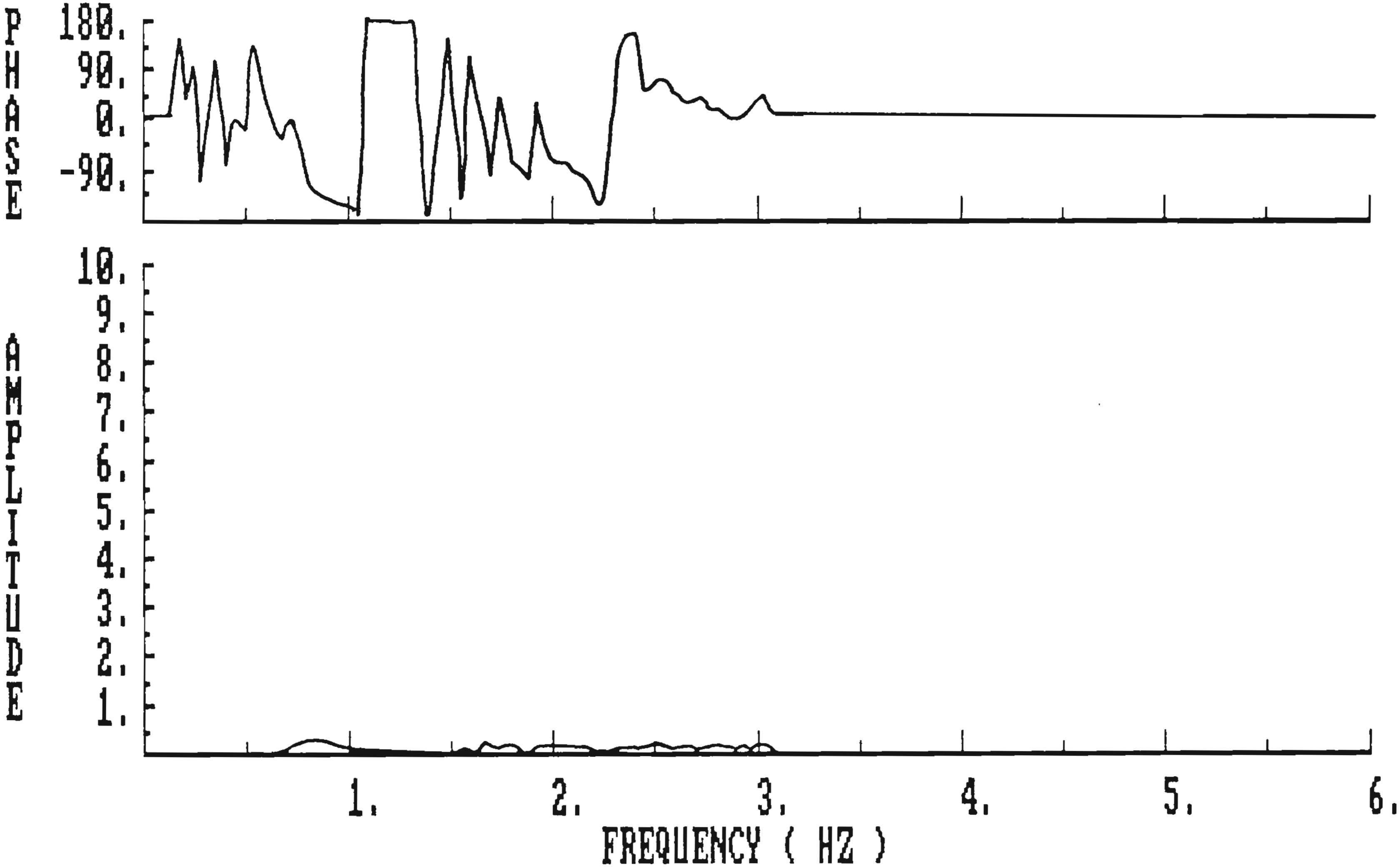


FIG. C-14 LOADED CAR SWAY MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, HITCH END, RELATIVE TO VTU INPUT (D25X/1CX) 0.4 INCH

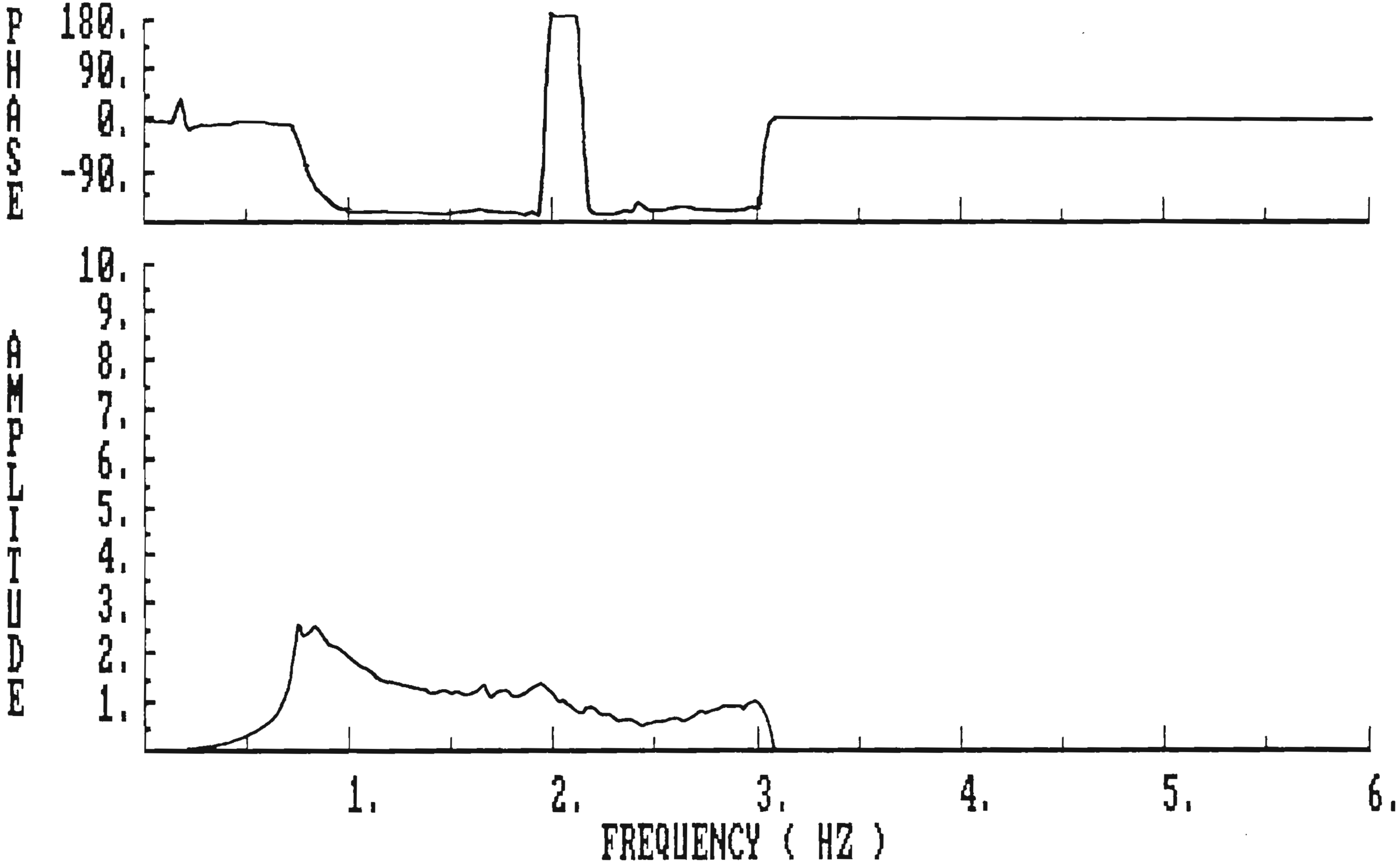


FIG. C-15 LOADED CAR SWAY MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VTU INPUT (D26X/1CX) 0.4 INCH

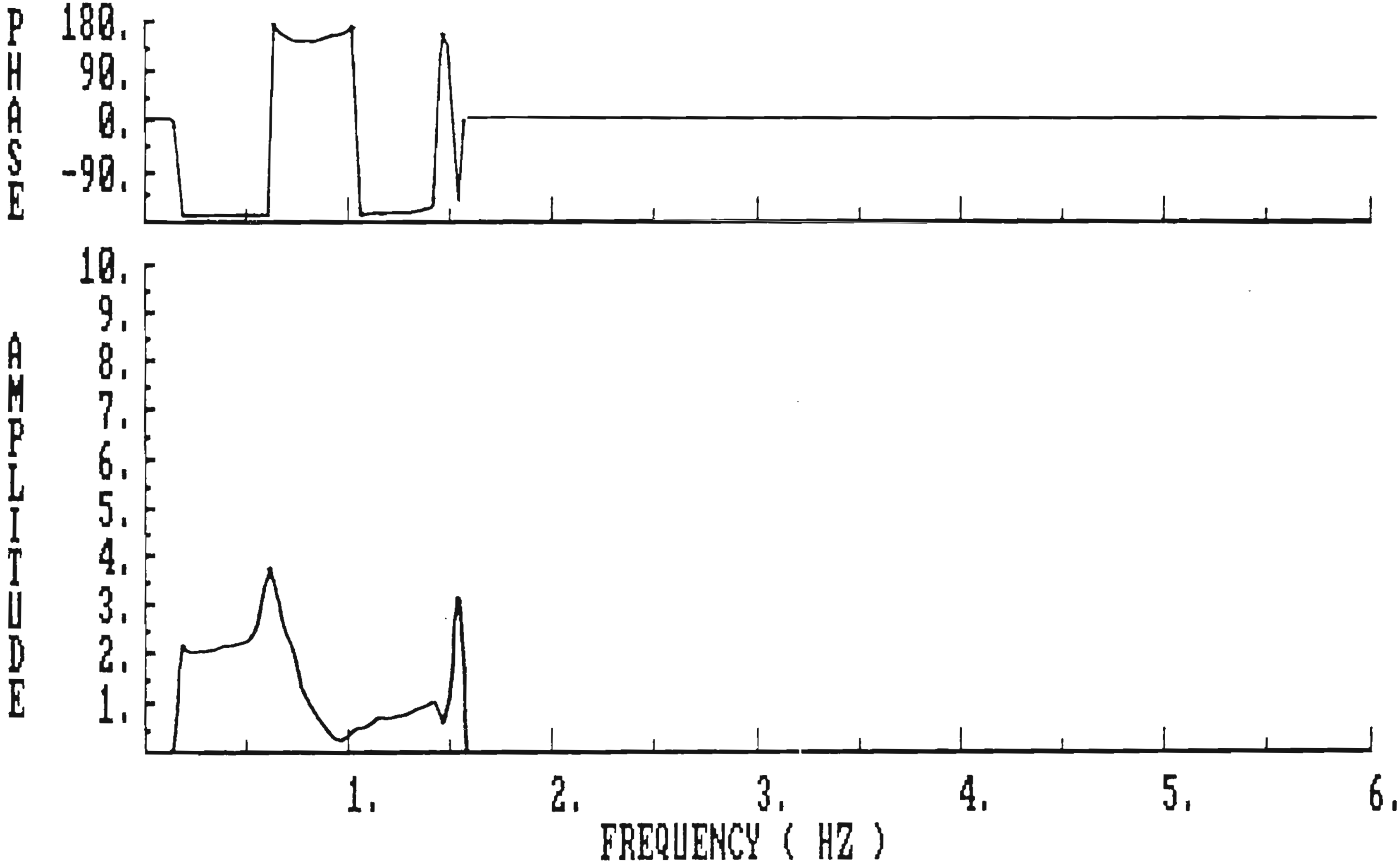


FIG. C-16 LOADED CAR LOWER CENTER ROLL MODE, TRANSFER FUNCTION OF CARBODY ROLL, A-END, RELATIVE TO VTU INPUT (GR2/1AZ) OF 0.3 INCH

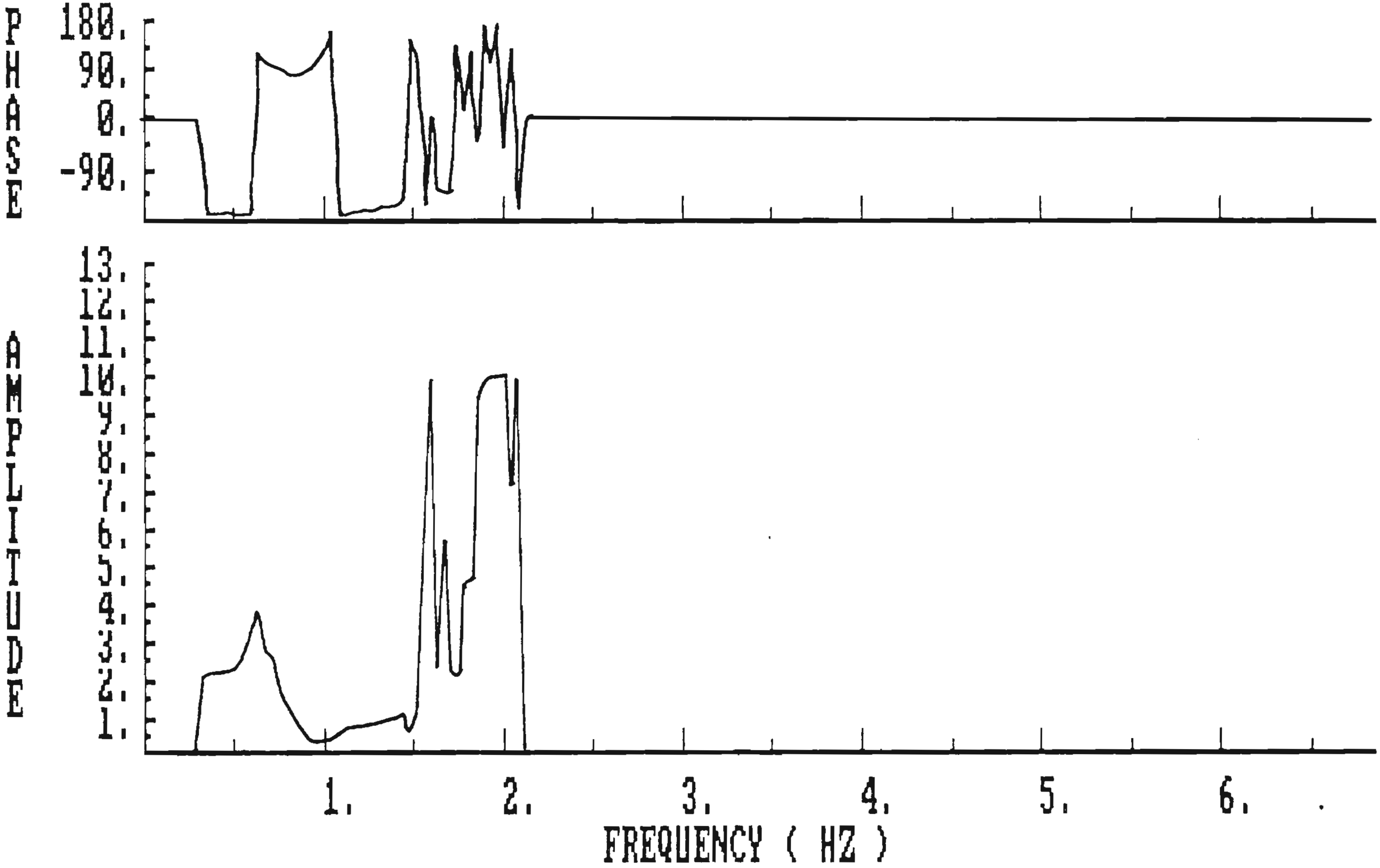


FIG. C-17 LOADED CAR LOWER CENTER ROLL MODE, TRANSFER FUNCTION OF CARBODY ROLL, B-END, RELATIVE TO VTU INPUT (GR3/1AZ) 0.3 INCH

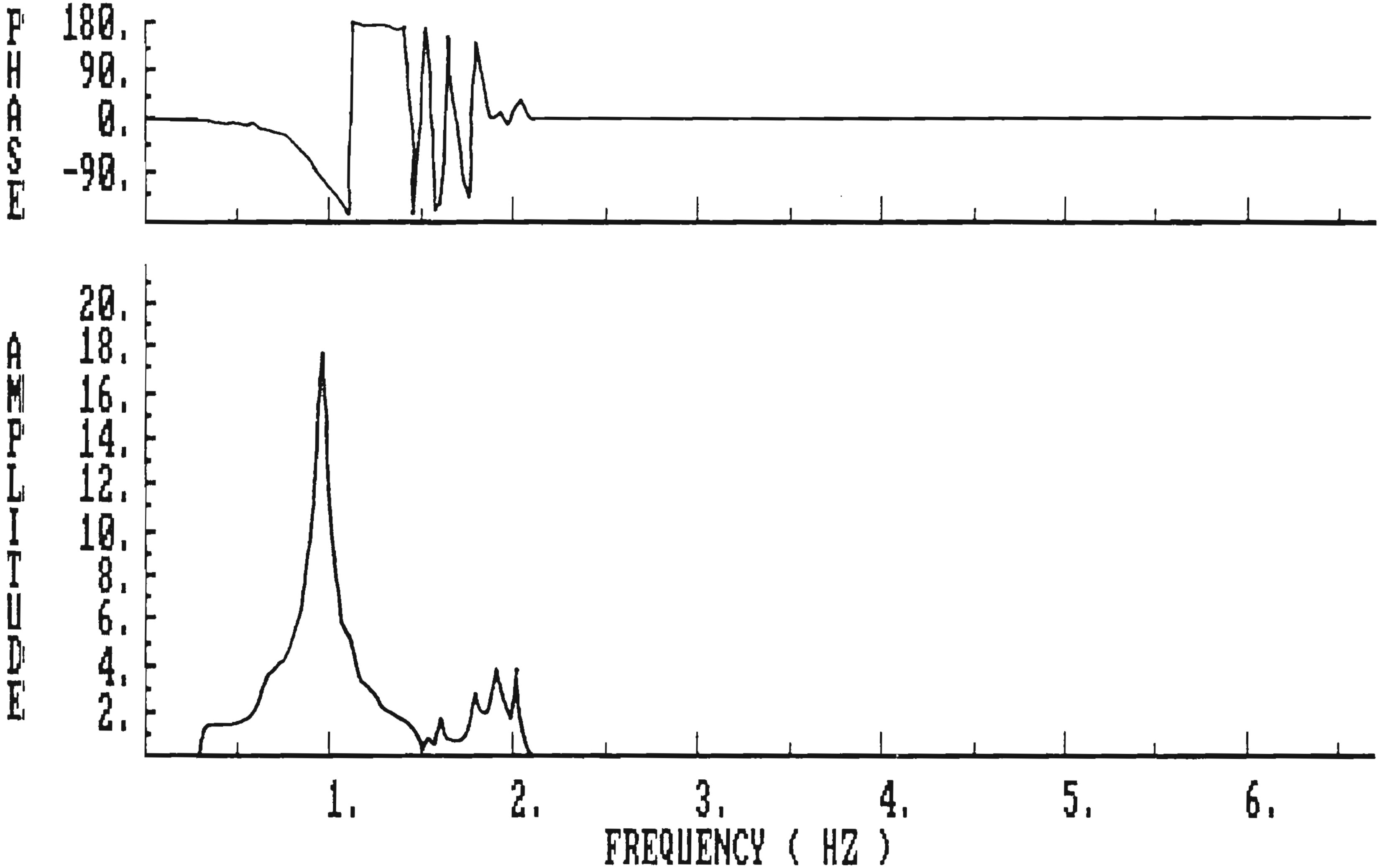


FIG. C-18 LOADED CAR LOWER CENTER ROLL MODE, TRANSFER FUNCTION OF TRAILER ROLL, TANDEM END, RELATIVE TO CARBODY ROLL, A-END

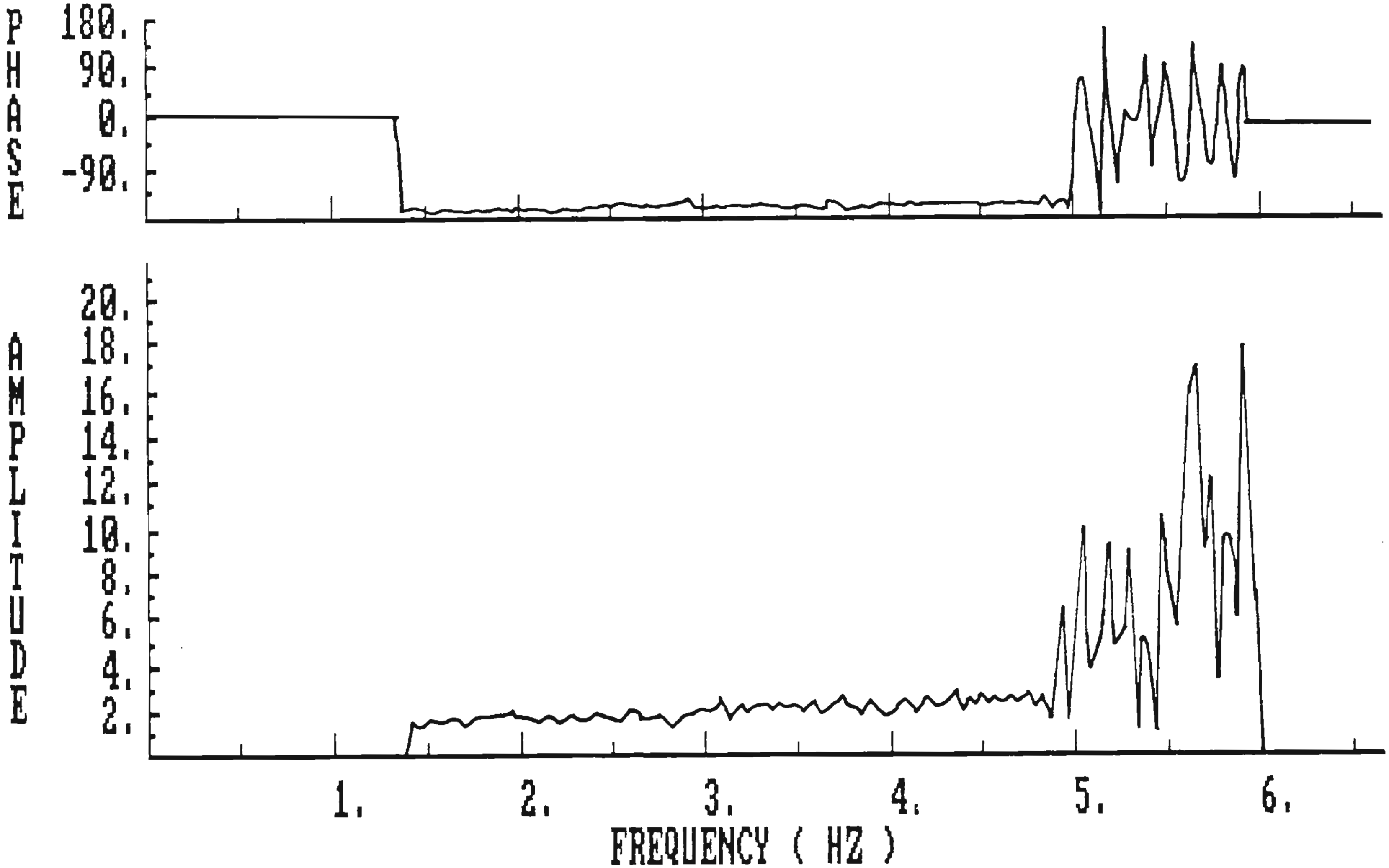


FIG. C-19 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF CARBODY ROLL, A-END, RELATIVE TO VTU INPUT (GR2/1AZ) OF 0.3 INCH

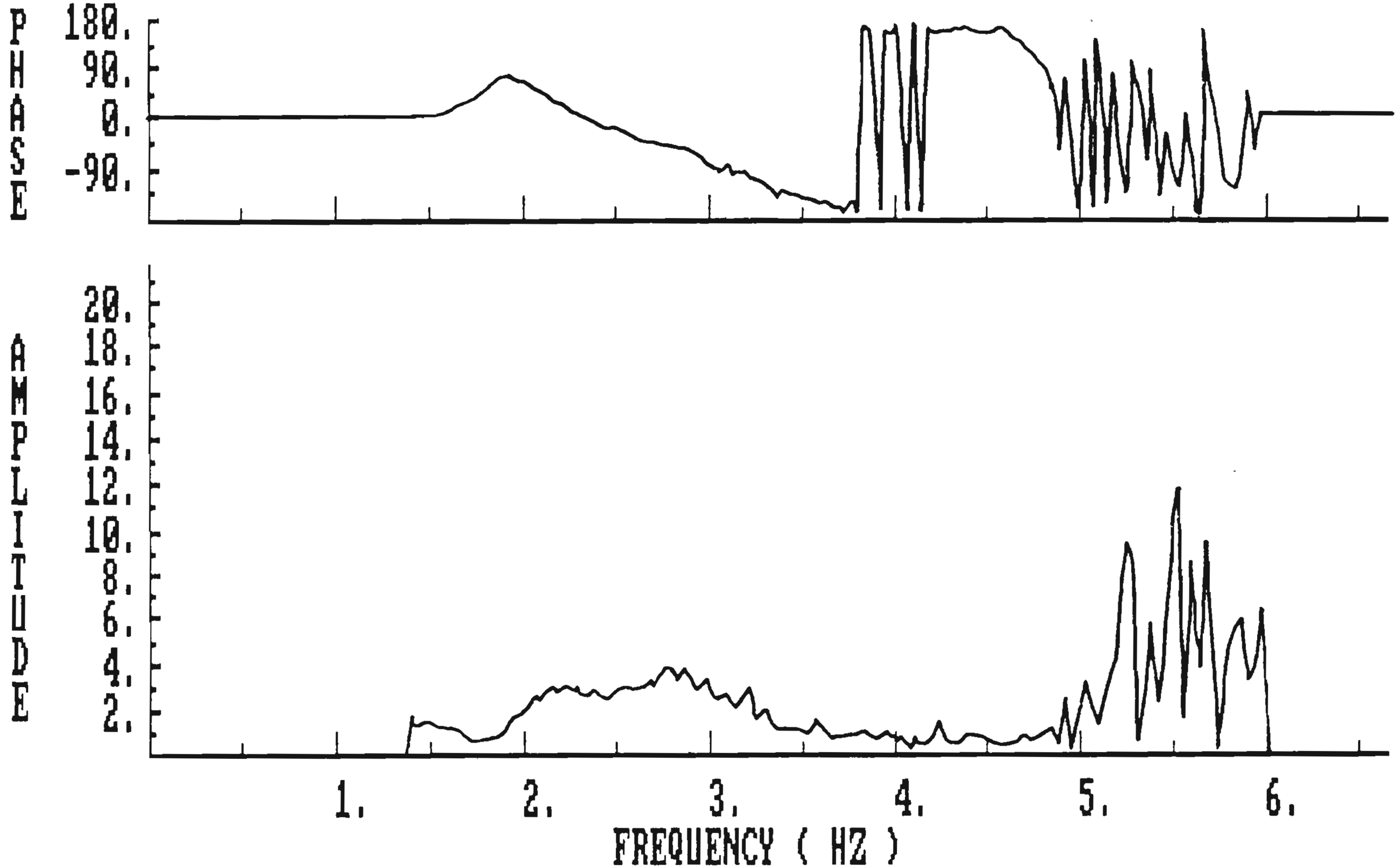


FIG. C-20 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF CARBODY ROLL, B-END, RELATIVE TO VTU INPUT (GR3/1AZ) OF 0.3 INCH

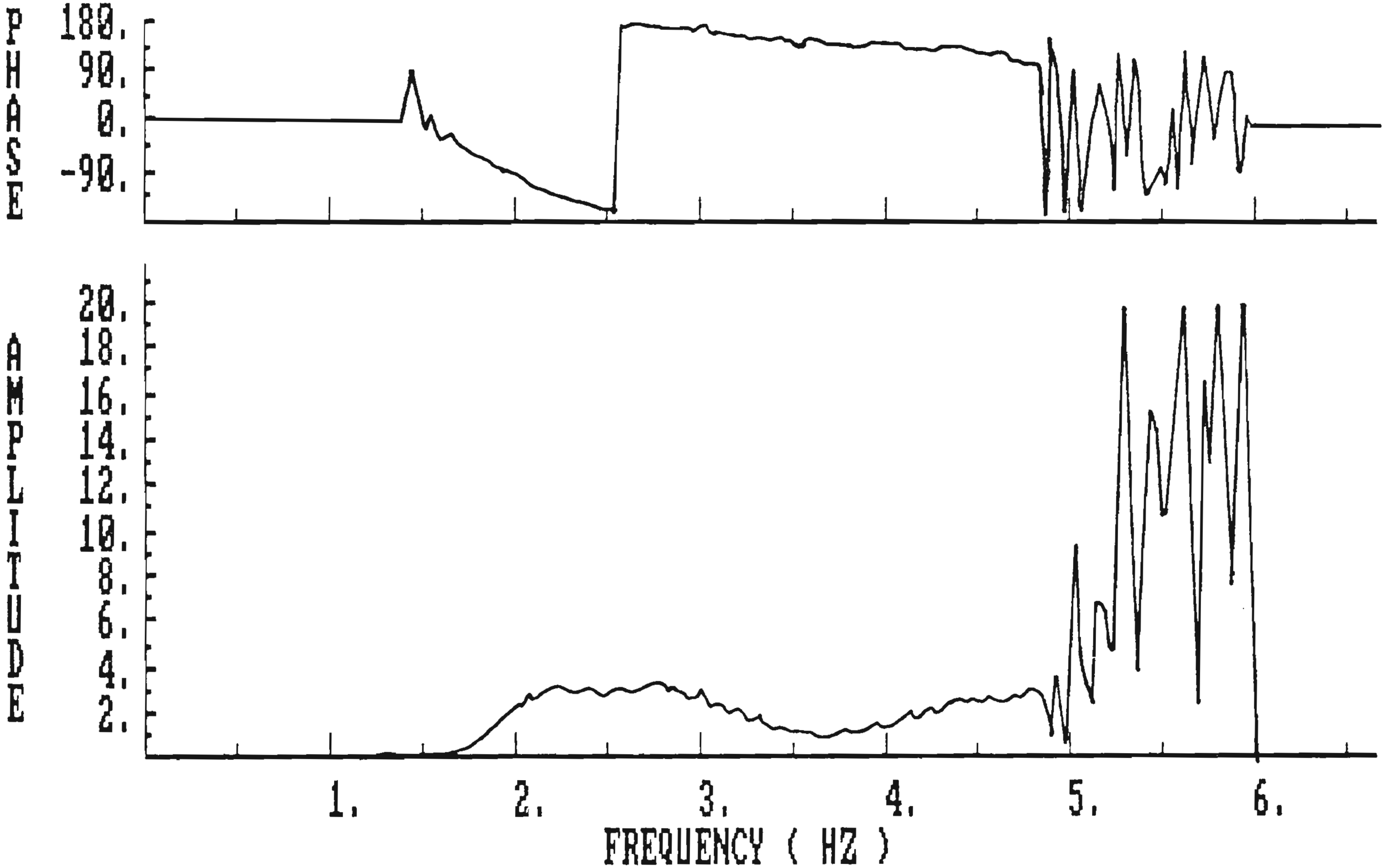


FIG. C-21 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, A-END LEFT SIDE, RELATIVE TO VTU INPUT (D17X/1AZ) OF 0.3 INCH

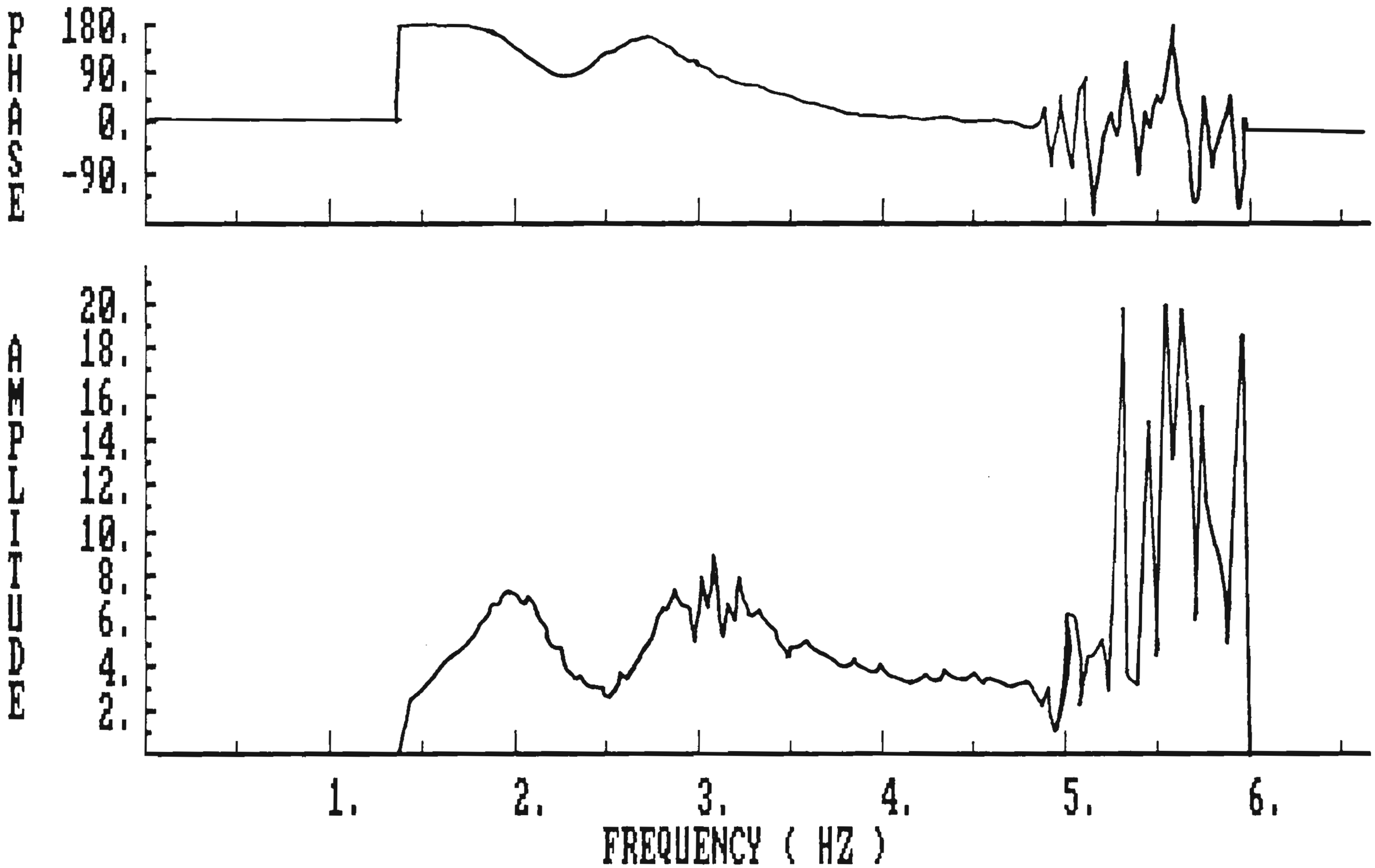


FIG. C-22 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF LATERAL CARBODY DISPLACEMENT, B-END LEFT SIDE, RELATIVE TO VTU INPUT (D20X/1AZ) OF 0.3 INCH

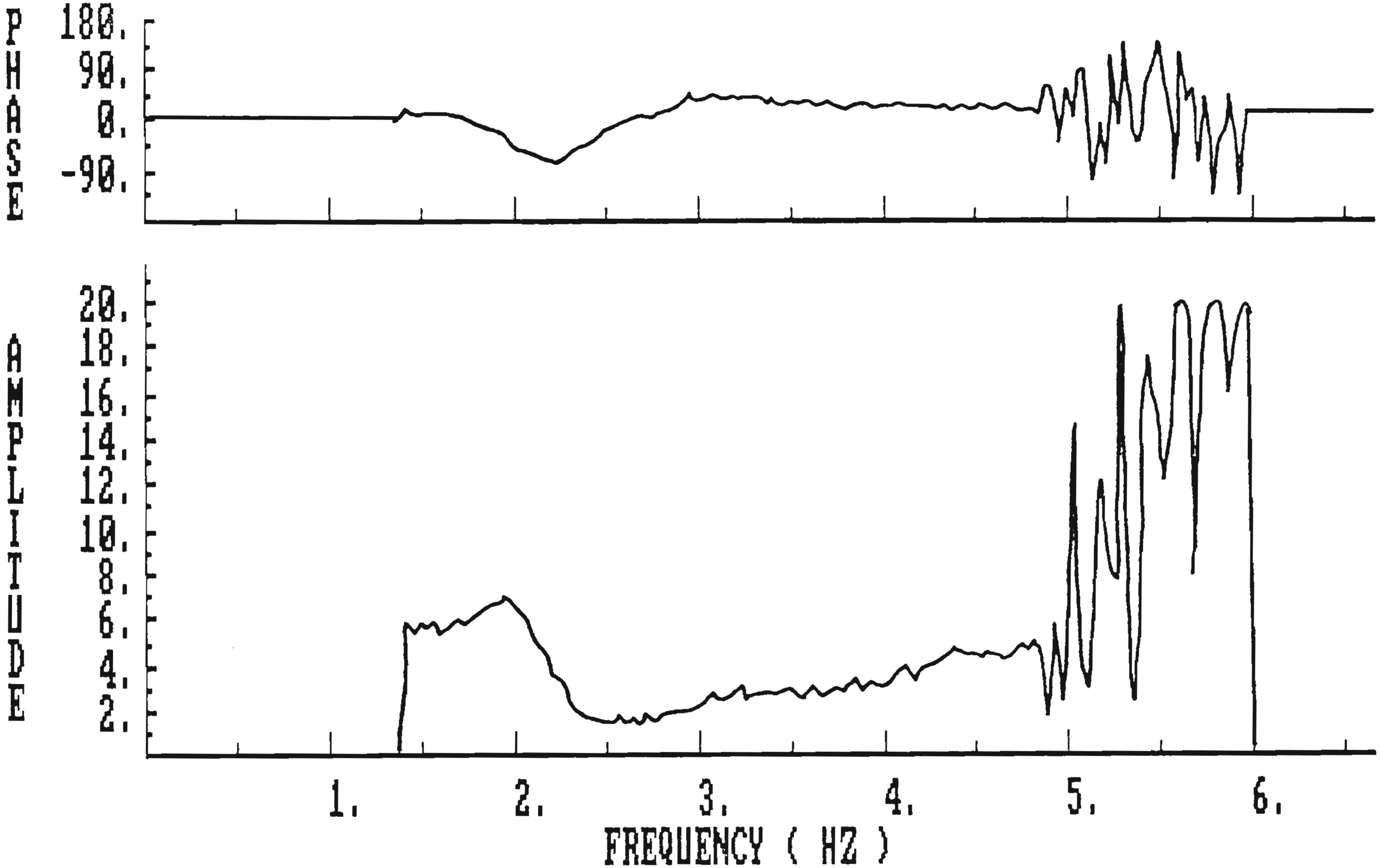


FIG. C-23 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, TANDEM END, RELATIVE TO VTU INPUT (D26X/1AZ) OF 0.3 INCH

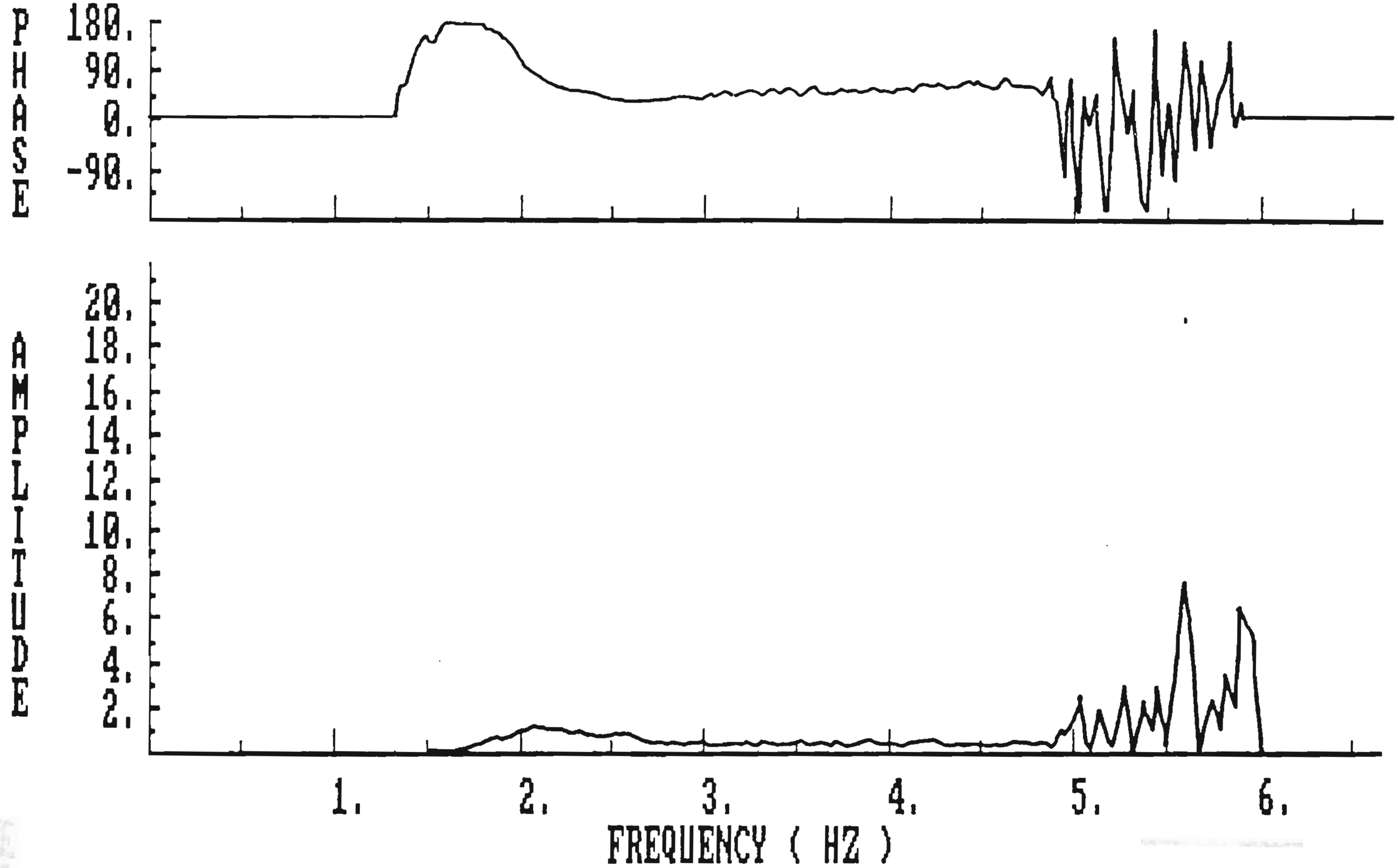


FIG. C-24 LOADED CAR UPPER CENTER ROLL MODE, TRANSFER FUNCTION OF LATERAL TRAILER DISPLACEMENT, HITCH END, RELATIVE TO VTU INPUT (D25X/1AZ) OF 0.3 INCH

Thus, at 2.0 Hz, the trailer and car are undergoing some form of near resonant yaw motion, which is coupled with the trailer's 2.4 Hz yaw-roll mode. At 2.8 Hz, the trailer and carbody are out of phase with each other, while the ends of the trailer are in phase, as are the ends of the carbody. This clearly indicates that the upper center roll resonant frequency is 2.8 Hz.

Additional Data Plots - VTU Tests

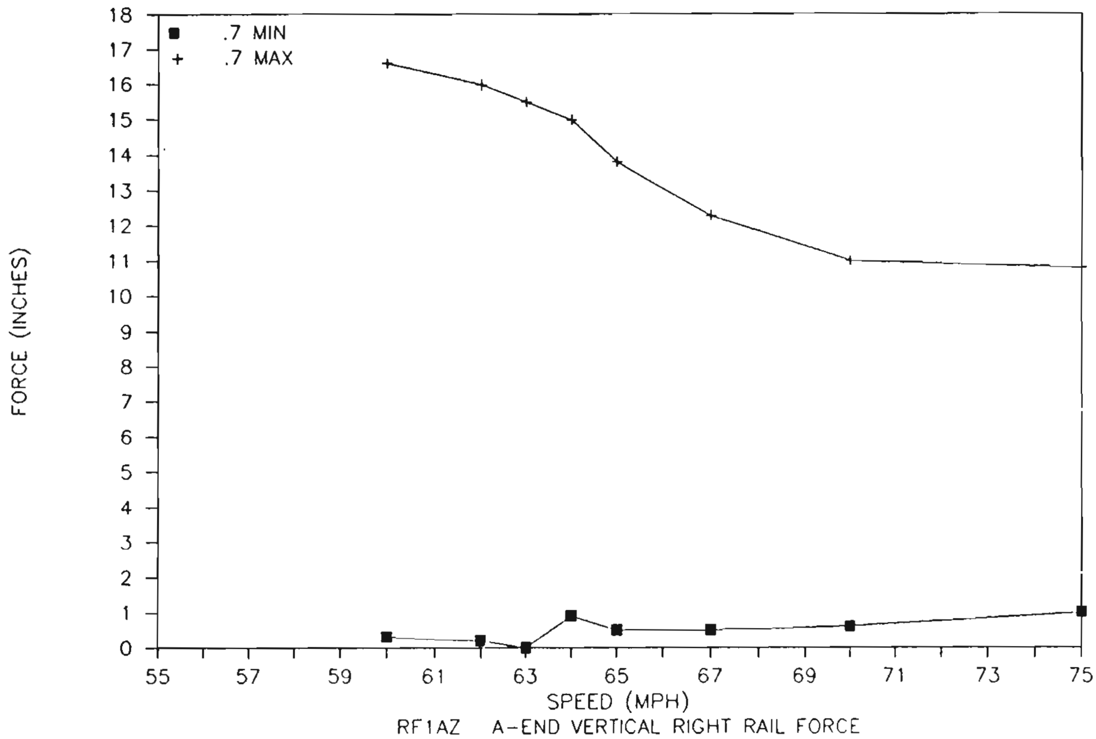


FIG.C-25 VTU 33'PARALLEL RAILS EMPTY CAR

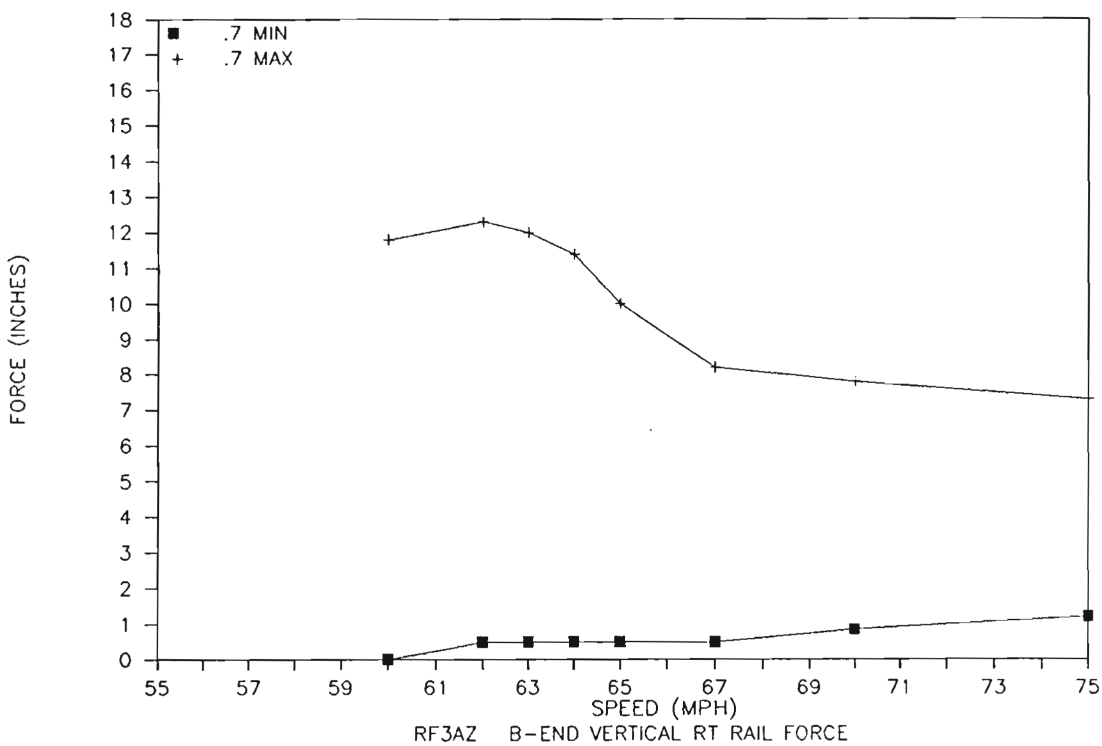


FIG.C-26 VTU 33'PARALLEL RAILS EMPTY CAR

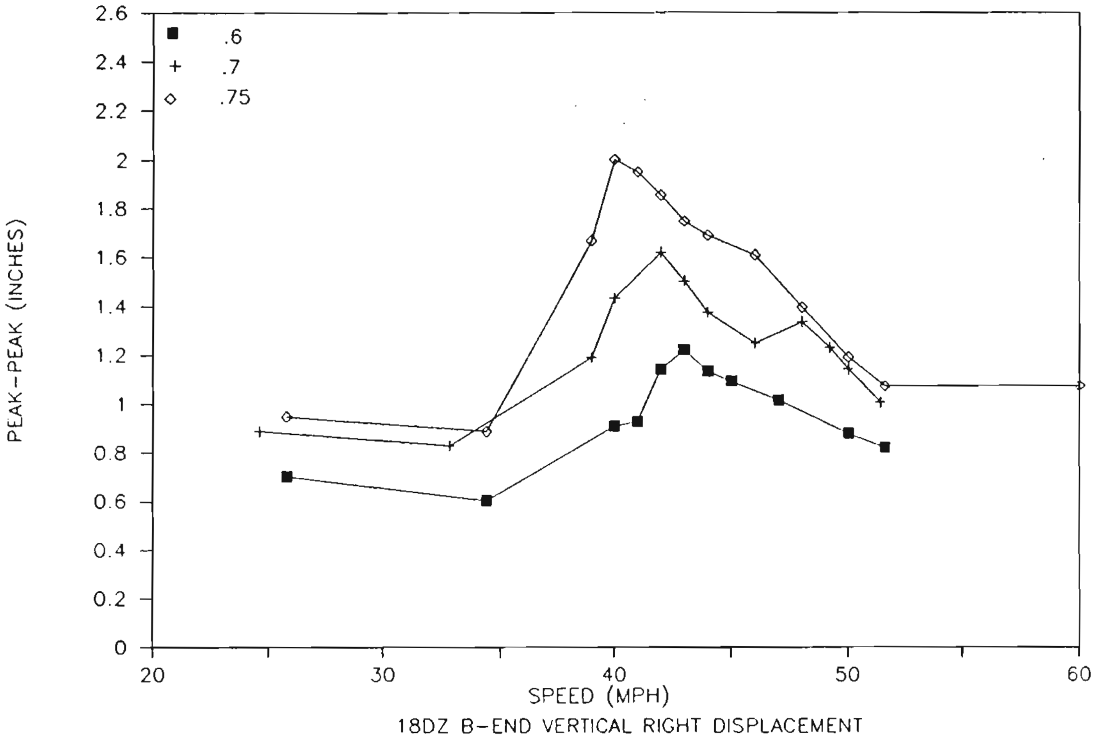


FIG.C-27 VTU 33'PARALLEL RAILS LOADED CAR

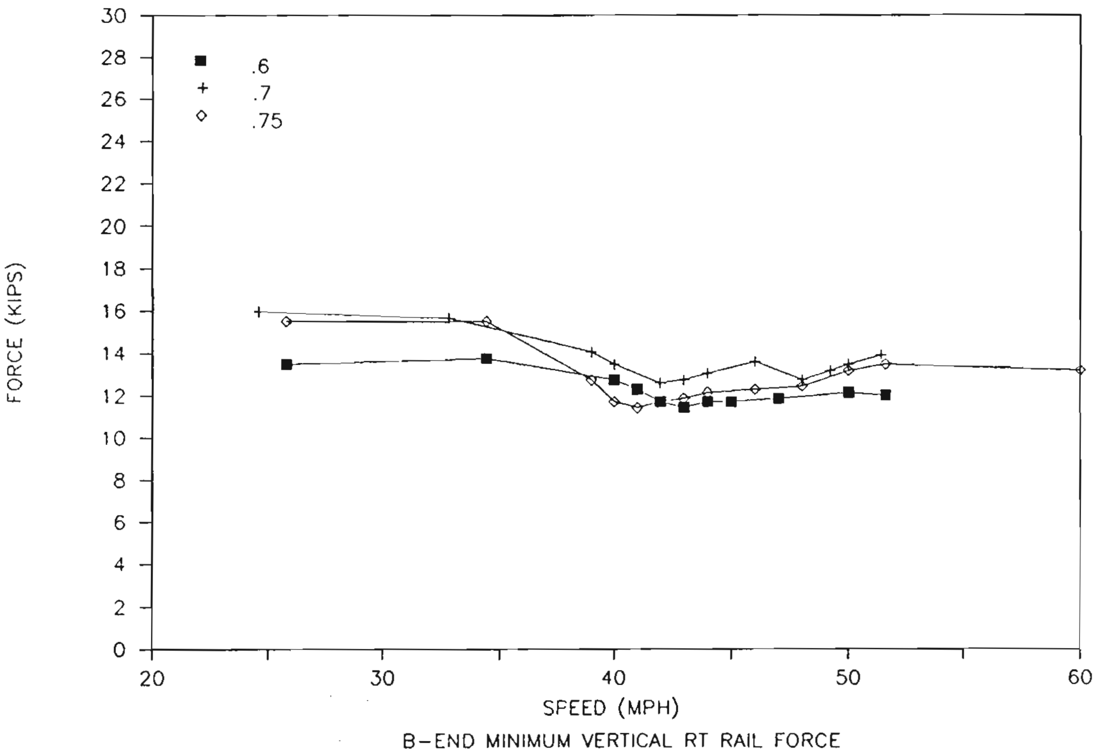


FIG.C-28 VTU 33'PARALLEL RAILS LOADED CAR

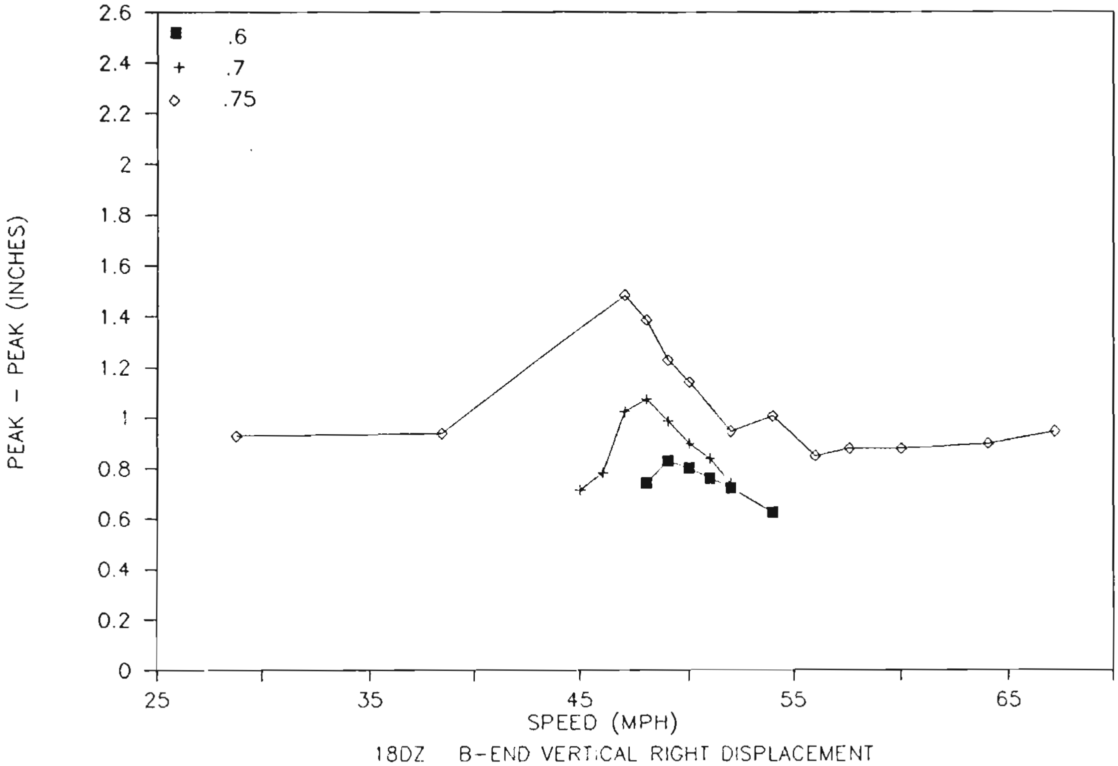


FIG.C-29 VTU 39'PARALLEL RAILS LOADED CAR

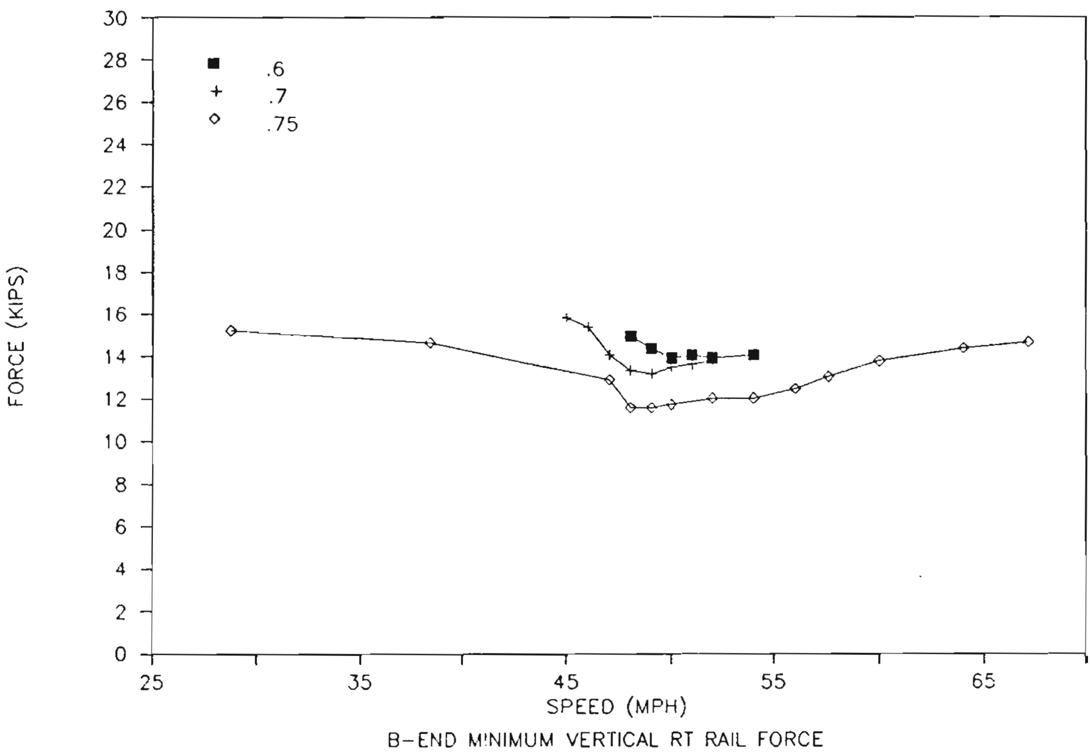


FIG.C-30 VTU 39'PARALLEL RAILS LOADED CAR

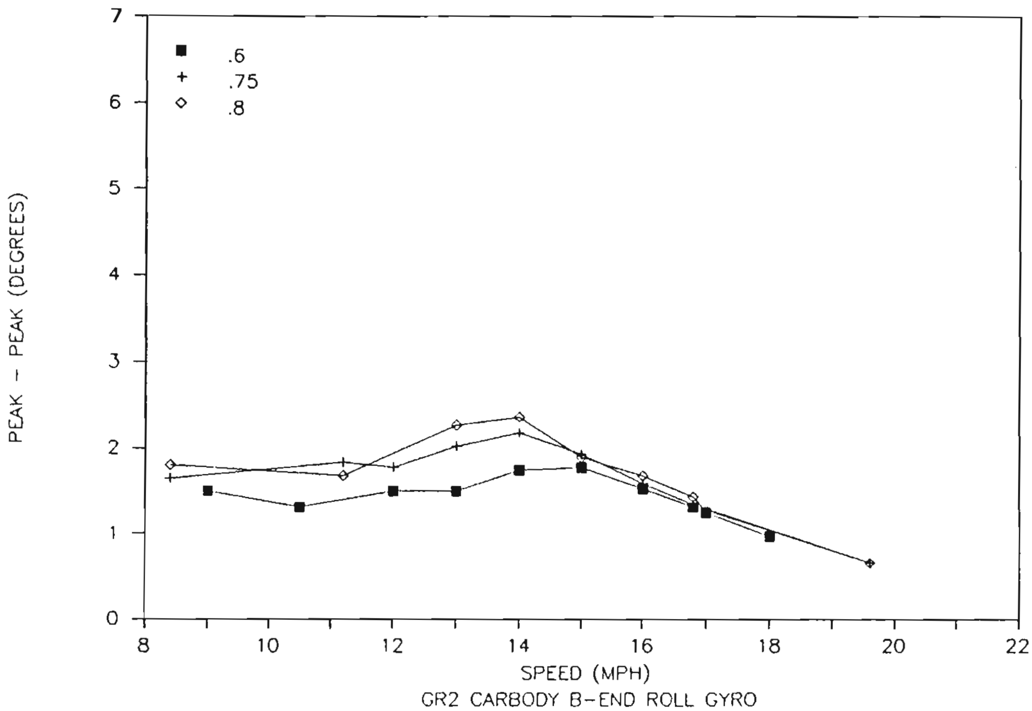


FIG.C-31 VTU 33'STAGGERED RAILS LOADED CAR

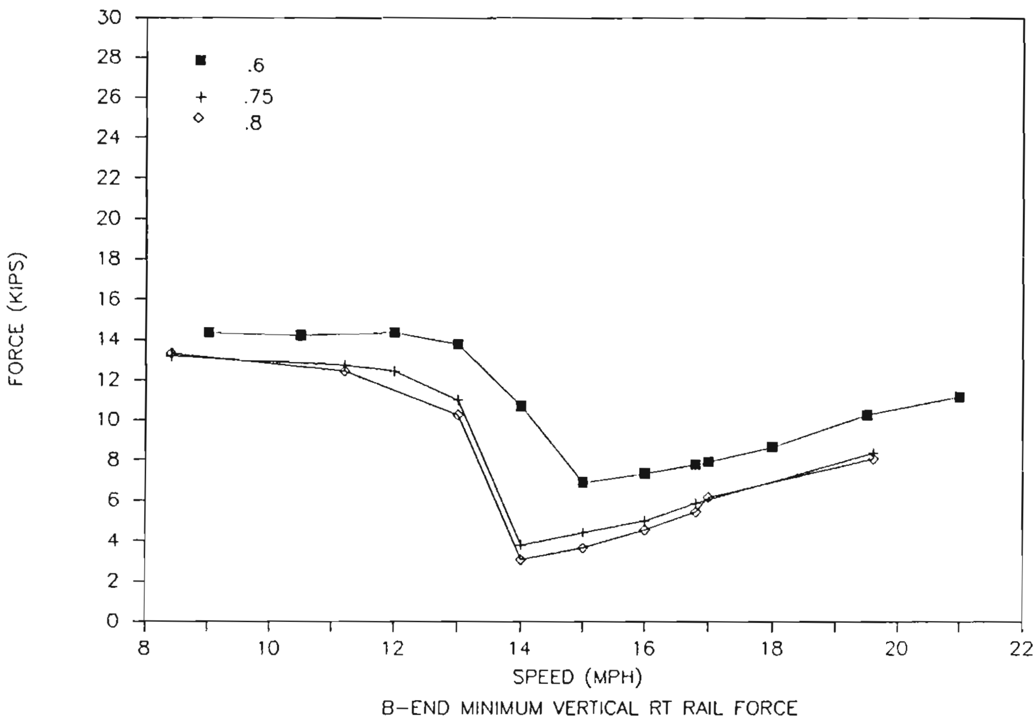


FIG.C-32 VTU 33'STAGGERED RAILS LOADED CAR

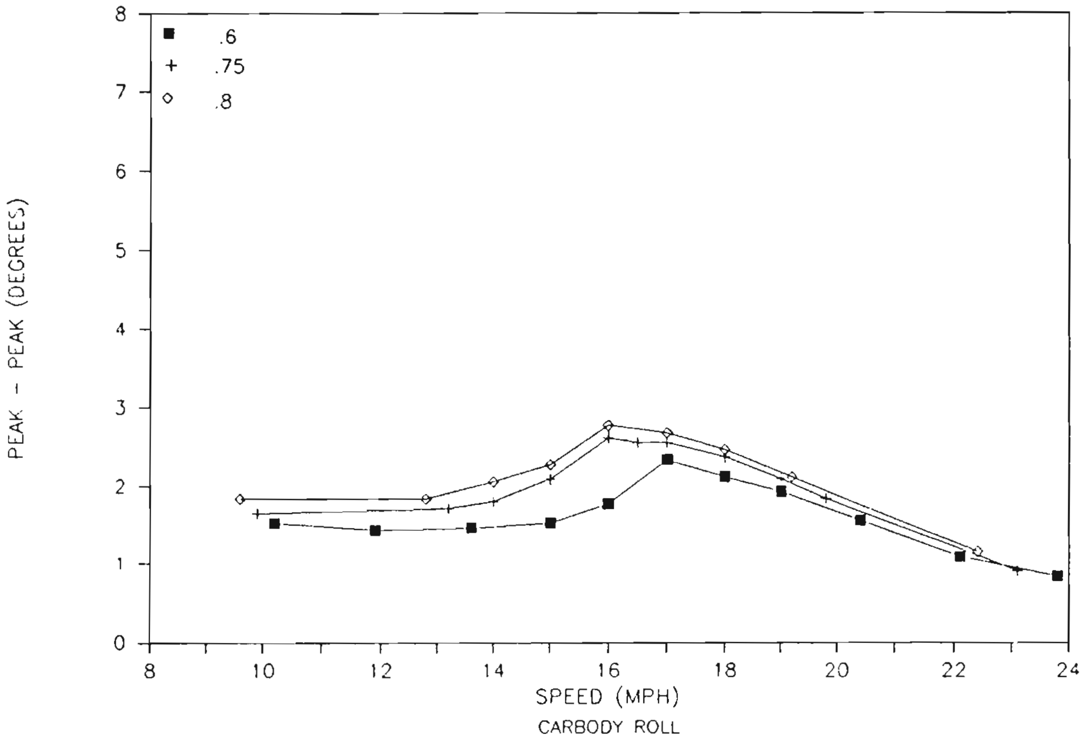


FIG.C-33 VTU 39'STAGGERED RAILS LOADED CAR

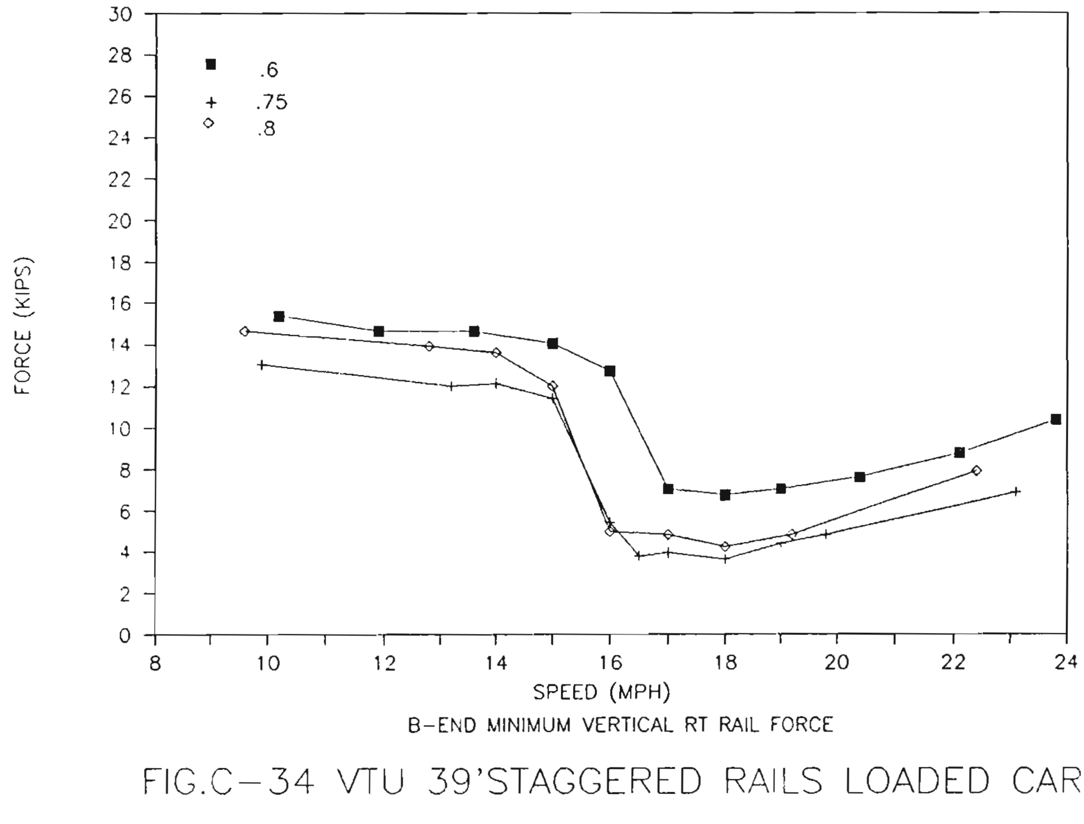


FIG.C-34 VTU 39'STAGGERED RAILS LOADED CAR

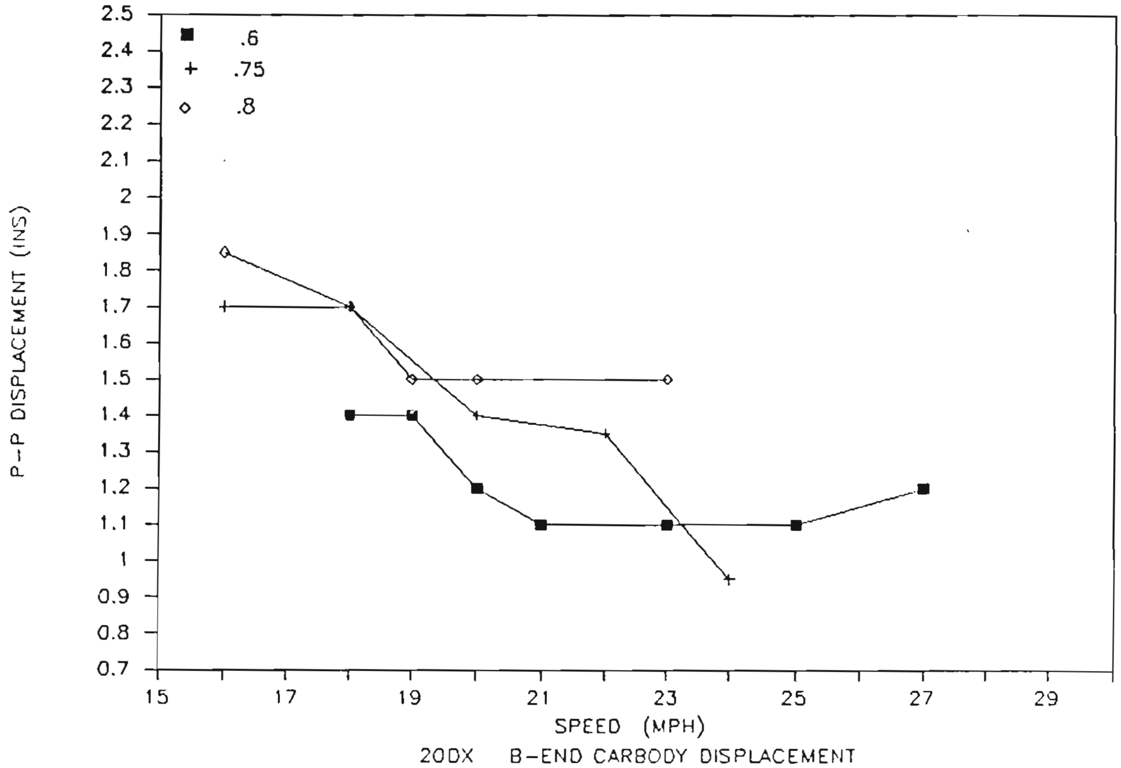


FIG.C-35 VTU 39' YAW/SWAY LOADED CAR

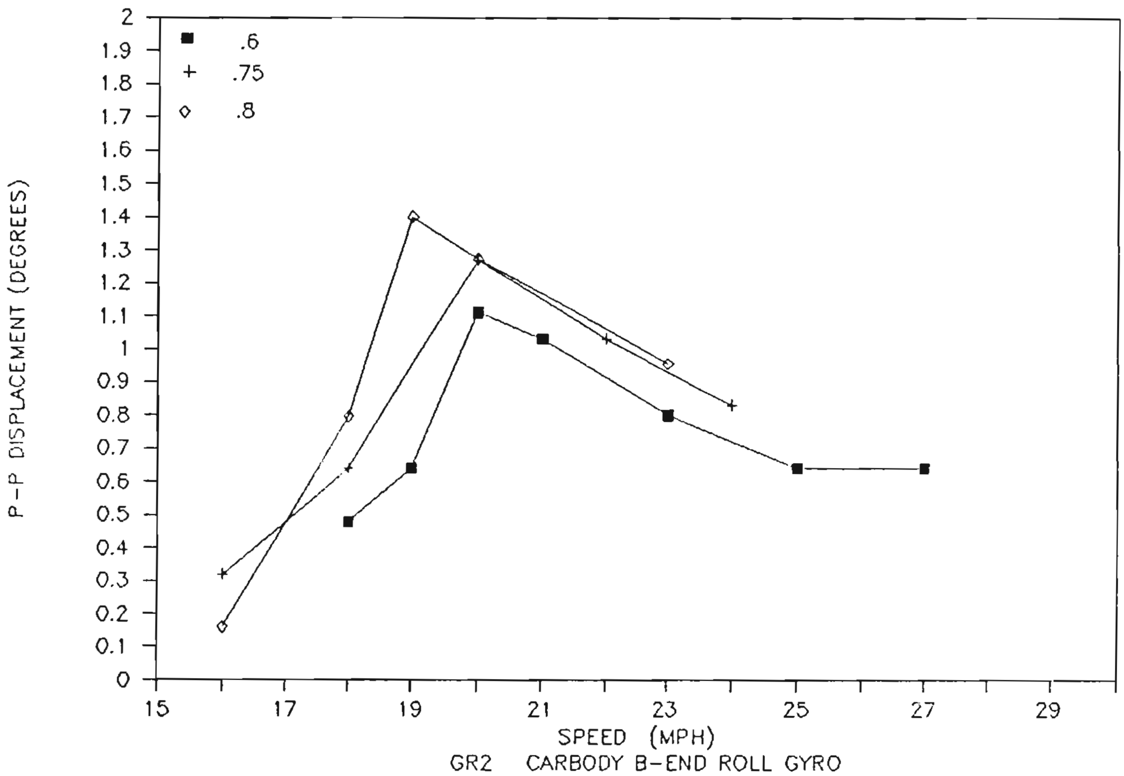


FIG.C-36 VTU 39' YAW/SWAY LOADED CAR

Instrumentation List - Track Tests

Table C-2. Instrumentation Summary - Empty Car Track Tests

CH #	MEAS #	Description/Location of the Transducers
1	TACH	Consist speed recorded from T-7 lab coach tachometer
2	ALD1	Automatic location device, leading end of locomotive
3	ALD2	Automatic location device, leading end of test vehicle
4	MALD	Manual location device, on-board T-7 lab coach
		<u>Locomotive Transducer Location</u>
5	1WV-1	Left vertical wheel force, lead truck, lead axle
6	1WL-1	Left lateral wheel force, lead truck, lead axle
7	1WLV1	Left lateral/vertical wheel force ratio, lead truck, lead axle
8	1WV-2	Right vertical wheel force, lead truck, trail axle
9	1WL-2	Right lateral wheel force, lead truck, trail axle
10	1WLV2	Right lateral/vertical wheel force ratio, lead truck, trail axle
11	2WV-3	Left vertical wheel force, lead truck, trail axle
12	2WL-3	Left lateral wheel force, lead truck, trail axle
13	2WLV3	Left lateral/vertical wheel force ratio, lead truck, trail axle
14	2WV-4	Right vertical wheel force, lead truck, trail axle
15	2WL-4	Right lateral wheel force, lead truck, trail axle
16	2WLV4	Right lateral/vertical wheel force ratio, lead truck, trail axle
		<u>Test Vehicle Transducer Locations</u>
17	9WV-5	Left vertical wheel force, lead axle viewed from A-end
18	9WL-5	Left lateral wheel force, lead axle viewed from A-end
19	9WLV5	Left lateral/vertical wheel force ratio, lead axle
20	9WV-6	Right vertical wheel force, lead axle
21	9WL-6	Right lateral wheel force, lead axle
22	9WLV6	Right lateral/vertical wheel force ratio, lead axle
23	9LF-1	Longitudinal axle force, lead axle
24	10WV-7	Left vertical wheel force, trail axle
25	10WL-7	Left lateral wheel force, trail axle
26	10WLV7	Left lateral/vertical wheel force ratio, trail axle
27	10MV-8	Right vertical wheel force, trail axle
28	10WL-8	Right lateral wheel force, trail axle
29	10WLV8	Right lateral/vertical wheel force ratio, trail axle
30	10LF-2	Longitudinal axle force, trail axle
31	ARZD1	Vertical spring displacement, A-end right side, as viewed from B-end
32	ALZD2	Vertical spring displacement, A-end left side, as viewed from B-end

Table C-2. Instrumentation Summary - Empty Car Track Tests (Continued)

CH #	MEAS #	Description/Location of the Transducers
		Test Vehicle Transducer Locations (Continued)
33	BRZD3	Vertical spring displacement, B-end right side, as viewed from B-end
34	BLZD4	Vertical spring displacement, B-end left side, as viewed from B-end
35	ARYD1	Longitudinal axle yaw displacement, B-end right side, as viewed from B-end
36	ALYD2	Longitudinal axle yaw displacement, A-end left side, as viewed from B-end
37	BRYD3	Longitudinal axle yaw displacement, B-end right side, as viewed from B-end
38	BLYD4	Longitudinal axle yaw displacement, B-end left side, as viewed from B-end
39	ALXD1	Lateral axle displacement, B-end left side, as viewed from B-end
40	BLXD2	Lateral axle displacement, A-end left side, as viewed from B-end
41	ARG-1	Car body roll, test vehicle A-end
42	BRG-2	Car body roll, test vehicle B-end
43	ARXA1	Lateral car body accelerometer, A-end right corner, as viewed from B-end
44	CZA1	Lateral car body accelerometer, center
45	ARZA2	Vertical car body accelerometer, A-end right corner, as viewed from B-end
46	CXA3	Vertical car body accelerometer, center
47	BRXA2	Lateral Car body accelerometer, B-end right corner, as viewed from B-end
48	BRZA3	Vertical car body accelerometer, B-end right corner, as viewed from B-end
49	ARZA5	Vertical bearing adapter accelerometer, A-end left side, as viewed from B-end
50	ALZA6	Vertical bearing adapter accelerometer, A-end right side, as viewed from B-end
51	BRAZ7	Vertical bearing adapter accelerometer, B-end left side, as viewed from B-end
52	BLZA8	Vertical bearing adapter accelerometer, B-end right side, as viewed from B-end
53	ALXA5	Lateral bearing adpater accelerometer, A-end left side, as viewed from B-end
54	BLXA6	Lateral bearing adapter accelerometer, B-end left side, as viewed from B-end
55	ARXA4	Lateral car body accelerometer, A-end right side, 5.5′ above axle height
56	BRXA5	Lateral car body accelerometer, B-end right side, 5.5′ above axle height

* All tests performed with B-end leading

Table C-3. Instrumentation Summary -
Loaded Car Track Tests

CH #	MEAS #	Description/Location of the Transducers
1	TACH	Consist speed recorded from T-7 lab coach tachometer
2	ALD1	Automatic location device, leading end of locomotive
3	ALD2	Automatic location device, leading end of test vehicle
4	MALD	Manual location device on-board T-7 lab coach
		<u>Locomotive Transducer Locations</u>
5	1WV-1	Left vertical wheel force, lead truck, lead axle
6	1WL-1	Left lateral wheel force, lead truck, lead axle
7	1WLV1	Left lateral/vertical wheel force ratio, lead truck, lead axle
8	1MV-2	Right vertical wheel force, lead truck, trail axle
9	1WL-2	Right lateral wheel force, lead truck, trail axle
10	1WLV2	Right lateral/vertical wheel force ratio, lead truck, trail axle
11	2WV-3	Left vertical wheel force, lead truck, trail axle
12	2WL-3	Left lateral wheel force, lead truck, trail axle
13	2WLV3	Left lateral/vertical wheel force ratio, lead truck, trail axle
14	2WV-4	Right vertical wheel force, lead truck, trail axle
15	2WL-4	Right lateral wheel force, lead truck, trail axle
16	2WLV4	Right lateral/vertical wheel force ratio, lead truck, trail axle
		<u>Test Vehicle Transducer Locations</u>
17	9WV-5	Left vertical wheel force, lead axle viewed from A-end
18	9WL-5	Left lateral wheel force, lead axle viewed from A-end
19	9WLV5	Left lateral/vertical wheel force ratio, lead axle
20	9WV-6	Right vertical wheel force, lead axle
21	9WL-6	Right lateral wheel force, lead axle
22	9WLV6	Right lateral/vertical wheel force ratio, lead axle
23	9LF-1	Longitudinal axle force, lead axle
24	10WV-7	Left vertical wheel force, trail axle
25	10WL-7	Left lateral wheel force, trail axle
26	10WLV7	Left lateral/vertical wheel force ratio, trail axle
27	10WV-8	Right vertical wheel force, trail axle
28	10WL-8	Right lateral wheel force, trail axle
29	10WLV8	Right lateral/vertical wheel force ratio, trail axle
30	10LF-2	Longitudinal axle force, trail axle
31	ARZD1	Vertical spring displacement, A-end right side, as viewed from B-end
32	ALZD2	Vertical spring displacmement, A-end left side, as viewed from B-end

Table C-3. Instrumentation Summary -
Loaded Car Track Tests (Continued)

CH #	MEAS #	Description/Location of the Transducers
		Test Vehicle Transducer Locations (Continued)
33	BRZD3	Vertical spring displacement, B-end right side, as viewed from B-end
34	BLZD4	Vertical spring displacement, B-end left side, as viewed from B-end
35	ARYD1	Longitudinal axle yaw displacement, A-end right side, as viewed from B-end
36	ALYD2	Longitudinal axle yaw displacement, A-end left side, as viewed from B-end
37	BRYD3	Longitudinal axle yaw displacement, B-end right side, as viewed from B-end
38	BLYD4	Longitudinal axle yaw displacement, B-end left side, as viewed from B-end
39	ALXD1	Lateral axle displacement, B-end left side, as viewed from B-end
40	BLXD2	Lateral axle displacement, A-end left side, as viewed from B-end
41	ARG-1	Car body roll, test vehicle A-end
42	BRG-2	Car body roll, test vehicle B-end
43	TRG-3	Trailer roll, test trailer tandem end
44	ARXA1	Lateral car body accelerometer, A-end right corner, as viewed from B-end
45	CZA1	Lateral car body accelerometer, center
46	ARZA2	Vertical car body accelerometer, A-end right corner, aas viewed from B-end
47	CXA3	Vertical car body accelerometer, center
48	BRXA2	Lateral car body accelerometer, B-end right corner, as viewed from B-end
49	BRZA3	Vertical car body accelerometer, B-end right corner, as viewed from B-end
50	TRZA4	Vertical trailer accelerometer, tandem A-end, as viewed from B-end
51	TRXA4	Lateral trailer accelerometer, right corner tandem end
52	TRZD5	Vertical trailer displacement, right corner tandem end
53	TRXD3	Lateral trailer displacement, right corner tandem end
54	TRZD6	Vertical trailer axle displacement, right trailing trailer axle
55	ALXA5	Lateral bearing adapter accelerometer, A-end left side, as viewed from B-end
56	BLXA6	Lateral bearing adapter accelerometer, B-end left side, as viewed from B-end
57	TCYD5	Longitudinal trailer displacement, center B-end hitch end
58	TRXD4	Lateral trailer displacement, left corner hitch end

* All tests performed with B-end leading

Table C-4. Instrumentation Summary - Buff and Draft Simulation Tests

CH #	MEAS #	Description/Location of the Transducers
1	TACH	Consist speed recorded from T-7 lab coach tachometer
2	ALD1	Automatic location device, leading end of locomotive
3	ALD2	Automatic location device, leading end of test vehicle
4	MALD	Manual location device, on-board T-7 lab coach
		Test Vehicle Transducer Locations
5	1WV-1	Left vertical wheel force, lead truck, lead axle
6	1WL-1	Left lateral wheel force, lead truck, lead axle
7	1WLV1	Left lateral/vertical wheel force ratio, lead truck, lead axle
8	1WV-2	Right vertical wheel force, lead truck, trail axle
9	1WL-2	Right lateral wheel force, lead truck, trail axle
10	1WLV2	Right lateral/vertical wheel force ratio, lead truck, trail axle
11	2WV-3	Left vertical wheel force, lead truck, trail axle
12	2WL-3	Left lateral wheel force, lead truck, trail axle
13	2WLV3	Left lateral/vertical wheel force ratio, lead truck, trail axle
14	2WV-4	Right vertical wheel force, lead truck, trail axle
15	2WL-4	Right lateral wheel force, lead truck, trail axle
16	2WLV4	Right lateral/vertical wheel force ratio, lead truck, trail axle
		Test Vehicle Transducer Locations
17	9WV-5	Left vertical wheel force, lead axle viewed from A-end
18	9WL-5	Left lateral wheel force, lead axle viewed from A-end
19	9WLV5	Left lateral/vertical wheel force ratio, lead axle
20	9WV-6	Right vertical wheel force, lead axle
21	9WL-6	Right lateral wheel force, lead axle
22	9WLV6	Right lateral/vertical wheel force ratio, lead axle
23	9LF-1	Longitudinal axle force, lead axle
24	10WV-7	Left vertical wheel force, trail axle
25	10WL-7	Left lateral wheel force, trail axle
26	10WLV7	Left lateral/vertical wheel force ratio, trail axle
27	10MV-8	Right vertical wheel force, trail axle
28	10WL-8	Right lateral wheel force, trail axle
29	10WLV8	Right lateral/vertical wheel force ratio, trail axle
30	10LF-2	Longitudinal axle force, trail axle
31	ARZD1	Vertical spring displacement, A-end right side, as viewed from B-end
32	ALZD2	Vertical spring displacement, A-end left side, as viewed from B-end

Additional Data Plots - Track Tests

Table C-4. Instrumentation Summary - Buff and Draft Simulation Tests (Continued)

CH #	MEAS #	Description/Location of the Transducers
		Test Vehicle Transducer Locations (Continued)
33	BRZD3	Vertical spring displacement, B-end right side, as viewed from B-end
34	BLZD4	Vertical spring displacement, B-end left side, as viewed from B-end
35	ARYD1	Longitudinal axle yaw displacement, A-end right side, as viewed from B-end
36	ALYD2	Longitudinal axle yaw displacement, A-end left side, as viewed from B-end
37	BRYD3	Longitudinal axle yaw displacement, B-end right side, as viewed from B-end
38	BLYD4	Longitudinal axle yaw displacement, B-end left side, as viewed from B-end
39	ALXD1	Lateral axle displacement, B-end left side, as viewed from B-end
40	BLXD2	Lateral axle displacement, A-end left side, as viewed from B-end
41	ARG-1	Car body roll, test vehicle A-end
42	BRG-2	Car body roll, test vehicle B-end
43	ARXA1	Lateral car body accelerometer, A-end right corner, as viewed from B-end
44	CZA1	Lateral car body accelerometer, center
45	ARZA2	Vertical car body accelerometer, A-end right corner, as viewed from B-end
46	CXA3	Vertical car body accelerometer, center
47	BRXA2	Lateral car body accelerometer, B-end right corner, as viewed from B-end
48	BRZA3	Vertical car body accelerometer, B-end right corner, as viewed from B-end
49	ARYD5	Longitudinal car displacement between load car and test car, A-end right side
50	ALYD6	Longitudinal car displacement between load car and test car, A-end left side
51	RCXD3	Lateral car displacement between load car and test car, A-end
52	RCZD5	Vertical car displacement between load car and test car, A-end
53	ALXA5	Lateral bearing adapter accelerometer, A-end left side, as viewed from B-end
54	BLXA6	Lateral bearing adapter accelerometer, B-end left side, as viewed from B-end
55	RCXF1	Lateral actuator force between load car and test car, A-end
56	RCZF1	Vertical actuator force between load car and test car, A-end

* All tests performed with B-end leading. Buff and draft simulated loads reacted at the A-end of the test vehicle.

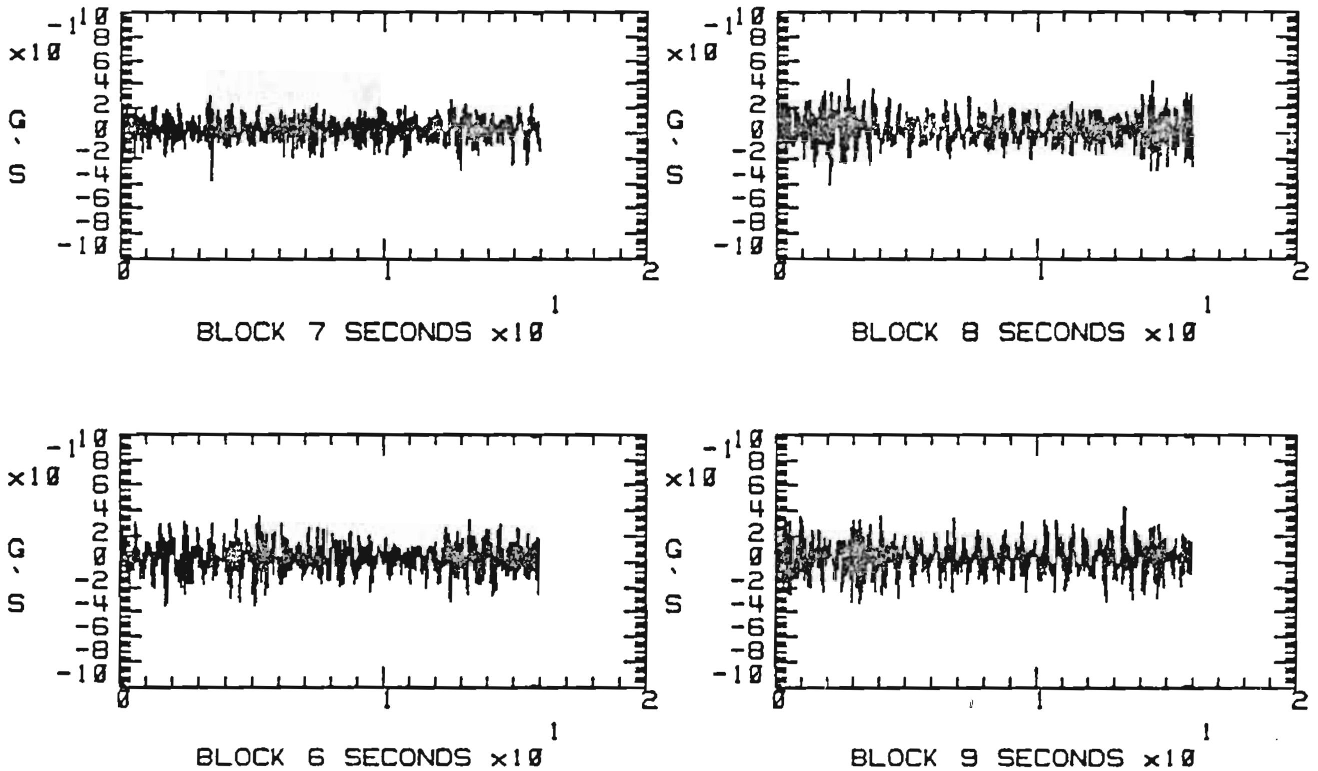


FIG. C-37   EMPTY HUNTING TEST 40 MPH B-END ACCELEROMETER

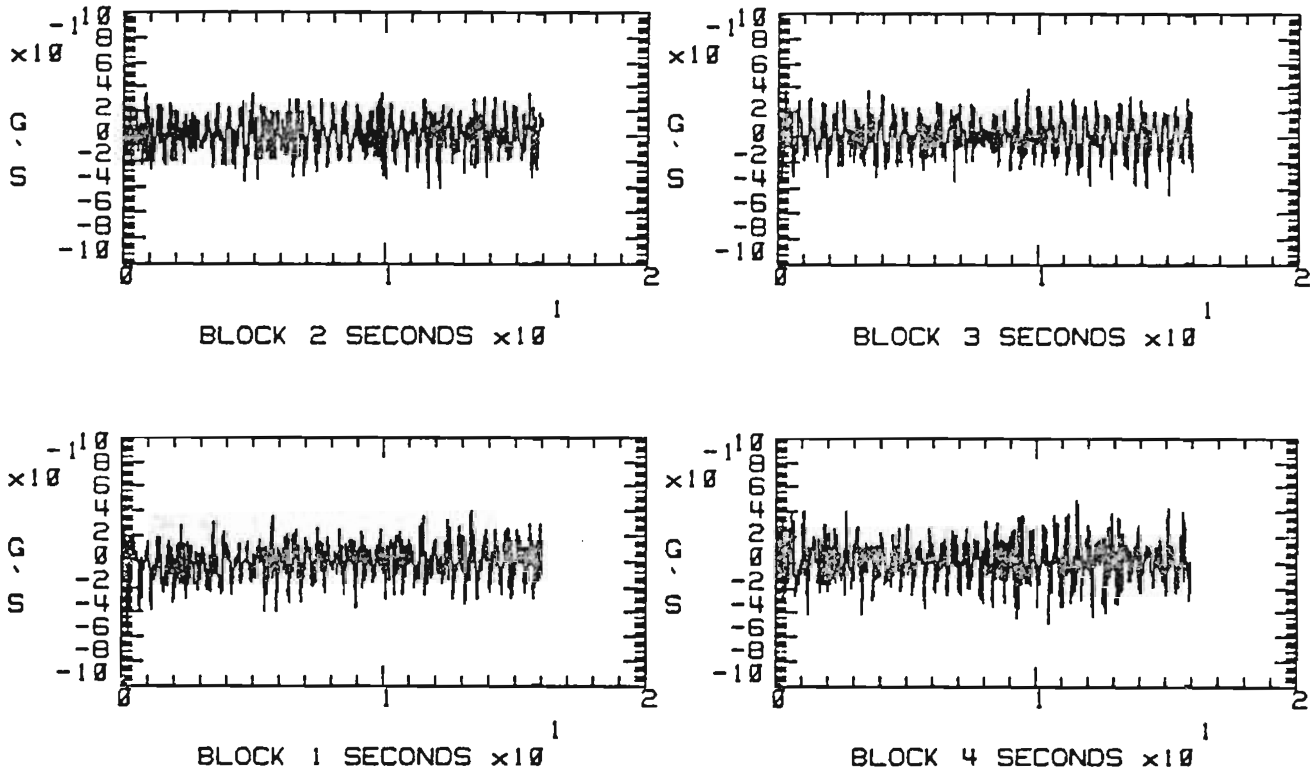


FIG. C-39 EMPTY HUNTING TEST 60 MPH B-END ACCELEROMETER

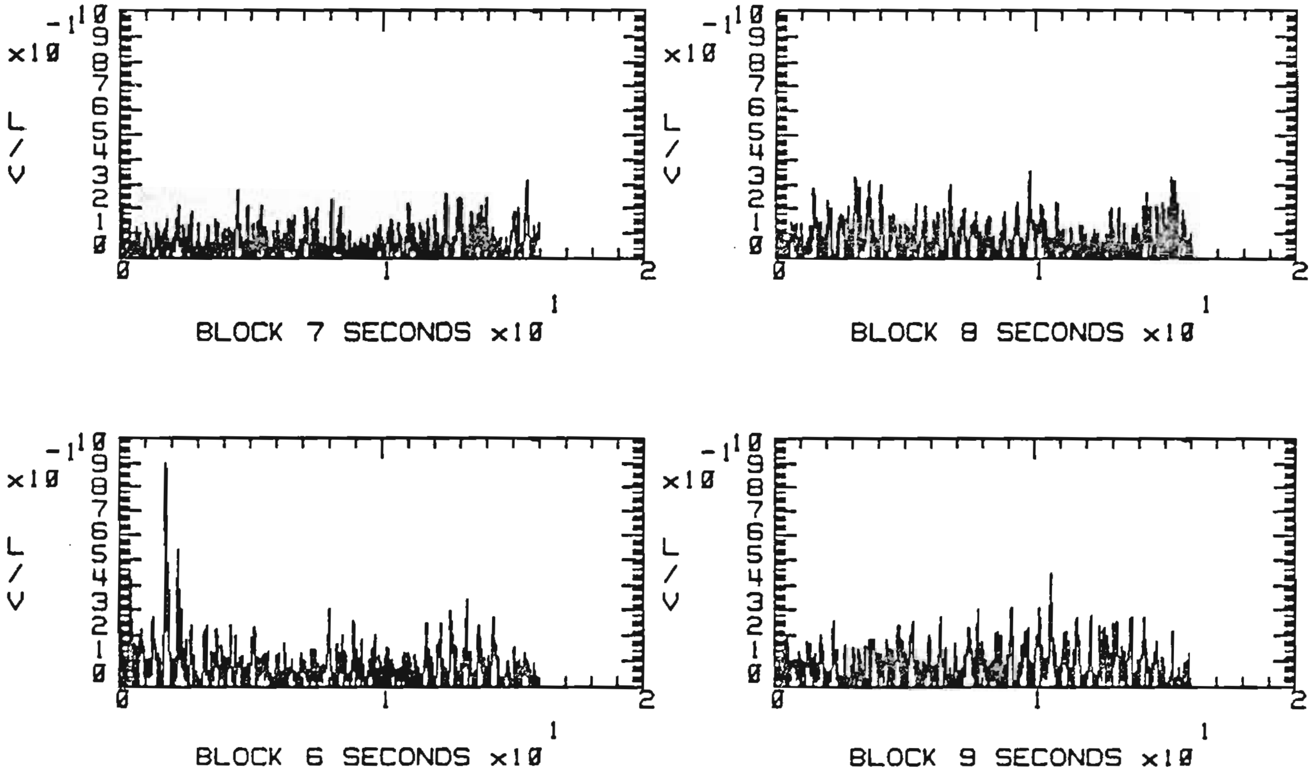


FIG. C-38 EMPTY HUNTING TEST 40 MPH LEADING SUM L/V AXLE

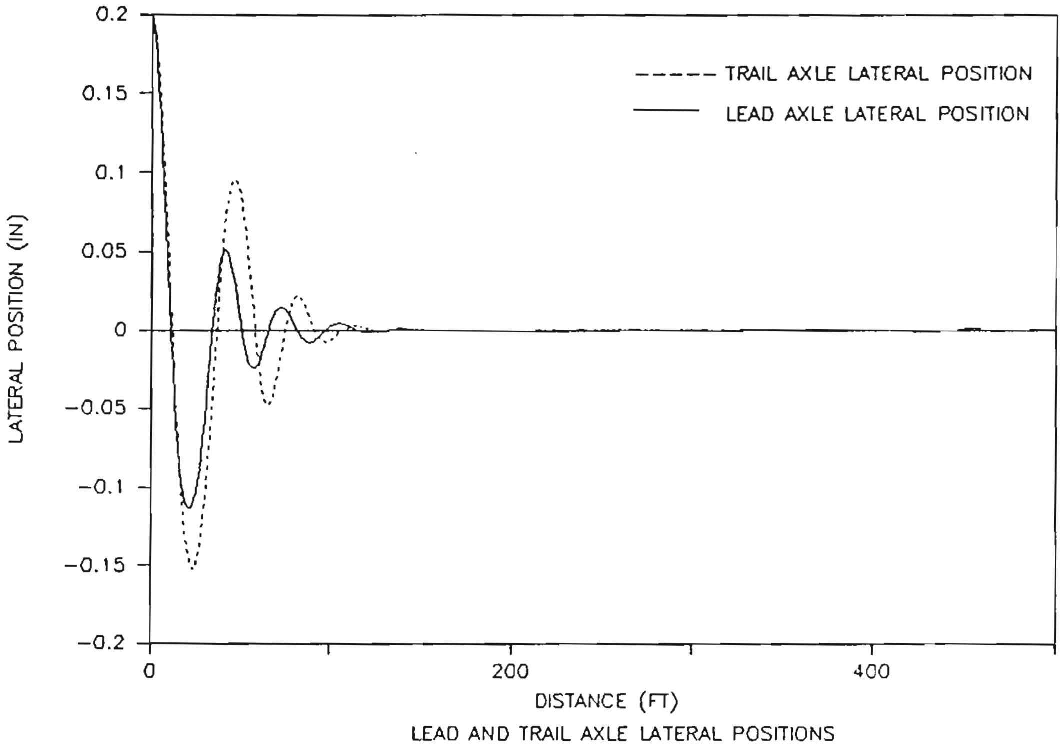


FIG.C-41 40 MPH HUNTING MATH MODEL

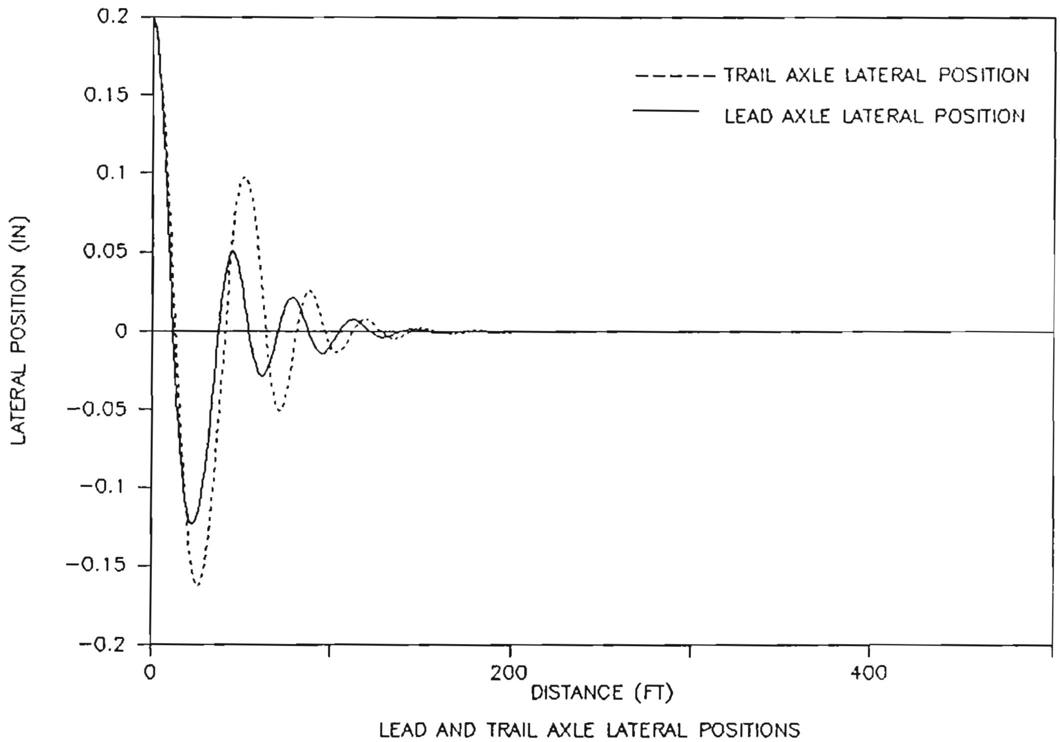


FIG.C-42 60 MPH HUNTING MATH MODEL

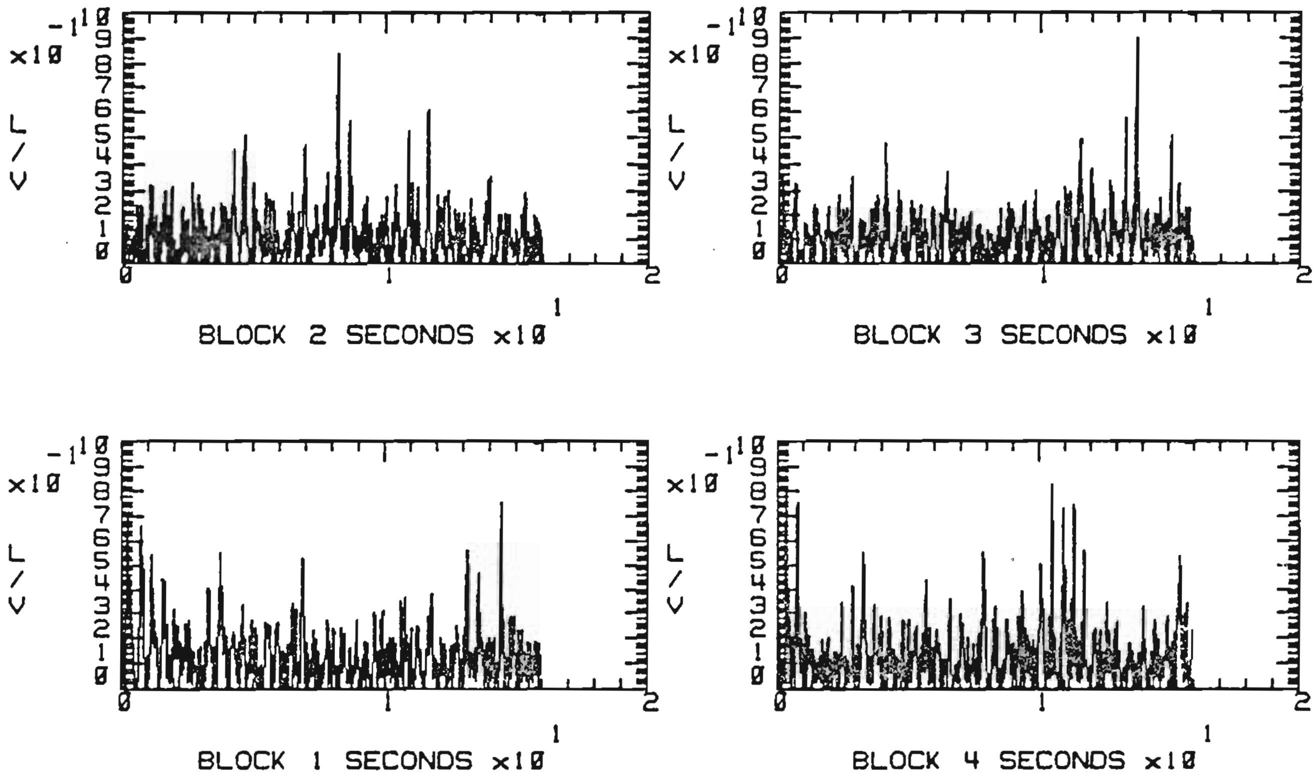


FIG. C-40 EMPTY HUNTING TEST 60 MPH LEADING SUM L/V AXLE

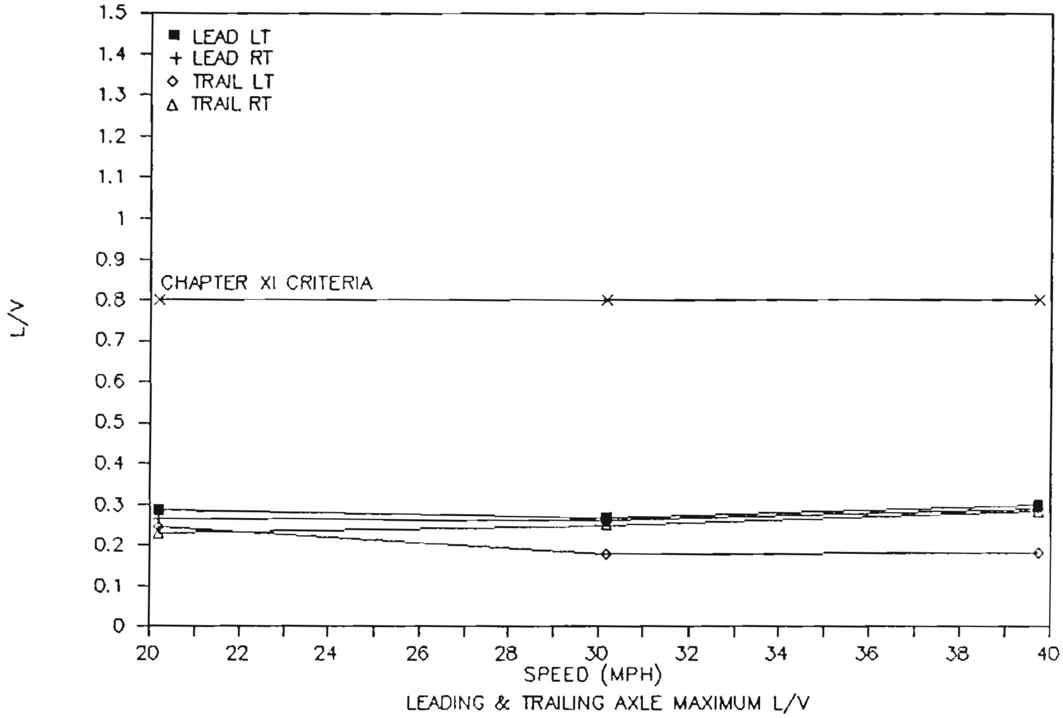


FIG.C-45 LOADED CAR STEADY STATE CURVE CCW

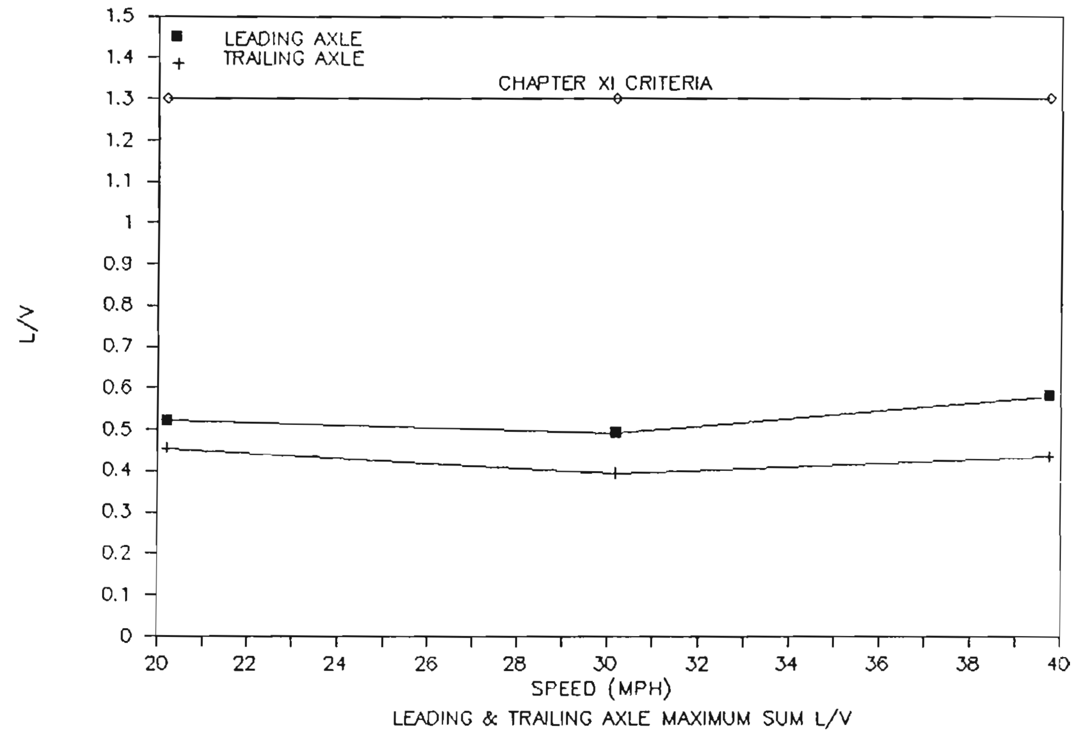


FIG.C-46 LOADED CAR STEADY STATE CURVE CCW

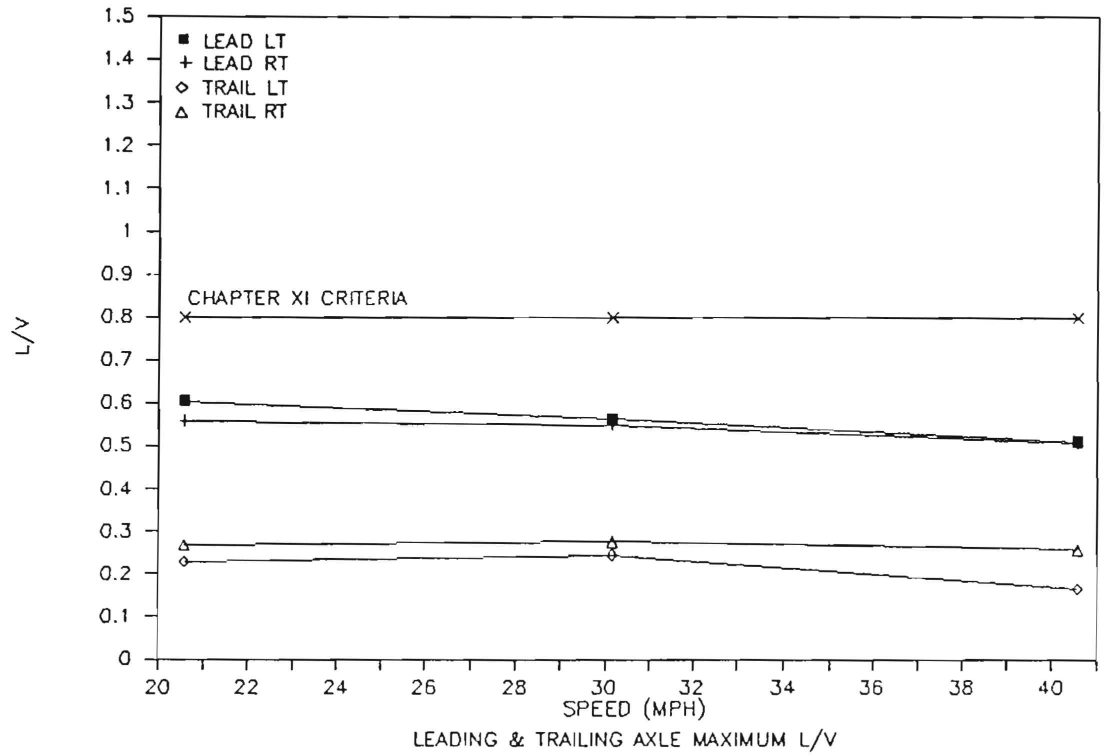


FIG.C-43 EMPTY CAR STEADY STATE CURVE CCW

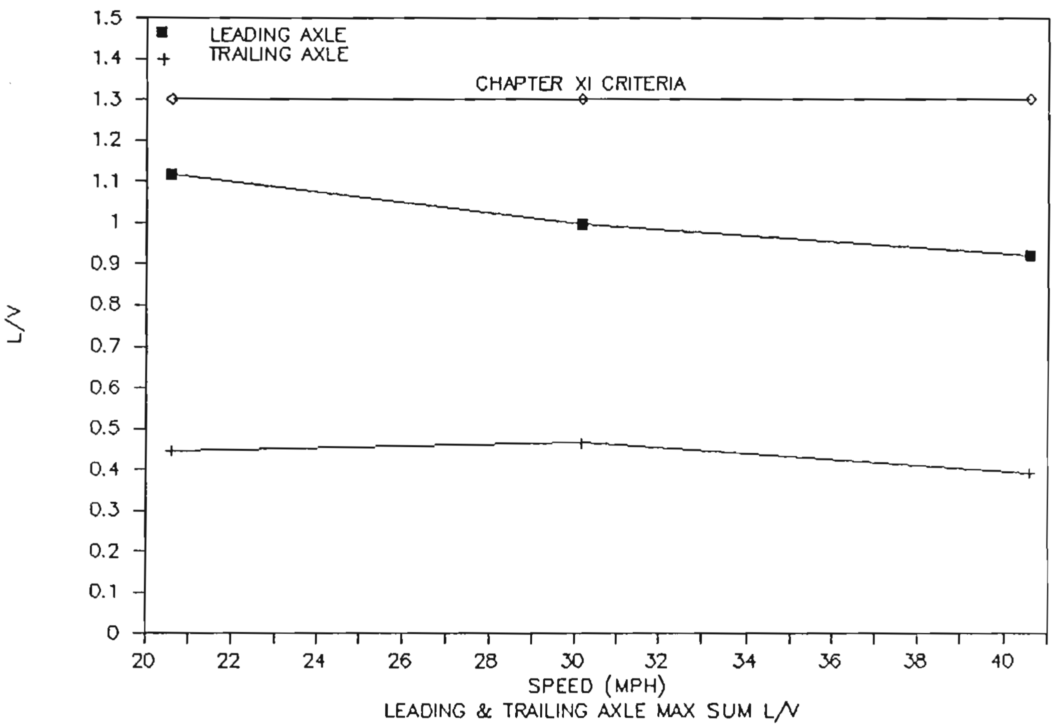


FIG.C-44 EMPTY CAR STEADY STATE CURVE CCW

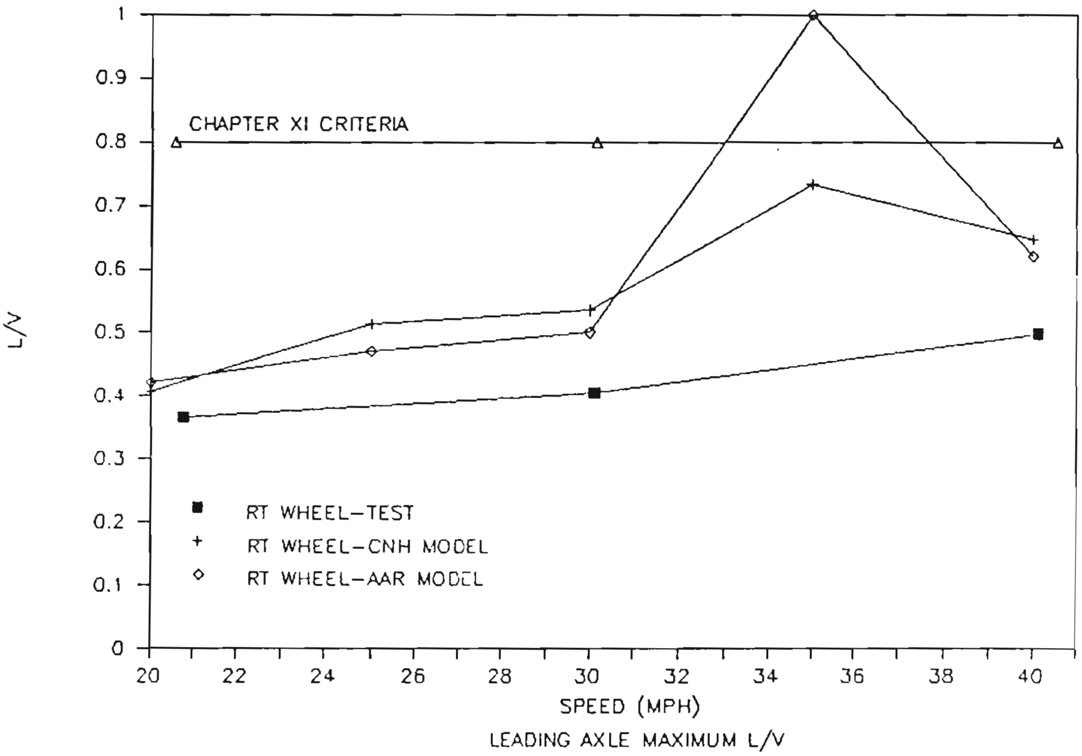


FIG.C-49 EMPTY CAR BUNCHED SPIRAL ENTRY CCW

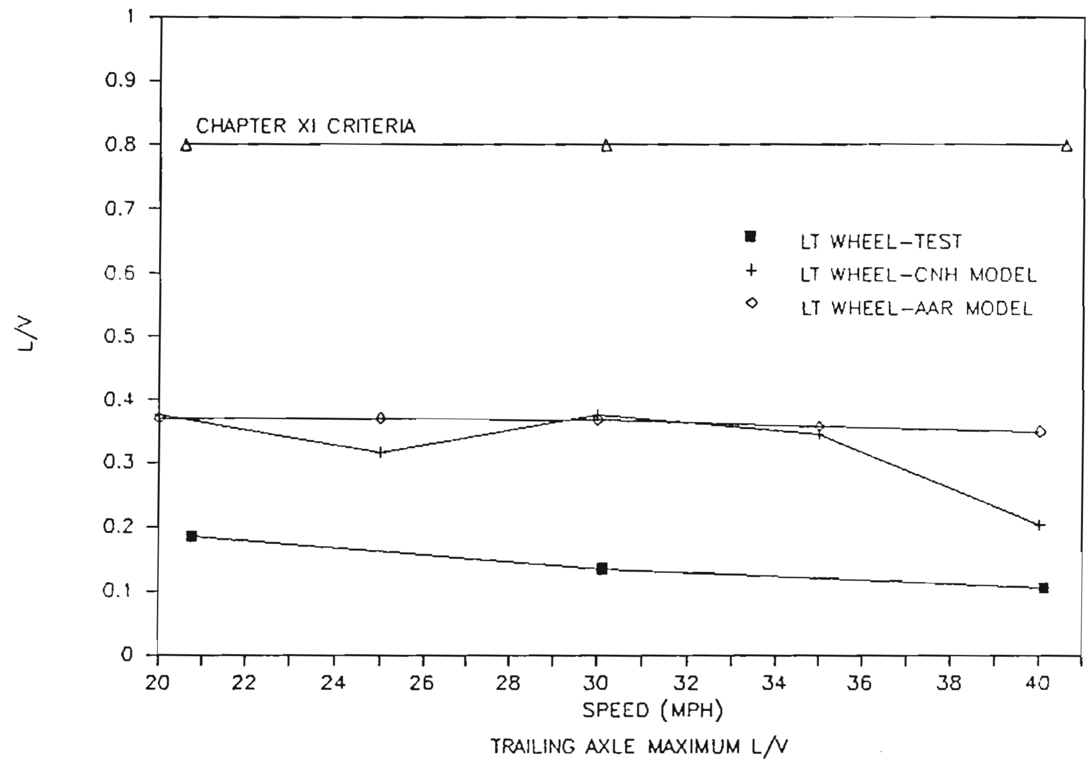


FIG.C-50 EMPTY CAR BUNCHED SPIRAL ENTRY CCW

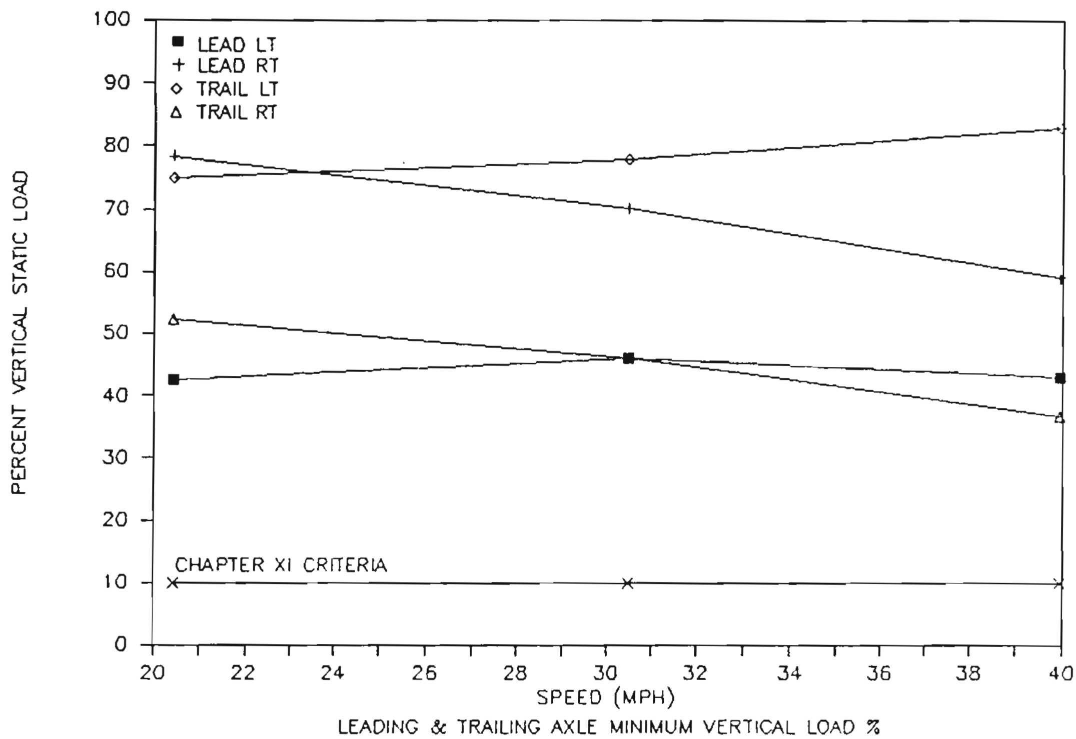


FIG.C-47 EMPTY CAR BUNCHED SPIRAL EXIT CW

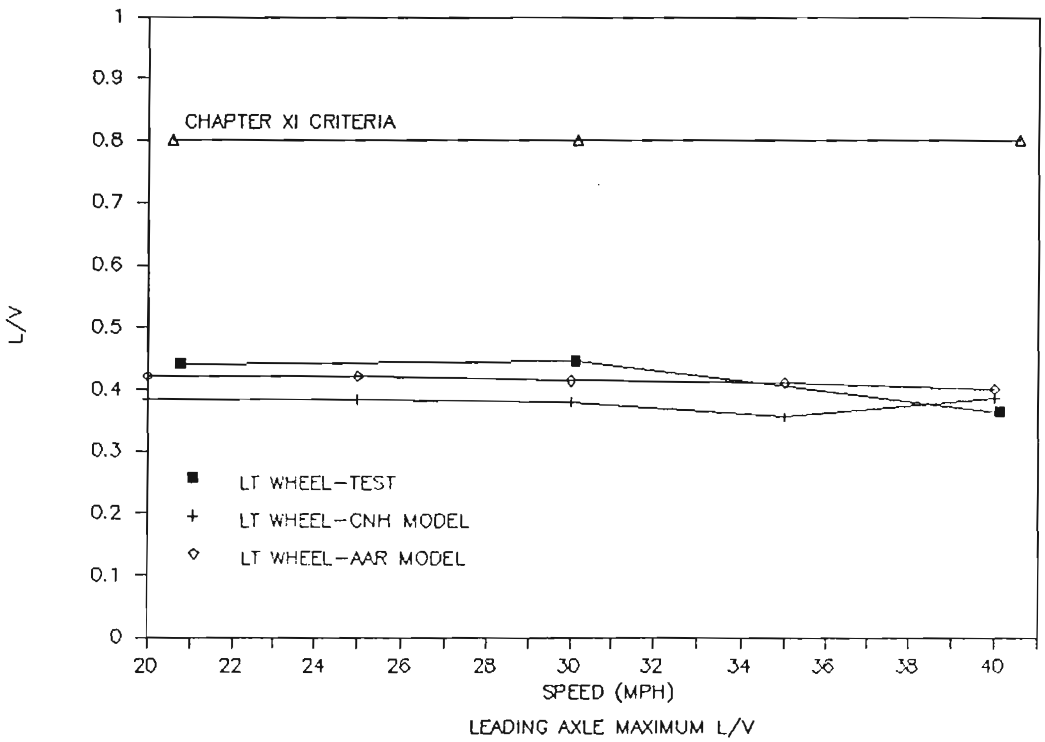


FIG.C-48 EMPTY CAR BUNCHED SPIRAL ENTRY CCW

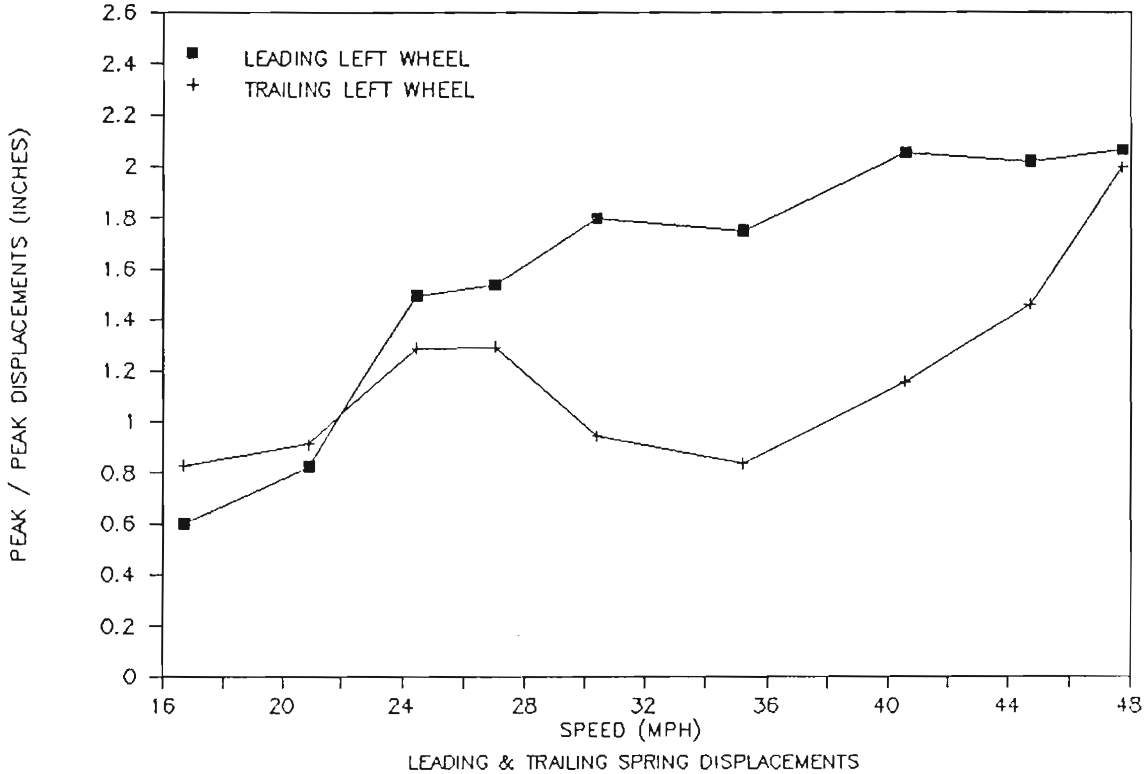


FIG.C-52 LOADED CAR SINGLE BOUNCE

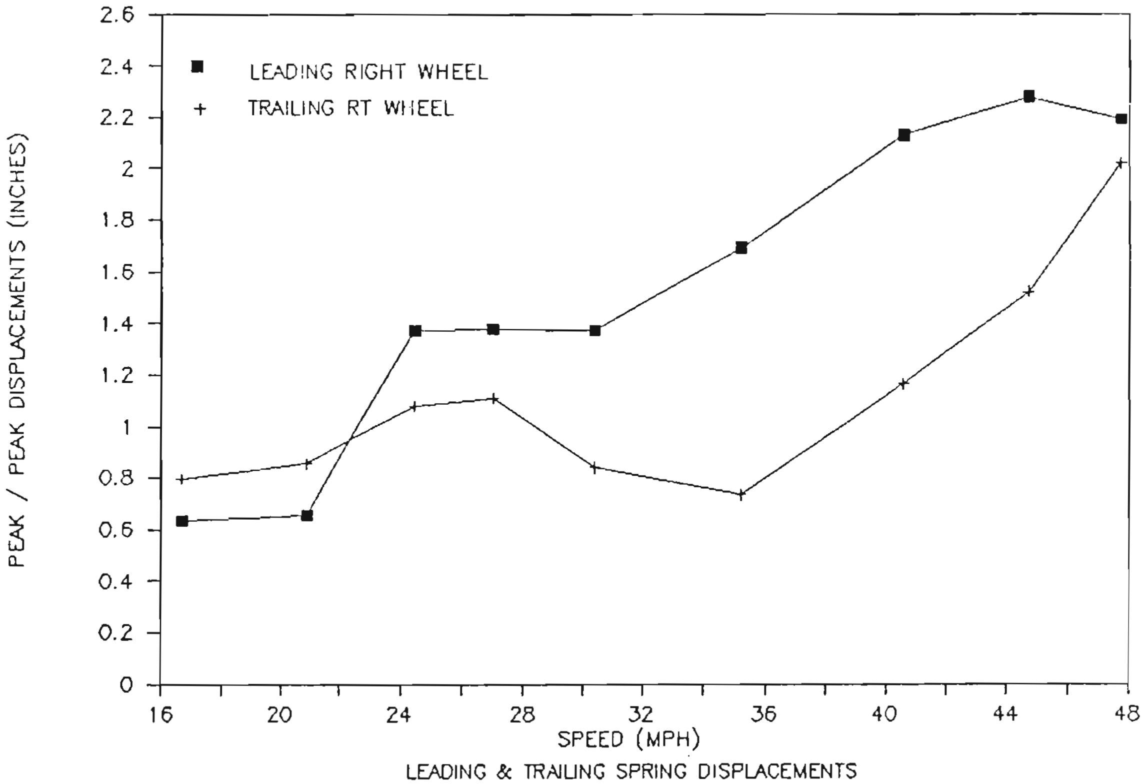


FIG.C-53 LOADED CAR SINGLE BOUNCE

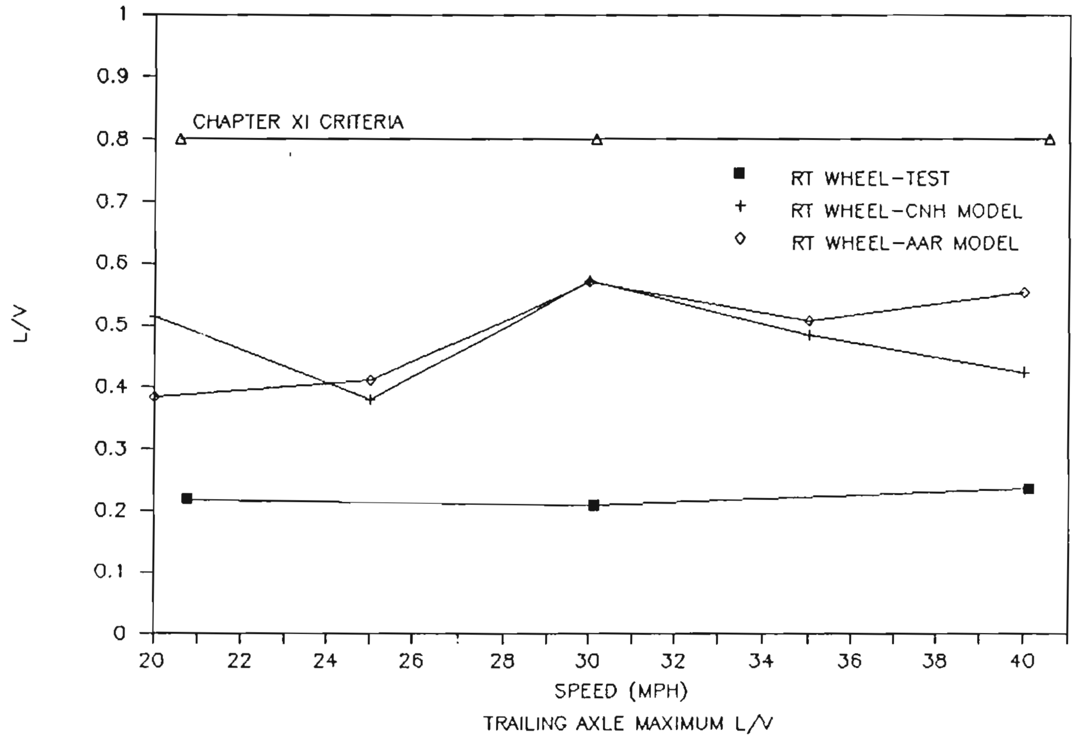


FIG.C-51 EMPTY CAR BUNCHED SPIRAL ENTRY CCW

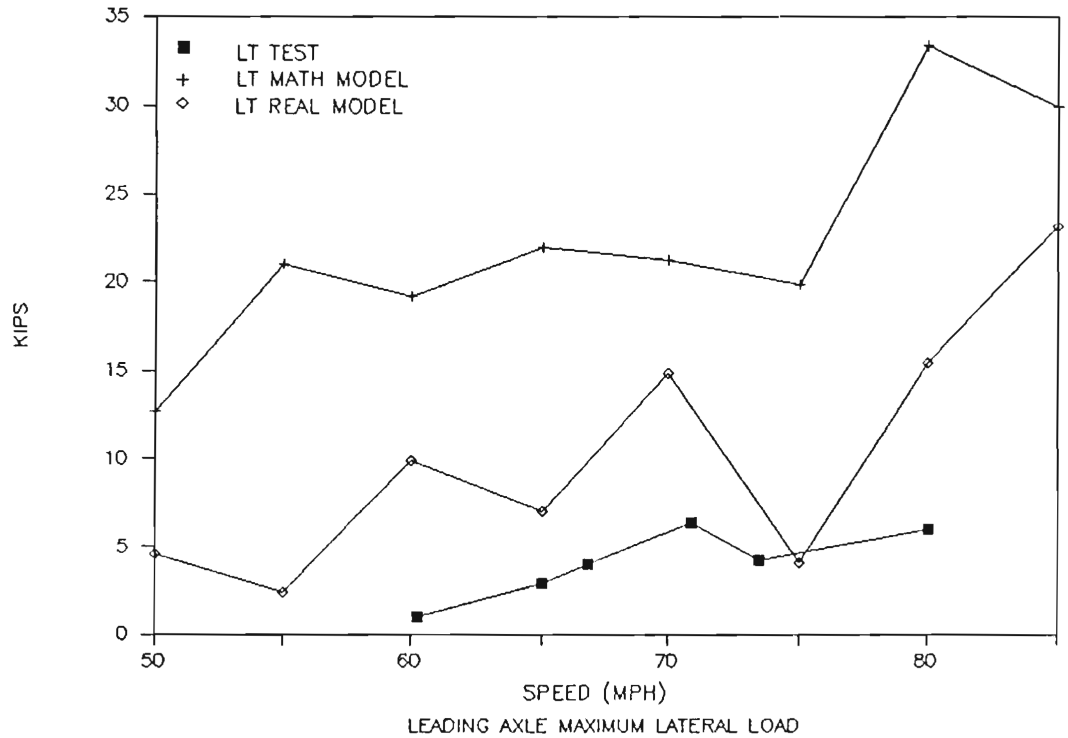


FIG.C-56 EMPTY CAR YAW/SWAY

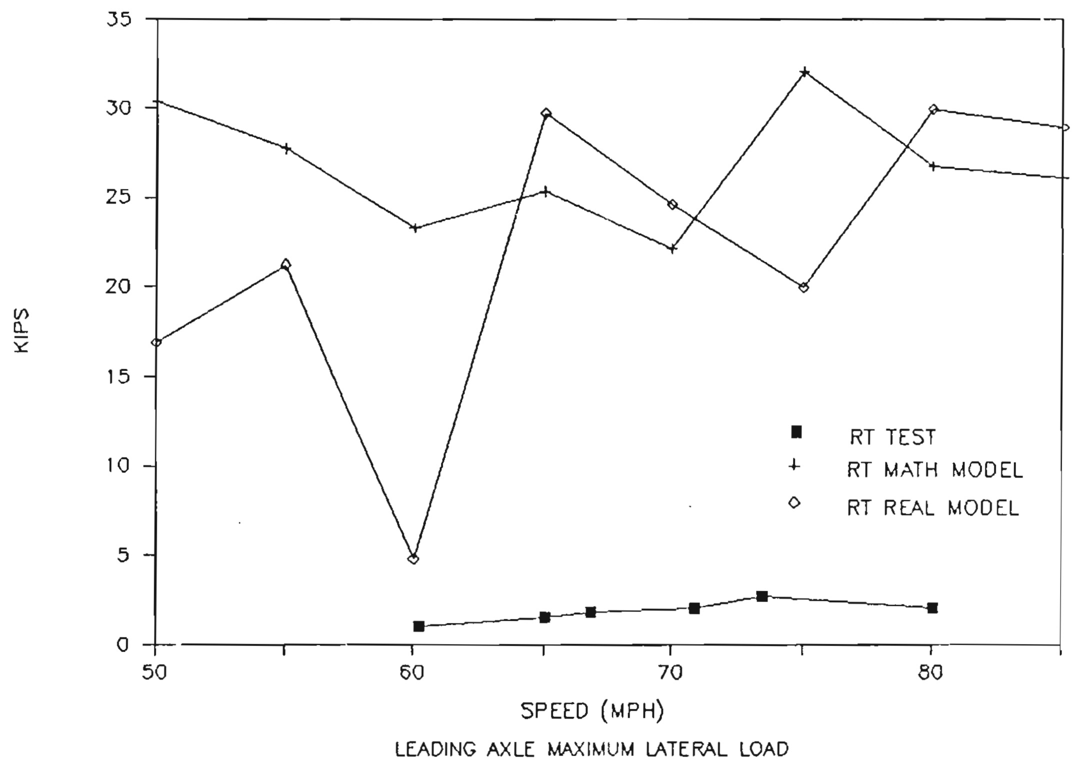


FIG.C-57 EMPTY CAR YAW/SWAY

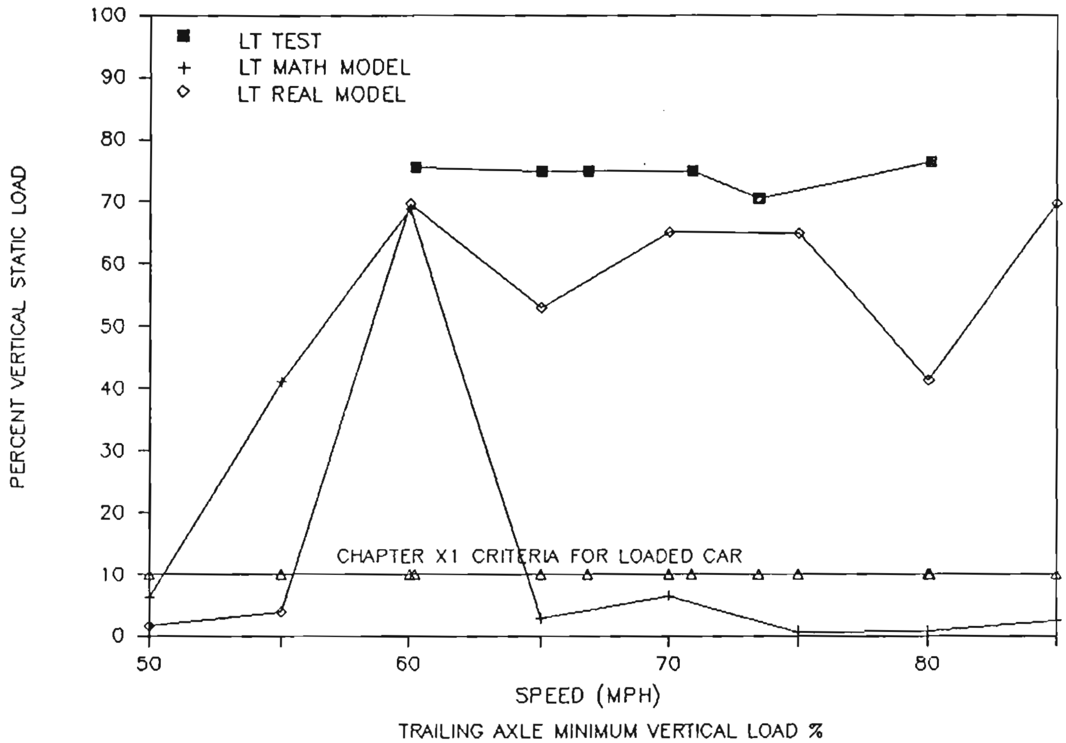


FIG.C-54 EMPTY CAR YAW/SWAY

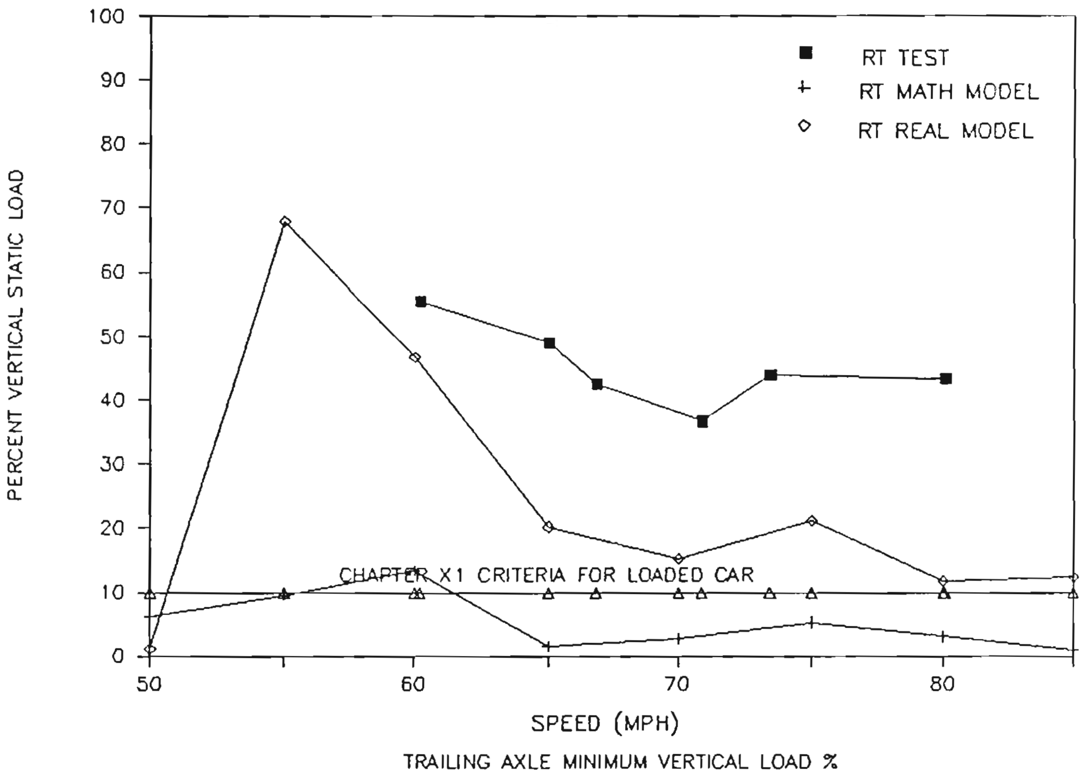


FIG.C-55 EMPTY CAR YAW/SWAY

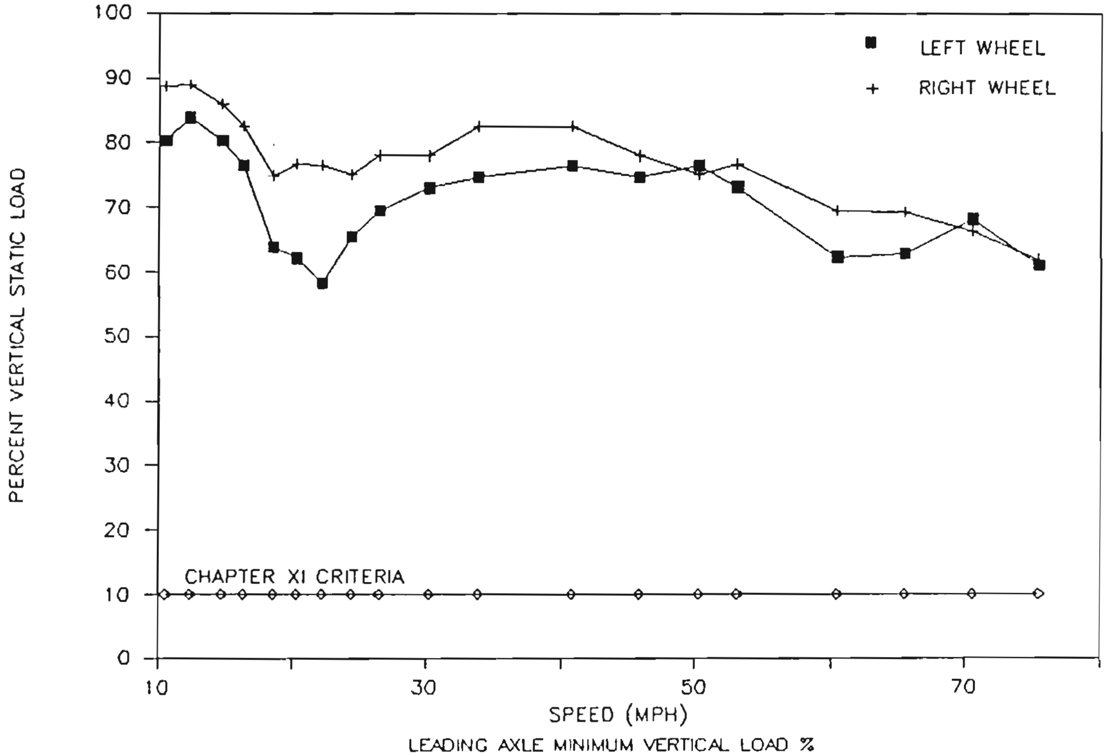


FIG.C-60 LOADED CAR YAW/SWAY

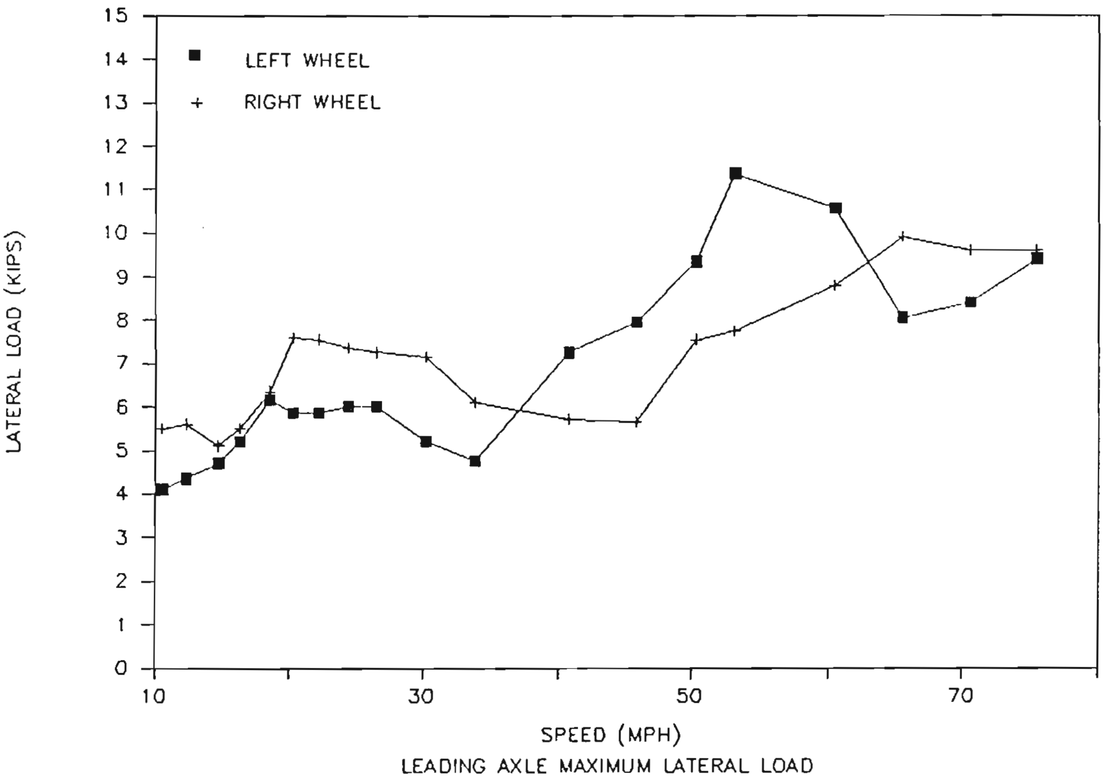


FIG.C-61 LOADED CAR YAW/SWAY

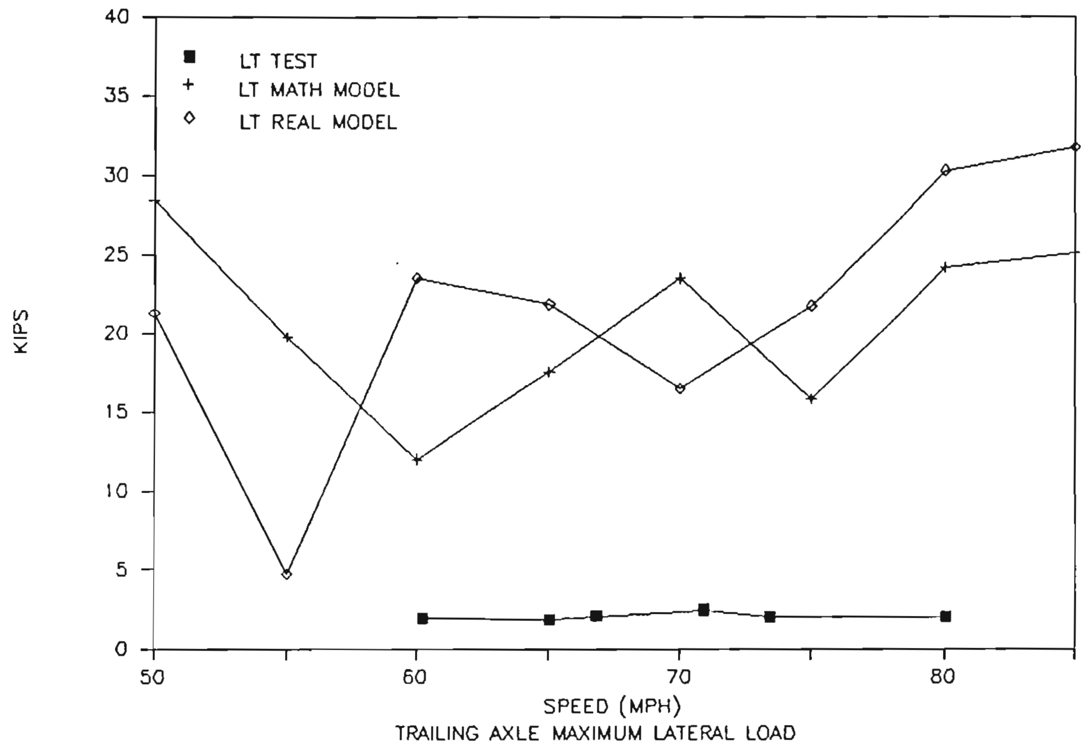


FIG.C−58 EMPTY CAR YAW/SWAY

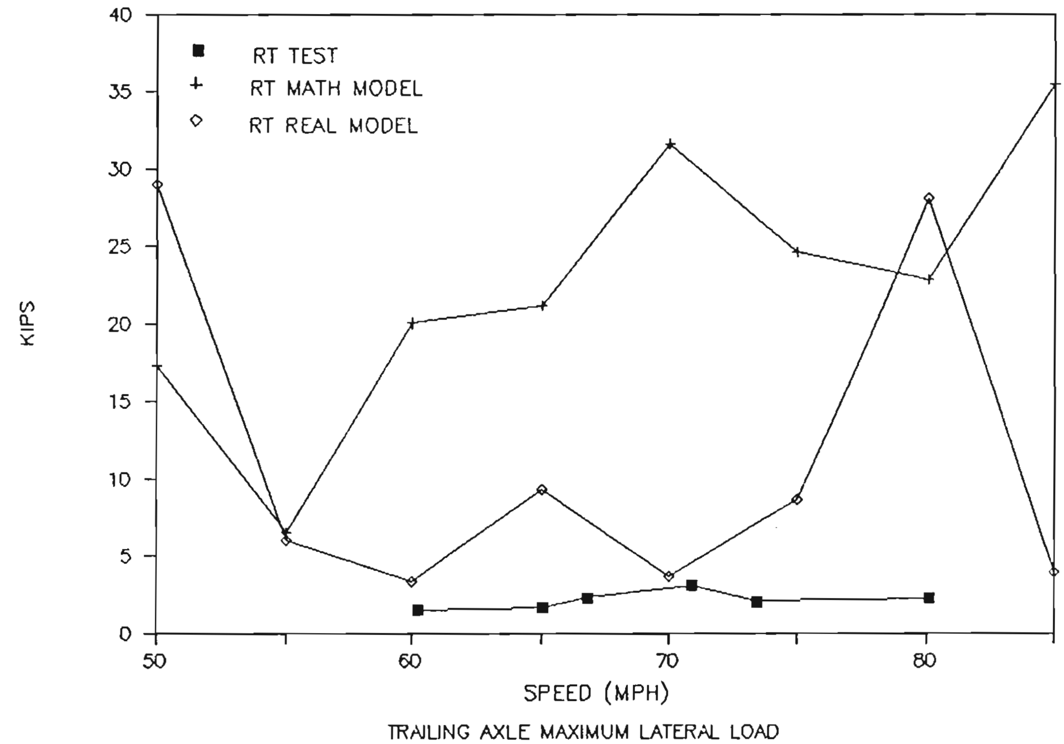


FIG.C−59 EMPTY CAR YAW/SWAY

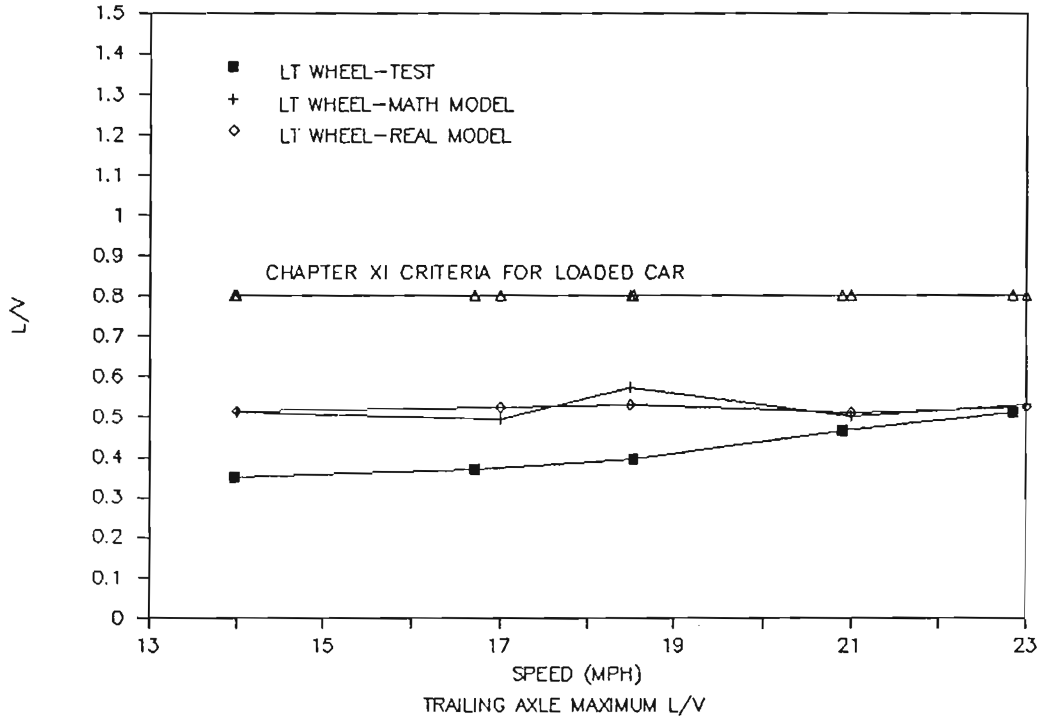


FIG.C-63 EMPTY CAR DYNAMIC CURVE CCW

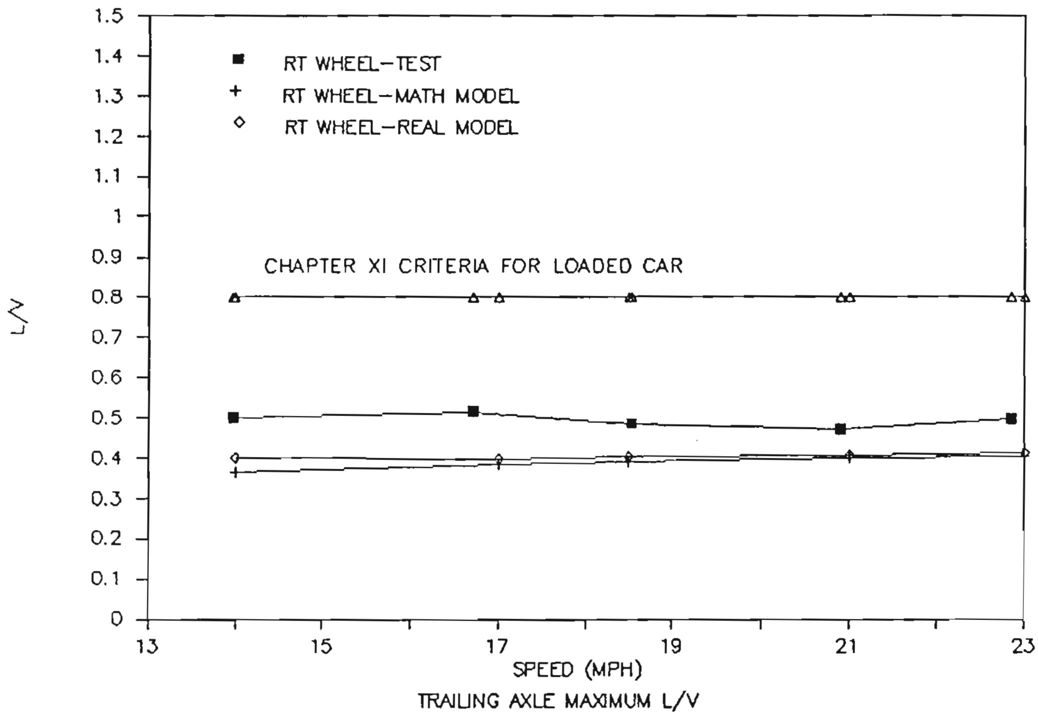
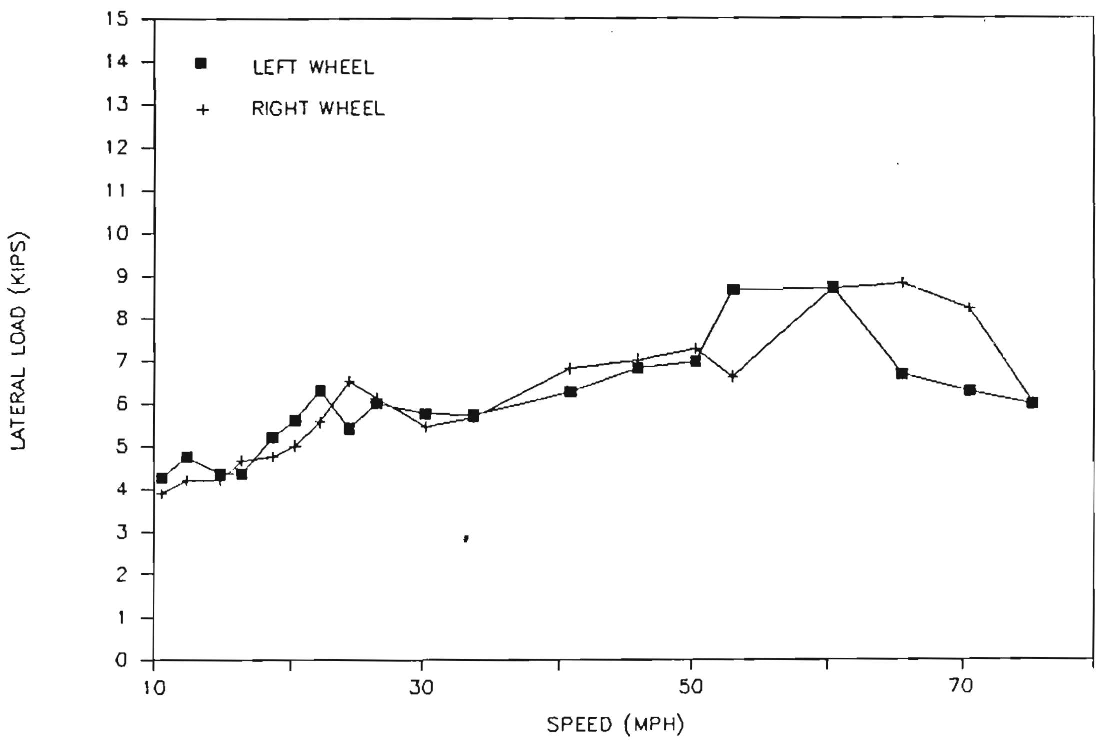


FIG.C-64 EMPTY CAR DYNAMIC CURVE CCW



TRAILING AXLE MAXIMUM LATERAL LOAD

FIG.C-62 LOADED CAR YAW/SWAY

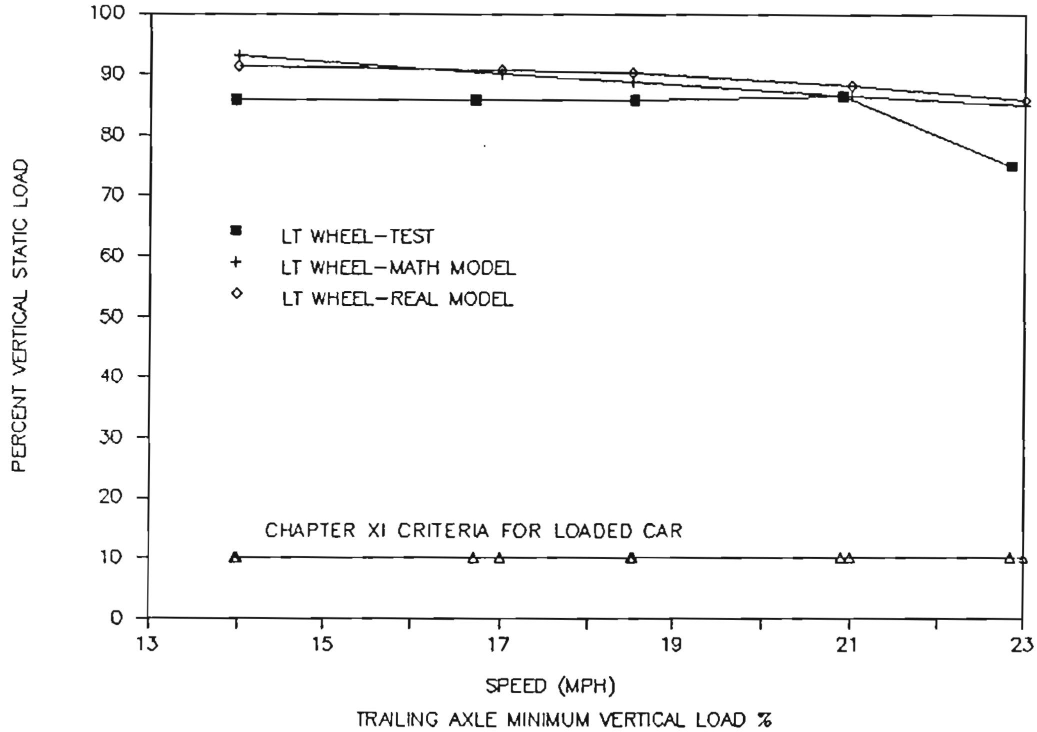


FIG.C-67 EMPTY CAR DYNAMIC CURVE CCW

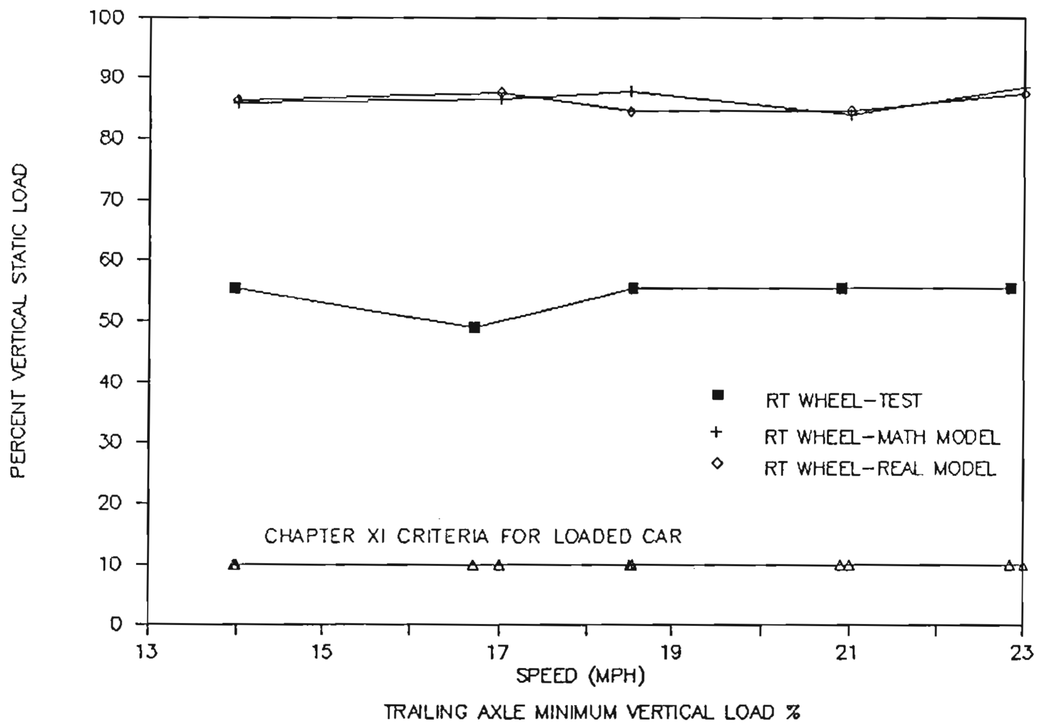


FIG.C-68 EMPTY CAR DYNAMIC CURVE CCW

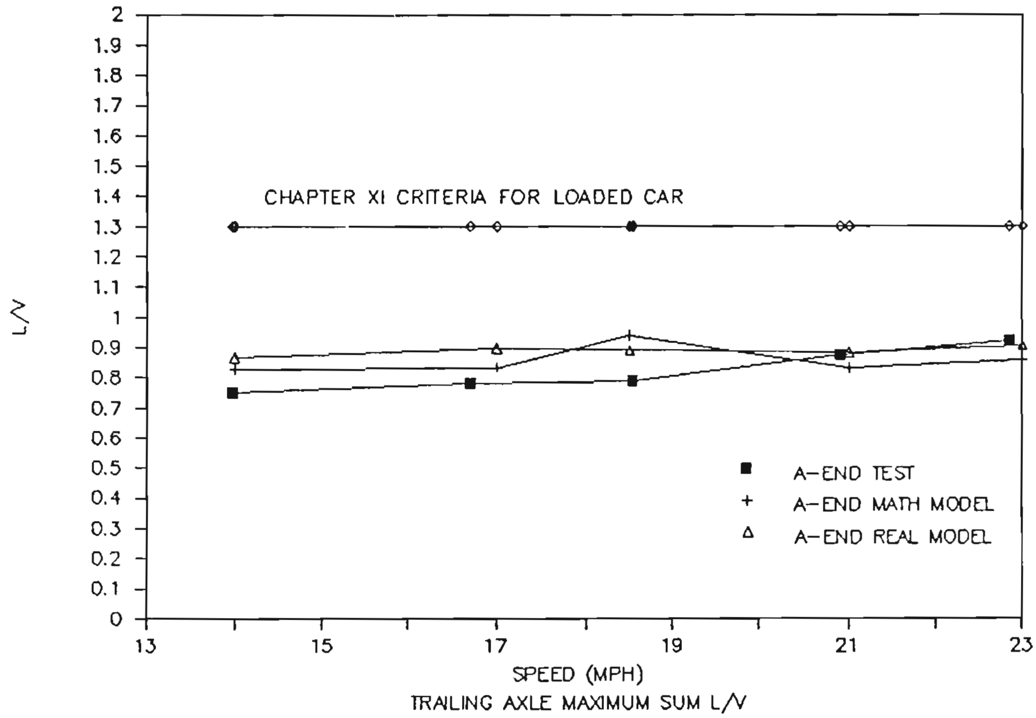


FIG.C-65 EMPTY CAR DYNAMIC CURVE CCW

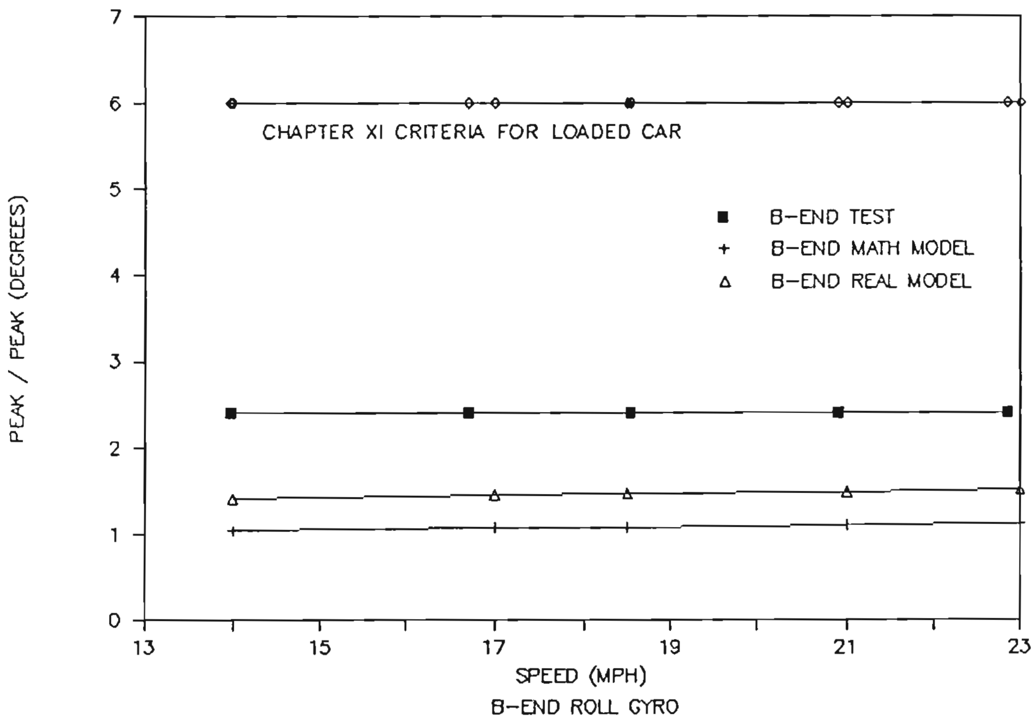


FIG.C-66 EMPTY CAR DYNAMIC CURVE CCW

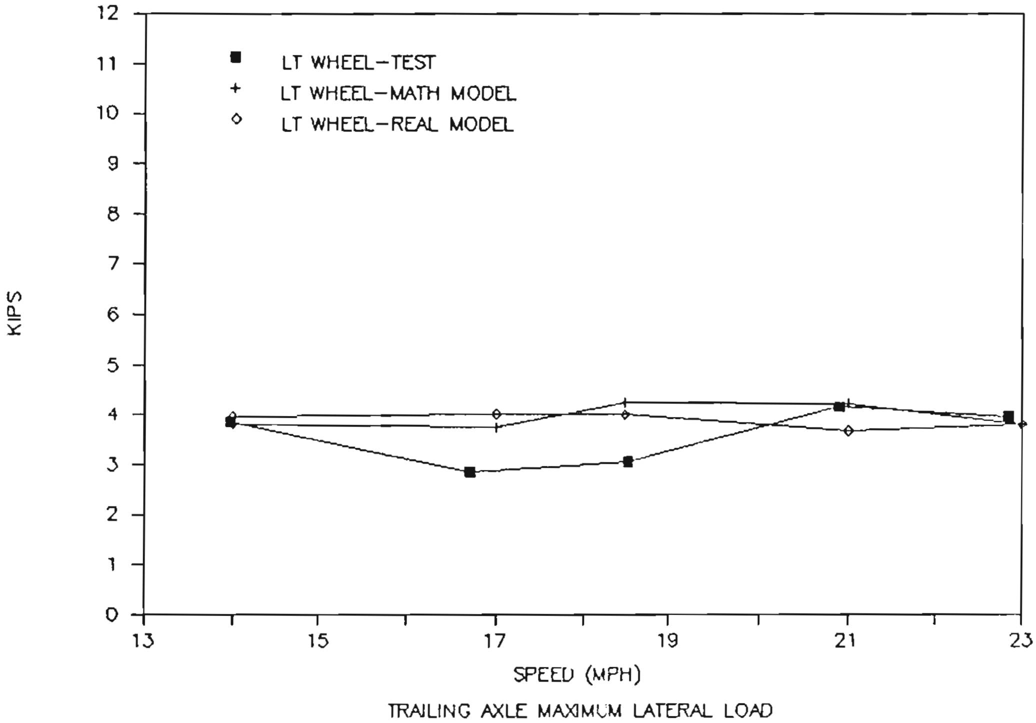


FIG.C-71 EMPTY CAR DYNAMIC CURVE CCW

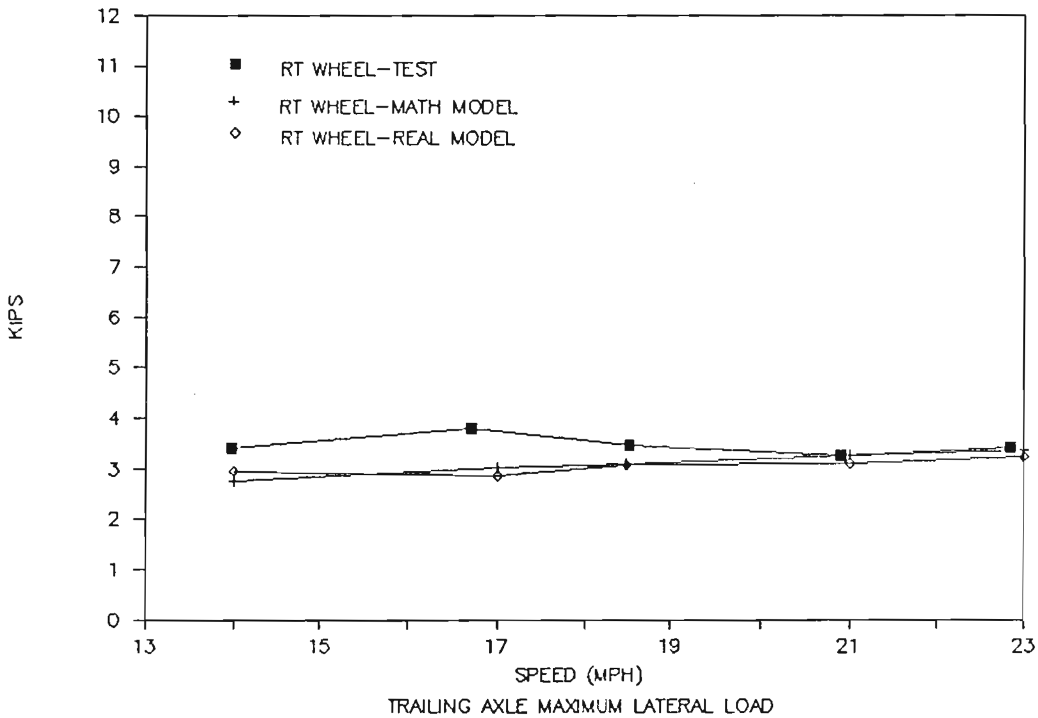


FIG.C-72 EMPTY CAR DYNAMIC CURVE CCW

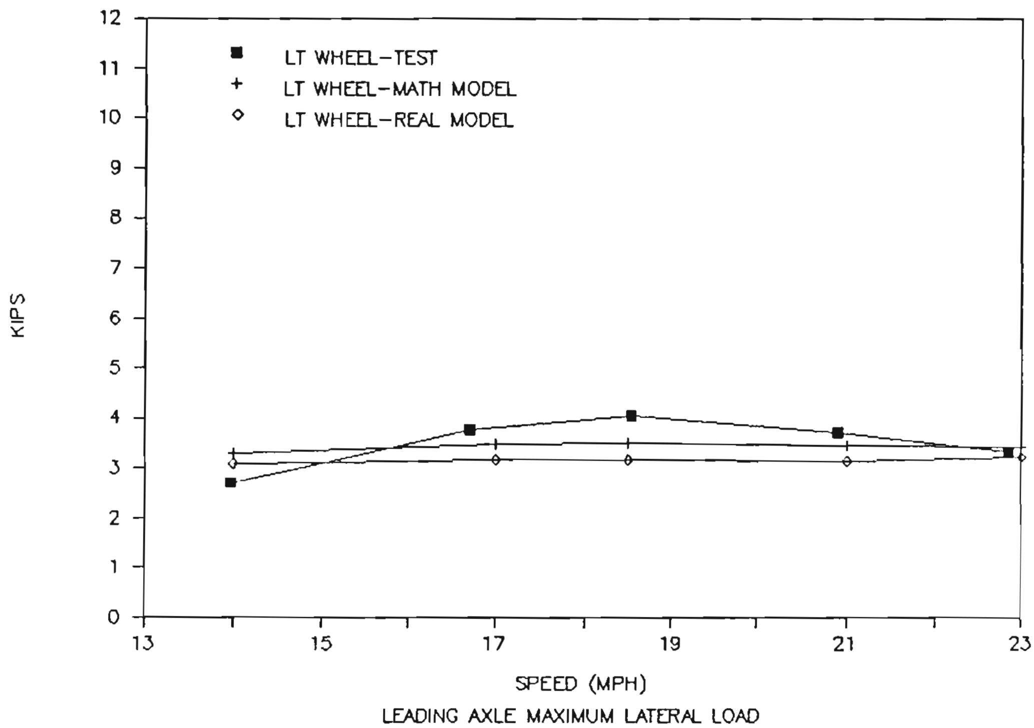


FIG.C-69 EMPTY CAR DYNAMIC CURVE CCW

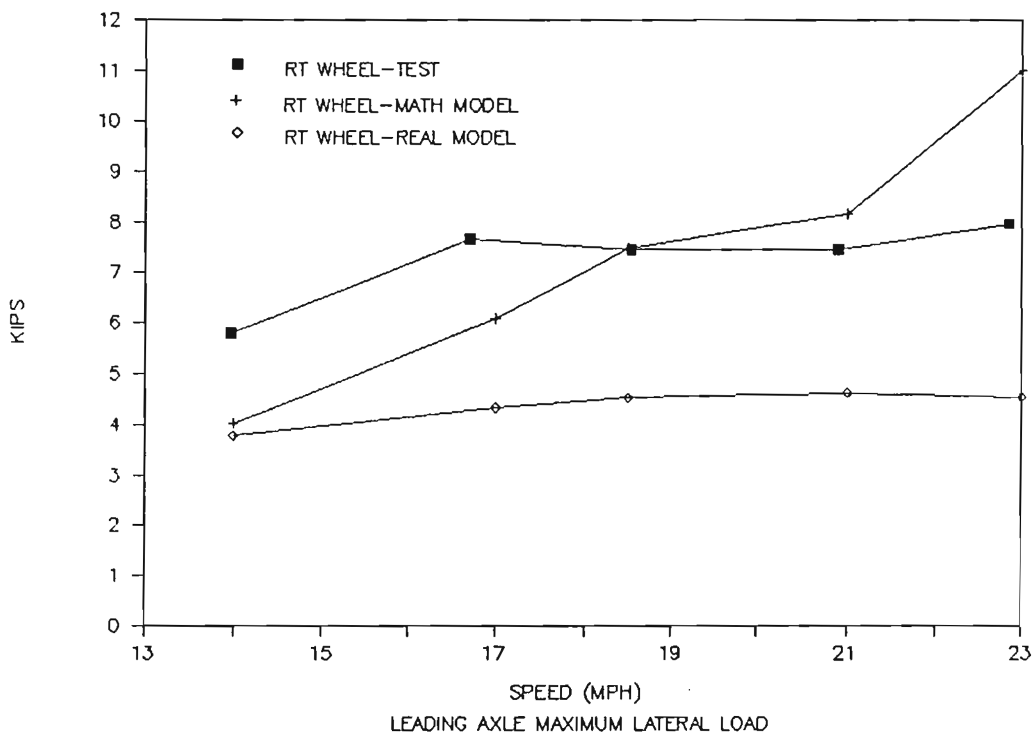


FIG.C-70 EMPTY CAR DYNAMIC CURVE CCW

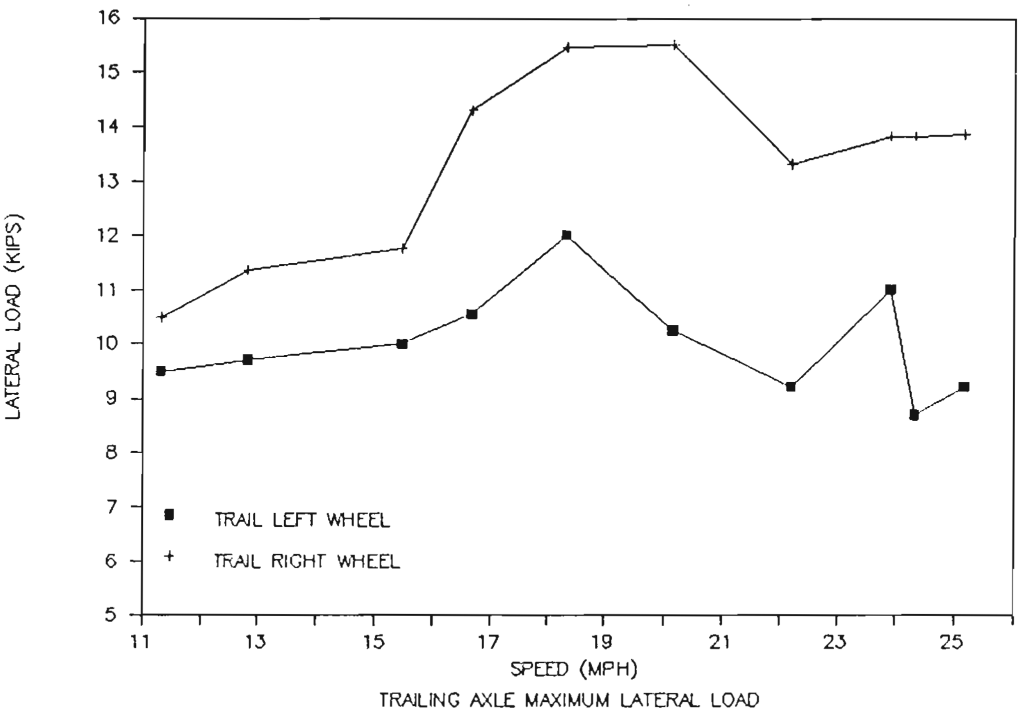


FIG.C-75 LOADED CAR DYNAMIC CURVE CCW

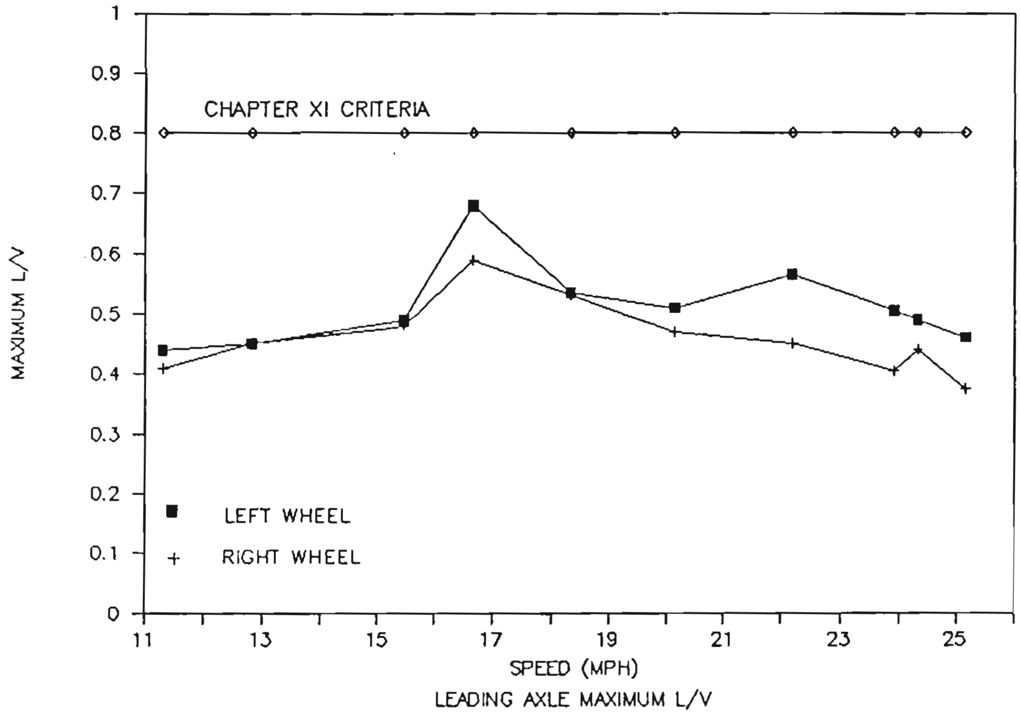


FIG.C-73 LOADED CAR DYNAMIC CURVE CCW

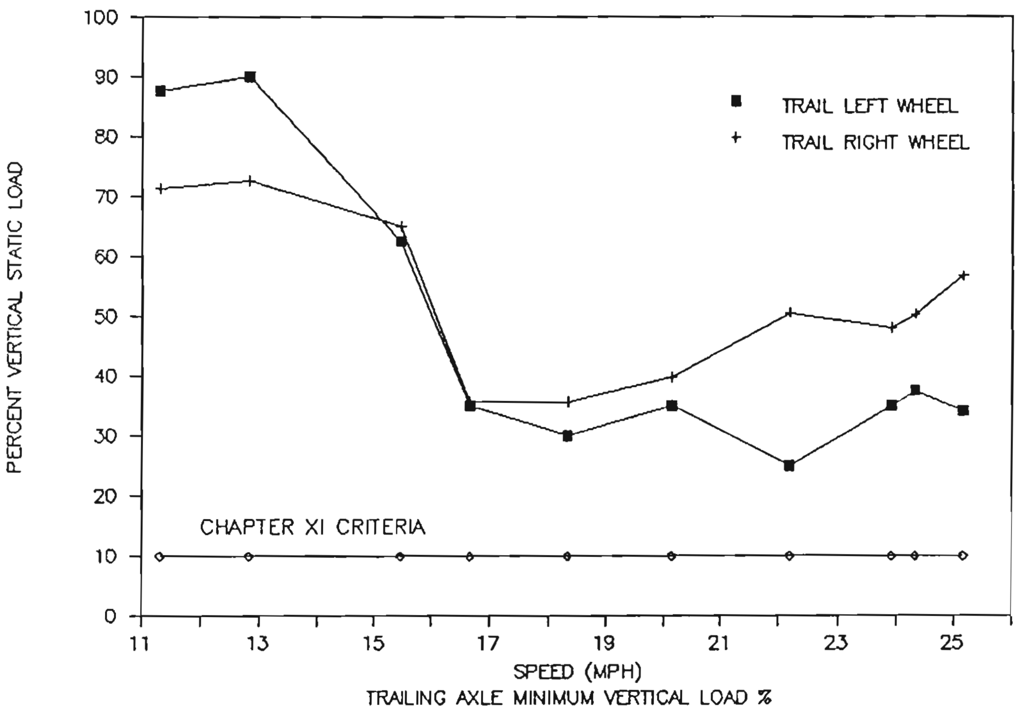


FIG.C-74 LOADED CAR DYNAMIC CURVE CCW