ENGINEERING DYNAMICS COMPANY

# EDVDS

HVE Human Vehicle Environment

Markdown Edition — revised to describe the current version of the software

# Contents

1. EDVDS — Vehicle Dynamics Simulator
2. Chapter 1 — EDVDS Program Description
3. Chapter 2 — EDVDS Program Input
4. Chapter 3 — EDVDS Program Output
5. Chapter 4 — Calculation Method
6. Chapter 5 — EDVDS Tutorial
7. Chapter 6 — Messages
8. Chapter 7 — References

# EDVDS — Vehicle Dynamics Simulator

**EDVDS** — Engineering Dynamics Company Vehicle Dynamics Simulator, Version 2

*User's Manual, Fourth Edition (January 2006), converted to Markdown and updated to match the current HVE software.*

> *(updated: this edition describes the current EDVDS program and the current HVE user interface. Notable updates: the **Tire Model Method** calculation option is **Linear** (default) or **Semi-Empirical** — the **Table Look-Up** option is disabled in the dialog and is not supported by the physics program; the terrain search options have moved to the separate **Get Surface Information Options** dialog, where the **By Elevation** method is unsupported; and the message catalog has grown from 7 to 12 messages. See the individual chapters for details, and EDVDS Calculation Options for the current dialog.)*

## How to Use This Manual

This manual is the user's manual for the EDVDS simulation model. The manual describes the model features and use. Input parameters and output reports are described at a high level. This manual is intended to be used in conjunction with the HVE User's Manual. The HVE User's Manual provides in-depth coverage of the human, vehicle and environment models, as well as the HVE Event Editor and Playback Editor. For specific model definitions, the user is referred to the HVE Operations Manual.

## If You Have Questions

Engineering Dynamics Company, LLC provides technical assistance for supported users. The questions may relate to general usage or to specific engineering applications. Please call — we're glad to help!

When you call, you should have the following information available:

- Your User ID number (available from the HVE Help System)
- Your System Hardware Profile Report (available from EDC)
- HVE Version Information (available from the HVE Help System)
- EDVDS Version Information (available from the EDVDS Program Data report)

## Contents


- Chapter 1 — EDVDS Program Description
- Overview, Model Inputs, Model Outputs, Validation, Basic Procedure
- Chapter 2 — EDVDS Program Input
- Objects Overview; Vehicles (sprung mass, unsprung mass, tires, suspensions, steering, brakes, drivetrain); Environment; Event set-up; Simulation Controls; Calculation Options
- Chapter 3 — EDVDS Program Output
- Alpha-numeric Reports (Messages, Accident History, Driver Controls, Environment Data, Program Data, Vehicle Data); Graphic Reports; Variable Output; Trajectory Simulations
- Chapter 4 — Calculation Method
- Basis for Analysis; Equations of Motion; External Forces (tire, connection and suspension forces); Brake System; Steering System; Dollys; Assumptions

- Chapter 5 — EDVDS Tutorial
- A complete worked example: highway doubles losing control on a downhill curve (creating the vehicles, environment and event; executing; viewing and printing results)
- Chapter 6 — Messages
- Complete catalog of EDVDS run-time messages for the current version
- Chapter 7 — References
- Bibliography


> *(updated: the printed manual's Chapter 8, a page-number index, is superseded by full-text search of these Markdown files and is not reproduced.)*

# Chapter 1 — EDVDS Program Description

## Overview

**EDVDS** (**E**ngineering **D**ynamics Corporation **V**ehicle **D**ynamics **S**imulator) is a simulation of the dynamic response of a vehicle towing up to three trailers. It is based on a program called Phase 4 developed at the University of Michigan Transportation Research Institute [1]. EDVDS simulates the vehicle's response to driver inputs (accelerating, braking and steering). EDVDS determines how the vehicle responds to these inputs by generating the vehicle path, velocity, acceleration, tire forces, and other data as a function of time.

EDVDS includes several extensions to the original Phase 4 program. These extensions, developed by Engineering Dynamics Company, LLC, include a full 3-dimensional simulation capability, an updated suspension model with jounce and rebound stops, an updated semi-empirical tire model that supports a full 360 degree range of slip angles and a 2-step radial tire stiffness, and the ability of each tire to respond to an arbitrary 3-D terrain.

Vehicle design engineers can use EDVDS to assess how various changes to suspension and tire parameters affect vehicle handling behavior. After setting up a series of simulation experiments, such as step-steer or J-turn maneuvers, alternate ramp traversals or a timed series of brake application pressures, engineers can vary the vehicle design parameters of interest and quickly determine their effect. Other examples include the effect of changes in vehicle weight distribution, wheelbase, track width, CG height, tire friction, cornering stiffness, hitch or kingpin location and other parameters.

Accident investigators can use EDVDS to determine how a driver may have lost vehicular control. By repeated adjustments of the throttle, braking and steering input tables, the researcher will converge on those driver inputs which match accident site evidence. Thus, the user learns how a driver's inputs may have affected the cause and/or outcome of an accident.

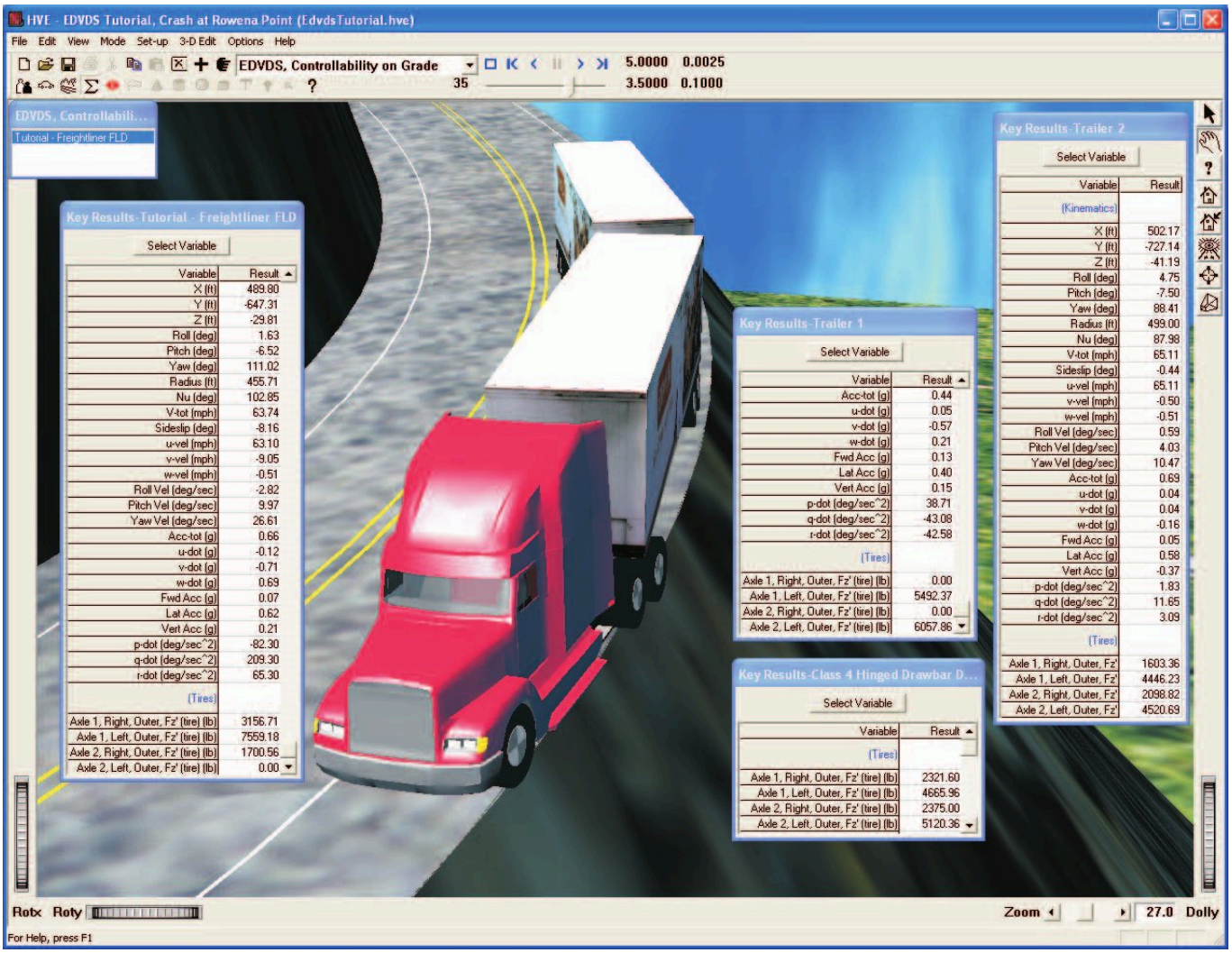



*Figure 1-1: EDVDS Event illustrating a commercial vehicle loss of control on a downhill grade.*

EDVDS employs full 3-dimensional engineering models with up to 23 degrees of freedom for each vehicle. The program supports up to 4 axles per vehicle, solid axle suspension types with inter-tandem load transfer, and single and dual tires. Combination vehicles are connected using fixed and converter dollys with rigid or hinged drawbars. EDVDS also employs a comprehensive drivetrain model with engine performance parameters and multi-gear transmissions and differentials.

Tire vs terrain is modeled transparently to the user. At each simulation timestep, the EDVDS tire model uses HVE's Get Surface Information search to query the terrain's physical characteristics (elevation, slope and friction) beneath each tire. The EDVDS tire model then uses this information to determine current tire forces at each tire.

## Model Inputs

EDVDS inputs include one to six vehicles (a tow vehicle and up to three trailers; the latter two including front dollys with drawbars) and an optional 3-D environment. Event set-up parameters include vehicle initial positions and velocities, various driver control options (steering, braking and throttle) and payloads.

## Model Outputs

EDVDS output reports include Messages, Accident History, Program Data, Vehicle Data, Variable Output and Trajectory Simulations.

## Validation

An interim version of the EDVDS simulation model (internally referred to as EDPH4) was first ported to HVE from the original Phase 4 code. EDPH4 was then validated by direct comparison with results obtained using Phase 4. These in-house validations included validation studies in the original Phase 4 research documents [1,3], as well as additional validations to test the various program options. The equations of motion were then extended significantly; this resulted in the code called EDVDS. The code was extended to eliminate many of the simplifying assumptions in the original Phase 4 code. These changes are described in Chapter 4 of this manual as well as in reference [28]. Final validation of the EDVDS is also presented in reference [28].

One of the main reasons for extending the original code was to allow it to take advantage of the HVE simulation environment. These changes allow the user to position the combination vehicle anywhere in the environment (the original code required the tow vehicle to begin at the inertial origin) and to drive directly on a 3-D terrain.

## Basic Procedure

The procedure for using EDVDS is substantially the same as using any simulator in the HVE environment:

- Use the Vehicle Editor to add a tow vehicle, up to three trailers and up to two dollys to the case. Optionally, edit any of the default vehicle parameters.
- Optionally, use the Environment Editor to create a visual and physical environment.
- Use the Event Editor to set up and execute the EDVDS simulation model by performing the following steps:
- Choose the tow vehicle and trailer(s) *in that order* from the list of vehicles created earlier.
- Choose the EDVDS calculation model.
- Position the tow vehicle in the environment, and assign an initial velocity.
- Optionally, edit the trailer's default position and velocity.
- Assign driver controls (Steering, Braking, Throttle) for the tow vehicle and trailer.
- Optionally, assign payloads to any of the vehicles.
- Execute the simulation event.
- Modify the initial conditions and driver inputs as required to achieve the desired match between the simulation and actual event.
- Use the Playback Editor to view the various reports and trajectory simulations. If desired, produce a video output of the simulation.

# Chapter 2 — EDVDS Program Input

This chapter defines the objects (humans, vehicles and environment) and the event set-up parameters (positions, damage profiles, driver controls, and so forth) used by the EDVDS analysis. In general, the chapter is divided into the following sections:

- **Objects** — The number of humans and vehicles, and the specific human and vehicle parameters actually used by EDVDS.
- **Events** — The various HVE options available for setting up and executing an EDVDS event.

## Objects Overview

The objects used by the EDVDS model are:

- **Humans** — Humans are not simulated by EDVDS.
- **Vehicles** — Up to six vehicles (a tow vehicle and up to three trailers and two dollys) may be included in an EDVDS event.
- **Environment** — Like the *real* world, EDVDS has exactly one environment.

> **NOTE:** The environment is used in any HVE-compatible reconstruction or simulation model.

The following sections describe how the vehicle and environment provide the required inputs to the EDVDS calculation model.

## Vehicles

EDVDS uses up to six vehicles created using the HVE Vehicle Editor (see Figures 2-1, 2-2 and 2-3). Vehicles are selected from the Vehicle Database by choosing the following attributes:

- **Type** — EDVDS supports the following vehicle types: *Passenger Car, Pickup, Van, Sport-Utility, Truck, Trailer* and *Dolly*.
- **Make** — EDVDS supports all available vehicle makes.
- **Model** — EDVDS supports all available vehicle models, within the limits defined by number of axles and drive axles; see below.
- **Year** — EDVDS supports all available vehicle years.
- **Body Style** — EDVDS supports all available vehicle body styles.

Each vehicle also has the following additional user-editable parameters:

- **Driver Location** — The *Driver Location* is not used by EDVDS. However, *Driver Location* for the tow vehicle must not be *None*; otherwise, the Driver Controls (Steering, Brakes, Throttle, Gear Selection) will not be available during Event mode.
- **Engine Location** — The *Engine Location* is not used by EDVDS. However, *Engine Location* for the tow vehicle must not be *None*; otherwise, the Throttle Table will not be available during Event mode.

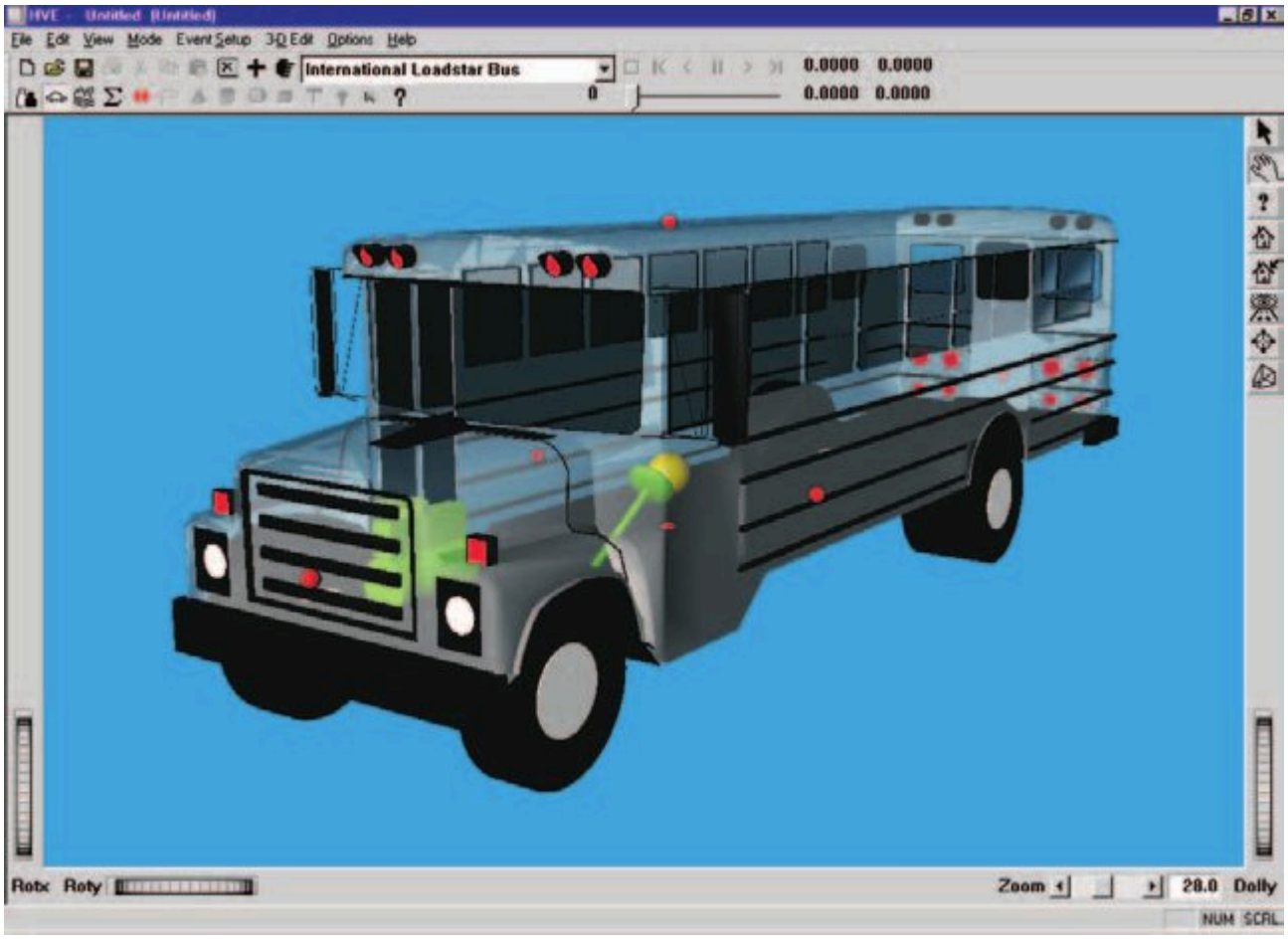
- **Number of Axles** — The tow vehicle may include two or three axles; trailers and dollys may have either one or two axles.
- **Drive Axle(s)** — EDVDS supports all drive axles.

To add a vehicle to the current HVE case, perform the following steps:

1. Choose Vehicle Mode. The Vehicle Editor is displayed.
2. Choose *Add New Object*. The Vehicle Information dialog is displayed.
3. Click on the *Type, Make, Model, Year* and *Body Style* option buttons to select a vehicle from the database.
4. If desired, modify the *Driver Location, Engine Location, Number of Axles* and *Drive Axle(s)* for the current vehicle.
5. Enter a name for the current vehicle. A default name is supplied for each selected vehicle. Its name is user-editable, and does not affect calculations.

> **NOTE:** Duplicate vehicle names are not allowed in the same case.

1. Click *OK* to add the vehicle to the current case.



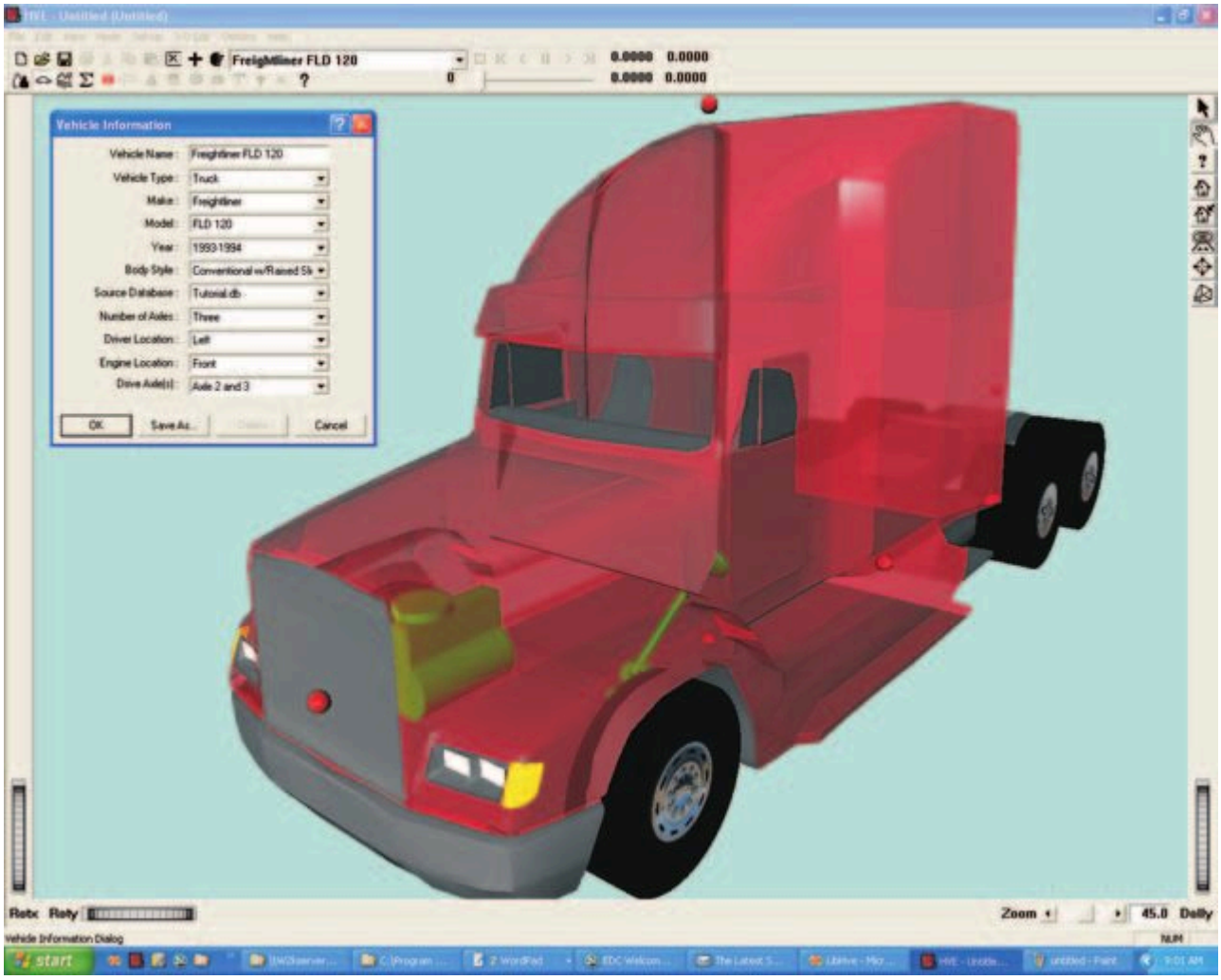



*Figure 2-1: Typical Truck (above) and Tow Vehicle (below).*

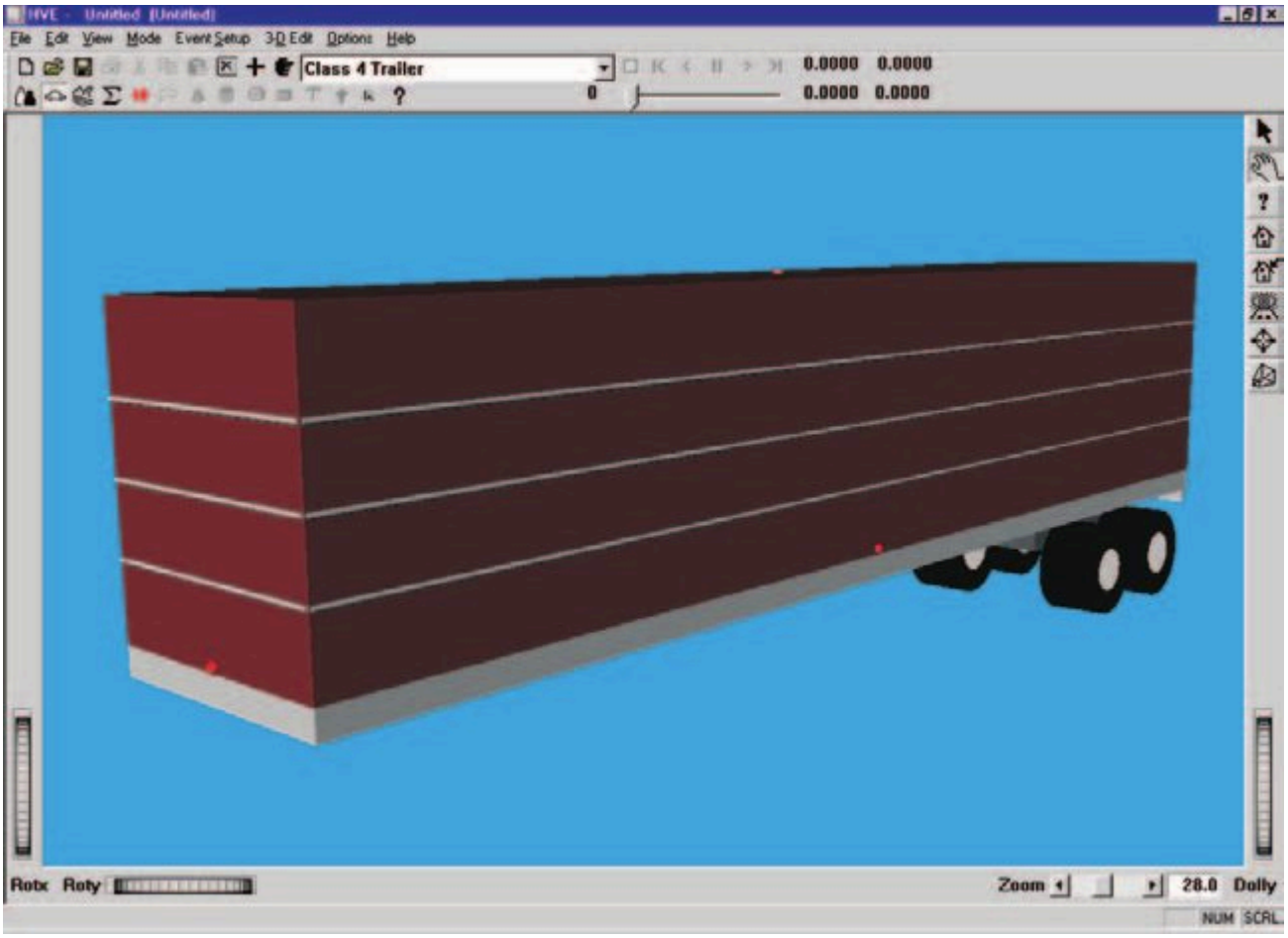



*Figure 2-2: EDVDS Trailer — a Class 4 trailer from the HVE Generic Vehicle library.*

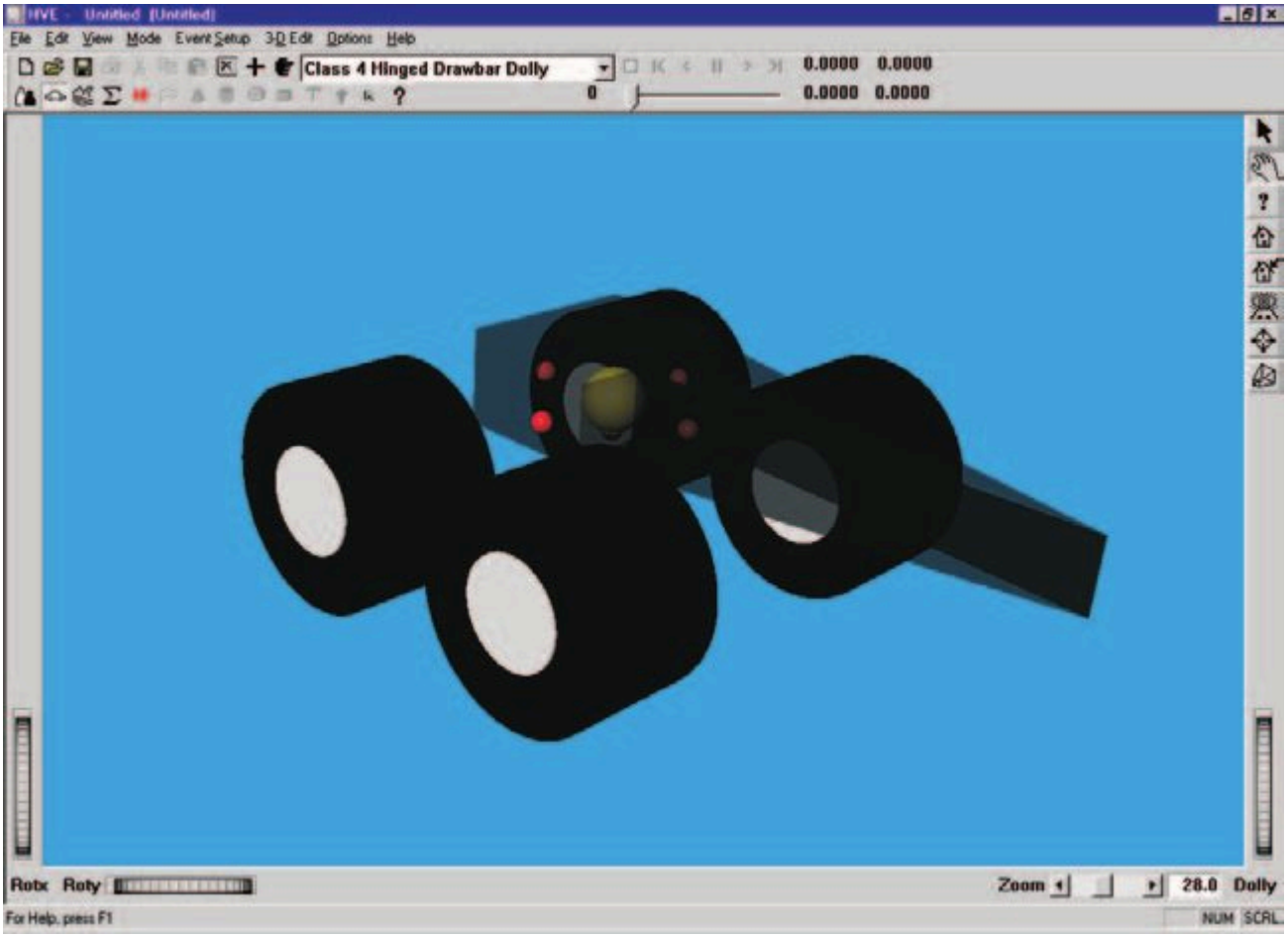



*Figure 2-3: EDVDS Dolly — a Class 4 Converter Dolly from the HVE Generic Vehicle library.*

The following Vehicle Parameter groups are used by EDVDS:

- Sprung Mass
- Inertias
- Move CG
- Inter-vehicle Connections
- Unsprung Mass
- Wheel Location
- Tire Data
- Suspension Data
- Brake Data
- Steering System
- Brake System
- Drivetrain

> **NOTE:** The Exterior Data Group (Overall Dimensions, Structural Stiffness Coefficients) is not used by EDVDS.
>
> **NOTE:** Be sure both vehicles have the proper connections (King Pin/Fifth Wheel, Pintle Hook/Eye, or Ball/Hitch). If the connections are not compatible, or if connections are not supplied, a message will be issued during Event Set-up.

The specific vehicle data used in each of the above parameter groups are defined in Tables 2-1 through 2-5.

## Sprung Mass

The Sprung Mass parameter groups used by EDVDS are shown in Table 2-1. Information on each group is provided below.

**Table 2-1: Vehicle Sprung Mass Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Sprung Weight | Weight of sprung mass |
| Sprung Mass Roll, Pitch and Yaw Inertia | Rotational inertias of sprung mass about the vehicle-fixed x, y and z axes, respectively |
| Move CG x,z | Relocates the CG in the vehicle-fixed x and z directions (lateral relocation is not supported by EDVDS). This entry causes an automatic adjustment of all vehicle coordinate-related parameters (e.g., contact surface, belt anchor points). |
| Inter-vehicle Connections | Vehicle-fixed x,y,z connection coordinates; rear connections also include maximum articulation angle. |

### *Inertias*

EDVDS uses the total vehicle weight (converted to mass according to the current gravitational constant; see Environment), and the roll, pitch and yaw rotational inertias of the sprung mass.

The total weight is used because it is the value traditionally obtained from data sources. The equations of motion require that the sprung mass be known. To obtain this value, EDVDS simply deducts the weight of the suspensions and wheels.

> **NOTE:** The inertial contributions of the front and rear suspensions are added to calculate the total yaw inertia reported in the Vehicle Data output report.

### *Move CG*

Move CG is not directly used by EDVDS. Its current value does not show up in the results. However, the Move CG fields may be used to quickly move the vehicle's center of gravity; the x,y,z coordinates for the wheels are updated to reflect the new CG location.

### *Geometry File*

The Geometry File is not used by EDVDS.

### *Contact Surfaces*

Contact Surface parameters are not used by EDVDS.

#### *Belt Restraints*

Belt Restraint parameters are not used by EDVDS.

#### *Airbag Restraints*

Airbag Restraint parameters are not used by EDVDS.

#### *Inter-vehicle Connections*

Inter-vehicle Connection parameters define the type, location and properties of the front and rear vehicle connections. The x,z location is specified relative to the vehicle CG. The z coordinates for each vehicle determine the elevation at the connection point, and thus establish the pitch angle of the trailer.

Dollys may be either *fixed* or *converter* dollys. A fixed dolly is permanently attached to the front of the trailer and normally has a hinged drawbar. A converter dolly is removable. It normally has a hinged fifth wheel and a fixed drawbar. See Chapter 4 for more information about drawbar types and their characteristics.

*Maximum Articulation Angle*

is only supplied for rear connections.

> **NOTE:** Every trailer will have a pre-defined front connection. However, not every tow vehicle has a pre-defined rear connection. Use the Vehicle Editor to confirm the vehicle has a connection.
>
> **NOTE:** If no connection is supplied, EDVDS cannot be executed; a message will be displayed during Event Set-up.
>
> **NOTE:** The rear connection of the first tow vehicle must be a fifth wheel. If it is not, a message will be displayed during Event Set-up.

#### *Drag Forces*

Drag Force parameters are not used by EDVDS.

### Unsprung Mass

The Unsprung Mass parameters used by EDVDS are shown in Table 2-2. Information on each group is provided in this section.

**Table 2-2: Vehicle Unsprung Mass Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Wheel Location | Vehicle-fixed x,y,z coordinates for each wheel |
| Brake Time Lag | Time required for brake system pressure to reach the brake actuation chamber |
| Brake Time Rise | Time required for air to fill the brake actuation chamber and begin stroking the pushrod |
| Brake Torque Ratio | The ratio of effective brake torque at the wheel to fluid pressure in the wheel cylinder |

#### *Wheel Location*

For each vehicle in the simulation, EDVDS uses the following wheel location parameters:

- **X_wheel** — the longitudinal distance from the CG to each axle.

> **NOTE:** X_wheel is assumed to be the same for left and right-side tires. If different values are entered, EDVDS uses the average.

- **Y_wheel** — the lateral distance from the CG to each axle.

> **NOTE:** Y_wheel is assumed to be the same for left and right-side tires. If different values are entered, EDVDS uses the average (thus, bilateral symmetry is assumed).

- **Z_wheel** — the vertical distance from the CG to each axle.

> **NOTE:** Z_wheel is initially assumed to be the same for left and right-side tires.

***Brake***

EDVDS uses the wheel brake system *Time Lag*, *Time Rise* and *Brake Torque Ratio*. The specific parameters used by EDVDS are shown in Table 2-2.

EDVDS also fully supports the HVE Brake Designer. Refer to the Brake Designer section of the HVE User's Manual for more information.

***Tire***

EDVDS allows the user to choose from three tire models:

- **Linear** — A simplified model, useful for non-limit maneuvers
- **Tire Model (Semi-Empirical)** — A good, general purpose tire modeling method
- **Tire Table** — The most sophisticated tire modeling technique *(updated: the **Table Look-Up** method is not currently available; it is greyed out in the Calculation Options dialog, and if it is ever selected the event terminates with a fatal error.)*

The modeling technique selected is dependent upon the particular needs of the analysis. The desired tire model is an EDVDS calculation option (see Event).

The HVE tire parameters provide the following data groups:

- Physical Data
- Friction Table
- Cornering Stiffness Table
- Camber Stiffness Table
- Slip-vs Rolloff Table

EDVDS's use of these parameters is described below.

***Physical Data***

The Tire Physical Data used by EDVDS are shown in Table 2-3. When AutoPosition is

*On*

, the tires' unloaded radii are used to establish the vehicle's initial CG elevation.

### *Friction Table*

The Friction Data used by EDVDS are shown in Table 2-3. The EDVDS tire model includes load- and speed-dependent friction properties.

The

*In-use Factor*

is a convenient way to reduce or increase the dependent friction values (peak and slide friction) by making just one adjustment.

**Table 2-3: Vehicle Unsprung Mass, Tire Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Tire Unloaded Radius | Radius of the undeflected tire |
| Tire Initial and Secondary Deflection Rates, the Deflection at Secondary Rate and Maximum Deflection | The initial spring rate of the tire, and the spring rate after a specified amount of tire deflection. The maximum deflection is used to determine when tire deflection exceeds an allowable value. |
| Pneumatic Trail | The distance from the center of the contact patch to the center of pressure |
| Aligning Torque Coefficient | Moment about tire's vertical axis as a result of slip angle |
| Weight, Spin Inertia | The weight and rotational inertia (about the spin axis) of the tire/wheel/brake assembly |
| Tire Friction Table, Test Load/Speed | The load and speed for a given set of friction results |
| Peak Longitudinal and Lateral Friction, Slide Friction, Slip at Peak Friction and Longitudinal Stiffness | Tire frictional properties at the specified load and speed |
| Friction In-use Factor | Multiplier for Longitudinal, Lateral and Slide friction and Longitudinal Stiffness |
| Tire Cornering Stiffness Table, Test Load and Speed | The load and speed for a given cornering stiffness result |
| Cornering Stiffness | Tire lateral force per unit of tire lateral slip for small amounts of lateral slip |
| Cornering Stiffness In-use Factor | Multiplier for Cornering Stiffness values |
| Tire Camber Stiffness Table, Test Load and Speed | The load and speed for a given camber stiffness result |
| Camber Stiffness | Tire lateral force per unit of camber angle for small camber angles |
| Camber Stiffness In-use Factor | Multiplier for Camber Stiffness values |
| Slip vs Rolloff Data | Reduction in longitudinal tire force as a result of lateral slip, and the reduction in lateral tire force as a result of concurrent longitudinal tire slip |

### *Cornering Stiffness Table*

The Cornering Stiffness data used by EDVDS are shown in Table 2-3. EDVDS uses the $F_y$ vs Slip Angle table if the Tire Table modeling option is selected; otherwise, the cornering stiffness is used. Cornering stiffness data may be load- and speed-dependent.

The

*In-use Factor*

is a convenient way to reduce or increase the dependent cornering stiffness values for all speeds and loads by making just one adjustment.

> **NOTE:** If you are simulating a vehicle with a flat tire, you probably want to reduce the In-use Factor to about 0.1.

***Camber Stiffness Table***

The Camber Stiffness data used by EDVDS are shown in Table 2-3. EDVDS uses the $F_y$ vs Camber Angle table if the Tire Table modeling option is selected; otherwise, the Camber Stiffness is used. Camber stiffness data may be load- and speed-dependent.

The

*In-use Factor*

is a convenient way to reduce or increase the dependent camber stiffness values for all speeds and loads by making just one adjustment.

> **NOTE:** If you are simulating a vehicle with a flat tire, you'll probably want to reduce the In-use Factor to about 0.1.

***Slip vs Rolloff Table***

The Longitudinal and Lateral Slip vs Rolloff Tables are used if the Tire Table tire model method is used. The longitudinal slip vs rolloff table defines the loss of longitudinal tire force when the tire is steered (compared to an un-steered tire). The lateral slip vs rolloff table defines the loss in lateral tire force when the tire is braked or accelerated (compared to a free-rolling tire).

*(updated: because the Table Look-Up tire model method is currently disabled, the $F_y$ vs Slip Angle, $F_y$ vs Camber Angle and Slip vs Rolloff tables are not used by the current version of EDVDS.)*

***Suspension***

The HVE Suspension Model provides the following data groups:

- Springs and Shocks
- Inertia
- Jounce/Rebound Stops
- Spindle Axis
- Camber Table
- Anti-pitch Table
- Roll Steer Table

EDVDS supports only solid axle suspensions. EDVDS's use of the suspension parameters is described below.

***Inter-tandem Load Transfer***

If three axles are supplied for the tow vehicle, or two axles are supplied for the trailer or dolly, the vehicle is assumed to have tandem axles. In this case, a longitudinal load transfer due to braking may be simulated by supplying an Inter-tandem Load Transfer Coefficient.

### *Springs and Shocks*

EDVDS uses the individual spring rates for the right and left springs on an axle. They need not be equal.

Roll Center Height and Lateral Spring Spacing apply for each axle.

> **NOTE:** Remember that roll center height is measured from the sprung mass CG, and is positive downwards.

Damping properties, like spring rates, are applied to the right and left sides of each axle; they need not be equal.

The Spring and Shock data used by EDVDS are shown in Table 2-4.

### *Inertias*

Inertial mass parameters do not include the weight of the brake assemblies or wheels (brake and wheel inertias are included with the tire). The Suspension Inertia data used by EDVDS are shown in Table 2-4.

**Table 2-4: Vehicle Unsprung Mass, Suspension Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Suspension Type | Solid Axle, Tandem Axles (4-Spring or Walking Beam) |
| Ride Rate, Front and Rear | Linear spring rate for the selected suspension |
| Auxiliary Roll Stiffness | Roll stiffness from an anti-sway bar |
| Roll Center Height | For solid axle suspensions, the distance from the CG to the roll axis at the suspension |
| Lateral Spring Spacing | The lateral distance between springs |
| Damping Rate | Velocity-dependent suspension damping rate |
| Coulomb Friction | Force required to initiate suspension movement |
| Friction Null Band | Suspension velocity required for full coulomb friction |
| Suspension Weight | For solid axle suspensions, the weight of the axle, not including tires, wheels and brakes |
| Suspension Roll/Yaw Inertia | For solid axle suspensions, the rotational inertia about the vehicle-fixed x and z axes |
| Jounce/Rebound Stop, Max Deflection | Deflection from equilibrium to jounce and rebound stops |
| Jounce/Rebound Stop Linear, Cubic Stiffness | Stiffness constants for suspension stops |
| Jounce/Rebound Stop Energy Ratio | Restitution for stop, defined as the ratio of the non-conserved energy to total energy absorbed by the suspension stop |
| Camber | Camber value |
| Roll Steer | The ratio of axle steer to sprung mass roll angle |

### *Jounce and Rebound Stops*

The linear and cubic deflection rate of the suspension stops is used to limit the travel of each suspension. The values need not be exact; their primary purpose is to prevent excessive excursion of an axle. The Jounce and Rebound Stop data used by EDVDS are shown in Table 2-4.

#### *Spindle Axis*

The Spindle Axis data are not used by EDVDS.

#### *Camber and Half-Track Change Tables*

Solid axle camber may be assigned to each wheel. The camber data used by EDVDS are shown in Table 2-4. Half-track change tables are not used by EDVDS.

#### *Anti-pitch*

The Anti-pitch tables are not used by EDVDS.

#### *Roll Steer*

The roll steer constant is used by each axle. Roll steer defines the amount of steering produced as the sprung mass rolls about the roll axis.

### Exterior

The Vehicle Exterior Data (Exterior Dimensions, Stiffness) are not used by EDVDS.

### Steering System Data

EDVDS uses the steering gear ratio if the

*At Driver*

Steering Table option is used during Event set-up. See Table 2-5. Otherwise the steering system data are not used.

### Brake System Data

The brake system pedal ratio (system pressure per unit of pedal force) is used if the

*At Driver*

Brake Table option is used during Event set-up. See Table 2-5. Otherwise the Brake System Data are not used by EDVDS.

**Table 2-5: Vehicle Steering, Brake System and Drivetrain Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Steering Gear Ratio | Ratio of the angle at the steering wheel to the angle at the tire |
| Brake Master Cylinder Ratio | Brake system pressure produced per unit of pedal force applied by the driver |
| Engine Table | Engine Torque vs Speed Table for Wide-open and Closed Throttle Tables for Torque vs speed. Defines range from idle to maximum RPM. |
| Transmission Gear Table | Table of numeric ratio for each of up to 12 forward speeds plus reverse |
| Differential Gear Table | Differential numeric ratio (only single speed is supported) |

> **NOTE:** For vehicles with air brake systems, the Pedal Ratio is assigned a value of 1.0; thus, the entered pedal force is the same as the system brake application pressure.
>
> **NOTE:** See also Wheel Brake Data (Unsprung Mass Parameters) for related information about the vehicle's brake system parameters.

### Drivetrain Data

Engine power as a function of engine speed is defined for both wide-open throttle and closed throttle positions. The Drivetrain data (engine power vs. speed, transmission ratio, differential ratio, drivetrain inertia) are used if the

*Percent Wide-open Throttle*

option is used during Event set-up (see Table 2-7).

The drivetrain data used by EDVDS are shown in Table 2-5.

The user-entered Power vs. Engine Speed Table defines the valid range of engine speeds for a given event. If the maximum engine speed in the table is exceeded, the simulation terminates with an error message (see Messages).

> **NOTE:** The typical solution to this problem is to shift sooner.

The transmission may have up to 12 forward ratios, plus reverse and neutral. The differential may have up to three ratios.

## Environment

EDVDS uses the environment created by the HVE Environment Editor (see Figure 2-4). The environment is created by defining the following groups of attributes:

- Visual Data
- Physical Data

### Creating an Environment

To add an environment to the current HVE case, perform the following steps:

1. Choose Environment Mode. The Environment Editor is displayed.
2. Click on *Add New Object*. The Environment Information dialog is displayed.
3. Click on the *Location* combo box to select the desired city, state and country, and associated *Latitude, Longitude* and *GMT*.
4. Enter the *Time* and *Date* for the event.
5. Enter the *Angle of the X axis, Wind Speed* and *Direction, Barometric Pressure* and *Temperature* for the event.
6. Enter the *Gravity Constant* for the event.
7. Enter an environment name. A default name is supplied for the current environment. The name is user-editable, and does not affect calculations.
8. Click *OK* to add the environment to the current case.

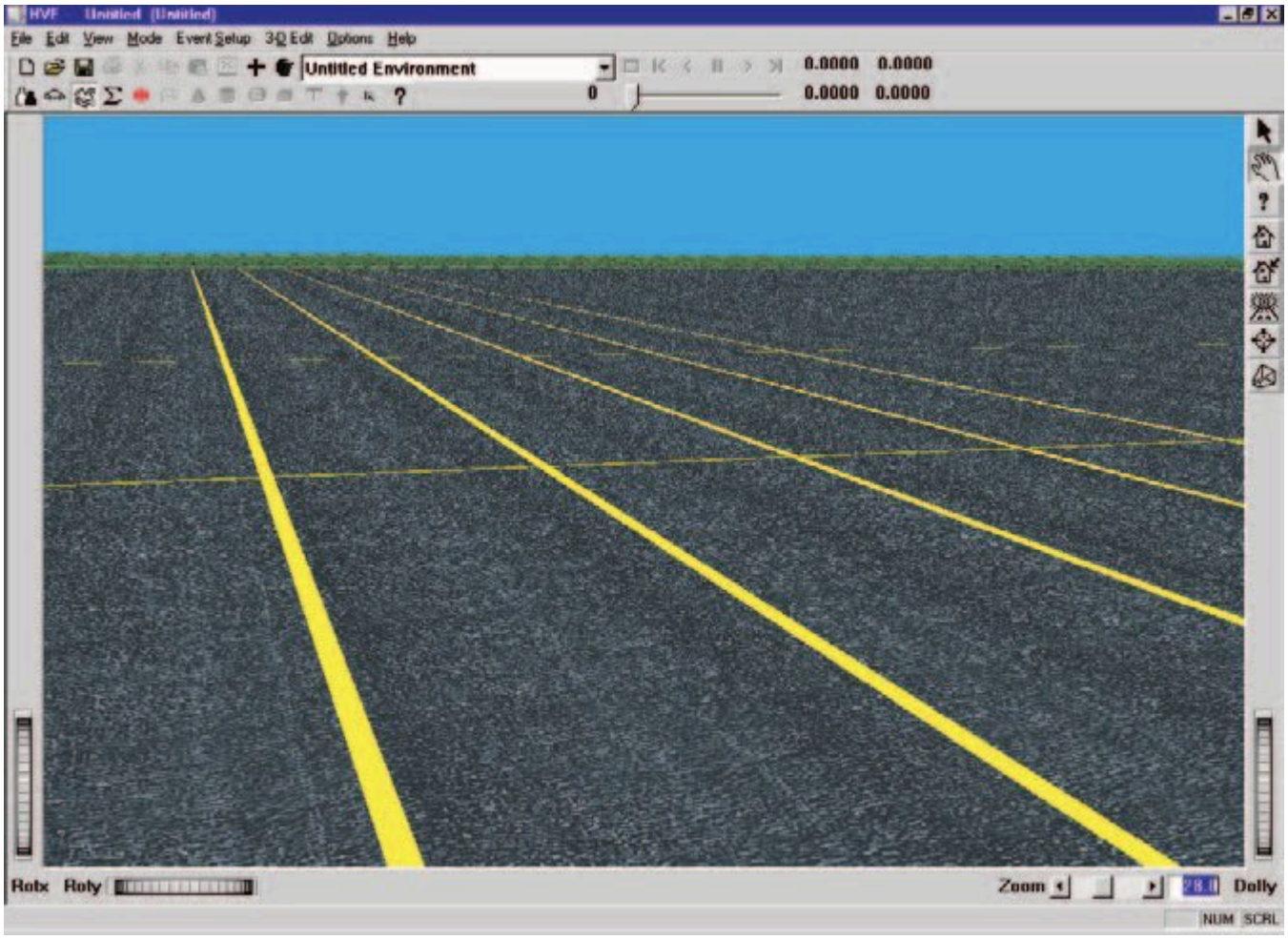



*Figure 2-4: HVE Environment Editor.*

### Visual Data

The following visual parameters may be edited:

- **Environment Location** — A database containing the name (City/State/Country), Latitude and Longitude and GMT for the selected location.
- **Time and Date** — The local standard time and date for the event.

The visual data are not used by the event; they are provided for studies related to visibility at the time of an event (e.g., avoidability of an accident).

> **NOTE:** The visual data (Location, Time, Date and Angle of earth-fixed X axis) affect the lighting of the event! Depending on your view (Camera Position) the scene may be shaded and difficult to see. If the time is after sundown, the view will be dark.

### Physical Data

The Physical Data groups are:

- Angle of X Axis

- Wind Speed and Direction
- Atmospheric Temperature and Pressure
- Gravity Constant
- 3-D Surface Geometry

The specific physical environment data used by EDVDS are described below; see also Table 2-6.

**Table 2-6: Environment Model Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Gravitational Constant | Local gravitational constant |
| 3-D Surface Geometry (Elevation, Surface Normal, Friction Factor) | The polygon database used to create the 3-D environment |

***Angle Of X Axis***

The angle of the X axis is used to position the earth-fixed coordinate system on the surface of the earth.

> **NOTE:** The angle is specified relative to true north. If you are using a compass to determine direction at the scene of an accident, you should provide a correction factor before entering this angle.
>
> **NOTE:** The angle of the X axis affects how you visualize an EDVDS event because it affects the location of the sun.

***Wind Speed and Direction***

Wind Speed and Direction are not used by EDVDS.

***Atmospheric Temperature and Pressure***

Atmospheric temperature and pressure are not used by EDVDS unless the HVE Brake Designer is used. If the Brake Designer is used, atmospheric temperature and pressure are used in the calculation of brake temperatures.

***Gravity Constant***

The gravity constant converts mass to force. An object's mass and rotational inertias are properties that are the same throughout the universe; however the weight of an object is dependent on the local gravitational constant.

***3-D Surface Geometry***

The 3-D Surface Geometry is used by the tire model in EDVDS to calculate the elevation, slope and friction multiplier for the current X,Y position of the tire.

## Event

EDVDS uses the HVE Event Editor (see Figure 2-5) to create, set up and execute an event. Each of these topics is described below.

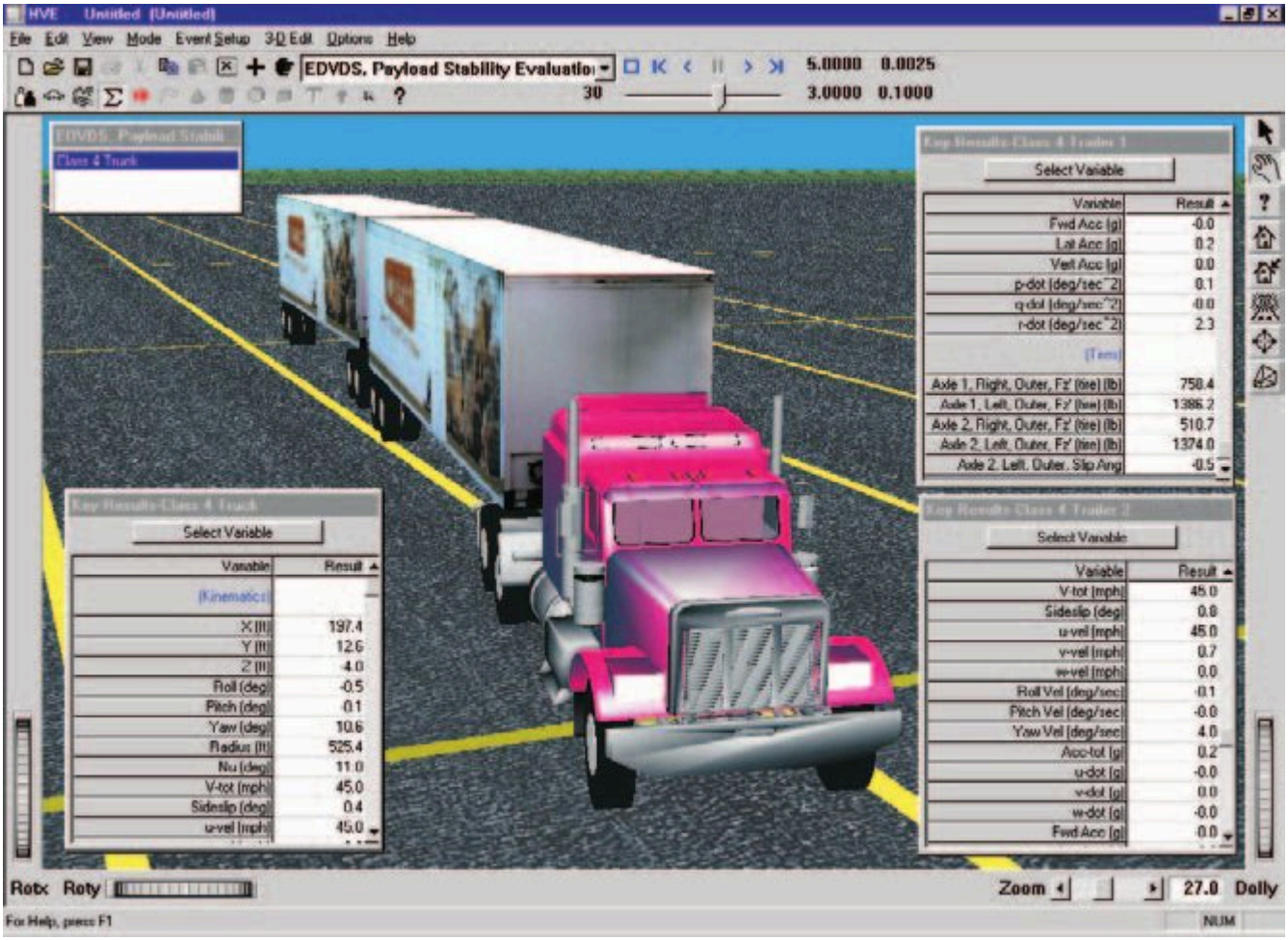



*Figure 2-5: HVE Event Editor.*

### Creating An Event

An EDVDS event is created using the Event Information dialog.

To create an EDVDS event:

1. Choose Event Mode. The Event Editor is displayed.
2. Click on *Add New Object*. The Event Information dialog is displayed.
3. Select the tow vehicle from the Active Vehicles list.
4. Optionally, select the trailer or trailers and dollys from the Active Vehicles list.

> **NOTE:** HVE creates the vehicle train in the order the vehicles are selected. Therefore, the vehicles must be selected in the correct order.

1. Select the calculation model, *EDVDS*, from the Calculation Model options list.
2. Enter an event name. A default name is supplied for the selected event. The name is user-editable, and does not affect calculations.

> **NOTE:** Duplicate event names are not allowed in the same case.

1. Click *OK* to create the EDVDS event.

> **NOTE:** If you choose a vehicle that is not compatible with EDVDS, or if the tow vehicle connections are incompatible with the trailer, a message will be displayed describing the problem. You will not be allowed to proceed until EDVDS-compatible objects are selected.

**Table 2-7: Event Set-up Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Vehicle Initial Position | The earth-fixed X,Y,Z coordinates and roll, pitch, yaw angles of the vehicle at the start of the simulation |
| Vehicle Initial Velocity | The forward, lateral and vertical linear velocities, and the roll, pitch and yaw angular velocities at the start of the run |
| Driver Controls, Steer Table | Steer Table Option; Steering Wheel Angle vs Time or Tire Steer Angle vs Time |
| Driver Controls, Brake Table | Brake Table Option; Brake Pedal Force vs Time |
| Driver Controls, Throttle Table | Throttle Table Option; Throttle Position vs Time |
| Driver Controls, Gear Table | Transmission Gear, Differential Gear vs. Time |
| Driver Controls, HVE Driver Model | Path Follower parameters; see HVE User's Manual |
| Payload Data | Payload Exists Option; Payload CG x,z coordinates; Payload Weight; Payload Roll, Pitch and Yaw Rotational Inertias |

## Setting Up an Event

EDVDS uses the following

*event set-up*

options:

- Position/Velocity
- Driver Controls
- Payloads

The specific Event Set-up data used by EDVDS are defined in Table 2-7.

### *Position/Velocity*

Like all simulations, EDVDS requires initial positions and velocities to be supplied by the user.

The tow vehicle is positioned relative to the earth-fixed coordinate system by supplying the X,Y,Z coordinates of its CG, and roll ($\Phi$), pitch ($\Theta$) and yaw ($\Psi$) angles about vehicle x, y and z axes, respectively.

> **NOTE:** Z, roll and pitch may be supplied automatically by HVE using AutoPosition.

The trailer is positioned relative to the tow vehicle by supplying the initial roll, pitch and yaw articulation angles. The default articulation angles are 0.0 degrees.

The tow vehicle linear velocities are supplied in the form of a total velocity and sideslip angle.

> **NOTE:** The vehicle-fixed u (forward) and v (side) velocity components are calculated using the total velocity and sideslip angle.

The trailer articulation angular velocities are assigned relative to the tow vehicle. Zero angular velocity is assumed as a default, and values need not be entered.

#### *Driver Controls*

EDVDS uses the following Driver Controls:

- **Steering** — A table of steering inputs as a function of time. The *At Driver* and *At Axle* options are supported.
- **Braking** — A table of braking inputs as a function of time. The *Wheel Force* and *Percent Available Friction* options are supported.
- **Throttle** — A table of throttle inputs as a function of time. The *Wheel Force* and *Percent Available Friction* options are supported.
- **Gears** — A table of transmission and differential gear selections as a function of time.
- **HVE Driver Model** — A closed-loop model that determines the driver steering inputs required to cause the vehicle to follow the desired path. The HVE Driver Model is described in the HVE User's Manual and in Reference [29].

The Driver Controls Data used by EDVDS are shown in Table 2-7.

#### *Damage Profile*

The Damage Profile Data are not used by EDVDS.

#### *Payload*

The Payload Data used by EDVDS include the payload coordinates relative to the vehicle's CG, and the payload rotational inertias.

> **NOTE:** Lateral payload offset is not supported.
>
> **NOTE:** Payload positioning is relative to the vehicle CG, not the rear suspension.

#### *Collision Pulse*

The Collision Pulse data are not used by EDVDS.

#### *Contacts*

The Contacts data are not used by EDVDS.

#### *Restraints*

The Restraints data are not used by EDVDS.

### Simulation Controls

EDVDS uses the current simulation control parameters in the Simulation Controls dialog (see Options Menu, Simulation Controls). The Simulation parameters used by EDVDS are shown in Table 2-8.

**Table 2-8: Simulation Control Parameters Used By EDVDS**

| Parameter | Description |
|---|---|
| Vehicle Trajectory Integration Timestep | The integration timestep used by the numerical integration routine |
| Output Interval | The timestep used to send output results back to HVE |
| Maximum Simulation Time | Maximum length of the run |
| Minimum Linear Velocity | The linear velocity used to terminate the run (if the linear and angular velocities are simultaneously less than these termination velocities, the run terminates) |
| Minimum Angular Velocity | The angular velocity used to terminate the run (if the linear and angular velocities are simultaneously less than these termination velocities, the run terminates) |

> **NOTE:** The output time interval should be an even multiple of the vehicle trajectory integration timestep. For example, if the integration timestep is 0.0025 sec, the output interval might be 20 x 0.0025, or 0.0500 sec.

## Executing An Event

### *Calculation Options*

EDVDS has one calculation option (see Figure 2-6); for full details see EDVDS Calculation Options:

- **Tire Model Method** — Select from three methods: **Linear** (the default; to be used only for simple, non-limit maneuvers), **Semi-Empirical** (the most robust method) and **Table Look-Up** (not currently implemented; the choice is greyed out in the dialog, and selecting it produces a fatal error and the event will not run).

*(updated: the original manual stated that Semi-Empirical is the default. In the current version the Calculation Options dialog opens with **Linear** selected; **Semi-Empirical** must be chosen explicitly.)*

> **NOTE:** EDVDS will terminate with an error message if you select the Linear tire model method for an event that results in tire longitudinal or lateral slip beyond the linear range.

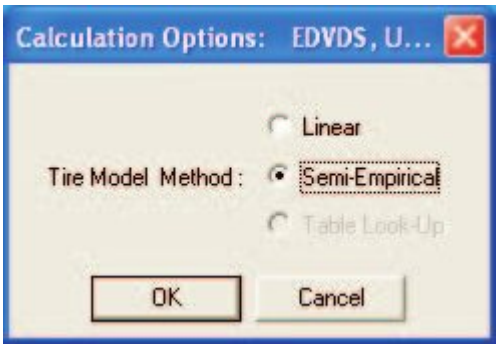



*Figure 2-6: EDVDS Calculation Options dialog.*

### *Get Surface Information*

This option determines how EDVDS selects the current terrain properties from the environment 3-D geometry file. The default value is

*From Previous Polygon*

. This option results in fastest execution, but does not work for all environments. Refer to the HVE User's Manual for further information about how the surface information lookup works.

*(updated: the terrain search method is no longer part of the EDVDS Calculation Options dialog; it is selected in the separate **Get Surface Information Options** dialog (Options menu). The available methods are **From First Polygon**, **From Previous Polygon** and **From Previous Polygon, Sorted**. The **By Elevation** method is not supported by EDVDS — selecting it causes the event to terminate with a fatal error.)*

***Event Execution***

To execute an EDVDS event, use the Event Controller, shown in Figure 2-7. The Event Controller's buttons have the following functions:

- **Reset** — Reinitialize the calculation model for re-execution
- **Rewind to Start** — Return to the start of the simulation
- **Reverse** — Play the simulation backwards
- **Pause** — Pause the simulation
- **Play** — Execute the event or play the simulation forwards
- **Advance to End** — Advance to the end of the simulation




*Figure 2-7: Event Controller, used for starting and stopping event execution. The Event Controller can also be used for replaying previously executed events, both forward and backward.*

> **NOTE:** If you make changes to any of the event set-up options (see previous section), those changes will have no effect unless you press Reset before pressing Play.
>
> **NOTE:** Remember to use HVE's Options Menu to choose useful options, such as Key Results, Axes, Velocity Vectors and Skidmarks.

# Chapter 3 — EDVDS Program Output

This chapter defines the outputs available from an EDVDS event. The reports produced by EDVDS are available in the HVE Playback Editor.

## Overview

EDVDS produces three types of output reports:

- **Alpha-Numeric Reports** — Reports containing text and numeric information, such as vehicle dimensional parameters
- **Variable Output Tables** — Reports containing tabular simulation results as a function of time
- **Trajectory Simulations** — Viewers containing dynamic, 3-D visual simulations

> **NOTE:** Each of these reports may be printed on the system printer. To print a report, click on the menu bar of the desired output report (the menu bar will change colors indicating that it is selected), then either choose Print from HVE's Files menu or click on the Print icon in the toolbar. Refer to the HVE User's Manual for further details.

To view any of these reports, perform the following steps:

1. Choose Playback Mode. The Playback Editor is displayed.
2. Click *Add New Object*. The Report Window Information dialog is displayed, showing a list of all the current events in the case.
3. Select an EDVDS event from the list. Once an event is selected, the Report Type list is displayed, containing all the available reports for the selected event.
4. Select the desired report in the Report Type list. To open several reports at once, select more than one (*Select All* selects every report); each opens in its own Report Window. The available output reports are:
5. Messages
6. Accident History
7. Program Data
8. Vehicle Data
9. Trajectory Simulation
10. Variable Output
11. If desired, edit the Name. A default name is supplied for the report window. The name is user-editable, and does not affect calculations.

> **NOTE:** Duplicate Report Window names are not allowed. Because HVE truncates the name to 30 characters, you should ensure that two truncated names are not the same.

1. Click *OK* to display the report.

## Alpha-Numeric Reports

EDVDS produces the following alpha-numeric reports:

- **Messages** — A list of messages produced by the current run
- **Accident History** — A table of initial and final positions and velocities
- **Driver Controls** — A table of user-entered vehicle driver controls
- **Environment Data** — A table describing the environment physical and geometrical properties
- **Program Data** — A table containing program control information for the current run
- **Vehicle Data** — A series of tables containing the vehicle data used by EDVDS

An example of each of these numeric output reports from EDVDS is shown on the following pages.

### Messages

A typical Messages Report is shown in Figure 3-1. For a complete listing of messages issued by EDVDS, see Chapter 6.




*Figure 3-1: An Example of a Message Output Report issued by EDVDS.*

### Accident History

The Accident History Report displays a table of initial and final positions and velocities for each vehicle (tow vehicle and trailers). A typical Accident History Report is shown in Figure 3-2.

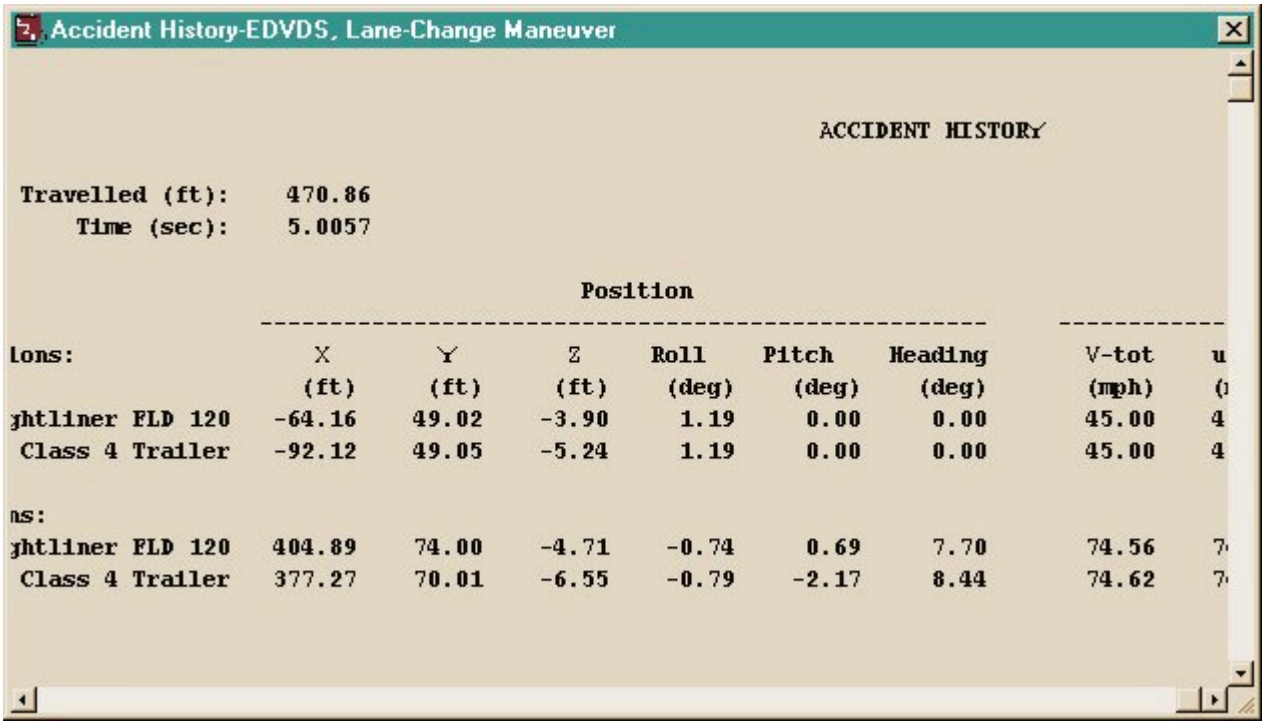



*Figure 3-2: An Example of an Accident History Output Report issued by EDVDS.*

### Driver Controls

The Driver Controls report displays a table of user-entered driver control tables for steering, braking and throttle for each vehicle in the event. A portion of a typical Driver Data report is displayed in Figure 3-3.

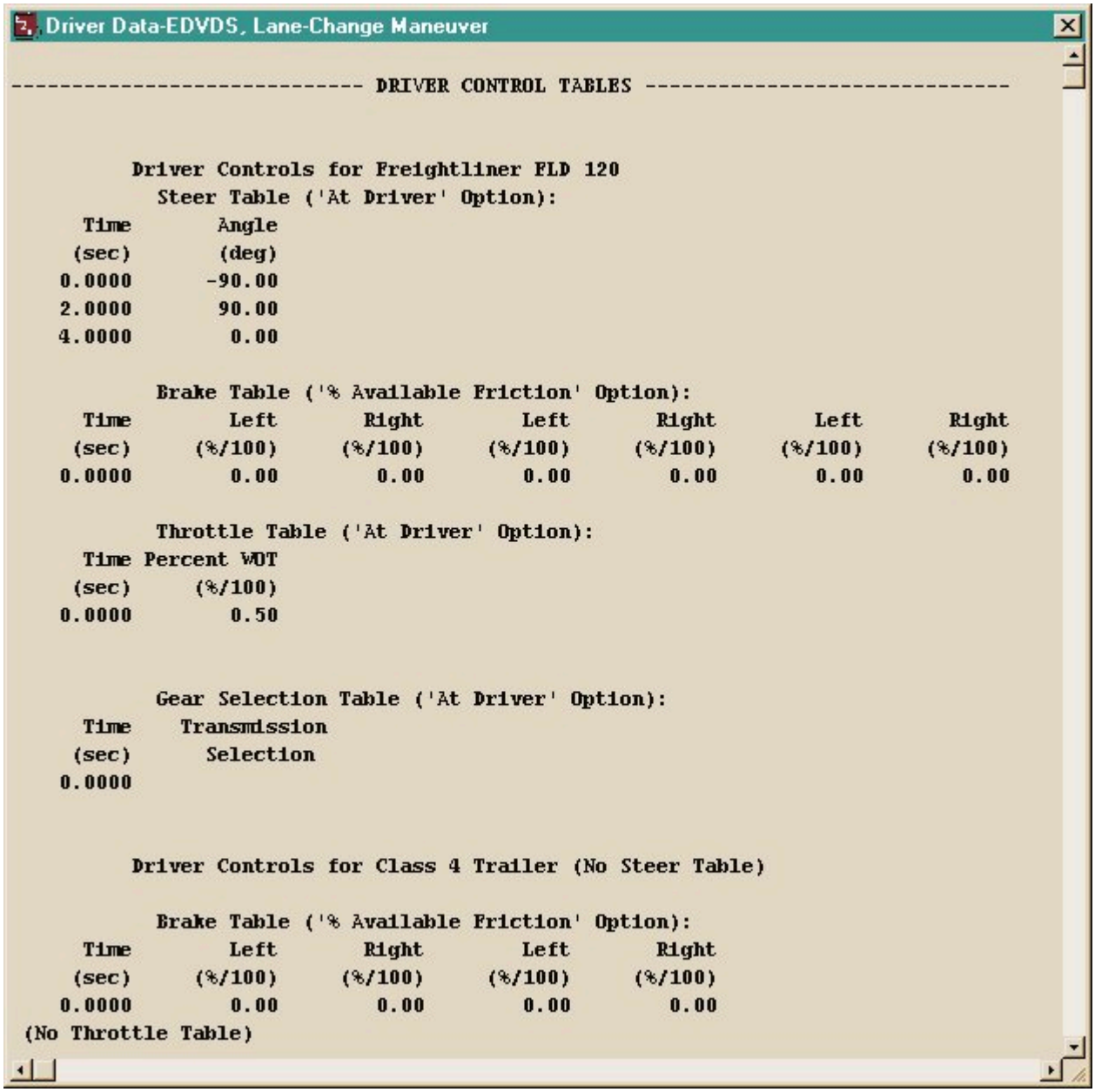



*Figure 3-3: An Example of a Driver Controls Output Report issued by EDVDS.*

### Environment Data

The Environment Data report displays the physical and visual information describing the environment. This information is displayed in two sections:

- **General Environment Data** — Physical parameters describing the environment (Temperature and Pressure are not used in the EDVDS calculations) *(updated: the original manual said "EDSMAC4" here, a typographical error carried over from another manual)*
- **3-D Environment Terrain Data** — Geometric parameters describing the terrain, including the 3-D geometry filename, number of polygons, the current Get Surface Information method (From First Polygon, From Previous Polygon, From Previous Polygon Sorted, or By Elevation) and the minimum/maximum terrain elevations.

A typical Environment Data report is displayed in Figure 3-4.

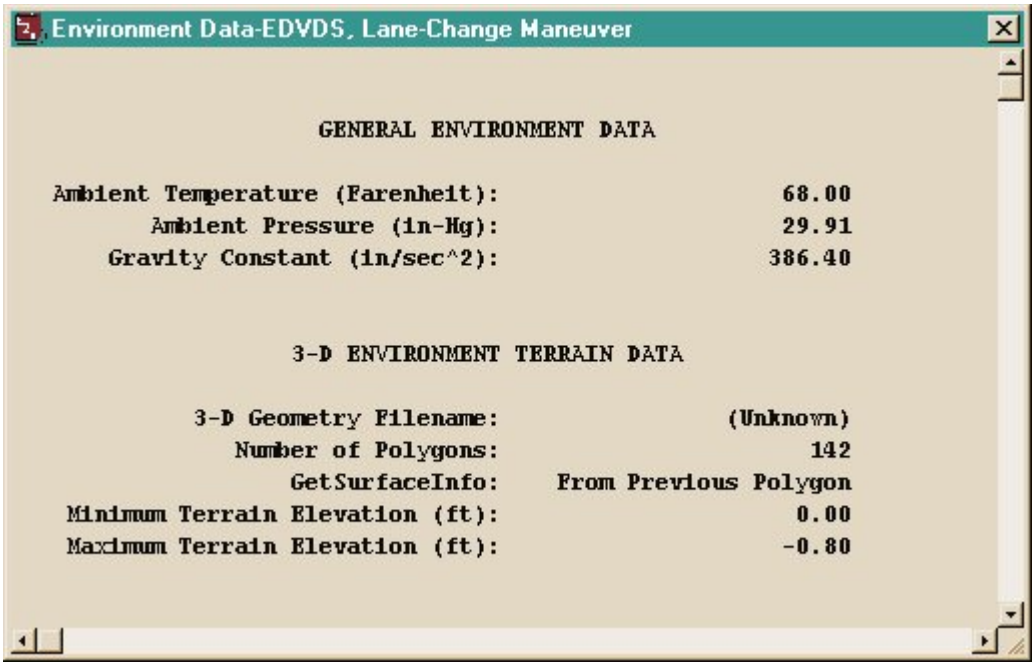



*Figure 3-4: An Example of an Environment Data Output Report issued by EDVDS.*

> **NOTE:** A detailed description of the terrain vertex information is not practical owing to its large size (a terrain is often composed of several thousand vertices). However, it is possible to view the terrain information (friction multiplier, slope, elevation, and so forth) beneath each tire at each timestep during the simulation by selecting the tire terrain outputs in the Variable Output, Tires output group (see Variable Output later in this chapter).

### Program Data

The Program Data Report includes the following information:

- **General Information** — EDVDS version number and model options used for the current event (HVE version, EDVDS version, date and time of execution, Tire Model Method and dimension basis)
- **Simulation Controls** — Integration parameters used for the current event (Maximum Simulation Time, Integration Time Step, Output Interval, Linear Termination Velocity, Velocity Convergence Criterion, Maximum Bisections)

A typical Program Data Report is shown in Figure 3-5.

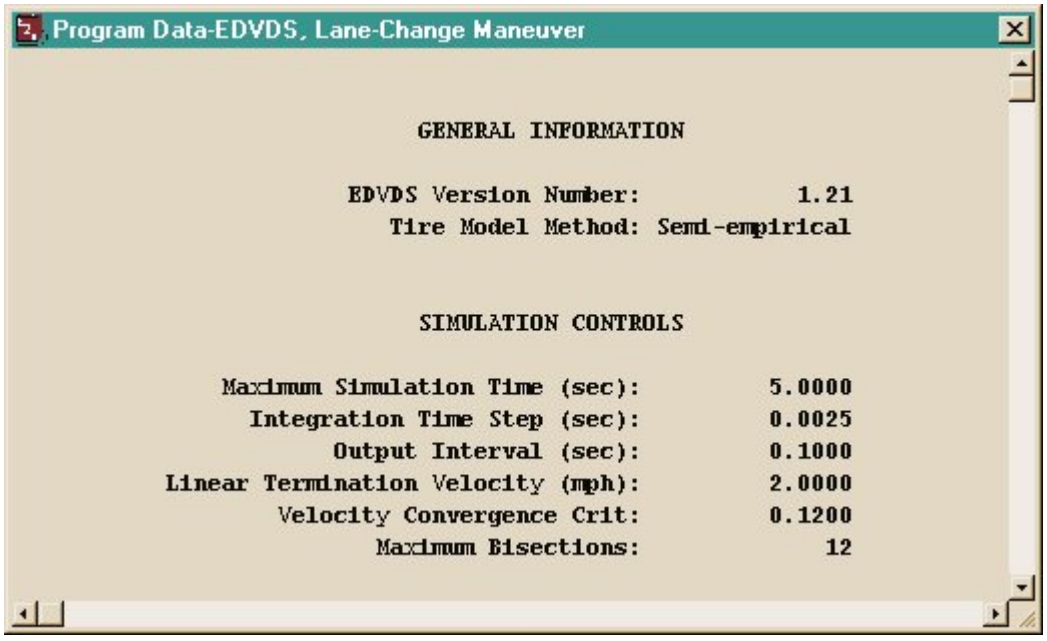



*Figure 3-5: An Example of a Program Data Output Report issued by EDVDS.*

### Vehicle Data

The Vehicle Data Report includes the following information:

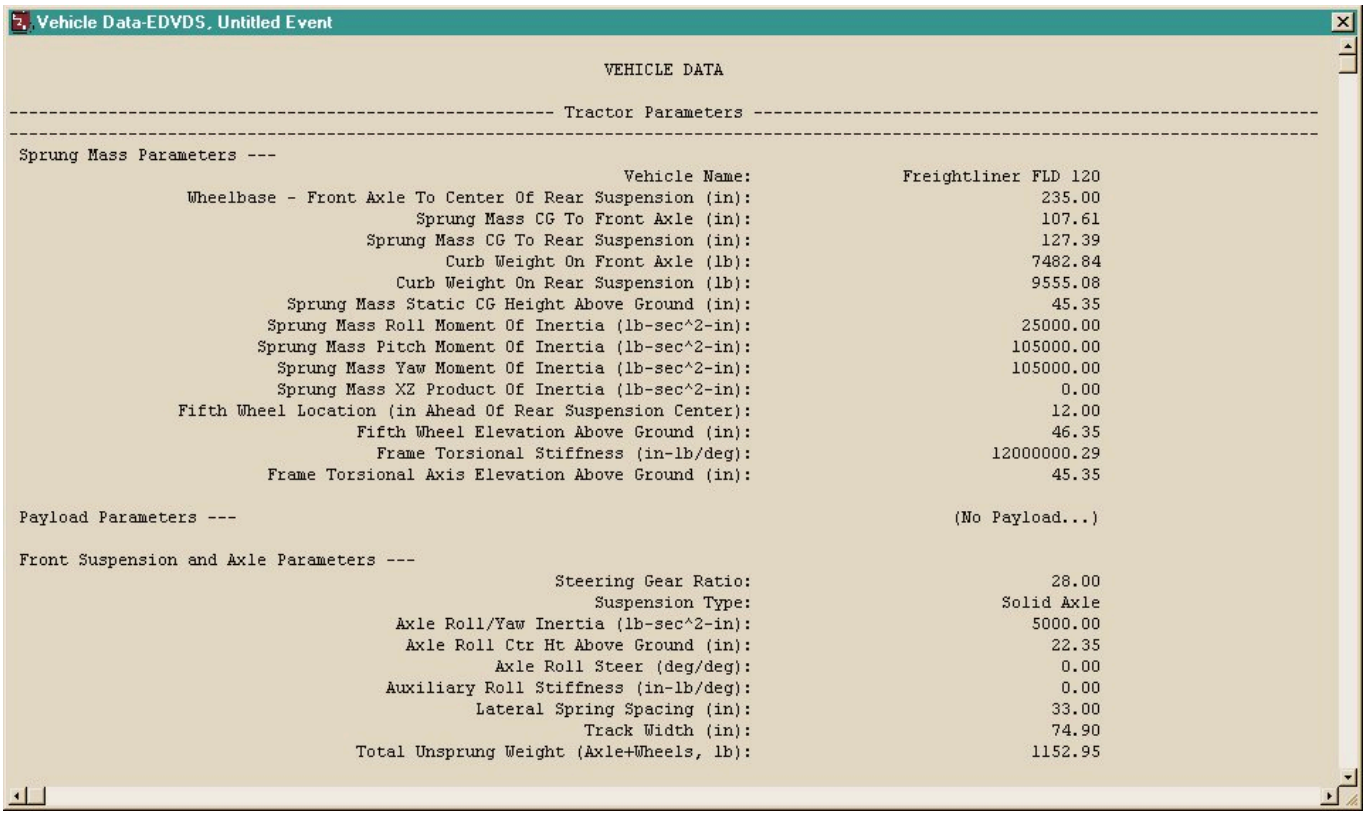
- **Vehicle Dimensional and Inertial Properties** — The dimensional and inertial parameters used by EDVDS in the current event.

> **NOTE:** The Total Yaw Inertia adds the effect of the unsprung masses (i.e., the wheel and axle masses) to the sprung mass; thus, the value printed is greater than the one displayed in the Vehicle Editor's Inertias dialog.

- **Suspension Properties** — The suspension parameters used by EDVDS in the current event.
- **Tire Properties** — The tire parameters used by EDVDS in the current event.
- **Brake Properties** — The wheel brake parameters used by EDVDS in the current event.

A portion of a typical Vehicle Data Report is shown in Figure 3-6 (Parts 1-5).

> **NOTE:** The entire Vehicle Data report can be quite lengthy, especially for a combination vehicle with several trailers and dollys.



Vehicle Data-EDVDS, Untitled Event

VEHICLE DATA

---------- Tractor Parameters ----------

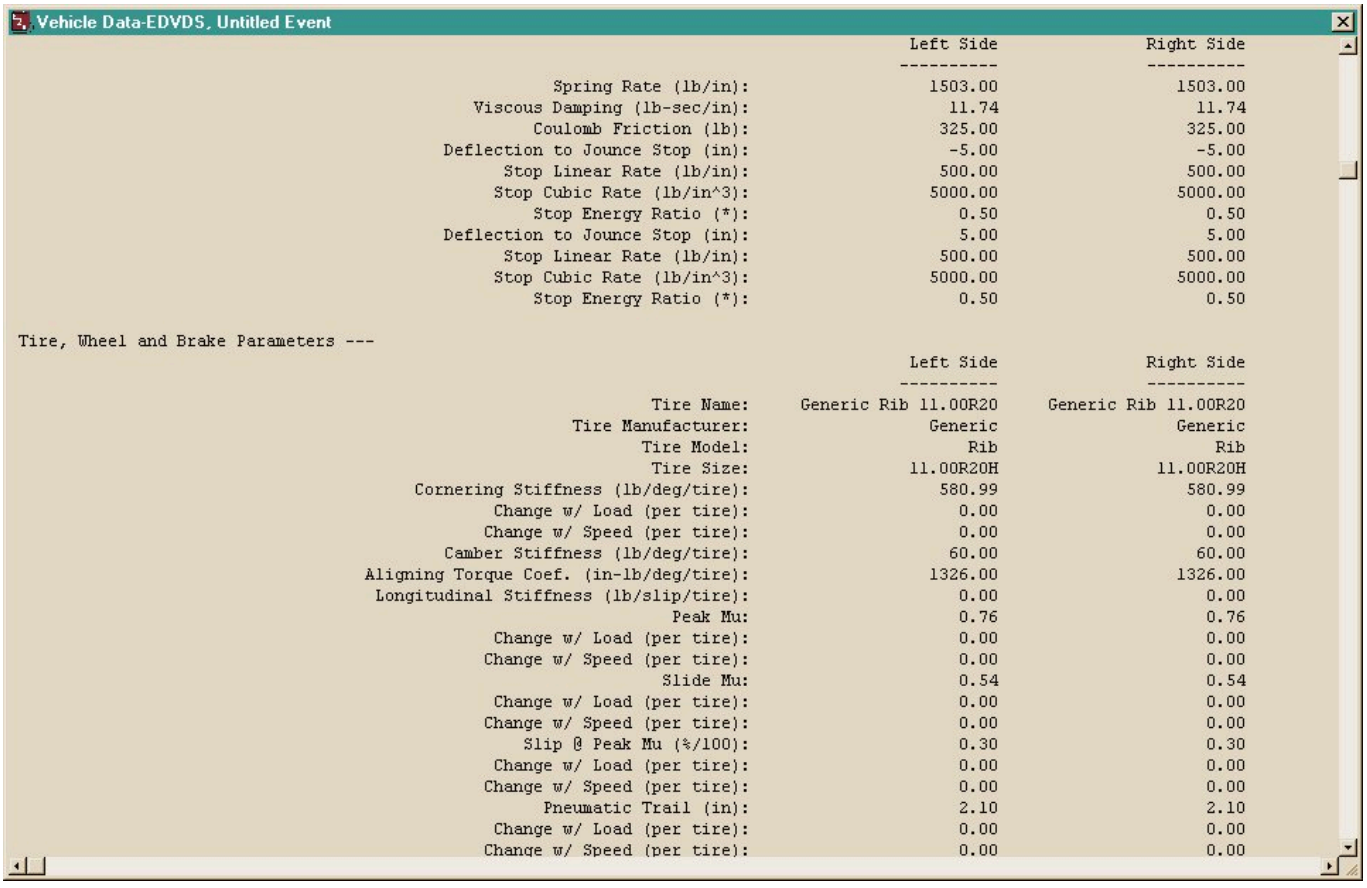
Sprung Mass Parameters ---

| | |
|---|---|
| Vehicle Name: | Freightliner FLD 120 |
| Wheelbase - Front Axle To Center Of Rear Suspension (in): | 235.00 |
| Sprung Mass CG To Front Axle (in): | 107.61 |
| Sprung Mass CG To Rear Suspension (in): | 127.39 |
| Curb Weight On Front Axle (lb): | 7482.84 |
| Curb Weight On Rear Suspension (lb): | 9555.08 |
| Sprung Mass Static CG Height Above Ground (in): | 45.35 |
| Sprung Mass Roll Moment Of Inertia (lb-sec^2-in): | 25000.00 |
| Sprung Mass Pitch Moment Of Inertia (lb-sec^2-in): | 105000.00 |
| Sprung Mass Yaw Moment Of Inertia (lb-sec^2-in): | 105000.00 |
| Sprung Mass XZ Product Of Inertia (lb-sec^2-in): | 0.00 |
| Fifth Wheel Location (in Ahead Of Rear Suspension Center): | 12.00 |
| Fifth Wheel Elevation Above Ground (in): | 46.35 |
| Frame Torsional Stiffness (in-lb/deg): | 12000000.29 |
| Frame Torsional Axis Elevation Above Ground (in): | 45.35 |

Payload Parameters --- (No Payload...)

Front Suspension and Axle Parameters ---

| | |
|---|---|
| Steering Gear Ratio: | 28.00 |
| Suspension Type: | Solid Axle |
| Axle Roll/Yaw Inertia (lb-sec^2-in): | 5000.00 |
| Axle Roll Ctr Ht Above Ground (in): | 22.35 |
| Axle Roll Steer (deg/deg): | 0.00 |
| Auxiliary Roll Stiffness (in-lb/deg): | 0.00 |
| Lateral Spring Spacing (in): | 33.00 |
| Track Width (in): | 74.90 |
| Total Unsprung Weight (Axle+Wheels, lb): | 1152.95 |

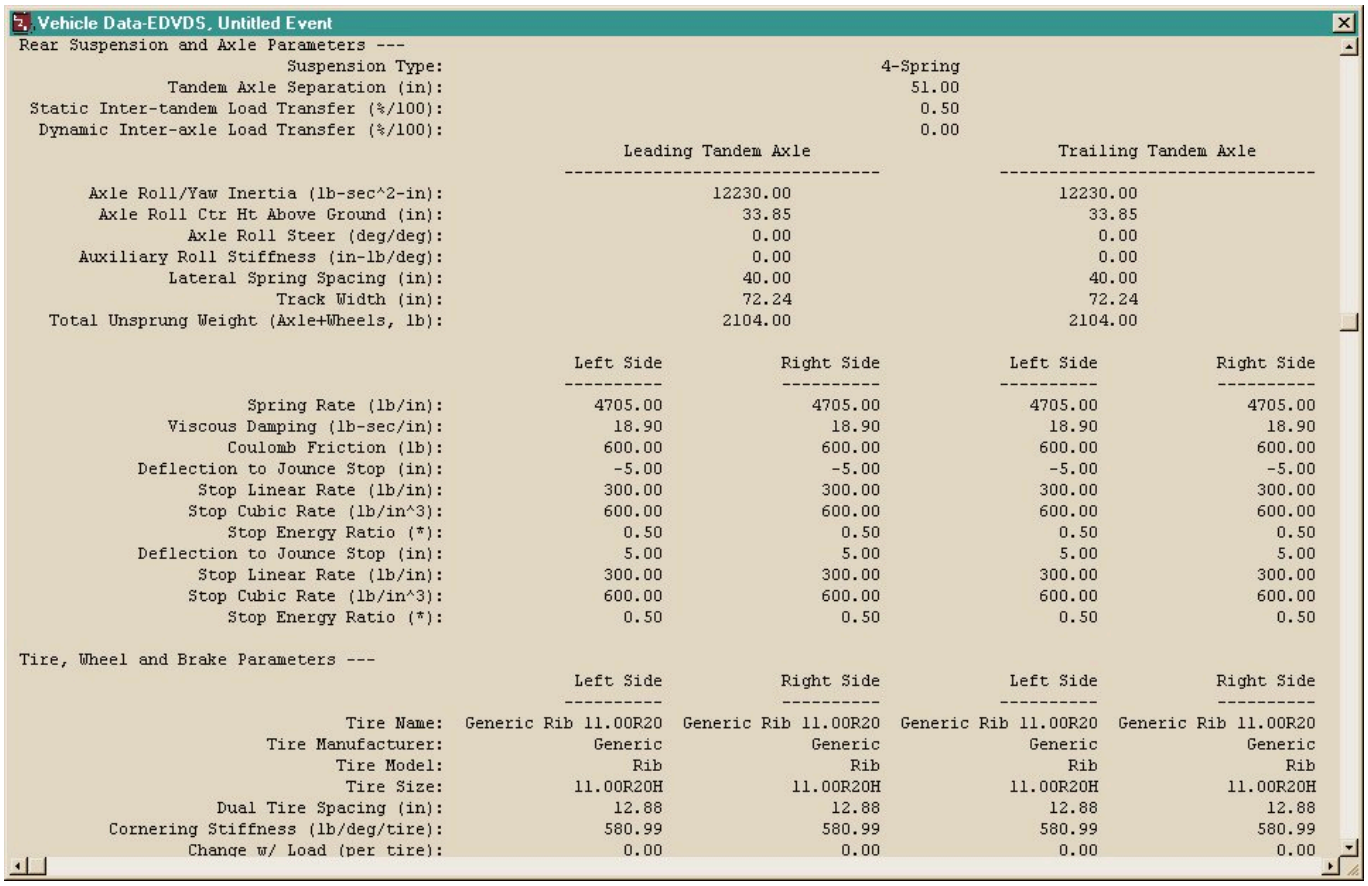


Vehicle Data-EDVDS, Untitled Event

| | Left Side | Right Side |
|---|---|---|
| Spring Rate (lb/in): | 1503.00 | 1503.00 |
| Viscous Damping (lb-sec/in): | 11.74 | 11.74 |
| Coulomb Friction (lb): | 325.00 | 325.00 |
| Deflection to Jounce Stop (in): | -5.00 | -5.00 |
| Stop Linear Rate (lb/in): | 500.00 | 500.00 |
| Stop Cubic Rate (lb/in^3): | 5000.00 | 5000.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 |
| Deflection to Jounce Stop (in): | 5.00 | 5.00 |
| Stop Linear Rate (lb/in): | 500.00 | 500.00 |
| Stop Cubic Rate (lb/in^3): | 5000.00 | 5000.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 |

Tire, Wheel and Brake Parameters ---

| | Left Side | Right Side |
|---|---|---|
| Tire Name: | Generic Rib 11.00R20 | Generic Rib 11.00R20 |
| Tire Manufacturer: | Generic | Generic |
| Tire Model: | Rib | Rib |
| Tire Size: | 11.00R20H | 11.00R20H |
| Cornering Stiffness (lb/deg/tire): | 580.99 | 580.99 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |
| Camber Stiffness (lb/deg/tire): | 60.00 | 60.00 |
| Aligning Torque Coef. (in-lb/deg/tire): | 1326.00 | 1326.00 |
| Longitudinal Stiffness (lb/slip/tire): | 0.00 | 0.00 |
| Peak Mu: | 0.76 | 0.76 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |
| Slide Mu: | 0.54 | 0.54 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |
| Slip @ Peak Mu (%/100): | 0.30 | 0.30 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |
| Pneumatic Trail (in): | 2.10 | 2.10 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |



Vehicle Data-EDVDS, Untitled Event

Rear Suspension and Axle Parameters ---

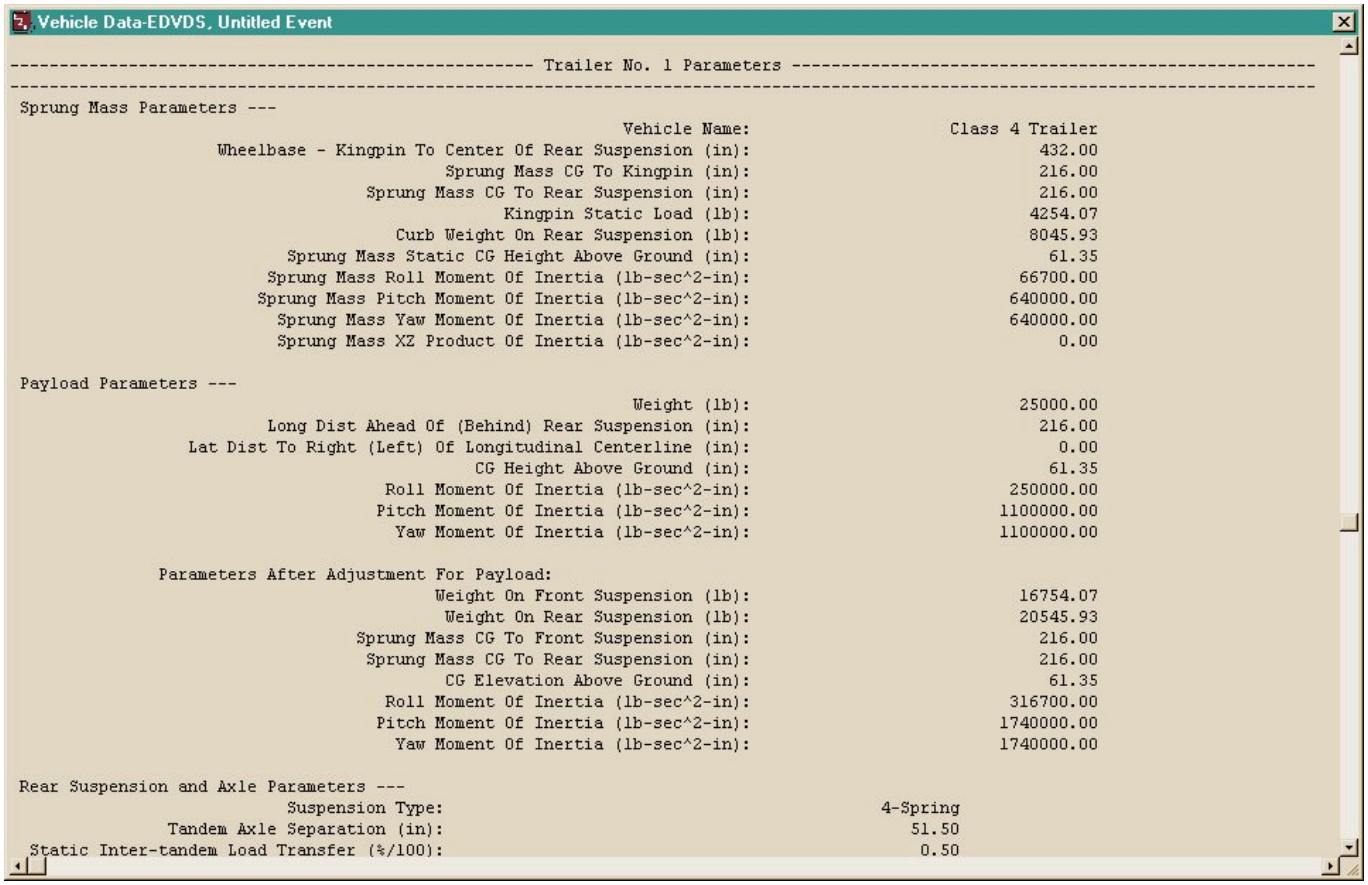
| | | |
|---|---|---|
| Suspension Type: | 4-Spring | |
| Tandem Axle Separation (in): | 51.00 | |
| Static Inter-tandem Load Transfer (%/100): | 0.50 | |
| Dynamic Inter-axle Load Transfer (%/100): | 0.00 | |

| | Leading Tandem Axle | Trailing Tandem Axle |
|---|---|---|
| Axle Roll/Yaw Inertia (lb-sec^2-in): | 12230.00 | 12230.00 |
| Axle Roll Ctr Ht Above Ground (in): | 33.85 | 33.85 |
| Axle Roll Steer (deg/deg): | 0.00 | 0.00 |
| Auxiliary Roll Stiffness (in-lb/deg): | 0.00 | 0.00 |
| Lateral Spring Spacing (in): | 40.00 | 40.00 |
| Track Width (in): | 72.24 | 72.24 |
| Total Unsprung Weight (Axle+Wheels, lb): | 2104.00 | 2104.00 |

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|
| Spring Rate (lb/in): | 4705.00 | 4705.00 | 4705.00 | 4705.00 |
| Viscous Damping (lb-sec/in): | 18.90 | 18.90 | 18.90 | 18.90 |
| Coulomb Friction (lb): | 600.00 | 600.00 | 600.00 | 600.00 |
| Deflection to Jounce Stop (in): | -5.00 | -5.00 | -5.00 | -5.00 |
| Stop Linear Rate (lb/in): | 300.00 | 300.00 | 300.00 | 300.00 |
| Stop Cubic Rate (lb/in^3): | 600.00 | 600.00 | 600.00 | 600.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |
| Deflection to Jounce Stop (in): | 5.00 | 5.00 | 5.00 | 5.00 |
| Stop Linear Rate (lb/in): | 300.00 | 300.00 | 300.00 | 300.00 |
| Stop Cubic Rate (lb/in^3): | 600.00 | 600.00 | 600.00 | 600.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |

Tire, Wheel and Brake Parameters ---

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|
| Tire Name: | Generic Rib 11.00R20 | Generic Rib 11.00R20 | Generic Rib 11.00R20 | Generic Rib 11.00R20 |
| Tire Manufacturer: | Generic | Generic | Generic | Generic |
| Tire Model: | Rib | Rib | Rib | Rib |
| Tire Size: | 11.00R20H | 11.00R20H | 11.00R20H | 11.00R20H |
| Dual Tire Spacing (in): | 12.88 | 12.88 | 12.88 | 12.88 |
| Cornering Stiffness (lb/deg/tire): | 580.99 | 580.99 | 580.99 | 580.99 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |



Vehicle Data-EDVDS, Untitled Event

---------- Trailer No. 1 Parameters ----------

Sprung Mass Parameters ---

| | |
|---|---|
| Vehicle Name: | Class 4 Trailer |
| Wheelbase - Kingpin To Center Of Rear Suspension (in): | 432.00 |
| Sprung Mass CG To Kingpin (in): | 216.00 |
| Sprung Mass CG To Rear Suspension (in): | 216.00 |
| Kingpin Static Load (lb): | 4254.07 |
| Curb Weight On Rear Suspension (lb): | 8045.93 |
| Sprung Mass Static CG Height Above Ground (in): | 61.35 |
| Sprung Mass Roll Moment Of Inertia (lb-sec^2-in): | 66700.00 |
| Sprung Mass Pitch Moment Of Inertia (lb-sec^2-in): | 640000.00 |
| Sprung Mass Yaw Moment Of Inertia (lb-sec^2-in): | 640000.00 |
| Sprung Mass XZ Product Of Inertia (lb-sec^2-in): | 0.00 |

Payload Parameters ---

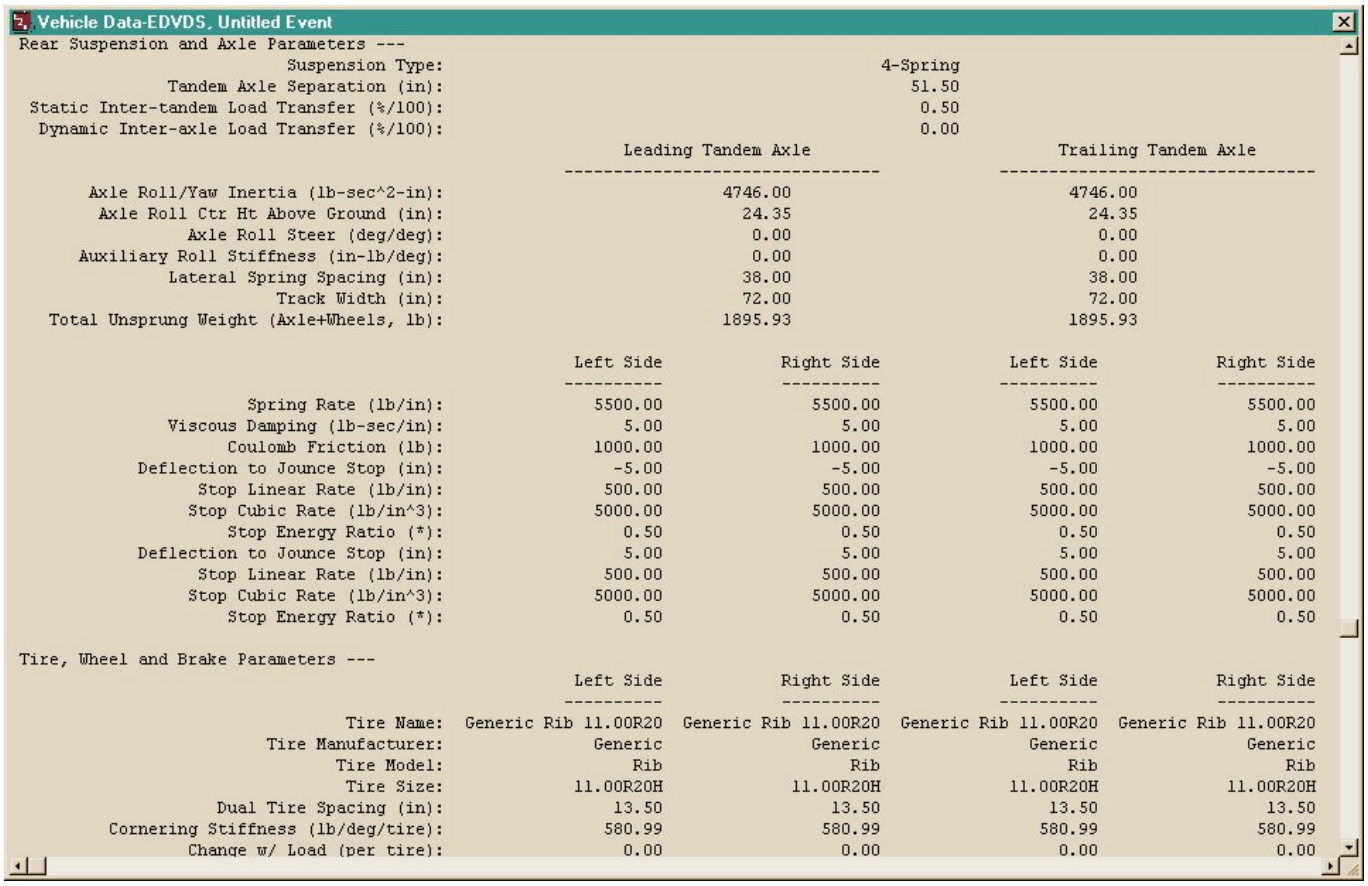
| | |
|---|---|
| Weight (lb): | 25000.00 |
| Long Dist Ahead Of (Behind) Rear Suspension (in): | 216.00 |
| Lat Dist To Right (Left) Of Longitudinal Centerline (in): | 0.00 |
| CG Height Above Ground (in): | 61.35 |
| Roll Moment Of Inertia (lb-sec^2-in): | 250000.00 |
| Pitch Moment Of Inertia (lb-sec^2-in): | 1100000.00 |
| Yaw Moment Of Inertia (lb-sec^2-in): | 1100000.00 |

Parameters After Adjustment For Payload:

| | |
|---|---|
| Weight On Front Suspension (lb): | 16754.07 |
| Weight On Rear Suspension (lb): | 20545.93 |
| Sprung Mass CG To Front Suspension (in): | 216.00 |
| Sprung Mass CG To Rear Suspension (in): | 216.00 |
| CG Elevation Above Ground (in): | 61.35 |
| Roll Moment Of Inertia (lb-sec^2-in): | 316700.00 |
| Pitch Moment Of Inertia (lb-sec^2-in): | 1740000.00 |
| Yaw Moment Of Inertia (lb-sec^2-in): | 1740000.00 |

Rear Suspension and Axle Parameters ---

| | |
|---|---|
| Suspension Type: | 4-Spring |
| Tandem Axle Separation (in): | 51.50 |
| Static Inter-tandem Load Transfer (%/100): | 0.50 |



Vehicle Data-EDVDS, Untitled Event

Rear Suspension and Axle Parameters ---

| | | |
|---|---|---|
| Suspension Type: | 4-Spring | |
| Tandem Axle Separation (in): | 51.50 | |
| Static Inter-tandem Load Transfer (%/100): | 0.50 | |
| Dynamic Inter-axle Load Transfer (%/100): | 0.00 | |

| | Leading Tandem Axle | Trailing Tandem Axle |
|---|---|---|
| Axle Roll/Yaw Inertia (lb-sec^2-in): | 4746.00 | 4746.00 |
| Axle Roll Ctr Ht Above Ground (in): | 24.35 | 24.35 |
| Axle Roll Steer (deg/deg): | 0.00 | 0.00 |
| Auxiliary Roll Stiffness (in-lb/deg): | 0.00 | 0.00 |
| Lateral Spring Spacing (in): | 38.00 | 38.00 |
| Track Width (in): | 72.00 | 72.00 |
| Total Unsprung Weight (Axle+Wheels, lb): | 1895.93 | 1895.93 |

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|
| Spring Rate (lb/in): | 5500.00 | 5500.00 | 5500.00 | 5500.00 |
| Viscous Damping (lb-sec/in): | 5.00 | 5.00 | 5.00 | 5.00 |
| Coulomb Friction (lb): | 1000.00 | 1000.00 | 1000.00 | 1000.00 |
| Deflection to Jounce Stop (in): | -5.00 | -5.00 | -5.00 | -5.00 |
| Stop Linear Rate (lb/in): | 500.00 | 500.00 | 500.00 | 500.00 |
| Stop Cubic Rate (lb/in^3): | 5000.00 | 5000.00 | 5000.00 | 5000.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |
| Deflection to Jounce Stop (in): | 5.00 | 5.00 | 5.00 | 5.00 |
| Stop Linear Rate (lb/in): | 500.00 | 500.00 | 500.00 | 500.00 |
| Stop Cubic Rate (lb/in^3): | 5000.00 | 5000.00 | 5000.00 | 5000.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |

Tire, Wheel and Brake Parameters ---

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|
| Tire Name: | Generic Rib 11.00R20 | Generic Rib 11.00R20 | Generic Rib 11.00R20 | Generic Rib 11.00R20 |
| Tire Manufacturer: | Generic | Generic | Generic | Generic |
| Tire Model: | Rib | Rib | Rib | Rib |
| Tire Size: | 11.00R20H | 11.00R20H | 11.00R20H | 11.00R20H |
| Dual Tire Spacing (in): | 13.50 | 13.50 | 13.50 | 13.50 |
| Cornering Stiffness (lb/deg/tire): | 580.99 | 580.99 | 580.99 | 580.99 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |

*Figure 3-6 (parts 1-5): An Example of a Vehicle Data Output Report issued by EDVDS, showing Tractor Sprung Mass, Suspension and Axle, Tire/Wheel/Brake, Trailer and Payload parameter sections.*

## Graphic Reports

EDVDS produces no Graphic Output Reports.

> **NOTE:** Graphs of simulation results vs time may be produced using the Variable Output window (see next section).

## Variable Output Table

EDVDS produces a Variable Output table containing the time-based simulation results. The Variable Output groups produced by EDVDS are as follows:

### Vehicle Output Groups

- **Kinematics** — Position, velocity and acceleration for the vehicle
- **Kinetics** — Forces and moments acting on the sprung mass
- **Accelerometers** — Linear accelerations at user-specified locations on the vehicle
- **Tire** — The tire output parameters existing at the tire contact patch (compare with Wheel Output, below)

- **Wheel** — The wheel output parameters existing at the wheel's hub. Information about the position of each wheel (compare with Tire output, above)
- **Connections** — The articulation angles and inter-vehicle connection forces
- **Driver** — Current levels of driver inputs (steering, braking, throttle and gear ratios)

An example of a Variable Output table is shown in Figure 3-7. A detailed listing of each Variable Output parameter produced by EDVDS is found in Table 3-1. For more information about HVE Variable Output parameters, refer to the HVE User's Manual, Chapter 16, Event Model.

**Table 3-1: Vehicle Variable Output Data**

| Parameter | Description |
|---|---|
| Vehicle Kinematic Data | X,Y,Z position of CG; $\Phi, \Theta, \Psi$ orientation; Total linear velocity, u,v,w components; Sideslip, course angles; p,q,r angular velocity; Total linear accel, fwd, side, vert components; u-dot, v-dot, w-dot linear components; p-dot, q-dot, r-dot angular components |
| Kinetic Data | $\Sigma F_x$, $\Sigma F_y$, $\Sigma F_z$ (Suspension); $\Sigma M_x$, $\Sigma M_y$, $\Sigma M_z$ (Suspension); $\Sigma F_x$, $\Sigma F_y$, $\Sigma F_z$ (Connection); $\Sigma M_x$, $\Sigma M_y$, $\Sigma M_z$ (Connection) |
| Accelerometer Data | Total linear acceleration; forward, lateral, vertical components for each accelerometer |
| Tire Data | X,Y,Z position of tire contact patch; $F'_x$, $F'_y$, $F'_z$ of tire contact patch; Loaded Tire Radius; Longitudinal Slip; Slip Angle; Skid Flag |
| Wheel Data | x,y,z location of wheel; Camber, Steer angle of wheel; Wheel Spin Velocity; $F_x$, $F_y$, $F_z$ of wheel; Jounce/Rebound displacement, velocity; Spring, Damping and Anti-pitch Suspension Force; Drive and Brake Torque at wheel; Brake Pressure at wheel |
| Connection Data | Articulation roll, pitch, yaw; Articulation p,q,r angular velocity; Articulation p-dot, q-dot, r-dot angular acceleration; Connection $F_x$, $F_y$, $F_z$; Connection $M_x$, $M_y$, $M_z$ |
| Drivetrain Data | Engine Speed, Power and Torque; Transmission and Differential Numeric Ratio |
| Driver Data (*) | Steering wheel angle; Throttle position; Brake Pedal Force and Master Cylinder Pressure; Transmission and Differential Gear Selection |

(*) If Driver Control option was 'At Driver'

Variable Output-EDVDS, Lane-Change Maneuver

Select... Graph... Edit...

| Time (sec) | Freightliner F X (ft) | Freightliner F Y (ft) | Freightliner F Z (ft) | Freightliner F Roll (deg) | Freightliner F Pitch (deg) | Freightliner F Yaw (deg) | Freightliner F Radius (ft) | Freightline Nu (deg) |
|---|---|---|---|---|---|---|---|---|
| 2.8000 | 171.0 | 47.2 | -3.9 | 0.6 | -0.1 | 5.0 | 1242.2 | 4.8 |
| 2.9000 | 181.0 | 48.1 | -3.9 | 0.6 | -0.1 | 5.5 | 1358.7 | 5.2 |
| 3.0000 | 191.2 | 49.1 | -3.9 | 0.7 | -0.1 | 5.9 | 1490.9 | 5.7 |
| 3.1000 | 201.5 | 50.1 | -3.8 | 0.7 | -0.1 | 6.2 | 1647.9 | 6.0 |
| 3.2000 | 211.9 | 51.2 | -3.9 | 0.7 | 0.1 | 6.6 | 5509.9 | 6.3 |
| 3.3000 | 222.3 | 52.4 | -4.1 | 0.5 | 1.2 | 6.8 | 2.9 | 6.5 |
| 3.4000 | 232.8 | 53.6 | -4.3 | 0.2 | 0.2 | 7.0 | 1550.2 | 6.5 |
| 3.5000 | 243.4 | 54.8 | -4.4 | -2.9 | -2.2 | 7.0 | -4992.8 | 6.7 |
| 3.6000 | 254.0 | 56.0 | -4.4 | -3.7 | -2.5 | 7.0 | -1829.1 | 6.7 |
| 3.7000 | 264.6 | 57.2 | -4.3 | -2.7 | -0.4 | 7.2 | 3675.4 | 6.5 |
| 3.8000 | 275.2 | 58.5 | -4.3 | -3.3 | 2.9 | 7.3 | -989.6 | 6.5 |
| 3.9000 | 285.9 | 59.7 | -4.5 | -4.7 | 0.1 | 7.7 | 672.3 | 6.7 |
| 4.0000 | 296.6 | 60.9 | -4.8 | -7.1 | -4.0 | 7.8 | -2292.1 | 7.1 |
| 4.1000 | 307.3 | 62.1 | -5.1 | -4.6 | -5.0 | 8.2 | -3215.0 | 6.9 |
| 4.2000 | 318.1 | 63.3 | -5.4 | -3.4 | -3.6 | 8.5 | 7245.3 | 6.8 |
| 4.3000 | 328.8 | 64.5 | -5.4 | -5.0 | -1.2 | 8.7 | -6765.5 | 6.6 |
| 4.4000 | 339.6 | 65.8 | -5.1 | -1.5 | 1.6 | 9.2 | 5922.9 | 6.3 |
| 4.5000 | 350.3 | 67.0 | -4.6 | -0.8 | 1.5 | 8.9 | 1968.0 | 6.7 |
| 4.6000 | 361.1 | 68.3 | -4.3 | 1.3 | -2.4 | 8.6 | 3164.5 | 7.0 |
| 4.7000 | 371.9 | 69.7 | -4.5 | 0.1 | -0.4 | 8.4 | -1867.2 | 7.4 |
| 4.8000 | 382.7 | 71.1 | -4.8 | -0.0 | 1.3 | 8.2 | -1708.7 | 7.5 |

*Figure 3-7: Typical Variable Output Table for an EDVDS event.*

## Trajectory Simulations

EDVDS produces a trajectory simulation of the current event. The trajectory simulation is a 3-D visualization of the data displayed in the Variable Output table (see previous section). An example of a trajectory simulation is shown in Figure 3-8.




*Figure 3-8: Typical EDVDS Trajectory Simulation.*

### Displaying a Trajectory Simulation

The Trajectory Simulation is controlled using the Playback Controller (Figure 3-9). The Playback Controller's buttons have the following functions:

- **Reset** — Returns to the start of the simulation and reinitializes the video output device (this applies a hardware reset and is otherwise the same as the *Rewind to Start* button, below)
- **Rewind to Start** — Return to the start of the simulation
- **Reverse** — Play the simulation backwards
- **Pause** — Pause the simulation
- **Play** — Execute the event or play the simulation forwards
- **Advance to End** — Advance to the end of the simulation



*Figure 3-9: Playback Controller.*

# Chapter 4 — Calculation Method

## Basis for Analysis

EDVDS is a dynamic analysis of a unit or combination vehicle (tractor towing up to three trailers). The first trailer is a semi-trailer, while the second and third trailers are full trailers with the front of the trailer supported by a dolly (fixed or converter type). Each vehicle front and rear suspension may have single or tandem axles. Tandem axles may be of the 4-spring or walking beam variety. The vehicles have user-definable steering and brake systems.

The mathematical model for EDVDS was developed from a program, called Phase 4, developed for the U.S. Federal Highway Administration (FHWA) by the University of Michigan Transportation Research Institute [1-5]. EDC ported the original Phase 4 to execute in the HVE simulation environment (this process also involved rewriting the model using the C programming language). EDC then modified the code as follows:

- The equations of motion were rewritten and extended to allow complete 3-dimensional motion. The small angle assumption was eliminated.
- The equations of motion were generalized to allow the vehicle positions to be at any location (the original Phase 4 code required the tow vehicle to start in equilibrium at the earth-fixed origin) at the start of the simulation.
- The Phase 4 user-written ROAD subroutine was replaced by HVE's terrain surface information lookup, allowing the vehicles to drive on an arbitrary 3-D surface.
- The in-line solution of the equations of motion was replaced by a simultaneous solutions procedure.

For successful use of EDVDS, a good understanding of vehicle and tire dynamics is extremely useful and is recommended. However, the following discussion is limited to the general analytical approach. For a detailed treatise on the subject of vehicle dynamics and simulation programs, the user is referred to the references listed at the end of this Program Manual as well as those listed in HVE Appendix VI, References.

## Equations of Motion

Three coordinate systems are required for the equations of motion:

- The vehicle-fixed x,y,z coordinate system is fixed to the vehicle's CG and defines motion of the vehicle sprung mass, with x defined along the longitudinal vehicle axis, y defined to the right, and z directed down. Vehicle rotations are defined about these axes as roll (about the x axis), pitch (about the y axis) and yaw (about the z axis).
- The earth-fixed X,Y,Z coordinate system is fixed to the earth (as its name implies). The current vehicle sprung mass position is defined by this coordinate system.
- The tire axis system is fixed to the tire, and defines the direction of the tire plane, x′, relative to the vehicle-fixed coordinate system due to its current steer angle, $\delta$.

Each sprung mass includes six degrees of freedom (X,Y,Z, roll, pitch, yaw). Each axle includes two degrees of freedom (axle z and roll). Each wheel also includes a spin degree of freedom for dynamic braking calculations.

The required equations of motion for each vehicle sprung mass are:

$$\Sigma F_x = m(\dot{u} - vr + wq)$$

$$\Sigma F_y = m(\dot{v} + ur - wp)$$

$$\Sigma F_z = m(\dot{w} + uq - vp)$$

$$\Sigma M_x = I_x \dot{p} - I_{xz} \dot{r} + qr(I_z - I_y) - I_{xz}\, pq$$

$$\Sigma M_y = I_y \dot{q} + pr(I_x - I_z) + I_{xz}(p^2 - r^2)$$

$$\Sigma M_z = I_z \dot{r} - I_{xz} \dot{p} + pq(I_y - I_x) + I_{xz}\, qr$$

where:

| Symbol | Definition |
|---|---|
| $m$ | vehicle sprung mass |
| $I_x, I_y, I_z$ | roll, pitch and yaw rotational moments of inertia |
| $u, v, w$ | forward, lateral and vertical velocities (vehicle-fixed components) |
| $p, q, r$ | roll, pitch and yaw angular velocities (about vehicle-fixed x, y and z axes, respectively) |
| $\Sigma F_x, \Sigma F_y, \Sigma F_z$ | summation of external forces in the vehicle-fixed x, y and z directions, respectively |
| $I_{xz}$ | roll-yaw product of inertia |
| $\Sigma M_x, \Sigma M_y, \Sigma M_z$ | summation of external moments about the vehicle-fixed x, y and z axes, respectively |

> **NOTE:** The roll-yaw product of inertia, $I_{xz}$, is entered in the Vehicle Editor and *is* used. It appears twice in each moment equation — once coupling the roll and yaw accelerations, and once among the gyroscopic terms. For a tractor-semitrailer this is not a refinement that can be ignored: it is the inertial coupling that ties roll motion to yaw motion, and therefore part of what governs rollover and trailer sway. Earlier editions of this chapter gave the moment equations in their principal-axes form, with $I_{xz}$ absent.

*(updated: the moment equations above previously omitted all product-of-inertia terms.)*

The equations of motion for each axle are

$$\Sigma F_{z,u} = m_u \ddot{z}_{axle}$$

$$\Sigma M_{x,u} = I_{x,u} \ddot{\phi}$$

where:

| Symbol | Definition |
|---|---|
| $m_u$ | axle unsprung mass (including wheels) |
| $I_{x,u}$ | axle roll moment of inertia |
| $z_{axle}$ | vertical axle displacement (vehicle-fixed z component) |
| $\phi$ | axle roll displacement (vehicle-fixed roll angle) |
| $\Sigma F_{z,u}$ | summation of external forces acting on the axle (vehicle-fixed component) |
| $\Sigma M_{x,u}$ | summation of external moments acting on the axle about the vehicle-fixed x axis |

Finally, the equations of motion for wheel spin for each wheel are

$$\Sigma M_w = I_w \ddot{\Omega}$$

where:

| Symbol | Definition |
|---|---|
| $I_w$ | wheel total spin inertia (including tire, rim and rotating brake components) |
| $\Omega$ | wheel rotational displacement about spin axis |
| $\Sigma M_w$ | summation of moments acting about the vehicle-fixed wheel spin axis |

### How the equations are actually solved

The equations above are written one group at a time for clarity, but they are not solved that way. The sprung-mass degrees of freedom and every axle degree of freedom are assembled into a **single coupled system** and solved simultaneously at each timestep:

$$\mathbf{M}\,\ddot{\mathbf{q}} = \mathbf{Q}$$

Two properties of that system are worth understanding, because neither is visible in the equations as written above.

**The mass matrix is not diagonal.** Besides the roll-yaw coupling through $I_{xz}$, each axle's vertical and roll acceleration is inertially coupled to the sprung mass's lateral, roll and yaw accelerations, through the axle's mass and its position relative to the vehicle CG. Moving an axle vertically therefore produces a moment on the sprung mass directly, independently of any suspension force.

**The inertia terms are rebuilt every timestep.** The total mass carried in the translational equations is the sprung mass **plus** every unsprung mass, and the rotational inertias carry each unsprung mass's parallel-axis contribution evaluated at that axle's *current* displacement. Because the axles move, the vehicle's effective inertia changes during the run. The axles also generate a roll-yaw product of inertia of their own, from being both fore or aft of the CG and above or below it, which adds to the vehicle's entered $I_{xz}$.

*(updated: earlier editions presented the sprung mass, axle and wheel spin equations as three independent sets and did not state that they are solved as one coupled system, nor that the inertia terms vary with axle position.)*

EDVDS solves these equations of motion at discrete time intervals (specified by the vehicle trajectory integration timestep, see HVE User's Manual, Simulation Controls). The current accelerations are integrated, using numerical integration, to predict velocity and position at the start of the next timestep. EDVDS uses

*Hamming's Modified Predictor-Corrector*

integration method [22]. Use of a predictor-corrector method helps to ensure stable results. A predictor-corrector method estimates the future position and velocity based on the current acceleration history, and then, once they are calculated, compares the predicted results with the calculated results. If the error is too large (as defined by the user-entered Velocity Convergence Criterion; see Simulation Controls), the integration timestep is halved and the equations of motion are re-executed until a stable solution is found (or until the number of re-executions exceeds the user-entered value for Maximum Bisections, causing the run to terminate; see Simulation Controls).

## External Forces

External forces are applied at the tire-road interface and at the inter-vehicle connections. Because these forces completely define the motion of the vehicle(s), it is important that the user fully understand how they are calculated.

### Tire Forces

Unfortunately, pneumatic tires do not behave in an easy-to-calculate manner. Rather, these properties are functions of several variables and are extremely non-linear.

Vertical tire force, $F_z$, is calculated directly from tire radial stiffness and current tire deflection (that is, the difference between undeflected tire radius and the current distance from the wheel center to the road surface). Mathematically, this is expressed as

$$F_z = k_t \delta$$

where:

| Symbol | Definition |
|---|---|
| $k_t$ | radial tire stiffness |
| $\delta$ | radial tire deflection |

Longitudinal tire force, $F_x$, and lateral tire force, $F_y$, are strongly dependent on the current vertical tire force. Historically, two methods have been used to compute longitudinal and lateral tire forces. Either formulas utilizing experimental coefficients are used (this method is referred to as a *tire model*) or tables containing test data at various speed and load conditions are applied according to the current speed and load conditions (this method is referred to as a *table look-up* method). EDVDS uses both of these methods, allowing the user to choose from three tire model options:

- Linear Tire Model
- Semi-empirical Tire Model
- Table Look-up with Slip vs Roll-off *(updated: not implemented in the current version — see below)*

These tire modeling options are described below.

> **NOTE:** The desired tire model is selected by choosing Calculation Options during Event Set-up. See Chapter 2 (Program Input) and Chapter 5 (EDVDS Tutorial) for further details, and the EDVDS Calculation Options reference.

*(updated: hydroplaning is **not** modeled by EDVDS. Hydroplaning models (NASA, NASA-TTI, Gallaway) are available in HVE, but only through SIMON and EDSMAC4; EDVDS offers no Hydroplaning Model calculation option, and any water-related tire output variables it reports are unused placeholders. See SIMON — Hydroplaning Model.)*

#### *Linear Tire Model*

The linear tire model is the simplest of models and should be used only for non-limit maneuvers. In fact, the simulation will terminate if the longitudinal tire slip exceeds 0.25 (25 percent) or the lateral tire slip angle exceeds 0.25 radians.

The linear tire model uses the tire's longitudinal and lateral stiffnesses to calculate $F_x$ and $F_y$, respectively. The linear model has no load- or speed-dependence. Rather, a simple linear relationship is assumed:

$$F_x = C_s S$$

and

$$F_y = C_\alpha \alpha$$

where:

| Symbol | Definition |
|---|---|
| $F_x$ | Longitudinal Tire Force |
| $C_s$ | Tire Longitudinal Stiffness |
| $S$ | Longitudinal Slip |
| $F_y$ | Lateral Tire Force |
| $C_\alpha$ | Tire Cornering Stiffness |
| $\alpha$ | Tire Slip Angle |

These relationships are shown in Figures 4-1 and 4-2. Note that tire forces in the linear tire model are not assumed to be limited by friction because, as mentioned above, the simulation terminates before a friction-limiting condition exists.

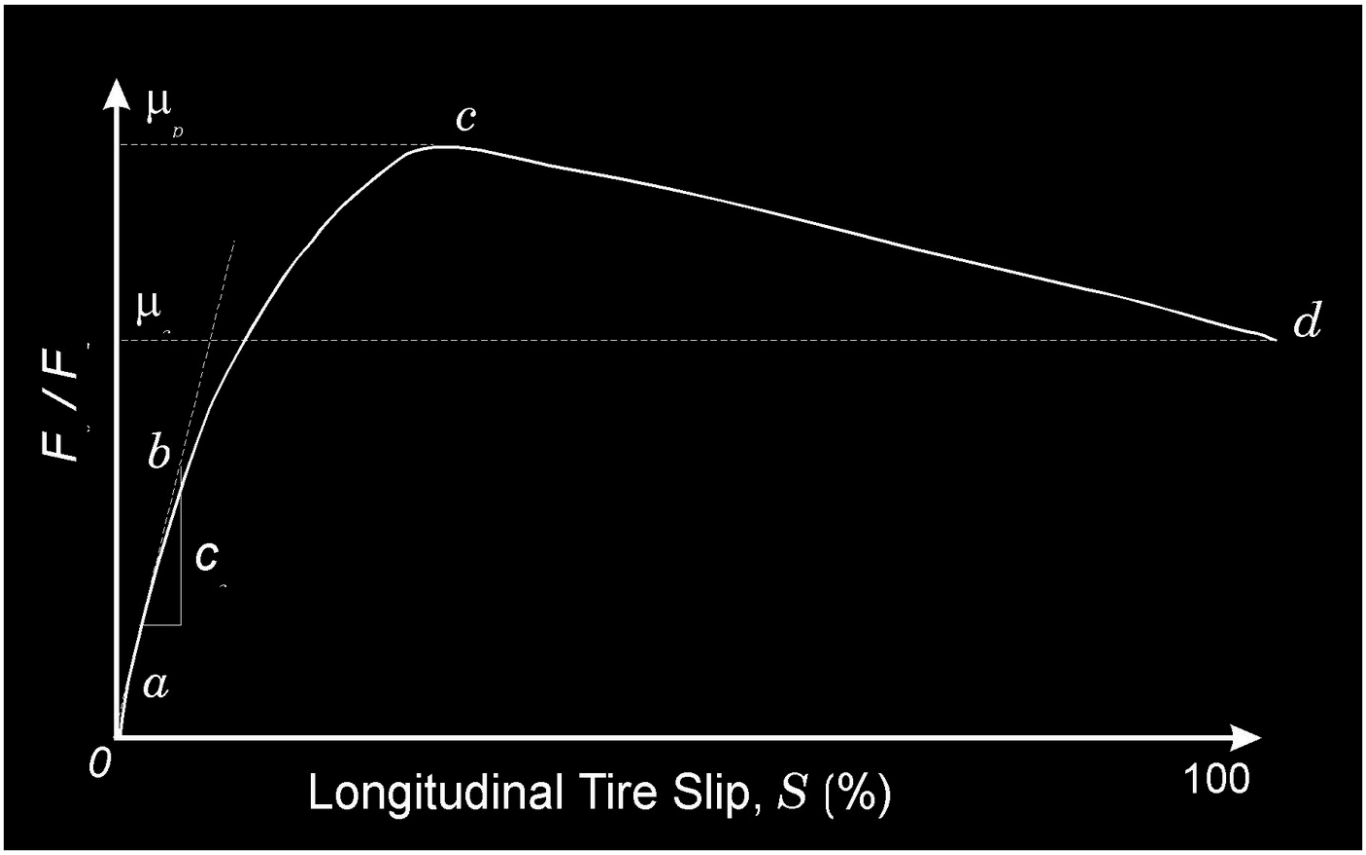



*Figure 4-1: Typical longitudinal tire force vs slip relationship. A linear tire model would use slope b, while a robust tire model would follow the slope from a to d. $\mu_p$ and $\mu_s$ are peak and slide friction, respectively; $C_s$ is the longitudinal stiffness.*

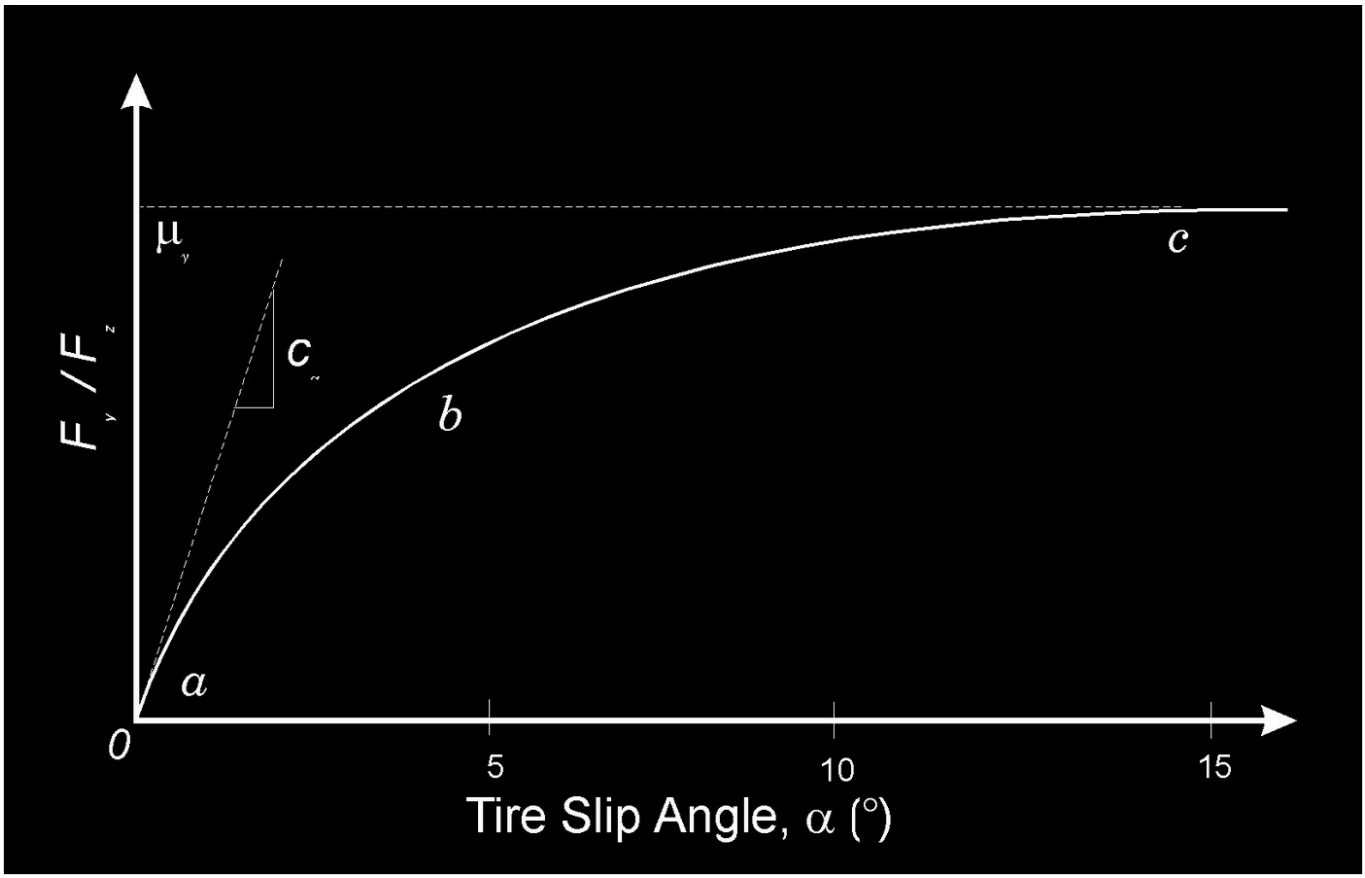



*Figure 4-2: Typical lateral tire force vs slip angle relationship. $C_\alpha$ is the cornering stiffness and $\mu_y$ is the lateral friction coefficient.*

***Semi-empirical Tire Model***

The semi-empirical tire model was developed at the University of Michigan Transportation Research Institute and is described fully in reference [1]. An overview of that discussion is provided below for completeness.

The semi-empirical tire model describes empirically what is occurring at the tire-road shear interface, according to the current tire-road conditions. It employs a simplified theory including an adhesion region and a sliding region.

The major assumptions made by the tire model are:

- The contact patch can be divided into two regions; an adhesion region and a sliding region.
- The shear force generated in the adhesion region depends on the elastic properties of the tire and the shear force generated in the sliding region depends on the frictional properties at the tire-road interface.

The inputs required by the tire model are:

- $F_o$ — Vertical load for middle of up to three test loads.
- $V_o$ — Longitudinal velocity for middle of up to three test speeds.
- $\mu_p, \mu_s, S_p$ — Peak and slide tire-road friction and longitudinal slip at $\mu_p$, at $F_o$ and $V_o$ (these data generate a $\mu$ -slip curve at $F_o, V_o$).
- $C_\alpha$ — Cornering stiffness at $F_o, V_o$.

The tire data for the semi-empirical tire model require the above data at one load and speed. If the HVE tire data for the selected tire contain data for more than one load or speed, the rates of change for those parameters with respect to load

and/or speed are also used by the model. For example, if $C_\alpha$ data for more than one load are supplied, then $\partial C_\alpha / \partial F_z$ is calculated from the difference in $C_\alpha$ for the maximum and minimum loads.

From these data, the following intermediate parameters are computed:

$$a = (1.0 - S_p')^2 (1.0 + S_p')$$

$$b = (1.0 - S_p')(\mu_s'(S_p' + 2.0) - \mu_p'(2.0 S_p' + 1.0))$$

$$c = (\mu_s' - \mu_p')\,\mu_s'$$

$$B = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

$$A = \mu_s' + B$$

$$C = \mu_s' + B(1.0 - S_p')$$

$\mu$ and $C_s$ are then computed as follows:

$$C_s = \frac{C^2 F_{z_0} (1.0 - S_p')}{4.0\, S_p' (C - \mu_p')}$$

$$\mu = A - B|S|$$

$\mu$ is not allowed to fall below the value it takes at fully locked or fully spinning slip, $\mu \geq A - B$.

Based on these parameters $X_s / L$, the fraction of the total contact patch in the **adhesion** region ($L$ is the total length of the contact patch, and $X_s$ is the distance from the front of the contact patch to the point where sliding starts), is calculated as follows:

$$D_i = \sqrt{(C_s S)^2 + (C_\alpha' \sin\alpha)^2}$$

$$\frac{X_s}{L} = \frac{\mu F_z (1.0 - |S|)}{2.0\, D_i}$$

If $X_s / L > 1.0$ it is limited to 1.0 (note that $X_s / L = 1.0$ means there is no sliding region). If $X_s / L \geq 1.0$, the longitudinal and lateral tire forces, $F_x$ and $F_y$, respectively, are:

$$F_x = s_u \frac{C_s S}{1.0 - |S|}$$

$$F_y = \frac{-C_\alpha' \sin\alpha}{1.0 - |S|}$$

where $s_u = -\operatorname{sgn}(u)$ orients the longitudinal force against the tire's direction of travel, so that a braking slip always retards the vehicle whether it is rolling forward or backward.

If $X_s / L < 1.0$, there is some sliding at the tire-road interface. For this condition, the tire forces in the adhesion region and sliding region are computed separately. The $F_x$ and $F_y$ tire forces in the adhesion region are:

$$F_{x_a} = C_s S \left(\frac{\mu F_z}{2.0 D_i}\right)^2 (1.0 - |S|)$$

and

$$F_{y_a} = -C'_\alpha \sin\alpha \left(\frac{\mu F_z}{2.0 D_i}\right)^2 (1.0 - |S|)$$

The tire force components in the sliding region are:

$$F_{x_s} = \mu F_z (1.0 - X_s / L)\left(\frac{S}{\sqrt{S^2 + \sin^2\alpha}}\right)$$

$$F_{y_s} = -\mu F_z (1.0 - X_s / L)\left(\frac{\sin\alpha}{\sqrt{S^2 + \sin^2\alpha}}\right)$$

The total tire force is the sum of the force in the adhesion and sliding regions,

$$F_x = s_u (F_{x_a} + F_{x_s})$$

and

$$F_y = F_{y_a} + F_{y_s}$$

*(updated: several corrections to the equations above, which were transcribed from the published UMTRI development rather than from the EDC implementation:*

- *The slip angle enters through* $\sin\alpha$*, not* $\tan\alpha$*. Replacing the tangent with the sine is the EDC modification that lets the model handle slip angles through the full range* $-\pi \le \alpha \le \pi$ *without the lateral force diverging at 90 degrees.*
- *Longitudinal slip appears as* $|S|$ *wherever it appears as a magnitude, which is what allows drive torque and rearward travel.*
- *The quadratic root* $B$ *negates only* $b$*, not the whole numerator.*
- *A lower limit is placed on the effective friction.*
- *A direction-of-travel factor is applied to the longitudinal force.*
- $X_s / L$ *is the fraction of the contact patch in the adhesion region, not the sliding region; the earlier description contradicted the statement that* $X_s / L = 1.0$ *means there is no sliding region.)*

The aligning torque, $A_t$, is approximated as follows:

$$A_t \cong -F_y X'_p (X_s / L) + F_y F_x C'_y$$

The tire model uses the current vertical tire load, $F_z$, and the fraction of the sliding region at the tire-road interface to set the skid flag, $SF$:

$$\text{if}\left\{ \begin{array}{c} F_z > F_{z,min} \\ \text{and} \\ X_s / L < \tau \end{array} \right\},\ SF = TRUE$$

***Table Look-up Tire Model***

The table look-up tire model is not implemented in EDVDS.

*(This remains true in the current version: the* ***Table Look-Up*** *option is greyed out in the Calculation Options dialog, and if it is selected the event terminates with a fatal error.)*

## Connection Forces

The equations of motion are solved by assuming constraint forces exist at the inter-vehicle connection locations. The constraint equations are solved for each integration timestep by calculating the earth-fixed X,Y,Z location of the connections on each vehicle, and assuming a constraint force exists between the connections, acting along a line between the connection points. The constraint force is equal to the product of the spring rate and distance between connections plus the product of the damping rate and the linear velocity between connections. For 5th wheel connections between vehicles, the relative roll angular displacements and velocities are used, in conjunction with torsional stiffness and damping factors, to calculate the roll transfer between tow vehicle and trailer. This method also allows for the ability to model the roll compliance at the 5th wheel connection.

## Suspension Forces

The suspension is modeled by linear springs and dampers on each axle, separated by a user-specified lateral spring spacing. The suspension is free to move only in the linear z direction, and to rotate about the user-entered suspension roll center, so longitudinal and lateral forces from the tires are applied directly at the CG.

The current suspension force in the z direction is the product of the user-entered spring rate and the spring deflection, plus the product of the user-entered damping rate and the spring deflection rate, plus the coulomb friction in the suspension.

Axle roll is calculated using the current spring force and lateral spring spacing. Roll stiffness may be increased with the addition of an anti-sway bar.

As a result of the changes made to the original Phase 4 model, the static suspension force no longer drops out of the equations. For a vehicle in equilibrium, the force reported for each suspension is that force required to support the sprung mass in static equilibrium.

### *Tandem Axles*

For tandem axles, braking causes suspension force to be added to the lead axle and removed from the trailing axle as follows:

$$SF_{LeadingAxle} = SF_{LeadingAxle} + (F_{Shift} T_{Brake}) / \Delta X$$

$$SF_{TrailingAxle} = SF_{TrailingAxle} - (F_{Shift} T_{Brake}) / \Delta X$$

where:

| Symbol | Definition |
|---|---|
| $SF_{LeadingAxle}$ | Total suspension force on lead axle |
| $SF_{TrailingAxle}$ | Total suspension force on trailing axle |
| $F_{Shift}$ | User-entered *Inter-tandem Load Transfer Coefficient* |
| $T_{Brake}$ | Total brake torque for all axles on the tandem axle set |
| $\Delta X$ | Tandem axle spacing |

> **NOTE:** A negative coefficient reduces the suspension force on the lead axle.

## Brake System

EDVDS uses HVE's *At Pedal* driver controls option. Using this option, the user enters a table of *Brake Pedal Force vs Time*.

> **NOTE:** The concept of brake pedal application force does not apply to air brake systems that use a treadle valve. Therefore, all HVE heavy truck models set the brake Pedal Ratio equal to 1.0; thus, your entry into the brake table is really System Pressure vs Time.

EDVDS also uses the following wheel brake options:

- **T_Lag** — Time lag between the time of pedal application and the onset of pressure rise at the wheel.
- **T_Rise** — Time required to fill the air chamber and begin producing brake torque
- **Brake Torque Ratio** — The resulting brake torque per unit of brake pressure in the air chamber.

> **NOTE:** T_Lag and T_Rise are often ignored for passenger cars. However, for truck air brake systems, T_Lag and T_Rise may be significant and should be considered.

The current brake torque, $TQ_{Brake}$, at each wheel is calculated as follows:

$$TQ_{Brake} = BTQ \times \max(0,\ P_{Brake} - P_0)$$

where:

| Symbol | Definition |
|---|---|
| $BTQ$ | Brake torque ratio for the wheel |
| $P_{Brake}$ | Current brake pressure at the wheel, including time lag and time rise |
| $P_0$ | Pushout pressure for the wheel |

EDVDS uses the HVE Brake Designer to obtain $BTQ$. Before the torque is calculated, the brake temperatures at the wheel are updated from the work done during the previous step, the wheel's rotational speed, the vehicle's total velocity and the ambient air temperature; the resulting lining temperature and sliding speed then determine the current lining friction and therefore $BTQ$. Brake fade is produced this way.

*(updated: earlier editions gave the brake torque as a fixed torque ratio times the wheel pressure. The wheel produces no torque until the pressure exceeds the pushout pressure, and the torque ratio is not fixed — it comes from the brake design and varies with lining temperature and sliding speed.)*

### *Brake hysteresis*

If a hysteresis multiplier is entered for a wheel, the brake torque follows a different curve on release than on application. While the wheel pressure is above the pushout pressure the torque is not allowed to fall below its value at the previous timestep, and once the pressure drops back below pushout the torque is scaled by the hysteresis multiplier. A separate multiplier is used once the wheel has locked.

*(updated: the brake hysteresis model was not described in earlier editions.)*

***Wheel torque limit***

The net torque applied about the wheel spin axis is the brake torque less the engine torque. Once a wheel is fully locked, that net torque is limited to the torque the tire's longitudinal force can react against the road, so that a locked wheel cannot be driven backwards by excess brake torque.

*(updated: this limit was not described in earlier editions.)*

### Antilock Model

The EDVDS anti-lock model is not implemented. The antilock option is present but permanently disabled, so a wheel's antilock settings have no effect on an EDVDS event. Use EDSVS, EDVSM or SIMON for studies that require antilock braking.

## Steering System

The steer angle at each steerable wheel is determined from the current user-entered Steer Table value or the HVE Driver Model calculated value for steer angle.

If the current angle is determined from the HVE Steer Table, the user has two options for entering steer angles:

- **At Axle** — The angle at each wheel is derived directly from the steer table for each wheel. Left and right wheels need not have the same steer angle.
- **At Steering Wheel** — The angle at each wheel is the user-entered steering wheel angle divided by the vehicle's steering gear ratio, plus a compliance term. The steer angles at the two wheels differ only through that compliance term.

*(updated: earlier editions gave the wheel angle as the product of the steering wheel angle and the gear ratio. It is the quotient.)*

The compliance term accounts for the steering system twisting under the aligning moments fed back from the tires:

$$\delta_{Wheel} = \frac{\delta_{SW}}{\eta} + \frac{M_{Left} + M_{Right}}{K_{Steering}}$$

where $\eta$ is the steering gear ratio, $M_{Left}$ and $M_{Right}$ are the steer axis moments at the two front wheels, and $K_{Steering}$ is the steering system stiffness. A separate tie rod stiffness allows the two wheels to deflect relative to one another.

*(updated: the steering system compliance was not described in earlier editions.)*

If the HVE Driver Model has been used, the HVE Driver Model is a closed-loop driver control model that uses driver control attributes and the EDVDS vehicle dynamics model to attempt to follow a user-specified path.

## Dollys

Two types of dollys are supported by EDVDS:

- **Converter (Fixed Drawbar) Dolly** — The fifth wheel articulates about the pitch axis, and the drawbar is rigidly attached to the dolly. The result is that brake torque is resisted at the pintle hook of the tow vehicle.

> **NOTE:** Thus, trailer braking results in a vertical load transfer to the rear of the tow vehicle.

- **Fixed (Hinged Drawbar) Dolly** — The fifth wheel is fixed to the trailer and is not free to articulate about its pitch axis. The drawbar is hinged.

> **NOTE:** Thus, there is no load transfer to the tow vehicle.

These two dolly types are shown in Figure 4-3.

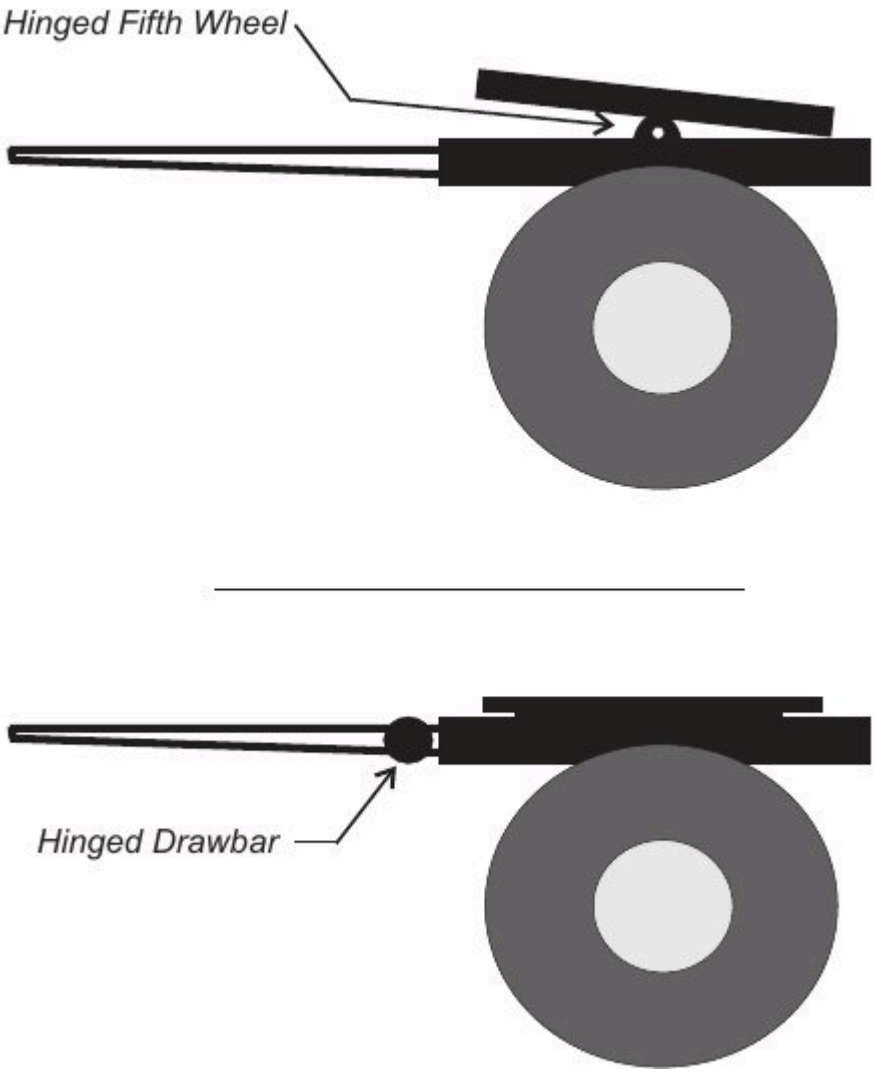



*Figure 4-3: Converter (above, hinged fifth wheel) and Fixed (below, hinged drawbar) dollys.*

## Assumptions

In order to provide a useful analysis, EDVDS makes several assumptions. If EDVDS is to be properly used, it is important these assumptions and their consequences be understood. In some cases, data which violate these assumptions will cause a fatal error, along with a message indicating the reason for the error. In other cases, the error is not with the data but with the use of the program under conditions which violate the assumptions inherent to the computations. EDVDS will issue results which may not be valid for the given circumstances.

Before using EDVDS, be sure the events you wish to simulate are within the scope of the program analysis defined by the following assumptions:

### All External Forces Applied At Tires

Aerodynamic effects are ignored. This assumption may become a significant factor at excessive speeds. In addition, undercarriage contact with the ground caused by impact-related damage is not considered.

# Chapter 5 — EDVDS Tutorial

## Description

This tutorial examines the use of EDVDS to study the controllability of a truck tractor towing a set of 45-foot highway doubles down a mountain road. The vehicle is attempting to negotiate a down-hill curve to the right; the maneuver is further complicated by a substantial super-elevation, a narrow shoulder, and a near-vertical cliff at the shoulder's edge. Ultimately, the combination vehicle leaves the road and rolls over (one question we wish to address in our simulation analysis is whether the vehicle rolled over *before* or *after* it left the road), tumbling down the steep embankment. This sequence of events serves to illustrate the sophisticated capabilities of EDVDS.

Like all EDVDS events, the procedure involves the following basic steps:

- Create the vehicle(s)
- Create the environment
- Execute the EDVDS event(s)
- Review the EDVDS output reports

This basic procedure is described in detail in this tutorial.

> **NOTE:** We assume that HVE is up and running, and that you are familiar with HVE's basic features, such as using HVE's dialogs and viewers, as well as the HVE Editors. The purpose of this tutorial is to illustrate those features while setting up and executing an EDVDS event.

## Getting Started

As in other tutorials, before we get started with our current tutorial, let's set the user options so we're all starting on the same page.

> **NOTE:** Most options simply affect the appearance in a viewer during Event or Playback mode. However, some options affect the data used in the analysis. For example, if AutoPosition is On, the vehicle position conforms to the local surface; otherwise, the position is set by the Position/Velocity dialog. Obviously, the resulting difference in initial conditions could substantially change the event.
>
> **NOTE:** Some of the following options are "Toggles" that switch between two different modes. Make sure these options are set correctly.

To set the initial user options, choose the following from the Options Menu:

- ON: Show Key Results
- OFF: Show Axes
- ON: Show Contacts
- OFF: Show Velocity Vectors
- ON: Show Skidmarks
- OFF: Show Targets

- ON: AutoPosition
- Units equals U.S.
- Render Options:
- Show Humans as *Actual*
- Show Vehicles as *Actual*
- *Phong* Render Method
- Complexity equals *Object*
- Render Quality equals *5*
- Anti-aliasing equals *1*

The remaining options will automatically initialize to their default conditions. We're now ready to proceed with the tutorial.

## Creating the Vehicles

Now let's add the vehicles to our case. The tow vehicle is a 1994 Freightliner FLD-120 conventional tractor; the trailers are both 45-ft semi-trailers. The second semi-trailer is supported at the front by a tandem-axle converter dolly.

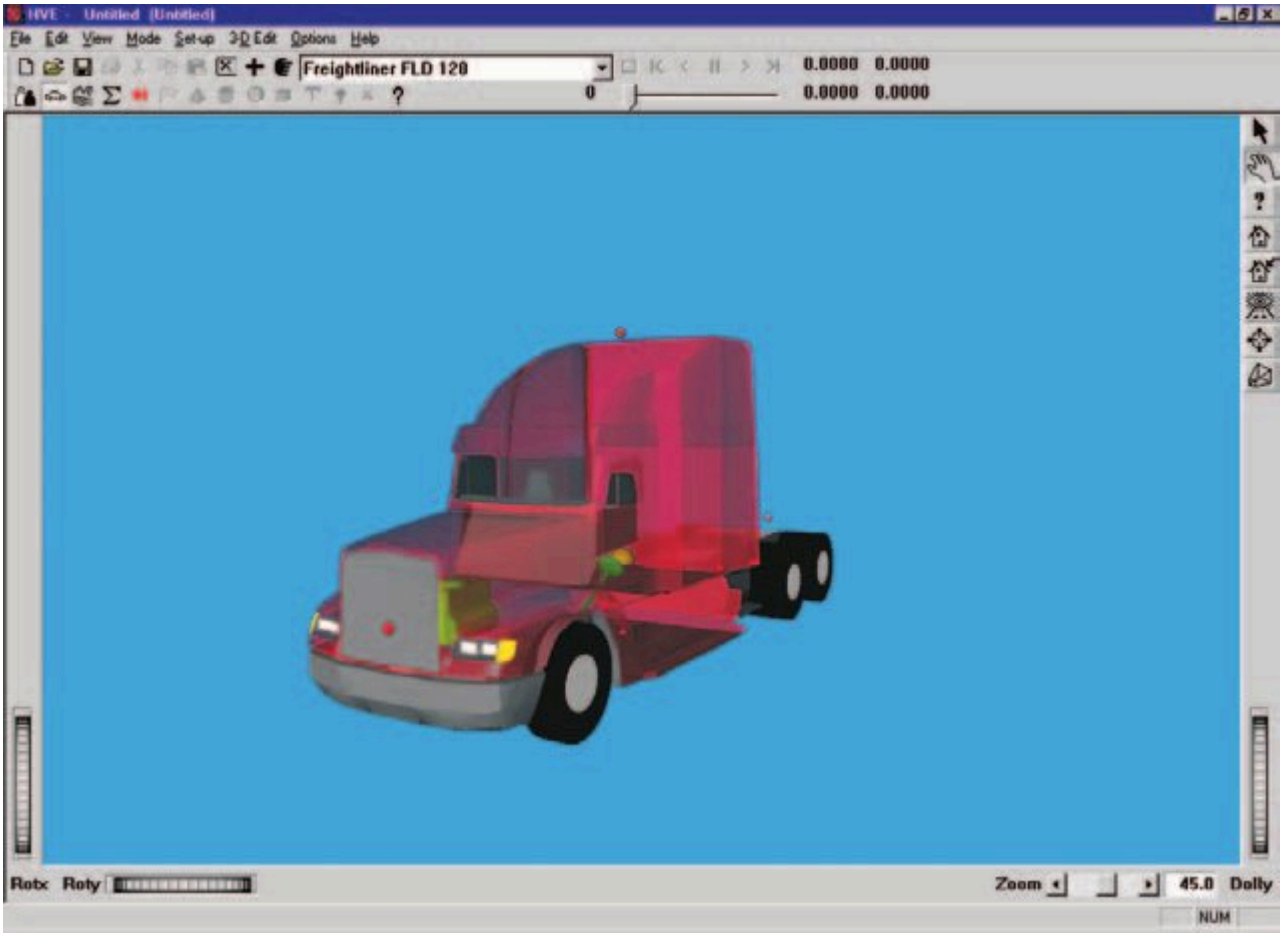
Let's create the vehicles, starting with the tractor:

- If the Vehicle Editor is not the current editor, choose *Vehicle Mode*. The Vehicle Editor is displayed.
- Click *Add New Object*. The Vehicle Information dialog is displayed. The Vehicle Information dialog allows the user to select the basic vehicle attributes according to *Type, Make, Model, Year* and *Body Style*.

> **NOTE:** The Vehicle Information dialog also allows you to edit the Driver Location, Engine Location, Number of Axles and Drive Axle(s). Our tutorial does not require any of these modifications.
>
> **NOTE:** A 'tractor' is a 'truck' with a fifth wheel; there is no need for a separate 'tractor' vehicle type.

- Using the option buttons, click each button to choose the following vehicle from the database:
- Type = *Truck*
- Make = *Freightliner*
- Model = *FLD-120*
- Year = *1994*
- Body Style = *Conventional w/Raised Sleeper*
- Source Database = *Tutorial.db*
- Click *OK* to add *Freightliner FLD-120* to the Active Vehicles list.

The Freightliner tractor is displayed in the 3-D viewer, as shown in Figure 5-1.


HVE - Untitled [Untitled]
File Edit View Mode Set-up 3D Edit Options Help
Freightliner FLD 120
0.0000 0.0000
0.0000 0.0000
Rotx Roty
Zoom
45.0
Dolly
NUM

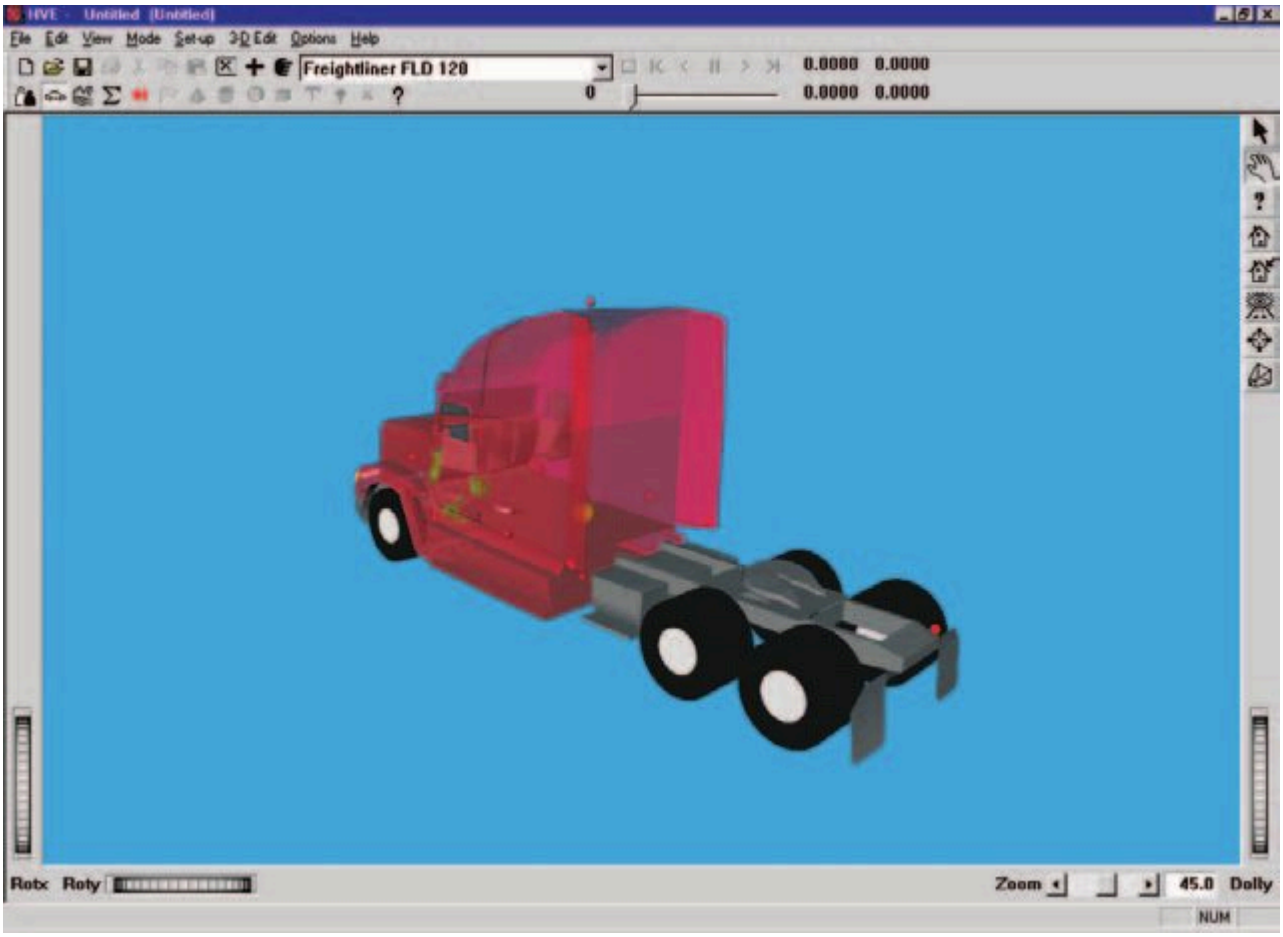



*Figure 5-1: 1994 Freightliner FLD-120 Conventional Tractor, front view (top) and rear view (bottom)*

Next, let's add the first semi-trailer. We don't have the exact vehicle, so we'll create it from the Generic Vehicle database:

- Click *Add New Object*. The Vehicle Information dialog is displayed.
- Using the option buttons, click each button to choose the following vehicle from the database:
- Type = *Trailer*
- Make = *Generic*
- Model = *Generic*
- Year = *Generic*
- Body Style = *Class 4*

The default vehicle name is

*Class 4 Trailer*

. Let's change it:

- Replace the default name; enter `Trailer 1`.
- Click *OK* to add *Trailer 1* to the Active Vehicles list.

The 45-ft semi-trailer is displayed in the viewer, as shown in Figure 5-2.

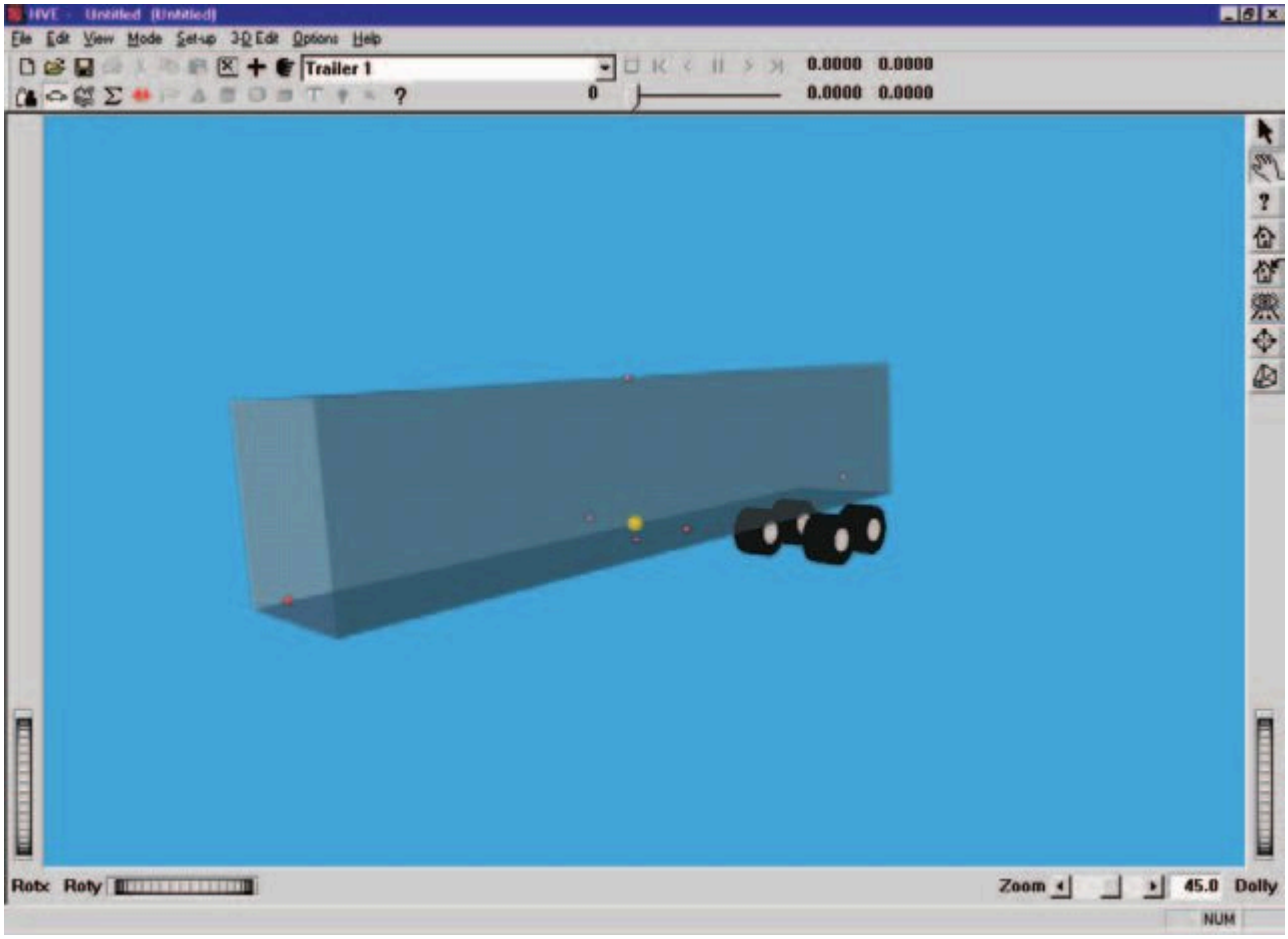



*Figure 5-2: Trailer 1, a 45-ft semi-trailer.*

Now let's add the second semi-trailer. Again, we don't have the exact vehicle, so we'll create it from the Generic Vehicle database:

- Click *Add New Object*. The Vehicle Information dialog is displayed.
- Using the option buttons, click each button to choose the following vehicle from the database:
- Type = *Trailer*
- Make = *Generic*
- Model = *Generic*
- Year = *Generic*
- Body Style = *Class 4*

The default vehicle name is

*Class 4 Trailer*

. Let's change it:

- Replace the default name; enter `Trailer 2`.
- Click *OK* to add *Trailer 2* to the Active Vehicles list.

The second semi-trailer is displayed in the viewer, as shown in Figure 5-3.

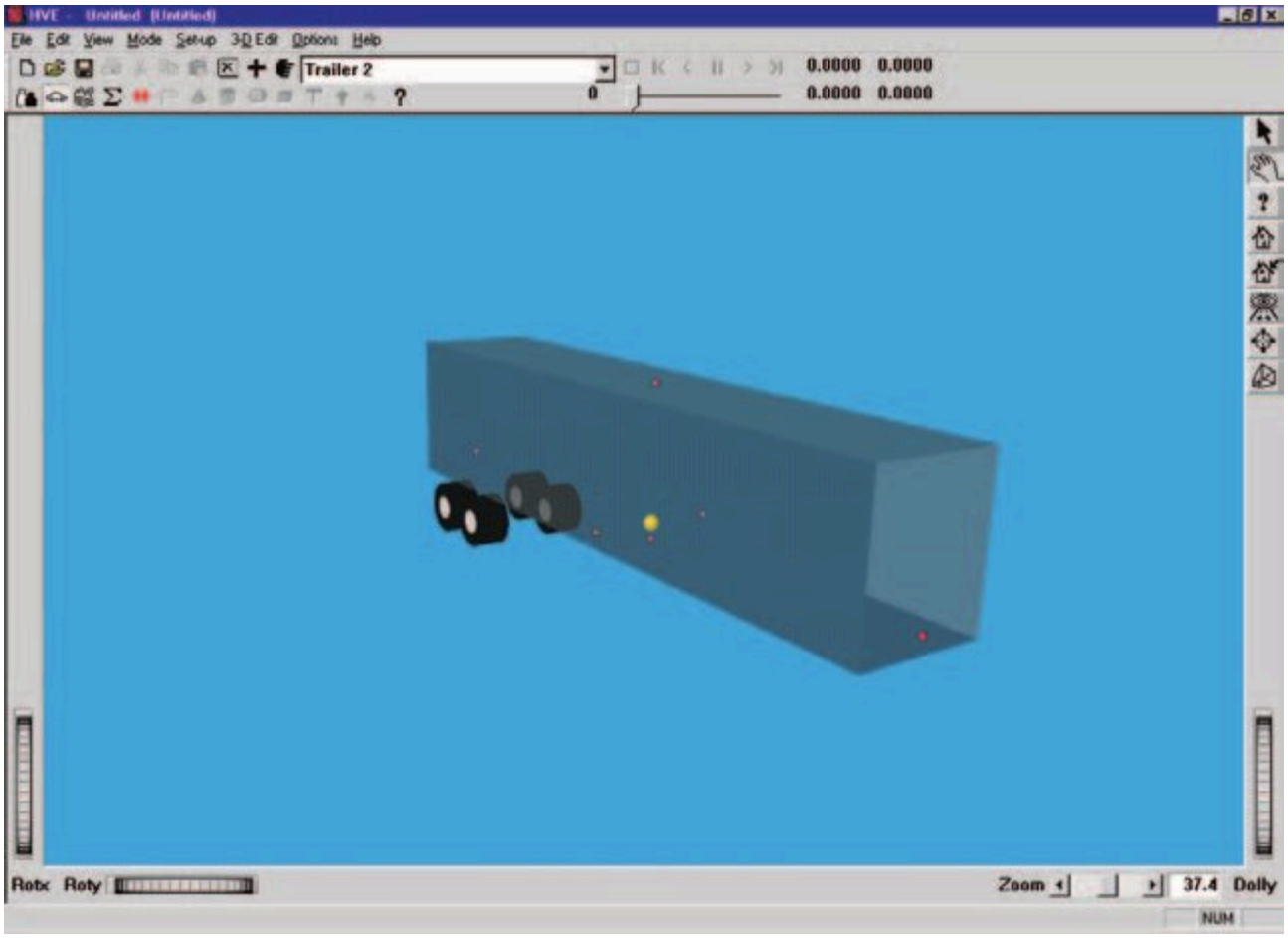



*Figure 5-3: Trailer 2, also a 45-ft semi-trailer. The front of this trailer is supported by the converter dolly displayed in Figure 5-4.*

Finally, let's add the converter dolly that supports the front of the second semi-trailer. Again, we don't have the exact vehicle, so we'll create it from the Generic Vehicle database:

- Click *Add New Object*. The Vehicle Information dialog is displayed.
- Using the option buttons, click each button to choose the following vehicle from the database:
- Type = *Dolly*
- Make = *Generic*
- Model = *Generic*
- Year = *Generic*
- Body Style = *Class 4 Hinged Drawbar*

The default vehicle name is

*Class 4 Hinged Drawbar Dolly*

. Let's change it:

- Replace the default name; enter `Trailer 2 Dolly`.
- Click *OK* to add *Trailer 2 Dolly* to the Active Vehicles list.

The dolly is displayed in the viewer, as shown in Figure 5-4.

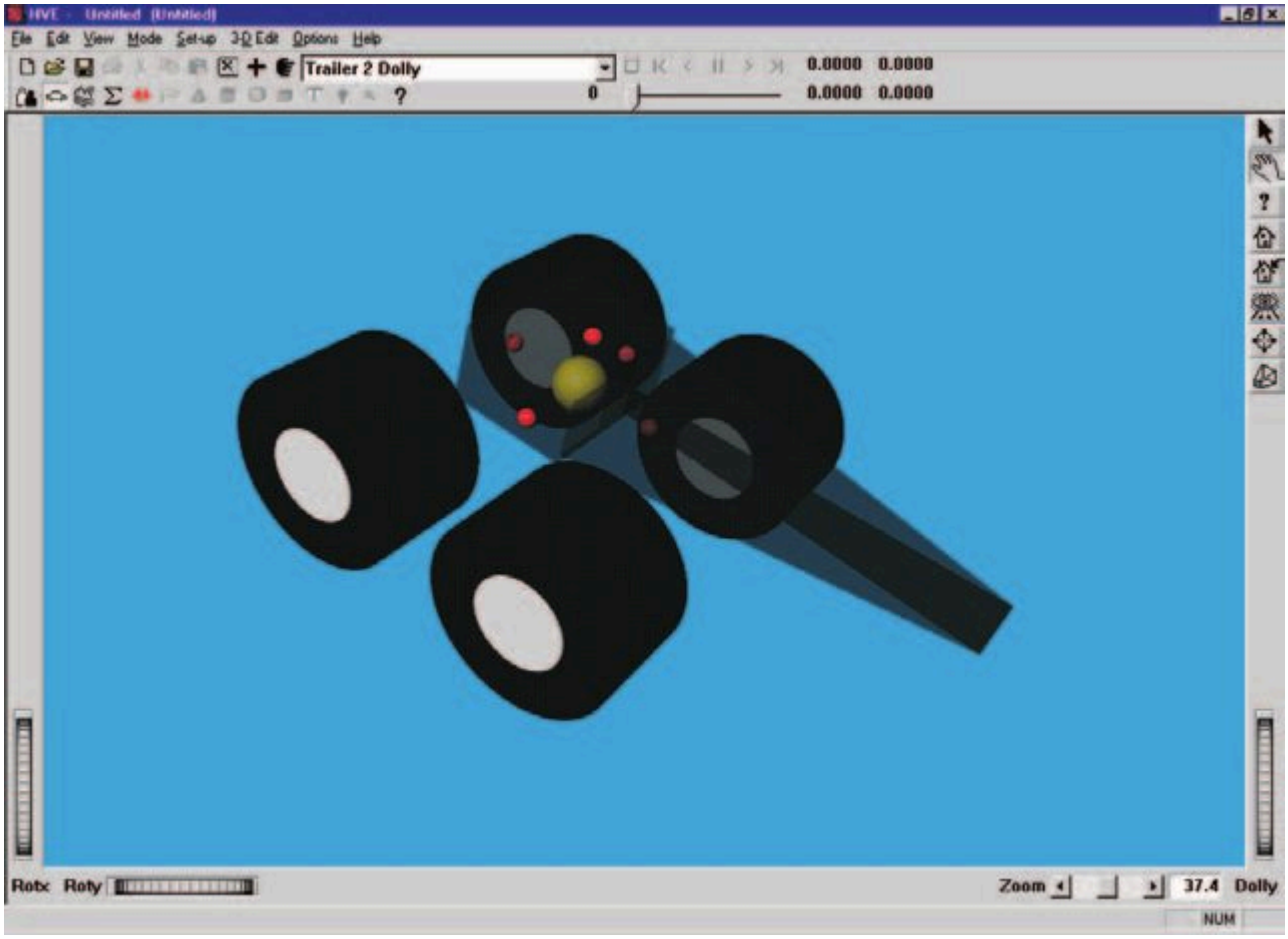



*Figure 5-4: Trailer 2 Dolly, a Generic Class 4 dolly from the HVE Generic Vehicle Database. It has a hinged fifth wheel and fixed drawbar.*

### Editing the Vehicles

Our Freightliner is ready to go, with the exception of changing its color. However, the trailers and dolly require some editing. Let's begin by editing the color of the Freightliner tractor:

- Choose *Freightliner FLD-120* from the Active Vehicles drop-down list, making it the current vehicle. The Freightliner tractor is now displayed in the Vehicle Editor.
- Click on the CG and choose *Color*. The Vehicle Color dialog is displayed (see Figure 5-5), showing the vehicle's current color (the small black square, or *hot spot*, in the *color wheel*) and intensity (the arrow in the *intensity slider*). Click on the hot spot and drag it to the center of the color wheel, making it white. To dull the color slightly, click on the intensity slider and drag it towards the center of the slider's range.

> **NOTE:** The color chip on the left shows the current color.

- When the color is to your liking, close the dialog by clicking on the close button in the upper right-hand corner of the dialog.

> **NOTE:** The vehicle's apparent color may be slightly misleading because the vehicle is translucent when displayed in the Vehicle Editor. The actual color will be used whenever the vehicle is displayed during Event and Playback mode.

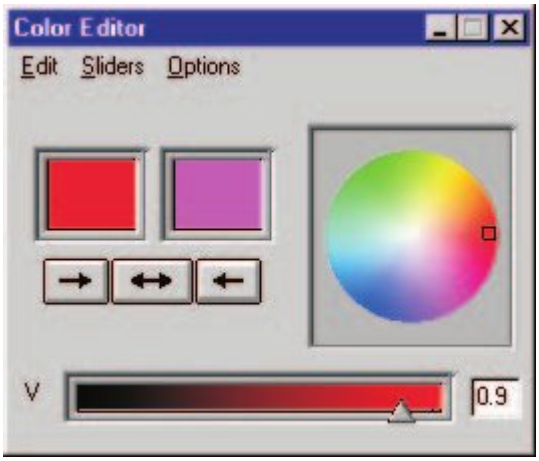



*Figure 5-5: Vehicle Color dialog, used for assigning the vehicle color.*

Next, let's edit the first semi-trailer by adding a geometry file, changing the weight and changing the connection height. Let's begin by adding the 3-D geometry file. A 45 foot van trailer geometry file, appropriately named *TLVdsTutorTrlr45Van.h3d*, was prepared by EDC and placed in the `../images/vehicles` subdirectory. To attach the geometry file to the trailer, perform the following steps:

- Choose *Trailer 1* from the Active Vehicles drop-down list, making it the current vehicle. Trailer 1 is now displayed in the 3-D Vehicle Viewer.
- Click on the CG, choose *Geometry File* and select *Open*. The Geometry dialog is displayed (see Figure 5-6), and we're ready to select a geometry file from the list box.
- Set Files of Type to be *HVE Geometry Files (*.h3d)*.
- Scroll down the list and double-click on *TLVdsTutorTrlr45Van.h3d*.

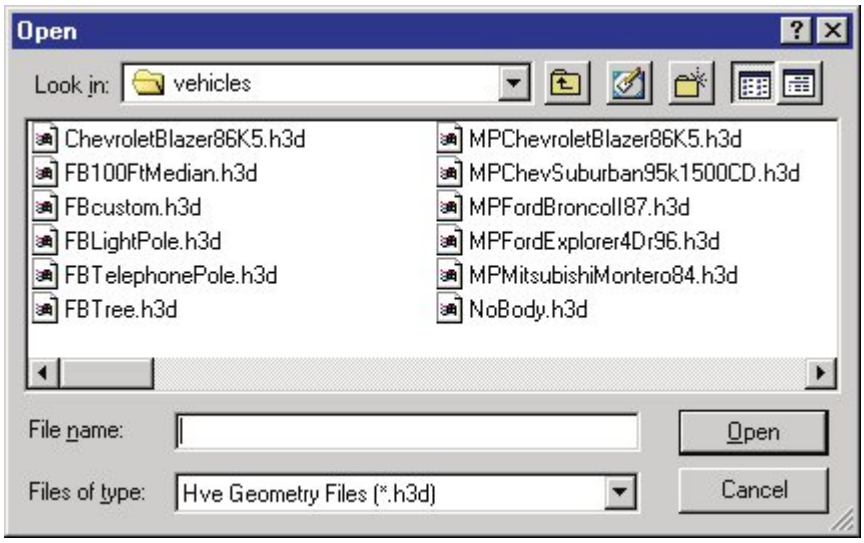



*Figure 5-6: Vehicle Geometry File selection dialog, used for adding or changing the vehicle 3-D geometry file for the current vehicle.*

The new geometry file is applied to the generic trailer (see Figure 5-7).

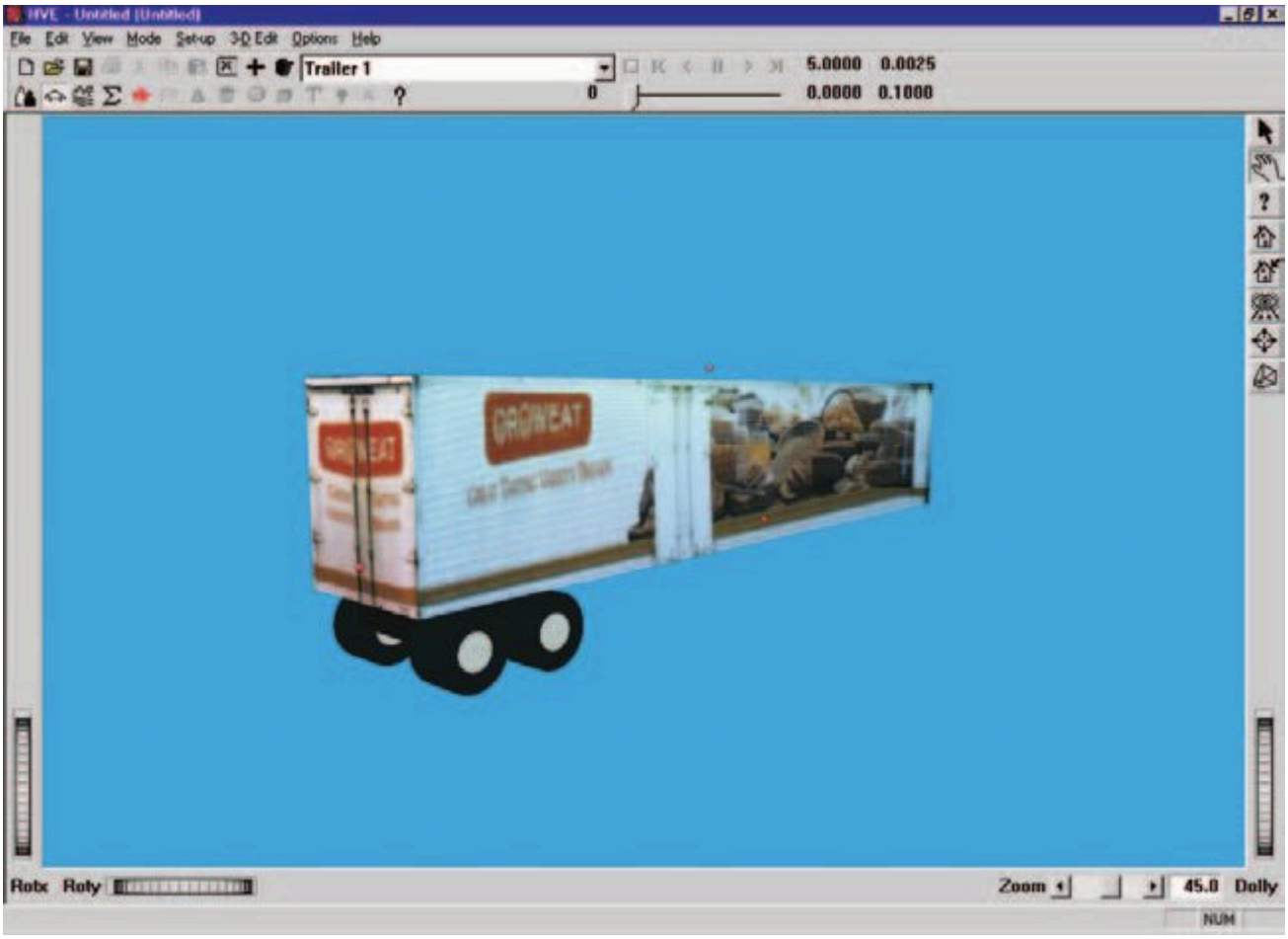



*Figure 5-7: Trailer 1 after adding its geometry file. Note the geometry file includes texture maps to create its realistic appearance.*

Next, let's change the trailer's weight:

- Click on the CG and choose *Inertias*. The Inertias dialog is displayed (see Figure 5-8), and we're ready to change the weight.
- In the *Total Weight* text field, replace the existing weight, 12,300 lb, with the measured value, `13135` lb.

> **NOTE:** The dialog might initially display 12300.001, or a similar number, because the weight is actually divided by the current gravity constant and stored as mass. Extra precision results when the mass is multiplied by the current gravity constant and redisplayed.

- If not already selected, click the checkbox for *Auto Update Inertia When Weight Changes*.
- Press *OK* to update the trailer's inertial properties.

Finally let's change the connection height:

- Click on the CG and choose *Connections*. The Connections dialog is displayed.
- In the z field for the Front Connection, replace the existing height, 12 in, with the value to match the tractor of `15` in.
- Press *OK* to update the trailer's connection height.

The first semi-trailer is ready for our EDVDS simulation analysis.

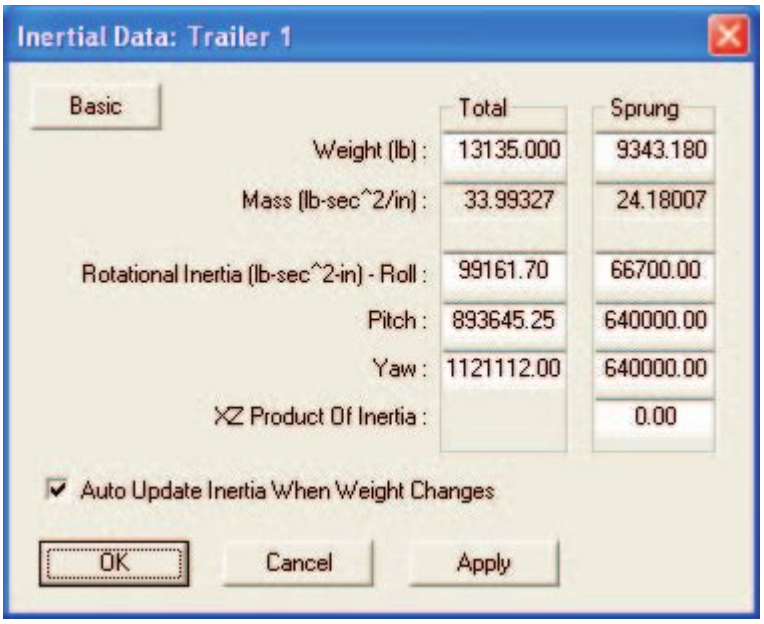



*Figure 5-8: Vehicle Inertias dialog, used for editing the current weight and roll, pitch and yaw rotational inertias.*

Let's change the parameters for the second trailer, starting with the geometry file:

- Choose *Trailer 2* in the Active Vehicles drop-down list, making it the current vehicle. Trailer 2 is now displayed in the 3-D Vehicle Viewer.
- Click on the CG, choose *Geometry File* and select *Open*. The Geometry dialog is displayed (same as shown earlier in Figure 5-6), and we're ready to select a geometry file from the list box.
- Set Files of Type to be *HVE Geometry Files (*.h3d)*.
- Scroll down the list and double-click on *TLVdsTutorTrlr45Van.h3d*.

The new geometry file is applied to the generic trailer, and it should look just like the first trailer (see Figure 5-7). Next, let's change the trailer's weight:

- Click on the CG and choose *Inertias*. The Inertias dialog is displayed, as shown in Figure 5-8, and we're ready to change the weight.
- In the *Total Weight* text field, replace the existing weight, 12,300 lb, with the measured value, `13135` lb.
- If not already selected, click the checkbox for *Auto Update Inertia When Weight Changes*.
- Press *OK* to update the trailer's inertial properties.

Finally, let's increase the default lag time in the left rear trailer brake:

- Click on the left rear wheel and choose *Brake*. The Wheel Brake dialog is displayed (see Figure 5-9), and we're ready to edit the brake characteristics for the left rear wheel.
- In the *Time Lag* data field, replace the default value, 0.175 sec, with `0.305` sec.
- Press *OK* to update the trailer's brake characteristics for the left rear wheel position.

The second semi-trailer is now ready for our EDVDS simulation analysis.

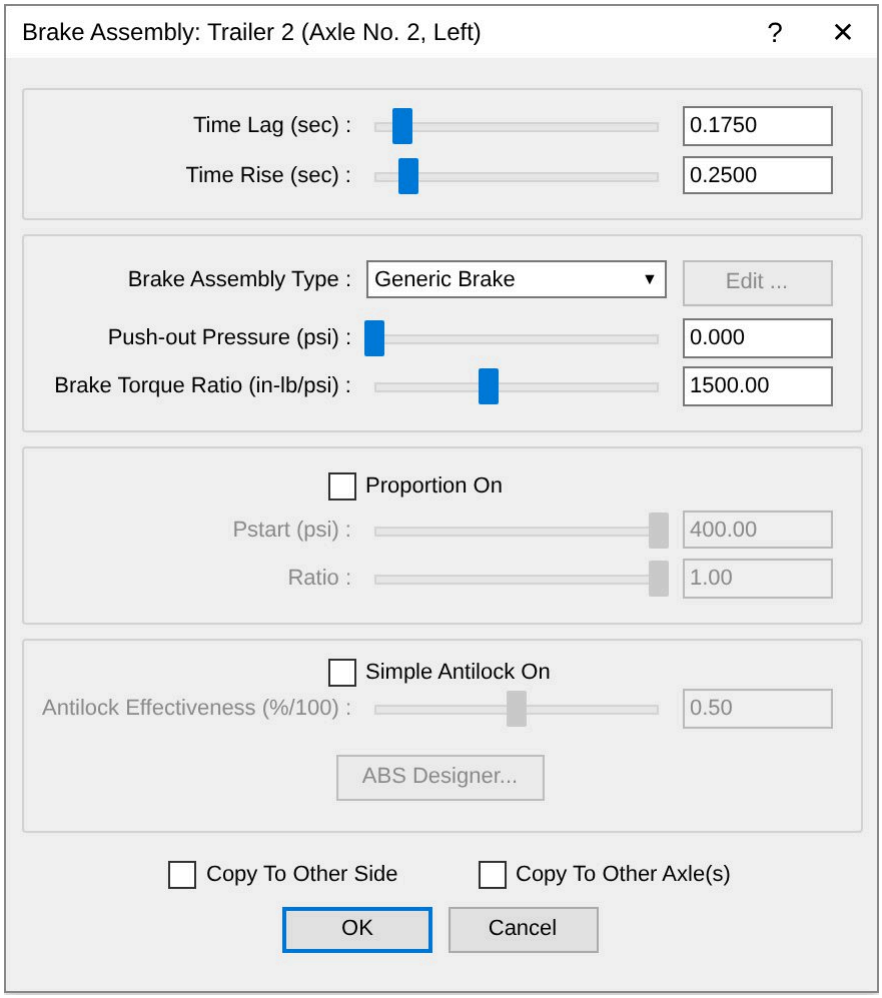



*Figure 5-9: Vehicle Wheel Brake dialog, used for editing the brake attributes for the selected wheel.*

Finally, let's increase the dolly's drawbar length:

- Choose *Trailer 2 Dolly* from the Active Vehicles drop-down list, making it the current vehicle. Trailer 2 Dolly is now displayed in the 3-D Vehicle Viewer.
- Click on the CG and choose *Connections*. The Vehicle Connections dialog is displayed (see Figure 5-10).
- In the *Front Connection, x-coordinate* data field, replace the default value, 96.0 in, with `120.0` in.
- Press *OK* to update the dolly's drawbar length.

The dolly is redisplayed with its new drawbar length.

> **NOTE:** The default geometry file is automatically modified to include the increased drawbar length. This would not be true if we had used a custom 3-D geometry file; we'd have to explicitly edit the geometry file if we wished to visualize the increased length.

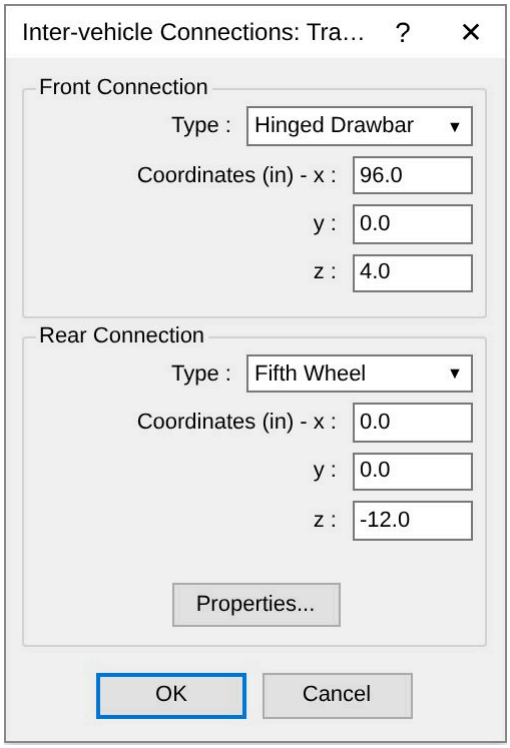



*Figure 5-10: Vehicle Connections dialog, used for editing the current front and rear inter-vehicle connections.*

All the vehicle units are now ready for our simulation study. Using the viewer controls (thumb wheels and manipulators), rotate and look at each of the vehicles we've created.

## Creating the Environment

Now, let's add the environment:

- Choose *Environment Mode*. The Environment Editor is displayed.
- Click on *Add New Object*. The Environment Information dialog is displayed.
- Using the Location Database combo box, choose *Hood River, Oregon, USA*. The latitude (45.40.00N), longitude (121.11.00W) and GMT, hours from the prime meridian (-8.0) are displayed for the selected location.
- Enter a name for the environment: `Rowena Point`.
- Enter the date and time of the incident we are studying, `4/30/98` and `1330`, respectively.
- Enter the angle from *true north* to the earth-fixed X axis in our environment, `180.0` degrees.

> **NOTE:** The Latitude, Longitude, GMT, Date/Time and angle from true north are used to position the sun in the scene. This is, of course, important because the sun is the primary light source for the scene.

- To add the environment geometry file to our case, click on *Open*. The Environment Geometry File Selection dialog is displayed.
- Choose *Files of Type* to *HVE Geometry Files (*.h3d)*. A list of environment geometry files using the HVE file format is displayed in a list box.
- Double-click on *RowenaPoint.h3d* to choose the environment file and remove the dialog.

> **NOTE:** We used a total station to survey this site, downloaded the resulting 3-D geometry data into a popular CAD program, performed some editing operations, and imported the result into HVE. We then used HVE's 3-D Editor to apply textures, which were actually photos of the rock walls and vegetation taken at the scene.
>
> **NOTE:** You have probably seen this view many times in nationally televised car commercials.

- Press *OK*.

The selected environment is added to our case and displayed in the Environment Viewer (see Figure 5-11). Use the viewer thumb wheels to view the scene.

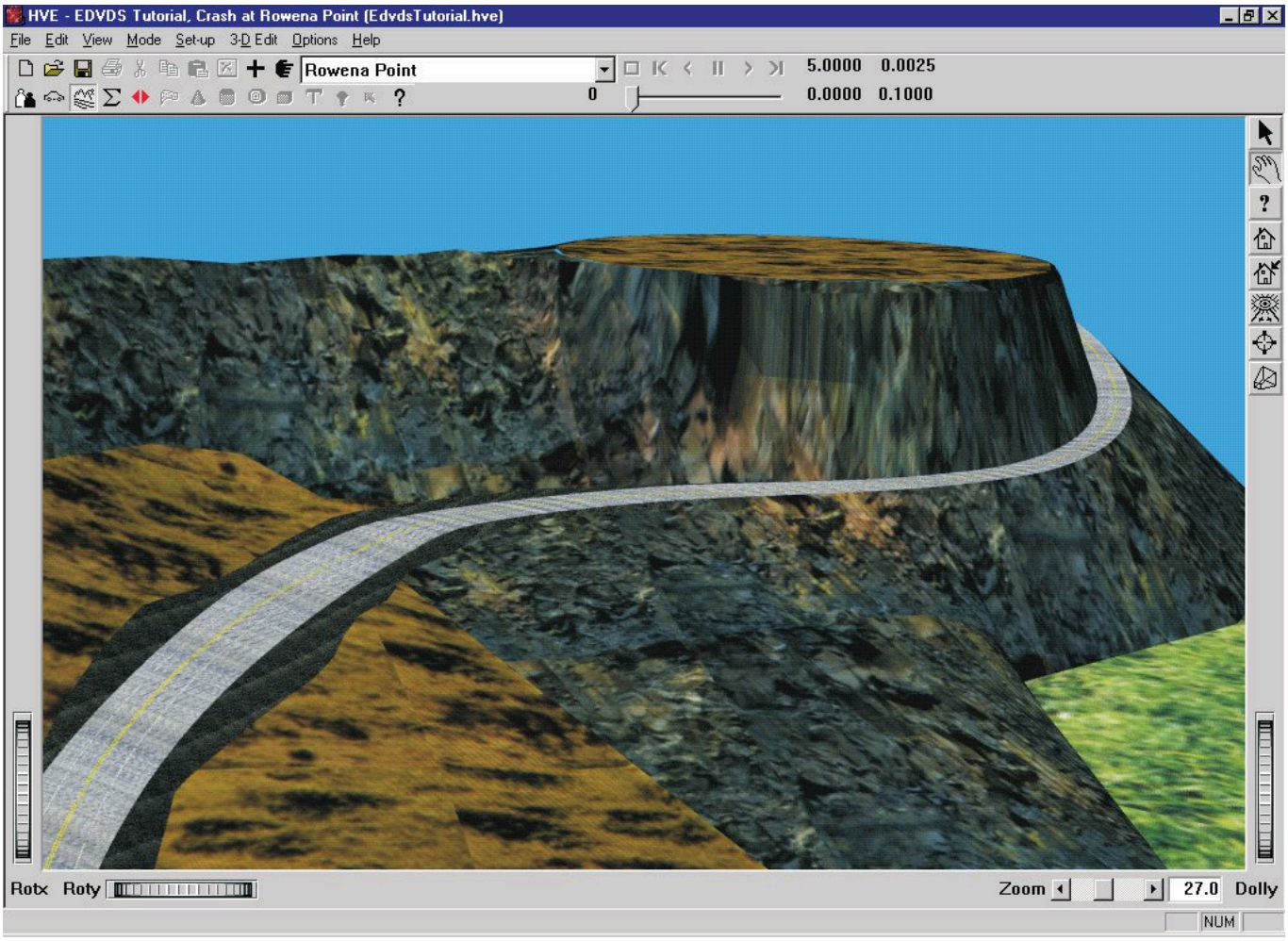



*Figure 5-11: 3-D Environment for our EDVDS tutorial. The original 3-D geometry for this environment was obtained using a total station. Textures were created from photos taken at the scene.*

## Saving the Case

Now that we've created all the objects (*vehicles* and *environment*) for our case, let's save the case file.

- Click on the *File* menu and choose *Save*. The Save-as File Selection dialog is displayed.

> **NOTE:** The Save-as dialog is displayed because the case has not been saved previously, so we need to enter a filename.

- Place the mouse cursor in the Case Title text field and enter `EDVDS Tutorial, Crash at Rowena Point`.

> **NOTE:** The Case Title is displayed as a heading on all printed output reports.

- Place the mouse cursor in the Filename text field and enter `EdvdsTutorial`.
- Click *SAVE*. The current case data are saved in the `hve/supportFiles/case` subdirectory.

> **NOTE:** Saving the file occasionally is a highly recommended practice.

## Creating the Event

As mentioned at the outset of the tutorial, we are going to simulate the loss of control of a set of highway doubles while attempting to negotiate a curve. To create the event, perform the following steps:

- Choose *Event Mode*. The Event Editor is displayed.
- Click on *Add New Object*. The Event Information dialog is displayed.
- Select *Freightliner FLD-120, Trailer 1, Trailer 2 Dolly* and *Trailer 2* **in that order** from the Active Vehicles list.

> **NOTE:** The vehicles **must** be selected in that order! The order of selection is used by HVE to determine the order of the vehicles in the combination vehicle.

- Select *EDVDS* from the *Calculation Method* options list.
- Enter a name for the event, `Controllability on Grade`.

> **NOTE:** HVE will append the name of the calculation method to the event name, thus the complete event name will become "EDVDS, Controllability on Grade."

- Press *OK* to display the event editor.

Now, we're ready to set up the event.

- Using the Event Editor dialog, select *Freightliner FLD-120* from the Event Humans & Vehicles list, then choose *Set-up* from the menu and select *Position/Velocity*. The complete combination vehicle is displayed in the environment, with the Freightliner's CG located at the earth-fixed X,Y origin, as shown in Figure 5-12. The entire vehicle is resting on the inclined surface with the trailers and dollys connected at a zero articulation angle.

> **NOTE:** Even though you didn't select the trailers or dolly from the Event Humans and Vehicles list (in fact, they're not even in the list), they are automatically attached to the tractor and displayed in the Event viewer because the trailer and dolly are "child" vehicles, that is, HVE knows that their positions are not independent from the tractor; they are attached to it.

Our EDVDS Tutorial provides us with a great opportunity to thoroughly explore the subject of positioning vehicles in a 3-D environment. We face the following challenges:

- First, we don't know the coordinates of the desired initial position, so we can't simply enter them in the Position/Velocity dialog.

- We have a complex, 3-dimensional surface, so placing the vehicles in a near-equilibrium position could take a lot of time and patience.
- We have a combination vehicle with four individual units (tow vehicle, two trailers and a dolly) and a total of 18 wheels to position on the surface, so positioning each individual vehicle wheel could take even more time and patience.

Fortunately, HVE's AutoPosition feature greatly simplifies the task of positioning vehicles in a complex, 3-dimensional environment:

- Click on the Freightliner's X-Y manipulator (see Figure 5-12), wait for it to turn bright yellow (indicating it has been selected), and drag the vehicle slowly down towards the road.

> **NOTE:** To select the X-Y manipulator, the viewer must be in Pick mode, as indicated by the highlighted arrow in the upper right corner of the viewer (see Figure 5-12).
>
> **NOTE:** Be sure to keep the mouse button depressed while you drag the manipulators.
>
> **NOTE:** The Z coordinates for the tow vehicle and each trailer are automatically determined using HVE's AutoPosition feature option.
>
> **NOTE:** As you drag the tow vehicle, the trailers follow the tow vehicle down the slope.
>
> **NOTE:** Adjust the viewer by panning, rotating and dollying back (use either the thumb wheels or direct manipulation of the viewer) until you can see the desired portion of the downhill grade.

- Click the yaw manipulator and rotate the tow vehicle until it is aligned with the road, approximately `90` degrees.
- Again, click on the X-Y manipulator and drag the vehicle up the hill, intermittently clicking on the yaw manipulator to keep the entire trailer-train on the road.
- Ultimately, the tow vehicle should be placed at X=`445` ft, Y=`-945` ft and Yaw=`65` deg as shown in Figure 5-13.
- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `55` mph.

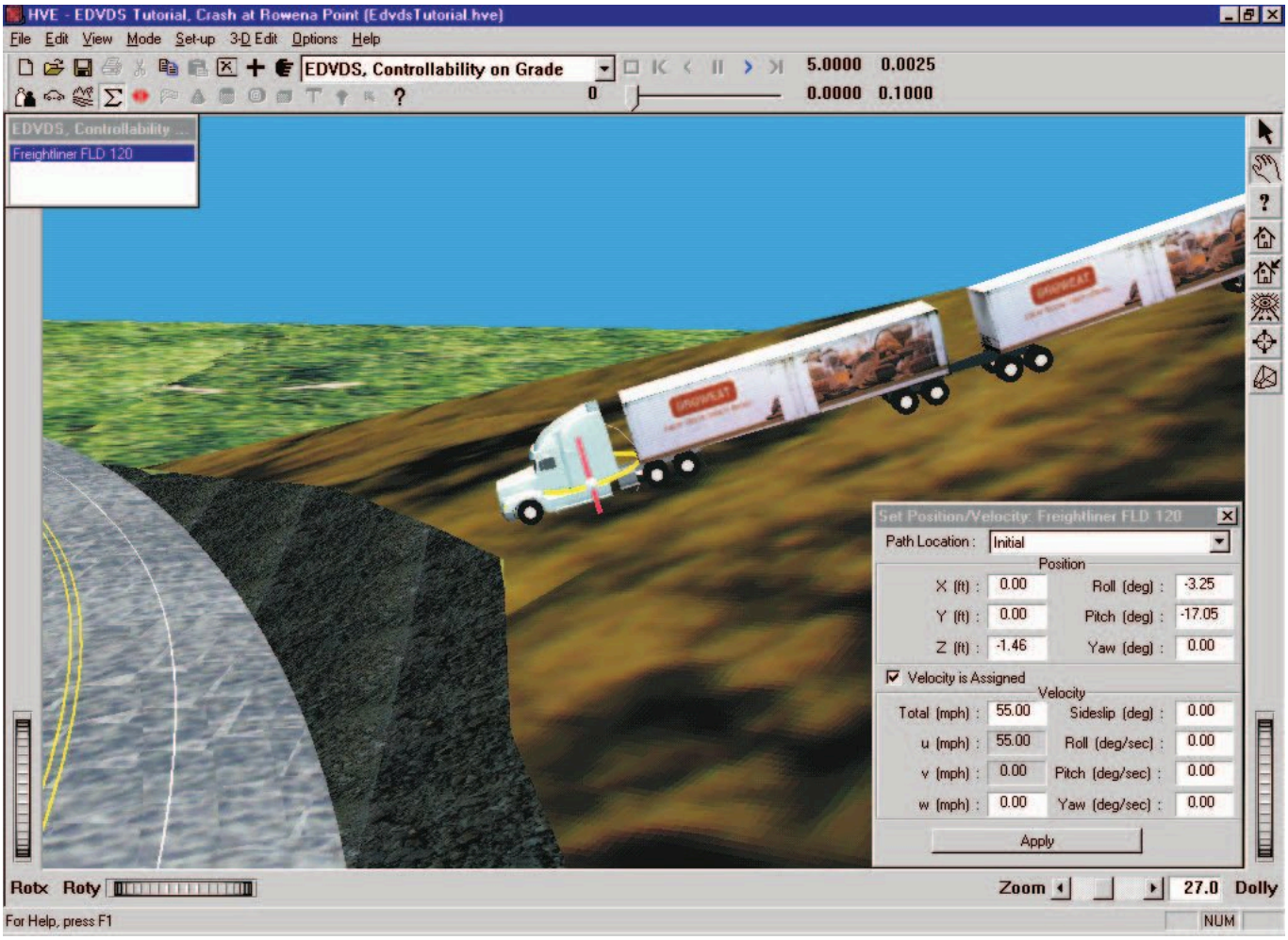



*Figure 5-12: Positioning the combination vehicles in the environment. The vehicle is initially placed at the earth-fixed origin. AutoPosition is a big help for complex, 3-dimensional environments such as this one because it places the entire trailer-train on the earth's surface. Without AutoPosition, we'd first have to find the vehicles, and then spend a lot of time positioning the individual vehicles so each tire was on the surface.*

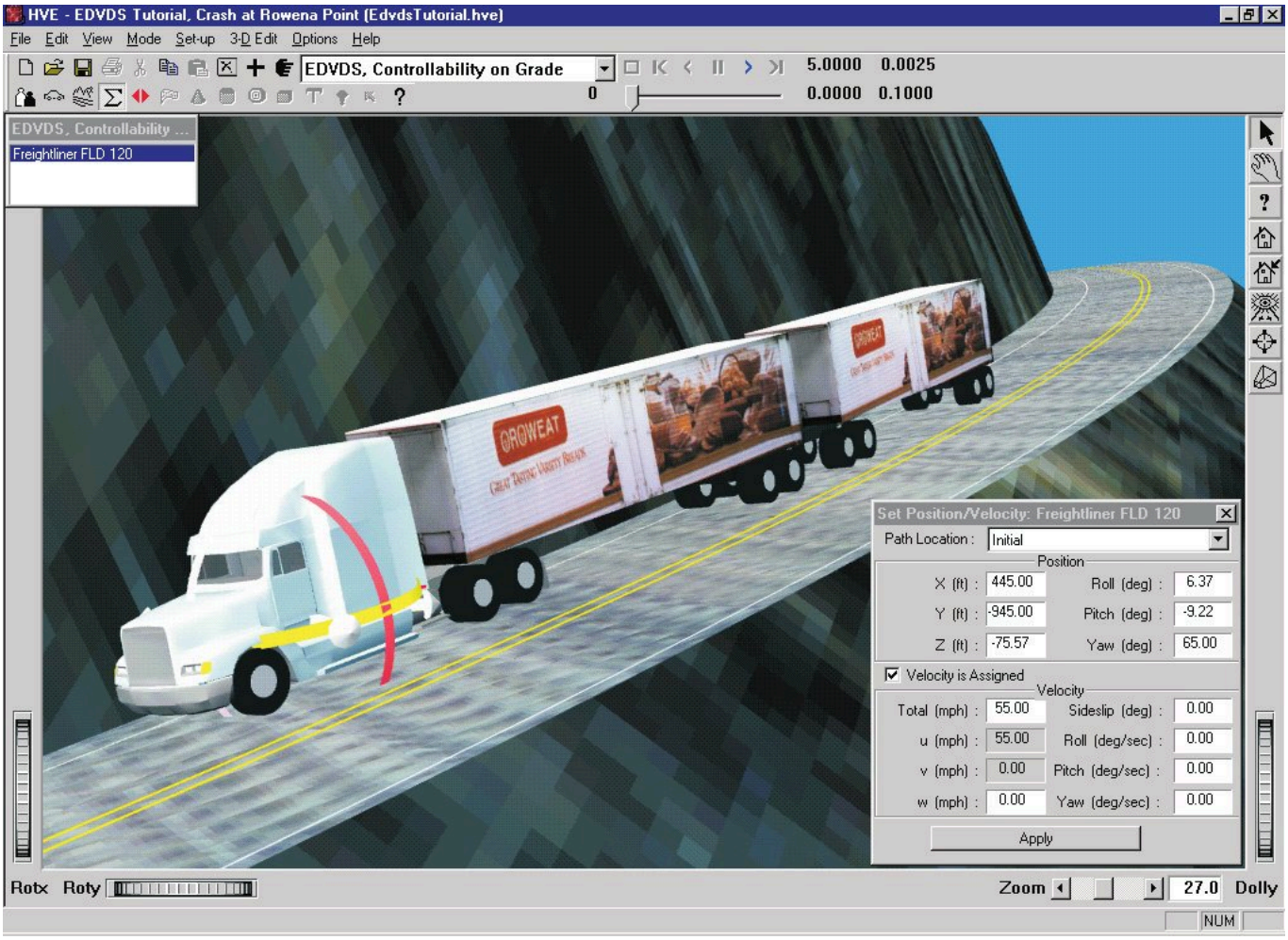



*Figure 5-13: Positioning the Freightliner FLD-120 tractor at its initial position.*

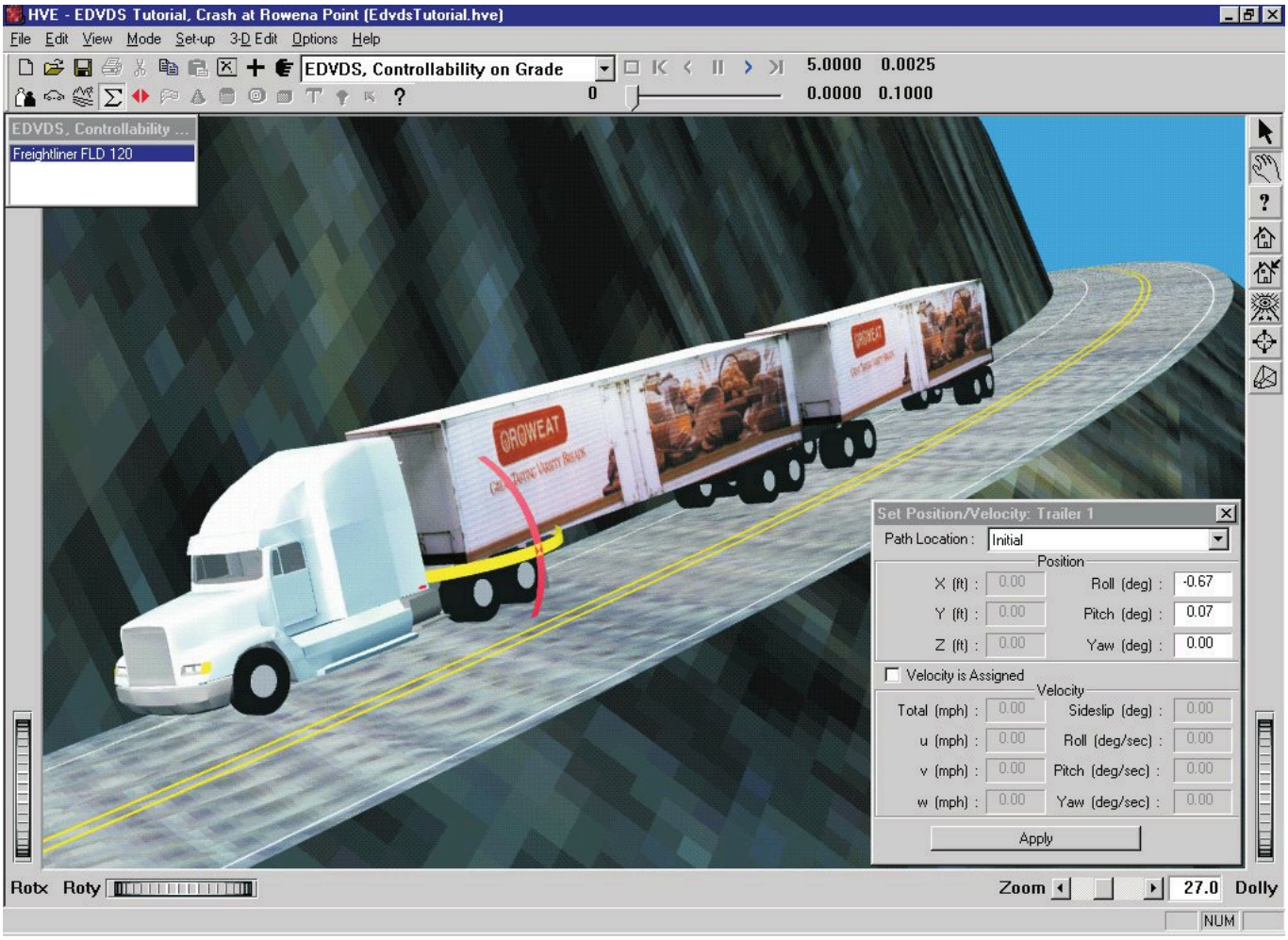



*Figure 5-14: Positioning Trailer 1 at its initial position.*

After the Freightliner tractor is positioned (see Figure 5-13), we need to position the trailers and dolly:

- Click on *Trailer 1*. The orientation manipulator is displayed and its initial orientation is displayed in the Position/Velocity dialog, as shown in Figure 5-14.

> **NOTE:** The X,Y,Z coordinates are not displayed because the trailer is connected to a tow vehicle, thus, it has no X,Y,Z degrees of freedom.
>
> **NOTE:** Because the trailer is attached to a tow vehicle, the angles shown are articulation angles relative to the tow vehicle, not absolute (earth-fixed) angles.

Trailer 1's position is acceptable, so let's position the dolly and second trailer:

- Click on *Trailer 2 Dolly* (it's easiest to click on its wheels). The orientation manipulator is displayed and its initial orientation is displayed in the Position/Velocity dialog.
- Click and drag the yellow yaw manipulator until the dolly's initial yaw articulation angle is about `-2` degrees, as shown in Figure 5-15.
- Click on *Trailer 2*. The orientation manipulator is displayed and its initial orientation is displayed in the Position/Velocity dialog.

- Click and drag the yellow yaw manipulator until *Trailer 2*'s initial yaw articulation angle is about `-2` degrees, as shown in Figure 5-16.

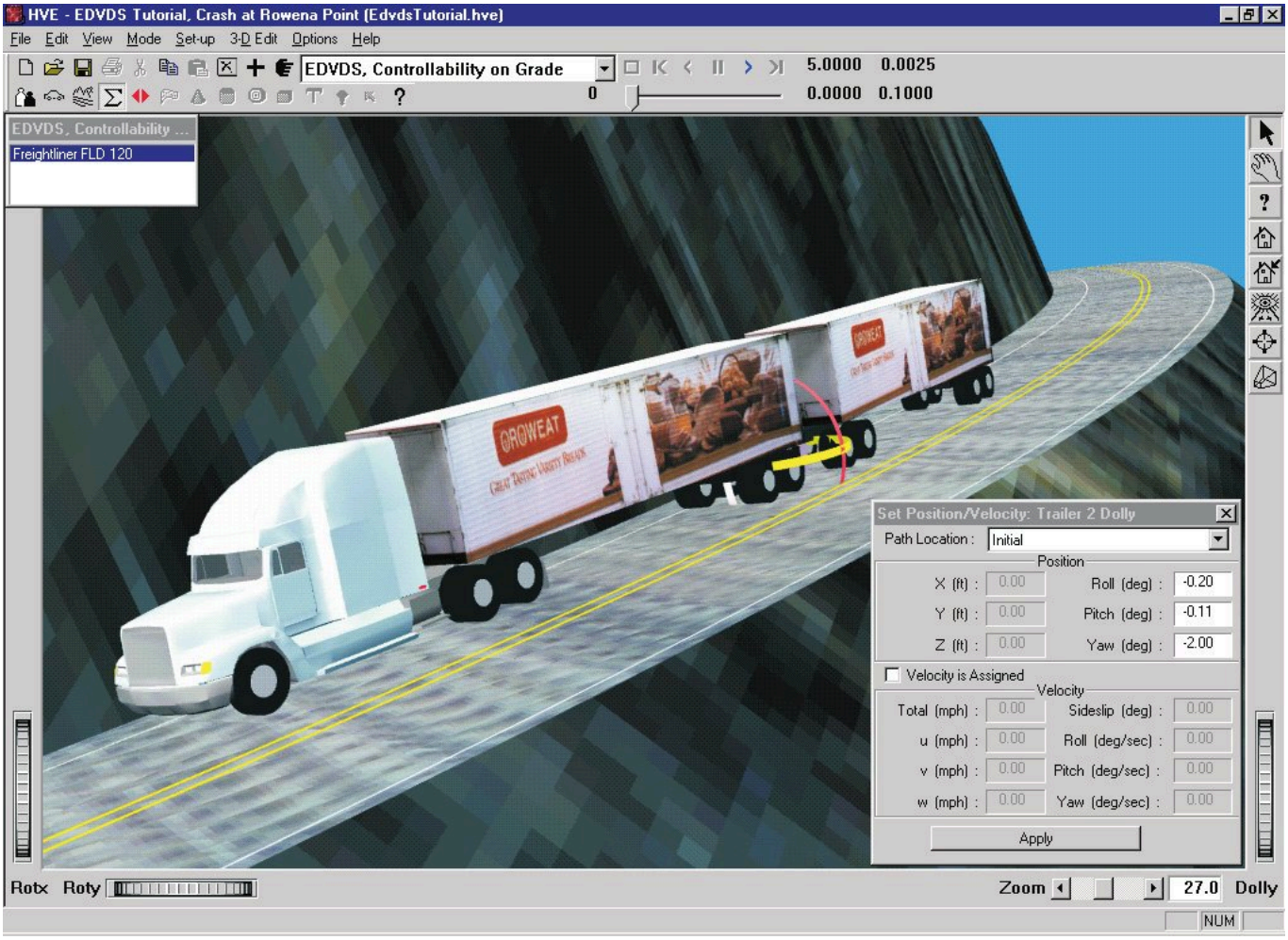



*Figure 5-15: Positioning Trailer 2 Dolly at its initial position.*

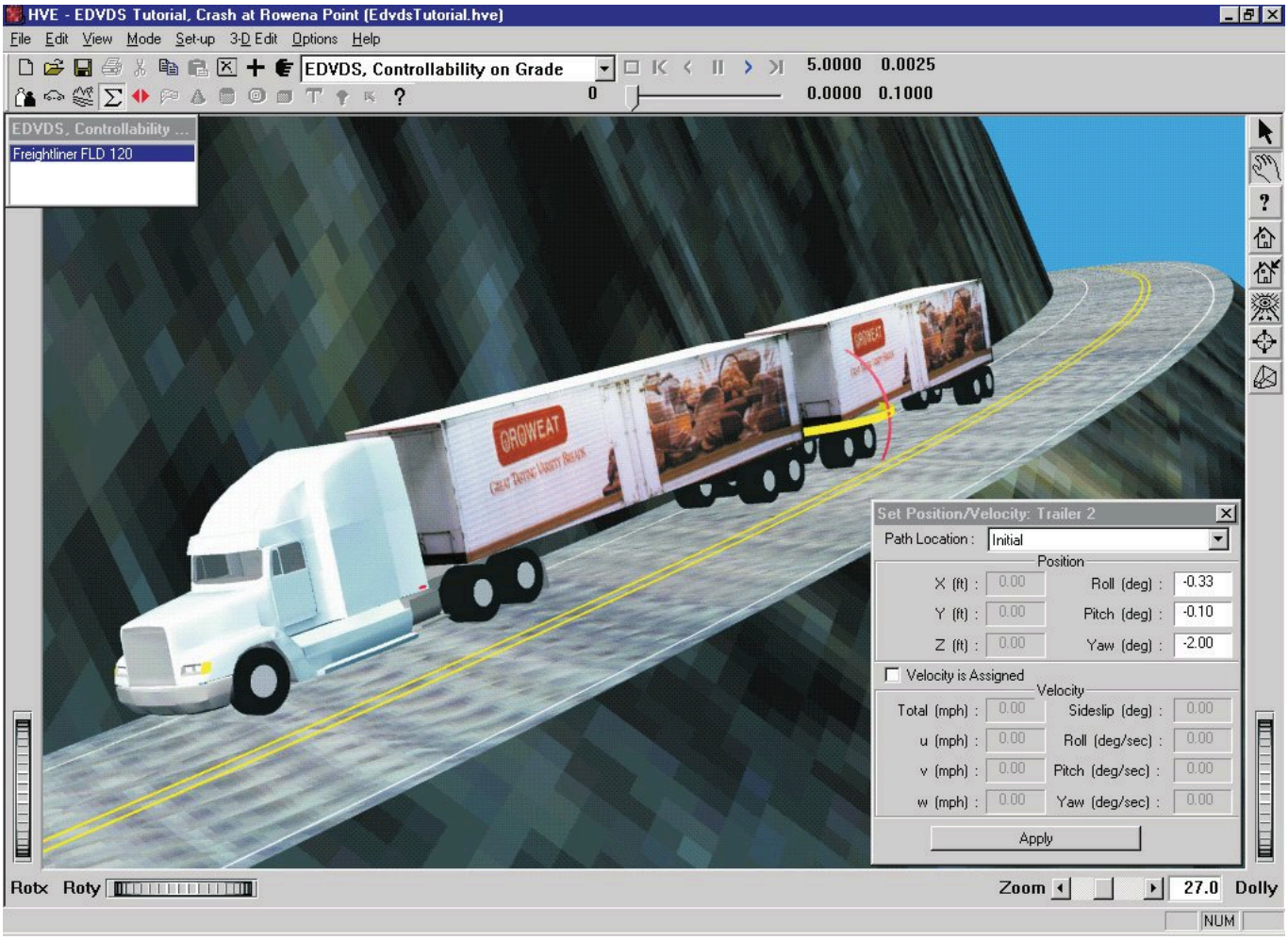



*Figure 5-16: Positioning Trailer 2 at its initial position.*

The vehicles' initial conditions are now established. Let's enter a payload for each trailer:

- Using the Event viewer, click on *Trailer 1*. The orientation manipulator is displayed and its initial orientation is displayed in the Position/Velocity dialog.
- Click on the *Set-up* menu and choose *Payload*. The Payload dialog for Trailer 1 is displayed (see Figure 5-17).
- Click on the *Payload Exists* check box. The data fields in the Payload dialog are enabled.
- Enter a weight for the payload; enter `25000` lb.
- Enter a roll moment of inertia; enter `200000` lb-sec²-in.
- Enter a pitch moment of inertia; enter `1500000` lb-sec²-in.
- Enter a yaw moment of inertia; enter `1500000` lb-sec²-in.
- Press *OK* to accept the payload data for *Trailer 1*.

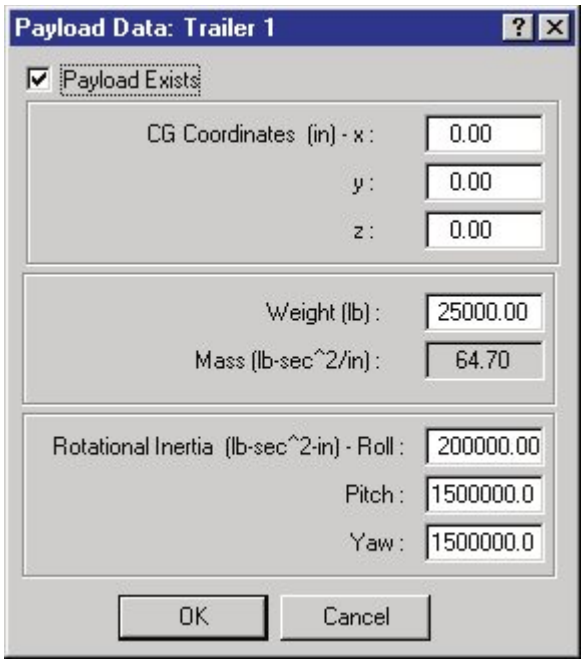



*Figure 5-17: Payload dialog, used for assigning a payload to each trailer.*

Next, let's add a payload to the second trailer:

- Using the Event viewer, click on *Trailer 2*. The orientation manipulator is displayed and its initial orientation is displayed in the Position/Velocity dialog.
- Click on the *Set-up* menu and choose *Payload*. The Payload dialog for *Trailer 2* is displayed (refer to the dialog shown earlier in Figure 5-17).
- Click on the *Payload Exists* check box. The data fields in the Payload dialog are enabled.
- Enter a weight for the payload; enter `25000` lb.
- Enter a roll moment of inertia; enter `200000` lb-sec²-in.
- Enter a pitch moment of inertia; enter `1500000` lb-sec²-in.
- Enter a yaw moment of inertia; enter `1500000` lb-sec²-in.
- Press *OK* to accept the payload data for *Trailer 2*.

> **NOTE:** EDVDS does not support lateral payload offset.
>
> **NOTE:** The version of EDVDS used in this tutorial requires that the payload CG coordinates be 0,0,0. This will not be the case in future versions; check your release notes to confirm the status of your version of EDVDS.

Next, let's enter the driver controls. We'll start with the Freightliner's Steer Table. To enter the steer angles, perform the following steps:

- Choose *Set-up* from the Menu and select *Driver Controls*. The Driver Controls dialog is displayed. The default driver control table, *Steering*, is also displayed for editing.
- Click on the *Table Is* option list and choose the *At Steering Wheel* option.
- Enter the steer angles for the Freightliner Tractor, as shown in Table 5-1 and Figure 5-18.

**Table 5-1: Steering Table for the Freightliner tractor**

| Time (sec) | Steering Wheel Angle (degrees) |
|---|---|
| 0.00 | 75.0 |
| 2.00 | 180.0 |
| 5.00 | 220.0 |

Next, let's assign the Brake Table for the Freightliner:

- Click the Brake tab on the Driver Controls dialog. The Brake Table is displayed.
- Click on the *Table Is* option list and choose the *Pedal Force* option (for air brakes, *Pedal Force* equals *Treadle Pressure*).
- Enter the values shown in Table 5-2 and Figure 5-19.
- Press *OK* to accept the steering and brake tables.

**Table 5-2: Brake Table entries for the Freightliner tractor**

| Time (sec) | Brake Pedal Force (lb) |
|---|---|
| 0.00 | 0.00 |
| 3.50 | 0.00 |
| 3.60 | 65.00 |

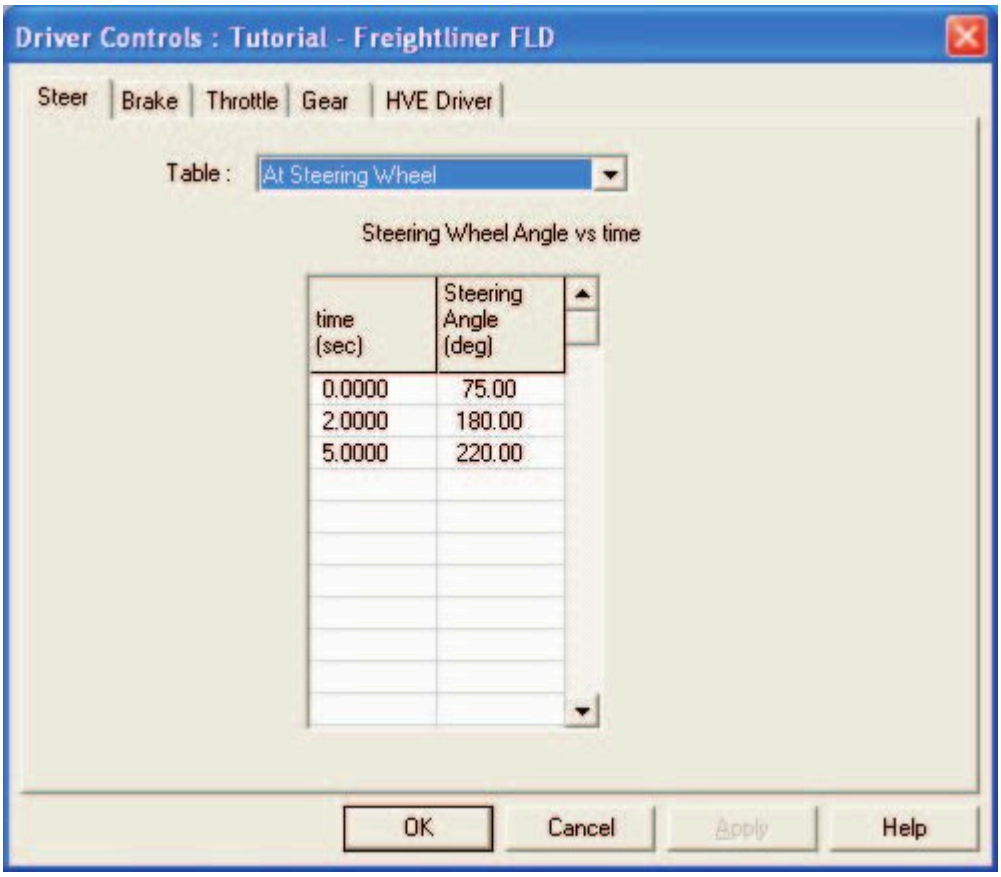



*Figure 5-18: Driver Controls, Steer Table dialog. Our tutorial uses the At Steering Wheel option.*

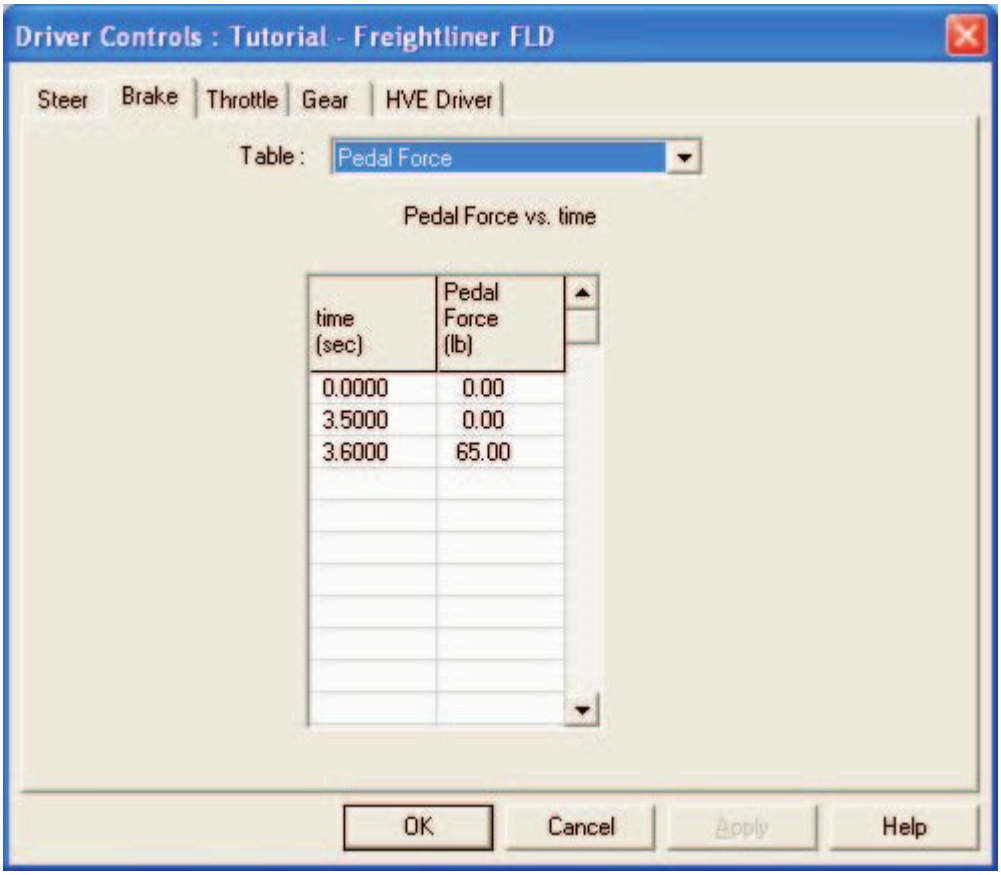



*Figure 5-19: Driver Controls, Brake Table dialog. Our tutorial uses the Pedal Force option. (NOTE: For trucks with air brake systems, the vehicle's Brake Pedal Ratio is set equal to 1.0; thus, the entered pedal force value equals the treadle valve pressure.)*

Since our goal for this event is to see what causes the vehicle to roll over, let's look at some Key Results during execution:

- If Key Results windows are not displayed, choose *Show Key Results* from the Options menu.
- Drag the Key Results windows to a convenient location, where they do not block the view but still allow us access to the viewer thumb wheel controls (in case we want to change the view).
- Click on *Select Variables* in the *Freightliner FLD-120* Key Results window. The Variable Selection dialog for *Freightliner FLD-120* is displayed.

Let's add

*Tire Fz'*

to the Freightliner's Key Results window:

- Click *Tires* and choose *Axle 1, Right, Outer* from the cascade menus. The Variable Selection list for the right front tire is displayed (see Figure 5-20).
- Select *Fz'* from the list.
- Click *Tires* and choose *Axle 1, Left, Outer* from the cascade menus. The Variable Selection list for the left front tire is displayed; select *Fz'* from the list.
- Repeat the above steps for Freightliner's rear tandem axles, choosing *Fz'* for *Axle 2* and *Axle 3*.
- Press *OK* to include the new variables in the Key Results dialog.

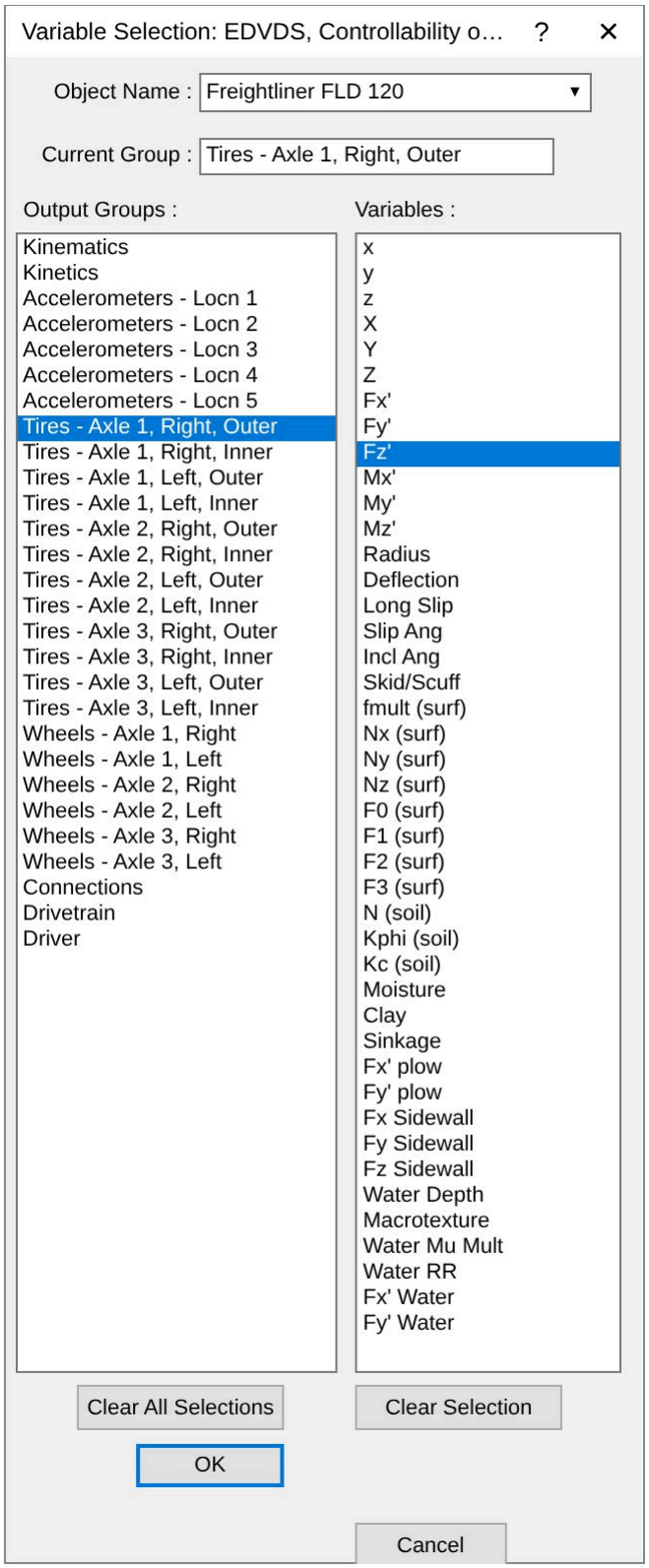



*Figure 5-20: Key Results Variable Selection dialog, used for selecting variables to be displayed in the Key Results window.*

Next, let's add the vertical tire forces for the trailers:

- Click on *Select Variables* in the *Trailer 1* Key Results window. The Variable Selection dialog for *Trailer 1* is displayed.

Let's add

*Tire Fz'*

to the trailer's Key Results window:

- Click *Tires* and choose *Axle 1, Right, Outer* from the cascade menus. The Variable Selection list for the front tandem axle, right side, is displayed; select *Fz'* from the list.
- Repeat the above steps for the trailer's remaining tires.
- Press *OK* to display the new variables in the Key Results dialog.

Using the same procedure, proceed to add any other Key Results of interest to you.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event. Allow the event to run until completion.

> **NOTE:** While the event is executing, watch the current results (especially the Velocity, Acceleration and Fz values) in the Key Results windows.

The EDVDS event is shown at time, t = 3.5 seconds in Figure 5-21, just as the vehicle is leaving the road.

> **NOTE:** By reviewing the individual wheel vertical wheel loads, Fz, in the Key Results windows, we can see it was the trailer's right front wheel that lifted, as noted by the negative value for Fz.

We have now completed the event.

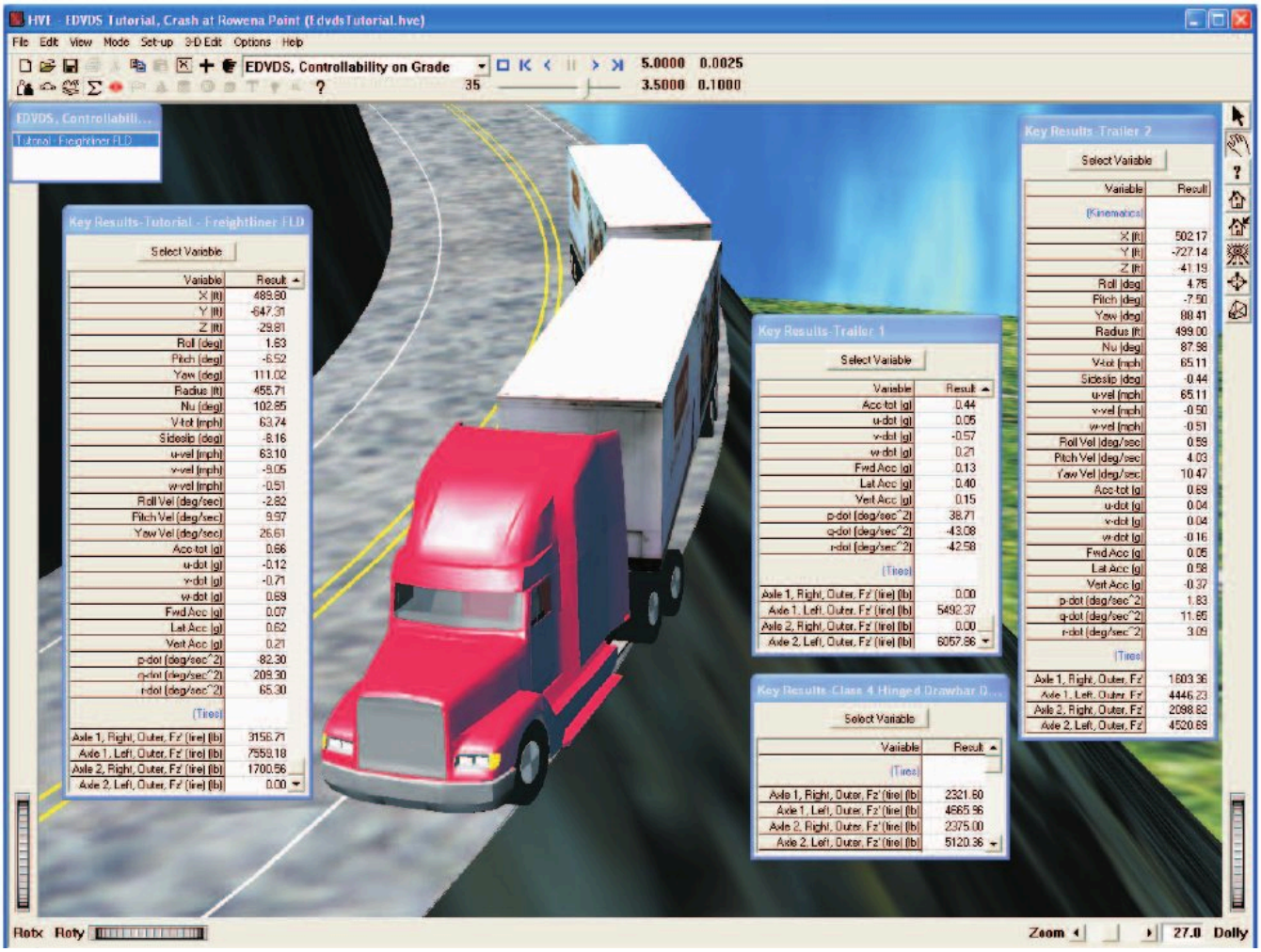



*Figure 5-21: EDVDS Controllability on Grade Event at t = 3.5 seconds.*

## Viewing Results

Now that we have produced our EDVDS simulations, let's take a detailed look at the results. The Playback Editor is used for reviewing and printing reports for each event in the current case, as well as for producing video output.

EDVDS produces the following reports:

- **Messages** — A list of messages produced by the current run
- **Accident History** — A table of initial and final positions and velocities
- **Vehicle Data** — A series of tables containing the vehicle data used by EDVDS
- **Program Data** — A table containing program control information
- **Variable Output** — A table containing user-selected, time-dependent simulation results
- **Trajectory Simulation** — A 3-D visualization of the event, displayed at a user-selectable time interval

To view the output reports, we need to be in Playback mode:

- Choose *Playback Mode*. The Playback Editor is displayed.

### Report Windows

The reports listed above are displayed by selecting Report Windows. Each Report Window contains an individual report.

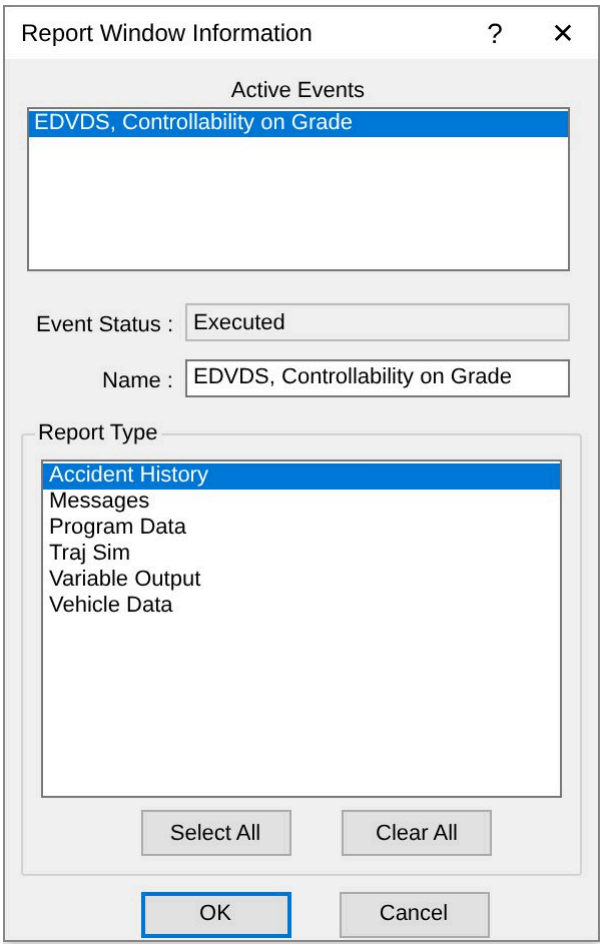



*Figure 5-22: Report Window Information dialog, showing the name of each event in the current case.*

To view the reports produced by the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed, as shown in Figure 5-22, and includes a list of the active events (*EDVDS, Controllability on Grade* is the only event in this tutorial). The Report Window Information dialog also includes the user-editable *Window Name* text field and the *Report Type* list.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select one or more of the available reports. *Select All* selects every report; each selected report opens in its own Report Window.
- Press *OK* to display the report.

The selected report will be displayed in a resizable window. The following pages illustrate the reports produced for the

*EDVDS, Controllability on Grade*

event.

### Messages

EDVDS produces a number of messages, depending on the outcome of the event. For a complete list and explanation of these messages, see Chapter 6.

To view the Messages report produced by the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Messages*.
- Press *OK*.

The Messages report is displayed for the

*EDVDS, Controllability on Grade*

event, as shown in Figure 5-23.

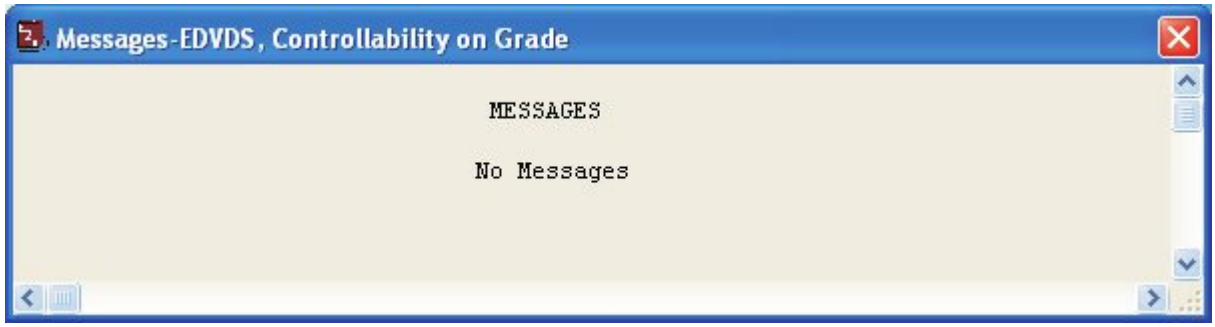



*Figure 5-23: Messages Report for EDVDS, Controllability on Grade.*

### Accident History

The Accident History report displays the time and total distance traveled, as well as position and velocity at the start and end of the run.

To view the Accident History report for the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Accident History*.
- Press *OK*.

The Accident History report is displayed for the

*EDVDS, Controllability on Grade*

event, as shown in Figure 5-24.

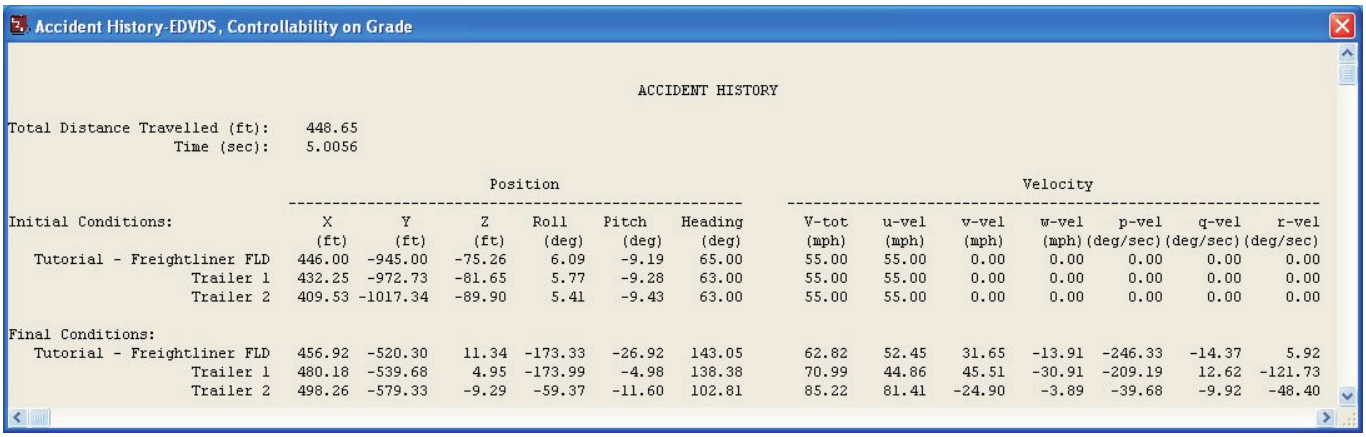



*Figure 5-24: Accident History Report for EDVDS, Controllability on Grade.*

## Vehicle Data

The Vehicle Data report for EDVDS displays vehicle data, tire data and driver control tables for each vehicle in the event.

> **NOTE:** The Vehicle Data report is too large to fit in the viewer. Use the scroll bars to view the entire report.

To view the Vehicle Data report for the

*EDVDS, Controllability on Grade*

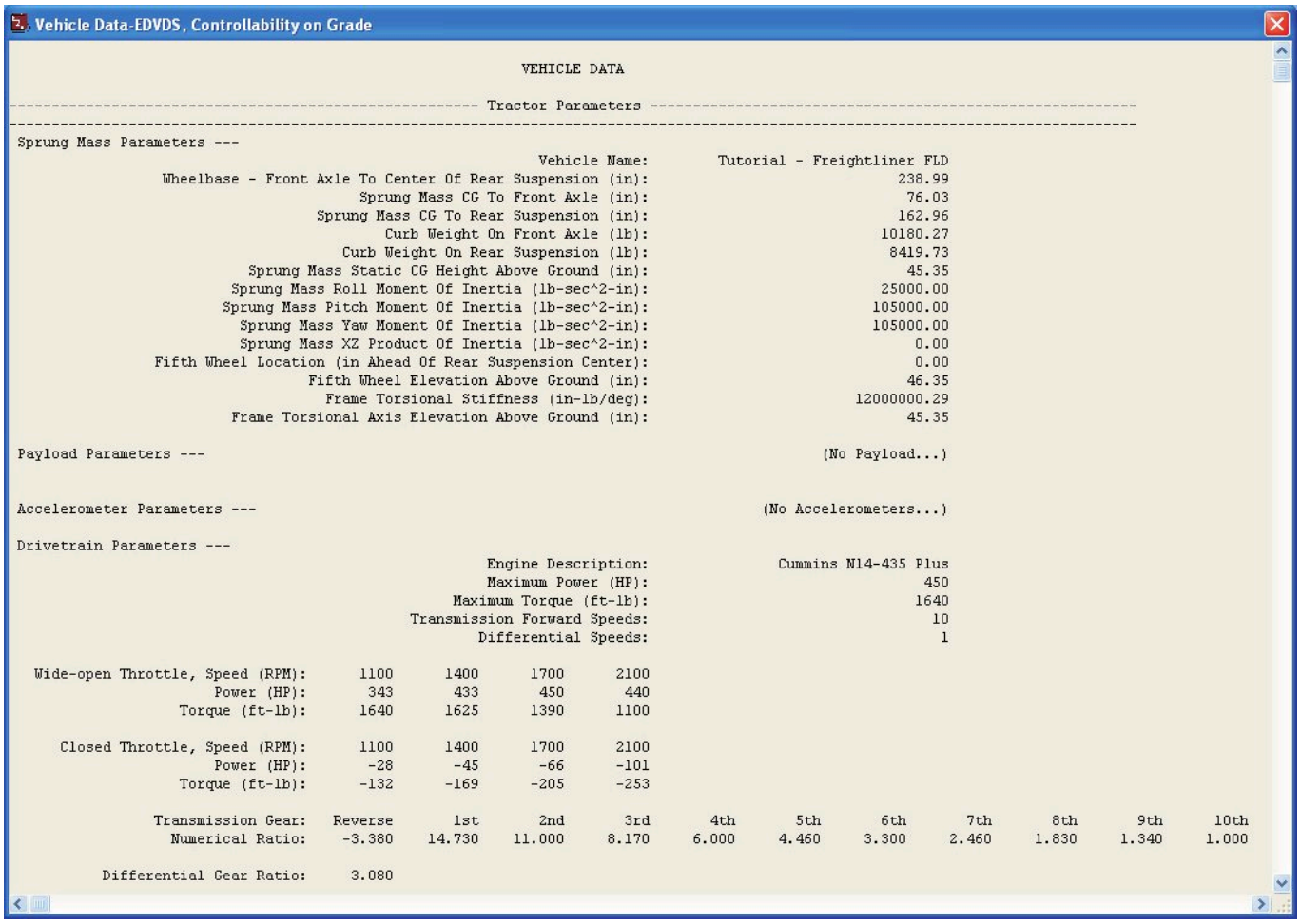
event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Vehicle Data*.
- Press *OK*.

A portion of the Vehicle Data report displayed for

*EDVDS, Controllability on Grade*

is shown in Figure 5-25.



Vehicle Data-EDVDS, Controllability on Grade

VEHICLE DATA

---------- Tractor Parameters ----------

Sprung Mass Parameters ---

| | |
|---|---|
| Vehicle Name: | Tutorial - Freightliner FLD |
| Wheelbase - Front Axle To Center Of Rear Suspension (in): | 238.99 |
| Sprung Mass CG To Front Axle (in): | 76.03 |
| Sprung Mass CG To Rear Suspension (in): | 162.96 |
| Curb Weight On Front Axle (lb): | 10180.27 |
| Curb Weight On Rear Suspension (lb): | 8419.73 |
| Sprung Mass Static CG Height Above Ground (in): | 45.35 |
| Sprung Mass Roll Moment Of Inertia (lb-sec^2-in): | 25000.00 |
| Sprung Mass Pitch Moment Of Inertia (lb-sec^2-in): | 105000.00 |
| Sprung Mass Yaw Moment Of Inertia (lb-sec^2-in): | 105000.00 |
| Sprung Mass XZ Product Of Inertia (lb-sec^2-in): | 0.00 |
| Fifth Wheel Location (in Ahead Of Rear Suspension Center): | 0.00 |
| Fifth Wheel Elevation Above Ground (in): | 46.35 |
| Frame Torsional Stiffness (in-lb/deg): | 12000000.29 |
| Frame Torsional Axis Elevation Above Ground (in): | 45.35 |

Payload Parameters --- (No Payload...)

Accelerometer Parameters --- (No Accelerometers...)

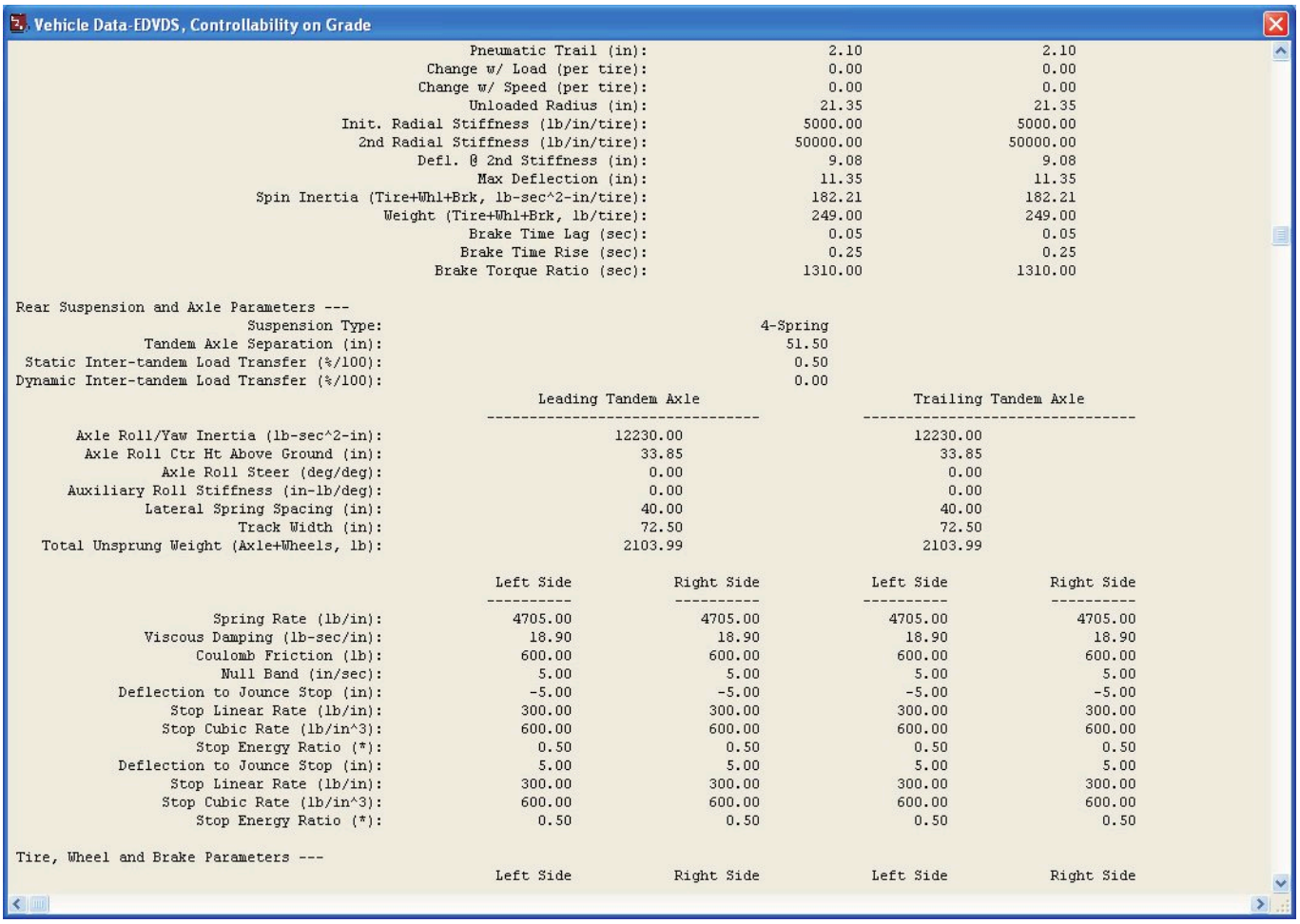
Drivetrain Parameters ---

| | |
|---|---|
| Engine Description: | Cummins N14-435 Plus |
| Maximum Power (HP): | 450 |
| Maximum Torque (ft-lb): | 1640 |
| Transmission Forward Speeds: | 10 |
| Differential Speeds: | 1 |

| | | | | |
|---|---|---|---|---|
| Wide-open Throttle, Speed (RPM): | 1100 | 1400 | 1700 | 2100 |
| Power (HP): | 343 | 433 | 450 | 440 |
| Torque (ft-lb): | 1640 | 1625 | 1390 | 1100 |
| Closed Throttle, Speed (RPM): | 1100 | 1400 | 1700 | 2100 |
| Power (HP): | -28 | -45 | -66 | -101 |
| Torque (ft-lb): | -132 | -169 | -205 | -253 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Transmission Gear: | Reverse | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th | 10th |
| Numerical Ratio: | -3.380 | 14.730 | 11.000 | 8.170 | 6.000 | 4.460 | 3.300 | 2.460 | 1.830 | 1.340 | 1.000 |

Differential Gear Ratio: 3.080



Vehicle Data-EDVDS, Controllability on Grade

| | | |
|---|---|---|
| Pneumatic Trail (in): | 2.10 | 2.10 |
| Change w/ Load (per tire): | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 |
| Unloaded Radius (in): | 21.35 | 21.35 |
| Init. Radial Stiffness (lb/in/tire): | 5000.00 | 5000.00 |
| 2nd Radial Stiffness (lb/in/tire): | 50000.00 | 50000.00 |
| Defl. @ 2nd Stiffness (in): | 9.08 | 9.08 |
| Max Deflection (in): | 11.35 | 11.35 |
| Spin Inertia (Tire+Whl+Brk, lb-sec^2-in/tire): | 182.21 | 182.21 |
| Weight (Tire+Whl+Brk, lb/tire): | 249.00 | 249.00 |
| Brake Time Lag (sec): | 0.05 | 0.05 |
| Brake Time Rise (sec): | 0.25 | 0.25 |
| Brake Torque Ratio (sec): | 1310.00 | 1310.00 |

Rear Suspension and Axle Parameters ---

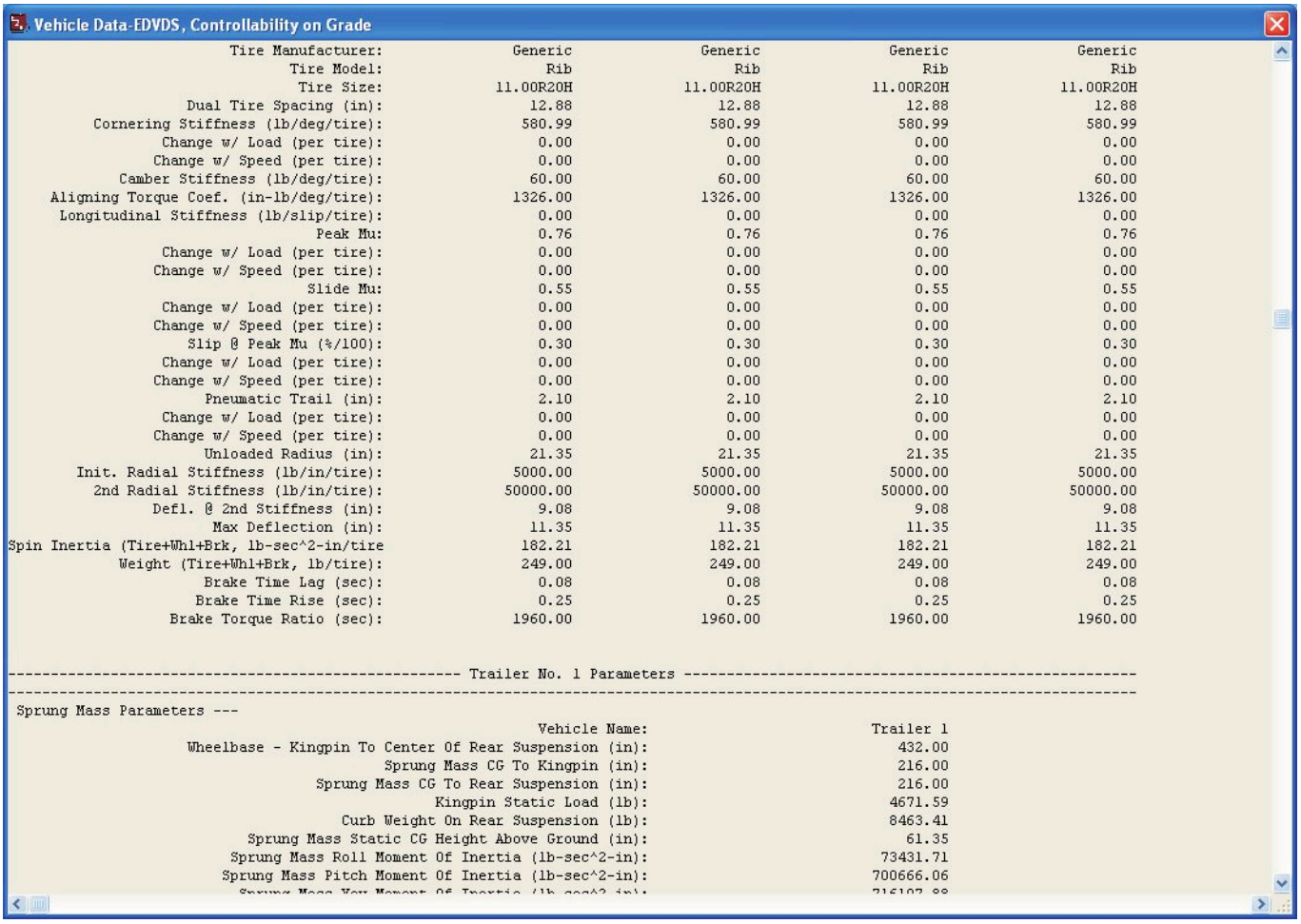
| | |
|---|---|
| Suspension Type: | 4-Spring |
| Tandem Axle Separation (in): | 51.50 |
| Static Inter-tandem Load Transfer (%/100): | 0.50 |
| Dynamic Inter-tandem Load Transfer (%/100): | 0.00 |

| | Leading Tandem Axle | Trailing Tandem Axle |
|---|---|---|
| Axle Roll/Yaw Inertia (lb-sec^2-in): | 12230.00 | 12230.00 |
| Axle Roll Ctr Ht Above Ground (in): | 33.85 | 33.85 |
| Axle Roll Steer (deg/deg): | 0.00 | 0.00 |
| Auxiliary Roll Stiffness (in-lb/deg): | 0.00 | 0.00 |
| Lateral Spring Spacing (in): | 40.00 | 40.00 |
| Track Width (in): | 72.50 | 72.50 |
| Total Unsprung Weight (Axle+Wheels, lb): | 2103.99 | 2103.99 |

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|
| Spring Rate (lb/in): | 4705.00 | 4705.00 | 4705.00 | 4705.00 |
| Viscous Damping (lb-sec/in): | 18.90 | 18.90 | 18.90 | 18.90 |
| Coulomb Friction (lb): | 600.00 | 600.00 | 600.00 | 600.00 |
| Null Band (in/sec): | 5.00 | 5.00 | 5.00 | 5.00 |
| Deflection to Jounce Stop (in): | -5.00 | -5.00 | -5.00 | -5.00 |
| Stop Linear Rate (lb/in): | 300.00 | 300.00 | 300.00 | 300.00 |
| Stop Cubic Rate (lb/in^3): | 600.00 | 600.00 | 600.00 | 600.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |
| Deflection to Jounce Stop (in): | 5.00 | 5.00 | 5.00 | 5.00 |
| Stop Linear Rate (lb/in): | 300.00 | 300.00 | 300.00 | 300.00 |
| Stop Cubic Rate (lb/in^3): | 600.00 | 600.00 | 600.00 | 600.00 |
| Stop Energy Ratio (*): | 0.50 | 0.50 | 0.50 | 0.50 |

Tire, Wheel and Brake Parameters ---

| | Left Side | Right Side | Left Side | Right Side |
|---|---|---|---|---|



Vehicle Data-EDVDS, Controllability on Grade

| | | | | |
|---|---|---|---|---|
| Tire Manufacturer: | Generic | Generic | Generic | Generic |
| Tire Model: | Rib | Rib | Rib | Rib |
| Tire Size: | 11.00R20H | 11.00R20H | 11.00R20H | 11.00R20H |
| Dual Tire Spacing (in): | 12.88 | 12.88 | 12.88 | 12.88 |
| Cornering Stiffness (lb/deg/tire): | 580.99 | 580.99 | 580.99 | 580.99 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Camber Stiffness (lb/deg/tire): | 60.00 | 60.00 | 60.00 | 60.00 |
| Aligning Torque Coef. (in-lb/deg/tire): | 1326.00 | 1326.00 | 1326.00 | 1326.00 |
| Longitudinal Stiffness (lb/slip/tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Peak Mu: | 0.76 | 0.76 | 0.76 | 0.76 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Slide Mu: | 0.55 | 0.55 | 0.55 | 0.55 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Slip @ Peak Mu (%/100): | 0.30 | 0.30 | 0.30 | 0.30 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Pneumatic Trail (in): | 2.10 | 2.10 | 2.10 | 2.10 |
| Change w/ Load (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Change w/ Speed (per tire): | 0.00 | 0.00 | 0.00 | 0.00 |
| Unloaded Radius (in): | 21.35 | 21.35 | 21.35 | 21.35 |
| Init. Radial Stiffness (lb/in/tire): | 5000.00 | 5000.00 | 5000.00 | 5000.00 |
| 2nd Radial Stiffness (lb/in/tire): | 50000.00 | 50000.00 | 50000.00 | 50000.00 |
| Defl. @ 2nd Stiffness (in): | 9.08 | 9.08 | 9.08 | 9.08 |
| Max Deflection (in): | 11.35 | 11.35 | 11.35 | 11.35 |
| Spin Inertia (Tire+Whl+Brk, lb-sec^2-in/tire | 182.21 | 182.21 | 182.21 | 182.21 |
| Weight (Tire+Whl+Brk, lb/tire): | 249.00 | 249.00 | 249.00 | 249.00 |
| Brake Time Lag (sec): | 0.08 | 0.08 | 0.08 | 0.08 |
| Brake Time Rise (sec): | 0.25 | 0.25 | 0.25 | 0.25 |
| Brake Torque Ratio (sec): | 1960.00 | 1960.00 | 1960.00 | 1960.00 |

---------- Trailer No. 1 Parameters ----------

Sprung Mass Parameters ---

| Vehicle Name: | Trailer 1 |
|---|---|
| Wheelbase - Kingpin To Center Of Rear Suspension (in): | 432.00 |
| Sprung Mass CG To Kingpin (in): | 216.00 |
| Sprung Mass CG To Rear Suspension (in): | 216.00 |
| Kingpin Static Load (lb): | 4671.59 |
| Curb Weight On Rear Suspension (lb): | 8463.41 |
| Sprung Mass Static CG Height Above Ground (in): | 61.35 |
| Sprung Mass Roll Moment Of Inertia (lb-sec^2-in): | 73431.71 |
| Sprung Mass Pitch Moment Of Inertia (lb-sec^2-in): | 700666.06 |

*Figure 5-25 (3 parts): Vehicle Data Report for EDVDS, Controllability on Grade — sprung mass parameters, drivetrain parameters, suspension and tire parameters for the Freightliner.*

## Program Data

The Program Data report contains the simulation controls used by the EDVDS event.

To view the Program Data report for the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Program Data*.
- Press *OK*.

The Program Data report is displayed for the *EDVDS, Controllability on Grade* event, as shown in Figure 5-26. The report includes the EDVDS version number and the tire model method under General Information, and the Maximum Simulation Time, Integration Time Step, Output Interval, Linear Termination Velocity, Velocity Convergence Criterion and Maximum Bisections under Simulation Controls. *(updated: the version number shown in the legacy figure reflects the release current at the time of printing; the current release reports version 18.00, and the Tire Model Method line reads either "Linear" or "Semi-empirical".)*

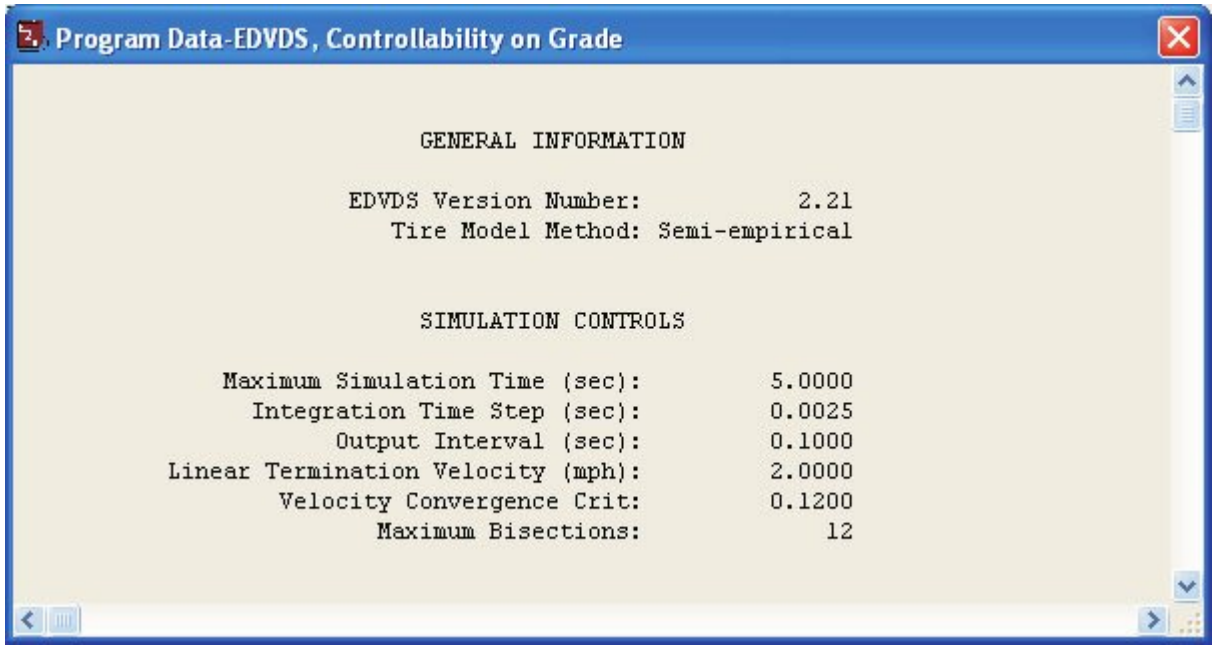



*Figure 5-26: Program Data Report for EDVDS, Controllability on Grade.*

## Variable Output

To view the Variable Output report for the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Variable Output*.
- Press *OK*.

The Variable Output report is displayed for the

*EDVDS, Controllability on Grade*

event. The table is initially empty, so the next step is to select the time-dependent results we wish to display in the table.

### *Variable Selection*

The purpose of our event is to determine the vehicle's propensity for rollover, so let's display the velocities, accelerations and vertical tire forces from the Variable Selection dialog.

- Click on *Select Variables* in the Variable Output window. The Variable Selection dialog is displayed, allowing us to choose variables to display in the Variable Output table.

First, let's add the velocities and accelerations. These variables belong to the Kinematics output group; this is the default group, and the Kinematics Variables list for the

*Freightliner FLD-120*

tractor is already displayed.

- Select *V-tot*, *Fwd Acc* and *Lat Acc* from the list.

Next, let's add the vertical wheel loads:

- Click *Tires* and choose *Axle 1, Right, Outer* from the cascade menus. The Variable Selection list for the right front tire is displayed (see Figure 5-27).
- Select *Fz'* from the list.
- Click *Tires* and choose *Axle 1, Left, Outer* from the cascade menus. The Variable Selection list for the left front tire is displayed; select *Fz'* from the list.
- Repeat the above steps for the Freightliner's rear tandem axles, choosing *Fz'* for *Axle 2* and *Axle 3*.

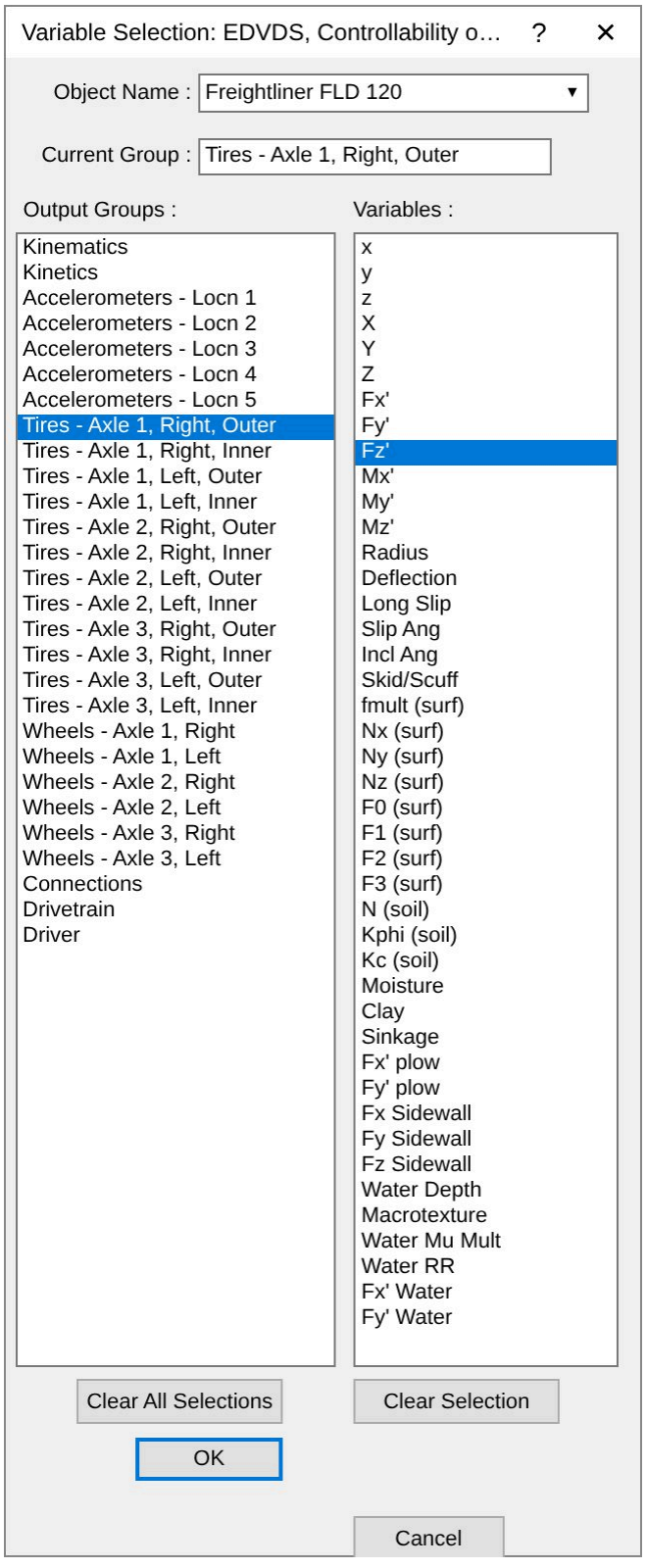



*Figure 5-27: Variable Selection Dialog.*

Next, let's add the vertical tire forces for the semi-trailer:

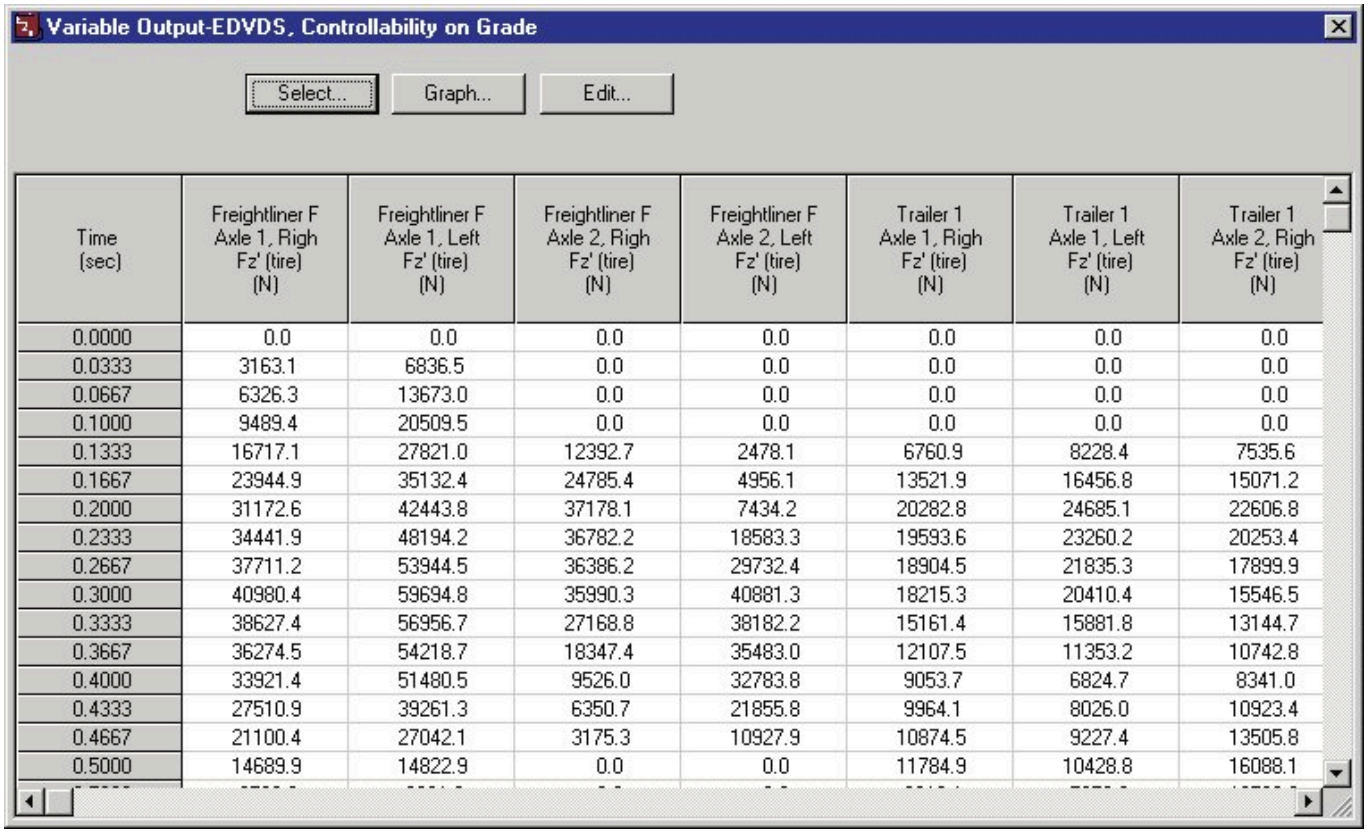
- Click on the *Object Name* option list and choose *Trailer 1*. The Kinematics Variables list for the first semi-trailer is displayed.

- Click *Tires* and choose *Axle 1, Right, Outer* from the cascade menus. The Variable Selection list for the front tandem axle, right side, is displayed; select *Fz'* from the list.
- Repeat the above steps for the trailer's remaining tires.
- Press *OK*.

The Variable Output report for the

*EDVDS, Controllability on Grade*

event now includes tow vehicle velocity and acceleration and vertical tire loads for each wheel location, as shown in Figure 5-28.




| Time (sec) | Freightliner F Axle 1, Righ Fz' (tire) (N) | Freightliner F Axle 1, Left Fz' (tire) (N) | Freightliner F Axle 2, Righ Fz' (tire) (N) | Freightliner F Axle 2, Left Fz' (tire) (N) | Trailer 1 Axle 1, Righ Fz' (tire) (N) | Trailer 1 Axle 1, Left Fz' (tire) (N) | Trailer 1 Axle 2, Righ Fz' (tire) (N) |
|---|---|---|---|---|---|---|---|
| 0.0000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0333 | 3163.1 | 6836.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0667 | 6326.3 | 13673.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1000 | 9489.4 | 20509.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1333 | 16717.1 | 27821.0 | 12392.7 | 2478.1 | 6760.9 | 8228.4 | 7535.6 |
| 0.1667 | 23944.9 | 35132.4 | 24785.4 | 4956.1 | 13521.9 | 16456.8 | 15071.2 |
| 0.2000 | 31172.6 | 42443.8 | 37178.1 | 7434.2 | 20282.8 | 24685.1 | 22606.8 |
| 0.2333 | 34441.9 | 48194.2 | 36782.2 | 18583.3 | 19593.6 | 23260.2 | 20253.4 |
| 0.2667 | 37711.2 | 53944.5 | 36386.2 | 29732.4 | 18904.5 | 21835.3 | 17899.9 |
| 0.3000 | 40980.4 | 59694.8 | 35990.3 | 40881.3 | 18215.3 | 20410.4 | 15546.5 |
| 0.3333 | 38627.4 | 56956.7 | 27168.8 | 38182.2 | 15161.4 | 15881.8 | 13144.7 |
| 0.3667 | 36274.5 | 54218.7 | 18347.4 | 35483.0 | 12107.5 | 11353.2 | 10742.8 |
| 0.4000 | 33921.4 | 51480.5 | 9526.0 | 32783.8 | 9053.7 | 6824.7 | 8341.0 |
| 0.4333 | 27510.9 | 39261.3 | 6350.7 | 21855.8 | 9964.1 | 8026.0 | 10923.4 |
| 0.4667 | 21100.4 | 27042.1 | 3175.3 | 10927.9 | 10874.5 | 9227.4 | 13505.8 |
| 0.5000 | 14689.9 | 14822.9 | 0.0 | 0.0 | 11784.9 | 10428.8 | 16088.1 |

*Figure 5-28: Variable Output Table for EDVDS, Controllability on Grade, showing the selected variables.*

## Trajectory Simulation

Finally, let's display a trajectory simulation for this event. To view the Trajectory Simulation for the

*EDVDS, Controllability on Grade*

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVDS, Controllability on Grade* from the Active Events list.
- In the *Report Type* list, select *Trajectory Simulation*.
- Press *OK*.

The Trajectory Simulation viewer is displayed for the

*EDVDS, Controllability on Grade*

event (see Figure 5-29). The tractor and trailer are shown at their initial positions.

To visualize the motion as the tractor-trailer attempts to negotiate the down-hill curve, perform the following steps:

- Click *Play* (single right-arrow). The simulation begins and is displayed at the current Playback output interval.
- Click *Pause*. The simulation stops.
- Click *Reverse* (single left-arrow). The simulation plays in reverse.
- Click *Pause*. The simulation stops.
- Click *Rewind* (left arrow with bar). The simulation returns to the start.
- Click *Advance to End* (right arrow with bar). The simulation advances to the end of the run.




*Figure 5-29: Trajectory Simulation for EDVDS, Controllability on Grade.*

### Printing

The final step is to print the above reports. Printing reports is simple. All you do is choose a report and print it. For example:

- Click on the dialog header of the *Accident History - EDVDS, Controllability on Grade* report. Your selection is highlighted and the Accident History window pops to the top of the display (if it isn't there already), indicating it is the current window.
- Click on the *File* menu and choose *Print*. The Print dialog is displayed, allowing the user to select from several available print options.

> **NOTE:** Alternatively, you can click on the print icon in the upper menu bar.

- Press *OK*. The Accident History output report is printed on the system printer.

That's all there is to it! You can print any other report using the same two steps described above.

> **NOTE:** The Print dialog provides several options. Refer to your Windows or printer manual for more information.
>
> **NOTE:** For several reports it may be best to print in landscape rather than portrait mode.
>
> **NOTE:** The font size of both the printed reports and screen display may be edited by clicking on the Options menu and choosing Preferences. Use the Font Size option list to change the size.

# Chapter 6 — Messages

Messages can be issued by either the operating system, HVE, or by EDVDS. Some of the more common operating system messages are described in the Appendix. A more thorough discussion of operating system messages may be found in the operating system manual.

Messages produced by HVE are described in the HVE User's Manual, Appendix II.

Errors issued by EDVDS appear in the EDVDS output and may be one of three types:

- **Fatal Messages (Level 1)** — These messages halt execution and are caused by the program's inability to continue the calculation procedure based on intermediate results that are inconsistent or incompatible with basic program assumptions.
- **Diagnostic Messages (Level 2)** — These messages do not halt execution, but are the result of the internal consistency checks performed by the program and suggest inconsistencies in the results of which the user should be aware. These inconsistencies may be the result of bad or suspicious data.
- **Informative Messages (Level 3)** — These messages do not halt execution, but provide information about execution, not affecting accuracy, but suggestive of something the user may want to review to ensure data were as intended.

All messages issued by EDVDS are listed below. Each message includes a description or nature of the cause, the level of the message (Informative, Diagnostic or Fatal), and the recommended action to eliminate the problem. If you receive an error message not listed below, first check to see if it is an HVE or operating system message by referring to the HVE Appendix or your computer's operating system manual. If the message is not listed in either place, please contact EDC with the offending error.

*(updated: messages 1–7 below appear in the original printed manual; messages 8–12 have been added to EDVDS since the Fourth Edition was printed and are documented here for completeness.)*

---

**Tire slip angle exceeded maximum value for linear tire. Run terminated!**

*(Level 1 - Fatal)*

This error occurs if the user selects the linear tire model (see Calculation Options), and the event includes a maneuver that results in significant lateral tire forces. If the tire slip angle exceeds a pre-defined limit for the linear tire model, normally 0.25 radians, the run terminates with this message.

To solve the problem the user must eliminate the cause of the lateral tire slip (normally substantial steering, often combined with braking), or change to a different tire model.

---

**Tire longitudinal slip exceeded maximum value for linear tire. Run terminated!**

*(Level 1 - Fatal)*

This error occurs if the user selects the linear tire model (see Calculation Options), and the event includes a maneuver that results in significant longitudinal tire forces. If the tire longitudinal slip exceeds a pre-defined limit for the linear tire model, normally 25 percent, the run terminates with this message.

To solve the problem the user must eliminate the cause of the longitudinal tire slip (normally substantial braking or accelerating), or change to a different tire model.

---

**The simulation was terminated because GetSurfaceInfo() failed to return a valid surface.**

*(Level 1 - Fatal)*

This message occurs if the Get Surface Information search failed to return a valid surface elevation. EDVDS should not return this condition; contact EDC if it occurs.

---

**The simulation was terminated because of an integration error. The numerical integration routine failed to converge to the specified Velocity Convergence Criterion after Maximum Bisections. These parameters are set in the Simulation Controls dialog. NOTE: The Velocity Convergence Criterion should be about 0.10 and Maximum Bisections should be about 10.**

*(Level 1 - Fatal)*

This condition indicates dynamic instability. Experience suggests if reasonable integration time steps and maximum bisections are used, this condition should not occur. If you confirm reasonable simulation controls are used and the condition still occurs, please contact EDC.

---

**The simulation was terminated because the user-specified maximum articulation angle between a tow vehicle and trailer was exceeded.**

*(Level 1 - Fatal)*

This message is self-explanatory. The maximum articulation angle is defined in the Rear Connections parameters (see Vehicle Editor). The value is established by the angle required to create pinching between the tow vehicle and trailer. Note that such pinching would cause forces not modeled by EDVDS, so the run is terminated.

---

**The simulation was terminated because the current deflection of a tire exceeded the user-specified Maximum Tire Deflection assigned for that tire. This problem can sometimes be solved by increasing slightly the Maximum Tire Deflection and/or reducing the Vehicle Trajectory Integration Timestep. This condition suggests that a wheel may have been broken during the event; EDVDS does not model failed wheel rims.**

*(Level 1 - Fatal)*

The first step in calculating tire forces is to calculate the radial tire force from the current tire deflection (the change in the tire rolling radius compared to an unloaded tire). If the deflection of a tire exceeds the user-specified Maximum Tire Deflection assigned for that tire the radial tire force could be substantial, leading to dynamic instability in the simulation. To prevent this from occurring, the run terminates.

This problem can sometimes be solved by increasing slightly the Maximum Tire Deflection (see Tire Physical Data parameters) and/or by reducing the Vehicle Trajectory Integration Timestep (see Simulation Controls).

*(updated: the current message text additionally notes that this condition suggests a wheel may have been broken during the event, and that EDVDS does not model failed wheel rims.)*

---

**The simulation was terminated because of a singular matrix. This condition usually suggests a defective inertial matrix. Please send the offending case file to EDC for evaluation.**

*(Level 1 - Fatal)*

While solving the equations of motion, EDVDS creates a matrix of inertial parameters. To solve the equations, this matrix must be inverted. Not all matrices have an inverse and thus, cannot be inverted. However, for the types of equations solved by EDVDS, the matrix should be invertible. If a problem occurs first check to see that no inertial elements of the vehicle (sprung mass, axles, wheels) have been assigned a zero mass or rotational moment of inertia. If the problem persists, please send the offending case file to EDC for evaluation.

---

**The simulation was terminated because the current engine speed (RPM) was greater than the maximum RPM specified for the engine (see Vehicle Editor, Drivetrain Data, Engine Power/Torque Table).** *(added since the printed manual)*

*(Level 1 - Fatal)*

This problem might occur if the wheels leave the ground during a heavy throttle application; in this case the problem may be eliminated by reducing the throttle input (see Driver Controls, Throttle Table). The problem might also occur while driving in a low gear if the driver has a "lead foot."

---

**The simulation was terminated by the HVE Driver Model because the maneuver required a steering wheel input rate that exceeded the user-defined Maximum Steering Velocity (see HVE Path Follower dialog).** *(added since the printed manual)*

*(Level 1 - Fatal)*

The HVE Driver Model computed a steering wheel rate greater than the maximum rate the modeled driver is permitted to produce. Increase the Maximum Steering Velocity in the HVE Path Follower dialog, reduce the initial speed, or adjust the target path so the required steering input rate is achievable.

---

**The simulation was terminated by the HVE Driver Model because the maneuver resulted in a lateral acceleration that exceeded the user-defined Driver Lateral Acceleration Comfort Level (see HVE Path Follower dialog).** *(added since the printed manual)*

*(Level 1 - Fatal)*

The maneuver required by the target path produced a lateral acceleration greater than the comfort level assigned to the modeled driver. Increase the Driver Lateral Acceleration Comfort Level in the HVE Path Follower dialog, reduce the speed, or adjust the target path.

---

**NOTE: The inter-vehicle connections for two connected vehicles have different elevations above ground. This is not an error condition, but it is unusual. CG Height + Connection z-coord are normally about equal for both vehicles.** *(added since the printed manual)*

*(Level 3 - Informative)*

This informative message alerts the user that the earth-fixed heights of the mating connection points (e.g., fifth wheel and kingpin) differ between a tow vehicle and its trailer. Review the CG heights and connection z-coordinates for both vehicles to confirm the data are as intended.

---

**NOTE: The vehicle-fixed connection z-coordinate was automatically calculated to make the earth-fixed connection height equal on each tow vehicle/trailer pair. The updated connection z-coordinate is displayed in the Vehicle Data Report.** *(added since the printed manual)*

*(Level 3 - Informative)*

When the connection heights of a connected pair do not match, the physics program can automatically adjust the vehicle-fixed connection z-coordinate so the earth-fixed connection heights are equal. The adjusted value is reported in the Vehicle Data report; no user action is required unless the adjusted value is not as intended.

# Chapter 7 — References

> *(updated: the printed Fourth Edition contains two entries numbered 19; that numbering is preserved here because in-text citations elsewhere in this manual — e.g. reference [28] in Chapter 1 — follow the printed numbering.)*


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